COGNITIVE 2011

The Third International Conference on Advanced Cognitive Technologies and Applications

ISBN: 978-1-61208-155-7

September 25-30, 2011
Rome, Italy

COGNITIVE 2011 Editors

Terry Bossomaier, Charles Sturt University, Australia

Pascal Lorenz, University of Haute Alsace, France

COGNITIVE 2011

Foreword

The Third International Conference on Advanced Cognitive Technologies and Applications [COGNITIVE 2011], held between September 25 and 30, 2011 in Rome, Italy, targeted advanced concepts, solutions and applications of artificial intelligence, knowledge processing, agents, as key-players, and autonomy as manifestation of self-organized entities and systems. The advances in applying ontology and semantics concepts, web-oriented agents, ambient intelligence, and coordination between autonomous entities led to different solutions on knowledge discovery, learning, and social solutions.

We take here the opportunity to warmly thank all the members of the COGNITIVE 2011 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to COGNITIVE 2011. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the COGNITIVE 2011 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that COGNITIVE 2011 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of advanced cognitive technologies and applications.

We are convinced that the participants found the event useful and communications very open. We also hope the attendees enjoyed the charm of Rome, Italy.

COGNITIVE 2011 Chairs:

Po-Hsun Cheng (鄭伯壎), National Kaohsiung Normal University, Taiwan
Petre Dini, Concordia University - Montreal, Canada / China Space Agency Center - Beijing, China
Hermann Kaindl, TU-Wien, Austria
Narayanan Kulathuramaiyer, UNIMAS, Malaysia
Jaime Lloret Mauri, Polytechnic University of Valencia, Spain
Sugata Sanyal, Tata Institute of Fundamental Research - Mumbai, India
Qin Xin, Simula Research Laboratory, Norway

COGNITIVE 2011

Committee

COGNITIVE Advisory Chairs

Hermann Kaindl, TU-Wien, Austria
Jaime Lloret Mauri, Polytechnic University of Valencia, Spain
Sugata Sanyal, Tata Institute of Fundamental Research - Mumbai, India
Petre Dini, Concordia University - Montreal, Canada / China Space Agency Center - Beijing, China
Po-Hsun Cheng (鄭伯壎), National Kaohsiung Normal University, Taiwan
Narayanan Kulathuramaiyer, UNIMAS, Malaysia

COGNITIVE 2011 IndUstry/Research Chair

Qin Xin, Simula Research Laboratory, Norway

COGNITIVE 2011 Technical Program Committee

Siby Abraham, Tata Institute of Fundamental Research - Mumbai, India
Witold Abramowicz, The Poznan University of Economics, Poland
Rajendra Akerkar, Western Norway Research Institute - Sogndal, Norway
José F. Aldana Montes, University of Málaga, Spain
Giner Alor Hernández, Instituto Tecnológico de Orizaba - Veracruz, México
Eckhard Ammann, Reutlingen University, Germany
Brahim Batouche, Public Research Centre Henri Tudor (CRP Henri Tudor) - Luxembourg-Kirchberg, Luxembourg
Petr Berka, University of Economics, Prague, Czech Republic
Ateet Bhalla, NRI Institute of Information Science and Technology - Bhopal, India
Mauro Birattari, Université Libre de Bruxelles, Belgium
Yaser Chaaban, Leibniz University of Hanover, Germany
Po-Hsun Cheng (鄭伯壎), National Kaohsiung Normal University, Taiwan
Sunil Choenni, Research & Documentation Centre (WODC)/Ministry of Justice and Rotterdam University, The Netherlands
Leonardo Dagui de Oliveira , Escola Politécnica of University of São Paulo, Brazil
Darryl N. Davis, University of Hull, UK
Rogerio A. Enriquez-Caldera, Instituto Nacional de Astrofísica, Óptica y Electrónica, Mexico
Juan Luis Fernández Martínez, Universidad de Oviedo, España
Simon Fong, University of Macau, Macao SAR
Qiang Fu, Broadcom Corporation, USA
Alain Giboin, INRIA Sophia-Antipolis, France
Maik Günther, SWM Versorgungs GmbH – München, Germany
Ioannis Hatzilygeroudis, University of Patras, Greece
Stijn Heymans, SemanticBits LLC, USA
Tzung-Pei Hong 洪宗貝 , National University of Kaohsiung, Taiwan
Kenneth Hopkinson, Air Force Institute of Technology, USA
Jianmin Jiang, University of Bradford, UK

Copyright Information

Table of Contents

Analysis of the Effect of Cognitive Load on Gait with off-the-shelf Accelerometers

Eladio Martin, Ruzena Bajcsy
EECS Department
University of California, Berkeley
Berkeley, CA, USA
{emartin, rbajcsy}@eecs.berkeley.edu

***Abstract*—Recent research has shown that cognitive load has an effect on gait, especially noticeable in people with neurodegenerative disorders. Sophisticated and expensive systems are commonly used to measure the variability of gait parameters under different cognitive loads. In this paper, we propose the use of smart phones and off-the-shelf wireless accelerometers to study the influence of cognitive load on gait. Making use of this new approach, we measure the effect of common "working memory" or "motor" tasks on gait. We also analyze the effect on gait variability derived from imposing a speed while walking in a treadmill. Our results show that current state-of-the-art smart phones and off-the-shelf accelerometers can be successfully used to analyze the effect of cognitive load on gait.**

Keywords- cognitive load, dual task, gait.

I. INTRODUCTION

There is a growing interest in clarifying the relationship between cognition and gait. In the past, walking was considered a motor activity independent of any cognitive processes and performed automatically by healthy adults. However, recent research shows that cognitive load has an effect on gait [1-4], especially noticeable in people with neurodegenerative disorders such as Alzheimer's disease [5], vascular dementia, mixed dementia [6] or Parkinson's disease [7]. Psycho affective conditions such as anxiety and depression are also linked to specific gait disorders [8]. More specifically, a decrease in the frontal cerebral blood flow has been associated with modifications in gait [9]. As shown in [10, 11] and references therein, cerebral vascular abnormalities are associated with modifications of the gait pattern, namely an increased variability of spatio-temporal gait parameters. These observations are consistent with studies claiming that gait requires cognitive processes such as attention, memory and planning [12, 13], demanding frontal and parietal activity in the brain [14, 15]. In fact, changes in the frontal regions including the bilateral medial areas of the frontal cortex have been identified as a risk factor for dementia [16-18], and reductions in the motor strength associated with aging increase the attentional demands needed for walking.

The most popular method to analyze the effect of cognitive load on gait is the dual task test [3, 4, 10, 12, 19, 20, 21-29], in which the subject under study performs a cognitive task while simultaneously walking. Most researchers choose to avoid prioritizing any of the tasks. Since the dual task conditions impose a higher attentional demand, the performance in one or both tasks can be impaired if the attentional reserve capacity available is challenged [22, 30, 31]. This is known as "dual task interference". The effect of the dual task test on gait can be quantified through the variability in the spatio-temporal parameters of gait, which will depend on the complexity of the task and the general condition of the subject [32-36]. For example, the effect of the cognitive task on gait can depend on factors such as age, gender, executive function, memory and verbal IQ [2, 32, 33, 37-42].

Another application of the dual task test is to show the link between attentional demands and postural control [32, 43-49]. Recent studies claim that postural stability requires both cognitive and sensorimotor processes [50], and researchers are analyzing the impact of different details (e.g. speech complexity [51]) on postural control. In the same sense, the dual task test can be utilized to study the capacity of older adults to avoid obstacles [52]. In fact, gait stability can be a better predictor of falling than static measures of balance [40]. Recent studies have shown a relationship between dual task interference and fall risk [53, 54]. For instance, a simple measurement of the counting performance while walking in comparison with while seated has proved to be a good indicator of fall risk in the elderly [53]. In particular, there is a growing interest in studying the link between the variability of spatial-temporal parameters in gait under dual task conditions and the risk of falling in seniors [20, 37, 38, 55, 56].

In this paper, we review the state of the art in the study of cognitive load on gait, showing the different systems, dual task tests and spatio-temporal parameters employed by researchers in this field. Subsequently, we propose the use of smart phones and off-the-shelf accelerometers to measure the effect of common "working memory" and "motor" tasks on gait. To the best of our knowledge, this is the first work in this field employing this new technology.

The rest of this paper is organized as follows. In Section 2, we survey the most common dual tasks employed by researchers, and in Section 3, we review the systems utilized to analyze the influence of cognitive load on gait and postural control. Section 4 focuses on the spatio-temporal parameters leveraged for the analysis of cognitive load on gait. In Section 5, we describe our proposed methodology using smart phones with off-the-shelf accelerometers, and summarize tests results. Conclusions are drawn in Section 6.

 ISBN: 978-1-61208-155-7

II. DUAL TASK TESTS

Most of the existing research in this field involves the analysis of the effect of a second task on gait or postural control. Some researchers claim that dual task interference is only possible if the neural networks involved in the two processes overlap [2]. For instance, reference [33] suggests that only visual/spatial dual tasks would interfere with postural control, since postural control demands visual/spatial processing. However, there is no consensus on the optimum dual tasks with which to evaluate gait or postural control.

Some of the dual tasks employed by researchers are borrowed from neuropsychological tests, while others are created specifically for each experiment. And even if there is a lack of a standardized evaluation technique to compare the cognitive loads demanded by each task, most researchers follow practical guidelines to carry out the tests: the task should be difficult enough to load the attentional system, but it should not cause undue stress or anxiety. Also, the test should take into consideration the subject's skills (e.g. mathematical, verbal fluency), since the cognitive loads brought by a same task can vary depending on the subject's skills [2]. Table I gathers the most common tasks employed by researchers. These tasks can be assigned different percentages according to their importance levels and the application context.

III. SYSTEMS EMPLOYED TO ANALYZE THE INFLUENCE OF COGNITIVE LOAD ON GAIT AND POSTURAL CONTROL

A basic approach to analyze human kinematics is chronophotography [57]. More sophisticated motion tracking systems utilize mechanical, acoustic (including ultrasounds), radio-frequency, optical, magnetic, and inertial sensors. Descriptions and examples of these systems can be found in [58]. The suitability of each system depends on the particular conditions and goals of each test. The combination of different methods in a multi-modal approach allows an enhancement in accuracy and robustness in terms of security. In other words, complementing methods can help overcome their weaknesses.

One of the most common and sophisticated commercial systems employed in existing research is the GAITRite walkway [59, 60], with embedded force sensors to detect footfalls and a length of nearly 5 meters, allowing the estimation of gait parameters such as speed, length and width of the step, and symmetry of the gait pattern. This system enjoys high reliability and high concurrent validity when compared with video-based motion analysis systems for spatiotemporal gait parameters such as gait speed, cadence, and stride length.

For the analysis of postural control, the most common solution consists of sensors or force plates installed on the floor [61-63]. Commercial examples of such systems employed in existing research are described in [20] and [51]. Other researchers utilize custom made plates attached to the subject to overcome the movement restriction due to the small size of force plates. Examples of these approaches include the employment of force transducers beneath the shoe, pressure insoles and miniature triaxial piezoelectric transducers inside the shoe [58].

TABLE I. COMMON TASKS EMPLOYED TO STUDY THE EFFECT OF COGNITIVE LOAD ON GAIT THROUGH "DUAL TASK TESTS".

Working memory tasks
Attention and articulation: counting backwards out loud
Attention without demands for articulation: silent counting backwards
Articulation alone: number repetition
Arithmetic task (backward counting, serial 3 or 7 subtractions)
Other arithmetic calculations
Counting backwards from 50 by steps of 2 out loud
Random digit generation
Backward digit recall
Digit span recall
Generating a monologue
Audibly reciting as many male names as possible
Backward spelling
Naming of months from December to January
Reciting the days of the week backwards
Counting backwards silently by 7's
Performing a rote repetition task
Verbal fluency tasks
Enumerating animals out loud
Modified Stroop test
Naming items that start with a certain letter or have a certain common characteristic (e.g., farm animals)
Conducting a conversation
Remembering similar sentences
Motor tasks
Fine motor task (opening and closing a coat button continuously during gait)
Finger tapping at 5 Hz or faster
Combination of memory-retention and fine motor tasks (digit recall and buttoning task)
Carrying a tray
Carrying a tray with four plastic glasses on it
Carrying a tray with filled glasses of water
Sequential finger movement
Transfer of coins between pockets
Other simple manual motor tasks
Auditory tasks
Listening to a spoken word recording of a book excerpt, or simple white noise
Auditory Stroop test
Visual tasks
Brooks spatial memory task
Carrying out tests under different visual conditions, no vision, static visual image, and a moving visual image
Color judgment
Other visual-spatial cognitive tasks
Classical tests of executive function
Wisconsin Card Sorting
Stroop test
Verbal fluency tests
The Executive Interview (EXIT25) test
CLOX (an executive clock drawing task)

More specific techniques employed to discover possible reasons for falling include Holter electrocardiography (ECG), 24-hour blood pressure monitoring, electromyography (EMG), electroencephalography (EEG), and Doppler and duplex sonography of the extra- and intracranial vessels [20]. Other methodologies utilized to diagnose clinical conditions that can influence gait are based

 ISBN: 978-1-61208-155-7

on the analysis of electroencephalogram (EEG) signals and magnetic resonance imaging (MRI) [1]. Methods such as single photon emission tomography, functional near infrared spectroscopy or functional Magnetic resonance imaging (fMRI) and positron emission tomography, have also been employed to identify brain areas related to attentional resources during walking [21].

Table II gathers a summary of systems employed by researchers for the measurement of kinematic parameters in gait.

TABLE II. COMMON SYSTEMS EMPLOYED TO ANALYZE THE SPATIO-TEMPORAL PARAMETERS OF GAIT.

Systems
Absorbent paper to record wet footprint placements
Talcum powder dusted on the plantar surface of the foot to record footprint placements
Ink pads on the sole of the shoes and walk along a large piece of paper
Shoe-integrated wireless sensor systems (e.g. Stride Analyzer; B&L Engineering, Tustin, Calif., USA)
Accelerometers (e.g. DynaPort MiniMod; McRoberts Moving Technology, The Hague, The Netherlands)
Angular velocity transducer systems (e.g. Sway- Star; Balance International Innovations GmbH, Iseltwald, Switzerland)
Electronic walkways with integrated pressure sensors (e.g. GAITRite; CIR Systems, Havertown, Pa., USA)
Video-based motion analysis systems (e.g. Vicon Motion Systems, Los Angeles, Calif., USA)
On-body sensors based systems (e.g. STEP 32 gait analysis system by DEM, Italy)
Inner soles with 4 pressure-sensitive footswitches
Muscle activity measured with electromyography (EMG)

IV. SPATIO-TEMPORAL PARAMETERS EMPLOYED TO ANALYZE THE EFFECT OF COGNITIVE LOAD ON GAIT

Gait velocity can be used as an indicator of the quality of life in the elderly [64]. In this sense, increased variability of spatio-temporal gait parameters has been linked to cognitive abnormalities [1, 11]. And although numerous gait parameters can be measured in sophisticated gait labs, many studies focus basically on mean gait speed and stride-to-stride variability in gait speed [37]. In fact, gait velocity and stride-to-stride variability in gait velocity have been identified as the best predictors of falls for the elderly [38, 65]. Stride-to-stride variability (*V*) in gait speed is commonly quantified as the percentage of the standard deviation (*SD*) to the mean [37]:

$$V(\%) = \frac{SD}{mean} * 100 \tag{1}$$

Other researchers also focus on stride time and swing time variabilities [66, 67]. Table III gathers representative gait parameters used by researchers to analyze the effect of cognitive load on gait.

TABLE III. COMMON SPATIO-TEMPORAL GAIT PARAMETERS ANALYZED BY RESEARCHERS TO STUDY THE INFLUENCE OF COGNITIVE LOAD ON GAIT.

Gait Parameters
Gait speed
Stride-to-stride variability in gait speed
Stride time
Double support time
Stride length
Cadence
Percentage of the gait cycle in double-limb stance
Range of motion and peak velocity of the center of mass
Duration of single and double support
Step time
Swing time
Stance time

Table IV gathers a summary of the typical modifications measured for the spatio-temporal parameters of gait under dual task conditions.

TABLE IV. SUMMARY OF MODIFICATIONS IN SPATIO-TEMPORAL GAIT PARAMETERS UNDER DUAL TASK CONDITIONS.

Gait Parameters
Decreased gait velocity (as a compensation mechanism which people take when stability is challenged). It is interesting to note that this parameter is associated with errors in the cognitive dual-task (e.g. poorer arithmetic ability [12] or verbal reaction time [52])
Decreased stride length
Increased double support time
Increased gait cycle time variability
Increased variability in stride length
Increased variability in gait speed (greater variability in men than in women)
Decreased cadence
Increased lateral gait instability (only with arithmetic dual task, but not with verbal fluency task)
Increased postural sway, which is impacted by articulation and visual conditions, but not by attentional load (e.g. silent counting)

V. PROPOSED METHODOLOGY AND TESTS TO ANALIZE THE EFFECT OF COGNITIVE LOAD ON GAIT

We propose to study the effect of cognitive load on gait leveraging off-the-shelf wireless accelerometers and smart phones implementing a light-weight and low-cost system that enables the analysis of gait parameters' variability with an accuracy comparable to the most sophisticated and expensive systems available in the market. In particular, we analyze through the wavelet transform the signals obtained from off-the-shelf wireless accelerometers placed on the waist and the ankle of the person under study. These wireless accelerometers transmit their signals to a processing unit (e.g. smart phone or laptop) using Bluetooth. The signal processing methodology we use is summarized next.

Reviewing the wavelet transform decomposition of a signal *x(t)* into approximation $a_j(k)$ and detail $d_j(k)$ coefficients:

$$a_j(k) = \int x(t)\varphi_{j,k}(t)dt \tag{2}$$

 ISBN: 978-1-61208-155-7

$$d_j(k) = \int x(t)\psi_{j,k}^{\ *}(t)dt \tag{3}$$

where $\varphi_{j,k}(t)$ represents the scaling function and $\psi_{j,k}(t)$ the wavelet function (* represents conjugate), it can be seen that these coefficients are integrating the signal *x(t)*, weighted by the $\varphi_{j,k}(t)$ and $\psi_{j,k}(t)$ functions. Focusing on the acceleration from the waist (which approximately corresponds to the center of mass of the human body), the application of the wavelet transform delivers the integration of weighted accelerations, thus obtaining weighted velocities (of the center of mass). Further analyzing the relationship between the wavelet transform coefficients and the kinetic energy of different walking patterns, we can actually infer the speed of the movement with the following expression:

$$Speed = \frac{1}{2}\sqrt{WE_{d_1} + \frac{WE_{d_2}}{2} + \frac{WE_{d_3}}{3} + \frac{WE_{d_4}}{4} + \frac{WE_{d_5}}{5}} \tag{4}$$

in which we include a new metric that we call "Weighted Energy":

$$WE_{d_i} = \begin{cases} \dfrac{\sum d_i^{\ 2}}{n_0\sqrt{2}(J-i)} & i = 1..J-1 \\ \dfrac{\sum d_i^{\ 2}}{n_0\sqrt{2}} & i = J \end{cases} \tag{5}$$

where J represents the number of levels of decomposition we are using in the wavelet transform, i accounts for the specific level we are considering, d_i symbolizes the detail coefficients at level i, and n_0 represents the number of coefficients considered. In (4), we have considered the first 5 levels of decomposition in order to cover the frequency content of the acceleration ranging from 0.46 Hz to 15 Hz (our sampling frequency is 30 Hz), thus including the most important frequencies of gait, which are typically between 0.5 Hz and 4 Hz. We have tested this approach with a total of 14 individuals (males and females with ages ranging from 21 to 77), obtaining excellent accuracies in the velocities, with average errors around 5%. In fact, the accuracy of our approach is comparable to that obtained with more complex and expensive systems, and our results are achieved with significantly lower hardware requirements. Once we obtain the velocity of the movement, the step length can be calculated dividing the velocity by the step frequency, which we can obtain from an accelerometer on the ankle (through the detection of peaks).

Making use of this new approach, we carried out tests to study the influence of cognitive load on gait. In particular, we measured the variability of velocities and stride lengths under classical dual task tests such as walking while holding a tray with a glass full of water, or walking while performing arithmetic calculations out loud (serial 7 and 13 subtractions). Comparing these results with free walking conditions (summary in Table V), we can notice decreases in the mean velocities and stride lengths of the individuals while performing the dual tasks. Regarding the percentage variabilities of velocity and stride length, these terms increase in all the dual task tests. All these results match perfectly with those obtained by other researchers employing more sophisticated systems. In conclusion, the effect of common "working memory" or "motor" tasks employed in tests for the analysis of cognitive load on gait can be measured with current state-of-the-art smart phones and off-the-shelf accelerometers, without the need of sophisticated and expensive equipment.

TABLE V. MEASURED EFFECTS OF DIFFERENT DUAL TASKS ON GAIT

	Mean Velocity (mph)	Velocity Variability(%)	Mean Stride Length (meters)	Stride Length Variability(%)
Free Walk	3.05	23.2	1.25	32.04
Carrying tray	1.82	24.93	0.65	61.9
Walk while calculating	2.6	25.17	0.85	35.29

Making use of our new approach we also analyzed the effect of imposing a velocity (the person should walk on a treadmill at a selected speed). For these tests, 20 individuals (ages ranging from 11 to 59) walked in a treadmill at the suggested speeds of 1 mph, 2 mph, 3 mph, 5 mph and 2 mph with inclination. The results regarding the variabilities in velocities (obtained as the percentage of the standard deviation to the mean) are summarizes in Figure 1.

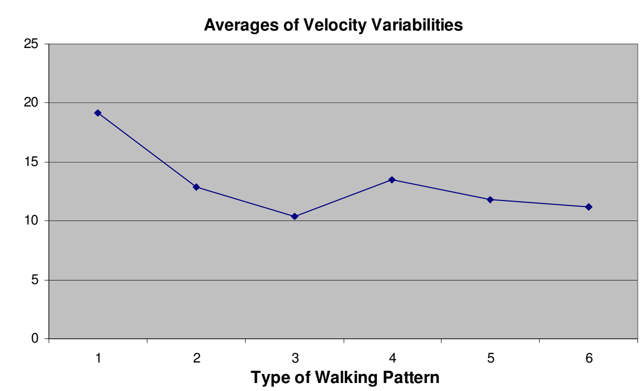


Figure 1. Averages of velocity variabilities for 20 individuals and 6 types of walking patterns: 1) 1mph, 2) 2mph, 3) 3mph, 4) 2mph inclined, 5) 5mph, 6) free walking.

As observed in Figure 1, there is no significant effect on the variability of velocity when the individual is told to keep a fixed speed, in comparison with walking at free speed. Only at very low speeds (walking type 1 in Figure 1) or when the walking surface is kept inclined (walking type 4 in Figure 1), the velocity variabilities are higher than those obtained without the cognitive load of having to keep a constant speed.

 ISBN: 978-1-61208-155-7

VI. CONCLUSION

In this paper, we have reviewed the most common systems, dual tasks and spatio-temporal parameters employed by researchers to analyze the influence of cognitive load on gait and postural control. We have also proposed a new methodology to study the effect of cognitive load on gait leveraging smart phones and off-the-shelf accelerometers. Making use of our new methodology, we have examined the influence on gait posed by common “working memory” or “motor” tasks, obtaining results that match perfectly with those obtained by other researchers employing more sophisticated systems. We have also studied the influence on gait derived from the imposition of a constant speed while walking on a treadmill. In conclusion, the effect of cognitive load on gait can be measured with current state-of-the-art smart phones and off-the-shelf accelerometers, without the need of sophisticated and expensive equipment.

REFERENCES

[1] Allali G., Meulen M., and Assal F., “Gait and cognition: the impact of executive function”, Schweizer Archiv. fur Neur. und Psych., 161, 6, 2010, pp. 195 – 199

[2] Yogev-Seligmann G., Hausdorff M., and Giladi N., “The Role of Executive Function and Attention in Gait”, Mov. Dis., Vol. 23, No. 3, 2008, pp. 329–342.

[3] Woollacott M. and Shumway-Cook A., “Attention and the control of posture and gait: a review of an emerging area of research”, Gait Posture, 16, 1, 2002, pp. 1–14.

[4] Beauchet O., Kressig R.W., Najafi B., Aminian K., Dubost V., and Mourey F. “Age-related decline of gait control under a dual-task condition”, J. Am. Geriatr. Soc. 51, 8, 2003; pp.1187–1188.

[5] Sheridan P.L., Solomont J., Kowall N., and Hausdorff J.M., “Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer’s disease”, J. Am. Geriatr. Soc. 51, 11, 2003, pp. 1633–1637.

[6] Allali G., Assal F., Kressig R.W., Dubost V., Herrmann F.R., and Beauchet O., “Impact of impaired executive function on gait stability”. Dement. Geriatr. Cogn. Disord. 26, 4, 2008; pp. 364–369.

[7] Yogev G., Plotnik M., Peretz C., Giladi N., and Hausdorff J.M., “Gait asymmetry in patients with Parkinson’s disease and elderly fallers: when does the bilateral coordination of gait require attention?” Exp. Brain Res. 177, 3, 2007, pp. 336–46.

[8] Hausdorff J.M., Peng C.K., Goldberger A.L., and Stoll A.L., “Gait unsteadiness and fall risk in two affective disorders: a preliminary study”, BMC Psychiatry. 2004, pp. 4-39.

[9] Nakamura T., Meguro K., Yamazaki H., Okuzumi H., Tanaka A., and Horikawa A., “Postural and gait disturbance correlated with decreased frontal cerebral blood flow in Alzheimer disease”. Alzheimer Dis. Assoc. Disord. 11, 3, 1997, pp. 132–9.

[10] Allali G., Meulen M, and Assal F., “Gait and cognition: the impact of executive function”, Schweizer Archiv fur Neur. und Psych., 161, 6, 2010, pp. 195–199

[11] Rosano C., Brach J., Studenski S., Longstreth W.T. Jr, and Newman A.B., “Gait variability is associated with subclinical brain vascular abnormalities in high-functioning older adults”. Neuroepidemiology. 29, 3-4, 2007, pp. 193–200.

[12] Paul B.M., Ellis G.P., Leese A., McFadyen K., and McMurray B., “The effect of a cognitive or motor task on gait parameters of diabetic patients, with and without neuropathy”, Diab. Med., Volume 26, Issue 3, March 2009, pp. 234–239.

[13] Deepak J. and Sneh A., “Cyclogram and cross correlation: A comparative study to quantify gait coordination in mental state”, J. of Biom. Sc. and Eng.. 2010, pp. 322-326.

[14] Malouin F., Richards C.L., Jackson P.L., Dumas F., and Doyon J., “Brain activations during motor imagery of locomotor-related tasks: a PET study”. Hum. Brain Mapp. 19, 2003; pp. 47-62.

[15] Sheridan P.L. and Hausdorff J.M., “The role of higher-level cognitive function in gait: executive dysfunction contributes to fall risk in Alzheimer’s disease”. Dement Geriatr. Cogn. Disord. 24, 2007, pp. 125-137.

[16] Tombu M. and Jolicoeur P., “A central capacity sharing model of dual-task performance”. J. Exp. Psychol. Hum. Percept. Perform. 29, 2003, pp. 3–18.

[17] Mayer Y.S. and Barron D.W., “Apraxia of gait: clinico-physiological study”. Brain. 83, 1960; pp. 261–84.

[18] Verghese J., Lipton R.B., Hall C.B., Kuslansky G., Katz M.J., and Buschke H., “Abnormality of gait as a predictor of non-Alzheimer’s dementia”, N. Engl. J. Med. 347, 22, 2002, pp. 1761–8.

[19] Allali G., Kressig R.W., Assal F., Herrmann F.R., Dubost V., and Beauchet O., “Changes in gait while backward counting in demented older adults with frontal lobe dysfunction”. Gait Posture. 26, 4, 2007, pp. 572–576.

[20] Bridenbaugh S.A. and Kressig R.W., “Laboratory Review: The Role of Gait Analysis in Seniors’ Mobility and Fall Prevention.” Gerontology, October 2010, pp. 1-9.

[21] Abbud G., Li K., and DeMont R., “Attentional requirements of walking according to the gait phase and onset of auditory stimuli”, Gait Posture, 30, 2009, pp. 227–232.

[22] Huang H.J. and Mercer V.S., “Dual-task methodology: applications in studies of cognitive and motor performance in adults and children”. Pediatr. Phys. Ther. 13, 2001, pp. 133–140.

[23] Yogev-Seligmann G., Hausdorff J.M., and Giladi N.; “The role of executive function and attention in gait”. Mov. Disord. 23, 2008; pp.329–342.

[24] Pashler H., “Dual-task interference in simple tasks: data and theory”. Psychol. Bull. 116, 1994, pp. 220–244.

[25] Sheridan P.L., Solomont J., Kowall N., and Hausdorff J.M., “Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer’s disease.”. J. Am. Geriatr. Soc. 51, 2003, pp. 1633–1637.

[26] Sheridan P.L., Solomont J., Kowall N., and Hausdorff J.M., “Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer’s disease.”. J. Am. Geriatr. Soc. 51, 2003, pp. 1633–1637.

[27] Allali G., Kressig R.W., Assal F., Herrmann F.R., Dubost V., and Beauchet O., “Changes in gait while backward counting in demented older adultswith frontal lobe dysfunction.” Gait Posture, 26, 2007, pp. 572–576.

[28] Allali G., Kressig R.W., Assal F., Herrmann F.R., Dubost V., and Beauchet O., “Changes in gait while backward counting in demented older adultswith frontal lobe dysfunction.” Gait Posture, 26, 2007, pp. 572–576.

[29] Dubost V., Kressig R.W., Gonthier R., Herrmann F.R., Aminian K., Najafi B., and Beauchet O., “Relationships between dual-task-related changes in stride velocity and stride time variability in healthy older adults”. Hum. Mov. Sci. 25, 2006, pp. 372–382.

[30] Woollacott M. and Shumway-Cook A., “Attention and the control of posture and gait: a review of an emerging area of research”, Gait Posture 16, 2002, pp. 1–14.

[31] Abernethy B., "Dual-task methodology and motor skills research: some applications and methodological constraints". J. Hum. Mov. Stud., 14, 1988; pp. 101–132.

[32] Ebersbach G., Dimitrijevic M.R., and Poewe W., "Influence of concurrent tasks on gait: a dual-task approach". Percept. Mot. Skills, 81, 1995; pp.107–113.

[33] Kerr B., Condon S.M., and McDonald L.A., "Cognitive spatial processing and the regulation of posture". J. Exp. Psychol. 11, 1985; pp. 617– 622.

[34] Yogev-Seligmann G., Hausdorff J., and Giladi N., "The role of executive function and attention in gait," Mov. Disord., vol. 23, no. 3, 2008, pp. 329–342.

[35] Beauchet O., Dubost V., Gonthier R., and Kressig R.W., "Dual-task-related gait changes in transitionally frail older adults: the type of the walking-associated cognitive task matters". Gerontology 51, 2005; pp. 48–52.

[36] Bloem B.R., Steijns J.A., and Smits-Engelsman B.C., "An update on falls". Curr. Opin. Neurol. 16, 2003; pp. 15–26.

[37] Hollman J., Youdas J., and Lanzino D., "Gender Differences in Dual Task Gait Performance in Older Adults", American J. of Men's Health 5(1) 2011, pp. 11–17

[38] Hollman, J., Kovash, F., Kubik, J., and Linbo R., "Age-related differences in spatiotemporal markers of gait stability during dual task walking", Volume 26, Issue 1, June 2007, pp. 113-119

[39] Hausdorff J.M., Edelberg H.K., Mitchell S.L., Goldberger A.L., and Wei J.Y., "Increased gait unsteadiness in community-dwelling elderly fallers". Arch. Phys. Med. Rehabil. 78 (3) 1997, pp. 278–83.

[40] Maki B.E., "Gait changes in older adults: predictors of falls or indicators of fear". J. Am. Geriatr. Soc. 45, 3, 1997, pp. 313–20.

[41] Krebs D.E., Jette A.M., and Assmann S.F., "Moderate exercise improves gait stability in disabled elders". Arch. Phys. Med. Rehabil. 79 (12), 1998, pp. 1489–95.

[42] Menz H.B., Lord S.R., and Fitzpatrick R.C., "Age-related differences in walking stability", Age Ageing 32 (2), 2003; pp.137–42.

[43] Woollacott M. and Shumway-Cook A., "Attention and the control of posture and gait: a review of an emerging area of research". Gait Posture. 2002;16(1), pp. 1–14.

[44] Yardley L., Gardner M., Leadbetter A., and Lavie N., "Effect of articulatory and mental tasks on postural control". NeuroReport; 10, 2, 1999, pp. 215–9.

[45] Teasdale N., Bard C., LaRue J., and Fleury M., "On the cognitive penetrability of postural control". Exp Aging Res 19, 1993; pp. 1–13.

[46] Shumway-Cook A. and Woollacott M., "Motor Control: Theory and Practical Applications", 2nd ed. Baltimore, MD: Lippincott, Williams and Wilkens, 2000.

[47] Shumway-Cook A. and Woollacott M., "Attentional demands and postural control: the effect of sensory context". J. Gerontol. 2000; 55 A:M10–6.

[48] Maylor E.A. and Wing A.M., "Age differences in postural stability are increased by additional cognitive demands". J. Gerontol. 51B, 1996, pp. 143–154.

[49] Shumway-Cook A., Woollacott M., Baldwin M., and Kerns K., "The effects of cognitive demands on postural sway in elderly fallers and non-fallers". J. Gerontol. 1997; 52:M232–40.

[50] Woollacott M. and Shumway-Cook A., "Attention and the control of posture and gait: a review of an emerging area of research". Gait Posture 16, 1, 2002, pp. 1–14.

[51] Holmes J., Jenkins M., Johnson A., Adams S., and Spaulding S., "Dual-Task Interference: The Effects of Verbal Cognitive Tasks on Upright Postural Stability in Parkinson's Disease", Parkinson's Disease, Volume 2010, pp. 1-5.

[52] Siu K.C., Lugade V., Chou L.S., van Donkelaar P., and Woollacott M. H., "Dual-task interference during obstacle clearance in healthy and balance-impaired older adults.", Aging Clin. Exp. Res.. Aug; 20 (4), 2008, pp. 349-354.

[53] Beauchet O., Dubost V., Allali G., Gonthier R., Hermann F.R., and Kressig R.W., "Faster counting while walking' as a predictor of falls in older adults". Age Ageing 36, 2007, pp. 418–423.

[54] Lundin-Olsson L., Nyberg L., and Gustafson Y., "Stops walking when talking as a predictor of falls in elderly people". Lancet 1997; 349, 9052, pp. 617.

[55] Lundin L., Nyberg L., and Gustafson Y., "Stops walking when talking as a predictor of falls in elderly people". Lancet 1997; 349, 9052, pp. 617.

[56] Verghese J., Buschke H., Viola L., Katz M., Hall C., Kuslansky G., and Lipton R., "Validity of divided attention tasks in predicting falls in older individuals: a preliminary study". J. Am. Geriatr. Soc. 50, 2002, pp. 1572–1576.

[57] Burkow-Heikkinen L., "Non-invasive physiological monitoring of exercise and fitness", Neurolog. Res., Volume 33, Number 1, January 2011, pp. 3-17

[58] Schepers H., "Ambulatory Assessment of Human Body Kinematics and Kinetics", PhD. Thesis, Universiteit Twente, June 2009.

[59] Bilney B., Morris M., and Webster K., "Concurrent related validity of the GAITRite walkway system for quantification of the spatial and temporal parameters of gait". Gait Posture, 17, 2003, pp. 68-74.

[60] McDonough A.L., Batavia M., Chen F.C., Kwon S., and Ziai J., "The validity and reliability of the GAITRite system's measurements: A preliminary evaluation". Arch. of Phys. Med. and Rehab., 82, 2001, pp. 419-425.

[61] Orr R. and Abowd G., "The smart floor: A mechanism for natural user identification and tracking". Proceed. of the Conf. on Hum. Fact. in Comp. Syst., 2000.

[62] Suutala J. and Rning. J., "Towards the adaptive identification of walkers: Automated feature selection of footsteps using distinction sensitive LVQ". Int. Works. on Proces. Sens. Inf. for Proact. Syst., June 14-15 2004.

[63] Lee M., Buss A., Bazin A., and Mark S., "A floor sensor system for gait recognition", Fourth IEEE Works. on Aut. Ident. Adv. Techn., 2005, pp. 171–176.

[64] Ferrucci L., Baldasseroni S., Bandinelli S., de Alfieri W., Cartei A., and Calvani D., "Disease severity and health-related quality of life across different chronic conditions". J. of the Amer. Geriat. Soc., 48, 2000, pp. 1490-1495.

[65] Maki B.E., "Gait changes in older adults: Predictors of falls or indicators of fear". J. of the Am. Ger. Soc., 45, 1997, pp. 313-320.

[66] Yogev G., Giladi N., Peretz C., Springer S., Simon E.S., and Hausdorff J.M., "Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding?" Eur. J. Neurosci. 22, 5, 2005; pp. 1248–56.

[67] Springer S., Giladi N., Peretz C., Yogev G., Simon E.S., and Hausdorff J.M., "Dual-tasking effects on gait variability: the role of aging, falls, and executive function". Mov. Disord. 21, 7, 2006, pp. 950–957.

 ISBN: 978-1-61208-155-7

The Entry Point in the Identification of Familiar Objects

Barbara Bazzanella
Department of Cognitive and Education Sciences
DISCOF, University of Trento
Corso Bettini 31, 38068 Rovereto, Italy
barbara.bazzanella@unitn.it

Paolo Bouquet
Department of Engineering and Computer Science
DISI, University of Trento
Via Sommarive 14, 38123 Trento, Italy
bouquet@disi.unitn.it

***Abstract*—This paper reports an experiment which explores whether there is a preferential level of abstraction that serves as the entry point in identification of familiar objects. In a category-verification task the participants were presented with a category label and asked to indicate whether a picture presented a brief time later was an example of the category. Familiar entities from three different categories of objects (artwork, building and product) and unfamiliar entities from three contrasting categories (home furnishing, utensil and musical instrument) were categorized at three different levels of abstraction (superordinate, basic and subordinate). We found that participants were faster to identify familiar entities at the unique level of identity (subordinate level) than they were to verify them at the basic level. On the contrary, verification times for unfamiliar entities were faster at the basic level than at the subordinate level. These results suggest that the entry point of familiar entities is shifted to the most subordinate level of abstraction in object identification (i.e., the level of singular concepts). Implications of these findings for the basic level advantage effect are discussed.**

***Keywords*-entry point; singular concepts; basic level advantage; unique level of identity.**

I. Introduction

Humans have an extraordinary ability to identify individual objects and this ability is crucial for daily life. We need to correctly recognize and identify all the individuals with which we interact (e.g., people, pets, objects) and successfully perform actions and have reactions that must be directed to these entities.

Any individual object can be identified at multiple levels of abstraction. For example, whereas a painting can be identified as a *painting* (basic level), the same painting can be identified more generally as an *artwork* (superordinate level) or more specifically as a *portrait* or *Mona Lisa* (subordinate or unique level, respectively). In this paper we aim to investigate whether there is a preferential level of abstraction at which an individual is first identified. Do we first identify the most famous Leonardo's painting as *Mona Lisa* or as a *painting*? Is there a direct and rapid access to the unique mental representation of Mona Lisa (i.e., the singular concept of Mona Lisa) during the identification process, or is this access mediated by accessing higher level conceptual representations (i.e., general concepts)? These questions deal with the bottom-up access to mental representations of individuals in object recognition. To investigate if the singular concept represents the first conceptual representation activated during the identification process - *the entry point* in individual object recognition to use a term proposed by Jolicoeur et at. [1] - we performed an experiment which investigates whether people identify individual artifacts from three different categories (i.e., artwork, building and product) as quickly (or more quickly) at the unique level of identity (e.g., Mona Lisa) as at the basic level (e.g., painting). The results of the experiment challenges the hypothesis that objects are necessarily first identified as members of basic-level categories before further identification, and provide preliminary evidence, which may stimulate the debate about individual objects and their conceptual representations. The rest of the paper is organized as follows. We review related work in Section II. In Section III we discuss the motivations and the hypothesis of the study. Section IV presents the experiment and results. Finally, the contribution of the paper with respect to the previous work is discussed in Section V.

II. Related Work

The idea that, of all the various categories to which a given entity belongs, some appear to be more readily accessible to the human mind than others, has been widely investigated by Rosch et al. since from their first studies on human categorization [2]. The authors found that, although all objects can be categorized at different levels of abstraction, there is one level, called the basic level, that has a special status in categorization (a phenomenon known as basic level advantage). To test the relation between basic level advantage and object identification, Rosch and colleagues [3][2] used several object-identification tasks. The authors found that people prefer to use basic-level terms to name objects (e.g., dog) over more general or specific terms (e.g., animal or poodle), they are faster to verify objects at an intermediate level of specificity than at more general and more specific levels and they are primed by basic-level terms more than by subordinate- or superordinate-level names.

To explain the basic-level effects, Jolicoeur, Gluck and Kosslyin [1] proposed that certain nodes within the hierarchical representation of object categories in memory serve as "entry points" for probing the semantic network. An

 ISBN: 978-1-61208-155-7

entry point corresponds to the level where “the perceptual stimulus first makes contact with its underlying memorial representation”. Visual stimuli are first identified through one of these entry-level categories so that any information stored directly with the corresponding entry-level node is activated earliest in the identification process. Additional information becomes available later, as activation spreads downward toward more specific concepts or upward toward more general concepts. Basic-level effects are observed for typical category members because the basic-level category nodes serve as the entry-point for such items.

However, research on human object identification have demonstrated that the entry point can be modulated by at least two factors: 1) typicality of an exemplar for its corresponding basic level and 2) domain-specific expertise. Jolicoeur et al. [1] suggested that atypical category members fail to show a basic level advantage because their entry-points are specific rather than basic. An atypical member is structurally dissimilar to the other members of the same basic level category and, therefore, it is more easily categorized at subordinate level than at the basic. Murphy and Brownell [4] explain this effect arguing that atypical subordinates have many of the characteristics of basic categories (i.e. they are specific) but, unlike other subordinates, they are also very distinctive.

Also expertise in a particular field is likely to shift entry level of many objects towards the subordinate level. Johnson and Mervis [5] and Tanaka and Taylor [6], for example, studied the interaction of knowledge and basic-level categorization in individuals with varying levels of knowledge about song-birds and dogs, respectively. They found that experience increased accessibility to categorical knowledge at subordinate levels, causing these levels to function as basic. However, the efficiency advantage of the previous basic level was not lost as knowledge about subbasic categories increased.

In the domain of face perception, Tanaka [7] proposed a similar expertise-mediated shift in identification of familiar faces. According to this hypothesis, even though few people are experts in recognition of objects from a particular category, all adults can be considered experts in human face recognition [8]. Therefore, if face recognition follows the pattern of other kinds of expert object recognition, people should show a downward shift in recognition as a result of experience. In this case, however, the face expertise hypothesis predicts that the entry point of face recognition is at the most subordinate level of abstraction that is the level of unique identity where the category label is a proper name referring to a single individual in the world (e.g., Barack Obama). The results from four experiments support the face expertise hypothesis showing that, for example, a face is more likely to be identified as *Barack Obama* rather than as a *person* or as *politician*. Similar results have been reported by Belke et al. [9] in the context of art recognition. In this study the authors provides empirical evidence that art is distinguished from other real world objects in human cognition, in that the identification of visual art is at the subordinate level of the producing artist rather than at the basic level of the object.

III. Rationale for the Study

The studies described above provide evidence that for many objects the identification process operates at levels other than the basic level. Moreover, for a special class of stimuli (i.e., familiar faces) the entry point appears to be shifted to the level of unique identity. Since human faces have been often considered special stimuli in visual recognition, the question whether a similar shift can happen for other types of familiar entities remains open.

The first aim of the present study is to investigate whether the entry point in the identification of unique non-face objects is at the level of unique identity as that of face objects. Up to now, research in the domain of object recognition has been concerned with object classes such as furniture, every-day-objects and even artificial objects, but very little is known about the representation and initial identification of unique entities belonging to these classes. For instance, what might be the first access to semantic memory when a person identifies the “Eiffel Tower”? According to a strong form of the basic-level advantage hypothesis, called by Murphy et al. [4] *basic-first hypothesis*, we should expect that the entry point in this case is at the level of “monument” or “tower”, or even more general “work of art”, corresponding to the basic level of the stimulus. People may access to the unique level of identity only after the basic level is activated. Therefore, if the access to the subordinate level of identity is mediated through the basic-level, we should predict that the basic-level categorization should be faster than the subordinate-level categorization. On the contrary, if the stimulus is recognized at the level of unique identity, as “Eiffel Tower”, recognition times should be as fast as or faster at this level than at the basic level.

Our hypothesis is that a person first recognizes an individual entity at the level of unique identity when she possesses a singular concept on that individual entity in semantic memory. We assume that the initial identification of an individual entity, whose information is structured in memory as a singular concept, yields cognitive processing that differs from that involved in the identification of objects which are not individuated in memory by means of singular concepts. Initializing the individual concept of an entity makes that entity unique and identifiable (i.e., atypical in a sense) from the other members of the same basic level category. Then, this entity can be categorized faster at the most subordinate level of categorization, namely the unique level of identity. Having the singular concept of an object entails the direct recognition of the object through that concept which serves as the access node to the knowledge that the agent has about the object. As a result, any information stored at the level of the singular concept becomes available earliest in processing.

On these premises, we hypothesize that the direct access to semantic information about unique individuals during the recognition process is not a cognitive process specialized for human faces, but is a general mechanism that humans use in the recognition process of unique identifiable entities. To test this hypothesis, we investigated the identification process using another category of unique entities, i.e., artifact. We predict that, if the entry point is set on the basis of the level of the uniqueness of the items within the category, the unique-level categorization of unique items should be faster than their upper-level categorizations.

IV. The experiment

In the experiment we used a category verification task similar to that adopted by Tanaka [7] in the domain of face recognition and by Belke [9] in art recognition. Participants were shown with a superordinate, basic or subordinate level category name and a brief time later were shown with a picture. Their task was to indicate whether the picture was an exemplar of the category. The results were compared between familiar and unfamiliar objects. Familiar entities were selected from three categories of objects (i.e., artwork, building and product) and contrasted with unfamiliar entities from three contrasting categories (home furnishing, utensil and musical instrument). In the experiment, participants were asked to verify exemplars from these categories at superordinate (e.g., “artwork”, “building”, “furnishing”), basic (e.g., “painting”, “tower”, “chair”) and subordinate levels (e.g., “Mona Lisa”, “Eiffel Tower”, “rocking chair”) of categorization. In previous research [2], [1], it has been shown that participants were faster to categorize exemplars at the basic level (e.g., verifying that an entity is a “dog”) than categorizing exemplars at the superordinate level (e.g., verifying that an entity is an “animal”) and at the subordinate level (e.g., verifying that an entity is a “poodle”). Therefore, according to the basic-first hypothesis, artifacts should be categorized first at the basic level (regardless of the fact that they are familiar or unfamiliar). That is, basic level verifications should be faster than superordinate verifications and than subordinate verifications (unique identity name or model name verifications). For instance, people should be faster to verify that a picture is a “painting” than to verify that it is an “artwork”or “Mona Lisa”. On the contrary, we expect that subordinate-level representations will be more accessible than the basic-level representations for familiar objects. That is, participants should be as fast or faster to verify the unique identity of a familiar object (e.g., “Mona Lisa”) than to verify that the object is an “artwork” or a “painting”. We expect the same pattern of results for very familiar products, like familiar car models. That is, people should be as fast or faster to verify that a car is a “Fiat 500” than to verify that is a “vehicle” or a “car”.

A. Method

1) Participants: Twenty participants (12 males and 8 females) took part in the experiment. Mean age was 31.15 (SD=6.35), ranging from 23 to 45 years. Participants were tested individually and they were not paid for participation.

2) Stimuli: Pictures were chosen from three categories of familiar entities (artwork, building and product) and from three contrasting categories of unfamiliar entities (home furnishing, utensil and musical instrument). As famous artworks, some of the most well-known paintings and sculptures in art history were selected (e.g., Mona Lisa, David). Famous building were selected from those used in [10] (e.g., Eiffel Tower, Twin Towers). Finally, for the product category we used some of the most popular models of vehicles and electronic devices in Italy (e.g., Fiat 500, Iphone). For each category we selected 4 items. Additionally, four pictures other than those used for experimental trials were selected for practice trials.

3) Procedure: At the beginning of the experimental session, participants were presented with instructions explaining the category verification task on a monitor screen. They were also provided with the complete list of the subordinate-level terms for all of the 24 target exemplars presented in a random order one after the other. Subsequently, to signal the beginning of each trial, a fixation cross appeared for 1000 ms on the monitor. Next, a blank screen appeared for 1000 ms, followed by a category word which remained for 2500 ms. Finally, after 500 ms blank interval, the category name was replaced with a picture. The participants’ task was to verify whether the picture matched the category name, by pressing as quickly as possible the corresponding TRUE or FALSE buttons. The picture remained on the screen until the answer was given. The two response keys were counterbalanced for hand across participants. Trial order was fully randomized. Figure 1 illustrates the design of a sample trial in the category-verification task used in the experiment. The experiment consisted of 144 experimental trials, resulting from 24 items with two response types (TRUE and FALSE) and three levels of categorizations. That is, each item was shown six times. In the superordinate level and true condition, the category-word could be “artwork”, “building”, “product”, “furnishing”, “utensil”, “musical instruments”. In the basic level and true condition it could be “painting”, “tower”, “phone” and so on. Finally, in the subordinate level and true condition the category word was the proper name of the artifact, the model name of the product or the specific type of furnishing, utensil or musical instrument. In the false conditions, category words were taken from a different exemplar of the same higher-order level category. For example, the “Eiffel Tower” letter string and the “Leaning Tower of Pisa” picture stimulus were paired, falling both

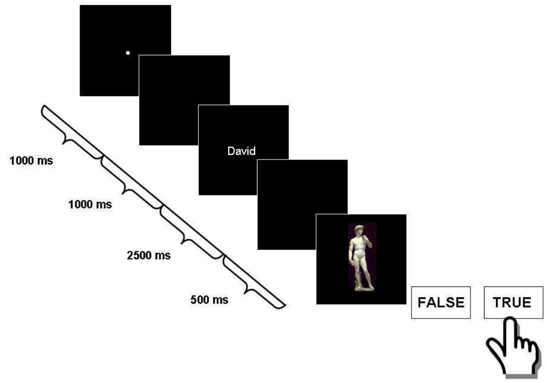


Figure 1. Trial presentation sequence in the category verification task. On each trial, a word was viewed (at superordinate, basic or subordinate level), followed by a picture, and the subjects were asked to indicate whether the picture matched the word.

under the same inclusive category "tower". In the basic level condition, a false word label that shared the same superordinate category was provided (e.g., the letter string "painting" was presented with a "statue" picture stimulus, with both referring to the superordinate category "artwork"). False trials were designed with the restriction that each word-picture combination at the subordinate level would appeared only once during the experiment and each word within a level of categorization would appeared with the same frequency in order to prevent response bias. The experiment was implemented in Matlab using the Psychtoolbox-3. An example of the category words used in the three categorization levels for true and false conditions is shown in Table I. We note that the results of the experiment critically depend on the ability of participants to identify the target stimuli at the subordinate level of identity. For example, a person who has never encountered the statue of David by Michelangelo and who is not familiar with his name would not be able to verify the David name in a category verification task. To exclude the possibility that basic-level categories were advantaged due to a lack of familiarity with the subordinate level categories, at the end of the experiment, participants were asked to identify each stimulus on a very specific (subordinate) level. For example, participants were asked to indicate the title of a painting or the model of a car. Pictures that could not be named at the subordinate level were omitted from the analysis for the corresponding participant.

		Category Word	
Stimulus	Level	True Condition	False Condition
Mona Lisa (familiar)	Sup.	artwork	building
	Basic	painting	sculpture
	Sub.	Mona Lisa	The Scream
Eiffel Tower (familiar)	Sup.	building	utensil
	Basic	tower	skyscraper
	Sub.	Eiffel Tower	Leaning Tower of Pisa
Fiat 500 (familiar)	Sup.	product	building
	Basic	car	audio player
	Sub.	Fiat 500	Mini Cooper
rocking chair (unfamiliar)	Sup.	furnishing	artwork
	Basic	chair	table
	Sub.	rocking chair	folding chair
bread knife (unfamiliar)	Sup.	utensil	artwork
	Basic	knife	spoon
	Sub.	bread knife	flick knife
electric guitar (unfamiliar)	Sup.	musical instrument	building
	Basic	guitar	drum
	Sub.	electric guitar	acoustic guitar

Table I
STIMULI AND CATEGORY WORDS USED IN THE EXPERIMENT

B. Results

An analysis of variance was performed on reaction times of correct true and, separately, of correct false responses. Before performing the analysis, trials with outlying RTs (i.e., below 300 ms or above 3000 ms) were excluded from the data set. To test for differences between the three familiar categories, mean RTs were submitted to two-way ANOVA with Category (artwork, building and product) and Category Level (superordinate, basic and subordinate) as within-participant factors. This analysis showed that the main effect of level of categorization was significant, $F(2,38) = 8.93$, $p < 0.001$. Neither the main effect of category $F(2,38) = 1.36$, $p = 0.27$, nor the interaction between category and category level were significant $F(4,76) = 0.20$, $p = 0.93$. The same analysis was performed to test for differences among the unfamiliar categories. Mean RTs were subjected to a 3 (Category: home furnishing, utensil and musical instrument) $\times$ 3 (Category Level: superordinate, basic and subordinate) within-participants ANOVA. As in the previous analysis, we found that neither the main effect of category $F(2,38) = 1.03$, $p = 0.36$, nor the interaction between category and category level were significant $F(4,76) = 1.73$, $p = 0.15$. On the contrary, the main effect of level of categorization was significant, $F(2,38) = 11.20$, $p < 0.001$.

Consequently, categories of familiar entities and categories of unfamiliar entities were collapsed to obtain individual mean RTs to familiar and unfamiliar entity types, respectively. Table II shows the separate reaction times for true responses as a function of category (Familiar vs. Unfamiliar) and category level (Superordinate, Basic and Subordinate). An analysis of variance (ANOVA) was performed for reaction times of correct true responses with Familiarity (familiar or unfamiliar) and Category Level (superordinate, basic and subordinate) as within participant factors. The main effect of Familiarity was not significant $F(1,19) = 0.93$, $p = 0.35$, indicating that overall participants were not faster to categorize familiar entities than they were to categorize unfamiliar entities. On the contrary, the main effect of category level was significant, $F(2,38) = 13.61$,

 ISBN: 978-1-61208-155-7

	Category Level		
Category	Superordinate	Basic	Subordinate
Familiar	1200	1072	949
Unfamiliar	1236	979	1096

Table II
MEAN REACTION TIMES FOR THE TRUE RESPONSES AS A FUNCTION OF CATEGORY (FAMILIAR VS. UNFAMILIAR) AND CATEGORY LEVEL (SUPERORDINATE, BASIC AND SUBORDINATE).

$p < 0.001$. Critically, the Familiarity $\times$ Category Level interaction was also significant, $F(2, 38) = 5.69$, $p < 0.01$. As shown in figure 2, participants were faster to categorize unfamiliar entities at the basic level than at subordinate level, $F(1, 19) = 4.10$, $p < 0.05$. For instance, they were faster to verify that a bread knife is a "knife" than they were to verify that it is a "bread knife". On the contrary, for familiar entities, participants were faster to categorize entities at the subordinate level (i.e., unique level) than at the basic level, $F(1, 19) = 7.72$, $p < 0.05$. For example, participants were faster to verify that the David is "The David" than to verify that it is "a statue". The results seem to confirm the assumption of a general basic-level advantage [2] for unfamiliar entities. However, contrary to this assumption, we found a different pattern of results for entities that can be identified at the unique level of identity (i.e., familiar entities). At the subordinate level (i.e., the unique level of identity) familiar entities were categorized faster than at the basic level, showing that the basic-level advantage disappears for entities that can be identified at the most specific level of identity.

Direct comparisons between TRUE judgments showed that subordinate-level judgments in the familiar category were significantly faster than subordinate judgments in the unfamiliar category, t(19)=3.74, p<0.01. The related comparison between reaction times for the familiar-basic and unfamiliar-basic categorizations showed the opposite pattern. Unfamiliar-basic judgments were significantly faster than familiar-basic judgments, t(19) = 2.36, p<0.05.

In summary, these results demonstrated that familiar entities were identified differently from unfamiliar entities. People are faster to categorize familiar entities at subordinate level than they are to verify them at the basic level. On the contrary, verification times for unfamiliar entities were faster at the basic level than at the subordinate level. Moreover, the results seem suggest that the shift of the entry point in recognition towards the subordinate level is not peculiar of some special categories of entities but is a more general phenomenon concerning all the entities that have a unique representation in memory. An ANOVA was also performed for correct false reaction times with familiarity (familiar or unfamiliar) and category level (superordinate, basic and subordinate) as within-participant factors. Table III shows the separate reaction times for false responses as a function

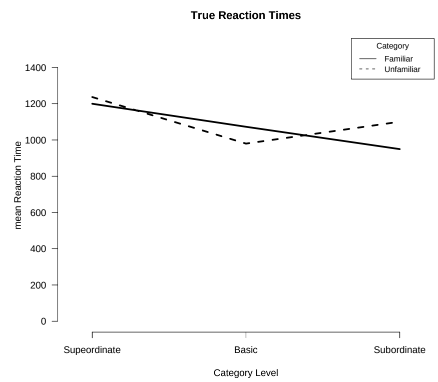


Figure 2. Mean Reaction Times for categorizing familiar and unfamiliar entities at superordinate, basic and subordinate levels in the TRUE condition.

of category (Familiar vs. Unfamiliar) and category level (Superordinate, Basic and Subordinate). The results of this

	Category Level		
Category	Superordinate	Basic	Subordinate
Familiar	1108	1104	1052
Unfamiliar	1118	1010	1182

Table III
MEAN REACTION TIMES FOR THE FALSE RESPONSES AS A FUNCTION OF CATEGORY (FAMILIAR VS. UNFAMILIAR) AND CATEGORY LEVEL (SUPERORDINATE, BASIC AND SUBORDINATE).

analysis were globally in accordance with those obtained for correct true response times. The main effect of familiarity was not significant, $F(1, 19) = 1.40$, $p = 0.24$. This means that people were not faster to verify familiar entities than unfamiliar entities. Instead, the main effect of level of categorization was significant, $F(2, 38) = 12.97$, $p < 0.001$, indicating slower responses for a more specific level of categorization. Critically, the Familiarity $\times$ Category Level interaction was also significant, $F(2, 38) = 6.59$, $p < 0.001$. The interaction indicates that participants were faster to correctly reject unfamiliar entities at the basic level than at the subordinate level, $F(1, 19) = 4.10$, $p < 0.05$, whereas they were equally faster to correctly reject familiar entities at basic level than at subordinate level, $F(1, 19) = 0.161$, $p = 0.69$. The last result represents a difference compared to the previous analysis on the correct true reaction times. While participants were faster to verify a familiar entity at the subordinate level than at the basic level, they were equally fast to correctly reject a familiar entity at the subordinate-level as at the basic-level. This result could be explained arguing that the mismatch between the singular concept activated by the word category and that activated by the picture takes more time to be recognized. However, the result does not contrast our hypothesis since it shows that it is not the case that correctly rejecting a familiar

 ISBN: 978-1-61208-155-7

entity at the basic-level is faster than rejecting a familiar entity an the subordinate level, as predicted by the basic-level advantage hypothesis. On the contrary, the lack of a basic level advantage for the true rejecting trials of familiar entities indicated that representations of familiar entities are highly accessible at a specific level of abstraction which is related to the proper name of the entities.

As in the TRUE condition, we found that direct comparisons between FALSE judgments showed that basic-level judgments in the unfamiliar category were significantly faster than basic-level judgments in the familiar category, $t(19)=4.07$, $p<0.001$. These results open the question whether a mechanism of inhibition may come into play to favor the access to singular representations compared to higher level representations. To answer this question, future experiments should compare familiar and unfamiliar entities from the same categories to reduce as much as possible processing differences due to the category.

V. Conclusion

The purpose of the study was to provide empirical evidence for the direct access to semantic memory of unique entities through individual concepts. The results from a category verification experiment, which has previously proved sensitive to address the entry point identification issue, suggest that the initial point of contact between the perceptual stimulus of a unique distinguishable object and its memory representation is not mediated by high level conceptual structures (i.e., general concepts).

The results of our study mirror previous findings in recognition of familiar faces [7] and visual art identification [9], in that a preferential accessibility to more specific representations in memory has been previously demonstrated for famous face and art recognition. However, in these studies the underlying idea is that there is something “special” in the target entities that lead people to develop specialized mechanisms of identification. Belke [9], for instance, explicitly states that “art has a special status amongst external-world objects since it allows for a memorial representation based on stylistic features that are linked in semantic memory to the creating artist” (p.199). The special status of faces was instead conceived by Tanaka [7] in terms of expertise. According to the face expertise hypothesis, the high level of specialization in face recognition explains the shift of the entry point for faces at the most subordinate level of abstraction. We suggest an alternative explanation for the preferential access to unique representations in memory. The idea is that having an individual representation of an object in memory is a sufficient condition to shift the entry point of recognition to the most subordinate level of categorization, that is the unique level of identification. The recognition mechanism of unique familiar entities is different from that of entities that can not be identified at the unique level of identity (i.e., unfamiliar entities). In principle, a familiar individual could be first recognized as whatever other unfamiliar individual, namely as a member of a basic level category. Our experiment provides evidence against this hypothesis. We found that unique familiar entities are verified more quickly (or rejected as quickly as) at the subordinate level of unique identity than they are at the basic level. In conclusion, the results of the experiment provided evidence in favor of our hypothesis that people are faster (or at least equally fast) to verify entities at the unique level than at higher levels of abstractions. These results suggest that whereas the entry point in recognition for most unfamiliar objects is a the basic level of categorization (i.e., the first contact with a memorial representation is at the level of a general concept), the entry point of unique familiar entities is at the subordinate level of unique identity (i.e., the first contact with a memorial representation is at the level of a singular concept).

References

[1] P. Jolicoeur, M. Gluck, and S. Kosslyn, “Pictures and names: Making the connection,” *Cognitive Psychology*, vol. 16, pp. 243–275, 1984.

[2] E. Rosch, C. Mervis, W. Gray, D.Johnson, and B.-P. Braem, “Basic objects in natural categories,” *Cognitive Psychology*, vol. 8, pp. 382–439, 1976.

[3] C. Mervis and E. Rosch, “Categorization of natural objects,” *Annual Review of Psychology*, vol. 32, pp. 89–115, 1981.

[4] G. L. Murphy and H. H. Brownell, “Category differentiation in object recognition: Typicality constraints on the basic category advantage,” *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 11, pp. 70–84, 1985.

[5] K. E. Johnson and C. B. Mervis, “Effects of varying levels of expertise on the basic level of categorization,” *Journal of Experimental Psychology: General*, vol. 126, pp. 248–277, 1997.

[6] J. Tanaka and M. Taylor, “Object categories and expertise: Is the basic level in the eye of the beholder?” *Cognitive Psychology*, vol. 23, pp. 457–482, 1991.

[7] J. W. Tanaka, “The entry point of face recogntion: Evidence for face expertise,” *Journal of Experimental Psychology: General*, vol. 130, pp. 534–543, 2001.

[8] J. Tanaka and I. Gauthier, “Expertise in object and face recognition,” in *Psychology of Learning and Motivation, Mechanisms of Perceptual Learning*, R. Goldstone, P. Schyns, and D. Medin, Eds. San Diego: Academic Press, 1997, pp. 83–125.

[9] B. Belke, H. Leder, G. Harsanyi, and C. Carbon, “When a picasso is a ”picasso”: The entry point in the identification of visual art,” *Acta Psychologica*, vol. 133, pp. 191–202, 2010.

[10] M. Gorno-Tempini and C. Price, “Identification of famous faces and buildings: a functional neuroimaging study of semantically unique items,” *Brain*, vol. 24, pp. 2087–2097, 2001.

 ISBN: 978-1-61208-155-7

From fMRI Data To Cognitive Models: Testing the ACT-R Brain Mapping Hypothesis with an Ex-Post Model

Jan Charles Lenk*, Claus Möbus†

Jale Özyurt‡, Christiane Margarete Thiel§, and Arno Claassen¶

*Human Centered Design
OFFIS Institute for Information Technology
Escherweg 2, 26121 Oldenburg, Germany
Email: lenk@offis.de
†Learning and Cognitive Systems
Department of Computing Science
University of Oldenburg
26111 Oldenburg, Germany
Email: claus.moebus@uni-oldenburg.de

‡§Biological Psychology Lab
Department of Psychology
University of Oldenburg
26111 Oldenburg, Germany
‡Email:jale.oezyurt@uni-oldenburg.de
§Email:christiane.thiel@uni-oldenburg.de
¶Email:arno.claassen@informatik.uni-oldenburg.de

***Abstract*—Recently, John R. Anderson proposed a correspondence between the modules of his cognitive architecture ACT-R and specific brain regions. This Brain Mapping Hypothesis allows the prediction of Blood-Oxygen-Level Dependent curves for these regions using cognitive models. These predictions may be compared to actual data from functional Magnetic Resonance Imaging experiments. While the Brain Mapping Hypothesis has been tested with very simple tasks mostly from algebraic problem solving, we conducted experiments with a more complex task to study the robustness of the Brain Mapping Hypothesis against different domains, multidimensional strategy spaces, and modeling errors. The ACT-R model in this paper is a synthesis of our prior models, providing a better fit imaging data. Our results show that the Brain Mapping Hypothesis is not to be dismissed, yet there still remain assumptions in the model that do cause inexact predictions for some modules. We discuss how models of complex problem solvers can achieve a better fit to data by adaptations to their symbolic structure.**

***Keywords*-Cognitive modeling, ACT-R, BOLD prediction, Brain Mapping Hypothesis**

I. INTRODUCTION

Cognitive architectures provide a modeling framework with constraints preventing modelers from creating unrealistic models of human cognitive processes [1] [2]. The prominent ACT-R (Atomic Components of Thought-Rational) by John R. Anderson has a long tradition, dating back at least to 1983 [3] [4]. The latest addition to the ACT-R theory is the mapping of its components to brain regions [5], and the enhancement of the architecture with an appropriate tooling to predict Blood Oxygen Level-Dependent (BOLD) responses for these regions.

In Section II, we shall first look into the ACT-R cognitive architecture in general and the Brain Mapping Hypothesis in more detail. We shall summarize our prior related work as well as specify our research question. Section III describes the experiment and fMRI data acquisition and preprocessing procedures. We proceed to the ACT-R model in Section IV. Results are featured in Section V and discussed in Section VI. We finally conclude in Section VII with a summary of this paper and our future directions.

II. STATE OF THE ART

The ACT-R cognitive architecture consists of eight modules: The Visual, Aural, Manual, Vocal, Declarative, Imaginal, Goal, and Production modules. Obviously, they perform specific functions: The Visual and Aural modules control the perceptual input channels of an ACT-R model, while the Manual and Vocal modules constitute its action apparatus. The Goal module stores the current goal in the form of control information, while the Imaginal module represents working memory. The Declarative module's purpose is to retrieve facts from long-term memory. All of these modules interface to the Production module via buffers. A buffer may hold a single chunk (i.e., fact) at a time. A chunk contains information in the form of slots, which may either hold atomic data or refer to other chunks in the Declarative memory. The Production module represents the procedural memory and matches, selects, and executes production rules, which compare and manipulate the buffers' contents. All actions triggered by a production in a specific module consume a certain amount of time. Thus, a model based on this architecture is an executable program in the form of production rules and may be used to predict a participant's performance in various tasks on trials of various domains, such as algebraic problem solving.

A. The ACT-R Brain Mapping Hypothesis

Anderson's latest addition to the ACT-R theory, the Brain Mapping Hypothesis, maps the activity of the ACT-R mod-

 ISBN: 978-1-61208-155-7

Table I
CENTERS AND DIMENSIONS OF THE ASSOCIATED BRAIN REGIONS FOR ACT-R MODULES[1]

Module	Region	X	Y	Z	Depth	Width	Height
Procedural	Caudate	±15	9	2	4	4	4
Goal	ACC	±5	10	38	5	3	4
Declarative	Prefrontal	±40	21	21	5	5	4
Imaginal	Parietal	±23	-64	34	5	5	4
Visual	Fusiform	±42	-61	-9	5	5	4
Aural	Auditory	±46	-22	9	5	5	4
Manual	Motor	±41	-20	50	5	5	4
Vocal	Motor	±43	-14	33	5	5	4

ules onto specific brain regions (Table I). Thus, ACT-R implements a tooling that enables BOLD signal predication for these brain regions. However, the regions cover only a very small volume of the brain altogether, and most studies were conducted using simple tasks with a limited strategy space.

Each activity inside an ACT-R module, such as fact retrieval for the Declarative or visual encoding for the Visual module, is recorded along with its duration by the architecture. This trace is used to predict the BOLD response with the following set of functions.

The function $H(t)$ (1) models the hemodynamic response for an active module. It is parameterized by its steepness a, magnitude m, and delay t.

$$H(t) = m(\frac{t}{s})^a e^{-(t/s)} \quad (1)$$

The module's activity trace is captured by the $D(t)$ function at a given time t, which evaluates to either 0 or 1. In combination with the hemodynamic function it accumulated to model the BOLD response (2).

$$B(t) = \int_0^t D(x)H(t-x)dx \quad (2)$$

The postulation of the Brain Mapping Hypothesis has been empirically validated with experiments and cognitive models for various domains, for instance algebra problem solving [6] [7] [8] or associative learning [9].

However, in these experiments the participants were urged to employ a single solving strategy either by instruction or the peculiarities of the experimental design. In contrast to this, our experimental design allowed for the participants to choose their personal strategies during trials.

B. Research Question and Prior Work

Thus, the research question of our project was to study the robustness of the Brain Mapping Hypothesis towards a non-algebraic task, a multidimensional strategy space, and programming or modeling errors. To our knowledge, our research group is, apart from Ragni et al. [10], the only independent research project outside Anderson's lab addressing the Brain Mapping Hypothesis.

Our first-pass models implemented a strategy each and were matched onto functional Magnetic Resonance Imaging (fMRI) data according to behavioral predictor such as response times [11]. With this approach we were able to calculate correlations between modules and regions [12] per strategy. We were not able to dismiss the Brain Mapping Hypothesis [13] and our results finally led to some conclusions for our second-pass model: First, models should use a multitasking approach during the first phase of a trial. Second, subgoals should be set as explicit chunks in the Goal buffer to predict a higher activation.

The model in this paper was implemented ex-post to achieve a better fit to experimental fMRI data. However, we did not touch all but one of ACT-R's internal or BOLD-tools parameters. Rather, we tried to adapt the symbolic structure of the model in order to achieve a better fit.

III. METHODS AND MATERIALS

The particular design of our experiment has been discussed in detail in our previous publications [13]. The task was to determine whether a structural formula matched a chemical compound. The participants in the fMRI study were 62 lower-grade school children ages ranging from 10 to 13. The chemical formula language is usually not known to children of that age group. To prevent carry-over effects in any case, fictional chemical elements and numerals were used. The fMRI experiments were conducted in a multi-disciplinary research project, which not only studied the Brain Mapping Hypothesis, but also the impact of affective feedback [14] and the processing of the chemical formula language for school children [15]. The problem may be described as a well-structured rule-using problem [16].

A. Experimental Design

Thus, a trial consisted of the visual and aural presentation of a chemical compound as in Fig. 1. Two structural formula were presented at the left and the right. The participant had to decide which one of these matched the chemical compound. For this, the participant was familiar with the following constraints for the chemical language:

1) The abbreviation for an element is defined by two letters
2) The first letter of the abbreviation is the same as the first letter in the name of the element
3) Both letters appear in the element's name.
4) An element may have a multiplicity from 1 to 4 in the compound. Distinct three letter words served as numerals to denote the multiplicity:
   - 1/-
   - 2/pli
   - 3/pla
   - 4/plo

[1]in Talairach coordinates, voxel size 3.125 mm × 3.125 mm × 3.2 mm

 ISBN: 978-1-61208-155-7

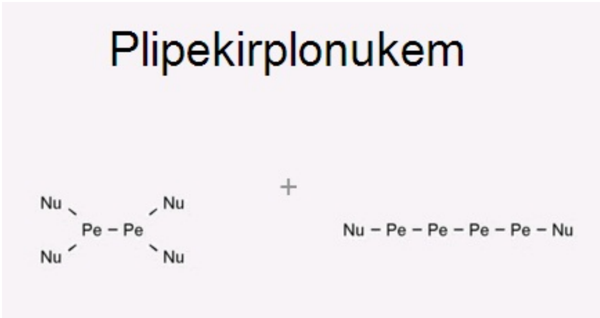


Figure 1. A sample trial [13] where a numeral constraint is violated

5) The position of a numeral is always in front of the owning element in the compound name
6) The central element of the structural formula is always the first in the compound name

The visual presentation of the problem lasted for 4.5 seconds. During this timespan and an additional second the participant could respond, so that the complete trial solving phase lasted for a maximum of 5.5 seconds. After that, a variable jitter time between 2 and 18 seconds followed before feedback presentation, which in turn lasted for 2.5 seconds. Subsequently, another jitter time between 2 and 18 seconds followed before the begin of the next trial.

B. fMRI Data Acquisition

The participants were presented 80 trials in two runs of 40. The fMRI data were acquired using a Siemens MAGNETOM Sonata (1.5 T) system with a standard whole-head coil, obtaining $T2*$-weighted echo planar images with BOLD contrast (matrix size: 64×64, pixel size: 3×3 mm^2).

Each functional run resulted in 408 volumes of 30 3-mm thick axial slices with a 0.6 mm gap (TR=2s, TE=50ms). Preprocessing was performed with the Statistical Parametric Mapping (SPM5) software. After rigid body motion correction, the time series from each voxel were temporally realigned to the middle slice. Structural and functional volumes were coregistered and spatially normalized to a standard T1 template based on the Montreal Neurological Institute (MNI) reference brain using $2 \times 2 \times 2$ mm^3 voxels. To accommodate inter-subject anatomical variability, the data were smoothed with a Gaussian kernel of 8 mm full-width-half-maximum.

After preprocessing, the fMRI data were analyzed with a Regions of Interest (ROI) approach [17]. The ROIs (see also Table I) were defined by the ACT-R Brain Mapping Hypothesis [5]. Locations and dimensions of the ROIs were transformed from Talairach into MNI coordinates. The raw gray values for all voxels contained by each ROI were averaged, resulting in time series of BOLD responses per participant for each ROI in left and right hemispheres respectively.

IV. Calculation

To find the correct structural formula, the constraints from Section III-A may be checked with the following tasks [13]:

- T1 Visually and/or auditorially perceive and the different parts of the compound name
- T2 Count the outer elements of a structural formula (T2a) and compare them with the second numeral in the compound name (T2b).
- T3 Count the inner elements of a structural formula (T3a) and compare them with the first numeral in the compound name (T3b)
- T4 Compare the inner element with the first element of the compound name
- T5 Compare the outer element with the second element of the compound name
- T6 Indicate the correct formula

Task T1 can be parallelized with T2a and T3a as the compound name is presented auditorially and does not necessarily need the visual input channel. Tasks T2-T5 may be applied to either the left or the right structural formula, or even both. Thus, the most efficient problem solver restricts himself to the evaluation of just one structural formula and decides whether it matches, or, in case a constraint is violated, if it does not.

A. ACT-R Model

Our prior models represented multiple strategies that differed in their sequences of T2 to T5 and formula positions. The model in this paper attempts to reunify these strategies.

Thus, the model may instantiate task sequence. Tasks T1, T2a, and T3a run parallel and share a common chunk in the Goal buffer, as our model validations favored multi-threaded models. Tasks T2a and T3a are always instantiated together and may run for both left and right formula locations.

The productions for Tasks T4 and T5 create separate subgoal chunks in the Goal buffer, thus they run single-threaded and no productions concerning other tasks may fire during their execution. They also regress to the visual presentation of the compound name to check whether the second letter of symbol appears in the elements name.

Each execution of the Tasks T2a/T3a, T4, and T5 creates a chunk in the Imaginal buffer to store the temporary information it needs for its context. Upon task completion this temporary information is translated into control information and transferred into the precedent parent goal.

If a constraint is violated, or all tests for a structural formula have a positive result, productions for T6 may fire and the model indicates the correct formula. If, however, 4.5 seconds have passed and the model is still busy, the model makes a guess and chooses the formula with the greater number of positive tests. It does not give a response if both formulae have the same number of positive tests.

In order to randomize the task execution sequence, the ACT-R parameter `:egs` for expected gain noise had been set to 0.04. The noise added to the productions' utilities results in random task sequences. This is based on the work of Jones et al. [18], who used this technique to differ between 'adult' and 'children' models, the latter being more explorative in terms of strategies.

For instance, the trial from Fig. 1 could be evaluated with the following three task sequences:

$$S_1 = \{T1, T2a/T3a[Left], T3b[Left], T4[Left], T2b[Left], T5[Left], T6[Left]\} \quad (3)$$

$$S_2 = \{T1, T2a/T3a[Left], T3b[Left], T4[Left], T2a/3a[Right], T3b[Right], T6[Left]\} \quad (4)$$

$$S_3 = \{T1, T2a/T3a[Right], T3b[Right], T6[Left]\} \quad (5)$$

Thus, the first sequence (3) would completely evaluate the left formula and come to the conclusion that it is indeed correct. The second sequence (4) would first evaluate parts of the left formula, then switch over to the right, find the discrepancy in the numerals and indicate the left formula as correct. The third sequence (5) would just evaluate the right formula and find the correct answer sooner than the other sequences. These sequences instantiate different strategies, which differ in their effectiveness for a given trial.

B. Data Analysis

The model makes adequate predictions for trials regarding response times as is shown in Fig. 2. It does not recapture the error rates, i.e., wrong responses and time-outs, correctly. This however, shall be of no concern in this work as we will only study correctly answered trials.

For data aggregation, the time series per ROI and participant for the whole experiment were split into short time series for each trial with a correct response by the participant. As the trials have different lengths, they were aligned onset-locked to a 12-scan template with the method from Carter, Anderson et al. [7]. In contrast to our previous studies, all scans from the trial and feedback phases were included.

After linear detrending, the percentual changes in the BOLD response were calculated and averaged across participant and trials, resulting in a single average BOLD response. Likewise, the model's BOLD predictions were aligned to a template and averaged. As the model can produce different traces for the same trial, this variability was captured by processing predictions from multiple model runs per trial. Both curves, averaged BOLD responses and predictions, were compared using Spearman's rank correlation coefficient for each Module/ROI pair.

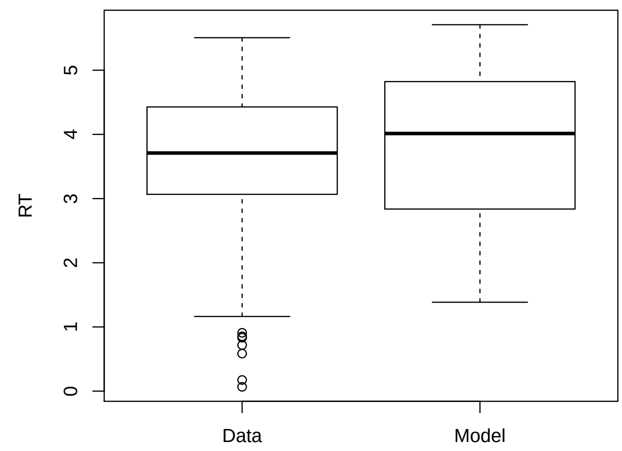


Figure 2. Response times (RT) in seconds for participants and model

V. RESULTS

The correlations in Table II between model and data are high for both regions for all modules but the Manual module, which only correlates with the left hemisphere. The predictions for the Production ROI in Fig. 3(a) fit the data well as in our previous studies, as do those for the Goal module in Fig. 3(b) when compared to our prior results. Apparently, the creation of extra subgoal chunks has raised the magnitude of the predictions. The predictions from the Imaginal module in Fig. 3(d) have a high correlation but do not reach the magnitude of the actual BOLD curves. So do the predictions for the Visual, Aural, and Manual ROIs in Figs. 3(e), 3(f), and 3(g) respectively, but the predictions from the Declarative manual in Fig. 3(c) exceed the actually measured BOLD signal greatly.

The latter observation of over-estimation may be easily explained. The ACT-R model makes heavy use of the Declarative module, by trying to recall previous problem instances of element symbols and names. This strategy is not necessary for solving the problem efficiently and may not be employed by participants. For the other modules except Production and Goal, the model apparently does not exert enough actions on the respective modules to explain data, at least if the ACT-R default value for the magnitude parameter m (Section II-A) is used.

VI. DISCUSSION

From these results, we can deduct some further guidelines for our model. First, we need to create even more extra subgoal chunks, for instance for Tasks T2a/T3a. This should heighten the magnitude of the predictions for the Goal module. However, the low magnitudes for the Visual, Aural, and Manual modules as well as the Imaginal module will not be as easily addressed. Chunk creation in ACT-R is time-costly. Thus, a model exerting many chunk creation actions

 ISBN: 978-1-61208-155-7

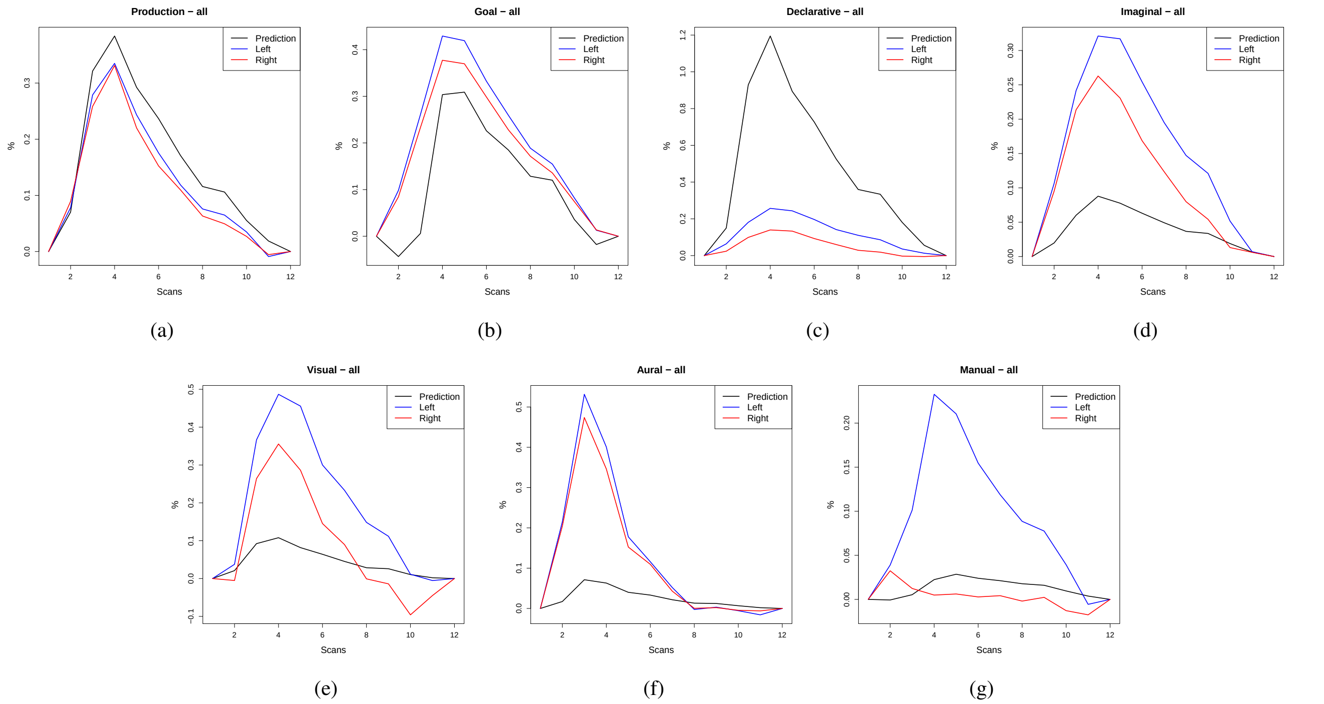


Figure 3. Predicted and actual BOLD curves for regions, averaged across all trials for Production 3(a), Goal 3(b), Declarative 3(c), Imaginal 3(d), Visual 3(e), Aural 3(f), and Manual 3(g) module/region pairs.

Table II
CORRELATION COEFFICIENT ρ FOR LEFT AND RIGHT HEMISPHERES

Module/Region	Left	Right
Production/Caudate	0.958	0.958
Goal/ACC	0.825	0.825
Declarative/Prefrontal	0.972	0.902
Imaginal/Parietal	1.000	0.972
Visual/Fusiform	0.972	0.734
Aural/Auditory	0.832	0.895
Manual/Motor	0.874	0.165

on these buffers would not be able to give a valid response within the maximum response time. We could adjust ACT-R's parameters for the BOLD tools, such as the magnitude parameter m (Section II-A), but since the Production and Goal predictions fit so well this does not seem the right approach. The internal ACT-R parameters for chunk creation latencies seem better suited for our purposes. The model spends too much effort into fact retrieval, thus the next model shall encode more factual knowledge directly in the production rules rather than in declarative memory.

VII. CONCLUSION

We were able to show that the ACT-R Brain Mapping Hypothesis also holds in large parts for tasks with multi-dimensional strategy spaces. However, our prior findings seem once more confirmed. ACT-R is under-constrained: A kind of 'best-practice' manual for ACT-R modeling is missing. Thus, an ACT-R modeler is free to implement many different strategies based on assumption, and some, if not all of these models would explain behavioral data. Still, these ACT-R models do not necessarily explain fMRI data according to the Brain Mapping Hypothesis. We have shown that the only reliable way to achieve a good fit is to adapt the model's structure to the fMRI data itself rather than to base it on behavioral predictors and task decompositions alone.

The ex-post model presented in this paper is able to reproduce a multitude of strategies. It explains fMRI data better than its single-strategy predecessors, yet the activation level is not high enough for some of the regions. From these results, we are able to make educated guesses, which shall guide our next steps and should result in an even more fine-tuned ACT-R model. It will be interesting to check whether the Brain Mapping Hypothesis in combination with this model finally allows to infer the particular task executed by individual participants, using the BOLD curves as predictors. By this, we hope to achieve the identification of Goal states for individual fMRI data. A cognitive model that is able to anticipate internal states for complex problems from neurobiological data could have many applications.

ACKNOWLEDGMENT

The study was supported by a grant from the German Ministry for Education and Research (BMBF Grant No: 01GJ0805). We wish to thank Mrs. P. Arndt, Mrs. B.

Moschner, Mrs. I. Parchmann, Mrs. A. Anschütz, and Mr. S. Bernholt for the experimental design and support by discussing our results.

REFERENCES

[1] K. A. Gluck and R. W. Pew, *Modeling Human Behavior with Integrated Cognitive Architectures*. Mahwah, NJ: Lawrence Erlbaum Associates, 2005.

[2] W. D. Gray, *Integrated Models of Cognitive Systems*. Oxford: Oxford University Press, 2007.

[3] J. R. Anderson, *The Architecture of Cognition*. Cambridge, MA: Harvard University Press, 1983.

[4] J. R. Anderson, D. Bothell, M. D. Byrne, S. Douglass, C. Lebiere, and Y. Qin, "An integrated theory of the mind," *Psychological Review*, vol. 111, pp. 1036–1060, 2004.

[5] J. R. Anderson, *How Can the Human Mind Occur in the Physical Universe*. Oxford: Oxford University Press, 2007.

[6] J. F. Danker and J. R. Anderson, "The roles of prefrontal and posterior parietal cortex in algebra problem-solving," *Neuroimage*, vol. 35, pp. 1365–1377, 2007.

[7] C. S. Carter, J. R. Anderson, J. M. Fincham, S. M. Ravizza, and M. Rosenberg-Lee, "Using fMRI to Test Models of Complex Cognition," *Cognitive Science*, vol. 32, pp. 1323–1348, 2008.

[8] A. Stocco and J. R. Anderson, "Endogenous control and task representation: An fMRI study in algebraic problem solving," *Journal of Cognitive Neuroscience*, vol. 20, no. 7, pp. 1300–1314, 2008.

[9] J. R. Anderson, D. Byrne, J. M. Fincham, and P. Gunn, "Role of prefrontal and parietal cortices in associative learning," *Cerebral Cortex*, vol. 18, no. 4, pp. 904–914, 2008.

[10] M. Ragni, T. Fangmeier, and S. Brüssow, "Deductive spatial reasoning: From neurological evidence to a cognitive model," in *Proceedings of the 10th International Conference on Cognitive Modeling*, D. D. Salvucci and G. Gunzelmann, Eds. Philadelphia, PA: Drexel University, 2010, pp. 193–198.

[11] C. Möbus and J. C. Lenk, "Bayesian identification of problem-solving strategies for checking the ACT-R/Brain-Mapping Hypothesis," in *Proceedings of the KI 2009 Workshop Complex Cognition, Paderborn, Germany*, ser. Bamberger Beiträge zur Wirtschaftsinformatik und Angewandten Informatik, U. Schmid, M. Ragni, and M. Knauff, Eds., no. 82. Bamberg University, October 2009, pp. 37–47.

[12] C. Möbus, J. C. Lenk, A. Claassen, J. Özyurt, and C. Thiel, "Checking the Brain Mapping Hypothesis: Predicting and Validating BOLD Curves for a Complex Task Using ACT-R," in *Proceedings of the 10th International Conference on Cognitive Modeling*, D. D. Salvucci and G. Gunzelmann, Eds., Philadelphia, PA: Drexel University, August 5-8, 2010 2010, pp. 163–168.

[13] C. Möbus, J. C. Lenk, J. Özyurt, C. M. Thiel, and A. Claassen, "Checking the ACT-R/Brain Mapping Hypothesis with a complex task: Using fMRI and Bayesian identification in a multi-dimensional strategy space," *Cognitive Systems Research*, vol. 12, Special Issue on Complex Cognition, pp. 321–334, 2011.

[14] B. Moschner, A. Anschütz, J. Özyurt, C. Thiel, and I. Parchmann, *Pädagogische Professionalität als Gegenstand empirischer Forschung*. Waxmann, 2008, ch. Fehlerrückmeldungen bei Lernaufgaben: Erste Ergebnisse aus Untersuchungen mit 10- bis 13jährigen, pp. 165–176.

[15] S. Heuer and I. Parchmann, "Son$_2$e oder Fus$_2$bal$_2$ - wie Sechstklässler die chemische Formelsprache interpretieren," *Naturwissenschaften im Unterricht - Chemie*, vol. 106/107, pp. 20–24, 2008.

[16] D. H. Jonassen, "Toward a design theory of problem solving," *Educational Technology Research and Development*, vol. 48, no. 4, pp. 63–85, 2000.

[17] L. Jänke, *Methoden der Bildgebung in der Psychologie und den kognitiven Neurowissenschaften*. Kohlhammer, 2005.

[18] G. Jones, F. E. Ritter, and D. J. Wood, "Using a cognitive architecture to examine what develops," *Psychological Science*, vol. 11, no. 2, pp. 93–100, 2000.

 ISBN: 978-1-61208-155-7

Discovering the Phase of a Dynamical System from a Stream of Partial Observations with a Multi-map Self-organizing Architecture

Bassem Khouzam, Hervé Frezza-Buet
Information, Multimodality and Signal
Supélec, UMI 2958 Georgia Tech/CNRS, Metz, France
{*Bassem.Khouzam,Herve.Frezza-Buet*}*@supelec.fr*

***Abstract*—This paper presents a self-organizing architecture made of several maps, implementing a recurrent neural network to cope with partial observations of the phase of some dynamical system. The purpose of self-organization is to set up a distributed representation of the actual phase, although the observations received from the system are ambiguous (i.e. the same observation may correspond to distinct phases). The setting up of such a representation is illustrated by experiments, and then the paper concludes on extensions toward adaptive state representations for partially observable Markovian decision processes.**

***Keywords*-Dynamical Systems; Recurrent Neural Networks; Self-Organization.**

I. Introduction

In the design of artificial agents evolving in some environment, one has to deal with information *streams*. Sensors provide input streams to the information processing system of the agent, and actuators actually produce a stream of actions performed in order to exploit the environment. Such an action stream is actually the output of the agent to the environment. The coupling of the agent and the environment through such information and energy streams is obvious for any biologist who analyzes the behavior of some animal. Nevertheless, in the field of Computer Science and Machine Learning, computation is often considered off-line, for technical reasons. The typical case is the use of data sets to train the models, before actually using the trained models on-line.

This paper is a contribution to the part of Computer Science that is rather involved in the design of situated systems, thus actually focusing on the process of *streams* of information. In that sense, it is related to reinforcement learning approaches, that deal with sequential decision making of an agent continuously interacting with its environment, as well as temporal systems like recurrent neural networks that handle sequences of input. Indeed, the model proposed here allows to extract the phase of some dynamical system from a sequence of observations computed from that phase. Let us illustrate the need for such a feature from a straightforward toy example.

Let us consider an animal perceiving the temperature T of the floor. Let us suppose that any temperature $T > T_0$ is dangerous to it. In our example, the temperature oscillates periodically between high and low values (for night and day). The whole solar system configuration is the *phase* of the environment, noted x^t here. It evolves in a deterministic way, according to Newton's law. The phase evolution is thus driven by a transition function ϕ such as $\forall t, x^{t+\mathrm{d}t} = \phi(x^t)$. The temperature perceived by the animal is an *observation* of the solar system, that can be expressed as $T^t = O\left(x^t\right)$ where O is the observation function, see figure 1. The sun position in the sky $P^t = O'(x^t)$ would have been another observation of the solar system phase. Let us now consider a time t for which the temperature $T^t = T_0 - \epsilon$ is just below the threshold. Should the animal try to hide away from the sun? The answer depends on the phase x^t, from which the animal could know if the temperature is currently decreasing or increasing. The decision would have been easier from the perception of sun position P^t, since O' is a bijective function, and thus the values of P^t allow to take the decision directly from the current perception. If only T^t is perceived by the animal, an efficient behavior requires that the animal is able to represent internally a value $\hat{x}^t$ from which it can take the right decision, since values of temperature may be ambiguous (similar temperatures are observed twice a day). T is thus said to be a partial observation of x. The current value $\hat{x}^t$ is inferred and updated from the successive observations T^t. It is not required that $\hat{x}$ be the exact representation of the phase x, i.e. the animal do not need to know where the planets are, but $\hat{x}$ has to be set up such that a bijective observation function implicitly exists from x to $\hat{x}$.

Partially observed environments are of interest in reinforcement learning domain. While the general trend is to find $\hat{x}^t$ before computing the corresponding value function of each state, other works like [1] implement evaluation with a recurrent network, but without explicitly extracting some $\hat{x}^t$.

The neural architecture presented in this paper relies on self-organizing neural networks in order to build such an internal representation from ambiguous sequences of observations. Many works in the literature try directly or indirectly to find $\hat{x}^t$. Concerning the use of self-organizing maps, many enhancements on Kohonen basic map [2] like in [3], [4], [5] consider the temporal dimension of input sequences but they deal with the recognition of manually

 ISBN: 978-1-61208-155-7

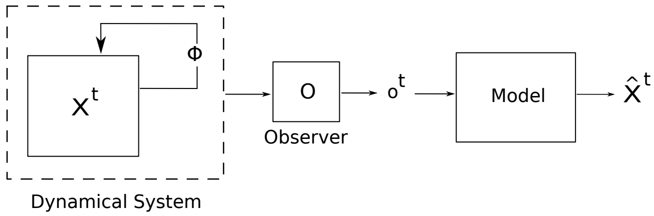


Figure 1. Dynamical system phase extraction.

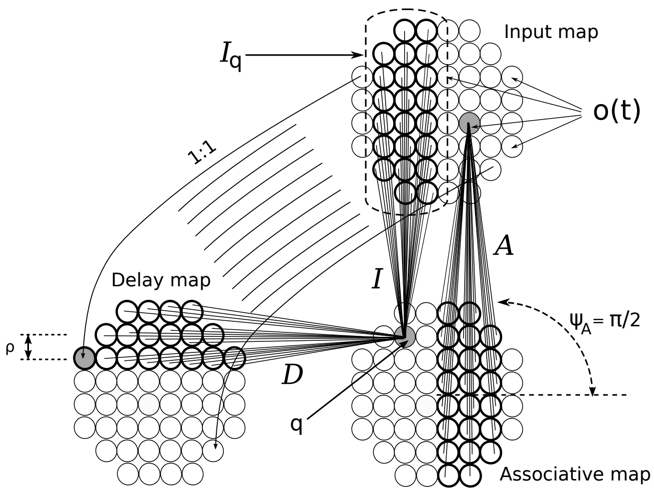


Figure 2. Model architecture. Input map and delay map are connected via one-to-one connections, other connections are one-to-many connections organized in strips. For unit q, $\mathcal{I}_q$ is the strip of kind $\mathcal{I}$ handled by q.

extracted sequences, rather than on-line stream of inputs.

Reservoir computing methods [6] are closer to that purpose, since they handle inputs from a stream one by one. Readout units then search the huge reservoir states in order to locate few significant states. The significant states represents the phases of the system that provide the inputs.

For the best of our knowledge, the present work is the first attempt to find a mapping of a dynamical system phase space using on-line self-organizing recurrent neural networks.

II. The model

As mentioned above, our goal is to design a system that generates an internal representation of the dynamical system phases from the stream of observations emerging from it. Our model is an effort in this direction, inspiring from biological information. It is based on the `bijama` model [7], proposed and developed in our team. It enables building computational cortical-like 2D-neural assemblies called *maps*, made of computational units representing cortical columns. Units allow to process in parallel external entry and internal signals carried out by connections. A schematic of the model is shown in Fig.s 2 and 3. The architecture comprises three maps, namely the input map, the delay map, and the associative map. The input map receives the external input stream. Its activity is expected to represent at time t the coding $\hat{x}^t$ of the actual dynamical system phase x^t.

The two other maps, the delay map and the associative map are auxiliary maps that play the role of intermediate structures for extracting $\hat{x}^t$ from the input stream o^t. Their purpose is to re-inject the delayed activity of the input map into its dynamics. This recurrent pathway actually reveals the temporal dimension of the input stream. Map activities are computed by a neural field. Each unit has lateral recurrent connections to other units within the map, implementing an on-center/off-surround connectivity [8], [9]. The field performs lateral competition between units and computes the activity of each one, so that the global map activity has the shape of a bump (see dark meshes in Fig. 4). The bump positions are actually the response of the map to its input. Lateral competition, from which activity bumps emerge, is used in the model in order to guide the process of self-organization of inputs over the map surface. This is indeed difficult with neural fields as explained in [9] from which the neural field process used in this paper is taken. The whole architecture evolution is controlled by successive *time steps*. A time step is a discrete time instance at which the activities of all units in all maps are evaluated once, using an asynchronous evaluation scheme [9]. Another kind of connectivity in the model is the inter-map connectivity. A unit at the bi-dimensional position p in some local map can be connected to a whole strip-shaped region $\mathcal{S}_p$ in some remote map. Then unit p handles connections from the units at positions $q \in \mathcal{S}_p$ in the remote map, as shown in Fig. 2. Each connection in a strip between p and a remote unit q handles a weight whose current value is $\bar{s}^t_{pq}$, so that the strip $\mathcal{S}_p$ owned by p handles a vector of weights $\bar{S}^t_p = \left(\bar{s}^t_{pq}\right)_{q\in\mathcal{S}_p}$. Let us note $\mathcal{S}$ the set of strips received by local map ($\mathcal{S} = \mathcal{A}, \mathcal{I}, \mathcal{D}$ in Fig. 2). Inter-map connections are referred to as *cortical connections*. Strips are characterized by their width $\rho_{\mathcal{S}}$ and direction $\psi_{\mathcal{S}}$ relative to the horizontal axis connecting the centers of the local and remote map. Let us note the activity of the unit at position p at time t as u^t_p, and the vector of remote unit activities perceived at p through the strip $\mathcal{S}_p$ as $S^t_p = \left(u^t_q\right)_{q\in\mathcal{S}_p}$. The computation of unit activity using `bijama` is achieved using a stack of modules (see Fig. 3). Each one handles a scalar value that may be received as input or computed from lower modules in the stack. The higher module (here, the neural field module) handles the unit output that is the one actually accessed through cortical connections.

Let us first describe the stack of modules used for the units in the input map, see Fig. 3 and 4 while reading the definitions which follow. In general terms, the input map, in the one hand, receives external observations o^t. In the other hand it also receives strips (noted $\mathcal{A}$) from the associative map. It outputs an activity bump as a response. This activity represents $\hat{x}^t$ as will be shown later. The lower module is

 ISBN: 978-1-61208-155-7

referred to as the *thalamic module*. It handles the external input o^t, and matches it against a stored prototype ω_p^t and computes the similarity θ_p^t.

$$\theta_p^t = e^{-\frac{\left(o^t-\omega_p^t\right)^2}{2\sigma^2}} \tag{1}$$

The second module is referred to as the *cortical module*. It handles the strip $\mathcal{A}_p$ emerging from the associative map, and computes the matching $c_{p,\mathcal{A}}^t$ between the strip weight vector $\bar{A}_p^t$ and the activity vector A_p^t. The matching is computed as follows, where B is a numerical constant:

$$c_{p,\mathcal{A}}^t = \frac{\left\langle A_p^t.\bar{A}_p^t\right\rangle}{\max\left(\left\|\bar{A}_p^t\right\|^2, B\right)} \tag{2}$$

The third module is referred to as *cortico-thalamaic merging*. It merges θ_p^t and $c_{p,\mathcal{A}}^t$ into one scalar ν_p^t as follows:

$$\nu_p^t = \sqrt{\theta_p^t.\beta + (1-\beta).c_{p,\mathcal{A}}^t} \tag{3}$$

Where β is a constant. The value of ν_p^t forms the final input ready to use by the neural field, i.e. the upper module, to compute the unit activity u_p^t.

The unit activity is used to modulate the learning. Thalamic learning implies moving θ_p^t towards o^t proportionally to u_p^t, as shown in (4).

$$\omega_p^{t+1} = \omega_p^t + \alpha_\omega.u_p^t.(o^t - \omega_p^t) \tag{4}$$

Where α_ω is a fixed thalamic learning rate for all units.

On the other hand, cortical learning implies moving the weight $\bar{a}_{pq}^t$ of each connection included in the strip $\mathcal{S}_p$ towards the cortical input u_q^t, as shown by 5.

$$\bar{a}_{pq}^{t+1} = \bar{a}_{pq}^t + \alpha_{\mathcal{S}}.u_p^t.(u_q^t - \bar{a}_{pq}^t) \tag{5}$$

Where $\alpha_{\mathcal{S}}$ is a fixed cortical learning rate for all model connections. The previous rule means that learning occurs only in connections to active units in local maps.

The next map in the model is the associative map. Its receives the actual activity of the input map as well as its delayed activity exhibited by the delayed map, then it performs lateral competition via the neural field, and re-injects the result into the input map through the previously mentioned $\mathcal{A}$ strips. The first module of a unit q of this map handles the strip $\mathcal{I}_q$ emerging from input map and computes the matching $c_{q,\mathcal{I}}^t$. The second module handles the strip $\mathcal{D}_q$ emerging from delay map and computes the matching $c_{q,\mathcal{D}}^t$. Both matching values are computed similarly to what was shown in input map units, according to 2. The third module is referred to as *cortico-cortical merging*. It merges $c_{q,\mathcal{I}}^t$ and $c_{q,\mathcal{D}}^t$ in one scalar μ_q^t as follows:

$$\mu_q^t = \sqrt{c_{q,\mathcal{I}}^t.c_{q,\mathcal{I}}^t} + \text{noise}_\mu \tag{6}$$

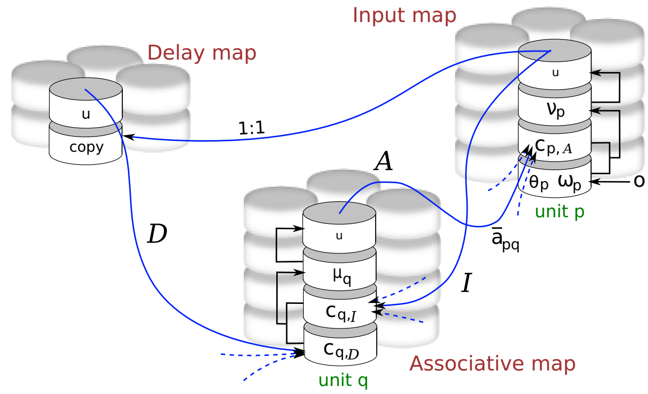


Figure 3. Module stacks of the units in the three maps, and their cortical inter-connections.

The purpose of noise is to boost the associative map activity in units receiving null cortical activity before being injected into the input map. The value of μ_q^t is actually the input to the associative map neural field module which computes the unit activity u_q^t.

The last map in the model is the delay map. It receives a unit-to-unit copy of the input map activity and delays it for some period of T time steps, using a T-length FIFO queue. Units in this maps have two modules. The first is the *copy* module that copies u_p^t from the input map. The second is the *FIFO* module. Thus $u_p^t = u_q^{t-T}$ where q is a position in the input map and p the same position in the delay map. There is no need for a neural field in this map.

As can be seen, the proposed architecture requires no prior conditions on the input stream, nor on the underlying dynamical system, it is thus a model free architecture. The model does not require to adjust any parameter during execution. Learning rates are thus constant. Moreover, there is no need for resetting output bump activities u when a new observation $o^{\tau+1}$ is presented.

III. EXPERIMENTS

In this section, the model is tested to validate its capability to find an internal state representation of some unknown dynamical system providing observations. A toy example of dynamical system is used here to test the capacity of spatio-temporal organization of the model. Let $x \in \mathbb{C}$ represent the system phase, and let the transition function be $\phi(x) = x.e^{i\varphi}$. Let us consider that the system transition occurs at instant τ, thus we can write $x^{\tau+1} = \phi(x^\tau)$ with $x^0 = 0.5$. Let the partial observation fed to the model be $O(x^\tau) = 0.5 + \Re(x^\tau) + \text{noise}_o$. Its values are kept in $[0, 1]$. The sampled stream values are perturbed by noise to test the robustness to noisy observations.

The dynamical system phase can be thought of as the position of a point moving in a steady speed on a circle, and the observation is its noisy abscissa. This sinusoidal observation is obviously ambiguous.

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-155-7

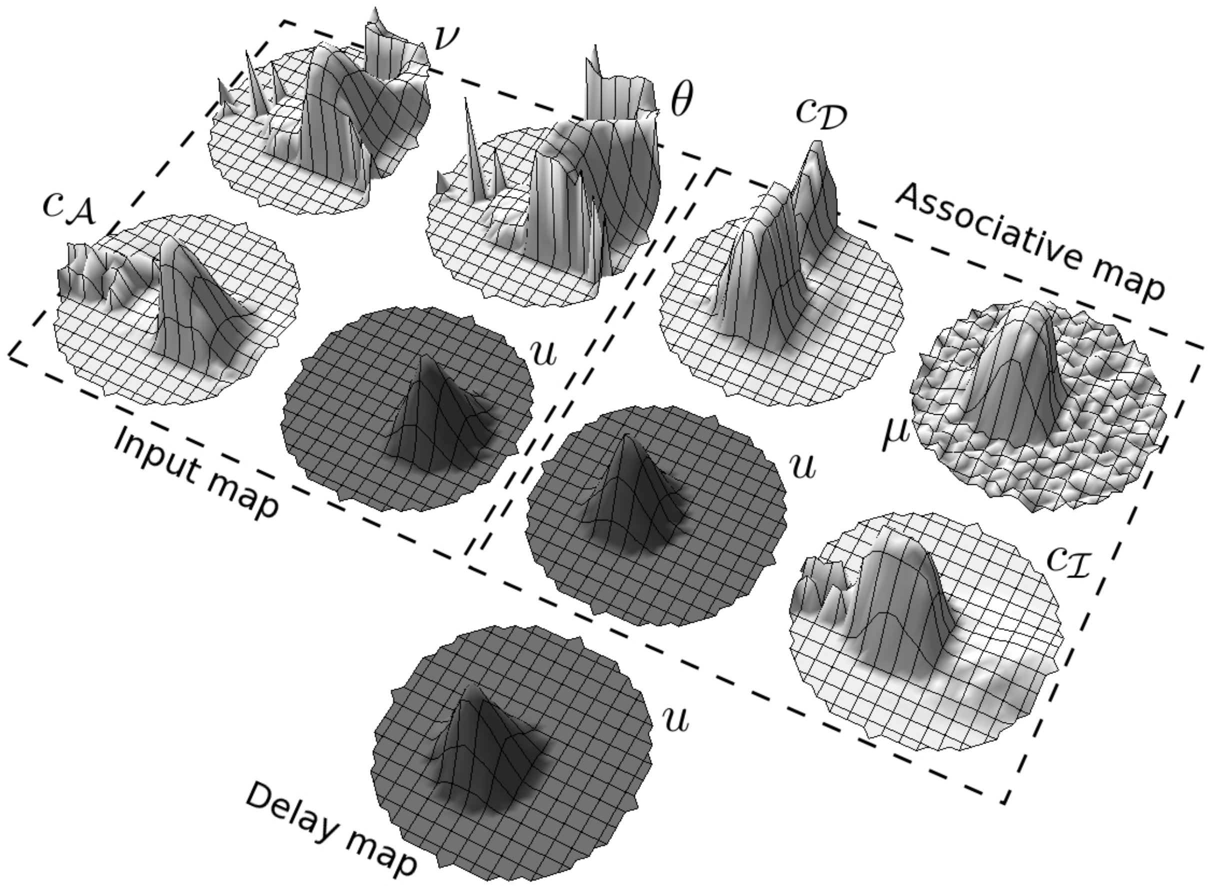


Figure 4. Activity of model maps modules.

In this experiment, τ is incremented every T time steps, and each observation $O(x^{\tau})$ is fed to the model during T time steps, i.e. $o^t = o^{t+1} = \cdots o^{t+T-1} = O(x^{\tau})$ and $o^{t+T} = o^{t+T+1} = \cdots o^{t+2T-1} = O\left(x^{\tau+1}\right)$, etc. The reason for that is to give enough time to the neural field to relax and form an appropriate bump, as well as for cortical and thalamic learning to influence significantly the weights. T value is the same as FIFO length used in delay map units, thus, it delays input maps activity until the next $O(x^{\tau})$ is sampled.

The input stream value o^t is presented to all the units in the input map as for Kohonen maps [2]. The map response is computed as the barycenter position G^{τ} of the u activity bump at the end of each chunk of T successive time steps. It is computed as follows:

$$G^{\tau} = \sum_p u_p^t.p / \sum_p u_p^t : p \in [1, M]^2 \qquad (7)$$

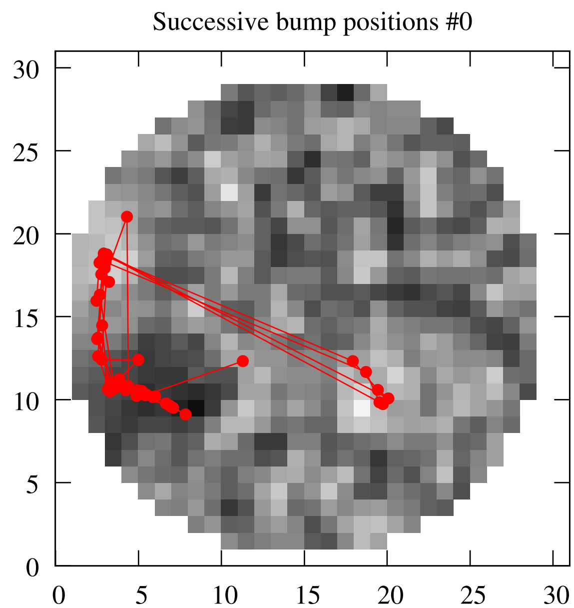
Where M is the dimension of the square surrounding the round map. Each time that l barycenters are computed, they are organized in a list $P^{\tau} = \{G^{\tau-l+1}, G^{\tau-l+2}, \cdots, G^{\tau}\}$ of positions forming l-length paths over the map as sketched in Fig. 5. Successive paths allow to track the evolution of the map state $\hat{x}^t$ through time.

Fig. 5 shows the evolution through time of the input map. At the experiment start, thalamic values ω_p^t are random and the activity is located in a limited regions on the map as illustrates Fig. 5(a). Activity bumps start to disperse in Fig. 5(b). At this stage, due to thalamic learning guided by the neural field, thalamic values start to exhibit spatial organization as the grey-scaled regions show. The reason is that ω_p^t mainly organize according to values of o^t which are in $[0, 1]$. Fig. 5(c) shows a better organization of the thalamic values, and different regions appear, each handling some different range of the o^t values. Besides, it exhibits a better dispersion of activity bumps in the each region.

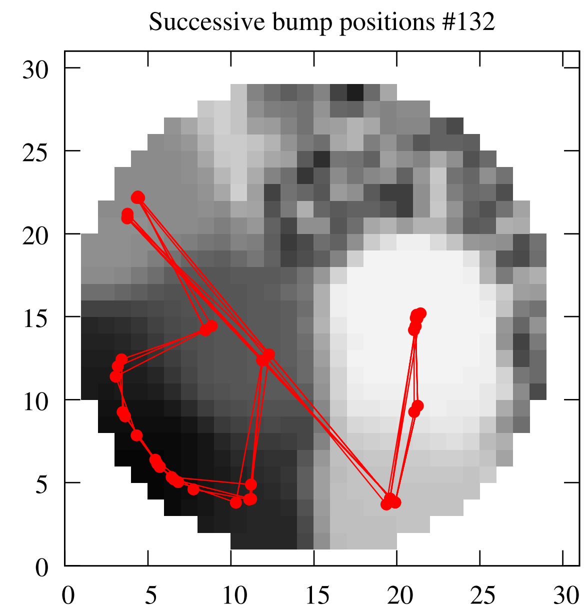
At the end of learning, Fig. 5(d) shows that different grey-scaled regions can be distinguished, indicating the spatial self-organization of thalamic values.

The poly-line in the figure is formed by $l = 50$ points, corresponding each to the representation $\hat{x}^t$ of a dynamical system phase x^t. As can be seen, points are clustered along

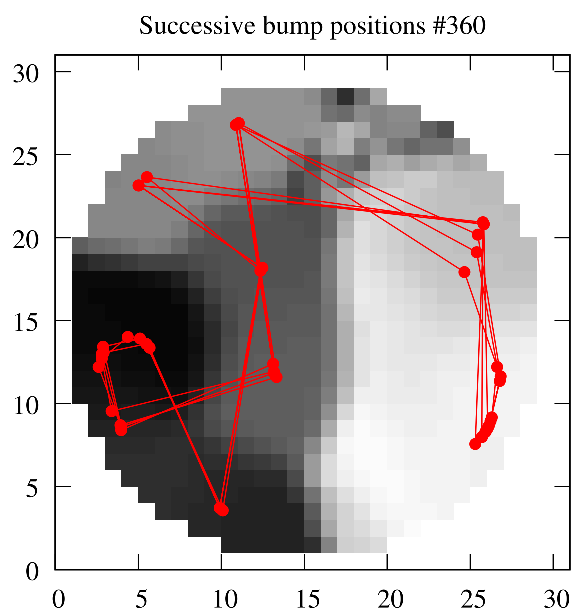
 ISBN: 978-1-61208-155-7



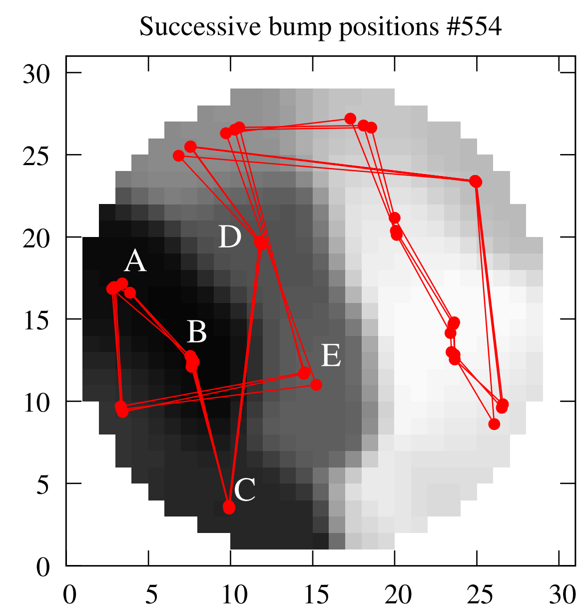
(a) Map activity $\tau = 1$ time steps.



(b) Map activity after $\tau = 132 \times 50$ i.e. $t = \tau \times T = 158400$ time steps.



(c) Map activity after $\tau = 360 \times 50$ i.e. $t = \tau \times T = 432000$ time steps.



(d) Map activity after $\tau = 554 \times 50$ i.e. $t = \tau \times T = 664800$ time steps.

Figure 5. Status of the input map during the system evolution. Grey-scaled values are the ω prototypes (white for 0, black for 1). P^{τ} is represented with a poly-line, linking successive positions $G^{\tau-l+1}, G^{\tau-l+2}, \cdots, G^{\tau}$, that are localized on the figures with red dots.

the poly-line. One cluster is formed by repeated visits of the same system state. This indicates the stable representations of states in the map space. Each thalamic region corresponds to a range of close observations values. Within each region there exists the representation of 2 or more states. For example, the black region corresponds to observation values close to 1, nevertheless, it contains 3 distinct successive state representations marked A,B,C. When a range of observations is located in the middle of the input values range, points (like D,E) express non-successive states corresponding to the same observation range, but in different temporal context. Such duplications of states, related to the same value of O, are progressively performed while the whole architecture gets organized. It removes observation ambiguity. Thus, the ensemble of state representations $\hat{x}$ (i.e. bump positions) expresses a bijective mapping between the map surface and the dynamical system phase space. This was possible because the model allowed the previous state of the input map to be considered in computing its new state, integrating this way, its state history. The added noise to the input stream did not affect the model capability to extract the mapping.

The experience was launched with numerical values for the dynamical system as follows: $\varphi = 2\pi/15$ and noise_o is sampled from a uniform random noise $\mathcal{U}\,[-0.05, 0.05]$.

Model numerical values was initialized as follows: $M = 30$ for all maps, $u_p^0 = 0$, ω_p^0 and $\bar{a}_{pq}^0, \bar{i}_{pq}^0, \bar{d}_{pq}^0$ are initialized to uniform random values from $\mathcal{U}\,[0, 1]$, $\sigma = 0.07$, $\alpha_\omega = \alpha_\mathcal{S} = 0.0416$, $B = 10$, $\beta = 0.25$, noise_μ is sampled from a uniform random noise $\mathcal{U}\,[0, 0.1]$, $\rho_\mathcal{I} = \rho_\mathcal{A} = \rho_\mathcal{D} = 5$. $\psi_\mathcal{I} = 90$, $\psi_\mathcal{A} = -90$, $\psi_\mathcal{D} = 0$, $T = 24$, and $l = 50$.

IV. Conclusion and future work

In this paper, a recurrent neural architecture is proposed for setting up a representation of the phases of a dynamical system from the stream of partial observations of that dynamical system. The phase extraction relies on three self-organizing modules, whose self-organizing processes are coupled via strip-like connections, according to the `bijama` model. Experiments show that this fully unsupervised architecture is able to self-organize so that the token of hidden phases of the dynamical system are explicitly built in the input map. Indeed, for each bump position in that map, a phase of the dynamical system can be assigned. Moreover, the topology preservation that is expected from self-organizing maps actually stands here, since the input map is still a continuous mapping of the space where the observation lives (here the interval $[0, 1]$).

In the one hand, seminal works by Elman and Jordan [10], [11] have already addressed the learning of a dynamical system from the stream of observation, but this was obtained from a supervised approach. In the other hand, as mentioned, reservoir computing approaches relies on high dimensional representation spaces to build an a priori set of states, from which the ones corresponding to the actual phases of the system can be extracted by readout units. In both cases, the setting up of a phase representation is not explicit. Here, the whole architecture adapts for extracting explicit phase representation by self-organization.

Future work will investigate the potential of the model self-organization features in both space and time when applied to systems exhibiting non-stationary dynamics. The goal is to see if the model would be able to recruit new regions in the input map or release useless regions when the dynamic change. Future work consists also in using the representation built in the input map as a state space for taking decisions within Markovian decision processes. In a more integrated model, such cortical representations could indeed feed actor and critic neural modules, inspired from basal ganglia modeling [12], [13], with a Markovian state space representation that is updated from the current partial information provided by the robot sensors.

Acknowledgments

This work is part of the InterCell project supported by INRIA, Région Lorraine and Supélec.

`http://intercell.metz.supelec.fr`

References

[1] I. Zhenzhen Liu; Elhanany, "A scalable model-free recurrent neural network framework for solving pomdps," in *Approximate Dynamic Programming and Reinforcement Learning, 2007. ADPRL 2007. IEEE International Symposium on*, 2007, pp. 119–126.

[2] T. Kohonen, M. R. Schroeder, and T. S. Huang, Eds., *Self-Organizing Maps*, 3rd ed. Springer-Verlag, Inc., 2001.

[3] G. J. Chappell and J. G. Taylor, "The temporal kohonen map," *Neural Netw.*, vol. 6, pp. 441–445, March 1993.

[4] M. Varstal, J. Milln, and J. Heikkonen, "A recurrent self-organizing map for temporal sequence processing," in *Artificial Neural Networks ICANN'97*. Springer Berlin / Heidelberg, 1997, pp. 421–426.

[5] T. Koskela, M. Varsta, J. Heikkonen, and K. Kaski, "Time series prediction using recurrent som with local linear models," *Int. J. of Knowledge-Based Intelligent Engineering Systems*, pp. 60–68, 1997.

[6] M. Lukoševičius and H. Jaeger, "Reservoir computing approaches to recurrent neural network training," *Computer Science Review*, vol. 3, no. 3, pp. 127–149, Aug. 2009.

[7] O. Ménard and H. Frezza-Buet, "Model of multi-modal cortical processing: Coherent learning in self-organizing modules," *Neural Networks*, vol. 18, no. 5-6, pp. 646 – 655, 2005, iJCNN 2005.

[8] S. Amari, "Dynamics of pattern formation in lateral-inhibition type neural fields," *Biol Cyb*, vol. 27, pp. 77–87, 1977.

[9] L. Alecu, H. Frezza-Buet, and F. Alexandre, "Can self-organization emerge through dynamic neural fields computation? ," *Connection Science*, vol. 23, no. 1, pp. 1–31, 2011.

[10] J. L. Elman, "Finding structure in time," *Cognitive Science*, vol. 14, pp. 179–211, 1990.

[11] M. I. Jordan, "Attractor dynamics and parallelism in a connectionnist sequential machine," in *Proc. 8th Annual Conference of the Cognitive Science Society*. Erlbaum, 1986, pp. 112–127.

[12] K. Doya, "What are the computations of the cerebellum, the basal ganglia and the cerebral cortex?" *Neural Networks*, vol. 12, no. 7-8, pp. 961–974, 1999.

[13] A. Leblois, T. Boraud, W. Meissner, H. Bergman, and D. Hansel, "Competition between feedback loops underlies normal and pathological dynamics in the basal ganglia," *Journal of Neuroscience*, vol. 26, no. 13, pp. 3567–83, 2006.

Global Context Influences Local Decisions

Terry Bossomaier
CRiCS (Centre for Research in Complex Systems)
Charles Sturt University
Australia.
Email: tbossomaier@csu.edu.au

Michael Harré
CRiCS, Charles Sturt University
& Centre for the Mind, University of Sydney
Australia.
Email: mike.harre@gmail.com

***Abstract*—This paper studies the development of human expertise in the game of Go. Although superficially a simple game, Go is the most difficult of all established games for artificial intelligence, no computer program yet achieving top international level on a full 19x19 board. On smaller boards, such as 9x9 computers *are* competitive, implying that the understanding of the complex global interactions is the key to human superiority. By mining thousands of positions online, we show that at some player levels the sequence of plays leading up to a *local* position is a stronger determinant of the next move than the position alone. This suggests that the sequence of plays is an indicator of global strategic factors and thus provides a context for the next move in addition to the local position itself.**

***Keywords*-game of go; decision making; entropy; online data mining**

I. Introduction

The big picture often influence or override local factors in many areas of human expertise, from board games to politics. Challenging games, such as Chess and Go, provide an excellent framework for studying expertise [1], [2], [3], [4] since they are both strategically deep but tightly constrained. This paper presents a striking demonstration of this, mined from thousands of decisions online. In recent work we have demonstrated transitions in the acquisition of expertise in the game of Go [5]. This game is interesting because it is currently the most difficult of all established games for computational intelligence. Unlike Chess, where the IBM computer Deep Blue [6], [7] triumphed over world champion Kasparov.

We also demonstrated therein, from calculation of mutual information between moves, that one of these transitions has the character of a *phase transition* [8]. The idea of a phase transition comes originally physics, such as the melting of ice to give water. When such a physical phase transition occurs there is a dramatic reorganisation of the system. In this case water molecules which were fixed rigidly in place in ice become free to move around and perhaps travel long distances. During a phase transition, systems exhibit long range order, where there are correlations in activity or structure over large distances and system parameters often exhibit power law behaviour, or fat-tailed distributions. Another example of a phase transition is in the formation of random graphs. At the transition the average path length, in other words the number of steps from one node in the graph to another rises to a peak, and then drops back down again.

A dynamical system examples is the Vicsek model developed for studying magnetic transitions in solid state physics [9]. In this model particles travel around a two dimensional grid, and, when they come within some specified distance of each other, their directions of movement get slightly closer together. Phase transitions occur in this system as particles flow around in groups, like flocks of birds, but these groups are dynamic, continually forming and dissolving.

Mutual information is a system property which measures the extent to which the structure or behaviour of one part of a system predicts the behaviour of another. In the Vicsek model of above, at the transition the direction and velocity of one particle provides some information about the direction of all the other particles. The mutual information peaks during the phase transition [9], [10], and this is thought to be a general property of phase transitions along with the other characteristics, notably long range order and power law characteristics. We found a peak in mutual information as a function of rank amongst Go players from 1 Dan Amateur through to the very top players, 9 Dan Professional [8]. The previous work [8] has demonstrated phase transitions in collective human decisions in Go. This paper presents evidence that there is global influence on local decisions and that the influence is greatest during the phase transition.

A. State of the Art in Game Expertise

Much of the work on human expertise has been based on games, especially Chess, as in Gobet's extensive work [1], [11]. One of the key ideas, essentially from Nobel Laureate Herbert Simon, is that human expertise involves building a huge library of patterns [12], [13], although the application of these ideas in artificial intelligence for games is relatively new [14].

These patterns build up through the formation of *chunks*, and psychological observables, such as memory for Chess positions are well predicted by models such as CHREST [3]. The way the cognitive structures in the brain might change as expertise develops, and in particular the appearance of

 ISBN: 978-1-61208-155-7

phase transitions, is relatively new introduced by Harré and Bossomaier [8], [5].

Further recent advances have been limited, particularly in Go where a combination of the game space complexity of Go [15] and a lack of genuinely human like heuristics such as an evaluation function make progress difficult. However with the development of ever more effective random sampling techniques, such as the UCT-Monte Carlo approach currently favoured by AI system developers [16], some progress has been made in achieving strong amateur play. However these techniques do not address the inherent complexity of the game and the techniques that humans have developed in order to address such issues, almost completely because such techniques are not subject to easy investigation.

We argue that the sources of information players use in order to make good decisions are of two types: *local* and *global.* While every level of player in our study has learned a great deal about the game of Go over the course of their lives, it is how this information is implemented via the choices they make that is of interest to us. This relevance of the division of the problem space in to these two parts can be seen in the work of Stern et al [17]. They were able to produce 'best in class' move prediction for professional players in Go, achieving a 34% success rate. This was achieved by training their system on 181,000 expert game records and using the most modern techniques available for their analysis. The level of success achieved in this work highlights one of the principal difficulties of good performance in complex tasks: exact pattern matching is not enough; AI systems need to be able to model how non-local aspects i.e. information that cannot be derived by exactly matching board configurations, influence decisions. Loosely interpreted this is what is called *influence* in Go and before our recent work it had not been reported in the research literature.

II. METHODS

Harré and Bossomaier [8] examined the game trees 6 moves (i.e. 3 black and three white) deep for around 8,000 games across a range of Go expertise. At the low end were 2 kyu Amateurs, a rank reached by serious players after a couple of years club play through the highest amateur rank of 6 Dan Amateur (6A) to the top professional rank of 9 Dan Professions (9P). Game data was obtained from the *pandanet* Go server. Full details of experimental procedures are given in Harré et al. [8]. The game trees were computed from 7x7 board sections in the corner, from games played between players of the same rank. No symmetry was exploited, apart from rotations to align each of the four corners (used to maximise data yield per game). Note that although these are the first 6 moves played in the region, they are not necessarily, and usually are not, the first 6 moves of the game.

For each possible move, m_i, three probability distributions were computed

1) the probability of the move, m_i, occurring, $P(m)$
2) the conditional probability, $P(m_I|q_i)$, of the move, m_i occurring from a given position, $q - I$
3) the conditional probability, $P(m_I|s_i)$ of the move occurring from a given position, *reached by a particular order of moves,* s_i

From these results the entropy and mutual information were calculated, but this paper addresses findings from the entropies alone. The move entropy, $H(M)$, is taken over all moves which can arise at each level in the game tree (i.e. for the 6 moves in the sequence). (eqn. 1).

$$H(M) = -\sum_i p(m_i)\log_2[p(m_i)] \tag{1}$$

Entropy is a measure of disorder or randomness and is maximal when the probabilities or all events are the same. When the first move in the region there are 49 possible positions and after 5 moves, 44, giving a maximal entropy of $\log_2 44 = 5.5$ bits. But since the moves are far from random the measured entropies are much lower than this.

The conditional entropy, $C(M|q_i)$, is the move entropy calculated from the moves which can arise in a given context, such as a position, q_j, or sequence of moves, s_j, leading to a position.

$$C(M|Q) = -\sum_i p(m_i|q_j)\log[p(m_i|q_j)] \tag{2}$$

with the same expression used for an ordered sequence of moves with s_j replacing q_j.

These entropic quantities are now calculated across all ranks from amateur 2q, denoted *am2q* through, the amateur dan ranks to *am6d*, and then to the highest rank of all, professional 9 dan, *pr9d* and are shown in figures 1–3.

III. RESULTS

Figure 1 summarises the key findings of the paper. It shows the conditional entropy as a function of move in the sequence of 6 averaged across all ranks, both amateur and professional. Error bars are calculated as in Harré et al. [5]. Up to move 3 the entropy for both the ordered and unordered cases are the same. At move three they fall dramatically, but the ordered average falls about a third more.

Figure 2 shows the entropy at each move from a given position. For purely random moves the entropy at each move in the sequence would be between 5 and 6 bits. The entropies observed are, of course, much lower, usually less than 2 bits, reflecting the structure inherent in the game.

The entropy for the third move is slightly less than for the first two, but the entropy falls a little for the fourth move and a lot more for the fifth and sixth moves. This is not surprising given the reduced options available as the number

 ISBN: 978-1-61208-155-7

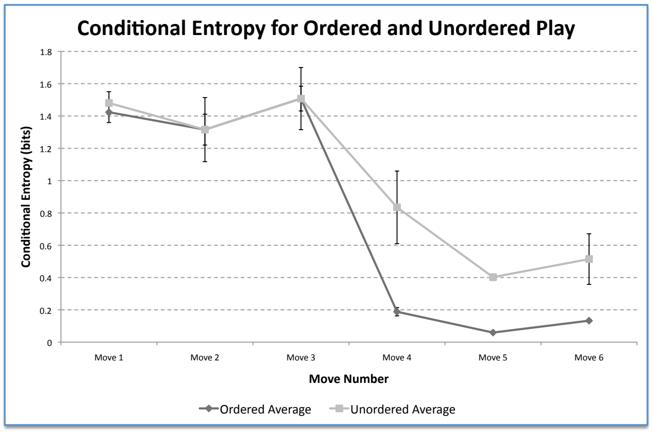


Figure 1. Conditional entropy (eqn. 2) as a function of move averaged over all ranks

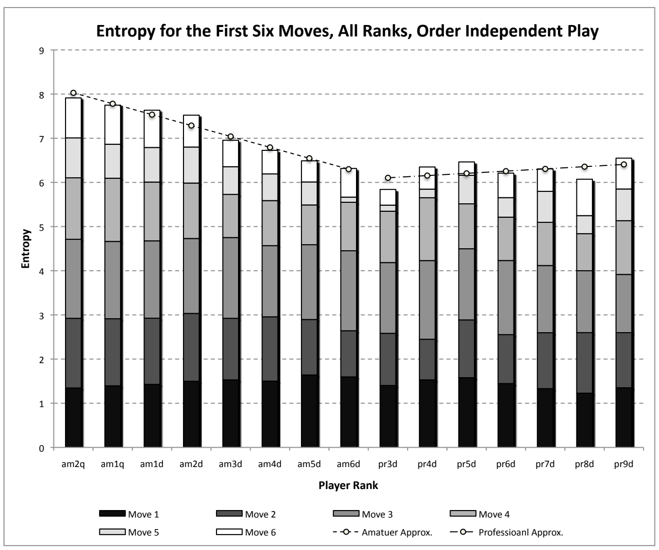


Figure 2. Entropies for moves from a given board position (reprinted from [8])

of stones on the board increases. The entropy summed over all moves declines linearly to the maximum amateur rank and then increases slightly from from the first professional rank.

Figure 3 shows the entropies which result from positions which arose from a particular sequence of play. These entropies are around 3 bits smaller, than for the unordered case. The slope of the regression line for the amateur levels is not so large, but the trend for the professionals displays a different pattern: the summed entropy jumps near the start of the professional ranks and then *decreases* with rank up to 9P with a slope very similar to that for the amateur ranks on the left of the figure.

The most interesting thing about this figure, though, is the way the entropy for the last three moves shrinks and vanishes as the amateur rank increases from 4A to 6A. In

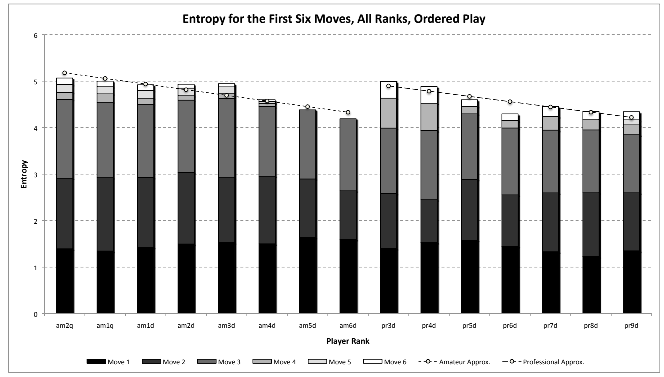


Figure 3. Entropy for the first six moves shown as a stacked bar chart. The black bars represent the entropy at move 1, the dark grey at move 2 ad so on for all six moves. The dashed regression lines show the total entropy for the amateur and professional sequences.

fact the summed entropy for the first three moves is quite similar to the unordered case, so the three bit loss is almost all in the last three moves.

IV. Discussion

There are two very interesting features of these results, which we consider in turn: the difference between ordered and unordered play; and the way the conditional entropy varies with rank.

That the ordered and unordered play differ, implies that the position at each move is *not* the sole determinant of the opponent response. The much lower conditional entropy after the first three moves for the ordered case strongly suggests that the sequence of moves has revealed something of the global context which has in turn fed back into move selection. To see this, imagine that black is strong in one area of the board and white in another. Since communication lines are of great strategic importance in Go, the locations of these areas will strongly influence the order of moves made in the local area we examine. The first three moves implicitly contain some of this information, which subsequently reduces the range of options in the second three moves.

The gradual decline in entropy with rank for amateur and professional reflects a gradual reduction in the space of range of options, which we could see as the elimination of poor moves in established situations, similar to the mastering of the opening in Chess.

Our data and results are explicitly based on an analysis of the local information, but by implication they also say a great deal about the global context that influences these localised decisions. The first three moves in our study have a reasonably similar conditional entropy of about 1.4-1.6 bits of information. This is the amount of information that is common between each successive move within the local region. Such measures of information are the best estimate of how much one stochastic variable can tell us about another [18]. The only other source of information available to the players are the pieces on the board that were not included within our local region. We exclude the possibility of being able to read the other opponent. While it is a debated issue as to the importance of such skills, we believe that it is much less significant than all the other pieces on the board that were not within the local area of study. The changing influence that non-local information has on decisions during a game, is evident in the the significant drop-off in the conditional entropy after move 3 in Figure 1, a drop-off of shared information from one move to the next of nearly an order of magnitude for the ordered play and about half that for unordered play.

This change in the levels of conditional entropy as the game progresses in the corner region of the board might be due to the reducing size of the move space as the board fills up. While this might have some minor influence on our results, we should also expect such changes to be almost linear as the number of available positions only drops by a total of 1/43 per move. It is also possible, but exceptionally unlikely, that after move 3 players choose much more randomly, i.e. without concern for the pieces on board either local or non-local, than they did for the first three moves. Considering the vast training literature available to players that readily teach them the many different variations of the first 6 moves within the corner, and then how to contextualise these decisions by considering what pieces occupy nearby areas, we consider this to be an unlikely strategy.

Instead we argue that it is just this external influence, the influence of the stones arrayed on the rest of the board that is having such a striking influence on the condition entropy. This is perhaps not so surprising when considered in the light of the state of the game itself after 3 moves have been played in the corner. These first moves can be thought of as establishing the game board layout in terms of an ‘opening book’, highly stylised moves of local pieces where the local pattern can be thought of as essentially uncoupled from the rest of the board, or at least coupled to the same extent for these first moves. This coupling then changes significantly from the 4th move onwards where greater consideration needs to be afforded to the other pieces on the board. This change in focus of the information effectively reduces significantly the information coupling between the local moves and the local stones on the board.

The complete disappearance of entropy at the high amateur ranks is very interesting. It suggests that the at this level play has become somewhat stereotyped, and a major change in thinking is needed to advance, which indeed seems to happen on turning professional. Thus this loss of entropy is consistent with the long range order found in phase transitions [8]. This accords with the findings in Harré et al [8], wherein a peak in mutual information is found at the transition to professional, indicating some sort of major cognitive reorganisation. At present we do not know how to quantify such a reorganisation and this remains an exciting open question. Ongoing work is attempting to apply the CHREST models to Go [3] and to determine how phase transitions might be predicted.

ACKNOWLEDGEMENTS

This work was supported by the Australian Research Council under Discovery Project DP0881829 and the US Airforce under grant 104116.

REFERENCES

[1] F. Gobet, A. d. Voogt, and J. Retschitzki, *Moves in Mind*. Psychology Press, 2004.

[2] A. D. Groot and F. Gobet, *Perception and memory in chess: Heuristics of the professional eye*. Assen: Van Gorcum, 1996.

[3] F. Gobet, P. Lane, S. Croker, P. Cheng, G. Jones, I. Oliver, and J. Pine, “Chunking mechanisms in human learning,” *Trends in Cognitive Sciences*, vol. 5, pp. 236–243, 2001.

[4] K. Ericsson and N. Charness, “Expert performance: its structure and acquisition,” *American Psychologist*, vol. 49, pp. 725–7247, 1994.

[5] M. Harré, T. Bossomaier, C. Ranqing, and A. Snyder, “The development of expertise in a complex environment,” *Minds and Machines*, vol. in press, 2011.

[6] X. Cai and D. Wunsch, “Computer Go: A grand challenge to AI,” in *Challenges for Computational Iintelligence*. Springer Berlin, 2007, pp. 443–465.

[7] M. Campbell, A. Hoane, and F. Hsu, “Deep blue,” *Artificial Intelligence*, vol. 134, no. 1-2, pp. 57–83, 2002.

[8] M. Harré, T. Bossomaier, A. Gillett, and A. Snyder, “The aggregate complexity of decisions in the game of go,” *European Physical Journal B* ***ERA A***, vol. in press, 2011.

[9] R. Wicks, S. Chapman, and R. Dendy, “Mutual information as a tool for identifying phase transitions in dynamical complex systems with limited data,” *Phys. Rev. E*, vol. 75, 2007.

[10] S.-J. Gu, C.-P. Sun, and H.-Q. Lin, “Universal role of correlation entropy in critical phenomena,” *Journal of physics A*, 5 2006.

[11] F. Gobet and P. Chassy, “Expertise and intuition: a tale of three theories,” *Minds and Machines*, vol. 19, pp. 151–180, 2009.

[12] W. Chase and H. Simon, “The mind’s eye in chess,” in *Visual Information Processing*, C. W.G., Ed. Academic Press, NY, 1973, pp. 215–281.

[13] F. Gobet and H. Simon, “Five seconds or sixty? presentation time in expert memory,” *Cognitive Science*, vol. 24, pp. 651–682, 2000.

[14] J. Rubin and I. Watson, “A memory-based approach to two-player texas hold’em,” in *AI 2009: Advances in Artificial Intelligence, Proceedings*, ser. Lecture Notes in Artificial Intelligence, A. Nicholson and X. Li, Eds. Springer, 2009, vol. 5866, pp. 465–474, 22nd Australian Joint Conference on Artificial Intelligence DEC 01-04, 2009 Melbourne, AUSTRALIA.

 ISBN: 978-1-61208-155-7

[15] J. Tromp and G. Farnebäck, "Combinatorics of go," *Computers and Games*, pp. 84–99, 2007.

[16] S. Gelly and Y. Wang, "Exploration exploitation in go: Uct for monte-carlo go," in *Twentieth Annual Conference on Neural Information Processing Systems (NIPS 2006)*. Citeseer, 2006.

[17] D. Stern, R. Herbrich, and T. Graepel, "Bayesian pattern ranking for move prediction in the game of go," in *Proceedings of the 23rd international conference on Machine learning*. ACM, 2006, pp. 873–880.

[18] C. Shannon and W. Weaver, *The Mathematical Theory of Communication*. Univ. Ill. Press, Urbana, 1949.

 ISBN: 978-1-61208-155-7

Cognitive System with VoIP Secondary Users over VoIP Primary Users

Yakim Y. Mihov and Boris P. Tsankov
Dept. of Telecommunications Networks
Technical University of Sofia
Sofia, Bulgaria
e-mails: yakim_mihov@abv.bg, bpt@tu-sofia.bg

Abstract—**This paper investigates the call-level traffic capacity for cognitive secondary VoIP users in a system with primary VoIP users. The system is modeled as a serving system with preemptive priority of primary calls over secondary calls. An analytical approach is developed to evaluate the VoIP service capacity and the quality of service provisioning for the secondary users, namely the call blocking and dropping probabilities. Methods for call dropping probability regulation are proposed. A novel analytical approach for approximate evaluation of the effect of limitation is developed and validated by simulation experiments.**

Keywords-call blocking probability; call dropping probability; cognitive radio; VoIP

I. INTRODUCTION

The combination of scarce radio spectrum and increasing demands due to newly emerging wireless services is a reason to search for a more efficient spectrum use. There are many different approaches, such as hierarchical structures with micro- and femto-cells, multi-hop connections, new multiple access methods, adaptive modulation and coding, etc. Not very long ago, a new non-traditional paradigm, namely Dynamic Spectrum Access (DSA), was proposed [1]–[4]. The main idea of hierarchical spectrum overlay as a method of DSA is that some sectors of licensed spectrum which are not currently being used by incumbent (primary) users might be temporarily and opportunistically used by other (secondary) users. If a primary user (PU) returns to activity, a secondary user (SU) has to leave the occupied spectrum. Cognitive radio (CR) is the key enabling technology for DSA. Among the essential CR functions are *spectrum sensing* and *admission control* dependent on available spectrum. The variable character of the spectrum available to SUs makes the service of multimedia traffic difficult due to its stringent packet delay requirements. This is particularly true for dialog traffic such as VoIP.

Because of the connection-oriented packet switching technique for the service of VoIP traffic and the preemptive priority of PU calls over SU calls, two important probabilities exist: call blocking probability and call dropping probability of a SU call. Since SUs must not affect the service of PUs, an ongoing SU call might be interrupted and prematurely terminated (dropped) due to the arrival of a new PU call. Furthermore, the available capacity to SUs is restricted not only by the overall system capacity but also by the number of ongoing PU calls.

The rest of the paper is organized as follows. Section II presents related work. The system model, the analytical approach, and methods for call dropping probability regulation are discussed in Sections III – V, followed by numerical results in Section VI. Finally, Section VII concludes the paper.

II. RELATED WORK

Although the application of CR for VoIP seems promising, there are only few papers about VoIP over CR published recently. The authors of [5] and its extension [6] use the well-known Markov Modulated Poisson Process (MMPP) [7] for characterization of SU VoIP traffic in a way similar to that in [8]. The PU traffic is modeled as generated by on-off sources and for each primary channel an individual Markov channel model (as in [9]) is applied. As a result, a combined complicated model is derived which is numerically clumsy. The non-explicit assumption that the same amount of bandwidth is utilized for PU and SU calls is not used for a more straightforward approach.

In [10] and its extension [11], the authors also claim to be the first to consider the voice-service capacity analysis for CR. These papers propose two cognitive MAC protocols for a single channel system shared in a slotted manner by PUs and SUs. The PU traffic influence is accounted by the probability that a channel time-slot is occupied by a PU packet transmission. The process of arrival and service of PU and SU packets is modeled by a discrete-time Markov chain.

A third approach to voice capacity evaluation of CR networks is presented in [12]. The transmission media is time-slotted and multi-channel. The main difference to the works mentioned above is the more general and system-oriented approach. The authors apply the definitions of *effective bandwidth* [13], [14] to determine the constant amount of radio resources required to provide the QoS guarantee and *effective capacity* [15] to determine the constant source rate that a channel can support.

In the literature, there are some papers devoted to CR call-level capacity and the corresponding study of SU call blocking and dropping probabilities. References [16] and [17] investigate the special case when the PU call bandwidth is exactly N times greater than the SU call bandwidth. A continuous time Markov chain is applied to obtain the call blocking and dropping probabilities. In [18], a case in which a PU needs the same bandwidth as a SU in order to be served is examined. The PU and SU traffic flows are assumed to have different arrival and service rates. The analytical evaluation of the call dropping probability is presumed to be difficult, so statistical simulation is applied.

III. THE TELETRAFFIC SYSTEM

The offered traffic is modeled by two arrival Poisson random processes – one for the PUs with rate λ_p and another for the SUs with rate λ_s. Therefore, the PU (SU) call inter-arrival time follows a negative exponential distribution with mean $1/\lambda_p$ ($1/\lambda_s$). The call duration also follows a negative exponential distribution with mean $1/\mu$ for both traffic flows.

We denote with C (bps) the overall system capacity and with c (bps) the necessary average rate for a VoIP PU or SU call to be served. The system is considered to have $n = C/c$ channels. PU calls have preemptive priority over SU calls. If a new SU call finds all of the n channels busy, it is blocked. If a new PU call finds all channels busy but there are some channels occupied by SU calls, one SU call will be interrupted and dismissed (dropped). Blocked and dropped calls are lost. Perfect spectrum sensing and spectrum handover procedures are assumed in order to implement the serving discipline described.

The teletraffic system described can be depicted by means of a 2-D continuous-time Markov chain (Fig. 1). Each state (i, j) is presented by two variables: i is the number of PU calls and j is the number of SU calls. The probability that the system is in state (i, j) is $P_{i,j}$. From the call admission algorithm, it follows that a PU call is blocked in state $(n, 0)$. SU call blocking appears in all states where $i+j=n$ (the outermost diagonal states in Fig. 1). In these states without state $(n, 0)$, one SU call is dropped when a PU call arrives.

It is clear that the PU call flow is served as if the SU call flow did not exist. Hence, the probability $P_{n,0}$ that the system is in state $(n,0)$ is easily obtained by the Erlang loss formula:

$$P_{n,0} = \frac{\frac{A_p^n}{n!}}{\sum_{i=0}^{n} \frac{A_p^i}{i!}} = B_p = E_n\left(A_p\right), \tag{1}$$

where A_p is the offered PU traffic:

$$A_p = \lambda_p / \mu. \tag{2}$$

Similarly, $A_s = \lambda_s / \mu$ is the offered SU traffic. The notation B_p refers to the PU call blocking probability and $E_n(A)$ stands for the Erlang loss formula.

The SU call blocking probability is:

$$B_s = \sum_{i+j=n} P_{i,j}. \tag{3}$$

The probability for SU call dropping is:

$$B_d = \sum_{i+j=n} P_{i,j} - P_{n,0}. \tag{4}$$

IV. THE ANALYTICAL MODEL

The state probabilities $P_{i,j}$ necessary to calculate the SU losses by means of (3) and (4) might be obtained using the global balance equations, which can be derived by inspecting the different states of the Markov chain (Fig. 1).

For the states in the first row of Fig. 1, we have:

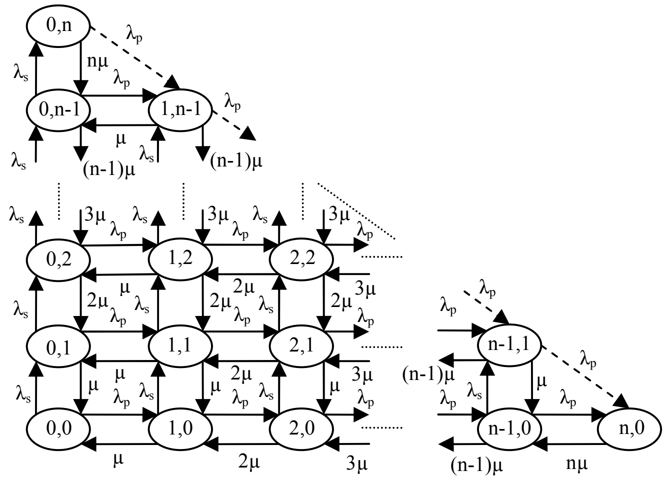


Figure 1. A state-transition diagram used for performance analysis of the teletraffic system.

$$(i = 0)$$
$$\left(\lambda_p + \lambda_s\right) P_{0,0} = \mu (P_{1,0} + P_{0,1}), \tag{5}$$

$$(0 < i < n)$$
$$\left(\lambda_p + \lambda_s + i\mu\right) P_{i,0} = \lambda_p P_{i-1,0} + \left(i+1\right)\mu P_{i+1,0} + \mu P_{i,1}, \tag{6}$$

$$(i = n)$$
$$n\mu P_{n.0} = \lambda_p (P_{n-1,0} + P_{n-1,1}). \tag{7}$$

For the states in the most left column, we obtain:

$$(0 < j < n)$$
$$\left(\lambda_p + \lambda_s + j\mu\right) P_{0,j} = \lambda_s P_{0,j-1} + \mu P_{1,j} + (j+1)\mu P_{0,j+1}, \tag{8}$$

$$(j = n)$$
$$\left(\lambda_p + n\mu\right) P_{0,n} = \lambda_s P_{0,n-1}. \tag{9}$$

For the states on the hypotenuse, we have:

$$(i > 0; j > 0; i + j = n)$$
$$\left(\lambda_p + n\mu\right) P_{i,j} = \lambda_p (P_{i-1,j} + P_{i-1,j+1}) + \lambda_s P_{i,j-1}. \tag{10}$$

For the rest states on Fig. 1, we have:

$$(i > 0; j > 0; i + j < n)$$
$$\left(\lambda_p + \lambda_s + (i + j)\mu\right) P_{i,j} = \lambda_p P_{i-1,j} + \lambda_s P_{i,j-1} + \left(i+1\right)\mu P_{i+1,j} + (j+1)\mu P_{i,j+1}. \tag{11}$$

Equations (5) – (11) contain (n+1)(n+2)/2 unknown variables. For our purposes, it is not necessary to calculate each separate state probability. Let us apply the notation:

$$P_{i,c} = \sum_{j=0}^{n-i} P_{i,j}, \tag{12}$$

where $P_{i,c}$ is the sum of the state probabilities of column i of our diagram. Summarizing (5), (8) and (9) for all values of j from 1 to n and after cancelation of equal terms, we obtain:

$$\lambda_p P_{0,c} = \mu P_{1,c}. \tag{13}$$

Applying the offered traffic (2), we have:

$$A_p P_{0,c} = P_{1,c}. \tag{14}$$

Summarizing (6), (10) and (11) for a given value of i and for all values of j from 1 to n - i, and after cancelation of equal terms, we obtain:

$$(0 < i < n) \\ \left(\lambda_p + i\mu\right) P_{i,c} = \lambda_p P_{i-1,c} + (i+1)\mu P_{i+1,c} \tag{15}$$

or

$$\left(A_p + i\right) P_{i,c} = A_p P_{i-1,c} + (i+1) P_{i+1,c}. \tag{16}$$

Simply applying notation (12) to (7), it becomes:

$$n\mu P_{n,c} = \lambda_p P_{n-1,c} \tag{17}$$

or

$$nP_{n,c} = A_p P_{n-1,c}. \tag{18}$$

Equations (14), (16) and (18) differ from the well-known Erlang distribution state equilibrium equations for the PU traffic only by the notation used and consequently could be considered as a proof of (1).

Let us apply the notations: $q = i + j$ and

$$P_q = \sum\nolimits_{i+j=q} P_{i,j}. \tag{19}$$

After substituting $i = q - j$ in (5) – (11) and summarizing for all values of j from 0 to q, we have:

$$(q = 0) \\ \left(A_p + A_s\right) P_0 = P_1, \tag{20}$$

$$(0 < q < n) \\ (A_p + A_s + q) P_q = \left(q+1\right) P_{q+1} + (A_p + A_s) P_{q-1}, \tag{21}$$

$$(q = n) \\ nP_n = (A_p + A_s) P_{n-1}. \tag{22}$$

These are Erlang distribution equilibrium equations for the total traffic flow $A_p + A_s$. The solution is the Erlang loss formula, which gives the SU call blocking probability:

$$P_{q=n} = \frac{\dfrac{\left(A_p + A_s\right)^n}{n!}}{\sum_{i=0}^{n} \dfrac{\left(A_p + A_s\right)^i}{i!}} = B_s = E_n\left(A_p + A_s\right). \tag{23}$$

There is also a more straightforward approach for the derivation of B_s. Our serving system state-transition diagram (Fig. 1) differs from an ordinary multi-dimensional state-transition diagram (with no preemptive priority) in the additional transitions designated with dashed arrows. For an ordinary multi-dimensional loss system [19] is valid the recursion:

$$(0 < q \le n) \\ P_q = \frac{1}{q}(A_p + A_s) P_{q-1}, \tag{24}$$

which also leads to the Erlang loss formula (23). Both relations are valid for our serving system because:

a) the additional transitions are only between states forming one macro-state $i + j = n$.

b) due to the memory-less property of the Poisson process, the displacement of a SU call by a PU call with the same mean service time of $1/\mu$ will not affect the expected time the system spends in the macro-state $i + j = n$.

Therefore, the SU call dropping probability B_d is:

$$B_d = E_n\left(A_p + A_s\right) - E_n\left(A_p\right). \tag{25}$$

Note that recursion (24) (called also Kaufman algorithm [20] for fast calculation of multi-dimensional Erlang loss formula) can be derived in our case from (20) – (22).

V. CALL DROPPING PROBABILITY REGULATION

The users are much more sensitive to interruption of an ongoing call than to rejection of a new call. Therefore, traffic losses due to SU call dropping has to be much lower than losses due to SU call blocking. A comparison between (23) and (25) shows that there is not a big difference between B_s and B_d. The call admission control (CAC) mechanism can be used to regulate the relation between these two probabilities.

A similar problem with handover call dropping occurs in wireless cellular networks. The most widely used method for reduction of handover call dropping probability is the so-called *channel* (*trunk*) *reservation* [21], [22]. Other techniques, commonly called *class limitation* or *threshold policy* [19], [23], have been used for QoS regulation in wireline integrated multiservice systems. For the system considered in our paper, we propose the application of analogous methods.

LIMITATION. The maximum number of admitted SU calls by the CAC should be limited to a certain threshold value $l < n$. Consequently, a new SU call will be admitted only if the number j of occupied channels by SU calls satisfies the following relation:

$$0 \le j < l < n. \tag{26}$$

RESERVATION. The admission of a new SU call is possible only if:

$$0 \le i + j < n - r, \tag{27}$$

where r is the number of reserved channels.

There is a close bond between n and A_p for a given B_p (1). Most often B_p is in the range of 0.5% – 2% for VoIP over wireless access networks. Considering the VoIP PU network as a given fact, our aim is to evaluate the VoIP capacity available to the CR network. The main constraint for the allowable SU traffic A_s is not B_s but B_d. The possibilities for reducing B_d are: decreasing A_s; applying limitation (26) or reservation (27), which also reduce A_s but to a lesser extent. Limitation is investigated in our paper.

Let us denote by $P_{r,j}$ the sum of the state probabilities of row j of our state-transition diagram (Fig. 1):

$$P_{r,j} = \sum\nolimits_{i=0}^{n-j} P_{i,j}, \tag{28}$$

Considering the truncated state space of the diagram due to applying limitation, we have:

$$B_s = P_{r,l} - P_{n-l,l} + \sum\nolimits_{i+j=n} P_{i,j}, \tag{29}$$

$$B_d = \sum\nolimits_{i+j=n} P_{i,j} - P_{n,0}. \tag{30}$$

Since the direct application of (28) – (30) is clumsy from numerical point of view, we propose a new approach for the evaluation of B_s and B_d that gives *approximate* results but has a relatively low computational complexity. Moreover, we validate this approach by simulation experiments.

Let us denote with $P_s^i(j)$ the conditional probability that there are j SU calls in the system, provided that the number of ongoing PU calls is i. Taking into account the facts that the PU and SU arrival traffic flows are independent of each other and that the service of PU calls is independent of the service of SU calls, we analyze our state-transition diagram that is truncated on the upper side due to (26) and obtain:

$$\begin{aligned} B_s &= \sum_{i=0}^{n-l-1} P_{i,c} P_s^i(l) + B_d + B_p = \\ &= E_l(A_s) \sum_{i=0}^{n-l-1} P_{i,c} + B_d + B_p, \end{aligned} \tag{31}$$

$$B_d = \sum_{i=n-l}^{n-1} P_{i,c} P_s^i(n-i), \tag{32}$$

where $P_{i,c}$ has already been introduced by (12); $E_l(A)$ stands for the Erlang loss formula; B_p is obtained from (1); $P_s^i(n\text{-}i), \{n\text{-}l \le i < n\}$ will further be derived.

The preemptive priority of PUs over SUs makes our state-transition diagram different from an ordinary multi-dimensional state-transition diagram and a simple and straightforward approach for the evaluation of the state probabilities cannot be used. Due to the unidirectional transitions, the diagram is not reversible and does not have the *product-form* solution property [19]. Therefore, a simple evaluation of $P_s^i(n\text{-}i)$ with either the *convolutional algorithm* for loss systems (which aggregates traffic streams) or with any *state-based algorithms* (which aggregate state space) cannot be applied. Recursion (24) is also inapplicable.

It is obvious that the state equilibrium equations for SU traffic only (the columns of the diagram) would resemble the equations of the Erlang distribution if the unidirectional transitions λ_p were not introduced. They affect the service of both PU and SU calls. On the one hand the unidirectional transition λ_p in state (i, $n\text{-}i$) depicts the admission of a PU call and from this point of view it does not differ from the other transitions λ_p. On the other hand it depicts the dropping of a SU call and from that point of view λ_p could be considered as the departure (service) rate of one SU call. Moreover, the inter-arrival time of PU calls and the service time of SU calls are independent and identically distributed variables. Based on these considerations, the total effective service rate of SU calls in state (i, $n\text{-}i$) is assumed to be $(n\text{-}i)\mu + \lambda_p$.

Solving the state equilibrium equations for the SU traffic by inspecting the states in column i, $P_s^i(n\text{-}i)$ can be obtained in a way very similar to the derivation of the Erlang loss formula. Thus, we obtain the approximation:

$$P_s^i(n-i) = \frac{\dfrac{A_s^{n-i}}{(n-i-1)!(n-i+A_p)}}{\sum_{j=0}^{n-i-1} \dfrac{A_s^j}{j!} + \dfrac{A_s^{n-i}}{(n-i-1)!(n-i+A_p)}}, \tag{33}$$

where $n\text{-}l \le i < n$.

Substituting (33) into (32), B_d can be evaluated. Substituting (32) into (31), B_s can be calculated.

VI. Numerical Results

In this section, we validate by simulation experiments our new analytical approach for approximate evaluation of B_s and B_d when limitation (26) is applied. Next, we present and analyze some numerical results obtained via the analytical model described above.

In our simulation model, we take into account all the essential factors required for the performance evaluation of the described teletraffic system, such as the Poisson PU and SU call arrival flows, the random service time of a call with negative exponential distribution, the preemptive priority of PU calls over SU calls, the application of limitation as a method for SU QoS provisioning, etc. In Table I, a comparison between analytical and simulation results for B_p, B_s and B_d is presented. The analytical results match well with the simulation results in all cases. This verifies and validates the use of approximation (33). Therefore, the proposed computationally efficient and simple novel approach for approximate evaluation of B_s and B_d when limitation is applied gives sufficiently precise results. Now we proceed to investigate the call-level traffic capacity and the QoS provisioning for the SUs based on our analytical model.

We first analyze the effect of the offered PU VoIP traffic A_p on the SU VoIP traffic capacity A_s. As A_p decreases, the utilization of transmission resources by PUs also decreases. Hence, A_s increases when A_p decreases, as shown in Fig. 2. This general relation reveals that the capacity of the CR network is variable and depends on the momentary PU activity. Therefore, CR should be deployed in primary networks whose transmission resources are underutilized.

TABLE I. Comparison between Analytical and Simulation Results

l=6; n=14; A_s=2 Erl; A_p =5 Erl;			
Analytical Results	B_p=0.0472%	B_s=1.4498%	B_d= 0.3551%
Simulation Results	B_p=0.05%	B_s=1.45%	B_d=0.36%
l=14; n=30; A_s=8 Erl; A_p =11 Erl;			
Analytical Results	B_p= 0.0001%	B_s= 1.7955%	B_d=0.2327%
Simulation Results	B_p=0.00%	B_s=1.80%	B_d=0.23%
n=30; A_s=7 Erl; A_p =15 Erl;			
Analytical Results	B_p=0.0221%	B_s=2.0535%	B_d=2.0314%
Simulation Results	B_p=0.02%	B_s=2.05%	B_d=2.03%

 ISBN: 978-1-61208-155-7

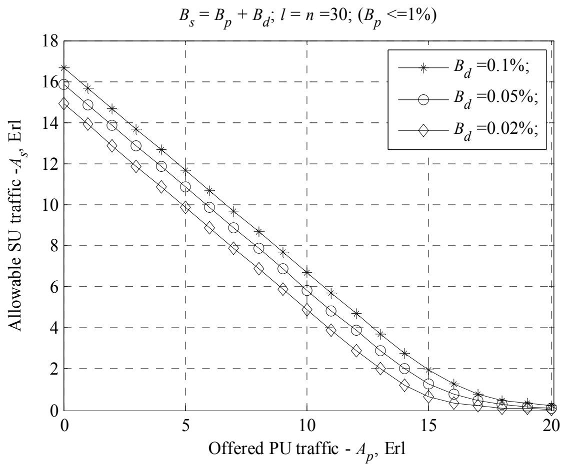


Figure 2. Cognitive VoIP traffic capacity versus the actual PU VoIP traffic load without CAC limitation of SU calls.

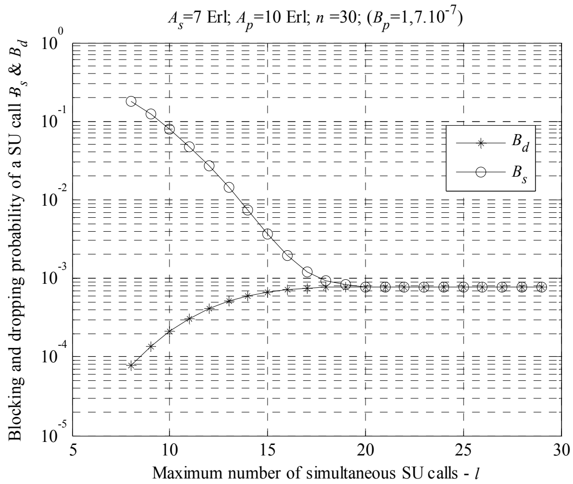


Figure 3. Blocking and dropping probability of a SU call versus the CAC threshold value l for SU calls.

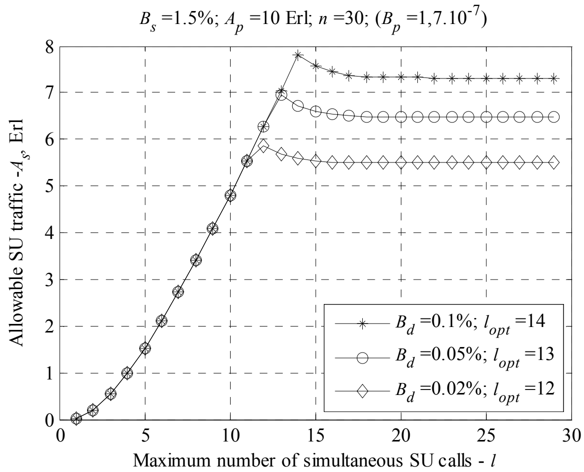


Figure 4. Cognitive VoIP capacity versus the CAC threshold value l for SU calls.

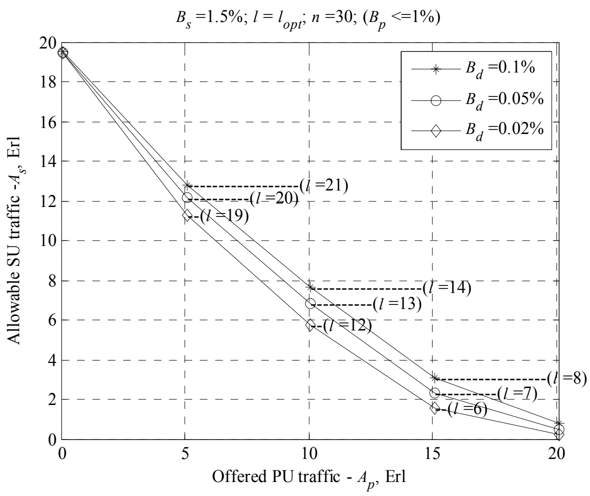


Figure 5. Cognitive VoIP capacity versus the actual PU VoIP traffic load with optimal CAC limitation of SU calls.

It is clear that a lower B_d, i.e. better SU QoS provisioning, could be achieved by reducing A_s, provided that A_p and the parameters of the serving system are fixed. In this case (Fig. 2), due to the relation $B_s = B_d + B_p$ and the stringent requirements on B_d, B_s is much lower than its maximum allowable value, which means that the QoS provisioning for the SUs is achieved at the price of a significant reduction in A_s. The use of limitation as a method for SU call dropping probability regulation enables us to achieve the SU QoS provisioning without severely reducing A_s.

Fig. 3 shows the effect of applying limitation (26). If the SU CAC threshold l is relatively large (close to n), the performance of the serving system is very similar to its performance without limitation, i.e. the values of B_s and B_d are approximately equal. If l is relatively small and decreases, B_s increases and B_d decreases. It is straightforward that when the admissible number of SU calls in the system is smaller, the probability for SU call dropping is also lower and the probability for SU call blocking is greater. On the one hand the decrease in B_d improves the SU QoS provisioning. On the other hand the allowable increase in B_s improves the CR traffic capacity. Hence, if properly applied, limitation can improve the overall performance of the CR network.

Fig. 4 shows the effect of varying l on A_s. There is an optimal value of l which maximizes A_s, provided that A_p and the parameters of the serving system are fixed. If l is relatively small ($l < l_{opt}$) and increases, A_s also increases, as long as B_s and B_d do not exceed their threshold values. If l is relatively large ($l > l_{opt}$ and close to n), the performance of the serving system is very similar to its performance when no limitation is applied, i.e. in order to achieve the SU QoS provisioning, A_s has to be reduced considerably. Therefore, if the optimal value (l_{opt}) of the SU CAC threshold is selected, the traffic capacity of the CR network can be maximized.

Fig. 5 shows the relation between A_s and A_p when limitation is used and $l = l_{opt}$. A comparison between Fig. 2 and Fig. 5 confirms that if limitation is optimally applied, A_s could be significantly increased.

VII. Conclusion and Future Work

In this paper, an analytical model is developed for evaluation of the cognitive SU VoIP traffic capacity and QoS provisioning, namely the SU call blocking and dropping probabilities, in a scenario with VoIP PUs. A method (i.e. limitation) for achieving the required SU QoS provisioning by adjusting the SU call dropping probability is analyzed. A novel computationally efficient and simple analytical approach for approximate evaluation of the effect of applying limitation is developed and validated by simulation experiments. Guidelines for maximizing the CR network capacity by the optimal application of limitation are also proposed.

Since CR utilizes dynamically unoccupied spectrum on an opportunistic basis, the cognitive network capacity is inconstant and depends on the momentary primary traffic load. Our study corroborates that the deployment of a cognitive system is reasonable only if the primary system is underutilized and demonstrates the feasibility of providing VoIP over CR.

The analytical model presented in this paper can be applied to the CR resource management and especially to the call admission control. It can be further elaborated and extended to consider the effects of imperfect spectrum sensing and spectrum handover procedures in order to improve its applicability to more realistic usage scenarios. The model could also be incorporated into a more general cross-layer design framework for the purpose of various system-level analyses.

For future research work, we plan to investigate throughput, QoS, and various cross-layer optimization issues in CR networks used for DSA. Our forthcoming work will be focused on the support of multimedia services over CR networks.

Acknowledgment

This research was supported by the Bulgarian Ministry of Education and Science under Grant DVU01/0109 (DO-02-135 / 2008).

References

[1] J. Mitola III and G. Q. Maguire, “Cognitive radio: making software radios more personal,” IEEE Pers. Commun., vol. 6, no. 4, pp. 13-18, Aug. 1999.

[2] J. Mitola III, “Cognitive radio: An integrated agent architecture for software defined radio,” Ph. D. dissertation, KTH, Royal Institute of Technology, Stockholm, Sweden, May, 8, 2000; (http://www.ict.kth.se/~maguire/jmitola)

[3] A. M. Wyglinski, (editor), “Cognitive radio communications and networks,” IEEE Communications Mag., vol. 46, no. 4, pp. 30-31, Apr. 2008.

[4] T. Yucek and H. Arslan, “A survey of spectrum sensing algorithms for cognitive radio applications,” IEEE Commun. Surveys & Tutorials, vol. 11, no. 1, pp. 116-130, first quarter 2009.

[5] H. Lee and D.-H. Cho. “VoIP capacity analysis in cognitive radio system,” IEEE Commun. Letters, vol. 13, no. 6, pp. 393-395, June 2009.

[6] H. Lee and D.-H. Cho. “Capacity improvement and analysis of VoIP service in a cognitive radio system,” IEEE Trans. on Vehicular Techn., vol. 59, no. 4, pp. 1646-1651, May 2010.

[7] H. Heffes and D. M. Lucantoni, “A Markov modulated characterization of packetized voice and data traffic and the related statistical multiplexer performance,” IEEE J. Selected Areas of Commun., vol. 4, no. 6, pp. 856-868, Sep. 1986.

[8] J.-W. So, “Performance analysis of VoIP services in the IEEE 802.16e OFDMA system with inband signaling,” IEEE Trans. on Vehicular Technology, vol. 57, no. 3, pp. 1878-1886, May 2010.

[9] Q. Zhao, L. Tong, A. Swami and Y. Chen, “Decentralized cognitive MAC for opportunistic spectrum access in ad hoc networks: a POMDP framework,” IEEE J. Selected Areas of Communications, vol. 25, no. 3, pp. 589-600, Apr. 2007.

[10] P. Wang, D. Niyato and H. Jang, “Voice service support over cognitive radio networks,” Proc. IEEE ICC, pp. 1-5, Dresden, Germany, June 2009.

[11] P. Wang, D. Niyato and H. Jang, “Voice-service capacity analysis in cognitive radio networks,” IEEE Trans..on Vehicular Techn., vol. 59, no. 4, pp. 1779-1790, May 2010.

[12] Gunawardena, S. and W. Zhuang, “Voice capacity of cognitive radio networks,” IEEE ICC, pp. 1-5, Cape Town, South Africa, May 2010.

[13] G. Kesidis, J. Walrand and C.-S. Chang, “Effective bandwidth for multiclass fluids and other ATM sources,” IEEE/ACM Trans. on Networking, vol. 1, no. 4, pp. 424-428, 1993.

[14] A. Elwalid and D. Mitra, “Effective bandwidth of general Markovian traffic sources and admission control of high speed networks,” IEEE/ACM Trans. on Networking, vol. 1, no. 3, pp. 329-343, 1993.

[15] D. Wu and R. Negi, “Effective capacity: a wireless link model for support of quality of service,” IEEE Trans. on Wireless Communications, vol. 2, no. 4, pp. 630-643, July 2003.

[16] W. Ahmed, J. Gao, H. A. Suraweera, and M. Faulkner, “Comment on “Analysis of cognitive radio spectrum access with optimal channel reservation”,” IEEE Trans. on Wireless Communications, vol. 8, no. 9, pp. 4480-4491, Sep. 2009.

[17] Y. Zhang, “Dynamic spectrum access in cognitive radio wireless networks,” IEEE ICC, pp. 4927-4932, Beijing, China, May 2008.

[18] F. Capar, I. Martoyo, T. Weiss and F. Jordan, “Comparison of bandwidth utilization for controlled and uncontrolled channel assignment in a spectrum pooling system,” 55th IEEE Vehicular Technology Conf., VTC Spring 2002, vol. 3, pp. 1069-1073, 2002.

[19] V. B. Iversen, “Teletraffic Engineering Handbook,” COM department, Technical University of Denmark, 2006.

[20] J. S. Kaufman, “Blocking in a shared resource environment,” IEEE Trans. on Communications, vol. 29, no. 10, pp. 1474-1481, Oct. 1981.

[21] E. C. Posner and R. Guerin, “Traffic policies in cellular radio that minimize blocking of handoff calls,” 11th International Teletraffic Congress, Kyoto, 1985.

[22] D. Hong and S. Rappaport, “Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and non-prioritized handoff procedure,” IEEE Trans. on Vehicular Technology, vol. 35, no. 3, pp. 77-92, 1986.

[23] R. Kleinnewillinghofer-Kopp and E. Wollner, “Comparison of access control strategies for ISDN-traffic on common trunk groups,” 12th International Teletraffic Congress, 5.4A.2.1-7, Torino, Italy, 1988.

Refining a User Behaviour Model Based on the Observation of Emotional States

[1]Yuska P. C. Aguiar, [1,2]Maria F. Q. Vieira
[1]LIHM, Electrical Engineering Department, UFCG
Campina Grande, Brazil
[2]CESIP, Dept of Electronic & Electrical Engineering, University of Strathclyde
Scotland, UK
yuska.aguiar@lihm.ufcg.edu.br, fatima@dee.ufcg.edu.br

Edith Galy
Université de Provence (Aix-Marseille I), Département de Psychologie Cognitive et Expérimentale
Centre de Recherche PsyCLE
Aix-en-Provence, France
edith.marie@univ-provence.fr

Jean-Marc Mercantini, Charles Santoni
Université Paul Cézanne (Aix-Marseille III), Département Génie Industriel et Informatique, LSIS
Marseille, France
jean-marc.mercantini@lsis.org, charles.santoni@polytech.univ-mrs.fr

***Abstract*— User behaviour models are important tools to study human error in the industrial context. With a programmable user model it is possible to simulate user activity, analyse the influence of context on user behaviour and impact of user behaviour on task outcomes. This paper proposes a procedure to refine user behaviour models. The procedure has been developed to support the analysis of accident and incident reports in the operation of electrical power systems. The procedure involves observing the user interacting with a system simulator that replicates situations described in accident and incident reports. This paper focuses on the emotional components of behaviour observed during the interaction.**

Keywords-User behaviour model; data gathering on human emotions; interaction observation; human error studies.

I. INTRODUCTION

The analysis of accidents and incidents is essential for the study of human error and central to strategies for preventing these: Human Computer Interaction (HCI) adaptation and improvement in training and task adaptation. Report analysis is the traditional path followed by many authors [3][15][23].This approach was adopted by the authors when investigating human error in the operation of an electrical power systems company in Brazil. The studies performed were based on a corpus of 31 reports of accidents and incidents that occurred over a ten-year period. Among the results, these studies resulted in a prototype of a system's operator behaviour model [1][17].

The operator model simulates the dynamic behaviour of a system operator performing tasks during situations and contexts that lead to error. This model has proved to be an important tool for studying, and understanding, human error in that it allows situation contexts to be simulated through the parameterization of behavioural variables cited in the error reports. The original intension was to replicate scenarios in which human error occurred and alter user behaviour to experiment with new scenarios. The parameterization of behavioural variables allowed the simulation of a range of external and internal aspects influences on operator behaviour.

The analysis of the corpus of reports revealed that the error reports focus on the technical aspects of the scenario in which the error occurred but rarely address the operator's state while performing the task, often omitting relevant information relating to emotion and behaviour. In its initial stage the model complexity was kept low, with a small number of variables representing operator state. Tiredness, stress, inattention and confusion, were the causes most frequently mentioned in the reports. To refine the original user behaviour model, and in order to better understand the error context, more information about the status of the operator during the performance of a task is required. The proposed refinement consists of adding new characteristics to the model, i.e., extending the set of variables that represent the operator's state. This requires immersing the operator in the work context and replicating scenarios described in the accident and incident reports in order to observe behaviour. The scenarios must account for the wider environment (e.g., the occurrence of lighting, noise, etc.) as well as the immediate environment. This will be achieved with a simulator that replicates the working environment, with all the objects needed to perform the task, as comprehensively as possible [24]. In order to analyse interactions and highlight elements that contribute to the occurrence of error, the observation should be informed by methods and tools found in psychology, such as task analysis and the observation of emotional components.

This paper proposes the application of Scherer's Components Model of Emotion (CME) [16] to the observation, recording and analysis of the emotional components of operator behaviour. The CME model considers emotion to be an episode of interrelated, synchronized, state changes of subsystems, that are a result of the evaluation of an external or internal stimulus event. The model components are: cognitive appraisal, physiological reactions, behaviour tendencies, motor expression, and subjective feeling (emotional experience). CME was used to structure a range of relevant emotion-measuring methods that can be used to find relevant emotions during the observation of user-system interaction (or with its representation such as the simulator used in this research). The emotions identified, and their relationships, are incorporated into the user behaviour model. To guide the observation an experimental protocol is needed that focuses, among other things, on the user behaviour components. The protocol consists of a set of procedures, activities and

 ISBN: 978-1-61208-155-7

documents that support the observers when planning, conducting and reporting an experiment.

This paper describes how emotions can be measured in accordance with CME and how this knowledge can be integrated into an experimental protocol devised to observe user interactions with systems. The text is organized as follows: Section 2 presents the CME and tools employed to collect emotion data, Section 3 presents the experimental protocol in its original formulation, and Section 4 presents an adaptation of the protocol with CME components. In the final section, the authors consider the future direction and developments this work which is still in progress.

II. COMPONENT MODEL OF EMOTION (CME)

With the advance, and popularization, of interactive technologies, the users' emotional state has become a valuable source of information with the potential to improve the interaction mechanisms offered by a system [20]. Studying human reactions to emotional episodes allows improved understanding of human behaviour.

Mahlke [9][10] identifies how usability and emotional reactions can determine a user's overall appraisal of a system and thus influence his future decisions and behaviour. This work used CME to structure a range of relevant emotion-measuring methods and was adopted as the starting point for the work described here. What follows is an explanation of CME, a list of emotions that can be measured and the tools necessary to make these measurements. It is proposed that these emotions will be integrated into the user model. Although quantitative measurement of the behavioural tendency component of CME has been referred in previous studies is the least explored in the literature and this component is not addressed here.

A. *Cognitive appraisals*

Cognitive appraisals are defined as a quick evaluation of a situation that can direct emotional responses (positive or negative). Based on a review of the literature, Demir et al. [4] propose the following set of appraisal components: consistency of motives, intrinsic pleasure, expectation confirmation, standard conformance, agency, coping potential, and certainty. The tool Geneva Appraisal Questionnaire (GAQ) [16] assesses the result of an individual's appraisal process in the case of a specific emotional episode. GAQ aims to measure: intrinsic pleasantness, novelty, goal/need conduciveness, coping potential and norm/self-compatibility. The emotions measured by GAC are: anxiety, irritation, contentment, joy, sadness, disgust, fear, anger and surprise.

B. *Physiological reactions*

These can be expressed in cardiovascular, electrodermal and respiratory measures. Kreibig [7] presents a review of investigations of different emotions using a range of emotional induction paradigms. The review argues that the elements most often investigated are distributed in three categories: (i) cardiovascular measurements, i.e., heart rate (HR), systolic and diastolic blood pressure (SBP) and heart rate variability (HRV); (ii) respiration rate (RR); and (iii) skin conductance level (SCL). These are also measurements of anxiety, contentment, joy and fear.

C. *Motor expressions*

These are postural, vocal and facial expressions. This work addresses only facial expressions. To use facial expressions it is necessary to classify and correlate them with the appropriated emotion (or set of emotions). The most widely reported work in this context is that of Ekman & Friesen [5], known as the Facial Action Coding System (FACS).Its adoption, however, requires a highly skilled professional. This work adopts a simplified system, FaceReader [22], for automatic real time analysis of facial expressions. FaceReader allows the measurement of the following emotions: sadness, disgust, fear, anger and surprise.

D. *Subjective feelings*

Subjective feelings refer to the unique mental and bodily experience during a particular event [19]. Scherer claims that no objective method for measuring the subjective experience exists. To access it one must ask the individual to report on his/ her experience. The Self-Assessment Manikin (SAM) [8] - is a non-verbal scale, using schematic manikins to represent the different feelings (anxiety, hope, boredom, relaxation, irritation and contentment). SAM manipulates the valence, the arousal, and the dominance dimensions. An alternative, the Activation-Deactivation Adjective Check List (AD-ACL) [21], is a multidimensional tool to test various transitory arousal states (interest, irritation, contentment, joy and fear). The tool considers four sub-scales to measure the relation between energetic and tense arousal: energy, tiredness, tension, and calmness. The Geneva Emotion Wheel (QEW) [19] - is a verbal self-reporting instrument in which the participant is asked to indicate the emotional intensity for a single emotion (or a blend of several emotions) on 20 distinct emotion families (including interest, irritation, contentment, joy, sadness, disgust, fear, anger and surprise). Five degrees of intensity are represented by circles of different sizes.

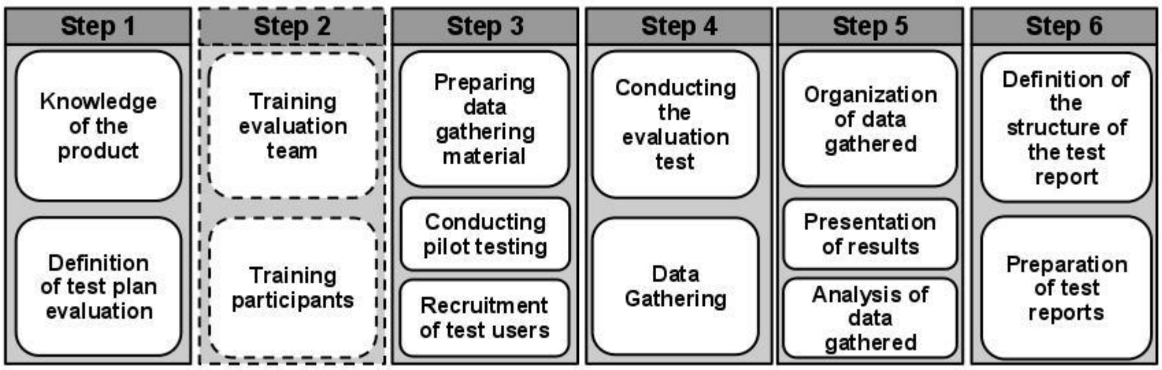
E. *Other tools*

In addition to the tools listed above, there are two others that are relevant to this study. The Objective and Cognitive Profile of the User (POCUS) [18] structures a system user profile using the categories: personal, professional, contextual, physical, psychological and clinical. The NASA Task Load Index (NASA-TLX) [6], employed to measure mental workload, employs three dimensions: behaviour (effort and performance), task (physical, mental and temporal demands), and subjective (frustration).

III. PROTOCOL FOR EXPERIMENTAL OBSERVATION OF THE INTERACTION (PEOI)

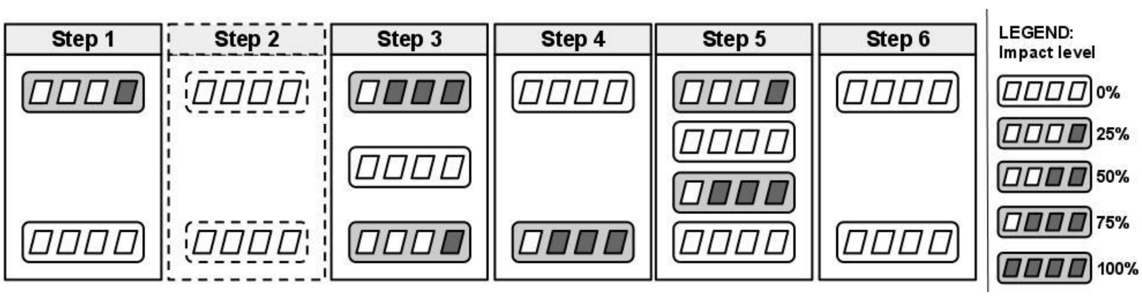
The Protocol for Experimental Observation of Interaction (PEOI) [2] structures the usability recommendations found in the literature [11][13][14]. PEOI was conceived to support the observation of a system-user interaction focusing on usability. It is adaptable to a range of usability testing contexts (in the laboratory, in the field and in situ) and to different product complexities. It was employed in the usability evaluation process of the electric system simulator [24].

The protocol is organized in six steps each of which consists of a process defined by a set of activities. The steps and respective processes are illustrated in Figure 1. Step 1: Planning the Test characterizes the product, its context and its users. Step 2: Training (when needed) prepares the evaluation team and/or the test participants with the product's context of use, tools and methods. Step 3: Preparation and Validation of the Test: structures the test, develops the necessary supporting materials (preparation) and performs a pilot test (validation) with a recruited participant. Step 4: Conducting the Test and Data gathering: executes the experiment resulting in a sample of data. Step 5: Data Tabulation and Analysis structures and organizes the gathered data for analysis and results in a diagnostic for the product-user interaction. Finally, Step 6 - Presentation of the Results specifies the form, content and media to report the experiment and its results.



1

Figure 1 Steps and Processes in PEOI



2

Figure 2 Distribution of proposed changes in PEOI

PEOI associates a set of methods employed for data gathering (observation, interview, questionnaire, document analysis) to four categories of data. General data is gathered through interview, and aims to clarify the test objectives. All four methods are employed to gather data on: task, product and context of use. Pre-interaction gathers data on the user profile (personal, professional and contextual using all methods except observation). Interaction gathers data on subjective indicators using observation. It also gathers objective indicators about user activity using all methods except document analysis. Post-interaction gathers data on user satisfaction level with the product or system under test using all methods except document analysis.

Given that the original purpose of the experimental protocol is to support usability evaluation, the target data and the methods used to gather data have proved adequate. Given the interest in extending the protocol to support the understanding of user behaviour, however, it needs to be adapted to gather data about the user emotional state. This additional data collection is associated with the interaction and post-interaction data categories. The adaptation of PEOI is described in the following section and was based on the CME approach.

IV. PEOI'S ADOPTION OF CME'S TOOLS

In spite of extending the protocol to support user behaviour observation, no changes are required in its general structure, thus its steps and processes remain the same. The changes required are: (i) extension of the range of data to be gathered; (ii) adding new methods for data collection; and (iii) including new activities to be performed by the evaluation team during the experiment.

Given the new aspects of interest in the pre-interaction step, it is proposed that POCUS be adopted when gathering data on the user profile. The extended profile identifies personality and temperament traits. During the interaction and post-interaction steps, the focus becomes that of gathering data about the operator´s emotional state. In these two steps the elements of interest are the following thirteen emotions (according to Geneva Affect Label Coder (GALC´s dictionary) [19]): anger, anxiety, boredom, contentment, disgust, fear, hope, interest, irritation, joy, relaxation, sadness and surprise.

With respect to data gathering methods four new groups are proposed: a) physiological measurement to gather physiological reactions, b) face recognition to gather motor expressions (FaceReader), and c) self-reporting to gather subjective feelings (SAM/AD-ACL/GEW).

The overall changes to team activities during the experiment concern the measurements to be performed relating to behaviour observation. Figure 2 illustrates, at an abstract level, how these changes map onto the protocol. In Figure 2, the processes associated to each step are represented as rectangles, and within each process the corresponding activities are represented as small parallelograms. The figure highlights where changes are being proposed and the overall level of change proposed within each step/process. The level of change represents the volume of new activities introduced in the process (five levels are represented: 0%, 25%, 50%, 75% and 100%).

The processes Knowledge of the Product, Recruitment of Test Users and Scheduling of Test Sessions and Data Gathering can be supported by POCUS. The highest impact of protocol adaptation is on these processes which relate to the test planning activity, test plan execution and data gathering.

In the process Preparing Data Gathering Material four activities were modified: (1) defining which data to gather in order to include variables related to the operator´s emotional state, (2) including tools for data gathering comprising cognitive appraisal (GAQ), physiological measures, motor expressions (FaceReader), subjective feelings (SAM/AD-ACL/GEW), user profile (POCUS) and workload (NASA-TLX), (3) specifying the tools and resources required to collect physiological reactions (HR, HRV, SBP, RR, SCL), (4) preparing the artefacts required to perform the experiment, e.g., questionnaire, forms/cards and self-reporting.

In the process Data Gathering three activities were modified: (5) pre-test activities in which POCUS is applied while measuring physiological variables which will be used as a reference for later comparison with the values collected during task activity; (6) conduct the observation in which physiological variables (HR/HRV/SBP/RR/SCL), motor expressions (FaceReader) and subjective feelings (SAM/AD-ACL) are measured; (7) conduct post-test activities in which cognitive appraisal (GAQ), subjective feelings (GEW), and workload (NASA-TLX) are measured.

In Step 5, the process Analysis of Data Gathered reflects all the changes introduced in the previous steps. The data gathered in Step 4 will impact the analyses process because it requires the correlation analysis between subjective and objective indicators.

Not all the tools and data types in the extended protocol must be adopted in every experiment of course. The choice of data types and corresponding data gathering tools depends on the specific aim of the observation. It is likely, therefore, that a specific experiment will only encompass a subset of the human behaviour related variables (i.e., subset of emotions) to be observed.

V. PROOF OF CONCEPT

An instantiation of the modified protocol is underway. It consists of an experiment in which a product developed for use in a critical situation is being used in order to validate the protocol and support the selection of tools used in the analysis of user behaviour during the task.

The experiment was conducted in the Research Center of Psychology of Cognition, Language, and Emotion of at the *Université de Provence*, in France. It consisted of eight test sessions (including the pilot), during which users were observed with the aid of the protocol. The evaluation team was comprised by one psychologist, two usability experts and two usability trainee students, with varying levels of knowledge about the protocol.

The product under observation was the *Generateur de Plans d'Intervention* (GENEPI) [12], which consists of a decision support system, to assist in preparing contingency plans to deal with maritime accidents. The usage scenario was the communication of an accident followed by preliminary data, which then had to be complemented by the user through the communication with various agencies such as a weather office. The user's goal is to propose an action plan, consistent with the situation of the accident, and the additional data obtained, in the shortest time possible. The whole process of supplying information about the accident (when requested), along with frequent calls demanding for an initial plan, was simulated by the research team during the test sessions.

The data collected from the test sessions is currently being analyzed, and will be used to evaluate the new version of the protocol in terms of ease of use, effectiveness and efficiency. More specifically the data will be used to analyze the impact of the changes made in the protocol, on its artefacts, on the actors and the interaction between them. It is also intended to select those tools that are most appropriate for the acquisition of knowledge about the emotions and behaviour of users. Finally it is intended to assess the adaptability of the protocol to a different context from that for which it was conceived (i.e., the observation of electrical systems operation).

From this experiment, it should be possible to identify any requirement for protocol refinement, before it is applied in the context of electrical systems and used to improve the user behaviour model.

VI. FINAL CONSIDERATIONS

The human error study based on document analysis (in particular error reports) will benefit from a user behaviour model extracted from the observation of the operator when confronted with the work context. To be a useful tool, the programmable user model must be refined with data gathered using tools and methods from the domain of psychology. This paper asserts that experiments to gather data on user behaviour must be supported by an experimental protocol. It describes such a protocol in the context of a product usability evaluation adapted to human behaviour observation. The observations supported by the protocol focus on aspects related to the user behaviour and emotional state. The proposed protocol supports: (i) identification of the emotions to be measured; (ii) identification of tools to be used when observing the user-system interaction; and (iii) structuring of the data gathering process to be employed during the interaction observation.

One innovative aspect of the work reported is the simultaneous application of different tools to collect data about the operator's emotion and behaviour, during their work activity, in order to evaluate their effectiveness. Another is the proposal of the experimental protocol itself. Although the existing literature cites both practices on usability evaluation of products and the observation of user behaviour in psychology, methods and procedures have not yet been made available in the form of a systematized protocol to support the reporting, interpretation and replication of experiments.

A limitation of the proposed protocol is that it has been designed to observe the behaviour of individuals under stress interacting with critical systems. Under these conditions human reactions are amplified and thus more easily measured. Furthermore, the observation is conducted in a simulated environment. This imposes two corresponding challenges for the future extension of this work: (i) to evaluate the applicability, efficiency and effectiveness of the protocol outside the domain of critical systems, and (ii) to investigate the degree to which the data collected by the protocol reflects that which would be collected in a real working environment.

In the current version of the protocol, data collection is focused on the following aspects: workload, attention, emotion and behaviour; complemented by data on the profile and personality of the operators. However, it is intended to extend this to include other aspects of user behaviour. This depends on identifying additional tools to collect human behaviour data. The observation of such supplementary factors will only be useful, of course, if the ranges of the metrics describing them in which human errors occur can be identified.

Improved understanding of human behaviour during situations leading to error will complement traditional information (such as accident and incident reports) and lead to reduction in the incidence of human error. Information on user behaviour projected onto a user programmable model will allow the relationship between user behaviour, work context and error occurrences in specific working scenarios to be investigated experimentally.

REFERENCES

[1] Netto, A. V. S., Aguiar, Y. P. C, Scherer, D., and Vieira, M. F. Q. Context analysis during task execution: an operator model. In: IADIS Multi Conference On Computer Science and Information Systems, 2009, Algarve, pp. 113-120.

[2] Aguiar, Y. P. C. and Vieira, M. F. Q. Proposal of a protocol to support product usability evaluation. Fourth IASTED International Conference Human-Computer Interaction, 2009, St. Thomas, pp. 282-289.

[3] Cellier, J. M. L'erreur humane dans le travail. In : Les facteurs humains de la fiabilité dans les systèmes complexes, by J. Leplat and G. De Terssac. 1990, Marseille.

[4] Demir, E., Desmet P.M.A., and Hekkert, P. Appraisal Patterns of Emotions in Human-Product Interaction. Int. J. of Design, 2009, pp.41-51.

[5] Ekman, P. and Friesen, V. W. Facial action coding system: A technique for the measurement of facial movement. Palo Alto, Ca.: Consulting Psychologists Press, 1978.

[6] Hart, S. G. and Staveland, L. E. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: P. A. Hancock and N. Meshkati (Eds.) Human Mental Workload. Amsterdam: North Holland Press, 1988, pp. 139-183.

[7] Kreibig, S. D. Autonomic nervous system activity in emotion: a review, Biological Psychology 84, 2010, pp. 394–421.

[8] Lang, P. J., Greenwald, M. K., Bradley, M. M., and Hamm, A. O. Looking at pictures: Affective, facial, visceral, and behavioral reactions. Psychophysiology, 30 (1993), pp. 261-273.

[9] Mahlke, S. and Lindgaard, G. Emotional Experiences and Quality Perceptions of Interactive Products. In J. Jacko (Ed.) Human-Computer Interaction, Part I, HCII 2007, LNCS 4550 pp.164-173. Berlin: Springer.

[10] Mahlke, S. and Thüring, M. Studying Antecedents of Emotional Experiences in Interactive Contexts.CHI 2007 Proceedings, pp. 915-918. New York: ACM Press.

[11] Mayhew, D. J. The usability engineering lifecycle: a practitioner's handbook for user interface design, San Francisco, CA: Morgan Kaufmann Publishers Inc., 1999

[12] Mercantini J.-M., Guerreiro C. V. S, and de Freitas D. D., Designing a Software Tool to Plan Fight Action against Marine Pollutions. The 7th International Mediterranean and Latin American Modelling Multiconference, October 13-15 2010, pp. 93-99, Fes, Morocco.

[13] Nielsen, J. Usability Engineering. Morgan Kaufmann, 1994

[14] Preece, J., Rogers, Y., and Sharp, H. Interaction Design: Beyond Human-Computer Interaction. 2nd Edition, 2007

[15] Rasmussen, J., O. M. Pedersen, A. Carmino, M. Griffon, and P. Gagnolet. Classification system for reporting events involving human malfunctions. RISO National Laboratory, Dennmark: RISO National Laboratory, 1981.

[16] Scherer K. R. Appraisal Considered as a Process of Multi-Level Sequential Checking; in K. R. Scherer, A. Schorr and T. Johnstone (eds.) Appraisal Processes in Emotion: Theory, Methods, Research, pp. 92-120. New York and Oxford: Oxford University Press, 2001.

[17] Scherer, D., Netto, A. V. S., Vieira, M. F. Q. and Aguiar, Y. P. C. Programming a user model with data gathered from a user profile. In: ADIS Multi Conference on Computer Science and Information Systems, 2010, Freiburg. , 2010. pp. 139-146.

[18] Scherer, D. and Vieira, M. F. Q. Accounting for the Human Error when Building the User Profile. In: Third IASTED International Conference Human-Computer Interaction, 2008, Innsbruck, 2008. v. 1. pp. 132-137.

[19] Scherer, K. R., What are emotions? And how can they be measured? Social Science Information 44, 2005, pp. 695–729.

[20] Tayari, I. and Le Thanh, N. "Modélisation des états émotionnels par un espace vectoriel multidimensionnel" Research Report 2009.

[21] Thayer, R. E. Toward a psychological theory of multidimensional activation (arousal). Motivation and Emotion, 2, 1978, pp. 1-34.

[22] den Uyl, M., Kuilenburg, H. V., and Lebert, E. FaceReader: an online facial expression recognition system. Measuring Behavior 2005, 5th International Conference on Methods and Techniques in Behavioral Research, 2005, Wageningen, The Netherlands, pp. 589-590.

[23] van Eekhout, J. M., and W. B. Rouse (1981). Human Errors in Detection, Diagnosis, and Compensations for Failures in the Engine Control Room of a Supertanker. IEEE Transactions on System, Man, and Cybernetics, 1981, 12 ed., pp. 813-816.

[24] Vieira, M. F. Q., Nascimento, J. A. N., Scaico, A., Santoni, C., and Mercantini, J.-M. A Model Based Operator Training Simulator to support Human Behavior Studies. Transactions of the Society for Computer Simulation, v. 86, pp. 41-51, 2010.

Knowledge Representation in Visual Design

Ewa Grabska, Grażyna Ślusarczyk, Szymon Gajek
The Faculty of Physics, Astronomy and Applied Computer Science,
Jagiellonian University,
Reymonta 4, 30-059 Kraków, Poland
ewa.grabska@uj.edu.pl, gslusarc@uj.edu.pl, szymon.gajek@gmail.com

***Abstract*—This paper deals with an approach to represent design knowledge and reasoning in computer systems supporting visual design. Both forms and layouts functionality of designed artifacts are visualized as design drawings with the use of a visual editor. Design knowledge about these drawings is formally represented in the framework of a computational ontology for design. This ontology allows the system to convert drawings into their internal representations. The defined ontological commitment transforms design knowledge encoded in the internal representations of drawings into logic formulas. The obtained logic language enables the system to reason about compatibility of designs with specified constraints. The presented approach is illustrated on the example of designing an indoor swimming pool.**

Keywords-design knowledge; CAD system; conceptual design; visual language; hypergraph

I. INTRODUCTION

This paper aims at introducing a new approach to represent design knowledge and knowledge-based reasoning in computer systems supporting the conceptual phase of visual design. The conceptual design takes place at various levels of abstraction. To externalize the design concepts and ideas the designer usually sketches in search of shapes and relations among them. Contemporary, the designer has the possibility to use specialized CAD tools (like ArchiCAD, Allplan, Revit [1-3]) in order to replace sketches by drawings.

In this paper, we present the knowledge representation, where the visualizations of early solutions made by the designer are the main source of knowledge about created designs. The structure of the design system consistent with the proposed method is presented in Figure 1. Based on this structure the prototype computer-aided visual design system is implemented. It serves to test designing of both two-dimensional floor-layouts and three-dimensional forms of buildings.

In the prototype system the designer creates solutions of a design task using a design interface composed of a visual editor and a rule editor. The former allows the designer both to describe the form and the functionality of the design artifact by means of problem-oriented visual languages. The latter enables him to specify design constraints which should be obeyed during the whole design process.

Designs with required functionality created in this system are represented as drawings forming specified visual languages. These drawings have their internal representations which encode the design knowledge about the design task solutions. Design knowledge is formally represented in the framework of computational ontologies [4]. An ontology for design is defined using a notion of a conceptualization which specifies concepts that are assumed to exist in a given design domain and relationships that hold among them [5]. In our approach the conceptualization is related to the internal representation of a drawing in the form of a specific graph (hypergraph), where graph atoms represent concepts and relations.

To make the design knowledge computer readable we use a first-order logical language to express it in a formal way. We specify the mapping called ontological commitment between elements of the vocabulary of this language and entities of the conceptualization. This mapping allows us to translate design knowledge captured in graph structures into logic formulas describing design drawings. The obtained logic language enables the system to reason about compatibility of designs with specified constraints.

The presented approach will be illustrated by the running example of designing an indoor swimming pool taking into consideration both its form and floor-layout.

The paper is organized as follows. Section 2 describes the related work. In Section 3, visual languages used in the visual design process are described. In Section 4 graph-based internal representations of design drawings are presented. Reasoning based on design knowledge encoded in the internal representation of solutions and translated into logic formulas is discussed in Section 5. The paper ends with a conclusion.

II. RELATED WORK

To construct knowledge-based design systems the representation and manipulation of knowledge in computers is needed [6]. Knowledge-based design systems, in which knowledge pertaining to a given design domain is represented, are integrated with CAD tools to facilitate design process [7-11]. Contemporary CAD systems are expected to extend their functionality far over merely producing drawings. These systems, following the Building Information Modeling paradigm [12] store all project's 3D elements in a central database and are able to generate 2D

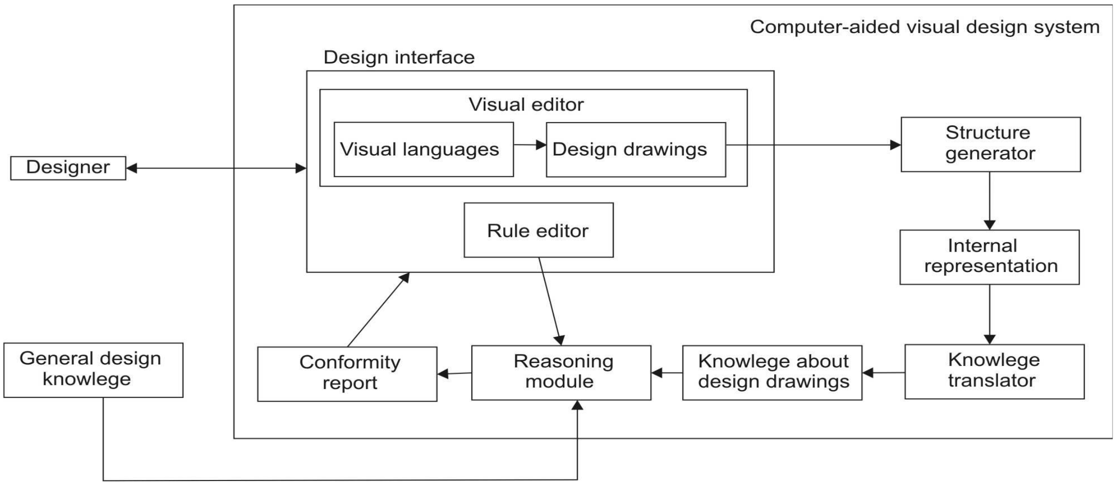


Figure 1. The schema of the computer-aided visual design system

drawings and 3D renderings. However, the most of these tools do not provide data structures related to designs and reflecting the design knowledge extracted from drawings being visualizations of designer ideas. In this paper it is shown how design drawings created by means of the visual editor can be automatically transformed into their internal computer representations.

There are two types of knowledge representations: symbolic and graphical ones. In the former, knowledge is represented explicitly in symbolic terms and reasoning is the manipulation of these terms [13, 14]. In the latter, the way of organization, processing and manipulation of knowledge is based on the spatial relations between objects [15-17]. In this paper both types of knowledge representations are used in such a way that the symbolic representation is based on the graphical one. We propose an extension of the approach presented in [15, 16, 18] where a visual representation of designs made by the designer is created simultaneously together with their internal representations. In this method initial visualizations of designer's solutions are the main sources of knowledge about designs. Up to now this approach has been used to functional designing two-dimensional floor-layouts. At present the designs of architectural forms are also studied based on this method. Design knowledge can be formally represented in the framework of computational ontologies [4]. The ontological framework used in this paper facilitates the description of the proposed design cycle.

Graphs and hypergraphs are used quite frequently in knowledge-based design tools [19]. Our approach is based on a formal model of hypergraphs introduced in [20] and extended in [21].

III. VISUAL LANGUAGES

In this section, we present visualizations of design solutions, which can be created by the designer in different phases of the visual design process.

On the basis of general requirements concerning a design task the designer starts with creating a three-dimensional visualization being a general form of an artifact. Then an outline of the floor is created as the intersection of this form with a plane at a given height. Such a shape can be also treated as a starting point of the design process when a floor-layout is created on the basis of functional aspects of the solution. At the outset of this process the conceptualization is modeled, i.e., the relevant entities and relations emerging from the design task under consideration are specified. In other words, having a 2D contour of a design object the designer describes the inner structure of the object. In our approach this structure is obtained by means of a visual editor and it is a floor-layout visualized as a design drawing.

The designer communicates with the design system using a visual editor which enables him to use different visual design languages. A visual language is a set of design drawings being configurations of basic shapes. Thus it is characterized by a vocabulary being a finite set of basic shapes and a finite set of rules specifying possible configurations of these shapes. The basic shapes of visual languages and their spatial relationships correspond to concepts and relations defined by the conceptualization of the design domain. During a design process each visual language allows the designer to specify the specialization hierarchy of design concepts.

Example. Let us consider an example of designing an indoor swimming pool in a one-storey building. At first a form of this building is created by the designer with the use of a 3D visual language (Figure 2). The vocabulary of the used language is composed of cubes which can be translated, rotated and scaled or undergo Boolean operations. It is worth noticing that the existing graphical tools like Revit [3] or ICE [22] can be used in this design phase. The 2D contour of the form located in an orthogonal grid is shown in Figure 3a. In the next step, taking into consideration the type of the swimming pool (recreational, sports, learner) and an approximate number of users, the designer decomposes this contour into functional areas represented by polygons

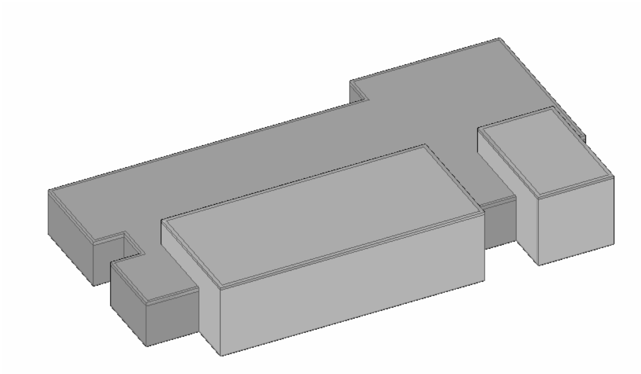


Figure 2. The proposed form of a swimming pool building

(Figure 3b). Then functional areas, namely the entrance area, swimming area and changing area, are decomposed into appropriate rooms. In the entrance area the main hall, the ticket desks, the cloak-room, the corridor, the toilets, the bar lobby and the bar kitchen are distinguished. The changing area is decomposed into women and men changing rooms, the toilets, the showers, the staff room and the first aid room. The swimming area is divided into the main pool, the jacuzzi, the kids pool, the lifeguard room and the hall. The obtained whole floor layout is shown in Figure 4. The vocabulary of the language, which enables the designer to design floor layouts, is composed of shapes corresponding to components like rooms, walls, and additional graphical symbols allowing the designer to express the relations between components. In Figure 4, segments with dashed lines represent the visibility relations among components, continuous segments shared by polygons denote the adjacency relations between them, while segments with rectangles on them represent the accessibility relations.

IV. THE INTERNAL REPRESENTATION OF DESIGN DRAWINGS

Our approach deals with visual designing i.e., during the design process the designer communicates with the system by means of design drawings automatically transformed by the structure generator module into their internal representations in the form of graphs. The graph structure enables the system to store the knowledge about syntactic aspects of created drawings [23]. Graph atoms represent concepts and relations corresponding to the elements of the conceptualization determined by the designer. To represent the top-down way of designing as well as the hierarchy of design concepts, a hierarchical data structure is needed [20, 21].

The internal data structure used in our approach is called an attributed hierarchical hypergraph. The prefix ‘hyper’ in the word ‘hypergraph’ denotes that this graph structure allows for expressing multi-argument relations between drawing components. The considered hypergraphs are composed of object hyperedges corresponding to layout components and relational hyperedges, which represent relations among fragments of components. The fragments of components that can be used as arguments of relations are represented by hypergraph nodes. Hyperedges are labelled by names of components or relations.

Drawing a design diagram the designer specifies labels of components related to room types. While he creates the diagram and/or modifies it using design actions, the hierarchical hypergraph is automatically generated. In our algorithm, for each labeled design component in the form of a polygon, one object hyperedge is created. Semantic information about this component describing it as a room is automatically completed by a hyperedge label describing a type of this room. When the designer divides a component into parts, the hierarchical hypergraph composed of object and relational hyperedges representing the arrangement of these parts is nested in the object hyperedge representing the divided component. For each line shared by polygons in the diagram one relational hyperedge connecting nodes representing corresponding sides of the polygons is generated. Semantic information about this relation depends on the line style and determines the type of the relational hyperedge label. The continuous lines correspond to adjacency relations, the dashed lines represent visibility relations, while the lines with small rectangles on them correspond to accessibility relations.

To represent design features being other type of semantic information concerning layout components, attribution of nodes and hyperedges is used. Attributes represent properties (like shape, size, position, material) of elements corresponding to object hyperedges and nodes.

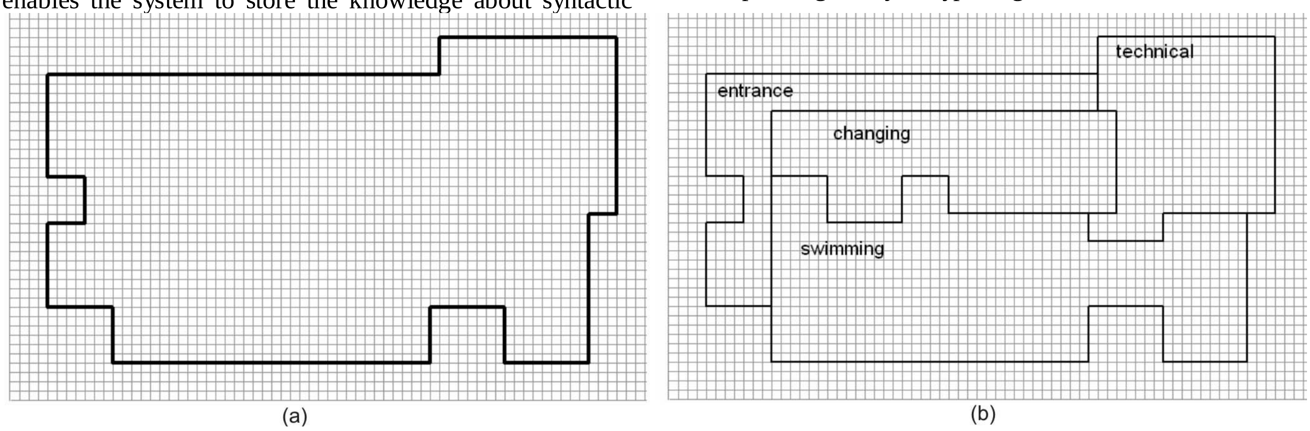


Figure 3. (a) The contour of the swimming pool, (b) the decomposition of the contour into four functional areas

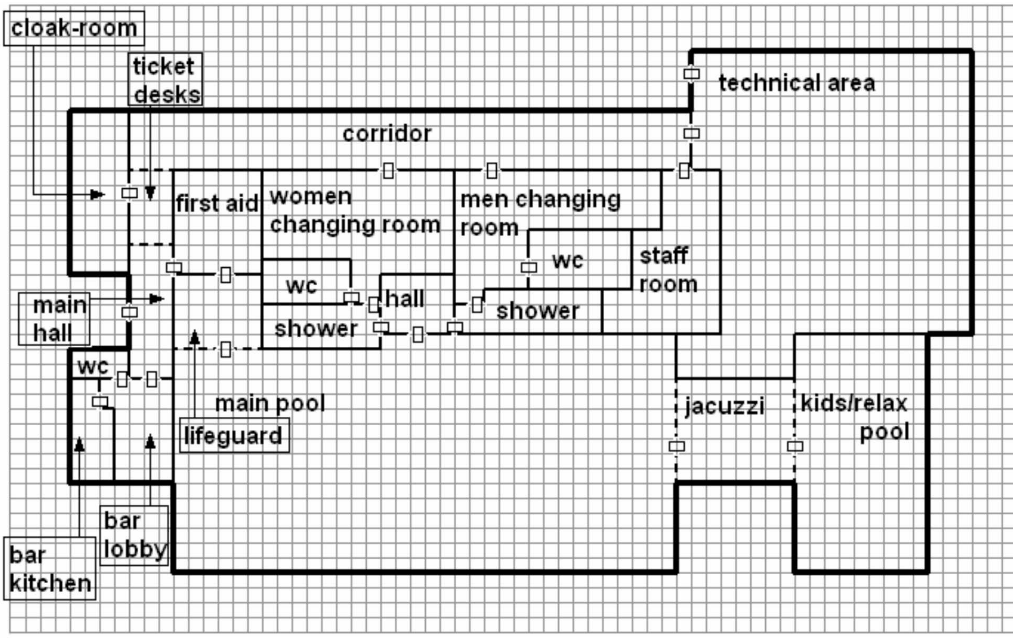


Figure 4. The floor layout of the swimming pool

The values of such attributes as *area* are automatically set by the system at the time of creating rooms on the basis of the occupied part of the grid on which diagrams are drawn. The values of other attributes, like *material* characterizing walls, can be specified by the designer at the time of establishing the relations between rooms.

Example. A fragment of the hierarchical hypergraph representing the layout of the designed swimming pool is presented in Figure 5. This hypergraph is composed of fourteen object hyperedges (denoted by rectangles) and thirty three non-directed relational hyperedges (denoted by ovals), where nine of them represent the accessibility relation, twenty three represent the adjacency relation and one represents the visibility relation. The swimming area and the changing area are represented by hierarchical object hyperedges. The nested object hyperedges correspond to the rooms in these areas. Hypergraph nodes represent walls of areas or rooms and are assigned as target nodes to object hyperedges representing these areas or rooms. The values of the attribute order are shown near nodes. They determine the order of walls as well as their level of hierarchy. The first element of the sequence denotes the number of a wall corresponding to one of the polygon sides, while the length of this sequence determines in which design step the wall was introduced.

V. REASONING BASED ON DESIGN KNOWLEDGE

In order to express the design knowledge about generated drawings in a formal way a first-order logical language is used [13]. We specify the mapping called ontological commitment between elements of the vocabulary of this language and entities of the conceptualization. The layout components are assigned to the constant symbols, their attributes are assigned to function symbols, while relations between the components correspond to the predicate symbols. This commitment allows the system to transform semantic and syntactic information encoded in the internal representations of drawings into logic formulas.

In the running example, elements of a set of concepts (areas, rooms, walls) and relations (adjacency, accessibility and visibility) of a given visual language are associated with symbols of the vocabulary of the logic language. The sides of polygons representing walls of rooms are associated with constant symbols, while lines shared by polygons representing relations between them are assigned to predicate symbols. Attributes determined for walls and rooms correspond to function symbols.

The formulas are interpreted using a relational structure, which assigns hypergraph nodes, object hyperedges and their attributes to the terms, and relational hyperedges to the predicates of the formulas. The logical language stores knowledge about created designs and enables the system to reason about compatibility of designs with specified constraints. It is worth noticing that design knowledge can be also expressed in different types of logic (e.g., propositional logic), depending on the considered design problem.

The system is also equipped with a knowledge base composed of formulas expressing general design knowledge specific to a particular design task. Restrictions and rules of this base describe design standards like architectural norms, fire regulations, etc. Additionally, there exists the possibility to specify designer's own requirements and restrictions using a rule editor being a part of a design interface.

 ISBN: 978-1-61208-155-7

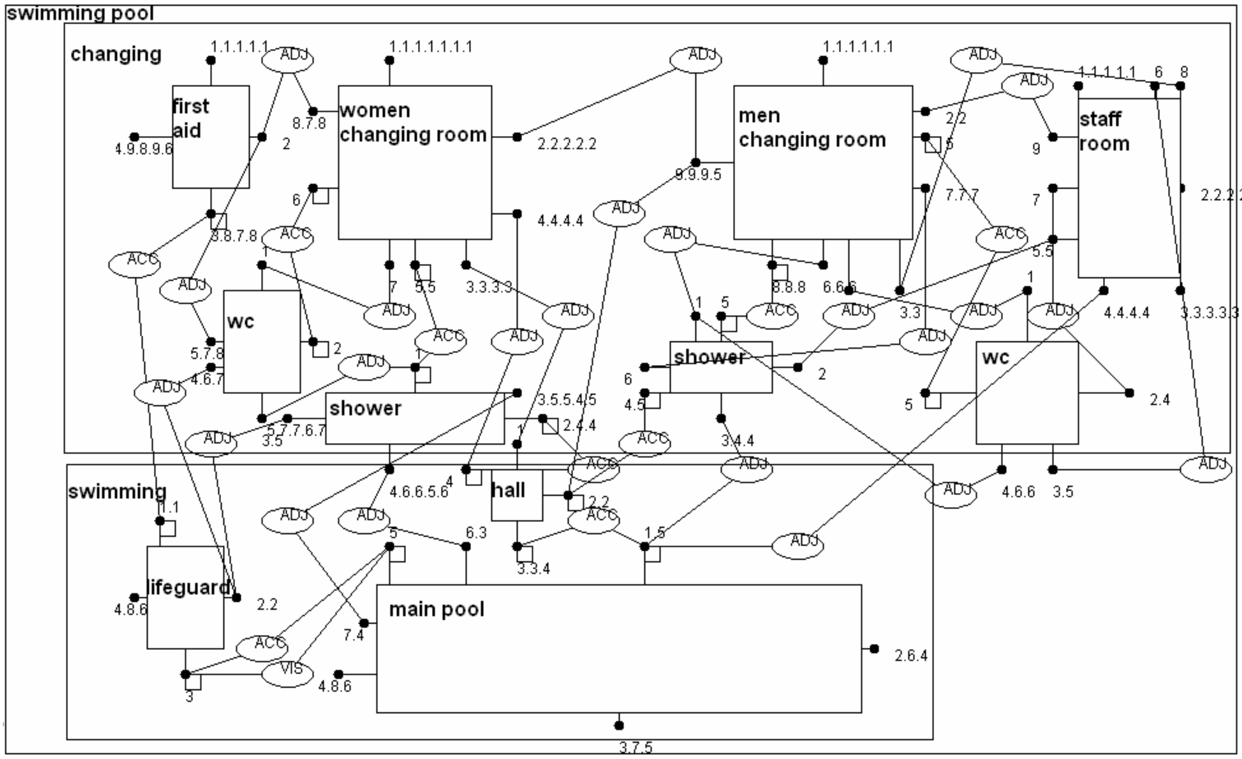


Figure 5. A fragment of the hierarchical hypergraph representing the layout of the swimming pool

All three kinds of formulas, namely formulas describing the created designs, formulas describing general design knowledge and rules defined by the designer, enable the system to support the user in creating admissible, acceptable and safe artifacts [24]. The reasoning module of the system checks the conformity of the design drawing representing the created design task solution with the specified design criteria. Then the conformity report is presented to the designer through the design interface.

Example. The knowledge stored in the hierarchical hypergraph presented in Figure 5 is translated into propositional logic formulas describing relations between rooms of the designed layout (Figure 4), like *visibility* (*lifeguard_room*, *main_pool*), *adjacency*(*staff_room*, *main_pool*), *accessibility*(*corridor*, *women_changing_room*). For instance the *visibility* relation between two rooms holds if there exist two hypergraph nodes representing walls and assigned to two different component hyperedges (representing rooms) and to the same relational hyperedge labeled *visibility*. Moreover the attributes assigned to these nodes and specifying the wall material should have the value corresponding to the glass.

For the drawn layout the system automatically calculates the values of the attribute specifying the area of rooms (e.g., *area*(*main_pool*) = 2120). Then the reasoning module can check the agreement between the proposed layout and standard architectural norms for swimming pool designs [25-27]. For example it test if the conditions *area*(*women_changing_room*) ≥ *area*(*main_pool*)/7, and *area*(*main_pool*)/20 ≤ *area*(*shower*)+*area*(*wc*) ≤ *area*(*women_changing_room*) are satisfied. Checking the fire regulations the system computes also the distance from all rooms to the main hall.

In the next step the conformity of the solution with constraints defined by the designer is checked. For example the system can check whether the rectangular swimming pool is placed with its longer wall towards the South. This constraint is satisfied if the following condition holds: *if length*(*main_pool*.1) > *length*(*main_pool*.2) *then location*(*main_pool*.1) = *S or location*(*main_pool*.1) = *N else location*(*main_pool*.2) = *S or location*(*main_pool*.2) = *N*, where *main_pool*.1 and *main_pool*.2 correspond to nodes, which are assigned to the hyperedge representing the main pool and denote the walls of the pool (in this case nodes with numbers 4.8.8.5 and 3.7.7.4) , while *length* and *location* are attributes specifying the length and geographical orientations of walls.

The hierarchical representation of design knowledge facilitates the reasoning process. Let us consider the formula which allows one to check "if there exists a staff room with the area of at least 10m^2 and located in the changing area". The formula is as follows: $\exists x, y$: $lb(y) = changing \wedge x \in ch^+(y) \wedge lb(x) = staff\_room \wedge area(x) \geq 10$, where x and y are variables, lb is a hypergraph labeling function, ch^+ is a function determining all ancestors of the given hyperedge.

After the design of the 2D floor layout is completed, the general form of the building with internal walls dividing the rooms is visualized (Figure 6). This visualization gives the designer the possibility to simulate the object behavior.

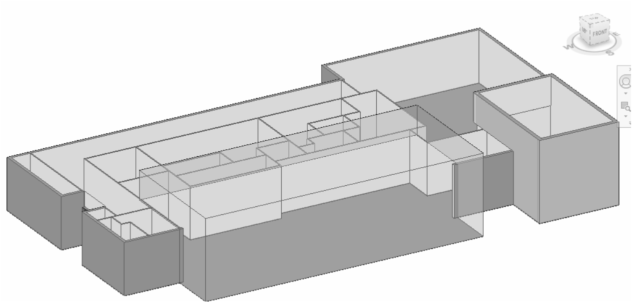


Figure 6. The form of the building with internal walls dividing the rooms

VI. CONCLUSION AND FUTURE WORKS

In this paper, an approach to visual design of buildings was considered. Different visual languages are used to design architectural forms and floor-layouts of buildings. A rule editor of the presented system enables the designer to specify design constraints which should be obeyed during the whole design process. The design drawings obtained during the design process have their internal representations in the form of attributed hierarchical hypergraphs encoding the design knowledge about the drawings. This knowledge is translated into logic formulas. The obtained logic language enables the system to reason about compatibility of designs with specified constraints by comparing its formulas with formulas expressing design knowledge specific to particular design tasks and requirements defined by the designer.

In the future work the multi-storey buildings will be designed with the use of visual languages. It will require extending generation methods used to create architectural forms to include for instance 3-D shape grammars which are present subjects of our studies.

REFERENCES

[1] ArchiCAD, Graphisoft, http://www.graphisoft.com/products/archicad/, 15.07.2011.

[2] Allplan Architecture, Nemetschek, http://www.allplan.com/, 15.07.2011.

[3] Autodesk Revit Architecture, Autodesk, http://www.autodesk.com/revit, 15.07.2011.

[4] N. Guarino, D. Oberle, and S. Staab, “What is an Ontology?”, Handbook on Ontologies, S. Staab, R. Studer, Eds. International Handbooks on Information Systems, Springer-Verlag, 2009.

[5] M.R. Genesereth and N.I. Nillson, Logical Foundations of Artificial Intelligence, Morgan Kaufmann, Los Altos, CA, 1987.

[6] R.D. Coyne, M.A. Rosenman, A.D. Radeford, M. Balachandran, and J.S. Gero, Knowledge based design systems, Addison-Wesley Publishing Company, 1990.

[7] A. Goel, S. Bhatta, and E. Stroulia, “KRITIK: An early case-based design system” in M.L. Maher and P. Perl, Eds., Issues and Applications of Case-Based Design, Erlbaum, Hillsdale, NJ, 1997, pp.87-132.

[8] U. Flemming and R. Woodbury, “Software Environment to support the Early phases in building Design (SEED): Overview, J. Arch. Engrg. 1, 147, 1995.

[9] U. Flemming, R. Coyne, T. Gavin, and M. Rychter, “A generative expert system for the design of building layouts - version 2”, in B. Topping, Ed., Artificial Intelligence in Engineering Design, Computational Mechanics Publications, Southampton, 1999, pp.445-464.

[10] K. Sycara, R. Guttal, J. Koning, S. Narasimhan, and D. Navinchandra, “CADET: a Case-based Synthesis Tool for Engineering Design”, International Journal of Expert Systems 4, 1992.

[11] A. Voß, “Case design specialists in FABEL”, in M.L. Maher and P. Perl, (Eds.), Issues and Applications of Case-Based Design, Erlbaum, Hillsdale, NJ, 1997, pp.301-336.

[12] Ch. Eastman, P. Teicholz, R. Sacks, and K. Liston, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, Wiley, 2008.

[13] R. Fagin, J.Y. Halpern, Y. Moses, and M.Y. Vardi, Reasoning About Knowledge, MIT Press, Cambridge, 1995.

[14] S.Garavaglia, PROLOG, Harper and Row, New York, 1984.

[15] E. Grabska, G. Ślusarczyk, and T.L. Le, “Visual design and reasoning with the use of hypergraph transformations”, Proc. of the Seventh International Workshop GT-VMT 2008, Budapest, Electronic Communications of EASST 10, 2008, pp. 305-318.

[16] E. Grabska, A. Łachwa, G. Ślusarczyk, K. Grzesiak-Kopeć, and J. Lembas, “Hierarchical layout hypergraph operations and diagrammatic reasoning”, Machine GRAPHICS and VISION, vol. 16, 2007, pp. 23-38.

[17] M. Nagl, (Ed.), “Building Thightly-Integrated (Software) Development Environments: The IPSEN Approach”, LNCS 1170, Berlin: Springer Verlag, 1996, pp.248-279.

[18] E. Grabska, A. Borkowski, W. Palacz, and S. Gajek, “Hypergraph system supporting design and reasoning”, EG-ICE International Workshop, Berlin, Germany, 2009.

[19] A. Schurr, A. Winter, and A. Zundorf, “Graph grammar engineering with PROGRES”, in W. Schafer and P. Botella Eds., Proc. of the 5th European Software Engineering Conference (ESEC95), LNCS 989, Springer-Verlag, Berlin, 1995, pp. 219–234.

[20] F. Drewes, B. Hoffmann, and D. Plump, “Hierarchical Graph Transformation”, Proc. of FOSSACS 2000, J. Turyn, Ed., LNCS, vol. 1784, Springer, 2000, pp. 98–113.

[21] G. Slusarczyk, “Hierarchical Hypergraph Transformations in Engineering Design”, Journal of Applied Computer Science, 11(2), 2003, pp.67–82.

[22] O. Akin and H. Moustapha, “Formalizing generation and transformation in design”, Proc. Design Computing and Cognition’04, J.S. Gero, Ed., Kluwer, Dordrecht, 2004, pp. 176-196.

[23] B. Kraft, “Conceptual Design Tools for Civil Engineering”, Proc. of AGTIVE’03, 2003, pp. 434-439.

[24] E. Grabska and G. Ślusarczyk, “Knowledge and reasoning in design systems”, Autom. Constr., in press, doi:10.1016/j.autcon.2011.03.009.

[25] D. Fabian, Bäderbauten: Aquatic buildings (Handbuch für Bäderbau und Badewesen: Anlage, Ausstattung, Betrieb, Wirtschaftlichkeit), Verl. Georg D. W. Callwey, München, 1970.

[26] E. Neufert, Architects' Data, BSP Professional Books, Oxford, 1990.

[27] R. Wirszyłło, Ed., Sport equipment. Designing and building (in Polish), Arkady, Warszawa, 1966.

Task-based Guidance of Multiple UAV Using Cognitive Automation

Johann Uhrmann & Axel Schulte
Institute of Flight Systems
Universität der Bundeswehr München
Munich, GERMANY
{johann.uhrmann|axel.schulte}@unibw.de

***Abstract*—This article discusses different dimensions of automation in the integration of multiple, detached, unmanned sensor platforms into a military helicopter scenario. Artificial cognitive units implement parts of human-like knowledge-rich task execution aboard a highly automated vehicle. Artificial cognition, being the method used, allows task execution beyond pre-scripted and predefined instruction sets, utilizing reasoning about the current situation to support goal-driven behaviour during task execution instead. The tasks assigned by the human operator are formulated at an abstraction level that might as well be used to task human subordinates within a mission. Like human subordinates, the UAV uses its cognitive capabilities to adapt task execution to the currently known situation including knowledge about the task assignments of teammates.**

Keywords – Task-based guidance; goal-driven behaviour; artificial cognititive units; artificial cognition; level of automation.

I. INTRODUCTION

The utilization of UAVs as detached sensor platforms of a manned helicopter in a military scenario requires a change in the UAV guidance paradigm that enables a single human operator to control the UAVs while being the commander of a manned aircraft.

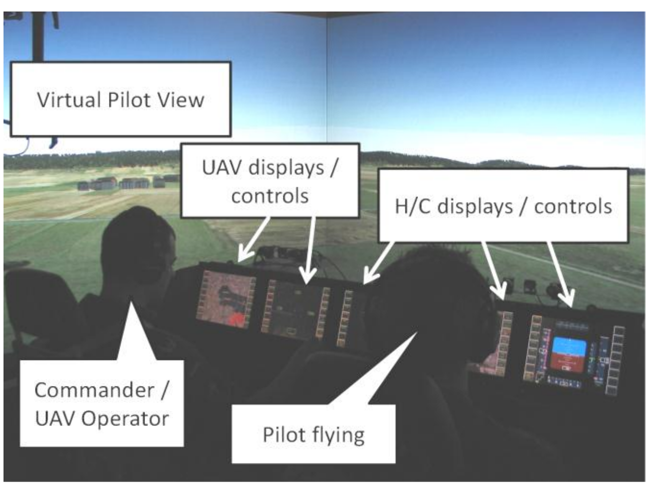


Figure 1. Helicopter simulator of the Institute of Flight Systems

If those UAVs were manned assets, the commander would just assign tasks referring to the mission elements and the current situation and leave the details of task execution as well as the application of "common sense"-knowledge generating local tactical behaviours to the human subordinate.

Some current research approaches concerning UAV guidance allow the definition of scripts or plays [1] to define action sequences for one or multiple UAVs. Moreover, some of these systems also react to changes in the situation like a new threat along a flight route [2]. However, the resulting behaviours of suchlike systems are solely defined at design-time. The goals of the behaviour of the UAVs are not expressed in the system but are implicitly encoded in the implementation of the guidance system. This article describes the system architecture, knowledge and goals driving task-based, cooperative and cognitive UAV automation. The resulting type of supervisory control shall avoid at least some of the issues of conventional automation by taking a step towards human-centred automation [3]. This is integrated in the helicopter research flight simulator of the Institute of Flight Systems at the Universität der Bundeswehr München and evaluated in experiments with experienced German Army aviators. In these experiments, the pilots had to perform several, dynamic troop transport missions including an unscheduled combat recovery task with the support of the manned helicopter and three UAVs.

The following sections describe the task-based guidance approach, its design, the resulting adaptable levels of automation and first experimental results.

II. RELATED WORK

Most current research projects in the area of UAV guidance and mission management focus on solving problems in the field of trajectory generation [4] and management and the achievement of what is mostly referred to as "full autonomy" by the application of control algorithms [5].

This research concentrates on optimizing within a given constraint set. However, such constraint sets and parameters are either static or the definition is left to the human operator or the experimenter. If the handling and monitoring of the control algorithms of multiple UAV is allocated to the commander of a manned helicopter, then the result is error-

 ISBN: 978-1-61208-155-7

prone behaviour and high workload for the operator [6]. Therefore, we present a system that integrates flight control, payload control and radio links into one entity. This entity uses its knowledge about the situation, the mission, the vehicle and its capabilities to provide an interface to the human operator that allows UAV guidance on a situation adaptive task level rather than sub-system handling.

Previous articles focus on the requirements engineering [6] and global system design and test environment including the integration of assistant systems [7] [8] [9]. The main contribution of this article consists of a discussion of the resulting levels of automation gained by task based guidance, a description of the knowledge base to realize task based guidance as well as the first experimental evaluation of the system.

III. TASK-BASED GUIDANCE

Task based guidance aims at integrating multiple unmanned vehicles into a manned helicopter mission in a similar manner as integrating additional manned helicopters into the scenario. Therefore, the guidance of unmanned vehicles should be on an abstraction level that allows the allocation of a series of tasks to each UAV. Suchlike tasks are issued by the human operator and request the achievement of goals, e.g., the request of reconnaissance information about a landing site. The interpretation of the tasks and the use of on-board systems to fulfil these tasks are left to the UAV. The series of tasks is on a similar abstraction level as tasks assigned to a pilot during mission briefing in a conventional, manned helicopter mission.

Moreover, just like a human pilot, UAVs should also use opportunities of supporting the mission, e.g., by getting sensor information of nearby objects, without a direct command from the operator.

This implies UAV guidance and mission management on a level where one or more UAVs are controlled by tasks that use mission terms instead of waypoints and the request of results rather than in-detail configuration of flight control functions and sensor payload. The latter should be generated aboard the UAV by its on-board automation.

The tasks currently implemented in the experimental setup are

- a *departure* task that respects basic air traffic regulations of the airfield and makes the UAV depart via a given, named departure location.
- a *transit* task that causes a flight to a specific, named location. While being in transit, the UAV configures the camera into forward looking mode. Known threats will be automatically avoided, if possible.
- a *recce route* task that causes the UAV to fly a route to a named destination. The sensor payload will be configured to provide reconnaissance information about the flight path. If the UAV possesses knowledge about another UAV also tasked with a recce of the same route, it will modify its flight path to maximize sensor coverage.
- a *recce area* task that causes the UAV to gather recce information about a named area. The camera will be used to provide ortho-photos of the area.
- an *object surveillance* task. While working on this task, the UAV will use the payload control to deliver a continuous video stream of a named location.
- a *cross corridor* task makes the UAV fly through a transition corridor between friendly and hostile territory. To avoid friendly fire and ease cooperation with the own ground based air defence; this crossing is modelled as separate task. Moreover, it is the only task allowed to cross the border between friendly and hostile territory.
- a *landing* task causes the UAV to take an approach route to an airfield and to land at that airfield.

The capability of understanding these tasks at mission level, i.e., understanding the current situation, planning towards task execution, using the flight control system, communication equipment and mission payload of the UAV requires an automation that incorporates certain sub-functions as found in cognitive behaviour of a human [7], thereby creating cognitive behaviour of the automation. The following chapters discuss the resulting levels of automation and describe the architecture and information processing of a so-called artificial cognitive unit (ACU).

IV. LEVELS OF AUTOMATION

Currently, UAV systems operate on a wide range of different guidance modes. That modes cover the whole range from direct manual control [10], flight control based [6], scripted behaviours [1] up to above-mentioned task-based guidance [7]. These guidance modes form a stack of abstraction layers as depicted in Figure 2.

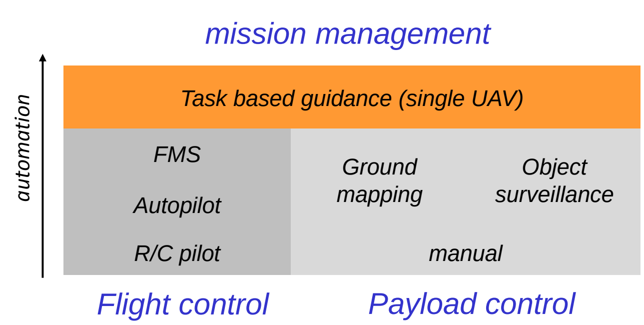


Figure 2. Levels of abstraction in UAV guidance

Sheridan and Verplank [11] describe a different view of levels of automation. These levels are mostly independent from the chosen abstraction layer but focus on task allocation and authority sharing between the human and the automation. They range from barely manual control to automation that does neither allow intervention from the human operator nor provide information about the action taken. In the design of current UAV guidance systems, various levels are present, e.g., in waypoint based guidance systems, the definition of waypoints is the sole responsibility of the human operator. No automation support is provided in that task. However, automatic flight termination systems do not allow the human to veto on the decision of the automation but merely report the flight termination after its execution, i.e., level 7 according to Sheridan and Verplank [11].

The task based guidance described further in this article introduces an additional dimension in the levels of automation. While the abstraction layer is fixed in the current setup, i.e., only the task based layer is available to the human operator, the operator can choose to provide different tasks to the UAV. The UAV will check the tasks for consistency and may insert additional tasks to restore a consistent task agenda. The consistency check and completion of the task agenda is based on a planning scheme, which behaves deterministic with respect to the current tactical situation and the task elements known so far. Thus, the operator may choose to specify only task elements relevant to him or her and leave the specification of other tasks to the UAV. This particular type of adaptable automation allows the specification of strict task agendas, i.e., the human operator defines every task of the UAV. However, also loose task agendas may be defined, i.e., the human operator only defines the most important tasks and leaves the details to the UAV.

Moreover, this kind of automation also can reduce the chance of human errors, because unintentionally omitted tasks are also completed by the automation.

V. System Architecture

In order to implement suchlike machine behaviours, this chapter will provide an overview of the design principles and information processing architecture enabling task based guidance capabilities.

A. *Design of knowledge-based Artificial Cognitive Units*

Based on models of cognitive capabilities of human pilots, artificial cognitive units (ACUs) were designed. As depicted in Figure 3, these units become the sole interface between the human operator and the vehicle [12] in the work system [13]. This additional automation allows the desired shift in the guidance paradigm from the subsystem level, i.e., separate flight guidance and payload management, to commanding intelligent participants in the mission context.

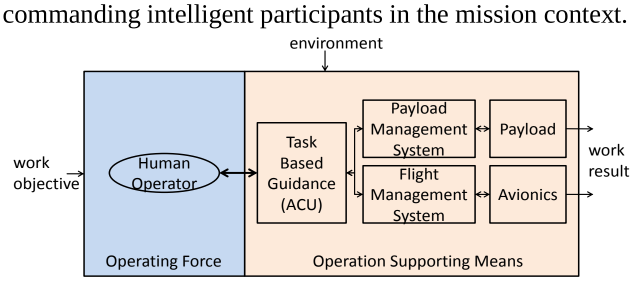


Figure 3. Work system “UAV guidance”

To understand and execute tasks with respect to the current situation, the ACU requires relevant parts of the knowledge and capabilities of human pilots. That knowledge can be grouped into system management, understanding and evaluating mission objectives in the context of the current scenario as well as knowledge to interact with the human operator [14]. This knowledge is derived by formalization of domain specific procedures defined in documents like the NATO doctrine for helicopter use in land operations [15]. Furthermore, interviews with experienced helicopter pilots revealed relevant knowledge. The interviews and the additional evaluation of recordings of training missions used the Cognitive Process Method [16]. For every phase, the human’s objective is evaluated. Moreover, all possible and hypothetic action alternatives to pursue the objective are determined. Furthermore, all environmental knowledge is gathered, which is used to select a particular action alternative or which influences the execution of a chosen action. At last, the procedures to execute the actions are evaluated.

B. *Human-Machine Interface*

To support the guidance of multiple UAV from a manned helicopter, the human-machine interface (HMI) has to integrate into the manned helicopter. Moreover, using an audio interface, i.e., speech recognition, to guide the UAV was rejected by a majority of the interviewed pilots due to the already high radio traffic that has to be handled by the helicopter crew.

Therefore, a graphical interface was chosen to interact with the UAV. This interface is integrated into two identical multifunctional displays available to the commander of the manned helicopter. Figure 4 depicts the implemented multifunctional display format.

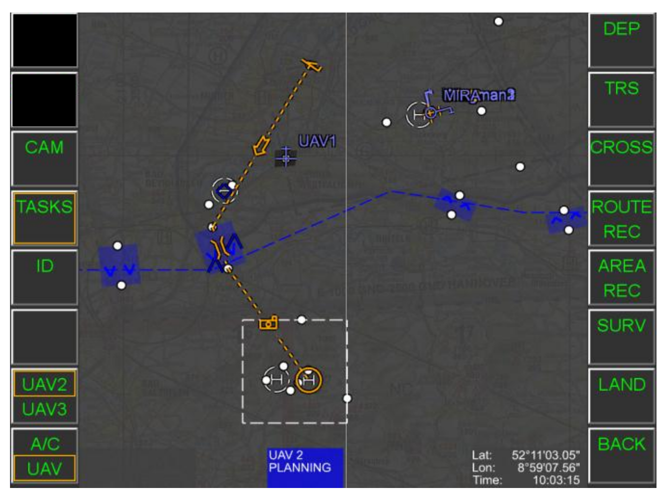


Figure 4. UAV tasking interface

On the lower left of the multifunctional keyboard, the operator can switch between UAV control and the displays of the manned helicopter (A/C / UAV). Above, the current UAV can be selected. On the top left, the operator can select three different modes: CAM, TASKS, and ID. The right multifunctional soft keyboard shows the context sensitive options for the current mode chosen on the left.

 ISBN: 978-1-61208-155-7

CAM provides a live video stream from the camera of the currently selected UAV. The TASKS can be used to monitor the current tactical situation and to manipulate the task elements of the currently selected UAV.

In TASKS, the current tactical situation is displayed as well as the task elements of the UAV. The currently active task is highlighted in yellow. A task can be inserted into the task agenda of the UAV by choosing the task type as shown on the right in Figure 4, optionally choosing the predecessor of the task on the map and selecting the target position of the task. A task can be selected for immediate execution. This functionality can be used to start the execution of the first task as well as for skipping tasks. Additionally, tasks can be deleted and moved, i.e., the target area description of the task is altered. If tasks are added, deleted or modified, the UAV will maintain a consistent task agenda by inserting missing tasks depending on the current tactical situation. As long as this planning is in progress, it is indicated on the bottom of the display as shown for UAV number 2 in Figure 4. To prevent immediate re-insertion of deleted task elements, the consistency checks are delayed after the operator deletes a task element. This allows further modifications of the task agenda by the human operator without being interrupted by the UAV.

The ID display mode is used to review photos taken by the UAV and to classify the objects on the images into pre-defined types (car, military vehicle, ground based air defence) and hostility, i.e., neutral, friend or foe. Those classifications are also reflected in the tactical situation shown in the task mode as well as the electronic map displays available to the pilot flying. Furthermore, those classifications will be transmitted to the UAVs in order to support reaction to the changed tactical environment, e.g., to plan flight routes around hostile air defence.

The combination of those display functionalities shall allow the human operator to guide the UAVs to support a military air assault mission that involves operation over hostile areas and support of infantry troops. Moreover, by tasking the UAVs using mission terms, e.g., by selection of "area reconnaissance of the primary landing site", the control of three UAVs shall be feasible and enhance mission safety by providing valuable information about mission relevant areas and routes without risking exposure of own troops to threats like ground based air defence and other opposing forces.

C. *Information Processing*

The implementation of artificial cognitive units is based on the Cognitive System Architecture (COSA) framework [16]. This framework is based upon Soar [17] and adds support for object-oriented programming as well as stereotypes for structuring the knowledge into environment models, desires, action alternatives and instruction models.

This (a-priori) knowledge constitutes the application specific part of the Cognitive Process, which is described in detail by Putzer and Onken [16] as well as Onken and Schulte [13]. Information and knowledge processing as well as interfacing with the environment is depicted in Figure 5.

The following describes the information processing steps using examples of the knowledge of the UAV's on-board ACU.

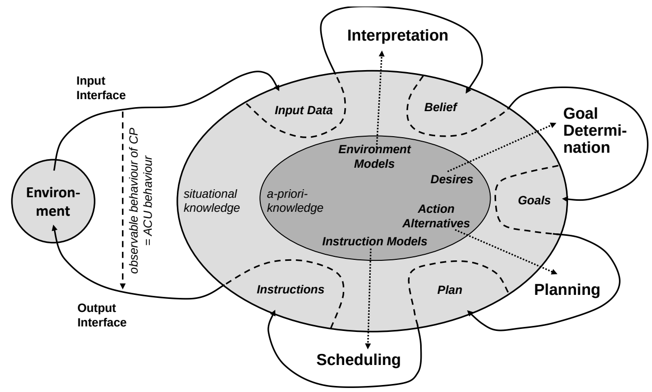


Figure 5. Knowledge processing in the Cognitive Process [16]

Input data are retrieved from the environment by input interfaces. There are three types of input interfaces: (1) reading sensor information from the sensors of the UAV, (2) reading information from the communication link of the UAV and (3) providing results from on-board automation, e.g., information about flight routes generated by an external route planner.

The *environment models* of the a-priori knowledge of the ACU drive the interpretation of input data into instances of semantic concepts. Those concepts form an understanding of the current tactical environment including knowledge about existence and positions of threats, areas, bases, landing sites, routes, waypoints etc. Environment models instantiate on the arrival of matching input data and matching situational knowledge. All instances of environment models, i.e., *beliefs*, form the picture of the current situation of the UAV. Notable examples for environment models are instructions, tasks and roles. Instructions represent requests sent from the operator to the UAV and instantiate upon the arrival of the corresponding input data. Instructions can request to insert, delete or immediately execute a task in the task agenda. If the instruction is to insert a new task into the agenda of the UAV, the corresponding task environment model becomes active and creates an instance. This instance will refer to the environmental models describing the target area of the task, the task type, and the state of the task, e.g., "scheduled for execution". For every task, there is an instance of a precondition and a postcondition. The precondition builds a representation of all required prerequisites of a task, e.g., being airborne and being near a specific location to start the task. The postcondition builds a representation of particular effects of the task, e.g., a transit flight has the postcondition of being airborne at the target location. A role is an environment model describing the specific part of the current UAV in a task shared among multiple UAV, e.g., if multiple UAV have the common task to retrieve recce information about a flight route, a role can tell the UAV to fly in a certain distance left from the route to maximize sensor coverage.

 ISBN: 978-1-61208-155-7

Desires describe world states the UAV should maintain. If a desire detects the violation of the state in the belief, then it activates by instantiating into an active goal. One example of a desire is “know what to do next”, i.e., to have a belief that designates the current task at hand. Whenever the UAV does not have the situational knowledge about its current task, this desire activates and makes the UAV act towards the determination of the next task. Another desire is to comply with the current task, i.e., to actually take the steps necessary to fulfil the task. The desire to “have a unique role” in common tasks enables multiple UAVs to work on the same task by sharing parts of it, i.e., roles in the task. For example, if three UAVs share the task of retrieving visual sensor information about a flight route, then the systems infer from this situation that the roles of flying the centre line of the track and to fly left and right of the track exist. Each UAV selects a role either random or – if selection knowledge is present – it selects a role that fits best for the UAV. To avoid duplicate roles for a single task, every UAV that has a non-unique role re-selects a role. This technique has shown to be sufficient for real-time conflict resolution of at least three UAV.

“Having a consistent agenda” is one of the central desires of the ACU. This desire activates if there is a mismatch between the aforementioned postconditions of a task and the preconditions of its successor. Moreover, it activates, if tactical restrictions are violated, e.g., if a task other than “cross corridor” crosses the border to the opposing terrain or if an area is not entered or left at the designated entry/exit points. The activation of this desire is reported to the human operator as “UAV planning” as depicted for UAV2 in Figure 4. Moreover, the desire of having a consistent agenda also provides knowledge about the severity of violations. This guides the resolution of inconsistencies from the most important violation to the least important violation. “Using opportunities” as they arise makes the UAV exploit chances of gathering additional reconnaissance information, if this does not lead to a neglect of the current task. For instance, if there is a sensor footprint of an unidentified force, then the ACU can decide to use the sensors of the UAV to generate additional information about that location to support the identification of that force. The ACU combines its knowledge about the type of sensor information, i.e., “unidentified sensor-hotspot”, the availability of its sensors, the availability of sensor information from its own sensors and from other UAV and its relative position to the unidentified force. This combination of knowledge enables the UAV to safely detect and use the chance of getting more information about the location. Moreover, the UAV also behave cooperative as the decision to generate additional sensor information is suppressed if another UAV has generated that sensor information from a similar angle to the unidentified force.

Action alternatives provide ways to support active goals. They instantiate if a corresponding goal is active, but only if the current situational knowledge allows the selection of the action alternative. If more than one action alternative can be proposed, then the action alternatives model selection knowledge to prefer one alternative over the other. To maintain a consistent agenda, action alternatives can propose to add additional tasks like recce route, transit or cross corridor. If the crossing of a corridor can be inserted, it is preferred over the other action alternatives to provide a separation between “tasks over own territory” and “tasks over opposing territory” for subsequent action alternatives. Depending on the tactical situation, further tasks are inserted until a consistent agenda is achieved, i.e., all active goals of having a consistent agenda are fulfilled. As mentioned in Section IV, the human operator can exploit this behaviour of the ACU by skipping tasks on purpose and thereby shifting the completion and specification of missing tasks to the ACU.

Every task of the ACU has its corresponding action alternative that supports the execution of the task in case of an active goal to comply with the current task.

After one or more action alternatives are chosen, the *instruction models* become active and support the action alternatives by generating instructions on the output interface of the ACU. Those instructions are read by the output interface and cause the transmission of radio messages, configuration changes at the flight control system or the payload system or activate on-board automation, e.g., a route planner.

In combination, all those processing steps depicted in Figure 5 generate purely goal-driven behaviour that allows reasoning over the tactical situation and the task elements entered by the human operator to provide situation-dependent actions, which are consistent with tactical concepts of operations.

VI. EXPERIMENTAL SETUP AND FIRST RESULTS

Experiments were conducted with experienced German Army helicopter pilots in order to evaluate the task based guidance approach. The simulator cockpit shown in Figure 1 has been used to perform military transport helicopter missions. The objective of the missions was to pick up troops from a known location and to carry them to a possibly threatened destination. According to the briefing, three UAVs should be used to provide reconnaissance information about the flight routes and landing sites in order to minimize exposure of the manned helicopter to threats. In addition to the tasks to perform in previous baseline experiments without task based guidance [6], in this experiment an unscheduled combat recovery task was issued to the crew as soon as the main mission objective had been accomplished.

Prior to the measurements, every test person had been given one and a half day of system training. The test persons acted as pilot flying and pilot non-flying. This configuration was chosen to evaluate the effects of the UAV guidance to crew cooperation and crew resource management.

The following data were recorded during the experiment:

- Interaction of the operator with the system
- Commands sent to the UAV via data link

In every simulation run, the simulation had been halted twice, i.e., in the ingress and during a demanding situation while the helicopter is near the hostile target area, to get measures of the operator’s workload using NASA TLX [18].

 ISBN: 978-1-61208-155-7

During the simulation halt, all displays and the virtual pilot view were blanked and the intercom between pilot flying and pilot non-flying was disabled. To get an indication of the test persons' situation awareness, the test persons were simultaneously questioned about the current tactical situations, system settings, e.g., radio configuration, and the upcoming tasks of the UAV and the manned helicopter. This measure is an adaption of the SAGAT technique [19]. After every mission, a debriefing follows which includes questions about the system acceptance, system handling, interface handling as well as feedback about the degree of realism of the simulation environment.

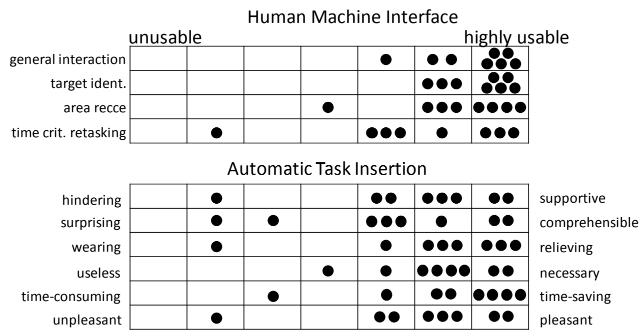


Figure 6. Subjective Pilot Ratings for HMI / Consistency Management

Figure 6 shows some of the subjective ratings of the test persons. The chosen type of human-machine interface and the automatic insertion of task elements to maintain a consistent agenda are generally accepted by all test persons. The test persons stated that handling the UAVs consumed an average of 62% of the time while 34% remained for acting as commander of the manned helicopter. Evaluation of the simulation data shows that test persons used less than 50% of the available time for UAV guidance.

TLX measures of the pilot non-flying range from 23% of subjective workload during the ingress over friendly territory up to a value of 60% during time-critical re-planning of multiple UAV in the target area.

While in hostile areas, the manned helicopter operated within the terrain mapped by ortho-photos 94.5% of the time.

VII. CONCLUSION

The experiments showed that artificial cognitive units make the guidance of multiple UAV in a military helicopter mission feasible with moderate workload. It was shown that artificial cognition aboard the UAVs effectively support the human operator in his/her task of increasing mission safety by providing recce information about flight routes and operation areas. Moreover, depending on the desired level of control over the UAVs, the test persons stated that they instructed the UAVs on a detailed or rough level, i.e., specification of every task element or skipping tasks on purpose and leaving the detailed planning to the UAV and its cognitive capabilities.

REFERENCES

[1] C. Miller, H. Funk, P. Wu, R. Goldman, J. Meisner, and M. Chapman, The Playbook™ Approach to Adaptive Automation, Ft. Belvoir: Defense Technical Information Center, 2005.

[2] M. Valenti, Implementation of a manned vehicle-UAV mission system, 2004.

[3] D. D. Woods and N. B. Sarter, “Learning from automation surprises and "going sour" accidents: Progress on human-centered automation : final report,” Va: Ohio State University, Institute for Ergonomics, Cognitive Systems Engineering Laboratory; National Aeronautics and Space Administration; National Technical Information Service, distributor, 1998.

[4] I. Kaminer, O. Yakimenko, A. Pascoal, and R. Ghabcheloo, “Path Generation, Path Following and Coordinated Control for TimeCritical Missions of Multiple UAVs,” in American Control Conference, 2006, pp. 4906–4913.

[5] S. Wegener, UAV autonomous operations for airborne science missions, 2004.

[6] J. Uhrmann, R. Strenzke, A. Rauschert, and A. Schulte, “Manned-unmanned teaming: Artificial cognition applied to multiple UAV guidance,” in NATO SCI-202 Symposium on Intelligent Uninhabited Vehicle Guidance Systems, 2009.

[7] J. Uhrmann, R. Strenzke, and A. Schulte, “Task-based Guidance of Multiple Detached Unmanned Sensor Platforms in Military Helicopter Opertations,” in COGIS 2010, 2010.

[8] R. Strenzke and A. Schulte, “The MMP: A Mixed-Initiative Mission Planning System for the Multi-Aircraft Domain,” in Scheduling and Planning Applications woRKshop (SPARK) at ICAPS, 2011.

[9] D. Donath, A. Rauschert, and A. Schulte, “Cognitive assistant system concept for multi-UAV guidance using human operator behaviour models,” in Conference on Humans Operating Unmanned Systems (HUMOUS'10), 2010.

[10] H. Eisenbeiss, “A mini unmanned aerial vehicle (UAV): system overview and image acquisition,” International Archives of Photogrammetry. Remote Sensing and Spatial Information Sciences, vol. 36, no. 5/W1, 2004.

[11] T. B. Sheridan and W. L. Verplank, “Human and Computer Control of Undersea Teleoperators,” Ft. Belvoir: Defense Technical Information Center, 1978.

[12] J. Uhrmann, R. Strenzke, and A. Schulte, “Human Supervisory Control of Multiple UAVs by use of Task Based Guidance,” in Conference on Humans Operating Unmanned Systems (HUMOUS'10), 2010.

[13] R. Onken and A. Schulte, “System-ergonomic design of cognitive automation: Dual-mode cognitive design of vehicle guidance and control work systems,” Heidelberg: Springer-Verlag, 2010.

[14] G. Jarasch, S. Meier, P. Kingsbury, M. Minas, and A. Schulte, “Design Methodology for an Artificial Cognitive System Applied to Human-Centred Semi-Autonomous UAV Guidance,” in Conference on Humans Operating Unmanned Systems (HUMOUS'10), 2010.

[15] NATO, Use of helicopters in land operations - doctrine, 49(E).

[16] H. Putzer and R. Onken, “COSA - A generic cognitive system architecture based on a cognitive model of human behavior,” Cognition, Technology & Work, vol. 5, no. 2, pp. 140–151, 2003.

[17] J. Laird, A. Newell, and P. S. Rosenbloom, “Soar: An architecture for general intelligence,” Stanford, CA: Dept. of Computer Science, Stanford University, 1986.

[18] S. G. Hart and L. E. Staveland, “Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research,” Human mental workload, vol. 1, pp. 139-183, 1988.

[19] M. R. Endsley, “Situation awareness global assessment technique (SAGAT),” in Aerospace and Electronics Conference 1988, pp. 789 – 795, 1988.

 ISBN: 978-1-61208-155-7

Learning Odors for Social Robots: The URBANO Experience

Daniel Galán, Ramón Galán, Ángel Luis Martínez
Intelligent Control Group
Universidad Politécnica de Madrid
Madrid, Spain
email: danielgalanv@gmail.com, ramon.galan@upm.es, almartinez@etsii.upm.es

Iveth Moreno
Facultad de Ciencias y Tecnología
Universidad Tecnológica de Panamá
Panamá, Panamá
email: iveth.moeno@utp.ac.pa

***Abstract*— This paper presents the experience of the Intelligence Control Group of UPM in the design of URBANO, a tour guide robot. It is a cognitive system based on distributed agents. One of these agents is an ontology that contains the knowledge used by the robot. This knowledge is mainly developed for linguistic applications. Here it is described how to add odor experiences to some available concepts in the ontology. Odor experiences evolve in time so the learning process must be adaptive and supervised. Neural networks, fuzzy logic, recursive least squares, Mahalanobis distance and genetic algorithms are tested over a low-cost multi-purpose electronic nose in the URBANO environment. The obtained results show how to add odors to the emotional model of the robot help it to increase its performance as a social robot.**

Keywords: Cognitive systems; Social robotics; Neural networks; Fuzzy logic; Genetic algorithms.

I. INTRODUCTION

Electronic noses are artificial olfactory systems whose operation is based on an array of chemical gas sensors with partially overlapping sensitivities. A series of electronic adjustments are made to the electrical values provided by the gas sensors in order to enable computer processing. At this stage, a pattern recognition technique is applied to the data so that the electronic nose will, eventually, be able to identify, classify and/or quantify odors.

Over the last two decades, electronic noses have increased significantly in importance due to the different applications in which they can be used: agribusiness, security, medicine and environmental pollution. During this period a great deal of research has been carried out, some of which is mentioned by Moreno [1].

Emotion importance in human intelligence has been underlined in latest decades. Neuroscientist studies show that people with their traditional logical reasoning intact but with their emotions disconnected make poor judgments, finding strong impairments in taking appropriate decisions [2]. An emotional balance benefits the problem resolution in a flexible and creative way. Evidences show that emotional skills are basic for adaptation and taking decisions. In other words, emotional control is an intelligence factor. Emotional Intelligence [3], is defined as an ability to perceive, assess and manage the emotions of one's self and of others.

In human communication, emotions take an important roll, emotion recognition and emotion expression are essential for a complete communication. That is in fact, what Affective Computing studies: giving to machines an ability to recognize, model and interpret human emotions [4].

The tour-guide robot URBANO emotional model [5] does not intend to be a biological model, not trying to reproduce human brain. The aim of this project is to develop the necessary tools to let the robot URBANO show an emotional behavior that can be understood and accepted by humans. In other words, to give autonomy to the robot so that it is able to take decisions and to show a social behavior that leads to a satisfactory human-robot interaction. Emotional abilities, in particular the ability to recognize and show emotions, are essential for the natural communication with humans, because of that an emotional model is developed.

This paper explains the experience of the Intelligent Control Research Group of UPM, in order to include an olfactory system in URBANO, a tour-guide robot that is described in Section II, and how to integrate olfactory stimuli in the behavior of the robot, explained in Section III. The e-nose prototype is a low-cost multi-purpose designed for this project, which is described in Section IV. Section V presents the experiments developed and the obtained results. It has been paid special attention to the learning process as is depicted in Section VI.

II. URBANO, AN INTERACTIVE TOUR-GUIDE ROBOT

This section describes the URBANO robot system, its hardware, software and the experience we have obtained through its development and use until its actual mature stage.

URBANO robot is a B21r platform from iRobot [6], equipped with a four wheeled synchrodrive locomotion system, a SICK LMS200 laser scanner mounted horizontally in the top used for navigation and SLAM, and a mechatronic face and two robotic arms used to express emotions as happiness, sadness, surprise or anger.

The robot is also equipped with two sonar rings and one infrared ring, which allows detecting obstacle at different heights that can be used for obstacle avoidance and safety.

 ISBN: 978-1-61208-155-7

The platform has also two onboard PCs and one touch screen.

The software is structured in a SOAP architecture with specialize agents in different functions: speaking, listening, navigating through the environment, moving his arm, responding to stimuli that affect its feelings. Some agents perform cognitive tasks.

The schedule for URBANO is defined by a diary with tasks. The way of making those tasks, the time when they are done and, in general, the behavior of URBANO while completing them will be based in its emotional state by optimizing its happiness function.

Is intended that, the identification of certain odors act as another stimulus and affect to its decision making. For example, if the person that is interacting with URBANO smells to cigarette, then it can exhort to quit smoking. Also URBANO can identify a person by his perfume.

A new agent has been developed in order to manage the odor information that controls the electronic nose and the classification algorithms.

This new agent collaborates directly with other agents: Knowledge Server and Emotional Model.

The knowledge server consists of a Java application developed using the libraries of Protégé-OWL API [7]. The tool is capable of reading and editing files in ".owl" format where the knowledge is stored in the form of ontologies and the management of the information from the kernel is made by means of messages that codify the request of specific information, and the reply is obtained from the server or the introduction of new data.

The functions of the knowledge server are: loading and saving ontologies; creating, renaming, and deleting classes or instances; displaying properties of a class; showing subclasses or superclasses; showing or entering the value of a property; integrating one ontology into another; handling queries.

III. EMOTIONAL MODEL IN URBANO

In order to reach a nearer approximation to human emotional system, the proposed model makes use of dynamic variables to represent internal emotional state. The model follows the classic diagram showed in Fig. 1, being the system stimuli *u(k)* considered as inputs variables, emotions *x(k)* as state variables and task modifiers *y(k)* as output variables.

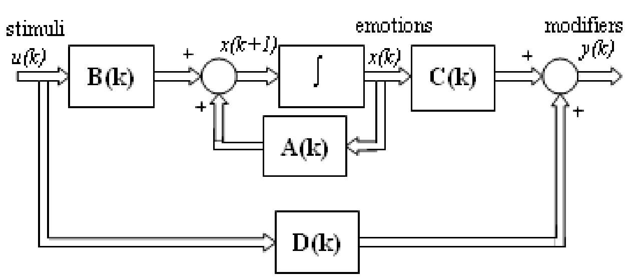


Figure 1. Emotional state model.

Following the classic state variable model, four matrices have to be defined.

A-matrix represents the model dynamic, the influence of each emotion over itself and over the other emotions. In other words, how the emotional state at the time *k* influences the emotional state of the next time *k+1*. Let us call the A-matrix *emotional dynamic matrix*.

Stimuli influence the system in a different way depending on its actual emotional state, i.e., the sensitivity information contained in the B-matrix. Let us call it *sensitivity matrix*.

C-matrix has the information of how emotional state influences modifiers. Let us call this matrix the *emotional behavior matrix*.

D-matrix contains the information of how the stimuli influence directly the task modifiers. Let us call the D-matrix *direct action matrix*. We usually consider it to be null, nevertheless its use would be analog to the rest of the state matrices.

Due to the difficulty of finding an analytic calculation for the matrices coefficients, a fuzzy rules set is used to obtain each coefficient. The matrices coefficients are function of time *k*, giving dynamics to the system. Because of that coefficients are calculated for each time *k*. To define fuzzy rules is a simple task; the information contained in the rules can be obtained from experts in emotions. The use of fuzzy knowledge bases opens the opportunity to a future automatic adjustment, e.g., genetic algorithms.

Model equations are analog to the equations used in multivariable systems and shown in (1) and (2).

$$\xi(\kappa+1) = \mathrm{A}(\kappa)\ \xi(\kappa) + \mathrm{B}(\kappa)\ \upsilon(\kappa) \quad (1)$$

$$\psi(\kappa+1) = \mathrm{X}(\kappa)\ \xi(\kappa+1) + \Delta(\kappa)\ \upsilon(\kappa) \quad (2)$$

The operation sequence follows the next steps:

1. Read stimuli *u(k)*. Stimulus is considered as an impulse: it appears and at the next time it disappears.
2. Stimuli and emotions fuzzification. Stimuli and emotions intensities are normalized in the range [0,100]. In order to transform these determinist values of stimuli and emotions into fuzzy values, following considerations has been done. Three linguistic terms have been considered: HIGH, NORMAL, and LOW. A triangle membership

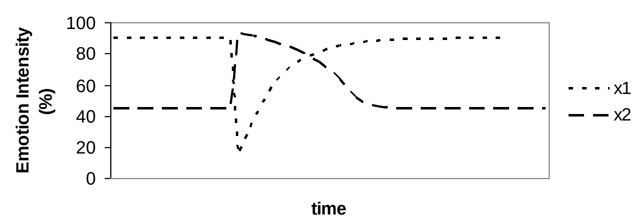


Figure 2. Time dynamics for different emotions.

function with a uniform distribution, as shown in Fig. 4, has been used.

3. Fuzzy inference. Let us consider two stimuli {u_1, u_2}, two emotions {x_1, x_2} and the three linguistic labels named previously. In that case, A-matrix would be a 2x2 matrix, with the coefficients a_{11}, a_{12}, a_{21} and a_{22}. For each coefficient there is a fuzzy knowledge base that contains the fuzzy rules to apply depending on the emotion fuzzy values.
4. Defuzzification to obtain the state matrices coefficients. The method of gravity centre is used as defuzzification function simplifying the calculation by equidistant membership functions which do not overlap. After this step, the matrices A(k), B(k) and C(k) are known.
5. Calculation of next time emotional state and task modifiers, x($k+1$) and y($k+1$). Knowing the state matrices at time k, $u(k)$ and $x(k)$, value of emotions and task modifiers at next time are obtained applying equations (1) and (2).

Nor the higher emotions number neither the higher number of linguistics terms would increase the complexity of the model. It would work with the same efficiency but with a higher computational work.

Task modifiers are used in the development of the tasks. This "way of being" is valued by the public through a poll. If the results are not satisfactory it is necessary to correct the robot "way of being", i.e., fuzzy rule bases that determine the matrices A, B and C. The proposed model adjusts in the way described by means of a genetic algorithm. The algorithm makes use of the information collected of other tried behaviors. It changes the fuzzy rules looking for an optimization of a desired function.

Human do or try to do things that make them happy, for that reason happiness would be an appropriate function to be optimized. Happiness understood no as an emotion but as an abstraction that indicates the personal fulfillment of the subject. Happiness used to be considered associated to the fulfilling of some norms in the development of our vital activities. The norms or scale of values are not the same for all humans, it exists differences. Helping to others produce happiness but we used to help more to friend than to enemies.

In order to implement this capacity in URBANO, it is necessary to define a scale of values or *robotics laws*. Done a task, a mathematical function calculates the fulfillment degree of these norms and a happiness value.

IV. Electronic Nose Hardware

Most of electronic noses comprise three modules: chemical, electronic and software The chemical module prepares the sample and takes the measurement made by the sensors; the electronic module prepares the electrical signal obtained at the sensor output and extracts the traits and electrical characteristics given by each of the sensors of the array; the software performs the signal recognition and produces the corresponding visualization in the system.

Electronic nose design depends on the applications in which the nose is to be used. The electronic nose under discussion is intended for use, mainly, in agribusiness. This intended purpose meant that it would be appropriate to use a wide range of chemical odor sensors. Therefore, MOS technology chemical odor sensors from Figaro Inc. [8] were chosen, from the TGS series, with target gases as organic solvents, ammonia, air pollutants, etc. These sensors are used in common applications such as monitoring air quality, detection of toxic gases, etc.; they are inexpensive and readily commercially available. In addition to these sensors, four temperature sensors, a relative humidity sensor and an atmospheric pressure sensor were fitted to the electronic nose with the aim of observing the effects of changes in the aforementioned parameters on the measurements produced by the electronic nose.

The different components that have been chosen for the design and construction of the electronic nose, have been selected based on the type of chemical odor sensors chosen for the sensor array.

The electronic nose constructed contains three modules, and it is small, facilitating the integration on a mobile robot.

The chemical module of the electronic nose consists of one chamber were the sensors are located. It contains a simple acquisition system for sampling the volatile components of the sample, in comparison to other more complex systems [9], [10], which include air pumps, reaction tubes, purge and trap systems etc., or other systems that keep the sample chamber completely separate from the sensor chamber [11]. The sensor chamber and the sample are separated by a cover, that can be open, and a small ventilation unit that draws the odor sample gas molecules from the sample chamber into the sensor chamber. After the sensors are exposed to the odor samples, this chemical signal is transferred, as an analog signal, to the next module, in this case, the electronic module, where the signal is amplified, filtered and converted into digital values; these will be used in the final module, where an algorithm has been developed based on neural networks, which will classify the odor that has been detected by the electronic nose. When the sample has been taken the nose open a backdoor and active another ventilation for cleaning the chamber.

Each sensor has been mounted on a separate card so that it can be easily removed or changed by the user.

V. Experiments and Results

A series of experiments was performed in order to validate the design and the use of the electronic nose; all testing was done indoors.

A. *Tests to improve signal stabilization*

Since the signal from the sensors received by the computer shows a significant degree of oscillation, an adjustment to that signal by means of the computer program was proposed.

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-155-7

The aim of the adjustments to the program is to filter the signal as far as possible, without losing relevant information, in order to later apply the pattern recognition algorithms. Therefore, the filtering of the signal obtained at the point of output of the electronic module was performed using different averages (10, 20, 30, 40 and 50) in the data. Ten data readings were taken, their average was calculated, a further reading was taken, and the average was re-calculated using the 10 most recent values, and so on. Using this technique means that the average value of the most recent 10, 20, 30, 40 or 50 values is always used, both for the display in graph form and for the application of the pattern recognition algorithms.

The average value that produced the best signal filtering was 50, and this is the average that was used to perform all the tests.

B. Tests on odor detection in semi-circles

Tests were carried out to determine the maximum distance at which the electronic nose is still capable of significantly detecting an odor. These distances were measured from the central point of the sample chamber and were arranged to form a semi-circle with different radii. The measurements used for the radii were 15, 20, 30, 40 and 50 cm.

In the first stage of this test, the sample chamber remained in its original location; in addition, two ammonia sensors were used, adjusted to different gains.

In the second phase of this test, the sample chamber was removed, thereby allowing the odor to disperse in the open air. The values measured by the sensors declined sharply as the distance of the odor source from the electronic nose was increased. Comparing the results of this phase with the previous phase, the measured values were lower than the corresponding values. It is interesting to note that, for radii very close to the electronic nose, whatever the position of the sample, the values measured by the sensors were equal or better than those obtained using the sample chamber.

The final results of this test demonstrated experimentally the need to use the sample chamber to carry out the odor measurements and that the best position for odor detection is locating the odor source in front of, or diagonal to, the electronic nose.

C. Test carried out to investigate the effect of temperature on electronic nose performance

In one of the tests performed for classification between red wine and white wine, data was obtained at a temperature of approximately 25ºC, and network training was initiated. However, when the tests were performed to verify the network learning, the values measured by the sensors were observed to be different from those obtained during the training phase. The possibility of achieving good classification was therefore minimal. The only condition that had altered with respect to the training phase was the ambient temperature, which had risen by three degrees Celsius.

This test demonstrated that changes in temperature affect the repeatability of the sensors. A change was therefore suggested in the computer program for odor classification.

D. Odor classification test

The aim of this test was to verify the effectiveness of the electronic nose at distinguishing between the odor given off by a glass of white wine and air molecules under normal conditions.

Before training the neural network, sensors were chosen that best reacted to the odor samples: three volatile organic compound sensors and one organic solvent vapor sensor. The selection of the sensors was based on the fact that the olfactory fingerprint obtained by a few sensors facilitates learning by the neural network. Subsequently, 50 measurements were taken in clean air, and 50 from white wine, and neural network training was performed.

The network was then verified with a further 200 samples, (100 air and 100 wine): with 100% of success. This same experiment was repeated using a glass of white wine and a glass of red wine. It was observed that using all the sensors complicated the network learning, and again, only the most representative sensors were chosen.

However, the problem that arose for this experiment is that the temperature affected the values measured by the sensors, resulting in different values being registered by the sensors during the training phase and at the verification phase. These drifts in response arise in the medium and long term.

Different algorithms have been used with different objectives. The Mahalanobis distance has given excellent results in the identification of the ripeness cherry states, green-mature-out. The use of back propagation neural networks and the recursive minimum squares allows an appropriate generalization in the classification. Because of the great influence of the temperature different categories it has been added for different temperatures which have significantly improved the identification.

E. Odor search test

The objective of this test was the validation of URBANOs capacity to locate the odor source. It starts by presenting the robot a sample of a particular odor, to then ask the robot to find a position in the workroom where the odor seems very similar to the sample.

Keep in main that the olfactory fingerprint will have an influenced distribution by the air movement in the workroom so keep a history of measurements may not provide any advantage.

Simply algorithms were proved were the robot measures in semicircles (-90, 0, 90 degrees) and advance in the direction where the samples mean square error is minimum. For the cases were local minimums are found it has been used the relaxation technique. To reduce the time to find the source location the algorithm has been modified so that progress, without checking the smell of 90 ° and -90 ° when the error decreases. This algorithm has been simulated in Matlab to verify its performance against abrupt changes of the fingerprint while the search. The results show that certain forms can significantly delay the location. The following figures show some examples of these simulations.

In the use of the algorithm on a real robot has shown that the time required to clean and stabilize the new measured value is high in the developed prototype, about a minute from one sample to another. If cleaning is not carried out the measurement quality decreases and the robot can pass through the vicinity of the source without finding a better error.

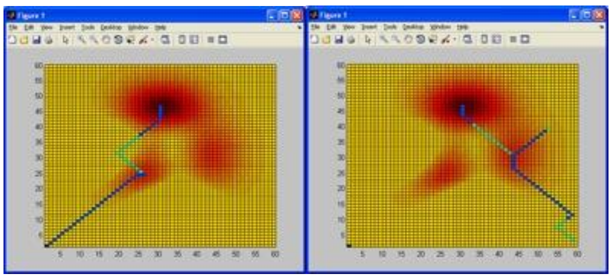


Figure 3. Matlab simulations of the odor search.

The algorithm described works and sources are located but must be combined improvements in design for easy cleaning and in the algorithm to try to estimate the best direction.

The photos below show the platform used for testing.

.

Figure 4. Urbano and the electronic nose with mobile plataform.

F. Odor identification test

Important tasks for URBANO are the location of an odor and the position of the odor source. To achieve this goal it is necessary to define the concept of "odor experience".

An odor experience is the set of available sensor values that characterize an odor for a period of time as well as an identifier for that odor.

The robot URBANO, in a normal performance, gets periodically samples of odor.

This process starts with cleaning of the chamber by circulating a stream of air by opening the two lids and turning on both fans, then, it is closed the back cover and rear fan is turned off, so a new sample enters in the camera, after settling time the sensor values are read. If the sample is identified as "similar" to one of the registered it is associated with the corresponding identifier and URBANO informs that it has detected the smell, except that corresponds to the sample labeled "clean air" or what is the same "odor default".

If it has a refutation by the "user that interacts" informing it that the odor is different, it verifies it knows the identifier and it adjusts the algorithm including that sample in the appropriate category, if it is unknown creates a new category with the single sample.

To validate the identification process, it has been used two basic techniques: back propagation neural networks and minimum squares. The results have been good with a success rate above 94%.

VI. LEARNING ODORS

As already stated the ultimate goal is to equip the robot URBANO with the capacity to learn odors and relate them to certain activities. This learning involves:

- Odor experiences
- Odor identifiers given by the supervisor
- Tasks to be associated to an odor identification

The supervisor is the system administrator.

It has been designed a new agent in the URBANOs architecture that performs the functions for measure odor, the identification and the proposal of appropriate tasks to that odor. In the following sections it is described with more detail this process.

A. Step 1: Identifying the odor

The process starts with de odor identification. After cleaning the camera and waiting to stabilize the sensor measures it is performed the average of 50 measurements. These values are used as inputs of the neural network that will result the similarity of the sample with other identified odors. The neural network provides outputs that can determine that a sample seems partially to various odors. Then it is "reacted" to that odor.

B. Step 2: Reaction to known odors

If the odor identified clearly (the response of the network is close to 1) belongs to the category of alarm it is activated the corresponding task, likewise the odor is introduced, as stimuli in the emotional model of the robot causing emotions of WORRY, FEAR.

If this is not an alarm is then introduced as a stimulus in the emotional model generates variations in the emotions and the behavior modifiers. For example, an unpleasant odor will produce and increment in the emotion value of DISGUST, which means that will mean that the task "TOUR GUIDE" will be performed in less time because the robot movement speed will increase and the modifier amount of information provided during the visit will be decremented.

For same odors will be activated tasks that, normally, involve an interruption to the task that is being performed for: greet the person to which it relates, to comment that is near a certain object or make a comment about the odor.

C. Step 3: Unkown odors

In this case, a task is activated that, by a dialogue with the supervisor, tries to get the information needed to incorporate the knowledge of the robot. If at that time there is no supervisor, the smell is stored as historical data.

In the performed demonstrator, as well as maintaining a question-answer dialogue is possible to complete a form by the supervisor, the voice recognition does not always work correctly.

The supplied information by the supervisor is:

- Odor ID.
- Category to which belongs. This will generate a default behavior for that type of odor. It can, also, assign a specific behavior relating a specific task for the smell or an additional task in addition to the standard category.
- The stimuli values when the odor is identified.
- If the category is new, it is necessary to propose the standard task, and if it were necessary to define a new one for the specific odor.

Considering that, during learning, the dependence of the robot's supervisor is very high, it has been proposed a class-based design that allows a very effective default behavior. The LEMON odor will belong to the class FRUITS, that inherit from PLEASANT_ODORS, so the identification of the ORANGE odor will only require by the supervisor to say that it belongs to the category FRUITS. Experimentally has been tested the feasibility of assigning an unknown odor without ID to an ODOR generic category, and has been given it a default behavior. The public appreciates the fact of recognizing the smell, but in general, requires identification.

The tasks performed by URBANO are defined in an own interpreted language, UPL. This language is C-Like and has features appropriate to the characteristics of URBANO, i.e.:

Say(“Hello”); Produce the synthesizing with the current voice of “Hello”.

SayDB(“Welcome”); Produce the synthesizing of a welcome message selected from the available database.

URBANO has, in its ontology, a hierarchical structure of tasks that can be performed; to facilitate the association of odors detected tasks has been created some basic tasks more, as: ESCAPE, ALARM_WARNING, GREETINGS, PLEASANT_ODOR_MSG, UNPLEASANT_ODOR_MSG, etc.

The genetic algorithm designed to optimize the performance of the emotional model, now lead the best use of possible tasks associated with a smell and how they are used, for it, only needs the public opinion. Since learning is based on the experience some performances of the robot may be inappropriate.

VII. CONCLUSIONS

This paper presents a successful experience in the use of an electronic nose on a service robot. On the path towards the final demonstrator it has been tried different classification algorithms on different elements (fruit, wine, etc.), likewise, it has been verified that it is possible to detect and locate the odor source for products or dangerous situations.

It is proposed a mechanism for identifying odors that fires robot activities. These tasks are related to security or they can help with the interaction with the public by identifying people, or simply noticing good or bad smells.

The incorporation of the ontology that relates linguistic concepts, which are used by the robot in their explanations, with certain smells greatly enriches the knowledge and facilitates public acceptance. The performed tests have shown a malfunction occurred as expected, with several categories of odors that are not detected by the 16 sensors selected. For example, infusions, tea, coffee, were not detected by our system.

ACKNOWLEDGMENT

This work is funded by the Spanish Ministry of Science and Innovation (ARABOT: DPI 2010-21247-C02-01) and supervised by CACSA whose kindness we gratefully acknowledge. We would also like to thank to the members of Research Group on electronic noses from UTP: Universidad Tecnológica de Panamá.

REFERENCES

[1] I. Moreno, R. Caballero, R. Galán, F. Matía, and A. Jiménez, "La Nariz Electrónica: Estado del Arte", Revista Iberoamericana de Automática e Informática Industrial (RIAI), vol. 6, no 3, 2009, pp. 76-91.

[2] A. R. Damasio, "Descartes’ Error: Emotion, Reason and the Human Brain", Gosset/Putnam Press, New York, 1994.

[3] D. Goleman, "Emotional Intelligence", Bantam Books, New York, 1995.

[4] M. Álvarez, R. Galán, F. Matía and, D. Rodríguez-Losada, "Emotional Model for Guide Robot", IEEE Transactions on Systems Man, and Cybernetics-Part A Systems and Humans, 4053, Sept. 2010, pp. 982-992.

[5] D. Rodríguez-Losada, F. Matía, A. Jiménez, and R. Galán, “Local map fusion for real-time indoor simultaneous localization and mapping”, Journal of Field Robotics, vol. 23, no. 5, May 2006, pp. 291-309.

[6] iRobot, “B21r Mobile Robot User’s Guide”, part number 2838, rev. 5.

[7] H. Knublauch, “Protégé OWL plugin tutorial”, 7th International Protégé Conference, Bethesda, MD, 2004, URL: http://protege.stanford.edu/plugins/owl/documentation.html, retrieved on June 20, 2011.

[8] Z. Hai and J. Wang, "Detection of adulteration in camellia seed oil and sesame oil using an electronic nose", European Journal of Lipid Science and Technology, vol. 108, no. 2, 2006, pp. 116-124.

[9] J. Hu, "Application of PCA Method on Pest Information Detection of Electronic Nose", IEEE International Conference on Information Acquisition, 2006, pp. 1465-1468.

[10] A. Campagnoli, F. Cheli, G. Savoini, A. Crotti, A.G.M. Pastori, and V. Dell'Orto, "Application of an electronic nose to detection of aflatoxins in corn", Veterinary Research Communications, vol. 33, no. 1, 2009 pp. 273-275.

[11] T.C. Pearce, S.S. Schiffman, H.T. Tagle, and J.W. Gardner, "Handbook of Machine Electronic Nose Technology", John-Wiley and Sons, 2003.

 ISBN: 978-1-61208-155-7

PREVIRNEC

A new platform for cognitive tele-rehabilitation

J. Solana, C. Caceres, EJ. Gomez
Bioengineering and Telemedicine Research Center
ETSIT-Technical University of Madrid / Ciber-bbn
Madrid, Spain
{jsolana,ccaceres,egomez}@gbt.tfo.upm.es

S. Ferrer-Celma, M. Ferre-Bergada, P. Garcia-Lopez
Informatics Engineering & Mathematics Research Center
Rovira i Virgili University
Tarragona, Spain
{sandra.ferrer,maria.ferre,pedro.garcia}@urv.cat

A. Garcia-Molina, A. Garcia-Rudolph, T. Roig, JM. Tormos
Neuropsychology and Research Departments
Institut Guttmann
Badalona, Spain
{agarciam,agarciar,troig,jmtormos}@guttmann.com

***Abstract* — Acquired Brain Injury (ABI), either caused by vascular or traumatic nature, is one of the most important causes for neurological disabilities. People who suffer ABI see how their quality of life decreases, due to the affection of one or some of the cognitive functions (memory, attention, language or executive functions). The traditional cognitive rehabilitation protocols are too expensive, so every help carried out in this area is justified. PREVIRNEC is a new platform for cognitive tele-rehabilitation that allows the neuropsychologist to schedule rehabilitation sessions consisted of specifically designed tasks, plus offering an additional way of communication between neuropsychologists and patients. Besides, the platform offers a knowledge management module that allows the optimization of the cognitive rehabilitation to this kind of patients.**

Keywords* — *PREVIRNEC; tele-rehabilitation; cognitive rehabilitation; Acquired Brain Injury (ABI).

I. INTRODUCTION

The World Health Organization (WHO) predicts that by the year 2020, stroke and traumatic brain injury (TBI) are within top five etiologies considering medical cost and cost of disability adjusted to life expectancy (DALY). These injuries produce a complex constellation of medical consequences including physical and cognitive deficits. Cognitive impairments in attention, memory, language, and executive function hamper the path to functional independence and a productive lifestyle for the person with acquired brain injury [1].

Every year, nine million people around the world suffer from stroke [2]. Globally, cerebrovascular disease (stroke) is the second leading cause of death and the eighth cause of severe disability in the elderly. The WHO estimated that in 2005, stroke accounted for 5.7 million deaths worldwide, equivalent to 9.9% of all deaths, and was the predominant cause of disability, afflicting 30.7 million people [2]. Statistical data show that after a stroke, one third of patients die during the first month, and 40% of people who recover from the acute phase exhibit a high degree of impairment that decreases their independence and quality of life. Only one third of patients recovers their basic functions and can resume a normal life [3]. There are not accurate data on the prevalence of TBI in Europe, meanwhile data from the United States show a high prevalence of this pathology, with 5.3 million people living with a disability caused by TBI [4]. New techniques of early intervention and the development of intensive ABI care have noticeably improved the survival rate. However, despite of these advances, brain injuries still have no surgical or pharmacological treatment to re-establish lost function. Cognitive rehabilitation, as part of neuropsychological rehabilitation, has been defined as the application of techniques and procedures, and the implementation of supports to allow individuals with cognitive impairment to function as safely, productively, and independently as possible within their environment. The provision of cognitive rehabilitation thus becomes an essential part of the services to manage the complex disablement that ABI provokes.

The use of Information and Communication Technologies (ICTs) to develop a tele-rehabilitation and tele-assistance allows:

- To improve the quality of clinical services, by facilitating the access to them, helping to break geographical barriers.
- To keep the objective in the assistance centered in the patient, facilitating the communication between different clinical levels.
- To extend the therapeutic processes beyond the hospital, like patient's home.
- A saving for unnecessary costs and a better costs/benefits ratio.

 ISBN: 978-1-61208-155-7

In the last years, several projects have been trying to demonstrate this utility of the ICTs as a better way to perform the neuro-rehabilitation.

The objectives of this paper are:

- Analyzing and modeling a tele-rehabilitation system, defining the objectives and user's requirements.
- Defining the platform architecture, highlighting the different modules involved.
- Designing and developing the platform, including the user interface, describing the different functionalities of the system for each defined profile.

PREVIRNEC [5] is a tele-rehabilitation platform that has been developed during the past six years by the Universitat Rovira i Virgili and Universidad Politécnica de Madrid, together with the Institut Guttmann (Spain) neuropsychology and research departments. The use and experience reached during this time with more than 500 patients been treated with PREVIRNEC, together with a deep study of the clinical problem and a modeling process of the system, have allowed the authors to improve considerably the system, creating a more complete cognitive tele-rehabilitation platform that is presented in this paper.

This paper starts with the system modeling, describing the different user profiles defined. Then, comes a description of the tele-rehabilitation itself, explaining their modules and the significant work done to achieve the objectives. Finally, some conclusions are shown.

II. System Modeling

A. *Requirements analysis*

For the system modeling Unified Modeling Language (UML) has been used, describing the system's behavior using use cases and sequence diagrams.

For the elicitation and definition of the objectives and user requirements a detailed process has been followed, including interviews and meetings with neuropsychologists from the Institut Guttmann, which is a specialized center in cognitive and functional neuro-rehabilitation.

B. *User Profiles*

For each person or entity using the system in a determined context and for a specific goal, four different user profiles have been defined:

- **Patients**: man or woman of any age with one or some cognitive functions affected, as a consequence of suffering ABI. Here appears the *caregiver* role, considered a secondary actor that will help the patient to use the system when necessary.
- **Therapist**: a neuropsychologist specialized in cognitive rehabilitation in patients with ABI, who will have a number of assigned patients to be responsible for their treatment, scheduling and monitoring personalized and individualized therapies.
- **Supervisor**: person in charge of the user management for each center, both patients and therapists and their assignments, apart from other management and control functions applied to center/s that supervises.
- **Administrator**: apart from all the typical administration tasks for every informatics system, the administrator will be the responsible for managing the categories, functions and tasks defined in the system, which is the content the therapist will use to schedule therapy sessions to their patients.

III. Cognitive Tele-rehabilitation Platform

PREVIRNEC is a cognitive tele-rehabilitation platform, developed over an architecture based on web technologies. PREVIRNEC is conceived as a tool to enhance cognitive rehabilitation, strengthening the relationship between the neuropsychologist and the patient, personalization of treatment, monitoring of results and the performance of tasks.

A. *Architecture*

The architecture presented here consists of five main modules, which group related functionalities vertically, sharing the user interface that is personalized depending on the user's role. This interface is also multi-language, with Catalan, Spanish and English already implemented, but being open to support any other language. The system also has a help module, which guides the user in order to complete each action. Security aspects are transversal and have to be taken into account in every module to keep information and all connections safe, due to the important of confidentiality in this kind of medical applications. The security module is the responsible of controlling every access, included the ones related to the patients' Electronic Health Record (EHR).

In Figure 1. this architecture is represented, where we can see the different modules, described below:

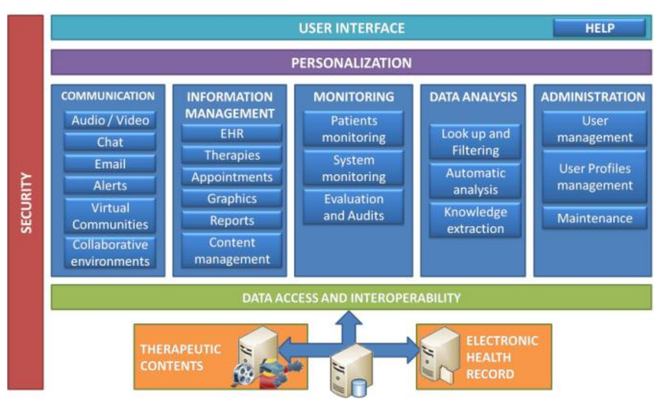


Figure 1. Tele-rehabilitation architecture modules

- **Communication**: the main element of this module is the videoconference that allows the users to communicate using video, audio and chat. Using the videoconference therapists can do tele-appointments with patients or other therapists, breaking the distance barriers between users, and helping the patients to feel closer to the clinical team. Apart from the videoconference, this module has a mailing service to exchange internal asynchronous messages and an alert service that let users know what tasks they have to accomplish.

- **Information management**: this module groups functionalities related with the generation and edition of information that depends on the patient's EHR. Interoperability with the clinical information system has been achieved in order to use the patient's data stored in the centers. Besides, this module controls the assignation of therapies to the patients, determining which computerized tasks a patient has to do in a certain day. The results of the execution of these tasks are registered in the system, and then can be used by the clinicians to see the evolution of the therapy, as well as showing graphics and reports related to the completion of the sessions, tasks that have been used, both global and individual results, and many more.

- **Monitoring**: in order to comply with the Data Protection Law every action carried out by any user is stored in both the database and also in a log file, so the administrator can track every action related to any patient and its data. Apart from this, the system offers a module to monitor the execution of the tasks, so the therapist can then reproduce a task as it was done by the patient. This allows the therapist to see exactly what a patient did in the monitored task, which is very useful because sometimes it is not enough to merely see the numeric results.

- **Data Analysis**: the main objective of this module is to extract the maximum knowledge from the information stored in the system. To achieve this there is a tool for knowledge management that is applied for each data collected, being able to filter, analyze and extract the necessary knowledge to help the neuropsychologists in their decision making. This module, by analyzing a set of data defined together with the clinicians, is able to assign a patient to an affectation profile. An affectation profile groups patients with similar characteristics using clustering techniques, in order to give the neuropsychologist information about how patients of the same profile have done a concrete task in the past, helping them to know how good a task is for that kind of patient. Moreover, this knowledge can be used to learn about the neuro-rehabilitation processes or to improve the designed tasks, modifying the ones that appear not to be appropriate for certain patients.

- **Administration**: this module, although it is the one with less functionalities and users, includes very important functionalities, like the users' management and their profiles, as well as the system monitoring (using logs).

B. User Interface

One of the main efforts of improvement for this new version of PREVIRNEC is the redesign of the user interface. This new design, apart from including all the new functionalities, has been based on the User-centered design model, which principles are a new definition of those from classic ergonomics and, in general, from the accessibility guides. At this point, it is important to enhance how difficult is to have an interface accessible for everybody, even more when the target users are patients who suffer ABI and as a consequence of this they have problems in their cognitive functions.

In the design of the user interface phase we have used an iterative mock-up to show the experts not only how it would look like, but also the different functionalities the users will find and how they will perform every action.

C. Contents and centers organization

The tele-rehabilitation sessions consist of computerized tasks, grouped by functions and categories. The neuropsychologist creates a tele-rehabilitation session by assigning a set of tasks to a certain day, being able to configure the difficulty of each task, by setting some input parameters.

The new concept of category has been created to treat different collectives apart from the initial ABI patients, such us the elderly, schizophrenia, childhood, and more.

Every category will cover different cognitive functions and subfunctions. Therefore every task will be particularly designed by neuropsychologists for a cognitive subfunction (e.g., sustained attention or visual memory) that can be used for a specific collective (category).

PREVIRNEC can be used not only in the Institut Guttmann, but also in other clinical centers and even neuropsychologists who work by their own. Besides, each center defines three assistance areas by default (generic, home and test), but they can also create new areas as needed. This gives the possibility to study separately, for example, patients that have been treated at the clinical center from those who execute tasks at home

Moreover, the system administrator defines the categories for each center, selecting for every category the specific tests used for the neuropsychology exploration. These tests allow neuropsychologists to determine the affectation grade of each cognitive function.

D. Technologies

As we have already said, the platform is based on open source web technologies. The main architecture of the platform is based on a client-server communication using HTTP and XML-RPC, as it is shown in Figure 2.

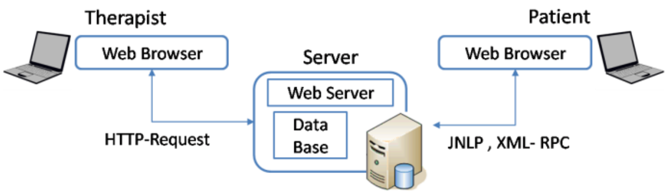


Figure 2. Client-server communication schema

In the developing phase, a Model-View-Controller pattern has been followed, so the view and the logic to access and process data are separated.

The new web application requires Java (jdk 1.6, jre 6.x) and it runs over Apache Tomcat 6.X, as it is based on Servlet/JSP. The database used is MySQL Server 5.X and MySQL Java Connector 5.X (JDBC). However, thanks to this division between data process and the view, the platform could be easily adapted to new other database models or new languages for the graphic user interface.

Relating to the programming languages used all the environment is Java 2 Platform (J2EE, Enterprise Edition), using JavaScript and AJAX (SACK library) to dynamically change the data showed on the HTML pages, so avoiding to reload the page every time the user wants to show or edit contents.

For the videoconference module OpenMeetings has been used, which implements the Real Time Multimedia Protocol (RTMP), using a red5 server for the audio and video streaming. One of the main challenges addresses in this work has been the implementation of a web-based videoconference application, so the user does not need any local application installed in their computers.

For the knowledge analysis, Weka has been used. Weka is a collection of machine learning algorithms for data mining tasks. This is the second main challenge of the work done, that is the process that groups patients into different clusters, helping the therapists to assign the more suitable task to each profile.

IV. CONCLUSIONS

The improvements on the platform presented in this paper have been tested with patients and neuropsychologists from the Institut Guttmann with very promising results. In the near future PREVIRNEC is expected to extend to the patient homes and other 17 centers.

The first results reveal that the platform is now more efficient and powerful thanks to the new functionalities added. The neuropsychologists particularly highlight the new design of the user interface that allows, for example, the possibility to see the results of a previous rehabilitation sessions while they are scheduling new ones. The development of the interoperability module that shows the patient's EHR is also well considered. Regarding the new content and center classification, users emphasize how this platform is open to future neuro-rehabilitation applications, allowing new centers to configure the system and manage their own users. Finally, neuropsychologists also find very useful the knowledge extracted by the data mining module, which helps them when assigning tasks to a specific patient.

As a conclusion, PREVIRNEC is revealed to be a powerful tele-rehabilitation platform, letting the patients to extend their treatment beyond the clinical centers, reducing travel costs and the distortion of the rest of the family, while neuropsychologists can monitor and evaluate their evolution.

ACKNOWLEDGMENT

This research was partially supported by the following grants: Spanish government, Ministry of Industry, Tourism and Trade AVANZA PLAN: Digital Citizen Subprogram (Neurolearning / Grant: TSI-020501-2008-0154); Institute of Health Carlos III (National Public Health Research Institute and the National Funding Agency for Health Research in Spain), Strategic Action Health's Call (Clinical implantation of PREVIRNEC platform in TBI and stroke patients / Grant: PI08/900525); EU ICT PSP call Identifier: CIP-ICT-PSP-2007-1 (Clinical Leading Environment for the Assessment and validation of Rehabilitation Protocols in home care - Grant agreement: 224985); Ministry of Science and Innovation INNPACTO Program (NeuroContent - Grant IPT: 300000-2010-30); Ministry of Education Social Policy and Social Services IMSERSO Program (Project title COGNIDAC - Grant 41/2008); MARATÓ TV3 Foundation (Improving Social Cognition and metacognition in schizophrenia: A tele-rehabilitation project - Grant 091330)

REFERENCES

[1] C.J. Murray and A.D. Lopez. Alternative projections of mortality and disability by cause 1990-2020: Global Burden of Disease Study. Lancet 1997a; 349: 1498-504.

[2] World Health Organization. Burden of Disease Statistics; Available online: http://www.who.org/ (accessed on 10 May 2011).

[3] L.C. Álvaro, P. López-Arbeloa, and R. Cozar. "Hospitalizations for acute cerebrovascular accidents and transient ischemic attacks in Spain: Temporal stability and spatial heterogeneity, 1998-2003". Rev. Calid. Asist 2009,vol. 24, pp. 16-23.

[4] Brain Injury Association of America; Available online: http://www.biausa.org/ (accessed on 10 May 2011).

[5] A. García-Molina, et al. "Clinical program of cognitive tele-rehabilitation for traumatic brain injury". eChallenges 2010, Warsaw (Poland). ISBN 978-1-4244-8390-7, pp. 1- 10.

Improvements on Relational Reinforcement Learning to Solve Joint Attention

Renato Ramos da Silva
Department of Computer Science
ICMC, University of Sao Paulo
São Carlos, São Paulo
ramos@icmc.usp.br

Roseli Ap. Francelin Romero
Department of Computer Science
ICMC, University of Sao Paulo
São Carlos, São Paulo
rafrance@icmc.usp.br

***Abstract*—The joint attention is an important cognitive function that human beings learn in childhood. This nonverbal communication is very important for a person understands other individuals and the environment during the interaction. Because of this, it is essential that the robots learn this skill to be inserted in the environment and interact socially. In this article, we have enhanced a robotic architecture, which is inspired on Behavior Analysis, to provide the capacity of learning joint attention on robots or agents using only relational reinforcement learning when the environment changes. Then, a set of empirical evaluations has been conducted in the social interactive simulator for performing the task of joint attention. The performance of this algorithm have been compared with the Q-Learning algorithm, contingency learning algorithm and ETG algorithm. The experimental results show that this algorithm solves the problems of learning and makes the architecture with greater flexibility to insert new modules.**

***Keywords*-joint attention; relational reinforcement learning; social robots; shared attention.**

I. Introduction

Attention is the process whereby an agent concentrates on some features of the environment to the exclusion of others. The agent's concentration can be broken when some event happens and the attention is changed by some gaze behavior. Gaze behavior is a crucial element of social interactions and helps to establish triadic relations between self, other, and the world. In others words, this ability is very important for communication among humans because it helps a person expresses his or her intentions around external entities [1], [2].

The term joint attention (JA) is one type of gaze behavior. It is typically used to denote when the directing of attention of a person is taken to a third entity, an object or an event (e.g., a sound or a common goal), by focusing attention sequentially (not simultaneously) from another person. In the final of the process, reinforcement is assimilated. The importance of JA in humans and the greater inclusion of robots in our environment led robotics researchers seek mechanism that enables robots with this capability. The researches include creating mechanism to provide robots with the skill of JA or the ability of robots to learn it.

Reinforcement Learning (RL) is a machine learning method used by computer scientist to provide a machine learn only interacting with the environment. This approach has been used on robots to provide robots the capability of learn JA because this approach emphasizes the role of biologically plausible reward-driven learning processes. This plausible is explained with a basic set to construct an agent by Triesch et al [3]. This set includes perceptual skills and preferences, reinforcement learning, habituation and a structured social environment.

When RL algorithm is used as learning mechanism it needs additional information for learning process and it causes difficulties to create new modules in the architecture. In order to provide this capability for a robot only using reinforcement learning (i.e., without additional information) by adopting Markovian assumption is respected, might be infeasible. For JA, the problem is when the robot must to return to eye contact from a state, which is characterized as empty.

In our previous work [4], we proposed an algorithm where the last action is associated with current state to choose the next action to solve the problem cited above. But some gaps need to be solved before we start to insert new modules in our architecture. One example is a necessity of a caregiver stay fixed while the robot learn to return the attention to the caregiver on early rounds of interaction.

Then, this paper reports an ongoing work aimed at developing the robotic architecture, which is inspired on Science of Behavior Analysis [5], [6], [7]. In order to provide this, we proposed an improvement on FAIETGQ algorithm using the idea of plan of actions to select an action to response only when the environment changes. After this, we have incorporated four different learning algorithms in the robotic architecture. It has been inserted and evaluated in the simulator of social interactions. Then, the robotic architecture has been evaluated in the context of the JA.

This article is organized as it follows. We start with related work section making the case for a rigorous experimental study of JA behaviors. After, we describe the robotic architecture, in which the learning mechanism will be inserted in. In Section IV, we present the FAIETGQ algorithm and the changes proposed in this paper and the advantages of it. Then, a social interaction simulator are presented in Section V. Afterward, in Section VI, the experimental

 ISBN: 978-1-61208-155-7

results from a set of experiments carried out to evaluate the performance of the proposed architecture with each learning algorithm tested. A comparative analysis among the four learning algorithms is also been presented. Finally, in Section VII, conclusion and future works are presented.

II. Related work

Despite the biological plausibility of the RL, it is not the only way exploited by researchers to enable a robot with the ability to learn to JA.

A temporal-difference (TD) reinforcement learning scheme for learning joint visual attention was proposed by Matsuda[8]. This model is limited because the robot only gets reward when the object, operated by the observer, moves itself. Also the caregiver's face is treated separately from the objects and does not lead to any reward, that is, mutual gaze was not considered in this work. Nagai et al. [9], [10] used face edge features and motion information (optical flow) to estimate the sensor motor coordination and the motor output using two separate neural networks. Their model does not utilize the depth information of the images and thus can not handle ambiguous situations where an object appears in robot's gaze direction that may not be located within the caregiver's gaze direction. Shon et al. [11] presented a probabilistic model of gaze following imitation in which estimated gaze vectors are used in conjunction with the saliency maps of the visual scenes to produce maximum a posteriori (MAP) estimative of the object positions attended by the caregiver. In another study, Triesh proposed a basic set of structures and mechanism for gaze following [3]. This set includes perceptual skills and preferences, reward-driven learning, habituation and a structured social environment. This work is evaluated only on simulator. Kim et al. [12] improved a model that uses a basic set [3], on a robotic head. They have been used an actor-critic reinforcement learning model for learning gaze following. The drawback of this proposed method is related of using a salient map as additional information. More specifically, this map uses representations of the caregiver head direction (h) and the caregiver eye direction (e). In our previous work [13], we applied the contingency learning in architecture for JA aiming to control a real robotic head.

III. Robotic Architecture

The robotic architecture is under development and aims to build intelligent agent based on Behavior Analysis theory [5], [6], [7]. This study is motivated to help understand the human being and help someone in many parts of our day, like robots assistants and entertainment activities. Thus, it is composed by two main modules: Stimulus Perception is State Estimation and Response Emission Module is the Controller.

Figure 1 illustrates the general organization of the architecture and the interaction between modules. Arrows indicate the flow of information in the three modules of the architecture. The circles indicate the methods and component structures of the modules. The Stimulus Perception Module encodes stimulus from environment then it is used by Response Emission Modules for learning and exhibition appropriate behaviors.

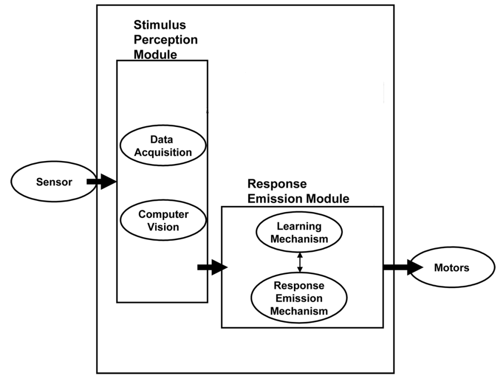


Figure 1. General organization of the architecture.

The Stimulus Perception Module (SPM) may employ algorithms of data acquisition, a vision system, and a voice system, depending on the application domain. This module detects the state from the environment and encodes this state using an appropriate representation. The relational representation was chosen because it enabling the representation of large spaces in an economical way.

The Response Emission Module (REM) is composed by a learning mechanism that constructs a nondeterministic policy for response emission, that is, what response is to be emitted on the presence of certain antecedent stimulus. Other function of this mechanism generates a reward on the basis of the internal state estimate. Other part of REM, the response emission mechanism receives the information from learning mechanism and converts it in action to be executed by the motors.

The original version of this robotic architecture has a Motivational Module and it was proposed by Policastro [13]. This module helps to provide the ability of learn JA to robots but it create some problems to insert new modules. Now, in the process of developing this robotics architecture with new abilities to be incorporated into, we remove the Motivational Module and we are looking for a better learning mechanism for it.

The Consequence Control Module (CCM) is composed by a motivational system that simulates internal necessities of the robot. The motivational system is formed by necessity units that are implemented as a simple perceptron [14] with recurrent connections. Those necessity units simulate the homeostasis of alive organisms. A positive value of a necessity unit, above a predefined threshold, indicates the privation of the robot to certain reinforcement stimulus. In

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-155-7

this way, the architecture supplies mechanisms to simulate privation states and satisfaction of necessities.

The motivational system works as it follows. Initially, the stimuli detected from the environment are sent to the consequence control module. Then, the *Preprocessor* encodes these stimuli to construct an appropriate input pattern. This input pattern may be or not normalized, depending on the numeric interval of the selected connection weights and problem domain. Afterwards, the necessity units calculate their activation values and their output values. After this, the *Mediator* performs a competition among all unit outputs and selects the winner. The *Mediator* checks if the winner is higher than the activation threshold. If so, the motivational system outputs the active necessity [13].

IV. Learning mechanism

A. FAIETGQ

The main idea of FAIETGQ algorithm is related with the possibility of using the previous action as a way of solving the problem of JA. Then, only with the action that resulted in the state that subsequently led to positive reinforcement are used as information to choose next action [4].

The FAIETGQ algorithm learns a control policy for an agent while it moves through the environment and receives rewards for its actions. An agent perceives a state s_i, decides to take some action a_i, makes a transition from s_i to s_{i+1} and receives the reward r_i. The task of the agent is to maximize the total reward it gets while doing actions. Agents have to learn a policy which maps states into actions. All knowledge is stored in a tree and the mechanism responsible to infer an action is called relational regression engine.

This engine is denominated relational because the representation of states. Moreover, the states use binarization by conversion of a categorical attribute to asymmetric binary attributes [15]. The regression is the mechanism of using a tree with a dependent variable action and the independent or predictor variable state [16].

The learning mechanism takes the state from the SPM and use the relational regression engine to select the action. This mechanism tries to find the current state in the intermediate nodes. If this operation is positive it takes an action which antecessor action executed in current action was positive, otherwise a random action is done. The action executed over the state changes it and the agent receives its reward. The reward can be either positive (equals to 10) or negative (equals to -1). After this occurred, the $qvalue$ is computed by:

$$\hat{Q}_i \leftarrow Q(s_i, a_i) + \alpha[r_{i+1} + \gamma \max(Q(s_{i+1}, a_{i+1})) - Q(s_i, a_i)] \quad (1)$$

Then, the relational regression engine is updated receiving a set of (state, action, $qvalue$, $last\_action$). The state is tested with internal nodes if it already exists. In the case

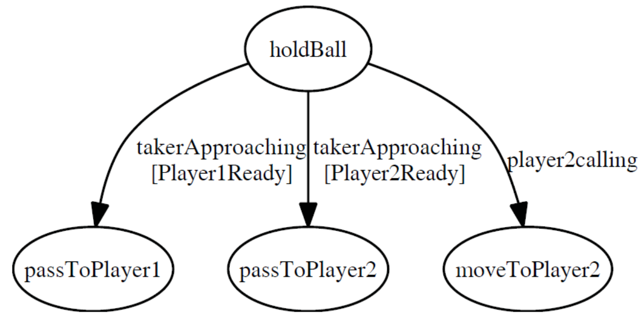


Figure 2. An example of simple plan. Actions label states, events and guards label transactions [17]

this performance is false, the state is inserted in the tree and the leaf receives the action with the $qvalue$ and $last\_action$, forming a new branch. Otherwise, it updates the $qvalue$ for respective action in the leaf node.

In a leaf node, more than one action can be considered. For an easier access to the most adequate action, these actions can be ordered in decreasing order according to their $qvalue$ always that an example is inserted or updated. Each leaf also has a $last\_action$ associated with action and it refers to a $last\_action$ of the robot to choose this action on this state. This process is repeated until there are not more interactions to be executed.

B. New FAIETGQ

In this section, we propose a simple modification on FAIETGQ algorithm based on the idea of agent plan by Leonetti [17]. His work used a reactive plans representation with graphs, or charts, for plan state and event. The plan states are the nodes of the graph which represent the actions that can be performed and the events are the vertices that reflect environment state. Moreover, the vertices may have guardians, which are conditions that must be satisfied to reach the other state. Thus, the agent remains on a node until the state is changed. If there is a guardian, the condition must be satisfied for the agent to move from one node to another.

The Figure 2 is an example of simple plan for robot soccer. The agent starts holding the ball until an event occurs. When *takerApproaching* or *player2calling* happen the agent can go to the next node. The agent reaches the node *passToPlayer1* or *passToPlayer2* if the condition of *Player1Ready* or *Player2Ready* is satisfied.

Our propose change the FAIETGQ to take an action only when a state changes. Then, in the beginning of the interaction the agent do not need to do a random search to find a target, object or human, and we can improve our experiments eliminating the necessity of the caregiver waiting fixed looking for a robot while it learns to return to mutual gaze. In addition this new algorithm is more natural

 ISBN: 978-1-61208-155-7

than the original because the robot only reacts to a change in the environment. In other words, the robot, in early learning stage, do not need to search disorderly to find a correct action to establish eye contact.

However, this algorithm creates a problem during the interaction. When the caregiver turns his head to the object and the robot turns wrongly to another place. At his moment, the robot does not find the object, receive a negative reward and the state will not change. Because this problem other addition to algorithm is inserted. When the robot receives the negative reward it does not wait to change the state of the environment, it immediately takes an action.

The new FAIETGQ algorithm learns a control policy for an agent. It learns only from the interaction with the environment and receives rewards for its actions. An agent perceives a state s_i and compare with its previous s_{i-1}. If they are the same, the algorithm verify if the reward is negative to take an action a_i randomly. Otherwise, the robot wait for the next state s_{i+1}. The other case is when the states are different, then the agent decides to take some action a_i following the knowledge stored. After it takes an action it always makes a transition from s_i to s_{i+1} and receives the reward r_i. The task of the agent is to receive positive reward while takes actions. Agents have to learn a policy which maps states into actions.

All new knowledge is stored in a tree. This relational engine receives a set of (state, action, $previous\_action$) and tests the internal nodes if the state already exists. In the case this performance is false, the state is inserted in the tree and the leaf receives the action with the $previous\_action$ and necessity values, forming a new branch. The tree is updated when a positive example occur.

V. Social Interactive Simulator

To evaluate the proposed architecture, an interactive social simulator has been developed by us and it is presented here. This social interaction simulator is able to simulate an interaction between a robot and a human in a controlled social environment.

In order to simulate the JA task, it has been defined three entities that can be manipulated through functions of the simulator. They are a human, a robot, and two toys. The human being and the robot are positioned face to face, at a distance of approximately 50 cm from each other. The simulator enables that up two toys are positioned in the social environment. A toy can be positioned at any empty place of the social environment at any moment.

The social environment was modeled in the following way. Both the robot and the human can turn left or right their heads up to 90°. The robot has its central focus in 0° and has its visual field limited by a foveation parameter $\lambda°$, starting from the central focus, in $[-\lambda°, +\lambda°]$.

The position of the robot's head is given by θ_r, that can assume values in $[-90°, +90°]$. The position of the human

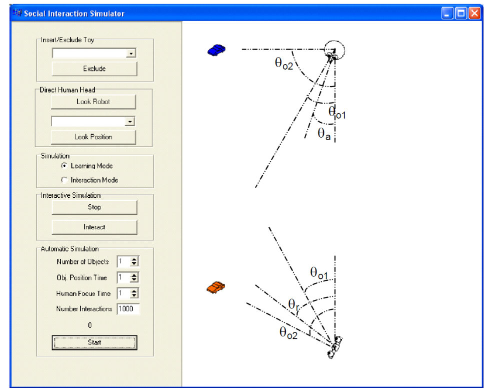


Figure 3. Positioning control [18].

being's head is given by θ_a, that also can assume values in $[-90°, +90°]$. When an object i is positioned in the social environment, the simulator maps the angle between this object and the robot's focus, that is, the distance that the robot must move its head to focus the positioned object. This mapping is given by θ_{oi}, that can assume values in $[-90°, +90°]$. In this way, if an object is positioned in the environment, the simulator verifies if the same is inside the robot's field of vision, by comparing its position in relation to the robot's focus, considering the foveation of the robot.

Figure 3 shows the interface of the developed simulator with the robot head position explained above. In this figure, on the left side of the interface is the control panel that enables interactive or automatic simulations, the human being is fixed on the upper side of the interface and the robot is fixed on the lower side of the interface.

Additionally, the simulator provides an adult attending stimulus that simulates attention from human being to the robot. The simulator provides the stimulus when the human and the robot are keeping eye contact and when the robot correctly follows the human gaze. This mechanism was incorporated in the simulator to validate the behavioral analysis presented by Dube and their colleagues [19], stating that the human serves as motivational operator in the context of JA learning.

During a simulation, the simulator executes interactions continually and each interaction takes 1 second. The simulator is able to position up to two simultaneous objects in the social environment, on places stochastically selected with probability ρ_o. These objects are positioned in the respective places for a time determined by the user (given in seconds). Additionally, the simulator is able to turn the human being's head to focus an object present in the environment or to focus the robot. The object that receives the human's focus is stochastically selected with probability ρ_{oi} and the human keeps his focus at the selected object for a time determined by the user (given in seconds), before turn his head to another object or to the robot.

 ISBN: 978-1-61208-155-7

VI. Experiment

In this section, the main results of the experiments carried out to evaluate the proposed learning algorithms are presented and discussed. The experiments were carried out employing the simulator previously presented, in the context of the emergence of JA. The purpose was to evaluate the capabilities of the new version of the robotic architecture on exhibit appropriate social behavior and learn from interaction.

For a complete evaluation of this previous proposed, we compared it with FAIETGQ to analyze the improvements of this algorithms. In addition, we used the old architecture with Contingency Learning, Q-learning and ETG algorithm to compare with new FAIETGQ to validate of this new architecture over the original version.

The experiments were composed by a learning phase of 10,000 time units (10,000 seconds in the simulator). During the learning phase, the human being initially kept the focus on the robot until it establish eye contact with him, characterized by 3 time units looking each other. Then, two objects were positioned in the environment and the human being turned his gaze for one of these objects, obeying the probabilities defined in the social interactive simulator. The human keeps his gaze at the object by 5 time units. Afterwards, the objects are then removed from the environment and the human turns his gaze to the robot, keeping the robot make eye contact again. This procedure is done in order to simulate an interaction where two agents are keeping eye contact and then one turns his gaze to an interesting event or object.

During the learning, the robot looks for the human. However, when an object is positioned in the environment and the human turns his gaze to it, the robot loses the human attention and starts to seek anything in the environment. Additionally, if the robot looks for a toy, which the human keeps his gaze turned on it, the robot receives a reinforcement and the human gives attention to the robot, in relation to that toy. In this way, after a history of reinforcement the robot will learn to follow the human's gaze to receive his attention.

The learning capabilities of the architecture were analyzed by observing the robot interacting with the human and the environment, and computing a measure, the *correct gaze index* (CGI). The CGI measure is based on measures prosed by Whalen [20] and is defined as the frequency of gaze shifts from the human to the correct location where the human is looking at, given by:

$$CGI = \frac{\#shifts\ from\ the\ human\ to\ correct\ location}{\#shifts\ from\ the\ human\ to\ any\ location} \qquad (2)$$

To quantify the learning capabilities of the architecture through the learning of gaze following, at specific points during the learning process we temporarily interrupt the learning phase to evaluate its behavior. This evaluation was done by 10 runs of 500 time units (500 seconds in the simulator). For each run, the CGI value, given by Equation (2) was computed. After the evaluation phase, the learning process was resumed. A total of 20 interrupt points were placed. The whole procedure was performed 10 times and then a mean and standard deviation was calculated for each evaluation phase.

During the evaluation phase, the human initially kept the focus on the robot until it establishes eye contact with the human, characterized by 3 time units keeping eye contact. Then two objects were positioned in the environment and the human turned his gaze for one of these objects. However, in the evaluation phase, the object to which the human should turn his gaze was place on a position given by pre-established sequence (to prevent non determinism in the results). The second object (the distractor) was placed on an empty position, obeying the probabilities defined in the social interactive simulator. Once the robot turns its head to any direction, the simulator verifies if it is looking to the correct position in the environment (a toy which the human is looking for) or not, and update the CGI measure. This procedure takes 1 time unit. Afterwards, the objects are then removed from the environment and the human turns his gaze to the robot, keeping the robot make eye contact again.

For the experiments, the architecture knowledge was set as follows. Four stimuli were declared: *face*, *object*, *attention*, and *environment*, where attention is a reinforcement stimuli. Two facts were declared to define that red and blue objects are toys. Thirteen facts where declared in order to differentiate the human's head pose in frontal pose, six poses of left profile and six poses of right profile. Additionally, two more facts were declared to define when the robot is focusing the human or a toy.

When we are dealing with JA, a fact very important that it must be considered in all interactions is the number of times that the robot establishes eye contact with human. This is an essential fact for JA. By the simulator, the robot can choose one of the options: to find anything in the environment or pay attention to human. If the robot chooses only the first option, it could not simulate the joint attention. Because this, it is important that the learning algorithm maximizes the number of established eye contacts.

The Figure 4 shows the average number of times that the robot establishes eye contact with human for each evaluation phase by using each one of the algorithms. In this figure, it is showed the beginning of the interaction between human and robot, in a total of 125 possible opportunities to establish eye contact each other.

In performing the analysis of the Figure 4 we can verify that the new FAIETGQ achieved a better final result than the other techniques.

It shows that the robot has an increasing learning in the beginning of process until find a threshold, after that, the agent no longer learns how to establish eye contact and will

 ISBN: 978-1-61208-155-7

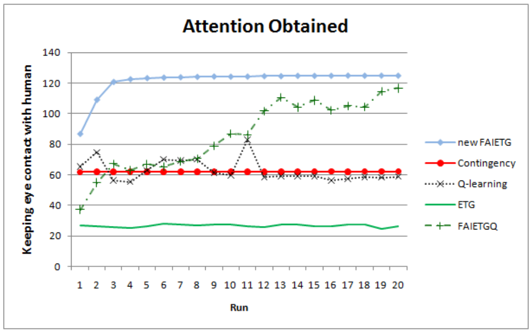


Figure 4. Average of attention obtained by human from the robot during evaluation phase.

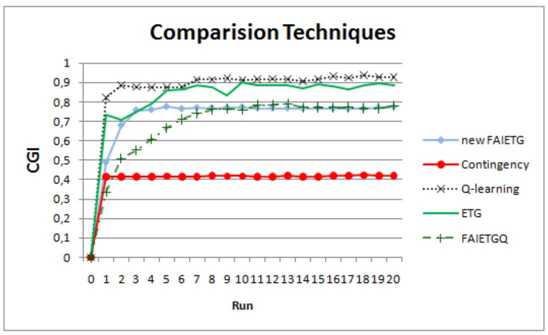


Figure 5. Learning evolution during the experiments.

only use the knowledge learned. This shows that it could learn to give attention to human. The graphics also show that the ETG technique achieves a lower level of the other algorithms and the Q-learning has irregular behavior.

Figure 5 shows the performance, the learning progress over the time, of five different learning algorithms used as learning mechanism in the architecture to solve JA. It plots the CGI average value measured for each evaluation phase, at specific points during the learning process.

Initially, it can be seen that all of the algorithms have not any knowledge about the problem. In the first run, all of them have a great improve your knowledge attaining at least 40% of maximum CGI value. In this stage, the robot or the agent learns a lot about the problem. After this, the contingency learning does not improve your knowledge until the end, remaining constant. In contrast, other algorithms have a reasonable growth until to attain a stabilization level.

In the end, the ETG and Q-learning algorithms have the best results for CGI. The new FAIETGQ and FAIETGQ algorithms have a good performance and has results close to the best. The contingency learning has result of CGI lower than the others.

A deeper analysis can be made considering Figures 4 and 5. Considering the factors of learning and the number of established eye contact, you can say that the new FAIETGQ algorithm achieved better results. This means that the robot can establish eye contact with some frequency and follows the attention to the object that is of caregiver's interest.

The experimental results also showed that the ETG and Q-learning algorithms have a high quality to follow the human gaze, but they have poor quality to establish eye contact. The ETG is the worst of this two. And finally, the contingency learning that can make half of the relations of JA, which is very low compared to other.

One good improvement can be seeing here if we compare the way as the experiment was made before. In other experiments performed so far was necessary that in the first 100 times units of learning phase, no objects are positioned in the environment and the human kept his focus on the robot the whole time, so the robot have learned that it may obtain the human attention by keeping eye contact with him. In others words, at this moment the robot explores the possibilities while the caregiver remains in the static way. This change decreases the performance of Contingency, Q-learning and ETG algorithms.

VII. Conclusion and Future Works

In this paper, we presented an ongoing work for the development of a robotic architecture inspired on Behavior Analysis [7]. Five different learning algorithms, RL, contingency, ETG, FAIETGQ and this improvement on FAIETGQ proposed, were incorporated to robotic architecture to provide to the robot the ability of sharing attention. The learning mechanism were evaluated on a social interactive simulator and made by interacting real robotic head and the human in the context of the emergence of JA.

The experimental results show the evaluation by using new FAIETGQ algorithm compared with others algorithms for JA problem. It can be considered as step forward in a more natural interaction.

Future works include the insertion of new modules, for instance *energy*, *emotions*, *needs*. Another planned advance is to work with learning the joint attention by the robot where the caregiver does not have just one fixed position. So, we can better evaluate the learning method. Furthermore, it would be more natural and the robot would not need to move its trunk if the caregiver changes your position.

Acknowledgment

The authors would like to thank FAPESP, CNPq and CAPES for support received.

References

[1] F. Kaplan and V. Hafner, "The challenges of joint attention," pp. 67–74, 2004. [Online]. Available: http://cogprints.org/4067/

[2] L. Schilbach, M. Wilms, S. B. Eickhoff, S. Romanzetti, R. Tepest, G. Bente, N. J. Shah, G. R. Fink, and K. Vogeley, “Minds made for sharing: Initiating joint attention recruits reward-related neurocircuitry,” *Journal of Cognitive Neuroscience*, vol. 22, no. 12, pp. 2702–2715, 2010. [Online]. Available: http://www.mitpressjournals.org/doi/abs/10.1162/jocn.2009.21401

[3] J. Triesch, C. Teuscher, G. O. Dek, and E. Carlson, “Gaze following: why (not) learn it?” *Developmental Science*, vol. 9, no. 2, pp. 125 – 147, 2006.

[4] R. R. da Silva and R. A. F. Romero, “Using only aspects of interaction to solve shared attention,” in *Proceedings of the 3rd International Workshop on Evolutionary and Reinforcement Learning for Autonomous Robot Systems (ERLARS 2010) - The 19th European Conference on Artificial Intelligence (ECAI 2010)*, 2010, pp. 43–52.

[5] A. Catania, *Learning, Interim (4th) Edition*. Sloan Publishing, 2006.

[6] J. O. Cooper, T. E. Heron, and W. L. Heward, *Applied Behavior Analysis (2nd Edition)*. Prentice Hall, 2007.

[7] W. D. Pierce and C. D. Cheney, *Learning, Interim (4th) Edition*. Psychology Press, 2008.

[8] G. Matsuda and T. Omori, “Learning of joint visual attention by reinforcement learning,” in *Int. Conf. on Cognitive Modeling (ICCM)*, 2001.

[9] Y. Nagai, A. Hosoda, and M. Asada, “A constructive model for the development of joint attention,” *Connection Science*, vol. 15, no. 4, pp. 211–229, 2003.

[10] Y. Nagai, “The role of motion information in learning human-robot joint attention,” in *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*, April 2005, pp. 2069–2074.

[11] A. Shon, D. Grimes, C. Baker, M. Hoffman, S. Zhou, and R. Rao, “Probabilistic gaze imitation and saliency learning in a robotic head,” in *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*, April 2005, pp. 2865–2870.

[12] H. Kim, H. Jasso, G. Deak, and J. Triesch, “A robotic model of the development of gaze following,” in *Development and Learning, 2008. ICDL 2008. 7th IEEE International Conference on*, aug. 2008, pp. 238–243.

[13] C. A. Policastro, R. A. F. Romero, G. Zuliani, and E. Pizzolato, “Learning of shared attention in sociable robotics,” *J. Algorithms*, vol. 64, no. 4, pp. 139–151, 2009.

[14] S. Haykin, *Neural Networks - A Comprehensive Foundation*. Prentice Hall, 1999.

[15] P.-N. Tan, M. Steinbach, and V. Kumar, *Introduction to Data Mining, (First Edition)*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2005.

[16] R. O. L. Breiman, J. Friedman and C. Stone, *Classification and Regression Trees*. Monterey, CA: Wadsworth and Brooks, 1984.

[17] M. Leonetti and L. Iocchi, “Improving the performance of complex agent plans through reinforcement learning,” in *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: volume 1 - Volume 1*, ser. AAMAS ’10. Richland, SC: International Foundation for Autonomous Agents and Multiagent Systems, 2010, pp. 723–730. [Online]. Available: http://portal.acm.org/citation.cfm?id=1838206.1838302

[18] C. A. Policastro, G. Zuliani, R. R. da Silva, V. R. Munhoz, and R. A. F. Romero, “Hybrid knowledge representation applied to the learning of the shared attention,” in *IJCNN*, 2008, pp. 1579–1584.

[19] W. Dube, R. McDonald, R. Mansfield, W. Holcomb, and W. Ahearn, “Toward a behavioral analisys of joint attention,” *The Behavior Analyst*, vol. 27, no. 2, pp. 197–207, 2004.

[20] C. Whalen and L. Schreibman, “Joint attention training for children with autism using behavior modification procedures,” *Journal of Child Psychology and Psychiatry*, vol. 44, no. 3, pp. 456–468, 2003.

Qualitative Spatial Knowledge Acquisition Based on the Connection Relation

Tiansi Dong
Department of Mathematics and Computer Science
University in Hagen
Hagen, Germany
Email: tiansi.dong@fernuni-hagen.de

Tim vor der Brück
Department for Computing in the Humanities
Goethe University Frankfurt am Main
Frankfurt am Main, Germany
Email: vorderBrueck@em.uni-frankfurt.de

***Abstract*—Research in cognitive psychology shows that the connection relation is the primitive spatial relation. This paper proposes a novel spatial knowledge representation of indoor environments based on the connection relation, and demonstrates how deictic orientation relations can be acquired from a map, which is constructed purely on connection relations between extended objects. Without loss of generality, we restrict indoor environments to be constructed by a set of rectangles, each representing either a room or a corridor. The term *fiat* cell is coined to represent a subjective partition along a corridor. Spatial knowledge includes rectangles, sides information of rectangles, connection relations among rectangles, and *fiat* cells of rectangles. Efficient algorithms are given for identifying one shortest path between two locations, transforming paths into *fiat* paths, and acquiring deictic orientations.**

***Keywords*-Deictic orientation; Connection relation; Indoor environments.**

I. Introduction

Human babies acquire connection relations before other spatial relations [8]; they first make a categorical distinction between contact and non-contact [1]. Qualitative distances between extended objects can be represented based on the connection relation [2]; the qualitative orientation relation can be understood through qualitative distance comparison [4]. Research in cognitive psychology shows that human babies acquire the spatial knowledge in a specific order: topological relations, orientation relations, and distance relations, [9]. The question raised in this paper can be stated as follows: given a spatial map which is purely based on the connection relation, can other spatial relations be acquired from this representation? We will construct a map for indoor environments only with the connect relation among rooms and corridors, and show how the deictic orientation instructions from one location to the other can be efficiently acquired. Without loss of generality we only consider rooms and corridors with four sides which can be approximated by rectangles. The method to acquire deictic orientation relations can be easily applied to spatial area with more than four sides, and curve-shaped corridors.

The following part is organized as follows: Section 2 briefly describes the knowledge acquisition problem of orientation instructions within indoor environments; Section 3 presents the spatial knowledge representation of indoor environments; Section 4 presents efficient algorithms which acquire orientation knowledge from connect-relation based spatial maps; Section 5 concludes the paper, and lists connections with other works.

II. Orientation within indoor environments

There are two different perspectives in describing orientations: the survey perspective and the route perspective [6]. In the survey perspective, orientation descriptions are constructed within the absolute orientation framework, e.g., *go south, at the next crossing, go west*; in the route perspective, orientation descriptions are constructed within the deictic orientation framework, e.g., *go ahead, at the next crossing turn left*. These descriptions are also called relative route descriptions. Acquiring orientation descriptions in the survey perspective requires information of absolute orientation. Such information is quite easy to obtain in outdoor environments where GPS is available. For in-indoor environments, it is reasonable to acquire relative orientation descriptions, not only due to the fact that GPS may not be available, but also due to the fact that many navigators do not know where the North is inside of indoor environments.

For classic mathematicians, orientation descriptions in natural languages are vague and imprecise. But not for cognitive psychologists: for them these descriptions serve as a window to explore mental spatial representations [12], which have systematical distortions from the external physical space [7]. Relative orientation knowledge is a useful route instruction which delineates a directed path in a distorted physical environment in mind. The basic components of relative route descriptions, addressed in this paper, are *go out of <somewhere>, go ahead till <somewhere>, turn left, turn right*. These components involve qualitative orientation instructions along with qualitative distance information.

In particular, people would like to hear pure qualitative spatial descriptions in indoor environments, as people are normally not so good at interpreting quantitative route descriptions, such as *go ahead for 15 meters, then turn clockwise 90 degrees* [5]. A preferred orientation description would be something like *go ahead and turn right at the end of the corridor* – even if the turning angle is less than 45 degrees, or the corridor has a strong curve. This

 ISBN: 978-1-61208-155-7

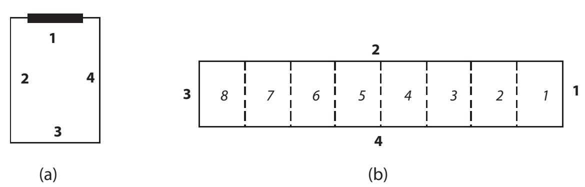


Figure 1. (a) A rectangle represents a room; (b) A rectangle represents a corridor, whose four sides are counterclockwise named from 1 to 4; *fiat* cells are named by the qualitative distance to the side with the name 1

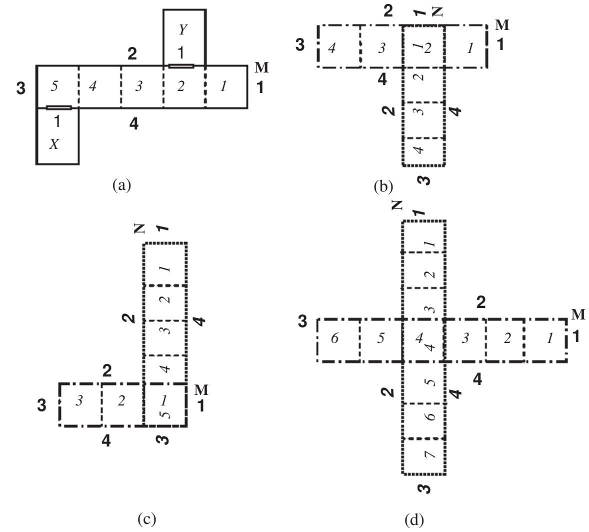


Figure 2. The connection relations between rooms and corridors

observation also explains why the fuzzy approach might fail in generating effective route descriptions in indoor environments. The problem addressed in this paper can be stated precisely as follows: with what kind of knowledge representations for indoor environments can qualitative deictic orientation knowledge be acquired, if the connection relation is primitive?

III. Spatial Representation of Indoor Environments

A. Rooms

The simplest component of an indoor environment is *room*. We assume that rooms have at least one door, and that rooms have four sides and are of rectangular shape. We name the four sides as 1, 2, 3, 4, and there must be a door in side 1, as illustrated in Figure 1(a). A room has a unique identification number, and a name for linguistic description, e.g., Prof. Helbig's office. Formally, we introduce the following definition.

Definition 1: $\mathcal{R}$ is the type of rooms. Let r be a room, ($r \in \mathcal{R}$), $r.\mathtt{side\_1}$, $r.\mathtt{side\_2}$, $r.\mathtt{side\_3}$, $r.\mathtt{side\_4}$ represent its four sides; $r.\mathtt{side}$ represents one of its four sides; $r.\mathtt{id}$ represents its identification number; $r.\mathtt{name}$ represents its name.

B. Corridors

Rooms may be connected with each other by *corridors*. We also assume that corridors have rectangular shape, and their four sides are named counterclockwise from 1 to 4. Two end-sides of the corridor are named as 1 and 3, respectively; two long-sides of the corridor are named as 2 and 4, respectively. A corridor has a unique identification number, and may have a name for linguistic description. A corridor can be partitioned into a list of small rectangles, each has exactly two sides that coincide with side 2 and 4 of the corridor. These small rectangles are named as *fiat* cellsSides of *fiat* cells are named counterclockwise from 1 to 4, such that the sides coincided with its corridor have the same name (2 or 4). *Fiat* cells refer to different locations along a corridor, e.g., *end of the corridor, in front of the lift*, etc. Each *fiat* cell is assigned a natural number representing its qualitative distance to side 1 of the corridor; this number uniquely identifies a *fiat* cell, as illustrated in Figure 1(b). Formally, we introduce definitions as follows.

Definition 2: $\mathcal{C}$ is the type for corridors. Let c be a corridor ($c \in \mathcal{C}$), $c.\mathtt{side\_1}$, $c.\mathtt{side\_2}$, $c.\mathtt{side\_3}$, $c.\mathtt{side\_4}$ represent its four sides; $c.\mathtt{side}$ represents one of its four sides; $c.\mathtt{id}$ represents its identification number; $c.\mathtt{name}$ represents its name.

Definition 3: $\mathcal{F}$ is the type for fiat cells. Let f be a fiat cell ($f \in \mathcal{F}$), $f.\mathtt{side\_1}$, $f.\mathtt{side\_2}$, $f.\mathtt{side\_3}$, $f.\mathtt{side\_4}$ represent its four sides; $f.\mathtt{side}$ represents one of its four sides; $f.\mathtt{cor}$ represents the corridor where it is located; $f.\mathtt{dis}$ represents its qualitative distance to side 1 of $f.\mathtt{cor}$.

C. Connections among rooms and corridors

By a room connecting with another room or a corridor, we assume that they share a common wall and that there is at least a door on the common wall, through which people can go. Otherwise, they might not know that they are connected. This can be easily represented by the shared side of two rectangles. For example, in Figure 2(a) Room X connects with Corridor M. The side 1 of Room X coincides with the side 4 of Corridor M. Formally, we define as follows.

Definition 4: Let $r, r_1, r_2 \in \mathcal{R}$, $c \in \mathcal{C}$. $r.\mathtt{side\_}i$ connecting with $c.\mathtt{side\_}j$ is written as $\mathsf{Con}(r, c) = (i, j)$; $c.\mathtt{side\_}j$ connecting with $r.\mathtt{side\_}i$ is written as $\mathsf{Con}(c, r) = (j, i)$; $r_1.\mathtt{side\_}i$ connecting with $r_2.\mathtt{side\_}j$ is written as $\mathsf{Con}(r_1, r_2) = (i, j)$, where $1 \leq i, j \leq 4$.

The location of a room in a corridor can be represented by the *fiat* cell in the corridor with which the room connects. We define the Loc function as follows.

Definition 5: Let $r \in \mathcal{R}$, $c \in \mathcal{C}$, r connects with the fiat cell in c whose qualitative distance is i, written as $\mathsf{Loc}(r, c) = i$.

 ISBN: 978-1-61208-155-7

In Figure 2(a), Room X connects with the *fiat* cell of Corridor M whose qualitative distance is 5. We represent this as $\mathsf{Loc}(X, M) = 5$.

D. Connections between corridors

Connection relations between two corridors can be one of three types: 'T' type, 'L' type, and '+' type, as illustrated in Figure 2 (b), (c), (d), respectively. For all types we assume there are two intersected corridors. That is, there is an overlapped *fiat* cell. For example, in Figure 2(b) the *fiat* cell 1 in corridor N is overlapped with the *fiat* cell 2 in corridor M. The spatial structure between two intersected corridors can be delineated by their coincided sides and qualitative distances. For example, in Figure 2(b) Corridor M intersects with the *fiat* cell 1 of Corridor N; if a navigator is located in the intersection of Corridor N and Corridor M, and faces to side 1 of Corridor N, then she/he also faces to side 2 of Corridor M; in Figure 2(c) Corridor M intersects with the *fiat* cell 5 of Corridor N; if a navigator is located in the intersection and faces to side 3 of Corridor N, then she/he also faces to side 4 of Corridor M. Formally, we define as follows.

Definition 6: Let $c_1, c_2 \in \mathcal{C}$, c_1 intersects with the *fiat* cell in c_2 whose qualitative distance is i. The location of c_1 with regard to c_2 is defined as $\mathsf{Loc}(c_1, c_2) = i$.

Definition 7: Let $c_1, c_2 \in \mathcal{C}$, c_1 intersects with c_2, *fiat* cell f_1 in c_1 is overlapped with *fiat* cell f_2 of c_2 in such a way that $f_1.\texttt{side\_}i$ coincides with $f_2.\texttt{side\_}j$. Their side overlapping relation is defined as $\mathsf{Overlap}(c_1, c_2) \doteq (i, j)$.

Remark 1: Suppose the side 1 of *fiat* cell f_1 ($f_1.\texttt{side\_}1$) coincides with the side 4 of *fiat* cell f_2 ($f_2.\texttt{side\_}4$), then $f_1.\texttt{side\_}2$ coincide with $f_2.\texttt{side\_}1$, $f_1.\texttt{side\_}3$ must coincide with of $f_2.\texttt{side\_}2$, $f_1.\texttt{side\_}4$ must coincide with $f_2.\texttt{side\_}3$. Therefore, we use '$\doteq$' to roughly denote 'one of the (four) values is'. Generally, we have the following theorem.

Theorem 1: Let $c_1, c_2 \in \mathcal{C}$, $\mathsf{Overlap}(c_1, c_2) \doteq (i, j)$. For any natural number k, i.e., $k \in \mathbb{N}$, $\mathsf{Overlap}(c_1, c_2) \doteq ((i + k - 1)\ mod\ 4 + 1, (j + k - 1)\ mod\ 4 + 1)$.

E. Indoor Map based on the connection relation

An indoor map can be represented as the connection relations among rooms and corridors, in particular with the partial functions Con, Loc and Overlap whose signatures are listed as follows.

Signature 1: Let $\mathcal{S}$ be the set of 1, 2, 3, 4; $\mathbb{N}$ be the set of natural numbers.

$$\begin{aligned}
&\mathsf{Con} : \mathcal{R} \times \mathcal{C} \to \mathcal{S} \times \mathcal{S}\\
&\mathsf{Con} : \mathcal{R} \times \mathcal{R} \to \mathcal{S} \times \mathcal{S}\\
&\mathsf{Con} : \mathcal{C} \times \mathcal{R} \to \mathcal{S} \times \mathcal{S}\\
&\mathsf{Loc} : \mathcal{R} \times \mathcal{C} \to \mathbb{N}\\
&\mathsf{Loc} : \mathcal{C} \times \mathcal{C} \to \mathbb{N}\\
&\mathsf{Overlap} : \mathcal{C} \times \mathcal{C} \to \mathcal{S} \times \mathcal{S}
\end{aligned}$$

Example 1: In Figure 2(a), there are one Corridor M, two rooms X and Y. Room X connects with the *fiat* cell 5 of M, Y connects with the *fiat* cell 2 of M. side 1 of X connects with side 4 of M; side 1 of Y connects with side 2 of M. The map is therefore,

$$\begin{aligned}
&\mathsf{Con}(X, M) = (1, 5)\\
&\mathsf{Con}(Y, M) = (1, 2)\\
&\mathsf{Loc}(X, M) = 5\\
&\mathsf{Loc}(Y, M) = 2
\end{aligned}$$

Example 2: In Figure 2(b), there are two Corridors M and N, Corridor M intersects with the *fiat* cell 1 of N, $f_{N,1}$; N intersects with the *fiat* cell 2 of M, $f_{M,2}$. The side 1 of $f_{N,1}$ coincides with the side 2 of $f_{M,2}$. The map is therefore,

$$\begin{aligned}
&\mathsf{Loc}(M, N) = 1\\
&\mathsf{Loc}(N, M) = 2\\
&\mathsf{Overlap}(N, M) \doteq (1, 2)
\end{aligned}$$

IV. ACQUIRING RELATIVE ORIENTATION KNOWLEDGE BASED ON THE CONNECTION RELATIONS

Acquisition of relative orientation knowledge in indoor environments can be separated into two steps: the first step is to find a path between the start location and the target location; the second step is to acquire relative orientations from the start location to the target along the path. This spatial knowledge acquisition process within indoor environments is normally not supported by GPS, therefore, the navigator needs to remember all the orientation knowledge at the beginning. This leads to some differences from orientation knowledge acquisition in outdoor environments. One important property which shall be emphasized in the indoor spatial knowledge acquisition is that the route instructions shall be short.

A. Find one of the shortest paths

In indoor environments, a path is a sequence of rooms and corridors. Let A_1 and A_n be the start location and the target location, respectively. A path between A_1 and A_n is a sequence $A_1, A_2, \ldots, A_{n-1}, A_n$ such that for any i($1 \leq i \leq n-1$) navigators can move between A_i and A_{i+1}. Formally, we introduce Path function as follows.

Definition 8: Let A_1 and A_n be two locations. A path between A_1 and A_n is a sequence $A_1, A_2, \ldots, A_{n-1}, A_n$ such that for any i, $1 \leq i \leq n - 1$, either (A_i, A_{i+1}) or (A_{i+1}, A_i) is in the domain of one of the partial functions Con, Loc and Overlap. $\mathsf{Path}(A_1, A_n)$ is the set of all paths between A_1 and A_n.

$$\begin{aligned}
\mathsf{Path}(A_1, A_n) \quad \stackrel{def}{=} \ &\{[A_1, A_2, \ldots, A_{n-1}, A_n]|\\
&\forall i : 1 \leq i \leq n-1, (A_i, A_{i+1}) \in \mathsf{DOM}\\
&\vee (A_{i+1}, A_i) \in \mathsf{DOM}\}
\end{aligned}$$

f.dom refers to the domain of function f.

DOM = Con.dom $\cup$ Loc.dom $\cup$ Overlap.dom

Theorem 2: $\mathsf{Path}(A_1, A_n) = \mathsf{Path}(A_n, A_1)$

Proof is trivial.

Remark 2: The path between two locations is understood as with no direction. To guarantee this property, we define the path as the set of all sequences (routes) from one location to the other.

Example 3: In Figure 2(a), [X,M,Y] is a path between Room X and Room Y, i.e., [X,M,Y]$\in$ Path(X,Y), because the following values are defined: Con(X, M) and Con(Y, M).

Given two locations inside of an indoor environment, one of the shortest paths between them can be identified by the breadth-first search algorithm as follows.

Algorithm 1: Search one of the shortest paths between two places, if exists

input : A map M, two different places A_1 and A_n
output: one of the shortest paths between A_1 and A_n, if there is a path between them; or NoPath if there is no path between them

```
All ←get all of the rooms and corridors from M;
Queue ← [A_1];
NotUsed ← All − {A_1};
i ← 0;
while i in the domain of Queue do
    if Queue(i) = A_n then
        Path ←get all the ancestors of A_n;
        return Reverse(Path)
    Temp ←get all of the the rooms and corridors
        connected with Queue(i);
    Temp ← Temp ∩ NotUsed;
    if Temp ≠ ∅ then
        set Queue(i) as the ancestor of each element
            in Temp ;
        append all elements in Temp to Queue ;
        NotUsed ← NotUsed − Temp;
    i ← i + 1;
return NoPath
```

Let n be the total number of rooms and corridors, $\mathsf{ConnectWith}(X)$ be the number of rooms and corridors that X directly connects with, and K be the maximum number of any $\mathsf{ConnectWith}(X)$. In indoor environments we assume K is not related with n. That is, K is a constant. The computational complexities of space and time of this algorithm are $\mathcal{O}(Kn) = \mathcal{O}(n)$.

B. Fiat *path*

To ease the acquisition of a relative orientation knowledge along a path, we introduce the term of *fiat* path. Each path has a *fiat* path which is a sequence of rooms and *fiat* cells

	$p=1$	$p=2$	$p=3$	$p=4$
$n=1$	-	*turn left*	*turn around*	*turn right*
$n=2$	*turn right*	-	*turn left*	*turn around*
$n=3$	*turn around*	*turn right*	-	*turn left*
$n=4$	*turn left*	*turn around*	*turn right*	-

Table I
TURNING INSTRUCTIONS INSIDE OF A ROOM OR A CORRIDOR; '-' MEANS THAT TURNING IS NOT REQUIRED

of corridors. If C is a corridor in the path, and a navigator enters C at its *fiat* cell i, and leaves C at its *fiat* cell j, C is replaced with $C.i, C.j$. Formally, we define as follows.

Definition 9: Let path $P = [A_1, A_2, \ldots, A_{n-1}, A_n]$, its *fiat* path, written as $f\mathsf{Path}(P)$, is defined as follows.

$$f\mathsf{Path}(P) \stackrel{def}{=} [f(A_1), f(A_2), \ldots, f(A_{n-1}), f(A_n)]$$

$$\begin{cases} f(A_i) = A_i & A_i \in \mathcal{R} \\ f(A_i) = A_i.s, A_i.e & Cond_2 \\ f(A_1) = A_1.s & Cond_3 \\ f(A_n) = A_n.e & Cond_4 \end{cases}$$

$Cond_2 : A_i \in \mathcal{C} \wedge \mathsf{Loc}(A_{i-1}, A_i) = A_i.s \wedge \mathsf{Loc}(A_{i+1}, A_i) = A_i.e, 2 \leq i \leq n-1$

$Cond_3 : A_1 \in \mathcal{C} \wedge \mathsf{Loc}(A_2, A_1) = A_1.s$

$Cond_4 : A_n \in \mathcal{C} \wedge \mathsf{Loc}(A_{n-1}, A_n) = A_i.e$

C. Spatial reasoning on acquiring relative orientation knowledge

Given a map and a *fiat* path, we can acquire relative orientation knowledge. The task can be described as follows: let $[A_i, A_{i+1}]$ be a path segment along a path and $[f(A_i), f(A_{i+1})]$ its corresponding *fiat* path segment, describe a relative route description from location A_i to A_{i+1}, $(1 \leq i \leq n-1)$.

1) Room A_i and Room A_{i+1}: Suppose now the navigator is in Room A_i and faces to side m of A_i, which connects with Room A_{i+1} such that $\mathsf{Con}(A_i, A_{i+1}) = (p, q)$, that is, side p of Room A_i connects with side q of Room A_{i+1}. Relative route instruction in this case has the form $<$*instruction for turning in* $A_i >$*, go out of the room*". At the end, the reasoning process shall acquire the knowledge of the navigator's facing direction in A_{i+1}, if A_{i+1} is not the target place.

In our proposed data model, sides of rooms and corridors are named counterclockwise with 1,2,3,4. So, given the starting facing side n and the target facing side p in the same location, we can acquire the instruction for turning with the matrix as shown in Table 1. If we calculate the value of $(n-p) \ mod \ 4$, we obtain a matrix as shown in Table 2.

The algorithm for generating turning instruction is quite simple, as illustrated in Algorithm 2.

When the navigator arrives in A_{i+1}, we need to know to which side she/he is now facing. As we have

 ISBN: 978-1-61208-155-7

	$p=1$	$p=2$	$p=3$	$p=4$
$n=1$	0	3	2	1
$n=2$	1	0	3	2
$n=3$	2	1	0	3
$n=4$	3	2	1	0

Table II
TURNING INSTRUCTIONS CAN BE ENCODED WITH A CYCLIC GROUP, 0:-;1:*turn right*; 2: *turn around*; 3:*turn left*

Algorithm 2: Acquiring turning instructions inside of a room or corridor

input : facing side n, facing side p
output: turning instruction

$v \leftarrow (n-p)\ mod\ 4$;
switch *v* **do**
  case *0 return "-"*;
  case *1 return "turn right"*;
  case *2 return "turn around"*;
  case *3 return "turn left"*;

$\mathsf{Con}(A_i, A_{i+1}) = (p, q)$, we know that after entering Room A_{i+1}, the navigator is back to side q of A_{i+1}. Therefore, she/he is facing to the opposite side of q, written as $\mathsf{Opp}(q)$, This can be easily computed by the formula as follows: $\mathsf{Opp}(q) = \begin{cases} q+2 & \text{if } q \leq 2 \\ q-2 & \text{if } q > 2 \end{cases}$.

The computational complexities for generating turning instruction, as well as updating facing direction, are $\mathcal{O}(1)$.

2) Room A_i and Corridor A_{i+1}: Suppose now the navigator is in Room A_i and faces to side m of A_i, who needs to enter Corridor A_{i+1}, and may go along the corridor to a certain location to enter A_{i+2}. We know $\mathsf{Con}(A_i, A_{i+1}) = (p, q)$ and $\mathsf{Loc}(A_i, A_{i+1}) = s$, and let the *fiat* path segment of $[A_i, A_{i+1}]$ be $[A_i, A_{i+1}.s, A_{i+1}.e]$.

The relative orientation knowledge in this case consists of two parts: the first part is on how to move from A_i to $A_{i+1}.s$; the second part is on how to move from $A_{i+1}.s$ to $A_{i+1}.e$. As the sides of *fiat* cells are named counterclockwise and such that two of them coincide with sides of corridors, the first part is the same as moving from room to room. Suppose the navigator is now in $A_{i+1}.s$ facing to side n, we need to give relative route instructions which help her/him to arrive at $A_{i+1}.e$. As *fiat* cells are named by numbers in such a way that the smaller the number is, the closer this cell is to the side 1 of the corridor, we can use this qualitative distance comparison method to figure out the turning instruction at $A_{i+1}.s$ as follows: if $s < e$, $A_{i+1}.s$ is nearer to side 1 of the corridor than $A_{i+1}.e$ is, so the navigator shall turn to side 3 of the corridor, which is defined as the same side of this *fiat* cell; if $s > e$, $A_{i+1}.e$ is nearer to side 1 of the corridor than $A_{i+1}.s$ is, so the navigator shall turn to side 1 of the corridor. So, we can use Algorithm 2 to generate turning instruction at $A_{i+1}.s$. Instruction for moving from $A_{i+1}.s$ to $A_{i+1}.e$ is quite simple, just *go ahead* plus some landmark information along this *fiat* path segment.

3) Corridor A_i and Room A_{i+1}: Suppose now the navigator is at *fiat* cell s of Corridor A_i and faces to side m of A_i ($A_i.\mathtt{side\_}m$), and needs to enter Room A_{i+1}. In this case she/he may go along the corridor first and then perform a turning to enter A_{i+1}. We know $\mathsf{Con}(A_i, A_{i+1}) = (p, q)$ and $\mathsf{Loc}(A_{i+1}, A_i) = e$, and let the *fiat* path segment of $[A_i, A_{i+1}]$ be $[A_i.s, A_i.e, A_{i+1}]$. No new algorithms are needed to acquire relative orientation knowledge from $A_i.s$ to $A_i.e$ and from $A_i.e$ to A_{i+1}.

4) Corridor A_i and Corridor A_{i+1}: Suppose now the navigator is at *fiat* cell s of Corridor A_i and faces to side m of A_i ($A_i.\mathtt{side\_}m$), and needs to enter Corridor A_{i+1}. We know that Corridor A_i and Corridor A_{i+1} overlaps in such a way that *fiat* cell u of A_i, $f_{i,u}$, connects with A_{i+1}, *fiat* cell w of A_{i+1}, $f_{i+1,w}$, connects with A_i, side p of $f_{i,u}$ coincide with side q of $f_{i+1,w}$. That is, $\mathsf{Loc}(A_{i+1}, A_i) = u$, $\mathsf{Loc}(A_i, A_{i+1}) = w$, $\mathsf{Overlap}(A_i, A_{i+1}) \doteq (p, q)$. In the most complicated case, the *fiat* path segment of $[A_i, A_{i+1}]$ is in the form of $A_i.s, A_i.u, A_{i+1}.w, A_{i+1}.e$, where the value e can be obtained from $[A_{i+1}, A_{i+2}]$, we can reuse above algorithms to acquire relative orientation knowledge between *fiat* cells within a corridor and between coincided *fiat* cells of different corridors.

The whole algorithm is illustrated in Algorithm 3, whose computational complexity is the same as that of algorithm 1: $\mathcal{O}(n)$.

V. CONCLUSIONS, DISCUSSIONS, AND OUTLOOKS

Spatial knowledge representation of orientation relations usually requires to represent a point-based orientation reference framework. A survey can be found in [11]. This paper presents a novel method showing that how deictic orientation relations between extended objects can be acquired without using orientation reference framework.

The advantages of this representation are as follow: this method is theoretically supported by results from cognitive psychology; practically this representation fills one gap between quantitative sensor representation, which are objective, and acquired by laser scanners, cameras, and spatial linguitistic descriptions, which are subjective, and delineate a *fiat* world [10]. By introducing granularities of *fiat* cells, cognitive agents will talk about a space as people do. Obtaining a map only based on the connection relation is an open question. However, cognitive psychology again provides useful guidelines: infants' developement of object concepts is closely related with their developement of spatial relations [8]. On the other hand, if a full environment map is available, the presented orientation acquisition method can be understood as a wayfinding method without GPS information, e.g., in the tunnel, under bad weather.

Algorithm 3: Acquiring relative orientation knowledge on a floor

```
input  : starting room, starting facing, target room,
         three tables
output: relative route instruction
Path ← apply Algorithm 1 to get one shortest paths;
fiatPath ← turn Path into fiat path;
Facing ←starting facing;
Route ←“”;
repeat
    Loc1 ← first(fiatPath );
    Loc2 ← second(fiatPath );
    if (type(Loc1)≠type(Loc2)
    ∨type(Loc1)=type(Loc2)=R) then  apply
    Algorithm 2 in Loc1, append result to Route;
    append go ahead to Route;
    else
        if Loc1 and Loc2 in the same corridor then
            determine targeting facing by distance
            comparison;
            apply Algorithm 2 in Loc1, append result
            to Route;
            append go ahead and landmark information
            to Route;
    updating Facing in Loc2;
    pop(fiatPath);
until length(fiatPath)≤ 1;
EndFacing ← get the side of current location
connecting with target room;
v ← (Facing − EndFacing) mod 4;
switch v do
    case 0 append the target room is in front of you to
    Route;
    case 1 append the target room is at the right side
    of you to Route;
    case 2 append the target room is back to you to
    Route;
    case 3 append the target room is at the left side of
    you to Route;
return Route;
```

Indoor spatial environments may be complex, some have layer-structures on a floor, some have concave shaped rooms. The method presented in this paper can be extended by considering granularities and more sides of spatial objects. For example, Yuan and Schneider [13] proposed a 3D method, LEGO representation, to construct maps of indoor environments. By extending rectangles into hexahedrals, we can develop similar method for 3D indoor environments. The path-finding algorithm for higher dimensional environment shall be more complex.

We can use the connection relation as primitive to recognize changed environment, [3]. However, it is still an open issue to explore unknown environments with this primitive relation. It is a piece of interesting future work for us to extend current work into robotics: How can a robot explore unknown environments based on the connection relation and some primitive perceptions and actions? There is already some similar work in the literature, e.g., spatial models developed at http://jrobot.gforge.inria.fr are based on primitive actions.

ACKNOWLEDGMENTS

Thanks go to Jianqiu Xu, Ingo Glöckner, Ralf Hartmut Güting, and Petre Dini for helpful comments and suggestions. Financial support from DFG is greatly acknowledged.

REFERENCES

[1] S. Carey. *The Origin of Concepts*. Oxford University Press, 2009.

[2] T. Dong. A Comment on RCC: from RCC to RCC^{++}. *Journal of Philosophical Logic*, 37(4):319–352, 2008.

[3] T. Dong. *Recognizing Variable Environments – The Theory of Cognitive Prism*. Springer, 2011.

[4] T. Dong and H. W. Guesgen. A Uniform Framework for Orientation Relation based on Distance Comparison. In *Proceedings of the 7th IEEE International Conference on Cognitive Informatics*, pages 75 – 82. IEEE CS Press, 2008.

[5] C. Freksa. Linguistic Description of Human Judgments In Expert Systems and In The ‘Soft’ Sciences. In M.M Gupta and E. Sanchez, editors, *Approximate Reasoning in Decision Analysis*. North-Holland Publishing Company, 1982.

[6] P. U. Lee. *Costs of Switching Perspectives in Route and Survey Descriptions*. PhD thesis, Department of Psychology, Stanford University, 2002.

[7] T. P. McNamara. Memory’s View of Space. *The Psychology of Learning and Motivation*, 27:147–186, 1991.

[8] J. Piaget. *The Construction of Reality in the Child*. Routledge & Kegan Paul Ltd, 1954.

[9] J. Piaget and B. Inhelder. *La représentation de l’espace chez l’enfant*. Bibliothèque de Philosophie Contemporaine, Paris: PUF, 1948. English translation by F. J. Langdon and J. L. Lunzer in 1956.

[10] B. Smith. *Fiat* objects. *Topoi*, 20(2):131–148, 2001.

[11] O. Stock, editor. *Spatial and Temporal Reasoning*. Kluwer Academic Publishers, 1997.

[12] B. Tversky. Distortions in Cognitive Maps. *Geoforum*, 23(2):131–138, 1992.

[13] W. Yuan and M. Schneider. Supporting 3D Route Planning in Indoor Space based on the LEGO Representation. In *ISA’10 Proceedings of the 2nd ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness*, pages 16–23, 2010.

Thought Experiments in Linguistic Geometry

Boris Stilman

STILMAN Advanced Strategies, Denver, CO, USA &
University of Colorado Denver, Denver, CO, USA
boris@stilman-strategies.com

***Abstract*—Linguistic Geometry (LG) is a type of game theory for extensive discrete games scalable to the level of real life defense systems. This scalability is based on changing the paradigm for game solving - from search to construction. LG was developed by generalizing experiences of the advanced chess players. LG is a formal model of human reasoning about armed conflict, a mental reality "hard-wired" in the human brain. This algorithm is an evolutionary product of millions of years of human warfare served in its turn as the principle mover for evolution of human intelligence. Its special role in human history and long coexistence with the Primary Language of the human brain (as introduced by J. Von Neumann) and the Algorithm of Discovery suggest utilizing LG for investigation of those two puzzles. This paper refining our experiences of discovering LG is the first step in this direction.**

Keywords—Linguistic Geometry; Primary Language; Artificial Intelligence; algorithm of discovery; game theory

I. INTRODUCTION

Linguistic Geometry (LG) [15] is a game-theoretic approach that has demonstrated a significant increase in size of problems solvable in real time (or near real time). This paper continues a series of papers [21], [22], [16], intended to discover role of LG in human culture.

Def. 1. LG is intended for solving Abstract Board Games (ABG) defined as follows (see full version in [15]):

$$< X, P, R_p, \text{SPACE}, val, S_0, S_t, \text{TR}>,$$

where

$X = \{x_i\}$ is a finite set of points (abstract board);

$P = \{p_i\}$ is a finite set of pieces; $P = P_1 \cup P_2$ called the opposing sides;

$R_p(x, y)$ is a set of binary relations of reachability in X ($x \in X$, $y \in X$, and $p \in P$);

val is a function on representing the values of pieces;

SPACE is the state space;

S_0 and S_t are the sets of start and target states. $S_t = S_t^1 \cup S_t^2 \cup S_t^3$, where all three are disjoint. S_t^1, S_t^2 are the subsets of target states for the opposing sides P_1 and P_2, respectively. S_t^3 is the subset of target draw states.

TR is a set of transitions (moves) of ABG between states.

The goal of each side is to reach a state from its subset of target states, S_t^1 or S_t^2, respectively, or, at least, a draw state from S_t^3. The problem of the optimal operation of ABG is considered as a problem of finding a sequence of transitions leading from a start state of S_0 to a target state of S_t assuming that each side makes only the best moves (if known), i.e., such moves that could lead ABG to the respective subset of target states. To solve ABG means to find a strategy (an algorithm to select moves) for one side, if it exists, that guarantees that the proper subset of target states will be reached assuming that the other side makes arbitrary moves.

The word *Linguistic* refers to the model of strategies formalized as a hierarchy of formal languages. These languages describe states of the game as well as moves from state to state. They utilize a powerful class of generating grammars, the controlled grammars [15], which employ formal semantics of the game to control generation of a string of symbols using mutual influence of the substring generated so far and the grammar's environment.

The word *Geometry* refers to the geometry of the game state space SPACE (Def. 1), which is a set of all the states resulting from all legal plays of ABG leading from a start state. Every state is an abstract board X with abstract pieces P, i.e., mobile entities, located on this board and acting upon each other. Thus, different states include the same board with different configurations of pieces resulting from the sequence of moves. In LG, the geometry of the state space is effectively reduced to the geometry of the board, which can also be called a game space. Thus, the state space is reduced to the projection of the "space-time" over "space", by introducing abstract relations defining the movements and other actions of the pieces as well as their mutual influence. This projection leads to efficient decomposition of the state space that permits replacing search by construction of strategies [15].

LG is a viable approach for solving board games such as the game of chess as well as practical problems such as mission planning and battle management. Historically, LG was developed, beginning from 1972, by generalizing experiences of the most advanced chess players including World Chess Champions and grandmasters [1], [15]. In the 70s and 80s this generalization resulted in the development of computer chess program PIONEER utilized successfully for solving chess endgames and complex chess positions with a number of variations considered in the order of 10^2 while the state spaces of those problems varied from 10^{10} to 15^{25}. The variations constructed by PIONEER were very close to those considered by the advanced chess experts when analyzing the same problems. Further generalization led to development of the new type of game theory, LG,

ISBN: 978-1-61208-155-7

changing the paradigm for solving game problems: "From Search to Construction" [15]. An LG-based technology was applied to more than 30 real life defense related projects [6]. On multiple experiments, LG successfully demonstrated the ability to solve extremely complex modern military scenarios in real time. The efficacy and sophistication of the courses of action developed by the LG tools exceeded consistently those developed by the commanders and staff members [19]-[20].

Almost forty years of development of LG including numerous successful applications to board games and, most importantly, to a highly diverse set of modern military operations [4]-[6], [20]-[22], from cruise missiles to military operations in urban terrain to ballistic missile defense to naval engagements, led us to believe that LG is something more fundamental than simply yet another mathematical model of efficient wargaming.

A universal applicability of LG in a variety of military domains, especially, in the domain of the ancient warfare, its total independence of nationality or country, its power in generating human-like strategies suggest that the algorithm of LG utilized by the human brain is "hard-wired" in the Primary Language (introduced by J. Von Neumann [23]). Moreover, the age of the Primary Language must be much greater than the age of human natural languages, and so the age of LG [16]. A highly intriguing and difficult issue is an algorithm of discovery, i.e., an algorithm of inventing new algorithms and new models. This algorithm should also be a major ancient item "recorded" in the Primary Language. In this paper, by investigating past discoveries, experiences of construction of various new algorithms, and the heritage of LG, we will make a step towards understanding of this puzzle.

II. BACK TO THE ORIGIN

In [21], [22], [16], we suggested that the game of chess served as a means for discovering LG. The original theory of LG was developed by generalizing algorithms implemented in the computer chess program PIONEER [1], [15]. Simultaneously, some of the similar algorithms were utilized for economic problems in the former USSR (programs PIONEER 2.0-4.0). Further development of LG, of course, took advantage of these new applications. However, the original major framework of LG, the hierarchy of three formal languages, was based exclusively on the chess domain, the only application available at that time. We must admit that over the following 30 years the structure of this framework has never changed.

By the end of the 80s, PIONEER solved a number of sophisticated endgames and positions but still could not play full games. It was clear for the developers that the main ideas are correct but further development for the chess domain was required. It was also expected that transferring LG to other domains, e.g., defense, should be tried only after the chess model would be completed. Besides incompleteness of this model, a number of other serious limitations based on the awkward nature of the game of chess (in comparison with real life) could have prevented from such transfer. These limitations were as follows.

- Totally discrete nature while the real world is mostly continuous (on macro level).
- Small number of agents while in the real world problems this number is often several orders of magnitude greater.
- Serial movement of agents in comparison with the real world agents such as humans, human-controlled vehicles, robots, etc. moving concurrently.
- Simplistic 2D mobility rules in comparison with sophisticated mobility patterns of the real world agents, which may require multi-dimensional phase space.
- Small, non-sophisticated 2D game board in comparison with real world 3D large-scale terrains with multiple different features.
- Awkward goals like checkmate in comparison with real life goals that vary significantly.

In addition, there was no theoretical evaluation of the accuracy of the LG solutions except for those experiments with chess positions approved by the chess experts.

The advanced version of LG, completed by Dr. Stilman by the end of the 90s [15], with contributions of Drs. V. Yakhnis and A. Yakhnis, had overcome some of the above limitations by further "wild" generalizations (Def. 1) and mathematical proofs of correctness of the algorithms and accuracy of the solutions. The major part of this research included thought experiments with applications of the new LG to the extended chess domain, such as the games with 3D board and concurrent movements. All the constructions of the old and new LG were tested in the thought experiments. Moreover, many of those constructions were conceived originally during such experiments. The constructions that successfully passed thought experiment (and some alternative constructions) were programmed and tested employing software applications [1], [15].

The new LG of the 90s definitely covered a number of different real life problem domains as many other mathematical theories do. But was it really an adequate model? In Physics, this means predicting results of experiments. In Computer Science, a requirement is similar. Software applications based on the new theory should yield plausible or satisfactory solutions for a new domain. In case of LG, this means consistently generating plans, i.e., military courses of action, comparable or even better than those of military experts. When the LG applications started consistently generate advanced courses of action for a number of defense sub-domains, the developers realized that the game of chess served the role of the eraser of particulars for the real world warfare. From the bird's eye view, military operations are incomparably more complex than this game. Interestingly, this fact was pointed out by many reviewers of our papers with the first generalizations of the original LG in the 90s. All the above limitations that could have prevented us from transferring LG to the real world, in a sense, enabled us to see the essence behind numerous particulars. Of course, we still needed an advanced chess player like World Chess Champion Professor Botvinnik who was able to analyze the chess master's approach to solving problems. We could only guess if such a grandmaster-commander capable of doing the same for the military strategies would have ever appeared. With all the ingenuity of such an expert, a task of refining the military strategies down to trajectories and networks of trajectories would have been significantly more complex due to those particulars that mud the picture.

III. Thought Experiments

Thought experiments allow us, by pure reflection, to draw conclusions about the laws of nature [2]. For example, Galileo before even starting dropping stones from the Tower in Pisa, used pure imaginative reasoning to conclude that two bodies of different masses fall at the same speed. The Albert Einstein's thought experiments inspiring his ideas of the special and general relativity are known even better. The efficiency and the very possibility of thought experiments show that our mind incorporates animated models of the reality, e.g., laws of physics, mathematics, human activities, etc. Scientists managed to decode some of the human mental images by visualizing their traces on the cortex [3]. It was shown that when we imagine a shape "in the mind's eye", the activity in the visual areas of the brain sketches the contours of the imagined object, thus, mental images have the analogical nature [2]. It appears that we simulate the laws of nature by physically reflecting the reality in our brain. The human species and even animals would have had difficulty to survive without even minimal "understanding" of the laws of environment. Over the course of evolution and during development of every organism, our nervous system learns to comprehend its environment, i.e., to "literally take it into ourselves" in the form of mental images, which is a small scale reproduction of the laws of nature. Neuropsychologists discovered that "we carry within ourselves a universe of mental objects whose laws imitate those of physics and geometry" [2]. In [16], we suggested that we also carry the laws of the major human relations including the laws of optimal warfighting. The laws of nature and human relations manifest themselves in many different ways. However, the clearest manifestation is in perception and in action. For example, we can say that the sensorimotor system of the human brain "understands kinematics" when it anticipates the trajectories of objects. It is really fascinating that these same "laws continue to be applicable in the absence of any action or perception when we merely imagine a moving object or a trajectory on a map" [2]. This observation, of course, covers actions of all kinds of objects, natural and artificial. Scientists have shown that the time needed to rotate or explore these mental images follows a linear function of the angle or distance traveled as if we really traveled with a constant speed. They concluded that "mental *trajectory* imitates that of a physical object" [2]. Further, we will consider mechanics of the thought experiments in the development of LG and, specifically, in the development of the advanced LG applicable to the defense problems.

IV. 2D/4A Experiment

The typical thought experiments in LG focused on several chess problems and variations of those problems. The major problem of this kind is the so-called 2D/4A problem [15]. This is a problem of simplified "air combat" with four aircraft and 2D operational district. It was simple enough to be used for the development of the original chess LG, for the first demonstration of the LG approach, and for generalization. Nevertheless, the 2D/4A is not trivial and requires approximately 9^{12} move search tree to be solved employing brute force search. This problem is an alteration of the famous Reti endgame for the game of chess. This endgame was compiled by Richard Reti in 1921. Program PIONEER solved this endgame in 1977 employing the search tree that includes 54 moves [1], [15].

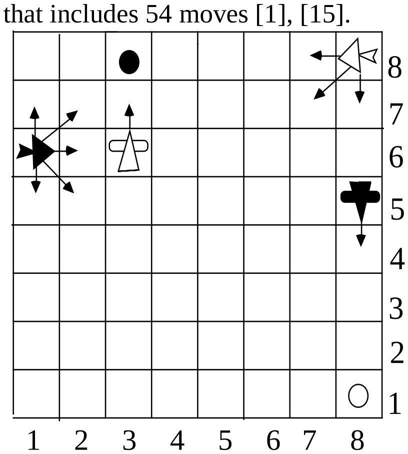


Figure 1. The 2D/4A serial problem with 8×8 district

The major components of the 2D/4A ABG (Def. 1) are as follows (Fig. 1). The abstract board X represents the area of combat operation, a 2D grid of 8×8. P is the set of robots or autonomous vehicles. It is partitioned into two subsets P_1 and P_2 (White and Black) with opposing interests. Relation $R_p(x, y)$ represents the moving abilities of robots, i.e., robot p can move from point x to point y if $R_p(x, y)$ holds.

Robot W-FIGHTER (White Fighter), standing on 88, can move to any adjacent square (shown by arrows). Thus, robot W-FIGHTER on 88 can reach any of the points y $\in${87, 77, 78} in one step, i.e., $R_{W\text{-}FIGHTER}(88, y)$ holds. The other robot, B-BOMBER (Black Bomber) from 85, can move only straight ahead, one square at a time, e.g., from 85 to 84, from 84 to 83, etc. Robot B-FIGHTER (Black Fighter) standing on 16, can move to any adjacent square similarly to robot W-FIGHTER. Robot W-BOMBER standing on 36 is analogous with the robot B-BOMBER; it can move only straight ahead but in the opposite direction (it can reach only 37 in one step).

Assume that robots W-FIGHTER and W-BOMBER belong to the White side, while B-FIGHTER and B-BOMBER belong to the opposing Black side: W-FIGHTER, W-BOMBER $\in P_1$, B-FIGHTER, B-BOMBER $\in P_2$. Also, assume that two more robots, W-TARGET and B-TARGET, (immobile devices or target areas) are located at 81 and 38, respectively: W-TARGET $\in P_1$, B-TARGET $\in P_2$. Each of the BOMBERs can destroy immobile TARGET ahead of its course; it also has powerful weapons able to destroy opposing FIGHTERs on the adjacent diagonal squares ahead of its course. For example, W-BOMBER from 36 can destroy opposing FIGHTERs on 27 and 47. Each of the FIGHTERs is capable of destroying an opposing BOMBER by approaching its location and moving there. But, it is also able to protect its friendly BOMBER on the adjacent locations. In the latter case, the joint protective power of the combined weapons of the friendly BOMBER and FIGHTER can protect the BOMBER from an interception. For example, the W-FIGHTER located at 46 can protect W-BOMBER on 36 and 37. Assume that the moves of the opposing sides *alternate* and *only one piece at a time* can move.

The combat considered can be broken down into two local operations. The first operation is as follows: robot B-BOMBER should reach point 81 to destroy the W-TARGET, while W-FIGHTER will try to intercept the B-BOMBER. The second operation is similar: robot W-BOMBER should reach point 38 to destroy the B-TARGET, while B-FIGHTER will try to intercept the W-BOMBER. Interception is impossible after a BOMBER hits a TARGET and stays safe for at least one time interval. After destroying the opposing TARGET and saving its BOMBER, the attacking side is considered a winner of the local operation. The only chance for the opposing side to avenge is to hit its TARGET, save its BOMBER for one time interval after that, and, this way, end the battle in a draw.

Let S_t^1 (the set of winning target states for White) be the set of states where B-BOMBER is destroyed, and W-BOMBER hit B-TARGET and has been safe for at least one time interval. Let S_t^2 (the set of winning target states for Black) be the set of states where W-BOMBER is destroyed, and B-BOMBER hit W-TARGET and has been safe for at least one time interval. Let S_t^3 (the set of draw states) be the set of states where both BOMBERs hit their targets and stay safe for at least one time interval, or both BOMBERs are destroyed before they hit their targets or immediately after that. Start State S_0 is shown in (Fig. 1). *Is there a strategy for White to force a draw*?

The draw strategy generated by the LG algorithm is to move W-FIGHTER along the diagonal to 77, 66 and, in some cases, to 55. It should deviate from this diagonal movement in response to the activities of the Black. In all cases employing such strategy it would have enough time either to approach W-BOMBER at 36 and support its safe attack of W-TARGET or to intercept B-BOMBER before it hits its target (or immediately after that).

The initial set of thought experiments with Reti endgame and 2D/4A problem consisted in mental execution of various versions of the LG algorithm and subsequent verification of those employing program PIONEER. The purpose of the next experiment was to investigate the impact of an increase in “dimension” of the abstract board and sophistication of the reachability relations.

V. 3D/4A EXPERIMENT

The 3D/4A thought experiment was constructed by morphing the start state S_0 of the 2D/4A problem (Fig. 1) into the start state of 3D/4A (Fig. 2) [15]. The key constraints for this morphing were based on the preservation of the R. Reti’s idea for W-INTERCEPTOR to be able to either protect W-STATION or to intercept B-STATION. As was the case with the 2D/4A problem, all the considerations were based on the Euclidean distances on the abstract 3D board (not in the state space). Recall that the definition of ABG (Def. 1) does not impose any constraints on the abstract board X – the board simply expands from 64 to 512 points. However, all the sophistication of the 3D/4A problem is built into the reachability relations of the INTERCEPTORs. They are able to move to the adjacent cubes in three layers, current, top and bottom.

The operational district X is the 3D grid of 8×8×8. Robot W-INTERCEPTOR (White Interceptor), located at 118 ($x = 1$, $y = 1$, $z = 8$), can move to any adjacent location, i.e., 117, 217, 218, 228, 227, 128, 127. Robot B-STATION (double-ring shape in Fig. 2) at 416, can move only straight ahead towards the goal area 816 (shaded), one cube area at a time, e.g., from 416 to 516, from 516 to 616, etc. Robot B-INTERCEPTOR (Black Interceptor), located at 186, can move to any adjacent square, just as robot W-INTERCEPTOR. Robotic vehicle W-STATION, located at 266, is analogous with robotic B-STATION; it can move only straight ahead towards the goal area 268 (shaded in (Fig. 2). Thus, robot W-INTERCEPTOR at 118 can reach any of the points $y \in \{117, 217, 218, 228, 227, 128, 127\}$ in one step, i.e., relation $R_{W\text{-}INTERCEPTOR}(118, y)$ holds, while W-STATION can reach only 267 in one step.

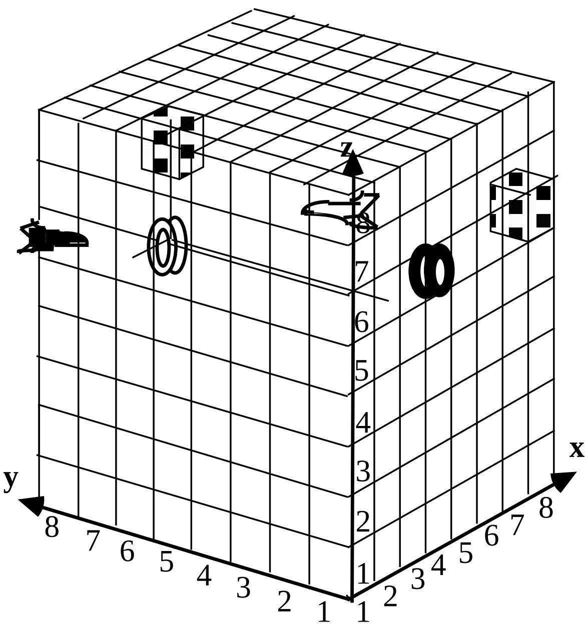


Figure 2. The 3D/4A serial problem

Assume that robots W-INTERCEPTOR and W-STATION belong to one side, P_1, while B-INTERCEPTOR and B-STATION belong to the opposing side, P_2. Also assume that both goal areas, 816 and 268, are the safe areas for B-STATION and W-STATION, respectively, if they reach the area and stay there for more than one time interval. Each of the STATIONs has weapons capable of destroying opposing INTERCEPTORs at the forward adjacent diagonal locations. For example, W-STATION at 266 can destroy opposing INTERCEPTORs at 157, 257, 357, 367, 377, 277, 177, 167. Each of the INTERCEPTORs is able to destroy an opposing STATION approaching its location from any direction, but it is also capable of protecting its friendly STATION. In the latter case, the joint protective power of the combined weapons of the friendly STATION and INTERCEPTOR (from any area adjacent to the STATION) can protect the STATION from an interception. For example, W-INTERCEPTOR located at 156 can protect W-STATION on 266 and 267. As in the 2D case, we assume that the moves of the opposing sides *alternate* and *only one piece at a time* can move.

The 3D combat can be broken into two local operations. The first operation is as follows: B-STATION should reach strategic point 816 safely, while W-INTERCEPTOR will try to intercept B-STATION. The second operation is similar: W-STATION should reach point 268, while B-INTERCEPTOR will try to intercept W-STATION. Interception is impossible after a STATION reaches the strategic point and stays safe for at least one time interval. After reaching safely its strategic point, the (attack) side is considered a winner of the local operation. The only chance for the opposing side to avenge is to reach safely its own strategic area and, this way, end the battle in a draw.

Let S_t^1 be the set of states where B-STATION is destroyed, and W-STATION reached strategic point 268 and has been safe for at least one time interval. Let S_t^2 be the set of states where W-STATION is destroyed, and B-STATION reached strategic point 816 and has been safe for at least one time interval. Let S_t^3 be the set of states where both STATIONs reached their strategic points and stay safe for at least one time interval, or both STATIONs are destroyed before they reached their targets, or immediately thereafter. The Start State S_0 is shown in Fig. 2.

As in the 2D problem, it seems that local operations are independent, because they are located far from each other. Moreover, the operation of B-STATION from 418 looks like an unconditionally winning operation, and, consequently, the global battle can be easily won by Black. *Is there a strategy for White to force a draw*?

The draw strategy generated by the LG algorithm is to move W-INTERCEPTOR along the main diagonal of the cube from 118 to 227 to 336, and, in some cases, to 445. There are several optional draw strategies. They include also moves "around" the main diagonal of the cube. In contrast to the 2D/4A problem, where W-FIGHTER has to follow exactly the diagonal of the square (Section IV), here, W-INTERCEPTOR has a number of options in moving around the main diagonal such as locations 337 and 338 (from 227). At some moment, following the response of Black, White should deviate from the diagonal by approaching either W-STATION or B-STATION.

VI. Experiment with Total Concurrency

The next thought experiment was constructed by morphing the 2D/4A problem (Section IV) to achieve total concurrency (TC) and variable size district, [15]. This morphing was made in two stages, from serial to alternating concurrent (AC, i.e., both sides alternate but pieces can move concurrently for each side) to totally concurrent (TC). As was the case for the 3D/4A problem, the key constraints for the morphing were based on the preservation of the R. Reti's idea for W-FIGHTER to be able to either protect W-BOMBER or to intercept B-BOMBER. It appears that this idea is inherent to the serial motion. To preserve it in the concurrent environment we introduced the awkward condition of "remote destruction" of the armed BOMBERs.

The operational district X is a 2D n×n square grid, $n > 7$. W-FIGHTER located at 11, can move to any adjacent square. It can reach any of the points $y \in \{12, 22, 21\}$ in one step, i.e., $R_{W\text{-}FIGHTER}(11, y)$ holds. B-BOMBER from 12 can move only straight ahead, one square at a time, e.g., from 12 to 13, from 13 to 14, etc. B-FIGHTER located at 83 can move to any adjacent square. W-BOMBER located at 63 is analogous with the robot B-BOMBER; it can move only straight ahead but in opposite direction. It can reach only 62 in one step.

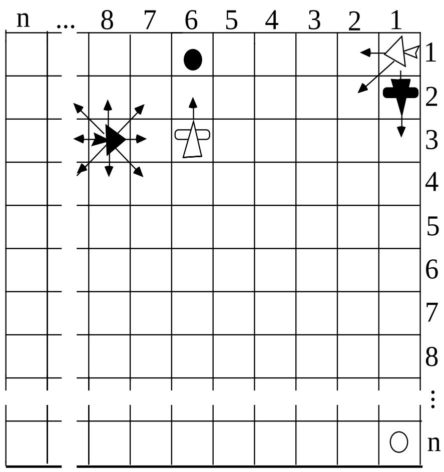


Figure 3. The 2D/4A TC problem for the n×n district

Assume that robots W-FIGHTER and W-BOMBER belong to one side, P_1, while B-FIGHTER and B-BOMBER belong to the opposing side, P_2. Also, assume that two robots, W-TARGET and B-TARGET, (immobile devices or target areas) are located at 1n and 61, respectively. W-TARGET $\in P_1$, while B-TARGET $\in P_2$. Each of the BOMBERs can destroy its immobile TARGET ahead. Each of the FIGHTERs is able to destroy the opposing BOMBER by moving to its location, but it is also able to destroy an opposing BOMBER if this BOMBER itself arrives at the current FIGHTER's location or at the location where the FIGHTER arrives simultaneously with the opposing BOMBER. For example, if B-FIGHTER is at location 61 and W-BOMBER arrives there (unprotected) then during the same time interval it destroys B-TARGET and is destroyed itself by B-FIGHTER. BOMBERs cannot destroy FIGHTERs. Each BOMBER can be protected by its friendly FIGHTER if it is at the location adjacent to the BOMBER. In this case, the joint protective power of the weapons of the friendly BOMBER and FIGHTER can protect the BOMBER from an interception. For example, W-FIGHTER located at 53 can protect W-BOMBER at 63 and 62.

Assume that *all the robots* can move *simultaneously* and there is no alternation of turns. This means that during the current time interval, all four vehicles, W-BOMBER, W-FIGHTER, B-BOMBER, and B-FIGHTER, three of them, two, one, or none of them, can move. Thus, every concurrent move could be considered as a 4-move, a 3-move, a 2-move or a 1-move.

As in all the TC systems [15], this is a model with incomplete information about the current move (before it is made). When moving, each side does not know the opposing side's component of the concurrent move, i.e., the immediate moves of the opposing side, if they are not limited down to the specific one or zero moves and, thus, can be predicted. Moreover, even after developing a deterministic strategy a side cannot follow it, because of the uncertainty about the concurrent moves of the opposing side. However, if the strategy resulted in the variants of concurrent moves with a single "universal" component (group of moves) for one side, which is good for all possible components of the other side, this strategy *can be* implemented.

As discussed at the beginning of this Section, to preserve the Reti's idea, we introduced the condition of remote destruction as follows. Each of the BOMBERs is vulnerable not only to a FIGHTER's attack, but also to the explosion of another BOMBER. If W-FIGHTER hits B-BOMBER while the latter is fully armed, i.e., it is not at its final destination – square 1n, and W-BOMBER is moving during the same time interval, it will be destroyed as a result of the B-BOMBER's explosion. If W-BOMBER is not moving at this moment, it is safe. Similar condition holds for B-BOMBER: it should not move at the moment when W-BOMBER is being destroyed (excluding 61). Therefore, under certain conditions, destruction of one of the BOMBERs triggers the explosion of the other one. This may be, for example, a result of a sudden change of atmospheric conditions or an electromagnetic field caused by a nuclear explosion.

Let S_t^1 be the set of states where the B-BOMBER is destroyed and W-BOMBER hit B-TARGET and has been safe during the hit. Let S_t^2 be the set of states where the W-BOMBER is destroyed, and B-BOMBER hit W-TARGET and has been safe during the hit. Let S_t^3 be the set of states where both BOMBERs hit their targets and stay safe, or both BOMBERs are destroyed before they hit their targets or during these hits. Start state S_0 is shown in Fig. 3.

The combat considered can be broken down into two local operations. The first operation is as follows: robot B-BOMBER should reach location 1n to destroy the W-TARGET, while the W-FIGHTER will try to intercept this movement. The second operation is similar: robot W-BOMBER should reach location 61 to destroy the B-TARGET, while B-FIGHTER will try to intercept this movement. Interception is impossible after a BOMBER has hit a TARGET and stayed safe during this hit. After destroying the opposing TARGET and keeping its BOMBER safe, the attacking side is considered a winner of the local operation. The only chance for the opposing side to avenge is to do the same: to hit its TARGET and keep its BOMBER safe. This will end the battle in a draw.

Is there a strategy for White to force a draw, i.e., a strategy that provides one of the following: both BOMBERs hit their targets and none of the BOMBERs is destroyed at the moment of strike, or both BOMBERs are destroyed before they hit their targets or at the moment of strike?

The conclusive draw strategy generated by LG is to move W-FIGHTER from 11 along the diagonal to 22, 33, 44 and

 ISBN: 978-1-61208-155-7

keep W-BOMBER at 63. From there, W-BOMBER and W-FIGHTER should move as a pair, simultaneously, to 62 and 53, then to 61 and 52, respectively. This variant leads to the safe attack of both targets. All other variants of draw are inconclusive – those strategies could be implemented with probability of 50% only.

VII. Experiment with Direct Construction

For decades the accuracy of the solutions generated by prototypes and applications of LG was evaluated with respect to the solutions obtained from the most advanced experts in the field. In particular, these were chess experts, authorities in power maintenance, vehicles routing, etc. Usually, the solutions generated by the LG systems were approved by domain experts or matched those published in the domain literature (like chess). However, nobody claimed that these published solutions are provably optimal. They are solutions which experts agreed upon.

The same approach was used for the development of the thought experiments described in Sections IV-VI and respective software applications. Our assumption was that the solution sought by the LG systems should be good, satisfactory, but not necessarily optimal. In our attempt to evaluate accuracy of the solution of the 2D/4A problem we followed the same pattern. By running thought experiments for solving 2D/4A (as well as other problems) by executing the LG algorithm we tried to evaluate the accuracy of the solutions. This means that we would have to evaluate the error, i.e., the “distance” between two solutions, the solution generated by LG and the optimal solution. Both solutions could be represented as variants of moves in the state space leading from the Start state. It is extremely difficult to understand the meaning of “distance” between two variant-solutions in the state space, especially, if the problem is an opposing game. By morphing the 2D/4A thought experiment in several directions and trying to visualize the notion of “distance” I suddenly realized that we can measure distances between subspaces of the state space (sets of states) by projecting these subspaces on the abstract board. This realization did not help us in evaluating the error, i.e.,

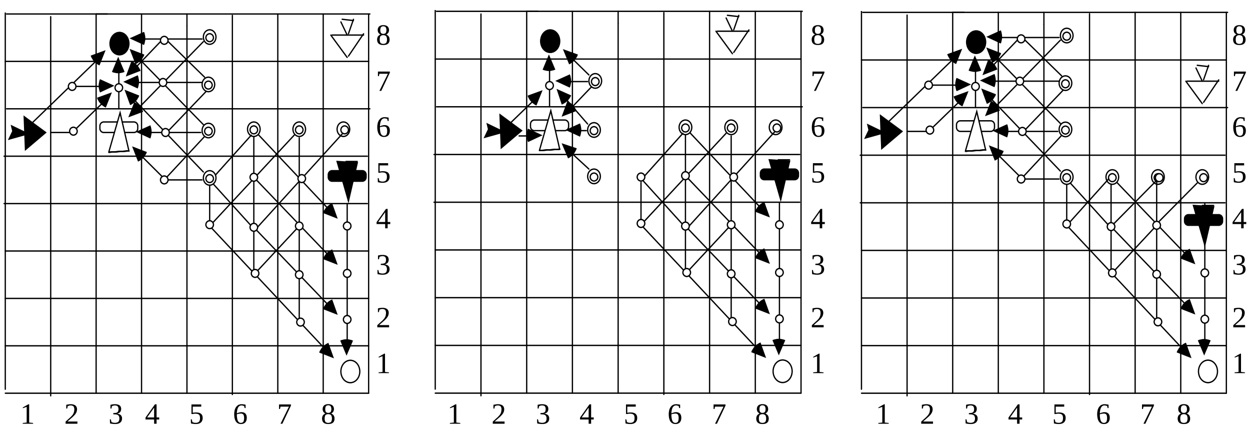


Figure 4. Projections of Draw Subspaces for three different states for the 2D/4A problem

the distance between solutions. However, it helped to evaluate classes of potential solutions, i.e., potential strategies. Indeed, from the LG algorithm it was known that two areas of the abstract board, the upper left and the bottom right networks (Fig. 4, left), are highly desirable for White. This means that arrival of W-FIGHTER in at least one of them may lead to the draw, i.e., the draw strategy. Such an arrival might happen through the entry points, the so-called zone gateways (double circles in Fig. 4).

It appears that these two networks represent projections (on the board) of the 2D/4A subspaces where the draw strategy exists. This means that the LG algorithm can identify the subspaces such that for every state from those there is a strategy leading to the draw. We can think about these subspaces as “black holes” – once you have got there you would not get out, i.e., the draw is guaranteed.

Unfortunately, these “black holes” depend on the location of the observer, i.e., on the current state. When the game moves to another state, the draw subspaces may shrink, expand, or even disappear. Fig. 4 shows projections of the “black holes” for 3 different states of the 2D/4A problem. Another difficulty is related to the presence of adversarial pieces – they may interfere. If W-FIGHTER gets into one of those areas on the board this does not assure that the game would actually get into the proper subspace – it is an effect of projection. However, it is known that in order for the game to eventually get to the draw target state W-FIGHTER must cross the boundaries of one of those areas. A simple analogy is for a point moving in 3D space in an attempt to get into the complex 3D shape. Consider a stationary 2D plain. If an orthogonal projection of this point on this plain gets inside the projection of the 3D shape (on the same plain), does it mean that our point actually reached inside the shape? Certainly, it is not the case. However, this is a necessary condition. Analogously, for W-FIGHTER to reach one of those areas is a necessary condition to achieve a draw. Consequently, if W-FIGHTER cannot reach those projections, there is no way the system can get into the draw subspaces from the start state (Fig. 4, left) - the "black holes" would be unreachable.

Now, we can come back to the notion of state distance. Consider the "board distances" (number of steps for W-FIGHTER) between the W-FIGHTER's current location at 81 and the entry points of the networks (the double circles) as the bottom values of the respective state distances. This means that the distance between the start state and the draw subspaces cannot be less than the board distances just described. Let us check these board distances (Fig. 4, left). The board distances from 88 to the entry points of the upper left network, 55, 56, 57 and 58, are the same and equal 3 steps. The board distances from 88 to entry points of the bottom right network are equal to 2 steps.

As I already mentioned the notion of state distances discovered from the thought experiment could be used to evaluate classes of potential strategies. Indeed, consider all the strategies leading to one of the draw subspaces. As we just realized, all of them must include the movement of W-FIGHTER approaching at least one of the areas, top or bottom (as a necessary condition). This means that the total of board distances must shrink. If W-FIGHTER moves 88-78, then Black "gets the message" about the specific draw subspace White is trying to approach. Based on this message, Black responds with B-FIGHTER 16-26; the draw subspace and its projection shrink (Fig. 4, middle) while both of the board distances stay the same, 2 and 3. If W-FIGHTER moves 88-87, then Black also gets the message about the specific draw subspace White is trying to approach. Based on this message, Black responds with B-BOMBER 85-84; the draw subspace and its projection shrink (Fig. 4, right) while both of the board distances stay the same, 2 and 3. In both cases W-FIGHTER approaches nothing because the board distances do not shrink. The only potential strategy that may lead to a draw must include diagonal movement of W-FIGHTER. For example, if W-FIGHTER moves 88-77, then Black gets the mixed message about a target of this movement because it is not clear which subspace is being approached. It does not matter how Black responds, i.e., which projection shrinks. In all cases, at least one of the distances will be reduced. This way we can eliminate all the potential draw strategies that do not include diagonal movement of W-FIGHTER as non-implementable.

The thought experiment described in this Section allowed us to develop the no-search approach in LG [13], [15], which permits generating solutions by direct construction (without search at all). Simultaneously, it includes proof of optimality of the constructed solution.

VIII. CONCLUSION AND FUTURE WORKS

This paper is the first step in our research, discovering the algorithm for inventing new algorithms. For this research we employed several thought experiments utilized over the years for developing LG. The preliminary conclusion (to be verified in our future research) is that these inventions never included the "search per se". Instead we morphed under certain constraints visual images of the existing dynamic objects into the new objects.

REFERENCES

[1] M.M. Botvinnik, *Computers in Chess: Solving Inexact Search Problems*, Springer-Verlag, 1984.

[2] S. Deheaene, A Few Steps Toward a Science of Mental Life, *Mind, Brain and Education*, Vol. 1, No. 1, pp. 28-47, 2007.

[3] S. Kosslyn, W. Thompson, I. Kim, and N. Alpert, Representations of mental images in primary visual cortex, *Nature*, 378 , 496–498, 1995.

[4] A. Kott (editor), *Advanced Technology Concepts for Command and Control*, Xlibris Corporation, 2004.

[5] A. Kott and W. McEneaney (editors), *Adversarial Reasoning: Computational Approaches to Reading the Opponent's Mind*, by, Chapman & Hall/CRC, 2007.

[6] *Linguistic Geometry Tools: LG-PACKAGE*, with Demo DVD, 60 pp., STILMAN Advanced Strategies, 2010. This brochure and 8 recorded demonstrations are also available at www.stilman-strategies.com

[7] B. Stilman, Formation of the Set of Trajectory Bundles, Appendix 1 to the book: *On the Cybernetic Goal of Games*, by Botvinnik, M. M., Soviet Radio, Moscow (in Russian), pp. 70–77, 1975.

[8] B. Stilman, A Formal Language for Hierarchical Systems Control, *Int. J. Languages of Design*, Vol. 1, No.4, pp. 333-356, 1993.

[9] B. Stilman, A Linguistic Approach to Geometric Reasoning, *Int. J. of Computers & Math. with Appl*, Vol. 26, No. 7, pp. 29-58, 1993,

[10] B. Stilman, Network Languages for Complex Systems, *Int. J. of Computers & Math. with Appl.*, Vol. 26, No. 8, pp. 51-80, 1993.

[11] B. Stilman, Linguistic Geometry for Control Systems Design, *Int. J. of Computers and Their Applications*, 1(2): 89-110, 1994.

[12] B. Stilman, Translations of Network Languages, *Int. J. of Computers & Math. with Appl.*, Vol. 27, No. 2, pp. 65-98, 1994.

[13] B. Stilman, Managing Search Complexity in Linguistic Geometry, *IEEE Trans. on Syst., Man, and Cybernetics*, 27(6): 978-998, 1997.

[14] B. Stilman, Network Languages for Concurrent Multi-agent Systems, *Intl. J. of Computers & Math. with Appl*., 34(1): 103-136, 1997.

[15] B. Stilman, *Linguistic Geometry: From Search to Construction*. Kluwer Acad. Publishers (now Springer-Verlag), 416 pp., 2000.

[16] B. Stilman, Linguistic Geometry and Evolution of Intelligence, *ISAST Trans. on Computers and Intelligent Systems*, 2011 (in press).

[17] B. Stilman, V. Yakhnis, and O. Umanskiy, Winning Strategies for Robotic Wars: Defense Applications of Linguistic Geometry, *Artificial Life and Robotics*, Vol. 4, No. 3, 2000.

[18] B. Stilman, V. Yakhnis, and O. Umanskiy, Knowledge Acquisition and Strategy Generation with LG Wargaming Tools, *Int. J. of Comp. Intelligence and Applications*, Vol 2, No.4, Dec. 2002, pp. 385-409.

[19] B. Stilman, V. Yakhnis, and O. Umanskiy, Chapter 3.3. Strategies in Large Scale Problems, in [5], pp. 251-285, 2007.

[20] B. Stilman, V. Yakhnis, and O. Umanskiy, Linguistic Geometry: The Age of Maturity, *J. of Advanced Computational Intelligence and Intelligent Informatics*, Vol 14, No. 6, pp. 684-699, Sep. 2010.

[21] B. Stilman, V. Yakhnis, and O. Umanskiy, Revisiting History with Linguistic Geometry, *ISAST Trans. on Computers and Intelligent Systems*, Vol. 2, No. 2, pp. 22-38, Oct. 2010.

[22] B. Stilman, V. Yakhnis, and O. Umanskiy, The Primary Language of Ancient Battles, *Int. J. of Mach. Learning and Cyber.*, 2011 (in press).

[23] J. Von Neumann, *The Computer and the Brain*, Yale U. Press, 1958.

Informed Virtual Geographic Environments for Knowledge Representation and Reasoning in Multiagent Geosimulations

Mehdi Mekni
Institut National de la Recherche Scientifique (INRS)
Eau Terre Environnement
Quebec city (Quebec) G1K 9A9, Canada
mmekni@gmail.com

Bernard Moulin
Department of Computer Science and Software Engineering
Laval University
Quebec city (Quebec) G1V 0A6, Canada
bernard.moulin@ift.ulaval.ca

***Abstract*—In this paper, we propose a novel approach that extends our Informed Virtual Geographic Environment (IVGE) model in order to effectively manage knowledge about the environment and support agents' cognitive capabilities and spatial behaviours. Our approach relies on previous well established theories on human spatial behaviours and the way people apprehend the spatial characteristics of their surroundings in order to navigate and to interact with the physical world. The main contribution of our approach is to provide cognitive situated agents with: (1) knowledge about the environment represented using Conceptual Graphs (CG); (2) tools and mechanisms that allow them to acquire knowledge about the environment; and (3) capabilities to reason about this knowledge and to autonomously make decisions and to act with respect to both their own and the virtual environment's characteristics.**

***Keywords*-Informed Virtual Geographic Environments, Knowledge Management, Agent and Action Archetypes, Agentification of Geographic Features, Spatial Situation.**

INTRODUCTION

During the last decade, the Multi-Agent Geo-Simulation (MAGS) approach has attracted a growing interest from researchers and practitioners to simulate phenomena in a variety of domains including traffic simulation, crowd simulation, urban dynamics, and changes of land use and cover, to name a few [3]. Such approaches are used to study various phenomena involving a large number of simulated actors (implemented as software agents) of various kinds evolving in, and interacting with, an explicit description of the geographic environment called Virtual Geographic Environment (VGE).

A critical step towards the development of a MAGS is the creation of a VGE, using appropriate representations of the geographic space and of the objects contained in it, in order to efficiently support the agents' situated reasoning. Since a geographic environment may be complex and large scale, the creation of a VGE is difficult and needs large quantities of geometrical data that characterise the environment as well as semantic information that qualifies space.

In order to yield realistic MAGSs, a VGE must precisely represent the geometrical information which corresponds to geographic features. It must also integrate several semantic notions about various geographic features. To this end, we propose to enrich the VGE data structure with semantic information that is associated with the geographic features [13], [14], [17]. This semantic information is structured using a standard knowledge representation formalism. Finally, we leverage such a structured knowledge representation using a novel model for knowledge management to enhance the support of spatial behaviours of agents in multi-agent geo-simulations.

The rest of the paper is organized as follows: Section I provides a short survey of works on geographic environment representation as well as on agents' spatial behaviours, introduces the *affordance* concept, presents the notion of *knowledge about the environment*, and outlines its importance for spatial agents in order to let them make decisions that take into account the characteristics of the virtual geographic environment in which they evolve. Section II briefly summarises our IVGE computation model. Section III introduces the concept of *Environment Knowledge* (EK) and details the method that we propose to define it using Conceptual Graphs (CGs) [22]. It also presents the environment knowledge base along with the associated decision making process which involves an inference engine. Section IV provides a description of the proposed agent model and presents patterns of spatial behaviours. To conclude, Sections V and VI illustrate and discuss, through a case study, how environment knowledge management supports situated agents's spatial behaviours in virtual urban environments.

I. RELATED WORKS

A. Environment Representation

Virtual environments and spatial representations have been used in several application domains. For example, Thalmann *et al.* proposed a virtual scene for virtual humans representing a part of a city for graphic animation purposes [4]. Donikian *et al.* proposed a modelling system which is able to produce a multi-level data-base of virtual urban environments devoted to driving simulations [25]. More recently, Shao *et al.* proposed a virtual environment representing the New York City's Pennsylvania Train Station populated by autonomous virtual pedestrians in order to simulate the movement of people [21]. However, since the focus of these approaches is computer animation and virtual reality, the virtual environment usually plays the role of a simple background scene in which agents mainly deal with geometric characteristics.

Despite the multiple designs and implementations of virtual environments frameworks and systems, the creation of geometrically-accurate and semantically-enriched geographic content is still an open issue. Indeed, research has focused almost exclusively on the geometric and topologic characteristics of the virtual geographic environment. However, the structure of the virtual environment description, the optimization of this description to support large-scale and complex geographic environments, the meaning of the geographic features contained in the environment as well as the ways to interact with them have received less attention.

B. Spatial Behaviours and Knowledge Management

Research on spatial behaviours investigates the processes that take place when spatial agents representing people or other dynamic actors orient themselves and navigate through complex and large-scale virtual geographic environments [18]. In order to build agents that exhibit plausible spatial behaviours with respect to their capabilities and to the virtual environment characteristics in which they evolve, we need to analyse humans' spatial behaviours in the physical world [29]. We also need to determine how spatial agents can make decisions using knowledge provided by the virtual environment. In this section, we present several works related to *spatial behaviours* and *affordances* and outline the importance of *knowledge about the environment* for the support of agents' spatial behaviours.

Several theories in the field of *human spatial behaviours* have been proposed in order to explain how people navigate in the physical world, what people need to find their ways, and how people's visual abilities influence their decisions [5]. Actually, these theories point out the use of various spatial and cognitive abilities to apprehend the physical world in which people evolve and with which they interact [7]. Weisman identified four classes of environmental variables that influence spatial behaviours in physical worlds: *visual access*; *architectural differentiation*; *signs to provide identification or directional information*; and *plan configuration* [26]. Seidel's study at the Dallas/Fort Worth Airport showed that the spatial structure of the physical environment has a strong influence on people's spatial behaviours [20]. Arthur and Passini introduced the term *environmental communication*, arguing that the built environment and its parts should function as a communication device [1]. Information about the geographic environment along with the spatial and cognitive capabilities are fundamental inputs to the spatial decision-making process [7]. This knowledge include information collected using perception capabilities, memorised information resulting from past experiences, and information provided by the environment it self [8].

Knowledge is an important asset for agents because it allows them to reason about it and to autonomously make informed decisions [28]. By its very nature, knowledge is *disparate* and *heterogeneous* and can be represented in various ways (qualitatively and quantitatively), and can be either structured or unstructured. Knowledge usually includes information about the agent's characteristics, as well as about the description of the geographic environment in which it is situated. Thus, spatial agents require knowledge about their environment in order to reason about it, to infer facts, and to draw conclusions which will guide them to make decisions and to act. A number of challenges arise when creating knowledge about the environment for spatial agents' decision-making, among which we mention: 1) to represent knowledge using a standard formalism; 2) to provide agents with tools and mechanisms to allow them acquire knowledge about the environment; and 3) to infer and to draw conclusions and facts using premises that characterise the geographic environment. The main reason why virtual environments have received less interest from practitioners is that geographic environments may be *complex*, *large-scale*, and *densely* populated with a variety of *geographic features*. As a consequence, formally representing knowledge about geographic environments is usually complex and time consuming [27]. Another issue which needs to be addressed is the way to allow spatial agents to acquire this knowledge in order to autonomously make decisions. There is a need for a *knowledge management* approach: (1) to represent knowledge about geographic environments using a standard formalism; (2) to allow spatial agents to acquire knowledge about the environment; (3) to allow agents to reason using knowledge about geographic environments.

II. Computation of IVGE

In this section, we briefly present our automated approach to compute the IVGE data using vector GIS data. This approach is based on four stages: *input data selection*, *spatial decomposition*, *maps unification*, and finally the generation of the *informed topologic graph* [14]. A detailed description of the spatial decomposition and layers integration techniques is provided in [12], [13], [17].

GIS Input Data Selection: The first step of our approach

 ISBN: 978-1-61208-155-7

consists of selecting the different vector data sets which are used to build the IVGE. The input data can be organized into two categories. First, *elevation layers* contain geographical marks indicating absolute terrain elevations [14]. Second, *semantic layers* are used to qualify various types of data in space. Each layer indicates the physical or virtual limits of a given set of features with identical semantics in the geographic environment, such as roads or buildings.

Spatial Decomposition: The second step consists of obtaining an exact spatial decomposition of the input data into cells. First, an elevation map is computed using the Constrained Delaunay Triangulation (CDT) technique. All the elevation points of the layers are injected into a 2D triangulation, the elevation being considered as an attribute of each node. Second, a merged semantics map is computed, corresponding to a constrained triangulation of the semantic layers. Indeed, each segment of a semantic layer is injected as a constraint which keeps track of the original semantic data by using an additional attribute for each semantic layer.

Map Unification: The third step to obtain our IVGE consists of unifying the two maps previously obtained. This phase can be depicted as mapping the $2D$ merged semantic map onto the $2.5D$ elevation map in order to obtain the final $2.5D$ elevated merged semantics map. First, preprocessing is carried out on the merged semantics map in order to preserve the elevation precision inside the unified map. Indeed, all the points of the elevation map are injected into the merged semantics triangulation, creating new triangles. Then, a second process elevates the merged semantics map.

Informed Topologic Graph: The resulting unified map now contains all the semantic information of the input layers, along with the elevation information. This map can be used as an *Informed Topologic Graph* (ITG), where each node corresponds to the map's triangles, and each arc corresponds to the adjacency relations between these triangles. Then, common graph algorithms can be applied to this topological graph, and graph traversal algorithms in particular [13].

III. From Semantic Information to Environment Knowledge

In [15], we proposed a novel model along with a complete methodology for the automated generation of informed VGEs. Then, we presented our abstraction approach which enriches and structures the description of the IVGE, using geometric, topologic and semantic characteristics of the geographic environment. In order to represent semantic information which characterises our informed virtual environment model, we also proposed to use Conceptual Graphs (CGs) [22]. Our aim now is to evolve the semantic information to the level of *knowledge* and hence to build a knowledge-oriented virtual geographic environment in which spatial agents autonomously make informed decisions.

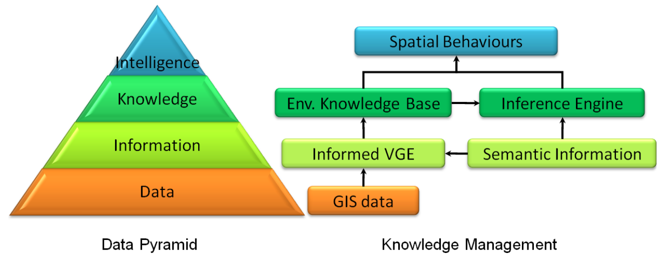


Figure 1: The proposed knowledge management approach; on the left hand side, the pyramid data [11]; on the right hand side, the knowledge management approach relying on our IVGE model and involving a knowledge base coupled with an inference engine to support agents' spatial behaviours.

The process of making an informed decision has been modelled as a pyramid built on data [11] as shown on the left hand side of *Figure 1*. *Data* corresponds to the transactional, incremental physical records [11]. In our IVGE model, this data corresponds to the geometric and geographic data provided by GIS. In and of itself this data is not sufficient to support spatial agents' decision-making. This data must be organized into information in order to be useful. *Information* is data that has been contextualized, categorized, often calculated (from initial data), corrected, and usually condensed [19]. In our IVGE model, information corresponds to the description of the IVGE resulting from the exact spatial decomposition of the geographic environment and enhanced with semantic information. Information often contains patterns within it and is sometimes useful for simple spatial behaviours such as motion planning. However, the context of these spatial behaviours can only be formed using some *knowledge*. *Knowledge* provides the next step of data organisation. For information to become knowledge, the context of the information needs to include predictive capabilities. Using predictive capabilities of knowledge, spatial agents can autonomously make informed decisions. The more complex and voluminous the underlying data sets are, the more effort is required to progressively organise it so that it becomes knowledge useful to the agents' decision-making. However, since our IVGE description is structured as a hierarchical topologic graph resulting from the geometric, topologic, and semantic abstraction processes, and since the semantic information is expressed using conceptual graphs, we are able to build knowledge about the environment to support agents' spatial behaviours.

A. Environment Knowledge

We define the notion of *Environment Knowledge* (EK) as a specification of a conceptualization of the environment characteristics: the objects, agents, and other entities that

 ISBN: 978-1-61208-155-7

are assumed to exist in the informed virtual geographic environment and the relationships that hold among them. Hence, EK is a description (like a formal specification of a program) of the spatial *concepts* (geographic features) and *relationships* (topologic, semantic) that may exist in a geographic environment. This description is provided by users in order to enrich the qualification of the geographic features which characterise the environment. It is expressed using a standard formalism which is close to natural language and computer tractable.

Let us emphasize that enhancing a multi-agent geosimulation with EK, allows spatial agents to reason about the characteristics of the virtual geographic environment. Practically, EK is composed of *spatial concepts* (i.e., ask queries and make assertions) and spatial relationships (i.e., describe actions and behaviours). Our aim is to improve the perception-decision-action loop on which rely most agent models. Considering Newell's pyramid [16] which comprises the reactive, cognitive, rational and social levels of agent behaviours, we mainly focus on the knowledge acquisition process in order to support the decision-making capabilities of spatial agents. *Figure 2* illustrates two elements: (1) the knowledge acquisition process, and (2) the action archetype process, that we introduced in order to extend Newell's initial pyramid.

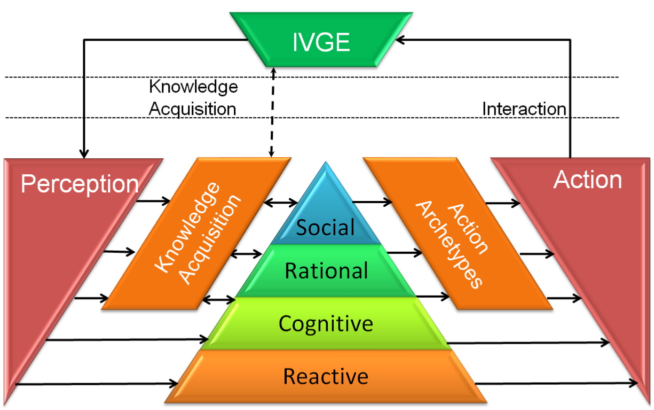


Figure 2: The enhanced perception-decision-action loop.

The management of the environment knowledge is composed of two main parts: (1) an *Environment Knowledge Base* (EKB) which relies on spatial semantics represented using the CG formalism; and (2) an *Inference Engine* (IE) which allows to manipulate and to acquire environment knowledge in order to provide spatial agents with the capability of reasoning about it.

Conceptual graphs are widely used to represent knowledge [22], [23]. Actually, CGs enable us to formally represent spatial semantics characterizing our IVGE model and allow us to build a structured *Environment Knowledge Base* (EKB) based on a finite bipartite graph [24]. The EKB allows MAGS users to represent, using a standard formalism, the information characterizing the virtual environment as well as the objects and agents it contains. Moreover, the EKB enables us to explicitly specify *affordances* [6] in order to support the agents spatial interactions with the informed virtual geographic environment in which they evolve. The environment knowledge base, which is part of this process relies on the notion of *spatial semantics*. *Spatial Semantics* (SS) consists of a structured, conceptualised, and organised representation of geographic features, agents, and objects that an informed virtual geographic environment may contain. Spatial semantics relies on two types of nodes: *semantic concepts* and *semantic relations*. Semantic concepts represent entities such as agents, objects and zones as well as attributes, states and events. Semantic relations represent the relationships that hold among semantic concepts.

The environment knowledge can be constructed by assembling percepts. In the process of assembly, semantic relations specify the role that each percept plays and semantic concepts represent the percepts themselves. Semantic concepts involve two types of functions; *referent* and *type*. The function *referent* maps semantic concepts to generic markers denoted by names starting with an asterisk * or individual markers usually denoted by numbers. For example, if the referent is just an asterisk, as in $[HOUSE : *]$, the concept is called a generic semantic concept, which may be read as *a house* or *some house*. The function *type* maps concepts to a set of type labels. A semantic concept s_c with type (s_c)= t and reference (s_c)= f is displayed as $[t{:}f]$. The function type can also be applied to relations. For example, if the referent is a number [HOUSE:#80972], the field to the left of the colon contains the type label HOUSE, the field to the right of the colon contains the referent #80972 which designates a particular house.

To sum up, the EKB contains knowledge about the informed virtual geographic environment that an agent may use. This knowledge is provided basically by users to enrich the qualification of the geographic features which characterise the IVGE. Finally, this knowledge is structured using semantic concepts and relations expressed using conceptual graphs.

B. Inference Engine

Now that we have defined the environment knowledge base as a structure which contains explicit descriptions of geographic features using CGs, let us describe the Inference Engine (IE) which is part of our knowledge management approach. The IE is a computer program that derives answers from our environment knowledge base. Therefore, the IE must be able to logically manipulate symbolic CGs using formulas in the first-order predicate calculus. In order to acquire knowledge about the virtual environment, agents use the IE and formulate queries using a semantic specification that is compatible with CGs. Agents interpret the answers provided by the IE and act on the environment. They can also enrich the EKB by adding new facts that result from their observation of the virtual environment (*Figure 3*).

In this sub-section, we first present how CGs allow us to map knowledge about the environment into first-order logic formulas. Then, we provide a short survey of existing tools that support the manipulation of CGs. We also discuss the capabilities of these tools to provide a programming language with CGs, related operations, and inference engine. Finally, we present the Amine platform [9], a platform to manipulate CGs using an inference engine embedded in PROLOG+CG language.

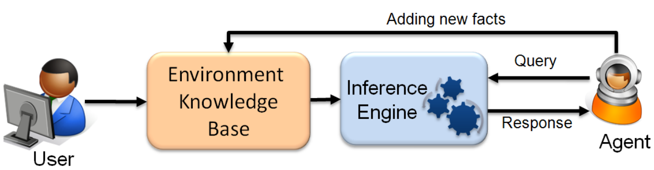


Figure 3: The inference engine uses the EKB for the purpose to answer queries formulated by agents.

Conceptual graphs offer the opportunity to map knowledge about the environment into formulas in the first-order predicate calculus.

Using formulas in the first-order predicate calculus, it is possible to build tools that allow spatial agents to manipulate knowledge about virtual environments represented using CGs. Moreover, it is possible to build tools that allow for logic and symbolic manipulations of environment knowledge and provide the opportunity to infer and to predict facts or assumptions about virtual environments. Several tools can be used to manipulate CGs (Amine, CGWorld, CoGITaNT, CPE, Notio, WebKB). These tools can be classified under at least 8 categories of tools: CG editors, executable CG tools, algebraic tools (tools that provides CG operations), KB/ontology tools, ontology server tools, CG-based programming languages, IDE tools for CG applications and, agents/MAS tools. The category "'*CG-based programming language*"' concerns any CG tool that provides a programming language with CG, related operations, and inference engine. Only Amine belongs to this category, with its programming language: *Prolog+CG*. Therefore, we propose to use the Amine platform and Prolog+CG in order to logically manipulate symbolic CGs and to provide spatial agents with an inference engine that allows them to query the environment knowledge, to acquire environment knowledge and reason about it.

Using Amine platform, users can build an environment knowledge base (EKB) using CGs and query the Amine's inference engine (IE) to derive new knowledge from the content of the EKB using queries. The Amine platform provides a graphic user interface to support the manipulation of the EKB. Agents are able to send queries, during the simulation process, in order to acquire the knowledge they need to make a decision, using the Prolog+CG language which is provided by the Amine platform. These queries are processed by the IE which interrogates the EKB and sends back the response to agents.

In order to illustrate such a querying process, let us consider the following simple environment knowledge, composed of a set of two facts which provide an idea of the use of conceptual structures as a Prolog+CG data structure:
cg([Man:Mehdi]←agnt-[Study]-loc→[University]).
cg([Man:Mehdi]←agnt-[Play]-obj→[Soccer]).

And the following request: "'*Which actions are done by Man Mehdi ?*"'
?- cg([Man:Mehdi]←agnt-[x]).

The answer provided by the Amine platform using its Prolog+CG inference engine is:
x = Study;
x = Play;

Now that we introduced the main parts of our environment knowledge management approach, namely EKB and IE, we detail in the following section the notions of agent and action archetypes and the way we use them to build spatial behaviours.

IV. From Environment Knowledge to Spatial Behaviours

When dealing with MAGS involving a large number of spatial agents of various kinds, the specification of their attributes and associated spatial behaviours might be complex and time and effort consuming. In order to characterise our spatial agents, we propose to specify: (1) the agent archetype, its super-types and sub-types according to the semantic type hierarchy; (2) the agent category (such as actor, object, and spatial area); and (3) the agent spatial behavioural capabilities, including moving within the IVGE content, perception of the IVGE and of other spatial agents. In the following subsections we discuss these elements.

A. Agent Archetypes

In our environment knowledge management approach, the description of agents as well as objects and geographic features (spatial areas and zones) is enriched with semantic information. This means that these spatial agents belong to a semantic type hierarchy. Using the semantic type hierarchy allows us to take advantage of *inheritance* mechanisms. Hence, when modelling a MAGS involving a large number

 ISBN: 978-1-61208-155-7

of agents, we only need to specify the attributes that are associated with the highest-level types of agents that we call agent archetypes rather than repeatedly specifying them for each lower-level agents. Let us define the Prolog+CG rule used to build a semantic type-hierarchy as follows: *Supertype* > *Subtype1*, *Subtype2*, ..., *SubtypeN*.

Below is an example of a portion of semantic type-lattice expressed in Prolog+CG whose graphical representation is provided in *Figure 4*. Note how each line conforms to the rule given above: *Entity* > *Physical*, *Abstract*.
Physical > *Object*, *Process*, *Property*.
Object > *Animate*, *Inanimate*.
Animate > *Human*, *Animal*, *Plant*.
We now explain this example. The example starts at the top of the lattice with Entity. This super-type is then declared to have two immediate sub-types: *Physical*, and *Abstract*. The *Abstract* node is not associated with any subtype, and so remains a leaf node. The *Physical* node is given three immediate subtypes: *Object*, *Process*, *Property*, each of them being associated with subtypes. These subtypes may also have subtypes, and so on down the lattice.

Another important characteristic of agent archetypes is the *multi-inheritance* property which allows an agent type to belong to two (or several) different agent archetypes and hence to inherit from their characteristics. Let us consider the following example:
Adult > *Woman*, *Man*.
Young > *Girl*, *Boy*.
Female > *Woman*, *Girl*.
Male > *Man*, *Boy*.

Let us notice that *Woman* occurs at several places. This is allowed, as long as there is no circularity (i.e., as long as a type is not specified to be a subtype of itself) whether immediately or indirectly.

There is a fundamental difference between an *archetype* on the one hand, and *instances* of that type on the other hand. For example, while *SchoolBus* is an archetype, *SchoolBus1* and *SchoolBus2* are instances of that archetype. Instances are members of the group of entities which is named by the archetype. The archetype is the name of the group.

In Prolog+CG, we have two ways of saying that a type has an instance: (1) we can simply declare it as an individual in the referent of some CG; (2) we can declare it at the top of the program in a catalog of individuals. A catalog of individuals for a given type is written as follows:
Archeype = *Instance1*, *Instance2*, ..., *InstanceN*.

B. Action Archetypes

Since our research addresses the simulation of spatial behaviours, it has been influenced by some basic tenets of

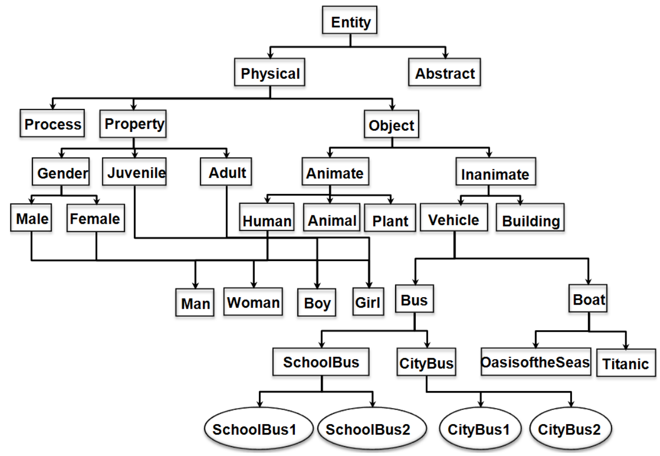


Figure 4: A graph of *Semantic Type Lattice* with instances attached to agents archetypes (circle shapes).

activity theory [2]. In particular, our approach to manage environment knowledge rests on the commitments in activity theory that: (1) activities are directed toward objects, zones, or actors [10]; (2) activities are hierarchically structured; and (3) activities capture some context-dependence of the meaning of information [2];

Theoretically, the common philosophy between our approach and activity theory is a view of the environment from the perspective of an agent interacting with it. Practically, we borrowed from activity theory two main ideas: (1) the semantics of activities and objects are inseparable [10]; and (2) activities, objects as well as agents are hierarchically structured [2].

We define an action archetype as a pattern of activities which are associated with agent archetypes. Hence, an action archetype describes a situation which involves one or several agent archetypes. We define an action archetype as a lattice of actions.

V. Case Study: Human agents taking buses

In this section, we present a case study that illustrates how the IVGE model and the proposed knowledge management approach are used in practice. This case study aims to illustrate how spatial agents representing humans leverage the environment knowledge management approach that we propose. In order to acquire knowledge about the environment and to reason about it, spatial agents apprehend the virtual environment and make decisions according to their types and capabilities and taking into account its characteristics. In this example, a few human agents representing students and workers interact with the IVGE and our EKB in order to plan their path using a bus to get to their final destinations (university and office). This case study also involves a few agents representing bus stations.

 ISBN: 978-1-61208-155-7

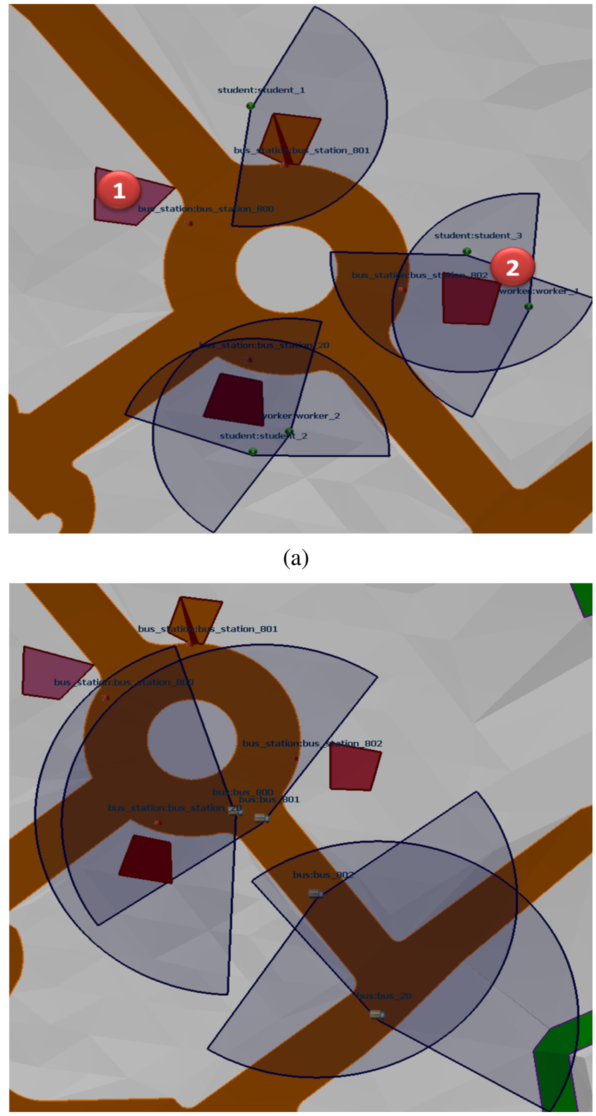
Figure 5: The IVGE representing a part of Quebec city where the spatial behaviour simulation takes place with five geo-referenced locations.

Let us consider three agent archetypes: *Bus*, *Student*, and *Worker* and several action archetypes including *STOP*, *GO*, *GETIN*, *WALK* and *ROLL*. The Bus archetype represents the different kinds of buses including city buses, school buses, etc. The Student archetype includes schoolchildness, pupils, students, etc. The Worker archetype represents working persons. This case study involves an informed virtual geographic environment representing a part of Quebec City (*Figure 5*). An environment knowledge base (EKB) is created using the Amine platform. In this EKB, we first specified the different semantic information that qualify our virtual urban environment. Second, we specified the above introduced agent archetypes namely, *BUS*, *STUDENT*, and *WORKER*. Two IVGE instances are specified: (1) *HUMAN-NAV* representing a view of the IVGE including the different geographic zones on which an agent of type human can move;(2) *VEHICLENAV* representing a view of the IVGE including the different geographic zones on which an agent of type vehicle can move. Besides, we specify the following facts: students and workers use buses to respectively reach universities and work places; humans walk on human navigable zones; vehicles roll on vehicle navigable zones; buses stop at stations.

In addition, two instances of buses, two instances of stations, and two instances of destinations are defined: Bus1, Bus2, Station1, Station2, w, and u . Bus1 which stops at station1 goes to the workplace w. Bus2 which stops at station2 goes to the university u.

cg([BUS: Bus1]←agnt-[GO]-loc→[WORKPLACE:w]).
cg([BUS: Bus2]←agnt-[GO]-loc→[UNIVERSITY: u]).
cg([BUS: Bus1]←agnt-[Stop]-loc→[STATION: Station1]).
cg([BUS: Bus2]←agnt-[Stop]-loc→[STATION: Station2]).

Now that the agent archetypes are specified, and the facts which characterise their instances are defined, we carry out the simulation in which two agents of type *student* and three agents of type *worker* interact with the IVGE in which they



(a)

(b)

Figure 6: Stations, student and worker passengers, and buses: (a) 3 students and 2 workers agents (green icon); (b) 4 agents of type *Bus* approaching the stations. Agents either students, workers, or buses are associated with their respective perception fields which are highlighted in blue.

evolve in order to localise the appropriate station from which they can catch the right bus to reach their final destinations. For simplification purposes, agents of type bus follow a pre-defined computed paths (*Figure 6(b)*). Agents of type student and worker start by identifying their own locations within the IVGE. Next, they interrogate the EKB in order to know which bus they should take in order to reach their final destinations (*Figure 6(a)*). The student agent asks the following query: *which bus goes to the university?*

?- cg([?]←agnt-[GO]-loc→[UNIVERSITY]).

The answer provided by the Amine platform is: x = *Bus2;*

Then, the student agent asks the following query: *where does Bus2 stop at?*

?- cg([BUS: Bus2]←agnt-[STOP]-loc→[?]).

The answer provided by the Amine platform is: x = *Station2;*

Once the answer is provided by the Amine platform, agents plan paths using this semantic description. Agents move towards the appropriate bus station, then wait for the bus (*Figure 6(b)*). Since our agents are endowed with perception capabilities, they are able to detect when a bus arrives at the station. The agent bus is also endowed with the same spatial capabilities and waits at the station until all the agents get in it.

VI. Conclusion and Discussion

In this paper, we presented a knowledge management approach which aims to provide spatial agents with knowledge about the environment in order to support their autonomous decision making process. Our approach is influenced by some basic tenets of *activity theory* [2] as well as by the notion of affordance [6]. It is based on our IVGE model to represent complex and large-scale geographic environments. It uses the *Conceptual Graphs* formalism to represent knowledge about the environment(*Environment Knowledge*) structured as an Environment Knowledge Base (EKB). This approach also includes an inference engine which uses the Prolog+GC language to interrogate, infer and make deductions based on facts, cases, situations, and rules stored within the EKB.

Our environment knowledge management approach is original in various aspects. First, a multi-agent geo-simulation model which integrates an informed virtual geographic environment populated with spatial agents capable of acquiring and reasoning about environment knowledge did not exist. Second, a formal representation of knowledge about the environment using CGs which leverages a semantically-enriched description of the virtual geographic environment has not yet been proposed. Third, providing agents with the capability to reason about a contextualised description of their virtual environment during the simulation is also an innovation that characterises our approach.

Nevertheless, some limits which characterise our environment knowledge management approach still need to be addressed. This approach, in its current version, is a proof of concept which demonstrates the capability of our IVGE model to : 1) integrate knowledge about the environment; 2) to allow agents to reason about it using an inference engine. Although the provided scenario is simplified, it illustrates the advantages of extending our IVGE model by: 1) using a standard knowledge representation formalism (Conceptual Graphs) and; 2) integrating an inference engine such as the Amine platform.

When the agent is acting, it uses the environment knowledge base, its observations of the virtual environment, and its goals and abilities to choose what to do and to update its own knowledge. Hence, the environment knowledge base corresponds to the agent's long-term memory, where it keeps the knowledge that is needed to act in the future. This knowledge comes from prior knowledge (provided by MAGS users) and is combined with what is learned from data and past experiences. The beliefs, intentions and desires of the agent correspond to its short-term memory. Although a clear distinction does not always exist between long-term memory and short-term memory, this issue might be addressed as part of the extension of our knowledge management approach. Moreover, there is feedback from the inference engine to the environment knowledge base, because observing and acting in the world provide more data from which the agents can learn. Evolving and allowing the agent model to learn from such data is another challenging task.

Acknowledgement

M. Mekni benefited from a PDF scholarship granted by FQRNT (***F**onds **Q**uebecois de la **R**echerche sur la **N**ature et les **T**echnologies*) as well as from the 2011 William L. Garrison award granted by the American Association of Geography (AAG).

References

[1] P. Arthur and R. Passini. *Wayfinding: People, Signs, and Architecture*. McGraw-Hill Companies, 1998.

[2] R. Bellamy, S. Bødker, E. Christiansen, Y. Engeström, V. Escalante, D. Holland, V. Kaptelinin, K. Kuutti, B. A. Nardi, A. Raeithel, J. Reeves, B. Velichkovksy, and V. P. Zinchenko. *Context and Consciousness: Activity Theory and Human-Computer Interaction*. The MIT Press, first edition, November 1996.

[3] I. Benenson and P. Torrens. *Geosimulation: Automata-Based Modeling of Urban Phenomena*. John Wiley and Sons Inc., 2004.

[4] N. Farenc, R. Boulic, and D. Thalmann. An informed environment dedicated to the simulation of virtual humans in urban context. In P. Brunet and R. Scopigno, editors, *Computer Graphics Forum (Eurographics '99)*, volume 18(3), pages 309–318. The Eurographics Association and Blackwell Publishers, 1999.

[5] A. Frank, S. Bittner, and M. Raubal. Spatial and cognitive simulation with multi-agent systems. In D. Montello, editor, *Spatial Information Theory - Foundations of Geographic Information Science, Proceedings of COSIT 2001, Morro Bay, CA, USA, September 2001*, volume 2205 of *Lecture Notes in Computer Science*, pages 124–139, Berlin, Heidelberg, New York, 2001. Springer.

[6] J. J. Gibson. *The Ecological Approach to Visual Perception*. London: Lawrence Erlbaum Associates, 1979.

[7] D. Guo, B. Ren, and C. Wang. *Advances in Computation and Intelligence*, volume 5370/2008, chapter Integrated Agent-Based Modeling with GIS for Large Scale Emergency Simulation, pages 618– 625. 2008.

[8] P. Jansen-Osmann and M. Heil. The process of spatial knowledge acquisition in a square and a circular virtual environment. *Advances in Cognitive Psychology*, 3(3):389–397, 2007.

[9] A. Kabbaj. Development of intelligent systems and multi-agents systems with Amine platform. In H. Schärfe, P. Hitzler, and P. Øhrstrøm, editors, *ICCS'06: Proceedings of the 14th International Conference on Conceptual Structures*, volume 4068 of *Lecture Notes in Computer Science*, pages 286–299. Springer, 2006.

[10] V. Kaptelinin, B. Nardi, and C. Macaulay. The activity checklist: a tool for representing the "'space"' of context. *Interactions Magazine*, 6(4):27–39, 1999.

[11] D. Lenat and R. Guha. *Building Large Knowledge-Based Systems; Representation and Inference in the Cyc Project*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1989.

[12] M. Mekni. Hierarchical path planning for situated agents in informed virtual geographic environments. In *SIMUTools10: Third International Conference on Simulation Tools and Techniques*, pages 15–19, Torremolinos, Malaga, Spain, March 2010.

[13] M. Mekni. Abstraction of informed virtual geographic environments for the modeling of large-scale and complex geographic environments. In *The 3rd International Conference on Information, Process, and Knowledge Management (eKnow11)*, volume 1, pages 1–10, Gosier, Guadeloupe, February 23-28 2011. IEEE Computer Society Press.

[14] M. Mekni and B. Moulin. Holonic modelling of large scale geographic environments. In *HOLOMAS'09: 4th International Conference on Industrial Applications of Holonic and Multi-Agent Systems*, Linz, Austria, September 2007.

[15] M. Mekni and B. Moulin. Hierarchical path planning for multi-agent systems situated in informed virtual geographic environments. In *eKnow10: 2nd International Conference on Information, Process, and Knowledge Management*, volume 1, pages 48–55, Sint-Marteen, Netherlands Antilles, February 10-16, 2010. IEEE Computer Society.

[16] A. Newell. *Unified theories of cognition*. Harvard University Press, Cambridge, Massachusetts, 1990.

[17] S. Paris, M. Mekni, and B. Moulin. Informed virtual geographic environments: an accurate topological approach. In *The International Conference on Advanced Geographic Information Systems & Web Services (GEOWS)*, pages 1 – 6. IEEE Computer Society Press, 2009.

[18] M. Raubal. Ontology and epistemology for agent-based wayfinding simulation. In S. Winter, editor, *Geographical Domain and Geographical Information Systems - EuroConference on Ontology and Epistemology for Spatial Data Standards*, volume 19 of *GeoInfo Series*, pages 85–87, France, September 2001. La Londe-les-Maures.

[19] P. S. Sajja. Multi-agent system for knowledge-based access to distributed databases. *Interdisciplinary Journal of Information, Knowledge, and Management*, 3:1–9, 2008.

[20] A. Seidel. Way-finding in public spaces: The dallas/fort worth, usa airport. In *Proceedings of the 20th International Congress of Applied Psychology*, Edinburgh, Scotland, 1982.

[21] W. Shao and D. Terzopoulos. Environmental modeling for autonomous virtual pedestrians. *Digital Human Modeling for Design and Engineering Symposium*, 2005.

[22] J. Sowa. *Knowledge Representation: Logical, Philosophical, and Computational Foundations*. Course Technology, August 1999.

[23] J. Sowa and E. Way. Implementing a semantic interpreter using conceptual graphs. *IBM J. Res. Dev.*, 30(1):57–69, 1986.

[24] J. F. Sowa. *Conceptual Structures: Information Processing in Mind and Machine*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1984.

[25] R. Thomas and S. Donikian. A model of hierarchical cognitive map and human memory designed for reactive and planned navigation. In *Proceedings of the 4th International Space Syntax Symposium*, volume 1, pages 72–100, Londres, 2003.

[26] J. Weisman. Evaluating architectural legibility: Way-finding in the built environment. *Environment and Behavior*, 13(2):189–204, March 1981.

[27] D. Weyns, K. Schelfthout, and T. Holvoet. Exploiting a virtual environment in a real-world application. Environments for Multi-Agent Systems II, february 2005.

[28] M. Wooldridge and N. Jennings. Intelligent agents: Theory and practice. *Knowledge Engineering Review*, 10(2), 1995.

[29] J. Zacharias. Exploratory spatial behaviour in real and virtual environments. *Landscape and Urban Planning*, 78(1-2):1–13, 2006.

A Holonic Approach for Providing Composite Services

Irina Diaconița, Florin Leon, Andrei Dan Leca
Department of Computer Science and Engineering
Technical University "Gheorghe Asachi" of Iaşi
Iaşi, Romania
irina.diaconita@gmail.com, fleon@cs.tuiasi.ro, andy_leca@yahoo.com

Abstract—**Holonic systems are a promising development of multiagent systems, where a holon is simultaneously a whole, composed of sub-structures, and a part of a larger entity, thus demonstrating a self-similar or fractal configuration. In this paper, we present a holon-based approach for complex multimedia processing based on elementary services that can self-organize in order to perform complex tasks. The reputations of agents are taken into account and a protocol is described that demonstrates the formation and stability of holonic coalitions that offer high quality services.**

Keywords-holonic multiagent systems; coalitions; composite services; agent reputation.

I. INTRODUCTION

A multiagent system (MAS) consists of a collection of individual agents, each of which displays a certain amount of autonomy with respect to its actions and perception of a domain [1]. While the traditional specification of a problem solving method at design time can be difficult or sometimes even unfeasible, MAS focuses on the interaction of the individual agents at run-time, and is more concerned about the way in which a solution can emerge from the interactions.

A further development on the theory of MAS is the concept of a holonic multiagent system. A holon is a self-similar or fractal structure that is stable and coherent and that consists of several holons as sub-structures [2]. Thus a holon is a complex whole that consists of substructures, and it is as well a part of a larger entity. It uses recursively nested self-similar structures which dynamically adapt to achieve the design goals of the system. In a holonic MAS, autonomous agents group together to form holons. However, in doing so they do not lose their autonomy completely. The agents can leave a holon and act autonomously again or they can rearrange themselves as new holons. According to this view, a holonic agent consists of sub-agents, which can separate and rearrange themselves and which may be holons themselves [3].

Following the general characterization of a holon, some principles can be ascertained [4]: • A holonic system possesses a tree structure, or it can be seen as a set of interwoven hierarchies; • A holon obeys precise principles, but is able to adopt different strategies according to its need; • The complex activities and behavior are situated at the top of the hierarchy, while the simple, reactive acts are to be found at the base of the holarchy; • The communications must follow the hierarchy. Messages are only possible between a holon and its responsible agent, or between holons on the same layer.

Holons have found applications in a variety of domains. A comprehensive survey [5] identifies real industrial applications such as: shipboard automation distributed control and diagnostics, production planning of engine assembling, air traffic control, and RFID-enabled material handling control. In the following paragraphs, we briefly describe some typical applications of holonic systems.

The TeleTruck system [6] is an example of an online order dispatching system for a transport company. Its task is to compute routes for a fleet of trucks for a given set of customer orders, and also handle online scheduling requests, in which new orders can arrive at any moment, and problems in the execution of the computed plans can appear.

A problem for which holons are very fit is train coupling and sharing [7]: a set of train modules are able to drive on their own on a railway network; however, if all the train modules drive separately, the capacity utilization of the railway network is not acceptable. The idea is that the module trains join together and jointly drive some distance, thus the overall goal is to reduce the cost for a given set of transportation tasks.

Another application is manufacturing scheduling, involving the allocation of jobs to machines over time, within a short temporal horizon and according to a specific criterion, such as cost or tardiness [8]. The authors suggest the use of three types of holons to handle the scheduling and control at shop floor level: task holons (production orders), operational holons (physical resources or operators available), and supervisor holons (which provide co-ordination and optimization services to the holons under their supervision).

In our paper, we analyze the use of holonic intelligent architecture to develop a cluster-based distributed application for complex media processing on demand, where the core services are libraries used in various combinations.

The structure of the article is as follows. In Section II, we describe the proposed protocol for holon interaction, including a simplified model of the underlying physical network infrastructure. In Section III, we present some case studies regarding the actual implementation of a holonic multiagent system whose behavior follows the above

 ISBN: 978-1-61208-155-7

mentioned design principles. Section IV presents the conclusions of our work.

II. PROTOCOL DESCRIPTION

The development of computer systems has always had the problem of the optimal use of hardware resources. The main reason for this constraint used to be the higher price of hardware. For dedicated applications that require high amounts of computer power this restriction remains true. But in the present information society computer applications enter each aspect of our lives, and even change the way we interact or work. As a result, large amounts of high and medium power computing nodes begin to be available both at the organizational level and at personal level. This involves changes in thinking software development itself. New approaches such as service-oriented architectures arise. This has many advantages because the granularity of the system can be quickly modified in accordance with the architecture chosen for the development, but the basic elements used in software construction remain the same. Also, the security aspects can be much better handled due to the inherent encapsulation on each level of the model. Thus, no matter the solution offered by the combination of hardware and operating system (such as grid, cloud, or other solutions), there is a support for the service-based applications.

For the application of the proposed model for holon collaboration and agent transfer, we consider a homogenous network with a constant transfer rate, where each machine initially hosts one holon, containing agents which offer specific elementary services. The restriction of having one top-level holon on each machine was enforced in order to avoid load balancing problems, e.g. when all the agents gathered on one or a few computers, and also to reveal that even if at the beginning there could be a positional bias for holons placed on machines closer to the client gateway, in time the holons with a better quality of service are favored.

The client agents send requests for composite services to the gateway agent, which will make calls for offers and choose the best ones. Thus, the clients only specify the combination of elementary services they need and the order of complexity of the tasks. The offer selection is provided by the gateway agent and the required service is controlled by the holons.

A holon consists of a representative agent and other agents or holons specialized in providing specific elementary services (we call a type *i* agent an agent specialized in providing the *i* service). A holon may contain one or more agents of the same type. Each service agent has its own quality, not known by others beforehand, for the service it provides, which is expressed as a percentage. Each holon has its own estimates for the quality of all service agents, also known as the reputations of the agents. Initially, the holons consider the quality of all service agents to be 100% and update the quality of the agents they use based on the feedback they receive from the client agents, after providing the requested services.

The representative agent is responsible for all the reputation estimation, communications, bidding, and agent transfer on behalf of the holon, as well as for the supervision of the tasks carried out by the service agents. Each representative knows the representatives of the other holons and the gateway agent, but does not know the clients.

In the following, we explain the way in which a request received by the gateway is treated.

In the first stage, the gateway agent sends a call for offers to all holons. When a holon receives such a request, its representative checks if there are local available agents for all the elementary services needed, with a reputation of at least ρ_{min}. If this condition is met, it sends an offer with the estimated processing time to the gateway:

$$t_p^{estimated} = \frac{C_{in}^2}{res \cdot n} + t_{dt}, \tag{1}$$

where C_{in} is the order of complexity of the tasks (as estimated by the client), *res* represents the resources of the machine, *n* is the estimated number of agents that will work simultaneously on the machine, and t_{dt} is the data transfer time from the gateway to the holon, defined as:

$$t_{dt} = \frac{C_{in}^2}{v_d \cdot n_{hi}}, \tag{2}$$

where v_d is the data transfer rate and n_{hi} the number of hops between the gateway and the holon (on the least cost path, as calculated by Dijkstra's algorithm [9]).

Several clarifications are needed concerning these formulas. The complexity of a task C_{in} and the resources of a machine *r* are generic. The complexity is squared because we assume that the processing would mainly follow an $O(n^2)$ complexity, which is not unusual when dealing with multimedia processing. Of course, it could also be greater, and in this case the equations should be changed accordingly. The resources mainly refer to the processing power of the machine; different real-world configurations could be eventually reduced to a number *r* that reflects the speed of the processing, affected for example by the processor performance, memory capacity, and harddisk size.

If the holon has suitable agents for all services, but one or more of them are busy at the moment, the representative sends a message to inform the gateway that it cannot offer the required services.

In the case that the holon does not have one or more types of agents needed (with a reputation greater than ρ_{min}) for the processing, its representative sends agent transfer requests to the other holons. For each type of agent, it waits until it receives an answer from all holons and then, if there are holons that have agreed to the agent transfer request, it chooses the one with the best reputation. After the holon receives an answer from all holons or after the wait time expires, if it has agents for all the required services, it sends

 ISBN: 978-1-61208-155-7

an offer to the gateway agent with an estimated processing time of:

$$t_p = \frac{C_{in}^2}{res \cdot n} + t_{dt} + \sum_{i=1}^{m} \frac{t_a}{n_{hi}}, \tag{3}$$

where m is the number of transferred agents, t_a is the transfer rate for an agent, and n_{hi} is the number of hops between the machines involved in the transfer.

If, on the contrary, the holon still has at least one missing type of agents, its representative sends a message to the gateway, telling that it cannot offer the required service.

When a holon receives a transfer request for a specific type of agent, it checks if it has any available agents of the required type. If this condition is met and the average estimated reputation of the holon is less than $\rho_{cohesion}$, the representative accepts the transfer. Otherwise, it rejects the transfer request.

In the second stage (after the gateway received an answer from all holons or the waiting time expired), the gateway agent chooses the best offer for the given service. If no holon made an offer, the gateway informs the client that the service is unavailable. In the other case, it chooses the best offer – the one with the best processing time – and informs the holon that its bid was accepted and that it should begin processing the data.

When a representative receives a message saying that its offer was accepted, it sends a message to the first agent from the list of agents involved, which contains the size of the task, the composite service, the ordered list of the agents involved in solving the task and the processing time (initially 0).

The moment when a service-providing agent receives a message asking it to do a processing, depending on whether it is busy or not, it adds the request to the waiting list or checks if it belongs to the holon responsible for the task and solves the required task. If it belongs to a different holon, it moves and joins the one that made the request. A holon can send a service or transfer request to an agent only if this action was previously approved by the representative of the holon to which the agent belongs. When an agent finishes a task, it takes the next one from the waiting list, it moves if necessary, and then provides the required service. Finally, the agent adds the time while the request was in the waiting list and the processing time to the current/received value of the computation time, and sends the request to the next agent from the list of agents involved in the processing. If the agent is the last one in the list, it sends a message to its representative that the task has been carried out successfully, and what was the processing time. The representative will forward this message to the gateway agent.

Therefore, the final processing time is:

$$t_p^{final} = t_{dt} + \sum_{i=1}^{n} p_i \cdot t_{p_i} + \sum_{i=1}^{m} t_{w_i} + \sum_{i=1}^{l} t_{m_i}, \tag{4}$$

where t_{dt} is the data transfer time between the gateway and the holon that provides the service, p_i is the number of type i tasks and t_{p_i} is the corresponding processing time, n is the total number of agents involved in solving the task, t_{w_i} represents the waiting time for agent i, m is the number of agents that caused delays, i.e. they were busy when they received the processing request, $\sum_{i=1}^{l} t_{m_i}$ is the sum of the times for moving agents that belong to other holons, t_{m_i} is the sum of times for the moving agent i (after the agent had joined the holon and made a processing it could have moved again to another holon to do another processing, before it had to do another processing in the given holon), and l is the number of the agents that were transferred to the holon.

The hierarchic and reflexive properties that define the holonic models are preserved in our approach. Thus, the holon representative is the one which decides if it will use an agent or if the agent is unfit, and therefore it will search for another to offer the same service. The representative of a holon makes requests for the agents or holons it needs to the representatives of the holons they are part of. Not only the individual agents, but also their representatives must agree to the movement.

After receiving the processed data from the selected holon, the gateway agent sends it to the client agent, which evaluates the quality of the service (as a percentage) and sends this value to the gateway agent, which forwards it to the responsible holon. Then, the holon updates its reputations for the agents involved in the processing as it follows:

$$\rho_{hi}(k+1) = (1-\alpha) \cdot \rho_{hi}(k) + \alpha \cdot \frac{e}{n_a} \cdot n_i \tag{5}$$

where $\rho_{hi}(k)$ represents the reputation of the service agent i estimated by the holon h after the k^{th} time it provided a service as a part of holon h, α is the learning rate, e is the evaluation provided by the client, n_a is the number of agents involved in the task, and n_i is the number of processings agent i did within the given task.

The choice of this function is based on a learning model encountered in other adaptive AI algorithms, such as Kohonen's self-organizing map or Q-learning. Basically, a fraction $(1-\alpha)$ of the old value is replaced with a fraction α of the new one. In our case, the evaluation of the client is equally distributed to all the agents involved.

An important aspect is the use of a variable learning rate, which depends on the number of processings an agent performs:

$$\alpha = \frac{\alpha_0}{n_a} \cdot n_i, \tag{6}$$

where α_0 is a constant.

TABLE I. THE QUALITIES OF THE AGENTS

Agents													
Holon1			**Holon2**			**Holon3**		**Holon4**				**Holon5**	
A1 (A)	A2 (B)	A3 (C)	A4 (A)	A5 (D)	A6 (E)	A7 (A)	A8 (F)	A9 (A)	A10 (C)	A11 (D)	A12 (F)	A13 (A)	A14 (E)
80	72	63	40	93	87	61	84	89	88	59	77	68	95

TABLE II. THE REPUTATIONS OF THE AGENTS (BEFORE RECEIVING THE REQUEST)

	Agents													
Holons	**Holon1**			**Holon2**			**Holon3**		**Holon4**				**Holon5**	
	A1 A	A2 B	A3 C	A4 A	A5 D	A6 E	A7 A	A8 F	A9 A	A10 C	A11 D	A12 F	A13 A	A14 E
Holon1	77	73	68	34	96	88	60	82	87	90	57	60	62	96
Holon2	80	69	71	38	92	86	57	79	88	95	62	67	64	98
Holon3	87	70	61	42	90	81	64	86	82	93	53	68	70	91
Holon4	74	80	68	45	93	85	65	84	90	97	59	65	67	92
Holon5	81	72	65	39	89	82	61	81	85	98	60	70	60	89

TABLE III. HOLONS AND THEIR MEMBERS AT DIFFERENT MOMENTS OF TIME

	Epochs		
	Epoch 2	**Epoch 3**	**Epoch 10**
Holons	Machine 1: H1 (A1, A3)	Machine 1: H1 (A3)	Machine 1: H1 (A3)
	Machine 2: H2 (A4, A5, A6)	Machine 2: H2 (A4, A5)	Machine 2: H2 (A4, A6)
	Machine 3: H3 (A7)	Machine 3: H3 (A1, A2, A6, A7)	Machine 3: H3 (H6 (A1,A2),A5,A7)
	Machine 4: H4(A2,A8,A9,A10,A11)	Machine 4: H4 (A8, A9, A10,A11)	Machine 4: H4 (A8, A9, A10)
	Machine 5: H5 (A13, A14)	Machine 5: H5 (A13, A14)	Machine 5: H5 (A11, A13, A14)

In case when only one agent does all the processing, it is certain that the client evaluation can only refer to that agent's quality. In case when more agents work on a task, the client evaluation is reflected in a different manner on the agents' reputation, according to their contribution to solving the task. The learning rate should be small enough to ensure convergence, therefore if we consider that 0.1 is an acceptable value and the composite services require approximately 3 agents on average, we could choose $\alpha_0 = 0.3$.

III. CASE STUDIES

We will first consider the network and the holons presented in Fig. 1 at the moment when a request arrives. We assume that all agents are free. The qualities of the services provided by the agents are presented in Table I and the reputations of the service agents for each holon are presented in Table II.

In both case studies, we chose $\rho_{min} = 50\%$ and $\rho_{cohesion} = 85\%$.

We used a sequence of requests (*ABFDAB, FAB, DCABAB, DCABDC, ABABAB, DABDAB, EADFAA, DDEB, FAADB, CEDAFBB*), over 1000 epochs to study the formation of new holons and the evolution of the agents' reputations. Table III presents as an example the holons and their distribution over the network at different moments as well as the formation of the first new holon (made up of agents 1 and 2), belonging to holon 3 at the moment. After collaborating for a few services and receiving good evaluations from their clients, agents 1 and 2 form a new holon. From this moment on, they move together and act as a distinct entity, which is still a member of holon 3.

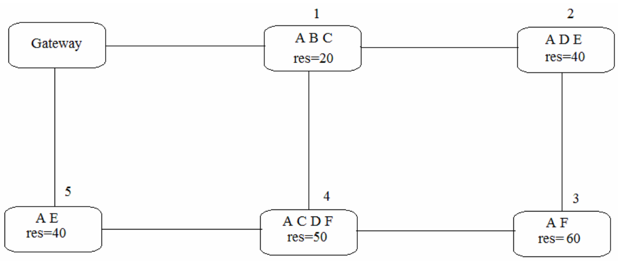


Figure 1. Simple network topology and the holons

The first request is for the service *ABFDAB* (with an order of complexity of 50). In the following, we present the steps taken to solve the request. The gateway agent sends requests for offers to all holons. The holons check whether they have all the types of agents needed. This is not the case for any of the holons, so they all send requests for agent transfers to the other holons. These transfers will be made only if the agent wins the auction, therefore a holon can approve more transfer requests for the same agent. The only criterion for choosing the transfer agent is the agent's reputation. Holon 1 chooses agents 5 (*D*) from holon 2 and 8 (*F*) from holon 3 as possible transfer agents and makes an offer of 93.38 to the gateway agent. Holon 2 chooses agents 1 (*A*) and 2 *(B)* from holon 1 and 8 (*F*) from holon 3 as possible transfer agents and makes an offer of 48.42 to the gateway agent. Holon 2 does not use its own *A* agent because of its low reputation. Holon 3 chooses agents 2 *(B)* from holon 1 and 5 (*D*) from holon 2 as possible transfer agents and makes an offer of 37.90 to the gateway agent. Holon 4 chooses agent 2 (*B*) from holon 2 as a possible transfer agent and makes an offer of 36.75 to the gateway agent. Holon 5 chooses agents 2 *(B)* from holon 1, 5 (*D*) from holon 2 and 8 (*F*) from holon 3 as possible transfer agents and makes an offer of 65.04 to the gateway agent. After receiving all offers, the gateway chooses and asks holon 4 to offer the service (because it has the smallest estimated time). Holon 4 sends a message to the first agent - *A* - to do the first task (and the ordered list of the IDs of the agents solving this request). Agent 9 (*A*) is free; it processes the data and sends a request to agent 2 (*B*). Agent 2 (*B*) is free, but it belongs to holon 1. Therefore, it announces the representative of holon 1 of its transfer, and then moves to holon 4. Afterwards, it processes the data and sends a request to agent 8 (*F*). Agent 8 (*F*) is free, but it belongs to holon 3. Therefore, it announces the representative of holon 3 of its transfer, and then moves to holon 4. Afterwards, it processes the data and sends a request to agent 11 (*D*). Agent 11 (*D*) is free; it processes the data and sends a request to agent 9 (*A*). Agent 9 (*A*) is free; it processes the data and sends a request to agent 2 (*B*). Agent 2 (*B*) is free; it processes the data and, because it is the last agent from the list, it informs the representative of the holon that the task was carried out successfully. The holon announces the gateway agent that the task was carried out successfully and sends the processed data. The gateway agent sends the processed data to the client agent. The client sends the evaluation of the quality of the service (77.5 %) back to the gateway, and the gateway forwards it to holon 4. Holon 4 updates its reputations for the agents involved; thus, the new reputations will be: $\rho_1 = 87.5$, $\rho_9 = 96.5$, $\rho_{11} = 60.85$ and $\rho_{12} = 66.25$.

It was quite easy to predict that holon 4 would win the auction because it had the smallest number of missing agents – and transferring agents is the most time consuming task. As agent 4 from holon 2 has a bad reputation among all holons because of its low quality of service, it wasn't requested by any holon, and even holon 2 refused to use it and made a request for another agent of the same type. Each holon chose its possible transfer agents from the holons that accepted the transfer, based on the reputation of the agents; different holons chose different transfer agents for the same services, because each holon had its own reputation estimates. After the data was processed, the reputations were updated using (5) with a learning rate of 0.1. As expected, agents with a lower reputation get an undeserved reputation increase because of the agents with higher reputation.

We analyze the variation of the reputation estimates of holon 3 for agents 1 and 2, after they have moved to holon 3 and formed a new holon, over 1000 epochs, when holon 3 wins the auctions and provides services involving both agents.

Fig. 2 shows the fact that the holon's reputation estimates quickly converge to the value of the quality of service of the agents. Initially, the quality of the agents is unknown, and the holon over-estimates it. However, by collaborating with the agents, the estimation quickly converges to a value close to the actual quality of the agent, and remains around that value. Even if it also works with other lower quality agents, its overall reputation does not vary much.

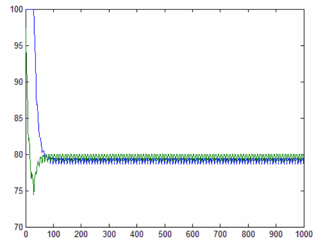


Figure 2. The variation of the reputation estimates made by holon 3 for agents 1 and 2 over 1000 epochs

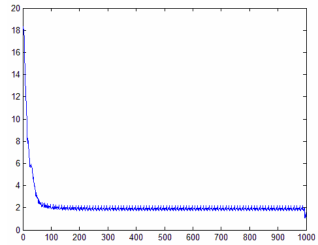


Figure 3. The evolution of the difference between the client's evaluation and holon 3's estimation over 1000 epochs

Fig. 3 presents the evolution of the mean difference between the client's evaluation and the service evaluation (based on the agents' reputation estimates) done by holon 3, over 1000 epochs. At the beginning, the difference between the two evaluations is 18%, but it decreases exponentially and converges to 2% in less than 100 epochs, i.e. the self-evaluation made by the holon converges to the actual quality of the service with a 2% error.

Next, we will consider the network presented in Fig. 4 and we analyze the way the reputations are adjusted for holon 5, when it solves a greater number of requests. There are 37 agents (with their IDs from 0 to 36, given in the order of the holons and the agents) and 8 elementary services. This network is more complex than the previous one and therefore the distances and connections between different machines will play a bigger role in the evolution of the holons. Due to the larger number of agents specialized on each service, the offers are more complex and the agents move a lot more across the network. Also, more new holons appear.

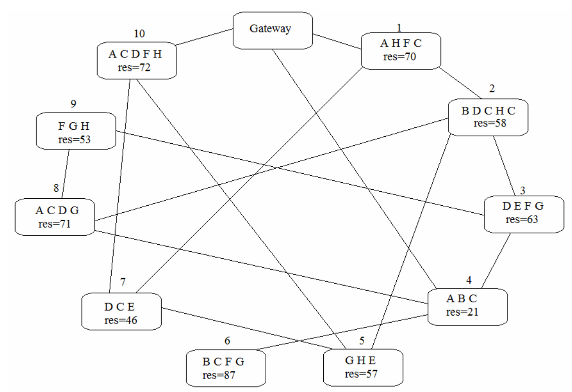


Figure 4. Complex network topology and the holons

Fig. 5 presents the evolution of the mean quality for a given service (*ABFDGFCFC)*, as it is evaluated by the client. In the first epochs the quality decreases because the agents with a better quality of service move to different holons for different tasks or are busy. However, over time, as the holons' estimates for the agents' quality improve and new holons appear, the quality of the composite services improves and remains high throughout the following epochs.

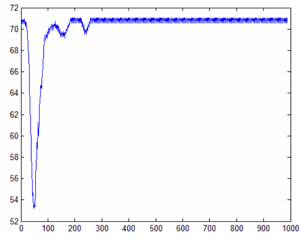


Figure 5. The evolution of the mean quality of a given service

It should be noted that the graphs, the reputations, and the initial positioning of the agents in the case studies were generated in a completely random manner. Therefore, we believe that the interaction model can be useful in any other context that complies with our basic assumptions presented in Section II.

There are many reputation and trust models currently available in the literature. Some approaches aggregate direct experience and indirect recommendations [10] or use probability theory [11]. Others apply typical artificial intelligence techniques such as: Bayesian networks [12], Dempster-Shafer theory [13], or reinforcement learning [14]. Compared to other reputation models, we consider that simplicity and rapidity are the main advantages of our approach. As each holon learns the quality of the other agents at run time, these estimations converge quite fast and the quality of the composite services themselves is shown to increase. Therefore, for the given problem of task allocation and service composition, it seems that our model is efficient.

IV. CONCLUSIONS

We have presented a model for holonic coalition formation and cooperation for providing different services over a homogenous network. The main elements that determine the holonic coalitions are the estimated reputations of the composing agents. At the beginning, all agents are assumed to provide their services with 100% quality, so the agent transfers are determined mainly by the distances between the holon machines, and, to a lesser degree, by the resources of these machines. After a few more epochs, the agents group themselves into holons based on the estimated quality of each other.

Also, at the beginning, the auctions could be won by holons with lower quality agents, because the winners are decided based on the estimated execution times. Over time, the estimated reputations of their agents decrease until they are no longer allowed to bid and the good agents leave as well. After collaborating more times for providing a service, if the feedback from the client is favorable, and their reputations do not suffer much variation, the agents remain together for the following epochs. If the overall reputation of a holon is over a given value, $\rho_{cohesion}$, its composing agents refuse to split. Also, if a group of agents collaborate and receive positive feedback from the client, after a few epochs they unite to form a new holon within the holon they were members of.

ACKNOWLEDGMENT

This work was supported by CNCSIS-UEFISCSU, project number PNII-IDEI 316/2008, *Behavioural Patterns Library for Intelligent Agents Used in Engineering and Management*.

REFERENCES

[1] Fischer, K., Schillo, M., and Siekmann, J.: Holonic Multiagent Systems: A Foundation for the Organisation of Multiagent Systems, Proceedings of the First International Conference on Applications of Holonic and Multiagent Systems, HoloMAS'03, LNAI vol. 2744, pp. 71-80, Springer Verlag, 2003.

[2] Koestler, A.: The Ghost in the Machine, Hutchinson & Co, London, 1967.

[3] Fischer, K.: Holonic Multiagent Systems – Theory and Applications, Proceedings of the 9th Portuguese Conference on Artificial Intelligence: Progress in Artificial Intelligence, EPIA'99, LNCS vol. 1695, pp. 850-864, Springer Verlag, 1999.

[4] Adam, E., Mandiau, R., and Kolski, C.: Application of a Holonic Multi-Agent System for Cooperative Work to Administrative Processes, Journal of Applied Systems Studies, no. 2, pp. 100-115, 2001.

[5] Pěchouček, M. and Mařík, V.: Industrial deployment of multi-agent technologies: review and selected case studies, Autonomous Agents and Multi-Agent Systems, vol. 17, no. 3, pp. 397-431, 2008.

[6] Bürckert, H.J., Fischer, K., and Vierke, G.: TeleTruck: A Holonic Fleet Management System, Proceedings of the 14th European Meeting on Cybernetics and Systems Research, vol. 2, pp. 695-700, 1998.

[7] Lind, J., Fischer, K., Böcker, J., and Zirkler, B.: Transportation scheduling and simulation in a railroad scenario: A multi-agent approach, Proceedings of the 4th International Conference on The Practical Application of Intelligent Agents and Multi-Agent Technology, pp. 325-344, London, UK, 1999.

[8] Leitão, P., and Restivo, F.: A holonic approach to dynamic manufacturing scheduling, Robotics and Computer-Integrated Manufacturing, no. 24, pp. 625-634, 2008.

[9] Dijkstra, E.W.: A note on two problems in connexion with graphs, Numerische Mathematik, no. 1, pp. 269-271, 1959.

[10] Zacharia, G.: Collaborative Reputation Mechanisms for Online Communities, Master's thesis, Massachusetts Institute of Technology, 1999.

[11] Schillo, M., Funk, P., and Rovatsos, M.: Using Trust for Detecting Deceitful Agents in Artificial Societites, Applied Artificial Intelligence, vol. 14, no. 8, pp. 825-848, 2000.

[12] Esfandiari, B. and Chandrasekharan, S.: On How Agents Make friends: Mechanisms for Trust Acquisition, Proceedings of the Fourth Workshop on Deception, Fraud and Trust in Agent Societies, Montreal, Canada, pp. 27-34, 2001.

[13] Yu, B. and Singh, M.P.: Distributed Reputation Management for Electronic Commerce, Computational Intelligence, vol. 18, no. 4, pp. 535-549, 2002.

[14] Sen, S. and Sajja, N.: Robustness of Reputation-based Trust: Booblean Case, Proceedings of the first international joint conference on autonomous agents and multiagent systems (AAMAS-02), Bologna, Italy, pp. 288-293, 2002.

Education Portal for Reactive and Proactive Service Provision

Stanimir Stoyanov
Department of Computer Systems
University of Plovidiv "Paisii Hilendarski",
bul. "Bulgaria" № 236, Plovidv, Bulgaria
e-mail: stani@uni-plovdiv.bg

Veselina Valkanova
Department of Computer Systems
University of Plovidiv "Paisii Hilendarski",
bul. "Bulgaria" № 236, Plovdiv, Bulgaria
e-mail: veselina_viva@abv.bg

Georgi Cholakov
Department of Computer Systems
University of Plovidiv "Paisii Hilendarski",
bul. "Bulgaria" № 236, Plovidv, Bulgaria
e-mail: gcholakov@uni-plovdiv.bg

Mincho Sandalski
Department of Computer Systems
University of Plovidiv "Paisii Hilendarski",
bul. "Bulgaria" № 236, Plovdiv, Bulgaria
e-mail: sandim@uni-plovdiv.bg

Abstract. **The DeLC (Distributed eLearning Center) project aims to develop a reactive, proactive and personalized e-Learning environment. In the paper the agent- and service-oriented portal architecture is presented, ensuring reactivity and proactivity. Furthermore, reactive and proactive behavior of the architecture has been demonstrated by help of the Evaluator Assistant (EA). EA provides expert assistance to the lecturer in assessment of the electronic tests. The results of experiments with the assistant have been discussed. The application of flexible software architecture with reactive and proactive behavior is demonstrated in the paper.**

Keywords - eLearning; education portals; agent- and service-oriented architectures; intelligent assistants; reactive and proactive behavior.

I. INTRODUCTION

In recent years, the interest towards electronic education has been growing stronger. As a result of that many universities have developed and implemented their own systems for electronic and long-distance education. Alternatively, many of the large IT corporations (e.g., Microsoft (Microsoft Class Server [1]), IBM (The IBM Learner Portal [2]), and HP (HP Learning Center [3]) have developed commercial systems. On the other hand, there are different open-source systems available on the market (the best known is Moodle [4]). A number of standards for electronic and life-long learning are also emerging. There are quite a few organizations working to develop specifications and standards such as IMS [11], ADL [5], ARIADNE [12], IEEE [13], ISO [14], etc. to provide a framework for e-Learning architectures, to facilitate interoperability, content packaging, content management, Learning Object Meta data, course sequencing, and many more. A significant role is played by the Sharable Content Object Reference Model 2004 (SCORM) standard [5].

DeLC (Distributed eLearning Center) is one of the projects aiming to develop an environment that supports electronic and long-distance forms of education. The center's main ideas are laid out in a number of publications [6]. Why, despite the presence of so many systems, do we find it necessary to dwell on this subject? DeLC is mainly a scientific research project for developing new context-oriented and adaptive architectures. An important goal of this project is the development and experimentation with prototypes of such architectures in a certain application area - in our case e-Learning. To achieve this goal we develop service- and agent-oriented environment for the delivery of teaching materials and educational electronic services.

Furthermore, in many of the existing e-Learning systems, the interaction with the teachers is somewhat static – this is achieved mainly through pre-defined templates for choosing information resources. The information resources are the electronic equivalent of the traditional textbooks. Some of the existing systems use visualization and animation for improving the means of presenting the teaching materials. In our project we would like to research how such architectures can promote the development of electronic education environments, which support an interactive, proactive and personalized process of education and stimulate the students' creative and innovative thinking and performance.

In this publication, we present the DeLC education portal, which supports a reactive and proactive service provision. The rest of the paper is organized as follows. The second section presents the portal architecture. In the third section the Evaluator Assistant is described and experiment results are summarized. Finally, the fifth section concludes the paper and considers the state of the current development.

II. REACTIVE AND PROACTIVE PORTAL ARCHITECTURE

The proactivity improves the usability and friendliness of the system to the users. Proactivity means that the software can operate „on behalf of the user" and „activate itself" when it „estimates" that its intervention is necessary. In the portal, proactivity is ensured through „reinforcement" of the service-oriented architecture with intelligent components,

 ISBN: 978-1-61208-155-7

which demonstrate proactive behavior. Two approaches are available:

- Direct integration of intelligent components in the service-oriented architecture.
- Building a two component architecture where the front-end delivers services to the users and the back-end implements the reactive and proactive behavior of the portal.

For technological reasons (difficulties in the integration of two environments with different characteristics – portal frame and agent-oriented environment) we chose the second approach. So the intelligent components (agents), called „assistants", will „live in" the back-end agent-oriented server (Figure 1).

The connection of the front-end and the AV is made through the middle layer of the portal architecture, where the electronic services are located. Depending on the direction of the asked assistance we distinguish reactive and proactive behavior of the architecture. In the reactive behavior the interaction between the two components is initiated by the portal. This is necessary in the cases when a user request is processed and a service needs an "expert" assistance. The service addresses the corresponding agent, located in the AV. The problem is that, in their nature, the services are passive and static software modules, intended mainly for the convenient realization and integration of some business functionality. Therefore they must „transfer" the responsibility for the activation and support of the connection to an active component of the architecture, as agents do. To do this, the service sends a concrete message to the agent's environment, which, on its behalf, identifies the change of the environment and reacts by interpreting the message. Depending on the identified need of assistance the agent activates the necessary actions. The reactive behavior of the architecture could be implemented using a:

- Synchronous model – this model is analogous to calling subroutines in programming languages. In this model the service sends a message to AV and waits for the result from the corresponding agent before continuing its execution.
- Asynchronous model – in the asynchronous model the interaction is accomplished through some kind of a mechanism for sending and receiving messages.

In the proactive behavior (agents work „on behalf of the user"), an agent from the AV can determine that in its environment "something is happening", that would be interesting for the user, who is assisted by that agent. The agent activates and it can perform certain actions to satisfy the preferences (wishes) of the user. The agent can inform the user of its actions through the educational portal.

The difficulties, associated with the management of the proactivity of our architecture, result from the fact that the portal is designed for reaction of the user's requests. Therefore the proactivity can be managed only asynchronously and for this purpose we provide development of a specialized service, which is to check a "mailbox" periodically for incoming messages from AV.

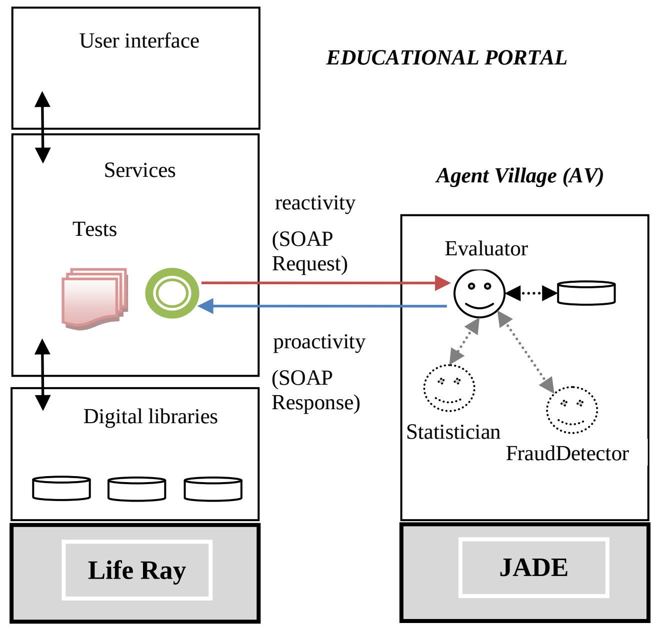


Figure 1. Extended architecture of the portal.

III. Evaluator Assistant

The Evaluator Assistant (EA) provides expert assistance to the teacher in assessment of the electronic tests. In the Test Engine a system service is built for automated assessment of "choice like" questions. In the standard version of the architecture questions of the "free text" type are assessed by the teacher and the ratings are entered manually in the service to prepare the final assessment of the test. In the new architecture the Test Engine calls the assistant (an intelligent agent), which makes an "external" assessment of the "free text" type questions.

In case of need of an "external" assessment, where the Test Engine initiates a „request" for expert assistance, the reactive behavior of the EA is exploited. In order to be identified, the EA has a wrapper (the environment of the agent), which "masks" it as a web service for the portal. The Test Engine is extended with a new system service EstimationProcessor, which takes care of forming the request and processing the answer. When a request for assistance arises, this service generates a SOAP Request message and sends it to the Agent Village. When a SOAP Response is received, it parses the answer and extracts the estimated rating by the EA.

In the surrounding environment of the EA, the received SOAP Request messages are transformed into Agent Communication Language [10] messages, understandable for the agent. Some of the basic parameters of the messages are:

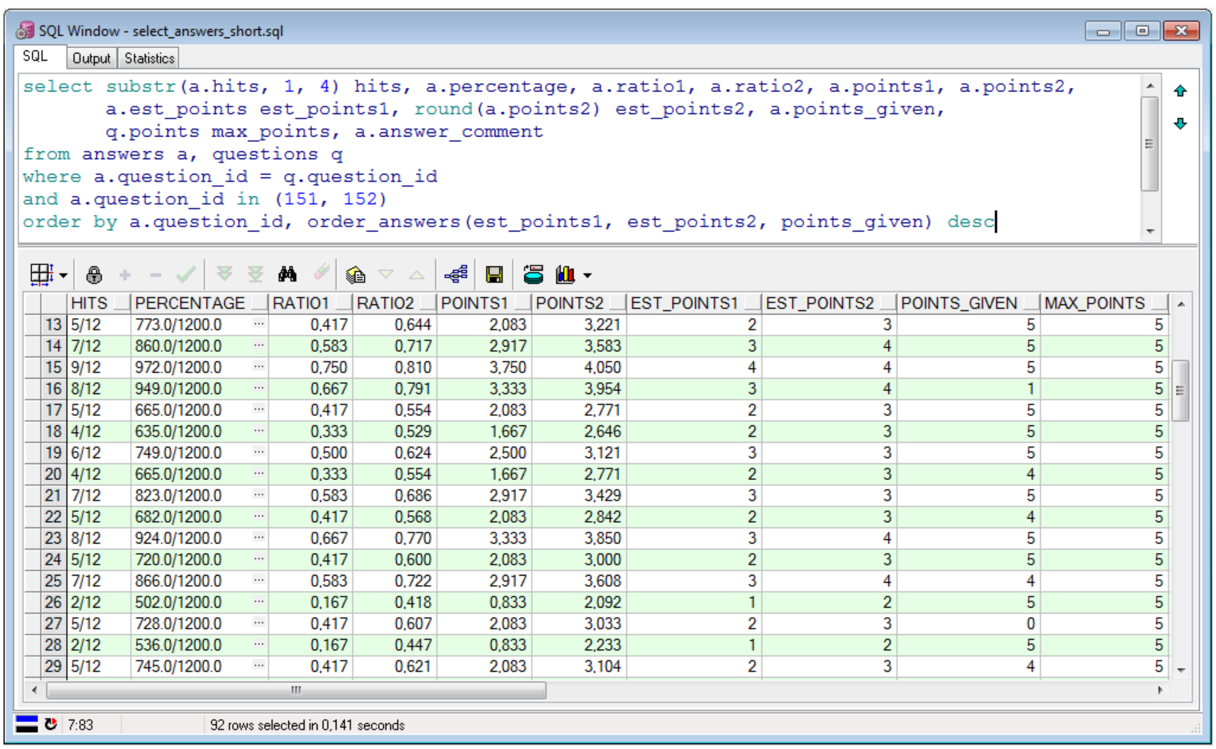
 ISBN: 978-1-61208-155-7

- Text, which is an answer of a “free text” type question.
- Parameters for the used estimation method.
- Maximum number of points for this answer.

The EA plans the processing of the request. In the current version of the assistant two methods are available for estimation. For these methods we have used some ideas from the existing algorithms for string matching [9]. The **Word-Matching (WM)** method counts „exact hits” of the keywords in the answer. The experiments show, that in short words (up to 5 symbols) this method gives relatively good results (over 50% matches). The minimum threshold of percentage match (i.e., a keyword to be considered as „guessed“), which is laid in the experiments, is between 70% and 80%. Intentionally, the method does not look for 100% match, in order to give a chance to words with some minor typos also to be recognized. To calculate the points, offered by this method, a coefficient is formed in the following way: the number of hits is divided by the number of keywords (RATIO1). The actual number of points for the answer is calculated as the maximum number of points is multiplied by this coefficient. The **Optimistic-Percentage (OP)** method makes an optimistic estimation of the points for the answer. Its essence is to iterate over the keywords list and summarize their percentage matches. Thus, the calculated amount of rates for each keyword, divided by the maximum possible match (in %), gives the reduction coefficient (RATIO2). The actual number of points for the answer is calculated by multiplying the maximum number of points by the coefficient of the reduction. This method is more „tolerant“ to allowing spelling mistakes in the answers, because low percentage matches are not ignored (unlike the first method) and are included in the formation of the final amount of points.

When the calculations finish, the EA generates an answer as an ACL message, which then is transformed by the environment into a SOAP Response message (a result from a web service call). In the answer there is a parameter, representing the calculated amount of points, extracted afterwards by the EstimationProcessor.

During the tests of the system there were used questions from the subjects “Introduction to Databases” (IDB) and “Enterprise Application Integration” (EAI). Here we will discuss some results from the tests of the EAI subject. The experiments show that while using the described methods above, the main challenge is the proper selection of a keywords set for each question. The exactness of the results depends on the length of the answer and on the length of the keywords list. The longer these lengths are, the greater is the probability of deviation of the results from the real ones. In Figure 2 is represented the raw data of the implemented tests in EAI using the described two methods, which is selected from the database containing all statistical data.


SQL Window - select_answers_short.sql

SQL | Output | Statistics

```
select substr(a.hits, 1, 4) hits, a.percentage, a.ratio1, a.ratio2, a.points1, a.points2,
       a.est_points est_points1, round(a.points2) est_points2, a.points_given,
       q.points max_points, a.answer_comment
from answers a, questions q
where a.question_id = q.question_id
and a.question_id in (151, 152)
order by a.question_id, order_answers(est_points1, est_points2, points_given) desc
```

	HITS	PERCENTAGE	RATIO1	RATIO2	POINTS1	POINTS2	EST_POINTS1	EST_POINTS2	POINTS_GIVEN	MAX_POINTS
13	5/12	773.0/1200.0	0,417	0,644	2,083	3,221	2	3	5	5
14	7/12	860.0/1200.0	0,583	0,717	2,917	3,583	3	4	5	5
15	9/12	972.0/1200.0	0,750	0,810	3,750	4,050	4	4	5	5
16	8/12	949.0/1200.0	0,667	0,791	3,333	3,954	3	4	1	5
17	5/12	665.0/1200.0	0,417	0,554	2,083	2,771	2	3	5	5
18	4/12	635.0/1200.0	0,333	0,529	1,667	2,646	2	3	5	5
19	6/12	749.0/1200.0	0,500	0,624	2,500	3,121	3	3	5	5
20	4/12	665.0/1200.0	0,333	0,554	1,667	2,771	2	3	4	5
21	7/12	823.0/1200.0	0,583	0,686	2,917	3,429	3	3	5	5
22	5/12	682.0/1200.0	0,417	0,568	2,083	2,842	2	3	4	5
23	8/12	924.0/1200.0	0,667	0,770	3,333	3,850	3	4	5	5
24	5/12	720.0/1200.0	0,417	0,600	2,083	3,000	2	3	5	5
25	7/12	866.0/1200.0	0,583	0,722	2,917	3,608	3	4	4	5
26	2/12	502.0/1200.0	0,167	0,418	0,833	2,092	1	2	5	5
27	5/12	728.0/1200.0	0,417	0,607	2,083	3,033	2	3	0	5
28	2/12	536.0/1200.0	0,167	0,447	0,833	2,233	1	2	5	5
29	5/12	745.0/1200.0	0,417	0,621	2,083	3,104	2	3	4	5

7:83 92 rows selected in 0,141 seconds

Figure 2. Raw results from processing the EAI subject answers.

 ISBN: 978-1-61208-155-7

The columns of the result set are HITS (keyword hits of WM), PERCENTAGE (summarized percents of OP), RATIO1 (a coefficient for calculating the points in WP), RATIO2 (a coefficient of reduction in OP), POINTS1 (points, calculated by WM, EST_POINTS1 – rounded), POINTS2 (points, calculated by OP, EST_POINTS2 – rounded), POINTS_GIVEN (points given by the assessing teacher), MAX_POINTS (maximum number of points for this answer).

Let us pay more attention to answers 16 and 27. The both methods calculated significally higher ratings than that of the teacher, whose comment about these answers is: "Copy/Paste does not bring points!". And these cases are not isolated. Here is where the functionality of FraudDetector agent would be particularly useful, and this inspired the idea for its appearance in the Agent Village.

In Figure 3, comparisons of the final scores given by the two methods, and by the assessing teacher are presented. It is a clear trend that the scores given by the teacher are the "most generous", the optimistic method (OP) is in the second place, and the most exacting method is the one for matching the words (WM).

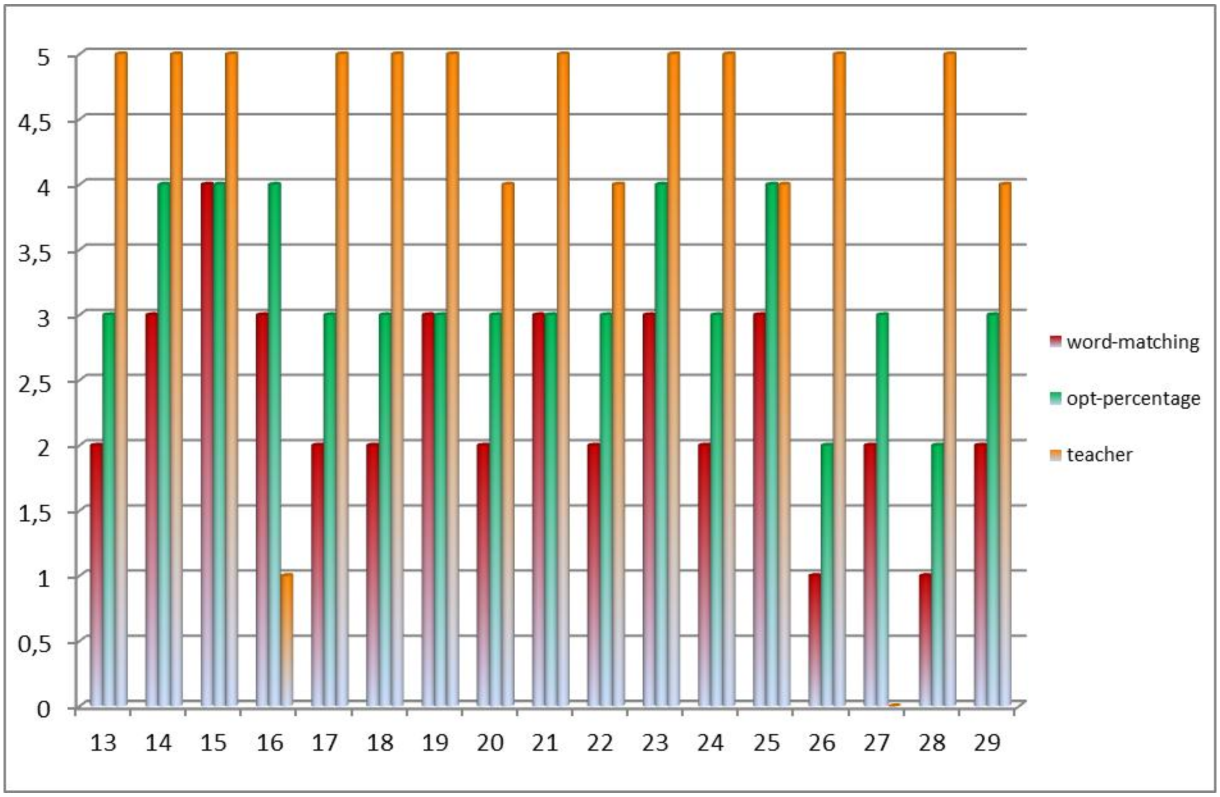


Figure 3. Comparison of the points given by the between algorithms and the teacher (EAI).

IV. Conclusion and Future Works

The portal is testing in the University of Plovdiv and a secondary school in Plovdiv for a year and 360 students had sat for examination in two subjects – „Introduction to Databases" and "Enterprise Application Integration". Two new assistants are in a process of development. The FraudDetector will try to recognize any attempts to cheat in the answers given by the students. Such attempts would be to guess the keywords or copy/paste results from Internet search engines. This assistant will cooperate with the Evaluator agent and if its receptors detect a probability of a cheating attempt, it will inform the Evaluator agent, which will inform the assessing teacher that this answer requires a special attention, because it is a suspicious one. The Statistician will store information about all processed answers with a full history of the details from all calculating methods used by the Evaluator agent. This assistant will need a feedback how many points are finally given by the teacher for each answer. Thus it will accumulate a knowledge base for each teacher and will be able to decide which of the methods best suits the assessment style of the current assessing teacher. Upon returning the results of the Evaluator assistant, information by this agent will determine which results from each method will be presented to the teacher as a main result, and the results of the other methods will be presented as an alternative. Another feature of this agent will be also to provide actual statistics on the performance of each of the calculating methods, as the "weakest" of them will go out of service until new and better performing methods are added to the Evaluator agent. This monitoring of the methods' behavior becomes really significant when the so-called genetic algorithms are added, which we are still working on – as it is known, they can be "trained" and thus their effectiveness can change. In this process a knowledge base will be developed for each specific subject, which will support the methods in their work. These knowledge bases later will be transformed into ontologies for the Evaluator agent.

ACKNOWLEDGMENT

The authors wish to acknowledge the support of the National Science Fund (Research Project Ref. No. DO02-149/2008 and IO-01-01/2006).

REFERENCES

[1] Microsoft Class Server, www.microsoft.com/education/products, (17.05.2011)

[2] The IBM Learner Portal, https://www-304.ibm.com/jct03001c/services/learning/ites.wss/us/en?pageType=page&c=a0006064, (29.03.2011)

[3] HP Learning Center, http://h30187.www3.hp.com/, (21.04.2011)

[4] Moodle, www.moodle.org, (11.05.2011)

[5] SCORM 2004, www.adlnet.gov/Technologies/scorm/SCORMSDocuments/, (16.05.2011)

[6] Stoyanov, S., Ganchev, I., Popchev I., and O'Droma, M., From CBT to e-Learning, Journal Information Technologies and Control, No. 4/2005, Bulgarian Academy of Sciences, pp. 2-10

[7] Stoyanov, S. and Popchev, I. (2006). Evolutionary Development of an Infrastructure Supporting the Transition from CBT to e-Learning, Cyberbetics and Information Technologies (CIT), 2/2006, Bulgarian Academy of Sciences, pp. 101-114

[8] Stoyanov, S., Popchev, I., Doychev, E., Mitev, D., Valkanov, V., Stoyanova-Doycheva, A., Valkanova, V., and Minov, I., DeLC Educational Portal, Cybernetics and Information Technologies (CIT), Vol.10, No 3., Bulgarian Academy of Sciences, pp. 49-69

[9] Knuth, D. E. , The Art of Computer Programming: Volume 3, Sorting and Searching, Addison-Wesley, 1973

[10] ACL. Agent Communication Language Specifications, www.fipa.org/repository/aclspecs.html, (28.03.2011)

[11] IMS Global Learning Consortium, www.imsglobal.org, (23.04.2011)

[12] ARIADNE, www.ariadne-eu.org/, (28.03.2011)

[13] IEEE, www.ieee.org, (20.03.2011)

[14] ISO, www.iso.org, (29.03.2011)

Supporting Adaptability in Agent-Based Digital Healthcare Ecosystem

Victor Rentea[a], Fabrizio L. Ricci[b], Luca Dan Serbanati[c], Andrei Vasilateanu[d]
[a,c,d] Faculty of Engineering Taught in Foreign Languages, Politehnica University of Bucharest
Bucharest, Romania
[b,c] Institute for Biomedical Technology, National Research Council
Rome, Italy
[a] victorrentea@gmail.com, [b] fabrizio.ricci@itb.cnr.it, [c] luca@serbanati.com, [d] andrei.vasilateanu@upb.ro

***Abstract*—The paper describes a new direction towards supporting a continuity of care by using the more natural and expressive paradigm of digital ecosystems. We introduce the conceptual model and architecture of the Digital Healthcare Ecosystem focusing on the reflection of the real to the virtual in healthcare followed by a "contamination" of the virtual in the real. We also propose a nature-inspired, agent-based approach to an adaptive mechanism supporting the evolution of the e-health services in the ecosystem. The mechanism is based on aggregation, migration and selection strategies inspired from biomimicry and distributed evolutionary computing.**

Keywords-virtual healthcare record; digital healthcare ecosystem; biomimicry; multi-agent systems; virtual organisms; adaptability

I. INTRODUCTION

The paper presents the conceptual model of a system supporting the following objectives with applicability in the e-health domain: to ensure a continuum of care on managerial, informational and relational dimensions, and to offer new opportunities to the stakeholders in the health system by introducing an evolution mechanism for the e-health services. Building towards these goals, we take inspiration from nature's mechanisms and shift the paradigm to a *Digital Healthcare Ecosystem* (DHE).

Like any other IT-supported domain, e-health also faces the gap between the business and IT, with domain specific peculiarities. An important concern of the stakeholders is the continuous alignment to norms that will probably increase in complexity due to the current trends towards wide interoperability. A rising number of e-services will be required from part of the e-health organizations, some of which will be also available for e-enabled healthcare actors. DHE attempts to provide a solution to this issue by disseminating and evolving the local human creative energy to meet future needs for e-services.

We start by an overview of the current healthcare and e-health context then introduce the theoretical background for our new direction based on biomimicry, digital ecosystems and multi-agent systems. Section III holds the description of our concept of Digital Health Ecosystems. After an overview of the base principles, we investigate how to achieve a seamless integration between the real and the virtual worlds in healthcare by relying on intertwined control loops. Starting with reflecting the real in the virtual, we introduce an evolutionary mechanism to produce better or locally innovating solutions that can influence back the reality in a positive way. Section IV resumes our current research and sets directions for future steps.

II. THE STATE OF THE ART

A. Healthcare context

In the past two decades, much of the growth in health expenditures has been attributable to chronic conditions in the context of global population ageing. Future health reform should address changed health needs through care coordination and support for patient self-management [2]. It is clear that efficiency and effectiveness of the health system and healthcare management of aged population become prime issues in the attempt of mobilizing the full potential of all people of all ages. The solution requires a shift of paradigm in healthcare towards patient-centric care provided by multidisciplinary teams in different settings along the continuum of a disease. To support the continuity of care for chronic pathologies, Information and Communications Technology (ICT) needs to address different dimensions of business modeling: informational, managerial and relational.

B. E-Health context

Supported by ICT, the management of chronic conditions, home recovery, patient empowerment and coordination of clinical pathways with multiple actors become possible [16]. IT adoption allows innovating or re-engineering healthcare sectors to promote the economic sustainability of healthcare services and improve their quality.

The existing healthcare information systems are not suitable to meet these requirements because they are oriented to acute disease care, emphasize short encounters of patients with their caregivers, favor diagnosis and treatment of only the current symptoms and usually support the caregiver's activity in solitude. Following the patient-centric trend, we consider that a solution should go along three directions:

1. Integration of healthcare systems in order to share common information health state of each individual;

2. Support of all various business processes in the health system ranging from patient care provision to health

governance with coordination, control, alert, and monitoring services;

3. Promotion of the collaboration between caregivers, organizations and patients by creation of ad-hoc teams of stakeholders involved in one patient's care.

C. Biomimicry

Biomimicry is the science that studies nature, its systems, processes and elements and takes creative inspiration from them for the design of modern technology [3]. In computer science, biomimicry produced Nature Inspired Computing with several branches of which we are interested in Biologically-Inspired Computing. BIC takes inspiration from nature for the development of complex problem-solving techniques such as Evolutionary Algorithms (EA), neural networks and swarm intelligence.

The method employed by using biomimicry tends to be ad-hoc and un-formalized [3] and generally involves an engineer or scientist observing an area of biological study which seems applicable to a research problem they are currently tackling. The biological mechanisms need then be well understood, abstracted and applied to the non-biological system whilst also being aware of its particularities.

An ecosystem is a natural unit made up of living (*biotic*) and non-living (*abiotic*) components, from whose interactions emerge a stable, self-perpetuating system [11]. In Computer Science, [20]Digital Ecosystems are a new research area that builds upon Multi-Agent Systems, Service Oriented Architectures and Evolutionary Computing.

D. Multi-Agent Systems

A software agent is a piece of software that acts autonomously in an environment to achieve its design objectives. A Multiple-Agent System (MAS) is a system composed of several software agents collectively capable of reaching goals unachievable by an individual agent or a monolithic system [4].

Healthcare is and has been a field of interest for the use of software agents [5] because the agent-based paradigm is a natural way of representing many recurrently occurring situations in medical environments such as: absence of a central control, bounded resources of a caregiver, and knowledge and data distribution. Research projects have targeted specific use-cases of healthcare, such as workflow-oriented care plan monitoring or the establishment of agent-based virtual organizations around a patient [6]. Also, recent research in agent development has stressed the need for collaborative environments such as e-health to focus also on organization- and artifact-based agent environment [18].

When mapping natural ecosystems in the virtual intelligent agents can conceptually represent organisms despite their lack of mobility and evolution. Even if mobility is added in Mobile Agent Systems, the lack of evolution limits the resemblance with their biological counterparts.

E. Service-Oriented Architectures

Trying to support adaptability in DHE, we need a modular reusable paradigm to software development that allows us to modify the virtual to comply with the changing reality. Often considered as developing the concepts of modular programming and distributed computing [7], SOA is the best choice. This encompassing paradigm is an approach to organizing software in the form of independent, interoperable services. A service is the encapsulation of some related software functionalities accessible by clients in network. It is exercised consistent with constraints and policies as specified by the service description and can be discovered using some interpretable metadata. The same service can have multiple implementations. It can be composed and recomposed from other services or participate in service compositions to fulfill multiple business requirements. SOA does not take into account evolutionary semantics and context-awareness for services. This is why it has been suggested [9] that the SOA approach is not adequate to face the dynamic interactions between evolving organizations and a shift of paradigm towards an Ecosystem-Oriented Architecture is required. However, we believe that any attempt to change the paradigm should build upon the current largely embraced technologies and one of the goals of our research is to investigate how such a shift can be achieved.

Our work builds towards the great promise of SOA that the marginal cost of creating the n^{th} application is virtually zero, as only the combination of existing software is required [8]. Taking into consideration the complexity of e-health, the approach should build upon the latest technologies in interoperability, such as Semantic Web Services.

F. Digital Ecosystems

The term *digital ecosystem* (DE) is being increasingly used for describing the future developments of ICT in e-business towards the so-called *digital business ecosystems* [17]. According to [1], we consider a DE as "an open, loosely coupled, domain clustered, demand-driven, self-organizing and agent-based environment within each species is proactive and responsive for its own benefit and profit".

A rigorous and somewhat revolutionary approach referring to digital ecosystems is that of [10] that aims to establish a novel form of Distributed Evolutionary Computing by creating a digital counterpart of biological ecosystems. The basic idea is to combine an Evolutionary Algorithm with the migration of solutions to face a dynamic stream of requests for software from a heterogeneous *User* base. The "organism" and the basic building block is the *Agent* that represents a software service or a SOA-style aggregation of services. In the envisioned distributed system, Agents move around Users to find the environments in which they prove most useful to subsequent requests for applications. Applications are assembled on-demand using a *Genetic Algorithm* (GA) seeded with the Agents "living" in a *Habitat* associated with that User. Our approach takes great inspiration from this work to which adds several innovating features, highlighted in the last section.

III. THE DIGITAL HEALTH ECOSYSTEM

A primary goal of our research in Digital Ecosystems is to explore the possibility to employ in the e-health domain the strengths of biological ecosystems, such as self-organization, adaptability, self-manageability and the ability to provide hierarchical solutions to complex problems [20]. In front of complex information-intensive decision tasks in e-health, we are attempting to move the control process in the virtual world, where information is fast and efficiently accessible. For doing this, we need to increase the permeability between the two worlds through bridges that must be added in the form of sensors and actuators, which bring in the virtual the state of the reality and act upon it, respectively. Due to the increased complexity of coordinating the processes in e-health, the traditional software controller responsible for this task is replaced in DHE with a mechanism that relies on evolution. The decisions are no longer taken based on an implicit or explicit rule set, but derive from a process of evolution that runs in a context reflecting the reality. Evolution mechanisms in the virtual operate both retrospectively, to align the virtual to changes sensed in the reality, and prospectively, to generate different models to propose or impose, depending on the case, to the real world. To be useful, the virtual must always remain in close contact with the real, such that any autonomous evolution of one of them must rapidly be followed by the other. In essence, the DHE tries to speed up the evolution process at a different level, by mapping the real to the virtual, evolving a solution or a proposition and then using it to influence back the real world.

Until now, the digital had to react to changes in the uncontrolled reality, but due to the recent advances in pervasive computing it is now becoming possible for the virtual to act upon the real in its turn and to achieve goals emerging from virtual.

The entities inhabiting the DHE are partitioned in two groups (Figure 1): entities that map a real entity into the virtual world and purely virtual entities without any real counterpart. The latter are further distinguished into passive *virtual artifacts* and proactive *virtual agents*, such as those that will perform monitoring and maintenance tasks in DHE. When mapping the real into the virtual, we recognize between mapping in an agency relationship or in a pure representational purpose. In this sense, an *avatar* is a proactive agent working towards the goals of the stakeholder it represents, but also following additional objectives related to the virtual environment in which it lives. On the other hand, an *artifact* is a passive or reactive entity, defined as a "first-class abstraction introduced to model and engineer general-purpose computational environments for multi-agent

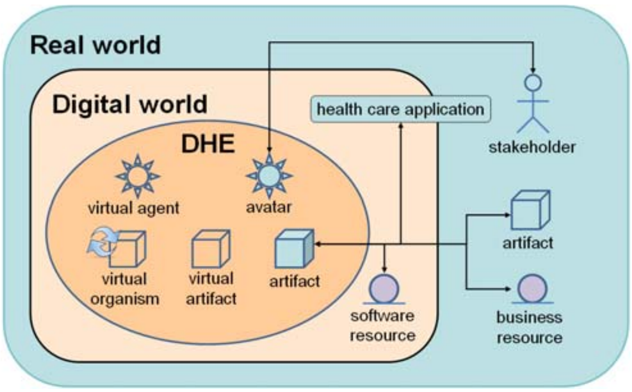


Figure 1. The Digital Health Ecosystem

systems" [18]. An artifact is the virtual projection of a real entity, either physical (e.g. device, drug, operation room) or digital (e.g. software application, resource, database).

Following a discussion on the control mechanisms in action, the rest of this chapter presents the system by following the natural flow, from real to virtual and back to real, focusing on the DHE distinctive features and the new evolution mechanism residing in the virtual world.

A. *Control loops*

In the real world the patient's health care is a typical control loop process where activities of human analysis (observation and diagnosis), planning (care plan delivering), and execution (treatment) must be completed by evaluation in order to measure the progress in the care.

DHE can support this process in its various activities but only being aware that the reality has been and will be the origin and destination of any immersion in the virtual. The virtual itself appears due to a need in the reality and therefore is subordinated to it. As a consequence, for the virtual to be helpful it must be able to influence the real world, thus closing the main control loop of DHE.

Both worlds aim at improving the current situation by inspiring one from another and evolving creative solutions.

The virtual should accurately reflect the most relevant aspects of the reality and be kept in tight contact by continuous update processes. In DHE, evolution processes take place in a context that mimics the real situations. Feedback information to assess the alignment between the two worlds is needed. In this way a second control loop is identified.

The evolution processes in DHE produces a creative energy that can be used for the benefit of the reality. Sometimes the evolution in the virtual may anticipate changes in the real and new ideas in virtual may accelerate the evolution of the real world by "osmosis". The proposals the DHE issues may be presented to stakeholders that can decide for restructuring the actual systems. Information about the success or failure of the solutions is reported back in the DHE and constitutes the feed-back for controlling future evolutions.

The three control loops are presented in Figure 2.

B. *Virtualization*

In DHE, the avatars live in an environment populated by artifacts (abiotic components) and governed by norms and laws inherited from the real world. Avatars are able to organize themselves in hierarchical structures mimicking the real organizational structures. Their proactivity follows some goals that are derived from the roles, goals and concerns of those real stakeholders that they represent and act as vectors for the self-conscious initiative of the humans.

Mapping the real to the virtual in this case is addressed differently depending on the role each stakeholder plays. In the case of the patient's avatar we are interested in an accurate reflection in the virtual of his/her health state, while for the doctor's avatar his/her medical knowledge is important to be reflected. For the former, we rely on our past research on the *Virtual Healthcare Record* [19], a complete

 ISBN: 978-1-61208-155-7

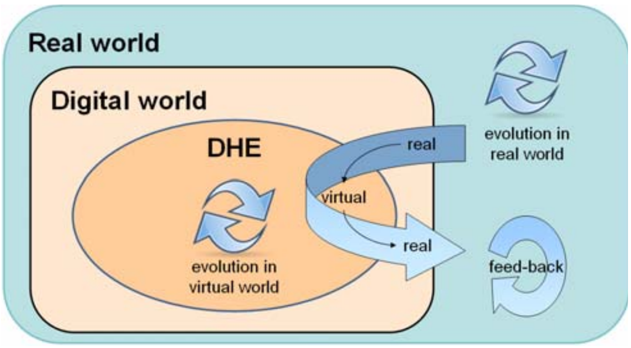


Figure 2. Real to Virtual to Real

and authoritative representation of the patient's current health state, clinical history and ongoing care processes, including information on demographics, past medical history, normal values of vital signs, medications and treatment plans. We designed our conceptual model for the virtual health state of the patient, by applying successive abstractions to the reality. The health state concept is an ideal, as we can never reach a perfect match between the real situation of the patient's health and the digitally represented health state. However we can strive towards it by multiplying the observations resulting from a diagnostic investigation process where additional investigations are needed to build a useful, reliable health information set that can be further used in decisions.

Activities in the ecosystem may be initiated by certain situations in the environment and in turn modify it. Such a situation is a *MedicalAct* and can be a condition found in the health state of the patient or a lack of knowledge thereof. An activity in the health ecosystem is transmitted through the stakeholder avatars in the digital ecosystem as an event or as a data flow. Subsequently, this will favor some activities to be executed by the digital ecosystem agents and may also change the knowledge about the real world. This means that activities inside the DHE are indirectly and partially determined by actions and events in the real world.

Clinical events, changes in the health state of the patient arrive through the information flow inside the digital ecosystem and can change the state of the patient avatar. A need in the real world is transformed into a care goal in the DHE. Reacting to this change in the environment, avatars representing different healthcare providers are assembled into an ad-hoc multidisciplinary team, having a structure generated by the process of solving that care goal.

In the paper, the focus is on the living environment of the avatars in DHE, filled with artifacts among which projections of the applications used by stakeholders. The digital part of the healthcare ecosystem reflected in DHE must be flexible and adaptable to support the dynamic stakeholder activity and organization.

C. *The virtual organisms*

We will refer to *virtual organisms* (VO or, hereafter, in short, *organism*) as a kind of virtual artifacts that can evolve autonomously, that is, change internal structure according to changes in their living environment. Although they lack proactivity, the collective behavior of the avatars regarding those reproduces the mechanisms we observe in the natural ecosystems, allowing them to evolve in ways similar to physical organisms. A VO can be used for various types of structured solutions, but in the paper we will focus on evolving software applications in a SOA meaning.

The VOs live near avatars that own and support their existence by providing them with living *Habitats*. The abiotic environment for VOs is a set of interconnected Habitats, each with its particular living conditions. The avatar uses the population in its Habitat for solving local requests for applications and effects explicit control on this population through new VO addition and removal. In this way the relations between avatar, Habitat and organism were defined. The following will further address the evolution of the organisms in the network of Habitats (Figure 3).

The living conditions of the Habitat change according to the application requests received, allowing potentially useful VOs to live longer and forcing the non-fitting to emigrate or die. Focused not only on software creation but also on its adaptation, we believe that after an application was generated similar requests will follow, due to the continuous change in the e-health domain. In order to gather more VOs for subsequent software changes, we set the environment of our Habitat stateful by storing every new application request. Based on the past requests, a fitness landscape can be calculated for the evaluation of incoming organisms and the estimation of their future usefulness and survival. In our approach, the avatar has full control over the parameters of the bio-mimicked processes in its Habitat, although recommendations will be formulated.

Virtual organisms represent software components or applications and carry a *semantic description* of their functionality and an *executable component* consisting in either a service or a service aggregation, in a SOA-style. On-demand software assembling and modification requires a component-oriented model of which SOA is the current state of the art [7] and a great degree of interoperability, featured

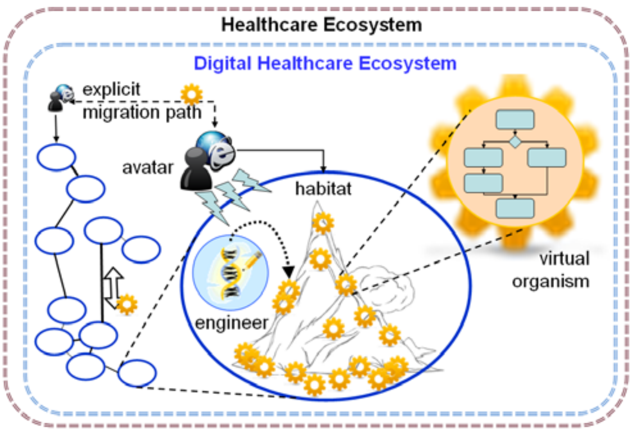


Figure 3. Virtual Organisms in the network of Habitats. The picture represents, from left to right: the weighted network of Habitats, each with its own avatar; the 2 types of VO migration; the structure of a Habitat with a specific landscape fitness; the meaning of an VO.

by the use of semantic descriptions for services [12]. The executable component of a composite VO is an encoding of the entire SOA workflow and represents its genetic material (*genotype*). Unlike other entities in DHE, autonomic evolution of VOs is possible by applying recombination and mutation on their genotype.

Special attention should be addressed to the distinction between *genotype* and *phenotype*, because it takes more than a genotype to produce a phenotype. In biological terms, the *phenotype* of an organism is the manifestation of its genotype in a given environment [13]. Similarly, we consider the phenotype of a VO to reflect the actual behavior of its executable component when operating in deployment environment. Examples of phenotype attributes include response time, availability, cost, quality and security. The same individual, carrying the same executable component, that is, the same genotype, expresses a different behavior in different environments, that is, a different phenotype [13]. Even though the distinction between genotype and phenotype is generally not present in today's EAs [14], it cannot be overlooked in our scenario, as the execution of a distributed SOA application depends on a variety of factors including different configuration parameters, geographical location, local resources, legacy systems and usage pattern.

When offering a software solution to an application request, we are interested in knowing not just the genotype but also the phenotype, i.e., the future actual behavior. Unfortunately, the entire phenotype cannot be known at generation time and querying, deductive, inductive or recommendation-based strategies could be employed to gather as many information as possible. We must also admit the multi-purpose optimization nature of the task, the variety of algorithms that can be employed and the difficulty to build a proper fitness function. Thus emerges the need of decoupling the application generation task and allowing various implementations to coexist in the form of *engineer agents* (as in "genetic engineering"). Whatever their implementation may be, these agents start with the population within the Habitat, localized and probably useful to the user, on which then apply an EA and derive a solution to produce the application requested. Although we admit the need of a type of EA, we do not commit ourselves to a genetic algorithm as [10] nor to any other particular algorithm. Instead, we only require that in each Habitat an engineer agent is in function. At this point, evolution has been added to our system, as an essential component of an ecosystem's stability.

There are additional key features that enable the strength of biological ecosystems: population dynamics, local interactions and spatial distribution. A natural consequence of the distinction between genotype and phenotype is the possibility that a solution inefficient in Habitat *A* may be of great help in Habitat *B*, operating within other conditions. On the other hand, the organism with a strong genotype has high chances of being useful in other Habitats in response to similar requests. In order to produce the best individuals, a mechanism for migration is required, that is, moving in the former case and copying in the latter case. While copying is intuitively best used for highly fit individuals and enable fast

```
deploy_agent(ag)
ag.max_cycles = ∞
for each h in ag.friendly_habitats
  send_success_feedback(h)
for each conn in this_h.connections
  if randomTrue(conn.strength) and
      not conn.remote_h in ag.visited_habitats
    copy(ag,conn.remote_h)
```

Figure 4. Successful agent usage algorithm

`ag` is set to "perpetuating", links are established or strengthened with the habitats in which `ag` was used, and `ag` is randomly migrated to connected Habitats

dissemination of quality software, moving weak organisms to other Habitats helps in maintaining diversity throughout the digital ecosystem and escaping the local optima locking [14]. Mechanisms such as organism's life duration should be enforced in order to limit the dissemination process when copying and to force low-quality solutions to eventually disappear after several migrations.

The feed-back produced by the *migration success* on the *migration path* is a simple improvement to Distributed Evolutionary Computing that eventually leads to self-organization of the Habitat network based on similar application requests [10]. Links between Habitats are weakened or strengthened by the migration *success*, i.e., when the organism proved useful in the remote Habitat (Figure 4). This represents a form of Hebbian learning [15] in which Habitats are seen as neuronal cells.

The migration mechanism represents a paradigm shift from pull-based, currently used with SOA, to push-based mechanisms, in which avatars collaborate on their own will, proactive for the society's benefit, to provide the real world with the best possible software with the lowest possible cost.

D. *Influencing the reality*

The final purpose of the DHE is to influence the reality by proposing a new or updated model, obtained through evolution. The virtual organisms produced in DHE lead to the creation of new e-health services in the reality, contextualized and adapted to the requirements, better or even completely new in that context. If such a proposal is accepted and deployed, it leaves the virtual world and becomes an artifact in the real world, that is, deployed software. Given a VO is a solution with applicability in the reality, its constituting elements must also be elements brought from the real world, i.e., artifacts representing software entities. As such, the responsibility of the DHE is not to invent new software from scratch but to evolve solutions by combining real components, seen as the manifestation of the human creative power in front of different problems. From this point of view, DHE is an enabler of global evolution based on local human creativity.

In DHE, the healthcare organizations will probably benefit most from evolving software e-services to conform to the norms, best practices and local specific requirements. For better understanding, the software adaptation to a change in the healthcare norms is presented next. The change in legislation is pushed in the DHE where subsequently threatens the compliancy of the current software applications. The avatar senses the situation and tries to adapt each impacted application deployed within its organization. For each of them, the previous request is edited accordingly to the change in norms and re-issued in the local Habitat. The decisions of the avatar may rely on a Belief-Desire-Intention model following the preferences and goals of the individuals in a community. Within several limits, the reality need not even be notified about the event, being shielded or at least helped in front of the continuous change.

The adapting of software services can prove useful also for those people that run locally deployed software, for their own use, most probably software clients. The evolution of the applications may offer a richer interface, self-adaptability to changes in provider-side and even support contextualization of e-health services. A form of evolution, context adaptation relies on ad-hoc connections between avatars in DHE that enable the migration of virtual organisms towards the local Habitat to support in context-dependent applications.

For both use-cases, the specific interests and preferences for software are reflected by the connections of the local Habitat within the Habitat network, gathering the most useful selection of software available.

IV. Conclusion and Future Work

Our research in Digital Healthcare Ecosystems is part of the project "An innovative approach to health care by a seamless integration of real and virtual worlds" which is now in the inception phase. This phase consists in defining the conceptual model of the DHE and in interviews with the involved stakeholders in order to achieve an accurate view of the business processes. The paper presents our research on evolutionary processes in DHE that is inspired from [10] to which adds the following contributions. The genotype of a virtual organism in DHE is not just an unordered set of genes but fully encodes the workflow it represents. The evolution is not strictly based on a genetic algorithm but various EAs are allowed, as different evolution mechanisms will help improve diversity of the VOs. Another improvement is the explicit specification that the evolved virtual organisms do not manifest proactivity in a MAS way. Instead, they follow nature-mimicked processes without being able to interfere, and therefore are seen as virtual artifacts in DHE.

In the paper, e-health services are created to support the evolution of software in a dynamic environment reflecting the reality. Our approach relies on a self-organizing network of localized Habitats that provide a scalable approach towards automatic composition from among numerous distributed services, therefore building towards the SOA great promise [8]. A great potential of DHE is to become an enabler of global evolution based on local human creativity manifested as disparate distributed services. The results of initial simulations of the evolution mechanisms are very promising but, to be relevant, must rely on an estimated usage profile, which we plan of building next. On the other hand, other applications for the evolution mechanisms are possible and will be analyzed in further work, including evolving and adapting treatment plans and wellness assistance for a patient having a monitored health state.

References

[1] E. Chang, M. Quaddus, and R. Ramaseshan, "The vision of DEBI Institute: digital ecosystems and business intelligence", DEBII, 2006.

[2] K. Thorpe, L. Ogden, and K. Galactionova, "Chronic conditions account for rise in medicare spending from 1987 to 2006", Health Aff, Feb. 2010, doi:10.1377/hlthaff.2009.0474.

[3] C. Hastrich, "Biomimicry: A tool for innovation" [online], 2007. Available from: http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html [14.05.2011].

[4] M. Wooldridge, "Introduction to MAS", Wiley, 2002.

[5] A. Villar, A. Federici, and R. Annicchiarico, "Agents and Healtcare: A Glance to the Future", Birkhauser, Agent Technology and e-Health, pp. 141-148, 2008.

[6] G. Leonardi, S. Panzarasa, S. Quaglini, M. Stefanelli, van der Aalst W.M.P. "Interacting Agents through a Web-based Health Serviceflow Management System", Journal of Biomedical Informatics, vol. 40(5), pp. 486–499, 2007.

[7] D. Krafzig, K. Banke, and D. Slama, "Enterprise SOA: Service-Oriented Architecture Best Practices", Prentice Hall, 2004.

[8] G. Modi, "Service oriented architecture & web 2.0", Technical report, Guru Tegh Bahadur Institute of Technology, 2007. Available from: http://www.gsmodi.com/files/SOA_Web2_Report.pdf [14.05.2011].

[9] P. Ferronato, "Architecture for digital ecosystems, beyond SOA", IEEE Digital EcoSytems and Technologies Conference, 2007

[10] G. Briscoe, M. Chli, and M. Vidal, "Creating a Digital Ecosystem: Service-oriented architectures with distributed evolutionary computing" in JavaOne Conference. Sun Microsystems, 2006. [online]. Available from: http://arxiv.org/abs/0712.4159 [14.05.2011]

[11] M. Begon, J. Harper and C. Townsend, "Ecology: Individuals, Populations and Communities", Blackwell Publishing, 1996.

[12] P. Rajasekaran, J. A. Miller, K. Verma, A. P. Sheth, "Enhancing Web Services description and discovery to facilitate composition", First International Workshop on Semantic Web Services and Web Process Composition (SWSWPC 2004), LNCS 3387, pp. 55-68.

[13] E. Lawrence, "Henderson's dictionary of biological terms", Pearson Education, 2005.

[14] M. Shackleton, R. Shipma and M. Ebner, "An investigation of redundant genotype-phenotype mappings and their role in evolutionary search", Congress on Evolutionary Computation, pp. 493–500, IEEE Press, 2000.

[15] D. Hebb, "The Organization of Behavior", Wiley, 1949.

[16] G. Demiris, et. al., "Patient-centered applications: use of information technology to promote disease management and wellness" Journal of the American Medical Informatics Association (JAMIA), vol. 15, Jan. 2008, pp. 8-13.

[17] F. Nachira, P. Dini and A. Nicolai, "Digital Business Ecosystems", European Commission, 2007.

[18] A. Ricci, M. Viroli and A. Omicini, "CArtAgO: An Infrastructure for Engineering Computational Environments in MAS", 3rd Workshop "Environments for Multi-Agent Systems", E4MAS 2006.

[19] L.D. Serbanati, F.L. Ricci, G. Mercurio, A. Vasilateanu Steps towards a digital health ecosystem.", Journal of Biomedical Informatics". in press, doi: 10.1016/j.jbi.2011.02.011.

[20] S. Levin, "Ecosystems and the biosphere as complex adaptive systems", Ecosystems, vol. 1, pp. 431– 436, 1998

 ISBN: 978-1-61208-155-7

A new Ranking Technique for Integration among Higher-Level and Lower-Level Domain Ontologies and its Application to the Electromagnetic Domain

Alessandra Esposito, Marco Zappatore and Luciano Tarricone
Dept. of Engineering for Innovation
University of Salento
73100 Lecce, ITALY
{alessandra.esposito; marcozappatore; luciano.tarricone}@unisalento.it

***Abstract* – Nowadays ontologies represent a largely adopted information codification technique in many knowledge domains. Complex ontological frameworks have been developed in diverse areas, presenting the association of different levels of logic and semantic abstraction. These structures gather general contents (*Domain Ontologies*) and integrate them with more specific concepts (*Subdomain* and *Application Ontologies*). However, integration procedures may bring about complex issues such as semantic overlaps and knowledge base modifications. In order to minimize the occurrence of such events, an accurate selection and evaluation phase is advisable. In this paper we propose a methodology to evaluate higher-level domain ontologies in order to determine which candidate ontology would perform better if integrated with lower-level ones. The methodology is based on the computation of a set of multi-purpose ad-hoc metrics that are used as evaluation criteria in a multi-decisional ranking process. The methodology is applied to a real-life integration case study in the Electromagnetic knowledge domain. Two well-known scientific ontology frameworks are selected and evaluated in order to determine their suitability to provide a mid-level to proprietary Electromagnetic ontologies.**

Keywords – ontology, metric, ranking technique, integration .

I. INTRODUCTION

Recent years have seen a constant increase in ontology usage among heterogeneous scientific domains. Such rigorous formalizations [1] provide a globally accepted way of codifying knowledge and promoting information sharing and reuse across different research organizations. From Astronomy [2] to Healthcare [3], ontologies find a great variety of applications. On the contrary, the Electromagnetic (EM) scientific area did not benefit from robust ontological codifications so far.

The authors paved this way by proposing OntoCEM (Ontological Codification of ElectroMagnetism) [4]. The semantic description and integration of different branches of Electromagnetism is at the basis of OntoCEM. However, such ambitious goal hides many of the issues related to ontology merging procedures. Indeed, joining diverse ontologies may collide with potentially severe semantic heterogeneity of data, causing content overlaps or requiring knowledge base adjustments. At the same time, the need of an ontological superstructure made up of general scientific concepts (i.e., *scientific domain ontologies*) from which EM concepts (i.e., *EM application ontologies*) can inherit properties is perceived as well. This leads to the adoption of a hierarchical architecture [5], based on different layers of semantic abstraction and on the reuse of available ontologies. As a consequence, a deep integration activity is required.

In order to reduce typical issues that weigh down integration procedures, specific techniques for examining the ontologies that should be merged together are needed. Semantic completeness, domain adequacy and reusable contents availability are just a small example of the requirements that should be satisfied.

Evaluation metrics represent a common method to numerically establish the “goodness” of an ontology, as they take into account many of its aspects. A great amount of these metrics is nowadays available in literature, which consider ontology structure [6] and contents [7].

In this paper, rather than focusing on single metrics we propose a thorough methodology based on the computation of heterogeneous metrics and on their synthetical evaluation through a multi-decisional scoring process. The methodology is adopted to determine the best candidate for the integration with the EM ontologies defined in OntoCEM.

OntoCEM is briefly described in Section II. Section III introduces the proposed analysis technique. Sections IV to VI detail such technique, providing a tangible evaluation use case in the EM domain.

II. RELATED WORK

Ontological evaluation techniques based on the analysis of the design choices [8] have been proposed since late ‘90s. These methods evaluate ontologies without considering how ontology contents affect integration procedures. Kalfoglu et al. [7], instead, focus on this aspect by proposing distance measurements among different entities belonging to the same ontology or among entities codifying the same concept in different ontologies. Hu et al. [9] present a lattice-based similarity metric. Yunjiao et al. [10] extend classical tree similarity measurements towards content examination by considering domain expert contribution in evaluating the similarity between concept meanings. Other works measure semantic similarity by adopting lexical databases (i.e., WordNet) and by analyzing synonyms and hierarchical relationships. Among them, we recall GLUE [11], COMA++ [12] and SeCoOn [13].

 ISBN: 978-1-61208-155-7

Our proposal differs from previous works as we suggest an integrated approach based on the computation of heterogeneous metrics, which examine different ontological issues and on their aggregation by means of a consolidated ranking procedure. Finally, the entire evaluation process adopts a real-life scenario as benchmark case: i.e., the choice of the best-suited ontology for providing a scientific mid-level to an ontological framework describing the electromagnetism knowledge domain.

III. OntoCEM Architecture

As depicted in Fig. 1, OntoCEM [14] is organized into three semantic layers codified in OWL2-DL [15] language. The top level comprises publicly reusable scientific domain ontologies, collecting general concepts that belong to Math and Physics knowledge domains. The mid level gathers EM domain ontologies: these proprietary modules describe several EM branches and topics such as antennas, EM fields, EM propagation mechanisms, EM measurement units, etc. At the bottom there are ontologies describing specific EM applications, such as: shielding techniques, specific microwave devices, CAD processes, etc. Moving upward along the stack, contents become more and more abstract.

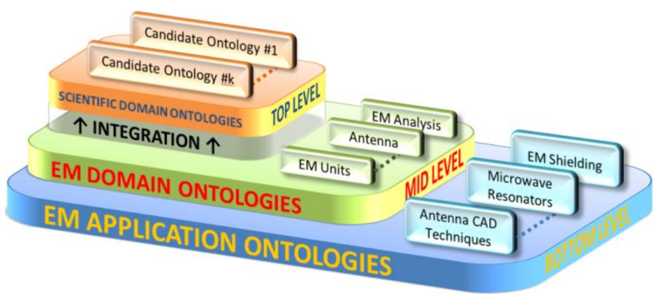


Figure 1. OntoCEM architecture.

IV. Ontology Evaluation Technique

Choosing the scientific domain ontology that would perform better if integrated with EM proprietary ontologies requires the application of a rigorous methodology. We propose a three-step technique, as described in Fig. 2.

Firstly, candidate scientific domain ontologies are selected by considering the following requirements: OWL-DL codification language, public availability and modularity.

Secondly, multi-purpose metrics are computed in order to analyze candidates in terms of size, structure, content, integration effort and reusability.

Thirdly, the candidates are ranked by using those metrics as performance criteria in a well-known multi-decisional process. This results in a rigorous, unambiguous classification.

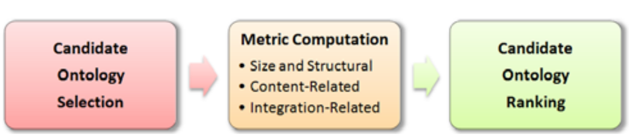


Figure 2. Proposed evaluation methodology.

V. Selecting the Candidate Ontologies

We selected candidate ontologies by identifying scientific semantic frameworks that mainly deal with Math and Physics domains. We searched for openly available, highly modular and wide ontology sets codified in OWL-DL in order to fulfill reusability and selective import requirements.

From such bases, two corpora of ontologies were chosen: the ontologies published by the Astronomical Department of the University of Maryland (UMD) [16] and the Semantic Web for Earth and Environmental Terminology (SWEET) Ontologies [17].

VI. Computing the Metrics

Three sets of metrics have been defined, each taking into account a different ontological aspect: 1) size and structure; 2) contents; 3) suitability to integration. In the following, the metrics are first described and then computed against the selected candidate ontologies.

A. Overall considerations

Although the proposed metrics refer to heterogeneous features of an ontology, they are designed to share common characteristics in order to make their behavior as uniform as possible.

- Metrics are closed-ended, i.e., defined in a closed numerical range. More in detail, the range is [0;1].
- Metrics producing out-of-bounds values require a linear scaling transformation (1) in order to be normalized to the definition range given above.

$$x_{norm} = \frac{x_{a} - \min_i\{x_i\}}{\max_i\{x_i\} - \min_i\{x_i\}} \quad (1)$$

  Where x_a is the actual value of the metric, x_{norm} its normalization and x_i all its possible values.
- Metrics must produce a maximization problem. Metrics behaving differently are suitably converted by complementing them.

B. Size and Structure-related Metrics

The first set of metrics monitors typical design aspects related to OWL language and do not consider any domain-related issue. Although they are relatively simple, structural metrics reveal themselves as an important source of information, especially for wide ontologies.

Class to Entity ratio (CtEr) measures the ratio between the total number of classes (*nCl*) and the total number of entities (*nEnt*).

$$CtEr = \frac{nCl}{nEnt} \quad (2)$$

Property to Entity ratio (PtEr) and **Instance to Entity ratio (ItEr)** quantify property and instance presence, as it is recognized to enrich the ontology [18]. Indeed, the less properties and instances there are, the more the ontology resembles a mere taxonomy made up only of “is-A” relationships.

$$PtEr = \frac{nOP + nDP}{nEnt} \quad (3)$$

$$ItEr = \frac{nInst}{nEnt} \quad (4)$$

where *nOP*, *nDP* and *nInst* represent the number of Object Properties, Datatype Properties and Instances respectively.

Entities per Module ratio (EpMr) is the ratio between the number of entities (*nEnt*) and the number of available modules (*nM*) in the ontology.

$$EpMr = \frac{nEnt}{nM} \quad (5)$$

This is a non-normalized, bounded quantity. Its lower bound is the case of one entity per module, $EpMr_{min}=1$ and its upper bound is represented by all the entities defined in only one module, that gives: $EpMr_{MAX}=nEnt$. Therefore, recalling (1), the normalized ratio ($EpMr_{norm}$) is:

$$EpMr_{norm} = \frac{\left(\frac{nEnt}{nM}\right) - 1}{nEnt - 1} \quad (6)$$

In order to avoid modules huge in size and problems in finding contents, the value of this metrics should be as low as possible. Therefore, the complemented metrics (7) is considered:

$$EpMr = 1 - EpMr_{norm} \quad (7)$$

Table I presents size metric computation results with respect to the candidates. UMD ontologies showed a better performance in terms of *CtEr* whilst SWEET are preferable in terms of the other metrics. Better values for each metric have been highlighted.

TABLE I. SIZE METRIC COMPUTATION RESULTS

Metric	UMD	SWEET
CtEr	0.88	0.63
PtEr	0.06	0.08
ItEr	0.05	0.28
EpMr	0.923	0.995

C. *Content-related Metrics*

These metrics examine domain-related information. Entities defined in candidate ontologies are partitioned into three subsets and must be identified by a domain expert.

- ***Scientific (S) entities***: scientific concepts capable of acting as valid superclasses or useful reusable properties for EM concepts defined in OntoCEM ontologies. Their number is indicated as *nS*.
- ***Electromagnetic (E) entities***: concepts concerning EM. As EM concepts are located in OntoCEM modules as well, *E* entities may generate semantic conflicts during the integration procedure. Therefore it is preferable to have only a small quantity (*nE*) of them in candidate ontologies.
- ***Unusable (U) entities*** are entities that belong neither to *S* nor to *E* set. The number *nU* of *U* entities should be as low as possible, in order to reduce ontology loading times.

Additionally, we indicated as *ES* modules the modules comprising at least one *S* or *E* entity.

Table II enlists some *S* and *E* entities.

TABLE II. EXAMPLES OF *S* AND *E* ENTITES

Scientific (*S*) Entities	Electromagnetic (*E*) Entities
Classes	
Physical Property; Energy; Function; Scientific Model; Vector; Integral; Transmitter; Orientation;; Algorithm...	*Remote Sensing; Electric Dipole; Diffraction; EM Spectrum; Antenna; Wavelength; Microwave…*
Object Properties	
has Effect; has Component; has Unit; has Force…	*Radiate; has Frequency; has Spectral Band…*
Datatype Properties	
has Probability; has Scale; has Numeric Value…	*has Scattering Coefficient; has Resonant Frequency...*
Instances	
Sn; X Axis; Meter; per Second; dB; Joule; FFT...	*SNR; Ohm; Refractive Index; MHz; Siemens; Volt per meter…*

Domain Scientific Richness (DSR) weights the presence of *S* concepts.

$$DSR = \frac{nS}{nS + nE + nU} \quad (8)$$

Domain EM Richness (DER) quantifies the presence of *E* concepts.

$$DER = 1 - \frac{nE}{nS + nE + nU} \quad (9)$$

Loading Overhead (LO) assess the presence of *U* concepts.

$$LO = 1 - \frac{nU}{nS + nE + nU} \quad (10)$$

Table III shows computation results for the candidates. Better values for each metric have been highlighted. As UMD and SWEET content metrics have discordant values, a unifying methodology is needed. This technique will be described in Section VI.

Copyright (c) IARIA, 2011. ISBN: 978-1-61208-155-7

TABLE III. CONTENT METRIC COMPUTATION RESULTS

Metric	UMD	SWEET
DSR	0.44	0.59
DER	0.94	0.93
LO	0.5	0.66

D. Integration-related Metrics

In order to evaluate how suitable a candidate ontology is to be integrated with available lower-level ontologies, we propose an approach based on the simulation of integration tasks.

First of all, a set of concepts (named *benchmark entities*, *BE*) codified in the lower-level ontology has to be identified on the basis of "structural" and/or "semantic" considerations. Indeed, we selected classes that subsume a great number of concepts and/or that are relevant from a domain expert point of view. Table IV enlists the chosen entities and provides a brief description for each of them. They are taken from each of the ten EM domain modules defined in OntoCEM mid-level (see Fig. 1).

TABLE IV. LIST OF BENCHMARK ENTITIES (*BE*)

EM Concept / *OntoCEM module*	Role in OntoCEM
Antenna / *Antenna*	Root concept subsuming all antenna typologies
Radio Propagation Model / *EM Propagation*	Root concept describing scientific models that estimate signal attenuation due to Path Loss in wireless communication systems
Uniform Plane Wave / *EM Waves*	Particular solution of Maxwell's equations with electric field assuming the same magnitude and phase in all planes perpendicular to the direction of propagation
MilliVolt per meter / *EM Units*	A common unit of measurement for electric field strength values
Dielectric Medium / *EM Medium*	Root concept extended by all other insulator media
Method of Moments / *EM Analysis*	It is a general numerical technique for solving EM problems stated in terms of an inhomogeneous equation
RF Measurement / *EM Measurements*	Root concept subsuming all kinds of measurements performed at RF frequencies
Plane Wave Shielding / *EM Compatibility*	It is the process that determines a total or partial block of EM radiation (propagating as a plane wave) in a far field region
Spectrum Analyzer / *EM Instruments*	Fundamental EM instrument for measuring the frequencies present in a complex signal or resulting from modulation on a carrier
Passive Microwave Device / *Microwave Devices*	Root concept subsuming all passive components operating at microwave frequencies

We designed three metrics adapting metrics proposed from Zhang in [6]. Such metrics must be computed with respect to each *BE*, then they are mediated over the total number of *BE* (*nBE*).

Ancestor Domain Pertinence (ADP). This metric was constructed starting from the so-called Depth of Inheritance metric (*DoI*) [6]. DoI quantifies the distance of the class identified as the best ancestor for the current *BE* from the root class of the candidate ontology. This distance represents the overall set of superclasses for the *BE*. However, *DoI* does not provide any information about the validity of those classes from a domain expert point of view. This additional feature is provided by *ADP* metric. It computes the ratio between the total number of "appropriate ancestors" (*nSA*) and *DoI*, according to the following formula:

$$ADP = \frac{\sum_{i=1}^{nBE} ADP_i}{nBE}, \quad ADP_i = \frac{nSA_i}{DoI_i} \tag{11}$$

ADP_i refers to the *i-th BE* and *ADP* is the arithmetic mean over the *nBE*. The closer to zero *ADP* is, the more unfitting the superclasses are.

DoI Deviation (DoID). This metric is derived from *DoI* as well. It takes into account the maintenance issues, which could occur when the distance from the root class is too long (i.e., *DoI* is high). In this case, a modification in higher-level scientific domain concepts can involve relevant modifications in lower-level EM ontologies [6]. Therefore we set a reference value (DoI_{REF}) and measure the deviation of DoI_i from it. $DoID_i$ is normalized to the range [0;1] and converted to a maximization metric. *DoID* is its arithmetic mean.

$$DoID = \frac{\sum_{i=1}^{nBE} DoID_i}{nBE}, \quad DoID_i = 1 - \frac{|DoI_{REF} - DoI_i|}{max\{DoI_i, DoI_{REF}\}} \tag{12}$$

The closer to one *DoID* is, the closer to the reference the actual *DoI* value is. We selected $DoI_{REF}=3$ as a proper reference.

Domain Property Reusability (DPR). It analyzes how the descriptive statements for the benchmark entity can be rendered. *DPR* is the ratio between the reusable OWL properties belonging to higher-level ontologies (nRP_i) and the number of natural language restrictions ($nNLR_i \geq nRP_i$) needed to codify the descriptive statement for the *i-th* benchmark entity:

$$DPR = \frac{\sum_{i=1}^{nBE} DPR_i}{nBE}, \quad DPR_i = \frac{nRP_i}{nNLR_i} \tag{12}$$

The closer to one the *DPR* is, the more preferable the ontology is. Indeed, by counting the number of reusable properties, we measure how the higher-level ontology facilitates the integration enhancement. On the contrary, a *DPR* close to zero denotes a small reusability.

Considering all the *BE* detailed in Table IV, the candidate ontologies feature the following mean values in terms of *ADP*, *DoID* and *DPR* metrics (Table V). SWEET ontologies performed better with respect to all the integration metrics. Better values for each metric have been highlighted.

TABLE V. INTEGRATION METRIC COMPUTATION RESULTS

Metric	UMD	SWEET
ADP	0.667	0.91
DoID	0.398	0.659
DPR	0.386	0.711

VII. RANKING THE CANDIDATE ONTOLOGIES

In previous sections, metric computation produced discordant results. In order to assess which candidate is the best suited for the integration procedure in a rigorous and unambiguous way, we adopted a multi-decisional scoring technique. We selected the ELECTRE-I method [19]. It is the simpler version of the ELECTRE methods (*ELimination Et choix Traduisant la REalité*, that stands for *Elimination and Choice Expressing the Reality*). Such methodologies are widely used for their ability to cope with criteria giving contrasting evaluations.

A. Overall Considerations

Our metrics, called evaluation criteria ($\boldsymbol{C}=\{C_i\}$, $i=1,...,m$) according to ELECTRE terminology, are weighted by using subjective quantities ($\boldsymbol{W}=\{w_i\}$, $i=1,...,m$). A decision table (Table VI) is populated by the scores a_{ij}, expressing the performance of the A_i alternative against the C_j criterion. The alternatives are compared, in pair, by calculating concordance (c_{jk}) or discordance (d_{jk}) indices [19] according to (13) formulas.

$$c_{jk} = \frac{\sum_{i\in\left(\boldsymbol{c}_{jk}^{+}\cup\boldsymbol{c}_{jk}^{=}\right)} w_i}{\sum_{i\in\boldsymbol{c}_{jk}} w_i} = \sum_{i\in\left(\boldsymbol{c}_{jk}^{+}\cup\boldsymbol{c}_{jk}^{=}\right)} w_i \quad ,$$

$$d_{jk} = \frac{\max_{i\in\boldsymbol{c}_{jk}^{-}}\{w_i|a_{ij}-a_{ik}|\}}{\max_{i\in\boldsymbol{c}}\{w_i|a_{ij}-a_{ik}|\}} \quad , \tag{13}$$

$$\boldsymbol{C}_{jk} = \boldsymbol{C}_{jk}^{+} \cup \boldsymbol{C}_{jk}^{=} \cup \boldsymbol{C}_{jk}^{-}$$

where $\boldsymbol{C}^{+}_{jk}$, $\boldsymbol{C}^{=}_{jk}$ and $\boldsymbol{C}^{-}_{jk}$ represent respectively the subset of criteria against which alternative A_j is better, equivalent and worst than A_k.

TABLE VI. ELECTRE-I TYPICAL DECISION TABLE

Criteria	Weights	Alternatives				
		A_1	.	.	A_n	
C_1	W_1	a_{11}	.	.	a_{1n}	A_1
.	.	.	.	.	.	.
.	.	.	.	.	.	.
C_m	w_m	a_{m1}	.	.	a_{mn}	A_n

In order to assert that the alternative A_j *outranks* A_k, the concordance index should be at the same time above a concordance threshold c_{th} and the discordance index should be below a discordance threshold d_{th} (14), where c_{th} and d_{th} are the mean values of the indices calculated over the *n* alternatives [19].

$$\begin{cases} c_{jk} \geq c_{th} = \dfrac{1}{n(n-1)}\displaystyle\sum_{j=1}^{n}\sum_{\substack{k=1,\\k\neq j}}^{n} c_{jk} \\ d_{jk} \leq d_{th} = \dfrac{1}{n(n-1)}\displaystyle\sum_{j=1}^{n}\sum_{\substack{k=1,\\k\neq j}}^{n} c_{jk} \end{cases} \tag{14}$$

B. Candidates ranking

First of all, criterion weights were defined. We assumed [19] that the sum of the weights of all criteria equals to 1. Then, we distributed the weights amongst the three sets of metrics. We assigned heavier weights to sets better complying with our major objective, i.e., integration between our EM ontologies. Therefore, content and integration sets were both given a weight of 0.4. The set containing size metrics, which are general-purpose, was instead given a weight equal to 0.2. The same criterium was adopted to distribute weights among the single metrics belonging to each set.

Therefore, size metrics (i.e., *CtEr*, *PtEr*, *ItEr* and *EpMr*) share the same weight.

Among content-related metrics (i.e., *DSR*, *DER* and *LO*), the first one is the most relevant in our opinion. Indeed, the more S entities there are, the more suitable to integration the scientific candidate ontology could be. In addition, E entities introduce semantic overlaps, which may render the integration task onerous, therefore the *DER* metric has the second heaviest weight.

As to integration metrics, we assigned the heaviest weight to *ADP*, as it expresses the scientific suitability of higher-level concepts.

Table VII resumes the final decision table. The highest scores for each criteria have been highlighted.

TABLE VII. CANDIDATE ONTOLOGIES DECISION TABLE

C_i	w_i	A_1 (UMD)	A_2 (SWEET)
CtEr	0.05	0.88	0.63
PtEr	0.05	0.06	0.08
ItEr	0.05	0.05	0.28
EpMr	0.05	0.923	0.995
DSR	0.2	0.44	0.59
DER	0.15	0.94	0.93
LO	0.05	0.5	0.66
ADP	0.2	0.667	0.91
DoID	0.1	0.398	0.659
DPR	0.15	0.386	0.711

The following matrices report the concordance and discordance indices of the alternatives.

$$C = \begin{bmatrix} \cdot & c_{12} \\ c_{21} & \cdot \end{bmatrix} = \begin{bmatrix} \cdot & 0.2 \\ 0.8 & \cdot \end{bmatrix} \quad (15)$$

$$D = \begin{bmatrix} \cdot & d_{12} \\ d_{21} & \cdot \end{bmatrix} = \begin{bmatrix} \cdot & 1 \\ 0.256 & \cdot \end{bmatrix} \quad (16)$$

According to (14), we have the following concordance and discordance conditions against respective thresholds:

$$\begin{cases} (c_{12} = 0.2) < (c_{th} = 0.5) \\ (d_{12} = 1) > (d_{th} = 0.628) \end{cases} \quad (17)$$

$$\begin{cases} (c_{21} = 0.8) > (c_{th} = 0.5) \\ (d_{21} = 0.256) < (d_{th} = 0.628) \end{cases} \quad (18)$$

Since (18) satisfies both the conditions, the alternative A_2 (i.e., SWEET ontologies) shows a better integration behavior rather than A_1 (i.e., the UMD ontologies).

These results confirmed the assessments given by independent electromagnetic knowledge domain experts who, based on a preliminary overview of their content and on the evaluation of their “electromagnetic soundness”, accounted SWEET ontologies as the most profitable choice among candidates.

VIII. CONCLUSIONS

In this paper, a proposal for a ranking methodology dealing with scientific domain ontologies has been proposed. The aim of this evaluation technique is to assess, in a possibly rigorous way, how suitable to be integrated with EM ontologies a scientific domain ontology could be. In order to do that, a set of multi-purpose ontological metrics has been defined. They consider different aspects such as size and structure, contents and integration worthiness for a given candidate ontology. Moreover, these metrics take into account both ontology designer and domain expert point of view. The metrics have been used as evaluation criteria in a widely adopted multi-decisional scoring process belonging to the ELECTRE method family. Two well known scientific ontological framework have been compared and ranked, showing the validity of the proposed methodology.

REFERENCES

[1] G.T. Gruber, “Towards Principles for the Design of Ontologies Used for Knowledge Sharing,” Int. Journal of Human-Computer Studies, vol. 43, issue 5-6, pp. 907-928, 1995.

[2] S. Lesteven et al., “Ontologies For Astronomy,” Library and Information Services in Astronomy V: Common Challenges, Uncommon Solutions. (Astronomical Society of the Pacific) ASP Conference Series, vol. 377, p. 193-196, 2006.

[3] OpenClinical Ontologies homepage. Available at: http://www.openclinical.org/ontologies.html, (last accessed: May 2011)

[4] A. Esposito, L. Tarricone, L. Vallone and M. Zappatore, “A Proposal for an Electromagnetic Ontology Framework,” Int. Journal of Web and Grid Services, Vol. 4, No. 3, pp. 284-302, 2008.

[5] N. Guarino, “Formal ontology and information systems,” Proc. of the 1st Int. Conf. on Formal Ontologies in Information Systems, FOIS98, IOS Press, pp. 3-15, 1998.

[6] H. Zhang, Y.-F. Li and H. B .K. Tan, “Measuring Design Complexity of Semantic Web Ontologies,” The Journal of Systems and Software, Science Direct, vol. 83, pp. 803-814, 2010.

[7] Y. Kalfoglou et al., "Semantic Metrics," Proc. of 5th Int. Conf. on Knowledge Engineering and Knowledge Management (EKAW06), pp. 166-181, 2006.

[8] T. Lethbridge, “Metrics for Concept-Oriented Knowledge Bases”, in: International Journal of Software Engineering and Knowledge Engineering, vol. 8(2), pp. 161-188, 1998.

[9] H. Hu and X.-Y. Du, “A Lattice Metric for Evaluating Ontology Hierarchies,” Proc. of International Conference on Machine Learning and Cibernetics, 2007, vol. 7, pp. 3880-3883, 2007.

[10] X. Yunjiao, W. Chun, H. H. Ghenniwa and S. Weiming, “A New Tree Similarity measuring method and its application to ontology comparison,” Proc. of CSCWD’08, pp. 258-263, 2008.

[11] A. Doan, J. Madhavan, P. Domingos and A. Halevy, “Learning to Map Between Ontologies on the Semantic Web,” Proc. of the WWW Conference, Hawaii, USA, pp. 662-673, ACM Press, 2002.

[12] D. Aumuller, H. H. Do, S. Massmann and E. Rahm, “Schema and ontology matching with COMA++,” Proc. of SIGMOD, Software Demonstration, pp. 906-908, ACM Press, 2005.

[13] E. Sosa, A. Lozano-Tello and A. E. Prieto, “Semantic Comparison of Ontologies Based on WordNet,” Proc. of Complex Intelligent and Software Intensive Systems (CISIS08), pp. 899-904, 2008.

[14] W3C OWL Working Group, “OWL2 Web Ontology Language Document Overview”, W3C Recomm., 27th October 2009. Available at: http://www.w3.org/TR/owl2-overview/ (last accessed: May 2011).

[15] Ontological Codification of ElectroMagnetism v.2.1 (OntoCEM), University of Salento, Electromagnetic Lab Lecce (EML2). http://www.electromagnetics.unisalento.it/ /ontologies/OntoCEM/2.1/ (progressively available).

[16] "Astronomy/Science Ontology", Department of Astronomy, University of Maryland, USA. Available at: http://www.astro.umd.edu/~eshaya (last accessed: May 2011).

[17] Semantic Web for Earth and Environmental Terminology (SWEET) Ontologies, NASA JPL, CA, USA Available at: http://sweet.jpl.nasa.gov/ (last accessed: May 2011).

[18] S. Tartir, I. B. Arpinar, M. Moore, A. P. Sheth and B. Aleman-Meza, "OntoQA: Metric-Based Ontology Quality Analysis," Proc. of IEEE Workshop on Knowledge Acquisition from Distributed, Autonomous, Semantically Heterogeneous Data and Knowledge Sources (KADASH), Houston, Texas, USA, pp. 45-53, 2005.

[19] J. Figueira, S. Greco and M. Ehrgott (Eds.), Multiple Criteria Decision Analysis: The State of the Art Surveys, Springer Science and Business Media, Inc., New York, 2005.

Generalized Implicative Model of a Fuzzy Rule Base and its Properties

Martina Daňková
Institute for Research and Applications of Fuzzy Modeling
University of Ostrava
Ostrava, Czech Republic
Email: martina.dankova@osu.cz

***Abstract*—In this contribution, an implicative variant of the conjunctive normal form will be recalled and further studied. This normal form is an alternative to the Perfilieva's conjunctive normal form. It will be shown that it is a suitable model for a particular case of graded fuzzy rules introduced as a generalization of classical fuzzy rules. Moreover, approximation properties of the implicative variant of the conjunctive normal form provide a view on a class of fuzzy relations that can be "efficiently" approximated using this normal form. Newly, a suitable inference rule the graded rules formalized using the implicative variant of the conjunctive normal form will be introduced and analyzed. Results in this field extend the theory of approximate reasoning as well as the theory of fuzzy functions.**

***Keywords*-Graded fuzzy rules; Normal forms; Approximate reasoning; Fuzzy functions; Fuzzy control;**

I. Introduction

The Implicative model [1], [2], [3] of fuzzy rules is present from the birth of the theory fuzzy rules. Unfortunately, they are used very rarely in practical applications and the Mamdani-Assilian model [4], [5] completely dominates the field [6]. Among others, the cause of this fact lies mainly in a visual simplicity of the Mamdani-Assilian model, more precisely, a vivid graphical representation by the membership function interpreting this model. Theoretical results (see, e.g., [2]) explain why it is so

- the Mamdani-Assilian model suites generally for a relation dependency;
- the Implicative model works well only for a functional dependency.

More precisely, the extensionality is required from a relation that we approximate by the Mamdani-Assilian model. While in the case of the Implicative model, we require additionally the functionality. Provided that the requirements are fulfilled we can expect a well behaving model in the following sense: the Mamdani-Assilian model provides approximation of an ideal fuzzy relation from below and the Implicative model from the above and moreover, it can be done with an arbitrary precision.

In this contribution, we present theoretical results relating to Implicative model of fuzzy rules that show for what kind of dependencies it will works properly and which type of inference has to be used to receive a desirable output. For this purpose, we will recall formalizations of *graded fuzzy rules* (introduced in [7] as a generalization of the known fuzzy rules) by fuzzy relations in three different forms known as normal forms. Two of them has been introduced by I. Perfilieva in [8] and therefore we denote them Perfilieva's normal forms. The remaining normal form has been introduced in [9] as a generalization of the Implicative model and it will be called *implicative normal form*. These formalizations allow to involve additional imprecision, uncertainty or vagueness related to each fuzzy rule in the form of particular degrees attached to the respective fragment of the normal form. Interpretation using the natural language is explained further in the text or we can refer to [7], [10], [9] for more details on this problematic.

It has been shown [11] that specially chosen normal forms can serve as the best approximating fuzzy relations. In the following we will not touch this problematic and we focus mainly on the explaining differences between the traditional approach to fuzzy rules represented by Hájek's work [2] and the graded approach to fuzzy rules [10]. Section IV will be devoted to implicative normal forms and their known properties. Newly, we will present in Section V properties related to approximate reasoning with graded fuzzy rules formalized by the implicative normal form.

II. Hájek's Approach to Fuzzy Control

One of the original approaches for a fuzzy rule base construction generally works only for the so called *positive samples* w.r.t. some (binary) fuzzy relation F, i.e., $(c,d) \in X \times Y$ is called the positive sample w.r.t. F if $F(c,d) = 1$. The definition can be extended for sets in the following way:

$$S = \{(c_i,d_i) |\, c_i \in X, d_i \in Y, i \in I = \{1,2,\ldots,n\}\} \qquad (1)$$

is a set of the positive samples w.r.t. F if each (c_i,d_i) is the positive sample w.r.t. F. Analogously, we say that S is a set of the negative samples w.r.t. F if for each $i \in I : F(c_i,d_i) = 0$ (or $\neg F(c_i,d_i) = 1$, where $\neg x = x \to 0$ and $\to$ stands for some fuzzy implication that is usually interpreted as the residuum to a t-norm).

In [2], Hájek used a set of the positive samples to create a fuzzy rule base using an indistinguishability (or similarity) relation. This procedure can be interpreted from the algebraic point of view it in the following way:

 ISBN: 978-1-61208-155-7

- Requirements:
  1) For the sequel, let X,Y be nonempty sets of objects, I be as above and

$$\mathscr{L} = \langle L, *, \rightarrow_*, \wedge, \vee, 0, 1\rangle,$$

  be a complete residuated lattice.
  2) Moreover, let $F \mathrel{\widetilde{\subseteq}} X \times Y$ (i.e., a fuzzy relation on $X \times Y$), $\approx_1 \mathrel{\widetilde{\subseteq}} X^2, \approx_2 \mathrel{\widetilde{\subseteq}} Y^2$ be similarity relations and $\bar{x} = [x,y]$, $\bar{x}' = [x',y']$;
  3) S be a set in the form (1) of the positive samples w.r.t. F.
- Fuzzy rules are defined as

$$\mathrm{Mamd}(x,y) =_{df} \bigvee_{i\in I}((x \approx_1 c_i) * (y \approx_2 d_i)),$$

$$\mathrm{Rules}(x,y) =_{df} \bigwedge_{i\in I}((x \approx_1 c_i) \rightarrow_* (y \approx_2 d_i)).$$

- Properties:
  1) If F is extensional then $\mathrm{Mamd} \subseteq F = 1$, where $A \subseteq B \equiv_{df} \bigwedge_{x\in X}(A(x) \rightarrow_* B(x))$ for the unary fuzzy relations A,B and analogously for n-ary fuzzy relations.
  2) If F is functional (for the definition see the following section) then $F \subseteq \mathrm{Rules} = 1$.
  3) If F is extensional (for the definition see the following section) and functional then

$$\bigwedge_{x\in X}\bigvee_{i\in I}(x \approx_1 c_i) * (x \approx_1 c_i) \le (\mathrm{Rules} \subseteq \mathrm{Mamd}), \tag{2}$$

  which consequently gives us the following estimations

$$\bigwedge_{x\in X}\bigvee_{i\in I}(x \approx_1 c_i) * (x \approx_1 c_i) \le \begin{matrix}(F \approx \mathrm{Mamd}),\\ (F \approx \mathrm{Rules}),\end{matrix} \tag{3}$$

  where $F \approx S \equiv_{df} (F \subseteq S) * (S \subseteq F)$.

In the original source, Hájek investigated also properties of fuzzy control based on Mamd and $(\max, *)$ compositional rule of inference.

III. Graded Fuzzy Rules Formalized by Perflieva's Normal Forms

Graded fuzzy rules (introduced in [7] and further elaborated in [10]) were motivated by a need of improvement of approximation using fuzzy rules. Graded fuzzy rules were originally formalized using Perfilieva's normal forms [8]. Let us provide the original definition [8] and further explain a connection to graded fuzzy rules.

For a generality, we do not put any requirements on $\approx_{1(2)}$, they are assume to be arbitrary binary fuzzy relations in the sequel.

Definition 1 *The* disjunctive normal form *(*DNF *for short) for a fuzzy relation F is*

$$\mathrm{DNF}_F(\bar{x}) =_{df} \bigvee_{i\in I}[(c_i \approx_1 x) * (d_i \approx_2 y) * F(c_i,d_i)], \tag{4}$$

The conjunctive normal form *(*CNF *for short) for F is given by*

$$\mathrm{CNF}_F(\bar{x}) =_{df} \bigwedge_{i\in I}[((x \approx_1 c_i) * (y \approx_2 d_i)) \rightarrow_* F(c_i,d_i)]. \tag{5}$$

As stated in [10], [7], an ambiguity or uncertainty over a certain fuzzy rule can be can be implemented using a degree that equips the respective rule and together they form the so called *graded fuzzy rule*. A visualization of a collection of graded fuzzy rules is the following:

$$\begin{array}{ll} {}^{f_1\succeq}/(x \in A_1 \text{ and } y \in B_1) & \text{OR} \\ \dots & \text{OR} \\ {}^{f_n\succeq}/(x \in A_n \text{ and } y \in B_n), & \end{array}$$

for the case of DNF and

$$\begin{array}{ll} {}^{f_1\preceq}/(x \in A_1 \text{ and } y \in B_1) & \text{AND} \\ \dots & \text{AND} \\ {}^{f_n\preceq}/(x \in A_n \text{ and } y \in B_n), & \end{array}$$

for the case of CNF, where

Symbol	Interpretation of
f_i	$F(c_i,d_i)$
$x \in A_i$	$(x \approx_1 c_i)$
$y \in B_i$	$(y \approx_2 d_i)$
$*$	and
$\vee$	OR
$\wedge$	AND

We can read a particular graded fuzzy rule ${}^{f\succeq}/[x,y] \in R$ as

"$[x,y]$ are related by R at most to the degree f",

analogously, ${}^{f\preceq}/A$ reads as

"$[x,y]$ are related by R at least to the degree f",

Let us explain why "at least" and "at most" are used in the reading of graded fuzzy rules by analyzing one particular graded rule for, i.e., the one particular fragment of the normal form:

1) In the case of DNF, we conclude that the operation of conjunction $*$ applied on the relation $\underbrace{[(c_i \approx_1 x) * (d_i \approx_2 y)]}_{R(x,y)}$ and the degree $F(c_i,d_i)$ exhibits as a kind of shift or resize operator. The reason for this claim is that the final fuzzy relation does not exceed this degree, i.e., $R(x,y) * F(c_i,d_i) \le F(c_i,d_i)$ (it follows from $a * b \le b$). This fact is distinguished by the symbol $\succeq$ that we read as "at most" in the associated graded fuzzy rule.

2) In the case of CNF, we have a different situation. The implication $\rightarrow_*$ with the degree on the right input position behaves as a rotation and shift (or resize) operator. It means that the final fuzzy relation fulfills $[((x \approx_1 c_i) * (y \approx_2 d_i)) \rightarrow_* F(c_i, d_i)] \geq F(c_i, d_i)$ (follows from $b \leq a \rightarrow_* b$). Analogously, we distinguish this fact by the symbol $\preceq$ in the graded fuzzy rule and we read it as "at least".

As shown in [8], [12] (generalized to non-symmetric $\approx_{1,2}$ in [13] and extended to graded theorems in [10]) graded fuzzy rules based on Perfilieva's normal forms are suitable for extensional fuzzy relations.

Definition 2 *F is extensional w.r.t. $\approx_1, \approx_2$ if*

$$x \approx_1 x' * y \approx_2 y' * F(\bar{x}) \leq F(\bar{x}'), \quad (6)$$

is valid for all $x, x' \in X$ and $y, y' \in Y$.

Theorem 3 *[8], [11] Let us consider an extensional fuzzy relation F in the above defined sense. Then*

- DNF_F *lies below F and* CNF_F *is above;*
- *a precision of the approximation expressed in terms of the equivalence $\leftrightarrow_*$ (bi-residual operation) depends on the distribution of (c_i, d_i)'s over $X \times Y$:*

$$\bigvee_{i \in I} [(c_i \approx_1 x) * (x \approx_1 c_i) * (d_i \approx_2 y) * (y \approx_2 d_i)] \leq \mathrm{DNF}_F(\bar{x}) \leftrightarrow_* F(\bar{x}), \quad (7)$$

and the same estimation is valid for $\mathrm{CNF}_F(\bar{x}) \leftrightarrow_* F(\bar{x})$.

These results can be extended to graded properties so that also partially extensional relations can be allowed. First, let us recall the graded extensionality taken from [10] and translated into our algebraic framework.

Definition 4 *A relation F is said to be a-extensional w.r.t. $\approx_1, \approx_2$ if*

$$a = \bigwedge_{x, x' \in X, y, y' \in Y} [[(x \approx_1 x') * (y \approx_2 y') * F(\bar{x})] \rightarrow_* F(\bar{x}')], \quad (8)$$

where $a \in L$. We will shortly denote the right side of the above equality by $\mathrm{Ext}_{\approx_1, \approx_2} F$.

Observe that using the classical definition of extensionality we determine a crisp class of fuzzy relations that are 1-extensional. a-extensionality also determines a crisp class of fuzzy relations that are a-extensional. But truth values computed by $\mathrm{Ext}_{\approx_1, \approx_2} F$ for all fuzzy relations over the universe of the discourse define the fuzzy class of fuzzy relations that are extensional.

Example 5 *Let $\mathscr{L}$ be the standard Łukasiewicz algebra and*

$$F(\bar{x}) =_{df} y \leftrightarrow_* (x \cdot x)$$

on M^2, where $M = \{0.05 \cdot k |\ k = 0, 1, \ldots, 20\}$. Then F is extensional w.r.t. $\approx_1, \approx_2$ defined as

$$x \approx_1 y =_{df} (x \leftrightarrow_* y) * (x \leftrightarrow_* y),$$
$$x \approx_2 y =_{df} x \leftrightarrow_* y.$$

In the terms of graded extensionality, it is

$$1\text{-}extensional\ w.r.t.\ \approx_1, \approx_2.$$

But if we change $\approx_1$ to $\leftrightarrow_*$ then we obtain that

$$F\ is\ 0.75\text{-}extensional\ w.r.t.\ \approx_2, \approx_2.$$

And even worse, if we take the original $\approx_1$ and change $\approx_2$ to $\approx_1$ then we have that

$$F\ is\ 0.19\text{-}extensional\ w.r.t.\ \approx_1, \approx_1.$$

The following theorem summarizes properties of approximation using the normal forms in the graded style that allows also not completely extensional relations and in this case, it provides information about the resulting quality of the approximation by estimation of degrees of the required properties.

Theorem 6 *[10]Let F be a-extensional. Then*

- *Subsethood: $a \leq (\mathrm{DNF}_F \subseteq F)$, $a \leq (F \subseteq \mathrm{CNF}_F)$.*
- *Estimation for a precision of the approximation:*

$$a * \bigwedge_{x \in X, y \in Y} C(\bar{x}) \leq (\mathrm{DNF}_F \approx F),$$

where $C(\bar{x})$ denotes the left side of the inequality (7). The same estimation holds for CNF_F.

The first two inequalities say that the degree of extensionality estimates the degree of inclusion of DNF_F in F and F in CNF_F, respectively. The last inequality provides the lower estimation of the quality of approximation using the normal form that is generated by the degree of extensionality and the degree of lets say the good covering expressed by $\bigwedge_{x \in X, y \in Y} C(\bar{x})$. Informally speaking, higher the degrees of requirements (extensionality and good covering) better is the resulting approximation.

IV. Graded Fuzzy Rules Formalized by the Implicative Normal Form

In this section, we are going to recall an implicative variant of the conjunctive normal form (implicative normal form for short) introduced in [9] and to show its properties. This normal form differs from the Perfilieva's conjunctive normal form and it has been introduced for a distinct purpose. While the Perfilieva's conjunctive normal form is suitable for extensional fuzzy relations and negative samples,

 ISBN: 978-1-61208-155-7

the implicative normal form has been aimed for functional fuzzy relations and positive samples.

Definition 7 *The* conjunctive normal form – implicative variant *(*INF *for short) for a fuzzy relation F is*

$$\mathrm{INF}_F(\bar{x}) =_{df} \bigwedge_{i\in I}[F(c_i,d_i) \to_* [(c_i \approx_1 x) \to_* (d_i \approx_2 y)]]. \quad (9)$$

For the sake of brevity and in order to simplify the distinction between the conjunctive normal forms, we will call the conjunctive normal form – implicative variant *as the* implicative normal form.

Generally for non-symmetric $\approx_1, \approx_2$, we can introduce also a variant of the above defined INF by juxtaposition of the variables and constants

$$\mathrm{INF}'_F(\bar{x}) =_{df} \bigwedge_{i\in I}[F(c_i,d_i) \to_* [(x \approx_1 c_i) \to_* (y \approx_2 d_i)]]. \quad (10)$$

Obviously, most of the results are valid for both implicative normal forms therefore, we will deal only with INF in the sequel and we will explain differences where it will be necessary.

Now, let us explain a connection with graded fuzzy rules. Let us take into account only a single segment of INF and we analyze its core, i.e., we have $F(c_i,d_i) \to_* [(c_i \approx_1 x) \to_* (d_i \approx_2 y)] = 1$ that is valid if and only if $(c_i \approx_1 x) \to_* (d_i \approx_2 y) \in [F(c_i,d_i),1]$. Therefore we interpret this fuzzy relation in INF as one graded fuzzy rule in the form

$${}^{f_i \preceq}/(\textsf{If } x \in A_i \textsf{ then } y \in B_i),$$

where the used symbols are interpreted as it was specified in the table in Section III and additionally, "If ... then" interprets $\to_*$. We read the above graded fuzzy rule as "(If $x \in A$ then $y \in B$) at least to the degree f_i" with the above explained meaning. Hence, INF formalizes the following collection of graded fuzzy rules:

$$\begin{array}{ll} {}^{f_1 \preceq}/(\textsf{If } x \in A_1 \textsf{ then } y \in B_1) & \text{AND} \\ \dots & \text{AND} \\ {}^{f_n \preceq}/(\textsf{If } x \in A_n \textsf{ then } y \in B_n). & \end{array}$$

As noted at the beginning of this section, the implicative normal forms are suited to approximate functional fuzzy relations (slightly less general version is used in the field of fuzzy control see, e.g., [14], [2], [15]). The following definition will be directly in the graded form inspired by [16], where it has been introduced within the formal framework of fuzzy class theory [17].

Definition 8 *A relation F is said to be a-functional w.r.t. $\approx_{1,2}$ if*

$$a = \bigwedge_{x,x'\in X, y,y'\in Y} [[(x \approx_1 x') * F(x,y) * F(x',y')] \to_* (y \approx_2 y')].$$

We will shortly denote the right side of the above equality by $\mathrm{Fun}_{\approx_{1,2}} F$.

Example 9 *In the setting of Example 5, we can compute the following degrees of functionality for F:*

F is 1-functional w.r.t. $\approx_1, \approx_2$;
F is 0.75-functional w.r.t. $\approx_2, \approx_2$;
F is 0.5-functional w.r.t. $\approx_1, \approx_1$;
F is 0.31-functional w.r.t. $\approx_2, \approx_1$.

If we change the background algebraic structure to the standard product algebra then the fist degree of functionality will remain the same and the rest will change to $0.25, 0.05, 0.0125$, *respectively.*

Let us provide the main results taken from [9] relating to properties of an approximation (analogous to the Hajek's results) using the implicative normal forms.

Theorem 10 *If F is a-functional then*

$$a \le \bigwedge_{x\in X, y\in Y} (F(x,y) \to_* \mathrm{INF}(x,y)).$$

It means that the degree of functionality $\mathrm{Fun}_{\approx_{1,2}} F$ is the lower estimation of the inclusion F and INF denoted as $F \subseteq \mathrm{INF}$, i.e., $\mathrm{Fun}_{\approx_{1,2}} F \le F \subseteq \mathrm{INF}$.

Theorem 11 *Let C and C' be given by*

$$C(x) =_{df} \bigvee_{i\in I}[(c_i \approx_1 x) * (c_i \approx_1 x)], \quad (11)$$

$$C'(x) =_{df} \bigvee_{i\in I}[(c_i \approx_1 x) * (x \approx_1 c_i)]. \quad (12)$$

If F is a-functional and b-extensional and moreover, the normal forms are constructed in the nodes taken from the set `Samples` *then*

$$a * b * \bigwedge_{x\in X} C(x) \le \bigwedge_{x\in X, y\in Y} (F(x,y) \leftrightarrow_* \mathrm{INF}(x,y)).$$

The result for INF'_F with symmetric $\approx_2$ is the same inequality with C' instead of C. Moreover, an interpretation of this result is analogous to the one given for Theorem 6.

Example 12 *From Example 5 and 9, it follows that the precision of approximation of F using* INF *w.r.t. $\approx_1, \approx_2$ depends only on the suitable partition of $X \times Y$ such that $\bigwedge_{x\in X} C(x)$ is as high as possible (it also leads to an optimization problem) in the both cases of the background algebra. While, e.g., in* *the case of* $\approx_2, \approx_2$ *and the Łukasiewicz standard algebra, we have that*

$$\underbrace{0.5}_{0.75*0.75} * \bigwedge_{x\in X} C(x) \leq \bigwedge_{x\in X, y\in Y} (F(x,y) \leftrightarrow_* \mathrm{INF}(x,y)).$$

From the sequence of examples, we see that the normal form based approximations and hence generally "fuzzy rule based approximations" are very sensitive to all choices of the input parameters such as the choice of the background algebra, binary fuzzy relations $\approx_1, \approx_2$ number of nodes and their distribution over the respective universe.

V. Consequences of the Implicative Normal Form Based Formalization to Fuzzy Control

From the point of view of fuzzy control, it is important to investigate the outputs of the particular approximate inference (reasoning). It appeared [10], that it is necessary to distinguish between approximate inference using DNF and CNF. Let us briefly describe them together with the new inference rule for INF:

$$R_{\mathrm{DNF}} : \frac{A', \mathrm{DNF}}{B^*}, \quad R_{\mathrm{CNF}} : \frac{A', \mathrm{CNF}}{B^{**}} \quad \text{and } R_{\mathrm{INF}} : \frac{A', \mathrm{INF}}{B'},$$

where

$$B^*(y) =_{df} \bigvee_{x\in X} (A'(x) * \mathrm{DNF}_F(x,y)),$$
$$B^{**}(y) =_{df} \bigwedge_{x\in X} (A'(x) \rightarrow_* \mathrm{CNF}_F(x,y)),$$
$$B'(y) =_{df} \bigvee_{x\in X} (A'(x) * \mathrm{INF}_F(x,y)).$$

We refer to [7], [10] for properties of R_{DNF} and R_{CNF}. Due to the space limitation, we will provide only properties of R_{INF} without proofs.

Theorem 13 *Let*

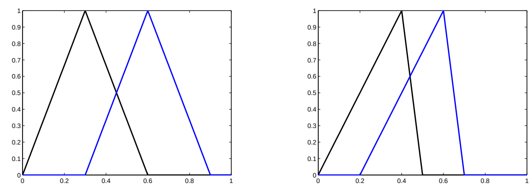
$$A_i(x) =_{df} (x \approx_1 c_i),$$
$$B_i(y) =_{df} F(c_i, d_i) \rightarrow_* (y \approx_2 d_i).$$

- $(A' \subseteq A_i) \rightarrow_* (B' \subseteq B_i)$;
- $\bigvee_{x\in X}(A_i(x)) * (A_i \subseteq A') \rightarrow_* (B_i \subseteq B')$;
- $\bigvee_{x\in X}(A_i(x)) * (A_i \approx A') \rightarrow_* (B_i \approx B')$.

From these properties we see that R_{INF} is very natural approximate inference since it provides an expected output without complicated requirements. Indeed, there is only one extraordinary requirement $\bigvee_{x\in X}(A_i(x))$ that can be characterized as non-emptiness and it can be read as: there exists $x \in A_i$.

Example 14 *As an illustration, let us consider Łukasiewicz standard algebra and two graded fuzzy rules*

$$^{0.9\preceq}/(\textit{If } x \in A_1 \textit{ then } y \in B_1) \quad \text{AND}$$
$$^{0.8\preceq}/(\textit{If } x \in A_2 \textit{ then } y \in B_2),$$



(a) Fuzzy sets on X, A_1 – black line; A_2 – blue line. (b) Fuzzy sets on Y, B_1 – black line; B_2 – blue line

Figure 1. Fuzzy sets in the graded fuzzy rules from Example 14

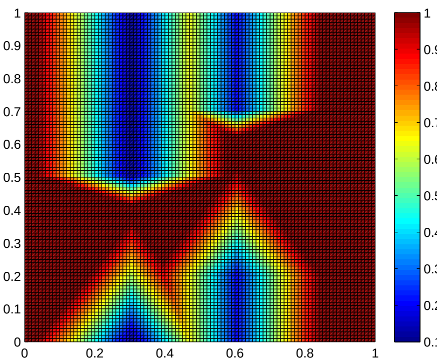
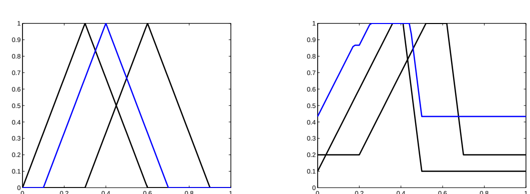


Figure 2. Graded fuzzy rules from Example 14

where A_i, B_i *are (non-symmetric) triangular fuzzy numbers depicted on Figure 1. The resulting fuzzy relation is visualized on Figure 2. The output of the inference* R_{INF} *with the input fuzzy set* A' *(blue line on Figure 3(a), i.e., shifted* A_1*) is a fuzzy set* B' *drawn on Figure 3(b). On these figures, we demonstrate the last inequality in the above theorem:* $(A_1 \approx A') \doteq 0.6667$ *and* $\bigvee_{x\in X}(A_1(x)) = 1$*, hence,* $0.06667 \leq (0.9 \rightarrow_* B_1) \approx B'$*. In the case of the input fuzzy set* A' *identical with* A_1 *(or* A_2*), we obtain exactly* $0.9 \rightarrow_* B_1$ *(*$0.8 \rightarrow_* B_2$*) as the output* B'*.*

The following properties relate to a position of the reconstructed implicative rule $A' \rightarrow_* B'$ and the ideal fuzzy relation F.

Theorem 15 *Assume the notational convention as in Theo-*



(a) A_1, A_2 – black line; A' – blue line. (b) $0.9 \rightarrow_* B_1, 0.8 \rightarrow_* B_2$ – black line; B' – blue line

Figure 3. Inference over the graded fuzzy rules from Example 14

 ISBN: 978-1-61208-155-7

rem 13 and moreover

$$F_h(y) =_{df} \bigvee_{x\in X} F(x,y);$$

- *If F is a-functional then $a \le F \subseteq (A' \to_* B')$;*
- *If F is a-functional and b-extensional then*

$$a * b * \bigwedge_{x\in X} C(x) \le (A' \to_* B') \subseteq (A' \to_* F_h).$$

The first inequality shows that the degree of functionality of F estimates the degree of inclusion of F in $A' \to_* B'$. And the second inequality provides an estimation of the reverse inclusion, i.e., the degrees of extensionality, functionality and the good partition estimates inclusion of $A' \to_* B'$ in $A' \to_* F_h$. An open question remains whether it is possible to prove $(A' \to_* B') \subseteq F$.

VI. Conclusions

In this contribution the INF has been recalled together with the results showing its suitability for an approximation of dependencies represented by functional and extensional fuzzy relations. In Theorem 11, an estimation of the equivalence between the given fuzzy relation and its INF has been provided. The resulting inequality is the same as in the case of DNF and CNF. Which gives us a confidence on the efficiency of INF. Moreover, we have worked purely with the graded notions and all provided results carry the information about the involved degrees. Hence, they widens an applicability of normal forms to partially extensional and partially functional fuzzy relations.

Additionally, a connection between graded fuzzy rules and the INF was explained. Indeed, graded fuzzy rules can be seen as classical fuzzy rules with the modified antecedent parts (a different modification for each normal form). This view provides an insight into the nature of descriptions formalized by normal forms.

Finally, a suitable inference rule has been introduced and studied. Our choice of the inference rule is supported by the theoretical results mainly by Theorem 13 that explains behavior of an output of this inference w.r.t. a particular fuzzy set on the consequent part of the respective fuzzy rule. This theoretical analysis of the generalized Implicative model of fuzzy rules is aimed to provide a complete view on the problematic of well setting of a fuzzy rule base system and indeed justifying its proper behavior.

Acknowledgment

We gratefully acknowledge support of the project MSM6198898701 of the MŠMT ČR.

References

[1] D. Dubois and H. Prade, “What are fuzzy rules and how to use them,” *Fuzzy Sets and Systems*, vol. 84, pp. 169–185, 1996.

[2] P. Hájek, *Metamathematics of Fuzzy Logic*, ser. Trends in Logic. Dordercht: Kluwer, 1998.

[3] V. Novák, I. Perfilieva, and J. Močkoř, *Mathematical Principles of Fuzzy Logic*. Dordrecht: Kluwer, 2000.

[4] E. H. Mamdani and S. Assilian, “An experiment in linguistic synthesis with a fuzzy logic controller,” *Int. J. Man-Mach. Stud.*, vol. 7, no. 3, pp. 1 – 13, 1975.

[5] L. A. Zadeh, “Outline of a new approach to the analysis of complex systems and decision processes,” *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 3, no. 1, pp. 28–44, 1973.

[6] M. Štěpnička, U. Bodenhofer, M. Daňková, and V. Novák, “Continuity issues of the implicational interpretation of fuzzy rules,” *Fuzzy Sets and Systems*, vol. 161, no. 14, pp. 1959–1972, 2010, theme: Fuzzy and Uncertainty Logics.

[7] M. Daňková, “Graded fuzzy rules,” in *Proceedings of the 12th international Fuzzy Systems Association world congress on Foundations of Fuzzy Logic and Soft Computing*, ser. IFSA ’07. Berlin, Heidelberg: Springer-Verlag, 2007, pp. 481–490.

[8] I. Perfilieva, “Normal forms in BL-algebra of functions and their contribution to universal approximation of functions,” *Fuzzy Sets and Systems*, vol. 143, pp. 111–127, 2004.

[9] M. Daňková, “Graded fuzzy rules for functional dependencies: Normal form based formalization,” in *Foundations of fuzzy logic and soft computing*. Springer-Verlag Berlin Heidelberg.

[10] M. Daňková, “On approximate reasoning with graded rules,” *Fuzzy Sets and Systems*, vol. 158, no. 6, pp. 652 – 673, 2007, the Logic of Soft Computing, The Logic of Soft Computing IV and Fourth Workshop of the ERCIM working group on soft computing.

[11] M. Daňková, “Approximation of extensional fuzzy relations over a residuated lattice,” *Fuzzy Sets and Systems*, vol. 161, no. 14, pp. 1973 – 1991, 2010, theme: Fuzzy and Uncertainty Logics.

[12] I. Perfilieva, “Logical approximation,” *Soft Computing*, vol. 2, pp. 73–78, 2001.

[13] M. Daňková and I. Perfilieva, “Logical approximation ii,” *Soft Computing*, vol. 7, pp. 228–233, 2003.

[14] M. Demirci, “Fuzzy functions and their fundamental properties,” *Fuzzy Sets and Systems*, vol. 106, pp. 239–246, 1999.

[15] R. Bělohlávek, *Fuzzy Relational Systems: Foundations and Principles*, ser. IFSR International Series on Systems Science and Engineering. New York: Kluwer Academic/Plenum Press, 2002, vol. 20.

[16] L. Běhounek, “Extensionality in graded properties of fuzzy relations,” in *Proceedings of 11th IPMU Conference*. Paris: Edition EDK, 2006, pp. 1604–1611.

[17] L. Běhounek and P. Cintula, “Fuzzy class theory,” *Fuzzy Sets and Systems*, vol. 154, no. 1, pp. 34–55, 2005.

A Two-Level Decision Support System For Supplier Diversification

Evrim Ursavas Guldogan
Industrial Engineering
Yasar University
Izmir, Turkey
email: evrim.guldogan@yasar.edu.tr

Onder Bulut
Industrial Engineering
Yasar University
Izmir, Turkey
email: onder.bulut@yasar.edu.tr

***Abstract*— In this study, we provide a two-level decision support system for the constitution of supplier pool and order quantity decision for each of the suppliers selected from a predetermined candidate list. The candidate suppliers are the current vendors in the market. The proposed decision support tool integrates a knowledge-based expert system and a genetic algorithm to consider both qualitative and quantitative criteria in supplier selection and order quantity decision. The expert system decreases the candidate suppliers to the most preferred ones according to quality, delivery and management core dimensions. Genetic algorithm then allocates order quantities to each supplier considering quantity discounts, preference factors and capacity constraints. A real-life case study at a steel structures manufacturing company demonstrates an application of the proposed support system.**

Keywords- expert systems; genetic algorithms; decision support systems; supply chain management; supplier selection

I. INTRODUCTION

Procurement expenses constitute a major component of the operating expenditures of the firms. Thus, supplier selection has become one of the key issues in supply chain management. Furthermore, choosing the right vendors would result in improved coordination with suppliers. In practice, the contemporary approach is to work with fewer but more fulfilling suppliers to build long term relationships with each of them. With the increasing diversity of suppliers, transaction costs, monitoring costs, supply chain strategic and operational risks, competition are increased, whereas supplier innovation and responsiveness are decreased [1-4]. However, firms benefit from the risk pooling effect with the increased number of suppliers.

Apparently, building a manageable supplier base is a multi-criteria decision making problem which requires the analysis of both quantitative and qualitative factors such as price, delivery leadtime and quality, and managerial issues (feedback, contingency planning, etc.). Consideration of quantity discounts also adds a new level of complexity to the supplier selection problem. That is, the decision maker must determine the order quantities for each supplier under several conflicting factors. In this context, the need for an effective decision support system is apparent.

In the literature, a vast number of studies focus on the supplier selection issue. One group of studies relies on the inventory management perspective. In such studies, delivery leadtime, quality, supplier capacity, and other factors are embedded into inventory control models. The other group of studies mainly concentrates on developing decision support systems (such as expert systems, data envelopment analysis) based on qualitative factors. In this study, we combine these two approaches and propose a two-level decision model consisting of a knowledge-based expert system and a genetic algorithm. The model is composed of two main stages: In the first stage, a knowledge- based expert system is used to discover the suppliers --with their preference factors-- that we can order for a certain type of product. The second stage aims at determining the order quantity allocated to each of the selected suppliers with the use of a genetic algorithm.

This paper is structured as follows. Section 2 presents a review of some of the related literature. Section 3 introduces the proposed methodology in an overall perspective. Sections 4 and 5 present the knowledge-based expert system and the genetic algorithm respectively. A case study is carried out in Section 6. The final section summarizes the paper and presents the conclusion.

II. LITERATURE REVIEW

In the area of supply base management numerous methods have been used for supplier evaluation and selection. We refer the reader to the recent survey of [5]. The research analyzes prevalently applied approaches and provides evidence that the multi-criteria decision making methods are better than the traditional cost-based approach.

With its practical usefulness, a majority of the studies are based on data envelopment analysis [6]. Mainly, the methodology seeks for relatively efficient suppliers based on multiple inputs and outputs. It relies on the assumption that more efficient suppliers are more effective. AHP (Analytical Hierarchy Process) is another popular method used widely in the literature [7]. It should be noted that, due to the number of evaluations required, for problems with a large number of alternatives or criteria, the use of this technique is unwieldy. The use of intelligent systems, such as case-based reasoning, neural networks and expert systems form another group of decision making tools [8-11].

Most studies in the literature have addressed the selection problem solely. Some articles considering the order quantity allocation to the selected suppliers under

 ISBN: 978-1-61208-155-7

multiple sourcing strategies. Degraeve and Roodhooft [12] followed a mathematical programming approach using activity-based costing for supplier selection. Karpak et al. [13] and Kumar et al. [14] used goal programming (GP) models to select suppliers and allocate orders under supplier's capacity constraints. Ghodsypour and O'Brien [15] proposed a mixed integer nonlinear programming model to minimize the total cost of logistics, including net price, storage, transportation and ordering costs.

In [16][17][18][19], integrated AHP and GP models are used. Relative performances of suppliers found from the AHP model was used as inputs to the GP model to find the optimal supplier base. Both quantitative and qualitative factors could be used for supplier evaluation, but the unit price of a product is assumed constant for different order quantities.

Xia and Wu [20] used AHP for searching potential suppliers and then used the multi-objective mixed integer programming to determine the number of suppliers to employ and the order quantity allocated to these suppliers. Mendoza and Ventura [21] also used AHP in the first phase to reduce the number of suppliers. At the second phase they implemented a mixed integer non-linear programming method to determine the optimal order quantites. Demirtas and Ustun [22] have used analytic network process (ANP) in the first step and for quantity allocation they followed the similar method used in [20].

In the studies of [23][24], fuzzy multi-objective programming models were developed for supplier selection and order quantity allocation. Their later work also considered price discounts. Chen [25] used the fuzzy set theory to select suppliers under supplier base limitations.

Eventually, while many studies in the literature address the quantity discounts in the economic order quantity subject, a little attention has been paid to the case in the supplier selection and order quantity allocation problem. This paper proposes a two-level approach to seek for the most appropriate supplier base by using the expert system and the genetic algorithm with quantity discount considerations.

III. THE PROPOSED METHODOLOGY

Supplier selection and order quantity allocation is a multi-step process which requires the evaluation of suppliers by quantitative and qualitative measures dependent on the product type and various constraints. The methodology proposed in this study follows a two-step architecture illustrated in Figure1.

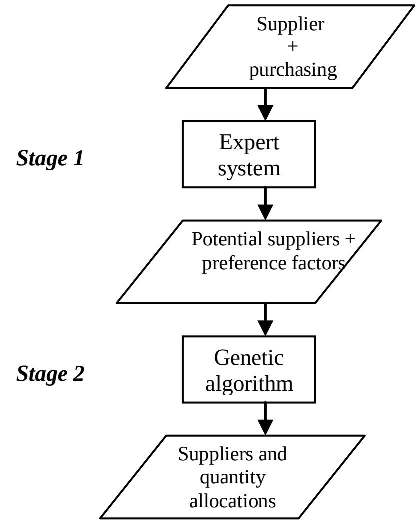


Figure 1. Main flowchart.

The first stage uses a knowledge- based expert system to select potential suppliers under quality, delivery and management dimensions. At the end of this step, a list of candidate suppliers with their preference factors is provided as an output to the second step. Using this data, the second stage searches throughout the solution space under supplier capacity constraints and price discounts to determine the optimal supplier base. Finally, at the end of this phase, optimal suppliers and their order quantity allocations are specified.

IV. STAGE I .THE KNOWLEDGE-BASED EXPERT SYSTEM

A. *Criteria determination and evaluation*

Dickson [26] listed 23 factors to consider for supplier evaluation and selection. Recently, Ho et al. [27] reviewed the literature to discover the criterion used by the decision makers. Studies identify more than hundreds of measures with quality, delivery, cost, manufacturing capability and service as being the most popular ones and some recently recognized criterions such as environmental standards. In general, the evaluation and selection process differs according to the purchased product type. Therefore, in the developed model, initial determinant in the system is the product's category, which may be either strategic or non-critical.

The criteria in this work were determined based on related literature and by interviews with the purchasing managers of a medium-sized company in the steel structure construction business. It should be noted that these criterions are subject to discussion and they may be defined in a different way for companies in different industries. Figure 2 shows the decision map for the strategic products.

 ISBN: 978-1-61208-155-7

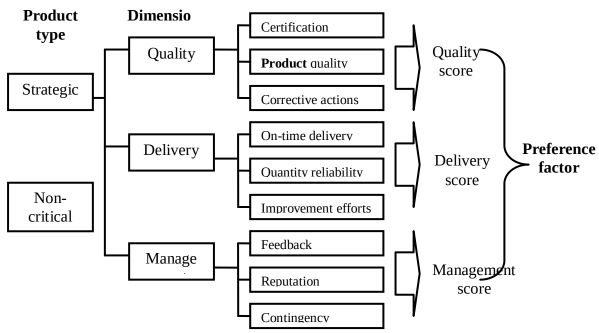


Figure 2: Decision map for strategic products

Additional details for the decision attributes and their values for strategic products are given in Table I.

TABLE I. DECISION ATTRIBUTES AND THEIR VALUES

Strategic product	
Does the supplier have the quality system certifications required?	No / Yes
At what level does the supplier meet the requirements for quality?	U / M / S / V / E
At what level does the supplier show vigorous and successful corrective actions?	U / M / S / V / E
Does the supplier comply with the delivery schedule?	U / M / S / V / E
Does the supplier comply with the delivery quantity?	U / M / S / V / E
What is the level of supplier's efforts for delivery recovery?	U / M / S / V / E
How is the supplier's communication skills and feedback?	U / M / S / V / E
How is the supplier's reputation and position in the industry?	U / M / S / V / E
At what level does the supplier have satisfactory contingency plans to ensure business continuity?	U / M / S / V / E

Key: U=Unsatisfactory, M= Marginal, S= Satisfactory, V= Very Good, E= Excellent

B. *Expert system architecture*

A knowledge-based expert system developed for determining the potential suppliers and their preference factors is composed of the following elements: User and expert interfaces, knowledge base, material requirements planning module and the inference engine. The user and the material requirements planning module together provide information related to the product to be purchased and the available suppliers. The knowledge base contains the problem specific information obtained from purchasing experts. The facts and rules (based on production rules semantics) are stored in the knowledge base are generally in the structure provided in Table II.

TABLE II. DECISION ATTRIBUTES AND THEIR VALUES

Rule id: ST_Q_5			
IF	certification	IS	Yes
AND IF	product quality	IS	Very good
AND IF	corrective actions	IS	Satisfactory
THEN	quality score	IS	Very good
Rule id: ST_D _12			
IF	on-time delivery	IS	Very good
AND IF	quantity reliability	IS	Excellent
AND IF	improvement efforts	IS	Excellent
THEN	delivery score	IS	Excellent
Rule id: ST_M _9			
IF	feedback	IS	Satisfactory
AND IF	reputation	IS	Very good
AND IF	contingency planning	IS	Satisfactory
THEN	management score	IS	Satisfactory
Rule id: ST_P _9			
IF	quality score	IS	Very good
AND IF	delivery score	IS	Excellent
AND IF	management score	IS	Satisfactory
THEN	preference factor	IS	Very good

Example rules given above are used for strategic products. Through rule ST_Q_5, the system determines the supplier's quality score as very good, if it is certified, its product quality is high and its corrective action management is satisfactory. According to the next rule, (ST_D _12), if a company's on-time delivery is rated very good, quantity reliability and improvement efforts are excellent then its delivery score is excellent. Rule ST_M _9 states that if supplier feedback is satisfactory, reputation is very good and contingency planning is satisfactory then the management score is satisfactory. The scores for the three main dimensions are then evaluated together to obtain the preference factor in terms of "Unsatisfactory; Marginal; Satisfactory; Very Good; Excellent". For instance, through rule ST_P _9, preference factor is rated as very good for a supplier with very good quality, excellent delivery and satisfactory management.

V. STAGE II

Previous phase determined the potential suppliers along with their preference scores. This stage allocates order quantities to each of these suppliers under supply constraints and price discounts. To search throughout the large solution space, a genetic algorithm, which is known as an effective method for solving complex optimization problems, was employed.

A. *Chromosome representation*

Each chromosome is designed in a way to represent a feasible solution with suppliers and their quantity allocations. As illustrated in Figure 3, each gene of a chromosome is designed to stand for the quantity allocation (q_i) for each supplier placed in a fixed position.

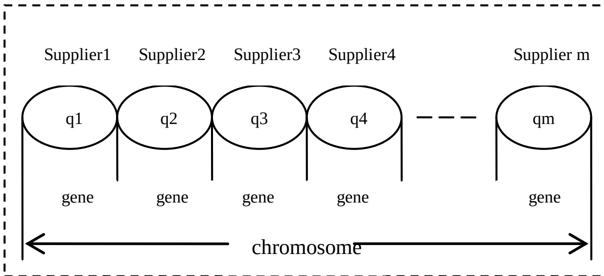


Figure 3: Chromosome representation

B. Genetic operators

In order to maintain the genetic diversity for evolution, selection, crossover and mutation operators are utilized. The selection process selects two individuals or parents for crossover. Rank selection technique is used for this purpose. Once the parents are selected offspring are created by the use of the crossover operator. With the aim of ensuring the variety of the individuals so as to prevent local optimum solutions, mutation operator is induced. Figure 4 demonstrates the two-point crossover and the mutation operators used in this study. To preserve the best individuals in an attempt to shelter the population, elitist strategy is adapted when creating the new population.

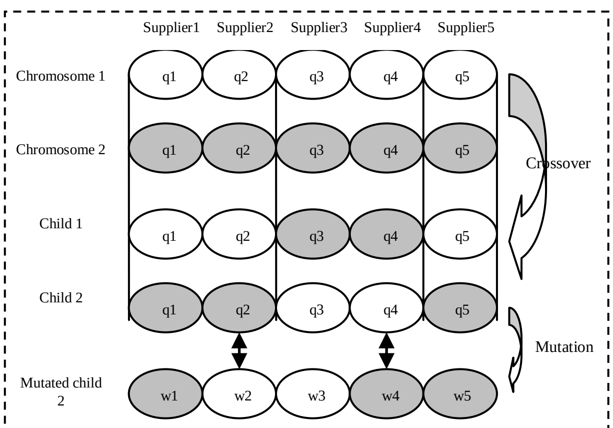


Figure 4: Crossover and mutation operators

C. Fitness function

Fitness value of a chromosome reveals its value compared to other individuals in terms of the defined objective. In this model, the fitness function is an arrangement of the measures unit and fixed purchasing prices, and preferences. Furthermore, diversity the total number of suppliers in the supplier set formed by the expert-system.

$$\min Z = F(diversity, price, preference)$$

The solution is reached through simultaneous minimization of those measures. Preference factor for each supplier is derived from the first stage expert system outputs. Unit price policies for different quantity ranges are prearranged for each supplier.

q_i quantity allocated to supplier i
x_i preference factor of supplier i
SC_i capacity of the i*th* supplier
D total demand
$P_i(q_i)$ unit price for supplier i if the order quantity is q_i
K_i fixed ordering cost for supplier i (setup cost)

We consider a single-buy model with deterministic demand. One may consider this model as a make-to-order model with known demand, say D, for a specific component. That is, the total quantity allocated to the suppliers should be defined as $\sum_i^n q_i = D$, where n is the total number of suppliers in the preferred list generated by the expert-system. Further, with a supplier capacity of SC_i, quantity must also be limited by $q_i \le SC_i$.

Preference factors derived from the expert system are converted to numeric values through one to five, with five being the least preferred and one the most preferred score. We then use the preference factors of the suppliers as the weights of their costs. Then the objective function is

$$\min_{q_1,\ldots,q_n} Z = \sum_i^n x_i (q_i P_i(q_i) + K_i 1(q_i > 0))$$

where $1(q_i > 0)$ is an indicator function; it returns 1 if $q_i > 0$ and 0 otherwise.

VI. CASE STUDY

The proposed method was coded in Microsoft Visual C++ with .NET Framework under Windows Vista. The model was then applied to a mid-size steel structures manufacturing company. The case selected for testing purposes was a strategic product with 12 potential suppliers. Some suppliers could meet the qualifications entirely and some partially. The input data related to the performance criteria in the model are given in Table III.

The solution procedure followed the structure outlined in Figure 1. The initial determinant is the product category. As the user selects the strategic product option, the expert system will follow the decision-tree structure depicted in Figure 2. The output preference factors for each supplier are shown in Table IV.

Since the maximum number of suppliers is limited by the company, the suppliers with the top preference scores are taken as input to the second phase of the model. The supply capacities, setup costs and price levels for different quantities for those suppliers are shown in Table V. Total demand of the product is given as 100 units.

TABLE III. SUPPLIER DATA

		s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12
Quality	Certification	Y	N	N	Y	Y	Y	Y	N	Y	Y	N	N
	Product quality	V	S	M	E	V	S	S	V	U	M	S	V
	Corrective action mgmt	S	M	U	E	V	S	V	E	M	M	S	V
Delivery	On-time delivery	V	S	M	E	V	S	M	M	V	V	S	M
	Quantity reliability	V	M	U	E	V	S	U	U	S	V	V	M
	Improvement efforts	E	M	S	S	V	E	E	M	S	V	E	S
Management	Feedback	M	S	S	V	V	S	M	U	S	V	E	S
	Reputation	E	M	U	E	V	V	V	M	V	S	M	V
	Business continuity	V	U	U	V	S	S	M	M	V	S	M	S

TABLE IV. SUPPLIER PREFERENCE VALUES

_	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12
Quality	V	M	U	E	V	S	V	S	M	M	M	M
Delivery	E	M	M	V	V	S	M	M	S	V	V	M
Management	V	M	U	E	V	S	M	M	S	S	M	S
Overall	E	M	U	E	V	S	M	M	M	S	M	M

TABLE V. SUPPLY CAPACITIES AND PRICE LEVELS FOR SUPPLIERS

Supplier	Quantity	Price	Capacity	Setup cost
s1	q<25	22	80	1
	25≤q<50	17		
	q≥50	11		
s4	q < 15	20	70	1
	15 ≤q< 40	16		
	q ≥ 40	11		
s5	q≤20	20	70	4
	20≤q<50	15		
	q≥50	10		
s6	q≤30	19	90	3
	30≤q<60	14		
	q≥60	10		
s10	q≤20	22	60	3
	20≤q<30	14		
	q≥30	10		

Parameters and attributes related to the genetic algorithm are as follows:

- The population size is set to 50
- Rank selection is used for choosing the candidates for breeding.
- Two-point crossover is implemented.
- Crossover and mutation probabilities are set to 0.9 and 0.2 accordingly.
- Elitist strategy is implemented.
- Maximum number of iterations is set as 250.

Genetic algorithm was run with the above parameters and the best solution found in ten runs is shown in Table VI. The supplier base is composed of two suppliers: Supplier 1 and Supplier 4. Supplier 1 scored “Very good” in quality, “Excellent” in delivery and “Very Good” in management, whereas Supplier 4 scored “Excellent” in quality, “Very Good” in delivery and “Excellent” in management aspects. The first supplier is assigned an order of 60% of demand (60 units). With this amount, the order size is above the second price breakpoint and the company can benefit from the price advantage. Remaining demand (40 units) is allocated to Supplier 4, where the third price level policy may again be adapted.

TABLE VI. BEST SOLUTION OUTPUT

Total demand	Fitness		Quantity	Price
100	13.224	Supplier 1	60	11
		Supplier 4	40	11
		Supplier 5	0	0
		Supplier 6	0	0
		Supplier 10	0	0

Within the genetic optimization stage, the solution fitness scores at each iteration were analyzed. Figure 5 and 6 demonstrate how the individuals persistently converged to better solutions, consistent with the genetic algorithms nature. While the first graph belongs to the population average progress, the second graph shows the evolution process of the best chromosome for ten runs.

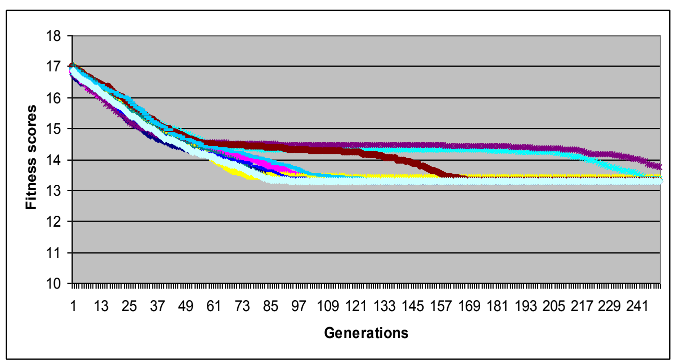


Figure 5: Fitness evolution of population average

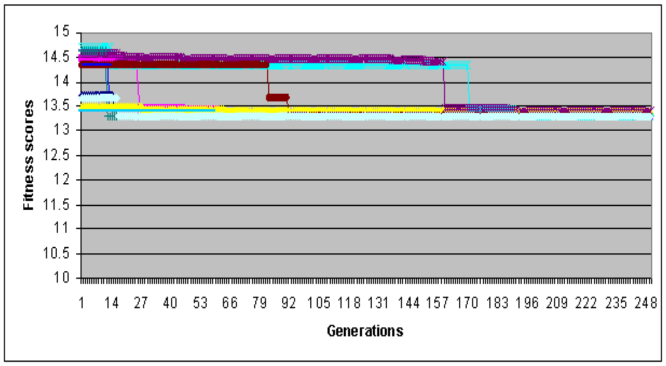


Figure 6: Fitness evolution of the best solution

Examination of the solutions proved that all solutions are feasible in terms of supplier capacities, demand and price polices. Criterion relating to quality, delivery, management, and price were considered simultaneously in decision of the final selection. The model showed strong tendency towards choosing the most appropriate suppliers in terms of quality, delivery and management as far as it would be economically reasonable. Furthermore, solutions also tempted to work with fewer but more reliable suppliers. These results verify the efficiency of the fitness function explained previously.

It should be noted that heuristic algorithm solutions do not guarantee an optimal result. Nevertheless, reaching a result close to the optimal solution, to some extent, is essential. To test the algorithms performance in this perspective, best and worst solutions throughout the experimental runs were collected. These two values may imply the upper and the lower bounds of the feasible solution space.

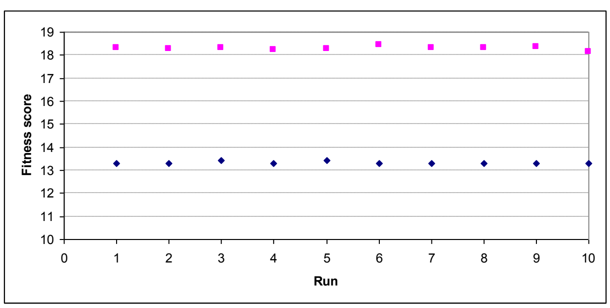


Figure 8: Solutions dispersion

In Figure 8, dispersion of the best and the worst scores in ten runs are illustrated. It can be observed that, best solutions are scattered within the top 2% of the feasible solution space. With these facts, it can be concluded that the developed genetic algorithm conforms to the fundamental requirement of a heuristic and the developed method can be employed as an efficient decision support tool in order to help purchasing managers.

VII. CONCLUSION

This paper proposes a new model integrating the expert system and the genetic algorithm to build the most appropriate supplier base. With the knowledge-based expert system potential suppliers are chosen with respect to quality, delivery and management dimensions and preference factors are assigned to each supplier. In the second phase order quantities are allocated to each supplier considering quantity discounts, preference factors and setup costs. A real-life case study at a steel structures manufacturing company illustrates the applicability of the proposed methodology.

As a future research, the model can be extended to tackle multi-product orders. Then, the model can be used for group decision making for a complete supplier base optimization.

REFERENCES

[1] Bhutta, K.S. and Huq, F. (2002), "Supplier selection problem: a comparison of the total cost of ownership and analytic hierarchy process approaches", Supply Chain Management: An International Journal, Vol. 7 No. 3, pp. 126-35.

[2] Fynes, B. and Voss, C. (2002), "The moderating effect of buyer-supplier relationships on quality practices and performance", International Journal of Operations and Production Management, Vol. 22 No. 6, pp. 589-613.

[3] Hvolby HH, Trienekensz J, and Steger-Jensen K (2007), "Buyer-supplier relationships and planning solutions", Production Planning and Control, 18(6), pp. 487-496

[4] Van Nyen PLM, Bertrand JWM,and Van Ooijen HPG. (2009), "Supplier managed inventory in the OEM supply chain: the impact of relationship types on total costs and cost distribution ", OR SPECTRUM, 31(1), pp. 167- 194

[5] Ho W., Xu X. , and K. Dey P. (2010),"Multi-criteria decision making approaches for supplier evaluation and selection: A literature review", European Journal of Operational Research, 202 , pp. 16–24

[6] Saen, R.F. (2007), "Suppliers selection in the presence of both cardinal and ordinal data", European Journal of Operational Research, 183 (2) , pp. 741–747.

[7] Chan, F.T.S. and Kumar, N. (2007), "Global supplier development considering risk factors using fuzzy extended AHP-based approach", OMEGA – International Journal of Management Science, 35 (4) , pp. 417–431.

[8] Siying, W., Jinlong, Z., and Zhicheng, L. (1997), "A supplier-selecting system using a neural network", Proceedings of IEEE International Conference on Intelligent Engineering Systems, pp. 468–471.

[9] Humphreys, P., McIvor, R., and Chan, F. (2003), "Using case-based reasoning to evaluate supplier environmental management performance", Expert Systems with Applications, 25, pp. 141–153.

[10] Choy, K.L., Lee, W.B. , and Lo, V. (2005), "A knowledge-based supplier intelligence retrieval system for outsource manufacturing", Knowledge-Based Systems 18 (1) , pp. 1–17.

[11] Ha, S.H. and Krishnan, R. (2008), "A hybrid approach to supplier selection for the maintenance of a competitive supply chain", Expert Systems with Applications, 34 (2) , pp. 1303–1311.

[12] Degraeve, Z. and Roodhooft, F. (2000). "A mathematical programming approach for procurement using activity based costing", Journal of Business Finance and Accounting, 27 (1–2) , pp. 69–98.

[13] Karpak, B., Kumcu, E. , and Kasuganti, R.R. (2001),"Purchasing materials in the supply chain: Managing a multi- objective task", European Journal of Purchasing and Supply Management 7 (3) , pp. 209–216.

[14] Kumar, M., Vrat P. , and Shankar R. (2004), "A fuzzy goal programming approach for vendor selection problem in a supply chain", Computers & Industrial Engineering, vol. 6, pp. 69–85

[15] Ghodsypour S.H. , and O'Brien C. (2001), "The total cost of logistic in supplier selection under conditions of multiple sourcing multiple criteria and capacity constraint", International Journal of Production Economics, 73 (1), pp. 15–27

[16] Cebi, F. and Bayraktar, D. (2003), "An integrated approach for supplier selection", Logistics Information Management, 16 (6) , pp. 395–400.

[17] Wang, G., Huang, S.H. , and Dismukes, J.P. (2004), "Product-driven supply chain selection using integrated multi-criteria decision-making methodology", International Journal of Production Economics, 91 (1) , pp. 1–15.8

[18] Perçin, S. (2006), "An application of the integrated AHP–PGP model in supplier selection", Measuring Business Excellence, 10 (4), pp. 34–49.

[19] Mendoza, A., Santiago, E. , and Ravindran, A.R. (2008), "A three-phase multicriteria method to the supplier selection problem", International Journal of Industrial Engineering, 15 (2) , pp. 195–210.

[20] Xia, W. and Wu, Z. (2007), "Supplier selection with multiple criteria in volume discount environments", OMEGA – International Journal of Management Science, 35 (5) , pp. 494–504.

[21] Mendoza, A. and Ventura, J.A. (2008), "An effective method to supplier selection and order quantity allocation", International Journal of Business and Systems Research 2 (1), pp. 1–15.

[22] Demirtas, E.A. and Ustun, O. (2008), "An integrated multiobjective decision making process for supplier selection and order allocation", Omega. The International Journal of Management Science,36, pp. 76–90.

[23] Amid, A., Ghodsypour, S.H. , and O'Brien, C. (2006), "Fuzzy multiobjective linear model for supplier selection in a supply chain", International Journal of Production Economics, 104 (2) , pp. 394–407.

[24] Amid, A., Ghodsypour, S.H. , and O'Brien, C. (2009), "A weighted additive fuzzy multiobjective model for the supplierselection problem under price breaks in a supply chain", International Journal Production Economics, 121, pp. 321-332

[25] Chen C.M. (2009), "A fuzzy-based decision-support model for rebuy procurement", International Journal Production Economics, 122, pp. 714–724

[26] Dickson, G.W. (1966), "An analysis of vendor selection systems and decisions", Journal of Purchasing 2 (1) , pp. 5–17

[27] Ho W., Xu X. , and K. Dey P. (2010),"Multi-criteria decision making approaches for supplier evaluation and selection: A literature review", European Journal of Operational Research, 202 , pp. 16–24

 ISBN: 978-1-61208-155-7

Developing a Decision Tool to Evaluate Unmanned System's Command and Control Technologies in Network Centric Operations Environments

Maria Olinda Rodas, Mark Veronda and Christian Szatkowski
Command and Control Engineering Division
Space and Naval Warfare System Center Pacific
San Diego, California
maria.rodas@navy.mil, mark.veronda@navy.mil, christian.szatkowski@navy.mil

***Abstract*—Expert systems that evaluate new Command and Control (C2) technologies are necessary to determine their adequacy for Network Centric Operations (NCO) missions. New technologies for complex C2 NCO scenarios are currently being developed. However, little has been done to evaluate these new technologies for specific sets of mission requirements. There is neither a standard methodology to evaluate these new technologies, nor a research environment to test these technologies under realistic assumptions. This paper will introduce an expert system that will help decision makers evaluate these technologies and determine whether they can transition into practical applications for the Navy, and under which limitations.**

Keywords-operator capacity; supervisory control; expert systems; unmanned vehicles.

I. INTRODUCTION

The Department of Defense's future vision for NCO is intended to increase combat control by networking relevant entities across a battlefield [1]. This new vision implies large amounts of information sharing and collaboration across different entities. An example of a futuristic NCO mission scenario is one in which a group of heterogeneous Unmanned Vehicles (UVs) are supervised by a single operator using NCO technology. In this type of complex C2 scenario, UV operators will be subjected to vast amounts of information as compared to today's command and control scenarios. Therefore, this vision brings with it a new problem that must be addressed: How to maintain an adequate workload to avoid information overload and resulting loss of situation awareness. Currently, C2 technologies that allow the operator to control multiple UVs in a NCO scenario are rapidly increasing. The development of these new C2 technologies generates the tendency to exponentially increase the ratio of UVs to operators. However, if systems are inadequately designed or are used beyond their design capabilities, they will not adequately control for increased workload, which in turn will cause the operator to become overloaded and lose situation awareness. It is critical that military decision makers develop predictive models of human and system performance to evaluate the adequacy of a system's design to satisfy specific mission requirements.

This paper will start by discussing previous research in the area of UV operator capacity, to later explain the project goals, methodology and experimental results. Finally, it will end with a brief discussion of the future research plans and the implications of this study on future human-UV interaction research.

II. BACKGROUND

Mental workload is a limiting factor in deciding how many UVs an operator can control or supervise. In the case of one operator supervising multiple vehicles, the operator's workload is measured by the effort required to supervise each vehicle and the overall task. The effort required to supervise an individual UV in a team depends on the efficiency of the system to reduce workload and increase situation awareness. Moreover, workload also depends on the complexity of the mission scenario. Some of the characteristics of a complex mission scenario as defined by military standards include: mission time constraints, precision constrains, repeatability in tasks (i.e., navigation, manipulations, etc.), level of collaboration required, concurrence and synchronization of events and behaviors, resource management (i.e., power, bandwidth, ammunition), rules of engagement, adversaries, and knowledge requirements [2]. The degree to which these characteristics are required also define workload. Consequently, if the system is not designed to achieve specific types of requirements, then when it is tested for those requirements the system may not perform them adequately.

Previous attempts to model operator capacity were developed to display temporal constraints associated with the system. The complexity of these measures progressed from measuring operator capacity in homogenous UVs controlled by one operator [3-7], to scenarios in which teams of heterogeneous UVs are supervised by one operator [8]. The first equation developed to predict operator capacity in homogenous UVs suggested that the operator capacity is a function of the Neglect Time (NT), or the time the UV operates independently, and Interaction Time (IT), or the time the operator is busy interacting, monitoring, and. making decisions with the system [3]. Critics of this method suggested that the equation lacked two critical considerations: 1) the importance of including Wait Times (WTs) caused by human-vehicle interaction, and 2) how to

 ISBN: 978-1-61208-155-7

link this equation to measure effective performance [6]. Hence, WT is added to the equation to account for the times the UV has to perform in degraded state because the operator is not able to attend to it or is not aware of a new incoming event. Three WTs were identified: Wait Times due to Interaction (WTI), Wait Times due to Loss of Situation Awareness (WTSA), and Wait Times due to Queue (WTQ).

Using a discrete event simulation, a research study attempted to create a link to performance by using a proxy to measure workload and situation awareness. In this model, the researcher intended to model heterogeneity in UV systems in order to evaluate the system's design [8]. The human was modeled as a server attending to vehicle-generated tasks – both exogenous and endogenous tasks – as defined by their arrival and service processes. The concept of utilization was introduced as a proxy for measuring mental workload. Utilization Time (UT) refers to the percentage of time the operator is busy. The concept of WTSA was used as a proxy to measure Situation Awareness. The UT and WTSA measures were computed as a type of aggregate effect of inefficiencies in information processing rather than being computed as individual measures of workload and situation awareness. The author of this model suggested that many other sources of cognitive inefficiencies, besides these two proxies, are manifested through cognitive delays. He emphasized that measures of UT and WTSA are extremely critical to determine supervisory performance and suggested that better methodologies to measure these variables need to be developed.

III. Project Goals

This study aims to develop a model of operator capacity in a complex mission scenario that will serve to help decision makers determine whether a particular technology is adequate for an NCO mission scenario. Moreover, this study aims to develop a model of operator capacity that is more comprehensive. This model is intended to fill in the gaps of current research by introducing new variables and relationships to previous models. The model will be constructed in a way so prior knowledge about the relationship between variables will serve to better predict missing data, such as workload and situation awareness. Moreover, the model will be structured in a way that will make it easy to determine which areas in the system design need improvement. The ultimate goal of this study is to develop a decision-making tool that will serve to evaluate and determine the effectiveness and limitations of a particular NCO technology in a complex mission scenario.

IV. Methodology

A. Approach

The approach taken by this research study was to model the decision-making process required to decide whether to increase a particular team size. This approach was taken in order to present decision makers with a decision-support tool that will ensure that knowledgeable decisions are made in regards to the adequacy of a given team size with a particular NCO technology. Modeling the decision-making process, as opposed to the environment, allows for more knowledgeable decisions because not only are the most important factors in the decision taken into account, but optimization of the recommended decision's outcome is also possible. This approach provides adequate information to the user to make a decision. And while the model is based on answering this particular question, the nature of the situation is manifested in the model, thus allowing users to draw more conclusions than only the adequacy of the team size.

B. The Decision Network Model

A decision network was developed to model the decision-making process required to decide whether to increase a given team size with the selected NCO technology. Netica Bayesian Belief Network (BBN) software [9] was used to develop a decision network that incorporates quantitative and qualitative information about the model. This software was chosen mainly because it provides an effective display of quantitative and qualitative data and it can accommodate missing or incomplete data. Using a BBN allows researchers to compute unobservable variables (i.e., missing data) based on measures that are observed (i.e., prior knowledge). This feature is very important to determine variables such as Situation Awareness and Workload that were only computed as proxies in previous models.

A decision network consists of nature, decision, and utility nodes. Nature nodes represent variables over which the decision maker has no control (see yellow nodes in Fig. 2). Decision nodes represent variables over which the decision maker can make a decision (see blue nodes in Fig. 2). Utility nodes represent a measure of value, or the decision maker's preferences for the states of the variables in the model (see pink nodes in Fig. 1). In this network, the outcome of a decision node is maximized by finding a configuration of the various states of the sets of variables that maximize the values of the utility node. Therefore, based on a series of requirements, or utility values, a decision network provides the user with the correct decision. Additionally, the arrows in the model represent reasoning relationships and are detailed in the conditional probability tables (CPTs) of the nature and utility nodes. In the CPT, the distribution of each node will be determined *a priori* based on the relationships specified in each conditional probability table.

This model makes several assumptions. First, the type of UV system addressed by this model is one in which a single human operator is responsible for supervising a team of heterogeneous UVs. The human operator is assumed to act in a supervisory control style, interacting with the system at discrete points in time (i.e., there is no manual control). Second, in this model, the human operator is responsible for supervising a team of heterogeneous UVs defending an oil

 ISBN: 978-1-61208-155-7

platform from potential enemies. Third, the human operator could be situated in a ground-based, sea-based, or airborne control station. Fourth, the model was built in a way such that decision makers will use this model to help them decide if a particular technology is adequate for specific mission requirements. Finally, the model assumes that the decision making process required to make this decision is hierarchical; therefore, later decisions are based on earlier ones. The model captures attributes from the Operator Performance Model, the System Performance Model, and the Operator Capacity Model as shown in Figure 1.

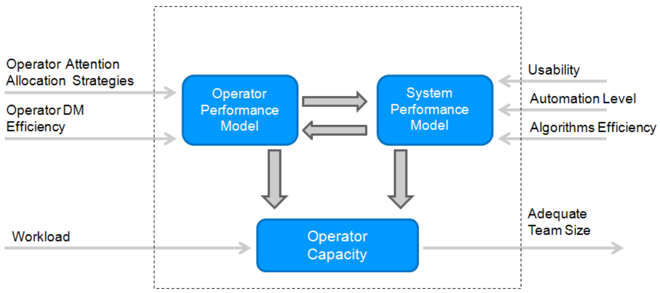


Figure 1. A high level representation on the attributes the model captures. Notice that variables of interest in Operator Performance Model are Operator Attention Allocation Strategies and Operator Decision Making Efficiency, while in the System Performance model are Usability, Automation Level and Algorithm Efficiency. The output of the operator capacity model is to determine an adequate team size.

The attributes captured in Figure 1 represent three major areas of relevance for the decision to increase the team size: system performance, operator performance, and cognitive workload (see Figure 2). These areas of relevance are represented in the model as sub-models; each of them contains one or more decision nodes that correspond to the decisions that must be made by the operator in each area to ensure that they are working adequately. The order in which the decision nodes have been organized represents the way in which decisions should be made (see blue nodes on Figure 2). The model represents a sequence of decisions in which later decisions depend on the results of earlier ones. In this model, the last decision is shown at the end of the sequence. The last decision determines whether a particular team size should be increased.

The first sub-model, system performance, includes three decision nodes with the followings decisions: 1) Is the interface effective? 2) Does the system have an adequate level of automation? 3) Are the system algorithms efficient for the task? These three decisions were included in this sub-model because they represent areas that are important to ensure good system performance. Some of the utility nodes for each of these decision nodes were identified from the literature, while some others were included to ensure that specific mission requirements are satisfied. For example, if the system has good interface usability, the situation awareness of the operator will be high. Moreover, if the situation awareness is high, the system's automation level must be somehow effective to avoid loss of situation awareness and/or complacency. Then, to ensure that the mission requirements are satisfied, the algorithms used must be working efficiently toward achieving the mission goal. This efficiency is measured by the number of times the operator reassigns a mission that was previously assigned by the system, with a lower number signaling higher efficiency. Note that algorithm efficiency is defined in this model only as a result of the operator's perceived trustworthiness of the system. If the system is not perceived as trustworthy, then the operator will tend to override the system frequently and the algorithm efficiency will be low.

The second sub-model, operator performance, needs to ensure that the operator performs effectively with the system being evaluated, as more UVs are introduced to the team, and the mission scenario becomes more complex. Since this is a supervisory control environment, operator performance is defined in terms of the operator's decision making. There are two decisions (decision nodes) that are important to evaluate whether the operator's performance is adequate for the task: 1) Is the operator's task management strategy efficient? 2) Is the operator's decision making efficient? The first decision is necessary to evaluate whether operators will efficiently prioritize different tasks that arrive simultaneously.

The second decision is necessary to evaluate whether the operator will successfully achieve the goals of the mission (i.e., protecting the asset from enemy attack). Together these two decisions summarize what is important to ensure a satisfactory operator performance. Please note that by measuring task management efficiency, an attention inefficiency component is included in this model.

Finally, the last sub-model, cognitive workload, includes the final decision node: "Increase Team?" For this decision, it is important to ensure that operators are not overloaded, but instead their workload is adequate to successfully complete the mission scenario. This final decision node is the end of a sequence of decisions and therefore it depends on the outcomes of the previous decisions made in the system performance and operator performance sub-models. Hence, in order to avoid cognitive overload, not only does the system have to efficiently perform in the mission scenario, but the operator also has to perform efficiently to ensure that tasks are adequately managed and do not overload the operator. The cognitive workload and operator performance sub-models are strongly associated. If cognitive workload is too high, then the operator performance will be low. Therefore, the more inadequate management and tactical decisions operators make, the higher their workload will be.

System performance, operator performance, and cognitive workload are the foundation of this model. Most of the knowledge about the model relationships between variables was acquired from a literature review. Variables such as "Information Overload" and "System Interruption" were included to emphasize the need to evaluate these aspects of the usability of the system (see Figure 2) in complex

 ISBN: 978-1-61208-155-7

supervisory control tasks. These variables are relevant because they contribute to design interfaces, especially in the supervisory control environment in which large amounts of information, and large event queues can result in information overload and frequent system interruptions.

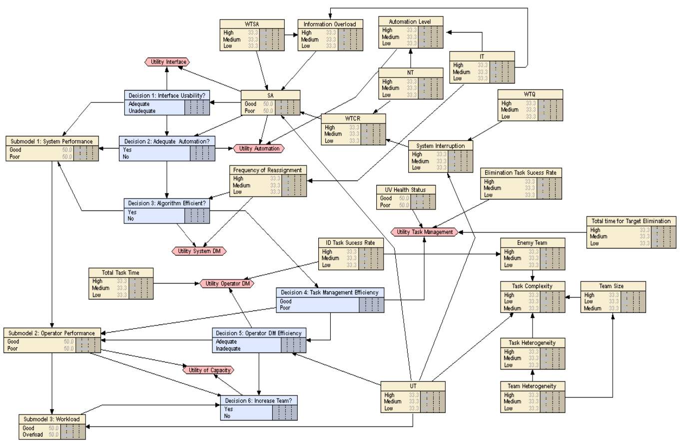


Figure 2. Decision network representing the decision process involved in deciding whether to increase a particular team size. Notice that this picture displays the model with no data. When data are introduced into the model, the system provides the user with a recommended course of action that will be displayed as a percentage (i.e., Yes 90%).

C. Performance Measures

The model allows for measurement of several output variables. These variables include those implemented in the previous models [3-7], as well as specific user-defined metrics that the model allows to capture. Temporal measures such as UT and WT are used because they are critical in a system where the operator has limited attention resources that must be divided across multiple tasks. UT is used to capture the effects of alternate design variables on operator workload. Some researchers indicate that average UT and WT can allow for benchmarking and comparison to be made across applications [8, 10]. The level of autonomy in the model is captured through the NT. In addition to the basic metrics inherently captured by previous models, this model also captures mission-specific metrics. Some of the mission-specific metrics include the rate at which tasks are successfully completed, the UVs' health status and the total time to complete the mission scenario. Furthermore, other measures being captured by the model include Information Overload, System Interruption, and Reassignment Rate. These three measures are important to evaluate the system performance. Information Overload and System Interruption are shown to be related to SA; therefore, they are used to help determine Situation Awareness (SA). For example, when the operator is overloaded with information, he/she is not able to focus on what is important, therefore vital SA is lost. Moreover, when the system is constantly interrupting the operator at any point in time, it drives the operator's attention away from one task to focus on another, therefore affecting their SA. The system's Frequency of Reassignment measure is used to evaluate the number of times the operator overrides the system. Identifying the amount of times the system has been overridden will help us determine how trustworthy the system is for the operator. The underlying assumption is that the more the operator overrides the system, the less reliable the algorithm for the system is. See Figure 3 for a list of the performance measures used as input in the model.

PERFORMANCE MEASURES	DEFINITION
Wait Times due to lost of Situation Awareness(WTSA)	Represents the amount of time the operator is not aware that the vehicle requires his attention.
Wait Times due to Queue (WTQ)	Represents the amount of time resulting from queues due to near simultaneous arrivals of tasks.
Interaction Times (IT)	Represents the amount of time the operator interacts with the vehicle. Includes monitoring and decision making time.
Neglected Times (NT)	Represents the amount of time each vehicle operates independently.
Utilization Times (UT)	Represents the amount of time the operator actively interacted with the display over the course of the experiment.
Total Task Time	Represents total time to complete the trial.
Information Overload	Represents information overload in the interface.
System Interruption	Represents the amount of time the operator was interrupted to attend a different task.
Target Elimination Task-Success Rate	Represents the ratio of eliminated enemies to the total number of identified enemies.
Identification Task-Success Rate	Represents the ratio of identified enemies to the total number of detected vehicles.
Frequency of Reassignment	Represents the operator's trust in the system. Accounts for the times the operator reassigned a vehicle once that it was assigned by the system.
UV Health Status	Represents the amount of damage experienced by the vehicle.

Figure 3. Performance measures collected during the experiment.

D. Experimental Apparatus

Since there is no test bed available that portrays all the complexities of a futuristic mission scenario, the Research Environment for Supervisory Control of Heterogeneous Unmanned Vehicles (RESCHU) developed by the Massachusetts Institute of Technology (MIT) was acquired and later modified to be used as a test bed in this study. The RESCHU simulator [8] is a test bed that allows operators to supervise a team of Unmaned Aerial Vehicles (UAVs) and Unmanned Underwater Vehicles (UUVs) while conducting surveillance and identification tasks. This simulation was modified for this study to include the following requirements: 1) a complex mission scenario with an asset to protect and multiple simultaneous enemies to attack, 2) a highly automated system such as mission definition language (MDL) and 3) a highly heterogeneous team that is made of at least three different types of UVs. The new version of the simulation is called RESCHU SPAWAR or RESCHU SP.

It is important to mention that the Unmanned System technology selected as an example of a NCO's technology that allows one operator to supervise multiple UVs is the Collaborative Sensing Language (CSL) developed at the

 ISBN: 978-1-61208-155-7

University of California, Berkeley. The CSL [11] is a high-level feedback control language for mobile sensor networks of UAVs. This system allows an operator to concentrate on high-level decisions, while the system takes care of low-level decisions, like choosing which UV to send for a particular type of task. A framework for the CSL was designed to integrate this technology into the complex mission scenario portrayed by the RESCHU SP simulator. The CSL version displayed in this simulation is only intended to illustrate one way to portray how this technology may work in more complex mission scenarios and with supervisory control of multiple heterogeneous UVs (see Figure 4).

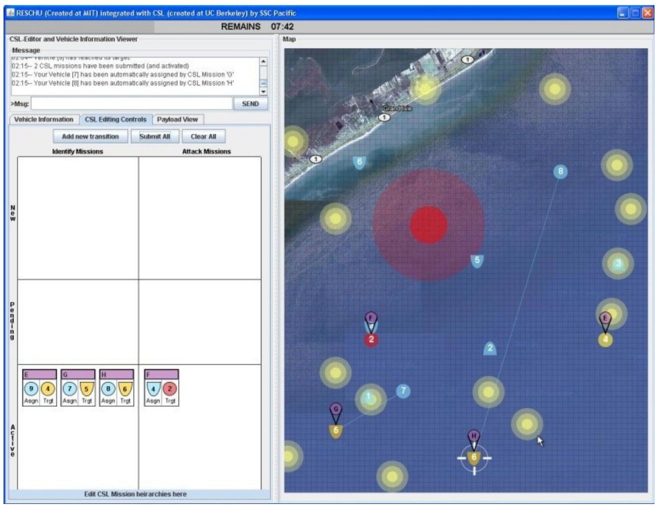


Figure 4. RESCHU SP simulator displays a mission scenario with a team size of nine UVs (blue icons in the map), three potential enemies (dark yellow icons in the map), and one identified enemy (red numbered icon in the map). The CSL tab shows missions that are currently active and other missions that are not yet submitted.

The team of UVs in the RESCHU SP simulator is composed of UAVs, UUVs, and Unmanned Surface Vehicles (USVs). There are two types of UAV, the MALE UAV and the HALE UAV; both travel to areas of interest to detect potential enemies. When a UAV detects a potential enemy, a USV is sent to the detection area to identify the vehicle (i.e., the unidentified vehicles appear as dark yellow numbered icons in map). Engaging the video payload that arrives at a detection area requires the operator to decide whether the vehicle detected is a potential enemy. If an enemy is identified, a UUV travels to the location to target the enemy. UUVs are slower than USVs and UAVs. UAVs are the fastest UVs.

The operator's main task is to identify and target potential enemies while protecting an asset (i.e., oil platform). At the same time, the operator is responsible for supervising the path of the UVs, in order to avoid traveling through potential threat areas (bright yellow areas on the map). Threat areas are zones that operators should avoid in order to protect the health of their vehicles. Moreover, operators are also responsible for following chat messages which provide them with the necessary Intelligence and guidance to complete their missions. When a UAV detects a potential enemy, a visual flashing alert is issued to warn the operator. This alert indicates that the operator should command the CSL system to assign a UV to complete the task. The operator commands the CSL to complete the task through a right-click interaction. The CSL system chooses a UV that is appropriate for the task and one that is also in close proximity to the potential target. The operator is in charge of approving the CSL selection by submitting the task through the *Submit All* button in the *CSL Editing Controls* tab. In the case of multiple identification tasks submitted to the CSL at the same time, the operator's task is to approve the CSL selection, and if applicable, determine the order in which the tasks should be conducted. For example, in a situation in which there is only one UV available for the task, the operator has to determine the order in which tasks should be conducted to ensure a good mission performance. Once the order of tasks has been determined, the operator needs to submit the commands so that the CSL can complete the tasks. Once that a task has been submitted, a selected UV is sent to location, when it arrives, a visual flashing alert warns the operator that the video payload is ready to engage. Then, the operator engages the video payload through a right-click interaction. The detected vehicle is viewed through the video image displayed in the *Payload View* tab to determine whether the detection is identified as the enemy. The operator identifies the vehicle by clicking on the *Yes* or *No* button below the payload view. A supervisor will inform the operator via chat whether the identification is correct or not. If the operator correctly identifies the vehicle as an enemy, the vehicle icon on the map becomes red. If the operator incorrectly identifies a detected vehicle as the enemy, the supervisor will override the operator; therefore, the icon will not change to red. The next step for the operator is to inform the CSL that a vehicle should be assigned to complete the target mission. Once again, the CSL system chooses a UV and sends it to the target location. When on target, a visual flashing alert is issued to inform the operator that the UV is ready to engage. The operator confirms this through a right-click interaction, and the target is eliminated. In this way, the operator is responsible to identify all detections and eliminate all enemies in order to protect the asset.

E. Participants, Experimental Design and Procedure

Experiments were designed to be completed in two phases: 1) the software and performance measures program verification phase, and 2) the model validation phase. First, it is desired to ensure that the requirements of the simulation and performance measures computation program are met. Second, it is desired to obtain data associated with the different levels of team size, in order to build confidence in the model's accuracy at replicating human-UV-interaction under different conditions. Having team size as the independent variable, the model's ability to replicate statistically significant effects on the operator performance and/or mission performance could be evaluated. Finally,

 ISBN: 978-1-61208-155-7

having data sets associated with the different levels of team size allows for predictive validation by selecting a single data set associated with one of the conditions and predicting the results observed for a second condition. The recruited participants for the first experimental phase are students from the Naval Postgraduate School (NPS). The online test bed includes: a background and exit survey, an interactive tutorial, a practice trial, and one of a set of possible experimental conditions.

In order to ensure the validity of the variables and relationships represented in the model, the decision network was converted into a Bayesian Belief Network (BBN) to run validation analysis. The software's Test with Cases analysis will be used to validate the network in the second phase of the experiments. The Test with Cases analysis examines if the predictions in the network match the actual cases. The goal of the test is to divide the nodes of the network into two types of nodes: observed and unobserved. The observed nodes are the nodes read from the case file, and their values are used to predict the unobserved nodes by using Bayesian belief updating. The test compares the predicted values for the unobserved nodes with the actual observed values in the case file and the successes and failures are then recorded. The report produced by this analysis has different measures that validate each node's predicted capabilities. After evaluating the validity of the model, we can determine which relationships are incorrect and we can make the network learn those relationships through the collected cases. Finally, we can run sensitivity analysis and predictive validation analysis to determine which variable has the biggest effect on team size and how each variable affects the overall result of the model.

The study design is a between-subject design with three conditions: high team size, medium team size, and low team size. The high team size condition is composed of 9 UVs: 3 UAVs, 3 USVs and 3 UUVs. The medium team size condition is composed of 7 UVs: 3 UAVs, 2 USVs and 2 UUVs. Finally, the low team size condition is composed of 5 UVs: 3 UAVs, 1 USV and 1 UUV. Notice that the UAV's number was kept constant through the different conditions because the UAVs produce little interaction with the operator (i.e., UAVs only patrol for detection and operators only have to supervise their flight path to avoid flying into threat areas). The number of USVs and UUVs was gradually incremented to investigate how they affect the performance measures and therefore the model outcome. Furthermore, the baseline of a team of 5 UVs was decided after pilot testing the simulation with different team sizes.

The experimental test bed was designed for a web-based delivery, with an interactive tutorial and practice trial. A web-based experimentation was chosen in order to obtain as much data as possible. The website is Common Access Card (CAC) protected and participation is via invitation. Data collected from the simulation is being recorded to an online database. Demographic information is collected via a background survey presented before the tutorial. Participants are instructed to maximize their overall performance by: 1) avoiding threat areas that dynamically changed and therefore minimizing damage to the UVs, 2) correctly identifying enemies, 3) targeting enemies before they reach the asset, 4) overriding the system when necessary to minimize vehicle travel times and maximize mission performance, and 5) eliminating potential enemies as soon as possible.

V. Experimental Results

Pilot tests were conducted at NPS and SPAWAR to evaluate the online test bed and performance measures. The results of these pilot tests indicated that the interactive tutorial was hard to understand, the simulation had bugs and the logic used for coding the performance measures was inaccurate. The test bed and performance measures were reviewed, a framework for improvement was developed and problematic areas were fixed. The first experiment was conducted at NPS in June, 2011. Data obtained is currently being analyzed. Results will be released in a future scientific publication. Due to the complexity of the software and the number of factors to be considered in the computation of the performance measures (i.e., multiple event types, vehicle types, performance measures, start and end times, etc.), we expect the verification phase to continue through next year. It is planned to start the validation phase in May, 2012.

VI. Future Research

In the validation phase of this study, the model will be first validated with the current implemented technology. Next, the model will be validated with a different NCO technology in order to test whether the results of the model can be generalized to other NCO technologies with different system's variables (i.e., usability, automation, etc.). Furthermore, learned workload and SA curves will be incorporated into the model to strength model predictions. Finally, a decision tool package will be developed to allow decision makers and/or system designers to evaluate NCO technologies. The decision tool package will include a program that will collect performance measures from simulations and feed the model in order to evaluate new NCO technologies.

VII. Implications for Future Research

The implications of this study are various. First, the results of this study will allow a better understanding of what enables operator capacity in complex NCO mission scenarios. Second, by understanding the variables that affect operator capacity and the decision making process involved in evaluating NCO technologies, the results of this study will allow the development of specific C2 design requirements for technologies to be used in complex NCO mission scenarios. Third, by acquiring a better understanding of the dynamic between the operator capacity, the system, and the mission requirements, the results of this study will not only define performance

 ISBN: 978-1-61208-155-7

measures for these complex environments but also determine an effective logic to extract them from any simulation and place them into the model for evaluation and prediction. Finally, the overall results of this study will help future research by providing scientists with a test bed and performance measures definitions for a NCO scenario to further expand this study and/ or conduct further studies in this crucial research area.

ACKNOWLEDGMENT

The authors wish to acknowledge the support of Dr. Mary Cummings (MIT) and Dr. Luca Bertuccelli (MIT) for providing guidance on the RESCHU code, Dr. Karl Hedrick (UC Berkeley) and Dr. Raja Sengupta (UC Berkeley) for providing guidance on the functionality of the CSL, Mr. John Falby (NPS) for recruiting participants for the pilot tests, and Dr. Douglas Lange (SSC Pacific) for being a great mentor and helping us through the process.

REFERENCES

[1] Department of Defense, Network Centric Warfare: Department of Defense Report to Congress, Office of the Secretary of Defense, Washington, DC, 2001.

[2] H.M. Huang, K. Pavek, B. Novak, J. Albus, and E. Messina. “A Framework for Autonomy Levels for Unmanned Systems (ALFUS)” presented at *Proceedings of the AUVSI's Unmanned Systems North America*, pp. 849–863, Baltimore, MD, USA, 2005.

[3] D.R. Olsen and S.B. Woods. Fan-Out Measuring Human Control of Multiple Robots*, CHI,* vol. 6 (1), pp. 231-238, 2004.

[4] M.L. Cummings and P.J. Mitchell. Predicting Controller Capacity in Supervisory Control of Multiple UAVs, *IEEE Systems, Man and Cybernetics, Part A System and Humans*, vol. 11(2), pp. 451-460, 2008.

[5] J.W. Crandall and M.L. Cummings. Identifying Predictive Metrics for Supervisory Control of Multiple Robots, *IEEE Transactions on Robotics Special Issue on Human-Robot Interaction*, vol. 23(5), pp. 942-951, 2007.

[6] M.L. Cummings, C.E Nehme, and J.W. Crandall. Predicting Operator Capacity for Supervisory Control of Multiple UAV, *Innovations in Intelligent Machines*, vol. 70, Studies in Computational Intelligence J.S. Chahl, L.C. Jain, A. Mizutani, and M. Sato-Ilic, Eds., 2007.

[7] J.W. Crandall and M.L. Cummings. Developing Performance Metrics for the Supervisory Control of Multiple Robots. Presented at *Proceedings of the 2nd Annual Conference on Human-Robot Interaction*, pp. 33-40, 2007.

[8] C.E. Nehme. *Modeling Human Supervisory Control in Heterogeneous Unmanned Vehicle Systems*, Ph.D. Thesis, MIT Dept. of Aeronautics and Astronautics, Cambridge, MA, 2009.

[9] Netica Software. Netica Bayesian Belief Network. *Norsys Software Corporation.* Vancouver, BC, Canada. *Retrieved on May 15, 2011 from www.norsys.com*.

[10] P.E. Pina, B. Donmez, and M.L. Cummings. *Selective Metrics to Evaluate Human Supervisory Control Applications*. Technical Report HAL 2008-04, Massachusetts Institute of Technology, May 2008.

[11] J. Love, J. Jariyasunant, E. Pereira, M. Zennaro, K. Hedrick, C. Kirsch, and R. Sengupta. CSL: A Language to Specify and Re-Specify Mobile Sensor Network Behavior*," 15th IEEE Real-Time and Embedded Technology and Applications Symposium,* pp. 67-76, 2009.

 ISBN: 978-1-61208-155-7

A Framework for Creativity-oriented Autonomy based on Online Social Networks

Balasubramaniam Shekar, Shamit Bagchi
Quantitative Methods and Information Systems Area
Indian Institute of Management Bangalore
Bangalore, India
e-mail: shek@iimb.ernet.in, shamit.bagchi08@iimb.ernet.in

***Abstract*—The paper deals with the problem of enabling greater autonomy in knowledge intensive organizations leading to innovation. Adoption of online social networks in organizations is a suggested solution. We draw lessons on autonomy and its effects from a real-world illustration. We examine the consequences of online social network adoption within businesses and societies. These may be viewed as self organizing systems. The autonomy-orientation of employees and members of a society is the underlying basis for this study. Stable states (attractors) in self organized systems are known to enslave or constrain the constituents of a system. The reduced enslavement in online social networks is a prominent feature of our proposed new attractor regime to which organizations in any society will shift. We discuss the enabling of this shift in terms of autonomy and self organization.**

Keywords-Organization Structures; Art Industry; Online Social Networks; Self-Organization Theory

I. INTRODUCTION

Knowledge-intensive organizations of today need creativity and innovation as driving forces necessitating greater autonomy in decision making and execution of creative ideas into tangible results.

The old paradigm of command and control to run an organization is no longer operant. Primary disadvantages include disharmony and erosion of creativity, resulting in high attrition rates and higher stress levels among employees. The consequences for organizations have been lower performance and missed opportunity in harnessing the creative potential. Recent practices towards a flat structure of organizations have led to better levels of talent utilization.

It may be noted that art galleries provide some answers as creative potential is what they thrive on. Now with the entry of new age tools such as OSNs (online social networks) [1], businesses and communication in general are rapidly adopting and using these tools.

With the adoption of OSNs in businesses, it is imperative to provide more autonomy and independence to the employees rather than continuing to operate with the hierarchical command and control paradigm. The latter would result in a clash between the mindset of the top management and the employees.

II. OBJECTIVE

We elucidate and elaborate the reasons for heavy OSN adoption worldwide. This is done by deducing a new finding from existing self organization systems theory [2]. We propose methods to enable greater autonomy and consequently creativity within organizations. These methods involve online social network usage. We also elaborate on why this OSN based approach will be successful in organizations. This elaboration is done with the help of another research finding of ours, namely existence of weak ties in the art industry. This approach is formulated as a framework. The framework helps in enabling the achievement of autonomy to tackle the challenge of continuous innovation in knowledge intensive organizations. We have provided an illustration that helps in arriving at our claims and in providing a rationale for substantiating our claim.

Existing literature talks about why autonomy is essential in prospector firms, i.e., firms that depend on innovation and differentiation [3]. Creativity arising out of autonomy and weak links is also discussed in some of the papers [3][4]. However, the existing literature focuses predominantly on usage of OSNs for knowledge management [5]. We instead argue for the adoption of OSN towards autonomy and not mere knowledge management.

III. PRELIMINARIES

A. Current Organization Structures

Organizations of today are “the large, vertically integrated, hierarchical organizations that have persisted throughout the latter half of the twentieth century.” [6]. The dominant form of control is by spurring competition. In order to further self interest employees are expected to either do as they are told, faster, better. Any deviation, is dealt by a punishment mechanism. This results in a highly competitive culture that gets built into the organization DNA. Such a culture is not sustainable in the long run.

“Hierarchical systems arose from models of creating systems with a high degree of certainty and security and delineated boundaries of function, structure, order and logic.” [6]. Leaders emerge as perceived knowledge holders by influencing and tightly controlling workers’ duties and hence most powerful.

 ISBN: 978-1-61208-155-7

The way individuals connect with one another and with the institutions in their lives is evolving. This has led to decentralization of power with greater faith amongst peers.

B. *Ties and Relations in a network*

Organizations may be viewed as 'holons' [7], or as networks of people, interacting among themselves based on their needs and with goals to achieve. In such networks, weak and strong ties indicate the strength of a relationship. However creativity is seen to increase with weak ties. Networks of optimal size and weak strength are more likely to boost creativity when they afford actors to access a wide range of different social circles. Weak ties are characterized by "social relationships, which are typified by infrequent interaction, short history, and limited emotional closeness." [4]. We draw heavily on the definition and attributes of Complex Adaptive Systems (CAS) [8].

C. *Society as a self organizing system*

Processes of self-organization create order out of chaos. They are responsible for most of the patterns, structures and orderly arrangements which we find in the natural world. Many of those are present in the realms of the mind, society and culture.

Society is a self-organizing system, because by definition, a society organizes itself without need for any external direction, manipulation, or control. The organization process in a self-organizing system refers to "increase in the structure or order of the system behavior through a dynamic and adaptive process where systems acquire and maintain themselves, without external control. Structure can be spatial, temporal or functional." [9].

D. *Attractors*

Self-organization means that "the system reaches an attractor, i.e., a part of the state space that it can enter but not leave. In that sense, an attractor is a region "preferred" by the global dynamics: states surrounding the attractor (the attractor basin) are unstable and will eventually be left and replaced by states inside the attractor." [2].

A self-organized configuration is more stable than a configuration before self-organization. The pattern formed by the stabilized interactions, mutual "fittings" (or "bonds") between the agents determines a purposeful or functional structure. Its function is to minimize friction between agents, and thus maximize their collective "fitness", "preference" or "utility". Therefore, we may call the resulting pattern as "organization": the agents are organized or coordinated in their actions so as to maximize their collective synergy and not individual utility.

However, this organization by definition imposes a constraint on the agents. Loss of freedom to visit states outside the attractor, i.e., states with a lower fitness or higher friction. The agents have to obey new "rules" that determine allowable actions. They lose some of their autonomy [2].

In a sense, the agents become subordinated (or "enslaved") [10] to the regulations of the collective. Different attractor regimes and imply a varying degrees of autonomy.

E. *Networks as Emergent Structures*

"The structure emerging from self-organization can often be represented as a network. Initially, agents interact more or less randomly with whatever other agents happen to pass in their neighborhood. Because of natural selection, however, some of these interactions will be preferentially retained, because they are synergetic. Such a preferentially stabilized interaction may be called a bond, relationship, or link. The different links turn the assembly of agents into a network. Within the network, the agents can now be seen as nodes where different links come together." [2]. In this regard perhaps the most intuitive example is a social network that links people on the basis of friendship, trust or collaboration.

IV. PROPOSED FRAMEWORK FOR ORGANIZATIONAL AUTONOMY

A. *Input 1: Online Social Networks*

This peer-dominated network has recently shifted online. Online communities and OSNs enable people to maintain their own profile on a website, which is akin to ego states. These also allow a person to connect with profiles of other members who are friends, acquaintances and contacts, thus creating a virtual network. "What OSNs do is to try to map out what exists in the real world. In the world, there's trust. As humans fundamentally parse the world through the people and relationships they have around them, so at its core, what a social network does is map out all of those trust relationships. So this map can be called the social graph, and it's a network of an entirely new kind and has real world implications." [1].

OSNs are increasingly mimicking the real world and yet are able to plug in some of the deficiencies of the real world arising out of geographical and temporal separation and persistence of communication. One can be in touch with multiple people from different spheres of their lives, at the same time and in the same virtual space. OSNs can be seen to be complex adaptive systems (CAS) as they evolve [8].

Most importantly, OSNs are based on broad patterns of independence and interaction without any hierarchy or coercive practices (gleaned from current adoptions such as Facebook, MySpace, LinkedIn, Mixi); an exploratory approach leads to sharing, learning and dissemination of information, knowledge and sometimes intense discussions. OSNs also have an independent structure to it, without any imposed rules.

OSNs have this novelty wherein the social context becomes more important as we are influenced by the decisions of our closest friends or peers.

B. *Input 2: Observations from the Art industry*

Weak ties, creativity and independence lead to success in the art industry. From this perspective an art gallery has some unique features. An art gallery in most cases is run as a proprietary firm with a few employees. The proprietor is involved in the primary activities and decision making processes.

 ISBN: 978-1-61208-155-7

The nature of this type of an art organization is significantly different as there is no joint coordinated effort to create a deliverable end-product. However from another perspective, the gallery itself runs based on the artworks created by affiliated artists. So there is a strong sense of co-operation along with autonomy for the artists who can be seen as pseudo-employees.

Apart from the gallery, middlemen exist in the industry - connecting artists to galleries, and, with knowledge of the varying art styles. Sometimes they may also act as curators. There is greater dependence on trust and the patronizing attitude of galleries towards artists, although contracts and agreements do exist too.

Exhibitions for individuals and groups of artists are often held. Partnerships exist between different stakeholders, and this leads to benefits of social capital such as information, artworks and allied services, emotional support and socio-political influence. In essence, weak ties and social organization-like structure are essential features of an art gallery.

Art galleries give artists independence and complete autonomy and yet artists cooperate with the gallery to sell their works. So it is a mutually beneficial, symbiotic relationship. Artists and art entrepreneurs are predominantly free agents [11].

Often galleries thrive on partnerships with bigger galleries or museums, wherein events, shows and exhibitions are conducted by multiple galleries [12] – leading to a more collaborative rather than a purely competitive scenario. When these art galleries rely upon weak or arm's-length ties, they enjoy flexibility and access to diverse information in their networks [13]. Smaller cliques also get formed as inferred from discussions with art gallery owners.

V. Key Features and Components of the Proposed Framework

Social self-organization means self-generation of order as an emergent phenomenon in a social system. In society self organization has reached an attractor or a current stable state, in which the hierarchical organization has become the dominant structure. Domination and coercion have become the prime methods for controlling employees. Individual freedom and independence have been drastically eroded.

Non-hierarchical, flat organizations are being touted in industry and academia but are very difficult to implement due to complexity. This complexity arises out of overheads required for monitoring discipline and mismatch in allocating human resources. Newer, knowledge-intensive organizations are becoming network-oriented, dynamic systems. Identification of both creativity and discipline as a necessity for organization excellence [14] makes the implementation even more convoluted.

The format of an OSN heavily leans towards a very open, autonomous system. Social networks allow multiple stakeholders to collaborate, co-create and co-command. "There is significant correlation between the use of social media and more collaborative working practices." [15].

Members of an OSN are relatively free of artificially imposed, embedded instructional strategies. Community members share information, creative work. They identify and share methods and knowledge on resources in a context-dependent manner. "Approaches in such communities rely on human beings to locate, assemble, and contextualize the resources. Meaningful learning support "anytime anywhere," is combined with rich support with human-to-human interaction." [5].

OSNs also create weak ties. The nature of an art gallery indicates that weak ties lead to success. Artists being highly independent do not want restraints by any organization setup and desire to work independently. They would like to work at their own pace and without any hindrance or interference and achieve artistic expression in the form of artwork. Any artificial speeding will actually lead to degradation of quality.

Key components of the proposed organization structure would comprise of the following elements. These are based on lessons drawn from the art industry:

i. High independence, autonomy in pursuing roles, decision-making and execution

ii. Low on competition – to counter the psychological costs of competition

iii. Cooperation for profits and benefits

iv. Employees excelling in what they are best at and what they have a passion for

v. Low on behavior change and control

Here employees will get paid to be creative, to innovate, and to find new ways of doing things. Individual idea recognition and information gathering will be valued. With increased importance placed on information flow from diverse sources and joint decision making within the organization, top management in the hierarchy will cease to be decision makers and power wielders.

Centuries-old practice of managing people through incentive structures – both rewards and punishment – based on an assumption of individual selfishness is going to decay [16]. Many successful institutions, specifically art galleries (as per our observations [11]) have turned to human cooperation to achieve desired ends. Recent work in evolutionary theory, behavioral and brain sciences suggests that collaborative systems work better and are attuned to higher human capacities.

The complexity of the evolving operating environment consisting of OSNs demands a change in the management techniques. The homogenous composition of employees that companies thought they were dealing with has now disappeared. There is far more fragmentation and companies are operating in multi-contextual environments.

People who like social media are used to sharing, collaborating, trusting and being transparent with regard to information. They are also becoming the biggest influencers of organization-wide adoption of online social networking.

An OSN viewed as a radical change is a self organizing system - people are much more independent and individuality may be expressed comfortably by logging into such a system and being a part of it. Thus we see that an OSN is akin to a cultural organization where there is independence and autonomy leading to holistic individuality of the performer/artist.

Autonomy may be defined as the degree to which one may make significant decisions without the consent of others. Low autonomy is associated with a low quality working life. Autonomy is a human need, in a sense similar to one of those in Maslow's hierarchy of needs.

Autonomy and strategy are interlinked through the vision of an organization. The polarized, two-fold "Miles and Snow strategies" for firms are:
(1) Defenders – they maintain a relatively stable offering (of products and services) to a relatively narrow, stable target market and gain competitive advantage through focusing on satisfying the demands and needs of their traditional customer base; and
(2) Prospectors – who generate revenues through seeking out new customer markets and developing additional offerings.

"For effectiveness of an organization, it helps if the structure supports the strategy. For instance, a strategy that emphasizes disciplined concentration on traditional customers and products—like the defender strategy—is best implemented with a structure that focuses and constrains the options of the CEO to service that market. On the other hand, a strategy that emphasizes innovation and differentiation—like the prospector strategy—is best implemented in a structure that gives managers the freedom and authority to try different approaches. Structures with low autonomy entail frequent reporting and tend to constrain the actions of organizational members." [3]. One of the means of achieving this autonomy (viz. OSN adoption) mandated for successful implementation of a prospector strategy is developed and elaborated in the following section.

A. *Analogical Structures*

As already mentioned, OSNs are having unprecedented growth with adoption by more than a billion users. Hence we see a possible societal paradigm shift from competitive hierarchical organizations to creative and more collaborative organizations. We bring in the concept of an attractor here. OSNs are thus the new attractor (virtual attractor) to which society shifts as their usage spreads. Adoption is getting spurred by the network effect due to perceived and real benefits.

Organizations and society may be viewed as social holons [7]. They are complex because not all parts comply to the same extent with the organizational architectural protocols. When a sufficient number of parts (individuals, groups) challenge/disobey/put stress on the protocols, there are two options; either the architecture adapts itself "i.e. shifts or it collapses as seen in revolutions, rebellions, systemic failures etc." [17]. We can apply the same argument in the usage of OSN.

"Complex systems exhibit an unusual degree of robustness to less radical changes in their component parts. The behavior of many complex systems emerges from the activities of lower-level components. Typically, this emergence is the result of a very powerful organizing force that can overcome a variety of changes to the lower-level components." [18]. We hypothesize that the effects of large scale adoption of OSNs within businesses are radical enough to make the complex societal system undergo a shift in paradigm.

As seen earlier in Section II-B, moving into an attractor that is a stable state within any social self organizing system implies mutual adaptation among agents. They coordinate their actions to minimize friction and "maximize synergy".

This brings in constraints and a form of structure along with sub-ordination for the members. However, the constraints and regulations imposed by the collective in order to maximize synergy have led to enslavement of individuals. Our significant deduction is the reduction in enslavement (perceived and real) within OSNs. The proliferation of virtual relationships and increased communication which result from this reduction, is another deduction.

Introduction of OSNs within organizations will lead to significant chaos in the short term as there is a schism between the old paradigm within organizations of control and hierarchy and the newly-found autonomy and individual power within OSNs. When OSN agglomerates have become the emergent across most organizations this chaos will subside and order will emerge once the virtual attractor is reached. This is also a new conceptual finding in terms of why and when an attractor shift happens in a complex adaptive self organizing system-- in this case, society. It primarily occurs only when an attractor regime provides greater autonomy and sufficient agents move towards so as to become the dominant attractor regime. This is a move away from an established, robust attractor to a new attractor. There may be an erosion of synergy in the process. However there is possibly an optimum autonomy level towards which each agent would trace the orbit within the state space and yet attain synergy. This is depicted in Figure 1.

The reduced enslavement in an OSN is the prominent feature of the proposed new attractor regime to which society will shift. The emergent structures (new organizations) in this phase of self organization will result in weak links (within employees) thus increasing creativity among OSN users.

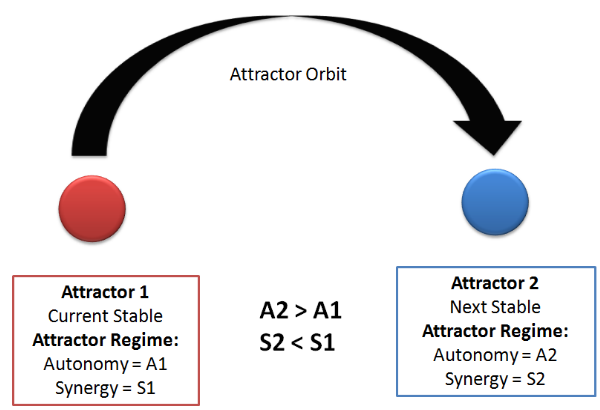


Figure 1. Autonomy-based attractor orbit

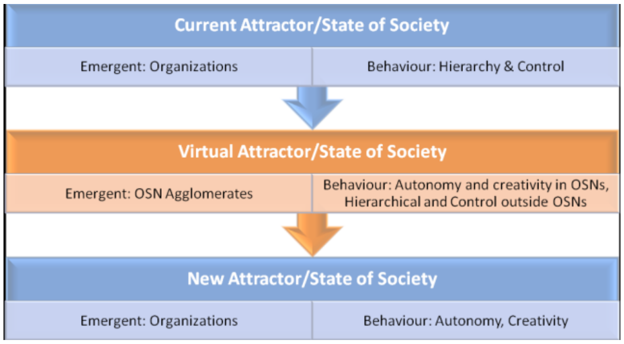


Figure 2. Stage of attractor shift

The new attractor has a regime which provides greater independence. It comprises of agglomerates of OSNs within organizations. Greater autonomy and individuality is the emergent (property) within OSNs in this new system. Since social structures emerge out of society and interactions within members of the society, these social structures in turn can "constrain or enable members". [19].

We shape our buildings, Winston Churchill argued, then they shape us. OSNs will lead to a change in the way organizations and the society itself behaves. Most organizations will be compelled to adopt these social networks online which are distributed, decentralized systems with independence to participate. The agglomerates of OSNs as emergent structures will in turn affect the creation of a society which has new organizations and structures as an emergent. These are more individualistic, comprising of greater autonomy to its members and yet being collaborative.

OSNs are the catalyst in the proposed societal paradigm shift: from a competitive hierarchical organization to a creative and .more collaborative organization that is high on autonomy, low on psychological costs of competition and low on behavior change. Metamorphosis of organizations, holistically modeled on OSNs, will be the end result. This entire paradigm shift is depicted in Figure 2.

VI. AUTONOMY-GEARED CREATIVITY IN ORGANIZATIONS

The second stage in Figure 2 can be modeled as a series of sub-stages as shown in Figure 3. We see that this virtual attractor has seen the emergence of agglomerates of OSNs. The adoption of OSNs will be championed by greater autonomy-seeking individuals or agents. These influencers will in turn propel the organizations towards adoption of OSNs. Within organizations as networks grow, splitting and breaking of links happens. This leads to intense activity for a while and then the network size again grows. In terms of attractors, this new phase of stabilizing around greater autonomy is the final stage. The degree of autonomy sought at each node goes up and as a result the overall autonomy seeking nature of the network goes up. This is a dynamic process. Optimum autonomy seeking behavior is different for different attractor regimes. The new stable state attractor in the emergent social organizations has the following properties:

- High Synergy within sub-networks
- High Creativity
- High Autonomy in all networks

Usually enablement of autonomy is seen to erode synergy as the agents no longer are bound by the rules of the collective. However in sub-networks agents have sufficient autonomy due to the smaller size and responsibilities. However network splitting simultaneously increases both synergy and autonomy because of co-working smaller teams!

Figure 3 shows state transitions within the state space which lead to dynamic equilibrium. Creation of feed-links between organizations or networks may take place. This means that some networks have higher autonomy and are thus more creative while other networks focus on innovation and execution of these creative ideas into tangible outcomes or output.

Greater autonomy is needed to break away from an existing order and to reach the next order. This is possible through creativity or in combination with self organization to reach the next new order. The chaos generated and subsequent self-organization may be viewed as constituents that are part of the process.

Autonomy leads to chaos and subsequent self-organization leads to the next higher order. The autonomy needed to transition to subsequent orders is higher than the prior stages of autonomy.

An optimal autonomy is needed to reach the maximum effective creativity in each order A_0. The optimal level occurs when the maximum effective creativity out of which a new order arises is attained in a state. Beyond this, there is fall in collaboration and effectiveness, and thus creativity ceases to be beneficial to an organization.

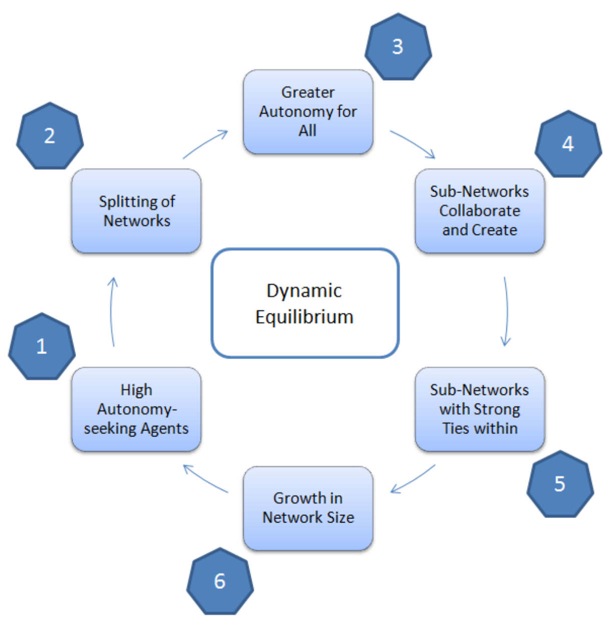


Figure 3: Cycle of States constituting Dynamic Equilibrium

VII. CONCLUSION AND FUTURE WORK

The cyclic process of splitting of links in networks by autonomy seeking individuals can be managed better by means of adoption of OSNs. The nature of command and control that needs to be broken to become more innovative is explained using our framework. Starting from existing organization structures involving command and control based on hierarchy, the paper identifies the resultant-states that an organization and the society may reach in the longer term. We also discuss how this is to be done by means of a systematic methodology using OSNs.

We suggest that OSNs create weak links which enhance creativity. We also show that OSNs increase autonomy which has been known to enhance creativity. OSNs provide a basis for systematic harnessing of knowledge as knowledge management is a stated benefit of their usage [5]. An amalgamation of the above, results in the proposed framework that is not available in current literature.

Advantages of our framework include the transformation of creativity into organized innovation. This transformation is based on the agglomerates of OSNs within the organization. OSN agglomerates outside the organization can also be accessed for open innovation with external agencies. In our view it has proved to be quite tedious to implement flat, non-hierarchical organization structures as it involves mindset change. However a system comprising of an agglomerate of OSNs will help usher in this mindset change.

Autonomy is sought after as a basic need in organizations. We explain the rationale behind its enablement through OSNs with the help of self organization theory. However autonomy also leads to chaos. Within organizations chaos may get generated in the short term. However the end result would be more agile, connected and innovative organizations. Knowledge-oriented organizations will need to adopt OSNs for survival.

This will generate a need for a new set of tools and resources to track and measure new organizational parameters redefining productivity and efficiency

From the self-organization perspective, future study could involve specific parameters that define OSNs as self-organizing systems enabling the emergence of holistic individuality and autonomy.

Another question that needs to be addressed pertains to the determination of optimal level of autonomy in an organization context. This is due to autonomy-seeking agents within the organization

Self organization in this chaotic state leads to generation of new orders. These orders may pertain to practices, processes, methodologies, or strategies in the organization. Every greater order in terms of scale of impact requires higher autonomy in that area. This is bound by an optimal autonomy after which the effective creativity starts falling.

The culmination would be a self-organized society with a form of socialization that enables individuals to establish a form of compatibility and satisfaction between their own interests and societal interests. It will mark the emergence of self-management in all areas.

ACKNOWLEDGMENT

We thank Indian Institute of Management Bangalore for supporting the research work behind this paper. We also thank the anonymous reviewers for helping in improving the clarity and quality of the paper.

REFERENCES

[1] L. Grossman. (2010, December) TIME. [Online]. http://www.time.com/time/specials/packages/article/0,28804,2036683_2037183_2037185,00.html 02.01.2011

[2] F. Heylighen, "Complexity and Self-organization," Encyclopedia of Library and Information Sciences, 2008.

[3] D. M. Brock, "Autonomy of Individuals and Organizations: Towards a Strategy Research Agenda," International Journal of Business and Economics, vol. 2, no. 1, pp. 57-73, 2003.

[4] M. Baer, "The Strength-of-Weak-Ties Perspective on Creativity: A Comprehensive Examination and Extension.," Journal of Applied Psychology, vol. 95, no. 3, pp. 592-601, May 2010.

[5] D. Wiley and E. Edwards. (2002) Commons Open Educational Re-sources. [Online]. http://opencontent.org//docs/ososs.pdf 30.01.2011

[6] B. J. Hilberts. (2010, October) Iconoclast @ work. [Online]. http://iconoclast.typepad.com/blog/etenen-drinken/ 10.12.2010

[7] A. Koestler, The Ghost in the Machine. London: Macmillan, 1967.

[8] A. Juarrero, Dynamics in Action: Intentional behaviour as a complex system.: MIT Press, 2000.

[9] T. D. Wolf and T. Holvoet, "Emergence Versus Self-Organisation: Different Concepts but Promising When Combined," Lecture Notes in Computer Science , vol. 3464/2005, pp. 77-91, 2005. [Online]. www.springerlink.com/index/p7k83kc3fkj8e42n.pdf 10.03.2011

[10] H. Haken, Information and Self-Organization, 2nd ed.: Springer, 2000.

[11] Multiple Authors. (2011, January) IIM Bangalore - B Shekar - Personal Webpage – Project on Cultural Entrepreneurship. [Online]. http://www.iimb.ernet.in/~shek/Audio_Rec_Several_Interviews_India_Art_Summit.mp3 28.06.2011

[12] M. Jaipuria. (2010, June) IIM Bangalore - B Shekar - Personal Webpage – Project on Cultural Entrepreneurship. [Online]. http://www.iimb.ernet.in/~shek/AudioRec_Meenu_Jaipuria_Interview.mp3 28.06.2011

[13] M. S. Granovetter, "The Strength of Weak Ties," The American Journal of Sociology, vol. 78, no. 6, pp. 1360-1380, May 1973.

[14] J. Collins, Good to Great. New York, NY: HarperCollins Publishers, Inc., October 2001.

[15] B. Wright. (2010, October) The Wall Street Journal. [Online]. http://online.wsj.com/article/SB1000142405274870379410457554557008571574.html#ixzz12YSOB7LW 10.01.2011

[16] Y. Benkler. (2010, December) SantaFe Institute. [Online]. http://www.santafe.edu/research/videos/play/?id=06d53b42-20a9-4234-998e-ac39f676b1e9 10.01.2011

[17] A. Mostashari. (2008, OCT) COMPASS Presentations: Organizations as Complex Adaptive Systems (by Dr. Ali Mostashari). Microsoft PPT. [Online]. http://www.socio-technical.org/ 10.03.2011

[18] J. H. Miller and S. E. Page, Complex Adaptive Systems: An Introduction to Computational Models of Social Life.: Princeton Univ. Press., 2007.

[19] C. Fuchs. (2002, August) Vienna University of Technology. [Online]. http://www.self-organization.org/results/papers/pdf/hsicpaper4.pdf 10.01.2011

Inverse ACO Applied for Exploration and Surveillance in Unknown Environments

Rodrigo Calvo, Janderson R. de Oliveira and Roseli A. F. Romero
Department of Computer Sciences
University of Sao Paulo
Sao Carlos - SP, Brazil
Email: {rcalvo,jrodrigo,rafrance}@icmc.usp.br

Mauricio Figueiredo
Department of Computer Sciences
Federal University of Sao Carlos
Sao Carlos - SP, Brazil
Email: mauricio@dc.ufscar.br

***Abstract*—This paper focuses on a distributed strategy proposed to coordinate a multiple robot system applied to exploration and surveillance tasks. The strategy is based on the artificial ant system theory. According to it robots are guided to unexplored or not recently explored regions. The main features of the strategy are, among others: low computation cost; and independence of the number of robots. Results from preceding investigations confirm the strategy is able to emerge a cooperative robot behavior, that is, the exploration and surveillance tasks are synergistically executed. This paper concerns specifically the robustness of the coordination strategy regarding to the environment structure. Two metrics are adopted for evaluation: needed time to conclude the exploration task, and time between two consecutive senses on a same region. Simulation results show that the coordination strategy is able to establish effective trajectories, that is, robots are guided to explore the environment and to sense repeatedly and completely the environment.**

Keywords-multiple robot systems; surveillance task; ant colony systems; environment exploration; swarm systems; mobile robots

I. Introduction

The more sophisticated is the robotic field technology the higher is the possibility of multiple agent systems to become usual. This expectation associated with the potential advantages of using multiple agents over a single one captivates the attention of the scientific community. Nowadays, the literature provides many articles that focus on multiple robot systems applied to basic tasks, such as: exploration, covering, and surveillance [1], [2].

The enormous potential associated with the multiple agent systems is exploited only if the respective coordination strategies are efficient. Whatever the task is considered, they have to satisfy some basic requirements, such as: small redundancy of agent effort; and strong cooperative agent behavior [3]. Other requirements come from the task the robots have to accomplish. Considering all things together, it is plausible the design of coordination strategies for multiple agent systems is a challenge problem in robotics [4].

The strategy described in [5] is able to guide robots applied to construct a common map cooperatively as they explore the environment. The authors introduce the notion of a frontier, which is a boundary between the explored and unexplored areas. As the robots move, new boundaries are detected and frontiers are grouped in regions. Then, robots navigate toward the centroid of the closest region, while sharing maps. The strategy, centralized and based on the A* algorithm, receives information from every robot and defines the next steering direction of each robot..

Several applications of multiple agents are designed to accomplish security and surveillance tasks [6]. Coordination strategies based solely on mathematical formulation are very parameter dependent and suffer critical degradation due to agent failure [7]. Bio-inspired and evolutionary theories provide fundamentals to design alternative strategies [8].

The technique in [9] focuses on intelligent decision making for security. During the security mission, robots engage in four behaviors: patrol, inspect, chase intruder and guard. A fuzzy logic-based method is used for decision making that establishes qualitative relationships, in terms meaningful to human information, between different possible input types and efficient outputs.

The surveillance system described in [10] is to detect changes in environment comparing color histograms between current images and those images previously taken. Unfortunately the environment is totally static.

Considering the surveillance problem, the coordination strategy named Inverse Ant System-Based Surveillance System (IAS-SS) is once more investigated. It is designed according to a modified version of the ant algorithm presented in [11]. Results from preceding investigations confirm that the strategy is able to emerge a cooperative robot behavior, that is, the exploration and surveillance tasks are synergistically executed. This paper concerns specifically the robustness of the coordination strategy regarding to the environment structure. Different environment structures are considered, all of them designed from a rectangular space divided in 10 small spaces. Passage ways that connect spaces may be partially or totally blocked using walls. Following this procedure, 10 environment structures, each of which associated with a particular degree of complexity, are considered to evaluate the performance of the coordination strategy. Two metrics are adopted for evaluation: needed time to conclude the exploration task, and time between two consecutive senses on a same region. Simulation results show that the coordination strategy is able establish

 ISBN: 978-1-61208-155-7

effective trajectories, that is, robots are guided to explore the environment and to sense repeatedly and completely the environment.

The remainder of the paper is organized such as follows. Section II provides fundamentals of the artificial ant system theory. The description of the multiple robot system for exploration and surveillance tasks and the coordination strategy IAS-SS are the focuses of the Section IV. Section V shows simulation results obtained from a set of experiments. The main contributions and relevant aspects of the paper as well as expectations for future works are highlighted in Section VI.

II. Ant System

Surprisingly the complex tasks that ant colonies perform, such as object transportation and build edges, demand relatively more capabilities that a single ant is endowed [12].

Biological ants have two known mechanisms to establish communication, namely, direct and indirect. Biological ants not only exchange stimuli when they meet; but also exchange stimuli indirectly (a communication mechanism called stigmergy). Ants deposit a specific type of substance (pheromone) on the ground while they move. There are different types of pheromone, each of which associated with a particular meaning. If a pheromone trail is found and this pheromone type indicates food, then more and more ants follow this trail, depositing more pheromone and reinforcing the stimuli. An opposite behavior happens if the pheromone is of the aversive type, indicating risk and danger. Stigmergy mechanism is considered one of the factors that decisively contribute to amplify the capabilities of a single ant. Ant colonies use the stigmergy mechanism to coordinate their activities in a distributed way [13].

Artificial ant systems are the artificial counterparts of the biological ant colonies, designed to solve complex problems, among others: optimization combinatorial problems [11]. Analogously artificial ants (e.g., robots) are able to use the stigmergic communication. Pheromone trail provides a type of distributed information that artificial agents may use to take decisions or modify to express previous experiences [14]. A distributed coordination behavior emerges from this capability, providing solutions to problems associated with exploration in hyperspace.

III. Definitions and Preliminary Concepts

The collaborative behavior of robots is based on the repulsion instead of the attraction to pheromone. In order to mark a specific region as visited, a robot leaves pheromone on its position along the navigation. According to adopted pheromone's repulsion characteristic, the robot's reaction consists in avoiding paths already covered. Analogous to real ants colony, the pheromone deposited by robots are open to evaporation phenomena. This provokes a gradual reduction of amount of pheromone of the region. Therefore, the robots are in constant searching regions with low amount of the pheromone. As consequence of evaporation, the robots realize exploration and surveillance behaviors.

Differently from works related, the surveillance term referred in this paper consists in the coverage of a determined environment in a continuous way. This requires that the robots to walk in the environment continuously and to visit many times parts of the environment. So, they are spread out in order to minimize the execution time and have the optimal coverage. The great challenge for solving this problem is in the coordination of the robots and in the definition of their trajectories.

The multiple robot system is composed by a group of $k \in \mathbb{N}^*$ identical robots vehicles, where each robot has the capacity for measuring a sensory function from the environment with sensor range radius R. The sensory function indicates the relative importance of different areas in the environment. It can represent the quantity that is detected by the robot's sensor directly, such as the temperature or lightness of the environment. More specifically, in our case, the sensory function measures the quantity of the detected concentration of a chemical substance. The sensory function is defined as

$$f : A \subset \mathbb{R} \quad \longmapsto \quad \mathbb{R} \qquad (1)$$

where A is the set of sensor signals received by robot at each instant.

We are assuming that robots r_i, $i = 1, \ldots, k$ move in planar workspace $Q \subset \mathbb{R}^2$ and that an arbitrary point in Q is denoted by q. It is also assumed that the robot's position in the environment is known previously. Let L_t^i be the covered area by the sensor of $r_i th$ robot at instant t. A point $q \in Q$ is visited by $r_i th$ robot at instant t, if $q \in L_t^i$ and $r_i(t^q) = 1$. Let us also to consider the following definitions. At the instant when the environment is entirely covered, it is said that a Surveillance Epoch (SE) is completed. In each SE, all points $q \in Q$ are visited at least once. The period of time needed to cover the whole environment (all points) and to conclude a SE is denoted by *Surveillance Interval (SI)*. So, we can define that an optimal coverage of the environment for surveillance task is achieved by minimizing the period of time SI.

Then, the main aim is to reduce the period which a point q is non visited. Let us to consider t_1^q and t_s^q be the instants when any robot visits the point q, such that, $t_1^q < t_2^q$ and that $q \in Q$ is non visited at any instant t within interval (t_1^q, t_2^q). Thus, the shortest time interval between any two consecutive visits of any point q is given by:

$$min \sum_{q \in Q} (t_2^q - t_1^q)$$

subject to:

$$r_i(t^q) = 0, \;\; \forall i = 1, \ldots, k \;\text{ and }\; \forall t^q, t_1^q < t^q < t_2^q;$$

$$r_i(t_1^q) = 1, \ \ \forall i = 1, , \ldots, k;$$

$$r_i(t_2^q) = 1, \ \ \forall i = 1, \ldots, k$$

IV. Inverse Ant System-Based Surveillance System (IAS-SS)

While the robots navigate, they deposit a specific substance, the pheromone (the analogue of the pheromone in biological ant systems), into the environment. At each time each robot receives stimuli from the pheromone and adjusts its navigation direction. This is the only one decision that a robot takes. In fact, the robot navigation system considers a set of stimuli detected at different angles and same distance. The lesser is the detected amount of the substance the greater is the probability that the robot takes the navigation direction equal to the angle where this amount of substance is.

The logic of the decision in the IAS-SS is the opposite of that adopted in the traditional ant system theory. The logic adopted there generates a positive feedback, that is, the greater the amount the substance the greater is the probability of the agent to follow the respective direction.

The block diagram in Figure 1 represents the sequence of main actions that an agent system performs at each iteration.

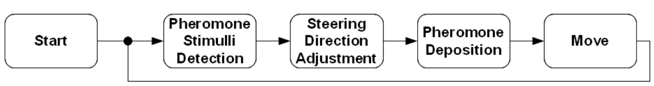


Figure 1. Functional Diagram Block for a single agent.

It is important to mention that the robots exhibit the obstacle avoidance behavior, but there is no specific embedded navigation mechanism for that. In fact this navigation skill emerges from the synergy among the artificial agents as a natural consequence of how the pheromone is released on the environment and the effects the pheromone stimuli generate.

A detailed description of the IAS-SS system is given below. Consider a group of N robots $k, k = 1, \ldots, N$. Every robot k performs two basic operations: steering direction adjustment and pheromone deposition.

A. Steering Direction Adjustment

Two strategies to determine the steering direction angle are adopted in [15]. The first, Stochastic Sampling (SS), considers all pheromone stimuli that the sensor detects at the border of its range (Figure 2). The second, Best Ranked Stochastic Sampling (BRSS), determines the adjusting of steering angle based on only those stimuli associated with the least amount of pheromone. However, Stochastic Sampling mechanism showed to be efficient for large areas where the amount of pheromone deposited is similar on every point due to the stochastic nature of the strategy. Because BRSS strategy maximizes the explored area in reduced period of time, only it is considered here.

The model of the sensor adopted is such that it detects pheromone stimuli at a specific distance R, from -90 degrees to 90 degrees, corresponding to the average of the amount of pheromone deposited in an angle interval. The total range of 180 degrees is divided in identical angle intervals, such that the sensor detects stimuli corresponding to different angles A_s, s = 1, ..., S.

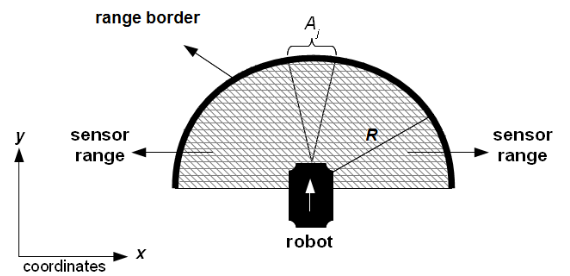


Figure 2. Robot and sensor models

1) Best Ranked Stochastic Sampling: Two subsets of angle intervals S is considered to define the steering direction. The first, subset U the angle intervals are those that the amount of pheromone is very low. Specifically, the strategy sorts the intervals according to the respective amount of the pheromone. Then only those angles A_s associated with the least amount of pheromone (best ranked intervals) are considered to define the steering direction. The second subset V consists of elements chosen randomly, according to a uniform distribution, from the angles A_s that are not in the first subset.

A probability value is assigned to each discrete angle in both of the subsets U and V. The probability assigned to the angle A_s is inversely proportional to the amount of pheromone deposited in the respective angle interval, that is, the lower is the amount of pheromone detected, the higher is the probability associated with the angle. Specifically, the probability $P(s)$ assigned to the angle A_s is:

$$P(s) = \frac{1}{\tau_s / \sum_{i \in \{U,V\}} \tau_i} \tag{2}$$

where τ_s is the amount of pheromone corresponding to the angle A_s.

The adjusting of steering direction is determined according to a discrete random variable a defined through the probability $P(s)$, assuming values in the set $A_s, s = 1, ..., S$.

According to this strategy, robots tend to move to directions where there is low amount of pheromone. The general behavior observed is that the robots move to unexplored areas or areas scarcely visited by robots during some period of time. The adjusting of steering direction is given by:

$$\Theta_k(t) = \Theta_k(t-1) + \gamma A(s^*) \tag{3}$$

where $\Theta_k(t)$ is the steering of movement of robot k at instant t, $\gamma \in [0, 1]$ is the constant coefficient for smoothing of steering direction adjusting and $A(s^*)$ is the selected direction by probability of equation 2.

 ISBN: 978-1-61208-155-7

B. Pheromone Releasing and Evaporation

In traditional artificial ant systems, agents release pheromone on the ground only on their respective positions signaling exactly the robot way [11]. Differently, the artificial agents in the IAS-SS spread pheromone on a wide area in front of their respective positions, corresponding to sensor range area.

Once the agent determines the steering direction, but before it moves, it spreads pheromone. The amount of pheromone deposited on the ground decreases as the distance from the robot increases. The model for the pheromone releasing is such as follows. Consider that L_t and Q are the sensor range area at iteration t and the entire environment space, respectively, such that $L_t \subset Q \subset \mathbb{R}^2$. Then, the amount of pheromone $\Delta_X^k(t)$, that the kth robot deposited on the position X at iteration t is:

$$\Delta_X^k = \begin{cases} e^{\frac{-(X-X_k)^2}{\sigma^2}}, \text{if } X \in L_t \\ 0, \text{otherwise} \end{cases} \tag{4}$$

where X_k is the position of the kth robot and σ is the Gaussian dispersion.

Multiple robots deposit pheromone in the environment at same time, then the total amount of pheromone deposited on the position X at iteration t depends on the contribution of every robot.

Furthermore, pheromone is not a stable substance, that is, it evaporates according to a specific rate. The total amount of the pheromone that evaporates $\Phi_X(t)$ at position X and time t is modeled such as follow:

$$\Phi_X(t) = (1-\rho)\tau_X(t) \tag{5}$$

where ρ is the evaporation rate and $\tau_X(t)$ is the total amount of pheromone on the position X at iteration t.

Therefore, the total amount of pheromone $\tau_X(t)$ at X and at time t is (Equation 6):

$$\tau_X(t) = \Phi(t-1) + \sum_{k=1}^{K} \Delta_{x,y}^k \tag{6}$$

V. Experimental Results

Experiment simulations are developed to evaluate preliminarily the bioinspired coordination strategy IAS-SS. The strategy is considered to generate the dynamics of multiple robot systems applied to exploration and surveillance tasks.

Experiments are carried out in Player/Stage platform that models various robots and sensors simulating simultaneously their exact dynamics. Although this platform includes navigation mechanism for obstacle avoidance, this behavior, in IAS-SS system, emerges only from consequence of repulsive nature of pheromone. The robot model used is Pioneer 2DX equipped with laser range-finder SICK LMS 200.

The exploration task is executed if the environment is completely covered. Moreover, the faster the system completes the task, the better is the performance; the system carries out the surveillance task if there is no instant T* such that after this instant exists a region that is not sensed anymore. Despite this definition for surveillance task is accurate, it is not suitable since may be impossible to find T*. Therefore, it is important that the system conclude the task continually, that is, the system has to be able to sense the entire environment considering that a new sensing task is started when the system concludes the previous one. Furthermore, the lesser is the maximum time between two consecutive sensing tasks, the better is the performance.

The system parameters used in the experiments are: $\sigma = 0.4R$ (pheromone releasing rate); $\rho = 10^{-4}$ (evaporation rate); $\tau_X(0) = 0.5$ (the amount of pheromone at iteration $t = 0$); $R = 8.00$ meters (radius of the semicircle where the pheromone is deposited and provided by laser range finder); $\gamma = 0.5$ (coefficient for smoothing of steering direction adjusting); Robot speed: 0.5 meter per second; $S = 360$ (number of angle intervals); Number of elements of subsets U and V correspond to 30% and 10% of size of S set, respectively; Maximum number of iterations of simulations: 1000. The values assigned to parameters σ and ρ are defined through analysis of performance of IAS-SS in [15].

The steering direction strategy adopted for all experiments is BRSS (see Section IV-A1) due to its more efficient performance than other strategies described in [15]. According to randomness characteristic of this strategy, all experiments are executed 3 times. Thus, average of performances are computed to evaluate them. The discrete time is adopted in simulation and it is equivalent to the number of iterations.

The environments where the IAS-SS system carries out the tasks are divided in connected small regions called here rooms. The used division model of environments in following experiments is illustrated in Figure 3(a). The environments are designed from the division model according to a complexity level. This complexity level is measured according to number of options to travel the environment (among rooms), that is, through graph structure resultant from connection among rooms Figure 3(b). The more path options to reach a specific region are available, the complexity level of environment is higher. For environments of Figures 3(c) and 3(d), the graph structure is the same of the graph of Figure 3(b), hence, the complexity is low. As obstacles are inserted into environments blocking the passage among rooms, the respective edges of graph are removed and, thus, the complexity is higher.

For analysis, the rooms are numbered (Figure 3(a)). A room is said to be visited if its central point is reached by any robot. In this case, the group of all central points corresponds to the set Q defined in equation 1. Hence, the scenario considered here is an instance of the problem formulated.

Since there are ten rooms, four robots are considered for

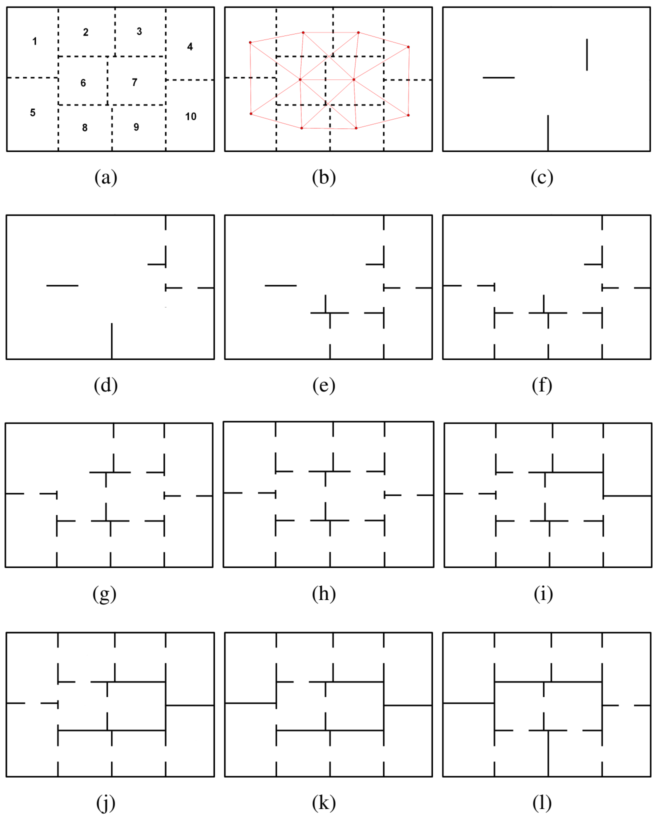


Figure 3. Environment models: (a) environment divided in rooms; (b) connection graph among rooms; (c)-(l) environment from $\#1$ to $\#10$.

Table I
PERFORMANCE OF CONFIGURATION WITH BRSS MECHANISM AND INCREASING THE COMPLEXITY LEVEL

Environment	Number of SE	Average of SI
$\#1$	17 ± 3	57.46 ± 10.41
$\#2$	15.66 ± 2.08	61.9 ± 7.83
$\#3$	13.66 ± 0.57	70.76 ± 6.27
$\#4$	15 ± 2	63.77 ± 8.91
$\#5$	12.66 ± 1.52	77.29 ± 11.58
$\#6$	11 ± 1.73	87.65 ± 19.59
$\#7$	9 ± 0.01	97.75 ± 7.7
$\#8$	7.66 ± 0.73	114.17 ± 23.82
$\#9$	7.51 ± 1.32	119.49 ± 3.88
$\#10$	7.33 ± 1.52	115.23 ± 24.9

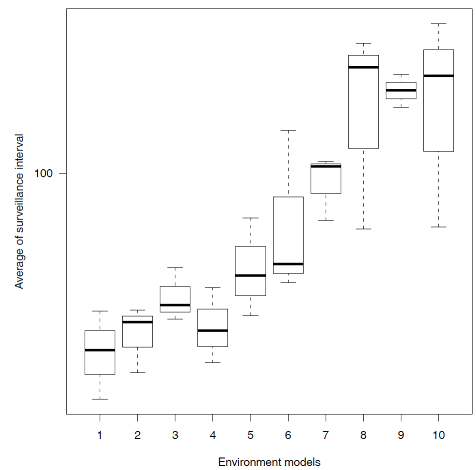


Figure 4. Boxplots of distribution of the average of surveillance intervals for different degree of complexity of environment.

experiments to assign at least two rooms to each robot. This forces the robots travels long distances increasing the likelihood find challenging situations as obstacles. All robots start at room 1.

Although it is clear that the exploration time increases as complexity level increases, the surveillance task is accomplished even with a restricted number of path options. This emphasizes that environment structure is not a factor that impedes the tasks to execute. Even robots in environments with higher complexity level can carry out the tasks. The environment sensing (SE) is completed independently of the environment structure. As general behavior of the system, the length of SI period is increased while the complexity level of environment increases. Also, as consequence of the higher complexity, the number of completed SE is smaller. This can be observed in Table I. The average of number of SE decreases and the average of SI presents a strong increasing tendency, which is not monotonic due to the random nature of experiments. Therefore, it is observed that the system self-adapt according to changes in the environment model. A more detailed view of results of table, regarding the average of SI, is presented in the Figure 4. It shows the boxplots of the distribution of the performance.

Additional information about the behavior of the system can be gathered observing the Figure 5. Data used to plot the graphic are from the trial with the median number of SI for simulation of environment $\#5$. Four graphics are presented, each of which registering the behavior (room changing) of one of the robots. Each vertical line indicates the SE, that is, the iteration when the IAS-SS senses the entire environment (the robots visit cooperatively all the 10 rooms), considering that a new sense task is started after the system concludes the earlier one.

The self-adapt trait of the system is visualized through the trajectories of robots in Figure 6. Due to limited space, only the obtained trajectories from simulation of environments $\#1$, $\#5$ and $\#10$ are showed in order to contrast the high difference of complexity level among them. It can be observed that the trajectories are concentrated in a trail when the rooms are small. An explanation for this outcome is the small size of rooms. In this case, the sensor range covers whole the room. While for large regions resultant from junction rooms in environments $\#1$ and $\#5$, the robots move away from the trail to cover the entire environment efficiently. The data presented are from the trial with the median number of SI for each environment.

 ISBN: 978-1-61208-155-7

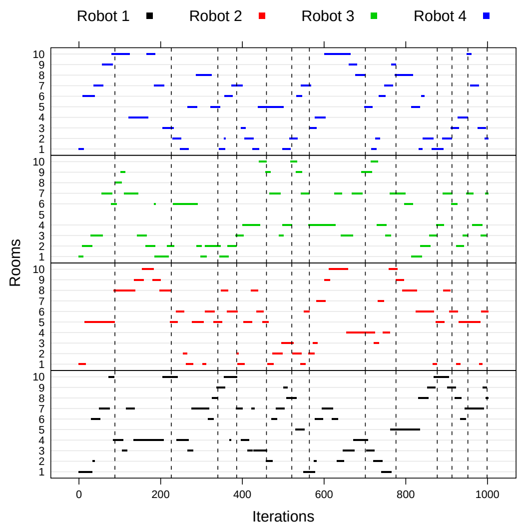
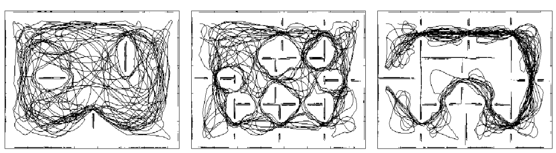


Figure 5. IAS-SS performance according to environment #5.



(a) (b) (c)

Figure 6. Trajectories of robots during exploration and surveillance tasks: environments (a) #1; (b) #5; (c) #10.

VI. Conclusions and Future Works

This work described a new bioinspired distributed coordination strategy, named IAS-SS, for multiple agent systems applied to exploration and surveillance tasks. The strategy is based on a swarm theory, specifically the ant system theory. The IAS-SS strategy defines steering directions that guide preferably the agents to where the amount of pheromone is lesser. The strategy is not dependent on the knowledge of the environment structure and changes the system dynamics in order to reach a good performance.

As future works some parameters of the IAS-SS system will be considered for analysis, e.g., the pheromone releasing mechanism. Moreover, a localization method will be integrated to IAS-SS system in order to deploy it in real robots. In this case, a chemical sensor will be attached to the front of robot. Similarly, a device to disperse the chemical will be deployed. A more simple way is to consider only distance sensor and set the cells of built map to indicate that there is amount of pheromone at respective position. In addition, more complex surveillance tasks, e.g., those that a strange agent invades the environment, will be investigated.

Acknowledgment

The authors would like to thank FAPESP and CNPq for their support.

References

[1] Q. Jiang. "An improved algorithm for coordination control of multi-agent system based on r-limited voronoi partitions". IEEE Int. Conf. on Automation Science and Engineering, 2006. CASE '06. pp. 667-671, 2006.

[2] F. Mazzini, D. Kettler, J. Guerrero and S. Dubowsky. "Tactile Robotic Mapping of Unknown Surfaces, With Application to Oil Wells". IEEE Transactions on Instrumentation and Measurement, vol. 60, pp. 420-429, 2011.

[3] A. Speranzon. "Coordination, Consensus and Comunnication in Multi-Robot Control Systems". PhD Thesis, Royal Institute of Technology, Stockholm/Sweden, 2006.

[4] F. Pasqualetti, A. Franchi, and F. Bullo. "On optimal cooperative patrolling". IEEE Conf. on Decision and Control, Atlanta, GA, USA, pages 7153-7158, December 2010.

[5] B. Yamauchi. "A frontier-based approach for autonomous exploration". Proc. of the 1997 IEEE Int. Symp. on Comp. Int. in Rob. and Aut., pp. 146-151, 1997.

[6] H. R. Everett. "A brief history of robotics in physical security". Space and Naval Warfare Systems Center, San Diego, Robotics Publications, 2010.

[7] R. A. Freeman, P. Yang and K. M. Lynch, "Distributed estimation and control of swarm formation statistics", *American Control Conference.*, 7, 2006.

[8] F. Kobayashi, N. Tomita, F. Kojima, "Re-formation of mobile robots using genetic algorithm and reinforcement learning", *SICE 2003 Annual Conference.*, vol. 3, pp. 2902-2907, 2003.

[9] M. Lee, M. Tarokh and M. Cross. "Fuzzy logic decision making for multi-robot security systems". Artif. Intell. Rev. vol. 34, issue 2., pp. 177-194. Kluwer Academic Publishers. Norwell, MA, USA, 2010.

[10] M. Castelnovi, P. Musso, A. Sgorbissa and R. Zaccaria. "Surveillance robotics: analyzing scenes by colors analysis and clustering," Proc. of 2003 IEEE Int. Symp. on Comp. Int. in Robotics and Automation. vol.1, no., pp. 229- 234 vol.1, 16-20 July 2003

[11] M. Dorigo. "Optimization, learning and natural algorithms". PhD thesis, Dipartimento di Elettronica, Polit. di Milano, 1992.

[12] M. Dorigo, G. Di Caro and L. Gambardella. "Ant Algorithms for Discrete Optimization". Technical Report IRIDIA/98-10, Universite Libre de Bruxelles, Belgium, 1999.

[13] D. Yingying, H. Yan and Jiang Jingping. "Multi-robot cooperation method based on the ant algorithm". Proc. of the 2003 IEEE Swarm Intelligence Symp., pp. 14-18, 2003.

[14] B. Christian. Review of "Ant colony optimization" by M.Dorigo, T.Stützle, MIT Press, Cambridge, MA, 2004. Artif. Intell., pp. 261-264, 2005.

[15] R. Calvo, J. R. de Oliveira, M. Figueiredo and R. A. F. Romero. "A Distributed, Bio-Inspired Coordination Strategy for Multiple Agent Systems Applied to Surveillance Tasks in Unknown Environments". Proc. of the IEEE IJCNN. San Jose, USA, 2011.

Basic Study for Human Brain Activity Based on the Spatial Cognitive Task

Shunji Shimizu / Tokyo University of Science, Suwa
Department of Electric Systems Engineering
Chino-city, Japan
shun@rs.suwa.tus.ac.jp

Hiroyuki Nara/ Hokkaido University
Graduate School of Information Science and Technology
Sapporo-city, Japan
nara@ssc.ssi.ist.hokudai.ac.jp

Noboru Takahashi/ Tokyo University of Science, Suwa
Research course of Engineering/Management
Chino-city, Japan
jgh10614@ed.suwa.tus.ac.jp

Hiroaki Inoue/ Tokyo University of Science, Suwa
Research course of Engineering/Management
Chino-city, Japan
jgh10603@ed.suwa.tus.ac.jp

Yukihiro Hirata/ Tokyo University of Science, Suwa
Department of Electric Systems Engineering
Chino-city, Japan
yhirata@rs.suwa.tus.ac.jp

Abstract— **Recently, there is a need to develop a new assist system which acts for car driving and wheelchair for the elderly and disability person as the population grows older. In terms of developing a new system, examining human spatial recognition has important implications. And so, we pay attention to spatial perception, especially left and right ones and differences in brain activity between right and left perception. The final goal of our research measuring brain activity is to contribute to developing of welfare robots with functions that are responsive like human. So, we have performed experiments for investigating human spatial perception by measuring brain blood flow when subjects perform driving tasks. In previous experiment, we measured brain activity when T-junctions were shown to subjects using driving movies. In this time, we performed experiment in which brain activities were measured during actual car driving. We are reporting on these analysis result and comparison result between virtual one and actual one.**

Keywords- spatial cognitive task; NIRS; determing direction during car driving

I. INTRODUCTION

Human can determine his movements and behaviors relative to his environment. In addition, he recognizes a new location and decides what behavior to take. It is important to examine the human spatial perception for developing autonomous robots or automatic driving.

The relation of the theta brain waves to the human spatial perception was discussed in [1][2]. For example, when human perceives space that surrounds him, he tries to decide the next action in a maze and the theta brain waves saliently appear. This means we have a searching behavior to find a goal at an unknown maze. From the side of human navigation, Maguire et al. measured the brain activations using complex virtual reality town [3]. But, each task was notional and the particulars about the mechanism that enables humans to perceive space and determine direction is yet unknown. From researches we performed, there were significant differences at dorsolateral prefrontal cortex in left hemisphere in turning a steering wheel at T-junction [4][5][6].

Brain activities concerned with cognitive tasks during car driving have been documented [7]. For example, there was a report about brain activity when disturbances were given to subjects who manipulated driving simulator. Then power spectra were increased in beta and theta bands. However, there is little report on the relationship between right and left perception and driving task. It is well known that higher order processing is done such as of memory, judgment, reasoning, etc in the frontal lobe [8].

We try to grasp mechanism of information processing of the brain by analyzing data on human brain activity during car driving. The goal of this study is to find a way to apply this result to new assist system with human motions. To achieve the goal, we try to examine the brain activity of frontal lobe, which related to behavioral decision-making, from the viewpoint of human spatial perception. As a first step, we measured the brain activity of frontal lobe relevant to right and left perceptions during car driving. Furthermore, the brain activity is to be measured and discussed about the mechanism of information processing of the brain by analyzing experimental data concerning human brain activity during car driving using NIRS (Near Infrared Spectroscopy).

II. EXPERIMENTS

A. Brain activity on driving movie is shown

The subjects for this experiment were eight males aged 22 to 24. The average age was 22.7 and the age of standard deviation was 0.74. All of the subjects were right handed. They were asked to read and sign an informed consent regarding the experiment.

NIRS (Hitachi Medical Corp ETG-100) with 24 channels (sampling frequency 10 Hz) was used to record the density of oxygenated hemoglobin (oxy hemoglobin) and deoxygenated hemoglobin (de oxy hemoglobin) in the frontal cortex area.

Driving movie for the experiment was recorded from a moving car, in which two T-junctions were included. In addition, there was a road sign with directions in the second scene. We used nine kinds of movies in about one minutes. Before showing the movie, subjects were taught directions turning to the right or left at the first T-junction. They were also taught the place which was on the road sign at the second T-junction. They had to decide the direction when they looked at the road sign. They were asked to push a button when they realized the direction in which they were to turn. Subjects took a rest during 10 seconds at least with their eyes close before movies were shown and they viewed the image after that. Finally, subjects took a rest again. The brain activity was recorded from the first eyes-closed rest to the last eyes- close rest.

Here, we defined Tasks A, B, and C; Tasks A and C were proposed as the same experiment tasks and subjects had to push the button. In tasks B, other operation was added. It was the operation that the steering wheel was turned in the direction of destination when subjects realized it.

For this experiment, driving movies were displayed on a HMD (Head Mounted Display). The PC emitted a trigger pulse at the start of the eyes-closed rest and driving movie. Then, NIRS was recorded the brain activity, the trigger pulse from PC and the pulse from the button pushed at the second T-junction.

Subjects were seated in car seat. Then they were fitted with the NIRS probe and the HMD. They were covered with black cloth to shut out the light from outside.

B. *Brain activity on handling motion*

In this experiments, measurements were performed by f-NIRS (Functional Near Infrared Spectroscopy) made by SHIMADZE Co. Ltd with 44ch. Five subjects were a healthy male in their 20s, right handed with a good driving history. The subject was asked to perform simulated car driving, moving their hand in circles as if handling a steering wheel. A PC mouse on the table was used to simulate handling a wheel, and NIRS (near-infrared spectroscopy) was used to monitor oxygen density changes in the subjects' brain.

NIRS irradiation was performed to measure brain activities when the subject sitting on a chair drew a circle line of the right/left hand 1) clockwise, and 2) counterclockwise. The part of measurement was the frontal lobe. The subject was asked to draw on the table a circle 30 cm in diameter five times consecutively, spending four seconds per a circle. The time design was rest (10 seconds at least), task (20 seconds), rest (10 seconds).

C. *Brain activity on car driving*

In general roads, experiments were performed by taking f-NIRS in the car, and measured the brain activity when subjects drove on designed road including intersections.

In this experiment, two kinds of measurements were performed. At first experiment, there were two intersections. And subjects were told to turn the right or left in first intersection. In addition, they were told to read the road map and judge the turning direction in the second intersection. And subjects were enlightened about turning direction before measurement. They were also taught the place on which the road sign was at the second T-junction. And, they were given the place where they have to go. So, they had to decide the direction when they looked at the road sign. Six subjects were a healthy male in their 20s, right handed with a good driving history. Subjects close their eyes for 10 seconds at least, and drove the car for 600 seconds. Three patterns were prepared for the task pattern.

Next, we performed second experiment to conduct verification about above experiment and increase number of subjects. We performed additional experiment which was achieved in a similar way. In this experiment, measuring and analyzing method was performed in same way, but experimental courses were different. Subjects were twelve males who were all right-handed.

III. EXPERIMENTAL RESULT

A. *Brain activity on driving movie is shown*

For task A and C, the subjects were informed direction by suggested movie, and they let decided which way to turn under the road sign. After first T-junction, they were to push the button when they realized the direction at second direction. In task B, they performed other task, turning the steering wheel actually in concert with suggested movie. The hemoglobin variation was compared in the results of Tasks A and B, A and C to see the brain activity pertaining to spatial perception during the same movie.

Equation (1) was used to compare the data. $\tau 1$ was set the time as its length was 1 second before being pushed the button. Similarly, $\tau 2$ was set in a way similar to $\tau 1$. And xi (t) indicates variation of i channel oxy hemoglobin or deoxy hemoglobin. We then took a average of xi(t) through $\tau 1$ and $\tau 2$. In this situation, i of the defined c (i) was the channel for the brain activity. Because of the sampling frequency was set on 10 Hz, we calculated 10 times per sec.

$$c(i) = \overline{\sum_{\tau_2} x_i(\tau_2)} - \overline{\sum_{\tau_1} x_i(\tau_1)} \quad (1)$$

A comparison was made between the situations in which the steering wheel was turned and when it was not. Figure 1 is the calculation result of oxy-Hb.

The next step was to calculate the average of all subjects. Figure 2 shows the results. This might have occurred when they realized direction from a road sign. In addition, the results indicated a greater increase when the subjects turned the steering wheel. That indicated observation of brain activity has been made during movement based on spatial perceptions.

On the whole, the variation in de-oxy hemoglobin was smaller than in the oxy hemoglobin. However, there was a great increase in Channel 18. This might be the variation based on the spatial perceptions.

Next, differences were investigated concerning the subject's brain activity. The First case was when the vision was directed after having been told the direction.

 ISBN: 978-1-61208-155-7

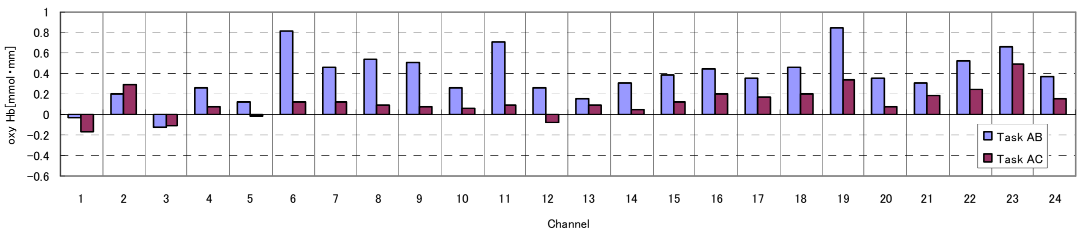


Figure 1. Result from subject A of task A

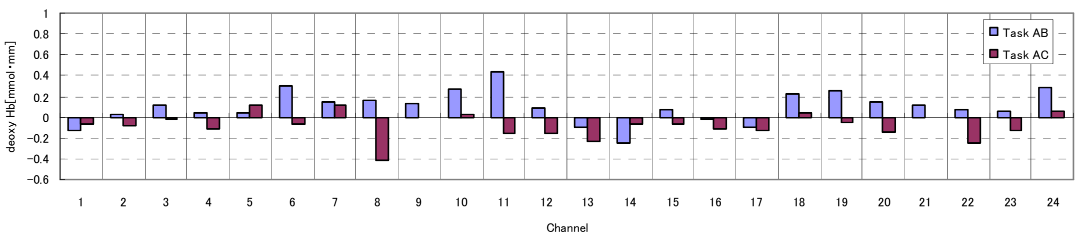


Figure 2. Compared between turrning the steering wheel and not (oxy Hb of subject A)

The Second case was when the vision was directed after having been told the direction gone to the direction which the subjects decided where to go from a road sign. d1 and d2 shown in Fig. 3 are defined as below. d1 is the variation of hemoglobin turning at the first T-junction. And d2 is variation of hemoglobin at the second one. From the measurement result, d1 and d2, all of the 269 times of each subject, there were significant differences in oxy hemoglobin 3ch. ($p < 0.02$: paired t test) and 20ch ($p < 0.03$) using NIRS.

Subjects pushed a button before turning at the second T-junction, so it influenced brain activities. The possibility of a correlation between d2 and the time until the movie was turned at the second T-junction after each subject pushed a button was investigated. Each correlation coefficient of hemoglobin channel was calculated. There was significant difference at only de-oxy hemoglobin 10ch. ($p < 0.07$) using paired t-test. In only this result, the relationship between pushing a button and d2 cannot be judged.

B. *Brain activity on and handling motion*

During the motion, the increase of oxy hemoglobin density of the brain was found in all subjects. The different regions of the brain were observed to be active, depending on the individual. The subjects were to be observed 1) on starting, and 2) 3-5 seconds after starting moving their 3) right hand 4) left hand 5) clockwise 6) counterclockwise. Although some individual variation existed, the result showed the significant differences and some characteristic patterns.

The obtained patterns were shown as follows. Regardless of 1), 2), 3) and 4) above, the change in the oxy hemoglobin density of the brain was seen within the significant difference level 5% or less in the three individuals out of all five subjects. The part was the adjacent part both of left pre-motor area and of left prefrontal cortex. Especially, in the adjacent parts of prefrontal cortex, a number of significant difference was seen among in four out of five subjects.

Next more emphasis was put on the rotation direction: 5) clockwise or 6) counterclockwise. No large density change was found in the brain with all the subjects employing 6). But the significant difference was seen in four out of five subjects employing 5) (Fig. 4). It is well known that in the outside prefrontal cortex higher order processing is done such as of behavior control. It was inferred that the pre-motor area was activated when the subjects moved the hand in the way stated above because the pre-motor area was responsible for behavior control, for transforming visual information, and for generating neural impulses controlling.

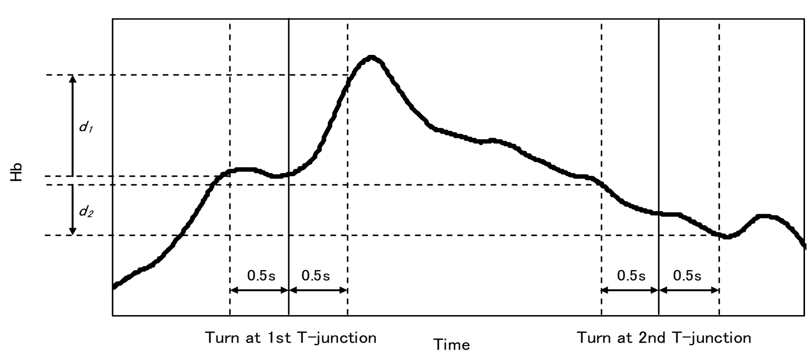


Figure 3. Define variation of hemoglobin d1 and d2

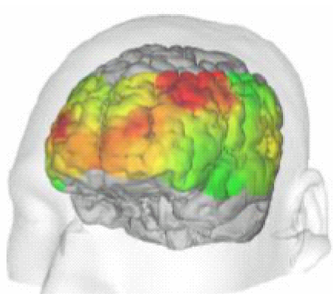


Figure 4. Brain activity (clockwise)

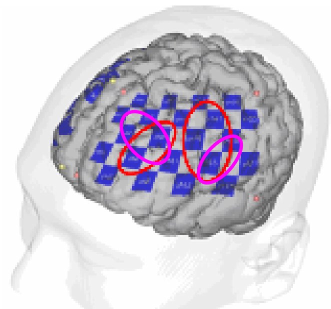


Figure 5. Significant differences at T-junctions in left direction

C. *Brain activity on car driving*

At the first, Hb-oxy was increased in overall frontal lobe after start of operation. This tendency was common among subjects. After that, Hb-oxy was decreased as subjects adjusted to driving the car. This meant that the brain activity changed from collective to local activities.

In this experiment, being considered time as zero when subjects turned a steering wheel. The analysis was performed one-sample t-test within the significant difference level 5% or less between zero and about four seconds after turning.

As the results, there were significant differences around #46 area of the dorsolateral prefrontal cortex and the premotor area of the left hemisphere brain at the turn left (Figure 5: red circles).

Around #46 area was corresponded to working memory. In additional experiment, analysis was conducted using same method, too. In this regard, we analyzed in both orders for confirming to be sequence-independent on the presence or absence of road sign (Figure 5: pink circles).

IV. CONCLUSION

The hemoglobin density change of the human subjects' frontal lobe was partly observed in the experiments we designed, where three kinds of tasks were performed to analyze human brain activity from the view point of spatial perception.

The NIRS measures of hemoglobin variation in the channels suggested that human behavioral decision-making of different types could cause different brain activities as we saw in the tasks: 1) taking a given direction at the first T-junction, 2) taking a self-chosen direction on a road sign at the second T-junction and 3) turning the wheel or not. Some significant differences (paired t test) on NIRS's oxy-hemoglobin and less interrelated results between "pushing a button" and brain activity at the second T-junction are obtained.

Furthermore, experimental results indicated that with the subjects moving their hand in circle, regardless of right or left, 1) the same response was observed in the prefrontal cortex and premotor area, and 2) different patterns of brain activities generated by moving either hand clockwise or counterclockwise.

The regions observed were only those with the 5% and less significance level. Possible extensions could be applied to other regions with the 10% and less significance level for the future study. With a larger number of subjects, brain activity patterns need to be made clear. In addition, it is thought to take particular note of participation concerning working memory when car is driven.

From results of these experiments, there was significant difference around working memory. So, experiments focusing on relationship turning wheel and working memory will be performed. On the other hand, experiments as to actual driving were required a broad range of perception and information processing. Especially, subjects had to determine behaves depending on various information at T-junctions, that is, the color of the traffic light, presence or absence foot passengers and so on. And so, we plan to perform more static experiments. we attention to differences on the basis of turning direction and dominant hand. In addition, we will conduct the experiments in which subjects were narrowed down to left-handedness. Furthermore, researches into other human brain activities than spatial perception are to be necessary with accumulated data from fMRI, EEG, etc.

REFERENCES

[1] M.J. Kahana, R. Sekuler, J.B. Caplan, M. Kirschen, and J.R. Madsen: "Human theta oscillations exhibit task dependence during virtual maze navigation." Nature, vol. 399, 1999, pp. 781-784.

[2] N. Nishiyama and Y. Yamaguchi: "Human EEG theta in the spatial recognition task", Proceedings of 5th World Multiconf. On Systemics, Cybernetics and Informatics (SCI 2001), Proc. 7th Int. Conf. on Information Systems, Analysis and Synthesis (ISAS 2001), pp. 497-500 (2001).

[3] E.A. Maguire, N. Burgess, J.G. Donnett, R.S.J. Frackowiak, C.D. Frith, and J.O. Keefe: "Knowing Where and Getting There: A Human Navigation Network," Science, vol. 280, 1998, pp. 921-924.

[4] S. Shimizu, N. Hirai, and F. Miwakeichi: "Fundamental Study for Relationship between Cognitive task and Brain Activity during Car Driving," Proc. the 13th International Conference on Human-Computer Interaction, (San Diego, CA, USA, 2009), Springer Berlin / Heidelberg, pp. 434-440.

[5] N. Takahashi, S. Shimizu,Y. Hirata, H. Nara, F. Miwakeichi, N. Hirai, S. Kikuchi, E. Watanabe, and S. Kato: "Fundamental Study for a New Assistive System during Car Driving," Proc. International Conference on Robotics and Biomimetics, 2010, China.

[6] N. Takahashi, S. Shimizu, Y. Hirata, H. Nara, F. Miwakeichi, N. Hirai, S. Kikuchi, E. Watanabe, and S. Kato: "Fundamental Study for a New Assistive System during Car Driving," The 28th Annual Conference of Robotics Society of Japan, 2011

[7] Chin-Teng Lin, Shi-An Chen, Tien-Ting Chiu, Hong-Zhang Lin, and Li-Wei Ko: "Spatial and temporal EEG dynamics of dual-task driving performance." Journal of NeuroEngineering and Rehabilitation, vol. 8-11, 2011.

[8] J. Cockburn: "Task interruption in prospective memory: "A frontal lobe function?." Cortex, vol. 31, 1995, pp. 87- 97.