COGNITIVE 2013

The Fifth International Conference on Advanced Cognitive Technologies and Applications

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COGNITIVE 2013

Foreword

The Fifth International Conference on Advanced Cognitive Technologies and Applications (COGNITIVE 2013), held between May 27 and June 1, 2013 in Valencia, Spain, 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 2013 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 2013. 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 2013 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that COGNITIVE 2013 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 hope that Valencia, Spain provided a pleasant environment during the conference and everyone saved some time to explore this historic city.

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Specifying Desired Behaviour in Hybrid Central/Self-Organising Multi-Agent Systems

Yaser Chaaban and Christian Müller-Schloer
Institute of Systems Engineering
Leibniz University of Hanover
Hanover, Germany
chaaban,cms@sra.uni-hannover.de

***Abstract*—Path planning for multiple agents in a common environment is a challenging research problem. In previous papers, we introduced a hybrid architecture solving the conflict between a central unit (an observer and a controller) and decentralised autonomous agents. This architecture should have mechanisms for planning, but only as recommendation, and control decisions. In this paper, we focus on planning of the desired behaviour of agents in a shared environment. The scenario used in this work is a traffic intersection without traffic lights. Therefore, an A*-algorithm was adapted for the path planning. Consequently, the designed algorithm calculates collision-free trajectories (central planning) for all agents (vehicles) in a shared environment (the centre of the intersection) enabling them to avoid collisions. The experimental results demonstrated a high performance of our adapted A*-algorithm.**

Keywords- Path planning; A*-algorithm; Multi-Agent Systems; autonomous vehicles; Hybrid Coordination; Organic Computing

I. INTRODUCTION

Organic systems [1] or autonomic systems try to realise quality in several aspects of system engineering [2][3]. The wide range of properties of organic systems can be used to establish the vital concept of "controlled self-organisation". Also, organic systems use the "controlled self-organisation" design paradigm, in which the unwanted behaviour should be prevented, whereas the desired behaviour should be rewarded.

In prior papers [4][5][6][7], we introduced the interdisciplinary methodology, "Robust Multi-Agent System" (RobustMAS). RobustMAS uses a central component that performs the desired behaviour (trajectories), where this planned behaviour is recommended to agents. RobustMAS applies a hybrid solution (central/self-organising), where collision-free trajectories for agents (the desired behaviour) are calculated by a central component and then given to agents only as a recommendation. Here, despite the autonomous behaviour of agents, they always get the best possible (desired) trajectories from the central unit.

In this context, a traffic intersection without traffic lights was chosen as a main testbed to apply the hybrid approach (RobustMAS), where autonomous agents are autonomous vehicles, and the controller of the intersection is the central

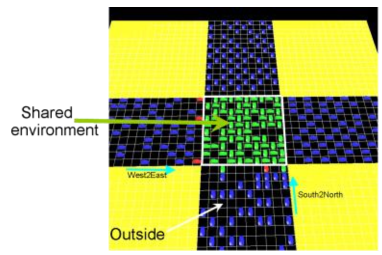

Figure 1. The traffic intersection without traffic lights

unit. However, the basic idea of a hybrid approach is applicable for other systems as well.

Figure 1 shows a screenshot from our project. In this regard, we presented the desired system architecture in [4][5]. This architecture was an observer/controller (O/C) architecture adapted to the scenario of traffic intersection.

In this paper, we concentrate on planning of the desired behaviour (trajectories) of agents (vehicles) in a shared environment (traffic intersection).

This paper is organised as follows. Section 2 presents a survey of related work concerning path planning. In Section 3 the realisation of the approach is discussed. This realisation includes: path planning, A*-algorithm, trajectories, an adapted A*-algorithm and virtual obstacles respectively. Section 4 introduces the evaluation of the system performance by means of experimental results. Section 5 draws the conclusion of this work. Finally, the future work is explicated in Section 6.

II. STATE OF THE ART

In the literature, there are many works concerning path planning, where common path search algorithms are investigated. The problem of path planning for multiple agents (robots) has been discussed in various papers in order to coordinate the movements of the agents [8][9][10]. There are various approaches to solve this problem. Two well-known approaches are: the coordination technique and an A*-based path planning technique [9]. The coordination technique [11] arranges and discovers the optimal paths of the individual agents (robots) and then computes a schedule how the robots have to traverse these trajectories. The A*-based technique applies the A* search algorithm (a graph search algorithm that finds the least-cost path from a given initial node to one goal node) to work out independent

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planning of the paths for the individual robots in their configuration time-spaces, which extends the configuration space of the robot by a time axis. In [9], a series of experiments have been performed to compare these approaches. These experiments demonstrate that the A*-based technique significantly outperforms the coordination technique. In many cases, the authors were convinced that the A*-based technique is much more efficient because of the independent planning of the paths for the individual robots in the time-spaces configuration. These experiments show also that the A*-based approach is well suited to control the motions of a team of robots in various environments and illustrate its advantages over the coordination technique.

III. THE APPROACH

In our approach, we model vehicles as agents. Also, we define the term "shared environment" as the centre of the intersection.

An intersection manager is responsible for coordinating tasks. It performs first a path planning to determine collision-free trajectories for the vehicles (central). This path planning is given to vehicles as a recommendation. Vehicles are modelled as agents.

For the path planning, common path search algorithms are investigated. Particularly interesting here is the A*-algorithm. The path planning is considered as a resource allocation problem (Resource Allocation Conflict), where several agents move in a shared environment and have to avoid collisions. The implementation should be carried out under consideration of virtual obstacles. Virtual obstacles model blocked surfaces, restricted areas (prohibited allocations of resources), which may arise as a result of reservations, accidents or other obstructions.

In this paper, we assume that all vehicles obey their planned trajectories (plan) and thus no deviations from the plan will occur. In addition, there are no accidents in the intersection. This means that everything is as planned.

A. Path planning

This section presents the realisation and requirement of path planning and illustrates the resulting trajectories. Accordingly, the adapted A*-algorithm to calculate collision-free trajectories for all agents is introduced using virtual obstacles.

When every agent has its unique path from one point to another, no conflict is possible when no unexpected errors or disturbances occur during movement of agents. In order to plan such unique paths for multiple agents that move in a shared space, global knowledge and centralised control will be needed so that it will be easy to prevent conflicts.

Path planning in this work is the applied coordination mechanism to solve the problem of resource sharing wherever multiple agents cross the shared environment avoiding collisions. Path planning delivers collision-free trajectories for all participants in this multi-agent system. The behaviour of an agent outside the shared environment do not need path planning, because an agent outside the shared environment has only local rules, through which it tries to move forward avoiding collisions with other agents. Path planning has to be done only for agents inside the shared environment.

When an agent arrives at a border of the shared environment (Figure 1), it sends a message (request) to the controller (intersection). The path planning unit of the controller has to reply to this message thereby the agent can cross the shared environment safely provided no unexpected errors or deviations from the plan occur within this process.

When the path planning unit of the controller receives a request from an agent (vehicle), it simulates the trip of that agent through the shared environment taking into consideration the presence of other agents and the geometry of the shared environment (intersection) in the configuration time-spaces. It calculates an appropriate trajectory and sends it to the agent. Furthermore, the calculated trajectory is stored in the trajectory memory.

The enquiring agent gets its trajectory, which guarantees a coordinated behaviour with the other agents in order to avoid traffic jams in the intersection.

B. A-algorithm*

Since our work uses the A*-based technique, which employs the A*-algorithm, this section presents the A* procedure described by Nilsson et al. in [12]. As mentioned above, A*-algorithm is a search algorithm to obtain the optimal path (minimum-cost path according to a given cost function) from a given start state to a target state in a graph. In order to build only paths that lead towards the target state, A* uses priorities assigned to each path. The priority of a path n is determined by the cost function: $f(n)=g(n)+h(n)$. It should be mentioned that using a priority queue to store paths through the graph (already visited nodes) together with their related A* costs is the most common implementation of the A*-algorithm. For this purpose, the lower the A* cost, i.e., the $f(n)$ cost, of the node n , the higher the priority assigned to this node.

Here, $f(n)$ is the total A* cost of the path from the start state (start node) until the current state (current node) n , where $f(n)$ is composed of $g(n)$ and $h(n)$. First, $g(n)$ represents the accumulated costs of reaching the state n from the start state. Second, $h(n)$ is the estimated cost of reaching the goal state from the state n . The estimated cost is called heuristics. The cost function $f(n)$ plays a main role in finding optimal paths, because A* takes into account the distance already travelled, the $g(n)$ function. Therefore, A* will only obtain the shortest path, if it exists, when a good heuristics is selected. The algorithm 1 gives an overview of how the A*-algorithm works.

C. Trajectories

A trajectory in our work represents the path of an agent only inside the shared environment (inside the intersection). The controller plans trajectories for all agents in the system, which have to be collision-free. If all agents comply with their planned trajectories, then the throughput of the system would be better (the intersection will be covered optimally by the vehicles), because RobustMAS uses a central algorithm in order to plan the trajectories. Here, the central planning algorithm (A*-algorithm) has a global view of all available resources (cells in the intersection) that can be allocated to the agents.

The agents get their planned trajectories only as recommendation from the controller, because they can behave in a fully autonomous way.

The memory of all trajectories serves the observer to detect any deviations from the planned trajectories occurred in the system, where the observer compares the actual travelled trajectories to this memory.

A trajectory is modelled as a vector (n *-tupel*) of space-time points, where each point has its coordinates (x_i, y_i) that can be reserved at time t_i :

$$trajectory = \{(x_1, y_1, t_1), \ldots\ldots, (x_n, y_n, t_n)\} \text{ with } 1 \le i \le n;\ i, n \in \mathbb{N} \quad (1)$$

D. An adapted A*-algorithm

In this paper, the A*-procedure for path planning of agents is applied and the minimum-cost path in its three-dimensional configuration time-space is searched. However this A*-based procedure has been adapted for the requirements of the used application scenario “intersection without traffic lights”, because a vehicle can only take a “rational” path, whereas an agent (e.g., robot) can take any calculated path. Here, the term "rational" denotes the fact that a vehicle carries out a goal-directed motion along a rational (most reasonable) path in the intersection when it moves towards its target. This path will be a straight or concave trajectory (or sections of a trajectory) with respect to the travel direction as depicted in Figure 2.

However, robots can follow an arbitrary (winding) path. As a result, due to the use of the A*-algorithm not adapted to a traffic intersection, “non-rational” path (or sections of the path) from one waypoint to the target can be built and consequently used, where vehicles can not take such paths in the centre of an intersection to reach their targets. Examples of “irrational” paths are due to repeated zigzag movements, or back and forth movements (crisscross).

Figure 3 shows how A* is used for the problem supported by an example. Here, the trajectory of the vehicle consists of six points. Every point has its (x, y, t) in the three-dimensional configuration time-space as follows:

$$trajectory = \{(x_1, y_1, t_1), (x_2, y_2, t_2), (x_3, y_3, t_3), (x_4, y_4, t_4), (x_5, y_5, t_5), (x_6, y_6, t_6)\} \quad (2)$$

Compared to the A*-algorithm described above, the adapted A*-algorithm, which is used in this work, has the following features:

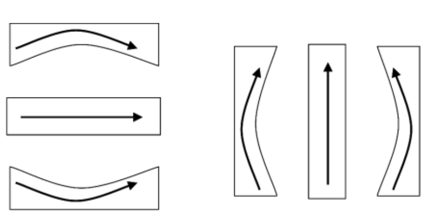

Figure 2. Rational paths of vehicles with respect to the travel direction

Algorithm 1: Overview of the A*-algorithm

```
A-Star (startNode, goalNode)
BEGIN
Initialise (G, Q, startNode); //G:graph, Q:priority queue
CostUntilNow [startNode] = 0;
optimalPathUntilNow [startNode] = startNode;
// Insert the start node in Q with the initial cost f=0
Q = addToQueue (startNode), f (startNode) = 0;
while not isEmpty (Q) do
     bestNode = returnFirstElementOfQueue (Q);
     if (bestNode = = goalNode) then
          // optimal path is given by optimalPathUntilNow []
          return optimalPathUntilNow [];
     end if
     // for each neighbour n of bestNode
     for all n in successors (bestNode) do
          // IS the path to n is shorter than the current way
          if (CostUntilNow[n] > CostUntilNow [bestNode] +
          CostDistBetweenNeighbour (bestNode, n)) then
          // Update the costs given by CostDistBetweenNeighbour
          CostUntilNow [n] = CostUntilNow [bestNode] +
          CostDistBetweenNeighbour (bestNode, n);
          optimalPathUntilNow [n] = bestNode;
               if (n in Q) then
                    update f(n)= CostUntilNow[n] + h(n,
               goalNode) in Q;
               else
                    Q = addToQueue (n), f(n) = CostUntilNow [n]
                    + h (n, goalNode);
               end if
          end if
     end for
end while
// No path could be found.
return failure;
END
```

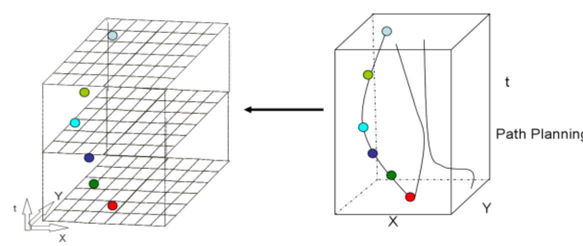

Figure 3. An adapted A*-algorithm used for the problem of path planning in the three- dimensional configuration time-space.

- The function **BuildVirtualObstacles (n)**: It uses this function in order to build virtual obstacles into the path from the current node n to the goal node, because a vehicle can only follow a “rational” path as explained above. Virtual obstacles are blocked areas, which can not be crossed by vehicles. For details see section E (Virtual obstacles).
- It plans independent paths for the individual vehicles in their three-dimensional configuration time-spaces. Thus, reservation of space-time points (x_i, y_i, t_i) is the key step of the adapted A*, where each node (space-time point, tile or cell in the intersection) of the graph that has its coordinates (x_i, y_i) can be reserved by one agent A_i at time t_i . For this purpose, the adapted A*-algorithm uses the function **isCellReserved (n, time)**. This function tests whether the node $n(x, y)$ has been already reserved for another agent for a specific time, where the parameter “time” represents the time at which the agent, for which A* is looking for the best trajectory,

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will reach the node $n(x,y)$ according to its planned trajectory so far. So, RobustMAS considers the problem of path planning for teams of agents.

- It provides the possibility to react to potential deviations of the agents from their planned trajectories during the plan execution. Deviations from the planned trajectories are detected by the observer of the O/C architecture, where the controller is informed of it. Consequently, the adapted A* re-plans the affected trajectories using the function **replanNewTrajectoriesOfAffectedAgents()**. Moreover, it takes into account the presence of disturbances (i.e., accidents in the intersections) by computing the paths.
- The heuristics used in the adapted algorithm for the estimated cost of reaching the goal state is based on the straight-line Euclidean distance from any given state (a node in the graph) to the goal state:

$$\min\|(x_s,y_s)-(x_g,y_g)\|;(x_s,y_s):start\,state,(x_g,y_g):goal\,state \quad (3)$$

This heuristics (a heuristic estimation of the distance in the case of path planning) will enable definitely A* finding the shortest path, if it exists, where the search will be limited to selected collections of the state space. Thus, a heuristic estimate of the distance to be travelled may be the straight-line distance between two states in a shared environment, so that optimal paths can be planned.

E. Virtual obstacles

The implementation of the adapted A*-algorithm in RobustMAS has been carried out under consideration of virtual obstacles. Virtual obstacles have been adopted, where blocked surfaces should not be considered by the planner. Virtual obstacles model blocked surfaces, restricted areas, which may arise as a result of reservations, accidents or other obstructions. In addition, virtual obstacles can be used for traffic control. Figure 4 shows the shape of the blocking surfaces (virtual obstacles), which are used by RobustMAS in order to plan trajectories using an adapted A*-algorithm.

IV. PERFORMANCE EVALUATION

In this section, we present an initial evaluation of our algorithm using the model of a traffic intersection, which was designed and described in our earlier papers [4][5].

Since the path planning algorithm plays an important role in our traffic system to achieve high performance, an evaluation of this algorithm is required under different test scenarios considering various loads of vehicles, where no deviations from plan and no accidents occur in the system. In our earlier papers, handling of deviations from planned (desired) behaviour was studied in [6], whereas handling of disturbances (accidents) was considered in [7].

The evaluation of the concept was carried out based on the basic metrics: throughput and mean waiting time. Throughput here is the total number of vehicles that left the intersection (simulation area) over time, whereas the mean waiting time is the average time (ticks or iterations) needed by vehicles to traverse the intersection:

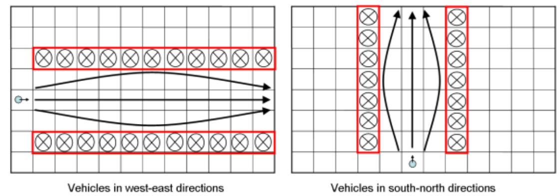

Figure 4. Blocking surfaces (virtual obstacles)

$$MWT_i = \frac{1}{v}\sum_{k=1}^{v} W_{k,i} \quad (4)$$

Where MWT_i is the mean waiting time of the system at the time (tick) i, $W_{k,i}$ is the waiting time of the vehicle k at the time i, and v is the total amount of vehicles.

A. Evaluation scenarios

Four different evaluation scenarios are used to measure and compare the system performance, which results from change of values of the following two simulation parameters: V_{max} is the maximum number of vehicles in each direction, and TL is the production rate of vehicles in each direction (traffic level or traffic flow rate). The four different evaluation scenarios ensure that the system performance in various combinations of the parameter remains effective even when the intersection is very busy, especially during rush hour (during morning and afternoon peak traffic).

The used metrics have been measured in an interval between 0 und 3000 ticks (time steps). As shown in Figure 1 two traffic flows with orthogonal directions are taken into account: $W2E$ (West2East) and $S2N$ (South2North).

Table I shows the resulting four evaluation scenarios. Here, "equal TL" means that the traffic flow rates of vehicles in each direction are the same, while these rates in each direction are different in the case of "not equal TL". Similarly, the "equal V_{max}" and "not equal V_{max}" can be expressed by the parameter "maximum number of vehicles". The values of both simulation parameters were chosen in such a way that a wide spectrum of traffic volumes can be covered (low, medium, high and extreme traffic volumes).

For example, in evaluation scenario I (Equal V_{max} – Equal TL), the throughput and the mean waiting time of the system have been measured in the case that the traffic flow rates (traffic levels) of vehicles in south-north and west-east directions is equal, namely 5 vehicles/tick, where the measurement has been repeated in the cases that the maximum number of vehicles in each direction is equal, namely 20, 40, 80, 100, and 500 vehicles. The case of 500 vehicles in every direction is an extreme case, where the maximum number of vehicles is greater than the capacity of the intersection (very busy intersection). Here, the intersection is a 10x10 grid of reservation tiles. Similarly, other evaluation scenarios II, III, and IV can be expressed.

B. Results of throughput measurement

Figure 5 shows the system throughput (#Vehicles/tick) for each evaluation scenario that was measured in an interval between 0 und 3000 ticks.

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TABLE I. THE FOUR EVALUATION SCENARIOS (TWO TRAFFIC FLOWS WITH ORTHOGONAL DIRECTIONS)

Scenarios	#Max. Number of Vehicles (V_{max})	# Traffic levels (TL) (Traffic flow rates)
I (Equal-Equal)	N2S = W2E	N2S = W2E
II (Equal-Not Equal)	N2S = W2E	N2S ≠ W2E
III (Not Equal-Equal)	N2S ≠ W2E	N2S = W2E
IV (Not Equal-Not Equal)	N2S ≠ W2E	N2S ≠ W2E

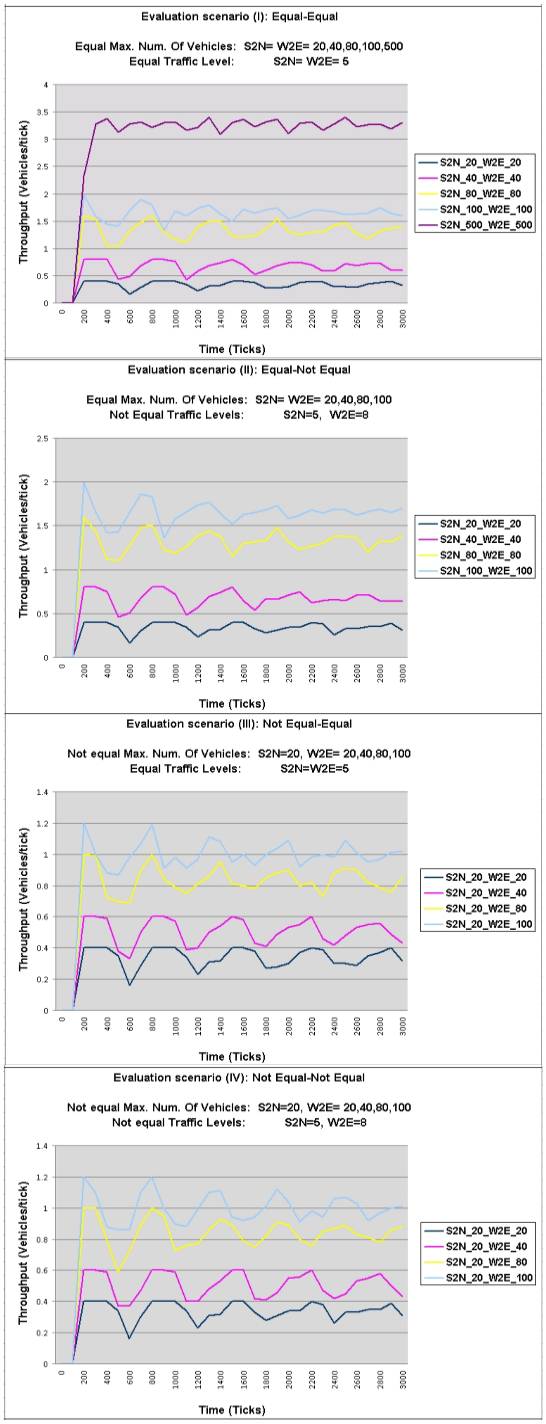

Figure 5. The system throughput (# Vehicles/tick) for each evaluation scenario (I, II, III, and IV) in an interval between 0 und 3000 ticks

It can be seen that from approximately the tick (120) the vehicles begin to leave the intersection, because at the beginning of the simulation the intersection was empty. Therefore, the system throughput in this interval [0-120] is zero. Thereafter, the system throughput increases always with time in the case of the cumulative system throughput (#Vehicles), or it is at its best (i.e., approximately constant) in the case of the throughput per time unit (#Vehicles/tick). This note applies to the four evaluation scenarios.

Figure 6 shows the system throughput comparing the four evaluation scenarios according to varying the value of the maximum number of vehicles in each direction after 3000 ticks including the extreme case. Here, on the x-axis is the maximum number of vehicles together in both directions $W2E$ and $S2N$.

In evaluation scenario I, the system throughput increases almost always linearly with the number of vehicles. In a similar manner, the same behaviour of the system throughput applies to the other evaluation scenarios. However, this behaviour of the system throughput will be changed only in the extreme case, (500-500) vehicles.

In the extreme case, the system performance achieves a value of around 9500 vehicles, because the maximum number of vehicles here is greater than the capacity of the intersection. Thus, it can be concluded that the system throughput within the capacity of the intersection increases almost always linearly with the number of vehicles.

In evaluation scenarios I and II, the values of the system throughput are approximately identical. This means that the maximum number of vehicles in each direction is relevant, not the traffic levels (traffic flow rates) of vehicles in each direction. The system achieves a throughput of around 5000 vehicles by 100 vehicles in every direction in both evaluation scenarios I and II (see Figure 6). A similar conclusion can be obtained when the values of the system throughput in evaluation scenarios III and IV are compared.

However, it is obvious that the values of the system throughput in evaluation scenario III are not similar to the values in the evaluation scenario I and II, because the total amount of vehicles in both directions in evaluation scenario III is less than the amount in evaluation scenarios I or II.

In general, it can be noted that the system throughput increases almost always linearly with the number of vehicles in all evaluation scenarios (I, II, III, and IV) as long as the maximum number of vehicles is not greater than the capacity of the intersection.

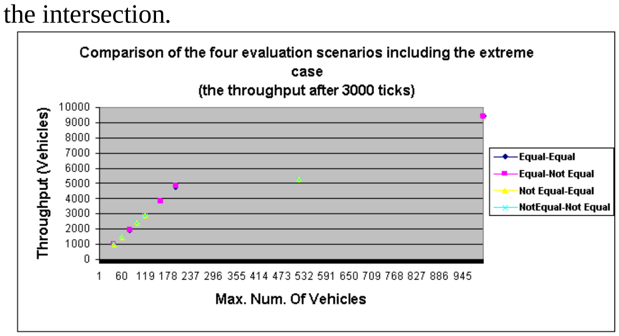

Figure 6. The throughput of system in the four evaluation scenarios including the extreme case after 3000 ticks

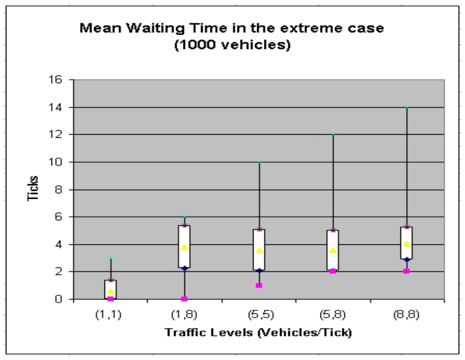

Figure 7. The mean waiting time in the extreme case (1000 vehicles)

C. *Results of mean waiting time measurement*

Here, the results of the mean waiting time metric will be discussed for the extreme case, 500 vehicles in every direction, where the maximum number of vehicles is greater than the capacity of the intersection (very busy intersection). That is done in order to show the longest waiting time at all with its standard deviation.

For this purpose, the measurements were repeated in the cases that the traffic levels of vehicles in south-north and west-east directions are: (1,1), (1,8), (5,5), (5,8), (8,8) vehicles/tick. The different rates at which vehicles enter each of the directions are chosen to investigate the effect of traffic streams with equal/unequal strength on the mean waiting time which vehicles experience as depicted in Figure 7 using a box plot. The mean waiting times and the standard deviations of all vehicles, that left the intersection, have been registered after 3000 ticks in the extreme case.

Despite the huge number of vehicles, which is greater than the capacity of the intersection, the resulting mean waiting times were low values with small standard deviations in all different traffic flow rates (traffic levels). The largest mean waiting time is by traffic rate (8,8) around $\Phi\ 4 \pm 1.19$.

V. CONCLUSIONS

In this paper, the path planning was the applied coordination mechanism to solve the problem of resource sharing wherever multiple agents (vehicles) cross the shared environment (centre of the intersection) avoiding collisions.

Path planning served to compute collision-free trajectories and to arrange the agents. The controller performs the path planning using a central planning algorithm and sends the planned trajectories to the agents only as recommendation. Here, a trajectory represents the path of an agent only inside the shared environment.

An adapted A*-algorithm for path planning of agents (vehicles) has been applied. The adaptation was necessary for the requirements of the used application scenario "intersection without traffic lights", because a vehicle can only take a "rational" path. A*-algorithm searches the minimum-cost path in its three-dimensional configuration time-spaces. The implementation has been carried out under consideration of virtual obstacles that model blocked surfaces, restricted areas, which may arise as a result of reservations, accidents or other obstructions. The experiments showed a high performance of this algorithm. The evaluation of this algorithm was based on different test scenarios considering various loads of vehicles.

VI. FUTURE WORK

One aspect that may be of interest for future work is the fairness between the system's agents (vehicles). In order to achieve this fairness, there are different approaches that deal with this issue. The other aspect that will be an important issue in the future is the coordination and cooperation of multiple intersections without traffic lights.

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A Survey of Robustness in Multi-Agent Systems

Yaser Chaaban and Christian Müller-Schloer
Institute of Systems Engineering
Leibniz University of Hanover
Hanover, Germany
Emails: {chaaban, cms}@sra.uni-hannover.de

***Abstract*—Nowadays, robustness is one of the several concepts that have to be considered when designing multi-agent systems. Thus, achieving robustness in multi-agent systems is of central importance. However, there is a clear lack of study of robustness in developing robust multi-agent systems in technical systems. In this paper, we provide a survey on robustness issues and mechanisms in multi-agent systems in diverse research fields. Afterwards, we suggest our interdisciplinary methodology, "Robust Multi-Agent System" (RobustMAS) to characterise robustness of multi-agent systems. RobustMAS poses a challenge to support the multi-agent system with mechanisms to keep the system at a desired performance level when disturbances and deviations from plan occur (robustness). Furthermore, RobustMAS proposes a new appropriate method to measure the robustness of such multi-agent systems.**

Keywords-Robustness; Survey; Multi-Agent Systems

I. INTRODUCTION

The ever increasing complexity of today's technical systems embodies a real challenge for their designers.

In this context, the design of the system architecture plays a main role in achieving a robust system so that its performance has to remain acceptable in the face of deviations or disturbances occurred in the system (intern) or in the environment (extern). That means, the development of robust systems needs to take into account that degradation of the system's performance in the presence of such disturbances should be limited in order to maintain a satisfying performance. Therefore, a robust system has the capability to act satisfactorily even when conditions change from those taken into account in the system design phase. Nevertheless, this capability has to be retained, because of the increasing complexity of novel systems where the environments change dynamically. As a result, fragile systems may fail unexpectedly even due to slightest disturbances. Thus, a robust system will continue working in spite of the presence of disturbances by counteracting them with corrective interventions.

Although there are numerous research projects made towards building robust multi-agent systems in diverse fields, a study of robustness of technical systems, which are modelled as multi-agent systems, does not exist yet (at least it is extremely rare, e.g., an attempt by the Organic Computing Initiative [5]).

The next section gives an overview of existing related work aiming at highlighting the need of a novel approach to cover the gap recognised by designing robust multi-agent systems.

This paper is organised as follows. Section 2 presents a survey of related work concerning robustness of multi-agent systems in various research fields. In Section 3, the concept and objectives of RobustMAS will be presented. Additionally, the measurement of robustness of a multi-agent system according to the RobustMAS concept will be presented, where a new method for their measurement has been developed. Section 4 draws the conclusion of this work. Finally, the future work is explicated in Section 5.

II. STATE OF THE ART

In the literature, there are enormous works concerning the robustness of systems. However, there is a clear lack of study of robustness, to the best of our knowledge, in developing robust multi-agent systems in technical systems.

The development of robust multi-agent systems can address the robustness in the face of various kinds of factors (i.e., in the sense of turbulences) such as unreliable agents, faulty agents, malicious attacks, system uncertainty, common disruptions, failing elements or components, unreliable components, variable (turbulent) environments, environmental catastrophes, unexpected situations and exceptional conditions. In short, the goal is to develop a robust multi-agent system despite disturbances and deviations occurred in the system (intern) or in the environment (extern).

A. Robustness approaches in MAS

It is noteworthy that the definition of system robustness varies according to the context in which the system is used. Therefore, manifold meanings of system robustness were introduced in the literature. Additionally, various formal measures and metrics were presented to achieve the system robustness.

In the following, several research projects and approaches will be presented that are of interest in the context of this survey. They deal in some way with robustness of multi-agent systems in various research fields.

1) Handling communication exceptions in double auctions

Parsons and Klein [6] tried to build robust multi-agent systems against unreliable agents and infrastructures using a

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domain-independent exception handling approach. They have proved that their approach has the ability to achieve the robustness of multi-agent systems. Parsons and Klein provided every agent with a sentinel, so that each message from and to an agent can be processed (guarded) by such a sentinel. These sentinels are able to detect corrupted messages. Consequently, exception handling services, which are provided by sentinels, will enable robust multi-agent systems. A point of interest in this approach is that the exception handlers are generic. Therefore, the same exception handlers may be required for a broader variety of multi-agent systems [6].

In this regard, Parsons and Klein implemented their proposed approach for multi-agent systems that accomplish resource allocation using double auctions to handle communication exceptions.

2) The "citizen" approach

Similar to the work in [6], the so-called "citizen" approach, was presented by Klein et al. in [7]. The "citizen" approach tries to improve the robustness of multi-agent systems by off-loading exception handling from problem solving agents to distinct domain-independent services. It facilitates robust open multi-agent systems. This approach observes a multi-agent system in order to detect problems (exceptions) and consequently to intervene if needed. The case study of this approach was handling the agent death exception in the contract net protocol. According to the "citizen" approach, citizens embrace optimistic rules of behaviour but a whole host of social institutions will be used so as most exceptions can be handled (institutions deals with exceptions more efficiently than individual citizens). The main factor, which leads to applying the citizen approach efficiently to the development of multi-agent systems, is that widely reusable, domain independent exception handling expertise can be separated from the knowledge that agents in MAS can act upon to perform their usual jobs [7].

3) Agent Programming Language for Robustness (APLR): BDI agent programming

Another approach to support robustness of multi-agent systems was introduced by Unruh et al. in [8]. This approach is based on logging aiming to build more robust multi-agent systems. It tries to deal with problems occurring in multi-agent systems and consequently to recover from them. It uses an execution logging in order to build robust agents. The execution logging (execution history) has to be ensured at the architectural level. This means that agents in MAS should possess architectural-level support for logging and recovery methods when the robustness of MAS is considered. They presented also how an infrastructure-level logging approach can sustain agents so that run-time problems in BDI agents can be recovered [8]. Additionally, Unruh et al. have defined a special programming language, called APLR (Agent Programming Language for Robustness). This language is a developer-level language and defined especially for BDI agent programming. It aims to encode agent problem-handling knowledge so that a specification of problem-handling information will be supported as well as the developer can be insulated and constrained from the infrastructure-level reasoning [8].

4) Karlsruhe Robust Agent SHell (KRASH): In production planning and control (PPC)

In production planning and control (PPC), an approach by Frey et al. in [9] has addressed the robustness of such systems that were designed as multi-agent systems. In this context, flexibility and robustness are especially looked for in the case of production environments that are subject to continual, substantial and rapid changes in conditions (disturbances or turbulences). Frey et al. have applied database technologies on the basis of transactions in order to achieve the robustness of multi-agent systems. They assumed that robustness and reliability, which are common characteristics of current database systems, will solve the detected lack of reliability and robustness in the industrial deployment whether database technologies are applied. The database technologies will allow agents to perform their tasks robustly via providing robustness services, since robustness services are widespread in database techniques.

In this regard, Frey et al. have used transaction trees (common tree-like structures) to represent the agent plans. Next, execution agents, which are particular components of their multi-agent system, were assigned to execute the agent plans in a robust manner. So, transactions (transaction-based recovery mechanisms) ensure the recoverability in presence of disturbances [9].

Additionally, it is assumed that MAS can handle this problem more effectively than conventional centralised approaches on account of their flexible and robust behaviour. Frey et al. have modelled a multi-agent system and then compared it to an Operations Research Job-Shop algorithm. The comparison was made using a simulation-based benchmarking scenario. According to this approach, robustness on the shop floor will be assured by using MAS and rescheduling algorithms. As a result, robustness of a production system against disturbances can be supported not only by scheduling algorithms but also by a proper MAS architecture [10]. On the other hand, a simulation-based benchmarking platform was developed at the University of Karlsruhe in Germany. This platform was part of the Karlsruhe Robust Agent SHell (KRASH) project that is based on a real world production scenario (shop floor scenario). The goal of the benchmarking platform was to discover whether MAS can improve the planning quality in the shop floor scenario. In short, due to the fact that robustness is a significant aspect of a manufacturing system, this approach presented a transaction-based robustness service using database technology so that disturbances (e.g., machine failures) can be handled [9].

5) Transactional conversation: Layered agent implementation architecture

Closely related to the work in [9], an approach was developed by Nimis and Lockemann in [11] aiming to increase the robustness of multi-agent systems. This approach is called transactional conversation. It applies transaction-based robustness mechanisms, which are common in database management systems (DBMS). These mechanisms were integrated in a robust FIPA-compliant MAS development framework.

(7)	user layer
(6)	mechanism layer
(5)	agent architecture
(4)	ontology layer
(3)	conversation layer
(2)	MAS infrastructure layer
(1)	communication layer

Figure 1. Layered agent implementation architecture [11]

More accurately, agent conversations will be handled as distributed transactions. Nimis and Lockemann have defined the robustness of MAS as following: "Robustness for Multi-Agent Systems means their ability to show predefined qualitative behavior in the presence of unaccounted types of events and technical disturbances". According to this definition, the problems arising from disturbances during the agent interaction should be resolved so that the operation of MAS will be more robust. This approach was applied to applications of production planning and control (PPC). Nimis and Lockemann have presented an agent implementation architecture that was used as a framework to argue about the various aspects of robustness as well as to categorise the heterogeneous approaches in this area to increase the robustness of MAS. This architecture is a structured overview that organises the development tasks in ascending order based on abstraction levels that lead in turn to several layers (layered architecture) as depicted in Figure 1. In this regard, diverse issues were taken into account from the point of view of developers through the development process in order to build that agent architecture [11].

Obviously, in this work, the concentration of robustness considerations has to be on the third layer, the conversation layer, where the agent cooperation is controlled, because this layer is the most critical layer for ensuring the general robustness of MAS.

6) Robustness in Information Systems (IS): an underlying middleware

Similar to the works in [9][11], a promising approach was developed by Nagi in [12] demonstrating a first step towards achieving robust multi-agent systems. This approach aims to increase the robustness of a multi-agent system that is applied in the distributed Information Systems (IS) field of study by means of an underlying middleware. This middleware has to guarantee the robustness of the MAS. The main point in this interdisciplinary approach is to discuss the relation between the technologies of both agents and databases, where agents need to share data asynchronously. Thus, Nagi claims that the agents of a MAS share a world model in which the present situations can be reflected in a common database. Nagi has defined the robustness as follows: "We define the robustness provided by the middleware in terms of guarantees given on a technical basis, which is guaranteeing the correctness in normal operation and recoverability of the system in case of disturbances." [12]. The key idea of this work is to develop an extended transaction model encompassing agent plans and their emergency behaviour (emergency behaviour in the case of disturbances in order to react to them). Additionally, an execution agent has to be involved in order to execute this transaction model. This execution agent ensures the robustness of execution of agent actions. At the same time, the execution agent characterises the interactions with different elements of a generic MAS architecture [12]. Figure 2 shows the proposed robust MAS architecture.

Here, the environment (the world) of the MAS is represented by databases. Every agent perceives its environment (reading from databases) and possibly changes it by producing certain actions (writing to databases). It is noteworthy that every agent is divided in two entities; a planning agent (located in the planning layer) and an execution agent (located in the execution layer) [13]. A planning agent has to cooperate with other planning agents to create the common shared plan, where each planning agent has its common goal and creates its local part of the shared plan and then hands it over to a peer execution agent. Every execution agent executes its received local plan, where coordination protocols will be used to coordinate the execution with other execution agents. In this context, local plans are represented by transaction trees, so that each single-agent action will be encapsulated in an ACID transaction (atomicity, consistency, isolation and durability). ACID transactions are utilities that can be used to guarantee the robust execution of agent actions, where it is known that the most commercial DBMS provide the ACID transactions [12].

7) Market-style open MAS: delegation concept, social agents

In the context of market-style open multi-agent systems, a study was introduced by Schillo et al. in [14] in order to define robustness quantitatively in such systems. This study assumes that robustness of MAS is more than redundancy, because problems caused by malicious agents in open systems can not be solved using redundancy. Therefore, it defines robustness of MAS with respect to performance measures and consequently a robust MAS keeps safety responsibilities despite events, which cause disturbances. Thus, a MAS system will be robust if it preserves a certain level of performance. Schillo et al. presented quantitative definition of robustness, using an electronic market, as follows: "the expected drop of the performance measure in four perturbation scenarios (i) increase of population size, (ii) change of task profile over time, (iii) malicious agent intrusion, and (iv) drop-outs of agents." [14]. According to this definition, robustness of the MAS presents the amount of performance decrease measured in a perturbation scenario (e.g., in case of double population size). The contribution of this study lies in social agents, organisation of agent societies and robustness of social systems.

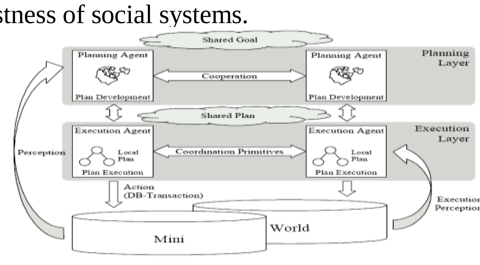

Figure 2. Proposed robust MAS architecture [13]

In short, Schillo et al. suppose that the four properties (scalability, flexibility, resistance, and drop-out safety), which are required to cope with the perturbation scenarios, will be accomplished using [14]:

1) Two types of operation (task delegation and social delegation).

2) Four mechanisms for delegation (voting, authority, economic exchange and social exchange).

It is important to pay attention that delegation is a complex concept that is very significant in the context of MAS. The delegation concept facilitates attaining robustness and flexibility of MAS. Task delegation is based on delegating tasks to other agents, which leads in turn to agents specialising in certain tasks [14].

8) Delegation concept: Holons, social order

Another related work to attain robustness of multi-agent systems using the delegation concept was introduced by Schillo et al. in [15]. This work is based on simulation of social systems using the "social order" concept in the social sciences, because social order bears similarity to robustness in this context. Additionally, it illustrates the properties that agents should have in order to develop them in complex social systems. In this regard, the concept of flexible holons was used. This concept depends on arrangement of agents in groups (task delegation and social delegation) to model institutions in MAS and consequently to utilise their facility of achieving robustness of MAS. Thus, Schillo et al. have analysed the delegation between agents and applied it to holonic systems. Holons (holonic agents) are a useful method for purposes of modelling institutions in MAS [15]. Here, a holon (a holonic agent) consists of parts, which in turn are agents. As a result, a holonic agent is part of a whole and consequently it assists to attain the aims of this superior whole. Additionally, modelling of institutions will make MAS robust, since institutions reduce complexity. A dynamic electronic market, which is able to manage transportation orders, has served as scenario for this work, where agents were created for this purpose [15].

9) Self-Organization and Robustness in Multi-agent systems (FORM)

One additional study was performed by Schillo et al. in [16], which proposed a new sociological concept. It studied self-organisation in multi-agent systems. Of particular interest in this study is the developed Framework for Self-Organization and Robustness in Multi-agent systems (FORM). The reason for that is that robustness (within the meaning of scalability) is closely related to self-organisation in some application scenarios. Schillo et al. have illustrated this framework with respect to the sociological features of organisations. FORM characterises organisational forms and relationships by means of the delegation concept in MAS. In short, the FORM-framework is used to model (and hereby to accomplish) self-organisation of MAS organisations [16].

10) Organisational forms of MAS: genetic algorithms

Most closely related to the work in [16], a new concept was introduced by Hahn et al. in [17] investigating organisational forms of MAS. This concept aims to build robust MAS utilising genetic algorithms that can be used as a search heuristic, since genetic algorithms are effective mechanisms to deal with enormous search spaces. Based on this, the implemented genetic algorithm searches this space for superior forms of organisation. Hahn et al. have defined robustness with respect to a performance measure as follows: "Robustness is considered as graceful degradation of a system's performance under perturbation." [17]. Therefore, in order to evaluate the performance of the recent discovered forms (will be formed by recombination of mechanisms) of organisation under various circumstances, diverse robustness criteria were defined according to sociological theory (for details see [17]). That means, the evaluation of those forms of organisation was based on their involvement (beneficial effects) in the performance and robustness of the MAS in order to search for optimal combinations of the mechanisms. On the other hand, organisational forms (structures) are characterised by the specific applied mechanisms. This means that the behaviour of each organisational form will develop via the different possible mechanisms used by the organisations to satisfy their particular attributes. Here, the numbers within the gene stand for the used mechanism. For example, the first gene characterises the mechanism used for task delegation, where three specific mechanisms were implemented (economic exchange, economic exchange combined with gift exchange or authority). Based on this, the search process delivers organisational forms that have the ability to conform and act in a certain way, so that they demonstrate the best possible performance [17].

B. Summary: Robustness in MAS

Many research projects in the area of multi-agent systems focus on robustness. These works investigate the robustness in various research fields, such as distributed Information Systems (IS), database technologies, social systems and organisation of agent societies. However, there is a clear lack of study of robustness in building robust technical systems, which are modelled as multi-agent systems.

It should be pointed out that only some of the aspects of the topic under study in this paper could be taken into account and therefore they were included in the survey. This can be traced back to the vastness of the topic. Therefore, the survey is concerned with some literature on robustness in multi-agent systems as found in a variety of fields.

There is also much other related work that can be found in the literature, e.g., on re-planning, plan repair, Teleo-Reactive (TR) behaviours [18], formal analysis of protocols for emergent behaviours, and so on. Finally, sensor networks can be considered as MAS and there is much research published on robustness and fault-tolerance in sensor networks (see [19] for an example).

III. THE ROBUSTMAS APPROACH

A. A concise introduction

The Organic Computing initiative [5] aims at building robust, flexible and adaptive technical systems. Future systems shall behave appropriately according to situational needs. But this is not guaranteed in novel systems, which are complex and act in dynamically changing environments.

The focus of the interdisciplinary methodology, RobustMAS, is to investigate the robustness of coordination mechanisms for multi-agent systems in the context of OC.

The next sections give an overview of the RobustMAS concept. It is a novel approach aiming to cover the gap, building robust technical multi-agent systems, recognised in the previous section.

B. An application scenario for RobustMAS concept

The application scenario used by RobustMAS is a traffic intersection without physical traffic lights. For this reason, an intersection control algorithm based on virtual traffic lights is used. Such scenarios contain and assemble the required concerns that can be used to build robust multi-agent systems. In this context, autonomous agents are autonomous vehicles, and the controller of the intersection is the central unit. However, the basic idea of the RobustMAS concept is applicable for other systems as well.

C. Generalisation of the RobustMAS concept

For generalisation of the RobustMAS concept, the current scenario used in this work, intersections without traffic lights, can be replaced also with the more general scenario, shared spaces. This generalisation may be possible due to the similarities between the working circumstances and the environments presented in both systems. In this regard, both systems can be considered as unregulated traffic space, where vehicles move in a fully autonomous way without traffic lights.

The general problem domain of RobustMAS is the resource sharing conflict (resource allocation problem). This is a dynamic coordination problem. RobustMAS tries to solve the question how agents move reliably in a common environment. Here, agents compete for the shared environment (shared resources) in order to move over it quickly, and coordination of these agents in their common environment has to be achieved. In order to avoid a potential resource sharing conflict in such multi-agent systems, RobustMAS introduces a coordination mechanism. This coordination mechanism is based on the idea of path planning (planning of resource allocation over a certain period of time), which must be performed taking into consideration other agents and the geometry of the shared environment in the configuration space-time (x, y, t).

However, the resource allocation in RobustMAS is characterised by “Spatial-dependent resource assignment”. Spatial-dependent resource assignment is a plan-based resource allocation in the 3-dimensional configuration space-time (x, y, t), so that the next requested resource at the next time-step is nearby (successive time-steps). That means if the space (x_1, y_1) is the allocated resource at the time-step (t_1) for an agent, then the planning algorithm must take into account that the next potential resource, the space (x_2, y_2), at the next time-step (t_2) for this agent has to be close (1-neighbourhood) to the previous allocated resource. In the same way, the next space (x_3, y_3), at the next time-step (t_3) for this agent has to be close to the former allocated resource, etc.

D. The RobustMAS concept

For the explanation of the RobustMAS concept, the words agent and vehicle are used interchangeably. Also, the term “shared environment” is used interchangeably for “centre of the intersection”.

RobustMAS focuses on the robustness of hybrid central/self-organising multi-agent systems. For this purpose, RobustMAS proposes the concept of relative robustness for measuring the ability to maintain a specific minimum level of system performance (a desired performance level) in the presence of deviations from desired behaviour (e.g., unplanned autonomous behaviour) and disturbances in the system environment. Based on this, according to the RobustMAS concept, robustness is the ability of the system, with minimal central planning intervention, to return after disturbances (internal and external changes) to the normal state. In this regard, the normal state represents the system performance level at its best when no disturbances occur (under normal operating conditions). RobustMAS proposes a hybrid architecture solving the conflict between a central unit (an observer and a controller) and decentralised autonomous agents.

The realisation of the three steps of the concept of RobustMAS (path planning, observation, controlling) has been introduced in our earlier papers [1][2][3][4]. First, RobustMAS concentrates on planning of the desired behaviour (trajectories) of agents (vehicles) in a shared environment (traffic intersection). Second, the observation process is designed to detect deviations from the planned trajectories (desired behaviour). Third, the controlling step concentrates on the control process of the system to cope with the occurred deviations from the planned trajectories or disturbances (accidents).

In this regard, we presented the desired system architecture in [1][2]. This architecture was an observer/controller (O/C) architecture adapted to the traffic scenario. The O/C architecture (an intersection manager) is responsible for coordinating tasks. It performs first a path planning to determine collision-free trajectories for the vehicles (central). Here, a trajectory represents the path of an agent only inside the shared environment. This path planning is given to vehicles as a recommendation. Here, the path planning is considered as a resource allocation problem (Resource Allocation Conflict), where several agents move in a shared environment and have to avoid collisions.

In addition, an observation of compliance with these trajectories is done, since the vehicles are autonomous (decentralised and they are allowed to behave in a completely autonomous way) and thus deviations from the plan (planned trajectories) are possible. Here, different coordination and replanning mechanisms as well as the capability of the system to operate under real time conditions have been investigated.

Finally, the controlling step is performed. For this purpose, a decision maker was used. This decision maker will be activated when the controller gets a deviation message from the observer. Based on this, the controller algorithm was developed and discussed, followed by the actions table of the controller. The actions table was structured to achieve a desired strategy distinguishing between four different situations (a deviation, a disturbance: an accident, a high priority agent: an emergency-car, and above emergency-threshold). Based on this, the controller decides on an appropriate corrective intervention. In this way, the controller aims to allow the system to return after deviations or disturbances to its normal state with minimal central planning intervention.

In earlier papers, we extended our prototype implementation with the aim of making it capable of handling disturbances (accidents) in the system environment (intersection) in [4]. Furthermore, handling of deviations from planned (desired) behaviour was studied in [3].

In order to conceive the basic idea of RobustMAS, three cases of the system operation will be considered:

1. Operation without disturbance.
2. Operation with disturbance without intervention.
3. Operation with disturbance with intelligent intervention.

Figure 3 illustrates the main idea of this concept in establishing a robust system that tolerates faults, disturbances and deviations, which could be occurred in the system.

As depicted in Figure 3, the performance (e.g., throughput) of the system is at its best (i.e., equal to 1) when no disturbances occur. When a disturbance occurs, the system performance would begin to fall and probably it would become worse (deteriorate) over time, if no corrective intervention is taken in due time. In contrast, if the corrective intervention is intelligent and fast enough, the system performance should improve in the course of time when a disturbance occurs. This means that the system performance remains acceptable despite the occurrence of disturbance.

The aims of the RobustMAS concept have been achieved by using different test situations, handling of deviations from desired behaviour [3] and handling of disturbances [4]. These test situations were proposed to perform the evaluation with respect to the goal of the RobustMAS concept and to measure its robustness.

E. Robustness metrics

In the context of the RobustMAS concept, we developed an appropriate metric for the quantitative determination of the robustness. It is a new method to measure the robustness of hybrid multi-agent systems [4].

In this regard, the cumulative system performance, i.e., the cumulative throughput (#Agents) was used for determining the reduction of the performance (system throughput) of RobustMAS after disturbances (accidents) and deviations from the planned trajectories occur.

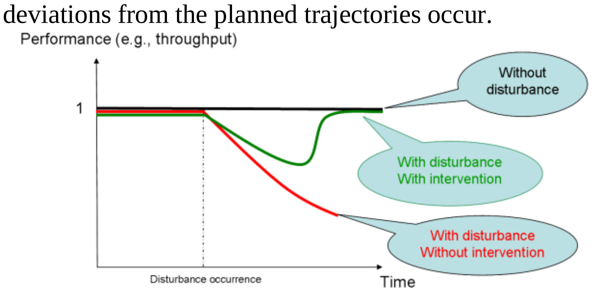

Figure 3. Robust system with disturbance occurrence

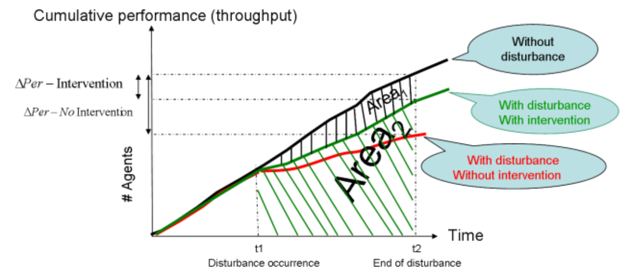

Figure 4. Measuring robustness using cumulative system performance

Here, the system is considered until the time when the disturbance ends. Therefore, the comparison of the throughput values is required in the three cases: without disturbance, with disturbance with intervention, and with disturbance without intervention (as depicted in Figure 4). It should be pointed out that the cumulative system throughput, #Agents, (the intersection throughput, #Vehicles) here is the total number of vehicles that left the intersection (simulation area) over time.

According to the RobustMAS concept, the relative robustness of a multi-agent system can be defined as follows: "The relative robustness of a (multi-agent) system in the presence of a disturbance is the ratio of the performance degradation due to the disturbance divided by the undisturbed performance". Consequently, the relative robustness (R) of a system (S) can be determined as described in the next formula [4]:

$$R = \frac{Area_2}{Area_1 + Area_2} = \frac{\int_{t1}^{t2} Per(t)_{(withIntervention)}\, d(t)}{\int_{t1}^{t2} Per(t)_{(NoDisturbance)}\, d(t)} \qquad (1)$$

Additionally, the discussion of the robustness measurement was based on the simulation parameter, the disturbance strength (the size of the accident). The measurement has been repeated in the cases that the disturbance strength is 1, 2, and 4. That means, the accident occupies an area of size 1, 2 and 4 cells in the traffic intersection. The robustness values for the three cases were: 87%, 86%, and 83% respectively (for details see [4]).

However, the proposed robustness metric is not highly dependent on the application scenario studied by RobustMAS, a traffic system, and consequently it can be generalised to other application domains. In this regard, the general problem domain of RobustMAS, a resource allocation problem, can also be handled in a similar manner.

Here, agents consume the allocated resources. However, since the agents are allowed to behave in a completely autonomous way, they may agree to the allocation of resources (agree to the central plan) or they reject the allocation of resources (do not obey the central plan).

In the case of agent's consent to the plan, the resource allocation is optimal (no deviations from plan, the black curve), because the plan is performed by a central algorithm, which has a global view of all available resources that can be allocated to the system agents.

However, in the case of an agent's rejection of the plan, a potential resource allocation conflict between the agents is

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recognised, because of the consumption of resources, which are possibly reserved for other agents. When a conflict arises, it may be distinguished between two cases: (1) no new resource allocation is performed (the red curve) and (2) new resource allocation is made (the green curve).

IV. CONCLUSION

Robustness is a fundamental concern in multi-agent systems. The analysis of the state-of-the-art confirms that none of the addressed approaches or projects has filled the recognised gap, building robust technical systems, which are modelled as multi-agent systems. That means, there is no approach that is able to achieve such needed systems satisfactorily.

The new developed methodology (RobustMAS) has the goal of keeping a multi-agent system running at a desired performance level when disturbances (accidents, unplanned autonomous behaviour) occur. Therefore, RobustMAS supports the multi-agent system with mechanisms aiming to achieve the required robustness against disturbances. Additionally, it suggests a new method to measure the robustness of hybrid central/self-organising multi-agent systems.

Briefly, the RobustMAS concept raises the question how the robustness can be guaranteed and measured in technical systems. As a result, RobustMAS ensures a relatively acceptable level of reduction of the system robustness against increasing of disturbance strength.

V. FUTURE WORK

There are many interesting issues that can be explored beyond the mentioned above such as the extent of knowability. Furthermore, meta-cognition is a personal quest for insights and consequently it holds a potential for expanding to personalised models, community model, etc.

As mentioned above, the basic idea of the RobustMAS concept is applicable for other systems as well. This paper leaves space for the applicability of the RobustMAS concept for shared spaces. The current traffic scenario used in this work has similarities to shared spaces in the working environments and conditions, where vehicles move autonomously in a shared environment.

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An Overview of Data Privacy in Multi-Agent Learning Systems

Kato Mivule
Computer Science Department
Bowie State University
Bowie MD, USA
Mivulek0220@students.bowiestate.edu

Darsana Josyula, Claude Turner
Computer Science Department
Bowie State University
Bowie MD, USA
djosyula@bowiestate.edu, cturner@bowiestate.edu

***Abstract*— Public and private sector entities continuously produce, store, and transact in large amounts of data. However, combined with the growth of the internet, such datasets get stored and accessed on multiple devices, locations, and across the globe. Therefore, the necessity for autonomous agents that can learn across distributed systems to extract knowledge from large datasets while at the same time taking into account data privacy considerations while interacting with other agents remains a challenge. In this paper, we endeavor to provide an overview of data privacy in multi-agent learning systems, while at the same time highlighting current challenges and future areas of work and research.**

Keywords: Multi-Agents; Inductive Learning; Data Privacy

I. INTRODUCTION

Public and private sector entities constantly generate, collect, and transact in large quantities of data (big data). However, with the growth of the internet, such datasets are stored and retrieved across numerous devices, and localities, across the globe. Therefore, there is necessity for artificial intelligence (AI) agents that can learn across distributed systems to extract knowledge from large datasets while at the same time taking into consideration data privacy and security issues in relation to other independent agents.

The problem of privacy and security in multi-agent systems has been an area of research interest for some time. As of 1996, Forner (1996) observed that the handling of sensitive data in multi-agent systems was still problematic due to privacy enhancing design challenges in multi-agent systems; Forner (1996) suggested cryptographic solutions to deal with privacy issues in multi-agent systems [34]. Wong et al. (2000) further addressed the problem of security and trust in multi-agent systems and proposed a security and trust architecture that ensured that agents do not act in contradiction to their designed purpose and that agents self-authenticate to ensure trust by retaining traits of correct naming and matchmaking services, secure communication channels, secure delegation when acting on behalf of other agents, and accountability [35]. However, Yu et al. (2003), succinctly and aptly observed that in multi-agent systems, privacy may have various meanings and importance for different agents; and that when designing architectures for multi-agent systems, there should be room for a diversity of perceptions and views on privacy [36]. In this article, we take this conceptual approach to privacy preservation in multi-agent systems. It is very difficult to define precisely what privacy is and therefore it becomes problematic to create a generalized solution to privacy complications.

As Spiekermann (2012) observed, one of the challenges of engineering privacy is that privacy is a fuzzy concept often confused with security, and, as such, difficult to implement [40]. Additionally, Friedewald et al. (2010) in their research on the legal characteristics of privacy, made a critical observation, that privacy is an evolving and shifting complex multi-layered concept, described differently by different people [41]. To add to this point, Katos et al. (2011) noted that privacy is a human and socially driven distinctive made up of human mannerisms, perceptions, and opinions [39]. Therefore, definitions for data utility get taken in the same light as privacy that is, data utility is the concept of how useful a privatized dataset is to the user of that particular privatized dataset [11]. Furthermore, despite various approximation methods that have been developed and designed to quantify data utility, researchers have noted that data utility varies from one scenario to the next, and, as such, problematic to have a generalized data utility gauge [12]. We believe that it is imperative that such fuzzy definitions of privacy and utility be taken into consideration when engineering privacy in multi-agent systems to avoid the pitfall of a generalized one-size-fits-all model.

Moreover Ramchurn et al. (2004) gave a detailed overview of the problem of trust in multi-agent systems due to the interactions that agents have in such environments; they observed three main aspects of problematic areas of trust in multi-agent systems: (i) how to engineer protocols for multi-agent interactions, (ii) how would agents decide who to interrelate with, and (ii) how agents decide when to cooperate with each other [37]. In their survey of security issues in multi-agent systems, Jung et al. (2012) made an important observation that multi-agent systems have become critical to autonomous computing today and therefore matters of security such as access control and trust are issues that need to be addressed [38]. This argument is further exemplified by Martins et al. (2012) in their review of security mechanisms in mobile agents, by pointing out the security threats that multi-agents face the need for agents to conform to the three canons of privacy and security, namely, confidentiality, accessibility, and integrity [26]. Lastly, Nagaraj (2012) observed that the analysis of security requirements for multi-agents, and, in this case, privacy requirements, is often neglected during the requirements phase of designing multi-agents [25]. Therefore, we believe that it is essential that any architecture, design, and engineering of multi-agent systems seriously take privacy and security issues into consideration.

A number of data privacy enhancing algorithms have been suggested. Yet adopting the proposed algorithms for privacy preservation among autonomous agents remains a challenge. In multi-agent systems, communication and learning among the various autonomous agents involve dealing with privacy and security issues when one considers what sensitive and personal information autonomous agents can or cannot share. An example would include how multi-agents would transact data in a health care system in which compliance to Federal and state laws require that personal identifiable information (PII) be kept confidential. Although a number of ongoing challenges exist for multi-agents in a distributed environment, in this paper we focus on data privacy issues in multi-agent learning systems as presented in current literature. The remaining part of the paper is ordered as follows: In Section II, we take a look at background of multi-agents as described in the literature. Section III deals with how multi-agents learn while in Section IV, we look at current data privacy issues in multi-agent learning systems. In Section V, we outline a conceptual architecture for privacy preserving multi-agent learning systems, and, finally, in Sections VI and VII, we provide our conclusion while highlighting future areas of research.

II. BACKGROUND

Agents: Wooldridge (2003) defined agents as computer systems that are located in a particular environment with the capability of independent and autonomous action in that particular environment so as to achieve the goals of what they were designed to do [1]. *Multi-Agents:* Wooldridge (2003) further described multi-agents as a group of autonomous agents combined into one system, independently solving simpler problems while communicating with each other to accomplish bigger and complex objectives [1]. *Multi-agent systems (MAS):* Da Silva (2005) noted that multi-agent systems are formed to deal with complex applications in a distributed systems environment. Da Silva (2005) also observed that examining data in distributed environments is a difficult problem since agents face several restrictions; for example, limited bandwidth in wireless networks and privacy issues with sensitive data [2]. *MAS characteristics*: However, Albashiri (2010) illuminated in his dissertation that MAS are defined by the following three traits [3]: *(i)* MAS essentially have to stipulate proper communication and interfacing protocols to efficiently connect with other agents; *(ii)* MAS need to be open and distributed with no previous information of other agents and their activities; *(iii)* MAS may consist of conceivably diverse agents that are distributed in that particular environment and acting independently or cooperatively to accomplish an objective. *Machine Learning:* Machine learning was described earlier by Samuel (1959) as the ability to encode and train computers to learn from experience and ultimately eliminate the necessity for the much exhaustive programming effort [4]. However, a more concise and commonly used formal description was given by Tom Mitchel (1997): "A computer program is said to learn from experience ***E*** with respect to some class of tasks ***T*** and performance measure ***P***, if its performance at tasks in ***T***, as measured by ***P***, improves with experience ***E***" [5].

Big data: According to IBM, a private sector business leader in handling large amounts of data, 'big data' is a collection of large quantities of data that hold the following four characteristics, *(i) volume*, concerned with the large amounts of data, *(ii) velocity*, which has to do with the utilization of data as it is being produced, *(iii) variety*, concerned with various data types, from text, numeric, image, video, and sound, just to mention a few, *(iv) veracity*, as in such data must be authentic and secure for transaction [6]. *Data privacy and security*: Pfleeger et al. (2006), identified data *privacy* as a controlled disclosure in which an entity decides when and to whom to disclose its data, while *security* has to do with access control, as in who is allowed legitimate access to data and systems [8]. The three aspects of information security are further described by Pfleeger et al. (2006) as: *(i) confidentiality*, ensuring the concealment and privacy of data and systems, *(ii) availability*, ensuring the availability of data and systems at all times, and lastly, *(iii) integrity*, ensuring that data and systems are altered by only the authorized [8]. *Data de-identification* is the exclusion of personally identifiable information (PII) from a data set [9, 10]. *PII attributes* are properties that uniquely identify an individual; an example includes social security number. *Data utility versus privacy* is the concept of how beneficial a privatized dataset is to the user of that dataset. Achieving a balance between privacy and utility needs remains an intractable problem requiring trade-offs [11, 12, 13, 14].

III. LEARNING IN MULTI-AGENT SYSTEMS

Researchers have been fascinated by multi-agent learning for some time, and although a number of learning approaches have been proposed, in this paper we focus on two learning methods from literature to highlight the need for integration of data privacy principles in multi-agent learning systems. In an extensive review, Davies (1994) noted that Inductive Logic Programming (ILP) techniques were deployed as software agents for first order knowledge discovery in distributed databases [7]. Davies (1994) described how users are able to instruct a group of agents to discover information from particular databases. In general, a user presents an objective, and then the agents cooperate with other agents to accomplish this goal. Davis (1994) employed a combined approach with empirical first order inductive learning (inductive logic programming), data mining, and software multi-agent systems [7].

Moreover, Davies et al. (1995) explained in additional detail how agents learn in stages while discovering information in a distributed environment [15]: *First phase*: agents gather data in a centralized location. *Second phase*: agents interchange information while learning on resident data. *Third phase*: agents learn locally and then distribute results among fellow agents, after which the results are retuned and absorbed by other agents based on their own data and knowledge. Davies et al. (1995) categorized agents in a distributive environment as: *Non Distribution Agents*: agents learn from local training examples. *Incremental Theory Revision Agents*: agents learn a local theory from existing training examples, and then share the learnt theory to the next agent. *Simple Knowledge Integration Agents*: agents learn a local theory, get tested on the training examples, and after comparison of results, the agent with the best theory is chosen. *Theory Revision and Simple Knowledge Integration Agents*: multiple agents learn a local theory and distribute the learned local theories to all the other agents. At this point each local agent then revises the received theories to fit local data, after which the agent tests each theory with the local training set and chooses the best theory after comparison of results [15].

Support Vector Machines (SVM), Multi-agents, and Incremental Learning: A description of how SVM based agents learn was given by Caraga et al. (2002) in which SVM based incremental learning involves an agent working on a dataset D_1 to produce a group of support vectors SV_1, the results of SV_1 are then added to dataset D_2 to produce dataset D_2'; after, another SVM based learning agent processes dataset D_2' generating SV_2 results. The process continues, utilizing datasets D_1 and D_2, until a resulting classifier is learned, such that $D = D_1 \cup D_2$ [16]; where D_1 and D_2 are datasets, SV_1 and SV_2 are a group of produced support vectors. However, in their paper on the subject of SVM multi-agents and refuse data Ontanon et al. (2005) expounded on the cooperative learning of SVM multi-agents that utilized an ensemble effect for learning, by basically engaging in negotiating activities to improve individual agent and collective committee agent performance. Such agents have the capability of self-assessment and making decisions that some data used for learning is not needed [17]. Multi-agents situated in a distribution environment engage in communication and transaction of data and therefore questions of how such autonomous agents can learn by integrating data privacy and security principles remains a challenge.

IV. PRIVACY ISSUES IN MULTI-AGENT SYSTEMS

Privacy preserving architectures for multi-agent systems have been proposed but they mainly focus on access control rather than confidentiality. For instance, Cissee (2003) proposed a privacy preserving information filtering agent based architecture in which private or sensitive information was neither controlled by the user or provider of data gathering service but user and provider profiles could be shared between the two parties based on a trust relationship and thus filter any untrusted party [18]. In addition, Crepin et al., (2009) proposed specification for Hippocratic multi-agent systems in which each transaction of data requires a provider's consent, limited collection of data, limited use of data, limited disclosure of data, limited retention of data, safety, and openness of data transactions by the multi-agents [19]. Another instance of access control trade-offs was the proposal by Leaute et al. (2009) in which multi-agents employ constraint satisfaction techniques, often used in resource allocation problems, and might consider trade-offs of their privacy constraints and decisions in the privacy preservation process [20]. Also, Such et al. (2012), proposed a self-disclosure system in which autonomous agents make decisions whether to disclose personal attributes to other agents mirrored after human relationships in which cost benefits are considered before disclosing private information [21]. Challenges of privacy preservation in multi-agent systems still remain an open research problem. Such et al. (2012), observed that multi-agents are vulnerable to three information-related activities: *(i) information collection* in which agents collect and store data about an individual, *(ii) information processing* whereby agents modify data that has been collected, and finally *(iii) information dissemination*, whereby agents publish data [22].

Klusch et al. (2003) observed then that one of the major challenges with distributed data mining was the issue of autonomy and privacy of agents in a distributed environment [23]. Albashiri (2010) indicated yet another challenge that multi heterogeneous agent systems, have to specify suitable communication and interfacing protocols and must be decentralized with new agents connecting at will by adapting to the communication protocol [3]. However, Rashvand et al. (2010) showed that multi-agent security requirements might appear in three categories: *(i) service-agent protection*, in which agents are protected from external threats; *(ii) system vulnerability* protection, in which the platforms and agents are protected from insecure internal processes; lastly, *(iii) protective security services*, in which the main objective of an agent is to provide security [24].

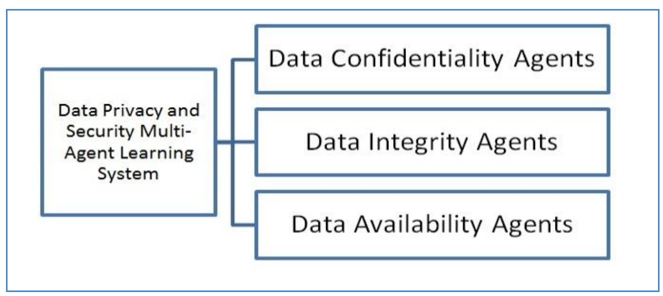

Figure 1. Conceptual Categories of Data Privacy Multi-agents.

On the issue of software engineering security requirements, Nagaraj (2012) indicated that security concerns such as, agent misbehavior (e.g., denial of service attacks), are still not taken into consideration while designing multi-agent systems and that if attempts are made, tackling such security issues in multi-agent systems tends to happen after the design phase [25]. Additionally, Martins et al., 2012) noted that for secure mobile agent communication, key security concerns of authentication, confidentiality, and integrity must be taken into consideration by multi-agents [26]. Krupa et al. (2012) suggested the utilization of 'Privacy Enforcing Norms' in which agents learn a set of acceptable privacy agent social behavior and when such Norms are violated, other fellow agents are notified and penalties to the offending agent are issued [27]. Lastly, Krupa (2012) observed that implementing privacy for multi-agents in a

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distributed system is still problematic and a challenge, whereby, *(i)* agents have to learn how to sense privacy violations; *(ii)* how such a multi-agent system can be managed without centralization to deter and halt confidentiality abuses; *(iii)* and the need to find flexible solutions to the inapplicability of most existing privacy enhancement methodologies [28].

V. An Architecture for Privacy Preserving Multi-agent Learning System

Observations from our literature review on privacy issues in multi-agents, show that a number of research challenges still exist, mainly, how to integrate privacy and security principles in multi-agent learning architectures. In our conceptual contribution, we suggest an organizational structure as shown in Figure 1, that categorizes privacy preserving multi-agents as: *(i) Confidentiality agents*, those that handle data concealment and privacy; *(ii) Integrity agents*, those that handle non repudiation in data transactions, ensuring that data is altered by only authorized agents; and lastly, *(iii) Availability agents*, these are agents that ensure that all other agents are available for communication and that their resources are available at all times, by preventing and reporting attempted denial of service attacks.

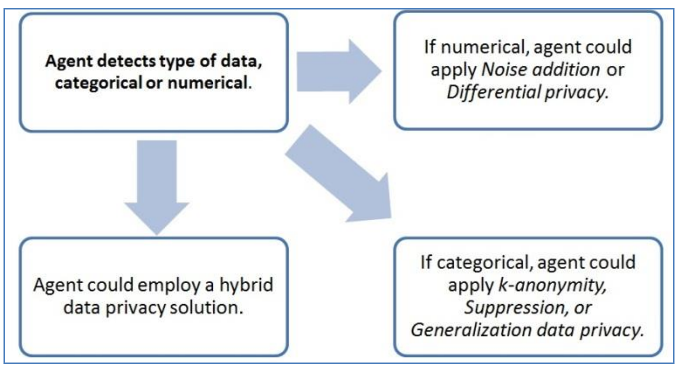

Figure 2. A data privacy procedure selecting autonomous agent.

In this way, the data privacy multi-agent system would conform to the three aspects of data privacy and security, that is, confidentiality, integrity, and availability. Communication between these multi-agents in the various levels of the architecture is a must. Secondly, we could have various data privacy roles under the specified major categories; for instance, since our focus in this paper is on data privacy preservation, under the Confidentiality category, we suggest *data privacy algorithm selector multi-agents* that would autonomously check what type of dataset that it is handling (categorical or numerical) as shown in Figure 2. If the data is numerical, then an agent applies *Noise addition* or *Differential privacy data privacy algorithms* [30]. If the data is categorical, the agent applies *k-anonymity algorithm, Suppression, or Generalization data privacy algorithms* [31, 32] on that dataset. Another agent could be employed for a hybrid solution. A different agent measures and reports on the data utility of the privatized dataset. Additionally, in this suggested framework, under the confidentiality multi-agent, we could have *privacy and utility trade-off agents* as shown in Figure 3. These agents would ensure the privacy and utility of privatized datasets, first, by outlining the various levels of parameters in the data privacy process.

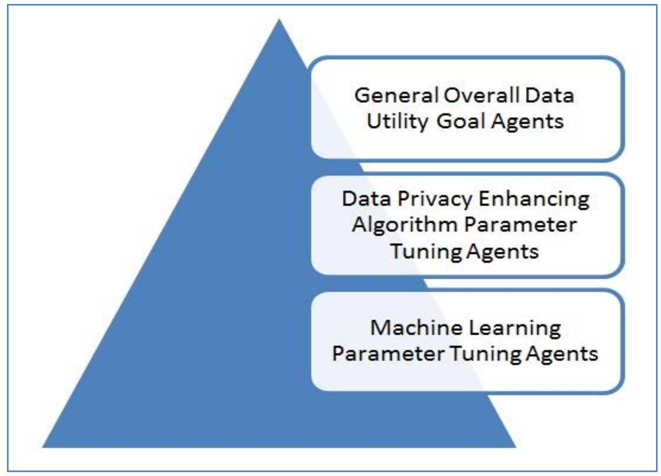

Figure 3. Hierarchical view of Parameter Tuning Agents

These agents could belong to different groups based on the parameters in the data privacy process as shown in Figure 4. *General overall data utility goal agents*: these would ensure that the general utility or the overall goal parameters like accuracy, currency, and completeness are attained [30].

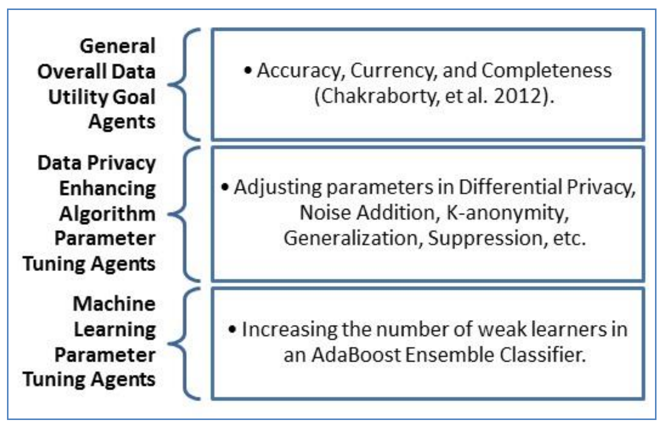

Figure 4. Functionalities of the various Parameter Tuning Agents

In this case, agents would ensure how accurate, how current, and how complete a privatized dataset ought to be. *The data privacy enhancing algorithm parameters tuning agents*: These agents would be responsible for autonomous adjustment and fine-tuning of parameters in the selected data privacy algorithm to ensure that not too much privacy is added while data utility diminishes. Finally, *the machine learning parameter tuning agents*: these agents would make adjustments to the parameters of the machine learner, such as increasing the number of weak learners. Even when multi-agents fully apply data privacy algorithms on data, the question of how such autonomous agents would have to learn to deal with the intractable problem of *privacy versus utility*, as illustrated in Figure 5; and how to make the trade-offs, remains open for further research.

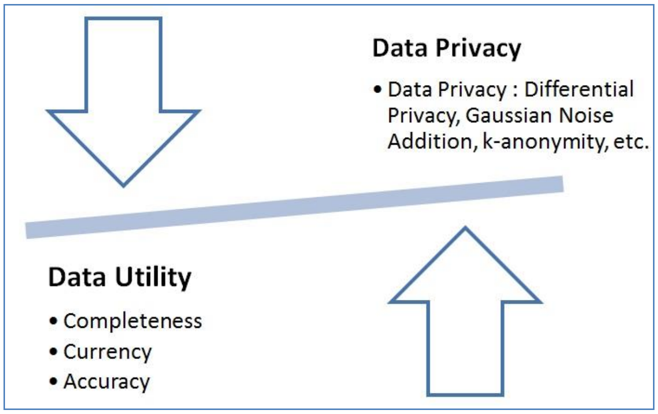

Figure 5. Trade-offs between privacy and utility are sought.

To illustrate this point, we added Differential privacy to a democratic political donation dataset, made public by the US Federal Election Commission and available online [33].

TABLE I. ORIGINAL DATA BEFORE AND SYTHETIC DATA AFTER PIVACY ENHANCEMENT

Original Data	Data after Differential Privacy
100	126.46
100	122.72
100	145.16
25	106.57
5	66.04
5	69.41
100	131.59
30	62.32
50	123.38
30	99.22

Our goal was to create a synthetic dataset that met the requirements of differential privacy so as to conceal donations made by individuals; and while that was possible our results showed that the privacy added was at the cost of data utility. For instance, as shown in Figure 6, someone who gave a donation of US $25 is reported in the privatized database as giving US $106.57. While concealment is provided, the utility of that data diminishes.

Therefore, finding the optimal balance between privacy and utility remains a challenge for multi-agents. How autonomous agents could be trained to learn to achieve to such optimality and make trade-offs in the privacy versus utility challenge remains an open question for further investigation.

VI. CONCLUSION

In this article, we have endeavored to give a preliminary overview on privacy preservation in multi-agent learning systems in a distributed data systems environment. Our review of multi-agent data privacy issues from literature shows that the intractable problem of privacy in distributed data mining and machine learning is still a challenge with questions such as how can multi-agents in a distributed environment keep their autonomy and ensure privacy of data without disclosure of sensitive and personal information. The need for intelligent multi-agents that can learn how to discern private and sensitive data, and ensure confidentiality while communicating with other agents remains a challenge.

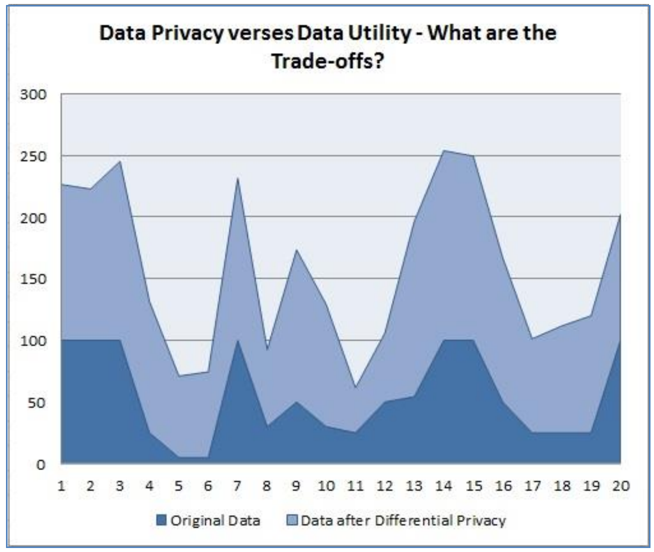

Figure 6. Trade-offs between privacy and utility are sought.

While a number of data privacy algorithms have been designed, it is important to note that they are not autonomous and do not act independently in a given environment, therefore the challenge is how to adapt such data privacy and utility algorithms for multi-agent systems. How agents can keep their autonomy, ensure privacy and confidentiality while at the same time adapting to various communication and interfacing protocols, remains a research question to be further pursued for various tailored privacy enhancing solutions. Research in data privacy enhancing algorithms is still a wide open area and applications of such data privacy algorithms in autonomous multi-agent systems still remains a challenge.

VII. FUTURE WORK

For future work, we plan to implement our conceptual privacy preserving multi-agent learning architecture, run simulation tests including automated software prototype, identify a data privacy and utility taxonomy for the prototype, and generate empirical results to map out the optimal balance between privacy and utility needs for various data privacy scenarios.

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Multi-agent System for Skills Sharing in Sustainable Development Projects

Olivier Chator
Conseil Général de la Gironde
IMS Laboratory, UMR 5218, ENSC/IPB
Bordeaux, France
o.chator@cg33.fr

Pierre-Alexandre Favier, Jean-Marc Salotti
Ecole Nationale Supérieure de Cognitique
IMS Laboratory, UMR 5218, ENSC/IPB
Bordeaux, France
pierre-alexandre.favier@ensc.fr, jean-marc.salotti@ensc.fr

***Abstract*— A local authority, the "Conseil Général de la Gironde" in France, works in the field of Sustainable Development and coordinates public and private partners. Sharing skills between them is one of the identified problems. Another difficulty is that nobody has a global vision of all know-hows of each partner. This work addresses these problems by building a collaborative multi-agent system called "sustainable development skills sharing". One of the innovations of this framework is that skills are represented as agents, not just as capabilities, as it is usually the case.**

Keywords-Multi-agent systems; sustainable development; skills; governance

I. INTRODUCTION

A local authority, the "Conseil Général de la Gironde" (CG33) is responsible for public actions for 1.5 million inhabitants. Numerous domains are concerned: school transportation, management of middle schools, tourism development, solidarity, integration and support for elderly people. One of the CG33 missions is to define policies and practices for the Sustainable Development (SD) of the department (a territorial division lower than regions). For example, the objective could be to transform a neighborhood into an eco-district [1]. Experience shows that this type of project is very complex and requires the collaboration of many public and private actors under the supervision and management of a "maître d'oeuvre" (MO), for instance an architectural firm. Each actor has only a partial knowledge of the capabilities of the other and some information is sometimes lacking, but the MO has to take decisions anyway. In addition, the objective is often to minimize the costs and to obtain energetic or ecological labels, which are typically antagonist objectives. For the MO, it is often difficult to understand the impact of each parameter. The preferred option is usually the one that is better understood at the expense of other options because there was insufficient knowledge on their impact, cost, and implementation. In order to help the actors, and especially the MO, to find the best partners, the CG33 decided to build a database of skills and actors. For example, it should be possible for a MO who wants to renovate some buildings to identify skills and actors in various domains such as thermal insulation, thermal simulation, air tightness, and installation of different types of photovoltaic panels on the roof. In turn, the partner who has an expertise in thermal insulation may require the help of another partner who is specialized in the use of specific insulation materials. Thus, the challenge is here to allow each stakeholder of an SD project to share and learn more about the expertise and know-how of the others.

A traditional approach could be to build a simple database with a direct link between actors and skills. However, considering the central role of skills and the needs for constant evolution and modifications of the data, a research project has been carried out in our laboratory to find and implement a better solution. It is suggested here that a multi-agent system (MAS) is more appropriate [2, 3, 12].

The model is described in Section II. The first results are shown in Section III and Section IV concludes this document.

II. MODEL

A. *Problematic*

Let us introduce the problematic with a concrete example of an SD project that aims to "transform a neighborhood into an eco-district". Let us assume that a MO has to build a HQE building. HQE stands for "Haute Qualité Environnementale" and is a standard for green building in France [13]. For this kind of project, the MO needs:

- A definition of the objective.
- Skills such as "integrating insulation materials" in order to meet the HQE objectives.
- Actors such as private building companies to implement the skills.

Using our "SD skill sharing" system, the MO should be able to identify a list of possible partners. Intuitively, we could think that this list could be simply sorted according to the most experimented partners for the given task. However, other criteria should be taken into account than just experience: price, quality, duration, localization, expertise with specific materials, etc. The system may suggest a partner according to this list of criteria. In addition, it also has to select different companies over time. The problem is to determine a good strategy to achieve that goal.

B. *Defining a Skill*

The skill is the ability to exploit some knowledge and know-hows in order to solve a class of problems. It is different from a competency, which is generally accepted as a set of behaviors or actions needed to successfully be

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performed within a particular context [4]. In this study, for the sake of simplicity, it is assumed that a skill is a sum of elementary competencies.

The main specifications of our application are to store information about the skills of possible participants to SD projects and to suggest interesting partners for a given skill. An important issue is to make the link between observations (e.g., “partner A has been assigned the role of task 1 and 2 in project X and succeeded in implementing solutions”) and skills, which do not correspond to the names of the task. Let us present an example:

Integrating glass wool for the insulation of northern walls in a specific building in a given project is related to the skill “integrating insulation materials”. However, integrating isolated wood panels under roofs might be very different from integrating glass wool in walls and the best expert for the first task might not be the best one for the second. The skills might be differentiated by small details, but, for the proposed application, it would be irrelevant. It is expected that the users of the application will ask general questions such as “who has skills in insulation materials”. The key problem is to find the appropriate level of details for each skill and to make the difference between an elementary competency that belongs to a skill and the skill itself. Then, assuming that a skill is defined at the right level and includes a list of possible elementary competencies, the question is to determine how each of them participates to the definition of the skill. For instance, for the skill “integrating insulation materials”, how important it is to have the know-how for isolated wood panels? In other words, there should be an associated weight for each elementary competency and there should be a mechanism integrated in the skill agent to learn them.

According to the needs of the project, a skill can be created at any moment, its definition (the list of elementary competencies) may evolve, it can eventually be split in different skills and it might even be removed. Such constraints cannot easily be handled in a standard database in which the actors and their skills would be stored. Because of the central role of the skills, it is suggested in this paper to consider the skills as agents of a multi-agent system. However, in most applications, agents are associated to models of actors in the real world, the skills defining the behavioral rules [2, 16]. The problem is that the skills have their own dynamics and are rather independent from the actors. The skills should be agents with their own life. In addition, if the skills and the actors are distinguished, it is difficult to define actors as other agents of the system. In cognitive science, the embodiment of mind is often considered a requirement to obtain an effective agent [9, 10, 11]. Skills alone have no perception, no motivation and no means to perform an action and change their environment. Nevertheless, it is possible to define these elements artificially. Intuitively, a skill can be motivated by the improvement of its own definition, e.g., a weighted list of elementary competencies and the clarification of its relationships with the other skills. The user of the system has another motivation: he wants to find a partner for his project. The system should provide some criteria and suggest an actor for the required skill. The user makes his choice, then the work is carried out (embodiment of the skill) and an evaluation of the realization is performed. The key idea is to consider that a criterion is no more than an abstraction of a hidden list of elementary competencies. For example, the duration of a work is not a competency. However, implicitly, it is closely related to the ability to work fast, which is an elementary competency of the skill. Therefore, the skill can exploit the definition of the criteria, which evolve according to the evolution of the projects, to characterize its definition. Another issue concerns the links between the skills. Different skills may have several elementary competencies in common. If no actor is found for a given skill, an interesting idea is to make suggestions with actors associated to the skills that are closely related.

In addition, a database is still required for the storage of past observations (e.g., Actor A has been involved in project X for the embodiment of skill S with an evaluation of a list of criteria $C_1..C_n$).

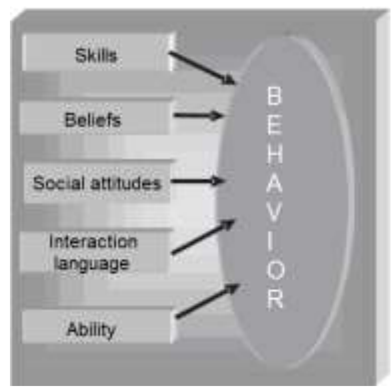

Figure 1. Agent's behavioural characteristics.

The details of our proposal are given in the next sections.

C. *Skill Agents: theoretical proposal*

It is assumed that a skill is unique and can be implemented as an agent in a multi-agent system. It has resources (a list of physical actors) and its own life cycle. It can be created, can evolve and eventually be removed when not used anymore or replaced by another skill agent. Skills agents fit in a multi-agent system, where the environment is defined by the interactions with the users. They are cognitive, non-conversational and non-dialogic [2, 12]. They never directly communicate with human users. They react and evolve according to information modifications and requests from the user via a WebRequester agent. An important feature is their ability to learn how to define themselves and how they are linked to the other skills. Skill agents are defined by three main parts: perception, internal attributes and actions:

- Perception: Skill agents are listening to information broadcasted by the system after interaction with the users. It can be, for instance, an update after external observations (e.g., a new project is started or the result of a work for a given project is inserted in the database) or a request is sent by another agent within the MAS.

- Internal attributes: A skill agent is determined by the list of elementary competencies that defines the skill, a creation date (appearance into the MAS), a domain(s) of activity and a specific "*age*" (see further).
- Action: If there is an update of an external observation that is linked to the skill, the agent updates its database and its weights according to a learning rule. It provides an answer to the WebRequester agent (which, in turn, informs the user) according to a strategy defined by behavioral rules.

D. Learning mechanisms

1) Actor selection

When the user asks the system to suggest an actor for a given skill, a list of criteria is presented to him with undetermined weights. For instance, if the user wants to know who has the best skill in "thermal insulation", the system asks the user to define the weight associated to each criterion "wall insulation", "roof insulation", "wood based materials", "diagnostic", "price", "duration", etc. This information is used to update the definition of the skill. Let $W_{1,t}..W_{n,t}$ be the list of weights associated to n criteria $C_1..C_n$ for request number t. The skill is defined by a weighted list of elementary competencies (the criteria). Let $E_1..E_n$ be the weights associated to them. They are calculated according to equation (1).

$$E_k = \frac{\sum_{i=1}^{t} W_{k,i} \quad i}{t} \qquad (1)$$

Once the request is correctly specified, the agent returns a sorted list of possible actors. The notation is based on the evaluation of the work after its realization. Let $A_{k,i}$ be the average evaluation of actor k for criterion i. For m actors, let $A_{1,1}$ .. $A_{m,n}$ be the past evaluations of the actors for each criterion associated to the skill. Each actor k is then evaluated for the new request according to equation (2).

$$Eval(k) = \frac{1}{\sum_{i=1}^{n} A_{k,i}} \sum_{j=1}^{n} A_{k,j} W_k \qquad (2)$$

The first term allows a normalization of the notation, such that an actor with systematic lower evaluations is not penalized. In any case, the user can still select an actor who is not at the top of the list.

2) Life cycle

Each skill agent has a "life cycle". It is divided into 3 states called "*ages*".

a) Childhood

The agent runs in a "learning" mode. During this age, the aim is to make the agent "grow". When an agent is created, a list of criteria is assigned to it. A list of actors is also associated to the agent but there is no evaluation in the database. If a user looks for a partner with this skill, the agent is not able to make relevant suggestions (childhood). It simply returns a list of potential actors ranked according to the number of times they have been involved in realizations (the most experimented at the end). Once the result of the work is available, the user evaluates the criteria associated to the skill and the data are stored in the database.

b) Teenage

When three evaluations are available in the database, the agent grows to the teenage age. If a user looks for a partner with this skill, the agent exploits the previous results to propose a list of actors sorted according to the criteria and their weights (equation (2)). If no data is available for an actor, default values are used.

The autonomy of the agent is rather limited. It communicates and tries to build relationships with other agents (see section II.D.3).

c) Mature

When the agent has accumulated sufficient knowledge (10 evaluations are available), it is able to make direct suggestions to the user as soon as a project is created. A list of skills is proposed with possible actors. Obviously, the user can still make modifications but he can save a lot of time if the choices correspond to his needs. In addition, the agent has a good knowledge of its relationships with the other agents (see next section).

3) Learning agent links

A user who is not experimented may not necessarily know all the skills that are required for the realization of a project. He can ask the system to help him by the suggestion of a list of skills that may be of interest. In order to provide a relevant answer, it is possible to exploit the links that can be found among the skill agents that are at least in the teenage age. The search is based on similarities. Different features are examined: the domain of activity, the number of common elementary competencies and the number of projects in which the same skills have been involved. For each skill agent and each feature, a "proximity coefficient" is calculated. The list of linked agents is then returned to the user for validation (or not). Importantly, when a skill agent is in the mature age, no human validation is needed. Thus, the agent is completely autonomous, generates links according to its existing behavioral rules.

III. IMPLEMENTATION AND RESULTS

A. Implementation: main points of interest

1) Architecture

The model has been implemented using the JADE MAS and standard multi-agent tools [5, 6, 7, 8].

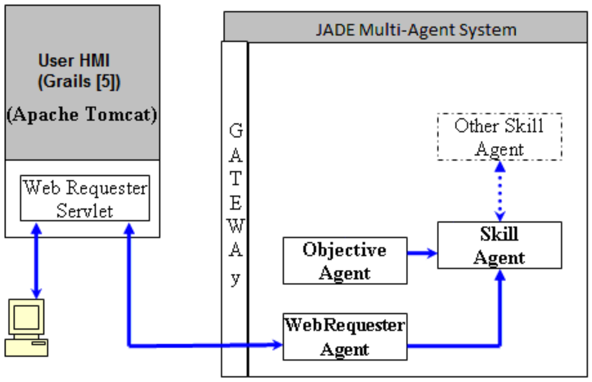

Figure 2. The MAS.

The main components of the MAS are presented in Figure 2:

- *User workstation*: exchange using a web browser.
- *WebRequester Servlet*: This java component is used for the management of the exchanges between human users and the MAS itself.
- *Gateway*: It is a standard component of a JADE MAS standard component allowing dialogues among agents operating within the SMA and external programs (WebRequester Servlet) [8].
- *WebRequester Agent*: This agent is in charge of the interactions with the human user, forwarding requests to skill agents and sending back their answers. It guarantees (FIPA compliance) that no direct exchange is possible between human users and skill agents.
- *Objective Agent*: According to Ferber's classification, the objective agent is reactive [2]. When a new project with a new objective is inserted within the system, information messages are broadcasted to all skill agents.
- *Skill Agents*: already presented.

2) *Behavioral rules*

The behavioral rules have been implemented in XML with a specific grammar (hierarchy, attributes, tags). See Table I for their description.

TABLE I. LIST OF THE BEHAVIORAL RULES

XML Tag	**Attribute**	**Manda-tory**	**Comment**
rules	description	X	Main tag
ruleGroup	description		Text describing the rule group
	weight		
rule	description	X	Text describing the rule
	weight		Weight of the rule in the rule group
	mandatory		Value is 1 if rule is mandatory, 0 otherwise
when	description		Text describing the condition
	sensor		Sensor java class name used to verify rule condition
	params		Parameters in format name=value, separated by | character. Passed to the sensor
	result		Result variable name beginning with $
	operator	X	Logical operator used within condition expression
	table		Table name from which we try to verify condition
	field		Table field name or variable name from which we try to verify condition
	value		Value of field attribute, expressed as a regular expression
otherwise			Used if **<when>** has not been verified
do	effector	X	Effector java class name to start if rule condition is verified
	description		Text describing the action
	params		Parameters in format name=value, separated by | character. Passed to the effector.
	result		Result variable name, beginning with $

3) *Skill agent memories*

Each skill agent owns a dedicated memory table in which it stores the incoming parameters and the related computed decisions. See Table II for a description of what is stored in memory.

TABLE II. MEMORY TABLE OF A SKILL

Field	**Type**	**Comment**
code	Long integer	Memory unique key code
ev_date	Date	Event date (record creation date)
evt_id	Long integer	Foreign key to event type table, describing the type of memorized event
agentid	Long integer	The current skill agent unique id
parametersin	String	Request parameters list in string format
decisionstring	String	Computed decision in string format
Humanvalidate	Boolean	Decision validated (or not) by human action
Comment	String	Free field

B. *Results*

In Gironde, 61 of the local authorities are part of an "SD Network", where they share experiences and skills. They started to use and test the system by the beginning of the year 2013. The experiment concerned the management of SD projects. A preliminary study has been carried out, showing that most projects fall into 9 domains of activity. These domains are: political wishes, sensitization, diagnostic, prospective, developing the strategy, elaborating the action plan, implementation of the action plan, evaluation, and

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continuous improvement. Skills are related to one or more domains. For instance:

- The skill "animation capability" is attached to the "political wishes" and "diagnostic" domains.
- The skill "identification and mobilization of expertise" is attached to the "prospective" domain.
- The skill "development of the sustainability report" is attached to the "continuous improvement" domain.

Currently, even if the experiment has just started, it is observed that the skills evolve in the system and provide answers. The positive point is that the skills provide valuable information to the actors who have poor understanding of the elementary competencies. The drawback, however, is that the initialization of the system is fastidious. The first definition of the skills requires a strong expertise of the domain. The updates can be done at any time, but it takes a long time to collaborate with experts in order to capitalize their knowledge and insert relevant skills and elementary competencies in the system. Therefore, it is difficult at the moment to conclude about the efficiency of our model because we are still in the early stages of the tests. We hope to present interesting results in a near future.

In order to demonstrate the versatility of our proposal, other tests have been performed using another functional domain: the selection of the best players for rugby. In this application, each player's position is considered a different skill. Elementary competencies are for instance the ability to tackle and stop an opponent or to be accurate in the shoot of the ball. The evaluation of a player for the embodiment of a given skill is based on his performance for each criterion and on the number of selections. When the system is asked to suggest a player for a given skill, equation (2) is used. Then the propositions elaborated by each skill agent are validated (or not) by the user, the players are evaluated and the database is updated. The results are positive for the identification of players over the different iterations.

C. Discussion

In most SMA applications, the skills are not agents. They are typically described by behavioral rules that determine the actions of the agents [16]. The difficulty is often to make the link between tacit and explicit knowledge and to learn from the real world [14, 15]. For instance, in other applications such as the management of skills in the context of e-learning, one of the main problems is to determine and explicit the tacit knowledge that has not been understood and to adapt the courses [14]. The advantage of our approach is that it is skill centered. The skills are learning agents and their motivation is to determine the list of elementary competencies that define themselves and their relationships with the other skills. These elementary competencies usually correspond to tacit knowledge and know-hows that cannot be easily defined. One of the key ideas of our model is to consider that the weighted list of criteria defined by the users to determine the best actor for a given skill are abstractions of a hidden list of elementary competencies. The system learns from the requests of the users.

IV. Conclusion and Future Work

A multi-agent system has been proposed for skills sharing between actors in collaborative projects in the domain of sustainable development. The key point of this work is the definition of skills as agents with their own rules for learning and evolving in an environment where actors are considered resources for the embodiment of the agents.

Several issues have been identified for future works. The current tests are preliminary. The system has to be tested with a comprehensive list of skills and elementary competencies provided by experts of the domain. A large number of evaluations is also required to test the evolution of the agents at different ages.

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A Model of Burden Sense from Psychophysical Factors in Lifting Action with and without Power Assist Device

Kosuke Takahashi, Takayuki Tanaka,
Hiroyuki Nara and Shun'ichi Kaneko
Graduate School of Information Science and Technology
Hokkaido University, Japan
e-mail: ktakahashi@ssc.ssi.ist.hokudai.ac.jp
ttanaka@ssi.ist.hokudai.ac.jp
nara@ssc.ssi.ist.hokudai.ac.jp
kaneko@ssi.ist.hokudai.ac.jp

Eiichi Yoshida
CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218/CRT
AIST, Japan
e-mail: e.yoshida@aist.go.jp

***Abstract*—In light of Japan's low birthrate and aging population, technology is needed for facilitating the activities of elderly persons as well as their caregivers. Wearable assist devices, such as the Smart Suit Lite (SSL) developed at our laboratory, are effective for this purpose. It is important to evaluate such devices from not only physical, but also from psychophysical perspectives. Experiments involving lifting a heavy object with and without SSL were conducted, and SSL was evaluated psychophysically. The muscle activity was measured by surface electromyography. The psychophysiological evaluation was conducted by using the visual analogue scale, in which reductions in load of 22.01% for muscles and 19.74% for the sense of lumbar load were confirmed. This report proposes the human load sense model based on the sense of weight and the amount of muscular activation. This model is expected to find application in humanoid robots for robust evaluation of power assist devices.**

Keywords-Human Sense Model; Burden Model; Power Assist; EMG.

I. INTRODUCTION

Support technology that facilitates daily operations is necessary for Japan's aging society. In addition to activities associated with caregiving and agricultural work, lifting of heavy objects in everyday activities undoubtedly applies a heavy burden on the low back[1][2].

At present, many researchers are focusing on power assist devices that can amplify muscle force or support movements. Among these, wearable power assist devices are attracting particular attention. Such wearable power assist devices can be categorized into active power assist devices with drives, such as Hybrid Assistive Limb (HAL) by Sankai[3] and a muscle suit by Kobayashi[4], and passive power assist devices, such as a suit-type back muscle supporter by Yamazaki[5] and an assist suit by Maeda[6]. Generally, active power assist devices with large force output necessary for several-fold amplification of forces applied by the wearer require power sources and many actuators, which makes them extremely heavy. In contrast, the main purpose of passive power assist devices without power sources is the reduction of the physical burden on the wearer rather than force amplification.

Figure 1. Smart Suit Lite

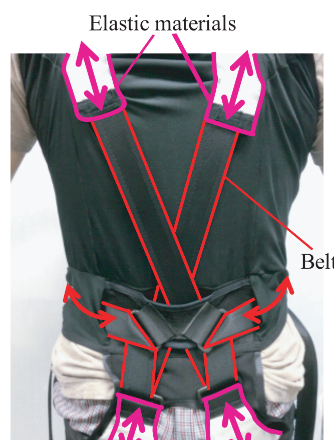


Figure 2. Appearance of elastic materials

We are developing a passive power assist supporter named "Smart Suit Lite (SSL)[7]" shown in Figure 1 for the purpose of preventing lumbar injuries. SSL is an assistive power suit made of elastic materials (rubber belts). It uses elastomeric forces generated when wearers change their posture to reduce burden in the lumbar region. The appearance of the elastic materials is shown at Figure 2.

The evaluation of such support devices is as important as their actual development. Related works evaluated the assist technology only physically. However this study evaluated SSL not only physically but also psychologically. It is important to evaluate from the both sides of the psychological and physical because these technologies are used by human. Inoue develops evaluation method based on physical and psychological burden in care[8]. In fact, evaluation by humans it is important to evaluate from the both sides of the psychological and physical. In this regard, SSL has been evaluated physically by humans[7]. Although its power assistance effect has been confirmed, its effect on the senses of the wearer should also be evaluated. Inspection of the psychophysical effect of such devices by humans is associated with difficulties in considering individual differences and the condition of the wearer on the day of the experiment. This is a disadvantage in comparison with related study evaluating only physically.

In a recent study, wearable assist devices were evaluated by humanoid robots[9]. In this approach, if the motor torque of the humanoid robot is assumed to be the same as the average torque of a human limb joint, the burden on a human limb joint can be estimated virtually by the value of motor torque of the humanoid robot. Humanoid robots thus make it possible to perform evaluations that are not influenced by individual differences and conditions. However, it is difficult for humanoid robots to evaluate the sense of burden. Thus, we considered that humans evaluate the sense of burden from some information, for example, the weight of the lifted object, the amount of muscle force and the motion trajectory. In this way, it is possible for humanoid robots to evaluate the sense of burden from equivalent values.

In this study, we inspected the physical and psychophysiological effects of wearing SSL and evaluated the human burden sense model in lifting a heavy object from the sense of weight and the amount of muscle force.

In this paper, first, we proposed the Human burden sense model. Next, The experiment of lifting with/without SSL was explained and the results were shown psychophysically. Finally, we considered the the Human burden sense model.

II. Human burden sense model

In this section, we suggest the human burden sense (HBS) model based on four following hypotheses.

- Hypothesis 1:
  First, we suppose that the HBS is expressed to the sense of weight and the amount of muscular activation. We consider that the sense of weight might not be constant for a given object weight in the lifting. The cases of lifting the same weight many times and becoming used to the weight, and the case of lifting a weight without prior weight lifting experience or information about the weight are different from the perspective of the sense of weight [10]. Therefore, using the sense of weight as a constitution parameter of the HBS model is suggested. In addition, we consider that the burden sense changes by the quantity of muscular strength.
- Hypothesis 2:
  We suppose that the HBS is proportional to the sense of weight and the amount of muscular activation, and expressed by those linear combination. We defined sense of weight as S_w, sense of lumbar burden as S_{lb}, muscular activity as E_l. The formula of the HBS model is

$$S_{lb} = \alpha S_w + \beta E_l + L_0 \qquad (1)$$

- Hypothesis 3:
  The coefficient α denotes the sensitivity with respect to the sense of weight, and the coefficient β denotes the sensitivity with respect to the amount of muscular activation. Even though S_w has 0, muscular activity is needed for lifting and S_{lb} has a minute value. The constant term L_0 is the adjustment term for it. We hypothesized that the sense of weight does not change when wearing SSL, and a person wearing SSL has the same sense of weight as when not wearing SSL. In addition, we hypothesized that the sense of lumbar burden in lifting with SSL is the same in value as lifting without SSL when the sense of weight and the amount of muscular activation have the same values as in the case of lifting without SSL. In other words, α, β and L_0 is formed independent of whether SSL is worn.
- Hypothesis 4:
  The sense of lumbar burden is considered to increase together with the increase in intensity of the sense of weight and the amount of muscular activation. Therefore, in the ideal model, α and β are as follows:

$$\alpha > 0, \beta > 0 \qquad (2)$$

Therefore we consider that the HBS model is expressed by formula(1) and satisfied formula(2). A value of E_l becomes small by wearing SSL, and the value of S_{lb} becomes small with it.

III. Lifting with/without SSL

We measured the amount of muscular activation to quantify the effects of SSL in terms of reduction in burden and the intensity of the sense of burden in lifting a heavy box. The subjects were 5 healthy men without past or present clinical history of musculoskeletal system injury. The number of subjects is small because it was a purpose to look at the validity of the experiment technique and the tendency of the model that hypothesized. Information about each subject is given in TABLE I. The details of the experiment were explained in advance to the subjects, and their consent to participate was obtained.

There are two main lifting movements. The first involves squatting, in which the knees are bent and subsequently extended as the person lifts the object. The second involves

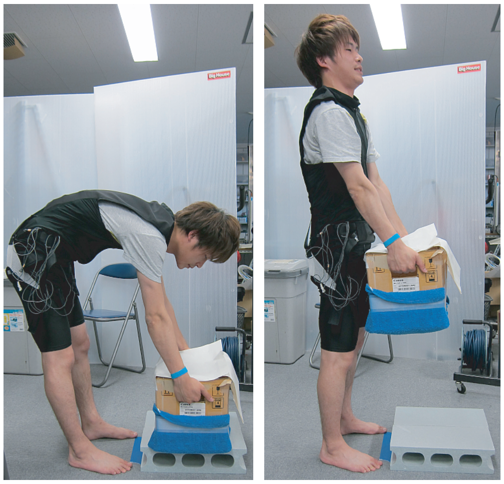


Figure 3. Lifting motion

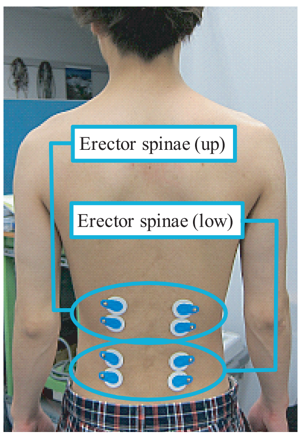


Figure 4. Sites measured by electromyography

stooping, in which the knees remain extended and the back is bent instead.

In this experiment, subjects were instructed to lift a heavy object from the stooping posture (Figure 3). Fujimura has reported that the maximal voluntary contraction (%MVC) of erector spinae in the stooping posture is larger than in the squatting posture in the lifting action[11]. The aim of this research was to examine the effect of wearing SSL on the low back; for this reason, we adopted the stooping posture for evaluating the burden on the erector spinae.

The center of gravity of a box (40 (W) × 25 (D) × 28 (H) cm) was situated at its geometrical center, and the handle of a heavy object was placed at a height of 32 cm above the ground. The subjects stood in front of the object, with their feet positioned such that the distance between them was the same as the distance between the shoulders. The weight of the box was changed in units of 5 kg between 15 and 25 kg,. The box was covered in order to prevent the subjects from estimating its weight from its contents (Figure 3).

The motion period of 8 s was controlled with a metronome. Each subject lifted each weight 4 times (for a total of 12 lifting motions) in random order. The experiment was conducted on 2 different days, where subjects lifted the box with SSL on one day and without SSL on the other. The second dynamic lifting session was conducted at least 2 days after the first session to allow for fatigue recovery.

TABLE I. SUBJECT DATA

Subject	Age	Height[cm]	Weight[kg]
A	23	181	78
B	25	165	57
C	23	166	58
D	22	172	60
E	23	164	62
Average	23.2	169.6	63.0
SD	1.10	7.09	8.60

The muscular electric potential at the erector spinae muscles was measured with a data logger (DL2000; S&ME Inc.) with a sampling period of 1 millisecond. The measuring sites are shown in Figure 4. The skin was prepared at each site by abrading the area with tissues soaked in alcohol. We measured the muscular activation from the time to start bending towards for lifting to the time to be in an upright stance after putting the object. In this research, average rectified values (ARVs) obtained by integrating by unit time the rectified waveforms in the electromyograms were taken as the amounts of muscular activation. ARVs were normalized by the 100%MVC method, in which the amount of muscular activation in certain aspects of the movement are represented by their ratios to the amount of muscular activation at MVC. Given that MVC represents in its own terms voluntary and static conditions, muscular activation during movements may sometimes exceed that at 100%MVC[12][13]. To calculate %MVC, the muscle action potential at the time of maximum voluntary contraction at erector spinae was measured for 5 s.

In terms of burden intensity, the sense of weight and the sense of lumbar burden were measured with the visual analogue scale (VAS) [14]. VAS is a simple and frequently used method for assessing variations in pain intensity. In clinical practice, the percentage of pain relief, assessed by VAS, is often considered as a measure of the efficacy of treatment. VAS is used widely as a tool for subjective evaluation and is not limited to the evaluation of pain. VAS is a line 10 cm in length with “no pain” at the left end and “worst pain imaginable” at the right end, and the subjects were instructed to rate the level of pain that they were currently experiencing. The intensity was measured for 4 subjects (A to D).

IV. MUSCLE BURDEN ASSISTANCE EFFECT

Figure 5 shows the average amount of muscular activation [%MVC] in lifting movement at the upper parts of erector spinae according to the lifted weight. The muscle burden assistance effect was evaluated by the total amount of muscular activation [%MVC] in the lifting movement. The amount of

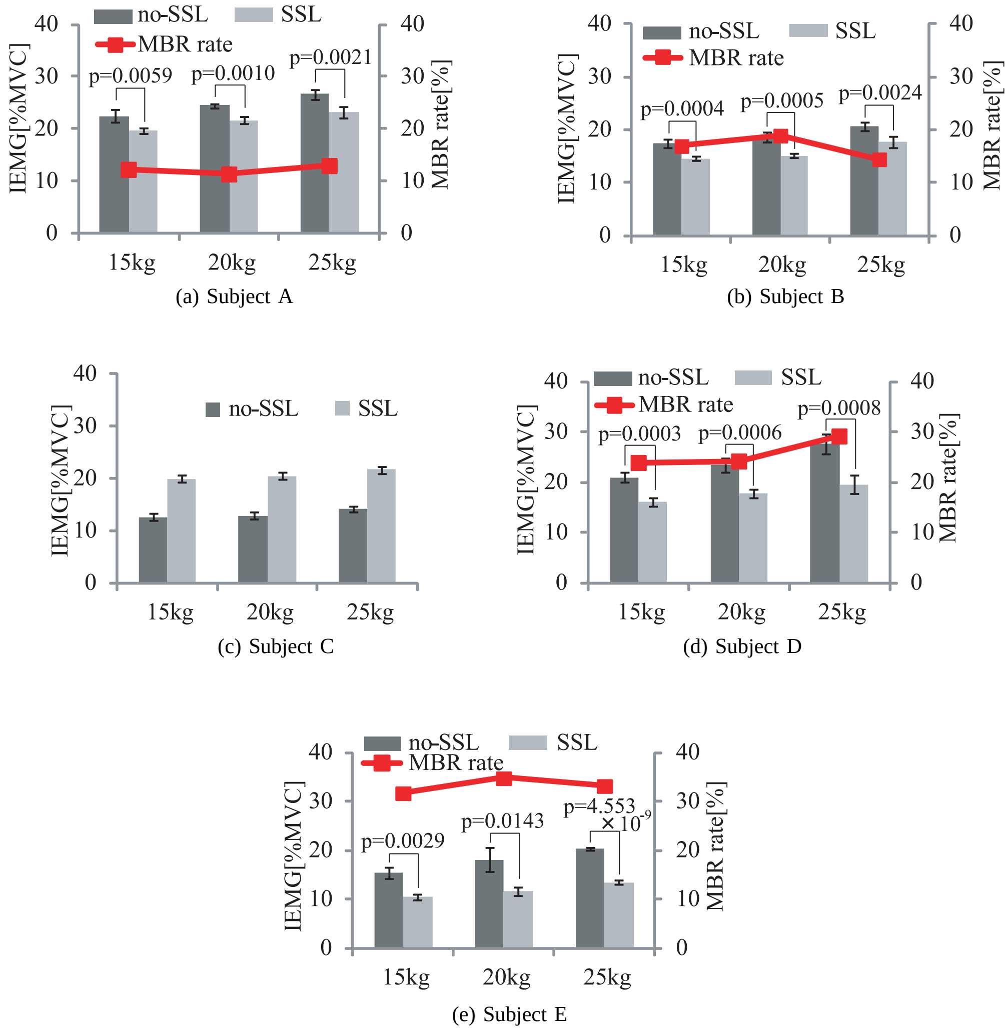


Figure 5. IEMG of erector spinae (upper part)

muscular activation in all subjects increased depending on the weight of the object.

In 4 of 5 subjects, the amount of muscular activation in the case of wearing SSL was lower than that in the case of not wearing SSL (no-SSL). Such effect was not seen in subject C. As described below, the amount of muscular activation decreased in the lower erector spinae for subject C. We consider that subject C changed the lifting motion because of SSL, and therefore the muscles used for lifting changed.

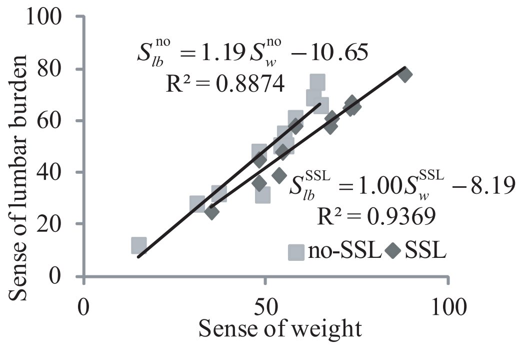
The muscular burden reduction (MBR) rate η was defined using the following equation for the evaluation function of the assistive effect.

$$\eta = \left(1 - \frac{\int_0^T V_{\mathrm{EMG}} dt}{\int_0^T V_{\mathrm{EMG0}} dt}\right) \times 100 \tag{3}$$

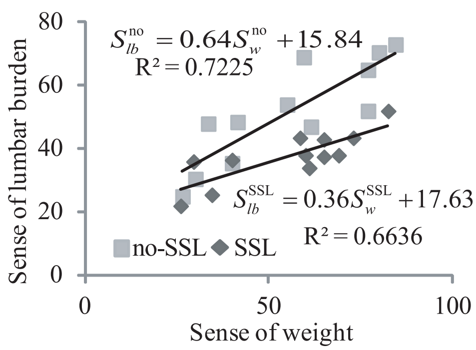
V_{EMG0} denotes the normal amount of muscular activation and V_{EMG} denotes the amount of muscular activation with assistive power provided by SSL, both of which are integrated by the motion period T. This represents the rate of reduction in the amount of muscular activation due to assistive power from SSL. In the 4 subjects whose respective amounts of muscular activation decreased. The analysis was performed t-test and each p-value was shown in Figure 5(a), 5(b), 5(d), and 5(e). Except only one result, p-values were lower than 0.01. Therefore significant difference was shown.

TABLE II. MBR RATE

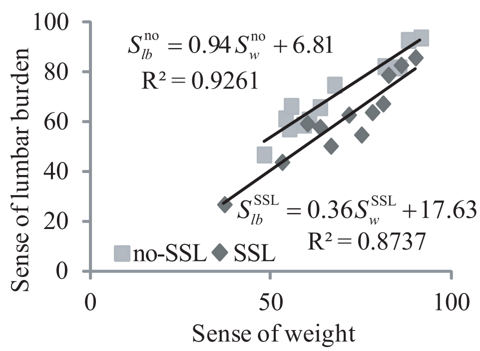
Subject	η[%]
A	12.16
B	16.78
D	25.73
E	33.37
Average	22.01



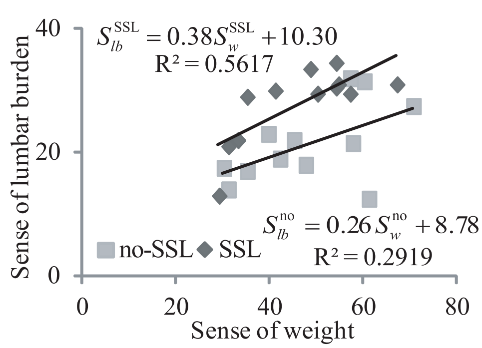
(a) Subject A



(b) Subject B



(c) Subject C



(d) Subject D

Figure 6. Sense of weight and sense of lumbar burden

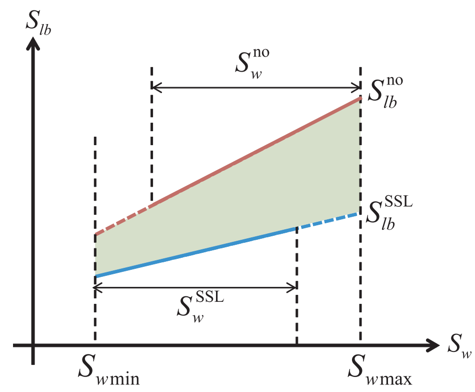


Figure 7. Interval of integration for calculating the MBR rate

TABLE III. SBR RATE

Subject	ς[%]
A	13.92
B	27.10
C	18.21
D	(-34.45)
Average	19.74

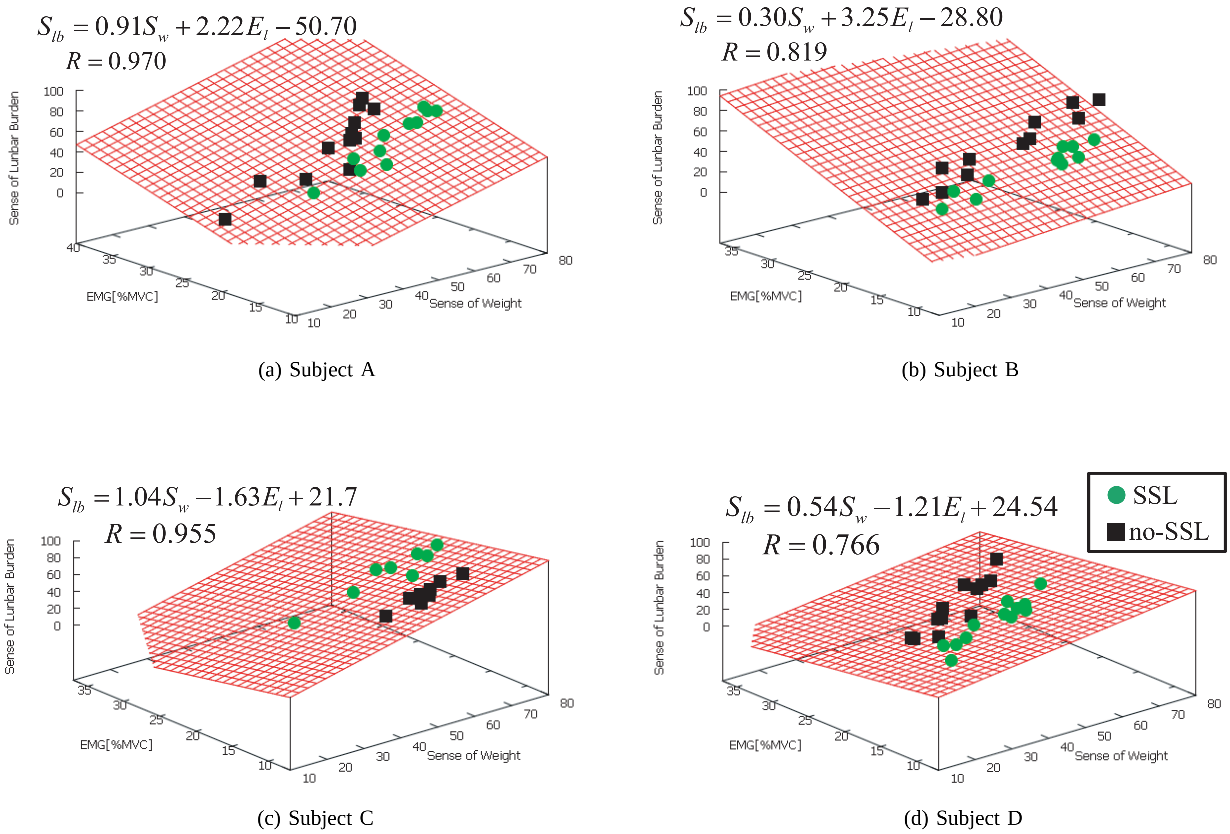
The MBR rates were calculated by fomula(3) according to the weight of object and shown as line graphs in Figure 5(a), 5(b), 5(d), and 5(e).

There was no correlation between the change in MBR rate and the lifted weight in the case of 4 subjects. Thus, we calculated the MBR rates for those 4 subjects by disregarding the lifted weight. The results are shown in TABLE II. According to the results, the average assistance rate at the erector spinae muscles in 4 subjects was 22.01%, and the amounts of activation of the erector spinae muscles subject to assistive power by SSL decreased accordingly.

V. SENSE OF LUMBAR BURDEN ASSISTANCE EFFECT

We measured the intensity of burden as the distance from the left edge in VAS to the line indicated by the subjects. The subjects were instructed to use VAS to score their evaluation of the burden on the low back as well as the entire body. At the same time, the subjects were also instructed to use VAS to estimate the weight of the object they lifted. An evaluation of the sense of lumbar burden was performed in terms of the relationship between lifting with SSL (With SSL) and without SSL (no-SSL). The relationship between sense of weight and sense of lumbar burden is shown in Figure 6. The horizontal axis denotes the sense of weight, and the vertical axis shows the sense of lumbar burden.

The relationship is derived from a regression formula that approximates the relationship between the two parameters by the least squares method depending on whether SSL is worn. S_w^{SSL} was bounded by S_w when the subject performed lifting with SSL, and S_w^{no} was bounded by S_w when the subject performed lifting without SSL. When we considered the range $S_{w\max}$ to $S_{w\min}$ (Figure 7), $S_w \leftarrow S_w^{\mathrm{SSL}} \cup S_w^{\mathrm{no}}$,



(a) Subject A (b) Subject B

(c) Subject C (d) Subject D

Figure 8. Burden sense model

S_{lb}^{SSL} show small values compared to S_{lb}^{no} in 3 of 4 subjects. From this result, it can be concluded that subjects felt a burden reduction effect by wearing SSL. We defined the sense burden reduction (SBR) rate ς as in formula (4) and calculated it for these 3 subjects.

$$\varsigma = \left(1 - \frac{\int_{S_{w\min}}^{S_{w\max}} S_{lb}^{\mathrm{SSL}}(S_w)dS_w}{\int_{S_{w\min}}^{S_{w\max}} S_{lb}^{\mathrm{no}}(S_w)dS_w}\right) \times 100 \qquad (4)$$

The results are shown in TABLE III. The average of ς for 3 subjects was 19.74%. Therefore, SSL could have the effect of reducing the sense of lumbar burden, similarly to the case of muscles.

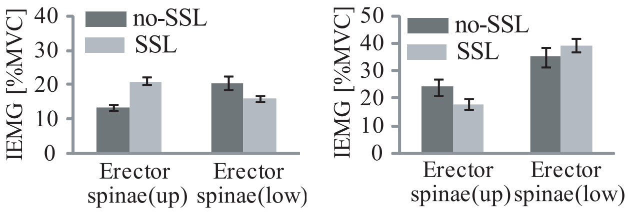
VI. Result of Human burden sense model

We inspected an effect of SSL from both physical and psychophysical points of view in Sections IV and V. We combine these perspectives in this section and consider the human burden sense (HBS) model from a psychophysical perspective. The results indicated that the amount of muscular activation decreased, and that the sense of lumbar burden decreased substantially through the use of SSL. The feeling of reduced burden due to the decreased amount of muscular activation is natural. Therefore, we concluded that the sense of burden in lifting depended on the amount of muscular activation and the weight of the lifted object.

We modeled HBS of each subject by formula(1) based on the least squares method using the sense of weight and the amounts of muscular activation not depending on whether SSL is worn. The results are shown in Figure 8 as aspect graphs. The multiple correlation coefficient is larger than 0.7 for all subjects. This value is sufficient for explaining the HBS from the sense of weight and the amount of muscular activation.

As a result, 2 of 4 subjects (A and B) satisfied the condition of the ideal model (formula(2)). We discuss the results for these 2 subjects who did not satisfy the conditions of the ideal model.

i) Subject C : We failed to obtain an ideal model for this subject, where β had a negative value. The sense of lumbar burden for subject C decreased when SSL was worn (Figure 6(c)). However, the amount of muscular activation of subject C increased in the upper parts and decreased in the lower parts of erector spinae (Figure 9(a)). The reason for this result was considered to be the change in the way muscles



(a) subject C (b) subject D

Figure 9. IEMG of erector spinae (upper and lower parts)

are used when wearing SSL.
ii) Subject D: We failed to obtain an ideal model for subject D as well, where β had a negative value. The amount of muscular activation for subject D decreased in the upper parts and increased in the lower parts of erector spinae (Figure 9(b)). We considered that subject D felt a more intense sense of lumbar burden with SSL than without SSL because of the increased amount of muscular activation in the lower parts of the muscles.

VII. Conclusion

The effect of wearing SSL when lifting a heavy object was examined, whereby it provided assistance amounting to an average of 22.01% of the force effected at erector spinae muscles. In addition, a reduction of an average of 19.74% in terms of the sense of burden was confirmed by using VAS. The burden reduction effect has been confirmed from the points of view of both muscular activity and subjective evaluation. In addition, the human burden sense model was formulated by using the sense of weight and the amount of muscular activation [%MVC]. The sense of lumbar burden was consequently expressed by a single formula not depending on whether SSL was worn. Only two subjects satisfied this ideal model. The amount of muscular activation in humans is considered to correspond to motor torque of in robots, and the sense of weight in humans is considered to correspond to the output of distortion sensors attached to the end effectors of robots. These correspondences show the possibility of applying the human burden sense model to robots and realize the evaluation by robots. Therefore, this study leads to the realization of the robust evaluation for assist technology.

Acknowledgment

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P300 Brain-Computer Interface Performance:

A dry electrode study

Arnau Espinosa, Guenter Edlinger
g.tec medical engineering GmbH
Schiedlberg, Austria
espinosa@gtec.at, edlinger@gtec.at

Christoph Guger
g.tec Guger Technologies OG
Graz, Austria
guger@gtec.at

***Abstract*— Most brain-computer interfaces (BCI) are based on one of three types of electroencephalogram (EEG) signals: P300s, steady-state visually evoked potentials (SSVEP), and event-related desynchronization (ERD). EEG is typically recorded non-invasively using active or passive electrodes mounted on the human scalp. The common setup requires conductive electrode gel to get the best entrance impedance and noise ratio. However, electrode gel is inconvenient, uncomfortable, and entails setting problems that are especially pronounced when trained users are not available. Some work has introduced dry electrode systems that do not require gel, but often entail reduced comfort and signal quality. The principal goal of this study was to compare the performance of dry vs. gel-based electrodes in a very common BCI system: P300 spelling.**

Keywords- Brain Computer Interface; BCI; Dry electrodes; P300 speller;Gel electrodes.

I. INTRODUCTION PER CERT

BRAIN - Computer Interfaces (BCIs) allow new communication channels based on different mental states. In a typical BCI, a user performs voluntary mental tasks that each produce distinct patterns of electrical activity in the electroencephalogram (EEG). Using monitoring systems and on-line signal processing software, it is possible to identify which mental tasks a user performed at a specific time. Most modern BCIs rely on one of three types of mental tasks, which are associated with different types of brain activity:

- Imagined movement, which produces event-related desynchronization (ERD) [1] and [2];
- Attention to oscillating visual stimuli, which produces steady-state visually evoked potentials (SSVEP) [3];
- Attention to transient stimuli, which produces the P300 event-related potential [4], [5] and [6].

Noninvasive BCIs are hampered by the need for conductive gel to get a good contact between electrodes and the user's scalp. The gel is uncomfortable to many subjects, and must be washed out of the cap and hair after each use. This procedure increases the time and inconvenience needed for each EEG recording session. Also, after a few hours, the gel dries and new gel has to be applied [7]. These problems reduce the appeal of EEG-based technologies to most users, and can be especially pronounced for severely disabled users – even though these are the people who need BCIs most.

Numerous articles that survey different end users have further confirmed that dry electrodes are a very high priority. Casson [8] surveyed neurologists and found that almost 90% agreed there is a clinical need for "wearable electrodes". Huggins [9] surveyed 61 ALS patients and found one of their main concerns was "set-up simplicity". Zickler [10] surveyed severely disabled users and found that major issues included "possibility of independent use" and "easiness of use". Blain [11] presented a focus group study with 8 ALS patients and 9 carers. One of their main concerns was a more convenient way to sense brain signals.

However, early dry electrodes had various problems, including reduced signal quality, inadequate robustness to movement, electrical artifacts, cost, and comfort. A second generation of dry electrodes based on an active system is used to study the difference in signal quality and robustness against artifacts.

In the following sections, we will first introduce the system components of the IntendiX P300 speller software; describe its characteristics and the workflow of our experiment. Then, we will provide our results comparing dry and gel electrodes obtained from 23 patients.

II. METHODS

A. Experimental procedure

23 subjects (6 female, age: 22-60) participated in the study. All subjects were free of medication, had normal vision, and no history of central nervous system abnormalities. Subjects sat in front of a laptop computer.

The laptop used the intendiX row/column (RC) speller shown in Figure 1. The RC speller presented 50 characters (the 26 letters of the English alphabet, integers from 0 to 9, and 14 special characters). Subjects were instructed to mentally count each time a target character flashed while ignoring other flashes. Subjects were first asked to spell the word "WATER" for calibration and then spell the word "LUCAS" (only the accuracy results of spell "LUCAS" are reported in this paper). The system randomly highlights one column or row for 100 ms, followed by a 60 ms dark time

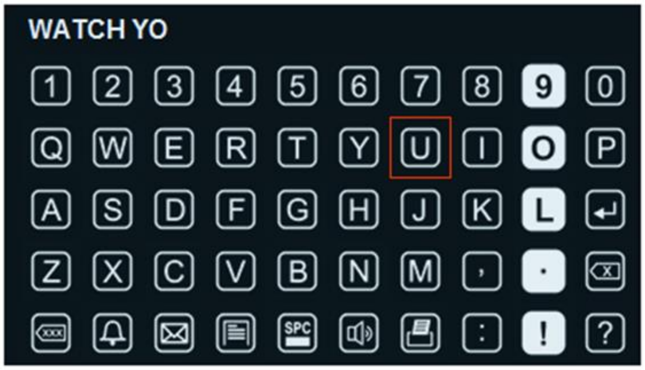

Figure 1. The intendiX spelling matrix. The phrase “WATCH YO” is feedback from the subject’s spelling. The target letter “U” is indicated by a red box.

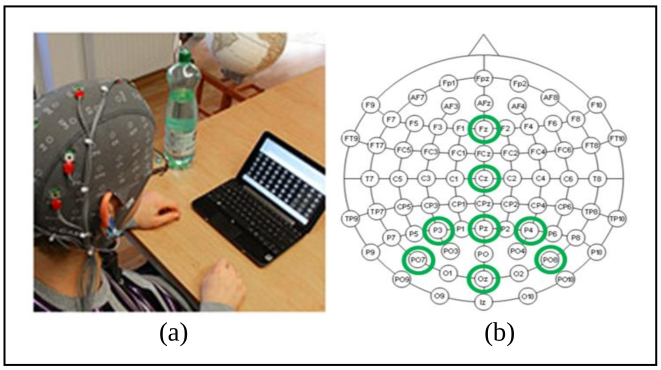

Figure 2. Left panel (a) shows a subject using the system with active g.BUTTERfly electrodes. The right panel (b) shows the electrode montage used with both gel and dry electrodes. The ground is on the left mastoid, and the reference is on the right mastoid.

between these flashes. Each row and column was highlighted 15 times for each letter, resulting in 225 flashes per trial, and 1125 flashes for a five-letter word. Signal processing software extracts ERPs (100ms to 700ms) after each flash and uses linear discriminant analysis (LDA) to classifier the most important P300 response. The intendiX system then presents the target character on the monitor, and the highlighting restarts so the user can spell the next letter.

P300 BCIs are relatively fast. The first BCI to exceed 100 bits/min was shown by P. Brunner in 2011 [12].

B. *Hardware and software*

IntendiX P300 software (from g.tec medical engineering GmbH, Austria) provides a full personal EEG-based spelling system. This application generates the visual simulation, calculates the parameters for the classification and processes the data to extract a target character.

Figure 2 shows the electrode configuration for the P300 speller. The EEG were acquired using a g.USBamp (24 Bit biosignal amplification unit from g.tec medical engineering GmbH, Austria) with a sampling frequency of 256 Hz. EEG electrodes were placed using the international 10/20 electrode system. EEG recordings based on gel electrodes

TABLE I. ACCURACY COMPARISON

Row-Column Speller accuracy (%)	Gel electrodes (N=81) [4]	Dry electrodes (N=23)
100	72.8 %	69.6 %
80-100	88.9 %	87.0 %
60-79	6.2 %	8.7 %
40-59	3.7 %	4.4 %
20-39	0.0 %	0.0 %
0-19	0.0 %	0.0 %
Average Accuracy of all subjects	91.0 %	90.4 %

a.Table I summarizes subjects’ accuracy for gel electrodes in an earlier study [4] and dry electrodes in the present study.

were conducted with active g.BUTTERfly electrodes (golden ring electrode type with a hole in the middle to inject the gel);EEG recordings based on dry electrodes instead used active g.SAHARA electrodes (8 gold-coated pins with 7 mm length mounted in a circular arrangement, diameter 15 mm) [13].

III. RESULTS

No significant differences were found between gel and dry electrodes. The raw data look similar for both electrode types, including the noise created by eye blink artifacts and some high frequency activity.

An accurate study of the evoked potentials shows that, in both cases, the evoked potential (EP) reaches its maximum of about 6 µV after about 340ms.

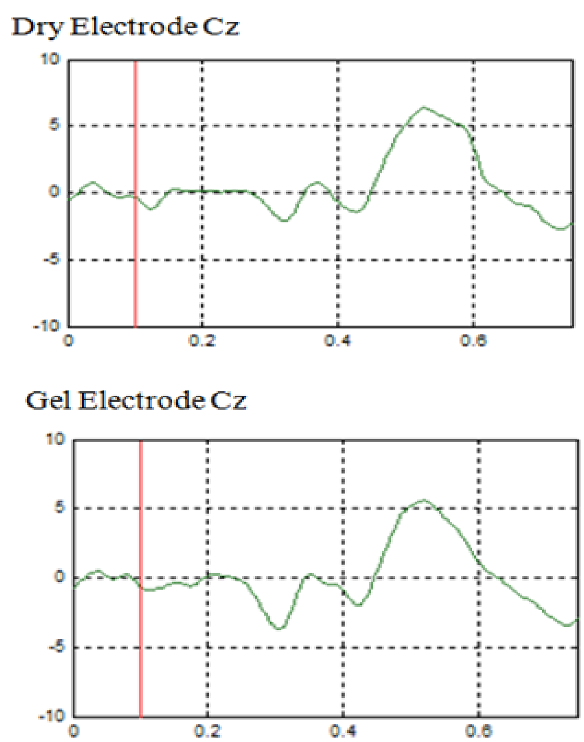

Figure 3. P300 response for dry and gel electrodes. The y-axis is acaled with +/-10 µV, with the x-axis in seconds.

The EP looks very similar for the dry and gel based electrodes; see Figure 3. This figure shows the P300 response for dry and gel electrodes in the copy spelling run of 1 subject. Each run had 5 characters flashed 30 times, 15 rows and 15 columns. The comparison of the training and copy spelling run shows that the EP is very stable over time.

Table I summarizes the BCI performance results. One column presents the results with dry electrodes from the present study. Another column summarizes gel electrodes from a large group study with gel based electrodes (N=81) [4]. N specifies the number of subjects summarized on each column.

IV. Discussion

We show that the used dry electrode sensor concept can be used for P300 based BCI systems. Dry electrodes do not use gel, resulting in higher skin impedance as well as greater comfort and convenience. The higher skin impedance can increase vulnerability to artifacts below 3 Hz.

To test the usefulness of dry electrodes for the P300 BCI we conducted a group study with 23 subjects, and compared the EPs (for 1 subject) and accuracies (for all subjects). The latencies and amplitudes of the P300 appeared to be similar for dry and gel based electrodes.

In this case, dry electrodes require about the same setup time as gel electrodes. P300 active electrodes can be mounted in about 3 minutes, and dry electrodes require about 1 minute or below. However, after the cap is mounted, dry electrodes need a few minutes to adjust, and therefore the preparation time is comparable to active electrodes.

The biggest advantage of dry electrodes is that no abrasive and conductive gel remains in the hair. Therefore, the time consuming cleaning of patient’s hair is avoided. Another big advantage is that the electrodes do not get in contact with water for cleaning and therefore the lifetime is enhanced. None of the subjects reported discomfort from the dry electrodes.

V. Conclusion

The results of the study have important consequences. Dry electrodes speed up the cap mounting process, enhance user acceptance, increase the possible recording time, and therefore bring the technology closer to many people. Although the dry electrodes show higher signal power below 3 Hz resulting from low frequency drifts, we did successfully show that the P300 speller works.

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The Cerebellum in the Ouroboros Model, the “Interpolator Hypothesis”

Knud Thomsen
Paul Scherrer Institut
PSI, NUM, ASQ
CH-5232 Villigen, Switzerland
knud.thomsen@psi.ch

***Abstract*—The Ouroboros Model offers a novel cognitive architecture with an algorithmic backbone of iterative and self-referential processing. All memory content is organized into meaningful pieces of data, chunks and schemata, which are laid down as a kind of snapshots of all activations at a relevant point in time. This entails a grainy structure of memory content. Whereas a core process of "consumption" analysis can naturally be defined taking advantage of this parcellation, it necessitates interpolation for fine nuances, especially for the representation of intermediate values during transients. It is hypothesized that, in the vertebrate brain, essential interpolation functionality is provided by the cerebellum. Findings concerning movement control as well as the involvement of the cerebellum in more abstract, cognitive, tasks can be interpreted as reflecting a function of the cerebellum as a co-processor, i.e., a general interpolator, boosting representations in cerebral cortex areas, which are reciprocally connected with cerebellar cortex areas. In this paper, it is sketched how the new "interpolator hypothesis" can explain manifold observations while embracing previous theories of the function of the cerebellum.**

Keywords - schemata; consumption analysis; iterative processing; grainy memory structure; interpolation; co-processor

I. INTRODUCTION

Strikingly diverse proposals have been made concerning the function of the cerebellum, and, so far, no consensus has been reached. Here, a novel functional account is proposed, which addresses a general need for interpolation and seems to allow to reconcile many of the previous concepts.

The paper is structured as follows. Sections II and III provide a short summary of key tenets of the Ouroboros Model. Motivation for an interpolation function and the “interpolator hypothesis” are formulated in Section IV. Hints from actual brains are presented in Section V. The relation to existing conceptions is clarified in Section VI, and one particular example supporting the interpolator hypothesis relating to motor control is described. Conclusions and future work are outlined in Section VII.

II. THE OUROBOROS MODEL IN A NUTSHELL

In a series of recent papers, the Ouroboros Model has been introduced as a novel attempt at explaining a wide range of findings pertaining to cognition and consciousness of natural and also of artificial agents [1-5]. It has been suggested how, within a single approach centered around a principal algorithmic process on a suitably structured memory, one can explain human cognitive performance and also formulate prescriptions of how to achieve comparable capabilities with artificial agents implemented in hard- or software, all iteratively and recursively following a similar self-steered evolutionary program.

Minds are seen as primarily data processing entities; an iterative and self-referential universal algorithmic layout on the basis of suitably stored data structures is essential [1,2].

A. Action and Memory Structure

The Ouroboros Model sees memory entries as effectively organized into (non-strict) hierarchies of schemata. Memory is made up of meaningful chunks, i.e., combinations of features and concepts belonging together [4]. In living brains, neural assemblies are permanently linked together when once co-activated in the right manner. Later re-activation of any one of the linked features excites the entire schema. In particular, also currently missing features are biased and thus expectations are triggered.

B. Principal Algorithmic Backbone

At the core of the Ouroboros Model lies a self-referential recursive process with alternating phases of data-acquisition and -evaluation. A monitor process termed 'consumption analysis' is checking how well expectations triggered at one point in time fit with successive activations; these principal stages are identified:

- ... anticipation,
- action / perception,
- evaluation,
- anticipation, ...

These steps are concatenated into a full repeating circle, and the activity continues at its former end, like the old alchemists' tail-devouring serpent called the Ouroboros. Most importantly, there is no detrimental circularity involved if the succession of the processing steps in time is well taken into account: teeth and tail of the name-giving snake belong to well distinct points in time.

C. Consumption Analysis

Any occurring activation, such as sensory-related, excites the associated schemata. The one with the highest activation is selected first. Other schemata, which possibly are also applicable, are inhibited and their activation suppressed. Taking the first selected schema and ensuing anticipations active at that time as reference and basis, consumption analysis checks how successive activations fit into this activated frame structure, i.e., how well lower level input data are "consumed" by the chosen schema. Features are assigned / attributes are 'explained away' and inhibited for immediate reuse [6].

If everything fits perfectly, the process comes to a momentary partly standstill and continues with new input data. If discrepancies surface, they have a strong impact on the elicited actions that follow [2]. In case of severe mismatch, the first schema is altogether discarded and another, new, conceptual frame is tried. The actual appropriateness of a schema can vary over a wide range. In any case, consumption analysis delivers a gradual measure for the goodness of fit between expectations and actual inputs.

III. Concept Formation

Two special types of occasions are specifically marked in the Ouroboros Model as interesting by the outcome of the consumption analysis when attention is triggered leading to higher than baseline excitement and to stronger activations; preferentially for these cases, new entries are laid down quickly in (episodic) memory [4]:

- Events, when everything fits perfectly; i.e., associated neural representations are stored as kind of “snapshots” of all concurrent activity, making them available for guidance in the future as they have proved useful once.
- Constellations, which led to an impasse or problem, are worthwhile remembering, too; in this case, for future avoidance.

In addition:

- Associations and categorizations are gradually distilled from the statistics of co-occurrences.

Novel categories and concepts can also be assembled on the spot by combining (parts of) existing memory entries following an external trigger [2].

Just the same as old memories, new concepts are laid down in the form of cohesive packages, immediately effective again as schemata, frames or scripts. Building blocks include whatever representations are active at the time when such a snapshot is taken, including sensory signals, abstractions, previously laid down concepts encompassing features relating to probable transients and causal structure, and also prevalent emotions and longer lasting moods. They might, in some cases, but need not correspond to direct representation units like words. At subsequent occasions, they will serve for controlling behavior, by guiding action towards or away from the marked tracks, depending on the sign of the associated emotion value (which was originally itself distilled from consumption analysis [2]).

IV. Need for Interpolation

Some structure and parcellation of all memory content into well separated schemata most probably is dictated quite generally by the need to keep the total amount of stored data manageable. It is a consequence of the generation of many entries as snapshots and ad-hoc assemblies seen from the Ouroboros Model´s perspective. Even in the case when a schematic relation, e.g., representing a movement, is distilled from repeated similar activations, it is most probably laid down economically as distinct (end)points, and the complete transient in between is not stored in arbitrary detail.

While perfectly suited for a process like consumption analysis, a coarse-grained structure of memories poses a challenge when details finer than available in the form of local recordings are needed, and in particular, when smooth transients in time are demanded for whatever actions.

With a focus on time, it seems obvious that interpolation can significantly enhance cortical representation capabilities over what is possible with only unitary activity.

A. *Various time scales*

The transition between distinct and separated stepping stones, decisive for the overall coherence of activity according to the Ouroboros Model, is affected by diverse processes at different timescales and levels of detail.

Starting from extended timescales, emotions and moods ensure some coherence and continuity of perceptions and for the actions of an agent [2].

Over short to medium durations in the order of seconds, the flow of action according to the Ouroboros Model is mediated by shared constituents, i.e., common attributes and features, of thus concatenated, otherwise distinct, schemata.

Closer to the short-term limit of action, both for bodily movements and also for abstract cognitive processes, it is hypothesized that representations pertaining to intermediate values are calculated from more directly accessible neighboring reference points by means of some type of averaging and interpolation.

Remarkable, at the other end of the timescale again, given the intrinsic dynamic characteristics of neural action, generating some truly constant level is not completely trivial and appears to mandatorily require some form of averaging.

All timescales are addressed in the Ouroboros Model by schemata including explicitly dynamic features, which code for changes and transients. Their effective resolution will be enhanced by interpolation again.

B. *The interpolator hypothesis of the cerebellum*

The novel proposal here is that the cerebellum provides fine-grained values for features in between well established, separately and distinctly represented reference points, i.e., interpolations between cerebral activations, which specify directly available values in a coarser way.

The cerebellum is thus seen as a dedicated co-processor working in close interplay with the cerebral cortex, greatly expanding the total achievable resolution of representations in living brains.

V. Implementation in Vertebrate Brains

As a theory of human cognition, the Ouroboros Model at some point needs to demonstrate the correspondence of the proposed structures and processes with actual facts from real brains. This is work in progress; first proposals have been presented in indentifying the hippocampal structures as providing an efficient rapidly established index to more extensive and detailed content like memory entries, laid down in cerebral cortex [5].

A. Selected hints from anatomy and established findings

First, looking only at a very coarse level, the cerebellum grew in tight lockstep with the cerebral cortex in its evolutionary trajectory in mammals, probably generally in vertebrates [7, 8]. Over long times, the cerebellum did not change in its comparatively simple internal cytoarchitectonic structure in rather diverse animals.

A very uniform layout lead early to the suspicion that the cerebellum does one and the same operation to all input arriving there. Some gross correspondence between different areas in cortex and sectors of the cerebellum is observed but the detailed organization into areas is well distinct from what is found in cerebral cortex [9, 10]. Input routes and the output tracts appear to establish links in separated closed loops between delimited patches of cerebellar cortex and distinct areas of cerebral cortex; in detail, parts of the body are not represented continuously over an extended area of the cerebellar cortex. Instead, representations are fractured into small discontinuous patches in an apparently uncorrelated manner with diverse sensory and motor areas arranged in close neighborhood [9, 11].

Mossy fiber and Climbing fiber input pathways converge on the level of single Purkinje cells [12].

Signals carried by relatively small numbers of input and also output fibers are in between expanded enormously with granule cells being by far the most numerous neurons in the brain. They are the origin of very many parallel fibers. It has been argued earlier that this stark contrast in numbers allows for (internal) very fine-grained encoding (and pattern separation) [13]. There is considerable evidence that mossy fiber input codes are preserved in synaptic responses of granule cells; this "similar coding principle" works as an ideal noise-reducing filter allowing the transmission of weak sensory inputs in a graded fashion [14]. In the following, temporal aspects shall be emphasized in particular.

Purkinje cells are triggered in a differential way by either a vast number of inputs from parallel fibers piercing their extended dendritic trees (eliciting simple spikes), or, by a single climbing fiber (sparking complex spikes). The response of synapses on Purkinje cells to input from parallel fibers is reduced if this parallel fiber activation "predicts" climbing fiber activity for this cell, i.e., if the latter arrives 50 - 200 ms later [15]. Persistent long term depression of the involved connections ensues after repeated pairings [16].

B. Effecting Interpolation

Interpolation by the cerebellum is hypothesized as being performed between reference points, i.e., between somehow distinct representations in the cerebral cortex, which are temporarily related, overlap to some extent or are in close timely vicinity like constituents of an overarching schema. As a prototypical example benefitting from interpolation, one can take a reaching movement including a start- and an end point as a goal, see Figure 1.

It is assumed that interpolation first is performed in a feed forward manner by determining a shortest trajectory between supporting points in a high-dimensional space defined by the activated feature representations in cerebral cortex, following a principle of least action. The interpolated values are then relayed back to the same cortex areas.

The simplest case would be the determination of a representation for some finely distinguished nuances between the endpoints of a scale for a single (dynamic) variable. When many feature dimensions are involved, derived intermediate values would lie in a hyper plane.

According to the interpolator hypothesis, in the example of a straight movement, all effected activations for starting- and end point, required muscles, expected sensory feedback as well as usual duration are taken into account; dimensions specifying an abstract goal for actually performing the movement come in addition. All considered feature dimensions are contributing according to some weight.

In any case, the resulting trajectory in this high dimensional space is hypothesized to be derived according to a suitably implemented principle of least action.

There exist uniquely outstanding points, i.e., when a given reference-point and the result of the interpolation are exactly equal; the obvious case would be a correctly reached intermediate or end point of a trajectory.

VI. RELATIONS TO PREVALENT CONCEPTUALIZATIONS

While not following any of the numerous existing proposals concerning the computational functions of the cerebellum (to the best knowledge of the author), it seems that the above advanced “interpolator hypothesis” fits rather well with observations and the prevailing ideas [13, 16, 17].

Very sketchy still, a core proposal of the interpolator hypothesis is that the vast number of granule cells effectively leads to an only very smoothly changing excitatory input to the numerous contacted Purkinje cells, influenced by a huge number of each very finely graded and reliably coded dimensions. Based on this input, Purkinje cells can deliver very high action-potential firing rates, which are probably effective as rather constant values in the further processing.

Special action, as expected for the exact coincidence between any preset value and an interpolation result, is then postulated to be signaled by climbing fiber input to Purkinje cells. This triggers the Purkinje cell (complex spike) and shuts it off for some time interval immediately afterwards when no addition or correction is required. The timing of the process could fit nicely if suitable anticipated values were effective at the outset; climbing fiber feedback activation via the inferior olive will arrive with a delay compared to the parallel fiber input.

Purkinje cells, in turn, provide the such calculated interpolated values via deep cerebellar nuclei to the same cortex areas which first prompted the interpolation operation.

Climbing fiber activation would thus be a confirmation signal rather than an error signal. As has been pointed out, “error” and “learning” do not make immediate sense if connections between identical features are affected [12].

Learning would be different in different phases; for system “set-up” during maturation, or, after a massive change, pronounced long term adaptations can be expected. In contrast, during "normal operations" no large persistent modifications in the cerebellum seem to be required. This matches with the experimental fact that genetically engineered mice exhibit normal motor learning in the absence of long term depression, LTD, at the parallel fiber - Purkinje cell synapse [18]. Consequently, learning, which takes place involving cerebellar activation, might mainly be implemented in the connected cerebral cortex areas [19, 20].

For body movements, also when only imagined, distinct postures are separated by a time interval, dictated by basic physics; it is therefore clear that a failure to follow a smooth path between them can be interpreted as a timing problem. Timing has been postulated as a main function of the cerebellum [21, 22].

Disturbances in postural tone and smooth movement were historically among the first deficiencies associated with cerebellar dysfunction [23]. Complex movements have been described as being broken down into components.

Figure 1 depicts a comparison between healthy control subjects (traces a) and c)) and patients with cerebellar damage (traces b) and d)). Moving, e.g., a finger from one point in space (A) to a prescribed goal (B), a healthy subject draws a straight line, whereas patients with a lesioned cerebellum produce wiggly trajectories (A' to B'), bearing witness to struggling for control and fine tuning. Comparing traces c) and d), latency after a go-signal in one and the same patient is higher for the impaired limb, in which the onset of action is reported as coincident with the reaching of the first hold point for the faultless movement. Here, especially the second hint is interesting; this illustration, based on [23] and [24], can be interpreted as an action with the impaired limb only starting at the instant when consumption analysis detects a discrepancy, i.e., a deviation from a set goal or reference. The figure is based on the work of G. Holmes in the 1920s, and it would be very interesting to scrutinize these old findings [23, 24].

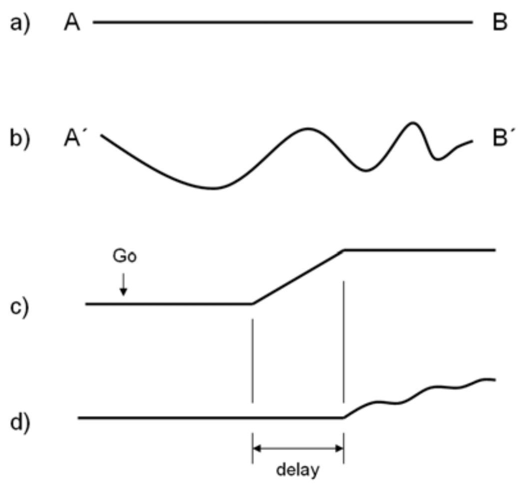

Figure 1. Sketch of principle findings contrasting healthy subjects (traces a and c)) with ones suffering from cerebellar damage (traces b and d)).

According to the Ouroboros Model, for any deviation between feedback and expectation, consumption analysis triggers attention and also delivers some affective signal (computed first in cingulate cortex areas). If the cerebellum is involved in calculating required intermediate values it is no wonder that it is activated at times when deviations are detected.

Failures to provide fitting interpolations would certainly provoke errors. In the realm of abstract cognition, the corresponding errors would most probably manifest as "dysmetria of thought" [25].

More cerebellar activity is probably linked to cases in which wider and more daring interpolations are needed and thus there is a higher risk to make an error. It can naturally be hypothesized that cerebellar activation increases with escalating requirements for interpolation.

VII. Conclusion and Future Work

Extensive detailed work is still needed. In particular, formalization and numerical simulations are required to illuminate details concerning timing and how to implement interpolation in a biologically plausible manner, most probably adhering to a principle of least action, with neural networks as found in the cerebellum.

At present time, it can be stated, that the tight interweaving of computational and neural perspectives appears to offer a fresh look and a new promising approach.

For functional activation studies, predictions can be made concerning differences and similarities of cerebellar contributions to movements, e.g., comparing the drawing of a complex figure either by hand and with a pencil or with a big brush and using wide arm movements: timing and also the involvement of the body would differ vastly but in the proper reference frame the abstract specifications for supporting points and their smooth interpolation, i.e., transients, should be rather similar.

The interpolator hypothesis proposes a new, coarse-grained and overarching picture. Preliminary evidence is presented that the cerebellum serves useful and deemed necessary functions as an interpolator for deriving fine-grained representations from distinct supporting points defined by activations in cerebral cortex and effectively referring to different points in time. This hypothesis, which is motivated by the Ouroboros Model, is testable, and it appears to comply with rather general considerations. At first sight, the interpolator hypothesis not only seems able to explain available observations but also to reconcile several diverse approaches and distinct earlier proposals documented in the literature.

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Brain Computer Interfaces as Stroke Rehabilitation Tools:

Optimization of current strategies

Arnau Espinosa, Rupert Ortner, Christoph Guger
g.Tec medical engineering GmbH
Schiedlberg, Austria
espinosa@gtec.at, ortner@gtec.at, guger@gtec.at

Danut Irimia
Faculty of Electrical Engineering
Technical University of Iasi
Iasi, Romania
danut.irimia@gmail.com

***Abstract*— Brain-computer interfaces (BCIs) allow human communication without using the brain's normal output pathways. A BCI is a tool that converts signals recorded from the user's brain into control signals for different applications. Most BCI systems are based on one of the following methods: P300; steady-state visually evoked potentials (SSVEP); and event-related desynchronization (ERD). Electroencephalogram (EEG) activity is typically recorded non-invasively using active or passive electrodes mounted on the human scalp. In recent years, a variety of different BCI applications for communication and control were developed. A promising new idea is to utilize BCI systems as tools for brain rehabilitation. The BCI can detect the user's movement intention and provide online feedback for rehabilitation sessions. In many cases, stroke patients can re-train their brains to restore effective movement. Previous work has continued to show that higher density electrode systems can reveal subtleties of brain dynamics that are not obvious with only few electrodes. This paper tries to optimize current BCI strategies for stroke rehabilitation by comparing conventional bar feedback (bFD) to immersive 3-D virtual reality feedback (VRFB). Different electrode montages were also compared.**

Keywords- Brain Computer Interface; virtual reality; electroencephalogram; high density electrodes montage; Stroke rehabilitation; 3D Feedback.

I. INTRODUCTION

Brain - Computer Interfaces (BCI) allow new communication channels using different mental states. In a typical BCI, a user performs voluntary mental tasks. Each task produces distinct patterns of electrical activity in the electroencephalogram (EEG). Using monitoring systems and on-line signal processing software, automatic tools can identify which mental tasks a user performed at specific times. Most modern BCI applications rely on one of three types of mental tasks, which are associated with different types of brain activity:

Imagined movement, which produces event-related desynchronization (ERD) dominant over central electrode sites [1, 2];

Attention to oscillating visual stimuli, which produces steady-state visual evoked potentials (SSVEPs) dominant over occipital sites [3];

Attention to transient stimuli, which produces the P300 event-related potential dominant over parietal and occipital sites [4, 5].

In the last few years, several publications suggested that using motor imagery based Brain-Computer Interface systems (MI-based BCI) can induce neural plasticity and thus serve as important tools to enhance motor rehabilitation for stroke patients [6, 7, 8, 9]. Ang et al. [6] reported higher 2-month post-rehabilitation gain on Fugl-Meyer (FM) assessment scale for patients using a BCI-driven robotic rehabilitation tool compared to a control group (6.0 versus 4.0), but without significant results. However, among subjects with positive gain, the initial difference of 2.8 between the two groups was increased to a significant 6.5 after adjustment for age and gender. Recently, Shindo et al. [7] tested the effectiveness of neurorehabilitation training when using a BCI for controlling online feedback from a hand orthosis. The motor-driven orthosis was hypothesized to help the patient extend his paralyzed fingers from 90 to 50 degrees. That article also concluded that the therapy improved rehabilitation. Grosse-Wentrup et al. summarize the state of the art in this research field [10].

Neurofeedback is a process that uses real-time displays of EEG or functional magnetic resonance imagining (fMRI) to illustrate brain activity, usually with the goal to control central nervous system activity. In MI-based BCIs, neurofeedback is critical to optimize the user's performance. As the user practices the skill, sensory and proprioceptive (awareness of body position) input initiates feedback regulation through the relevant motor circuits. Over time, the skill becomes more and more automatic. The learning mechanism in this case is similar to learning to ride a bicycle [2]. Hence, the feedback must reflect the user's task in an appropriate way. For example, when using the BCI for motor rehabilitation, the feedback should be similar to the motor activity.

In [9], Ramos-Murguialday et al. investigated an online proprioceptive BCI system linking hand movements and brain oscillations, eliciting implicit learning effects and producing an increase in sensory-motor rhythms (SMR) related neural network excitation during motor imagery, passive and active movement. Their results demonstrated that the use of contingent positive proprioceptive feedback BCI enhanced SMR desynchronization during motor tasks.

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In this study, two different feedback strategies that can be used for a rehabilitation task are evaluated. During two sessions, the participants were asked to perform MI of either the right or left hand (in random order) as dictated by a visual paradigm. The first feedback strategy shows the hands of an avatar in a 3-D Virtual Reality Feedback environment (VRFB; see section II). Either the left or the right hand of the avatar moves according to the MI. For comparison, a popular strategy (bFB, e.g., in [1]) was used. Here the feedback entails the movement of a bar on the computer screen. This bar always starts in the middle of the screen and extends either to the left or right side of the screen, according to the detected motor imagination. Nine subjects were recorded with 63 EEG channels. Two subjects performed the same tasks using 63 and 27 channels (see Fig. 1 and 2). For these two persons, we evaluated the resulting accuracy difference.

Recently, Neuper and colleagues compared different BCI feedback strategies [11]. There, the realistic feedback consisted of a hand grasping a target, and the bar feedback was similar to the present study. While Neuper used only three bipolar channels for the classification, the present study used a common spatial patterns (CSP) approach that takes advantage of the high number of EEG channels.

In the second section of this paper, subsections *A* and *B* describe the mathematical approach of the CSP method used for classification and the data analysis process. Subsections *C* and *D* present the workflow during one MI-based BCI session and the evaluated feedback strategies.

II. Methods

A. Common spatial patterns

The method of CSP is often used to discriminate two motor imagery tasks [12] and was first used for extracting abnormal components from the clinical EEG [13]. By applying the simultaneous diagonalization of two covariance matrices, researchers can construct new time series that maximize the variance for one task, while minimizing it for the other one.

Given N channels of EEG for each left and right trial, the CSP method gives an N x N projection matrix. This matrix is a set of subject-dependent spatial patterns, which reflect the specific activation of cortical areas during hand movement imagination. With the projection matrix W, the decomposition of a single trial (denoted by X) is described by:

$$Z = WX \tag{1}$$

This transformation projects the variance of X onto the rows of Z and results in N new time series. The columns of W^{-1} are a set of CSPs and can be considered time-invariant EEG source distributions.

Due to the definition of W, the variance for a left movement imagination is largest in the first row of Z and decreases with the increasing number of the subsequent rows. The opposite occurs for a trial with right motor imagery. For classification of the left and right trials, the variances have to be extracted as reliable features of the newly designed N time series. However, it is not necessary to calculate the variances of all N time series. The method provides a dimensionality reduction of the EEG. Mueller-Gerking and colleagues [14] showed that the optimal number of common spatial patterns is four. Following their results, after building the projection matrix W from an artifact corrected training set X_T, only the first and last two rows (p=4) of W are used to process new input data X. Then the variance (VAR_p) of the resulting four time series is calculated for a time window T:

$$VAR_p = \sum_{t=1}^{T} \left(Z_{p(t)}\right)^2 \tag{2}$$

After normalizing and log-transforming, four feature vectors are obtained.

$$f_p = \log\left(\frac{VAR_p}{\sum_{p=1}^{4} VAR_p}\right) \tag{3}$$

With these four features, a linear discriminant analysis (LDA) classification is done to categorize the movement either as left-hand or right-hand.

B. Data processing

EEG data were recorded over 63 positions (see Fig. 1) or 27 channels (see Fig. 2) of the motor cortex, using active electrodes (g.LADYbird, g.tec medical engineering GmbH, Austria). The single small spots show the electrode positions with 63 or 27 channels. C3, Cz and C4 are marked separately. A multichannel EEG-amplifier was used (g.HIamp, g.tec medical engineering GmbH) to record the data with a sampling frequency of 256 Hz. The workflow model is shown in Fig. 3. The sampled data went into a bandpass filter (Butterworth, 5th order) between 8 Hz and 30 Hz before the four spatial filters were applied. The variance was computed for a moving window of one second. Normalization is done according to Eq. (3). Finally, the LDA classification drives the feedback block of the paradigm.

C. Paradigm and sessions

Before the tests started, the healthy users (all male right handed persons between 25 and 30 years old) were trained on motor imagery tasks until their performance was stable. After that, the two sessions with different feedback were executed. The workflow can be seen in the middle of Fig. 3. Each session consisted of seven runs; each run included 20 trials for left-hand movement and 20 trials for right-hand movement in a randomized order. The first run (run1) was performed without providing any feedback. The resulting data were visually inspected, and trials containing artifacts

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were manually rejected. These data were used to compute a first set of spatial filters (CSP1) and a classifier (WV1).

With this first set of spatial filters and classifier, another four runs (run2, run3, run4, run5) were performed while giving online feedback to the user. The merged data of these four runs (run 2, 3, 4 and 5) were used again to set up a second set of spatial filters (CSP2) and a classifier (WV2) that used a higher number of trials and was more accurate. Finally, to test the online accuracy during the feedback sessions, two more runs (run 6, run 7; merged data: run 6 and 7) were done.

Each trial lasted eight seconds; between each trial there was a random trial to trial interval between 0.5s and 1.5s to avoid adaptation. After two seconds, a beep directed the user to the upcoming cue. The cue-phase, during which the subject was told to imagine moving either the left or right hand, started at 3s and stopped at 4.25s.

The end of the cue-phase was marked by a second beep. The feedback-phase started at 4.25s and lasted until the end of the trial (8s). The user was asked to perform the MI from the beginning of the cue-phase until the end of the feedback-phase.

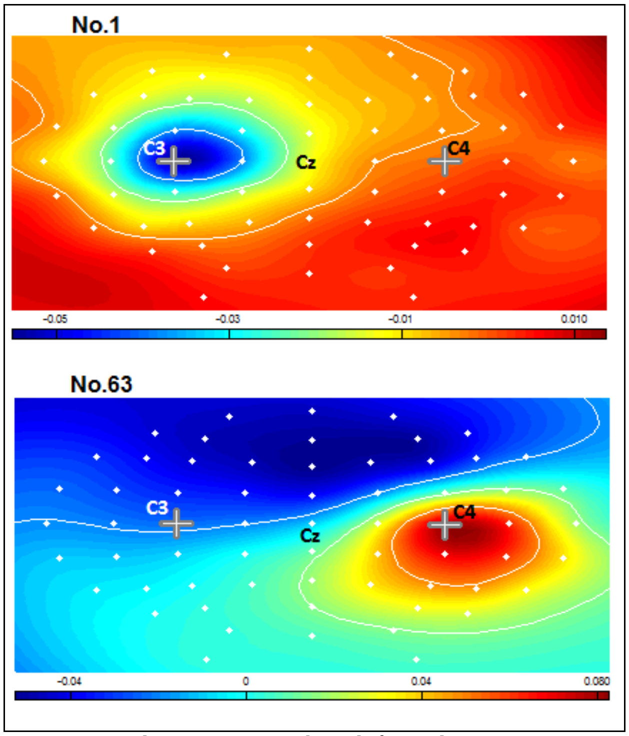

Figure 1. Spatial patterns over 63 channels for S1 during VRFB runs 2, 3, 4 and 5. The upper panel shows the first spatial filter. The lower panel is the last spatial filter.

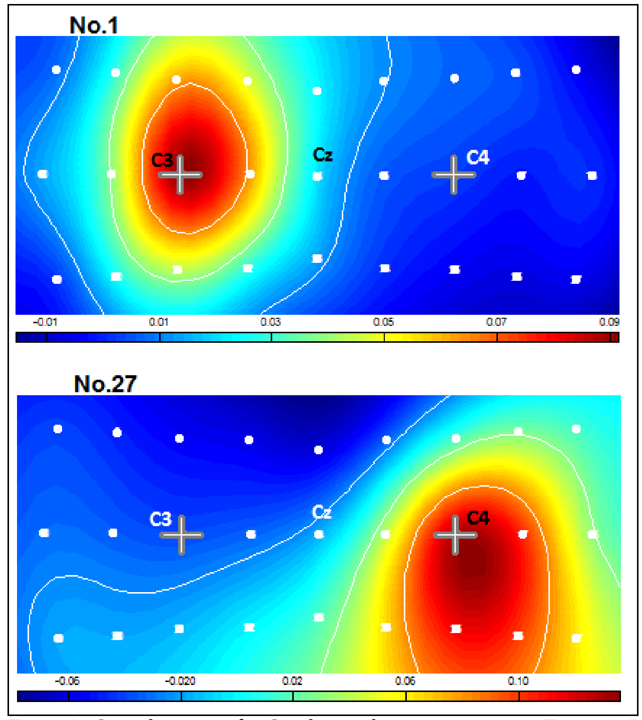

Figure 2. Spatial patterns for S1, during the same runs as in Figure 1. In this figure, only 27 channels were used .

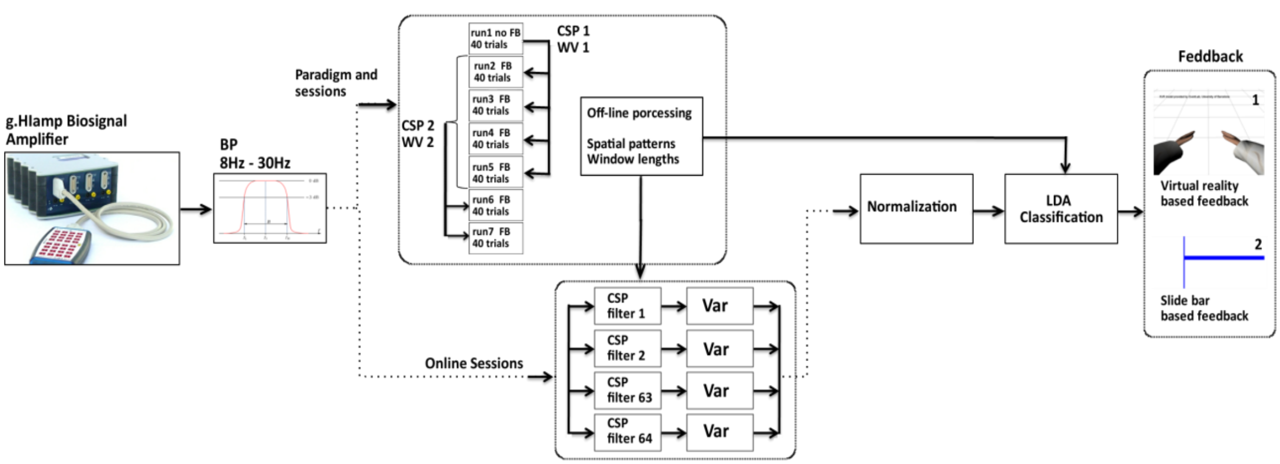

Figure 3. Workflow of the model.

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The error rate can be calculated by comparing the presented cue and the classified movement. The error rate, as displayed in Table I, was calculated by applying CSP2 and WV2 onto the merged datasets run 6 and 7. The classifier and the errors were calculated every 500 ms. For every such calculation, the classifier was applied to the features and the classification result compared to the cue, resulting in the error rate that was averaged over all trials. The "accuracy" term used in this paper refers to the difference between 100% and the calculated error rate.

D. *Feedback strategies*

Feedback strategy number one (bar feedback; bFB, see Fig. 4) is quite common for motor imagery tasks. A bar begins in the middle of the computer screen and extends either to the left or the right of the screen. If a left-hand movement is detected, the bar grows to the left; for a right-hand movement, it extends to the right side. The length of the bar is proportional to the classified LDA-distance. During the cue phase, in addition to the bFB, a red arrow points to the left or to the right side of the screen, indicating to the user which MI he or she should perform.

The virtual reality feedback (VRFB) strategy instead uses a virtual reality research system (g.VRsys, g.tec medical engineering GmbH, Austria). The user sits in front of a 3D-PowerWall wearing shutter glasses. The size of the PowerWall is 3.2m x 2.45m, and the distance between PowerWall and user is about 1.5m. The user sees the left and right hands of an avatar from a first-person point of view (see Fig. 5). The only movement the avatar performs is the continuous opening and closing of either the left or the right hand. No modulation of the speed of the movement is done. During the cue-phase (from second 3 until second 4.25 of the experiment), the user needs to know which MI has to be performed. In the VRFB task, the opening/closing of one of the hands provides this information. After second 4.25, a second beep appears, and the observed movement of the avatar is the feedback to the performed MI.

III. RESULTS

We first compared results with 27 versus 63 channels across two subjects. For each session, the averaged error rate over all trials and over the single time-steps starting from 3.5s until 8s is shown. Table I summarizes the results from these subjects, and a third subject (S3) who was only tested with 27 channels. These values reflect the accuracy resulting from applying CSP2 and WV2 to the data of runs 6 and 7, and show the online accuracy that the users experienced during these runs. The first number in each cell shows rhe mean error rate, the number in parentheses shows the minimum error for the single time-steps. For S1 and S2, the error rate was recorded twice: once with all 63 channels and again with only 27 channels (see Fig. 2).

These data only reflect estimated error rates that the user would have experienced if only the subset of 27 electrodes would have been used. For S3, only the 27 channels were recorded. In three out of four sessions, the error rate increased as the number of electrodes was reduced, but in one session, it increased from 14.8% to 19.8% (S1, VFRB). The minimum error rate increased in three sessions and stayed constant in one of them (S1, bFB). The only exception where the mean error was higher for 63 channels than for 27 was for subject S1, while using virtual reality feedback. The main reason for this exception was the artifact contaminated EEG signal recorded by one of the electrodes placed on the forehead, where the conductive gel dried while performing the first 5 runs of the session.

Fig. 6 shows an example of the error rate from S1 during the two sessions that used all 63 channels for classification. The black vertical line at second no. 3 indicates the onset of the cue.

The error rate before the cue is about 50 percent and then drops below ten percent for both sessions. It stays below ten percent from second 5.5 until the end of the trial.

TABLE I. RESULTS FROM THE SIX SESSIONS

	bFB		**VRFB**	
	Mean Err. (Min. Err.) (%)		Mean Err. (Min. Err.) (%)	
Subject	27ch	63ch	27ch	63ch
S1	12.8 (2.5)	12.75 (2.5)	14.8 (5)	19.8 (4.5)
S2	20.8 (11.25)	19.9 (5.0)	25 (12.5)	19.2 (5.9)
S3	25.0 (8.0)		21.8 (10.0)	
mean	19.5 (7.25)	16.3 (3.75)	20.5 (10.1)	19.5 (5.2)

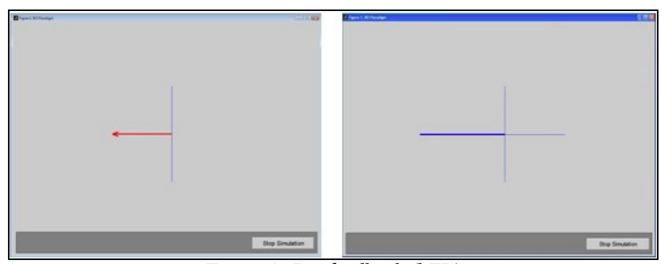

Figure 4. Bar feedback (bFB).

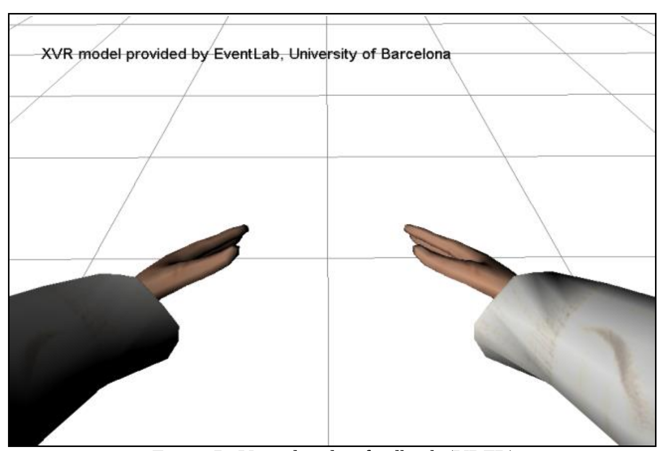

Figure 5. Virtual reality feedback (VRFB).

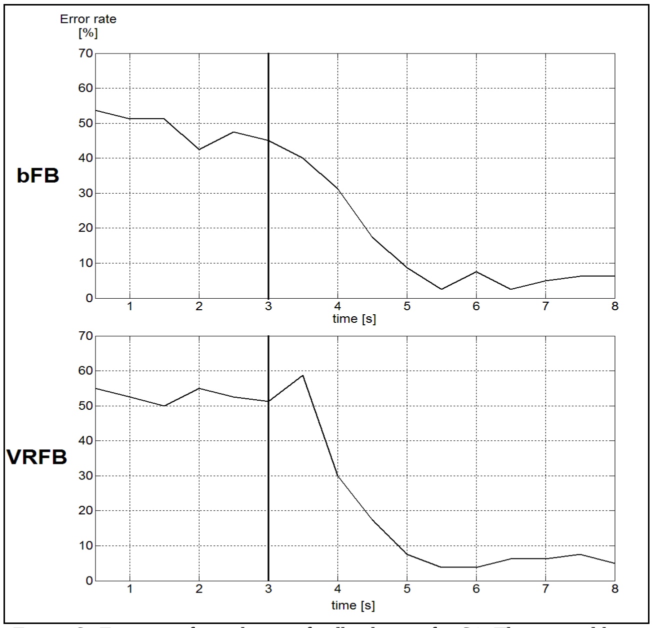

Figure 6. Error rate from the two feedback runs for S1. The vertical bar at 3 seconds indicates the cue onset.

TABLE II. ACCURACY OF 7 SUBJECTS USING THE 63 CHANNEL SYSTEM.

	bFB (63ch)		**VRFB (63ch)**	
Subject	Mean Err. (%)	Min. Err. (%)	Mean Err. (%)	Min Err. (%)
S4	42.30	33.80	37.30	31.30
S5	5.50	0.00	3.20	0.00
S6	35.50	20.00	37	25.00
S7	45.70	37.50	30.70	25.00
S8	5.20	2.50	14.10	5.00
S9	17.00	11.30	5	1.30
S10	3.90	1.30	4.60	0.00
mean	22.16	15.20	18.84	12.51

Table II summarizes the accuracy results of the seven subjects using all 63 channels. The first number shows the mean error rate and the second number shows the minimum error rate. The averaged and minimal error rates have been calculated using the same methods as Table I. The results show a significant performance variance between subjects.

In three out of seven subjects, the error rate increased with the VRFB, but overall, the bFB yielded worse results compared to the virtual reality (S4, S5, S7 and S9). Better results are under 5% error in 3 subjects (S5, S6 and S10).

IV. CONCLUSIONS

This study compared two different feedback strategies for performing MI for stroke rehabilitation. The VRFB provided realistic feedback that was similar to the imagined movements. Hence, we expected this strategy would lead to better classification. This hypothesis was not consistent with the results. In fact, performance was slightly worse with the VRFB in comparison to the bFB sessions. After the sessions, subjects said that it was quite disturbing when the classifier erred, and hence the “wrong” hand moved during the VRFB session. We propose that this mismatch between expected and actual feedback was primarily responsible for both this cognitive dissonance and worse performance. In future studies, we will only feedback when the correct hand is classified.

The BCI performs better using 63 EEG channels instead of 27. This result should encourage the use of larger montages. Furthermore, the comparison of the spatial patterns shows that electrodes that are mounted over the motor cortex and near C3 and C4 (which are present in the 63 and 27 channel configurations) are the most important. Furthermore, some positions that are not part of the 27 channel-configuration are important for classification.

The results we obtained with 64 electrodes encourage us to test 128 EEG-channel montages in future work. Also, the current study only shows results achieved by healthy users. A future goal will be to utilize the knowledge obtained here for rehabilitation of patients suffering from stroke.

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When Brain Informs Us About Mind: a Neuro-Ergonomic Approach to Study Web Sites.

Guercio Elena
Telecom Italia S.p.A.
Torino, Italy
elena.guercio@telecomitalia.it

Roberto Montanari; Chiara Ferrarini
Università degli Studi di Modena e Reggio Emilia
Reggio Emilia, Italy
roberto.montanari@unimore.it; chiara.ferrarini@unimore.it

Simona Collina
Università degli Studi Suor Orsola Benincasa
Napoli, Italy
simona.collina@unisob.na.it

Gabriele Garbin
Università degli Studi di Trieste
Trieste, Italy
g@gabrielegarbin.it

***Abstract*— In two pieces of research the role of information processing to evaluate a web site dedicated to the green culture and information has been investigated. The first study was based on behavioral techniques whereas in the second study participants were requested to perform an fMRI experiment. The purpose of the two pieces of research was to analyze the usability, and cognitive load of the website but, most important, to validate the reliability of the neuro-ergonomic approach while carrying out these analyses. The results put into evidence a correlation between behavioural and neuroimaging results. More important, neuroimaging methodologies proved to be sensitive to study the understanding of users 'cognitive load.**

Keywords- ergonomics; neuroscience; cognition; web-site; information processing

I. INTRODUCTION

Neuroergonomics is the application of neuroscience to ergonomics. Recent researches in experimental psychology felt the need to integrate the classic behavioural paradigms with the recent neuroimaging methodologies [5]. Neuroimaging results can test and constraint cognition by evidencing whether a cognitive model formulated on behavioural results is biologically valid. Second, neuroimaging techniques can provide interesting insight on whether a function is processed by the brain in a localised or in a holistic fashion, providing evidence on the debates on classic cognition versus new embodied theories [1;3]. At the same time, neuroimaging needs experimental psychology and behavioural tests to explain the steps necessary to perform a given cognitive activity. The activation of neural circuits cannot explain alone the complexity of the cognitive experience [4]. So far, the introduction of neuroimaging techniques as the functional magnetic resonance (fMRI) has the advantage to map the brain circuits involved in a given activity thus reducing the gap between cognitive processes (mind) and the neural substrate supporting them (brain) whereas the behavioural methods clarify and specify the steps and the processes involved at each functional level. Since the birth of cognitive science these points have been source of interesting debates. However, not all the fields of cognition have been investigated in equal manner in this perspective and even if the application/integration of behavioural and neuroimaging methodologies to study mind/brain dichotomy is well known, for example, in perception, attention, memory, language, and reasoning, some fields, especially the ones positing at the User Interface, has been often neglected. For this reason, data available in the ergonomic are far from being unitary.

Some attempts are going in this direction: as noted by Parasuraman [2] neuroergonomics can be a powerful tool to investigate cognitive functions in the real world, in the context, thus overcoming classic lab research where each variable is studied almost in isolation. In this respect, many different approaches have been proposed to apply neuroscience and ergonomics: electroencephalography (EEG), which represents the electrical activity of neural cells populations, event related-brain potentials (ERPs) which detect a specific cognitive event, and more spatially sophisticated methods as the functional magnetic resonance (fMRI). fMRI is becoming pervasive in neurocognitive research. It offers a very good spatial resolution and with an appropriate experimental design, the initial limit posited by the temporal resolution can be encompassed. So far, as it is a non-invasive method that offers the detection of brain activity while a cognitive task is performed, many areas of cognition make use of this method to investigate which neural circuits are responsible for a given cognitive process. One may argue that the method, for the limits given by the experimental set, may have ecological validity only when small portions of the cognitive activity are studied. However, the recent development of new experimental design gave the possibility to study also integrated-complex cognitive processes [6].

In this paper, a new approach will be presented. Two experiments were performed: the first experiment aimed at evaluating participants performance in interacting a web site

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dedicated to the green culture (GREEN in the following) through a well validated battery of behavioural tests. In the second experiment, participants performed an fMRI experiment on the same web-site. The results evidenced a high correlation among participants performance in the two experiments. Moreover, fMRI was a sensitive tool to measure the cognitive load and actual understanding of the web-site "conceptual model", opening a new scenario in the ergonomic studies.

The GREEN website investigated represents the major referent in Italy on the green world along three lines, namely ecology, environment and sustainability. As ecology is becoming more and more important in people lives, and the web site should be fruitful, easy and informative for everybody who wants to be informed on a green lifestyle. The website is structured in different sections: green world, news, events, experts, for company, shopping, community. These different sections have been studied in the two experiments.

Following, the two experiments will be presented. In Experiment 1 behavioural data will be described and discussed. In Experiment 2 an fMRI experiment will be presented as a new methodology to study web interfaces.

II. EXPERIMENT 1

A. *Participants*

Twenty adult participants (aged between 20 and 50) took part in the experiment. The 25% of them were female, the 75% were male. All participants were native Italian speakers. They had normal or correct to normal vision. Each of them owns a computer and spends at least three hours per week on internet. They received no compensation or credits for their participation.

B. *Materials and methods*

The GREEN webpage has been selected as key study. Two versions of the page were created, one reflecting how the page appears on the web, Fig. 1, (experimental condition), and one representing only a wireframe, Fig. 2, with no colours and only category names information to use as a control condition.

The logic followed was to compare the webpage with a wireframe in order to extract the weight of the form and content information. Six different tasks were built according to the web page and wire frame structure. The design was a two level within factors so that each participant performed the task in the web page and wire frame condition. In the following, the tasks' list is reported:

- Task 1: Search and visualize by clicking on it the most important news present in the website Task;
- Task 2: Search and visualize the third information of the "focus on area";
- Task 3: Please find and click on the information that for you represent the most important advertising of the website;
- Task 4: You want to plan an ecologic tour. Please search in GREEN where you can find an eco-travel planner and click on it;
- Task 5: Buy a trash bin for waste separation;
- Task 6: You want to learn how to farm in an ecologic way. Visualize the advice of the bio-farmer.

C. *Procedure*

Participants were tested individually in a quiet room. They were seated in front of a computer at a distance of 1 m from the screen. Instructions were given by the experimenter. Before the experiment proper, participants were asked to familiarize with the materials (website and wireframe); they were encouraged to explore the pages and think aloud on the content and form. Next they were presented with the websites and with the wireframe.

The order of presentation of the tasks changed across the participants in a Latin-square design. In addition, if one participant was presented the website and then the wireframe condition, the following participant was presented them in reverse order so that materials were counterbalanced across participants.

Figure 1. Example of the GREEN webpage

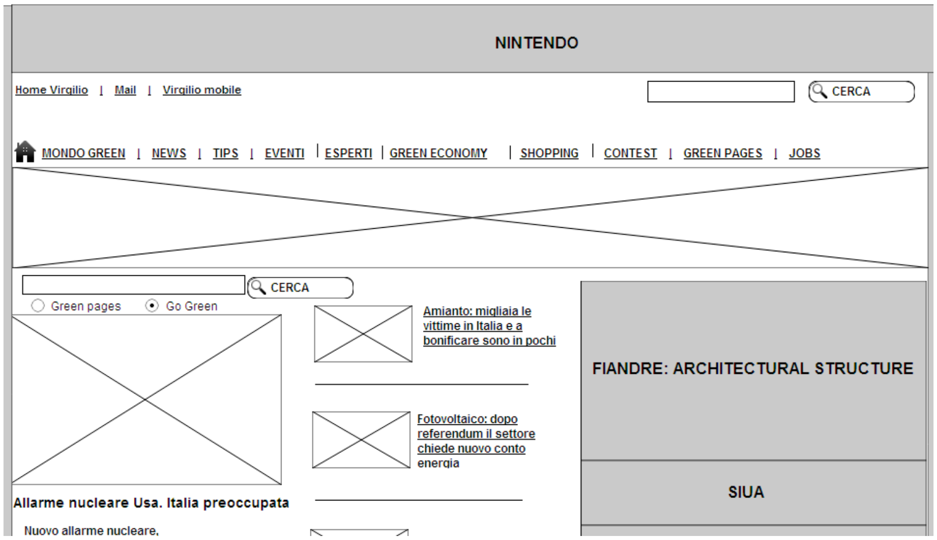

Figure 2. Example of the GREEN wireframe

Data were collected using a logger system (i.e. the remote usability Loop11) to plot and log parameters as time to task conclusion, errors committed, etc. At the end of the task a questionnaire on usability and cognitive load was administered to each participant. The experiment lasted for about one hour.

D. *Results*

Time to complete the tasks for the two conditions (webpage vs. wireframe) was recorded and submitted to t-test, Fig. 3. The result of task 1, 2 and 3 put into evidence a difference (even if for task 2 was not significant) between the two conditions, with an advantage in time completion for the wireframe (Task 1 F= 2,137; Task 2= ns; Task 3 F= 3,650, respectively). The result of task 4, 5 evidenced the opposite trend (Task 4 = 2,134; Task 5= 4,036). No difference was observed for task 6.

The percentage of errors was equally distributed across conditions. No other sources or interactions were found significant.

E. *Discussion*

The result of the behavioural experiment evidenced that participants easily found the information required as suggested by the low percentage of errors. The result of the tasks can be explained on a base of a form semantic distinction: in the first three tasks a strategy based on form could help in finding the information. So far, there was an advantage for the GREEN page compared to the wire-frame. This interpretation was supported by the results of the questionnaire administered. For the first three tasks the results evidenced that features as for example image dimension and position were crucial to correctly solve the task. On the contrary for task 5 and 6 content/semantic information were crucial so that a wireframe website, free of form information could help to solve the tasks. Task 6 was the more complex one: one possible hypothesis to explain the results is that here the joint effect of form and content gave rise to a null effect. Of course this is only a speculation as the result was null. Finally, the questionnaire administered after the task suggested that the website induce qualitative considerations among participants. However, data were equally distributed in a range from positive to negative evaluations.

III. EXPERIMENT 2

The aim of the second experiment was to study participants' performance on the website from a neuroergonomic perspective. An fMRI experiment was designed in order to map the activation of the neural circuits involved in task performance reflecting the mental processes of the human-web interaction. The experiment was explorative in nature and can be considered a pilot experiment to test if fMRI is a useful tool in the research field.

A. *Participants*

Six participants were selected for the second experiment. All subjects were Italian monolingual or had no more than basic skills in one foreign language, as resulting after personal interview. All participants were healthy volunteers with a normal or corrected-to normal vision. None of the volunteers had a history of dyslexia or any neurological or psychiatric disorder. They were fully informed on the modality and execution of the scans before signing an informed consent agreement. Participant could leave the experiment at any time, although all completed the experimental sessions, and gave written permission to the treatment of personal data.

B. *Materials and methods*

The GREEN website was presented to participants in the 1, 5 Tesla scanner. They could see the webpage projected as long as they want.

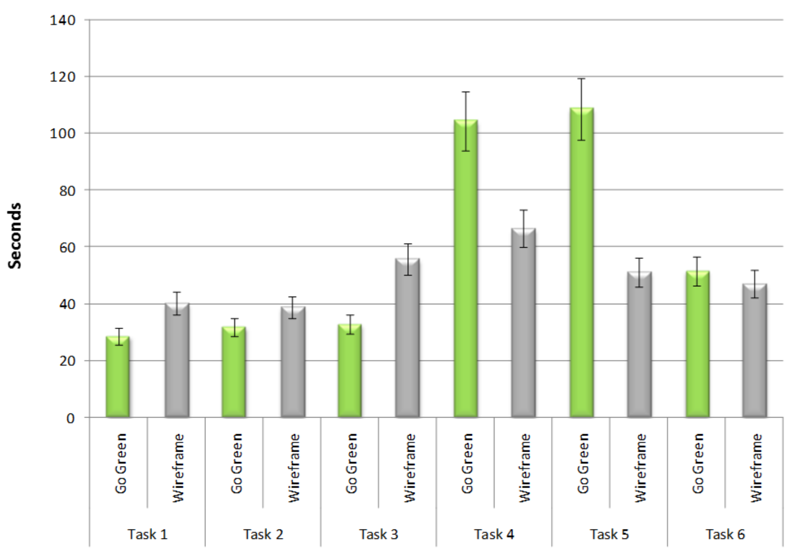

Figure 3. Time (sec) to complete the tasks (N=20)

Experimental sessions and rest alternate each other. Six experimental tasks were performed by participants. Experimental sessions, comparable to that of experiment 1, were adapted to the fMRI experimental settings. Silent reading tasks substituted task involving movements in order to avoid movement artefact. For the same reason a silent reading was preferred to an overt speech. Following, the list of the tasks:

- Task 1: Search the most important news in the website. When you find it read it silently;
- Task 2: Search the third information in the "focus area" and silently read the first word;
- Task 3: Please find the information that for you represent the most important advertising of the website and read the first word silently;
- Task 4: Search the animals represented in the community and think how many is there;
- Task 5: Think about an adjective to define the website;
- Task 6: Think about an adjective to define the colours.

C. Results

Pre-processed images were analysed on blocked protocol. Rests period were taken as baseline.

Encephalic volumes have been acquired using an MRI Achieva (Philips, The Netherlands) of 1.5T. Images obtained have been analysed using the SPM5 (Standard Parametric Mapping) [7] and the resulting activations have been identified with the results obtained by MSU (Michigan State University) and WFU PickAtlas.

Images have been realigned and the variation of intensity, due to local differences in the magnetic field, has been corrected. Volumes have been normalized on the standard coordinate space MNI (Montreal Neurological Institute). For each participant, images sequences of each session have been submitted to a blocked- design t-test. Cumulative analyses have been run for the activation matrixes. Only cortical activations with a threshold of $p<0.01$ were considered statistically reliable.

The cerebral activations obtained have been compared analysed, Table 1. Main results evidenced an activation of the frontal circuits (left and right) involved in linguistic tasks, but also involved in tasks requiring even simple problem solving, an example of activation areas is shown in Fig. 4. Linguistic components produced a strong activation that could have been overlapped other cognitive components, thus rendering difficult in task 4, for example the interpretation of the results.

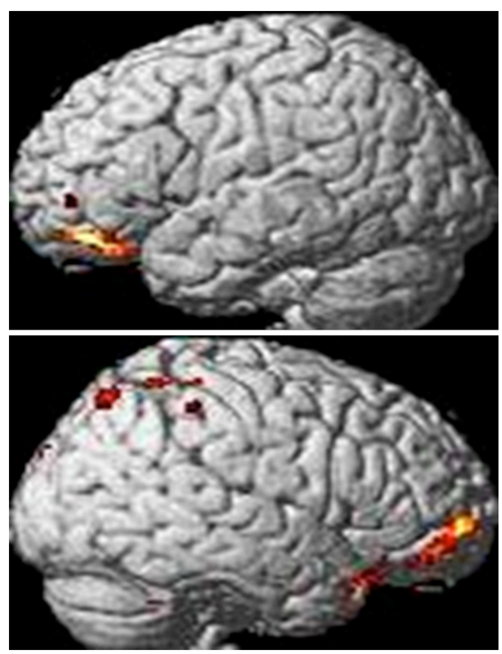

Figure 4. Example of activation areas for task 1 (experiment2)

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TABLE I. ACTIVATION RELATED TO EACH TASK

Task	Areas	Brodmann Areas
1	Middle and Inferior Frontal Gyrus (L, R)	10, 11, 47
2	Frontal Lobe (L)	11, 47
3	Frontal Lobe (L,R)	10, 11, 45, 46
4	Inferior Frontal Gyrus (R)	46, 45
5	Inferior Frontal Gyrus and Insula (L)	47, 13
6	Parahippocampal Gyrus and Lingual Gyrus (R)	27, 18

IV. CONCLUSIONS

In two experiments, we tested whether behavioural and neuroergonomic methods can integrate each other to study web user interface. The case study was the GREEN web page. The results evidenced that neuroergonomic can be a useful tool to investigate the neural circuits involved in complex cognitive activities. In addition, it can be informative of the cognitive load a task requires for participants, opening a new scenario in the ergonomic research. It is a granted data that ergonomic is very well studied in its perceptual and attentive components.

However, less has been done on the central components of the activity as linguistic, semantic, comprehension components often required by tasks. Behavioural results evidenced that perceptual and semantic components can act with different weight and change the polarity of a result (task 1,2,3 vs. 4,5). An indication in this direction is also evidenced by the fMRI experiment with areas of activation linked to the cognitive components sensitive to tasks' requirements.

But, even if the neuroergonomic results were comparable to the behavioural results some problems still persist: the second experiment was just a pilot, with a low number of participants and explorative tasks used. But, in order to start a new line of investigation our main goal was to assess whether the tool could be a sensitive one for our purposes. By adding new data through the use of neuroimaging technique we may now formulate new hypothesis, that can take into account not only the cognitive variables implicated in an ergonomic- at work- scenario, but taking into account also the impact of these variables and task requirements on participants performance, thus disentangling effects due to the cognitive activity per se from methodological issue. In this respect, fMRI is sensitive to detect the cognitive load required by a task. However, the use of neuroimaging technique will be possible only because of behavioural tests, more conceptually sophisticated, replicated and able to overcome the limit in ecological validity sometimes suffering neuroimaging designs and settings. The research presented reflects an interdisciplinary approach that can be fruitful for future studies. This will be the challenge.

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The Neurological Scaling of Human Expertise

T. Bossomaier, A. Delaney, J. Crane
Centre for Research in Complex Systems
Charles Sturt University
Bathurst, Australia
Email:tbossomaier@csu.edu.au

F. Gobet
Department of Psychology
University of Liverpool
Liverpool, UK
Email:Fernand.Gobet@brunel.ac.uk

M. Harré
Complex Systems Group
Fac. of Eng. and Info. Technologies
The University of Sydney
Sydney, Australia
Email: mike.harre@gmail.com

***Abstract*—Although chip clock rates seem to have plateaued, the inexorable rise of computing power in accordance with Moore's law continues. We can easily measure the increase in performance using a portfolio of metrics or a Pareto surface across them, including clock rate, memory latency, bus speeds and so on. In this paper, we address two questions. The first of these is what it would mean to scale a human brain, in the way that the primate brain has been getting steadily bigger and more powerful in the lead up to *homo sapiens.* The second is whether, if we could scale the human brain at the same rate as computer power, human algorithms and computational processes would continue to dominate in the domains where humans still reign supreme. To consider these questions we will phrase much of our practical considerations in terms of board games, particularly the games of Go and Chess.**

Keywords*—*neural energy use; scaling; expertise; patterns.

I. Introduction

The last couple of decades have seen a steady erosion of the superiority of human cognition over that of computers. A decade ago, humans were vastly superior at face recognition. Now computer face recognition is a routine technology, albeit with people still better in poor light, or with distorted or corrupted images. CAPTCHAs have to be made increasingly difficult for people to avoid their interpretation by web bots.

The key questions of this paper surround whether the *computational strategies of the human brain would scale if the brain were to become more powerful.* Put another way, were we able to build computers of the power of the human brain, to what extent would we want to adopt the brain's strategies for these powerful computers? To provide some definite focus, we consider expertise in games, particularly Go, where humans still reign supreme.

A key dimension of such questions, particularly with respect to problem solving in the broad sense (finding food, finding a mate, playing the best move in a Go position) is that of pattern recognition and search [1], [2]. Pattern recognition makes it possible to solve problems by quickly recognising important and often frequently occurring pieces of information that elicit good-enough actions. Search is the systematic exploration of the space of possible solutions, possibly those that have been prompted by pattern recognition [3].

The human cognitive architecture excels at pattern recognition. This makes sense from an evolutionary point of view: it is more important to react quickly to a threat with an action, one that might not be optimal, but is good enough, than it is to find the optimal solution. By contrast, the architecture of most computers (Von Neumann serial architecture) offers an excellent support for search.

Although computers are catching up, they frequently are doing so by using different routes to humans, typically involving much more search. Take the case of Deep Blue, the IBM Chess computer which beat world champion Gary Kasparov in 1997. Deep Blue did incorporate some heuristics derived from human play, but its fundamental approach to the game was different – pruning and *search of the game tree,* carried out far, far faster than any human could ever achieve [4]. There is no reason why advanced computation should track the strategies of the human brain. Aircraft were inspired by birds, but they are now much bigger, faster and don't flap their wings.

A successor to Deep Blue attacks a different game, this time with a focus on natural language processing and understanding. IBM's Watson [5] played the TV game show "Jeopardy!" against two of the most successful players of all time and defeated them quite readily. The importance in this outcome lies in the nature of the game Jeopardy! Contestants are provided the answer to a question and they have to provide the question. The answers are notoriously ambiguous and typically require very subtle contextualisation of the clues in order to play successfully. Watson consists of 90 substantial computer servers with 15 terabytes of RAM and 2,880 processor cores. It operates through massively parallel search of documents without any understanding in a human sense.

We show that increases in the power of the brain will enhance pattern recognition, but not necessarily search. Evolution has produced a human brain that is massively parallel at the neural level and has only limited serial capacity at the cognitive level. The latter can be seen in the limited capacity

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of short-term memory and the narrow focus of attention. Most people can recall only about 7±2 digits when they are rapidly dictated [6], and people are surprisingly bad at identifying the difference between two alternating pictures that are nearly the same – a phenomenon called change blindness [7]. The bottleneck of attention also affects learning, including a large part of implicit learning, as it is unlikely that unattended stimuli will be learnt.

Will then humans be increasingly good at pattern recognition, without improving significantly their search behaviour? Compared to computers, will they continue to excel at Go but be weak in games where pattern recognition is hard? More generally, the human brain has evolved a specific path in the space of possible cognitive architectures. This means that, if one does not modify the basic architecture of the human brain, there are things that are very difficult for the human brain to do. Search behaviour is one example.

Watson fills a big room and uses 200KW, 10,000 times the brains of the human contestants at a mere 20W. We argue that some aspects of human expertise are extremely energy efficient and some recent brain imaging results reinforce this point. Considerations such as energy consumption as well neural architecture, conductance speed and total numbers of neurons will be considered in terms of what is currently understood regarding human expertise.

II. Complex Games and go

Go, one of the most popular and well studied recreational board games in the world, originated in China sometime before 400 BC. Since that time, it has spread throughout Asia and the rest of the world.

Perhaps the most striking aspect of Go is that it combines three characteristics that are not commonly found in a single game: relatively simple rules; combinatorically large search space for moves; and gameplay that is incredibly engaging for human players. Games with simple rules and large search spaces are almost trivial to generate, but they are very rarely interesting enough for people to want to play them at length, and certainly it is rare for any game to survive for 2,500 years.

Current research interest in Go comes from two particular communities: artificial intelligence (AI) and cognitive psychology. The psychological community's interest in Go has been similar in nature to that of Chess in that these games are a fascinating and contrasting source of data on both the extent and the limits of trained and untrained human abilities. On the other hand, for the AI community Go has replaced Chess as a grand challenge since Deep Blue's success against Kasparov.

A. Comparing Go with Chess

Serious Go players can rapidly acquire some competency within a year but understanding the game to any significant depth can take a lifetime. In technical terms, the search space of moves is considerably more vast than Chess, as is the number of possible games that can be played.

The success of Deep Blue in Chess has stimulated recent attempts to achieve the same result for Go. Deep Blue relied extensively on brute force search of many different lines of play and a relatively weak evaluation function of 8,000 features [4], compared to the tens of thousands of chunks in human expertise [8]. The weak evaluation function was compensated for by the extremely large size of the move tree Deep Blue was able to search.

In the case of Go, there is no accurate, explicit evaluation function for intermediate positions, i.e., positions that are not at the end of the game. Instead, a new and very efficient tree search algorithm, called UCT Monte Carlo, has recently been introduced. It has been very successful on small boards and is the leading contender for algorithms in current Go AI Research [9]). The *pattern recognition strategies of human players do not dominate the current best AIs.*

B. The Nature of Human Game Expertise

A popular explanation for expertise in general and in board games in particular is that players acquire a large number of *chunks,* patterns that become increasingly large with practice and that not only encode perceptual information, such as the location of pieces on a Go board, but also provide information about what kind of actions could be profitably carried out given the presence of a given pattern [8] Pattern recognition works in most board games because features tend to be correlated. For example, the pawn structure in Chess provides a considerable amount of information about the likely placement of pieces.

Simon, Gobet and others [10], [8] studied how skilled practitioners in games such as Chess are able to overcome limitations such as working memory. Subsequently these results were incorporated and extensively discussed in Chess simulation software.

High-levels of expertise implicate a number of brain areas, well illustrated by board games, since a Go or Chess player has to recognise patterns, look-ahead for tactical opportunities, plan ahead at a higher level of abstraction, remember standard tactics and strategies, to mention just some of the cognitive processes involved [8].

Several studies have attempted to identify the location of chunks in the brain. For example, comparing the memory for Chess positions having actually occurred in masters' game and random positions, as well as memory for visual scenes unrelated to Chess, Campitelli et al. [11] showed that the fusiform gyrus and parahippocampal gyrus, both located in the temporal lobe regions were engaged. Bilalić et al. [12] found that Chess experts used temporal and parietal object-recognition areas bilaterally in an identification task with Chess stimuli, but only in the left hemisphere in a control task involving geometrical shapes. Wan et al. [13], using shogi (Japanese Chess), have identified a neural circuit that implements the idea that experts recognize patterns giving access to information on the type of action to take. Pattern recognition would be in the precuneus (part of the parietal lobe), while information on possible action would be stored in a more central and older part of the brain, the caudate nucleus, one of the basal ganglia.

However, some of the patterns of Go expertise are low-level perceptual templates [14], akin to the eyes, nose, mouth features which make up a face. Such patterns are likely to occur lower down, in visual areas or infero-temporal cortex.

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1) Patterns and their Frequency of Occurrence in Go: Like Chess, Go throws up a huge range of positional patterns but these are not uniformly likely. The distribution of contextual patterns follows in such games a Zipf-like power law [15]. A useful form of Zipf's law for the k^{th} most frequently occurring element from a set of elements is given by: $freq(k^{\text{th}}$ ranked item$) = c(k+b)^{-\rho}$ where c, b and ρ are constants to be estimated from the data. These distributions are typically associated with 'complex systems' where there are many strongly interacting components giving rise to surprising patterns and dynamics.

Such a power law appears in Go. Liu et al. [15] extracted patterns from 9,447 professional games, featuring over 2 million moves. In terms of the above equation expressed in logs, $\log(freq) = c' - \rho \log(k+b)$ we have $c' = \log(50,000)$, $k \in \{1, 2, \ldots, 20\}$, $\rho = 0.91$ and $b = 0.5$.

Given these frequencies, it is interesting to note some of the previous results of pattern chunking. Simon and collaborators have estimated the number of such patterns needed to be learned to be in the order of 50,000 to 100,000 in order to attain the level of 'master' or above (see Figure 2). Using the equation for the frequency of pattern occurrences and the parameter estimates, we can solve for the frequency of occurrence of patterns of the 50,000 most frequently occurring pattern. All patterns that occur more frequently than the fifty thousandth are presumably more easily learned as they occurred more often. The equation we are left to solve is: $\log(freq) = \log(50,000) - 0.91 \times \log(50,000 + 0.5)$, i.e., $freq = 2.65$. This is significant in that if the frequency were less than 1 then the fifty thousandth pattern is unlikely to be seen during the play of 10,000 games. Note that the $\log(50,000)$ term comes from the parameter estimation whereas the 50,000 in this term: $0.91 \times \log(50,000 + 0.5)$ comes from the need to find the frequency of the fifty thousandth pattern.

This is an important result combining the empirical distribution of pattern frequencies and the number of pattern necessary to be learned in order for a level of expertise to be attained: to become an expert you will have seen the fifty thousandth chunk in your repertoire somewhere between 2 and 3 times. At an estimate of one game per day, this would take over a decade, consistent with the ball park of the 10,000 hours or 10 years required to become an expert that has been suggested in the literature on expertise [16].

If a player has seen significantly less than 10,000 games, then the frequency of patterns seen will drop and a player will not observe a pattern often enough in order to have placed it in memory. For example, if a player has only seen the most frequently occurring pattern in the game 10,000 times (i.e., $k = 1$, all other parameters remain the same), then the pattern that has been observed on average about 2.5 times is the pattern $k = 9,084$, i.e., if 2.5 observations is the frequency required to learn a pattern, then if you reduce the number of games played by a factor of 5 (the $k = 1$ frequency drops from 50,000 to 10,000) then the highest ranked pattern that you can expect to observe 2.5 times is about the nine thousandth most frequently occurring pattern. 9,084 patterns is a significant reduction in the numberof patterns that a player can have acquired given their reduced experience of the game. Considered in the light of Figure 2, it can be seen that such a reduction in the count of acquired patterns, such a player could only expect to achieve

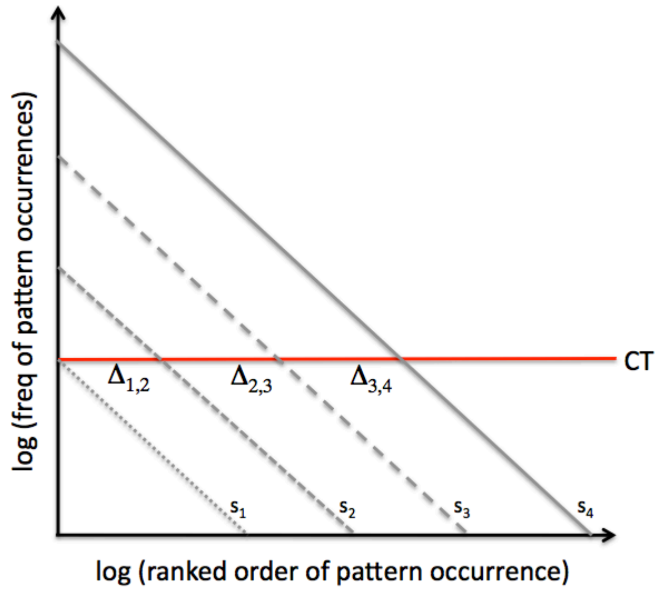

Fig. 1. A stylised log transformed plot of the ranked order of pattern occurrence against the frequency with which each pattern occurs, adapted after [15].

the rank of 'expert' rather than 'master'. Figure 1 shows four different instances of fat-tailed curves (straight lines on a log-log plot) for the frequency of contextual patterns in Go [15]. The CT line is the comprehension threshold, so called because it represents the minimum number of observations required before a player is able to remember a given pattern (2.5 observations based on the calculations above). In terms of Gobet et al's work [8], this is the threshold regular patterns of play have been learned sufficiently to be understood as unitary chunks of information. We assume this threshold is fixed, although in practice it is likely influenced by multiple factors. The $\Delta_{i,i+1}$ terms represent the count of extra patterns that have been observed often enough to breach the CT barrier between ranks i and $i+1$. Note that for linear increases in rank, i.e., skill level s_{i+1} is *reasonably approximated* as a fixed multiple of skill level s_i, $\Delta_{i,i+1}$ is exponential in i due to the logarithmic scale of the x-axis. This approximation is accurate if skill level s_i corresponds to player rank and patterns *above* the comprehension threshold correspond to chunks as in Figure 2.

Recent work by Gobet and Lane has shown that the number of chunks increases exponentially with rank (Figure 2). As players increase in skill they master more and more patterns, but each new pattern is likely to be less common than its predecessors. So in a game or tournament, which is a roughly constant number of patterns, then to have a good chance of being aware of a pattern unseen by the opponent, requires an exponential increase in known patterns.

Humans have essentially an infinite capacity for remembering patterns or chunks of data [17]. The decreasing frequency with which rarer patterns are observed puts an upper bound on how much can be stored in practice. To see this, note that the number of patterns that needs to be observed frequently enough to be turned into chunks (i.e., above the comprehension threshold in Figure 1) increases exponentially with increasing

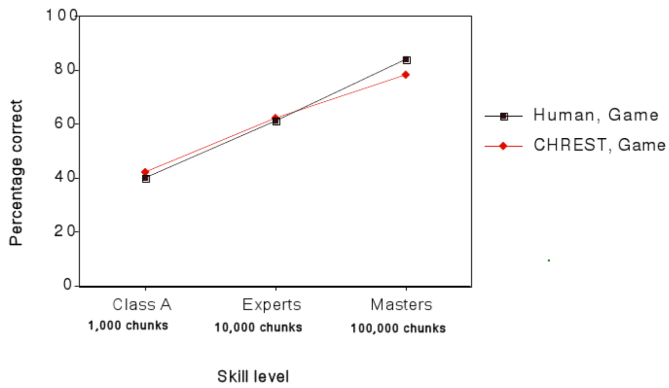

Fig. 2. Graph showing the number of chunks needed with expertise and corresponding model predictions. (courtesy of Gobet and Lane)

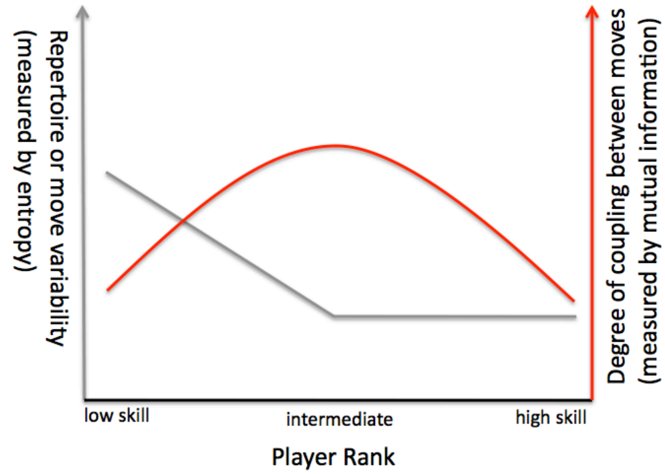

Fig. 3. A stylised plot of the two principal results in [18]. The entropy linearly decreases with rank indicating that certain moves are preferentially chosen more often as skill increases (grey curve). The red curve shows the mutual information between position and move as a function of skill

rank, i.e., the $\Delta_{i,i+1}$ terms in Figure 1 increase *exponentially.* Thus, players need to improve in some other aspect of play and we argue that this improvement occurs in refining the relationships between the patterns learned rather than learning more patterns.

But technology has led to players being able to gain experience faster. In 2009, Joe Cada set the record for the youngest ever Poker World Series Champion at just 21. It is now possible to play many more hands in a given time online than at the table. In Chess, the career peak was around 35 years of age. Recently, this peak went down and it is more like 25 years of age, although Anand, the current world champion, is 40. Thus, the limit of expertise might be set by age. In the absence of dementia or trauma, is it brain size or the slow loss of neurons with age which is limiting?

2) Information Content in Human Decisions: As skill levels increase in Go, the entropy, a measure of the diversity of strategies used, *decreases* to a point where it plateaus. This is where the players have been able to acquire as much information as is extractable from the local configuration of the board, (grey curve in Figure 3).

The difference between strong players and weak players lies in the degree to which the *local* information on the board interacts with the *global* information, i.e., expertise past a certain point is mediated not by a repertoire of patterns, but by the relationships (correlations) between those patterns (see figure 3). We conjecture that this implies *simultaneous grasp* of these global properties, or in psychology terminology, *holding them in working memory* (§II-B3).

Figure 3 also shows a phase transition in expertise, measured by a peak in mutual information [18]. Here, there is some reorganisation of patterns and relationships, necessary before advancing in expertise.

3) Working Memory in Games: At the time of writing (late 2012), computer Go programs have reached professional dan levels on 19x19 boards [19]. However as the handicaps (in terms of speed and board positioning) that favour the computer decreases, human players rapidly gain dominance. In other words, humans have a much better grasp of the interaction between local and global positional elements. In most positions, a maximum of around five live masses can exist on the Go equivalent of 19x19 board. Given that there may be more candidates for ultimate survival, this number is about the order of working memory.

Consistent with a possible relationship with working memory is that the board size for almost all (human) competition play evolved to 19x19 and locked in at this figure. Now, with any game, there is always a lock-in factor for tournaments and rankings to remain coherent. Nevertheless, moving to a 21x21 board would create a greater number of global chunks to be manipulated, making an increase in working memory necessary. On the other hand, tree search scales exponentially with board size.

III. Scaling the Brain's Performance

Despite its impressive performance, the human brain is far from perfect. Gary Marcus in his book [20] catalogues numerous ways in which the brain is biased, gets confused and is prone to all sorts of extraneous influences. He argues that the brain is non-optimal because evolution is a tinkerer, only able to use what is at hand, even though better designs are possible. Thus, some improvements in our cognitive abilities are beyond the space of possible human brain architectures.

An important aspect of expertise in board games is that pattern recognition and search are interleaved [8], [21]. When exploring the space of possible moves, players generate a search tree, albeit much smaller than computers. When trying to find a move in a given position, possibly after having already generated several moves, players tend to use pattern recognition to generate moves automatically [8], [21]. When evaluating a position at the end of branch in their search tree, players also tend to use pattern recognition, rather than a systematic and conscious combination of features of the position on the board. A consequence of this interleaving between pattern recognition and search is that it is likely that the effect of increasing neural efficiency, which is likely to benefit pattern recognition, will be mitigated because of the relative slow speed with which search can be carried out with a human brain.

A. Evolution of Brain Architecture

Brain architecture has been relatively constant since the appearance of mammals, but the neocortex has got bigger. Obviously there might be new transitions in brain evolution, which will create entirely new capabilities, but for the purpose of this article, the primary concern is further increases along alreeady established directions, such as that of size (§III-A1).

The one aspect of architecture that could change is the overarching connectivity. The brain has small world network characteristics and this seems to be important on energetic grounds [22]. But increasing the number of connections per neuron will have an energy penalty, but could increase working memory (§III-B). Could higher levels of connectivity make it any better? But a big new wave is building of sophisticated computation at the sub-neuron level, computation on the dendritic tree (§III-C). The potential here is enormous, but it is intricately tied up with synaptic noise.

Where the human brain is orders of magnitude ahead of its silicon counterpart in terms of energy use, some of the possible wetware enhancements, such as increase in connections per neuron, come at an energy cost (§III-D).

1) The Neocortex and its Recent Evolutionary Enlargement: There are a great many different explanations as to why the human neocortex is as relatively large as it is, but perhaps the most influential has been the demands of living in large, complex groups [23]. Such drivers would also have contributed to good play in complex games.

The relative size of major brain components scales with total brain size across a large number of species [24]. The relative size of the neocortex to whole brain volume scales with the size of a species' typical social group size. It is the neocortex size, which is of interest here, since overall brain size is strongly correlated with body size.

2) Impulse Conduction Speed: If we discount the need to respond in real-time, then conduction speed and age are to first order reciprocally related. However, there could be other considerations. Maintaining synchronised activity across the brain has been advocated for solving the binding problem in perception through to the emergence of consciousness itself. Thus, increasing conduction speed within a given brain, may allow a greater level of synchonisation, since impulses may then arrive before small synaptic activities have decayed away.

B. Connections per Neuron

Increasing the number of dendrites, synapses and links to other neurons offers several advantages. It will likely to increase the, already huge, number of patterns that the brain can discriminate [17]. The number of connections also constrains *working memory*. Roudi et al. [25], using a detailed biologically realistic neural network simulation, show that working memory depends strongly on the average number of connections made per neuron and, at most weakly, on the number of brains cells. The number of connections imposes an energy penalty, however (§III-D). The energy penalty arises because the Excitatory Post Synaptic Potentials (EPSPs), where the spike is converted to activity in the neurons to which it is connected, require slightly more energy than spike generation in human cortex, so increasing connectivity will increase energy requirements [26], [27].

C. Computation on the Dendritic Tree

Over two decades of research in artificial neural networks and a great deal of computational neuroscience has assumed that the inputs to a neuron from other neurons arrive at a single point (effectively the soma). The dendritic tree has often been considered as an anatomical detail, of little computational importance.

But no longer are dendrites viewed as passive players in neural networks. Both the passive and active properties of dendrites endow them with a range of computational abilities [28], such as OR and AND-NOT logic operations (passive), and powerful mechanisms for temporal integration and co-incidence detection (active) [29]. Indeed, it has now been suggested that individual dendritic branchlets should be considered computational units in their own right.

Enhancements in dendritic processing might arise through increased complexity in the morphology of the dendritic tree; more complex patterning of synaptic inputs; alterations in the amount and pattern of expression of active conductances; alterations in the biochemical signalling within dendrites [30]; and increases in hippocampal dependent learning and memory in mice [31].

The computational potential is huge and so far not clearly understood, or at least, its real-world significance has not yet been demonstrated. Furthermore, using the models of neuronal energy use discussed in section III-D, since the dendritic computation is neither part of the axonal or EPSP costs of the cell, it would seem to be exceptionally efficient compared to computation at the network level.

D. Energy Issues

Laughlin and Ruderman found that transferring one bit of information at a synapse needs about 10^4 ATP molecules, the energy transfer mechanism used throughout the animal kingdom [22]. So the brain is operating around 10^5 times above the absolute theoretical limit. Current computers, such as Watson, are at least 10^4 worse.

A later study by Lennie [27] revealed that not only is the human brain relatively efficient compared to computers, its rate of glucose metabolism, the brain's only energy source, is three times lower than in rat and 1.5 times lower than in monkey. He concludes that far fewer neurons are active in human cortex. This would seem to fit the pattern model of expertise rather well. The human brain is much more diverse than rat, storing, and being able to do, many more things. Since these are not all happening at the same time, its *average* energy use is lower.

The wave of connectionist thinking, which began in the mid 80s, emphasised distributed representations. Recent evidence suggests, however, that individual neurons may be extremely specific, such as having a response just to the *concept* of Bill Clinton, regardless of whether this is a picture, his voice, or some ideas or events with which he is strongly associated [32].Clearly such representations engender very low average cortical activity. Thus, if increasing expertise involves laying down more and more increasingly rare patterns, then energy costs may not go up. Where the human brain might seem to score would be in retrieval of a rare, little used pattern with very little additional latency over something used everyday.

Recalling that the biggest consumer of the energy in the neural activity in the brain is in the delivery of the spikes (III-B), the EPSPs. The more synapses a neuron makes (i.e., the higher the number of connections), the greater the energy cost. Thus working memory, which depends on number of connections according to simulations carried out by Roudi et al [25] will demand an energy increase approximately linear in the number of connections.

IV. Conclusions

Human expertise relies strongly on pattern recognition and the building of very large pattern libraries over time. Since patterns themselves do not occur with equal frequency, and often follow a power law in probability of occurrence, this strategy has excellent scaling properties for energy consumption.

The use of the patterns requires some sort of addressing mechanism and this probably occurs through working memory. The best simulations to date suggest that working memory scales linearly with the average number of connections made by a neuron, and, in turn, energy consumption is approximately linear in number of synapses. Thus, although we do not at present know how to calculate the address space (i.e., total possible number of patterns one can store/access), it seems likely that the energy penalty will be logarithmic in number of patterns.

Thus, our view would be that the pattern recognition strategies of human expertise would scale exceptionally well for feasible enhancements in neural architecture. However, it would be significantly harder to improve search. We are left to conclude that neural enhancements to the brain would likely enhance that which it is already good at.

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Basic study for Human Spatial Cognition Based on Brain Activity during Car Driving

Shunji Shimizu
Tokyo University of Science, Suwa
Department of Electric Systems Engineering
Chino-city, Japan
shun@rs.suwa.tus.ac.jp

Hiroaki Inoue
Tokyo University of Science, Suwa
Research course of Engineering/Management
Chino-city, Japan
jgh12701@ed.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

Fumikazu Miwakeichi
The Institute of Statistical Mathematics
Spatial and Time Series Modeling Group
Tachikawa-city, Japan
miwake1@ism.ac.jp

Nobuhide Hirai, Senichiro Kikuchi, and Satoshi Kato
Department of PsychiatryJichi Medical University
Shimotsukeshi-city, Japan
nobu@nobu.com, skikuchi@jichi.ac.jp,
psykato@jichi.ac.jp

Eiju Watanabe
Jichi Medical University
Department of Neurosrugery
Shimotsuke-city, Japan
eiju-ind@umin.ac.jp

***Abstract*—The purpose in this research is to contribute to developing of assistive robot and related-apparatus. Recently, there is a pressing need to develop a new system which assists and acts for car driving and wheelchair for the elderly as the population grows older. In terms of developing a new system, it is thought that it is important to examine behaviors as well as spatial recognition. Therefore, experiments have been performed for an examination of human spatial perceptions, especially right and left recognition, during car driving using NIRS. In previous research, it has been documented that there were significant differences at dorsolateral prefrontal cortex at left hemisphere during virtual driving task and actual driving. In this paper, brain activity during car driving was measured and detailed analysis was performed by segmentalizing brain activity during car driving on the basis of subjects' motion. So, we report the relationship between brain activity and movement concerned with perception during driving in this paper.**

Keywords-brain information processing during driving task; spatial cognitive task;determining direction; NIRS.

I. Introduction

Human movements change relative to his environment. Nevertheless, he/she recognizes a new location and decides what behavior to take. It is important to analyze 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]. When humans perceive space, for example, try to decide the next action in a maze, 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, every task is notional and the particulars about the mechanism that enables humans to perceive space and direction are yet unknown. Also, Brain activities concerned with cognitive tasks during car driving have been examined. For example, there was a report about brain activity when disturbances were given to subjects who manipulated a driving simulator. Also, power spectrums increased in beta and theta bands [4]. However, there is little report on the relationship among right and left perception and driving task.

So, we performed experiments in which perception tasks were required during virtual car driving using Near Infrared Spectroscopy (NIRS) [5]. From experimental results, there were significant differences at dorsolateral prefrontal cortex in left hemisphere via one-sample t-test when subjects watched driving movie and moving their hand in circles as if handling a steering wheel [6].

In addition, we conducted experiments in real-space, which were performed by taking NIRS in the car, and measured the brain activity during actual driving. A purpose in this experiment was to measure and analyze the brain activity during actual driving to compare results between virtual and actual results. As a result, there were significant differences at similar regions [7][8]. In addition, we measured the brain activity of frontal lobe, which is related to behavioral decision-making, during car driving in different experimental design from previous one to verify previous results [9][10].

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It is well known that higher order processing, such as memory, judgment, reasoning, etc. is done in the frontal lobe [11]. We tried to grasp the mechanism of information processing of the brain by analyzing data about human brain activity during car driving. Also, the goal of this study is to find a way to apply this result to new assist system.

So, with the aim of increasing number of subjects and examining more closely the brain activity concerned with spatial perception and direction determination during car driving, we performed additional experiments.

In this time, the brain activity of same lobe with human spatial perception and direction determination was discussed on the basis on changing direction of the gaze and starting to turn the steering wheel. Furthermore, we examined the mechanism of information processing of the brain and human spatial perception during car driving.

II. EXPERIMENT

A. *Brain activity on virtual driving*

1) Brain activity on driving movie is shown

The subjects for this experiment were eight males who were right handed. They were asked to read and sign an informed consent regarding the experiment.

An 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.

The movie is included two scenes at a T-junction in which it must be decided either to turn to the right or left. In the second scene, there is a road sign with directions. We used nine kinds of movies in about one minute. Before showing the movie, subjects were given directions to turn 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.

2) Brain activity on handling motion

In this experiment, measuring was performed by NIRS, made by SHIMADZU Co. Ltd with 44ch. Five subjects were healthy males in their 20s, right handed with a good driving history. They were asked to read and sign an informed consent regarding the experiment.

The subject was asked to perform simulated car driving, moving their hand in circles as if using a steering wheel. A PC mouse on the table was used to simulate handling a wheel, and NIRS (near-infrared spectroscopy) to monitor oxygen content change in the subjects' brain. NIRS irradiation was performed to measure brain activities when the subject sitting on a chair make a drawing 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) - close rest.

B. *Brain activity during actual car driving*

1) Brain activity during actual car driving

In general roads, experiments were performed by taking NIRS in the car, and measuring the brain activity when car driven by subjects was went through two different intersections. Six subjects were a healthy male in their 20s, right handed with a good driving history. They were asked to read and sign an informed consent regarding the experiment. In all experiments, measurements were performed by NIRS (Near Infrared Spectroscopy), made by SHIMADZU Co. Ltd [11].

Subjects took a rest during 10 seconds at least with their eye close before driving task and they drove a car during about 600 seconds. Finally, subject closed their eyes for 10 seconds again after task. Then, the brain activity was recorded from the first eyes-closed rest to the last eyes. Subjects were given directions to turn to the right or left at the first T-junction during driving task. They were also taught the place which was on the road sign at the second T-junction. And, they were given the place where they have to go to. So, they had to decide the direction when they looked at the road sign.

A trigger pulse was emitted on stop lines at T-Junctions to use as a measuring stick for the analysis.

Figure. 1. Recorded movie during measurement.
(This picture was view subjects was watched.)

Figure. 2. Sample of first T-Junction
(This T-junction has no sign.)

Figure. 3. Sample of second T-Junction
(This T-junction had a load sign which was shown the direction and place name.)

Also, we recorded movie during the experiment from a car with a video camera aimed toward the direction of movement (Figure. 1). Recorded movies were used to exempt measurement result including disturbances, such as foot passengers and oncoming cars, from analysis. Figureure.2 and figureure.3 shows one sample of T-junction.

2) Verification Experiment

To conduct verification for experimental results in previous experiment, we performed additional experiment which was achieved in a similar way.

In this experiment, experimental course was different from previous one. While previous one was included two T-junctions in which there was road sign at second one and not at first one per a measurement, there were multiple T-junctions. Three were 5 T-junction without road sign and 4 T-junctions with road sing.

Subjects were twelve males who were all right-handed. They drove a car during about 20 minutes after a rest during 10 seconds at least with their eyes close. Subjects were enlightened about turning direction and the place on which road signs was at T-junction during measurement. And, they arbitrarily decided the direction to turn when they confirmed road signs. Also, a trigger pulse was emitted in the same way.

3) Detailed analysis based on driving behavior

In this analysis, movies aimed toward the direction of movement as well as ones aimed subject movement like ocular motion and arm movement were recorded. This is to analyze brain activity using ocular motion in looking at road signs as a trigger. In previous research we performed, stop line at T-junction was used as a trigger. But, brain activity in T-junction involved movement task such as turning steering wheel, changing neck direction, hitting the brake. So, it is thought that brain activity derived from cognitive tasks was overwritten with brain activity due to movement tasks. Therefore, we tried to analyze brain activity on the basis of ocular motions to examine significant differences with cognitive tasks.

III. EXPERIMENTAL RESULTS

A. Brain activity on virtual driving

1) Brain activity on driving movie is shown

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(around #10 area of the dorsolateral prefrontal cortex of the right hemisphere). This might be the variation based on the spatial perceptions

Next, differences were investigated concerning the subject's brain activity. As the first case, it was when the vision was directed after having been told the direction. As the Second, it was when the vision was directed after having been decided the direction under the road sign.

Here, d1 and d2 were defined to analyze measurement data. d1 is the variation of hemoglobin turning of one second 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. These regions were corresponded to around #46 area of the dorsolateral prefrontal cortex of the left hemisphere and around #10 area of the dorsolateral prefrontal cortex of the right hemisphere, respectively.

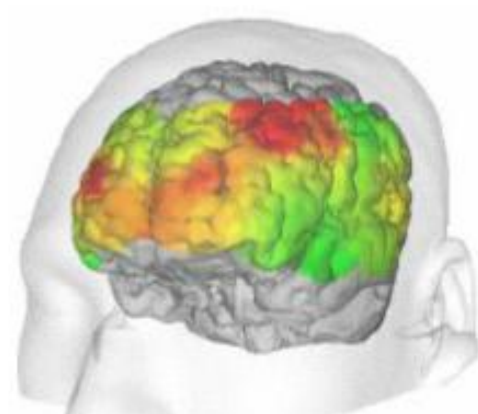

Figure. 4. Brain activity (clockwise)

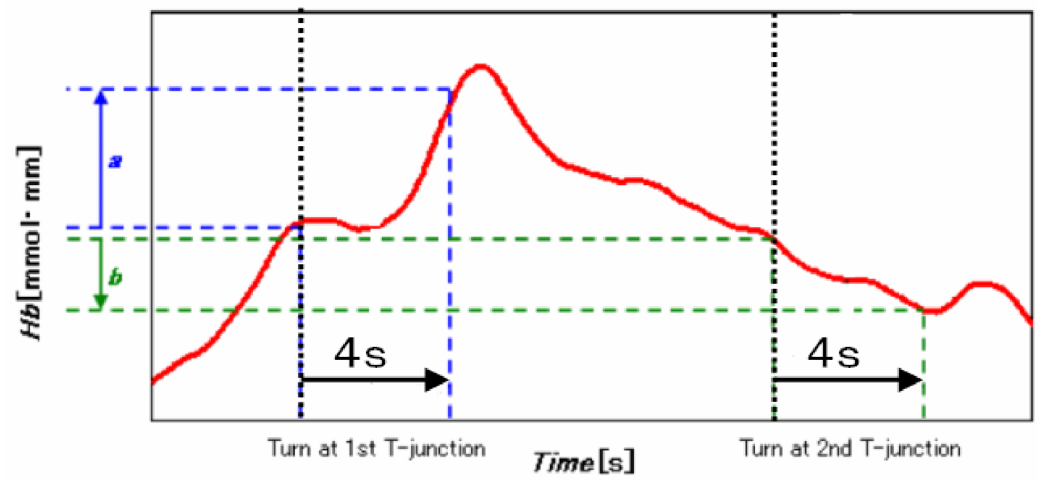

Figure. 5 Analysis method

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 (around #10 area of the dorsolateral prefrontal cortex of the right hemisphere) using paired t test. In only this result, the relationship between pushing a button and d2 cannot be judged.

2) Brain activity on 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 are 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 part of prefrontal cortex a number of significant differences were 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) (Figure.4). It is well known that in the outside prefrontal cortex higher order processing is done such as of behavior control. It is inferred that the pre-motor area was activated when the subjects moved the hand in the way stated above because the pre-motor area is responsible for behavior control, for transforming visual information, and for generating neural impulses controlling.

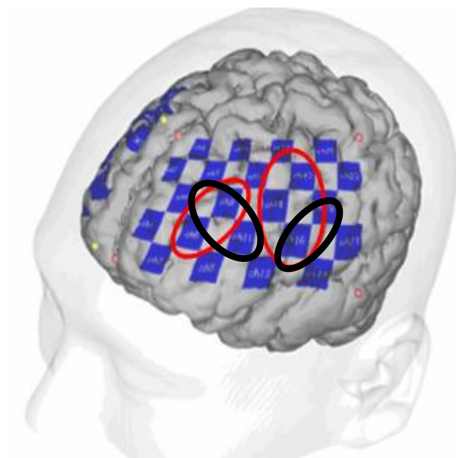

Figure. 6 Significant differences at the turn left

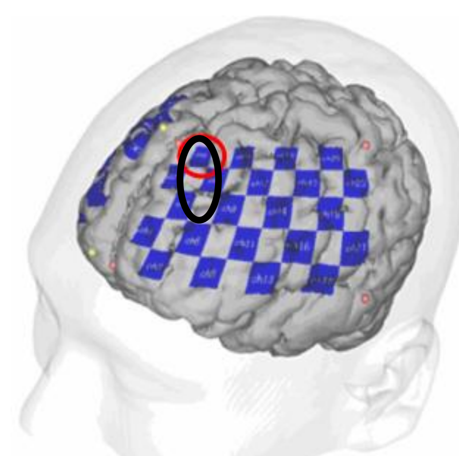

Figure. 7. Significant differences at the turn right

B. Brain activity during actual car driving

1) Brain activity during actual 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 experimental vehicle reached stop line at T-junction. The analysis was performed one-sample t-test using a and b within the significant difference level 5% or less between zero and about four seconds (Figure.5). Here, a is the variation of hemoglobin turning of one second at the first T-junction. And b is variation of hemoglobin at the second one. As the results, there were significant differences around #46 area of the dorsolateral prefrontal cortex and the premotor area of the left hemisphere brain in turning left(Figure. 6:red). Also, there were significant differences #9 of the dorsolateral prefrontal cortex of the left hemisphere brain at the turn right (Figure. 7: red).

2) Verification Experiment

Various tendencies among individuals were observed in comparison with results in B. However, there were tendency that oxy-Hb was increased when car turned left or right at T-junctions and oxy-Hb was decreased during going straight

The analysis method was the same as previous one. Though Gaps were shown regions at which there were significant differences, there were significant differences in common region, too (Figure. 6, 7: black). In the analysis, measurement results including disturbance at T-junctions were excluded as analysis object.

3) Detailed analysis based on driving behavior

The analysis was performed one-sample t-test within the significant difference level 5% or less between brain activity before and after looking at road sign. Each of sample data for analysis was 1 second. Also, analysis was performed with respect to each direction which subject had to go at next T-junction. As a consequence of analysis, there were significant differences at interior front gyrus of flontal lobe of left hemisphere without reference of direction (Figure 8 and Figure 9).

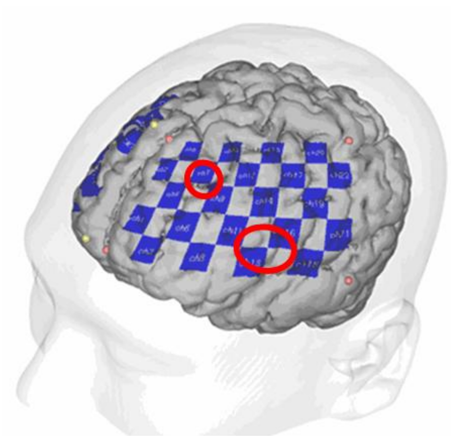

Figure. 8. Significant difference at left direction of road sign

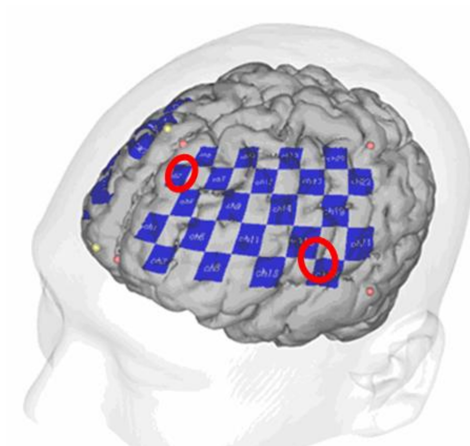

Figure. 9. Significant difference at right direction of road sign

IV. CONCLUSION AND FUTURE WORK

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.

Furthermore, it was found that there were significant differences around #44-45 area. It is well known that this region is corresponding to language area. So, it is thought

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that subjects look at road map to determine direction that they have to go according to word described in road sign.

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 (functional magnetic resonance imaging), EEG (Electroencephalogram), etc.

When compared virtual result to actual ones, there were significant differences around #46 area in both experiments, which were performed in virtual and actual condition, as a common result. It is thought that this result is due to activities of working memory because subjects must to recall memories of movements required for car driving and turning steering wheel. Conversely, there were significant differences around #10 in virtual experiments and around premotor area in actual driving, respectively. In the virtual case, it is thought to result from inhabitation of task without movement. In the actual case, subjects had to perceive space information in real time. So, it is considered that there were significant differences around premotor area because they always ready up to manipulate steering wheel.

As a future plan, we aim to apply these results to assistive human interface. As a matter of course, we plan to performed additional experiments including the verification of these results. And final purpose is to develop a new system for manipulating wheelchair and information presentation system to assist recognition of information including spatial one during car driving.

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Consideration for Evaluation Method of Human Behavior based on Brain Activity

Hiroaki Inoue
Research course of Engineering/Management
Tokyo University of Science, Suwa
Chino-city, Japan
jgh12701@ed.suwa.tus.ac.jp

Shunji Shimizu
Department of Electric Systems Engineering
Tokyo University of Science, Suwa
Chino-city, Japan
shun@rs.suwa.tus.ac.jp

Hiroyuki Nara
Graduate School of Information Science and Technology
Hokkaido University
Sapporo-city, Japan
nara@ssc.ssi.ist.hokudai.ac.jp

Fumikazu Miwakeichi
Spatial and Time Series Modeling Group
The Institute of Statical Mathematics
Tachikawa-city, Japan
miwake1@ism.ac.jp

Takeshi Tsuruga
Department of Clinical and Rehabilitation Engineering
Hokkaido Institute of Technology
Sapporo-city, Japan
tsuruga@hit.ac.jp

Nobuhide Hirai, Senichiro Kikuchi, and Satoshi Kato
Department of Psychiatry
Jichi Medical University
Shimotsukeshi-city, Japan
nobu@nobu.com, skikuchi@jichi.ac.jp, psykato@jichi.ac.jp

Eiju Watanabe
Department of Neurosurgery
Jichi Medical University
Shimotsukeshi-city, Japan
eiju-ind@umin.ac.jp

***Abstract*—Recently, Japan (also world-wide countries) has become aged society, and a wide variety welfare device and system have been developed. But evaluation of welfare system and device are limited only stability, intensity and partial operability. So, evaluation of usefulness is insufficient. Therefore, we will attempt to establish the standard to evaluate usefulness for objectively and quantitatively on the basis of including non-verbal cognition. In this paper, we measure load of sitting and standing movement to use Electoromyogram (EMG) and 3D Motion Capture and set a goal to establish objective evaluation method. We think that establishing objective evaluation method is necessity to develop useful welfare device. We examined possibility of assessing load and fatigue from measuring brain activity to use Near Infra-Red Spectroscopy (NIRS). The idea of universal design is widespread in welfare device and system. Measuring requires verification of all generations. But, we performed to measure younger subjects as a first step. We think that younger subjects were observed the significant difference, because they had enough physical function. Considering younger subjects as a benchmark is appropriate for creating evaluation method.**

Keywords-Evaluation; Movement; Exercise; 3D Motion Capture; NIRS; EMG; Care; Welfare Technology; Usefulwelfare device evaluation; Evaluation method.

I. INTRODUCTION

With the increasing aging population in Japan and world-wide countries, welfare systems and device are rapidly developing, and various devices are manufactured based on the increased popularity of welfare device and system. Also, the market of welfare device and system is expanding. However, the evaluation method is limited respectively to stability, strength and a part of operability for individual system or device. It means that evaluation methodology for usefulness of them was not established. Therefore, we will attempt to establish a standard to evaluate the usefulness for objectively and quantitatively on the basis of cognition such as physical load, reduction of fatigue and postural stability. Especially, in considering universality, it is necessary to measure human movement in daily life. Movement was not measured by using particular device, but routinely-performed movement in daily life.

So, we examined the possibility of evaluation by measuring physical load due to activities of daily living with using 3D Motion Analysis System [1] and EMG [2]. Also, we looked into the possibility of quantitative evaluation of tiredness and load on the basis of brain activity using NIRS [4]. Also, we consider that physical and psychological load are linked to cognition including non-verbal cognition. In this paper, the purpose of experiments is to evaluate motion focusing on sitting and standing movement, which is usually done in our life by using 3D Motion Analysis System, EMG, NIRS. We consider that human feel physical and psychological load during life motion. We tried to measure physical load by using 3D Motion Analysis System, EMG. Additionally, we tried to measure non-verbal cognition about psychological load by using NIRS.

Subjects were healthy males in twenty, because the elderly people who have various types of disease is inept in quantitative evaluation.

II. EXPERIMENTAL METHOD

A. Evaluation by using 3D Motion Analysisand EMG

We simultaneously measured 3D position and muscle potential of subject during task by using 3D Motion Analysis System (nac IMAGE TECHNOLOGY Inc. products-MAC3DSYSTEM [1]) and EMG (KISSEI COMTEC Inc. products-MQ16 [2]).

Regarding to measuring 3D position, 8 Infrared cameras were placed around subject, and 27 makers of the body surface were set on the basis of Helen-Hayes Hospital Marker set (Figure 1). In measuring muscle potential, measurement regions were tibialis anterior muscle, gastrocnemius muscle, quadriceps femoris muscle, hamstring, flexor carpi ulnaris muscle, extensoe carpiulnaris muscle, triceps branchii, latissimus dorsi muscle of the right side of the body because these muscle were deeply associated with standing and sitting movement. Also, wireless measurement was used so that subject was constrained as little as possible. As sampling frequency, 3D Motion Analysis System was 100Hz, and EMG was 1kHz.

Subjects were three males aged twenty. They were asked to read and sign an informed consent regarding the experiment.

In this experiment, subject repeated one series of movements, which was to transfer from chair to seat face of welfare device (IDEA LIFE CARE Co. Ltd products-NORISUKEsan [3]) and opposite one with alternating between standing and sitting, at five times per one measurement. Seating face of welfare device, which was designed to assist transfer movement, was manipulated by simple method and appeared on the top of chair.

Subjects were heard buzzer every one second and kept a constant motion of speed to satisfy certain measuring conditions. Also, they transferred from seat face to chair or conversely every 8 seconds with consideration for movement of elderly persons.

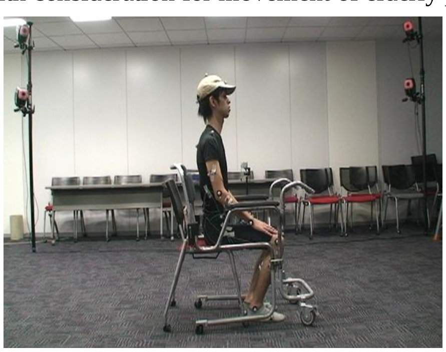

Figure 1. Experimental View of 3D motion Analysis and EMG

Operation of welfare device was performed by the operator other than subject.

B. Evaluation by using NIRS

We measured brain activity during motion with the purpose of establishing evaluation method based on generality (Figure 2).

Subjects were six males aged twenty. They were asked to read and sign an informed consent regarding the experiment. Measurement apparatus was NIRS (SHIMADZU CO. Ltd products-FOIRE3000 [4]). Measurement region was at right and left prefrontal cortex.

1) Measuring brain activity during transfer with standing position (task1)

At this measurement, the subjects used welfare device to perform transferring in a standing position. In this measurement, subject sat on seating face of welfare device appeared on the top of chair after raising hip until kneeling position. Also, subject performed inverse transferring from seating face to chair. Time design was rest (5 seconds), task (10 seconds), and rest (5 seconds). This time design was repeated 30 times. Rest time is to stabilize the brain activity. In the measurement NIRS,

2) Measuring brain activity during transfer with half-crouching position (task2)

At this measurement,the subjects used welfare device to perform transferring in a half-crouch position. In this measurement, the subjects sat on seating face of welfare device appeared on the top of chair after raising hip until kneeling position. Also, the subject performed inverse transfer from seating face to chair.Time design was rest (5 seconds), task (10 seconds) and rest (5 seconds). This time design was repeated 30 times.

In experiments of task1 and task2, the operation of welfare device was performed by an operator other than subject. Before this measuring, subjects adjusted to transferring by use of welfare device.

3) Measuring brain activity during keeping a half-crouch position (task3).

The subjects performed two tasks at this measurement. During task3-1, subject sat on seating face of welfare device with eyes open. During task3-2, they kept a half-crouch position.

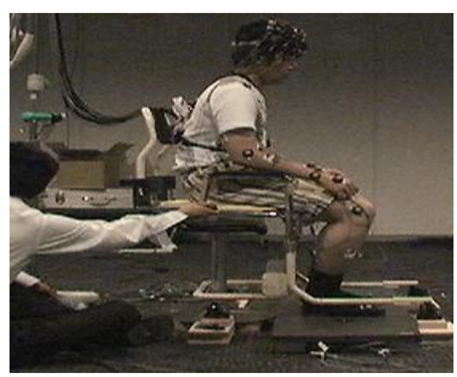

Figure 2. Experimental View of NIRS

Subjects alternated task3-1 and task3-2. Also, subjects took resting time between two types of motion with eyes close. Therefore time design was rest (5 seconds), task3-1 (10 seconds), rest (5 seconds), task3-2 (10 seconds) and rest (5 seconds). This time design was repeated 15 times.

III. EXPERIMENTAL RESULT

A. *Evaluation by using 3D Motion Analysis and EMG*

Figure 3 shows the result of transferring which was measured by 3D motion analysis and EMG. In Figure 3, middle trochanter is the height of midpoint between right and left trochanter from the floor. Trunk angle is the forward slope of trunk. Also, following terms are arectifying voltage wave for each eight muscles, which are Tibialis anterior muscle, Astrocnemius muscle, Quadriceps femoris muscle, Hamstring, Triceps brachii muscle, Etensor carpi ulnaris muscle, Flexor carpi ulnaris muscle and Latissimus dorsi muscle.

Next, analysis was performed by extracting muscle potential during standing and sitting movement from the measuring result with reference to middle trochanter and trunk angle and calculating value of interal during movement. Table 1 shows the ratio of value integral with welfare device to one without device. Also, we compared moving distance of median point between using welfare device and not. Table 2 shows the comparison results in a manner similar to Table 1.

B. *Evaluation by using NIRS*

As the common result of all subjects, oxy-Hb tended to increase during task and to decrease in resting state. Therefore, it was thought that change of hemoglobin density due to task was measured. Figure. 7, Figure. 8 and Figure. 9 show trend of the channel in which significant different was shown. Analysis was performed via one-sample t-test [5,6,7,8,9] by a method similar to previous researches [5,6,7,8,9]. In this analysis, it was necessary to remove other than change of blood flow due to fatigue. So, our method was mainly focused on resting state to compare with the 1st trial and another trials of brain activity.

In task1, 1 and 2, each of sample data for analysis was 4 seconds after the task (Figure. 4). In task 3, sample data was 4 seconds during task (Figure. 5).

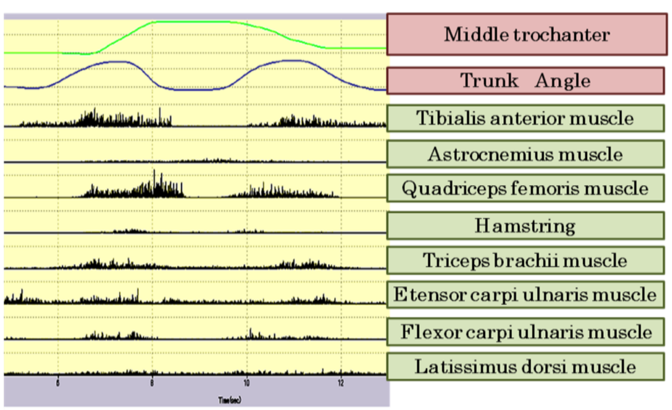

Figure 3. Result of 3D Motion Analysis and EMG

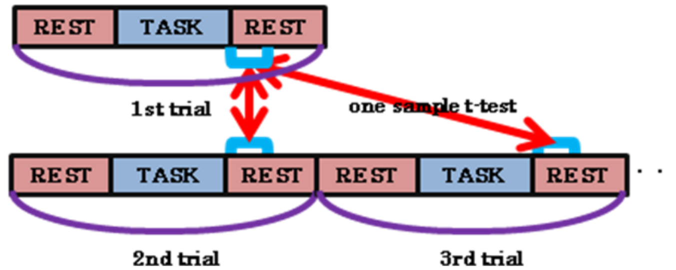

Figure 4. T-test of sample-data of task1 and 2

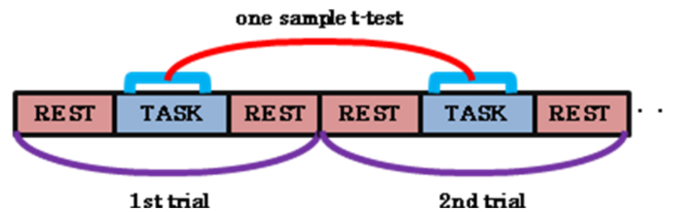

Figure 5. T-test of sample-data of task3

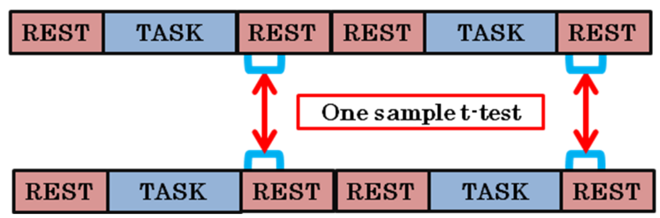

Figure 6. T-test with different sample-datas

In the t-test of the same task, we performed t-test with first time trial and other trial which was from second times to thirty times, and examined relationship the number of trials and significant differences.

In task 1, significant different could be found from the about 10th trials. Figure. 10 shows the region confirmed significant difference.

In task 2, significant different could be found from the about 10th trials too. Figure. 11 shows region confirmed significant difference.

Next, we performed t-test with case of standing position (task 1) and half-crouch position (task 2). In this analysis (Figure.6), significant different could be found at prefrontal area (14ch, 17ch, 28ch and 32ch). Figure. 12 shows the region confirmed significant different.

Also, two types of motion which was sitting and keeping a half-crouching position were repeated alternatively in task 3. At first, we performed t-test using 4 seconds during first trial and 4 seconds during other trials, which were from second to fifteenth in same position. Regarding to the analysis result using sample data during sitting position and half-crouching position, there were significant different at Prefrontal area. Figure. 13 confirms a significant difference.

TABLE I. COMPARISON OF INTEGRAL EMG

muscle	region	Subject1	Subject2	Subject3
Standing	Tibialis anterior muscle	0.37	0.49	0.64
	Astrocnemius muscle	0.83	0.78	0.97
	Quadriceps femoris muscle	0.66	0.36	0.81
	Hamstring	1.90	0.50	1.07
	Triceps brachii muscle	1.07	3.34	1.01
	Etensor carpi ulnaris muscle	1.08	1.31	0.96
	Flexor carpi ulnaris muscle	1.07	0.89	0.85
	Lattissimus dorsi muscle	0.98	0.87	1.20
Sitting	Tibialis anterior muscle	0.50	0.59	0.80
	Astrocnemius muscle	1.01	0.92	0.94
	Quadriceps femoris muscle	0.49	0.57	0.85
	Hamstring	2.16	1.60	0.96
	Triceps brachii muscle	0.89	0.96	1.07
	Etensor carpi ulnaris muscle	0.79	0.89	0.86
	Flexor carpi ulnaris muscle	0.79	0.86	0.95
	Lattissimus dorsi muscle	1.16	1.18	0.93

TABLE II. COMPARISON OF CHANGE IN MEDIAL POINT

	Subject1	Subject2	Subject3
Sitting	0.89	1.03	0.90
Standing	1.00	0.84	1.08

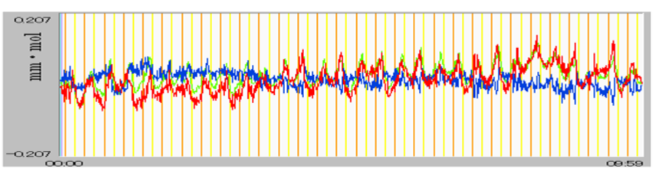

Figure 7. Measuring Result of Task1

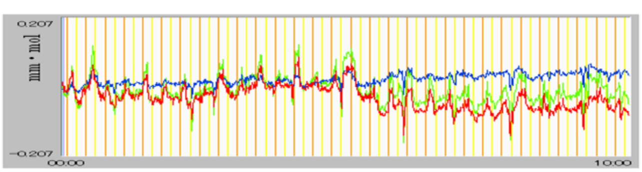

Figure 8. Measuring Result of Task2

Figure 9. Measuring Result of Task3

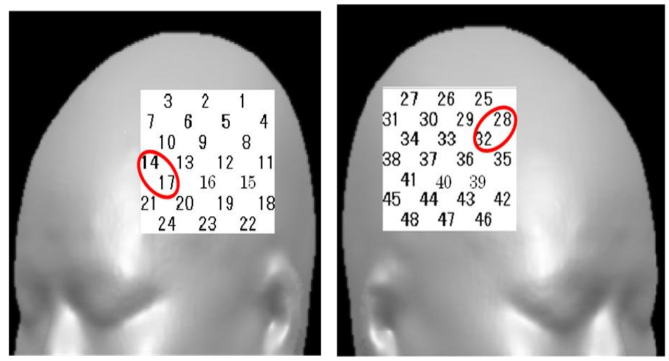

Figure 10. Signififant Difference of task1

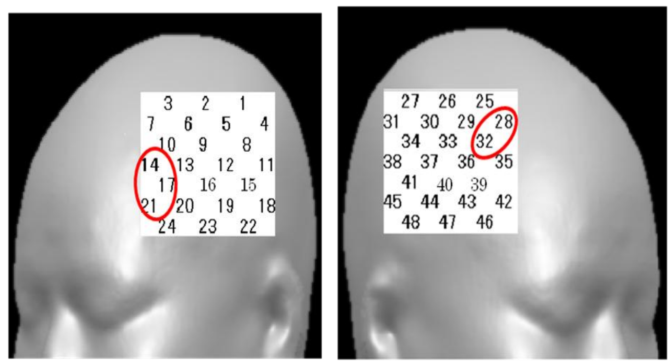

Figure 11. Significant difference of task2

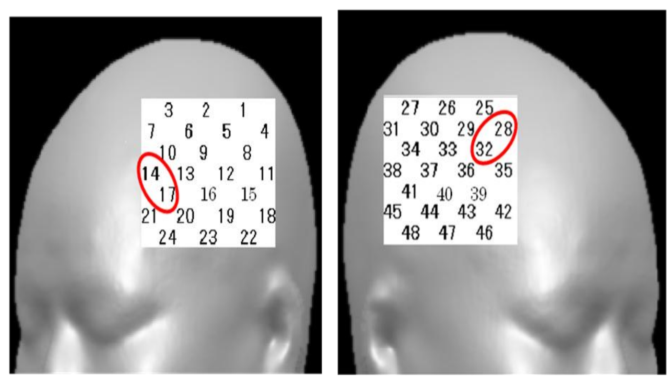

Figure 12. Significant Difference of task 1 and 2

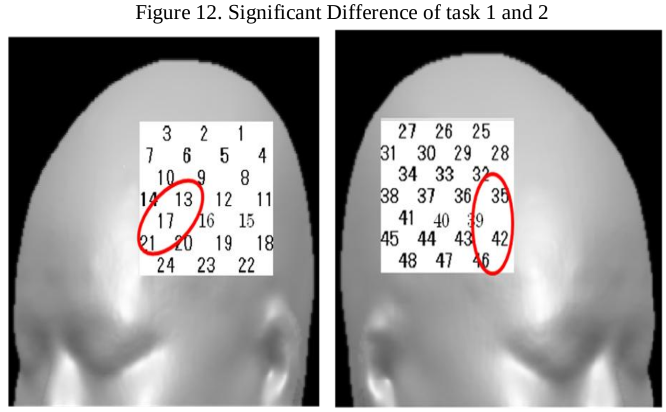

Figure 13. Significant Difference in sitting position

IV. Discussion

1) Evaluation by using 3D Motion Analysis and EMG

From the analysis result, it was shown that value of integral was decreased by using assistive apparatus for transfer. Especially, there was remarkable decrease in value of integral at tibialis anterior muscle, quadriceps femoris muscle. On the other hand, it was shown to be minor decrease in one at upper limb and muscles of the back. Also, moving distance of barycentric position was decreased by the use of welfare device.

On the ground of this result, it was thought to be due to difference in height between chair and seating face of welfare device. Therefore, it was thought that the use of assistive apparatus is useful to lighten burden on lower limb. Thus, it is contemplated that muscle load during standing and sitting movement was decreased and reduced centroid fluctuation to lower the possibility of turnover.

Even if subjects performed daily movements of standing and sitting with the use of assistive equipment, it was shown that the integral of muscle potential and distance of centroid change was decreased. Therefore, it was proved that there is the possibility of evaluation of daily performance except for movement with welfare device.

2) Evaluation by using NIRS

In this experiment, we tried to measure quantitatively the physical and psychological strain on the basis of brain activity. Also, we think that brain activity disclose human cognitive including non-verbal. As a result, it was shown that there were differences at brain activity due to number of trials and postural. In this time, analysis was performed via one-sample t-test using sample of brain activity in resting state during task or after task. Hence, analysis method was to remove disturbance such as body motion and angular variation of neck to the extent possible although there was the possibility to measure skin blood flow. Therefore, it was thought that strain due to tasks was quantitatively measured by being recognized significant differences

Also, in previous research, it was reported to decrease in activity in the brain around #10, 11 [10], as the result of measuring brain activity during Advanced Trial Making Test using PET [11]. Therefore, this result came out in support of previous research in no small part.

Of course, it is necessary to increase number of subject at the present stage. In addition, there are problems associated with experiment, number of subject, method and measured region. However, in terms of being recognized significant differences at brain activity due to movement, it was thought to show useful result in evaluating quantitatively daily movements.

V. Conclusion and Future Work

In this experiment, our purpose was to evaluate quantitatively physical load with focusing on standing and sitting movement which was part of daily movements using 3D motion analysis system and EMG.

As the result, it was shown that the integral of lower-limb muscle, such as tibialis anterior muscle and gastrocremius muscle, significantly decreased by the use of welfare device.

Also, it was reported that there is a positive correlation between anteversion angle of body trunk and movement duration in previous research [12]. But, our experiment method was to estimate the possibility of falling in rising from a sitting position by calculating moving distance of median point. And, it was confirmed that the possibility of falling was decreased by using device.

Next, we tried to measure physical and psychological load quantitatively on the basis of brain activity. And there were significant differences due to number of trials, holding position. In this experiment, analysis method was to remove disturbance such as body motion and angular variation of neck to the extent possible by using the measurement result in resting state as sample. Therefore, it was thought to show the useful result in evaluating quantitatively load due to movement task by being recognized difference in brain activity caused by number of trials, substance of task and holding position.

Main purpose in this study is to evaluate physical load and fatigue quantitatively. So, we tried to evaluate change of muscle load due to difference of motion by simultaneous measuring with 3D motion analysis System and EMG quantitatively.

However, evaluation of psychological load is necessary, too. In terms of using welfare device, prolonged use must be taken into account. In this case, it is important to consider not only physical load but also psychological load due to prolonged use from standpoint of developing welfare device and keeping up surviving bodily function.

Also, in previous research, separation between physical and psychological load has been performed. But, our view is that there is correlation with physical and psychological load. So, we tried to measure psychological load including physical one based on brain activity and quantitatively evaluate both load.

For the future, our aim is to establish method of discussing useful of welfare device by evaluating load involved in other daily movements with increasing number of subjects.

Acknowledgment

This research was supported as follow. There dimensional motion analysis and commodious room were provided from nac Image Techonogy Inc. EMG and analysis software were provided from KISSEI COMTEC. NIRS was provided from SHIMADZU COPPORATION. Developing welfare device was provided from IDEA SYSTEM CO., LTD. We are deeply grateful to them.

This study contributes to become the basis for one of theme of s-innovation program in Japan Science and Technology Agency which was named “Development Fatigue-reduction Technology for Social Contribution of Aged Person and Establishment System for Evaluation.

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Forecasting Negotiation Counterpart's Offers

A Focus on Session-long Learning Agents

Marisa Masvoula
Department of Informatics and Telecommunications
National and Kapodistrian University of Athens
Athens, Greece
marisa.diuoa@gmail.com

***Abstract*— Predictive decision making is characteristic to current state of the art socio-technical systems that guide negotiation processes under electronic settings. Back end participants are particularly benefited by the use of models of computational intelligence, which help them adapt their strategy and evaluate risks and dynamics of the current negotiation. In this paper, the skill of forecasting the counterpart's future offers with the use of neural networks is investigated. Current systems base their learning models on data acquired from previous interactions. Such systems are once trained in an offline mode and are thereafter expected to operate in a real environment. However, when data distributions change, the systems no longer provide accurate estimations. A new perspective to the issue is introduced, by highlighting the need of learning during the negotiation session, with the use of "session-long learning" agents. These agents prove capable of capturing the negotiation dynamics by training their learning models with the data from the current negotiation thread. In this paper a static session-long learning agent, based on a simple neural network model, as well as an adaptive session-long learning agent, based on a neural network which evolves its structure and input features with the use of a genetic algorithm in each negotiation round, are presented and assessed.**

Keywords-Predictive negotiator; genetic algorithm; adaptive negotiation strategy; neural network applications

I. INTRODUCTION

Electronic Marketplaces (E-markets) is an important component of e-business that brings demand and supply of commodities and services into balance. They are the meeting places of producers and consumers that use exchange mechanisms, such as catalogues, negotiations, and auctions [1].

This paper is focused on the negotiation mechanism, defined as an iterative communication and distributed decision-making process, where participants, humans or agents, are searching for an agreement. Computer science has significantly contributed to the field, since the use of information systems has moved the negotiation arenas to electronic settings, and the development of models of computational intelligence has extended the cognitive abilities of negotiators. Current research efforts concentrate on the enhancement of support systems that assist negotiators, and on software agents that fully automate negotiation processes using learning techniques. One such technique is related to the ability of negotiators to forecast their counterpart's future offers and accordingly adjust their strategy. This research considers agent to agent interactions, and investigates the skill of forecasting the other party's responses.

In section 2, related work is presented and the value of forecasting, measured in terms of utility gain, is highlighted. In section 3, it is argued that neural network models trained with data from previous interactions are not capable of retaining their accuracy when used in open dynamic environments. The key issue is to retrain the neural networks involved, with data extracted from the current negotiation thread. Agents that retrain the employed networks are termed Session-long Learning. In section 4, two types of such agents are illustrated; Static session-long learning Agents (SSLAs), which are enhanced with a Multi-layer Perceptron (MLP) that has a static architecture, and Adaptive Session-long Learning Agents (ASLAs), which make use of an MLP that evolves its architecture and input features with a genetic algorithm. In section 5, the two types of session-long learning agents are compared, while in section 6, conclusions and future research issues are discussed.

II. TERMINOLOGY AND RELATED WORK

The outcome of a negotiation can be a compromise or a failure, and the gain (profit) an offer X incurs to participant (agent) α is measured by a utility function $U^a(X)$ that takes values in [0,1]. In multi-issue negotiations multiple attributes (issues) are considered negotiable and are exchanged between the engaged parties. Each offer X can be expressed as a vector in the n-dimensional space, where n is the number of issues under negotiation. For each issue, participants specify a range of permissible (reservation) values (a minimum and a maximum), which they are not willing to exceed. Additionally in many cases time is crucial and participants set a deadline indicating the maximum time they can spend in a negotiation encounter.

The specific rules of communication that guide the interaction constitute the negotiation protocol and determine the way messages are exchanged. The decision making rules or strategies are used to determine, select and analyze the decision alternatives. In a simple case where negotiation is

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conducted between two non learning agents, alternatives are generated with the use of formal decision functions, and three groups of strategies are identified (time, behavior and resource dependent) as described in [2]. More sophisticated agents use AI-based techniques aiming to maximize the incurred utility. In the work presented in [3] categorization of such agents to those that follow explorative, repetitive and predictive strategies is given. The first category consists of agents that search the strategy space usually through trial-and-error learning processes, the second category consists of agents who repeat strategies that have proved efficient in past similar situations, while the third category consists of agents that adopt a strategy, based on estimations of environmental parameters and/or opponent.

This research is focused on the third category and particularly on the issue of predicting the counterpart's future offers. Predictive agents are distinguished into those who engage in single-lag predictions and estimate the very next offer of their counterpart, and into those who engage in multi-lag predictions and foresee future offers of their counterpart several time steps ahead. For applications of single-lag predictive decision making in negotiation support systems the interested reader may refer to [4,5], which present a neural network that simulates the possible responses to the alternative offers the negotiator is contemplating. For strategies of automated negotiators that are based on single-lag predictions the reader may refer to [6–9], where agents are developed with the scope to increase individual gain of the final outcome. In the case of multi-lag predictions, [10-12], demonstrate agents who decide to withdraw from pointless negotiations based on the forecasts of their counterpart's future values. Finally, Brzostowski and Kowalczyk [13-15] depict an agent who determines the sequence of optimal offers, "knowing" the sequence of opponent's responses.

This paper uses the protocol and strategy described in [9] where different agent strategies emerge from different attitudes towards risk. For a more thorough understanding a brief review of the strategy is provided. The negotiation environment considered is tied to bilateral (two parties are involved) multi-issue negotiations, where all issues are bundled and discussed together (package deal). The formal model of negotiation is comprised by the set of agents $A = \{a, b\}$, a finite set of quantitative issues under negotiation $I = \{i_1, i_2, \ldots, i_n\}$, the domain of reservation values $D_i^a : [\min_i^a, \max_i^a]$ for issue i attributed by agent α, and the deadline $T_{\max}^a$ of agent α, where $i \in$ I and $a \in$A. In the cases studied time variable t is discrete and expresses the interaction step (negotiation round). The possible outcomes of a negotiation can be understood in terms of utility $U^a(X_{(a\to b)}^t)$ where $X_{(a\to b)}^t = (\mathrm{x}_{1(a\to b)}^t, \mathrm{x}_{2(a\to b)}^t, \ldots, \mathrm{x}_{n(a\to b)}^t)^T$ is the negotiation offer sent from agent α to b at time t, and each x_i denotes the offered value of negotiable issue i. Each agent α is configured with a default strategy S^{α}, which determines the level of concession in each round [2]. In each time step t agent α estimates the next offer of his counterpart $\hat{X}_{(a\to b)}^t = (\hat{\mathrm{x}}_{1(a\to b)}^t, \hat{\mathrm{x}}_{2(a\to b)}^t, \ldots, \hat{\mathrm{x}}_{n(a\to b)}^t)^T$.

The decision rule makes use of the default strategy (S^{α}) of the predictive agent to generate offers until the detection of a "meeting point" (MP) with the "opponent". MP is a point which would result an established agreement if the agent was guided solely by his default strategy. When such point is detected, and according to the agent's attitude towards risk, agent risks staying in the negotiation in order to maximize the utility of the final agreement. At that point agent makes use of the estimation and refines the offer he sends at each time step. Two extreme attitudes can be generated: risk-seeking and risk-averse. The risk-seeking agent is willing to spend all the remaining time until expiration of his deadline engaging in an adaptive behavior to turn the estimations of his counterpart's responses to profit. On the other hand risk-averse agents follow a more conservative behavior when they detect an MP. They do not make any further concessions and insist on sending their previous offer, waiting for the opponent to establish an agreement.

In the following section, shortcomings of existing systems and the approach to address them is discussed.

III. PROBLEM STATEMENT

Methodologies that have been used for the purpose of forecasting the counterpart's future offers can be summarized into those based on statistical approaches (particularly non-linear regression) [10,14], mathematical models based on differences [13,15], and connectionist approaches, particularly some special types of neural networks [4-8,11,12].

Experiments have shown that mathematical models give poorer results when compared to non-linear regression models [14]. Non-linear regression models are restrictive, since they require the assumption of a known function form of the counterpart's behavior, and mathematical models are empirically proved less accurate than neural networks in the negotiation domain [16]. Focus is set on the application of neural networks, which can be utilized in the general case and have proved efficient in the problem of forecasting the counterpart's next offer.

However, two issues need to be addressed. The first concerns lack of homogeneity. Artificial Neural Networks (ANNs) employed by current state of the art negotiators have significant differences in terms of network architectures and input features. The second is that these models are particularly tied to bound domains, since in the majority they are trained and applied to environments with data of the same underlying distributions. The networks are trained before the initiation of the current negotiation instance with data from previous interactions, and are then set to operate in the current discourse. As a consequence, the predictors' accuracy depends heavily on data acquired from previous negotiations.

To address the second issue, this work highlights the need to retrain the MLPs with data acquired from the current

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negotiation thread. In this respect two types of agents termed Session-long learning are developed and assessed. The first type, Static Session-long Learning Agent (SSLA), makes use of a Multi-layer Perceptron (MLP) with a static structure which is retrained at each predictive step, while the second, Adaptive Session-long Learning Agent (ASLA), makes use of an MLP which optimizes its structure and subset of input features during negotiation.

In the following sections SSLA and ASLA are described and compared.

IV. SESSION-LONG LEARNING AGENTS

A. *Static Session-long Learning Agent*

In this section we describe a Static Session-long Learning Agent (SSLA), which is defined as a session-long learning agent with a fixed MLP architecture during the discourse. Without loss of generality, the predictive agent is assumed to be the consumer who initiates the negotiation process at time t_1=0. The two agents take alternate turns until an agreement is established or until any of the two agents decides to terminate the procedure. In the general case, the forecasting tool of the SSLA makes use of the *n* previous counterpart's offers to estimate the next offer (at time *t*+1), as is illustrated in Figure 1. At time *t* the consumer formulates a new training set which is constructed from the series of the counterpart's offers.

It should be noted that in order to apply the Levenberg and Marquardt (LM) method, at least two training patterns are required, therefore the MLP is initially trained at round

$$t_{init} = 2*n+4 \tag{1}$$

The size of the dataset $|Dataset|$ at time $t \geq t_{init}$ is given by

$$|Dataset| = \frac{t}{2} - n \tag{2}$$

$|Dataset|$ is initially 2 in order to apply the LM method, and increases by 1 in each turn of the predictive agent. After training the MLP, SSLA makes use of the network to estimate his counterpart's next offer.

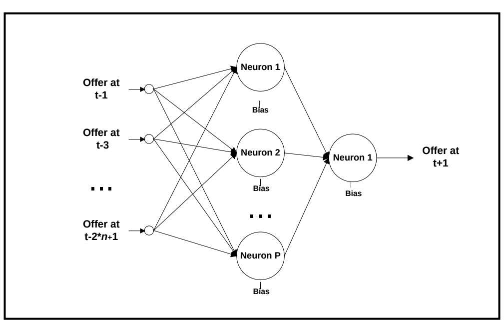

Figure 1. Forecasting tool of the negotiator.

More specifically, the actions an SSLA undertakes at each predictive round *t* are described as follows:

Step 1. Receive Opponent's Offer,

Step 2. Update Negotiation Thread by storing the received offer

Step 3. Formulate training set:
Consider a time series of the opponent's past offers: $\{X^{1}_{(\mathrm{Pr}->Con)}, X^{3}_{(\mathrm{Pr}->Con)}, ..., X^{t-1}_{(\mathrm{Pr}->Con)}\}$
Formulate the set of input-output patterns with respect to the number of input nodes

Step 4. Use the patterns yielded in Step 3 to train the network with the LM method

Step 5. Formulate current input pattern $\{X^{t-2*n+1}_{(\mathrm{Pr}->Con)}, ..., X^{t-1}_{(\mathrm{Pr}->Con)}\}$

Step 6. Apply input to the trained network

Step 7. Obtain forecast of opponent's next offer,

Step 8. Generate next offer based on the predictive strategy

The forecasting tool of the SSLA was selected to be very small and consist of three inputs (*n*=3), representing the three previous offers of the counterpart (as in [8]), and two hidden nodes (P=2). This architecture is even simpler than the one proposed in [8], since it uses one hidden neuron less. Although the optimal network architecture cannot be extracted from theoretical findings, it is rather empirically found that the ratio of learning parameters with respect to the size of the training data should be kept small. As stated in [17,18] the generalization error can be decomposed into an approximation error due to the number of parameters and to an estimation error due to the finite number of data available. A bound for the generalization error E is given by

$$E \leq O\left(\frac{1}{P}\right) + O\left(\left[\frac{Pn\ln(P|Dataset|) - \ln\delta}{|Dataset|}\right]^{1/2}\right) \tag{3}$$

where *n* is the number of input units, P is the number of hidden nodes, δ is a confidence parameter, $\delta \in (0,1)$, and $|Dataset|$ is the size of the dataset. Since in each subsequent step $|Dataset|$ increases, the bound of the generalization error E is expected to decrease, therefore the learning model provides more accurate estimations as the negotiation proceeds. Applying in (2) *n*=3 and $|Dataset|$ = 2 (minimum value required by the LM method), yields that the agent can initially train and use the MLP at the tenth round.

As far as complexity is concerned, storage of the Jacobian matrix ($|Dataset|$ xP), as well as computations for matrix inversion that are of order $O(P^3)$, are required at each iterative step of the LM method. The LM is considered efficient since it can be defined as a polynomial time algorithm (an algorithm that has time complexity that is bounded by a polynomial in the length of the input) [19].

B. Adaptive Session-long Learning Agents (ASLAs)

Unlike SSLA, the ASLA considers not only the series of his counterpart's past offers, but also the series of his own past offers, to formulate the subset of input features. Particularly, in order to find the optimal subset which will guide the prediction, two time series are taken into account: one resulting from past offers of the predicting agent $\{X^{0}_{(Con\rightarrow \Pr)}, X^{2}_{(Con\rightarrow \Pr)},...., X^{t-2}_{(Con\rightarrow \Pr)}\}$, and one resulting from the past offers of the opponent $\{X^{1}_{(\Pr\rightarrow Con)}, X^{3}_{(\Pr\rightarrow Con)},...., X^{t-1}_{(\Pr\rightarrow Con)}\}$. The encoded information represents the number of previously offered values of each agent. Using a binary grammar, three bits are sufficient to encode up to seven past offers for each agent. Consequently a 6-bit length string represents the subset of input features. Since it has been proved that an MLP with one hidden layer can conduct function approximation, and since it has been widely used by existing predicting agents, the architecture of a two layered MLP is assumed, and focus is set on searching the optimal number of hidden units. In an attempt to keep the network small, three bits are used for the representation of the hidden units, resulting to a chromosome of nine bits which simultaneously evolves the subset of input features and architecture of the network (Figure 2).

The ASLA appropriately adjusts the architecture of the employed MLP by applying the following genetic algorithm.

Step 1. Randomly generate the initial population P
Step 2. Decode each individual (chromosome) into an architecture
Step 3. Evaluate individuals:

a. Train each network with a predefined training algorithm and parameters
b. Define the fitness of each individual according to the training result and other performance criteria, such as the complexity of the architecture

Repeat
Step 4. Select a set of promising individuals and place them in the mating pool
Step 5. Apply crossover to generate offspring individuals
Step 6. Apply mutation to perturb offspring individuals
Step 7. Replace P with the new population
Step 8. Evaluate all individuals in P (as in step 3)
Until 10 generations

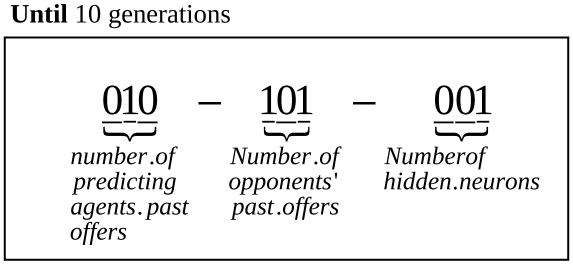

Figure 2. A chromosome consisting of 9 bits is used to evolve the input subset and the number of hidden neurons of the neural network.

Every time the genetic algorithm is run, the agent selects the MLP with the lowest fitness function. He then applies the MLP to forecast his counterpart's response in a similar way to that of the SSLA. More specifically, the ASLA initially generates a random population of individuals (Step 1). Each individual is translated to the respective MLP (Step 2), which is then trained and evaluated (Step 3).

The training patterns are extracted from the current negotiation thread. If the available number of previous predicting agent's offers at decision making time t is m, and for opponent's offers is n, where m,n ϵ {0,1,…,t/2} and m+n>0, the first observation is extracted at time t' is:

$$t' = \begin{cases} 2m+2, if .2m-2n-1>0 \\ 2n+2, if .2m-2n-1<0 \end{cases} \tag{4}$$

and the size of the available dataset at time t is:

$$|Dataset| = 1 + \frac{t-t'}{2} \tag{5}$$

As far as the objective (fitness) function is concerned, since $|Dataset|$ must be at least 2 to apply the LM method, the ASLA favors solutions that result to $|Dataset| \geq 2$. Furthermore, in cases where it is possible to divide the available data in three sets (training, validation and test set), the objective (fitness) function, which is minimized through the GA solver, is proportional to the Mean Squared Error (MSE) of the test set. Preference is given to solutions which result to more data patterns, in order to apply an early stopping learning method, which guarantees better generalization.

After evaluation, the most promising individuals are placed in the mating pool (Step 4), and GA operators are applied (Steps 5 and 6) to formulate the new population (Step 7). The new individuals are in turn evaluated (Step 8) and the process is repeated for 10 generations. The trained MLP that yields from the most promising individual is applied for the purpose of forecasting the counterpart's next offer.

It is important to note that implementation of ASLA advances the state of the art in the field of applying Neural Networks in negotiations to predict the counterpart's responses. It is based on an optimization technique and illustrates a pathway of finding a sub-optimal structure and subset of input features for the network. It could be used as a reference point in the development of other forecasting tools that assist negotiators. Additionally, it is a way of addressing the issue of heterogeneity of existing systems when it comes to selecting the offers of the negotiation thread which will constitute the input of the forecasting tool. In the following section SSLAs and ASLAs are compared.

V. Comparison of SSLAs and ASLAs

For the conduction of the experiments we have developed a simulator that produces negotiator objects in Java (Jdk version 1.6), which are then extended in Matlab (version 2008R) and are enhanced with learning techniques. The negotiator objects are capable of conducting bilateral multi-issued negotiations. Experiments involve the generation of different negotiation environments, with provider and consumer agents, which can perform learning tasks, and engage in negotiations following the predictive strategy discussed in [9].

To compare session-long learning agents and current state of the art agents we conducted numerous experiments, simulating different negotiation environments. The cases studied involved short negotiations, where each counterpart set a deadline of 50 steps, as well as long negotiations, where the counterparts set a deadline of 350 steps. It was observed that SSLAs reduced the average of absolute prediction error by 92.67% compared to agents that only trained the MLP at a pre-negotiation stage, in cases where data distributions changed (turbulent settings).

In this research, focus is set on the comparison of the two types of session-long learning agents. In this respect 1,359 negotiation environments, where the participants adopted various strategies, deadlines and reservation values, were simulated. Negotiations were conducted between SSLAs and non-learning agents, and between ASLAs and non-learning agents with the objective to measure the accuracy of the predictions in each case. More specifically, in each negotiation round the absolute error, defined as the difference between the prediction and the actual value, is computed. Assessment is provided through the computation of statistical information (mean, standard deviation and maximum value of the absolute errors) in each negotiation instance. The purpose of the comparison is to illustrate the deviation of the error as the agents negotiate in new settings.

Results which illustrate average and maximum values of the computed variables are summarized in Table 1. Avg Mean and Max Mean refer to the average and maximum value of the mean of absolute errors. Accordingly, Avg Std and Max Std refer to the average and maximum standard deviation observed, while Avg Max and Highest Max stand for the average and maximum of the highest error values acquired in negotiations. The ASLA is shown to be more accurate in the general case since it yields reduction of the mean of absolute errors (Avg Mean) by 38.34%, reduction of Avg Max by 44.74% and reduction of Avg Std by 38.03%. More specifically, when the ASLA deals with counterparts following time dependent (TD) strategies the same measures (Avg Mean, Avg Max and Avg Std) are reduced by 36.11%, 37.24%, and 31.52% respectively, while when it deals with counterparts following behavior dependent (BD) strategies Avg Mean, Avg Max and Avg Std are reduced by 38.45%, 45.29%, and 38.32%.

SSLAs and ASLAs can be safely used in cases where the counterpart's strategy can be expressed by continuous functions. In the scenarios described, these are the cases with TD strategies, yielding to SSLA and ASLA Avg Mean of 0.36 and 0.23, Avg Max of 6.66 and 4.18, and Avg Std of 0.92 and 0.63 respectively.

On the contrary, when opponents' behavior is sharp (as is the case of BD strategies), neural networks are less accurate. In the experiments conducted, cases with BD strategies yield to SSLA and ASLA Avg Mean of 11.91 and 7.33, Avg Max of 88.96 and 48.67, and Avg Std of 19.23 and 11.86 respectively.

ASLAs are not as fast as SSLAs and have higher storage requirements. However, they yield better results as they prove more accurate with decreased standard deviation and maximum error values.

VI. Conclusions and Future Reasearch

Current state of the art negotiating agents and support tools are enhanced with learning techniques in order to provide increased benefit to the parties they represent or support. A very promising skill is to foresee the counterpart's future moves and accordingly adapt one's decisions. The trend lies on neural networks, which have been proved efficient for various systems and domains. These models are capable of mapping input to output space, as long as appropriate data are used for training. The networks' accuracy is dependent on the training set. The problem that arises from current implementations is that (in the majority) the employed networks are trained at a pre-negotiation step. Results are impressive if data with similar underlying distributions are considered. However this is not the case in turbulent environments. In this research, the perspective of using data solely extracted from the actual negotiation thread is considered, and focus is set on the employment of very simple networks initiated without any a priori knowledge (random initial weights). A static session-long learning agent (SSLA), using a network with fixed architecture and standard input features, and an adaptive session-long learning agent (ASLA), evolving its network structure and feature subset in each negotiation round, are described and implemented.

The adaptive agent, ASLA, is empirically proved to be more accurate when dealing with opponents that adopt time and behavior dependent strategies; however it is observed that both agents yield high utility gain in cases where the counterpart's strategy is defined by continuous functions (which is the case of time dependent strategies), and do not score that high when opponents adopt behavior dependent strategies. Refinement of the predictive strategy discussed in [9] will be considered in the future, in order to also tackle opponents with smart or hybrid behaviors.

SSLAs and ASLAs have been implemented without any assumption of data distributions and for this reason they could also be applied in different types of negotiation arenas.

ASLAs have proved more efficient than SSLAs, however the trade-off is the increased time of convergence. Other efficient adaptive structures can be considered, such as Evolving Fuzzy Neural Networks (EFuNNs) or DENFIS, which are Evolving Connectionist Systems (ECoS) that continuously evolve their structure and functionality to capture the dynamics of turbulent settings [20].

TABLE I. COMPARISON OF SESSION-LONG LEARNING AGENTS

Measured Variables		Avg Mean		Max Mean		Avg Max		Highest Max		Avg Std		Max Std	
		SSLA	ASLA	SSLA	ASLA	SSLA	ASLA	SSLA	ASLA	SSLA	ASLA	SSLA	ASLA
Totals	TD	0.36	**0.23**	8.9	**4.67**	6.66	**4.18**	476.61	**127.14**	0.92	**0.63**	49.85	**15.19**
	BD	11.91	**7.33**	183.92	**52.16**	88.96	**48.67**	3050	**264.78**	19.23	**11.86**	346.99	**68.11**
Overall	TD,BD	6.13	**3.78**	183.92	**52.16**	47.81	**26.42**	3050	**264.78**	10.07	**6.24**	346.99	**68.11**

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Using Ontology and RFID Technology to Develop an Agent-based System for Campus-safety Management

Sheng-Tzong Cheng and Jian-Pan Li
Department of Computer Science and Information Engineering, National Cheng Kung University
Tainan, Taiwan
E-mail: stcheng@mail.ncku.edu.tw, keyboard802@hotmail.com

***Abstract*—This study proposes a distributed multiagent system combining radio-frequency identification press (RFID) technology with an ontology for real-time monitoring in support of dynamic campus-safety management. Safety management on campus typically involves relevant supporting measures and manuals, but serious safety-related incidents continue to take place on campuses. The goal of campus security should be to identify an incident and resolve it effectively and in real time before the incident evolves into an actual crisis. Our purpose here is to improve the traceability of students involved in campus activities—that is, to identify students' whereabouts throughout the entire school day. When an incident occurs, our system will notify the relevant parties immediately. In the present study, the agents real-time event processing increases their situational awareness and reduces the likelihood and the severity of unwanted outcomes.**

Keywords- multiagent system; RFID; campus-safety management; real-time event processing

I. INTRODUCTION

Campuses should provide students with educational activities, and safety on campus is fundamental to all education. Safety incidents occur year after year, resulting in injury to students. To enhance the management of campus safety, schools should consider real-time monitoring of the campus environment. In recent years, campus-safety issues have garnered considerable attention, some of which has taken the form of studies on campus-safety technology. Many studies have integrated information technology into campus-safety management. In [5], the authors explored the relationship between communication technology and campus safety, and presented some ideas about early-warning mechanisms. In [3], the authors proposed an intelligent campus-safety tracking system using radio-frequency identification (RFID) and Zigbee technology. In [13], the authors proposed an innovative application for RFID systems in special-education schools. RFID technology is an important tool in many fields of study. In [11], when the RFID tag cost is very small, employing the RFID technology yields an improved larger expected profit and smaller risk. In [9], the authors developed an application system using contactless IC card and RFID reader related to the improvement of the campus safety protection. RFID middleware is one of the main research areas in the field of RFID applications in the near future [1]. We have been using agent technology to solve RFID middleware overloading problem. Our system uses artificial intelligence techniques to learn and automate certain processes. Many experts found that characteristics of intelligent behavior do not rely on individual agents that can be generated. According to researchers in the cognitive sciences [2], agents use mechanisms that facilitate communication and cooperation. Agents interact with one another in networks' open environments, and in this type of scenario, two conditions must be met: first, agents must be able to find one another [7]; and second, agents must be able to interact with one another. To permit interactions among multiple agents [8, 10], designers must give the agents a common language and rules. In [4], the authors developed a conceptual framework based on multi-agent systems and ontology technology in order to create a virtual observatory with semantically enriched web services. In [6], the author proposed an ontology-based and rule-based relevant learning objects discovery.

The purpose of this paper is to improve the traceability of campus-safety management systems on the basis of RFID technology and ontology technology. We propose an agent-based system for tracking students during campus activities, thus permitting knowledge of students' whereabouts throughout the entire school day. Our system would help school staff monitor many types of situations in schools. This paper's focus is on how to utilize ontology-based campus-safety management for multi-agent systems. We explore campus-safety management problems associated with imported multi-agent systems. Our proposed system should strengthen campus safety. This paper is organized as follows. Section 2 describes related problems and presents a scenario analysis. Section 3 describes the agent-based system's design using ontology and RFID technology. Section 4 presents the actual implementation and evaluation of the proposed system. The final section presents our conclusions.

II. PROBLEM STATEMENTS AND SCENARIO ANALYSIS

A. Case study

We discuss campus-safety management at the Tainan School of Special Education in Taiwan. According to the inspection results regarding to our campus visits, most of the students studying in Tainan School of Special Education have multiple disabilities. Therefore, we take the situation of students with special needs into consideration and let them know how we can assure a safe-learning environment. In this paper, we first surveyed the whole campus environment and some areas where students' activities take place. From our survey, we can understand the students' everyday life at school during the whole school days. We then analyzed the findings, paying particular attention to student-safety incidents associated with specific areas on the school campus.

B. Problem statements

The Tainan School of Special Education in the past only installed surveillance camera at specific fixed points. Students were particularly prone to damage in such dangerous areas as restrooms, where the school had installed emergency call buttons that maybe could not provide immediate assistance. After the occurrence of safety incidents on campus, school staff began discussing in greater depth various issues related to possible improvements in accident-prevention mechanisms. Relying on just one specific surveillance camera is difficult to monitor students' activities. If we want to track the current state of the students on campus, it is a really difficult task. When school staff traced the cause and whole story of the incident, they might not reach an accurate conclusion. In this case, school staff doesn't seem to figure this accident out in the meeting hence it is inevitable that the similar accident may happen again in the future. Once we fail to guarantee a safe campus environment where the students' activities take place, it will result in the inefficiency of campus safety protection. If we do not really realize the reasons causing dangerous accidents, it may result in very serious consequences regarding to the maintenance and operation of the follow-up campus safety issues. We will find out the potential safety problems, which make the maintenance of campus safety and operational efficiency too low when we survey a safe-learning environment issues in school.

C. Scenario analysis

We developed several scenarios regarding campus-safety management service by using RFID ubiquities technology and ontology.

- Student-tracking management service

In the classroom, this service can accurately determine student's identity, while recording students attend status information. If students have not yet entered a classroom after the start of class, the teacher should immediately track the location by using RFID technology of the students.

- Dangerous-area warning service

When students enter danger zones, the proposed system can immediately determine the students' position and identify the pertinent characteristics of real-time situations. Then the system can inform guards that students are to be removed from the danger zones.

- Body-temperature monitoring service

An RFID tag can measure the student's body temperature that it can also measure the indoor temperature. Each student wears an RFID tag which has an important function measuring body temperature on the wrist. When students into the classroom after 20 minutes, this service can accurately determine student's identity, and began to measure the student's body temperature up to 5 minutes average temperature.

- Mobility-impairment assistance service

When mobility-impaired students wear RFID tags into the restroom after the system accurately determine the student's identity, the system will start record time of students into the restroom. If a student stays in the restroom for a long time, the system will automatically determine the student in the restroom for unusual events. Then this service will inform school staff go to the restroom and confirm the status of the students.

- The school-bus roll-call service

The school bus is identified through GPS positioning. We set up an RFID reader in the school bus. When a student goes to school by school bus, he only must access the bus. If a student by school bus after school, he only must leave the bus. A teacher will connect to RFID reader using mobile phone's Bluetooth. Therefore, once there are any students fail to catch the bus on time, the only thing that the teacher on the school bus has to do is report the abnormal situation to the school's back-end management system via 3G mobile phone.

- Extracurricular-education roll-call service

The teachers should be able to keep abreast of the location and the status of the students during extracurricular-education events. Therefore, the teacher should use a dynamically configured RFID reader and a wireless access point to communicate over wireless networks so as to judge students' status. When a student's RFID tag signal disappears from a monitoring range, the system will send a message to teachers' PDA, and then the teachers can find the student according to the student's final position.

III. AGENT-BASED CAMPUS-SAFETY MANAGEMENT SYSTEM

We propose an agent-based system for the management of campus safety, and use RFID devices to determine students' identity and location on campus. We also use ontology to provide for efficient communication among agents.

A. Analysis of the proposed system

We have tried to design an agent-based campus-safety management (ACSM) system, and in this endeavor, we have used RFID technology to solve campus-safety issues. Figure 1 illustrates our proposed campus-safety information system. Part one of this paper discussed deployment of RFID systems in campus scenarios, with particular regard to data collection and transmission systems. We summarized students' behavior patterns in different types of scenarios. These RFID readers can cover a wide range of student activities, including off-campus education and recreational activities. The gateway interface would be responsible for real-time data collection and transmission. In part two, we will discuss how our proposed information system integrates RFID technology into ACSM systems. We developed the RFID monitoring system to aid students at an assisted-living facility during the school day. The system displays students' location and other pertinent information via a web interface. The system uses active tags to communicate with a number of fixed active readers. The early-warning system is a component of real-time monitoring and recording of data in a campus environment. The early-warning system would involve the transmission of automatic alerts and real-time information to appropriate personnel. In part three, we will discuss software and hardware features of database system with RFID middleware. In part four, we will discuss automatic early-warning information systems, which can alert parents, teachers, system administrators, and other school staff of potential problems.

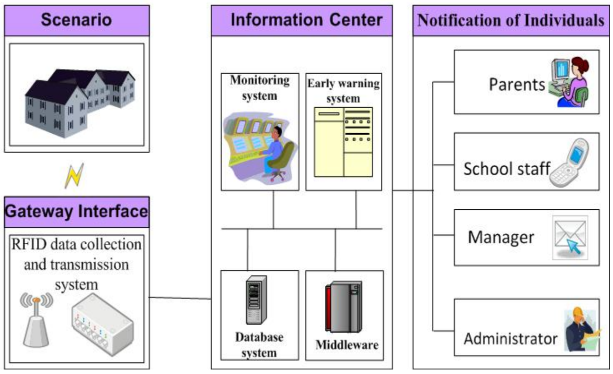

Figure 1. Campus-safety information system.

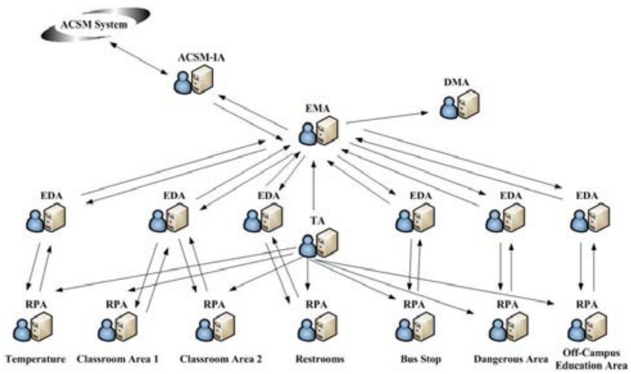

Figure 2. Multi-layered agent system

B. Multi-layered agent system

The multi-layered agent system can be observed from two perspectives. The first one involves individual agents playing their own role, while the second one involves the interactions of all agents with one another. If one agent requires the assistance of another agent in order to achieve a goal, then we can say that a relationship of dependence exists between the two agents. Agents need to take requests from and communicate the results back to school staff. Our aim is to help multiple agents collaborate intelligently and effectively with one another, so that they can provide immediate assistance to students in campus environments. We designed the proposed system on the basis of the multi-layered agent model shown in Figure 2. We define six types of agents, as described in the following bulleted points.

- RFID Process Agent (RPA): We have deployed an RPA in classrooms, restrooms, bus stops, dangerous areas, and off-campus education areas. The RPA is responsible for gathering all the information in these zones. This agent is deployed in each region. Combining an RFID reader with middleware on a local PC facilitates the real-time monitoring of students' temperatures. After collecting information about students' status, the RPA sends the information to the event-decision agent (EDA).
- Trace Agent (TA): This agent is responsible for monitoring the operating status of the RPA. The TA will continue to detect whether the RPA is engaged in normal operations or not. The TA will report the actual situation of the regional RPA to the event-management agent (EMA) at any time.
- Event-decision Agent (EDA): Every region of the campus has an EDA. When the EDA receives information collected from the RPA, the EDA will be responsible for analyzing this information to determine whether the students' independent behavior is normal or abnormal. The EDA will make use of the appropriate decision-making mechanism, and at the same time inform the responsible units in the region. The EDA will process independent events, and will then process the results and send them to the EMA.
- Event-management Agent (EMA): This agent plays a role in coordination and communication with several different agents. The EMA will receive all campus information from TAs. The EMA is also responsible for receiving each region's EDA decision-making

event results and for managing all events. The EMA will notify the agent-based campus-safety management interface agent (ACSM-IA) while EMA stores event-related information in the database-management agent (DMA).

- Database-management Agent (DMA): The DMA is responsible for records all the event process results. The DMA also conducts database management and provides queries for specific events that match a specific criterion.
- Agent-based Campus-safety Management Interface Agent (ACSM-IA): This agent serves as an interface to the ACSM system.

We have used the model of the block-like representation of interactive components [12] (BRIC) to build and simulate the behaviors of a multi-layered agent system. We have also used the BRIC model to characterize agents' internal status and agent–agent interactions. We will describe agent modeling because the internal structure of event-management agent is more complex than the internal structure of other agent types. Figure 3 illustrates the BRIC model for the EMA, and TABLE I describes in details the agent modeling to the EMA. In the BRIC model described in Figure 3, one symbol denotes 'Input/Output' representing the relationships between agents and their environment while the other symbol represents the agent's internal mechanisms and actions.

C. Agent-ontology model for an ACSM system

It is important for agents to interact with one another on campus. In our multi-agent environment, agents need to exchange results with one another. We use ontology in order to knowledge sharing agents' establishment of effective communication in a multi-layered agent system. For our current study, we began the ontology-modeling phase by conducting an extensive case analysis of campus scenarios.

This study proposes a campus knowledge base (CKB) design for ontology modeling and implementation. The CKB defines a new efficient and flexible resource-ontology model able to be immediately applied to multi-agent environments. Organization of a hierarchical CKB is illustrated in Figure 4. The CKB maintains all campus data in semantic storage. These resources are available to agents, and can help agents maintain the safety of campus activities. The ontology of data collection and transmission supports efficient data collection, transmission, and management.

Events ontology deals with real-time incidents. An event must have location information, an event time, agent information, event-trigger factors, and student identifications. Our rules ontology plays a key role in the hierarchical architecture of agents' coordination of accident-prevention mechanisms and communications with other

TABLE I. DESCRIPTION OF A BRIC MODEL FOR AN EVENT-MANAGEMENT AGENT

P01 Receiving data from an event-decision agent
P02 Processing data
P03 Creating an event-management agent based on campus information
P04 Initiating an event-management agent with log information
P05 Dispatching an event-management agent to an agent environment
P06 Receiving requests from a trace agent
P07 Evaluating requests from a trace agent
P08 Sending requests to an ACSM-IA agent
P09 Receiving feedback information from an ACSM-IA agent
P10 Consolidating feedback information from an ACSM-IA agent
P11 Sending consolidated feedback to a database-management agent
P12 Receiving requests from an event-decision agent
P13 Evaluating an event's priority
P14 Sending requests to a database-management agent
P15 Receiving feedback information from a database-management agent
P16 Evaluating information from all sources
P17 Sending results to an ACSM-IA agent

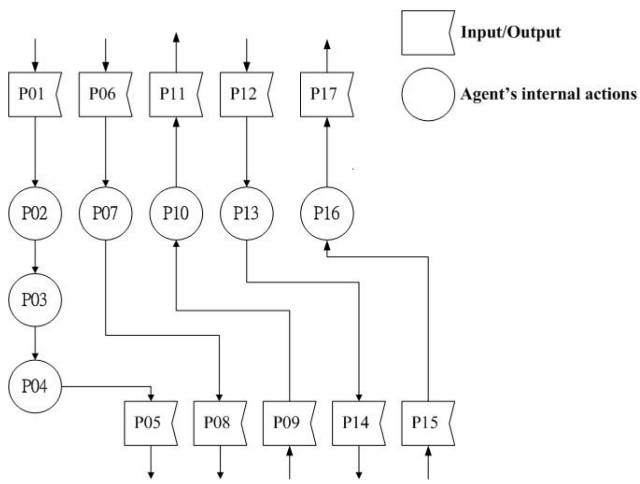

Figure 3. A BRIC model of an event-management agent

agents. Environmental ontology deals with the definition of the roles and behaviors corresponding to agents in charge of executing resource-related tasks.

IV. SYSTEM DESIGN AND IMPLEMENTATION

In order to validate the proposed system architecture, we tested various scenarios which the students may encounter in Tainan School of Special Education. In this paper, we discussed the implementation of a system, including different scenarios for the subsystems and hardware devices and clear demonstration for the proposed system design.

A. Development environment

The development environment for the prototype system is described below:

- Operating Systems: server = Microsoft Windows Server; client = Web-based operating system.
- Backend Database Server: Microsoft SQL Server.
- Application program: Microsoft .NET Framework, ASPs (Active Server Pages), PHP (Hypertext Preprocessor), J2EE technology stack.
- Frontend RFID Middleware Server: Windows Server.
- Frontend RFID Application Server: Windows Server.
- WiNOC (Wired/Wireless Network Operations Center.
- RFID tag: 2.45GHz Active RFID tag. RFID reader: 2.45 GHz Active RFID reader (shown in Figure 5).

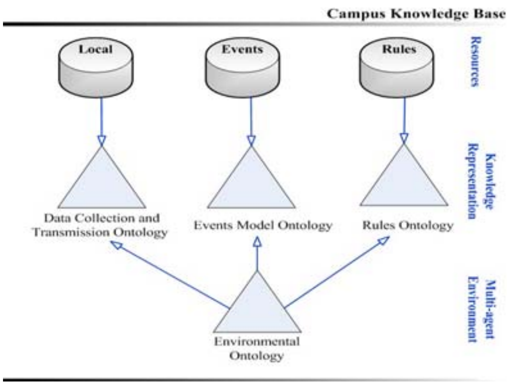

Figure 4. Organization of a hierarchical campus knowledge base

Figure 5. RFID reader and tag

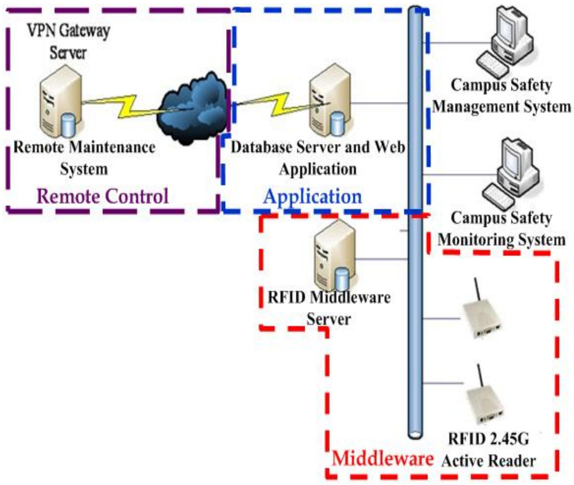

Figure 6. RFID system for campus safety

B. System implementation

This paper presents an integrated information system that real-time monitoring in support of dynamic accident-prevention mechanisms. Our research in an agent-based system is built upon a Java Agent Development (JADE) framework. JADE involves a set of agents that execute tasks and interact with one another by exchanging messages according to FIPA specifications governing the agent communication language (ACL). The agents work collectively to achieve common goals in a JADE environment. JADE simplifies the implementation of the multi-layered agent system through a set of graphical tools that supports the deployment phases. The agent platform can be distributed across machines and the configuration can be controlled via a remote graphical user interface. The system is divided into three parts: remote control, web application and RFID middleware server, as shown in Figure 6.

C. Performance evaluation

We will now present a test scenario for the dangerous-area warning service. Figure 7 presents a diagram of the dangerous-area test architecture. The danger zone size is 2.5M by 2.5M. When a student from point A into the danger zone that the average walking time requires is 4.5 seconds, the average running time that a student requires is 1.5 seconds. When a student from point B into the danger zone that the average walking time requires is 4.8 seconds, the average running time that a student requires is 1.9 seconds. In order to prevent students from entering the danger zone, both RFID Reader 1 and RFID Reader 2 can simultaneously detect an active tag. We used ten active tags to carry out this simulation. The percentage of accurate tag readings is illustrated in Figure 8. Figure 9 presents the tag-reading response times.

V. CONCLUSION

Through RFID technology and ontology technology, we can transform passive security systems into active security systems. When students encounter emergencies, their RFID tags can send out a distress message from any corner of a campus. Basically, in this paper, we aim to demonstrate the feasibility and applicability of utilizing agent-based technologies to the special-education students. In summary, this research makes the following contributions to improving the traceability and the efficiency of campus-safety management systems.

- We proposed a distributed multiagent system combining RFID technology with a hierarchical campus knowledge base ontology model to strengthen real-time monitoring and dynamic accident-prevention mechanisms in respect of ubiquitous campuses.
- We classified students' behavior patterns regarding different types of scenario relationships.
- The proposed framework can indeed improve the traceability of students throughout the entire school day.
- Our system can provide both school staff and parents with real-time information, helping them both respond to the status of students in real time and make better decisions in handling independent events.

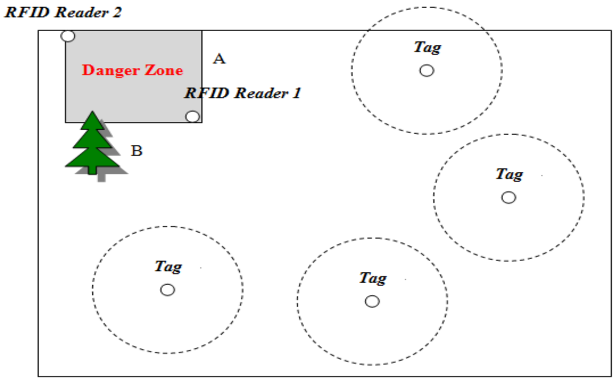

Figure 7. Diagram of the dangerous-area test architecture

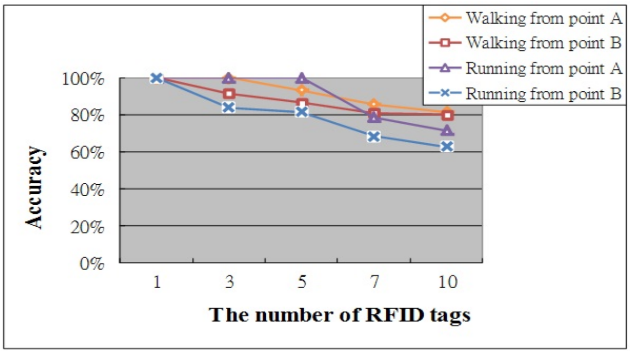

Figure 8. The percentage of accurate tag readings

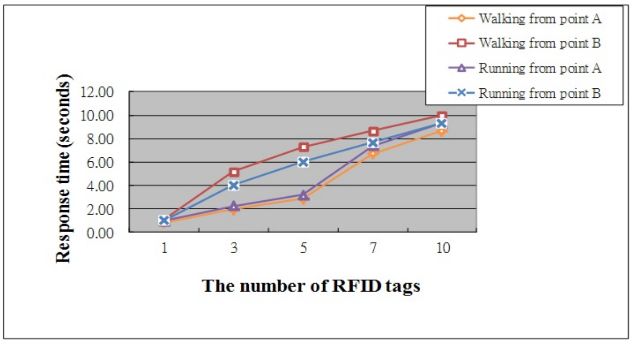

Figure 9. Tag-reading response times

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Compositions of Fuzzy Weights for Double Inner Dependence AHP

Shin-ichi Ohnishi
Faculty of Engineering
Hokkai-Gakuen University
Sapporo, Japan
ohnishi@hgu.jp

Takashi Furukawa
Graduate school of Engineering
Hokkai-Gakuen University
Sapporo, Japan
6512103t@edu.hgu.jp

Takahiro Yamanoi
Faculty of Engineering
Hokkai-Gakuen University
Sapporo, Japan
yamanoi@lst.hokkai-s-u.ac.jp

***Abstract* - Analytic Hierarchy Process (AHP) is major method for decision making now and decision maker's answers are strongly related to his or her cognitive abilities. Inner dependence AHP is used for cases in which criteria or alternatives are not independent enough. In the process, calculations and compositions of weights are very important steps. Using the original AHP or inner dependence AHP may cause results losing reliability because the comparison matrix is not necessarily sufficiently consistent. In such cases, fuzzy representation for weighting criteria or alternatives using results from sensitivity analysis is useful. In the previous papers, we defined local weights of criteria and alternatives for inner dependence AHP via fuzzy sets. In this paper, we deal with overall weights of alternatives for double inner dependence structure AHP (among criteria and among alternatives respectively). Results show the fuzziness of double inner dependence structure AHP in different way of composition of weights.**

Keywords - decision making; AHP; fuzzy sets; sensitivity analysis.

I. Introduction

The Analytic Hierarchy Process (AHP) proposed by T.L. Saaty in 1977 [1][2] is widely used in decision making, because it reflects humans feelings "naturally". A normal AHP assumes independence among criteria and alternatives, although it is difficult to choose enough independent elements. Inner dependence method AHP [3] is used to solve this problem even for criteria or alternatives having dependence.

A comparison matrix may not, however, have enough consistency when AHP or inner dependence is used because, for instance, a problem may contain too many criteria or alternatives for decision making, meaning that answers from decision-makers, i.e., comparison matrix components, do not have enough reliability, they are too ambiguous or too fuzzy [4]. To avoid this problem, we usually have to revise again or abandon the data, but it takes a lot of time and costs[2][3].

Then, we consider that weights should also have ambiguity or fuzziness. Therefore, it is necessary to represent these weights using fuzzy sets.

Our research first applied sensitivity analysis [5] to inner dependence AHP to analyze how much the components of a pairwise comparison matrix influence the weights and consistency of a matrix [6]. This may enable us to show the magnitude of fuzziness in weights. We previously proposed new representation for criteria and alternatives weights in AHP, also representation for criteria weights for inner dependence, as L-R fuzzy numbers [7]. In the next step, we stated deal with double inner dependence structure [8]. In this paper, we consider composition of weights to obtain over all alternative weights for double inner dependence structure AHP, using results from sensitivity analysis and fuzzy operations. We then consider fuzziness as a result of double inner dependence AHP when a comparison matrix among alternatives does not have enough consistency.

In Section II, we introduce AHP and its inner dependence method. The sensitivity analyses for AHP are described in Section III. Then the fuzzy weight representation is defined in Section IV, and Section V is a example and conclusions.

II. Inner Dependence AHP and Consistency

In this section, we introduce process of AHP, consistency of data (comparison matrix) and inner dependence method.

A. Process of Normal AHP

(Process 1) Representation of structure by a hierarchy. The problem under consideration can be represented in a hierarchical structure. At the middle levels, there are multiple criteria. Alternative elements are put at the lowest level of the hierarchy.

(Process 2) Paired comparison between elements at each level. A pairwise comparison matrix A is created from a decision maker's answers. Let n be the number of elements at a certain level, the upper triangular components of the matrix a_{ij} ($i< j = 1,\ldots,n$) are 9, 8, .. , 2, 1, 1/2, …, or 1/9. These denote intensities of importance from element i to j. The lower triangular components a_{ji} are described with reciprocal numbers, for diagonal elements, let $a_{ii} = 1$.

(Process 3) Calculations of weight at each level. The weights of the elements, which represent grade of importance among each element, are calculated from the pairwise comparison matrix. The eigenvector that corresponds to a positive eigenvalue of the matrix is used in calculations throughout in this paper.

(Process 4) Priority of an alternative by a composition of weights. With repetition of composition of weights, the overall weights of the alternative, which are the priorities of

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the alternatives with respect to the overall objective, are finally found**.**

B. Consistency

Since components of the comparison matrix are obtained by comparisons between two elements, coherent consistency is not guaranteed. In AHP, the consistency of the comparison matrix *A* is measured by the following consistency index (C.I.)

$$\text{C.I.} = \frac{\lambda_A - n}{n-1}, \tag{1}$$

where n is the order of comparison matrix A, and λ_A is its maximum eigenvalue (Frobenius root).

If the value of C.I. becomes smaller, then the degree of consistency becomes higher, and vice versa. The omparison matrix is consistent if the following inequality holds.

$$\text{C.I.} \leq 0.1 \tag{2}$$

C. Inner Dependence Structure

The normal AHP ordinarily assumes independence among criteria and alternatives, although it is difficult to choose enough independent elements. Inner dependence AHP [3] is used to solve this type of problem even for criteria or alternatives having dependence.

In the method, using a dependency matrix $F=\{ f_{ij} \}$, we can calculate modified weights $\boldsymbol{w}^{(n)}$ as follows,

$$\boldsymbol{w}^{(n)}=F\boldsymbol{w} \tag{3}$$

where $\boldsymbol{w}$ is weights from independent criteria or alternatives, i.e., normal weights of normal AHP and dependency matrix F is consist of eigenvectors of influence matrices showing dependency among criteria or alternatives.

If there is dependence both lower levels, i.e., not only among criteria but also among alternatives, we call such kind of structure "double inner dependence". In the double inner dependence structure, we have to calculate modified weights of criteria and alternatives, $\boldsymbol{w}^{(n)}$ and $\boldsymbol{u}_i^{(n)}$. Then we composite these 2 modified weights to obtain overall weights of alternative k, $v_k^{(n)}$ as follow:

$$v_k^{(n)} = \sum_i^m w_i^{(n)} u_{ik}^{(n)} \tag{4}$$

where m is number of criteria.

III. Sensitivity Analyses

When we actually use AHP, it often occurs that a comparison matrix is not consistent or that there is not great difference among the overall weights of the alternatives. In these cases, it is very important to investigate how components of the pairwise comparison matrix influence on its consistency or on the weights. To analyse how results are influenced when a certain variable has changed, we can use sensitivity analysis.

In this study, we use a method that some of the present authors have proposed before. It evaluates a fluctuation of the consistency index and the weights when the comparison matrix is perturbed. It is useful because it does not change a structure of the data.

Since the pairwise comparison matrix is a positive square matrix, Perron-Frobenius theorem holds. From Perron-Frobenius theorem, following theorem about a perturbed comparison matrix holds.

Theorem 1 *Let* $A = (a_{ij})$, $(i, j = 1,\dots, n)$ *denote a comparison matrix and let* $A(\varepsilon) = A+ \varepsilon D_A$, $D_A=(a_{ij}d_{ij})$ *denote a matrix that has been perturbed. Let* λ_A *be the Frobenius root of A,* $\boldsymbol{w}$ *be the eigenvector corresponding to* λ_A*, and* $\boldsymbol{v}$ *be the eigenvector corresponding to the Frobenius root of* A'*. Then, a Frobenius root* $\lambda(\varepsilon)$ *of* $A(\varepsilon)$ *and a corresponding eigenvector* $\boldsymbol{w}(\varepsilon)$ *can be expressed as follows*

$$\lambda(\varepsilon) = \lambda_A + \varepsilon\lambda^{(1)} + o(\varepsilon), \tag{5}$$

$$\boldsymbol{w}(\varepsilon) = \boldsymbol{w} + \varepsilon\boldsymbol{w}^{(1)} + \boldsymbol{o}(\varepsilon), \tag{6}$$

where

$$\lambda^{(1)} = \frac{\boldsymbol{v}' D_A \boldsymbol{w}}{\boldsymbol{v}' \boldsymbol{w}}, \tag{7}$$

$\boldsymbol{w}^{(1)}$ *is an n-dimension vector that satisfies*

$$(A - \lambda_A I)\boldsymbol{w}^{(1)} = -(D_A - \lambda^{(1)} I)\boldsymbol{w}\ , \tag{8}$$

where $\boldsymbol{o}(\varepsilon)$ *denotes an n-dimension vector in which all components are* $o(\varepsilon)$.

A. Analysis for Consistency of Pairwise Comparison

About a fluctuation of the consistency index, following corollary can be obtained from Theorem 1.

Corollary 1 *Using appropriate* g_{ij}*, we can represent the consistency index* C.I.(ε) *of the perturbed comparison matrix* $A(\varepsilon)$ *as follows*

$$\text{C.I.}(\varepsilon) = \text{C.I.} + \varepsilon \sum_i^n \sum_j^n g_{ij} d_{ij} + o(\varepsilon). \tag{9}$$

To see g_{ij} in the equation (9) in Corollary 1, how the components of a comparison matrix impart influence on its consistency can be found.

B. Analysis for Weights of AHP

About the fluctuation of the weights, following corollary also can be obtained from Theorem 1.

Corollary 2 *Using appropriate* $h_{ij}^{(k)}$, *we can represent the fluctuation* $\boldsymbol{w}^{(1)}=(w_k^{(1)})$ *of the weight* (*i.e., the eigenvector corresponding to the Frobenius root*) *as follows*

$$w_k^{(1)} = \sum_i^n \sum_j^n h_{ij}^{(k)} d_{ij}. \tag{10}$$

From the equation (6) in Theorem 1, the component that has a great influence on weight $\boldsymbol{w}(\varepsilon)$ is the component which has the greatest influence on $\boldsymbol{w}^{(1)}$. Accordingly, from Corollary 2, how components of a comparison matrix impart influence on the weights, can be found, to see $h_{ij}^{(k)}$ in the equation (10).

Calculations or proofs of these theorem and corollaries are shown in [7].

IV. Fuzzy Weights Representations

A comparison matrix often has poor consistency (i.e., 0.1<C.I.<0.2) because it encompasses several criteria or elements. In these cases, comparison matrix components are considered to be fuzzy because they are results from human fuzzy judgment. Weights should therefore be treated as fuzzy numbers.

A. L-R Fuzzy Number

L-R fuzzy number

$$M = (m, \alpha, \beta)_{LR} \tag{11}$$

is defined as fuzzy sets whose membership function is as follows.

$$\mu_M(x) = \begin{cases} R\left(\dfrac{x-m}{\beta}\right) & (x > m), \\ L\left(\dfrac{m-x}{\alpha}\right) & (x \le m). \end{cases}$$

where $L(x)$ and $R(x)$ are shape function .

B. Fuzzy Weights of Criteria or Alternatives of Normal AHP

From the fluctuation of the consistency index, the multiple coefficient $g_{ij}h_{ij}^{(k)}$ in Corollary 1 and 2 is considered as the influence on a_{ij} .

Since g_{ij} is always positive, if the coefficient $h_{ij}^{(k)}$ is positive, the real weight of criterion or alternative k is considered to be larger than w_k. Conversely, if $h_{ij}^{(k)}$ is negative, the real weight of criterion or alternative k is considered to be smaller. Therefore, the sign of $h_{ij}^{(k)}$ represents the direction of the fuzzy number spread. The absolute value $g_{ij}\,|\,h_{ij}^{(k)}|$ represents the size of the influence.

On the other hand, if C.I. becomes bigger, then the judgment becomes fuzzier.

Consequently, multiple C.I. $g_{ij}|h_{ij}^{(k)}|$ can be regarded as a spread of a fuzzy weight concerned with a_{ij}.

Definition 1 (fuzzy weight) Let $w_k^{(n)}$ be a crisp weight of criterion or alternative k of inner dependence model, and $g_{ij}\,|\,h_{ij}^{(k)}|$ denote the coefficients found in Corollary 1 and 2. If 0.1<C.I.<0.2, then a fuzzy weight $\tilde{w}_k$ is defined by

$$\tilde{w}_k = (w_k, \alpha_k, \beta_k)_{LR} \tag{12}$$

where

$$\alpha_k = \text{C.I.}\sum_i^n \sum_j^n s(-, h_{kij}) g_{ij}\,|\,h_{kij}\,|, \tag{13}$$

$$\beta_k = \text{C.I.}\sum_i^n \sum_j^n s(+, h_{kij}) g_{ij}\,|\,h_{kij}\,|, \tag{14}$$

$$s(+,h) = \begin{cases} 1, (h \ge 0) \\ 0. (h < 0) \end{cases}, \quad s(-,h) = \begin{cases} 1, (h < 0) \\ 0. (h \ge 0) \end{cases}$$

C. Fuzzy Weights for double inner dependence AHP

For double inner dependence structure, we can define and calculate modified fuzzy local weights of a criteria $\tilde{\boldsymbol{w}}^{(n)} = (\tilde{w}_i^{(n)}),\ i = 1, \ldots, n$ and also weights of alternatives $\tilde{\boldsymbol{u}}_i^{(n)} = (\tilde{u}_{ik}^{(n)}),\ k = 1, \ldots, m$ with only respect to criterion i using an dependence matrix F_C, F_A, as follows

$$\tilde{w}_i^{(n)} = (w_i^{(n)}, \alpha_i^{(n)}, \beta_i^{(n)})_{LR} \tag{15}$$

$$\tilde{u}_{ik}^{(n)} = (u_{ik}^{(n)}, \alpha_{ik}^{(n)}, \beta_{ik}^{(n)})_{LR} \tag{16}$$

where

$$\boldsymbol{w}^{(n)} = (w_i^{(n)}) = F_C \boldsymbol{w} \tag{17}$$

$$\boldsymbol{u}_i^{(n)} = (u_{ik}^{(n)}) = F_A \boldsymbol{u}_i \tag{18}$$

$\boldsymbol{w}$ is crisp weights of criteria and $\boldsymbol{u}_i$ is crisp local alternative weights with only respect to criterion *i*. $\alpha_i, \beta_i, \alpha_{ik}, \beta_{ik}$ are calculated by fuzzy multiple operations, equation(3) and definition 1.

Fuzzy overall weights of alternative k in double inner dependence AHP can be also calculated as follows using fuzzy multiple $\otimes$ and fuzzy summation operations:

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$$\tilde{v}_k^{(n)} = \sum_i^m \tilde{w}_i^{(n)} \otimes \tilde{u}_{ik}^{(n)} \quad (19)$$

Fuzzy weights $\tilde{w}_i^{(n)}$ becomes crisp weights $w_i^{(n)}$ if there is good consistency among criteria. Therefore

$$\tilde{v}_k^{(n)} = \sum_i^m w_i^{(n)} \otimes \tilde{u}_{ik}^{(n)} \quad (20)$$

In any cases we can evaluate fuzzy overall weights of alternatives with their centers and spreads.

V. EXAMPLE AND CONCLUSIONS

In this section, we introduce an example of the leasure. Criteria are {congestion, good for rain (rain), trouble, cost} and alternatives are {Theme park (park), Indoor theme park (indoor), Movie, Zoo}.

Table I shows a comparison matrix of criteria and weights, where its consistency is not so good (C.I. >0.1). Then using results of sensitivity analyses of consistency and weights, we can calculate fuzzy weights. Next using a dependency matrix, modified fuzzy weights are obtained as shown in Table II. There is bad dependency and dependency between alternatives with only respect to criterion "congestion", we also calculate fuzzy modified weights of alternatives shown in Table III. Finally, we evaluate overall fuzzy weights of alternatives as in Table IV.

On the other hand, TableV shows a comparison matrix and weights of criteria with enough consistency.

TABLE I. COMPARISON OF CRITERIA

	congestion	rain	trouble	cost	Weights
congestion	1	1/3	5	1	0.206
rain		1	2	1/2	0.165
trouble			1	1/3	0.499
cost				1	0.129

C.I.=0.169

TABLE II. FUZZY MODIFIED WEIGHTS OF CRITERIA

	Center	Left	Right
congestion	0.105	0.0170	0.0051
rain	0.202	0.0080	0.0098
trouble	0.523	0.0080	0.0056
cost	0.162	0.0140	0.0126

TABLE III. FUZZY MODIFIED WEIGHTS OF ALTERNATIVES WITH ONLY RESPECT TO "CONGESTIONS"

	Center	Left	Right
Park	0.257	0.0079	0.0094
Indoor	0.087	0.0029	0.0031
Movie	0.304	0.0113	0.0110
Zoo	0.351	0.1210	0.0097

TABLE IV. FUZZY OVERALL MODIFIED WEIGHTS OF ALTERNATIVES

	Center	Left	Right
Park	0.182	0.0091	0.0091
Indoor	0.277	0.0089	0.0089
Movie	0.405	0.0094	0.0094
Zoo	0.129	0.0050	0.0031

TABLE V. COMPARISON OF CRITERIA

	congestion	rain	trouble	cost	Weights
congestion	1	2	5	3	0.491
rain		1	2	3	0.266
trouble			1	2	0.140
cost				1	0.103

C.I.=0.044

TABLE VI. FUZZY OVERALL MODIFIED WEIGHTS OF ALTERNATIVES WI

	Center	Left	Right
Park	0.177	0.0012	0.0014
Indoor	0.296	0.0004	0.0005
Movie	0.378	0.0017	0.0017
Zoo	0.150	0.0018	0.0015

In this case, overall fuzzy weights are shown in Table VI. (lower weights are same as fuzzy criteria weight case).

There are a lot of cases that data of AHP do not have enough consistent or reliable. We propose these 2 compositions of weights, and our approach can show how to represent weights and will be efficient to investigate how the result of AHP has fuzziness when data is not sufficiently consistent or reliable.

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Cyber Forensics: Representing and Managing Tangible Chain of Custody Using the Linked Data Principles

Tamer Fares Gayed,
Hakim Lounis
Dépt. d'Informatique
Université du Québec à Montréal
Succursale Centre-ville, H3C 3P8,
Montréal, Canada
gayed.tamer@courrier.uqam.ca
lounis.hakim@uqam.ca

Moncef Bari
Dépt. de Didactique
Université du Québec à Montréal
Succursale Centre-ville, H3C 3P8,
Montréal, Canada
bari.moncef@uqam.ca

Rafek Nicolas
Service Technique Global
IBM
1360 René Lévesque, H3G 2W6
Montréal, Canada
rnicolas@ca.ibm.com

Abstract—**Tangible Chain of Custody (*CoC*) in cyber forensics (*CF*) is a document accompanying digital evidences. It records all information related to the evidences at each phase of the forensics investigation process in order to improve and prosecute them in a court of law. Because a digital evidence can be easily altered and loses its value, the *CoC* plays a vital role in the digital investigation by demonstrating the road map of Who exactly, When, Where, Why, What and How came into contact with the digital evidence. With the advent of the digital age, the tangible *CoC* document needs to undergo a radical transformation from paper to electronic data (*e-CoC*). This *e-CoC* will be readable, and consumed by computers. The semantic web is a fertile land to represent and manage the tangible *CoC* because it uses web principles known as Linked Data Principles (LDP), which provide useful information in Resource Description Framework (RDF) upon Unified Resource Identifier (URI) resolution. These principles are used to publish data publicly on the web and provide a standard framework that allows such data to be shared, and consumed in a machine readable format. This paper provides a framework explaining how these principles are applied to represent the chain of custodies and used only by actors in each forensics process, in order to be consumed at the end by the jury in a court of law. This paper also illustrates this idea by giving an example of the authentication phase imported from the Kruse forensics process.**

Keywords-Chain of Custody; Knowledge Representation; Provenance Vocabularies; Forensic Models; Semantic Web; Linked Data Principles; Public Key Infrastructure.

I. INTRODUCTION

Digital forensic is a technique for acquiring, preserving, examining, analyzing and presenting digital evidence in accordance with evidentiary rules and legal standards. One of the most essential parts of the digital investigation process is the chain of custody (*CoC*) [18]. *CoC* is a chronological document that accompanies all digital evidence in order to avoid later allegations of tampering with such evidences. *CoC* provides useful information about the digital evidences studied using a certain forensic process by answering 5 W and 1 H questions. The 5 W are the When, Who, Where, Why, What and the 1 H is the How. Because cyber forensic is a daily growing field and requires the accommodation on the continuous changes of digital technologies (i.e., concurrency with the knowledge management), the tangible *CoC* information also needs to undergo a radical transformation from paper to electronic data (*e-CoC*), readable and consumed by the computers. This transformation will be achieved through the support of different technologies used by the semantic web [3][7][8].

Today, the semantic web is the web of data, which is not just concentrated for the interrelation between web documents but also between the raw data within these documents. This data interrelation is based on four aspects known as the linked data principles (LDP). In 2006, Berners Lee outlined a set of rules [3][10] for publishing data on the web using these principles. They are used to apply general architecture of the World Wide Web [11] and explain that the data (content/resources) should be related to one another just as documents are already:

- Use Unified Resource Identifier (URI) as names for things and they are used as globally unique identification mechanism [12].
- Use Hyper Text Transfer Protocol (HTTP) as universal access mechanism so that people can look up those names [13].
- When someone looks up a URI, provide useful information using the standards (Resource Description Framework, SPARQL).
- Include RDF statements that link to other URIs so that they can discover related things (i.e., people locations, or abstract concepts).

Publishing data in a structured way can facilitate the consumption of such data and help its consumer to take the proper decision.

This paper resumes the task provided in [1][2]. These works provided a novel framework that uses the LDP to represent the tangible *CoC* in order to be consumed by the juries in the court of law. The framework provided in these works was abstract. This paper elaborates it into a set of layers and explains in detail the performed task in each of them by giving an example of the authentication phase imported from Kruse model [17]. This is the first

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work combining in the same framework the following disciplines: cyber forensics, semantic web, provenance of information, and security. We present how the semantic web and its technologies is a fertile land to represent the tangible *CoC* knowledge using the principles of the linked data and how this data is controlled/managed, and consumed only by the role player at each forensic phase and the jury of the court, respectively.

This work expands the framework provided in [1][2] with a security approach such as Public Key Infrastructure (PKI)[15][58] to ensure the identity and the authentication of each role player participating in the investigation process. Thus, the security approach arises in this context to protect and foster the published information related to the case in hand from unauthorized access.

This work also argues against the solution proposed in [65] concerning the judges' awareness and understanding of the digital evidence. This solution seeks to educate the juries about the field of Information and Communication Technology (ICT). However, the aim of this paper is the construction of an assistant system, offering the ability to juries to navigate, discover (dereference) and execute different queries on the represented information. This idea is underlined using code examples describing different aspects related to the representation of the chain of custody using LDP (e.g., Figure 2,3 and 4 are generated from RDF/XML codes using [66]). However, the PKI approach provided in this paper is theoretically presented and will be implemented in later publications. All concepts and components of this future system are discussed through the solution framework in Section 5.

The organization of this paper is as follows: the next section discuses the state of the art of the semantic web and the web of data. Section 3 outlines the reasons why the authors used LDP for representing the *CoC*. Section 4 provides a quick view about the forensics models and describes the tasks that are performed in the authentication phase and how forensics terms are specified in order to be later represented using LDP. Section 5 explains the solution framework in detail from the representation of data to its consumption by juries and explains how such data is controlled by only the authorized actors (i.e., role players and juries who participated in the court case). Finally, the last section concludes and summarizes this work, and presents the future extensions of the proposed framework. The related works in this paper are not presented in a separate section. However, they are mentioned in detail in [1][2], and through different references along the paper, especially in the explanation for each layer.

II. STATE OF THE ART: SEMANTIC WEB AND THE WEB OF DATA

Semantic web is an extension of the current web (i.e., from document to data) [7][8], designed to represent information in a machine readable format by introducing RDF model [16] to describe the meaning of data and allows them to be shared on the web in a flexible way. The classical way for publishing documents on the web is just naming these documents using URI and hypertext links. This fact allows the consumer to navigate over the information on the web using a web browser application and querying the information by typing keywords in a search engine that is working using the support of HTTP protocol. This is called the web of documents.

With the same analogy, entities and contents (data) within documents can be linked between each others using typed linked and with the same principles used by the web (i.e., web aspects). This is called the web of data. The Linking Open Data (LOD) project is the most visible project using this technology stack (URLs, HTTP, and RDF) and converts existing open license data on the web into RDF according to the LDP [3][10]. The LOD project created a shift in the semantic web community. Instead the concern was on the ontologies for their own sake and semantic, it becomes on the web aspects (how to publish and consume data on the web). Ontologies are used then to foster and serve the semantic interoperability between parts that want to exchange such data. There are known as lightweight ontologies [23] that use the full advantages of semantic web technologies, minimum OWL constructs, and reuse existing RDF vocabularies wherever possible.

According to the W3C recommendation [16], RDF is a foundation for encoding, exchange, and reuse of structured metadata. It can be serialized using different languages (e.g., RDF/XML [40], Turtle [41], RDFa [42], N-Triples [43], N3 [44]). RDF consists of three slots called triples: resource, property, and object. Also, resources are entities retrieved from the web (e.g., persons, places, web documents, pictures, abstract concepts, etc,). RDF resources are represented by uniform resource identifiers (URIs), of which URLs are a subset. Resources have properties (attributes) that admit a certain range of values or that are attached to another resource. The object can be a literal value or a resource.

While RDF provides the model and syntax for describing resources, it does not define the meaning of those resources. That is where other technologies such as RDF Schema (RDFS) come in. RDFS specifies extensions to RDF that are used to define the common vocabularies in RDF metadata statement and enables specification of schema knowledge. It develops classes for both resources and properties. However, RDFS is limited to a subclass hierarchy and a property hierarchy with domain and range definitions of these properties. RDFS limitations are: range restrictions, disability of expressing disjoitness between classes, combination between classes, cardinality restriction, and characteristics of properties [22].

The work presented in this paper is a framework based on the RDF model and its related vocabularies, managed by different web aspects (LDP), for representing and managing the tangible chains of custody of digital investigations. Next section provides the reasons why LDPs are suitable and useful to represent the digital investigation *CoCs*.

III. Advantages Of Using LDP for Representing *CoC*

Knowledge representation has been persistent at the centre of the field of Artificial Intelligence (AI) since its founding conference in the mid 50's. This concept is described by Davis et al. [33] through five distinct roles. The most important is the definition of knowledge representation as a surrogate for things. Thus, before providing the solution framework, we decided to underline why linked data is selected to represent the tangible *CoC* in cyber forensics. Thus, this section lists all the advantages and the common features of using linked data to represent the *CoC* for cyber forensics:

1. *CoC* and LDP are metaphors for each others. The nature of *CoC* is characterized by interrelation/dependency of information between different phases of the forensics process. Each phase can lead to another one. This interrelation fact is the basic idea over which the linked data is published, discoverable, and significantly navigated using RDF links. RDF links in LDP will not be used only to relate the different forensic phase together, but it can also assert connection between the entities described in each forensic phase. Also, RDF typed links enable the data publisher (role player) to state explicitly the nature of connection between different entities in different and also same phases, which is not the case with the un-typed hyperlinks used in HTML.
2. Linked data enables links to be set between items/entities in different data sources using common data model (RDF) and web standards (HTTP, URI, and URL). As well, if the *CoC* is represented using the LDP, the items/entities in different phases can be also linked together in forensics process. This will generate a space over which different generic applications can be implemented:
   - *Browsing applications*: enable juries to view data from one phase and then follow RDF links within the data to other phases in the forensics process.
   - *Search engines*: juries can crawl the different phases of the forensics process and provide sophisticated queries.
3. Linked data applications that are planned to be used by juries, will be able to translate any data even it is represented with unknown vocabulary. This can be realized using two methodologies. First, by making the URIs that identify vocabulary terms dereferenceable (i.e., it means that HTTP clients can look up the URI using the HTTP protocol and retrieve a description of the resource that is identified by the URI) so that the client applications can look up the terms, which are defined using RDFS and OWL. Secondly, by publishing mappings between terms from different vocabularies in the form of RDF links. So, for any new term definition, the consumption applications are able to provide and retrieve for the juries extra information describing the provided data.
4. Nowadays, RDFS [34] and OWL [35] are partially adopted on the web of data. Both are used to provide vocabularies for describing conceptual models in terms of classes and their properties (definition of proprietary terms). RDFS vocabularies consist of class *rdfs:class* and property *rdf:property* definitions, which allow the subsumption relationships between terms. This option is useful for juries to infer more information from the data in hand using different reasoning engines. For example, RDFS uses a set of relational primitives (e.g., *rdfs:subclassof*, *rdfs:subpropertyof*, *rdfs:domain,* and *rdfs:range* that can be used to define rules that allow additional information to be inferred from RDF graphs). Also, OWL extends the expressivity of RDFS with additional modeling primitives that provide mapping between property terms and class terms, at the level of equivalency or inversion (e.g., *owl: equivalentProperty*, *owl:equivalentClass*, *owl:inverseof*).
   RDFS and OWL are not yet fully adopted on LDP, but soon the full adaptation will be achieved. This will be a great advantage to add more property and class terms to the semantic dimension of the linked data, and therefore, provide useful and descriptive information [4] [5].
5. Representing *CoC* data using LDP will be enriched with different vocabularies such as Dublin Core (DC) [30], Friend of a Friend (FOAF) [31], and Semantic Web Publishing (SWP). Also, vocabulary links is one type of RDF links that can be used to point from data to the definitions of the vocabulary terms, which are used to represent the data, as well as from these definitions of related terms into other vocabularies. This mixture is called schema in the linked data; it is a mixture of distinct terms from different vocabularies to publish the data in question. This mixture may include terms from widely used vocabularies as well as proprietary terms. Thus, we can have several vocabulary terms to represent the forensics data and make it self descriptive (using the 2 methodologies mentioned in point 3) and enable linked data applications to integrate the data across vocabularies and enrich the data being published.
6. Juries need to avoid heterogeneity and contradictions about the information, which are provided to them in the court in order to take the proper decision. Linked data try to avoid heterogeneity by advocating the reuse of terms from widely deployed vocabularies

(same agreement of ontology). LDP is then useful to represent this type of information.

7. As mentioned at point 1, a forensics process contains several phases which are dependent and related to each others. Each entity is identified by a URI namespace to which it belongs. An entity appearing in a phase may be the same entity in another phase. The result is multiple URIs identifying the same entity. These URIs are called URI aliases. In this case, linked data rely on setting RDF links between URI aliases using the *owl#sameas* that connect these URIs to refer to the same entity. The advantages of this option in *CoC* representation are:
    - *Social function*: investigation process is a common task between different players. The descriptions of the same resource provided by different players allow different views and opinions to be expressed.
    - *Traceability*: using different URIs for the same entity allows juries that use the *CoC* published data to know what a particular player in the investigation process has to say about a specific entity of the case in hand.

    Same thing occurs not only at the level of URI but also at the level of terms. Players of the forensics process may discover at a later point that a property vocabulary contains the same term as the built in one. Players could relate both terms, stating that both terms actually refer to the same concept using the OWL (*owl: equivalentClass*, *owl: equivalentProperty)* and RDFS vocabularies (*rdfs: subclassOf*, *rdfs:subProperyOf*).
8. Provenance metadata can also be published and consumed on the web of data [6]. Such metadata provide also an answer to six questions, but at the level of the data origin (i.e., Who published/created the data, Where this data is initially published/created, What is the published data, When/Why the data is published, and How the data is published). These vocabularies can be used concurrently with the forensics data, to describe their provenance and complement the missing answers related to the forensic investigation.

All these advantages are motivations for using LDP to represent the tangible *CoC* in cyber forensics. Next section explains the first step of representing a forensic phase using LDP. This is illustrated through the authentication phase imported from Kruse [17] forensics model.

IV. DIGITAL FORENSICS PROCESS MODELS

Different Digital Forensics Process Models (DFPM) has been proposed since 2000 (e.g., Kruse [17], the United State Department of Justice (USDOJ) [18], Casey [19], Digital Forensics Research Workshop (DFRW) [25], and Ciarhuin [21]) to assist the players of investigations process reaching conclusions upon completion of the investigation.

TABLE I. THE *CoC* OF THE AUTHENTICATION PHASE

Questions	Subject	Terms (Custom / Built in)
Who	The Role Player	Investigator
What	Verify the integrity of the acquired data	Evidence
Why	Ensure the completeness and integrity of data	Hash
Where	The place that this task took place	Location
When	The time that this task took place	Date
How	Procedures utilized to perform the checking task	Algorithm

Investigation models are numerous. Many works were provided to explain and compare such models [18][19][21][26][29]. Nevertheless, all works provided in the forensics process globalize the 5 W and 1 H questions once over the whole forensics process. However, these questions must be posed over each phase of the forensics process, separately, since each question in a forensic phase is not the same for another phase (i.e., 'What' question, of the collection phase is not the same as the 'What' for the identification phase). For example, the Kruse model has 3 forensics phases, thus, it should have 3 different *CoCs*.

Furthermore, some phases from different forensics models may have unique technical requirement but they differ only on their names [24]. The work presented by Yussof et al. [26] underlines 46 phases from 15 selected investigation models that have been produced throughout 1995 to 2010, and then identifies the commonly shared processes between these models.

The first step of representing *CoC* for a phase in a forensics process is to identify the essential terms that can be used to describe this phase. The identification of terms is achieved through the descriptions of different processes and tasks performed within this phase. For instance, the essential task of Authentication in the Kruse model, is to verify the integrity of acquired/extracted data. The verification of integrity is to ensure that the information presented is complete and has not been altered in any authorized/unauthorized manner, since the time it was extracted, transmitted, and stored by an authorized source [27].

The role player of this task is called the investigator. He is responsible (Who) to check the integrity of the extracted evidence (What), by comparing the checksum generated from hashing algorithm (How) (e.g., CRC-Cyclic Redundancy, Cryptographic Hash function such as MD5 and SHA1), in order to ensure the completeness and the integrity of data (Why), by comparing the hash/checksum of the original data with the hash/checksum of the copied data [28]. If the checksum of the original data is not the same as the checksum of the copied one, the data is then altered. If not, it keeps always its integrity. The *CoC* should also record the date/time (When) and the location/machine (Where) this task took

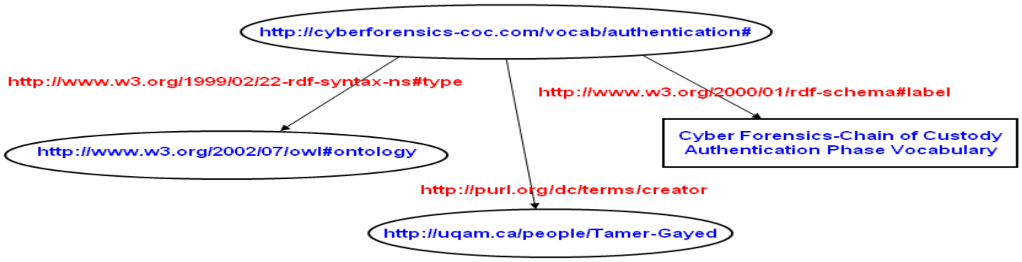

Figure 1. Definition of Authentication Ontology

place. Table I defines the essential terms used to describe the authentication phase. Definition of such terms is explained in next section. Figure 4 provides an example of this chain of custody.

V. CYBER FORENSICS *CoC* FRAMEWORK

CF-CoC framework provided in this paper (see figure 2) explains how tangible *CoCs* are represented.

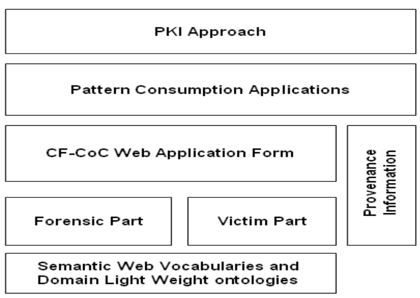

Figure 2. CF-*CoC* Framework

*CoC*s are described using RDF model, which integrate well defined vocabularies in the semantic web. *CoCs* contains mainly forensics information that needs to be described with new proprietary terms.

Creating the vocabularies and terms of each phase is performed through the construction of lightweight ontology using RDFS and the Web Ontology Language OWL (see Figure 3). These terms are used to represent and describe different information related to a victim of any cyber crime (e.g., child pornography, pedophilia, prostitution, blackmail, extortion, harassment, defamation, forgery, spam, theft, etc), and the forensics part, who is responsible to investigate and provide the result of the investigation process. Such information together forms the *CoC*.

Each forensics phase has its own *CoC*. In each phase, the player role is responsible to prepare and create the *CoC* of the phase in which he worked in. Each player role constructs his *CoC* using a web form that allows the player to import different resources (i.e., from the victim and forensic parts) or create new triples using well predefined/custom vocabularies. The results will be a set of interrelated triples describing all phases in the forensics process. These triples are consumed by juries in a court of law, using different patterns of consumption applications on the semantic web. Along this scenario, provenance dimension (metadata/model) is also integrated with the forensics data to answer all questions related to the origins of this data. Published data and their consumption will be published and consumed by the authorized people who can to work on the current cyber crime case. PKI is used to ensure identities and authorization of each role player. Next sub-sections will describe each layer in detail.

A. Semantic web vocabularies and domain light weight ontologies

All the vocabularies of the semantic web can be divided into two main categories: built-in vocabularies and custom (property terms) vocabularies. The latter are created using the former (known as light weight ontology) upon the needs to describe particular domain (i.e., cyber forensics), when the former do not provide all terms that are needed to publish/describe the content of a data set. In this context, the data set is the chains of custodies. The custom vocabulary will be an ontology created for each phase in forensics models. Each ontology contains a set of terms (classes or properties) describing the forensic phase that this ontology represents. Player records all information that he encountered in the forensics phase through the support of these property terms and the terms of the built-in vocabulary.

Some examples of common well established vocabularies are RDFS, OWL, Dublin Core Metadata Initiative (DCMI) vocabulary [30], Friend-of-a-friend (FOAF) vocabulary [36], Semantically-interlinked Online Communities (SIOC) vocabulary [37], and Description of a Project (DOAP) Vocabulary [38]. For instance, Table I contains terms that should be defined (e.g., investigator term is defined by the investigated verb) and terms that are predefined (e.g., date, evidence).

The name space defined for this phase is given in [64]. The *cfcoc-auth:investigator* and *cfcoc-auth:investigated* terms are defined in this ontology (figure 3) using well defined terms (e.g., *foaf: person* and *owl:ObjectProperty* respectively). Some principles are provided in [14] describing how to select existing vocabularies and how to develop new terms. Some tools

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Figure 3. Definition of investigator and investigated term (Class and Property)

can be used in the development of new terms such as Neologism [45], Protégé [46], TopBraid Composer [47].

B. *Victim and Forensics Parts*

This section describes the mechanism of how the resources of victim and forensics parts are represented on the web. The essential thing to publish data is to have a unique domain/namespace minted by unique URL owned by the publisher. URI HTPP is used to relate, and identify real-world objects and abstract concepts, thereby maximizing the discoverability of more data. Thus, URIs need to be dereferenceable to identify real objects (i.e., objects and documents should not be confused between each others). Therefore, a common practice called contents negotiating is used by an HTTP mechanism [13] that sends HTTP headers with each request to indicate what kind of documents they prefer. Servers can inspect then these headers and select an appropriate representation of resources (HTML document or RDF document). Content negotiation uses two different types of URIs:

- **303 URIs** (known as 303 redirect): server used to redirect the client request to see another URI of a web document, which describes the concept in question.
- **Hash URIs:** to avoid two http requests used by the 303 URIs. Its format contains the base part of the URI and a fragment identifier separated from the base by a hash symbol. When a client requests hash URI, the fragment part is stripped off before requesting the URI from the server. This means that the hash URI does not necessarily identify a web document and can be used to identify real-world objects.

Using first type of URI, victim or forensics part could publish on their servers the description of any concepts (e.g., real world object: persons) using two types of representations: HTML document containing a human-readable representation about a concept, and RDF document about the same concept. We will imagine here a victim company called Digital Test that wants to publish information about an investigator (i.e., we assume that the company has forensics department). This company can use 3 different patterns to describe the concept employee (the following can be applied to any resource):

- In [59], the URI identifying the person Jean-Pierre.
- In [60], the URI identifying the RDF/XML document describing Jean-Pierre.
- In [61], the URI identifying the HTML document describing Jean-Pierre.

Using the second type of URI, forensic or victim part can define different vocabulary terms in order to describe their profile in data published on the web. They may use also the Hash URI to serve an RDF/XML file containing the definitions of all these vocabulary terms. For example, Digital Test may assign the URL in [62] to the file, which contains a custom vocabulary describing different employee's concepts and appends fragment identifiers (using #), to the file's URI in order to identify the different vocabulary terms.

Furthermore, the forensic part will publish different resources and integrate forensic data resulted from the investigation process. This can be realized using the Advanced Forensic Format (AFF4). It is an open format for the storage and processing of digital evidences. Its design adopts a scheme of globally unique identifiers (URN) for identifying and referring to all evidences [32]. The great advantage of this format is representing different forensics metadata in the form of RDF triples (subject, predicate, and value), where the subject is the URN of the object the statement is made about and the predicate (e.g., datelogin, datelogout, evidenceid, affiliation, etc.) can be any arbitrary attribute, which can be used to store any object in the AFF4 universe. Thus, any information of victim and forensics part related to their profiles or forensics data can be easily represented and integrated together in a unified RDF model. Figure 4 shows an example of how the custom terms (e.g., investigator) are defined using lightweight ontology. Victim resources (e.g., who: Jean-Pierre defined by Digital Test), and forensics resources (e.g., What: evidence, Why: hash, Where: location defined in the AFF4), and terms from the DC vocabulary (e.g., When: date) are all integrated together in a unified framework answering the six questions of the authentication phase.

Figure 4. *CoC* for the authentication phase

The big difference between the terms defined in the AFF4 format and the customs terms is that the latter are URI resources that can be dereferenced while the former are a set of literals that are terminals. The higher the number of dereferenceable terms, the more the data provided to juries are descriptive.

C. *CF-CoC Web Application Form*

This section answers the question of how RDF triples are generated and connected to be later consumed and crawled by juries. In order to create manageable and electronic linked data *CoC*, the *CF-CoC* HTML web application form should be designed to:

- Import resources from the forensics parts (e.g., role players' profiles, results of forensic investigation).
- Import resources from the victim part (departments names, employees names, machines IDs, etc.).
- Create and describe resources by the support of, (i) existing terms imported from well established vocabularies, and (ii) new terms imported from custom vocabulary created to describe the *CoC* for each forensics phase.
- Add provenance metadata to forensics data. (i.e., provenance vocabularies are used to prove the origin of the imported data and improve their representation).

The work in this part is divided into two main tasks: entities identification, and the description of such entities with RDF using predefined or custom terms.

Entities identification is divided into two subtasks. Whether is to create/mint a new URL for a new entity or to import predefined URI for an existing entity from the victim or forensics part. *CF-CoC* will have its own domain name (cyberforensics-coc.com). This domain allows only each authorized player in the forensic process to use the namespace of this domain. After running the web server of this domain name at [63], players that are allowed to participate in the forensics process are free to mint URI in this namespace to use as names for things they want to describe. For example, if the investigator player of the authentication phase wishes to mint URIs to indentify different new entities in this forensics phase, he/she does extend the URI assigned to the domain URI in [63].

On the other hand, each player will create different types of triples that describe each resource of the forensics process with literals, linked to other resources, linked from other resources, and the resource itself using provenance metadata. The links that connect different phases to each others can be incoming or outcoming links. If a RDF triple links a resource A in a forensics phase to a resource B in another phase, the document describing B should include this triple. This triple is called incoming link to B and allows to navigate back to A even if the latter is not an object of any triples in the description of B. Also, the triple in the document describing A is called outcoming link.

Two languages can be used to generate RDF models from the data entered in the web form application: script languages or mapping ones. In both cases, the data is posted first in a relational database, and queried or mapped later. Script languages, for example PHP, can generate linked data in RDF/XML format by the help of the ARC library for working with RDF in PHP [48]. Mapping languages, for example D2RQ [49][50], map database contents into RDF vocabularies and OWL ontologies, and allow RDF data to be browsed and searched.

D. *Pattern Consumption Application*

Linked data is a style of publishing data that makes it easy to interlink, discover, and consume them on the semantic web. The idea explained in this section underlines how juries can consume (navigate and search) data at run-time, among different meaningful collection of triples published by role players.

As mentioned in the last section, the first way to publish linked data on the web is to make URIs that identifies data items dereferenceable into RDF descriptions. Three main patterns can be used by juries to consume this information of the *CoC* published by role players: browsing, searching, and querying. Browsing is like traditional web browsers that allow users to navigate between HTML pages. Same idea is applied for linked data, but the browsing is performed through the navigation over different resources, by following RDF links and downloads them from a separate URL (e.g., RDF browsers such as Disco, Tabulator, or OpenLink) [51].

RDF crawlers are also developed to crawl linked data from the web by following RDF links. Crawling linked data is a search using a keyword related to the item in which juries are interested (e.g., SWSE and Swoogle). Juries can also perform extra search filtering using query agents. This type of searching is performed when SPARQL endpoints are installed, which allow expressive queries to be asked against the dataset. Furthermore, a void vocabulary (vocabulary of interlinked datasets) [39] contains a set of instructions that enables the discovery and usage of linked datasets through dereferenceable HTTP URIs (navigation) or SPARQL endpoints (searching), using SPARQL (*void:sparqlendpoint*) or URI protocol.

E. Provenance Metadata

Provenance of information is an essential ingredient of any tangible *CoC* quality. The ability to track the origin of data is a key component in building trustworthy, which is required for the admissibility of digital evidences. Classically, the provenance information about Who created and published the data and How the data is published, provides the means for quality assessment. Such information can be queried and consumed to identify also the outdated information. *CoC* data source should include provenance metadata together with the forensics data. Such metadata can be used to give juries data clarity about the provenance, completeness, and timeliness of forensics information and to strength the provenance dimension for the published data.

Provenance information can be integrated within the forensics data using three different methods. The first method is using the provenance vocabularies of the semantic web. The second one is to use open provenance model [31], and the last method is by exploiting named graphs for RDF triples, to add provenance metadata about each group of triples.

A widely deployed provenance vocabulary is Dublin Core [30]. For example, this vocabulary contains different predicates that can provide extra information related to the forensics data like the *dc:creator*, *dc:publisher,* and *dc:date*. The objects of these predicates can be represented by URI (e.g., deferenceable resources like the investigator Jean-Pierre) or literal/terminal (date) (see figure 4), identifying such objects. Another provenance vocabularies provided in [52][53], describe how provenance metadata can be created and accessed on the web of data. These vocabularies assess the quality and trustworthiness of the published data.

Open Provenance Model (OPM) provides an alternative and more expressive vocabulary that describes provenance in terms of agents, artifacts, and processes [54]. An extension of this work is the Open Provenance Model Vocabulary (OPMV), provided in [55]; it implements the OPM model using lightweight OWL. OPVM can be used also with other provenance vocabularies such as Dublin Core, FOAF, and the provenance vocabulary.

While many authors advocate the use of semantic web technologies (i.e., vocabularies, Light weight ontologies), Carroll et al. [56] take the opposite view and proposed named graphs as an entity denoting a collection of triples, which can be annotated with relevant provenance information. The idea of a named graph is to take a set of RDF triples, and consider them as one graph, and then assign to it a URI reference. Thus, RDF can be used to describe this graph using RDF triples, which describe the creator or the retrieval data of the graph. Linked data applications can use this description to access easily a particular graph (e.g., graph for the authentication phase) and back to the original source, if required.

The named graph is useful to juries to navigate and access provenance metadata related to a certain set of triples, and get more description about them (e.g., LDspider [57] allows crawled data to be stored in an RDF store using the named graphs data model). As the SPARQL is widely used for querying RDF data, it can also be used to query named graphs.

Recently, Omitola et al. [9] allows publishers to add provenance metadata to the elements of their datasets. This is presented through the extension of the void vocabulary into *voidp* vocabulary (light weight provenance extension for the void vocabulary). This vocabulary considers different properties, such as dataset signature, signature method, certification, and authority, in order to prove the origin of a dataset and its authentication.

F. PKI Approach

Provenance metadata are not sufficient to ensure that the published data belong to the right players. PKI approach allows juries to ensure from the identity of role players participated in the forensics investigation. PKI is a combination of softwares and procedures providing a way for managing keys and certificates, and using them efficiently. A certificate is a piece of information (like a passport) that provides a recognized proof of a person (or entity) identity. A very recent work provided by Rajabi et al. [58] explains how PKI is used to achieve the trustworthiness of linked data. In this work, PKI is used for trust management over the web linked data, where datasets are exchanged in a trusted way. PKI is adapted for a new application supporting juries to verify the

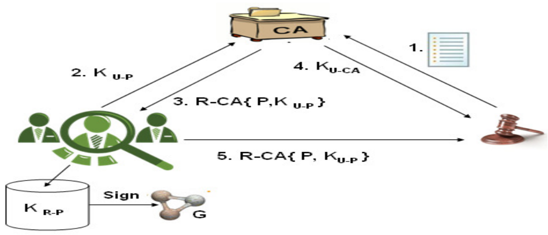

Figure 5. Application of PKI in *CoC* representation

identity of each role player who published the provided data through the investigation of their certificates. Each player in the forensics process should have his own certificate, which contains information about his identity and his digital signature.

A digital certificate alone can never be a proof of anyone's identity. A third trusted party is needed to confirm and sign the validity and authority of each player certificate. This party is then called certification authority (CA). Since a CA (e.g., VeriSign Inc.) relies on public trust, it will not put its reputation on the line by signing a certificate unless it is sure of its validity, the fact that makes them acceptable to the cyber security and cyber forensics fields. Any certificate contains pieces of information about the identity of the certificate owner (role player), such as distinguisher's name, and information about the CA (issuer of certification), such as CA's signature of that certificate, and general information about the expiration and the issue date of that certificate.

Generally, the scenario starts when the jury of the court sends a list of all players' cyber crime to the CA [15]. Each player sends a certificate request to the CA, to be signed, containing the requester's name, his PK, and his own signature. CA verifies the role player's signature with the public key in the digital signature to ensure that the private key used to generate the request matches with the public key in the certificate request. Figure 5 shows how the PKI certifications are applied in this context:

1. Juries send a list of players who are supposed to work on the current cyber crime case. Sending this list to the CA, controls the data access to only these players. This prevents the disclosure (keeps the confidentiality) of data to unauthorized people.
2. The role player generates a public-private key pair ({$K_{U\text{-}P}$, $K_{R\text{-}P}$}), where P is all information identifying the player, R is private, and U is public. The player stores the private key in a secure storage to keep its integrity and confidentiality, and then sends the public key $K_{U\text{-}P}$ to the CA.
3. The player's public key and its identifying information P are signed by the authority using its ({$K_{R\text{-}CA}$}) private key. The resulting data structure is back to the role player. R-CA {P, $K_{U\text{-}P}$} is called the public key certificate of the role player, and the authority is called a public key certification authority (i.e., symbols outside brackets mean the signature of the data structure).
4. Juries obtain the authority's public key {$K_{U\text{-}CA}$}.
5. Each player creating a *CoC* must authenticate himself to juries by signing his RDF graph G using his private key R-P{G} (i.e., all triples describing a phase are assembled in one graph called G). Later, before the court session, each player sends the certification R-CA {P, $K_{U\text{-}P}$} to juries accompanied with the signed graph R-P{G}.

The main idea behind this scenario is based on the PK cryptography, where senders (role players and CA) make signature using their private key, and the jury verifies these signatures using their public key.

VI. CONCLUSION AND FUTURE WORK

This paper explained how LDP can be applied to represent tangible *CoCs*. This paper provides several design options to construct the *CF-CoC* system. The best design combination is not on the scope of this paper. Along this dissertation, several contributions are provided:

1. New combination of several fields in the same framework, such as cyber forensics, semantic web, provenance vocabularies, PKI Approach, and LDP.
2. Underline that each phase in the forensics process should have its own *CoC* along any forensics model.
3. Provide a framework that leads to the creation of an assistance system for juries in a court of law.
4. Integrate provenance metadata to the victim/forensics data, in order to answer questions about the origin of information published by the role players during the forensics investigation.
5. Using the PKI approach to ensure the identities of each player participating in the forensics process.

In future work, the current framework will be extended by extra educational resources for aid purposes. These educational resources provide help to the role players and juries to respectively publish and consume the represented data.

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Towards an Artificially Intelligent System: Philosophical and Cognitive Presumptions of Hybrid Systems

Ondřej Vadinský
Department of Information and Knowledge Engineering
University of Economics, Prague
náměstí Winstona Churchilla 4, Prague 3, Czech Republic
Email: ondrej.vadinsky@vse.cz

***Abstract*—This contribution summarizes philosophical and cognitive presumptions of intelligence and looks at their realization in paradigms of artificial intelligence with emphasis on hybrid systems. It gives specifications of research concerning analysis of presumptions of intelligence in computer systems. Finally, the paper outlines preliminary research results, regarding the relationship of intentionality and representation and about viewing the strong artificial intelligence in the context of perception, action, learning and development. The paper suggests that there are aspects of intentionality which can be captured by hybrid representation.**

Keywords-strong artificial intelligence; hybrid systems; representation; intentionality; stratified model of perception.

I. INTRODUCTION

In this contribution, some ideas on intelligence in computer systems will be presented, as well as the preliminary results of the research concerning the analysis of the presumptions of intelligence of computer systems.

The main goal in the field of artificial intelligence (AI) is considered to be the creation of so-called *strong AI*, that is, artificial intelligence in all its aspects as powerful as human intelligence. For such an effort to succeed, a thorough analysis of the characteristics of intelligence has to be done to identify its essential aspects and properties [1], [2], [3].

Here, an opportunity arises to use philosophical reflection and knowledge of cognitive sciences about intelligence to make a better AI. This contribution focuses on hybrid systems and hybrid-system-based cognitive architectures. Hybrid systems are systems using both symbolic and connectionist representation of knowledge while cognitive architectures are domain-generic models of human cognition [3], [4], [5].

In Section II, presumptions of intelligence will be detailed, namely from the point of view of philosophy (II-A) and of the cognitive sciences (II-B). Section III will refer to current paradigms of AI, including logical symbolism (III-A), connectionism (III-B) and hybrid systems (III-C). Section IV will discuss how to combine philosophy, the cognitive sciences and artificial intelligence into one multidisciplinary endeavour. The research program will be specified (IV-A) and initial results outlined (IV-B and IV-C). This contribution will be concluded in Section V together with a discussion about the future work.

II. PRESUMPTIONS OF INTELLIGENCE

If an intelligent machine is to be constructed, the following questions should first be considered: What is intelligence and what are its essential properties? How do we decide what is intelligent and what is not? How is intelligence related to other abilities of the mind?

Current scientific study of intelligence within the broader context of the human mind and cognition is underway in the cognitive sciences. The cognitive view on artificial intelligence was discussed in more detail in [6]. Therefore, only the main ideas will be presented in this contribution. Several areas of philosophy also discuss these issues from interesting perspectives, as explored thoroughly in [3]. Only a brief summary will be given here.

A. Philosophical Point of View

In philosophy, there is a long debate about whether or not a machine can think. It can be traced back to Descartes, who raises two presumptions of intelligence: ability of rational speech and universality of thought [7].

This question was famously inverted by Turing. He asks whether a machine can mimic human beahviour and thinking in such a way, that an average human cannot tell who is the human and who is the machine while communicating with both. This is known as *the Turing test* and, as is the case with Descartes, it is strongly related to rational speech [1].

The issue was further addressed by Searle [2] in his attempt to look into the machine in what is known as *the Chinese room argument*. Searle states that for rational speech, *understanding* is needed. Humans have it due to *intentionality*, that is "[a] feature of certain mental states by which they are directed at or about objects and states of affairs in the world." Searle also notes that humans incline to ascribe *intentionality* to others based only on similarity in behaviour, which can lead to serious errors, as is the case with computers.

Pstružina [8] points out that the special settings of both *the Turing test* and *the Chinese room argument* disable many aspects of real-life communication and also neglect many aspects of thought that take part in it. He also gives a more elaborate *definition of intentionality* in which the meaning of mental states is given by the integration of intentional concept into the structure of other concepts and endocepts, and also by reflection of this emergence of the meaning.

B. Cognitive Point of View

A central point of cognitivism is that information processing requires a system to have an internal *representation* of its environment. Such a model is called a *world view*, and as De Mey [9] shows, there are several of them dynamically combined to cognitive schemata. This way a structure combining and organizing knowledge about concepts is created.

Another important issue brought forward by cognitivism is the role of perception. Perception is always understood as an indirect process mediated by a certain *world view*. De Mey mentions the so-called *stratified model of perception*: A subject accesses a perceived object in several layers of granularity, which are partially independent of each other. A percept is, therefore, an amalgam of perceived shapes strengthened by relations of concepts within a subject‘s *world view*. This means that both the subject and the object contribute to the act of perception [9].

De Mey's cognitivism also stresses the importance of the *connection between knowledge and action*, in which he is inspired by Piaget. Acquiring knowledge is about realizing the interaction between the subject and the object. It goes through several phases, firstly building *implicit* knowledge which is later made *explicit*. As a suitable *representation* of knowledge, De Mey sees Minski's frames. *Frames* create a backbone of stereotypical knowledge in which specific knowledge can be inserted. The structure of *frames* can be recombined during the development of *world views* [9].

III. Hybrid Systems and the Paradigms of AI

As the initial questions about intelligence have been considered, the ways of making it artificial should now be examined. This includes questions such as: What means can be used to create an AI system? How adequate those means are to the properties of intelligence? Are they limited by some of the properties? A more elaborate description of the means to create an AI system was given in [3]. Also, the question of adequacy of the paradigms was discussed there, having led to the focus on hybrid systems. For the sake of completeness, a brief summary of the paradigms of AI and their adequacy will be given in this section.

As the field of artificial intelligence developed, several paradigms emerged. Logical symbolism has foundations in logic and *explicit symbolic representation*. Trying to solve the shortcomings of symbolism, connectionism draws its inspiration from biological neural networks. Recently, there was a growing effort to combine symbolic and connectionist paradigms into so-called hybrid systems. Aside from these paradigms which are somewhat similar due to their focus on *computation* and *representation*, there is also another paradigm called enacted cognition or enactivism. It seems to be a promising point of view, but it will not be discussed in this contribution.

A. Logical Symbolism

Logical symbolism operates with a term *physical symbol system* which is a structure of instances of symbols arranged in physical patterns. The meaning of a symbol in a system is given by its connections to other symbols [4].

The issue of meaning is tightly connected with the *grounding problem*: that is, the question of where the meaning of symbols comes from. Rapaport tries to solve this with his *syntactic semantics*. He shows a way how meaning can ensue from connections between symbols of two distinct symbolic systems, say of language and sensual perception. One symbol system can then be grounded in the other [10].

A similar approach as *syntactic semantics* is used in *semantic computing*. The meaning of the data is given by its connection to metadata in the form of ontology.

Symbolism creates *explicit* highly structured and abstract models. Despite several extensions of the original concept, it is problematic to deal with incomplete, vague or noisy data [4].

B. Connectionism

The Churchlands [11] point out that the *massively parallel architecture* of the human brain is what makes it powerful in the tasks it performs. They suggest making *computers architecturally similar to the human brain*. This could be done by employing artificial neural networks and other connectionist methods.

Connectionism uses great numbers of simple computational units such as artificial neurons connected together into a network. Although a single unit can solve only simple tasks, the network as a whole succeeds in solving much more complex problems [4].

However, the complexity of the human brain is far beyond current connectionist models. There are both quantitative and qualitative aspects in which the models are lacking. An example of the quantitative aspect is the number of neurons and synapses. Some examples of the qualitative aspects include: the way in which the electric impulses arise and in which they are propagated in the network, various kinds of oscillations and continuity of learning. Currently, there are projects underway which try to find out and model the ways in which the human brain works such as the *Blue Brain Project* [12].

Connectionism creates *implicit* models capable of learning. Due to its parallelism it can cope with incomplete, vague or noisy data easily. Such models are, however, difficult to understand by the human observer [4].

C. Hybrid Systems

Since both symbolism and connectionism have their strong and weak points, and since a weak point of one is often a strong point of the other, it seems natural to combine them.

Hybrid systems in general use different models of knowledge *representation*. It is possible for the models to be a mere duplication of each other, to take part in different tasks, to cooperate or to compete. The models can be combined in different ways, loosely or tightly. All these architectural decisions influence greatly the properties and capabilities of such a hybrid system [4].

Further on, only such hybrid systems which combine symbolic and connectionist models will be considered. *Combining explicit and implicit representation creates synergy* which makes such systems robust and general-purpose. In such a system, there are processes of internal learning, when knowledge is transferred between different models: *explicit knowledge can gradually descend to the implicit model* while, on the other hand, *implicit knowledge can cause the explicit knowledge to emerge from the implicit model*. Due to its multiple *representations* of knowledge, hybrid systems keep the advantages of both connectionist and symbolic approaches [4].

An example of hybrid systems usage is Sun's *CLARION cognitive architecture*. It strives to create a *domain-generic* model of human cognition. Such a model should be cognitively realistic on social, psychological, componential and physiological levels [5].

IV. Combining Philosophy, Cognitive Science and Artificial Intelligence

After the initial discussion of the presumptions of intelligence and paradigms of the AI, this paper tries to combine philosophical and cognitive knowledge to make better artificial intelligence. Furthermore, the two research ideas concerning the relation of *intentionality* and *representation* in hybrid systems and the context of perception and action in hybrid systems will be sketched.

A. Research Specification

The long-term goal related to my research is to create such an artificially intelligent system that would be as powerful as human intelligence. Such artificial intelligence has been called *strong AI* by Searle. Recently, it has also been called *general artificial intelligence* in a new attempt to bring back this project from the beginnings of artificial intelligence.

The analysis of presumptions of intelligence of computer systems includes three goals:

- To examine different possible ways of creating a *strong AI*;
- To analyze architectures of hybrid systems suitable for creating a *strong AI*;
- To propose and verify an extension of a chosen architecture.

To reach these goals, a multidisciplinary approach is needed. Therefore, inspirations will be drawn from the fields of philosophy, cognitive sciences and artificial intelligence. Many specialists have examined related partial topics, but without much effort to integrate their results. However, such an integration and synthesis is crutial if we are to reach the long-term goal.

B. Intentionality and Representation in Hybrid Systems

Let us review Pstružina's definition of *intentionality*. In [8], he describes three aspects of *intentionality*:

- Directedness at things or aboutness;
- Gaining the meaning through integration into the structure of other intentional concepts and endocepts;
- Realization of the previous two aspects.

Are these aspects of *intentionality* somehow connected to the *hybrid representation*?

Let us first consider the second aspect of *intentionality*. The hypothesis is that the structure of intentional concepts can be understood as the symbolic model of a hybrid system. Also, the structure of endocepts can be understood as the connectionist model of a hybrid system. The process of integration of an intentional concept into such structures can then be identified with the process of adding new symbols into the symbolic model or the process of learning of the connectionist model. Through its position in a symbolic system, concept gains a certain aspect of meaning. The meaning of a concept is not only about connections of a symbol to other symbols, although those connections among symbols certainly participate in the emergence of meaning. This meaning is further enriched by the connections between the symbolic and connectionist model, and by the connectionist model itself.

A brief look at the aboutness aspect of *intentionality* will now be presented. The preliminary hypothesis states that to represent and to be directed at are two sides of the relation between the representing and represented thing. Therefore, there is a kind of directedness and aboutness in a *representation*. The question is whether it is the same, or to what degree it is similar or different.

As for the realization of the previous two aspects of *intentionality*, a hypothesis has not yet been formulated. This aspect is connected to consciousness and requires further study.

C. Model of Stratified Perception in Hybrid Systems

An important issue when considering *intentionality* is its origin. As has been mentioned by Searle in [2], it can come from the artificial system itself, or from the human observer. Searle's conclusion is the latter. But can the former be somehow achieved?

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Robotic answer to the Chinese room argument shows a promising way. Having a computer in a robotic body connected to sensors and actuators enables it to interact with the world. This should ground its *representation* of the world [2].

The robotic answer can be further specified, if a hybrid system is considered as the architecture of the computer system. Then, an implementation of a *stratified model of perception* can be used to integrate the information into the hybrid system in relation to its own expectations. Finally, Piaget inspired learning of knowledge from the interaction with the world through concretization of *implicit* knowledge can be used. Such implementation of artificial intelligence respecting the context of perception, action, learning and development should give it a more solid *grounding* than just manipulation with *representation*.

V. Conclusion and Future Work

In this contribution, philosophical presumptions of intelligence were summarized. The main focus of philosophical reflection of intelligence lies in the ability of rational speech and universality of thought. These are tightly connected with the concept of *intentionality*, as used by Searle and Pstružina. Other notable concepts include the *Turing test*, though in need of extension, and the *Chinese room*.

Furthermore, cognitive presumptions of intelligence as understood by De Mey were summarized. His position emphasizes the concept of *world views* and the importance of perception and its integration with the *world views* in a *stratified model of perception*. On top of that, it shows a special link among knowledge, perception and action, in which knowledge comes from realization of the interaction of the subject and object.

Symbolic and connectionist paradigms of artificial intelligence were described and it was shown how they can be combined in *hybrid systems*. These are useful for generic *cognitive architectures* due to synergy between symbolic and connectionist knowledge *representation*.

Since the focus is on hybrid systems together with *strong AI*, as it have been specified, two ideas about how to improve them using previously described presumptions of intelligence were pursued. First, the ideas about *intentionality* and *representation* were sketched. Then, Pstružina's definition of intentionality was used to show similarities between those concepts. Furthermore, the ideas about viewing the hybrid-system-based AI in the context of perception, action, learning and development were outlined.

Future work in several areas of the research is needed. First, the ideas mentioned in this contribution need some more development. Especially, the aspect of intentionality related to consciousness is in a need of thorough examination. Furthermore, a way of putting all three aspects together in a hybrid system should be devised. Also, the research of other presumptions of intelligence in philosophy and cognitive sciences should be done as part of the first, most theoretical, research goal. In the next phase the research should focus on analysis of existing architectures of hybrid systems. Theoretical findings of the first stage should be compared to the analysis, so that in the third phase concrete ways to apply them can be found.

The other area related to the research is to propose ways to validate the results. This may pose a serious chalenge, since opposing factors need to be reconciled. As mentioned in [5], testing cognitive architectures is a very demanding process due to their general-purpose nature. As the goal of the research is to provide an extension of a hybrid system to make it closer to *strong AI*, similar or even more adverse cicumstances as with testing cognitive architectures are to be met. Therefore, it may be possible to adapt some approaches and experiments which are used to validate cognitive architectures. However, a mere comparison of performances in several experiments may not be enough. Currently, hopes are placed in existing extensions of *the Turing test*.

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Cartesian Intuitionism for Program Synthesis

Marta Franova
Laboratoire de Recherche en Informatique, UMR8623 du CNRS
Orsay, France
mf@lri.fr

***Abstract*—This paper presents two possible approaches to scientific discovery, the Newtonian and the Cartesian one. The paper explains the main difference between these two styles and underlines the importance of each of them. Its specific scientific contribution is presenting the less known Cartesian approach and the main problems that can be solved by it, in the light of our research in Automated Program Synthesis. The paper is thus related to the creative framework of modeling human reasoning mechanisms, cognitive and computational models, as well as modeling brain information processing mechanisms.**

Keywords-creativity; Program Synthesis; Newtonian style; Cartesian style; Constructive Matching Methodology

I. Introduction

This paper suggests a model of human creativity, inspired by our experience on Program Synthesis. In the following sections we shall describe a way of transforming a formal specification, and possibly a partially incomplete one, into a program computing in accordance with this specification. Our purpose is to show that the solution we propose to this problem strongly suggests a model for mathematical creativity.

A. *Newtonian Creativity*

Newtonian creativity (represented in program synthesis mainly by ([25], [28], [4], [3], [10]) consists essentially in the choice of a statement of the problem so that it can be handled linearly; the problems met have to be solved at once when met, independently of the other problems that are going to be found 'later'. That does not go without creativity, obviously needed to solve these problems. Thus, the creativity process in Newtonian creativity is considered as a cycle of five distinct stages where every stage must be completed before envisaging the next stage. These stages are the following ones.

1. The first one is that of the preparation, where all the important information is collected to correctly express the problem,
2. the one of incubation that supposes the contribution of the whole personality of the mathematician,
3. the one of discovery where an inspiration occurs and finally
4. the stage of verification.

In the case of failure, the creator is forced to undertake

5. the fifth stage which we can qualify as 'incubation of the failure'.

When the failure has been 'incubated' enough, the creator has to take up again the first four stages. This characterizes a behavior where learning from failures is made only after the observation of the global failure of the process of creation. Stated in more formal way, the Newtonian approach hypothesizes that we believe in the following rigid, 'unfriendly' universe: There exists a universal theory, in which the tools necessary to solve **all** problems are available. This is logically expressed as follows:

[The following problem has a solution: {∃ formal framework (a theory) ∀ problem}]

Failure to find a solution is answered by looking for a new universal theory that will provide the appropriate tools. The reader will recognize here the classical behavior of Physics as a Science.

B. *Cartesian Creativity*

Cartesian creativity (represented in program synthesis mainly by [14]) consists essentially in a 'less conquering' or more 'cautious' approach in which the five Newtonian stages are not so clearly distinguished. For the sake of simplicity let us distinguish phases that run in parallel without, at first, emphasizing their mutual dependencies.

The first phase is the phase of an informal familiarization with the problem which results in a formulation of an ***informal specification*** of the problem that may seem, and often is, absurd or unfeasible to solve in the standard context.

The second phase is the one where, given an informal specification, we try to estimate what we can possibly attempt in order to solve the problem. It consists in performing two actions, specific for the given problem. The first action is gathering the tools that might be usable in *handling* the problem. These tools will be quite general since we do not restrict ourselves to the tools usable in *solving* the problem. For example, in the example that follows, the tool we chose is the one of mathematical induction and various techniques, such as replacing a term by a parameter. The second action is a search for a set of minimal restrictions that are necessary for the problem to be solved. In other word, we try to define the largest possible context in which we can hope to solve the problem. This is symmetrically defined as the smallest context in which we know that no solution will be possible.

The third phase starts once these choices have been done. They are applied to the informal specification, until we succeed into obtaining a specification in which no contradiction is still observable within the context of the problem, as it has been defined during the second phase. This result is called a ***coherent (or 'reasonable') specification.***

The fourth phase consists in a sequence of attempts at proving the validity of the coherent specification. If this succeeds, then this proof is also a solution to the problem. Failures at obtaining of proof does not lead us to reformulate the problem, or to choose a new theory, as happens in the Newtonian approach. A failure does not lead us further than modifying the coherent specification.

Stated in more formal way, the Cartesian approach hypothesizes that we believe in the following flexible, 'friendlier' universe: Given a problem, we will be able to find or build a theory dedicated to solving the **specific** problem at hand. Failure to find a solution will be answered by building a theory in which a solution is possible (instead of looking for a new existing theory). This is logically expressed as follows:

[The following problem has a solution: {∀ problems ∃ appropriate framework (a theory)}].

The reader will recognize here the classical behavior of an artist in front of a task to execute (the specific specification) that he will fulfill either by using existing tools (the existing 'universal' theory of Art, the so-called "academic artists") or by creating a theory specific to his problems (the so-called "new Art").

These two types of creativity cannot, however, in isolation render the richness of mathematician thought. We do not yet have the weapons necessary to describe how may happen a 'pulsation' between the two above approaches. We are nevertheless able to provide a formal specification for it. A formal specification of the pulsating between Newtonian and Cartesian approaches is represented by inversing the ordering of the two quantified terms 'theory' and 'problem'. Newtonian states that ∃ a (universal) theory usable ∀ problems, while Cartesian states that ∀ problems that ∃ a (particular) theory.

The following of this paper will explain how the problem of program synthesis from specification demands such a pulsative approach in order to find a solution. Note that **automatic** program synthesis is difficult enough to be still unable to be applicable to real world problems while the humans called 'programmers' seem to be able to often provide solutions often satisfactory.

The rest of the paper is structured as follows. In section II we shall formalize a bit more the Newtonian and the Cartesian styles of the research. In section III we recall the goal of Program Synthesis and we shall relate the main features of the Newtonian and the Cartesian styles to program synthesis. In section IV we shall present what we call conceptual oscillation in our approach. Sections V and VI are devoted to the main perspectives of these approaches. Section VII recalls the main building strategy of our approach and illustrates it on a simple example.

II. NEWTONIAN AND CARTESIAN STYLES OF RESEARCH

The main difference between these two approaches is easily perceptible from comments pronounced by Newton and Descartes themselves. Newton wrote: "If I have seen further (than you and Descartes) it is by standing upon the shoulders of Giants."

Descartes wrote his first rule in the *Discourse on the Method of Rightly Conducting the Reason, and Seeking Truth in the Sciences* in the following way: "The first was never to accept anything for true which I did not obviously know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to comprise nothing more in my judgement than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt."

Newtonian science is thus established on a logic of sequential research, where the reference system of the problem, that is, the axioms, the rules of inference and the mechanism of control of the system intended to solve the problem, and the milestones (that is, the definitions and the rules of inference of the specified concrete problem) on which we build the solution are given at the beginning by the past history of scientific research. It is in this perspective of work that are situated the results of Gödel of which we will speak later.

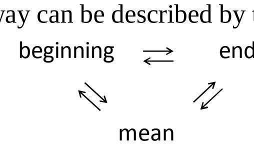
Descartes speaks about the obvious truth. As says the commentator of Descartes Ferdinand Alquié ([11], p. 586), the act of thought which seizes the obvious truth is the intuition defined by Descartes in his *Rules for the direction of the mind*. So, the study of Descartes intuition, as presented in the book *Formal Creativity* [17] enables to notice that Cartesian science is based on a logic of recursive research, where the reference system of the problem and the milestones of construction of the solution are formulated hand in hand with the development of the solution, and where the exact demarcation of the reference system and the milestones of construction is the final stage of the process, and is too a part of the solution. The Cartesian approach thus takes into account that the demarcation of a notion is not the initial stage but the final stage of its formation.

The same thing is expressed by Descartes in a little more complicated way by saying that "beginnings … can be persuaded well only by the knowledge of all the things which follow later; and that these things which follow cannot be understood well, if we do not remember all those that precede them." [11], p. 797.

In a little more formalized way, we can thus describe the Newtonian way by the sequence

beginning … advancement-1 … advancement-2 … advancement-n … end.

The Cartesian way can be described by the loop



where the arrow $\rightarrow$ means "leads to". Because of the complexity of the Cartesian way and since neither the external observation nor the sequential transmission are suited to the appreciation of the work made in this way, this way presents more obstacles than the Newtonian style.

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III. Program Synthesis and Approaches

By program synthesis we call here the deductive approach to automatic construction of recursive programs introduced in [25]. This approach starts with a specification formula of the form $\forall x\ \exists z\ P(x) \Rightarrow R(x,z)$, where x is a vector of input variables, z is a vector of output variables, P(x) is the input condition. R(x,z) contains no universal quantifiers and expresses the input-output relation, i.e. what the synthesized program should do. A proof by recursion of this formula, when successful, provides a program for the Skolem function sf that represents this program, i.e. R(x,sf(x)) holds. In other words, program synthesis transforms the problem of program construction into a particular theorem proving problem. The role of the deductive approach is thus to build an inductive theorem prover specialized for specification formulas.

Thus, there are two basic styles to approach the problem of Program Synthesis.

A. Newtonian approach to Program Synthesis

The Newtonian approach takes as foundation the standard knowledge of the mathematical formal framework, which inevitably inherits the negative results of Kurt Gödel. By consulting the first paragraph of his article *On formally undecidable propositions of Principia Mathematica and related systems I* [23], we can observe that the keywords of this standard knowledge are

- exactness
- formal system justified in a logical way
- methods of demonstration reduced to some axioms and rules of inference
- decision and undecidability

Previously, we have described the Newtonian style by the sequence that starts by a well-defined beginning and progresses by advancements to a desired end.

The results of Gödel are said negative because they show that the objective of synthesis of programs formulated as the "beginning" in the classic framework cannot lead to a successful end of the task. In other words, they show the impossibility to define a formal logical framework containing the natural numbers allowing to approach the resolution (confirm or counter) of specifications given in a general way. Nevertheless, there are approaches that work in the Newtonian style.

In the introduction we have mentioned the most known Newtonian approaches to program synthesis. Since the problem of proving by induction specification formulas, i.e. formulas containing existential quantifiers is very difficult, researchers focused on the problem of proving purely universally quantified formulas and on treating formulas with existential quantifiers by assisting the users in developing their own proofs. The best known are the system ACL2 [5], the system RRL [24], the system NuPRL [8], the Oyster-Clam system [6], the extensions of ISABELLE [27], the system COQ [26], Matita Proof Assistant [1] and Otter-Lambda [2]. All the mentioned approaches have done a very good work in modelling human reasoning by exploring possibilities of *transformational* methods to inductive theorem proving and program synthesis. The construction calculus of [9], that is the basis of the system COQ, is a constructive way of *representing* transformational methods. The approach presented in the next section attempts to find a *constructive* way of solving an 'almost' same problem by modelling human reasoning based on Cartesian style of research.

B. Cartesian approach to Program Synthesis

The Cartesian approach specifies at the beginning the reference system in an informal way only, by a necessarily informal formulation of the purpose to be reached. It is much like a hypothetico-deductive method. The hypothetico-deductive method is a procedure of construction of a theory which consists in putting, at the start, a certain number of loosely defined concepts or proposals that are obtained by an analysis of experiments undertaken to specify these starting concepts or hypotheses. Then, by deductive reasoning, are obtained postulates that, when they are true, confirm the effectiveness of chosen concepts and hypotheses. If they are not true, the problem, because of the loose definitions of concepts, allows their new reformulation and the process is thus repeated on these new still loosely defined reformulations. In Cartesian style one can specify even the goal in a rather 'vague' manner. This is why we introduced the term of 'quite precise' purpose to indicate that this formulation, though informal, must describe a real well-known situation.

For the construction of recursive programs from formal specifications, it is possible to give a 'quite precise' purpose by considering program synthesis as a problem of realization or creation, rather than a decision-making problem. We adopted this approach when starting to develop the *Constructive Matching Methodology* (*CMM*) for Program Synthesis in 1983. In contrast with the Newtonian approach, the keywords of our particular Cartesian approach are

- rigor, realization and creativity
- system justified in an epistemological way
- methodology of construction
- realization of a program or sufficient conditions for the realization of such a program.

The most suitable way is thus to consider *CMM* as a technology (in general sense) rather than a theory.

IV. Conceptual Oscillation of *CMM*

Our approach oscillates between a Newtonian formulation of Program Synthesis and a Cartesian formulation of the same problem. It is clear that this purpose seems thus very ambitious when one forgets the preliminary restrictions (not considering efficiency of synthesised programs and proofs by structural induction only).

In practice, this oscillation is performed in the following way. For a given specification formula, we attempt to perform a constructive proof relying on the results already achieved by *CMM*. In other words, we start to solve the problem having in mind the specification '$\exists$solution $\forall$problem', where the solution is the *CMM* and the problem is the given specification formula. If the power of the *CMM* is not sufficient to prove the given specification formula, by a failure analysis we try to conceptualize the problems met as methods rather than heuristics. In other words, we solve the problem by putting focus on the problem '∀problem ∃solution' and then by a suitable process of conceptualization based on hypothetico-deductive method we try to come back to the specification '∃solution ∀problem', where the solution is now the extended *CMM*. This is why this approach is more the one of a mathematician trying to build a new theory-technology rather than that of a programmer focusing on obtaining efficient programs.

In this way, we have conceptualized many new methods in inductive theorem proving for specification formulas, for instance: implicative generalization, predicate synthesis from formal specification, synthesis of formal specifications of predicates, introduction of universally quantified induction hypotheses whenever appropriate, a particular evaluation tool and a particular equation solving tool. We explain this conceptual richness of inspirations of *CMM* proofs by the basic method for constructing atomic formulas '*CM-formula construction*' that has been introduced in [13] and the most complete presentation of which can be found in [16]. In contrast to the basic methods in Newtonian approaches that rely on simplification and rewriting, our *CM-formula construction* is a constructive method and thus it is very suitable for generating missing lemmas and even axioms when the given data are incomplete as it is illustrated in [22].

V. Newtonian and Cartesian perspectives

In many cases, including Program Construction, researchers and engineers look at their problems in a goal driven perspective, that is, they try to select beforehand axioms useful for obtaining a particular proof. This approach becomes however less and less successful when it is applied to goals of increasing complexity requiring less and less trivial lemmas, especially when it becomes necessary to simultaneously take into account all the axioms, together with the set of their consequences. In the specific case of Program Synthesis, we have seen, in section III, that the Newtonian approach has been very successful in producing systems that request human help as soon as some 'creativity' is needed in order to provide a lemma or a heuristic not already included in the system library. Since one of ultimate goals is modeling some form of mathematical creativity by building a computer simulation of these creative steps, we had to adopt a new perspective, the one of Cartesian intuitionism.

When non-trivial lemmas are generated in an autonomous way by the computer system itself, and when it is required that we simultaneously take into account axioms and the set of their consequences, our *CMM* fits into Cartesian intuitionism as Descartes himself specified it by defining:

- a form of constructive intuition, in the Latin version of his *Rules for the direction of the mind*
- the ability of thinking as isolated, one of many mutually dependant features in §62 of *The principles of the philosophy* ;
- clear and distinct perception in §45 and §46 of *The principles of the philosophy*;
- the four rules of his method, in his *Discourse on the method*.

Thus, the research program of *CMM* approaches the construction of axioms and intermediate lemmas and the theorem proving system in dependence on the specifications of program synthesis. It is important to note that these three stages (generating missing axioms – in case of undecidability, generating missing lemmas, developing the procedure of demonstration or of control) are interdependent and that the advances of one of three stages can modify the internal objective of the two others.

VI. Assessment and perspectives of *CMM*

The stage relative to the procedure of demonstration was elaborated in all our publications until 2000 [12]. An experimental system called Proofs Educed by Constructive Matching for Synthesis (PRECOMAS) showing the well-founded character of the *CM-formula construction* that is the basis for *CMM* was developed in the 90s [15].

The stage relative to the specification of the intermediate lemmas advances well and concerns also the scientific domain known as 'computational creativity' [20], [21].

The stage which concerns the clear and distinct perception (in the Cartesian sense) of the targeted strategic recursive axiomatization has begun in the article [19]. It must be improved and pursued by an adequate formalization of different fundamental interrelated problems which are met in the oscillatory design of the recursive systems, namely

- one - multiple (part - whole)
- static - dynamic (permanence - change)
- finite - infinite (visible - invisible)
- complete - incomplete (rigor - creativity).

In Program Synthesis, the problem between a whole and its parts is expressed as a strong and special interdependence between the diverse parts of the system, because a part or the whole can itself assume the failure cases and the weaknesses of the other parts. For example, the failure of a resolution of an equation can call in a recursive way the system for help. Or, the deductive parts of the system can call inductive parts, and vice versa. This particular interdependence is described by Descartes as "the distinction which is made by the thought" presented above as "the ability of thinking as isolated, one of many mutually dependant features."

The problem of the oscillation between a static representation and a dynamic representation appears in the process of search and creation of the structures and the mechanisms of the control of proofs. This process oscillates between a formalized shape and an informal shape of a given mechanism. As we said above, the definitive demarcation which consists of fixing a final version of the mechanism is only made at the end of development of the whole system.

The problem of the regulation of the finite and the infinite appears in program synthesis especially by the fact that an infinite visible variety of possible formal specifications must be managed by finite invisible structures. In other words, the final system of Program Synthesis has to represent a finite solution of the infinite problem 'to think of everything at the same time'. So, for this problem, Ackermann's function in an oscillatory version models in a curiously proper way the solution which we envisage for this problem.

The problem of the oscillation between completeness and incompleteness is described in an informal way by the notion of pulsation which allows a controlled oscillation between rigor and creativity. In a concrete way, the *CM-formula construction* allows such a controlled oscillation and has influences on all the *CMM*.

These four fundamental problems are stemming from our perception of Cartesian intuitionism. They appear as ideas of directions to be developed and to be formalized. These tasks will continue in our future work.

The power of *CMM* was illustrated on a number of interesting problems such as n-queens, the quotient and the rest of two numbers, a problem in robotics and more recently the construction of a definition of Ackermann's function with respect to the second variable [18]. This last illustration is important because it shows the capacity of the system to find another form of defining axioms, the final version of which is not known beforehand.

CMM is even suitable for proving some purely universally quantified theorems. The advantage lies in the fact that, in contrast for instance to [7], during a proof of a universally quantified formula, a formula containing existential quantifiers can be generated which replaces the problem of unification in the framework of inductive theorem proving and thus it seems to be conceptually more natural.

In the following section we shall recall our *CM-formula construction* and we shall give a very simple example to illustrate it.

VII. *CM-FORMULA CONSTRUCTION*

A. *Formulation*

In the following, for simplicity, let us suppose that the formula to be proven has two arguments, that is to say that we need to prove that $F(t_1,t_2)$ is true, where F is the given theorem. We introduce a new type of argument in the predicates a feature of which has to be proven true, we call **abstract arguments**. They are denoted by ξ (or ξ' etc.) in the following. The abstract argument replaces, in a purely syntactical way, one of the arguments of the given formula. The first step is choosing which of the arguments will be replaced by an abstract argument, ξ. Thus, the value of this argument is looked upon as being known and, in a usual proof, its characteristics are used in order to prove the given formula. In our approach, we 'forget' for some time these characteristics and we concentrate on studying the features ξ should have so as insuring that the theorem with a substituted argument is true.

Suppose that we have chosen to work with $F(t_1,\xi)$. We shall then look for the features shown by all the ξ such that $F(t_1,\xi)$ is true. Given axioms defining F and the functions occurring in t_1, we are able to obtain a set C expressing the conditions on the set { ξ } for which $F(t_1,\xi)$ is true. In other words, calling 'cond' these conditions and C the set of the ξ such that cond(ξ) is true, we define C by C = {ξ ⎮ cond(ξ)}. We can also say that, with the help of the given axioms, we build a 'cond' such that the formula: $\forall\xi \in$ C, $F(t_1,\xi)$ is true. We thus propose a 'detour' that will enable us to prove also the theorems that cannot be directly proven by the so-called simplification methods, i.e., without this 'detour'. Using the characteristics of C and the definition axioms in order to perform evaluations, and also using the induction hypothesis, we shall build a form of ξ such that $F(t_1,\xi)$. Even though it is still 'ξ' and only for the sake of clarity, let us call ξ_C an axiom evaluated form to which, possibly, the induction hypothesis has been applied. It is thus such that $F(t_1,\xi_C)$ is true. We are still left with a hard work to do: modify ξ_C in such a way that ξ_C and t_2 will be made identical, which finally completes the proof. [16] gives a detailed description of handling the abstract argument in a rigorous framework.

B. *Example*

In this section we shall give a very simple illustration of the *CM-formula construction*. The goal will be to synthesize a recursive program for computing the last element of a non-empty list. The formal specification $\forall$x $\exists$z1 $\exists$z2 F(x,z1,z2) for this problem writes

$$\forall x\ \exists z1\ \exists z2\ \{\ x \neq nil \Rightarrow x = app(z1,cons(z2,nil))\ \}. \quad (1)$$

We shall name sf1 the Skolem function for z1 and sf2 the Skolem function for z2.The definition for the function append 'app' writes

$$app(nil,v) = v. \quad (2)$$

$$app(cons(c,u),v) = cons(c,app(u,v)). \quad (3)$$

With respect to the input condition x $\neq$ nil the structural induction principle means to prove in the base step $\exists$z1 $\exists$z2 cons(a,nil) = app(z1,cons(z2,nil)), where a is an arbitrary constant. The induction step means to represent x in the form x = cons(b,l), where l $\neq$ nil, to suppose the induction hypothesis $\exists$e1 $\exists$e2 l = app(e1,cons(e2,nil)) and prove cons(b,l) = app(z1,cons(z2,nil)). In this induction hypothesis e1 is sf1(l) and e2 is sf2(l).

The solution of the base step: Since the right hand side of the equation in (1) contains the existentially quantified variables, this side is replaced by the abstract argument ξ. We thus have C = {ξ ⎮ cond(ξ)} = {ξ ⎮ cons(a,nil) = ξ}. The goal is now to make ξ and app(z1,cons(z2,nil)) identical. In this case, using (2), the *CM-term transformer* presented in [14] returns z1 = nil and z2 = a. The base step is thus solved.

Let us consider the induction step. In this step, we have C = {ξ ⎮ cond(ξ)} = {ξ ⎮ cons(b,l) = ξ}. By applying the induction hypothesis to cons(b,l) we obtain {ξ_C ⎮ cons(b,app(e1,cons(e2,nil))) = ξ_C}. The goal now is to transform ξ_C i.e., cons(b,app(e1,cons(e2,nil))) into the form app(z1,cons(z2,nil)). Using (3), the *CM-term transformer* returns z1 = cons(b,e1), z2 = e2. The proof is thus performed and the program for sf1 and sf2 is trivially extracted.

$$sf1(cons(a,nil)) = nil. \quad (4)$$

$$sf1(cons(b,l)) = cons(b,sf1(l)). \quad (5)$$

$$sf2(cons(a,nil)) = a. \quad (6)$$

$$sf2(cons(b,l)) = sf2(l). \quad (7)$$

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This example is interesting not only as a very simple illustration of *CM-formula construction*, but also as a suggestion to use program synthesis as a powerful unification tool.

VIII. Conclusion

We have been able to express formally the difference between strictly scientific approach (Newtonian) and an 'artistic' one (Cartesian) closer to what is generally understood by creativity (scientific, artistic, etc.). The purely scientific approach expresses the work to perform as ∃ theory ∀ problems. The 'artistic' approach expresses the work to perform as ∀ problems ∃ theory.

This is a new result about the difference between Science and Art. Scientific mind will stick as far as possible to the Newtonian approach and resorts to the Cartesian one in cases of failures only. Inversely, the creative artist sticks to the Cartesian one and the academic one to the Newtonian.

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Cognitive Prognosis of Acquired Brain Injury Patients Using Machine Learning Techniques

Joan Serrà, Josep Ll. Arcos
IIIA-CSIC, Artificial Intelligence Research Institute,
Spanish National Research Council,
Bellaterra, Spain.
Email: {jserra,arcos}@iiia.csic.es

Alejandro Garcia-Rudolph, Alberto García-Molina,
Teresa Roig Rovira, Josep M. Tormos
Institut Guttmann Neurorehabilitation Hospital, Badalona, Spain.
Email: alejandropablogarcia@gmail.com,
{agarciam,troig,jmtormos}@guttmann.com

***Abstract*—The cognitive prognosis of acquired brain injury (ABI) patients is a valuable tool for an improved and personalized treatment. In this paper, we explore the task of automatic cognitive prognosis of ABI patients via machine learning techniques. Based on a set of pre-treatment assessments, distinct classifiers are trained to predict whether the patient will improve in one or any of three cognitive areas: attention, memory, and executive functioning. Results show that variables such as the age at the moment of the injury, the patient's etiology, or the neuropsychological evaluation scores obtained before the treatment are relevant for prognosis and easily yield statistically significant accuracies. Additionally, the prognostic relevance of these and other variables is studied by means of standard feature selection methodologies. The outputs of the present paper add to the discussion on current cognitive rehabilitation practices and push towards the exploitation of existing technologies for improving medical evaluations and treatments.**

***Keywords*—machine learning; brain injury; prognosis; classifiers; cognitive rehabilitation; neuropsychological evaluations.**

I. Introduction

Acquired brain injury (ABI) is a leading cause of death and disability worldwide [24]. It is considered one of the most common neurological disorders and, for survivors, it is widely regarded as a very debilitating condition [13]. ABI patients experience multiple impairments, specially physical (e.g., mobility, vision, sleep) and/or cognitive (e.g., attention, memory, executive function, language) impairments.

Cognitive impairments are particularly problematic, since they can limit daily activities and restrict participation in community, employment, recreation, and social relationships [11]. In particular, disturbances in basic cognitive functions such as attention and memory may cause or exacerbate additional disturbances in executive functioning, communication, and other relatively more complex cognitive functions. Attention is defined as a set of multifaceted processes including abilities to select relevant stimuli, manipulate and contain mental images and modulate responses to the environment [23]. Memory is the process of encoding, storing and retrieving information. Executive functions are those functions that allow us to function effectively and adaptively succeed within our social contexts [23]. Cognitive measures are among the most important predictors of patients' return to work and independent living, even among those with good medical recoveries [6].

The design of therapies for improving or potentially recovering the cognitive abilities of ABI patients is still an open issue [4]. Determining the appropriate method and timing of treatment for an individual with ABI depends on a number of factors, including severity of injury, stage in recovery, and premorbid, comorbid and environmental conditions, unique to each individual [15]. Although there is substantial evidence for cognitive rehabilitation treatments, additional research is required to guide the development of better clinical practices, particularly with respect to selecting the most effective treatment for a particular patient [4], [15].

A valuable tool for a more effective treatment of ABI patients is prognosis [18], i.e., anticipating the treatment's outcome from the usual course of the disease and/or the peculiarities of each individual case. Outcome prediction and early identification of reliable prognostic factors is of paramount importance to direct treatments, shape general policies, identify critical subjects, adapt treatment protocols to specific individuals, perform a more exhaustive monitoring of selected patients, and much else [18]. However, predictive modeling is particularly difficult when considering the numerous complex clinical elements that occur after ABI and their interplay.

In this paper, we exploit machine learning techniques [9], [10], [16] to predict the expected cognitive outcome of ABI patients using pre-treatment diagnosis data (prognosis). A number of studies employ machine learning techniques for the automatic prognosis of ABI patients [2], [3], [17], [19], [21]. Decision trees are the most common choice [2], [3], [17], [19], but also neural networks [17], [21] or different regression models [2], [17], [21] are used. Overall, these studies focus on determining survival, predicting gross outcome, and/or identifying predictive factors of a patient's condition after traumatic brain injury (TBI; usually acute TBI). In addition, to the best of our knowledge, no studies focus on long-term cognitive rehabilitation and, in particular, on the neuropsychological evaluations that are commonly used for assessing improvements at the cognitive level [23].

Our study shows that pre-treatment diagnosis data is predictive of ABI patients' response to cognitive rehabilitation. Specifically, we show that initial neuropsychological evaluations, and also their combination with generic information such as the patient's age, studies, or the cause of the injury, have a considerable power for predicting treatment responses. Moreover, our results suggest that such predictive power relies on the data itself, as similar accuracies are obtained by a number of machine learning algorithms based on different principles. An additional goal of our study is to see whether our specific results add to current knowledge of relevant risk

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TABLE I. SUMMARY OF DIAGNOSIS DATA (SEE TEXT). PRE-EVALUATION SCORES CORRESPOND TO: NO IMPAIRMENT (0), MILD IMPAIRMENT (1), MODERATE IMPAIRMENT (2), SEVERE IMPAIRMENT (3), AND VERY SEVERE IMPAIRMENT (4). THE LETTER υ DENOTES MEAN $\pm$ STANDARD DEVIATION.

Demographic data		Pre-evaluation tests ([0,4])		Pre-evaluation diagnosis ([0,4])	
Gender	{'male', 'female'}	1	Digit span forward WAIS	Spec. 1	Categorization
Studies	{'no studies', 'primary', 'secondary', 'degree'}	2	Trail marking test, part A	Spec. 2	Divided attention
		3	Stroop word	Spec. 3	Flexibility
Age at injury	$[17, 76]$; $\upsilon = 40.6 \pm 14.5$	4	Stroop color	Spec. 4	Inhibition
Age treatment	$[17, 76]$; $\upsilon = 41.2 \pm 14.5$	5	Stroop word-color	Spec. 5	Planning
Delay treatment	$[0, 31]$; $\upsilon = 1.1 \pm 2.8$	6	Digit symbol WAIS	Spec. 6	Sequencing
Treatment weeks	$[1, 77]$; $\upsilon = 17.5 \pm 12.8$	7	Block design WAIS	Spec. 7	Selective attention
Sessions per week	$[1, 5]$; $\upsilon = 3.0 \pm 1.3$	8	Digit span backward WAIS	Spec. 8	Sustained attention
Etiology (specific)	{'TBI', 'multiple sclerosis', 'hemorrhagic stroke', 'ischemic-thrombotic stroke', 'ischemic-embolic stroke', 'ischemic undetermined stroke', 'other non-TBI', 'other'}	9	Letter-number sequencing WAIS	Spec. 9	Working memory
		10	RAVLT short-term memory	Spec. 10	Verbal memory
		11	RAVLT long-term memory	Spec. 11	Visual memory
		12	RAVLT recognition	Gen. 1	Attention
		13	Trail marking test, part B	Gen. 2	Executive functions
		14	WCST categories	Gen. 3	Memory
Etiology (general)	{'stroke', 'TBI', 'other'}	15	WCST perseverative errors		
		16	Stroop interference		
		17	PMR maximally produce words		

factors or help in assessing critical values of the considered pre-treatment data.

The remainder of the paper is organized as follows. We first present our methodology (Sec. II), including a description of the considered data (Sec. II-A), our feature pre-processing steps (Sec. II-B), the machine learning tools we use (Sec. II-C), and the followed evaluation strategy (Sec. II-D). We next show the obtained results and discuss them to some detail (Sec. III). A brief summary section concludes the paper (Sec. IV).

II. MATERIALS AND METHODS

A. Diagnosis data

The considered data comes from PREVIRNEC©, a web-based tele-rehabilitation platform conceived as a tool to enhance cognitive rehabilitation [22]. Every participant considered in this analysis underwent a pre-treatment evaluation involving the three main cognitive functions (*attention*, *memory*, and *executive functions*) by means of a standard tests battery detailed below. After treatment, participants were again evaluated using the same tests battery to measure improvement/non-improvement in the respective functions. A pool of 503 patients is considered: all of them were assessed in *attention* (299 improved), 496 in *memory* (317 improved), and 501 in *executive functions* (334 improved). We additionally consider a further category, *any*, where we assess whether there is an improvement in, at least, one cognitive function, and no worsening in any of the others (503 assessments, 368 improved). In total, we face four binary classification [16] problems (two classes: improvement/non-improvement in *attention*, *memory*, *executive functions*, and *any*). As input variables we dispose of (Table I):

- Demographic data: *gender*, level of *studies*, and the patient's age at the time of the injury (denoted by *age at injury*).
- Clinical data: this includes a *general etiology* description and a more *specific* one. It also includes a neuropsychological assessment battery consisting of 17 *tests* across the three main cognitive functions [23]. The obtained *test* scores are combined into 11 *specific diagnosis* scores, representing the respective sub-functions of attention (sustained, selective, divided), memory (visual, verbal, working), and executive functions (inhibition, planning, flexibility, sequencing, categorization). *Specific diagnosis* scores are further summarized into 3 *general diagnosis* scores, corresponding to the 3 main cognitive functions (*attention*, *executive functions*, and *memory*).
- Treatment data: the patient's age at the time of starting the treatment (denoted by *age treatment*), the delay between injury and treatment (in years, named *delay treatment*), the treatment duration (in weeks, named *treatment weeks*), and the number of *sessions per week*.

B. Feature pre-processing

The previous data comprises qualitative as well as quantitative variables (nouns/text and numbers, respectively). As quantitative variables are majority, we first convert qualitative variables into quantitative features. In particular, binary variables are directly coded as binary features and m-level qualitative variables are coded as vectors of m binary features [10]. For instance, with our data, *gender* = {'male', 'female'} becomes *gender* = {0, 1} and *studies* = {'no studies', 'primary', 'secondary', 'degree'} becomes *studies* = {{1,0,0,0}, {0,1,0,0}, {0,0,1,0}, {0,0,0,1}}. For dates, we use only the integer corresponding to the year, and thus, e.g., *date* = '1998/04/27' becomes *date* = 1998. Fields with integer or real values are kept as they are.

Before training our classifiers we normalize all features to a common range, considering a low and a high percentile for each feature. Specifically, we re-scale individual features so that their values at the 5 and 95 percentiles correspond to 0 and 1, respectively. These percentile values are kept for applying the same normalization at the testing stage. To avoid ties in feature vectors we add a small jitter η after normalization, $\eta = 10^{-6}\xi$, where ξ is a Gaussian random number generator with zero mean and unit variance.

A few missing values are present in our data. A fraction of patients have not performed *pre-evaluation tests 14* ($\approx$5%), *15* ($\approx$5%), and *16* ($\approx$0.4%). In addition, we do not dispose of the *age at injury* and, consequently, of the *delay treatment* for approximately 4% of the patients. In all these missing value cases we opt for distribution-based imputation [20]. For *pre-evaluation tests*, we impute distribution means, directly computed from the other patients that have completed the corresponding evaluation test. For *age at injury* and *delay treatment* we proceed similarly.

C. Machine learning tools

To show that the predictive power of the considered features is generic and not biased towards a specific classification scheme, we employ basic algorithms exploiting four different machine learning principles [10], [16]: decision tree learning, instance-based learning, probabilistic learning, and support vector machines. The implementations we use come from the scikits-learn package (version 0.10: http://scikit-learn.org) and, unless stated otherwise, their default parameters are taken. In total we use six implementations [10], [16]:

- Tree: Classification and regression tree (CART) classifier. We use the Gini coefficient as the measure of node impurity and an arbitrarily set minimum number of 7 instances per leaf.
- KNN: k-Nearest neighbor classifier. We use the Euclidean distance and an arbitrary value of $k = 9$.
- NB: Naive Bayes classifier. We loosely employ a Gaussian function to estimate the likelihood of all of features.
- SVM: Support vector machine. We consider a linear kernel (SVM_L), a polynomial kernel of degree 2 (SVM_P), and a radial basis function kernel (SVM_R).

Apart from classification performance, we also apply some alternative/complementary techniques to assess the importance of individual features and groups of them. For this part of the analysis we use balanced data samples (same number of instances per class) from the full data set and resort to the Weka package [9] (version 3.6.6: http://www.cs.waikato.ac.nz/ml/weka/) for algorithm implementations, also taking the default parameters, if not stated otherwise. Depending on the required assessment, we look at the binary splits of the tree-based classifier [16], the feature weights assigned by SVM_L [8], or the feature rankings produced by χ^2 feature evaluation [9]. Additionally, we consider class-conditioned feature distributions [10].

D. Evaluation measure and statistical significance

We measure binary classification performance with the out-of-sample percentage of correctly classified instances. We perform a 20 times 10-fold cross-validation on balanced data (same number of instances per class in train and test sets; two classes) and take the average accuracy [10]. For space reasons we omit confusion matrices and class/label-dependent accuracies (in the big majority of cases we obtained rather even confusion matrices and thus very similar accuracies for improvement or non-improvement classes).

To assess the merit of the classifiers' predictions we run the same experiment with a randomized data set with shuffled feature values. This way, we maintain the same distribution for each feature and keep the original dimensionality of the problem. The accuracies for this random baseline, always around 50%, can then be used to assess the statistical significance of the increment provided by the original features under the same classification algorithm. For determining statistical significance we employ the Wilcoxon signed-rank test [12] on the 200 individual accuracy values obtained for each fold. The Wilcoxon signed-rank test is a non-parametric statistical hypothesis test used when comparing two related samples (or two repeated measurements on a single sample) in order to assess whether their population mean ranks differ. We use a two-tailed p-value of 0.01 but apply the Bonferroni adjustment to compensate for multiple tests [1]. Considering 6 classifiers, 4 cognitive functions, and a number of data trials below 50 we have a final p^*-value of $p^* = 0.01/(6 \cdot 4 \cdot 50) = 8.33 \cdot 10^{-6}$. Notice that the combined use of a non-parametric test for related samples together with the aforementioned Bonferroni adjustment represents a strict and conservative criteria for determining statistical significance (cf. [1], [5]). Therefore, it enforces a high standard for reporting that a set of accuracies for a given classifier, test label, and data trial is better than another.

III. Results and discussion

We start looking at the predictive power of individual concepts (Table II). We see that *gender* never achieves a single statistically significant accuracy. Hence, when taken alone, it can be regarded as irrelevant for prognosis. The level of *studies* presents some controversy. Although this concept is frequently used as a proxy for cognitive reserve [14], we obtain few statistically significant accuracies, and these are usually below 55%. Thus, we cannot strongly confirm its use as a proxy. In future work we plan a deeper study of this issue.

According to our results, two highly prognostic concepts are *age at injury* and *age treatment*, with statistically significant accuracies above 55% most of the time (notice that they are highly correlated: $\rho = 0.98$, $p < 10^{-6}$). A tree split analysis (Sec. II-C) for these two individual concepts reveals two thresholds at which the possibilities for *any* improvement relatively diminish: below 37 years old we find more recoveries than non-recoveries and above 57 years old we find more non-recoveries than recoveries. The time elapsed between the injury and the beginning of the treatment (*delay treatment*) is not much predictive of the patient's improvement after treatment. However, we could assume some prognostic value in the case of *attention*, where all classifiers report statistically significant accuracies (Table II, top left). Indeed, with the class-conditioned distributions for *attention* we see a slight tendency towards non-improvement for delays larger than 1 or 2 years. In the future, we will consider days or weeks instead of years as units, so that a better refinement is possible.

Clearly, the most informative concepts are *specific* and *general etiologies* and *pre-evaluation tests* and *diagnoses* (Table II). In particular, we see that they all reach statistically significant accuracies beyond 55% most of the time, independently of the classifier used (Table II, middle rows). A further inspection with the χ^2 feature ranker considering all *etiologies* deems the *general etiologies* 'stroke' and 'other' as very relevant, together with the *specific etiology* 'other'. The SVM_L weights also point to 'strokes' as a relevant *general etiology* for prognosis, and specially to 'schemic-thrombotic stroke' and 'undetermined stroke' *specific etiologies*. These two are usually associated with improvement.

TABLE II. CLASSIFICATION ACCURACIES FOR DIFFERENT CONCEPTS, FUNCTIONS, AND CLASSIFIERS. FOR EASE OF VISUALIZATION, ONLY STATISTICALLY SIGNIFICANT ACCURACIES ARE SHOWN (BASELINE RANDOM ACCURACY IS CLOSE TO 50%, SEE SEC. II-D). THE LARGEST ACCURACIES FOR EACH COGNITIVE FUNCTION AND CLASSIFIER ARE SHOWN IN BOLD. THE FIRST ROWS OF EACH TABLE CORRESPOND TO SINGLE CONCEPTS AND THE LAST ONES TO A COMBINATION OF CONCEPTS.

Data	*Attention*						*Memory*					
	Tree	KNN	NB	SVM_L	SVM_P	SVM_R	Tree	KNN	NB	SVM_L	SVM_P	SVM_R
Gender												
Studies			51.8		53.8	53.5		50.8	50.2		54.7	55.0
Age at injury			58.2	58.1	56.7	58.0	53.4	53.1	57.1	56.8	56.6	56.5
Age treatment			**58.5**	58.5	56.8				56.0	57.6	57.1	56.7
Delay treatment	53.7	53.6	54.0	56.3	53.9	55.7			50.9			
Treatment weeks	54.5			57.3		57.8				51.4		
Sessions per week									51.0	50.2		
Etiology (specific)		51.9	52.6	55.4	55.1	55.9		54.1	54.3	60.7	60.1	59.9
Etiology (general)			56.5	57.1	57.1	56.5		55.2	59.6	59.7	59.7	59.5
Pre-evaluation (tests)	53.5		53.4		55.8	54.6	61.4	64.1	67.8	65.7	**66.1**	66.3
Pre-evaluation (specific diagnoses)	52.8	55.4	55.2	55.7	56.0	55.1	61.9	**65.2**	66.5	65.5	64.8	66.4
Pre-evaluation (general diagnoses)			54.4		54.6	55.5	62.1	64.7	**68.3**	**66.9**	62.9	66.9
Etiology (specific+general)				55.7	56.8	56.0	53.2	54.9	55.7	60.7	59.4	59.2
Pre-evaluation (all diagnoses)	52.8	56.5	54.8	55.1	55.3		61.8	65.3	67.1	65.3	64.2	65.6
Pre-evaluation (tests+diagnoses)	54.7	54.7	54.5	54.9	56.1	55.8	**62.5**	64.9	67.0	65.8	66.0	66.7
Etiology (gen.) + Pre-eval (diag.)	53.9	55.7	56.4	58.3	**58.8**	58.0	62.3	65.1	66.9	66.1	65.8	66.1
Etiol(g)+Pre-eval(d)+AgeInj+Delay	**55.3**	57.0	56.7	59.8	58.6	58.5	60.2	65.0	67.4	66.0	65.2	66.1
Informative mixture (see text)	55.1	**57.9**	52.6	**60.8**	58.1	**61.0**	60.6	64.0	60.6	66.5	64.8	**67.7**

Data	*Executive Functions*						*Any*					
	Tree	KNN	NB	SVM_L	SVM_P	SVM_R	Tree	KNN	NB	SVM_L	SVM_P	SVM_R
Gender												
Studies					50.4				50.4	55.6	56.0	
Age at injury			57.4	57.2	56.8	56.8			57.7	58.0	57.7	58.6
Age treatment			56.9	57.7	56.9	57.9		52.7	58.1	57.9	58.5	58.9
Delay treatment				55.8		54.5			52.7	55.2		52.7
Treatment weeks		52.9				53.5	51.7	54.1		51.2		
Sessions per week												
Etiology (specific)			53.0	56.3	56.7	57.2		55.5	56.2	59.8	58.3	58.6
Etiology (general)			55.8	57.0	56.3			55.2	58.7	57.1	58.9	58.5
Pre-evaluation (tests)		56.0	60.4	57.3	58.8	58.5	57.5	61.1	62.3	61.4	62.2	63.0
Pre-evaluation (specific diagnoses)	55.9	56.4	60.8	58.2	59.6	59.3	58.3	60.9	62.1	62.9	62.0	63.5
Pre-evaluation (general diagnoses)	56.8	57.9	61.3	59.7	58.3	59.4	58.1	60.9	62.5	64.3	61.8	62.7
Ethiology (specific+general)		53.9	53.0	54.7	57.0		53.2	55.5	55.3	59.0	58.8	59.6
Pre-evaluation (all diagnoses)	56.9	56.5	61.5	57.6	59.5	58.9	**60.0**	60.3	62.6	63.0	62.3	63.6
Pre-evaluation (tests+diagnoses)	55.5	57.7	61.2	55.9	58.7	58.0	57.2	60.6	62.8	59.8	62.5	62.4
Etiology (gen.) + Pre-eval (diag.)	57.0	57.2	**61.6**	59.3	**60.6**	**60.4**	58.9	61.3	**64.0**	63.1	62.7	63.4
Etiol(g)+Pre-eval(d)+AgeInj+Delay	**57.3**	**59.2**	61.2	60.2	59.8	59.9	59.9	**61.5**	62.9	62.9	63.1	63.1
Informative mixture (see text)	55.7	56.6	60.1	**60.8**	60.2	60.2	57.8	60.8	59.0	**64.5**	**64.2**	**64.8**

The best accuracies though are achieved by *pre-evaluation tests* and *diagnoses*, which generally score around or above 60%. The only cognitive function that could be an exception is *attention*. For this, perhaps etiology is more predictive. In general, accuracies for individual *pre-evaluations* are around 55% for *attention*, 66% for *memory*, 59% for *executive functions*, and 61% for *any*. Noticeably, we find that the predictive power of *pre-evaluation* scores (*tests* and *diagnoses*) comes from very high or very low values. In fact, looking at the decision trees and the class-conditioned distributions we see that, in general, score values below 2 (moderate impairment) tend to indicate improvement, whereas score values above 3 (severe impairment) tend to indicate non-improvement.

Overall, the combinations of *general* and *specific etiologies*, or *general* and *specific pre-evaluation* scores, do not increase accuracy significantly (Table II, middle rows). This was somehow expected, as the information of the *general pre-evaluation diagnosis* is derived from the *specific pre-evaluation diagnosis* which, in turn, is derived from the *pre-evaluation test* scores (see Sec. II-A). A similar reasoning can be made with *general* and *specific etiologies*. However, by combining etiologies or pre-evaluations themselves, we generally see that a larger number of classifiers reach statistically significant accuracies. Thus, we could say that their predictive power is somehow reinforced.

When we do see an accuracy increment is when mixing these two concepts (*etiologies* and *pre-evaluation* scores), or when further considering other slightly predictive concepts such as *age at injury* or *delay treatment* (Table II, bottom rows). The best results are probably achieved by an arbitrary combination of different concepts, excluding some non-significant and some correlated ones. The “informative mixture” result in Table II corresponds to combining all *diagnosis pre-evaluations* with *general etiology*, *age at injury*, *age treatment*, *treatment weeks*, and *studies*. Notice that the fact that some concepts are non-significant/correlated when taken individually does not imply that they are useless for classification when combined with other features [7]. The

TABLE III. TEN MOST INFORMATIVE FEATURES ACCORDING TO THE CHOSEN FEATURE RELEVANCE ANALYSIS METHODS (FROM A TOTAL OF 52 FEATURES). FEATURES CHOSEN BY AT LEAST TWO METHODS ARE HIGHLIGHTED IN BOLD. WE SEE THAT METHODS AGREE IN MANY OF THEM. REPEATEDLY CHOSEN FEATURES THAT DO NOT DIRECTLY MATCH THE GENERAL COGNITIVE FUNCTION ARE HIGHLIGHTED WITH THE * SYMBOL.

Attention	Feature relevance analysis method		
	Tree	SVM_L	χ^2
1	**Pre-eval. test 7 (exec. func.)***	Pre-eval. test 16 (exec. func.)	**Pre-eval. diag. spec. 6 (exec. func.)***
2	**Pre-eval. diag. spec. 6 (exec. func.)***	**Treatment weeks**	**Pre-eval. diag. spec. 2 (attention)**
3	**Age treatment**	**Pre-eval. test 7 (exec. func.)***	Pre-eval. test 13 (attention)
4	**Treatment weeks**	Pre-eval. test 15 (exec. func.)	**Pre-eval. diag. spec. 8 (attention)**
5	Pre-eval. test 8 (memory)	**Age treatment**	**Age treatment**
6	**Pre-eval. diag. gen. 1 (attention)**	Pre-eval. test 3 (attention)	**Delay treatment**
7	Pre-eval. test 12 (memory)	Age at injury	**Pre-eval. test 7 (exec. func.)***
8	**Pre-eval. test 10 (memory)**	**Delay treatment**	**Pre-eval. diag. gen. 1 (attention)**
9	**Pre-eval. diag. spec. 2 (attention)**	Pre-eval. test 2 (attention)	Pre-eval. test 10 (memory)
10	Studies 1 (primary)	**Pre-eval. diag. spec. 8 (attention)**	Etiology spec. 8 (TCE)
Memory	Feature relevance analysis method		
	Tree	SVM_L	χ^2
1	**Pre-eval. diag. gen. 3 (memory)**	**Pre-eval. test 17 (exec. func.)***	**Pre-eval. diag. gen. 3 (memory)**
2	**Pre-eval. diag. spec. 9 (memory)**	Pre-eval. test 13 (attention)	**Pre-eval. test 2 (attention)***
3	Sessions per week	**Pre-eval. test 5 (attention)***	Pre-eval. diag. spec. 11 (memory)
4	Pre-eval. diag. spec. 6 (exec. func.)	Etiology spec. 3 (exec. func.)	Pre-eval. diag. spec. 10 (memory)
5	**Pre-eval. test 2 (attention)***	Pre-eval. diag. spec. 1 (attention)	**Pre-eval. diag. spec. 9 (memory)**
6	**Pre-eval. test 5 (attention)***	**Pre-eval. test 6 (attention)***	**Pre-eval. test 5 (attention)***
7	**Pre-eval. test 17 (exec. func.)***	Pre-eval. diag. spec. 8 (attention)	Pre-eval. test 12 (memory)
8	Studies 1 (primary)	Pre-eval. test 16 (attention)	**Pre-eval. test 4 (attention)***
9	Age treatment	**Pre-eval. test 4 (attention)***	Pre-eval. test 3 (attention)
10	Treatment weeks	Gender	**Pre-eval. test 6 (attention)***
Executive functions	Feature relevance analysis method		
	Tree	SVM_L	χ^2
1	**Pre-eval. diag. spec. 10 (memory)***	**Etiology spec. 1 (multiple sclerosis)**	**Pre-eval. diag. spec. 5 (exec. func.)**
2	**Pre-eval. diag. spec. 5 (exec. func.)**	**Delay treatment**	**Pre-eval. diag. gen. 2 (exec. func.)**
3	Treatment weeks	**Pre-eval. test 12 (memory)***	Pre-eval. diag. spec. 4 (exec. func.)
4	**Pre-eval. diag. gen. 2 (exec. func.)**	Pre-eval. test 5 (attention)	Pre-eval. diag. spec. 6 (exec. func.)
5	Age at injury	Etiology spec. 5 (undetermined stroke)	Pre-eval. test 9 (exec. func.)
6	**Etiology spec. 1 (multiple sclerosis)**	**Pre-eval. test 8 (memory)***	Pre-eval. diag. spec. 11 (memory)
7	**Pre-eval. test 12 (memory)***	Pre-eval. test 15 (exec. func.)	**Pre-eval. diag. spec. 10 (memory)***
8	**Pre-eval. test 1 (memory)***	Etiology spec. 6 (other non-TBI)	**Pre-eval. test 8 (memory)***
9	**Pre-eval. test 17 (exec. func.)**	Pre-eval. test 4 (attention)	**Pre-eval. test 1 (memory)***
10	**Delay treatment**	Pre-eval. test 2 (attention)	**Pre-eval. test 17 (exec. func.)**
Any	Feature relevance analysis method		
	Tree	SVM_L	χ^2
1	**Pre-eval. diag. spec. 10 (memory)**	**Pre-eval. diag. spec. 8 (attention)**	**Pre-eval. diag. gen. 3 (memory)**
2	**Etiology gen. 2** (other)	Etiology spec. 3 (ischemic-thrombotic stroke)	Pre-eval. diag. spec. 11 (memory)
3	**Pre-eval. diag. gen. 3 (memory)**	**Pre-eval. test 5 (attention)**	**Pre-eval. diag. spec. 10 (memory)**
4	Age treatment	Pre-eval. test 11 (memory)	Pre-eval. test 12 (memory)
5	**Pre-eval. test 2 (attention)**	Pre-eval. test 15 (exec. func.)	**Pre-eval. test 2 (attention)**
6	**Pre-eval. diag. spec. 5 (exec. func.)**	Pre-eval. diag. spec. 1 (exec. func.)	**Pre-eval. test 5 (attention)**
7	Age at injury	Pre-eval. test 2 (attention)	Pre-eval. diag. spec. 4 (exec. func.)
8	**Pre-eval. diag. spec. 8 (attention)**	Pre-eval. test 3 (attention)	Pre-eval. diag. spec. 8 (attention)
9	Pre-eval. diag. spec. 6 (exec. func.)	Pre-eval. test 9 (exec. func.)	Pre-eval. diag. spec. 9 (memory)
10	Pre-eval. diag. gen. 1 (attention)	**Etiology gen. 2 (other)**	**Pre-eval. diag. spec. 5 (exec. func.)**

accuracies achieved by combining concepts are practically always above 60% in all cognitive functions. The highest ones correspond to 61% for *attention*, 67% for *memory*, 61% for *executive functions*, and 64% for *any*. Combining all concepts did not yield to any notable improvement over the other combinations shown in Table II.

We finally perform a brief feature relevance analysis. From the pool of all available features, we run the chosen feature relevance analysis methods (Sec. II-C) and show the 10 best ranked features for each one (Table III). As expected, we see that *pre-evaluation* scores (both *tests* and *diagnoses*) are the majority among the most relevant features. Additionally, we see that *age treatment* and *delay treatment* appear frequently among the 10 best features.

For every cognitive function we find some 'obviously selected' *pre-evaluations*. For instance, *general diagnosis 1*, which evaluates attention, is selected in *attention*, or *specific diagnosis 9*, which corresponds to working memory, is selected for *memory*. There are a number of these rather obvious correspondences. However, we see some *pre-evaluations* that do not directly match the cognitive function they help to predict. The full account of such *pre-evaluations* can be gathered from Table III. We now enumerate some of them: regarding *attention*, we find *test 7* (block design WAIS, executive functions), *test 10* (RAVLT short-term memory, memory), and *specific diagnosis 6* (sequencing, executive functions); regarding *memory*, we find *test 2* (trail marking test part A, attention), *test 5* (stroop word-color, attention), and *test*

6 (digit symbol WAIS, attention); finally, regarding *executive functions*, we find *test 1* (digit span forward WAIS, attention), *test 8* (digit span backward WAIS, memory), and *test 12* (RAVLT recognition, memory).

From our point of view, all these emerging associations between tests/diagnoses and cognitive functions only highlight the interconnectedness of our brain and, therefore, the large dependencies that exist between different cognitive functions. If these associations acquire support or show some persistence in future investigations, one could potentially think of additionally considering them for the assessment of those cognitive functions whose improvement they help to predict. As shown, machine learning techniques can bring valuable guidance in discovering such hidden connections.

IV. Conclusion

In this paper, we provide an application of machine learning techniques to assess acquired brain injury data. In particular, we focus on automatic cognitive prognosis, i.e., the task of predicting whether the patient will improve in a number of cognitive functions using only pre-treatment data. Our contribution shows that variables such as age at injury, etiology, or neuropsychological evaluation scores are relevant for prognosis, yielding statistically significant prediction accuracies. Importantly, the obtained results are independent of the classification scheme, what stresses the predictive power of the considered variables. Finally, machine learning techniques also prove capable of discovering hidden and emerging relations involving pre-evaluation tests and the studied cognitive functions. Overall, these are largely unexplored areas with a high and valuable potential.

In future work we plan to include treatment data to our analysis. This way, combining treatment with diagnosis data, we may be able to advance the outcome of a new patient from a pool of previous patients. In particular, considering both diagnosis data and the performance of the treatment activities that have been already carried out, similar machine learning techniques could be trained to assess whether the patient is correctly responding to treatment or whether such treatment needs to be revised.

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Online Sliding Window Based Self-Organising Fuzzy Neural Network for Cognitive Reasoning

Gang Leng, Anjan Kumar Ray, T. M. McGinnity, Sonya Coleman, Liam Maguire
Intelligent Systems Research Centre (ISRC), Faculty of Computing and Engineering
University of Ulster, Magee Campus, Londonderry, U.K.
e-mail: {g.leng, ak.ray, tm.mcginnity, sa.coleman, lp.maguire}@ulster.ac.uk

Abstract **—We propose an online sliding window based self-organising fuzzy neural network (SOFNN) as the core component of a cognitive reasoning system for a smart home environment. The network has the ability to configure its neuronal structure through adding and pruning of neurons while exploring the relationships between the inputs and the desired reasoning outputs, thus enabling continuous learning and reasoning to provide meaningful cognitive understanding of the environment. Initially, the network is trained with environmentally realistic synthesised data thus demonstrating its adaptation capabilities. The network is then validated using unseen data. In the simulation, we have studied the network structures and responses for three different scenarios with and without online sliding window based approaches and the results obtained show the effectiveness of the proposed method.**

Keywords- ***self-organise; fuzzy logic; neural network; reasoning module***

I. INTRODUCTION

Smart home environments are emerging rapidly as sensor rich systems. These systems require substantial computation to extract high level knowledge and understanding from low level sensory information, so as to enable appropriate decisions to be made regarding the state of the environment, i.e., the ecology. The main objectives of introducing intelligence into a smart home environment are to identify events with various degrees of importance and automatically activate suitable responses [1]. The intelligence comes from the adaptive behaviour of the overall ecology as per the requirements of the user. Different aspects of smart home environments have been reported in the literature [2][11]. These include an intelligent just-in-time Activity of Daily Living (ADL) assistance provision within an integrated system architecture [3], a home monitoring system for elderly-care application [2], and a context aware system for smart home applications [9][11][19]. Researchers have used different methods for contextual representations. Mastrogiovanni et al., [5] have integrated ontology and logic based approaches to map numerical data to symbolic representations. Roy et al. [6] have used possibility theory and description logic (DL) as the semantic model of the agent's behaviour for activity recognition.

Detection of anomalous events within a smart home is an important aspect of situation awareness. Jakkula [4] has used One Class Support Vector Machines (OCSVM) techniques to address this issue. In [15], we have shown that the SOFNN based cognitive reasoning module can be utilised to extract knowledge from everyday events occurring within a smart home environment. The SOFNN has a self-organising capability to configure its structure and identify parameters of the fuzzy neural network from data. We explored the potential of the SOFNN as a core component of a cognitive system unfolding the relations of its inputs and the desired reasoning outputs and showed its ability to adapt its neuronal structure through adding and pruning of neurons. In this work, we show that the proposed sliding window based online SOFNN can achieve similar knowledge via a simpler structure with a reduced number of neurons.

The remainder of this paper is organised as follows: Section II presents an overview of the SOFNN. A sliding window based online SOFNN is described in Section III. Section IV presents the implementation results of the proposed work in a smart home environment. We consider three cases: case 1 represents purely offline training and testing; case 2 represents offline initial training and then online training and testing simultaneously during the verification stage with sliding window control; case 3 represents fully online situation utilising the proposed method. Section V presents the overall conclusion of this work.

II. AN OVERVIEW OF THE SOFNN

The self-organising fuzzy neural network (SOFNN) [14], implementing Takagi-Sugeno (TS) fuzzy models [16] online, is a five-layer fuzzy neural network with the ability

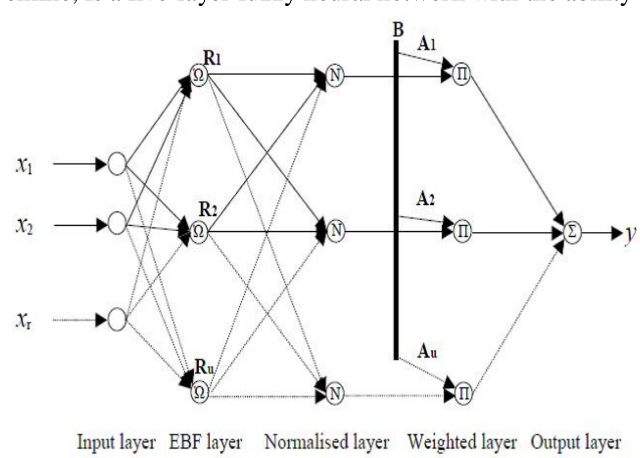

Figure 1. Structure of self-organising fuzzy neural networks

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to self-organise its own structure during the learning process. The structure of SOFNN is shown in Fig. 1.

Consider the t-th observation $(X_t\ d_t)$. We define $X_t = [x_{1t}\ x_{2t}\ \cdots\ x_{rt}]$ as the input vector, r is the number of inputs, d_t is the desired output (target) at time t and y_t is the actual output of the current network at time t. Then, the output in layer 5 is obtained as

$$y(\mathbf{x}) = \frac{\sum_{j=1}^{u} w_{2j} \exp\left[-\sum_{i=1}^{r} \frac{(x_i - c_{ij})^2}{2\sigma_{ij}^2}\right]}{\sum_{k=1}^{u} \exp\left[-\sum_{i=1}^{r} \frac{(x_i - c_{ik})^2}{2\sigma_{ik}^2}\right]}. \quad (1)$$

Here, u is the number of neurons, c_{ij} is the centre of the i-th membership function in the j-th neuron, σ_{ij} is the width of the i-th membership function in the j-th neuron; j and k are variables of the number of neurons and i is the variable of the number of membership functions in each neuron. The row vector $\mathbf{A_j} = [a_{j0}\ a_{j1}\ a_{j2}\ \cdots\cdots\ a_{jr}]$ represents the set of parameters corresponding to the neuron j and w_{2j} is the weighted bias, which is defined for the TS model as

$$w_{2j} = \mathbf{A_j} \times [1\ x_1\ x_2\ \cdots\cdots\ x_r]^T = a_{j0} + a_{j1}x_1 + \cdots + a_{jr}x_r \quad j = 1, 2, \cdots, u. \quad (2)$$

For learning purposes, the output of the network can be described in matrix form as

$$Y = W_2 \Psi \quad (3)$$

$$Y = [y_1\ y_2\ \cdots\ y_n] \quad (4)$$

$$W_2 = \left[a_{10}\ \ a_{11} \cdots a_{1r} \cdots a_{u0}\ \ a_{u1} \cdots a_{ur}\right] \quad (5)$$

$$\Psi = \begin{bmatrix} \psi_{11} & \cdots & \psi_{1n} \\ \psi_{11} x11 & \cdots & \psi_{1n} x1n \\ \vdots & \vdots & \vdots \\ \psi_{11} xr1 & \cdots & \psi_{1n} xrn \\ \vdots & \vdots & \vdots \\ \psi_{u1} & \cdots & \psi_{un} \\ \psi_{u1} x11 & \cdots & \psi_{un} x1n \\ \vdots & \vdots & \vdots \\ \psi_{u1} xr1 & \cdots & \psi_{un} xrn \end{bmatrix} \quad (6)$$

where W_2 is the parameter matrix, ψ_{jt} is the output of the j-th neuron in the normalised layer when the t-th training pattern enters the network.

The learning process of the SOFNN can be divided into structure learning and parameter learning. The structure learning combines adding new EBF (ellipsoidal basis function) neurons and pruning unimportant EBF neurons [14]-[15]. The parameter learning is based on the linear least squares method and the recursive least squares algorithm [17]. The recursive parameter matrix learning algorithm developed in [14] is as follows

$$L(t) = Q(t)p(t) = Q(t-1)p(t)\left[1 + p^T(t)Q(t-1)p(t)\right]^{-1} \quad (7)$$

$$Q(t) = \left[I - \alpha L(t)p^T(t)\right]Q(t-1) \quad (8)$$

$$\hat{\Theta}(t) = \hat{\Theta}(t-1) + \alpha L(t)[d_t - p^T(t)\hat{\Theta}(t-1)] \quad (9)$$

$$\alpha = \begin{cases} 1, & |e(t)| \ge |\varepsilon(t)| \\ 0, & |e(t)| < |\varepsilon(t)| \end{cases} \quad (10)$$

where $\mathrm{Q(t)} = \left[\mathrm{P^T(t)P(t)}\right]^{-1}$ is an MxM Hermitian matrix (Q-matrix), $\mathrm{P(t)} = \Psi^{\mathrm{T}} = \left[\mathrm{p^T(1)\,p^T(2)\cdots p^T(t)}\right]^{\mathrm{T}}$, $M = u \times (r+1)$, $\Theta(\mathrm{t}) = \mathrm{W_2^T} = \left[\theta_1\ \theta_2\ \cdots \theta_M\right]^{\mathrm{T}}$, $e(t) = d_t - p^T(t)\hat{\Theta}(t-1)$ is the estimation error and $\varepsilon(t) = d_t - y_t = d_t - p^T(t)\hat{\Theta}(t)$ is the approximation error. More details can be found in [14].

III. THE PROPOSED ONLINE APPROACH OF SOFNN

The dynamic structure of a SOFNN enables the cognitive system to learn different situations online via self-adaptation. To facilitate online training a sliding-window (SW) [12][13], as a data pool, has been employed. In this case the Q-matrix has to be updated based on limited historical data and current data.

The proposed online approach implements a first-in-first-out sliding window (FIFO-SW) (Fig. 2) with the SOFNN. When new data are obtained the oldest data will be discarded and the new data will be added to this window. The data in the sliding window include the current input-target learning pair as in (11) and limited historical input-target learning pairs as shown in (12) where W is the width of the sliding window.

$$Data_t = [\mathrm{X}_t\ d_t]^T \quad (11)$$

$$Data_{SW} = [Data_{t-W+1}\ Data_{t-W+2}\ \ldots\ Data_t]. \quad (12)$$

Fig. 3 is the block diagram of the proposed online SOFNN. The structure of the SOFNN is self-organised during the

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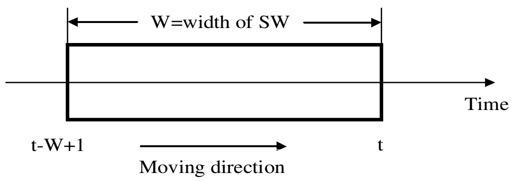

Figure 2. First-in-first-out sliding window

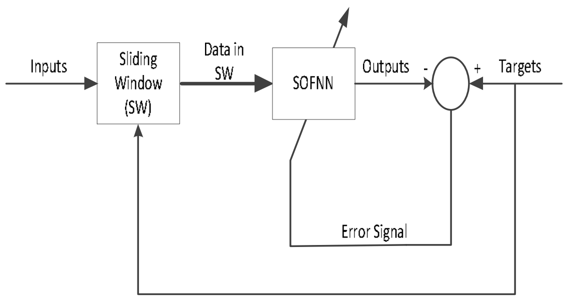

Figure 3. Block diagram of the online SOFNN

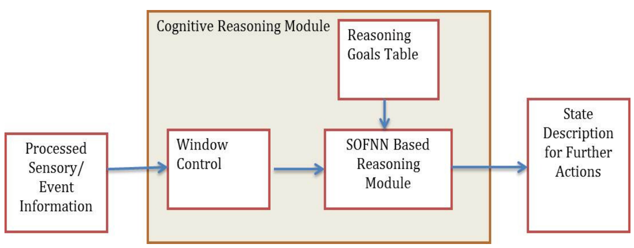

Figure 4. Outline of cognitive reasoning system

learning process. A new SOFNN structure is generated if EBF neurons have been added or pruned in the existing SOFNN structure. In the proposed recursive parameter matrix learning algorithm, the size of the Hermitian matrix (Q-matrix) depends on the number of neurons as $Q(t)=\left[P^{T}(t)P(t)\right]^{-1}$ and $P(t)=\Psi^{T}$. If the number of neurons in the SOFNN structure is changed, the data organized in the sliding window will be used to update the parameter $\hat{\Theta}(t)$ and Q-matrix $Q(t)$ through equations (13) and (14) as follows

$$\hat{\Theta}(t)=\left[P^{T}(t)P(t)\right]^{-1}P^{T}(t)D(t) \tag{13}$$

$$Q(1)=\left[P^{T}(1)P(1)\right]^{-1} \tag{14}$$

where $D(t)=\left[d_{t-W+1}\ d_{t-W+2}\cdots d_{t}\right]^{T}$. The proposed recursive parameter matrix learning algorithm is then applied to update the parameters during subsequent learning. It is clear that if the width of the sliding window is the same as the number of entire training data, then this can be considered as offline training.

IV. RESULTS

In order to evaluate the proposed approach we consider a smart home environment with different sensors and actuators as in the EU FP7 RUBICON project (contract no. 269914) [7]. There are four technical layers named learning, control, communication and cognitive layers, which explore and support the smart home environment. The learning layer addresses sensory information for event classification, the control layer employs robots for different goals within the ecology whereas the communication layer is responsible for data transmission among the layers. The cognitive layer seeks to acquire knowledge and understanding of the state of the ecology as per the event information, while accurately reflecting its dynamics. The proposed online algorithm is employed in the reasoning module of the cognitive layer as shown in Fig. 4. To demonstrate the cognitive capability, it is necessary to handle multiple events that may occur in the ecology, and in particular extract higher-level intelligence. We have anticipated 19 events as inputs from a home environment reflecting activities of a user and the states of the environment and a set of 10 reasoning goals as outputs are chosen to reflect the network's capabilities of reasoning across user activities and current state of the ecology. Table I and II show the chosen inputs and outputs [15]. Values of inputs and outputs represent confidence levels between 0 and 1. We synthesize 4500 data samples including data for 19 inputs and 10 reasoning outputs. To validate the performance of the proposed online algorithm, three cases have been designed.

A. *Case 1: Offline Training and Learning*

The first 3900 data are chosen as the training data and the last 600 data are used as the testing data. We use the training data to obtain the SOFNN structure. We then test the performance using the testing data based on the obtained SOFNN structure during which the structure is not refined. This is an offline training process without sliding window control.

B. *Case 2: Pseudo Online Training and Learning*

In case 2, the first 3900 data are used as the first group of training data. The remaining 600 data are used as the testing data, as well as the second group of training data. The first phase is offline training without sliding window control. In the testing process using the second group of data, the obtained structure is also updated based on the FIFO sliding window with the size of 300 samples. In this phase, the refining process is based on the proposed online training algorithm as equations (7) to (14). The testing data are used to validate the performance of the obtained SOFNN structure. This case is a combination of offline and online training process (pseudo online). This process also shows that the approach can continue its training and learning from a previously offline trained network.

TABLE I. THE EVENT INPUTS FOR REASONING MODULE

Synthesized Input	Events
1	User in room 1
2	User in room 2
3	User in room 3
4	Visitor detection
5	Phone event
6	Doorbell event
7	Dripping event
8	Music event
9	Fire alarm
10	Microwave usage
11	Dishwasher usage
12	TV usage
13	Cleaning operation
14	Cooking
15	Use of oven
16	Smoke detection
17	Room temperature
18	Burglary alarm
19	Front door usage

TABLE II. TARGETED OUTPUT OF SOFNN REASONING

ID	Potential reasoning outputs
1	User exercise
2	User relaxing
3	User in kitchen
4	Bring phone
5	Open door
6	Cooking activity
7	Fire alert situation
8	Burglary alert situation
9	Dripping alert situation
10	Cleaning situation

C. *Case 3: Fully Online*

In case 3, all 4500 data are used as the training data. The rear 600 data are the testing data used to validate the performance of the obtained SOFNN structure. For this case, we use the training data to train the SOFNN structure, based on the FIFO sliding window with the size of 300 samples from the beginning of the training. No offline training occurs in this case. To compare with case 1 and case 2, the testing data are used to validate the performance of the obtained SOFNN structure. In this testing process, the obtained structure is also continuing its refinement. So, the structure and parameters are also changing based on the proposed online algorithm.

During the training process in all cases, event inputs and reasoning outputs form the training data as presented in (11). However, during the testing phase, only event data are presented to the network and the reasoning outputs are obtained from the trained network. The results achieved for each of the three cases are presented in Tables III, IV and V. It is observed in Table III that case 1 through to case 3 have 42, 42 and 28 neurons respectively to reason across the reasoning outputs for the smart home environment. The root mean square errors (RMSE) of the training are presented in Table IV for the first set of 3900 data. As case 2 incorporates offline training with the first set of data, the RMSEs are same as case 1. RMSEs of testing of case 2 are better than those of case 1 (Table V) as the obtained structure for case 2 has been refined during the testing process. For a number of the reasoning outputs, the RMSEs of the training and testing of cases 1 and 2 are smaller than the corresponding values in case 3. This is because of the sliding window with limited data has been applied in case 3 from the beginning of the training process as opposed to offline training without sliding window in other cases. However, the reduced number of neurons in case 3 than those in case 1 and case 2 highlights the potential for the proposed online sliding window based approach. Fig. 5 shows the change in neuronal structure for each of these cases. It is observed that case 3 has 28 neurons compared to 42 neurons for cases 1 and 2 respectively. Hence in comparison with the offline approach in case 1 and the pseudo online approach in case 2, the fully online approach in case 3 with FIFO sliding window has the capability to generate a simple structure and achieve similar performances.

Fig. 6 presents an example of the online case 3 with the output “User Exercise”. Fig. 6-(a) shows the training process where the network has identified the transitions when the user starts and ends exercising. In this case, the plot shows only data samples from 3301 to 3900 for clarity. It shows the desired state and the training output of the user exercise situation. It is observed that the network is able to learn this situation. For this output, there are two neurons generated during the training process, which are shown in Fig. 7. It also shows that the number of neurons in the network is changed dynamically during the training process illustrating the self-organising capability of the proposed network. The final 600 data, from 3901 to 4500, have been used in the testing process. The testing results are given in Fig. 6-(b). It is observed that the network is capable of identifying the user exercise situation as desired.

Fig. 8 presents an example of the online case 3 for the open door situation. Fig. 8-(a) shows the desired and actual outputs during the training process where the network has identified the requirements to open the door of the home. In

TABLE III. NUMBERS OF NEURONS FOR 3 CASES

Outputs	Case 1	Case 2	Case 3
User Exercise	3	3	2
User Relaxing	9	9	4
User in Kitchen	2	2	2
Bring Phone	2	2	2
Open Door	2	2	2
Cooking Activity	2	2	2
Fire Alert Situation	2	2	2
Burglary Alert Situation	3	3	3
Dripping Alert Situation	14	14	6
Cleaning Situation	3	3	3
Total Number	42	42	28

TABLE IV. RMSES OF THE TRAINING FOR 3 CASES

Outputs	Case 1	Case 2	Case 3
User Exercise	0.0566	0.0566	0.0566
User Relaxing	0.0463	0.0463	0.0478
User in Kitchen	0.0562	0.0562	0.0551
Bring Phone	0.0641	0.0641	0.0596
Open Door	0.0540	0.0540	0.0507
Cooking Activity	0.0629	0.0629	0.0617
Fire Alert Situation	0.0393	0.0393	0.0311
Burglary Alert Situation	0.0395	0.0395	0.0463
Dripping Alert Situation	0.0359	0.0359	0.0378
Cleaning Situation	0.0385	0.0385	0.0481

TABLE V. RMSES OF THE TESTING FOR 3 CASES

Outputs	Case 1	Case 2	Case 3
User Exercise	0.0580	0.0577	0.0631
User Relaxing	0.0492	0.0490	0.0558
User in Kitchen	0.0558	0.0557	0.0555
Bring Phone	0.0652	0.0650	0.0683
Open Door	0.0498	0.0496	0.0533
Cooking Activity	0.0658	0.0650	0.0705
Fire Alert Situation	0.0401	0.0397	0.0432
Burglary Alert Situation	0.0189	0.0184	0.0187
Dripping Alert Situation	0.0484	0.0481	0.0832
Cleaning Situation	0.0443	0.0526	0.0532

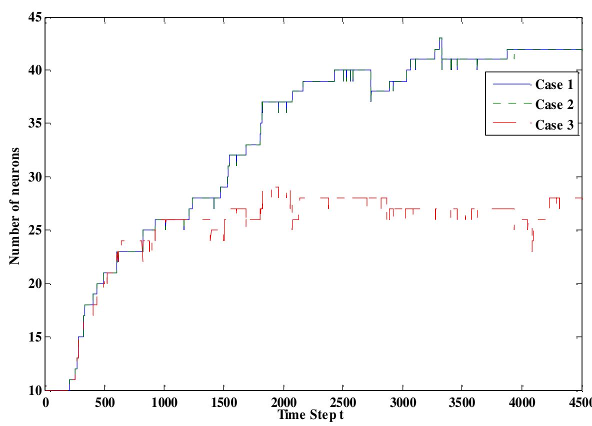

Figure 5. Change of neuronal structure for case 1 through to 3

this case, the plot shows only data samples from 3301 to 3900 for clarity. For this output, there are two neurons generated during the training process, which are shown in Fig. 9. It also shows that the number of neurons in the network is changing dynamically during the training process. The final 600 data, from 3901 to 4500, have been used in the testing process. The testing results are given in Fig. 8-(b). It is observed that the network is capable of identifying the situation as desired.

The Mackey-Glass time-series with a 6-step-ahead prediction model [18] is simulated to show the advantage of the proposed online algorithm in machine learning. This is a benchmark example of a chaotic system. We have chosen the parameters as in [18] for consistency with earlier work.

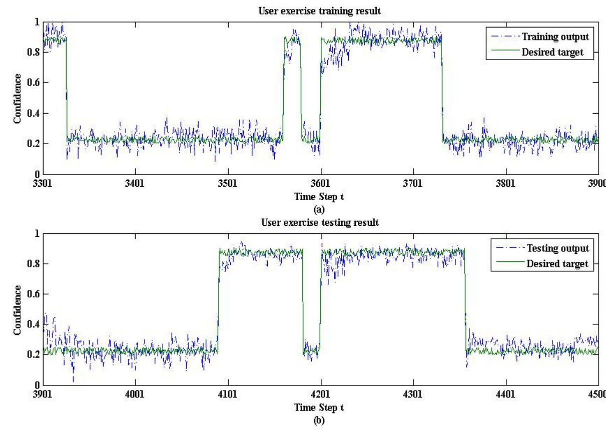

Figure 6. Results of case 3 for user exercise situation

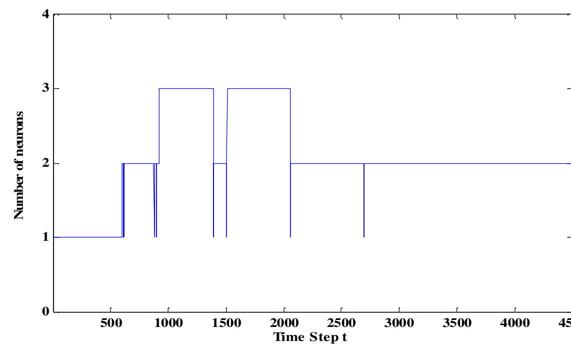

Figure 7. Growth of neurons for user exercise in case 3

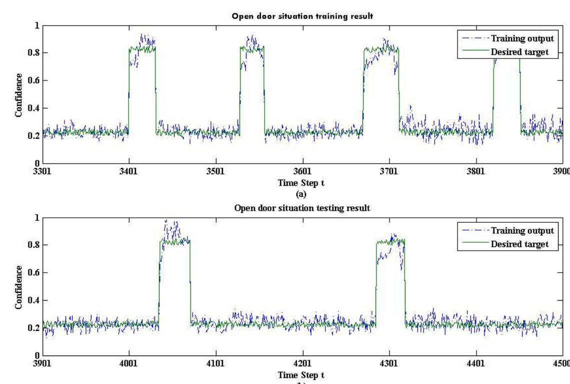

Figure 8. Results of case 3 for open door situation

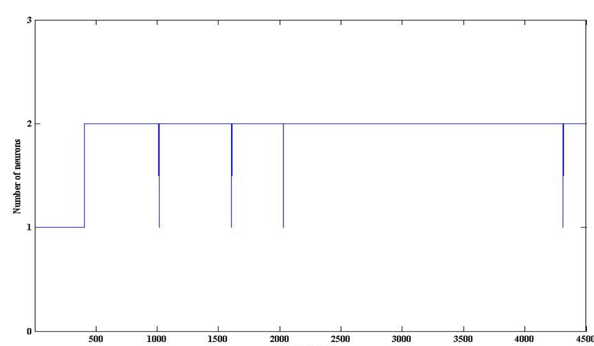

Figure 9. Growth of neurons for open door situation in case 3

TABLE VI. RESULTS OF MACKEY-GLASS TIME-SERIES PREDICTION

Approach	Number of neurons	RMSE of training	RMSE of testing
WNN [18]	4	-	0.0153
Case 1 (no SW)	4	0.0114	0.0116
Case 2 (SW 100 during testing)	4	0.0113	0.0151
Case 2 (SW 200 during testing)	4	0.0114	0.0148
Case 2 (SW 300 during testing)	4	0.0113	0.0123
Case 3 (SW 100)	4	0.0141	0.0151
Case 3 (SW 200)	4	0.0142	0.0148
Case 3 (SW 300)	4	0.0142	0.0123

The results of this simulation are shown in Table VI. We compare our results with the wavelet based neural network (WNN) in [18] which also tabulated further comparative results with other existing methods. It is observed from the RMSE values that our approach produces better results for all three cases presented when compared with the WNN.

V. CONCLUSIONS

This paper presents an online self-organising fuzzy neural network based on the sliding window. The proposed online algorithm has been applied to a smart home situation. The method is also compared with two other designed cases (cases 1 and 2) to show its advantage. A more compact structure and similar performance are obtained using this proposed online algorithm (case 3). Furthermore, we also show through case 2 that the proposed algorithm can be combined with a previously learnt system for continuous learning with new available data. From these results, we can conclude that the proposed method is suitable for online cognitive reasoning. We also consider a benchmark chaotic system prediction using our proposed method and present comparative results with an existing wavelet neural network based approach. The results show that the proposed sliding window based online approach is suitable for machine learning.

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Inducing models of vehicular traffic complex vague concepts by interaction with domain experts

Paweł Gora
Faculty of Mathematics, Computer Science and Mechanics
University of Warsaw
Warsaw, Poland
Email: pawelg@mimuw.edu.pl

Piotr Wasilewski
Faculty of Mathematics, Computer Science and Mechanics
University of Warsaw
Warsaw, Poland
Email: piotr@mimuw.edu.pl

***Abstract*—In the paper, we outline our research on obtaining domain knowledge related to vehicular traffic in cities using interaction with experts. The goal of acquiring such knowledge is to construct hierarchical domain oriented classifiers for approximation of complex vague concepts related to the road traffic. Interaction with experts in construction of hierarchical classifiers is supported by the software for agent-based simulation of vehicular traffic in cities, Traffic Simulation Framework, developed by the first author.**

***Keywords*-vehicular traffic; interaction with expert; complex vague concepts; perception based computing;**

I. Introduction

Vehicular traffic in cities is a complex phenomenon, which has a significant impact on environment and life of many people. Understanding the phenomenon and learning how to control it is a very important task.

One of the main objectives of our research is to detect traffic jam patterns from low level data using domain knowledge. We propose to support the searching process by interaction with domain experts ([2]). This can be done by acquiring from experts the relevant concepts, e.g. *traffic jam*, *traffic congestion*, *traffic jam formation*, and next by making it "understandable" to the system using classifiers. The key issue here is how to dialogize with experts.

In this research, we focus on a single basic traffic concept - *traffic congestion on a single crossroad* - and we elaborate methods for approximating this concept from sensory data. Sensory data come from simulating traffic using the Traffic Simulation Framework software [6], [7], [8]. Data from the software may slightly differ from real-world traffic data (which are very difficult to obtain), but are confirmed to be quite realistic [9], enough to conduct our research and get meaningful results. These data will be used to construct hierarchical classifiers based on rough set methods [2], [16], [22], which will approximate the concept of a traffic jam on a single crossroad. The concept is complex, vague and semantically distant from sensory data, so it is difficult to construct such classifiers explicitly. Classifiers constructed using universal methods (independent on domain knowledge) were not able to approximate such complex traffic concepts with satisfactory accuracy. It is necessary to construct domain oriented classifiers [2]. However, it is not clear how to obtain domain knowledge related to such complex phenomenon as traffic jam and it motivates research presented in the paper.

The paper has the following organization. In Section II we present the idea of interaction with domain experts and explain why it is important in the contemporary machine learning and data mining, particularly in acquiring domain knowledge about complex processes as vehicular traffic in cities. In Section III, we argue that vehicular traffic should be considered as a complex system and its understanding and modeling is a difficult task. Section IV outlines past approaches to traffic modeling, recent approaches based on probabilistic cellular automatons and the model developed and implemented by the first author of the paper. Section V presents our methodology in details: the procedure of dialogizing with domain experts, design of our experiments and expert decisions evaluation. In this section, we also present values of parameters that are used in our traffic simulations.

II. Interaction with domain experts

Contemporary machine learning faces a couple of big challenges. One of them is the problem of data mining (DM) and knowledge discovery in databases (KDD) with dynamically evolving complex data (e.g. stream data sources, sensory data). Another challenge for machine learning is a growth of size and complexity of data sources (e.g. Web sources, neuro-imaging data, data from network interactions). These challenges, in particular, discovery of complex concepts, hardly can be met by classical methods [19]. They can be met by KDD systems dialogizing with experts or users (e.g. interview with V. Vapnik [29]) or by adaptive learning systems changing themselves during the learning process as the response to evolving data. Another challenge comes from a field of multi-agent systems. Behavior steering and coordination of multi-agent coalitions acting and cooperating in open, unpredictable environments call for interactive algorithms, i.e. algorithms interacting with the environment during performing particular steps of computation or chang-

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ing themselves during the process of computation. All of these challenges are present in a domain of traffic control and modeling and can be approached using Perception Based Computing paradigm [25], [26], [27].

Coordination and control are essentially perception based. We understand perception as a process of interpreting sensory data. In the case of road traffic, sensory data can be acquired from traffic control systems as well as from traffic simulators. A crucial issue is how to apply such lower-level data to reason about satisfiability of complex vague concepts including complex spatio-temporal concepts as the concept of a traffic jam or traffic congestion leading to a traffic jam. Complex vague concepts can be used as guards for actions or invariants to be preserved by agents. Such reasoning is often referred as adaptive judgment [10]. Vague concepts can be approximated on the basis of sensory attributes rather than defined precisely. Approximations usually need to be induced by using hierarchical modeling. Unfortunately, discovery of structures for hierarchical modeling is still a challenge. On the other hand, it is often possible to acquire or approximate them from domain knowledge. Given appropriate hierarchical structures, it becomes feasible to perform adaptive judgment [10], starting from sensory measurements and ending with conclusions about satisfiability degrees of vague target guards.

III. Vehicular traffic as a complex system

Vehicular traffic in cities may be considered as a complex dynamic system, which consists of hundreds of thousands independent agents (cars), which drive in the road network realizing a specific goal. This goal is usually reaching a destination point located somewhere in the road network, fulfilling some additional conditions, e.g. minimizing travel time, fuel consumption etc., and following the rules of drive. Agents interact with each other since they use the same road network. This interaction may be purpose of exhibiting new properties of the traffic, such as formation of traffic jams. This property is not obvious from the properties of individual agents (cars) and it is very difficult to predict this phenomenon in advance (e.g. $5 - 10$ minutes before jamming) and to prevent it. In order to ensure collision-free drive of cars, traffic engineers introduce mechanisms, e.g. traffic control systems such as traffic signals at crossroads, which control drive of cars and optimize the traffic.

Despite many years of extensive research, it is still difficult and challenging task to model the traffic in cities properly and with satisfactory accuracy using standard mathematical tools or computer simulations. In addition, the phenomenon may be even more complex and difficult if we assume, that drivers know the real state of the current traffic and choose their routes adaptively. Similarly, it is possible that the traffic control system adapts to the traffic in order to optimize it, which makes the traffic prediction and modeling even more complex. In this kind of complex processes, often the only possible way to model and analyze the process is by making a computer simulation.

IV. Modeling and simulating vehicular traffic

A. Early models

From few decades scientists and traffic engineers have been working on modeling and better understanding the vehicular traffic. They created complex mathematical models, often based on analogies to other real physical phenomenons. For example, some interesting results were obtained by investigating analogy of the vehicular traffic to fluid dynamics. However, traffic flow is significantly different phenomenon, it consists of several substreams, cars have their own start and destination points [12], [23]. There were also approaches to model the traffic using analogies to the kinetic gas theory [20]. These macroscopic models were not able to model the real traffic with satisfactory accuracy. The reason was that they did not take into account local interactions between agents (cars), which are crucial properties of the road traffic.

One of the considered approaches to solve the problem was introducing microscopic models, in which agents (cars) and their interactions were described by mathematical equations, for example *Car-following models* were based on analogy to Newton dynamics equations [23].

B. Models based on cellular automatons

An important progress in modeling vehicular traffic in cities was made by introducing traffic simulation models based on probabilistic cellular automatons. An example of such model is a Nagel-Schreckenberg model (Na-Sch model) [13], [24], which emulates a freeway traffic. Space, time and velocities in the model are discrete, the road is divided into cells, which may be empty or occupied by at least one car, cars motion is defined by properly selected rules. The model was broadly investigated and generalized, e.g. to simulate 2-lane traffic ([21], [14]) or simple crossroads [4].

C. TSF model and software

The Na-Sch model was also used as a base model for a new traffic simulation model developed by the first author of the paper (P. Gora, [6], [8]). The model extends the standard Na-Sch model and enables conducting simulations on a realistic road network, structuralized as a directed graph. The model takes into account, e.g. driver's profile, road's profile, traffic signals, distributions of start and destination points.

The TSF model was later implemented in an advanced software for simulating vehicular traffic in cities, Traffic Simulation Framework. The main window of the software is presented in the Figure 1.

The software uses maps taken from the OpenStreetMap project ([15]) and currently it is able to simulate the traffic in Warsaw. It was confirmed by Warsaw citizens that the

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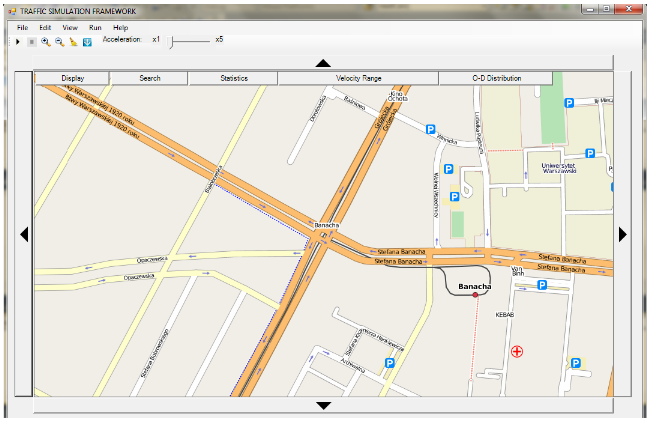

Figure 1. Traffic Simulation Framework - the main window of the application

software can reproduce traffic jams in the same places as they occur in reality. The software is still being developed, its functionality was described in papers [6], [8]. TSF has been already used, e.g. for generating data for the IEEE ICDM 2010 contest [9], [28] and is used by scientists from few countries. The TSF software will be also used for simulating the traffic and interaction with experts. It possesses a multifunctional Graphical User Interface, which can be used to present simulations to experts and acquiring their knowledge about the simulated traffic.

V. METHOD

Traffic is a very complex phenomenon and many high level concepts related to that phenomenon are complex and vague and we do not know how to define it mathematically (also it may depend on many factors such as a type of crossroad, city etc.). However, human brain can recognize such concepts much better. Experts who often drive by cars and stay in traffic jams are able to recognize the traffic situation easily by observing the traffic for some period (e.g. 10 minutes).

In this research, we will acquire such domain knowledge by interaction with experts. We will show short (2-minutes long) movies, presenting simulated traffic, to domain experts. After watching the movie, experts will have to decide what was the state of the traffic. We will also have low level data related to presented traffic situations. Based on the expert domain knowledge and these sensory data, it will be possible to construct hierarchical classifiers (e.g. using rough sets methods [2]) that will approximate the concept of a traffic jam on a given crossroad and extract traffic jams formation models.

Hierarchical classifiers are examples of classifiers which are decision algorithms that map objects to decisions [1], [3]. Objects could be described by low-level numerical or symbolical attributes. Decisions, in many cases, are vague, complex concepts, which are semantically distant from original low-level data. Hierarchical classifiers could be viewed as tools to cover that distance by approximating complex, vague concepts, using low-level data. In such classifiers the classification process goes from input data to decisions through at least few hierarchy levels, from lower data levels to higher, more abstract, complex concept levels. Objects and/or attributes on higher levels are constructed based on objects and/or attributes from lower levels [26], [27]. This process may be supported by domain knowledge, given e.g. in the form of ontologies. To cover the semantic distance, training sets can be constructed with experts support. Decisions could be also complex, temporal or spatio-temporal objects as automated planning of complex objects behaviour, e.g. safe diriving through a crossroad or medical diagnosis, see [2].

In case of our hierarchical classifier, approximating the traffic congestion concept, low-level data, such as number of cars, car's position, current car's speed, will be taken from our traffic simulator ([6], [8]), and decisions will be taken from experts by mean of a dialog. In our traffic congestion hierarchical classifier, objects and attributes from consecutive hierarchy levels will be constructed by information systems, decision tables and decision rules taken from the rough set theory [16], [17], [18] as it was done in [2].

This section describes construction of a traffic congestion training set.

A. Dialog procedure

In this research, we focus on a single crossroad in order to obtain domain knowledge about the traffic congestion and presence of a traffic jam near that crossroad during a given traffic situation, which corresponds to 10 minutes of simulation. This will be done by a dialog with domain experts.

We will conduct some number of simulations using the Traffic Simulation Framework and we will refer to them as *traffic situations* or simply *situations*. For the purpose of the paper we assume to conduct 51 simulations (the proper number should be also subject of further research and experiments). Every situation will last 10 minutes and be run with different parameters, such as:

1) number of cars,
2) start and destination points distributions,
3) initial configuration of traffic lights on a given crossroad.

We selected values of all important simulation parameters in our past research and experiments. These values are presented in the section V-B.

Every situation will be "recorded" - Traffic Simulation Framework will log information about positions and velocities of cars during the simulation in order to read it later and show the same traffic situation to experts using Graphical

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User Interface of our software. The following information will be logged to the output file:

- Timestamp (simulation step),
- Car positions (link in the road network, position within the link, geographical longitude and latitude),
- Current car's speed (in km/h).

This logged information enabled reconstruction of the situation, which will be shown as a movie to experts.

We assume that duration of a single phase of traffic lights is constant and lasts 2 minutes for every traffic signal, so every 10-minutes long situation will consist of 5 parts, each of which will last 2 minutes and will correspond to 1 phase of a traffic light. To these situation parts we will refer simply as *phases*.

We divided logs from our 10-minutes long simulations, so it will be possible to show to domain experts 2-minutes long phases separately. Totally, it will give us 255 phases, which lasts 2 minutes each.

Each of 51 situations will be evaluated by domain experts and their task will be to provide information about a traffic state in the area close to the crossroad during every 2-minutes long part of the simulation. In our case (vehicular traffic in cities) a domain expert may be any person who has experience with the city traffic, the most preferable should be drivers, which use road networks in Warsaw often and have to cope with traffic jams.

1 of 51 situations will be analyzed by all experts, while every situation from the rest 50 will be analyzed by 3 experts giving 50×3 situation evaluations. Every expert will analyze 1 situations: 1 common to all experts and 2 taken from the rest 50. Therefore, we will construct 150 / 2 = 75 different tests, one for each expert, so we will need 75 experts. In every test each 10-minutes long situation will be divided into 2-minutes long phases. Thus, every test will be constructed from 15 phases (2-minutes long movies). Additionally, from every situation two phases will be randomly selected to be presented and labeled by experts twice. Therefore, every test will consist of 21 phases presented to the expert in a random order. Experts will not be informed that some of this phases are repeated in a test. After a presentation of a particular movie, the question will be displayed: *What was the traffic congestion?*, and experts will answer the question with one of five possible answers: *Small*, *Medium*, *Large*, *Traffic jam*, *I don't know*. The answer will be provided using the window presented in the Figure 2 which will be shown after every movie.

In the next step, the system will ask experts for the response justification, which they can provide in natural language using the window presented in the Figure 3.

If the user selects *I don't know* response in the first window, the system will ask for checking two closest options from other options available in the window which is presented in the Figure 4.

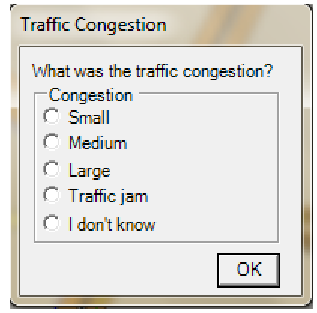

Figure 2. Window that will be shown to experts after every movie

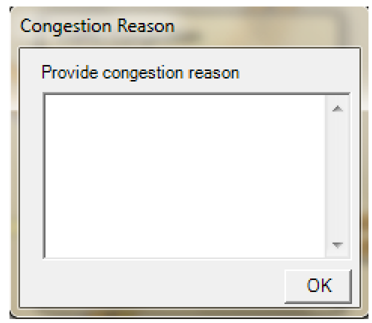

Figure 3. Window to justify the response

After checking the answers and submitting justifications, the next movie will be presented to the expert.

B. Conducting experiments

In our research we will examine the area close to the intersection of streets Banacha, Grójecka, Bitwy Warszawskiej 1920 in Warsaw, which are very close to our Faculty and this crossroad is a place were large traffic congestion occurs very often. The area under investigation is presented in the Figure 5.

We prepared 51 traffic simulation scenarios, each of which will be run using the TSF software producing 51 traffic situations. Every situation lasts 10 minutes and will be run using simulation parameters presented in the table V-B. These parameters were selected based on our preliminary experiments.

Simulations differ in distributions of start and destination points of cars (and routes calculated based on that distributions) and number of cars that start drive every TimeGap steps (V-B). We prepared 5 different distributions of starting points and 5 different distributions of destination points. Distributions of starting points were named ”From East”, ”From West”, ”From North”, ”From South”, ”Uniform”, distributions of destination points were named ”To East”, ”To West”, ”To North”, ”To South”, ”Uniform”. It gives us 25 configurations of pairs: (start points distribution, destination points distribution). Names of distributions indicates were is the major concentration of start or destination points, respectively. The detailed description of these distributions

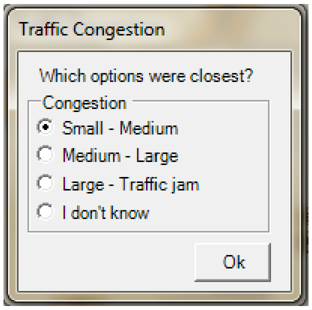

Figure 4. Window for submitting two closest options

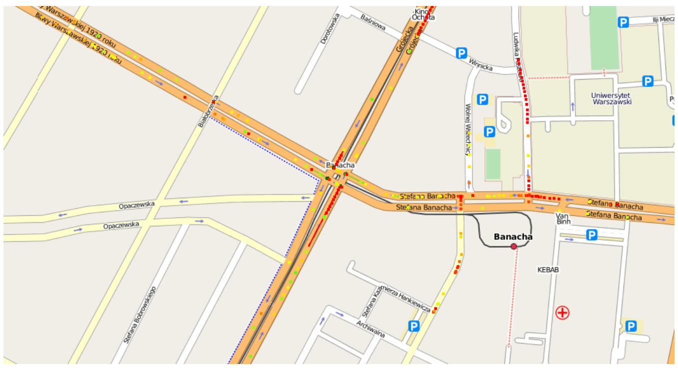

Figure 5. Crossroad of streets Banacha, Grójecka, Bitwy Warszawskiej

and procedures for editing start points and destination points is described in the paper [6].

For every combination of pairs (start points distribution, destination pionts distribution) we still have few degrees of freedom that can be manipulated in order to produce different simulation scenarios. Some of these degrees of freedom correspond to parameters named in the first column of the table V-B: $NrOfCars$, $NewCars$, $Acceleration$, $CrossroadPenalty$, $TurningPenalty$. Other parameters may be related to the initial configuration of traffic signals at the crossroad or maximal velocity permissible on a given street. For our current research we need only 51 simulation scenarios, so we decided to manipulate the parameter $NewCars$. 5 different start points distributions, 5 different destination points distributions and 3 different values of the $NewCars$ parameter gives us 125 possible simulation scenarios, from which we chose 51 that are the most realistic appropriate to conduct our research.

C. Evaluation of obtained decisions

Evaluation of expert decisions can be either *expert-oriented* or *case-oriented*. In the expert-oriented evaluation we will check a consistency of decisions made by a given expert. In this case, the evaluated situation should be labeled by an expert (before evaluation) at least twice for checking stability of the expert decision making. In order to do that, from every situation two phases will be selected to be labeled

Table I
SIMULATION PARAMETERS USED IN OUR EXPERIMENTS

Name of the parameter	**Description**	**Value**
NrOfCars	Initial number of cars for a single traffic situation	1000
TimeGap	Time after which new cars start their movement	1 second
Step	Time of a single simulation step	1000 miliseconds
NewCars	Number of cars which start movement after every TimeGap seconds	$5, 3, 1$
Steps	Duration of the simulation	600 simulation steps
Acceleration	Acceleration of cars per simulation step	10 km/h
CrossroadPenalty	Percentage of velocity reduction before the crossroad	25%
TurningPenalty	Percentage of velocity reduction during turning	50%

by an expert twice. In the case-oriented evaluation we will analyze how a given case (phase or situation) is labeled by different experts. For this purpose, every phase will be labeled by three different experts. Their decisions will be used either to determine the final aggregated decision, e.g. by voting, or to find a uniformity of decisions about a given phase. It should be noted that our approach is only one of possible and that decision evaluation itself is a novel and interesting issue and a topic for further research.

VI. Conclusions and future work

In the paper, we presented a method for obtaining vehicular traffic domain knowledge using interaction with experts. The method also requires realistic simulations of vehicular traffic, which can be performed using an advanced software Traffic Simulation Framework [6], [7], [8], developed by the first author of the paper. This is still work in progress and presented method will be a subject of our future research. We still need to conduct required experiments and evaluate obtained knowledge. In the next step, we will construct hierarchical classifiers for approximating spatio-temporal complex vague concepts related to vehicular traffic. According to the paradigm of Perception Based Computing, satisfiability of such concepts may activate complex actions, such as reconfiguring traffic lights at crossroads in order to prevent traffic jams or to optimize some key parameters of the traffic. Such classifiers may be used, e.g. for discovering models of complex processes, such as formation of traffic jams, which may be later used to analyze many properties of the traffic. All of this may be a subject of extensive research and obtaining domain knowledge from experts is just the first step. As we argued in the introduction, this step is crucial to construct efficient hierarchical classifiers from low level sensory data in case of such complex process as vehicular traffic in cities.

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Decision-Making Mechanism to Organize the Agenda of a Guide-Robot

José Javier Rainer, Rafael León, Ramón Galán, Agustín Jiménez
Intelligent Control Group.
Universidad Politécnica de Madrid
Madrid, Spain
e-mail: javier.rainer@upm.es

***Abstract*— One of the major challenges in evolutionary robotics is constituted by the need of the robot being able to make decisions on its own, in accordance with the multiple tasks programmed, optimizing its timings and power. In this paper, we present a new automatic decision making mechanism for a robot guide that allows the robot to make the best choice in order to reach its aims, performing its tasks in an optimal way. The election of which is the best alternative is based on a series of criteria and restrictions of the tasks to perform. The software developed in the project has been verified on the tour-guide robot Urbano. The most important aspect of this proposal is that the design uses learning as the means to optimize the quality in the decision making. The modeling of the quality index of the best choice to perform is made using fuzzy logic and it represents the *beliefs* of the robot, which continue to evolve in order to match the "external reality". This fuzzy system is used to select the most appropriate set of tasks to perform during the day. With this tool, the tour guide-robot prepares its agenda daily, which satisfies the objectives and restrictions, and it identifies the best task to perform at each moment. This work is part of the ARABOT project of the Intelligent Control Research Group at the Universidad Politécnica de Madrid to create "awareness" in a robot guide.**

Keywords- Cognitive systems; decision making; learning; autonomous robot; fuzzy systems.

I. INTRODUCTION

Any given autonomous system should be able to make its own decisions in order to perform all the tasks commanded. Autonomous robots are intelligent machines capable of performing tasks in the world by themselves, without explicit human control over their actions [1].

Within the development of multiple applications for a mobile robot, probably one of the first real world applications of indoor service robots has been mobile robots serving as tour guides in museums or exhibitions. We have developed our own interactive mobile robot called Urbano specially designed to be a tour guide in exhibitions [2].

The acquisition of new behavioral skills and the ability to progressively expand our behavioral repertoire represents one key aspect of human intelligence and a fundamental capacity for robots companion, i.e. robots that should cooperate with humans in everyday environments [3]. Unfortunately, the issue of how robots can acquire new action skills by integrating them into their existing behavioral repertoire still represents an open challenge for evolutionary/developmental robotics [3] [4] [5].

In this paper, we provide a model validated through a series of experiments that demonstrates how a robot can be trained incrementally for the ability to develop lower-level and then higher-level goal directed action skills.

The knowledge is based on an ontology of domain-specific concept words. Ontologies have been known in computer science as consensual models of domains of discourse, usually implemented as formal definitions of the relevant conceptual entities [6].

The criteria, in order to make a decision to organize the agenda of a guide robot, must be linked to the knowledge of every task to perform that day, being also aware that some new activities might appear during the day. Therefore, the system must regularly check if any new task has come along. Each task to perform might also be composed by several tasks on its own. This set of tasks makes up the agenda. It contains the information required in order to know, through the decision making mechanism, how to perform every task, when and in which order.

Some of the most recent works about decision-making are described in [7-13]. These works propose different architectures and methodologies than those presented here.

This paper is structured in the following sections: in section II, the basic features of URBANO are depicted. In section III, DMM (Decision Making Mechanism) agent software is described. This agent is the one that decides commands, selects or creates specific tasks, so it is the most significant agent within the software of the robot. Section IV is about the agenda that will be optimized by the learning system and the work tree. In section V decision-making mechanisms are discussed and in section VI the learning method is described. Finally, in section VII, conclusions derived from this work are discussed.

II. URBANO, AN INTERACTIVE MOBILE 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.

This Section does not want to be an exhaustive technical description of algorithms, mathematical or implementation detail, but just an overview of the system.

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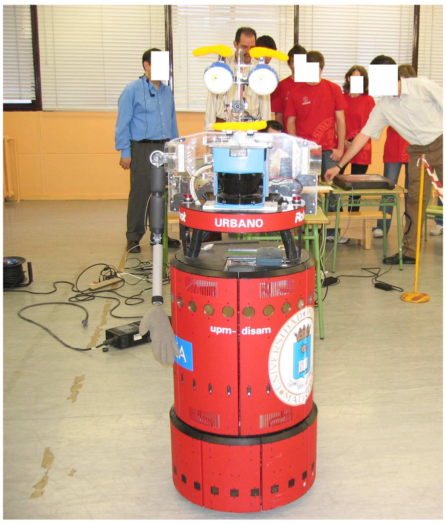

Figure 1. Urbano Tour-Guide Robot.

Urbano robot is a B21r platform from iRobot, 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 a robotic arm used to express emotions as happiness, sadness, surprise or anger.

The robot is also equipped with two sonar rings and one infrared ring, which allow detecting obstacles at different heights. Those devices can be used for obstacle avoidance and safety. The platform has also two onboard PCs and one touch screen.

The software is structured in several executable modules to allow a decoupled development by several teams of programmers, and they are connected via TCP/IP. Most of these executables are conceived as servers or service providers, as the face control, the arm control, the navigation systems voice synthesis and recognition, and the web server. The client-server paradigm is used, being the only client a central module that we call the Urbano Kernel. This kernel is the responsible of managing the whole system [2].

The notion of *agent* more and more appears in different contexts of computer science, often with different meanings.

In the context of Artificial Intelligence (AI) or Distributed AI, agents and multi-agent systems are typically exploited as a technique to tackle complex problems and develop intelligent software systems [14][15].

URBANO robot has a technology based on distributed application software. The recent version is an agent based on architecture that uses a specific CORBA approach as an integration tool. The robot has many functions: speaks, listens, navigates through the environment, moves his arm, responses to stimuli that affect its feelings. Figure 1 shows a picture of Urbano.

A. URBANOntology

Nowadays, ontologies represent a largely adopted information codification technique in many knowledge domains.

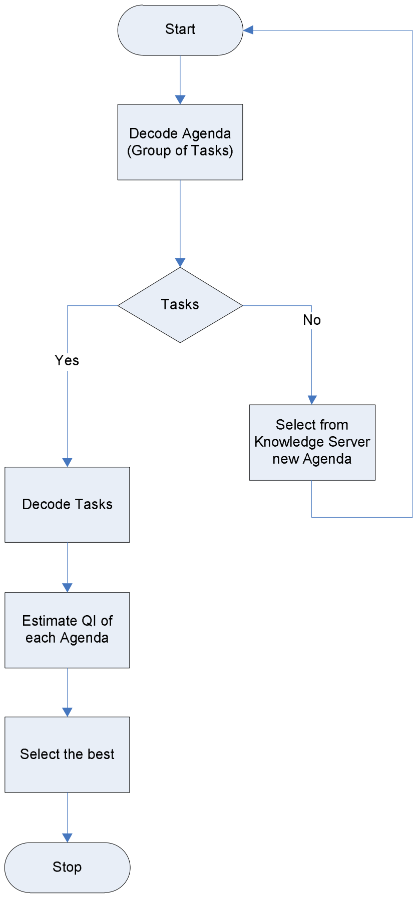

Figure 2. Flowchart of DMM agent

The knowledge server consists of a Java application developed using the libraries of Protégé-OWL API. 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. DMM AGENT

DMM (Decision Making Mechanism) agent software has been developed to be integrated in the architecture based on the agents that constitute the software of the Urbano robot.

DMM is the most significant agent since it is the one that decides commands, selects or creates a specific task in accordance with the quality index and the external information given by the environment.

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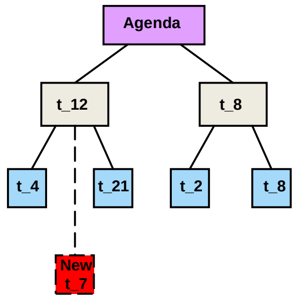

Figure 3. Tree Data Structure

Figure 2 shows the Flowchart. The system starts by decoding the agenda, which might be daily, or can be executed each time a task is finished, just in case a new task has been included on it, as Figure 3 shows.

When the agenda is decoded, the knowledge server provides all the information about the tasks to perform. The knowledge server also provides all the relevant information regarding each task. There are tasks that cannot be performed before than others, i.e., if Urbano must perform a lecture inside a Museum, before starting its speech about a certain painting, it should have taken its position in front of the painting before starting to describe it, as shown in Figure 4. This series of restrictions must be acknowledged at the time of establishing the tasks executing orders. DMM optimizes the tasks to perform within the multiple choices generated when establishing the daily agenda.

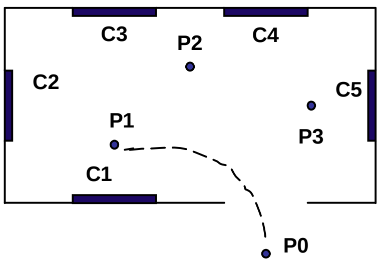

Figure 4. Itinerary to perform on a guided route.

IV. AGENDA AND WORK TREE

The agenda highlights the items that belong to each task to perform. For each item, these elements are established: its identification, its priority, its numerical order.

The tasks stored in the knowledge server are structured as shown in Figure 5. The agenda composes a list of the tasks with their parameters and in accordance with the acting mechanism. The simplest tasks correspond to basic tasks the robot can perform, with their own parameters; i.e.: task: “spin”, with a certain rotating “degrees” as a parameter. This list must be organized according the difficulty of the task, if they have a high, medium or low level, to associate a priority to each one.

Therefore, the following tasks are three different classes: go on to a point (Go on), walk to the left (Walk-Left), walk to the right (Walk-right). Meanwhile, the actions per se would be: go straight (Straight), rotate (Spin) or go backwards.

In the event of a time limit, because a task uses too much time, the priority index shows which activity should be included. On the other hand, if the tasks take too little time, it is possible to occupy the remaining time with a pending activity. Figure 4 describes a series of tasks that consist in: Go to P1, explain C1, go to P2, explain C2 and so on; in the event of running out of time, the DMM should be able to decide which task to exclude.

It is used XML as the language to represent the agenda, which guarantees an easy use with different tools and programming languages. XML has emerged as a de facto standard for encoding and sharing data between various applications. XML is also useful for structured information management, including information contained in knowledge server [16].

DMM requests from the knowledge server tasks to perform. The knowledge server will submit one or more actions for that task; because of a same task can have several actions.

The activities or tasks will be stored as a work tree in the knowledge server, as shown in Figure 6. When the system decodes the agenda, it shows every possible combination that can result of combining every task to perform.

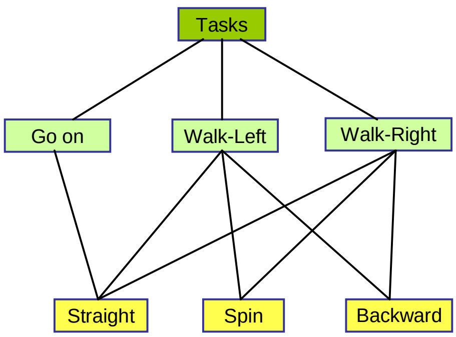

Figure 5. Connection between tasks and actions

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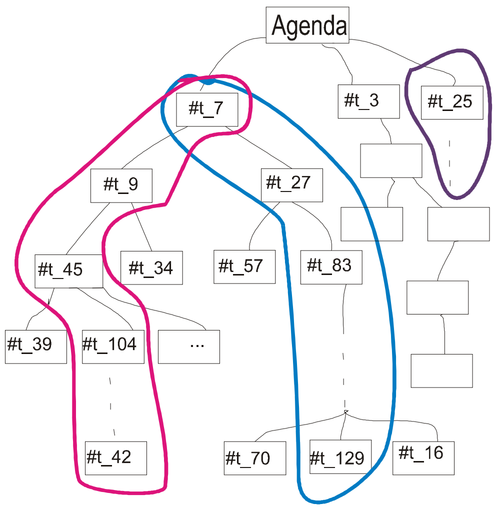

Figure 6. Different options to perform the agenda

Three typical alternative heuristic searches have been tested to trim the tree. The first one uses "brute force" to generate all the possible combinations and to group all the numeric values of the "quality criteria" of the paragraphs that form the presentation, and then, using a set of fuzzy rules, it estimates the quality index. It selects the agenda with the highest index.

The second alternative uses "best-first search" so that as it goes along, it takes the option that partially presents the best index. This alternative is, without a doubt, the fastest one, but it cannot guarantee the selection of the best option.

The third alternative is here described and it consists in calculating a global quality index for each one of the alternative possible agendas to accomplish each day, which is generated from all the combinations within every task. The agenda chosen will be the one with a higher quality index, according the fuzzy logic.

The agenda generated with this method analyzes the estimated time for its execution, and if this is greater than anticipated, it eliminates the tasks with the least necessary priority. On the other hand, if there is enough time, it includes some other pending task that did not need to be executed at a specific time of the day.

V. DECISION-MAKING

Decision-making is a part of the paradigm proposed by Zadeh [17] that has been currently examined in [18]. In a dynamic scenario as ours, and because of the nature of the information that the system will handle, proper tools are needed to provide the intelligence for decision-making and supervision.

Decision-making is the cognitive process of selecting a course of action from multiple alternatives. Fuzzy set approaches to decision-making are usually most appropriate when human evaluations and the modeling of human knowledge are needed.

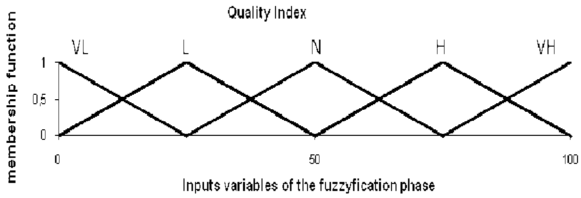

Figure 7. Inputs variables of the fuzzyfication phase

The proposed solution uses fuzzy rules to calculate the quality index of each alternative generated. The fuzzy rules enable more flexibility. These rules will be adjusted and expanded.

All information available at the moment about the quality criteria and its influence on the quality index is stored in the ontology of the knowledge server.

The semantic network will indicate that the influence of the task in the agenda, expressed in a percentage.

Five linguistic terms are defined: VERY_HIGH (VH), HIGH (H), NORMAL (N), LOW (L), VERY_LOW (VL), as it is depicted in Figure 7. The fuzzyfication phase uses the function of membership to initially equidistant triangles, but in the learning phase their centers can vary. The exit variable quality_index is also modeled with five terms and triangular functions. The technique of centroid method is used in the defuzzyfication phase.

The rules look like:

If Criteria1 is LOW and
Criteria2 is HIGH and
…
CriteriaN is NORMAL then
quality_index is NORMAL

This enables to obtain one quality index for each alternative, being the winner agenda the one which scores a highest quality index.

VI. LEARNING PHASE

The most important feature of the proposal is the ability of the robot to learn. Initially, it is thought that the robot will have a small number of quality criteria available to evaluate some tasks as good and others as bad, corresponding to the minimum level of knowledge on how to organize properly its time and agenda, in order to guarantee a minimum level of quality in its tasks performance.

In this section, we describe the results obtained during the first training phase in which the robot is trained for the ability to organize its agenda.

TABLE I. QUALITY CRITERIA

Quality Criteria	Should be
Order in which the tasks are performed	60%
Time spent in each task	80%
…	
New criteria to bear in mind	**%**
Global satisfaction on the accomplishment	25
Global evaluation	**%**
	80

To ensure that the making decisions mechanism works properly, tests have been conducted with an Urbano at a Museum, where it should guide a visit. To accomplish this, first it should welcome the group and then guide them across a room. Once the visit is over, a simple questionnaire has been designed and the audience is asked to fill it out after attending. That questionnaire is about how the robot has performed its tasks and how it has guided the visitors. It asks for an evaluation of each quality criteria known at the time, indicating whether the robot should spend more or less time on each item, and a percentage evaluation of what the visitors consider valuable in the presentation. The Table I shows an example.

A proper statistical treatment of the questionnaires is performed, eliminating extremes and requiring a minimal quantity of data.

Since the robot *beliefs* on how to execute the tasks might not meet the "external reality", it is very important to obtain this information from the visitors and feed it back to the robot, so that, in time, its beliefs will match with the opinion of the visitors on the correct tasks performance.

A genetic algorithm is used, an adjustment the membership functions, will allow the quality index to be the closest to the average expressed by the public.

The genetic algorithm realizes a readjustment of the rules when it produces a disparity between audience opinion and quality index

From the results obtained through genetic algorithms, it is possible to point out that they accomplish their agenda, but not in the expected time. Therefore, it is being studied some other improvement alternative. Table II shows the results obtained.

TABLE II. RESULTS OBTAINED THROUGH GENETIC ALGORITHMS

Quality criteria	Linguistic terms	Total variables	CPU time
3	5	125	0,5 hours
4	5	625	5 hours
7	5	78125	10 hours

VII. CONCLUSION

In this paper, a decision making mechanism has been introduced, which enables the robot to organize its agenda properly in a way that optimizes its tasks.

The learning phase is of paramount importance, since it is located in a dynamic environment, i.e., the information changes. Also, the environmental knowledge that the robot has must meet the "external reality". This optimization has to be based on the continuous contrast of "beliefs" and "external reality". Measuring this "realities" and feeding them back can be complicated when personal assessments are involved.

Also, it is proved that this mechanism enables to accomplish missions, sets of tasks, through a studied combination of all of them. For future studies, it is aimed that the system will have the ability of generating new missions (or new tasks) from basic tasks.

The proposed mechanism is exportable to other autonomous robots.

ACKNOWLEDGMENT

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A Framework for the Implementation of Artificial Robotic Emotional Brain Based on Embryonic and Evolutionary Hardware

Fernando Cortez Sica
Department of Computer Science
Federal University of Ouro Preto
Ouro Preto, Brazil
Graduate Program in Electrical Engineering
Federal University of Minas Gerais
Av. Antnio Carlos 6627, 31270-901
Belo Horizonte, MG, Brazil
sica@iceb.ufop.br

Ricardo de Oliveira Duarte
Department of Electronics
Federal University of Minas Gerais
Av. Antnio Carlos 6627, 31270-901
Belo Horizonte, MG, Brazil
ricardoduarte@ufmg.br

Frederico Gadelha Guimarães
Department of Electrical Engineering
Federal University of Minas Gerais
Av. Antnio Carlos 6627, 31270-901
Belo Horizonte, MG, Brazil
fredericoguimaraes@ufmg.br

***Abstract*—This paper proposes a framework architecture to export services and facilities for the implementation of artificial robotic emotional brain. The framework utilizes concepts from embryonic and evolutionary hardware. Additionally, we map correlations between computational systems with natural cognition, knowledge formation and representation. The main contribution of the paper relies in the utilization of symbolic and connexionist approaches to cover all the knowledge representation aspects. This way, this framework facilitates the implementation of generic intelligent systems.**

***Keywords*—embryonics; evolutionary systems; evolvable hardware; artificial brain; artificial life.**

I. Introduction

Many current systems that require action-behavior predictions, e.g., control systems, data mining, biomedical analysis and telemetry systems, are focused on the knowledge manipulation, whether deterministic or not. Real systems can be highly susceptible to environmental interferences, often not evaluated and not covered during the intelligent system modeling and simulation.

Considering these challenges and demands, this paper aims to develop a framework for developing artificial robotic emotional brains endowed with embryonic and evolutionary mechanisms. The model presented is general and can be used in many applications that require knowledge manipulation for decision making. A possible application of this framework is the implementation of decision support and diagnostic systems. In both cases, the artificial brain has the ability to learn, in a continuous way, new rules and structures on the manipulated knowledge.

In the intelligent systems area, we can find implementations using three different approaches: symbolic (which simulates the reasoning mechanism without considering the biological factor), connexionist (which simulates the biological brain structure to process knowledge) or hybrid approaches [4]. As examples of these approaches, we can cite the projects described in [1], [2] and [3], respectively. In our case, we adopt the hybrid approach to make the system flexible in relation to knowledge representation (as mentioned in Subsection III-B).

This framework implements embryonic and evolutionary mechanisms on a software and hardware integration solution. The solution adopted by this framework is used to map artificial robotic brain cognitive models and also to provide a direct mapping between cognitive science concepts and computer science.

In addition of being able to contribute to achieve the fusion between embryonic and evolutionary mechanisms, this project is also intended to make adaptation and modeling using autonomous intelligent agents in the computational design. The use of intelligent agents will facilitate the abstraction of the mental structures and their relations, allowing for a better representation of the artificial mental scheme. In this context, by artificial mental scheme we mean the way knowledge is represented and abstracted.

The manipulation of emotional factors will act as excitatory or inhibitory signals to the process of knowledge manipulation, learning and decision making.

In order to validate the proposed model, this project will be applied in an example of application that require knowledge manipulation for decision making: aircraft system health monitoring [5]. The artificial robotic emotional brain, substantiating the knowledge stored in his hybrid structure (connexionist and symbolic), will be able to assist the aircraft failure prevention systems. In this case, the stimuli and input information will be collected from the electronic components and, from these, the system will be able to generate, autonomously, the knowledge needed to be converted into preventive actions.

This paper is structured as follows. In Section II, the basic concepts in cognitive systems and evolutionary robotics are presented. In Section III, the proposed framework architecture is described and our basic mechanism is shown in Section IV. In Section V, the preliminary results are provided. Finally, we present our conclusions in Section VI.

II. Background

A. Cognitive Systems

Initially, it is interesting to mention that the cognitive process presents a dynamic behavior. This dynamic behavior is related to the environment interaction: collecting information, encoding it, storing it and processing it such that then there may be some action performed in the environment.

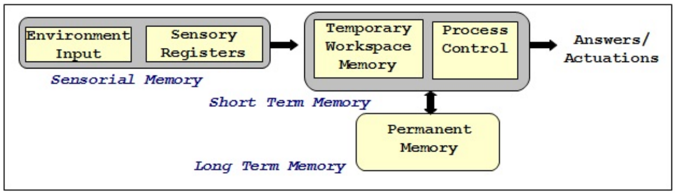

Fig. 1: Cognitive model proposed by Atkinson and Shiffrin in 1971 [6]

The work described by Atkinson and Shiffrin [6] portrays one of the first relevant cognitive computational systems. In that work, a cognitive system is described as a hierarchical memory system: sensory memory, short term memory and long term memory (Figure 1).

Other models, such as in [7] – [11], have been proposed with opposite ideas or complementary ideas to the model of hierarchical memory. Some of these proposals have incorporated the filter attention idea. Filters are capable of acting in the attenuation or amplification of signals to be inferred and manipulated by the cognitive system. Filters react due to the emotional aspects, stored knowledge and importance of the stimuli.

To better illustrate the cognitive systems idea, Figure 2 presents the model proposed in [12].

In the architecture shown in Figure 2, the perception and action events produce signs that can be evaluated for the formation of beliefs. Beliefs are states and interactions expected to be assumed by the agent. During the action event, there is a feedback for possible restructuring of signs, adapting them to the new situation imposed by the environment. Every action is the result of the Action Selection process computed by the deliberative module.

Another important issue in cognitive systems is the knowledge representation. The information to be stored for later processing represents information about the environment and about the system itself, rules, goals, heuristics, relationships, actions, events and other information used to represent the real world and its interaction with the computational system. The most well-known techniques for knowledge representation are based on logics (predicate calculus), production rules, frames, conceptual graphs and ontologies, and combinations of these techniques. [13]

B. Evolutionary Robotics

One of the first projects in evolutionary robotics is presented in [14]. In that work, a navigation system to enable a robot to move in an area with obstacles was designed.

Another application in evolutionary computation and electronics that deserves to be mentioned for its pioneering in the scope of artificial brains can be found in [15] and [16]. In these references, a brain structure is mapped through a three-dimensional arrangement using FPGA (Field-Programmable Gate Array) [17].

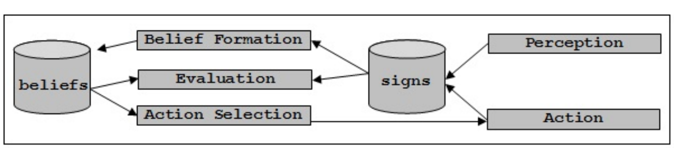

Fig. 2: IVA (Intelligent Virtual Agent) Architecture proposed by A. Arnellos et al. [12]

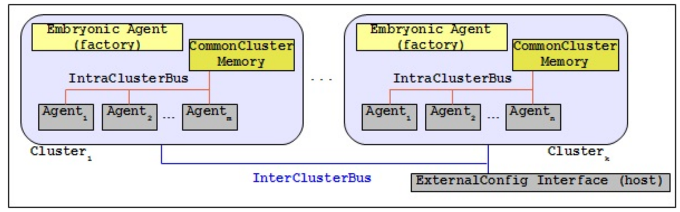

Fig. 3: Proposed architecture for the artificial robotic emotional brain

Others applications can be cited, as control engineering based on artificial brains endowed with emotions [18] – [20].

III. Proposed Architecture

In general terms, the proposed architecture (Figure 3) for the development of robotic artificial emotional brain based on embryonic and evolutionary hardware uses the idea of autonomous intelligent agents for clustering information and, consequently, to better express the knowledge incorporated by the agents. Another reason for clustering is to resemble the brain anatomy, where the cortex is divided into functional areas, allowing for a better computational performance and a higher system granularity.

Figure 3 shows a macroscopic view of the system with multiple clusters instantiated. Each cluster has three basic and fixed elements (*Embryonic Agent*, *CommonCluster Memory* and *IntraClusterBus*) and their respective agent instances.

The *Embryonic Agent* manages the creation or removal of agents instances. This mechanism allows for the self-adaptation of the multi-agent systems, given the environment dynamics. The *CommonCluster Memory* is a common area for information storage (long term memory). The *IntraClusterBus* and the *InterClusterBus* are communication elements based on the *Wishbone* standard [21].

Referring to Figure 3, notice the presence of instances of agents in the clusters. Each agent, operating autonomously and cooperatively, is responsible for: Sensory information acquisition (sensory system); Encoding, storage and data processing; Actuation on the environment.

To accomplish such functions, each agent has a functional structure illustrated in Figure 4.

Figure 4 presents the basic elements that comprise the cognitive agent: *sensory system*; *storage, coding and processing system (SCP System)*; *Agent Core* and *Agent Memory*, which will be described below.

A. Sensory System

The *sensory system* must be able to pick up stimuli from the environment to provide knowledge modifications and to make the

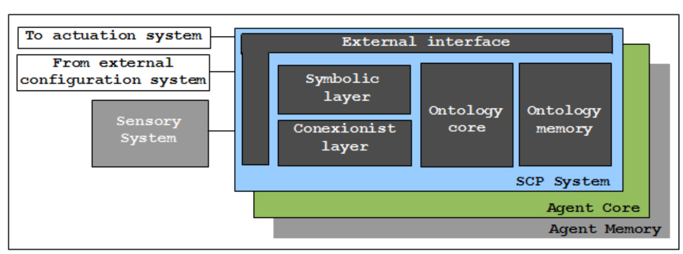

Fig. 4: Functional structure of each agent.

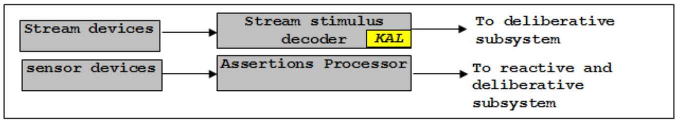

Fig. 5: Structure of the sensory system.

actuation on the external environment promptly. These two processing types represent the deliberative and reactive behavior, respectively [12].

The *sensory deliberative system* is responsible for interfacing the system with the environment to capture, for example, image, sound or other waveforms (stream devices). Regardless of the device type used to capture data, the goal of the sensory deliberative system consists in encoding external stimuli in connexionist mappings. The connexionist maps will be the cognitive system basis - in this case, the information will form, according to Peirce [22], the informational *Firstness*, i.e., isolated information that does not represent knowledge yet (*quali-signs*).

The Peirce categorizations (*Firstness*, *Secondness* and *Thirdness*) for the organization of symbols in the knowledge generation will be contextualized, in system level modeling, during the explanation inherent to the *SCP System*.

The reactive sensory system should observe environmental values, which represent exceptions to normal conditions. Therefore, in order to get a prompt response, this project utilizes a library for hardware failures verification: the *Open Verification Lib* (*OVL*) [23].

Since *OVL* is a library for fault verification and its utilization is motivated by:

- Continuous checking of critical elements (values);
- Product evaluation during all life cycle;
- Possibility of incorporating fault tolerance mechanisms. It is understood as those originating failures due to errors in design or transient errors;
- Possibility of activating reconfiguration mechanisms when hardware and software flaws are observed.

The use of *OVL* purely as a flaw verification and correction element can be found in [24], where chained assertions are used to send signals to a functional element (e.g., a processor) to perform specific events. However, in this project, *OVL* will be used as an inspection element of values that might result in events of the reactive system. This idea of using the library to launch various events can be found in [25], where assertions (monitoring points within the hardware) are used in order to extend the exception handling in the computing environment.

In conclusion, in order for the deliberative and reactive systems to receive information from the environment, the sensory system consists of two functional modules, as explained in Figure 5.

Also, in relation to Figure 5 and to the sensory system, the stimulus stream decoder aims to capture and process information streams (stimuli), e.g., video and sound, dividing them into frames such that they can be evaluated and handled by the deliberative system. The coding models used by the decoder are stored in a repository called *Knowledge Abstraction Layer* (denoted by *KAL*).

The assertions processor is a hardware that aims to collect information from sensors and to signal the reactive and deliberative systems when previously determined values (or range of values) occur. This information will shape or will interfere with the emotions or the artificial robotic brain learning rates.

B. Storage, coding and processing system (SCP System)

In order to allow greater modularity and reuse of the mental structures that represent knowledge, the *SCP System* is based on a hybrid topology, adopting, in this case, the connexionist and symbolic models. A hybrid modeling was adopted to best abstract Peirce's categorizations for knowledge representation and composition. In this case, one has:

- *Firstness*: connexionist model where each nerve cells cluster denotes a real-world object - the *quali-signs*;
- *Secondness*: mapping between the connexionist model and the stored knowledge by means of ontologies to denote the signs composition and structuring;
- *Thirdness*: application of high-level ontological rules to thought and logical reasoning formation, relating *Firstness* and *Secondness* instances.

The *SCP* internal elements form the robotic artificial emotional brain basis and can be replicated in clusters for better information representation (knowledge classes) and to provide greater dynamism to processing. Each cluster can evoke cluster creation or destruction functions exported by the *embryonic agent layer (factory)*, shown in Figure 3.

For a better detailing of the model, the components belonging to the *SCP* will be presented in the following sections.

1) connexionist Layer: Briefly, under the biological viewpoint, a neuron can have as basic functionalities: to receive external stimuli (afferent neurons), to provide the interneurons association (associative neurons) and to provide the output stimulus (motor neurons). Regarding its functionality in associative aspect, a neuron can be pyramidal (derived association between layers) and non-pyramidal (provides connection between neurons in the same layer).

For modeling purposes, this project will model only two neurotransmitters to incorporate the emotions idea: acetylcholine (acting in attention, learning and memory) and glutamate (associated with long-term memory and learning) [26]. The neurotransmitters act only in the symbolic processing layer because they are cognitive processes and long-term memory regulatory elements. The change in levels of neurotransmitters is due to the information values provided by the sensory acquisition.

Finally, completing the basic biological characterization and to give the clustering abstraction, the cortex is divided into association regions (where the motor and sensory areas are located) and projection regions (where the processing itself is performed). Initially, we mapped only two cell types: pyramidal and non pyramidal. This criterion was adopted to provide communication optimization and to better manipulate the attribute types associated with each cell. Pyramidal cells are modeled only as connection cells between layers. Non pyramidal cells can be classified as afferent, associative and motor.

The mechanisms for the creation of neuronal structures are contained in the acquisition layer, represented by the *KAL*.

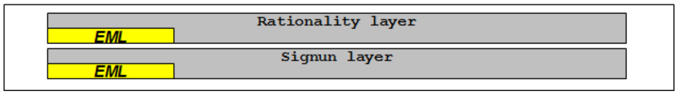

Fig. 6: Structure of the Symbolic Layer.

In this project, only projection cortex areas are mapped, since the mechanisms associated with the association areas are handled by the symbolic processing layer. The number of instantiated regions is related to the external stimuli types to be captured by the system. To facilitate the processing, the cortical regions may be further divided, making the system scalable according to the actual needs.

2) Symbolic Layer: The function of the Symbolic Layer is the formation of signs and reasoning in the artificial robotic emotional brain. It should act in accordance with the ontologies stored in its bases. Moreover, it is responsible for the implementation of the evolutionary mechanisms that allow a cognitive dynamics.

In order to abstract Peirce's categorizations as mentioned earlier, the symbolic layer is divided into two sublayers (Figure 6).

In Figure 6, note the presence of the evolutionary mechanisms layer (*EML - Evolutionary Mechanisms Layer*), which, as already mentioned, will provide system reconfiguration mechanisms to signs generation and logical reasoning improvement.

3) Ontology Core: The *Ontology Core* is based on a general purpose microprocessor optimized to memory access. The basic function of the Ontology Core is to execute the XML parser, which performs search and manipulation operators over the XML structures (*XML* denoting ontologies). It was decided, initially, to use a general-purpose microprocessor because of the ease to implement *XML* parser via software. The ontologies, in our project, provide the knowledge representation under manipulation, e.g., grammatical rules, a circuit specification or an initial Bayesian network [27].

4) Ontology Memory: The *Ontology Memory* module has the function of storing ontologies manipulated by each agent cluster.

5) Agent Core: The *Agent Core* is a general purpose processor to perform the agent functions. To ensure efficiency, flexibility and software availability, the *OpenRisc 1200* [28] has been chosen to equip the framework.

6) Agent Memory: Unlike *Ontology Memory*, the *Agent Memory* aims to store agents code and attributes (e.g., their states).

C. Actuation System

For initial and prototyping purposes, the *Actuation System* is modeled as simply a set of input and output pins in order to provide basic functionality, for example, digital output, strobe and *ACK* pins.

D. Communication System

Besides the need to represent the cognition environment, it is also necessary to have infrastructure for communication between agents and between agent clusters. Joining the cognitive functionalities, where each cluster stores part of the knowledge, intra and inter communication mechanisms are also required. Returning to Figure 1, these two communication levels are represented by *IntraClusterBus* and *InterClusterBus* respectively. To facilitate the initial prototype, it was decided to use an open model bus: the *Wishbone*.

TABLE I: Hardware Values

FPGA model	Xilinx Spartan 3
Number of LUTs	1% (9 of 15360)
Number of IO Ports	12% (27 of 221)
Number of Slice Flip-Flop	1% (15 of 15360)
Minimum period	4.238ns (Max. Freq.: 235.960MHz)
Minimum input arrival time before clock	7.032ns
Maximum output required time after clock	8.962n
Maximum combinational path delay	8.618ns

IV. PROPOSED BASIC MECHANISM

As mentioned earlier, our project uses a hybrid architecture to acquire, map and process information. More specifically, we used:

- SOFM (Self Organizing Feature Maps) and direct load values to discover new basic information types (Firstness);
- Bayesian Networks to map the relationship between the primary information;
- Extraction of production rules from the Bayesian Network;
- Conversion of production rules to electronic digital logic.

In brief, Figure 7 illustrates the information composition scenario.

Faced with this scenario, we adopted the following algorithm:

Algorithm 1 Basic Update Values Algorithm

```
if new external stimulus then
  if mapped knowledge then
    update the hardware registers values
    hardware inference start
  end if
  modify the Bayesian Network
  run learning evolutionary mechanisms (into Bayesian Network)
  run the mechanism to extract production rules from Bayesian
  Network
  transfer, on-the-fly, the new production rules structure to the
  programmable device (FPGA)
end if
```

V. PRELIMINARY RESULTS

A hardware prototype was designed to support production rules with up to 256 nodes (Figure 8 shows the hardware interface).

The modification of the production rules will change, only, the internal routing, without the insertion of new hardware structures. Table I shows relevant information about the hardware designed.

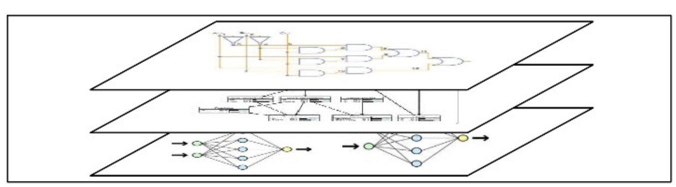

Fig. 7: Composition of information: the lower layer corresponds to the isolated values of information obtained from SOFM or general data input (e.g., sensors); the intermediate layer denotes the Bayesian Network and, finally, the upper layer represents the mapping in electronic digital logic.

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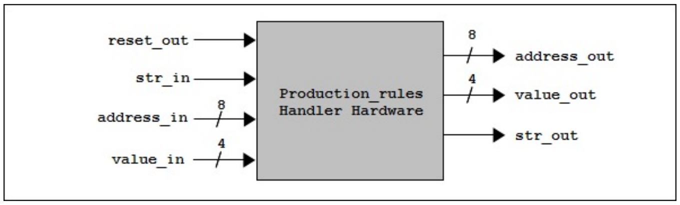

Fig. 8: Hardware interface of the production rules handler (reset_out: reset the strobe out pin; str_in: strobe input; address_in: input node identification; value_in: input node value; address_out: identification of activated output node; value_out: value of activated output node; str_out: strobe out).

VI. Conclusion and Future Work

This paper presented the framework architecture for the development of artificial robotic emotional brains based on embryonics and evolutionary hardware.

Our framework has been tested in small production rules. The result was satisfactory with respect to the response time of the external stimulus (in about 8ns). The FPGA reconfiguration time was not taken into account at this stage in the project.

As future plans, and for testing and validation purposes, this framework will be used in the implementation of a commercial aircraft proactive maintenance system. The signals from the aircraft systems and components will act in reactive and deliberative knowledge processing. The signs will also be modeled as emotional elements that interfere in the sensitivity level to be passed to the cognitive process and to the reactive actuation system.

Acknowledgment

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Metacognitive Guidance in a Dialog Agent

Elizabeth McNany*, Darsana Josyula*†, Michael Cox*, Matthew Paisner* and Don Perlis*
† Bowie State University, Bowie, MD, USA
* University of Maryland, College Park, MD, USA
{beth, darsana, mcox, mpaisner, perlis}@cs.umd.edu

***Abstract*—The paper discusses the benefits of metacognitive guidance for a natural language dialog agent. These capabilities may be included directly in the agent or through a general purpose external module. We report on the specific case of handling pause time in dialog, using a metacognitive loop within the agent, and discuss future experiments implementing guidance for this example also using the general module.**

Keywords-metacognition; dialog management

I. Introduction

In human dialog, if the listener does not understand the speaker, the listener will typically notice the problem and take some action to address it. He may ask the speaker to repeat the statement, ask for clarification, or ignore the anomaly in hopes of determining the meaning later from context. In this way normal flow of conversation may be maintained. Similarly, if the speaker does not respond, several scenarios may have occurred: the speaker has left the conversation; the speaker forgot; or the speaker is thinking, and does not yet have a response. The listener then has to choose an appropriate course of action. This may include reminding the speaker by repeating the question, waiting a bit longer for an answer, or deciding the speaker is no longer responsive and ending the conversation.

When faced with such anomalies in dialog, humans very effectively *note* the anomaly, *assess* how to deal with it, and *guide* a response strategy into place. We call this the N-A-G process [2], and have modeled it in our artificial dialog agent, Alfred.

N-A-G is an example of so-called *metacognition*. Normal cognition entails reasoning with knowledge available to the agent; meta-cognition is reasoning about this reasoning. For instance, in the previous example, the speaker reasons that after asking a question the listener will respond; after this fails, the speaker must then decide (via logical reasoning, presumably) where his or her logic failed and thus how to recover from the anomaly. N-A-G is an essential component of a larger reasoning process, which we call the metacognitive loop (MCL) [13], [3]. To employ MCL, a system must (i) have expectations about what it will observe; (ii) note deviations from those expectations, reason about, and respond to them; and (iii) adjust those expectations as suggested by experience; item (ii) is simply the N-A-G process.

We have implemented several applications with MCL built in; and we more recently implemented a general purpose MCL module, which we call GP-MCL. GP-MCL is designed to be attached to many types of systems and includes facilities to handle many types of anomalies - from physical or external errors such as unexpected obstacles or user input, to logical or internal errors based on incorrect assumptions. Because it is created with no specific system in mind, GP-MCL is flexible enough to deal with failures in a variety of possible situations.

We are exploring the possibility of applying the general guidance provided by MCL to the particular case of the dialog agent Alfred. The specific application we examine is that of an expected pause time between utterances in a conversation. We also propose future experiments in a 2x2 design, of location of anomaly versus location of anomaly handling, detailed later in Section VI.

II. Related Work

Work in linguistics focusing on conversational competence has shown the importance of meta-reasoning and error handling in natural dialog. Based on Chomsky's [6] notion of linguistic competence, Hymes introduced the idea of communicative competence [8]. Hymes identified four characteristics of communicative competence, namely if the utterance is: formally possible (that is, grammatical), feasible with available means, context-appropriate, and actually performed. Canale [5] expanded on this idea, also with four types of communicative competence: grammatical, sociolinguistic, discourse (cohesion of utterances within a dialog), and strategic (strategies used when communication breaks down). Of these four, sociolinguistic and strategic were identified by Savignon [12] as necessary and sufficient conditions for communicative competence. Some examples of strategies given in Tarone [14] include approximation, circumlocution, repetition, asking for help, and abandoning the utterance.

Even prior to these findings in linguistics, Rieger [11] concluded that sufficient meta-reasoning when handling natural language can overcome deficiences in other language skills. McRoy [10] echoed this, including the ability to deal with mistakes as a central component of reasoning and linguistic capabilities. These mistakes were defined as inconsistencies between actual utterances and expectations of the dialog participant in [7]. More recently, Anderson and Lee [1] found that more than half of dialog management is meta-linguistic, dealing with mistakes and references to previous conversation. Clearly, the ability to handle anomalies in conversation is a crucial part of natural dialog management.

III. ALFRED

Alfred is a dialog agent which acts as an interface between a human user and a task-oriented domain [9]. It accepts English sentences as input and parses them into appropriate commands, based on the particular domain and information in its knowledge base (KB). Alfred is designed to be a general agent and flexible enough to handle a variety of different scenarios. For each domain, Alfred has a dictionary listing the possible commands and objects, as well as specifying the command syntax for that domain.

To implement the N-A-G cycle, Alfred maintains a set of expectations regarding time, content and feedback; i.e, *when* a certain predicate is expected, the expected *values of parameters* in a predicate, and expected *predicate*. The expectations are represented as $expectation(\alpha, t1, t2)$, where $t1$ and $t2$ are values for time steps, and α is a predicate. That is, α is expected between time steps $t1$ and $t2$, or if $t2$ is zero, sometime after $t1$. If $t1$ is zero, α is expected to be true from the current time step, Now, until $t2$. If both times are zero, α is expected to always be true. $alpha$ is of the form $predicate(param\_list)$ where $param\_list$ can contain values, variables and predicates. Any parameter in the $param\_list$ can be set to _ to indicate that the specific parameter can take any value, that is, the value does not matter. If a parameter is set to a specific value then that value is expected for that parameter. On the other hand, if the parameter is set to a variable, then that variable is assumed to be universally quantified.

One specific expectation in Alfred is that of a pause time. During a typical dialog, Alfred will respond to the user, asking questions or informing them of a completed task. The user will then reply to carry the conversation forward. Thus, when Alfred speaks to the user, it has the expectation of a response within a reasonable time frame. If the user does not respond within this time frame, Alfred notes an expectation violation and may then take steps to respond to this violation.

In Alfred, the expected pause time is represented as $expectation(pause\_less\_than(100), 0, 0)$. An expectation of the form $expectation(pause\_less\_than(100), 0, 0)$ translates to expecting the predicate $pause\_less\_than(100)$ to be universally true across all time steps. As a result, Alfred asserts $pause\_less\_than(100)$ in its KB. However, when the current pause exceeds 100, $not(pause\_less\_than(100))$ gets asserted. As a result, a contradiction gets asserted in the Alfred knowledge base, and the corresponding formulas get distrusted. The contradiction handler built in to Alfred will then deal with the particular contradiction based on the type of violation that has occurred.

When the expectation is not met, Alfred interprets it as an indication of a failure: *noting* the problem, *assessing* the situation, and *guiding* a response strategy into place. In the example of a too-long pause, Alfred may say "Please tell me what to do now." When the expectation is met, the corresponding violation is removed from the knowledge base; when it is not, Alfred will attempt another response strategy until the issue is resolved.

IV. GP-MCL

GP-MCL has been used in a variety of other applications [3], [4], which indicates to us that it can be useful as a general component of any host system. As an addition to an existing system, it may monitor the host's expectations and attempt to resolve anomalies —but as a general component, it must handle many types of expectation failures and possible responses. We have developed a set of abstracted ontologies that aim to cover all potential categories of failures and responses [4]. They correspond to the steps of the N-A-G strategy: an ontology of *indications* for noticing expectation failures, an ontology of *failures* to categorize and assess the causes, and an ontology of *responses* to choose an appropriate strategy to guide the system in recovering.

A. Ontologies

The indications ontology corresponds to the Note phase, and includes definitions of nodes to represent various types of sensor and expectation failures (reading did not change, reading is out of range, etc.) and indications from the host (counter increased, current state, etc.). This layer is the entry point for information from the host into GP-MCL's reasoning system.

The second layer is the failures ontology, which roughly corresponds to the Assess phase. These nodes connect to the indications layer and represent the various types of errors possible in the host AI. The classes include categories for physical error, sensor noise or misconfiguration, and knowledge errors.

The responses ontology is the final layer, with connections from nodes from the previous. These nodes determine which course of action to recommend to the host, analogous to the Guide step of the N-A-G cycle. The classes are related to the action required, and whether it pertains to a physical error or knowledge error. Responses include recommendations to run a diagnostic, reset a sensor, rebuild models, fix the knowledge base, try again, or even ask for help.

B. Architecture

Given the general ontologies and nodes described, systems of arbitrary complexity may be constructed to handle errors in the host. Links between nodes are specified and given default weights, forming a chain of reasoning from the initial failed expectation to a possible solution. The ontologies and their linkages form a directed graph which can be viewed as a Bayes net. Conditional probability tables associated with each node allow computation of probabilities for responses.

The host may send information to a GP-MCL server over a TCP/IP interface using a socket interface. After initialization of the nodes, sensors, and expectations for the host, the host is responsible for sending periodic updates of the salient values. When updates are received, GP-MCL will respond with suggestions, if any, for the host to implement or ignore. Finally, the host replies to GP-MCL indicating whether it implemented the suggestion and if the action was successful.

GP-MCL stores certain information about the state of the host, including sensor states and type of expectation failure, as well as meta-information like previous ontology states and number of failed or successful repairs. This allows GP-MCL to update the probability tables such that it learns which responses are better for particular types of expectation failures and does not repeatedly suggest an action that fails.

V. Ongoing Application

In the initial design of Alfred, with minimal implementation of MCL, a too-long pause time was handled by asking the user, "Please tell me what to do now." This continues periodically each time the pause limit was exceeded, until the user responded or exited the program. However, if the user is always slow to respond or has left the conversation, asking again and again after the same pause time is not productive. Alfred must notice that it is repeatedly initiating the same response for an expectation violation (actual pause exceeded expected pause time) without making progress in the conversation, and hence consider an alternate response to the violation.

To achieve this, Alfred may keep track of the success of its repeated questioning. If the response is successful, the violation is removed from its KB. Otherwise, the original violation remains in the KB, and so when the same violation occurs again Alfred may evaluate candidate responses and choose an alternative. For example, the framework previously described may be extended to change the typical pause time dynamically when the user changes or responds at a slower pace. For instance, if the typical pause duration is t, a pause violation occurred at time $t1$, and removal of the violation occurred at $t1 + t + 5$, then Alfred's metacognitive reasoning can retract its expectation regarding a pause duration of t and assert an expectation of pause time $t + 5$.

An example in a different experimental set up involves using Alfred as an interface to direct trains. In this setting, we have implemented the monitoring of the success of initiated responses and evaluation of candidate options before immediately initiating the same response again. For instance, if a user requests "send the Chicago train to New York", Alfred may choose Metroliner as the candidate, a train that is currently in Chicago. However, if the user replies "No" and repeats the same request, Alfred evaluates its options, notices that its previous first choice, Metroliner, was an unsuccessful response, and instead chooses Northstar, a train that starts at Chicago. In this way Alfred is able to "learn" which entity is meant by "the Chicago train", instead of repeatedly choosing the same, incorrect train as a response to the user's request.

VI. Planned Experiments

Alfred's current set of expectations are based on its view of the current world. If the external world changes or Alfred's view of the external world changes, Alfred has to update its expectations. The mechanism for revising existing expectations may be implemented in either Alfred alone or with the attachment of GP-MCL to Alfred. This mechanism has two components: (i) noticing the need for revising expectations, and (ii) updating the expectations to match reality. The first component is implemented by keeping track of expectation violations, responses initiated to deal with the violations, and success of the responses initiated to deal with each violation. The second component is implemented by assessing how far Alfred's expectations deviated from the actual observations and making adjustments accordingly.

Expectation violations can be categorized as *internal errors* —ones due to internal model error, or *external errors* —ones due to changes in the external world. Internal errors refer to incorrect assumptions in Alfred's KB, which may be corrected by adjusting said expectations; external errors are anomalies that the agent cannot control, such as the user leaving the conversation. Although both types must be accounted for in a complete implementation, we have chosen to address these issues independent of each other using two different techniques: (i) through a metacognitive handler built in to Alfred, and (ii) via an external method such as GP-MCL.

If expectation violations are handled by internal MCL, then it is easy for the internal MCL to access any part of Alfred's KB, and hence, making changes to any part of Alfred's KB becomes easier. However, since the internal MCL would share the same resources as the underlying deliberative component, the metacognitive processing could potentially slow down the normal deliberative processing of Alfred. On the other hand, utilizing an external module like GP-MCL for handling expectation violations may involve additional overhead costs of connecting it to the host system, but may result in a more flexible system overall. In future work, we will examine this tradeoff between including MCL directly in Alfred versus externally through the GP-MCL framework to handle one or both types of anomalies.

With these variables we have a 2x2 experimental design, shown in Table I. Each number 1 - 4 in the table represents a potential experiment, combining techniques for handling the two categories of errors. Hence, set-up 1 handles both

TABLE I. FUTURE EXPERIMENTAL SETUPS.

	Expectation Error	User Error
Internal Handler	1, 2	1, 4
External Handler	3, 4	3, 2

internal and external errors by a metacognitive process built internally within Alfred, while set-up 3 handles both externally; setups 2 and 4 are combinations of the two. In set-up 2, internal errors are handled by the internal MCL, while external errors are handled by GP-MCL, and in set-up 4, internal errors are handled by GP-MCL and external errors are handled by the internal MCL. The ongoing application described previously thus corresponds to set-up 1 in Table I: implementing MCL within Alfred to handle both internal and external errors.

Many particular capacities can be tested with the above experimental setups, from pause time to word disambiguation, new words and/or meanings, etc. We are currently nearly finished with a Wizard-of-Oz pilot study of pause time in set-up 3: external MCL with both expectation- and user-error handling. We anticipate a complete implemented study of this and much more in the near future.

VII. CONCLUSION

Metacognition is a neccessity for natural dialog, and different strategies may be used to implement that capability. In the specific case of pauses in dialog, there is an expectation that the user will respond within a specified time. A failed expectation may be caused by an external (user) or internal (knowledge) error; both must be accounted for. However, these two types of anomalies may be handled either with logic internal to Alfred itself, or by the external module GP-MCL. Implementing MCL within Alfred requires keeping track of previous actions, to detect repeated failures and thus know when to adopt a new strategy. Future work will explore different methods of including MCL within Alfred's dialog system and the benefits and tradeoffs involved.

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Linearithmic Corpus to Corpus Comparison by Sentence Hashing Algorithm SHAPD2

Dariusz Ceglarek
Poznan School of Banking
Poznan, Poland
Email: dariusz.ceglarek@wsb.poznan.pl

***Abstract*—This work presents an innovative method of comparing sets of textual documents with an aim to identify common phrase sequences. The $SHAPD2$ (Sentence Hashing Algorithm for Plagiarism Detection 2) algorithm was designed to achieve the goal of a single-pass corpus to corpus comparison. The algorithm was developed taking into account results and observations from previous research activities. It is a highly efficient solution that finds application with considerable amounts of data and excels over other approaches. One of its possible applications is detection of potential plagiarisms comparing not a document against a corpus, but corpus to corpus. Algorithm's performance allows for applications in situations where results have to be served an instant after issuing a query. This makes the $SHAPD2$ algorithm a valuable alternative to the available solutions.**

***Keywords*—document comparison, plagiary detection, longest common subsequence, sentence hashing, Natural Language Processing, text mining, pattern matching**

I. INTRODUCTION

This article presents results of the research aimed at designing a novel algorithm capable of robust detection of common subsequences, which is more efficient than existing methods based on sentence hashing [12], [28]. The information retrieval task in which it is more efficient solution is to compare 2 large corpora of text documents in a sequential matter – a corpus of suspicious documents against a corpus of source documents (originals) – in order to detect possible plagiarism attempts. The $SHAPD2$ builds upon earlier research activities which produced good results. These solutions were part of research on Semantically Enhanced Intellectual Property Protection System (SeiPro2S)[6]. The final architecture of SeiPro2S and its functionality has been described in [11]. The novel algorithm proves to be effective in the task defined above, achieving the new level of applicability in previously unreachable scenarios. Such performance was verified throughout experiments considering millions of document-to-document comparisons.

The $SHAPD2$ algorithm operates on hash-sums that represent individual sentences. A similar method was used in a number of other known algorithms working with n-gramms, such as w–shingling [22], minhash [3], simhash [12], etc. It also includes findings from author' previous developments, namely the $SHAPD$ algorithm[8]. However, thanks to improvements, code optimization and introducing new approach, $SHAPD2$ is a new solution, described in detail in the following sections.

II. RELATED WORK

The $SHAPD2$ algorithm allows for a robust and a resilient computation of the longest common subsequence shared by one or many input documents. The $SHAPD2$ algorithm processes documents by dividing them into a stream of sentences, where unnaturally long sentences (enumerations, itemizations, etc.) are handled by a special procedure [8]. Such an approach allows to extract extremely long sentences from paragraphs and process them individually.

The process is driven by a modular additive hashing. Hashing is a commonly used technique in Natural Language Processing (NLP) and Information Retrieval (IR) tasks that is used in order to achieve faster word retrieval. In plagiarism detection it is crucial, however, to identify and match longer common word sequences (with special focus on sentences) function with collision lists. Every concept (term) in a sentence is hashed by assigning a number from a previously defined range (during the experiments the limit was set to a large prime number). Furthermore, the individual hashes are summed to represent a sentence. Thanks to the additive nature of the hashing function, sentences with a changed concept order are treated as equivalents. A collision of sentence hashes, where the individual concepts are assigned natural numbers is negligible. Thus, the resulting algorithm not only finds the longest common sequences, but also the longest common quasi-sequences (allowing minor editing changes such as syntactic changes, insertions, deletions and synonym replacements, as well as combining or splitting multiple sentences to change their structure).

The task of matching the longest common subsequence is an important one in the many sub-domains of computer science. Its most naive implementation was deemed to have a time complexity of $O(m_1 * m_2)$ (where m_1 and m_2 are the numbers of concepts in compared documents). The question whether it is possible to achieve significantly better results was first raised by Knuth in [13].

One of the most important implementations of the search for the longest common subsequence is to be found in [19], which features time complexity $O((m_1 * m_2)/log(m_2))$. This work presents an application of Smith-Waterman algorithm for matching the longest common subsequence in textual data. This is a top achievement of algorithms that do not operate with text frames and their hashes. Other works such as [15], [21] or [23] prove that better efficiency is yielded rather by careful engineering strategies than a fundamental change in time complexity. All of the above cited works use algorithms, which time complexity is near quadratic which results in drastic drop of efficiency when dealing with documents of considerable length.

It was first observed in [22] that the introduction of a special

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structure based on the hashing technique, which was known later as shingling or chunks (a continuous sequence of fixed-length tokens in a document) can substantially improve the efficiency of deciding about the level of similarity of two documents by observing the number of common shinglings. This technique was introduced to detect near duplicate web pages. The following works such as [3], [1] introduce further extensions to the original idea.

Charikar [12] proposed a locality sensitive hashing scheme for comparing documents. A number of works represented by publications such as [4] or [2] have provided plausible methods to further boost the measuring of similarities between entities. Later, Henzinger [16] combined the algorithms of Broder et al. and Charikar to improve overall precision and recall. Recently Zhang [28] suggested a new algorithm based on sequence matching, which determines the location of duplicated parts in documents. Algorithms based on shingling are commonly utilized to identify duplicates or near-duplicates because of their ability to perform clustering tasks in linear computational complexity[24][17].

The important distinction between those given above and the $SHAPD$ (version 1 and version 2) is the emphasis on a sentence as the basic structure for comparison of documents and a starting point of determining a longest common subsequence. Thanks to such an assumption, SHAPD (version 1 and version 2) provides better results in terms of time needed to compute the results. Moreover, its functioning does not end at the stage of establishing that two or more documents overlap. It readily delivers data on which sequences overlap, the length of the overlapping and it does so even when the sequences are locally discontinued.

The capability to perform these makes it a method that can be naturally chosen in plagiarism detection, because such situations are common when attempt to hide plagiarism. In addition, it implements the construction of hashes representing the sentence in an additive manner, thus word order is not an issue while comparing documents.

$W - shingling$ algorithm runs significantly slower when the task is to give a length of a long common subsequence. Due to the fixed frame orientation, when performing such operation $w - shingling$ behaves in a fashion similar to the Smith-Waterman algorithm resulting in a significant drop of efficiency.

The importance of plagiarism detection is recognized in many publications. One might argue that, it is an essential task in times, where access to information is nearly unrestricted and a culture for sharing without attribution is a recognized problem (see [25] and [5]). Yet, as this work presents a special case of an algorithm for a longest common subsequence that can be used in other applications.

III. THE SHAPD2 ALGORITHM

Hashing is a commonly used technique in Natural Language Processing tasks used in order to achieve faster word retrieval. In plagiarism detection it is crucial, however, to identify and match longer common word sequences (with special focus on sentences).

SHAPD2 focuses on whole sentence sequences. A natural way of splitting a text document is to divide it into sentences and it can be assumed that documents containing the same sequences also contain the same sentences.

However, in text documents, there are situations in which there are cases when there are extremely long passages of text without a full-stop mark (such as different types of enumerations, tables, listings, etc.). Some sort of strategy needs to be devised for such cases, i.e. how to split portions of text, which are longer than the reasonable length of a sentence in a natural language.

$SHAPD2$ utilizes a brand new mechanism to organizing the hash-index as well as to searching through the index. It uses additional data structures such as correspondence array to aid in the process.

As introduced before, there are two corpora of documents comprise the algorithm's input: a corpus of source documents (originals) $D = \{d_1, d_2, ..., d_n\}$, and a corpus of suspicious documents to be verified regarding possible plagiaries, $P = \{p_1, p_2, ..., p_r\}$.

Before applying algorithm for there is necessary to carry out text-refinement process what is standard procedure in NLP/IR task (starting from unstructured text document input to a structure containing stacked sequentially descriptors of concepts found in the input document). Action that make up the process of text-refinement in documents starts from extracting lexical units (tokenization), and further text-refinement operations are: elimination of the words without semantic importance from the so-called information stop-list, the identification of multiword concepts (when phrase of several words create one concept), bringing concepts to the main form by lemmatization (for Polish documents) or stemming (for English documents using a popular Porter stemmer [26]). It is particularly difficult task for highly flexible languages, such as Polish, Russian or French (multiple noun declination forms and verb conjugation forms). In lemmatization procedure there is used Ispell dictionary for Polish documents and finite state automaton (FSA). The goal of both stemming and lemmatization is to reduce inflectional forms and sometimes derivationally related forms of a word to a common base form.

Synonyms need to be represented with the same concept descriptors using lexical relationships of synonymy from semantic network. It allows correct similarity analysis and also increases classification algorithms efficiency without loss in comparison quality [18].

Abstracting process faces another problem here, which is polysemy. One word can represent multiple meanings, so the apparent similarity need to be eliminated. It is done by concept disambiguation, which identifies word meaning depending on its context, is important to ensure that no irrelevant documents will be returned in response to a query [20].

The final effect of refinement procedure is the structure of documents containing ordered descriptors of concepts derived from the input document. This structure can be stored as an abstract (data for creating index) of the document, and then use during phase 2 (comparing documents).

Then, all documents need to be split into text frames of comparable length – preferably sentences, or in the case of

TABLE I. SAMPLE KEY DETERMINATION IN $SHAPD2$ ALGORITHM

davies_scott_1998_1.pdf

Applying Online Search Techniques to Reinforcement Learning Scott Davies Andrew Y. Ng Andrew Moore

In reinforcement learning it is frequently necessary to resort to an approximation to the true optimal value function. Here we investigate the benefits of online search in such cases. We examine local searches, where the agent performs a nite-depth lookahead search, and global searches, where the agent performs a search for a trajectory all the way from the current state to a goal state.

hash value	sentence/frame
4176335	reinforcement learning frequently necessary resort approximation true optimal value function
1699726	investigate benefits online search cases
2842476	examine local searches agent performs nite depth
2710940	lookahead search global searches agent performs search
2448654	trajectory way current state goal state

dayan-92.pdf

The Convergence of TD(X) for General X PETER DAYAN Machine Learning, 8, 341-362 (1992), Kluwer Academic Publishers, Boston, 1992

The methods of temporal differences (TD), first defined as such by Sutton (1984; 1988), fall into this simpler category. Given some parametric way of predicting the expected values of states, they alter the parameters to reduce the inconsistency between the estimate from one state and the estimates from the next state or states.

hash value	sentence/frame
2906878	methods temporal differences td defined sutton fall simpler category
2496872	given parametric way predicting expected values states alter
2339613	parameters reduce inconsistency estimate state estimates state states

longer sentences – shorter phrases. A coefficient α is a user-defined value, which allows to set the expected number of frames that a longer sentence is split into. The coefficient ranges from 6 to 12 concepts. The new procedure of uniform fragmentation is described in listing of Algorithm 1.

Algorithm 1 Phase 1. Splitting text into comparable frames

```
f := round_up(l/α)
while f > 0 do
    a := round_up(d/f)
    c̄ := getConceptsFromSentence(s, a)
    calculateHash(c̄)
    l := l − a
    f := f − 1
end while
l - sentence s length
α - alpha coefficient
f – number of frames to split a longer sentence into
a – current frame length
c̄ – vector of frame concepts
```

The first version of the SHAPD algorithm was able to compare a suspicious document with exactly one document from the corpus P. The SHAPD2 algorithm is able to compare a suspicious document with the entire corpus of source documents. For all documents d_i from corpus P (containing suspicious documents), the correspondence array CL and maxima array TM are cleared. For each frame, set of tuples is retrieved from index table T. If there are any entries existing, it is then checked whether they point to the same source document and to the previous frame. If the condition is true, local correspondence maximum is increased by one. Otherwise, the local maximum is decreased.

After all of the frames are checked, table TM storing the correspondence maxima are searched for records whose correspondence maxima are greater than a threshold set e (the number of matching frames to be reported as a potential plagiarism). Frame and document number are returned in these cases.

Sample outputs from a sentence splitting and hash calculation in Phase 1 are shown in Table I. As a result, every document from the original corpus, as well as all suspicious documents, is represented by index as a list of sentence hashes. The first version of the SHAPD algorithm was able to compare a suspicious document with exactly one document from the corpus P. The SHAPD2 algorithm is able to compare a suspicious document with the entire corpus of source documents in single pass.

In the next step, a hash table T is created for all documents from corpus D, where for each key the following tuple of values is stored: $T[k_{i,j}] =< i, j >$, (document number, frame number) (see Figure 1).

For phase 2, a correspondence list CL is declared, with elements of the following structure: n_d – document number, m_l – local maximum, and n_l – frame number for local sequence match.

Another data structure is the maxima array TM for all r documents in corpus P, which contains records with structure as follows: m_g – global maximum, n_g – frame number with global sequence match.

Phase 2 is performed sequentially for all documents from corpus P. Its logic is listed in Algorithm 2.

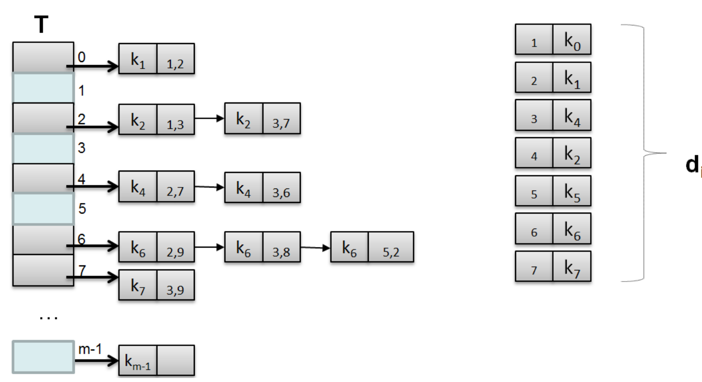

Fig. 1. Hash table T indexing a corpus D of source documents and hashes from suspicious document $d_i \in P$

IV. EXPERIMENT

In order to evaluate the algorithm's efficiency, a series of experiments were carried out. The most widely used test collection Reuters-21578 [27] for text categorization has been used as a source of the testing data. The Reuters-21578 corpus consists of multiple sets of annotated documents. A collection of source documents (originals) as well as suspicious documents (including potential plagiarism cases) has been derived from the Reuters corpus.

 ISBN: 978-1-61208-273-8

Algorithm 2 Phase 2

{Build hash table T}
for $d_i \in D$ **do**
  for $frame_j \in d_i$ **do**
    $addHashToIndex(T)$
  end for
end for{Find longest common frame sequences}
for $d_i \in P$ **do**
  $clear(CL)$
  $clear(TM)$
  for $frame_j \in d_i$ **do**
    if $existsT(k_{i,j})$ **then**
      if $T(k_{i,j}).i = i \wedge T(k_{i,j}).j = j - 1$ **then**
        $CL(i).m_l + +$
        $update(TM)$
      end if
    else
      $CL(i).m_l - -$
    end if
  end for
  for $tm \in TM$ **do**
    if $tm.m_g > e$ **then**
      $return(tm.n_g)$
    end if
  end for
end for

TABLE II. DETAILS OF COMPARISON (PRESENTED IN FIGURE 1) BETWEEN A SUSPICIOUS DOCUMENT d_i AND A CORPUS D REPRESENTED BY HASH TABLE T

	$k_i \in$T	CL table	TM table
1	$k_0 \notin$T		
2	$k_1 \in$T	$\{m_l = 1, n_d = 1, n_l = 2\}$	$TM_1 = \{m_g = 1, n_g = 2\}$
3	$k_4 \in$T	$\{m_l = 1, n_d = 2, n_l = 7\}$ $\{m_l = 1, n_d = 3, n_l = 6\}$	$TM_2 = \{m_g = 1, n_g = 7\}$ $TM_3 = \{m_g = 1, n_g = 6\}$
4	$k_2 \in$T	$\{m_l = 1, n_d = 1, n_l = 3\}$ $\{m_l = 2, n_d = 3, n_l = 7\}$	 $TM_3 = \{m_g = 2, n_g = 7\}$
5	$k_5 \notin$T	$\{m_l = 1, n_d = 3, n_l = 7\}$	
6	$k_6 \in$T	$\{m_l = 1, n_d = 2, n_l = 9\}$ $\{m_l = 2, n_d = 3, n_l = 8\}$ $\{m_l = 1, n_d = 5, n_l = 2\}$	 $TM_5 = \{m_g = 1, n_g = 2\}$
7	$k_7 \in$T	$\{m_l = 3, n_d = 3, n_l = 9\}$	$TM_3 = \{m_g = 3, n_g = 9\}$

k_j – hash key of frame j from document d_i

A set of 3,000 original documents was used as source set, and several sets including 1,000 to 6,000 suspicious documents were used as a set of suspicious documents. The sets were compared using two algorithms: w-shingling and SHAPD2. All tests were carried out on one computing platform, a stock laptop computer with an 8-core processor (four cores in hyper-threading mode), clocked at 2.0 GHz.

The basic results of efficiency test are as follows. A comparison of one suspicious document to a set of 3,000 originals (containing about 3060 words on average) takes 7.13 milliseconds. As many as 420,700 document-to-document comparisons were achieved in 1-second intervals.

As the hash-table remains unchanged after Phase 1, it is possible to run further processing in parallel threads, because of a sequential way of comparing the indiviual suspicious documents. In effect, further acceleration has been achieved, resulting in single comparison time of 3.45 milliseconds instead of 7.13 milliseconds.

TABLE III. PROCESSING TIME [MS] FOR COMPARING n SUSPICIOUS DOCUMENTS WITH A CORPUS OF 3,000 ORIGINAL DOCUMENTS

n	w-shingling	SHAPD2
1000	5680	4608
1500	6654	5114
2000	8581	5820
2500	9478	6374
3000	11967	7125
3500	14864	7213
4000	16899	7527
4500	20242	7818
5000	23200	8437
5500	33955	8656
6000	50586	8742

The resulting times of tests' execution are presented in Tables III and IV and visualized on Figure 2. One can observe that the efficiency turns out to be better by an order of magnitude from $w - shingling$. This enables a new area of applications, including plagiarism detection using much larger source document corpus, as well as making document comparisons against a medium-size corpus possible in nearly on-line time.

If two sentences differ only in one concept, the hash keys created for them will be different, even when those concepts are synonyms. In such situation the last operation in text refinement procedure should be a generalization of concepts using semantic compression. Moreover, the algorithm uses the same techniques whose high effectiveness has already been proven [10] in plagiarism detection employing semantic compression[7], as well as their strong resilience to false-positive examples of plagiarism[9], which may be an issue in cases when competitive algorithms are used.

The Clough & Stevenson Corpus of Plagiarised Short Answers[14] was used for the benchmark. It serves the purpose of plagiarism detection as it is built from an initial set of documents as the base, which was then altered by the participants in a number of ways so that everyone could measure how well their approach to plagiarism detection works.

One might address the issue of the common ancestor as a document that is cited the most in a number of documents. Thanks to $SHAPD2$, one can easly handle it with no additional modifications except for the length of text frame used in given application[10].

It is even more interesting to apply $SHAPD2$ in conjunction with semantic compression in order to handle situations in which author has not cited sources, yet used formulations that can be traced to some actual document.

V. CONCLUSIONS

To summarize, there should be emphasizee the following properties of the SHAPD2 algorithm:

- The algorithm developed has a very low computational complexity – evaluated to linearithmic, proving to be extremely efficient in a task of finding long common

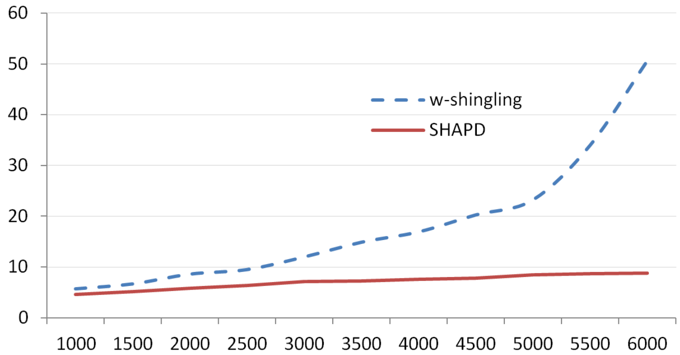

Fig. 2. Processing times (ms) of comparing n suspicious documents with a corpus of 3,000 documents using $w-shingling$ and $SHAPD2$ algorithms

TABLE IV. PROCESSING TIME [MS] FOR COMPARING 3,000 SUSPICIOUS DOCUMENTS WITH A CORPUS OF n ORIGINAL DOCUMENTS

n	SHAPD2
1000	3142
1500	4141
2000	5239
2500	5704
3000	7137
3500	9194
4000	9722
4500	10563
5000	11678
5500	15270
6000	22182

sequences in compared documents. This was confirmed on the experiments with Reuters-21578 corpus.

- $SHAPD2$ is resilient to fluctuating word order in sentences. It is especially important in use cases in languages with a highly flexible syntax (e.g. Polish, which allows multiple correct word sequences, although having a SVO-based (Subject-Verb-Object-based) syntax, like English).
- The algorithm is resilient to small sentence inclusions or deletions (as the Smith&Waterman algorithm is), which is an important feature in plagiarism detection, as it is a common strategy of slight modifications when committing plagiaries.
- The designed $SHAPD2$ algorithm employing semantic compression is highly efficient in plagiarism detection and is strongly resilient to false-positive examples of plagiarism, which may be an issue in cases when competitive algorithms are used.
- Utilization of NLP techniques, such as term identification and disambiguation, semantic compression, would surly improve the effectiveness of plagiarism detection, which is subject to further developments.

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Bounded Metacognition

Darsana Josyula and Kenneth M'Balé
Department of Computer Science
Bowie State University
Bowie, MD USA
E-mail: darsana@cs.umd.edu and kmbale@cs.umd.edu

***Abstract*—Agents situated in dynamic environments have limited time to deliberate before performing their actions. Cautious agents that deliberate for too long may miss deadlines to accomplish tasks whereas bold agents that deliberate for too little time may behave rashly or miss opportunities. There are several approaches discussed in the literature that rely on meta-level mechanisms to monitor and control the deliberation time. These approaches seem to follow the view that the meta-level mechanism is an external component not constrained by the same resource limitations as the underlying agent's deliberation mechanism. In this paper, we present an approach to resource bounded metacognition wherein an agent monitors and controls its deliberation and metacognition within the uniform framework of Active Logic.**

Keywords-metacognition; deliberation; reasoning; active logic

I. INTRODUCTION

Metacognition [1, 2] is the ability to monitor and control one's own thinking. This ability is important to control the time agents spend deliberating to choose their actions. For, in the process of achieving goals in a dynamic environment, an agent has a finite amount of time to make a decision (deliberate) and take an action (act). The circumstances that form the starting point of the deliberative process change at various rates. The best choice given one set of circumstances is not necessarily the correct choice in another set of circumstances, even when the differences are small. The quality of a decision correlates to the amount of time an agent deliberates. In this context, quality is the degree to which the decision fits the circumstances in which the action is taken.

Agents may choose to short-circuit the deliberation and perform a default action when there is not enough time to deliberate. On the other hand, when there is more time to deliberate, agents may choose to deliberate over its current knowledge to choose the best course of action. Cautious agents that deliberate for too long may miss deadlines to accomplish tasks, whereas bold agents that deliberate for too little time may behave rashly or miss opportunities [3]. Monitoring and controlling the deliberation process can help agents behave cautiously or boldly at different times depending on what is best suited for the situation.

Different approaches to monitoring and controlling deliberation, aim at explicitly setting time limits to deliberation [4] or limiting the size of current knowledge used for deliberation [5], or both [6, 7, 8]. Setting predefined limits for deliberation time is a simple strategy; however it constrains the adaptability of the agents — e.g., from being bold to cautious, as the environment changes. If the allowable deliberation time is not preset, but updated dynamically by a metacognitive process, then the resulting agents can adapt from being bold to cautious or vice-versa. However, this requires that the metacognitive process computes and updates the allowed deliberation time dynamically. Similarly, the current knowledge used for deliberation can be constrained by simply presetting a limit to the size of the knowledge base (KB) or, by computing and updating the size dynamically by a metacognitive process. Therefore, when adaptability is important, the metacognitive process has to perform non-trivial computations in a reasonable amount of time for such computations to remain effective.

If the metacognitive process shares the same computing resources as the underlying cognitive system, then decisions need to be made on when and how much of the computing resources are allocated for metacognitive processes versus cognitive activities. If too little resources are allocated for metacognition, the resulting agent may not have the ability to self-reflect and discover new methods and solutions. On the other hand, if the agent's resources are used mainly for metacognition, the resulting agent would be reflective, but may not have enough resources to deliberate and choose the best known course of action.

When the metacognitive process runs external to the cognitive sphere of the agent, and thus not sharing the same computing resources, synchronizing the communication between the two processes becomes non-trivial. The part of the underlying cognitive system that is accessible by the metacognitive process determines how much the resulting agent can affect its own thinking. Therefore, decisions need to be made on which parts of the cognitive system is accessible by the metacognitive process and when.

In this paper, we describe how we have addressed these issues in an agent based on Active Logic. We describe how the metacognitive process of the agent shares resources with the underlying cognitive process within a uniform framework based on Active Logic. We discuss how the two processes run in an interleaved manner (similar to the fully-interleaved deliberation strategy discussed in [9]) in order to manage the sharing of resources such that the resulting agent is self-reflective as well as deliberative.

The rest of the sections are organized as follows. Section II details features of Active Logic that facilitates the fully interleaved deliberation strategy. In Section III, we give a brief overview of Alma/Carne agent based on Active Logic. In Section IV, we discuss how automatic resource sharing occurs between the metacognitive and cognitive deliberation processes within the Alma/Carne agent. Section V discusses related work and Section VI gives the conclusion.

II. Active Logic

Active Logics [10, 11] are a family of formalisms that use time sensitive inference rules to have their KB evolve with the passage of time. Technically, an Active Logic consists of a first-order language, a set of time-sensitive inference rules and an observation function that specifies aspects of the environment as first order formulae. Therefore, Active Logic can be seen either as formalism per se, or as an inference engine that implements formalism.

In Active Logic, the basic unit of time is a *step* and the passage of time is represented by a predicate *Now* that is true only for the current step in the reasoning process. The formulae at each step include those formulae that are (i) inherited from the previous step, (ii) obtained by applying the rules of inference to the formulae in the previous step and (iii) added as observations at that step. Direct contradictions at one step are not inherited to the next step; hence, they do not derive new formulae thus avoiding the traditional issue with first order logics wherein all well formed formulae are concluded from a contradiction.

In the sub-sections that follow, some of the useful general features of Active Logics are discussed.

A. Inheritance of Formulae

By default, all formulae in a step that are not directly contradicting are inherited to the next step. However, some formulae like the ones related to the current time are not inherited to the next step. The inheritance of formulae from one step to the next is controlled by inheritance rules. One simple version of such an “inheritance rule”, which also illustrates the use of firing conditions, is shown in (1):

$$\begin{array}{ll} i: & A\ [\text{condition}: \neg A \notin KB,\ A \neq Now(i)] \\ i+1: & A \end{array} \tag{1}$$

B. Step-wise Reasoning

In Active Logic, the formulae at step i+1 are obtained by applying the rules of inference in the logic to the formulae in step i as illustrated in (2).

$$\begin{array}{ll} i: & A,\ A \rightarrow B,\ B \rightarrow X \\ i+1: & A,\ B,\ A \rightarrow B,\ B \rightarrow X \\ i+2: & A,\ B,\ X,\ A \rightarrow B,\ B \rightarrow X \end{array} \tag{2}$$

Here, at step i+1, B is derived using the formulae A and $A \rightarrow B$, and at step i+2, C is obtained from the formulae, B and $B \rightarrow C$. Each “step” in an Active Logic proof takes one Active Logic time-step; thus inference always moves into the future at least one step. Since the finitely-many inference rules when applied to the finite set of formulae in a step can produce only finitely-many conclusions for the next step, an Active Logic KB will have only a finite set of formulae at each time step,

C. Addition of New Formulae

The observation function can add new formulae into the logic at any step. The formulae that are added in a step are incorporated into the ongoing reasoning to derive the formulae for the next step. Step-wise reasoning coupled with this ability to add new formulae at any step, ensure that the logic will not get stuck in a lengthy proof, oblivious of the external changes that occur during the reasoning. That is; the external changes that occur while the logic is performing the lengthy proof can be added as new formulae at any step during the proof. In fact, these added formulae could change the course of reasoning, since they get included in the ongoing reasoning as soon as they are added into the knowledge base.

D. Time Sensitivity

To represent and reason about the passage of time, Active Logic employs a notion of “now” that is constantly updated by the “clock rule” shown in (3). The clock rule states that from the fact that it is step i at the current step, the step number of the next step is i + 1.

$$\begin{array}{ll} i: & Now(i) \\ i+1: & Now(i+1) \end{array} \tag{3}$$

With the help of the clock rule, Active Logic keeps track of the evolving time as the reasoning progresses from one step to the next. This evolving-during-inference model of time sharply contrasts with the frozen-during-inference characterization of time that temporal logics [12, 13] have. In temporal logics, the past, present and future do not change while theorems are being derived. This time-tracking property of Active Logic is especially useful when an agent’s reasoning is aimed towards meeting a deadline; see [14] for details.

E. Contradiction Tolerance

The ability of Active Logic to explicitly track the individual steps of a deduction makes it a natural mechanism for reasoning about contradictions and their causes. If directly contradictory wffs, P and ¬P, occur in the KB at time i, Active Logic notes the contradiction at i+1 using a ‘conflict-recognition” inference rule like (4), so that further reasoning can be initiated to repair the contradiction, or at least to adopt a strategy to deal with it, such as preventing the contradictions from deriving any new formulae in the later steps.

$$\begin{array}{ll} i: & P, \neg P \\ i+1: & Contra(i, P, \neg P) \end{array} \tag{4}$$

Disinheriting contradicting predicates is a reasonable immediate response to deal with a contradiction; however, it is not enough to "defuse" the contradiction for long. The formulae that derived P and ¬P may re-derive the contradicting predicates, or other conflicts may occur. Thus, [15, 16, 17] investigate ways to allow an Active Logic-based reasoner to retrace its history of inferences, examine what led to the contradiction, and perform meta-reasoning concerning which of these warrants continued belief.

The *Contra* predicate in (4) is a meta-predicate: it is about the course of reasoning itself (and yet is also part of that same evolving history). Thus, unlike in truth maintenance systems [18] where a separate process resolves contradictions using justification information, in Active Logic the contradiction detection and handling occur in the same reasoning process.

F. Representation of Defaults

If no evidence is already known that would prevent a default conclusion, then Active Logic derives that default conclusion. In Active Logic, defaults can be represented using default rules like (5), which states that if ¬P is not known at the current time, and if Q is known, then P is inferred by default at the next time step.

$$\begin{array}{ll} i: & Q, \neg Know(\neg P, i), Now(i) \\ i+1: & P \end{array} \quad (5)$$

Since, only a linear lookup in the belief set for time i is needed to tell that ¬P is not there (and that Q is there), the decidability issues of traditional default mechanisms do not arise in Active Logic. The default rule in itself does not deal with problems arising from interacting defaults. However, such cases tend to involve contradictory conclusions, as when, evidence for ¬P becomes known. Therefore, they can be treated as any other contradictions. One simple expedient in such cases is to disinherit the default conclusion and accept the non-default evidence.

G. Introspection

In Active Logic, negative introspection—the ability to determine that one does not know something—is often encoded as the following inference rule (where the notation [B] means that B is not present):

$$\begin{array}{ll} i: & ...[B] \\ i+1: & \neg Know(i,B) \end{array} \quad (6)$$

This mandates the conclusion at time i + 1 that statement B was not known to the logic at time i (that is, B does not appear among the beliefs at time i).

H. History Tracking

Active Logic maintains a temporal history of its reasoning process that can be used by the logic for further reasoning. The history enables the logic to determine when each formula was added or deleted in its past and thus provides a mechanism to reason about the past reasoning.

I. Quotation

Quotation mechanism names the different formulae in Active Logic. This allows an individual formula to be referenced using its name. The quotation and the history mechanism together provide a mechanism for meta-reasoning within the reasoning process itself.

J. Integration with non-logical processing

Finally, Active Logic can initiate, observe and respond to external events and non-logical processes by proving specialized predicates. For example, the proposition call initiates an external action.

III. ALMA/CARNE AGENT

Alma/Carne [19] is a general purpose implementation of Active Logic. It has a dual role: (i) as the language to specify Active Logic based applications and (ii) as the core reasoning engine for these applications.

In its role as a language, Alma/Carne allows applications to be specified as a set of logical sentences and procedures. When the sentences are loaded into Alma and the procedures into Carne, Alma/Carne takes the role of a reasoning engine. In this role, Alma generates Active Logic inferences, some of which trigger procedures in Carne. These procedures can perform computations or cause effects in the world, and can include non-logical reasoning procedures like probabilistic reasoners and parsers (thus, allowing close interaction between different kinds of reasoning). Alma's KB is updated with the status of the procedures (e.g., done, doing) which enables reasoning about the processes Alma triggered. Failure of a procedure, for instance, can lead to reasoning that causes retraction of earlier assumptions.

Carne can also monitor the world and assert formulae about the state of the world into Alma, implementing the observation functionality of Active Logic. This enables Alma to react to changes in the world. Thus Alma/Carne can initiate, observe and respond to external events and non-logical processes. Each step in Alma/Carne is bounded by a maximum time. Therefore, Alma/Carne remains responsive to incoming observations even when the size of the knowledge base increases.

Alma/Carne allows priorities to be set to formulae in its KB. Formulae are examined in the order of their priorities while deriving formulae for the next step. This provides a mechanism for limiting the formulae that are examined to derive the formulae at the next step.

Formulae in Alma/Carne have an associated name. This characteristic allows easy reference to a formula for deleting it from the KB or distrusting it at any step. Formula names also help to locate an existing formula in order to change its priority.

Alma/Carne agent is implemented by loading into the Alma KB a set of formulae that correspond to the agent's world knowledge, goals, plans, expectations, action rules, contradiction handlers, expectation handlers and expectation violations. Formulae corresponding to the agent's world

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knowledge include predicates that specify the objects in its domain, their properties and relationships. Plans are implication formulae with goals (or sub-goals) as consequents and preconditions as antecedents. Preconditions can be any predicates including goals or sub-goals. Expectation formulae are predicates or implications that specify what the agent expects or what the agent can expect when certain conditions are true. Action rules are implication formulae that specify the conditions under which each action can be performed. Goals appear as antecedents and actions (*call* predicate) appear as consequents in action rules. Contradiction handlers are implication formulae that specify how to deal with direct contradictions (*contra* predicate) in the Alma KB. Expectation handlers are implication formulae that detect and note expectation violations.

As step-wise reasoning proceeds with the initial KB, new formulae get derived. When a *call* predicate gets derived in the course of reasoning, Alma requests Carne to perform the corresponding action at the next time step. At the same time, the expectation formula associated with the action generates an expectation in the Alma KB. If the expectation is violated, then the agent notes the violation and reasons about it. Expectation violations can appear as preconditions in plans; therefore, the agent can adopt goals to deal with expectation violations. These goals can cause Alma to derive other actions based on the current set of action rules in the KB.

IV. COGNITION AND METACOGNITION IN ALMA/CARNE AGENT

A. Cognitive Deliberation

The cognitive deliberations of the agent are achieved by the set of formulae that specify the agent's world knowledge, goals, plans and action rules. The initial belief set of the agent includes its initial model of the world, initial set of goals, plans to achieve various goals, and action rules that specify when to perform different actions. As reasoning proceeds in Alma/Carne, formulae get added into the KB or retracted from the KB at each step, based on the formulae in the previous step. Observations of the agent also get asserted in the KB as beliefs of the agent in the next time step.

When a goal is derived in the agent's KB, the plans with the goal as one of the antecedents will cause new formulae (consequents) to get asserted in the Alma KB. These formulae may correspond to new goals (or sub-goals); in which case the new (sub-) goals get derived at the next time step. Some goals appear as preconditions in action rules. When all the preconditions for executing an action is met at a time step, then the *call* predicate for that action gets derived in the next time step. Thus, the agent's current set of beliefs about the world, goals, plans and action rules determine which action the agent chooses to execute.

When a *call(α)* predicate gets derived in a time step, Alma sends the action predicate α to Carne for execution. As Carne begins executing the action α, it asserts a *doing(α)* predicate in Alma. When the action is done, Carne asserts *done(α)* in the Alma KB.

B. Metacognition

Metacognition in Alma/Carne agent is achieved by the set of formulae that correspond to expectations, contradiction handlers and expectation handlers. The agent maintains expectations about how its KB evolves in order to perform metacognitive alterations to its deliberative process. The types of expectations include ones related to time, content and feedback. *Time related expectations* specify when a certain predicate is expected. *Content related expectations* specify the expected values of parameters in a predicate. *Feedback related expectations* specify the predicates that are expected.

Expectations are represented as $expectation(\rho, t_1, t_2)$, where t_1 and t_2 are values for time steps, and ρ is a predicate. That is, ρ is expected between time steps t_1 and t_2, or if t_2 is zero, sometime after t_1. If t_1 is zero, ρ is expected to be true from the current time step, Now, until t_2. If both t_1 and t_2 are zero, ρ is expected to always be true. ρ is of the form *predicate(paramlist)* where *paramlist* can contain values, variables and predicates. Any parameter in the *paramlist* can be set to "_" to indicate that the specific parameter can take any value, that is, the value does not matter as long as the parameter has some value (existential quantification). If a parameter is set to a specific value, then that value is expected for that parameter. On the other hand, if the parameter is set to a variable, then that variable is assumed to be universally quantified.

When a formula, $expectation(\rho, t_1, t_2)$, gets derived at a time step, the expectation handler rules in the KB monitors the KB for the presence of ρ during the time period specified by t_1, and t_2. If a violation occurs, an expectation handler notes the violation. Example of an expectation handler that notes a violation for expectations with values of t_1 and t_2 as 0, is given in (7).

$$\text{expectation}(\rho, 0, 0) \wedge \rho \rightarrow \text{violated}(\rho) \qquad (7)$$

When violated(ρ) appears in the KB, plans associated with the violation will create goals to deal with the specific violation in the next step. These goals in turn may cause new (sub-) goals to be derived; eventually, all the preconditions of some action rules become true and as a result the corresponding action gets executed.

The other type of metacognitive monitoring and control in Alma/Carne agent is achieved by the contradiction noting and handling mechanism. If *not*(ρ) gets proven in the KB during any time step when ρ is in the KB, a contradiction is asserted. This causes the contradiction handling rules to fire at the next time step. The contradiction handling rules evaluate the situation and assert new formulae or retract existing formulae from the KB. This would cause changes in the agent's normal deliberative process since the agent's reasoning at any step is solely dependent on the formulae at the previous step.

C. Discussion

Both the metacognitive process and the cognitive process have access to the formulae in each step; therefore,

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information sharing between the two processes is trivial. As a consequence, the metacognitive process can alter any aspect of the cognitive processing of the agent.

Since no distinction is made between the processing of formulae that contribute to metacognitive deliberations and those that contribute to cognitive deliberations, both processes happen simultaneously intertwined with each other in a step-by-step manner. Since each step is limited in time, neither the metacognitive process nor the cognitive process can monopolize the agent. Both processes are constrained by the same time and resource limitations.

The actions that the agent executes at any step depend on the facts that exist in its KB at the previous step; and not on what is derivable from the facts in the KB at a later step. As the agent deliberates using step-wise reasoning from its goals to actions, metacognitive suggestions and new observations are incorporated into the reasoning. Therefore, the agent may appear cautious when observations cause new formulae to be derived or deleted from the KB, and bold when new observations and suggestions are not added to the KB.

The likelihood of a new formula getting derived depends on the priority of the rules that can produce it; the higher the priority, the more the likelihood. This means that the formulae (low priority ones) that contribute to the creativity of the agent may not get its chance to fire during the time steps when the agent is busy with its high priority deliberations. During those time steps when fewer rules are fired by the deliberative process, the lower priority rules have the opportunity to manifest itself in the stepwise reasoning of the agent and alter the KB.

V. RELATED WORK

Research on metacognitive monitoring and controlling of deliberation can be broken into four broad classes. Each class — Heuristics, Focusing, Intermodal, and Short-Circuit, is described below using a representative paper.

The Heuristics class of approaches is represented by [6]. The paper proposes an approach to focusing deliberation by using heuristics to inform the unrolling of an agent's Markov decision process. A Markov decision process is a probabilistic model that, departing from a well-known current state, can predict the probability of future states based on a set of actions. A rule for choosing an action is called a policy. The process of projecting future states is called unrolling. New states are placed on an open list that is sorted based on relevance to the current context and environment of the agent. The agent balances unrolling with selecting the highest priority state on the open list to begin deriving new policies. The heuristics inform the agent in its decision to unroll or derive.

The Focusing class of approaches is represented by Fox and Leake [20]. The paper proposes to focus the deliberation process by narrowing the KB the agent uses to the subset relevant to the circumstances. The reduced focus set enables the agent to spend the available deliberation time to produce the optimal action by adapting to the current circumstances.

The Intermodal class of approaches is represented by Dylla et al. [21]. The paper proposes a hybrid approach where the deliberative process simultaneously produces an immediate action and a strategy. Since the action is immediately available, the component of the agent responsible for taking action does not need to wait for the strategy in circumstances that do not permit doing so. This approach implies that the action component is intelligent enough to determine when to wait for a strategy.

The Heuristics and Focusing classes above are representative of the current body of work where the function of the deliberative process is not affected by the deadline. Instead, the deadline affects the scope of the input into the process. These approaches suffer from an inability to adapt to circumstances that require an action sooner than the minimum deliberation time. The Intermodal class addresses the weakness by providing an immediate action while deliberating. This approach subordinates deliberation to action. The deliberation process is no longer responsible to action. Instead, an action process is able to ignore the results of deliberation. This approach does not actually solve the problem because the action process has to deliberate about when to act and when to wait for the strategy. This deliberation itself has a deadline.

The Short-Circuit class of approaches is represented by Josyula et al. [22]. The paper proposes to inform the deliberation process with the emotional state of the agent. The emotional state is defined over continuums of stress (y-axis) and pleasure (x-axis). Pleasure represents the level of discordance between expectations and observations, both in terms of the number of expectation failures and the magnitude of discrete failures. Stress represents the number of perturbations or observable environmental changes the agent has to deal with. The level of stress modulates deliberation by affecting the probability of the agent developing new strategies in response to environmental stimuli. This Short-Circuit class is representative of biologically inspired approaches. An emotional component informs the metacognitive process, based on the magnitude of expectation failures. Emotion can then affect how the agent uses its failure and response ontologies to decide on an action. The imminence of a deadline can directly affect the emotional state of the agent and short-circuit the deliberation similar to a biological emotional reaction.

VI. CONCLUSION AND FUTURE WORK

This paper described the implementation of a metacognitive process that shares resources with the underlying cognitive process, in a manner that allows the resulting agent to be both self-reflective and deliberative. In our implementation of the Alma/Carne agent, the cognitive component adds or prunes formulae from the agent's KB based on the agent's current set of goals and beliefs. At the same time, the metacognitive component monitors and adjusts the KB by also adding and removing formulae from the same KB. As a result, the KB contains formulae derived from cognitive and metacognitive reasoning.

Since both processes proceed simultaneously in a step-by-step manner, they can influence each other immediately. Therefore, the agent is seamlessly self-reflective and deliberative as it processes the two types of wffs in each step. When the agent has to deal with too many formulae in a step,

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then the default priorities help ensure that higher priority rules fire sooner than later. Also, by limiting the length of each step, the number of formulae processed in a step is kept within bounds and thus ensures that the agent remains responsive to new formulae that get added into the KB because of external changes or internal reasoning.

In the future, we plan to develop mechanisms to adapt metacognition to deal with changes in the intensity and frequency of violations. To this direction, we are currently exploring methods to change priorities of existing formulae.

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Ontologies in industrial Enterprise Content Management Systems: the EC^{2}M Project

Daniela Briola
DIBRIS
Genoa University
Genoa, Italy
daniela.briola@unige.it

Alessandro Amicone
Nacon Information Technology
Sempla Group
Genoa, Italy
alessandro.amicone@nacon.it

Dante Laudisa
SEMPLA
Sempla Group
Milan, Italy
dante.laudisa@sempla.it

***Abstract*—Enterprise Content Management (ECM) systems represent a crucial aspect in the efficient and effective management of large-scale enterprises, in particular for those made up of several sites distributed all over the world. Considering the increasing number of documents that large enterprises need to store and manage, and the need of classifying and retrieving them in real time, ECM systems need to be strengthened to represent not only standard "syntactic" information associated with documents but also more complex and structured information to represent the documents' semantic. In this paper, we present a joint project of the Department of Informatics, Bioengineering, Robotics and System Engineering of the University of Genoa, Italy, and two companies, Nacon (part of Sempla Group) and Nis, to create an improved ECM system (named EC^{2}M) exploiting ontologies to better classify, retrieve and share documentation among different sites of the involved companies. The overall architecture of the EC^{2}M system is presented with a detailed description of the ontology that has been created for the first EC^{2}M prototype, modeling the Sempla's business offers, to let users classify their documents in a semantically-driven way and search them using semantic tags. EC^{2}M is "parametric" in the used ontology: the system is currently used by Sempla, with the ontology presented in this paper.**

Keywords- Enterprise Content Management; Ontologies; Semantic Classification; Knowledge Representation; Industrial Application

I. Introduction and state of the art

The international Association for Information and Image Management (AIIM), the worldwide association for enterprise content management, defined the term "Enterprise Content Management" in 2000, but it has been updated many times to adhere to the continuous new market needs. The more recent definition is: *Enterprise Content Management (ECM) is the strategies, methods and tools used to capture, manage, store, preserve, and deliver content and documents related to organizational processes. ECM covers the management of information within the entire scope of an enterprise whether that information is in the form of a paper document, an electronic file, a database print stream, or even an email* [1]. ECM is an "umbrella term" covering document management, web content management, information search, collaboration, records management and many other tasks, but it is primarily aimed at managing the life-cycle of information, from initial publication or creation to its disposal, to preserve a company's internal (often unstructured) information, in all of its forms. Therefore, most ECM solutions focus on Business-to-Employee (B2E) systems, but nowadays, thanks to the improvement of the IT capabilities and because of the increasing users' need to classify documents according to their meaning, these systems have grown in complexity and often integrate modules to exploit more structured information, taxonomies, dictionaries and so on. Many vendors are offering products in this area, starting from the commercial ones (Microsoft, IBM and Oracle) moving to many powerful open source solutions (for example Alfresco [2], Plone [3] and SenseNet [4]). The new trend in this field is to create ECM systems that can automatically extract information from documents to classify them or add a semantic layer to tag documents in a more structured and interesting way: this is the area where the EC^{2}M project is located.

The problem of classifying, retrieving and sharing documents among users and companies pertains to the research field of knowledge sharing, whereas the problem of semantically tagging documents pertains to that of the knowledge representation. Both fields are relevant both from an academic and an industrial viewpoint, and this motivates the joint academic-industry EC^{2}M project. In EC^{2}M, we used ontologies as a way to structure information describing documents and their content. Many similar studies and projects have been conducted in this area: an example of a commercial ECM system semantically enriched is SmartLogic [5], that offers an automatic classification, based on an automatically-extracted taxonomy of documents. Many open source systems have been developed to integrate semantic services in the document/information management, among which H-DOSE ([6]), OPEN-CALAIS ([7]) and APACHE STANBOL ([8]). Even if they are not ECM systems according to the standard definition, they deal with very similar problems.

If we look at academic research, we can cite for example [9] (describing the Rhizomer CMS, that tags its items using semantic metadata semi-automatically extracted from multimedia sources), [10] (that proposes a framework to manage and share written information contents using an ad-hoc knowledge model for an industrial research center), and

[11] (that presents an open architecture framework based on the open-source CMS OpenCMS and a Java-based web management system for learning objects, which were derived from the instructional materials used in several postgraduate courses).

Our system exploits some of the above-mentioned open-source systems and integrates an ad hoc ontology, shared among the different nodes of the network, to model the documents types and their content. The system offers a publish/subscribe service and is based on a cloud platform. It also exploits contextual information on the location and device used by the user to implement context-awareness. EC^2M is thus a concrete industrial example of how these technologies can be coordinated to create a new powerful system, that can be actually used by existing enterprises.

The rest of the paper is organized in four sections: Section II describes the the EC^2M system, Section III presents the ontology, Section IV shows the prototype and, finally, in Section V, some considerations and conclusions are presented.

II. The EC^2M System

The Enterprise Cloud Content Management (EC^2M) system was born from the collaboration among the Department of Informatics, Bioengineering, Robotics and System Engineering of the University of Genoa and two outstanding IT Italian enterprises, namely Nacon (member of the Sempla Group and specialized in the design and implementation of complex systems, ECMs, and process management) and Network Integration & Solutions (Nis), specialized in the design and development of network products and services for businesses, public administration and end-users.

The developed system is a Content Management System that aims to semi-automatically classify documents with respect to a set of predefined tags: these documents will be then shared among different partners (called “Nodes of the EC^2M network”, that are companies, or companies’ sites, that need to collaborate and chose to agree on the common ontology to tag documents), located in various physical locations, in an automatic way.

The types of documents and their possible contents are modeled using an ontology that formally describes them; the ontology instances are used to tag the documents with semantic information. Every user in the system is able to subscribe to a set of “interests” (chosen from the instances in the ontology) so that when a new document is inserted in the EC^2M network and tagged (manually or partially automatically) with terms from the ontology, those users that are interested in those terms are pro-actively informed that a new document is available. A centralized “semantic router” is in charge of sharing these documents and the system is implemented exploiting a Cloud platform.

A software module manages the context (location and device) where the user is acting, to give the user a subset of the information he needs considering the device he is working on.

The system is deployed over the Cloud Amazon Web Services (AWS) platform (using it as an “Infrastructure as a Service”), that is a good compromise between cost and performances. This solution allows to simply scale the number of nodes in the EC^2M network or to scale the physical resources used to manage the network, to get better performances. The EC^2M system has been designed to run on a private physical network too.

The EC^2M system offers “internal services” to individual nodes (corresponding to an enterprise site) and “external services” to let nodes interact. Looking at individual nodes, the so called “semantic publish/subscribe” service allows every user to declare the arguments he is interested in, chosen from those described in the ontology, and then makes available (globally on the network and locally to the node) the documents matching the subscribed interests.

Looking at the complete network, that is, at the services connecting different nodes, the aim of the system is to allow users from different nodes to be informed of documents, on other nodes, that are interesting for them. This is where the ontology comes into play: sharing interesting documents across nodes is in fact possible because the nodes share a common ontology.

Every node in the network may have privacy policies, because not every document of a node should be read by all the other nodes: maybe only some information as title, abstracts, etc can be shared. These policies are managed by the nodes. Issues related to policy management are out of scope of this paper and are not described here.

Every document is characterized by a set of standard attributes (or tags), like its Name, Creation date, Abstract and so on, whereas the document type is chosen from the ontology: then the user can add other tags in a manual or semi-automatic way (see more details in Section IV), selecting the values from the instances of the ontology and driven by their relationships.

The EC^2M system can be “instantiated” many times, to be useful for different groups of enterprises (that is, for new enterprises’ networks): a new ontology, describing types of documents and their possible contents must be created, but the overall structure and behavior remain the same. In this sense, EC^2M is “parametric” in the used ontology.

At a high level of abstraction, the system is divided into different modules (see Figure 1):

- Graphical User Interface (GUI): front end of the system, where users can log in and insert/retrieve documents (based on the ontology);
- Crawler: software that explores predefined hard disk sectors to find documents that are sent to the Loader;
- Loader (or Classifier): module that automatically extracts from the documents tags corresponding to those in the ontology and that enriches the documents with

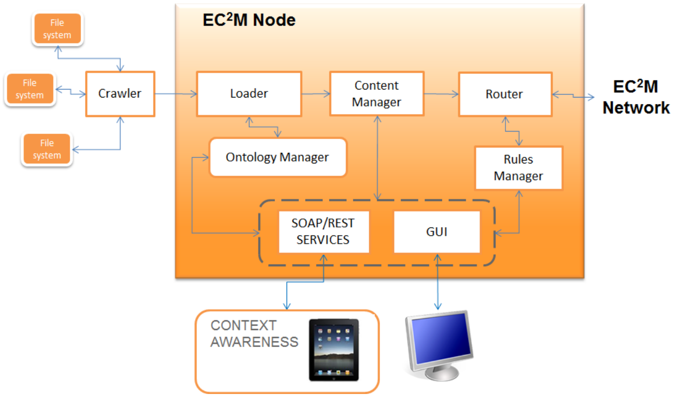

Figure 1. The high level architecture of the EC^{2}M system.

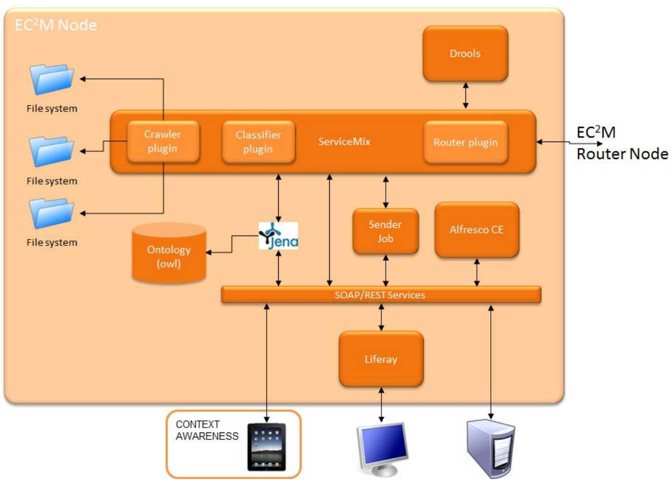

Figure 2. The software architecture of the EC^{2}M prototype.

tags related to those already manually associated with the document, using the instances in the ontology and their relationships;

- Ontology Manager: module that queries and manages the ontology;
- Content Manager: module that stores the documents and manages their sharing and retrieval;
- Router: module that manages the sharing of documents between nodes;
- Rules manager: module that the Router uses in order to define and dynamically create routing rules.

In Figure 2, the reader can see which (existing or new) software modules have been used to implement the first prototype of the EC^{2}M system. On the right side, the arrow points to the EC^{2}M Networks that is not reported in the figure and that is the core of the routing system. Since it is not in the scope of this paper, as the other modules not strictly connected to the ontology, it has been left out from the figure for readability.

To physically manage the documents, we adopted Alfresco, that is a well known open source Java Content Management System: this system allowed us to exploit all the facilities of a high performances business platform with the good property of being an open source software. Furthermore, Alfresco takes advantage of many other well known open source systems like Spring, Hibernate, Lucene and MyFaces.

To create and manage the ontology we adopted the Web Ontology Language (OWL [12]) and Protégé [13]. The ontology is not subject to frequent changes: if it needs to be modified, this is done using Protégé and then the new version is again made available to the framework for queries.

The other modules of the node are not described in details because out of scope, but they are shown anyway in Figure 2 to offer a complete view of the node implementation.

III. THE ONTOLOGY

The EC^{2}M system was designed to work with any ontology describing the documents to be shared and their contents. As a concrete example, we decided to design, implement and use an ontology modeling the Sempla's business proposal.

Sempla, as a brand, was founded in 2009 and operates in System Integration and Information Technology consulting. It has nearly three decades of experience with the most important Italian Groups from the Financial, Production and Public sectors.

This domain was chosen because Sempla is a very large enterprise, covering different business areas, so its documentation presents many types of documents and a large set of terms that are of interest for different users. These terms and types of documents are quite common in this business area, so modeling the Sempla domain is the best choice because the emerging ontology is correct also for Nacon (that is member of the Sempla Group) and for Nis (that often collaborates with Nacon so can easily adhere to the ontology), which are the other nodes in the first prototype.

A. The Ontology Design

To model the domain with an ontology (as defined in [14]), we adopted the Noy and McGuinness methodology [15], that being an agile method is very suitable for collaborating with industrial partners. This methodology foresees these stages:

1) determine the domain and scope of the ontology;
2) consider reusing existing ontologies;
3) enumerate important terms in the ontology;
4) define the classes and the class hierarchy;
5) define the properties of classes-slots;
6) define the facets of the slots;
7) create instances.

The first step was quite simple to follow: the domain of the ontology was the Sempla's business proposal. It is translated into a complex organization of the logic concepts

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that describe what Sempla offers to its costumers, in terms of products and high technical and management consultancy.

Documents must be tagged to describe, with instances found in the ontology, their structure (some type of documents can have many attachments) and above all their technical and business items: for every business market Sempla has a "portofolio" of products and consultancy services that is well organized and defined.

We searched for similar ontologies, but we were not able to find one that was useful for modeling our domain. Maybe other companies own a similar ontology, but they are not public. We also considered existing ontologies, for example Bibo ontology [16], but we did not use them because they share only very few terms with those used in our domain. We could use the already exiting Sempla's documentation, that offered us an already well-defined set of terms describing the domain, although in natural language and not structured in any standard format.

The third step was conducted with the collaboration of the domain experts, that were the scientists from Sempla, Nacon and Nis. The majority of the terms was collected analyzing the brochures describing Sempla's business proposal (one is summarized in Table I) as well as a large set of documents selected as example from the real ones and a list of terms created by the "users-to-be" of the system, that listed the terms (corresponding to logic concepts used in their work) that they would like to use to classify a document.

To define the classes and their structure, we asked the domain experts to describe in details the types of documents they use, the most relevant information characterizing them and how they model the different business markets. We also took inspiration from the file system where documents were stored: the directories were partially organized as the business areas, and this organization reflected the way Sempla divides its business proposal.

The definition of the properties was done following a similar process.

As a last step, we manually inserted the instances in the ontology: the instances are named using some of the terms listed before, and the properties join them to completely describe the domain. It should be noted that in this process, stating what had to become a class and what an instance was a complex task, because some domain's logical concepts may be mapped into a class (if we foresee a possible future extension) or into an instance as well (because they are something already stable and with different properties values), for example for *Market*'s instances. In these cases, we must consider that only instances will be used to tag documents, so it was an obliged decision to model those terms as instances.

Since the ontology is aimed at being used by Italian users it was created in Italian, but some terms (in particular the instances' names) are in English, to maintain a link with the existing documentation and Sempla's internal standards.

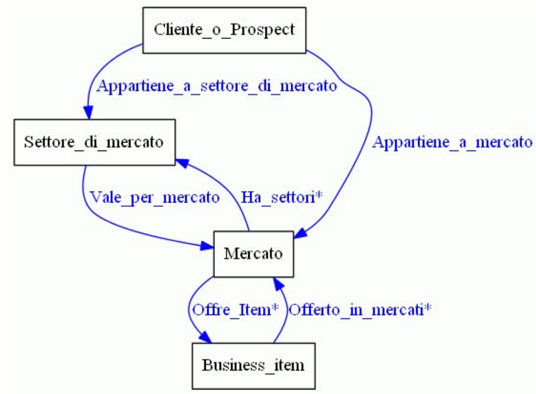

Figure 4. Class *Mercato* and its main relationships.

B. The ontology details

The Sempla business proposal is organized considering different business markets, to propose ad hoc solutions for each area. Each high level business market is called *Mercato* (Market), and each *Mercato* is characterized by some distinct *Settore* (Sectors). To give and explanation of what we assume to be a market, consider that its instances are "Product", "Financial Services" and "Insurance", describing the main activities of the costumers operating in each market. Starting from this macro division of areas, all the other classes are related and organized considering these three sectors. For example, each costumer (class *Cliente_o_Prospect*) refers to one sector, so that his market is uniquely identified.

The Sempla business proposal is created combining different items, identified with the class *Business_Item*, that are divided into different types (subclasses) and that refer to six different Business Areas (as shown in Table I), modeled with the class *Area_Business*, with instances: "Business_IT_consulting", "Business_project_outsourcing", "Web_digital_design", "Business_Solution", "IT_services", "IT_solution". Every *Business_Item* can be associated with only one *Area_business* but can be offered to different Markets. A business item that is offered in many markets is called "cross market". The class that groups these items is defined with a necessary and sufficient condition, and is called *BI_Cross_Mercato*. In a similar way, the class *AB_cross_mercato* is defined with the necessary and sufficient condition that it collects the business areas offering at least one "cross market" item.

The business items are divided into four disjoint subclasses (*Prodotto*, *Soluzione*, *Servizio*, *Attivitá_professionale*), and are related with class *Ambito_Tecnico* describing at high level the IT area they refer to.

In Figures 3 and 4, the relationships between the classes described above are shown.

The documents that must be classified are divided into different types, modeled with the classes (subclasses of

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Table I
THE SEMPLA BUSINESS PROPOSAL FOR THE "FINANCIAL SERVICES" MARKET, GROUPED BY BUSINESS AREAS.

Business IT Consulting	**Digital Marketing & Design**	**Business Solution**	**IT Solutions**	**IT Services**	**BPO**
BPR; Studi di fattibilitá; Enterprise architecture planning; Program management consulting; Organizzazione processi IT; Project portfolio management.	Web & Content Design; User Experience; Community management; Digital Advertising; Augmented Experience.	Credit & Risk Management; Filiale a CRM; Contact center; Pagamenti, Monetica, ATM/POS; Finance & Wealth Planning; Controlli e compliance; Sicurezza e Antifrode; Tesoreria; Human Resources; Reporting & Business Intelligence; Credito al consumo; Leasing & Factoring; Banca Virtuale; Project Portfolio; General ledger.	System Integration Framework; Application Frameworks; Metodologie di Delivery; Multicanalitá; Enterprise Content Management; DB Administrator.	Application Management; Application Modernization; IT Infrastructure Management; ITIL Implementation.	Contact Centre; Back Office; Fiscalitá Locale; Postalizzazione; Business travel management; Formazione, RollOut, Help Desk.

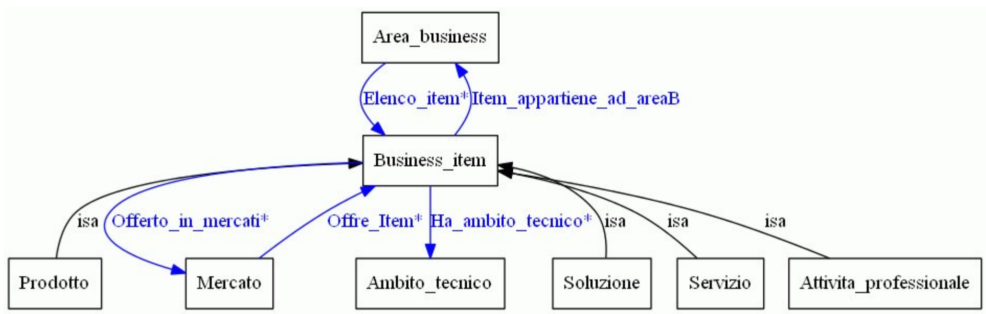

Figure 3. Class *Business_Item* and its main relationships.

Documento (Document)):

- Proposal (class *Documento_offerta*): it describes a business proposal to a costumer;
- Attachment (class *Allegato*) with its sublcasses *Allegato_generico* (generic attachment) and *Allegato_tecnico_offerta* (technical attachment of one specific proposal);
- Consultation document (class *Documento_di_consultazione*), representing documents available for information;
- Request for proposal (class *Request_for_proposal*) coming from a costumer (generally these documents are related to one or more Proposals);
- Marketing support documentation (*Supporto_marketing*), that is a document that describes a costumer and its business;
- Presentation (class *Presentazione*) divided into:
  - Presentation pertinent to a proposal (class *Presentazione_allegata_offerta*), that is a presentation prepared for a specific Proposal, and that can be related to some *Business_item*; and
  - Society presentation (class *Presentazione_istituzionale*) that describes the Sempla business proposal to a specific Market (that must be specified).

In Figure 5, an overview of the relationships among the different types of documents is reported, while in Figure 6 a detailed view of the relationships among *Proposal* and the other classes is shown.

We also created the classes *Ambito_Funzionale* and *Partnes*, representing a further classification of the business services from a commercial viewpoint and a list of possible third parties companies involved in the proposal, respectively.

Due to space limitation, we only show properties in figures and do not report instances of every class. In Section IV the reader can find some of these instances shown in the figures, while they are used by the EC^{2}M interface to help user tagging a document.

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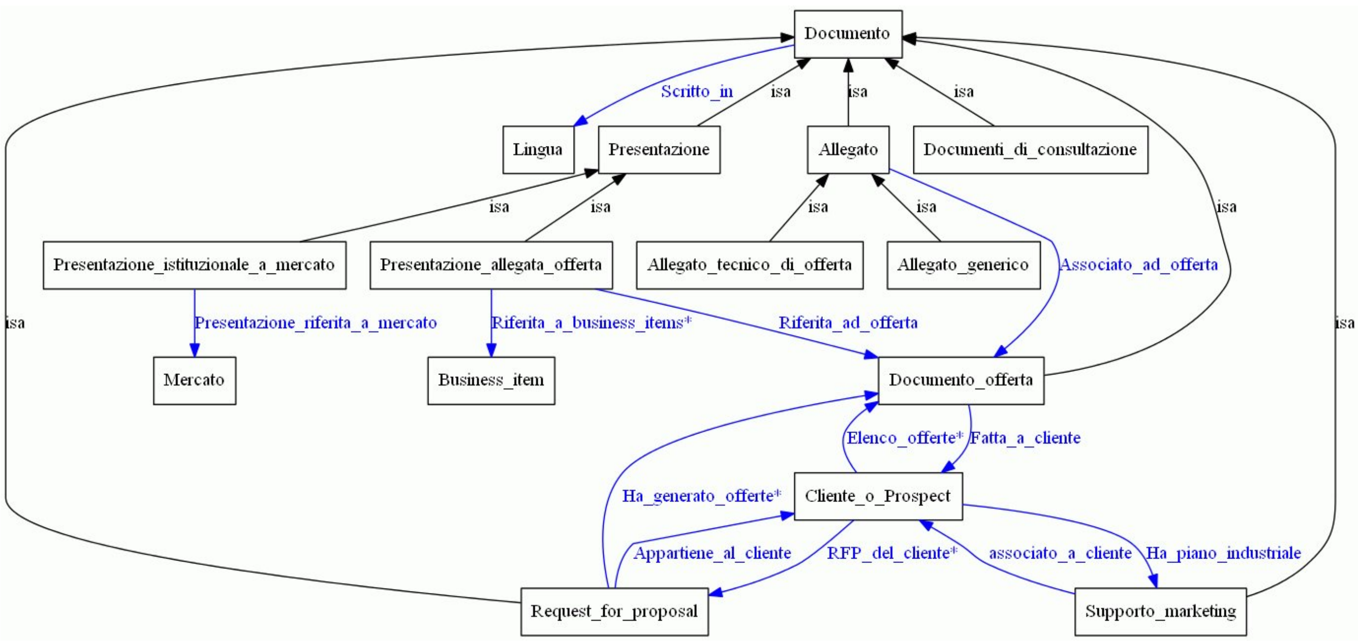

Figure 5. Relationships among classes starting from *Documento* (*Document*) and its subclasses.

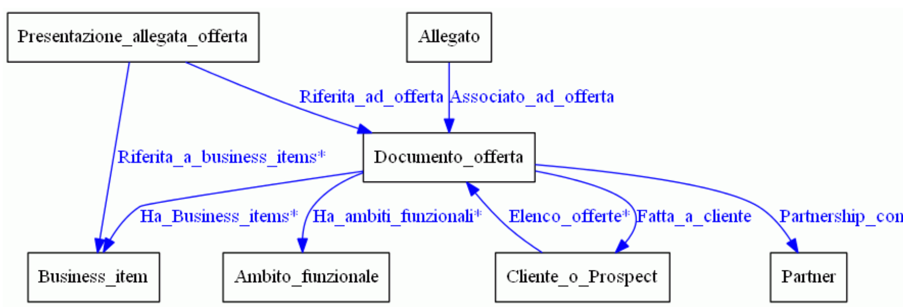

Figure 6. Class *Documento_offerta* (*Proposal*) and its main relationships.

IV. THE PROTOTYPE

A first prototype of the EC^{2}M system has been developed at the end of 2012, based on the ontology described in Section III, and has been tested concretely by Nacon, Nis and Sempla to manage the documents created in 2012 (3200 documents), with 31 users (that will become more than 600 in 2013).

Some images of the GUI are reported to give an example of usage. The GUI form in Figure 7 is the one where the user specifies: what kind of document he is inserting (a “Presentazione”), the market (in this case “Insurance”) and the business items the document is about (selecting these values using drop down lists that group the business item instances in their subclasses). In the example, the user chooses the instances “User_Experience”, “Web_development” and “Digital_media_strategy” from class *Attivitá_professionale*. Finally, the user chooses the language (“Italiano”).

In Figure 8, the system presents to the user the list of the current tags that he selected plus the tags that have been automatically added: in this case only the tag “Digital_Marketing_Design” from class *Business_Area*, because all the selected business items refer to this area, as shown in Table II.

Note that in the ontology, Labels have been added to

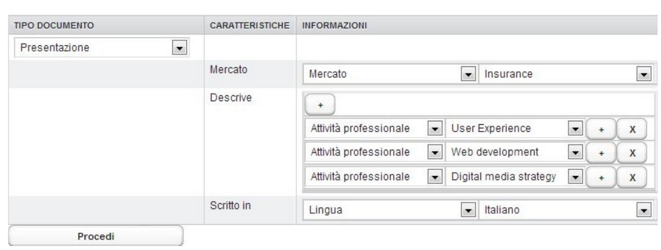

Figure 7. First GUI form for inserting a new document with some first tags. Screen shot.

TAG	CATEGORIA
Insurance	Mercato
User Experience	Elemento d'offerta
Web development	Elemento d'offerta
Digital media strategy	Elemento d'offerta
Italiano	Lingua
Digital_Marketing_Design	Area_business

Figure 8. List of a manually selected tags plus those automatically added. Screen shot.

Table II
Business_Item INSTANCES ASSOCIATED TO THE "DIGITAL_MARKETING_DESIGN" BUSINESS AREA.

Business_Item instances of "Digital_Marketing_Design" business area			
User experience	Movie Design	ADV Campaign	Brand Identity
Digital Media Strategy	Visual Graphic Design	Digital Marketing	Web Development

classes to store the term to be shown in the GUI, because sometime the class names are not "good to be visualized" (for example they contain the "_" character, or are in a different language from the GUI one). For example, in Figure 8 the tags from class *Business_Item* are called "Elemento d'offerta" instead of the standard class name.

Then the system asks the user if he wants to add some more tags, choosing from those connected to the already selected ones. In the example, the user chooses to add more tags starting from the business area "Digital_Marketing_Design". So the system shows the user the possible tags, choosing from the instances related to "Digital_Marketing_Design" (considering the properties with domain *Business_Area*) in the ontology (Figure 9). The user can add some of those tags and then saves the document.

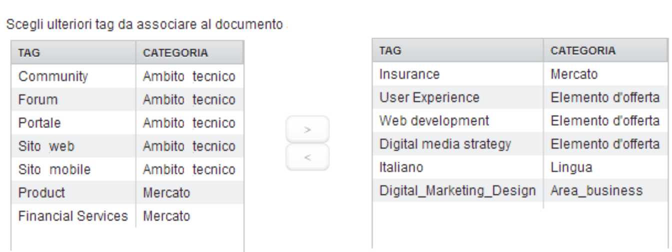

Figure 9. Possible new tags (left) and already associated tags (right). Screen shot.

In this first prototype of the EC^{2}M system, the Loader (or Classifier) module, based on Lucene and Jena, is already able to automatically classify a document given as input using a simple version of the algorithm described in [17]. The algorithm that automatically extracts the tags is based on the "term-frequency value" calculated for every possible tag selected from the ontology (the same that the user can choose in the manual process). For every possible tag in the ontology, its synset is read from the ontology (this set is made of the terms that are synonyms or related words, stored in labels in the ontology): then a score for the tag is calculated analyzing the document and searching in it the tag and its synset, using different weights. Lastly, only a subset of the tags is selected to be related to the document, with respect to a threshold.

V. CONCLUSION AND FUTURE WORK

The EC^{2}M project has been fully tested in 2012 and showed very good results with respect to a standard ECM system: it really helped users from different companies better collaborate, exploiting a semantic classification of their documentation and consequently offering a simpler searching phase and a better support in sharing information, that was impossible to obtain without a similar system. The ontology is now complete and model all the document's types and contents. The notification of new documents to subscribed users is done in quasi real time. Furthermore, with the deployment over the cloud platform, the performances can be enhanced with a new purchase of cloud services: with this architecture and deployment solution the system is really scalable. The system has been adopted by Sempla, and related companies, as their new content management system. Furthermore, from the industrial viewpoint, the system has a good "Return Of Investment" because the adoption of open source technologies and the chance of exploiting the system as a service over the cloud platform (with a pay-per-use solution) allowed a reasonable initial budget and a high scalability in the overall architecture.

Considering the automatic extraction of tag, those with a threshold higher than 0,3 are correctly associated with the document in the 95% of the executed tests: this module will be improved in the next months, but the first results are already promising.

Analyzing the state of the art, many other systems that exploit ontologies to improve knowledge sharing have been presented, dealing with domains that are completely different from ours (for example [18], that is a semantic television content management system based on ontologies) or relying on different architectures (for example [19], where an Ontology Server (OS) component is created to be used in a distributed content management grid system), but the underling problem still remains the same, proving that it is still open and studied. The solution that we adopted is a particular one, where an ad hoc ontology is integrated into a CMS and then deployed over a cloud platform, following the new trends in different research areas, but many other solutions exist, as those described here or previously in Section I. It is impossible to make a precise comparison with the other mentioned systems, because they are commercial and because a completely new system, using the other approaches, should be developed to be tested and compared, and this solution is not feasible.

In the next months, we are going to complete the EC^2M system enhancing the phase of automatic extraction of tags from texts, that is now at a very preliminary stage. Furthermore, we will investigate how dealing with the scenarios where the nodes in the EC^2M network use different ontologies to describe and tag their documentation: in this case, the common ontology must be anyway chosen and defined, but ontology matching techniques may be adopted to align the common and private ontologies before tagging and when receiving notifications from the other nodes, to let them keep on using their private ontology but also being able to share documents with common tags.

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