INFOCOMP 2013

The Third International Conference on Advanced Communications and Computation

ISBN: 978-1-61208-310-0

November 17 - 22, 2013

Lisbon, Portugal

INFOCOMP 2013 Editors

Claus-Peter Rückemann, Westfälische Wilhelms-Universität Münster / Leibniz Universität Hannover / North-German Supercomputing Alliance, Germany

Malgorzata Pankowska, University of Economics, Katowice, Poland

INFOCOMP 2013

Foreword

The Third International Conference on Advanced Communications and Computation (INFOCOMP 2013), held between November 17-22, 2013 in Lisbon, Portugal, continued a series of events dedicated to advanced communications and computing aspects, covering academic and industrial achievements and visions.

The diversity of semantics of data, context gathering and processing led to complex mechanisms for applications requiring special communication and computation support in terms of volume of data, processing speed, context variety, etc. The new computation paradigms and communications technologies are now driven by the needs for fast processing and requirements from data-intensive applications and domain-oriented applications (medicine, geoinformatics, climatology, remote learning, education, large scale digital libraries, social networks, etc.). Mobility, ubiquity, multicast, multi-access networks, data centers, cloud computing are now forming the spectrum of de factor approaches in response to the diversity of user demands and applications. In parallel, measurements control and management (self-management) of such environments evolved to deal with new complex situations.

We take here the opportunity to warmly thank all the members of the INFOCOMP 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 INFOCOMP 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 INFOCOMP 2013 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that INFOCOMP 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 communications and computation.

We are convinced that the participants found the event useful and communications very open. We hope that Lisbon, Portugal, provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of the city.

INFOCOMP 2013 Chairs:

INFOCOMP General Chair

Claus-Peter Rückemann, Westfälische Wilhelms-Universität Münster / Leibniz Universität Hannover / North-German Supercomputing Alliance, Germany

INFOCOMP Advisory Chairs

Hans-Joachim Bungartz, Technische Universität München (TUM) - Garching, Germany
Petre Dini, Concordia University - Montreal, Canada / China Space Agency Center - Beijing, China
Erik Elmroth, Department of Computing Science and HPC2N, Umeå University / High Performance

Computing Center North (HPC2N), Sweden
Sik Lee, Supercomputing Center / Korea Institute of Science and Technology Information (KISTI), Korea
Subhash Saini, NASA, USA

INFOCOMP Academia Chairs

Alexander Knapp, Universität Augsburg, Germany
Malgorzata Pankowska, University of Economics, Katowice, Poland

INFOCOMP Research Institute Liaison Chairs

Kei Davis, Los Alamos National Laboratory, USA
Edgar A. Leon, Lawrence Livermore National Laboratory, USA
Ivor Spence, School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, Northern Ireland, Research for High
Performance and Distributed Computing / Queen's University Belfast, UK

INFOCOMP Industry Chairs

Alfred Geiger, T-Systems Solutions for Research GmbH, Germany
Hans-Günther Müller, Cray, Germany

INFOCOMP Special Area Chairs on Large Scale and Fast Computation

José Gracia, High Performance Computing Center Stuttgart (HLRS), University of Stuttgart, Germany
Björn Hagemeier, Juelich Supercomputing Centre, Forschungszentrum Juelich GmbH, Germany
Walter Lioen, SURFsara, Netherlands
Lutz Schubert, Institute of Information Resource Management, University of Ulm, Germany

INFOCOMP Special Area Chairs on Networks and Communications

Noelia Correia, University of the Algarve, Portugal
Wolfgang Hommel, Leibniz Supercomputing Centre - Munich, Germany

INFOCOMP Special Area Chairs on Advanced Applications

Bernhard Bandow, Max Planck Institute for Solar System Research (MPS), Katlenburg-Lindau, Germany
Diglio A. Simoni, RTI International - Research Triangle Park, USA

INFOCOMP Special Area Chairs on Evaluation Context

Dominic Eschweiler, Frankfurt Institute for Advanced Studies (FIAS), Germany
Huong Ha, University of Newcastle, Australia (Singapore campus)
Philipp Kremer, German Aerospace Center (DLR), Institute of Robotics and Mechatronics, Oberpfaffenhofen, Germany

INFOCOMP Special Area Chairs on Biometry

Ulrich Norbisrath, BIOMETRY.com / University of Tartu, Estonia

INFOCOMP 2013

Committee

INFOCOMP General Chair

Claus-Peter Rückemann, Westfälische Wilhelms-Universität Münster / Leibniz Universität Hannover / North-German Supercomputing Alliance, Germany

INFOCOMP Advisory Chairs

Hans-Joachim Bungartz, Technische Universität München (TUM) - Garching, Germany
Petre Dini, Concordia University - Montreal, Canada / China Space Agency Center - Beijing, China
Erik Elmroth, Department of Computing Science and HPC2N, Umeå University / High Performance Computing Center North (HPC2N), Sweden
Sik Lee, Supercomputing Center / Korea Institute of Science and Technology Information (KISTI), Korea
Subhash Saini, NASA, USA

INFOCOMP Academia Chairs

Alexander Knapp, Universität Augsburg, Germany
Malgorzata Pankowska, University of Economics, Katowice, Poland

INFOCOMP Research Institute Liaison Chairs

Kei Davis, Los Alamos National Laboratory, USA
Edgar A. Leon, Lawrence Livermore National Laboratory, USA
Ivor Spence, School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, Northern Ireland, Research for High
Performance and Distributed Computing / Queen's University Belfast, UK

INFOCOMP Industry Chairs

Alfred Geiger, T-Systems Solutions for Research GmbH, Germany
Hans-Günther Müller, Cray, Germany

INFOCOMP Special Area Chairs on Large Scale and Fast Computation

José Gracia, High Performance Computing Center Stuttgart (HLRS), University of Stuttgart, Germany
Björn Hagemeier, Juelich Supercomputing Centre, Forschungszentrum Juelich GmbH, Germany
Walter Lioen, SURFsara, Netherlands
Lutz Schubert, Institute of Information Resource Management, University of Ulm, Germany

INFOCOMP Special Area Chairs on Networks and Communications

Noelia Correia, University of the Algarve, Portugal
Wolfgang Hommel, Leibniz Supercomputing Centre - Munich, Germany

INFOCOMP Special Area Chairs on Advanced Applications

Bernhard Bandow, Max Planck Institute for Solar System Research (MPS), Katlenburg-Lindau, Germany
Diglio A. Simoni, RTI International - Research Triangle Park, USA

INFOCOMP Special Area Chairs on Evaluation Context

Dominic Eschweiler, Frankfurt Institute for Advanced Studies (FIAS), Germany
Huong Ha, University of Newcastle, Australia (Singapore campus)
Philipp Kremer, German Aerospace Center (DLR), Institute of Robotics and Mechatronics, Oberpfaffenhofen, Germany

INFOCOMP Special Area Chairs on Biometry

Ulrich Norbisrath, BIOMETRY.com / University of Tartu, Estonia

INFOCOMP 2013 Technical Program Committee

Ajith Abraham, Machine Intelligence Research Labs (MIR Labs), USA
Ali I. Al Mussa, King Abdulaziz City for Science and Technology (KACST), Saudi Arabia
Bernadetta Kwintiana Ane, Institute of Computer-aided Product Development Systems, Universitaet Stuttgart, Germany
Douglas Archibald, University of Ottawa, Canada
Hazeline U. Asuncion, University of Washington, Bothell, USA
Tulin Atmaca, IT/Telecom&Management SudParis, France
Bernhard Bandow, Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany
Belgacem Ben Youssef, King Saud University Riyadh, KSA / Simon Fraser University Vancouver, British Columbia, Canada
Rupak Biswas, NASA Ames Research Center, USA
Rim Bouhouch, National Engineering School of Tunis, Tunisia
Elzbieta Bukowska, Poznan University of Economics, Poland
Hans-Joachim Bungartz, Technische Universität München (TUM) - Garching, Germany
Diletta Romana Cacciagrano, Computer Science Division, School of Science and Technology, University of Camerino, Italy
Elena Camossi, European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen (IPSC) - Ispra, Italy
Antonio Martí Campoy, Universitat Politècnica de València, Spain
Laura Carrington, University of California, San Diego/ San Diego Supercomputer Center, USA
Noelia Correia, University of Algarve, Portugal
Kei Davis, Los Alamos National Laboratory / Computer, Computational, and Statistical Sciences Division, USA
Sergio De Agostino, Sapienza University-Rome, Italy
Vieri del Bianco, Università dell'Insubria, Italia
Amine Dhraief, University of Kairouan, Tunisia

Beniamino Di Martino, Dipartimento di Ingegneria dell'Informazione, Seconda Università di Napoli, Italy
Erik Elmroth, Department of Computing Science and HPC2N, Umeå University, Sweden
Dominic Eschweiler, Frankfurt Institute for Advanced Studies (FIAS), Germany
Jürgen Falkner, Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO, Stuttgart, Germany
Lars Frank, Department of IT Management, Copenhagen Business School, Denmark
Munehiro Fukuda, Division of Computing and Software Systems, School of Science, Technology Engineering, and Math, University of Washington, Bothell, USA
José Gracia, High Performance Computing Center Stuttgart (HLRS), University of Stuttgart, Germany
Alfred Geiger, T-Systems Solutions for Research GmbH, Germany
Birgit Frida Stefanie Gersbeck-Schierholz, Leibniz Universität Hannover/Certification Authority University of Hannover (UH-CA), Germany
Franca Giannini, Consiglio Nazionale delle Ricerche - Genova, Italy
Fabio Gomes de Andrade, Federal Institute of Science, Education and Technology of Paraíba, Brazil
Conceicao Granja, Tromsø Telemedicine Laboratory - Norwegian Centre for Telemedicine, University Hospital of North Norway, Tromsø, Norway
Richard Gunstone, Bournemouth University, UK
Huong Ha, University of Newcastle, Australia (Singapore campus)
Björn Hagemeier, Juelich Supercomputing Centre, Forschungszentrum Juelich GmbH, Germany
Malgorzata Hanzl, Technical University of Lodz, Poland
Abbas Hijazi, Lebanese University, Lebanon
Wolfgang Hommel, Leibniz Supercomputing Centre - Munich, Germany
Jiman Hong, Soongsil University - Seoul, Korea
Tzyy-Leng Horng, Feng Chia University, Taiwan
Friedrich Hülsmann, Gottfried Wilhelm Leibniz Bibliothek - Hannover, Germany
Udo Inden, Cologne University of Applied Sciences, Research Centre for Applications of Intelligent Systems (CAIS), Germany
Kai Jiang, Shanghai Supercomputer Center, China
Izabela Karsznia, University of Warsaw, Department of Cartography, Warsaw, Poland
Abdelmajid Khelil, Huawei Research, Germany
Alexander Kipp, Robert Bosch GmbH., Germany
Christos Kloukinas, City University London, UK
Alexander Knapp, University of Augsburg, Germany
Manfred Krafczyk, Institute for Computational Modeling in Civil Engineering (iRMB), Braunschweig, Germany
Philipp Kremer, German Aerospace Center (DLR) / Institute of Robotics and Mechatronics - Oberpfaffenhofen, Germany
Herbert Kuchen, Westfälische Wilhelms-Universität Münster, Institut für Wirtschaftsinformatik, Praktische Informatik in der Wirtschaft, Münster, Germany
Sik Lee, Supercomputing Center / Korea Institute of Science and Technology Information (KISTI), Korea
Paulo Leitão, Polytechnic Institute of Braganca, Portugal
Edgar A. Leon, Lawrence Livermore National Laboratory, USA
Walter Lioen, SURFsara, Netherlands
Georgios Lioudakis, National Technical University of Athens (NTUA), Greece
Joan Lu, Informatics, University of Huddersfield, UK
Richard Lucas, University of Canberra and Charles Sturt University, Australia
Tony Maciejewski, Colorado State University, USA
Dirk Malzahn, OrgaTech, Lunen, Germany
Suresh Marru, Indiana University, USA

Nikolaos Matsatsinis, Technical University of Crete, Greece
Lois Curfman McInnes, Mathematics and Computer Science Division - Argonne National Laboratory, USA
Igor Melatti, Sapienza Università di Roma, Rome, Italy
Jelena Mirkovic, Center for Shared Decision Making and Collaborative Care Research, Oslo University Hospital, Norway
Hans-Günther Müller, Cray, Germany
Marian Mureșan, Faculty of Mathematics and Computer Science, Babes-Bolyai University, Cluj-Napoca, Romania
Lena Noack, Royal Observatory of Belgium, Brussels, Belgium
Ulrich Norbisrath, BIOMETRY.com / University of Tartu, Estonia
Aida Omerovic, SINTEF ICT, Norway
Stephan Onggo, Lancaster University, UK
Malgorzata Pankowska, University of Economics - Katowice, Poland
Giuseppe Patané CNR-IMATI, Italy
Raffaella Pavani, Department of Mathematics, Politecnico di Milano, Italy
Rasmus Ulslev Pedersen, Dept. of IT Management, Embedded Software Laboratory, Copenhagen Business School, Denmark
Guo Peiqing, Shanghai Supercomputer Center, China
Ana-Catalina Plesa, German Aerospace Center, Institute of Planetary Research, Planetary Physics, Berlin, Germany
Matthias Pocs, Stelar Security Technology Law Research, Germany
Mario Porrmann, Center of Excellence Cognitive Interaction Technology - Bielefeld University, Germany
Thomas E. Potok, Computational Data Analytics Group, Oak Ridge National Laboratory, USA
Iouldouz Raguimov, York University, Canada
Mohamed A. Rashed, Department of Geophysics, Faculty of Earth Sciences, King Abdulaziz University, Jeddah, Saudi Arabia
Sebastian Ritterbusch, Engineering Mathematics and Computing Lab (EMCL), Karlsruhe Institute of Technology (KIT), Germany
Ivan Rodero, Rutgers University - Piscataway, USA
Dieter Roller, University of Stuttgart, Director Institute of Computer-aided Product Development Systems - Stuttgart, Germany
Claus-Peter Rückemann, WWU Münster / Leibniz Universität Hannover / HLRN, Germany
H. Birali Runesha, University of Chicago, USA
Subhash Saini, NASA, USA
Lutz Schubert, Institute of Information Resource Management, University of Ulm, Germany
Damián Serrano, University of Grenoble - LIG, France
Gyuzel Shakhmametova, Ufa State Aviation Technical University, Russia
Diglio A. Simoni, RTI International - Research Triangle Park, USA
Theodore E. Simos, King Saud University & University of Peloponnese - Tripolis, Greece
Happy Sithole, Center for High Performance Computing - Cape Town, South Africa
Marcin Sokól, Gdansk University of Technology, Poland
Terje Sovoll, Tromsø Telemedicine Laboratory - Norwegian Centre for Telemedicine, University Hospital of North Norway, Tromsø, Norway
Ivor Spence, School of Electronics, Electrical Engineering and Computer Science, Research for High Performance and Distributed Computing, Queen's University Belfast, UK
Monika Steinberg, University of Applied Sciences and Arts Hanover, Germany
Christian Straube, MNM-Team, Institut für Informatik, Ludwig-Maximilians-Universität München (LMU), Germany

Zdenek Sustr, CESNET, Czech Republic
Rahim Tafazolli, CCSR Director, University of Surrey - Guildford, UK
Vrizlynn Thing, Institute for Infocomm Research, Singapore
Francesco Tiezzi, IMT Institute for Advanced Studies Lucca, Italy
Katya Toneva, International Community School and Middlesex University, London, UK
Nicola Tosi, Department of Planetary Geodesy, Technical University Berlin, Germany
Dan Tulpan, Information and Communications Technologies - National Research Council Canada / University of Moncton / University of New Brunswick / Atlantic Cancer Research Institute, Canada
Ravi Vadapalli, Texas Tech University, USA
Eloisa Vargiu, Barcelona Digital Technological Center, Spain
Domitila Violeta Velasco Mansilla, Hydrogeology Group (GHS), Institute of Environmental Assessment and Water Research (IDAEA), CSIC, Barcelona, Spain
Edward Walker, Whitworth University, USA
Iris Weber, Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Germany
Stephen White, The University of Huddersfield, UK
Qiang Xu, School of Science and Engineering, Tesside University, Middlesbrough, Tees Valley, England
Qimin Yang, Engineering Department, Harvey Mudd College, Claremont, CA, USA
Robin Jun Yang, Hong Kong University of Science and Technology, Hong Kong
May Yuan, Center for Spatial Analysis and Geoinformatics Program, College of Atmospheric and Geographic Sciences, University of Oklahoma, USA
Peter Zaspel, University of Bonn, Germany

Copyright Information

Table of Contents

Parallelising Multi-agent Systems for High Performance Computing

Paulo Leitão
Polytechnic Institute of Bragança
Bragança, Portugal

E-mail: pleitao@ipb.pt

Udo Inden
Cologne University of Applied Sciences
Köln, Germany

E-mail: udo.inden@fh-koeln.de

Claus-Peter Rückemann
Leibniz Universität Hannover / Westfälische Wilhelms-Universität Münster (WWU) / North-German Supercomputing Alliance (HLRN), Münster, Hannover, Germany
E-mail: ruckema@uni-muenster.de

***Abstract*— Multi-Agent Systems (MAS) are seen as a promising technology to face the current requirements of large-scale distributed and complex systems, e.g., autonomous traffic systems or risk management. The application of MAS to such large scale systems, characterised by millions of distributed nodes, imposes special demanding requirements in terms of fast computation. The paper discusses the parallelisation of MAS solutions using larger-scale distributed High End Computing platforms as well as High Performance Computing as a suitable approach to handle the complexity associated to collaborative solutions for large-scale systems.**

***Keywords-** Multi-Agent Systems; High Performance Computing; Parallel systems; Risk Management.*

I. Introduction

The dynamics of business environments and technological advancements are driving forces of an increasing demand for High-End and High- Performance Computing (HEC, HPC) for designing and operating highly customised and complex products and services like networked manufacturing systems (e.g., Nokia mobile phones), autonomous traffic systems (e.g., SESAR aviation), computational risk management (e.g., financial models), complex design (e.g., new aircrafts) and complex service operations (e.g., a large airport, harbour), oil and gas seismic imaging, climate and weather forecasting, bacteria modelling and estimated coverage of epidemics, considering huge population sizes. Therefore, more flexible, agile and reconfigurable systems are required, in opposite to the typical centralised solutions that are not enough to address the demanding requirements.

Multi-Agent Systems (MAS) [1], [2], [3] are a suitable approach to face this challenge, based on the decentralisation of functions by distributed nodes. The application of MAS principles to large scale systems (e.g., 6 million parts spanning across a supply-chain) imposes demanding requirements in terms of fast computation that significantly exceed any current MAS platform. The use of reliable, secure and "on demand" utilisation of high computing capacities to handle all or part of such complexity associated to large-scale systems within short periods of time is required.

High End Computing (HEC) and High Performance Computing (HPC) are widely perceived as only affordable to large corporations. However, a recent communication from the European Commission predicts that "*Exa-scale computers (machines capable of 1e+18 operations / second) will be in existence by 2020*" and suggests that "*97 % of industrial companies that employ HPC consider it indispensable for their ability to innovate, compete, and survive*" [4].

In this paper we discuss the parallelisation of MAS using larger-scale HEC or HPC platforms to handle the complexity associated to collaborative solutions for large-scale systems. The computational power of these platforms is useful for large-scale modelling and simulation of data and compute intensive applications like those mentioned above that often require the use of simulations because real-world testing would be too expensive, dangerous, environmentally damaging, or even physically impossible. For this purpose, agent-based simulation is a suitable approach, but its computing requirements can be high and demanding distributed and non-distributed highly performant computing platforms.

The rest of this paper is organised as follows: Section II overviews the MAS and HPC concepts and Section III discusses the combination of these technologies, namely the associated challenges and the existing approaches. Section IV presents some scenarios that benefit from the use of MAS solutions running in high end platforms. Section V describes the REPAST HPC tool, as an example of an agent-based modelling framework for large-scale distributed computing platforms. At last, Section VI rounds up the paper with the conclusions and points out the future work.

II. Background on Multi-agent Systems and High Performance Computing

A. Multi-agent Systems

MAS are a computational paradigm derived from the distributed artificial intelligence field, characterised by the decentralisation and parallel execution of activities based on autonomous agents. Since agents have limited knowledge and skills, they need to interact, e.g., through negotiation, to achieve their individual goals, as illustrated in Figure 1. The high-level of autonomy and cooperation exhibited by such solutions, allow them to fast respond to perturbations. MAS can be used to solve problems that are difficult or impossible for a monolithic system to solve, offering models for representing complex and dynamic real-world environments [5]. Examples of application areas are electronic commerce, manufacturing, robotics and telecommunications.

 ISBN: 978-1-61208-310-0

The development of multi-agent system solutions is strongly simplified if an agent development platform is used, taking advantage of the useful features and services provided, such as registry and management services. In some cases, they follow the specifications established by the Foundation for Intelligent Physical Agents (FIPA). Examples of such agent-development platforms are the Java Agent Development Framework (JADE), AGlobe and JACK. For example, JADE [6] is a Java based architecture that uses the Remote Method Invocation (RMI) to support the creation of distributed Java based applications. It is compliant with FIPA specifications, providing low programming effort and features to support the management of agent-based solutions, delivering an easy integration with other tools, namely Protégé and Java Expert System Shell (JESS).

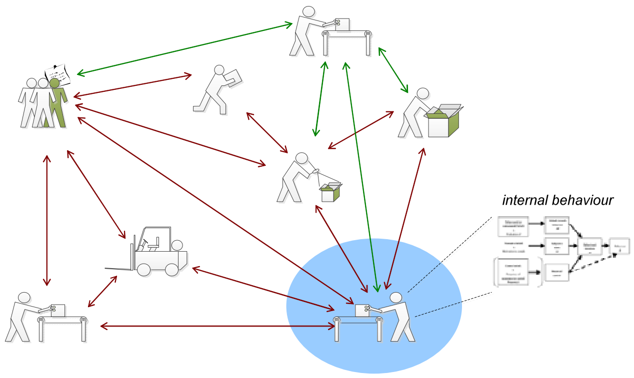


Figure 1. Example of a Multi-agent system.

Another level of using multi-agent systems principles is known as Agent-Based Modelling (ABM), which is a paradigm to create, analyse, experiment and simulate systems populated by cooperative agents. The dynamics of the simulation are specified as agent behaviour rules, and the purpose of the simulation is to reveal population-level structure that is the outcome of this individual-level behaviour. In particular, it supports the reproduction of a variety of patterns and complex phenomena observed in real world, such as evolution and self-organisation. Examples are the simulation of economic, biological and physical dynamics. Several ABM computational frameworks are currently available, such as Netlogo, Mason and Repast (for a comparative survey, see [7] and [8]). Applications of ABMs can be found in [9].

Note that there is a clear difference between multi-agent systems and agent-based simulation: MAS frameworks allow building agent-based systems, but they haven’t a simulation infrastructure (e.g., misses a scheduler and the notion of a "clock"). On contrary, ABM frameworks allow agent-based simulation but they have not the purpose of developing agent systems (nor FIPA compliant).

B. *High Performance Computing*

In the 21st century, highly performant computing, especially HEC and HPC, is a key enabling technology, with many countries world-wide investing huge sums of public money on related infrastructure, energy, and services. “High performance” is considered in its broadest definition covering demanding applications that are compute and / or data-centric, which can support the exploitation of parallelism on a large scale.

HEC systems can range from a desktop computer, through clusters of servers and data centres up to high-end custom supercomputers. Resources can be physically close to each other, e.g., in a highly performant compute cluster, or the compute power can be distributed on a large number of computers as with most Grid and Cloud computing concepts.

HPC systems are based on architectures with a large number of processors, for exploiting massive parallelism. Commonly used models are Massively Parallel Processing and Symmetric Multi-Processing, used with the concept of local islands. Due to physically shared memory usage and compute communication the physical architectures with these HPC systems are different.

Therefore, besides the compute power, the major challenges with the high end field of applications and economical resources usage are efficient communication and data locality. So, major requirements are the intelligent and autonomous distribution and scheduling of highly parallel and loosely coupled job tasks and processes as well as managing the automation of data distribution.

III. PARALLELISING MULTI-AGENT SYSTEMS OVER HIGH PERFORMANCE COMPUTING PLATFORMS

As previously described, HPC is nowadays a hot topic, with many high processing computing resources available through the organisation of grids or clusters of computers. The pertinent question arising in this context is how MAS can be integrated into HPC environments, allowing the development of solutions handling more efficiently complexity in large scale systems. This section discusses the challenges in this topic and particularly, the parallelisation of MAS solutions.

A. *Challenges, Requirements and Technical Issues*

The main issue related to this topic is to understand how to deploy societies of agents on a large scale computational platform. The challenges are mainly related to the parallelisation and HPC readiness of MAS applications.

Parallelising MAS applications means deploying and running these multiple intelligent agents on several computational resources nodes. As an example, if a simulation experiment plan defines 10000 simulations (e.g., each one carried out by one agent), and a computational Grid of 20 nodes is used, five hundred simulations can be assigned to each node (note that parallelising only one simulation is also possible by decomposing the simulation in independent agents). However, the distribution of the multi-agent system execution is a complex task, due to the technical particularities, and particularly, to the intensive communication among agents and the environment. Additionally, individual agents need to modify the environment during their decision-making processes, which in terms of parallelisation are translated to the need to share several layers of environmental data and agents, which is a complex process [10]. The access to these distributed nodes

 ISBN: 978-1-61208-310-0

to collect and synchronise the state and actions of the agents, e.g., to support decision-making and monitoring processes, are also required.

Traditionally, HPC are placed in one site, being a challenge to combine several HPC sites that work in a transparent way for the MAS applications. Usually the agent-development platforms support the distribution within a single computer, for example using threads or simple shared-memory parallelism. For example, JADE agents are based in a behaviour structure that are implemented a simple threads.

Having these considerations in mind, important requirements and constraints for each HPC provider with respect to the MAS applications are related to:

- *Integration and storage of data*: Middleware for integrating flow of data from distributed, heterogeneous sources, and also the agent's endogenous data and the agent topologies.
- *Synchronisation of distributed data and behaviour*: HPC systems primarily synchronise the distribution of data and algorithms of massive parallel applications across massive parallel hardware and are efficient if processor primarily compute rather than communicate or wait for input from other applications.
- *Communication scale and latency*: ICT platform that ensure the scalability of many agents and the fulfilment of communication constraints, and particularly, time latency in the interaction between MAS nodes and also with legacy systems.
- *Security*: Infrastructure granting high-level security and privacy of data (probably implementing risk-aware capabilities as feature of intelligent applications).
- *Interaction and searching*: Proper mechanisms for the scale design of interactions among agents, e.g., negotiation protocols using Agent Communication Languages (ACL), and the searching and discovering features in large-scale systems.

In conclusion, these systems should exhibit a set of properties that include a time scheduler for coordinating and synchronising flow of agent-based events, and storage systems for endogenous data, such as agents' internal state information and agents' topologies, synchronised to form a single data storage framework.

At this stage, the question is if agent development frameworks, such as JADE, or ABM frameworks, such as Repast, already fulfil these requirements. Basically, agent-development frameworks let these issues open to the developer, being necessary to consider a proper architecture that allows the integration. The architecture may consider three layers, as illustrated in **Figure 2**.

The *lower part* is about the MAS based application, using an agent development framework or an ABM tool. At this application level, the agent-based model may integrate relevant sources of knowledge distributed across organisations, functions, space, but also time (different latency, etc.) and technically to be parallel computed on thread level. An example is a risk management application designed as a MAS solution and able of running on HPC resources (chiefly effectively distributed with multiple HPC islands).

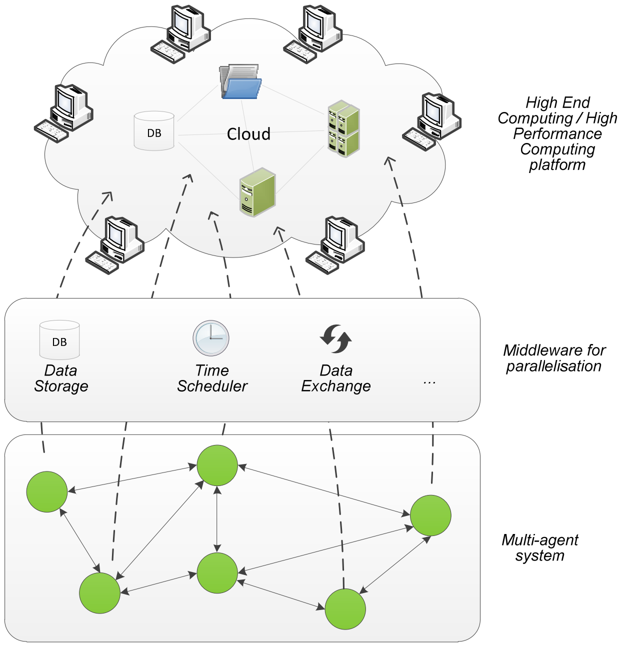


Figure 2. Architecture for an integrated MAS – HPC solution.

The *middle part* is related to the middleware that ensure the automatic parallelisation of the multi-agent system application, namely providing mechanisms for integration and storage of data, synchronisation of distributed data and behaviour and security of data.

The *upper part* is about the HPC/Cloud infrastructure. Access is provided by a service platform, including a "configurator" for adjusting demands of applications and HPC capacities, a "broker" system for access of configured applications to HPC capacity including commercial management functionality, an "application controller", e.g., for managing simulation, and "data exchange" functionality (which may include security systems).

The holonic principles may be considered to make more flexible the development of the multi-agent system applications, and also to reduce the communication across MAS nodes (note that holonic systems, following the Koestler observations, define intermediate stable control states [11]). This may simplify the achievement of the cross communication latency.

B. Existing Approaches

Multi-agent system technology is already being used in some HPC/Cloud projects as brokers for service search in the EU FP7 mOSIAC project [12] or as learning entities for energy efficiency in the EnerGy project [13].

However, the several available agent-development frameworks, as JADE is, are not completely aimed to run at extremely high-performance computing platforms, i.e., they are not HPC compliant. The same occur for the existing ABMs frameworks. Note that these frameworks can be used to distribute MAS applications across multiple computing resources, but this is a complex task that requires that developers codify by hand the HPC functionalities.

 ISBN: 978-1-61208-310-0

As explained by Dr. Michael North, deputy director of Argonne's Center for Complex Adaptive Agent Systems Simulation, "*Before we can efficiently use high-performance computing, we need to do research to understand how to best use the architectures. Switching our model to run on 10,000 nodes instead of 10 is not just a linearly scalable process. Moving from a few interactions to a million interactions is not just moving to greater numbers. Entire interactions change. Also, we need to consider implementation issues such as partitioning of the name space, memory space, communicate on, and the effect of noise and jitter on these large platforms. Ultimately, we need to make changes to our model to deal with such issues.*" [14].

The advent of HPC had driven the extension of some of the ABM tools to support the deployment of agent-based models into HPC environments aiming to have simulation results in a fast way. Examples are Repast HPC [15], Flexible Large-Scale Agent Modelling Environment (FLAME) [16], Pandora [10] and GridABM [17]. These ABM frameworks support the design and execution of large-scale social simulations in HPC environments. Examples of services and mechanisms provided by these tools are the cross-process communication and synchronisation, parallel scheduling, data collection and random number generation.

The EPIS project provides a general and user-friendly approach to combine multi-agent based simulation and HPC platforms, based on the definition of workflows, allowing to deploy simulations on a cluster of computers without any prior parallelising work [18].

However, the same effort is missing for the agent development frameworks. Probably, the reason for the missing HPC extensions in the agent development frameworks, and only focused in ABM frameworks, is that HPC platforms are more useful for simulation purposes that requires more computational power, due to the typical huge population size and short time response.

IV. Scenarios

Though *swarms* of software agents imply parallel operations, the title of this paper indicates that processing and communication in typical MAS are at least not fully parallel organised. Thus, which kind of problems drives the need of porting technological swarm intelligence to the capacity and capability levels of typically parallel high-end computing?

The industrial use-cases motivating our work on parallel MAS are marked by large landscapes of interdependent risks to be managed. First ideas (example 1) to model such landscapes and to make them accessible for computing grew in the Cargo-Lifter project that aimed at the development of the technology, the production and the operations of a 265-metres airship for transporting heavy and oversized goods. The venture failed because of its overwhelming and, in key areas of technology and operations, ignored complexity [23].

In current industry-driven research, the concept of risk landscapes again became relevant: The ARUM project [24] (example 2) addresses problems of the ramp-up of production of small series, particularly in aviation industry. Factors like a high capital intensity of product and production development and specifics of small series lead to a "point of no return" where a decision is to be made to start production. After this decision has been made, immatureness and undependability of technology, of suppliers or production processes and resources are left to ramp-up management.

Problems in this phase delayed the market introduction of the Boeing 787 "Dreamliner" for about 3 years and returned in January 2013 when fire hazards of a new type of Lithium-Ion batteries gave reason to ground 50 operating aircrafts for, at the time this text is written, for about 4 months [25]. Comparing, failures delayed the production of the Airbus A380 [26]. A core problem of the case is that events may interact in hardly predictable ways. These events affect revenues, translate into early depreciations, drive costs by disrupting operations or by re-engineering, and finally penalties or a loss of reputation.

A third industrial case relies on work with scientists and industry experts on a risk model for a complex change program of another globally operating technology provider in aviation industry. In the next four years the firm will face a multi ramp-up scenario by exchanging old by new products and production technologies. A factory-wide "Readiness Review" delivered more than 2200 issues, each representing a risk identified by an expert and in further analysis melted down to about 1000 problems that, in further steps, are to be operationalized by respective control parameters and to be assigned to "cells" of managerial responsibility.

In the first example about 20 factors were identified influencing the incidence rate per risk and another 20 their impact. Yet under ramp-up conditions, both, event-risk and impact may be not known and the view is to be altered from handling material risk to understanding holistic capabilities of the system to adapt.

Particularly, in the latter approach the computational scale of the problem matters: In example 1, a MAS has been used to support the development of a common domain ontology across teams in product-, production and operations' engineering and to integrate the knowledge from more than 60 large industrial lead-users worldwide. Yet the model just captured about 70 of about 1400 risks that had been identified in a high level analysis (comparing to example 3).

In ARUM semantic technologies will improve response to unplanned events as they occur by identifying, structuring and exploiting discretions to act in a scene and, in tactical planning, by enhancing capabilities to adapt to unplanned events. In order to demonstrate its value ARUM will focus exemplary cases and test scenarios like the scene of a workstation or of the production of a module of an aircraft. At the end, ARUM will come up with an intelligent enterprise bus integrating legacy with new intelligent planning systems.

In contrast, the third case puts the behaviour of the landscape into the foreground. This requires holistic modelling and, e.g., of running batches of Monte-Carlo simulations in reasonable response times. While in ARUM the operations' network is beyond the scope the third example will need further research and experiments.

As a first approach similarities between existing and envisioned industrial HPC applications may help to demarcate the dimension of the scale: Such a similarity is provided by events propagating across a network specified by dimensions like space and time, temperature and humidity, organisation or technology. For example, event A with a likelihood of p(A) may occur in place 1 at time t_1 and with a likelihood of p(AB) will cause event B at place 2 and time t_2. The event may be '*increase of humidity of x%*' propagating with the direction of wind in a geographic area, or *'failure of resource X'* affecting subsequent operations in a factory.

In natural sciences, an event can be linked to geographic areas while in a business environment it is linked to areas of managerial responsibility. Although the domains materially differ, the concept of propagation applies to both and, besides laws of physics, is controlled by two arguments: The event risk and the impact of the event. And, as events in weather models may result in rain or sunshine, an unavailability of a resource may induce a downside (a production delay), or an upside if, e.g., the analysis of an unavailability or failure can help to pave the way for change of the process that reduces risk.

Based on such initial and rough deliberations, the computational scale of simulating interdependent risks organised by "cells" of managerial responsibility may be compared to the scale of a weather model with a similar number of geographic "cells". So MAS-goes-HPC approaches as taken here may also contribute to discussions in the HPC community about the needs for more autonomic software [27] to master an increasing complexity.

V. REPAST FOR HIGH PERFORMANCE COMPUTING

The combination of MAS principles and HPC platforms can be illustrated with the Repast HPC tool, which constitutes an example of an ABM system for massively distributed MAS solutions over large-scale distributed computing platforms.

The Recursive Porous Agent Simulation Toolkit (Repast) is one of several available ABMs toolkits, developed by the Argonne National Laboratory's Decision and Information Sciences Division. In spite of borrowing many concepts from the Swarm agent-based modelling toolkit [28], Repast differentiates from Swarm since Repast has multiple pure implementations in several languages and built-in adaptive features such as genetic algorithms and neural networks. Repast is a free open source toolkit, which supports the development of extremely flexible models of social agents, being possible to dynamically access and modify the agent's model properties at run time. Repast includes a fully concurrent discrete event scheduler that supports both sequential and parallel discrete event operations, offering an automated Monte Carlo simulation framework.

Repast for High Performance Computing (Repast HPC), is written using C++ and makes use of the Message Passing Interface (MPI) [29] for parallel operations through distributed memory computing. Repast HPC is based on the development principles of the Repast Simphony toolkit (e.g., the Context and Projections concepts), and extended with functionalities to support the distribution of the agent-based model working in a parallel distributed environment. As an ABM toolkit, Repast HPC offers a suite of features that specifically facilitate creating, executing and evaluating agent-based models, but also provides the following key features that support the parallelisation of the agent-based model [30]:

- Synchronisation scheduling of events.
- Global data collection (similar to Repast Simphony).
- Automatic management of agent interactions across Processes.

Repast HPC is designed for a parallel environment in which many processes, each one containing several agents), are running in parallel and memory is not shared across processes. Since Repast HPC simulations are distributed across multiple processes, cross-process communication and synchronisation of the simulation state are required. This is performed automatically by Repast HPC.

A Repast HPC simulation consists of [30]:

- A set of agents, each one implemented as objects, i.e., as C++ classes (the agents' state is represented by the attributes of the classes and the agents' behaviour represented by the methods in those classes).
- The Package type code, that are typically implemented as structures containing the minimal amount of agent state necessary to copy an agent from one process to another one.
- A model class, which is responsible to initialise the simulation, namely to create the SharedContext and populated it with agents, create projections and add them to the SharedContext, initialise data collection, schedule simulation actions and perform an initial synchronisation of agents and projections.
- A main function, which initialises the MPI and Repast HPC environments, creates the model class and triggers the Scheduler Runner.

After the development of the agent-based model, the model is ready to be simulated, requiring the configuration of the simulation, as well the code to make scalable some actions in the simulation. Note that in spite of Repast HPC does much of the parallel programming of an agent simulation, developers should provide details of how the simulation can be properly implemented to run in the parallel environment

Repast HPC was successfully tested for scalability on the Blue Gene/P computer of the Argonne National Laboratory's, which is a first signal of the framework maturity and reliability to run simulations in HPC environments. However, a long step is required to ensure the desired reliability and robustness of MAS parallelisation for critical large-scale applications.

Other aspect to be considered is the possibility to connect Repast HPC with other systems (e.g., legacy systems) into larger, heterogeneous application landscapes (e.g., for risk management spanning domains of engineering and business operations). In the literature, several connections to other systems, e.g., JADE platform that is widely used for the development of MAS solutions, are found. Since the API is written in C++, the connection to legacy systems could be simplified. Note that the Repast HPC version has two types of programming languages/environments: Logo-style C++ for less demanding applications and a C++ version for more complex ones.

VI. Conclusions and Future Work

This paper discusses the combination of MAS and HPC concepts aiming to overcome the demanding computational requirements of MAS platforms when they are applied to very large-scale systems. For this purpose, several scenarios that benefit from the usage of MAS solutions running over high end platforms were presented, as well the emerging challenges of such combination.

In particular, it was noticed the importance of using such approach in the simulation of data considering huge population sizes. For this purpose, the Repast HPC framework was analysed, which is an agent-based modelling and simulation tool for handling massively distributed MAS solutions running over large-scale distributed platforms.

Future work is devoted to the application of mechanisms to parallelise MAS solutions, and particularly Repast HPC, for large-scale systems involving complex problems.

Acknowledgments

This work is partially supported by the EU FP7 Programme, in the frame of the ARUM project, Grant Agreement No. 31405.

References

[1] J. Ferber, Multi-Agent Systems, An Introduction to Distributed Artificial Intelligence. Addison-Wesley, 1999.

[2] M. Wooldridge, An Introduction to Multi-Agent Systems. John Wiley & Sons, 2002.

[3] S. Russell and P. Norvig, Artificial Intelligence: A Modern Approach. Prentice Hall, 1995.

[4] “High-Performance Computing: Europe's place in a Global Race”, Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions, Brussels, 15 Feb., 2012.

[5] M. Luck, “50 Facts about Agent-based Computing” AgentLink III.

[6] F. Bellifemine, G. Caire, and D. Greenwood, Developing Multi-Agent Systems with JADE. Wiley, 2007.

[7] N. Gilbert and S. Bankes, “Platforms and Methods for Agent-based Modeling”, Proc. of the National Academy of Sciences of the USA, vol. 99, suppl. 3, 2002, pp. 7197-7198.

[8] S. F. Railsback, S. L. Lytinen, and S. K. Jackson, “Agent-Based Simulation Platforms: Review and Development Recommendations”, Simulation, 82(9), 2006, pp. 609-623.

[9] P. Leitão, J. Barbosa, and D. Trentesaux, “Bio-inspired Multi-Agent Systems for Re-configurable Manufacturing Systems”, Engineering Applications of Artificial Intelligence, 25(5), 2012, pp. 934-944.

[10] P. Wittek and X. Rubio-Campillo, “Scalable Agent-based Modelling with Cloud HPC Resources for Social Simulations”, Proc. of the 4th IEEE Intern. Conf. on Cloud Computing Technology and Science, 2012, pp. 355-362.

[11] A. Koestler, “The Ghost in the Machine”, Arkana Books, London, 1969.

[12] mOSIAC project, http://www.mosaic-cloud.eu [accessed: 2013-04-12].

[13] EnerGy project, http://www.projectenergy.eu/flash.html [accessed: 2013-04-12].

[14] C. Macal, M. North, G. Pieper, and C. Drugan, "Agent-Based Modeling and Simulation for Exascale Computing", SciDAC Review, Issue 8, 2008, pp. 34-41.

[15] N. Collier and M. North, “Repast HPC: A Platform for Large-scale Agent-based Modeling”, Large-Scale Computing Techniques for Complex System Simulations, W. Dubitzky, K. Kurowski, and B. Schott (eds.), Wiley, 2011, pp. 81-110.

[16] S. Chin et al., “FLAME-II: A Redesign of the Flexible Large-scale Agent-based Modelling Environment”, RAL Technical Reports, RAL-TR-2012-019, November 2012.

[17] L. Gulýas et al., “Tools for Large Scale (distributed) Agent-based Computational Experiments”, Proc. of Computational Social Science Society of America Annual Conf. (CSSSA’11).

[18] E. Blanchart et al., “EPIS: A Grid Platform to Ease and Optimize Multi-agent Simulators Running”, Advances on Practical Applications of Agents and Multiagent Systems Advances in Intelligent and Soft Computing, vol. 88, 2011, pp. 129-134.

[19] http://cordis.europa.eu/fp7/ict/ssai/ [accessed: 2013-03-14].

[20] http://www.cvisproject.org/ [accessed: 2013-03-14].

[21] J. M. Mendes, F. Restivo, A. W. Colombo, and P. Leitão, “Behaviour and Integration of Service-oriented Automation and Production Devices at the Shop-Floor”, International Journal of Computer Aided Engineering and Technology, vol. 3, n. 3/4, 2011, pp. 281-291.

[22] http://www.eurocontrol.int/sesar/public/standard_page/overview.html [accessed: 2013-03-14].

[23] P. Hermanns, “Organizational Hubris, the Rise and Fall of the Celebrity Firm CargoLifter AG”, PhD Thesis, Kölner Wissenschaftsverlag Albers, Peters & Reihlen GbR, 2012, accessible online: http://www.diss.fu-berlin.de/diss/receive/FUDISS_thesis_000000039985?lang=en [accessed: 2013-07-02].

[24] http://www.eads.com/eads/int/en/news/press.20121105_eads_arum.html [accessed: 2013-03-14].

[25] --, “Dreamliner Grounded Until At Least End Of May”, Sky News, 25th February, 2013, accessible online: http://news.sky.com/story/1056514/dreamliner-grounded-until-at-least-end-of-may [accessed: 2013-07-02].

[26] J. M. Kingsley, “Airbus Slows A380 Final Assembly Ramp-up”, Flight global, 14th May 2009, accessible online: www.flightglobal.com/news/articles/airbus-slows-a380-final-assembly-ramp-up-326416/ [accessed: 2013-02-25].

[27] C. J. Earl, D. Chirag, and S. Conway, “World wide Technical Computing 2013 - Top 10 Predictions”, Filing Information: February 2013, IDC #239421, vol. 1, accessible online: http://www.idc.com/getdoc.jsp?containerId=239421 [accessed 2013-04-18].

[28] G. Madey, V. Freeh, and R. Tynan, “Agent-based Modelling of Open Source using Swarm”, Proceedings of the 8th Americas Conference on Information Systems, 2002, pp. 1472-1475.

[29] W. Gropp, E. Lusk, and A. Skjellum, “Using MPI: Portable Parallel Programming with the Message-Passing Interface”, 2nd Edition, MIT Press, 2000.

[30] N. Collier, “Repast HPC Manual”, 6th February, 2012.

FETOL: A Divide-and-Conquer Based Approach for Resilient HPC Applications

Wassim Abu Abed, Kostyantyn Kucher,
and Manfred Krafczyk
Institute for Computational Modeling in Civil Engineering
Technische Universität Braunschweig
Brunswick, Germany
Emails: {abuabed, kucher, kraft}
@irmb.tu-bs.de

Markus Wittmann, Thomas Zeiser
and Gerhard Wellein
Erlangen Regional Computing Center
University of Erlangen-Nuremberg
Erlangen, Germany
Emails: {markus.wittmann, thomas.zeiser, gerhard.wellein}
@fau.de

***Abstract*—The inevitable increase of the frequency of hard and soft faults in current and future high performance computing systems motivates the need of integrated approaches to improve the resilience of such systems. In this paper, a framework for a fault tolerant environment termed FETOL implementing an approach to achieve a coordinated resilience solution is presented. FETOL is based on a software solution exploiting a Divide-and-Conquer strategy that will offer comprehensive methods on the middleware and application level to deal with various failure scenarios.**

***Keywords*—hpc; resilience; fault-tolerance; divide-and-conquer.**

I. INTRODUCTION

The increasing size and complexity of HPC (High Performance Computing) systems are two major factors that are leading to an inevitable increase of the frequency of hard and soft faults in present Peta-Flop and future Exa-Flop systems. Therefore, these HPC systems are prone to become less robust and the operating efficiency and reliability of such systems tend to deteriorate profoundly. New integrated approaches to improve the resilience of HPC systems are undoubtedly needed in order to maintain a reasonable operation of such systems. Recent literature surveys have shown that resilience cannot be efficiently realised by implementing fault tolerance mechanisms on the system level only [1]. Different application domains have different methodological requirements to achieve resilience of an HPC application. Hence, an integrated application oriented approach is mandatory.

In this paper, the concept of an application oriented framework for a fault tolerant environment termed FETOL is presented. FETOL is an abbreviation of the German translation "Fehler Toleranz" of "Fault Tolerance". FETOL is based on a software solution exploiting a Divide-and-Conquer strategy. In the next section, the background and motivation of the presented work are given. The main idea of FETOL with its central operation of breaking down the HPC application into subtasks and grouping them into individually restartable process bundles is explained in Section III. In Section IV, the system architecture and design are presented including the checkpointing and the fault tolerance mechanisms. In Section V, the proposed approach is discussed in the context of related work in the field. An evaluation of a new communication component developed as part of the proposed framework is presented in Section VI. In the last section a brief conclusion and an outlook are given.

II. BACKGROUND

Different MPI (Message Passing Interface) implementations are presently the most used parallel programming libraries in developing large-scale parallel applications. A parallel application in the context of MPI usually runs on a cluster of computing nodes in the form of different MPI processes. MPI processes are grouped together in a so-called MPI communicator that takes care of the explicit and unambiguous identification of messages and addresses respectively. Accordingly, the frequently needed communication for the purpose of exchanging data or synchronising pace among these processes is carried out via MPI library calls. In the case of a network failure or the breakdown of one of the computing nodes the state of an MPI communicator becomes undefined and the entire parallel application will come to a halt and terminate without any protective or recovery actions. This serious drawback of the current existing MPI implementations causes the interrupted parallel application to terminate irrecoverablly and thereby the entire MPI parallel application must manually be restarted from scratch or at least from the last checkpoint data.

III. THE APPROACH IN FETOL

The divide-and-conquer strategy followed in FETOL aims at implicitly overcoming the limitation in the MPI implementations that renders the parallel application irrecoverable by grouping the processes of a parallel application into more than one so-called PB (Process Bundle), see Figure 1. Each of these PBs will be executed on one or more computing nodes of the cluster. The processes within each PB communicate with each other via native MPI using a PB specific MPI communicator. An additional cross PBs communicator called BOND, see Section IV-B, will take care of the needed communication between the processes of two different PBs. This alternative communicator is based on TCP/IP and on a multi-agent architecture.

The execution of the parallel application is started by sequential or parallel initialisation of all PBs, where each PB is regarded as a separate MPI parallel application that uses a bundle specific MPI communicator. In this case, a hardware failure will only affect one of the PBs and accordingly only the respective MPI communicator will be in an undefined state. As a result, there will be no need to restart the execution of the entire parallel application and only the affected PB must be restarted. Moreover, restarting the defect PB from the very

 ISBN: 978-1-61208-310-0

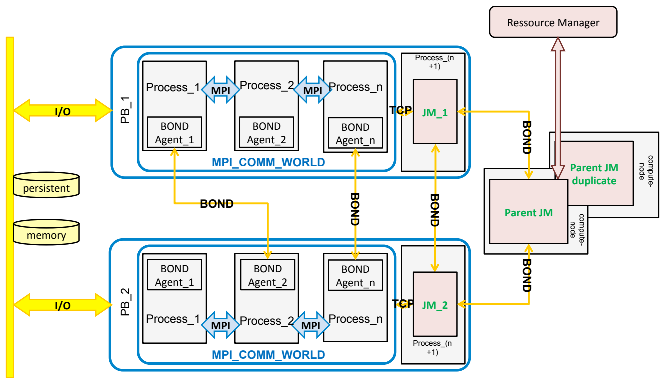


Figure 1. FETOL System architecture.

beginning can also be avoided in making use of the other PBs that are still running. The initialisation of the new PB can be done either from reconstructed data of the PBs that are still alive or from available check pointing data written by the lost PB before its crash. A coordinating middleware, called JM (Job Manager), is responsible for restoring and migrating any failed PB in cooperation with the resource manager that usually controls the computing nodes of the cluster.

IV. System Architecture and Design

Resilient high performance computing requires the collaboration between different software components. These components are: the resource manager with the associated hardware system monitoring tools, the communication libraries used to allow a parallel execution, the parallel application itself with its application level techniques of data persistency and the software monitoring and fault detection mechanisms. The collaboration between these components is managed in FETOL by introducing the JM middleware. Figure 1 schematically shows FETOL's system architecture. In the following sections the different components of this architecture will be described as well as the fault tolerance mechanism and the check-pointing approach adopted in FETOL.

A. *Job Manager*

The JM, as a coordinating middleware, has the task of bundling, orchestrating and extending the different functionalities of the other software components in FETOL. Different system and application information, which are delivered by the monitoring tools on the system level and the soft monitoring on the application level, will trigger the coordinated reactions of the Job Manager.

The JM should restore and migrate any failed PB. Restoring a PB includes managing and coordinating the process of retrieving application state data as well as remapping the cross PB communication channels between the restored processes and the still running processes of the other PBs. Application state data include the usual checkpointing data already stored on persistent storage or/and data sets that are reconstructed from the data of the still running processes, which are carrying computations on partitions of the application computational domain adjacent to that of the PB being restored. Migrating the restored PB to run on new hardware resources is being carried out in cooperation with the resource manager that is in control of the compute nodes of the cluster.

The system architecture shown in Figure 1 illustrates the implementation of the JM. The system JM consists of multiple software instances that run on different computing nodes. Each PB has its own JM software instance that is responsible for the specific PB. The different PB specific JM software instances are coordinated and managed by two identical central "Parent JM" software instances that operate in a synchronously parallel fashion on two different nodes of the cluster to increase the redundancy of the system. These two "Parent JM" instances assume the task of communicating with the resource manager and the responsibility of restoring any PB specific JM with failure. All software instances of the JM communicate and pass the needed information between each other using the BOND communication framework.

B. *BOND*

During the EU project COAST a software framework was developed to couple multiple individual software solvers in a flexible and distributed manner [2]. This framework allows distributed coupling according to agent oriented programming principles. Multi agent systems already proved their robustness and flexibility in other distributed systems [3][4].

With the acquired experiences in multi agent frameworks on HPC hardware, a successor framework coined BOND has been developed. This framework has been adapted to closely follow the programming paradigms known from MPI programmes, yet keep some of the benefits of multi agent platforms, such as robustness and scalability. The main use case of BOND is within the FETOL framework, where it serves as an alternative communication library to cover failures of MPI.

BOND is a C++ library with the corresponding API (programming interface). Bindings for Fortran and plain C are targeted for a later stage of the project. Within the C++ library, Java asynchronous socket communication is being used to deliver MPI style data buffers to a remote machine in a distributed HPC environment. BOND communication currently utilises the following primary communication calls: non-blocking send operation, blocking send operation and blocking receive operation.

On its way to the remote machine, the data is directly transferred to a user allocated target buffer, as it is common in MPI distributed HPC codes. The data buffer is never managed by the Java memory management, but always remains in native heap space. Due to this cautious data management, the Java garbage collector does not pose an overhead for data transfers, making communication speed via BOND comparable to that of MPI, see Section VI. Even high performance host channel adapters like Infiniband can be used effectively, bypassing most of the TCP/IP protocol overhead using the socket direct protocol.

C. *MPI Program*

The class of MPI programs considered in FETOL addresses primarily stencil based applications that are based on computational domain decomposition in the form of meshes to carry

ISBN: 978-1-61208-310-0

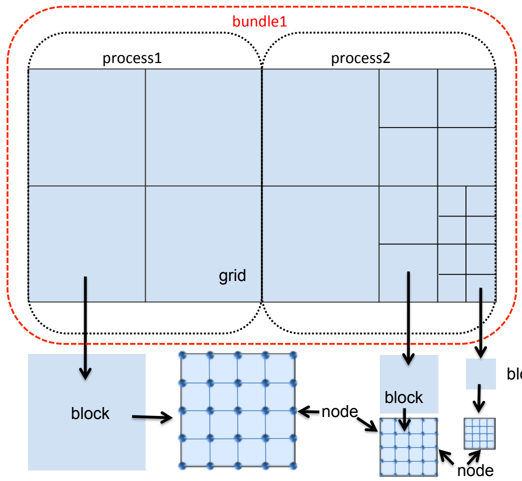


Figure 2. Data structure of the in-house LB solver and partitioning into bundles of processes.

on their calculations. LB (Lattice-Boltzmann) solvers can be regarded as an important example of this class of scientific applications. Our in-house Lattice-Boltzmann flow solver VirtualFluids [5] is an adaptive MPI based parallel application which is comprised of various cores. The software framework is based on object-oriented technology and uses tree-like data structures. The flow region is divided into discrete blocks on the basis of an Octa-tree. These discrete blocks contain the numerical sub-grids of the computational domain in the form of equally dimensioned matrices of nodes per block, see Figure 2. This structure has many advantages. The use of uniform girds in form of matrices within blocks allows the use of efficient algorithms and requires less computing resources since direct addressing is possible and the cache memory of CPU can be better utilised. Restricting the communication on the block-edges/-areas reduces the complexity of parallelisation. These data structures are also suitable for hierarchical parallelisation using a combination of PThreads and MPI and dynamic load balancing.

D. Check-Pointing Approach

Data persistency approaches in the field of fault-tolerant HPC applications can be divided into Message-logging and Check-pointing approaches. For the class of the scientific applications considered in FETOL, the approach of message-logging is not practical. Usually scientific applications of this class exchange too much data. In the case of recovery the live processes would have to wait too long until the recovered process computes the current actual consistent state and thus, the overall efficiency of the resilience mechanism would deteriorate unacceptably.

In FETOL, an application-level checkpointing approach is adopted and implemented in the framework of the in-house LB solver. In contrast to the widely used system-level checkpointing, where the system stores the complete state of the application independently, different mechanisms of data reduction can be implemented minimising the volume of stored data per checkpoint.

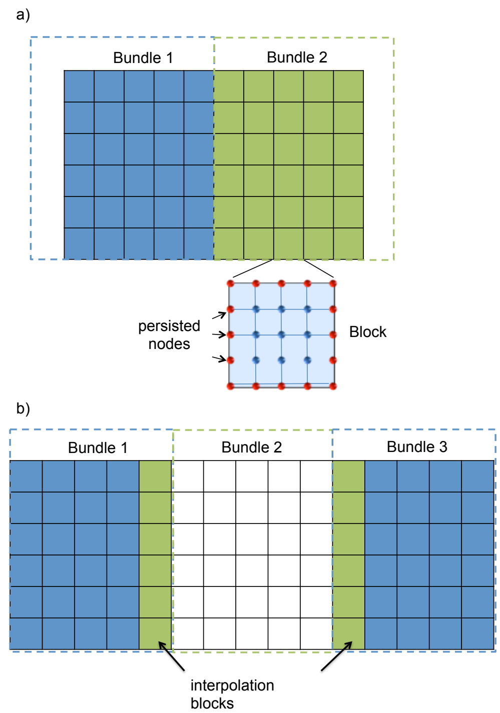


Figure 3. Data persistency (a) the boundary nodes of all blocks are stored. (b) recovery depending on neighbouring bundles

The individual steps of the periodical checkpointing procedure in VirtualFluids and a mechanism to deal with data consistency are given in the following: (1) The application periodically serialises and stores the state data of the corresponding blocks of the grid of each MPI process in the file system. (2) After saving each process state data the process internally sets a checkpoint counter variable. (3) This action is then synchronised by a root process that sets a global environment variable, that indicates the last successful checkpointing, at which the state of the application is consistent.

Two different mechanisms of data recovery after failure are implemented in VirtualFluids. The first one is based on a data reduction strategy that minimises the volume of the stored data per checkpoint. When checkpointing the simulation data of a process, only the information in the boundary nodes of each block is saved, see Figure 3 (a). The rest of the omitted information are then interpolated for the internal nodes of each block during the data recovery procedure. The second recovery mechanism is applied when no checkpointing data for a whole bundle can be retrieved at all. The missing data are then approximated from the data of the still running processes, which are carrying computations on partitions of the application computational domain adjacent to that of the bundle being restored, see Figure 3 (b).

E. Fault Tolerance Mechanism

After specifying the needed resources and the executable binary of the Parallel Application by the user the execution of the JM is started on the Cluster. The Resource Manager assigns the needed resources, which were specified by the User, plus additional so-called recovery resources to the JM. The JM

ISBN: 978-1-61208-310-0

starts the execution of the Parallel Application on the Cluster. The JM listens permanently to and analyses the information delivered by the Hardware and Software Monitors. The JM terminates when the Parallel Application successfully ends.

The occurrence of hardware faults will prevent the successful execution of the Parallel Application, which will result in two different scenarios. The first scenario happens when the JM identifies - according to the analysis of the information received from the Hardware and Software Monitors - any running vulnerable process that might put the execution of the Parallel Application at risk. In this case the JM initiates an active fault-tolerance action by stopping and then restoring the execution of the process bundle containing the vulnerable process on new resources and the execution of the Parallel Application continues.

The second scenario can occur, if the Hardware and/or Software Monitors are totally absent as software components or fail to report a failure. In this case the Parallel Application might fail to continue its execution unnoticed by the JM. For this reason, the BOND framework, which is imbedded in the Parallel Application, will support a passive fault-tolerance action of the JM and takes the responsibility of reporting any failed process bundle to the JM. The JM then restores the failed process bundle and the execution of the Parallel Application continues.

The step of restoring a process bundle requires the retrieval of the process state data for each process of the process bundle being restored from the Storage System. Here the Parallel Application retrieves the process state data stored in form of checkpointing data from the Storage System or approximates a set of process state data, using the still running processes' data, i.e, the corresponding ”neighbouring” PBs.

The JM then remaps the communication channels between the processes being restored and those still running. At the end the JM migrates and starts the restored process bundle on new nodes of the Cluster using its extra recovery resources. If the extra recovery resources of the JM are exhausted, the JM demands new recovery resources from the Resource Manager. The latter assigns then the demanded resources and the migration of the process bundle can be successfully accomplished.

V. Related Work

Different approaches that address the problem mentioned in Section II have recently been proposed and implemented. These approaches can be grouped into the two categories: MPI based and non MPI based approaches.

MPI based approaches [6][7][8]: In [6] a ULFM (User Level Failure Mitigation) approach is presented, where a set of five new interfaces are added to the MPI implementation. In contrast to [6], in this paper, no extension of the MPI standard or implementation is suggested. Hence, protective actions are located entirely outside the MPI implementation and the use of arbitrary MPI implementations is possible. The recovery processes is driven by three components (the Job Manager, the additional communication framework BOND and the parallel application). Only the MPI communicator of a group of processes Bundle is replaced by restarting a new mpirun instance that spawns replacement processes within a new MPI communicator. The MPI communication performance is essentially maintained inside each bundle.

The approach in [7] aims at enabling MPI implementations to support Algorithm-based Fault Tolerant techniques, see also [11]. It avoids any periodic checkpointing by storing the application state only after a failure is detected. The MPI runtime is augmented with a failure detection service and the MPI implementation is modified. In FETOL, instead of relaunching the entire MPI application, only the Process Bundle, which is a subset of the parallel application, is relaunched. The Checkpoint-on-failure approach in [7] can be integrated bundle-wise in FETOL to support an ABFT (Algorithm-Based Fault Tolerant) like technique used to recover data from checkpoints.

The fault tolerance mechanism of the Job Pause Service in [8] is implemented within LAM/MPI using the BLCR [9] as a checkpointing library. The fault tolerance mechanism allows live processes to remain active after a notification of a process failure. The live processes will roll back to the last checkpoint and retain the internal communication links. Failed processes are dynamically replaced by new ones on spare nodes before resuming from the last checkpoint.

The fault tolerance mechanism in [8] resembles the one proposed in this paper to a fair extent. For example, the Job Manager can be compared to the Scheduler daemon. BOND can be compared to the scalable communication infrastructure used to notify the active nodes about the replacement nodes and reconfigure the communication infrastructure. However, the following differences are significant: the fault tolerance mechanism in FETOL has the scope of bundles of processes as opposed to a single process; No modification to the MPI implementation is necessary; Checkpointing is carried out on the application level avoiding the lack of flexibility of the system level checkpointing.

Non MPI based approaches [10]: In [10] an object-oriented parallel programming library for C++ called Charm++ is presented. It differs from traditional message passing programming libraries (such as MPI) in that Charm++ is message-driven. Furthermore, it provides a methodology and a virtualisation infrastructure in which the programmer decomposes the data and computation in the program without worrying about the number of physical processors on which the program will run. The runtime system is in charge of distributing those objects among the processors.

FETOL does not offer the sophistication of Charm++ [10] and keeps the fault tolerance mechanism as simple as possible reducing the complexity of the implementation and the usage. Therefore, the user application can still rely on its favourite MPI implementation. In addition, the asynchronous communication framework BOND provides an automatic overlap of communication with computation, which facilitates the fault-tolerance mechanism in FETOL.

In the following, two categories of data recovery approaches that are tangential to the approach followed in this paper are also identified and briefly summarised.

Algorithm-based fault-tolerance [11][12]: The most significant and relevant aspect of ABFT techniques [11] is that

 ISBN: 978-1-61208-310-0

failures can be tolerated without checkpointing or message logging. Per definition as found in the literature, for example in [7], an ABFT uses mathematical and algorithmic properties to reconstruct failure-damaged data and to complete operations despite failures. The Algorithm-Based Checkpoint-Free Fault Tolerance Technique in [12] extends the ABFT idea to recover applications from failures, in which the failed process stops working and the data are totally lost.

In FETOL, a data recovery strategy similar to ABFT is adopted in that mathematical interpolations are used in two ways: first, in recovering reduced checkpointing data, second, in recovering and restoring missing data from living processes. Moreover, the assumptions about the capabilities of the runtime environment mentioned in [12] are guaranteed by FETOL.

Checkpointing and message-logging [13][14]: The partial message logging protocol proposed in [13] is based on process clustering and a hierarchical rollback-recovery protocol that applies different protocols for the communications inside a cluster of processes and for the communications among the cluster. The group-based Checkpoint/Restart solution in [14] combines coordinated checkpointing and message logging. In FETOL, message logging is totally avoided, since the properties of the scientific parallel application considered in FETOL make the use of message logging disadvantageous in terms of storage size and time overhead of recovery. One more distinction between FETOL and [14] is that the parallel application is responsible for receiving checkpoint requests and writing and reading checkpoints, instead of modifying mpirun. One similarity to the hierarchal rollback-recovery protocols mentioned in [13] that should be stated is the division of processes in groups called Bundles and the application of different communication protocols inside and among the different bundles. Therefore, FETOL can be regarded as a hierarchical rollback-recovery protocol.

VI. Evaluation

The low-level ping-pong benchmark was used to evaluate the bandwidth performance of BOND in comparison to Intel MPI, for given different message sizes, see Figure 4. The different tests were conducted on a cluster based on two-socket compute nodes equipped with 16-core AMD Opteron 6134 Magny Cours processors. The cluster is also equipped with a GE (Gigabit Ethernet), which can achieve around 125 MB/s, as well as with a fully non-blocking IB (QDR-InfiniBand) network with a bandwidth of ca. 3 GB/s. An implementation of the ping-pong benchmark using BOND was compared to the one included in the Intel MPI benchmarks [15] compiled with Intel MPI. The different tests have shown the following results, see Figure 4. Over GE both implementations can sustain nearly the full bandwidth. Moreover, both implementations show the same quantitative bandwidth when using IPoIB (IP protocol over the IB interconnect), however Intel MPI achieves a slightly higher bandwidth for messages smaller than 64 kB and BOND for messages larger than that. The usage of SDP (the Sockets Direct Protocol), which provides the advantages of RDMA transfers from IB to IP connections, only brings a benefit for Intel MPI. BOND stays nearly on the same bandwidth level in a similar way as in the IPoIB test version. Interestingly, the bandwidth for BOND drops below 1 MB/s when message sizes fall in the interval between 16 kB and 128 kB. It is suspected that the unchanged performance of BOND with SDP and the bandwidth drop could be due to implementation details of the Java SDP interface.

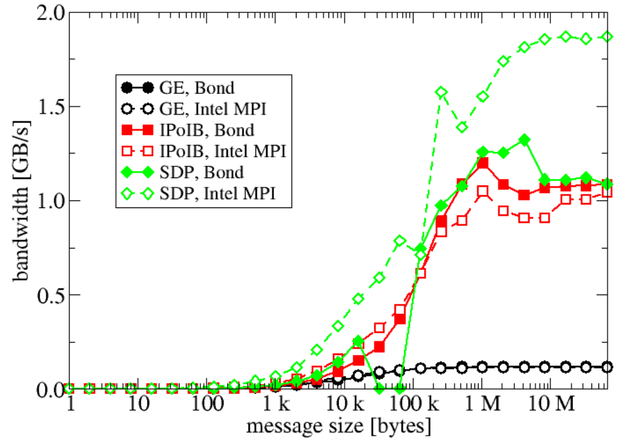


Figure 4. Performance evaluation - BOND in comparison to Intel MPI

VII. Conclusion

The full implementation of the divide-and-conquer strategy for a coordinated resilience of an HPC application presented in this paper is still under development. A "proof-of-concept" implementation is presently developed and first benchmarking tests of the new communication component BOND were presented in this paper. The presented results show that there are no substantial side effects of using BOND beside MPI. On the contrary, BOND might even outperform MPI in some cases. The implementation and test of a procedure for passive fault-tolerance is being addressed at the time of this writing. For the passive fault tolerance the BOND framework is exploited as a pseudo-monitoring tool that captures and reports any error collectively and indifferently as a failure of a process bundle. Addressing different categories of faults will then be handled in the context of implementing an active fault-tolerance approach that utilises a hardware monitoring tool on the system level and some software monitoring mechanism on the parallel application level. A fundamental problem that still has to be addressed for implementing an efficient active fault-tolerance is the definition and test of quality metrics that quantify and indicate the vulnerability of a process bundle. The identification of system parameter thresholds that indicate when the vulnerability of a PB is critical is a trade-off between the increased risk of complete failure, in case no intervention was undertaken, and the overhead incurred by a fault prevention measure, in which the execution of a still running PB, but yet considered as vulnerable, is stopped and restarted as a precaution.

Acknowledgement

The authors would like to thank the German Federal Ministry of Education and Research - BMBF for supporting this work (Grant Number 01 IH11011).

REFERENCES

[1] J. Daly (eds.), Inter-Agency Wrokshop on HPC Reilience at Extreme Scale, National Security Agency Advanced Computing Systems, Februrary 2012.

[2] Institute for Computational Modeling in Civil Engineering - Technische Universität Braunschweig, https://www.irmb.bau.tu-bs.de/muscle/, retrieved: Sep. 10. 2013.

[3] E. Cortese, F. Quarta and G. Vitaglione, "Scalability and Performance of JADE Message Transport System," AAMAS Workshop, Bologna, 2002.

[4] A. Helsinger, M. Thome and T. Wright, "Cougaar: a scalable, distributed multi-agent architecture," Proceedings of the IEEE International Conference on Systems, Man and Cybernetics 2004, 2, IEEE, 2004, pp. 1910–1917.

[5] M. Schönherr, K. Kucher, M. Geier, M. Stiebler, S. Freudiger and M. Krafczyk, "Multi-thread implementations of the lattice Boltzmann method on non-uniform grids for CPUs and GPUs," Int. J. Comp. Math. App. 61, 2011, pp. 3730–3743.

[6] W. Bland, A. Bouteiller, T. Herault, J. Hursey, G. Bosilca and J. Dongarra, "An Evaluation of User-Level Failure Mitigation Support in MPI," Proceedings of Recent Advances in Message Passing Interface 19th European MPI Users Group Meeting, EuroMPI 2012. Springer, Vienna, Austria, Sep. 2012, pp. 193–203.

[7] W. Bland, P. Du, A. Bouteiller, T. Herault, G. Bosilca and J. Dongarra, "A Checkpoint-on-Failure Protocol for Algorithm-Based Recovery in Standard MPI,"Kaklamanis et al. (eds.) Euro-Par 2012, LNCS, vol. 7484, Springer-Verlag, Berlin Heidelberg, 2012, pp. 477–488.

[8] C. Wang, F. Mueller, C. Engelmann and S. L. Scott, "A Job Pause Service under LAM/MPI+BLCR for Transparent Fault Tolerance," International Parallel and Distributed Processing Symposium, IPDPS 2007, IEEE International 2007, pp. 26–30.

[9] Berkeley Lab, http://crd.lbl.gov/groups-depts/ftg/projects/current-projects/BLCR, retrieved: Sep. 13. 2013.

[10] Parallel Programming Laboratory - University of Illinois at Urbana-Champaign, http://charm.cs.uiuc.edu/research/charm/, retrieved: Sep. 10. 2013.

[11] K. Huang and J.A. Abraham, "Algorithm-Based Fault Tolerance for Matrix Operations," IEEE Transactions on Computers, Vol. c-33, No. 6, 1984, pp.518–528.

[12] Z. Chen and J. Dongarra, "Algorithm-Based Fault Tolerance for Fail-Stop Failures," IEEE Transactions on Parallel And Distributed Systems, Vol. 19, No. 12, 2008, pp. 1628–1641.

[13] T. Ropars, A. Guermouche, B. Uar, E. Meneses, L.V. Kal and F. Cappello, "On the Use of Cluster-Based Partial Message Logging to Improve Fault Tolerance for MPI HPC Applications," In Jeannot, E. , Namyst, R., Roman J. (eds.) Euro-Par 2011, LNCS 6852, Part I, Springer, Heidelberg 2011, pp. 567–578.

[14] J. C. Y. Ho, C. Wang and F. C. M. Lau, "Scalable Group-based Checkpoint/Restart for Large-Scale Message-passing Systems." IEEE International Symposium on Parallel and Distributed Processing, IEEE, 2008, pp.1–12.

[15] Intel Corp, Intel MPI benchmarks, http://software.intel.com/en-us/articles/intel-mpi-benchmarks, retrieved: Sep. 12. 2013.

Rapid Prototyping of a Croatian Large Vocabulary Continuous Speech Recognition System

Dario Bajo, Danijel Turković, and Šandor Dembitz
University of Zagreb, Faculty of Electrical Engineering and Computing (FER)
e-mail: {dario.bajo, danijel.turkovic, sandor.dembitz}@fer.hr

***Abstract*—The Croatian language, like many minority languages used by less than 0.1% of the world population, is in need of mature automatic speech recognition (ASR) systems for applications such as transcription of speech recordings, voice control, an aid to impaired people, etc. This paper describes a short-term research and development project aimed to produce an applicable Croatian large vocabulary continuous speech recognition system from scratch. The open-source CMU Sphinx toolkit was our platform choice. For the purpose of acoustic model training, we made a speech training set of several hundred utterances, containing words carefully chosen according to their phonetic properties. Language models were derived from the Croatian large-scale n-gram system, which ensures the system's applicability. During the project, we succeeded in developing an ASR system able to recognize freely chosen utterances composed of 15,000 most frequently used Croatian words reasonably well.**

Keywords-automatic speech recognition; continuous speech; large-scale n-gram model; large vocabulary.

I. INTRODUCTION

The first research and development attempting to produce an applicable ASR system for the Croatian language was done at Carnegie Mellon University (CMU), Pittsburgh, PA, USA, motivated by the needs of the USA Army personnel located in the Balkans in that time [1]. Since the USA Army's priorities changed drastically after September 11, 2001, the project ended without delivering intended field system. After that, some attempts were made in Croatia too, but they did not result in publicly available ASR systems yet.

Non-existence of Croatian large vocabulary continuous speech recognition (LVCSR) systems was the main impulse for our research. In this paper, we examine the current state of Croatian ASR systems, shortly explain the most important theoretical concepts and techniques used in ASR and present our own implementation of Croatian ASR using CMU Sphinx, a state-of-the-art speech recognition toolkit created by one of the leading language technology laboratories in the world [2]. Our system is designed to recognize 15,000 most frequent Croatian words, or at least 75% of Croatian word usage, using the Sphinx4 speech recognition library.

An overview of the process of building such a system will be given with detailed examination of the parts which were most interesting during the research.

A. Related work

In [3], a Croatian ASR system is realized using the Sphinx3 speech recognition library. It was tested on many speakers and utterances. The vocabulary consisted of only 40 words, which resulted in very effective recognition. The English phonetic transcription was used to build a Croatian pronouncing dictionary in order to provide a recognition system exclusively for the Croatian language.

In [4], an acoustic model for Croatian LVCSR system, with vocabulary size of 14,551 words, was created using Croatian speech database of weather forecasts (VEPRAD), as well as read tales and spontaneous speech. A statistical bigram language model was used, which was derived from the training utterances. Their system was based upon the HTK speech recognition toolkit [5], which differs in many details from CMU Sphinx, and they report achieving word error rate (WER) below 5% for a test set which consisted only of weather related utterances from their training set.

In [6], Slovak ASR system is implemented using the Sphinx4 library for digits and application words recognition in GSM networks. The MOBILDAT-SK database for the Slovak language was used. The WER results were fairly low (below 10%). The context-dependent system gave slightly better results.

In [7], a task-oriented continuous speech recognition system for the Polish language is implemented as a voice interface for a computer game *Rally Navigator*, using the Sphinx4 library. They have managed to achieve sentence recognition accuracy of 97.6%.

Very successful ASR systems exist for English, even with unconstrained vocabularies. The Whisper system described in [8] is given as an example.

B. Organization of the paper

In Section II, some theoretical concepts are given, which are needed to understand the basics of acoustic and language modeling.

Section III presents the methods used to build our ASR system. First, in subsection A, the pronouncing dictionary creation is mentioned. In subsection B, all the required steps one would have to take to build an acoustic model in CMU Sphinx are described. In subsection C, a detailed overview of the development of our acoustic model is given. Subsection D demonstrates our approach to language modeling. In subsection E, we explain our ideas for further improvements of our language model. The development described in Section III lasted from October 2012 until March 2013.

In Section IV, we discuss our speech recognition results and present independent WER measurements that confirm them.

In Section V, we demonstrate further developments of large-scale language models for Croatian ASR purposes and discuss the feasibility of extending the vocabulary size in order to achieve larger word usage coverage.

Finally, in Section VI, we conclude the paper with a summary of our results and a thought about the possible use of our research in future projects aiming to create Croatian LVCSR systems.

II. THEORETICAL FOUNDATIONS

In order to understand how a speech recognition system works, one has to know the underlying concepts behind modeling two key parts of every ASR system: the acoustic model and the language model.

A. *Acoustic Modeling*

One of the main problems of this method is the adjustment of speech signal for processing and analysis of basic speech units - phonemes [8]. For effective phoneme detection, the main information carriers have to be extracted from a speech signal (features). Such carriers are mel-frequency cepstral coefficients [9]. For successful further processing, it is crucial for samples to be accurate (recognizable in different contexts), trainable (feasible parameter estimation), and generalizable (new words composition) [8].

A word, as a basic processing form and meaningful speech unit, is certainly one of the most important information carriers, but its recognition is very difficult since a language contains many words, including different word forms in highly inflected languages like Croatian. In the testing phase, it can lead to many obstacles (non-generalizable samples) and the results of the phonetic analysis may be inaccurate. Syllables, however, are inadequate as a training set, especially for the Indo-European languages [10].

A compromise is achieved by suing a specific array of three phonemes - triphone, which describes a clear pronunciation of the central phoneme - allophone (neighboring dependency). One of the biggest allophone and phoneme advantages in relation to the other units is parameter sharing. This significantly reduces computing time for parameter estimation, i.e., the parameters for allophones and phonemes can easily be estimated from acoustic parameters of a known training set.

Allophones may also differ by intonation (position in sentence) and degree of stress (vowels at higher dose of stress last longer, have higher pitch, and are more intense). Many similar phonemes (labials, velars) are grouped into corresponding classes (clusters) consisting of senones.

A senone is a specific phonetic subunit which describes the type of allophone. Their amount depends on the learning corpus, which highly influenced the construction of our final training set described in III.C. Decision trees contain senones and searching is enabled by many binary conditions as internal nodes.

Hidden Markov models (HMMs) are used for modeling segmented allophones from a language learning corpus [11]. HMM consists of states, transitions, and distributions. It represents the realization of a complex discrete finite state machine in which every next state depends only on the previous state. The state probability is computed as a product of initial state probabilities and transition conditional probabilities. As mentioned in [8], there are two characteristic assumptions employed in HMM studies - Markov's and event independence.

The HMM modeling and processing is decomposed into three problems: evaluation, decoding, and training [8]. The evaluation problem is subdued to the calculation of state posterior probability using Bayes' formula [12] and state output probabilities.

The decoding process results in the most probable set of states (deterministic states), where HMM becomes an ordinary Markov model. The most probable state sequence path and decoding is implemented by the Viterbi algorithm [13] and applied to the process.

The learning process is conducted several times during the construction of the acoustic model. The main goal is to estimate the model parameters using the Baum-Welch (forward-backward) algorithm, while HMMs can be implemented as continuous, semi-continuous or discrete [14].

Acoustic modeling is used to compute acoustic parameters by using loaded utterances and phonetic rules. Previously obtained feature vectors, along with the speech phonetic transcriptions and monophone labels, are used to train the parameters of newly created monophone HMMs. After monophone HMM is formed, the automatic segmentation process is applied. Monophones are aligned to the recorded speech sequence, and then trained with the Baum-Welch algorithm by incrementing Gaussian density mixtures [4][8].

After the training process, the triphone structures are built using estimated parameters and generated triphone labels. The senones [4][15] are classified using decision trees. After the state reduction, triphone HMMs are ready for merging into bigger units such as subwords and words. The phonetic dictionary and HMM-formatted phonetic transcriptions are employed to achieve merging.

Furthermore, the Baum-Welch training algorithm is applied once more including some slight modifications (insertion, replacement or deletion of allophones-triphones) in order to achieve correct utterance transcription. Triphones obtained by above-mentioned method represent acoustic modeling output and together with the n-gram language model form a system for speech recognition.

B. *Language Modeling*

The concept of language modeling is closely associated with word searching space reduction during the construction of sentences. The reduction degree depends on learning corpus size, number of phonetic transcriptions, dictionary size, and degree of the implemented grammatical model. In this project, we used statistical language modeling based on the Croatian large-scale n-gram system [16].

Value n denotes the number of words in a particular structure, i.e., for n=3, the likelihood of the 3^{rd} word will be computed on a basis of two words appearing before, according to the Bayes' formula [12].

In the case of word construction beyond the learning set, n-gram in utterance is marked with a minimal amount of probability. This method is also known as n-gram smoothing. It is executed by adjusting the maximum likelihood estimation [17] probabilities to obtain higher robustness.

III. Applied Procedure

The CMU Sphinx toolkit is based upon three main components: pronouncing dictionary, acoustic model, and language model. Pronouncing dictionary maps written word form into its pronunciation according to the predefined set of phonemes.

Acoustic model needs to be trained from pairs of spoken utterances and their transcriptions. After the previous step has been completed, the trained acoustic model with already prepared language model can be used in speech recognition of test utterances or live continuous speech.

A. Building the Pronouncing Dictionary

Because of Croatian phonemic orthography, when only words strictly obeying the orthography are considered, as this was in our case, the pronouncing dictionary creation is a straight mapping of written words into CMU Sphinx dictionary format.

B. Building the Acoustic Model

Necessary files needed to train an acoustic model are: phonetic dictionary, phoneme list, filler list, list of training audio files' IDs, and transcriptions of training audio files.

Phonetic dictionary must consist of all the words that occur in the training utterances with corresponding phonemes from which their spoken analogue is made of; phoneme list contains all the phonemes that occur in the spoken utterances; filler list is a file which consists of all the non-spoken sounds, such as the breathing sound, pause, etc.

List of training audio files' IDs consists of file names of all the training data that were used during the procedure of acoustic model training, while the transcriptions of training audio files contain all the utterances in their written form that correspond to the IDs of recordings mentioned earlier.

All the audio recordings were taken in MS WAV format with the sample rate of 16 kHz, 16 bit, mono. The lengths of recordings range from just a couple of seconds up to 30 seconds.

C. Developing the Acoustic Model

At the beginning of this project, we constrained ourselves to the subset of words which only covered letters of Croatian alphabet and digits from zero to nine. That system was tested and proved our suspicions that in this case the phoneme-based recognition system could not function properly because it did not have enough context to rely on.

The only result worth mentioning is the recognition of digits because those words consist of more phonemes and the system coped with them with ease.

After that stage, we moved to the domain of continuously spoken words by using a small training set of 270 short utterances, composed of 1,010 words. Initially, we constrained our recognition system to recognize just the words which have been already seen through the acoustic training process, although not necessarily in the same context as before.

After initial success, we decided to make a system able to recognize 15,000 most frequent words in the Croatian language, regardless of the amount of different recorded words in the training utterances.

In our new training set, there was a total of 657 utterances, built up of 4,145 different words, which were recorded by 15 non-professional speakers, 4 female and 11 male students. They produced 16-hour-long speech database for acoustic modeling. The utterance construction was governed by the idea of covering as many Croatian phoneme combinations and acoustic transitions as possible within a small sentence sample.

The recordings were not made in acoustically perfect conditions. On the contrary, the recordings were made in an environment which was likely to have noise and (at the time) we thought that it could ultimately make our ASR system more robust in a real-world situation.

After all prerequisite files are in place, the acoustic model training can begin. Important thing to notice is that many parameters of the procedure of acoustic model training can be changed from predefined values, but the parameters with the highest impact on the accuracy of the recognition itself are the number of Gaussian mixtures and the number of senones. The influence of these choices on the recognition accuracy is presented in Section IV.

D. Generating the Language Model

After the acoustic model has been trained, in order to use the recognition system, the language model must be generated. There are certainly many ways to do so, from web crawling to manually creating a set of possible word combinations which may occur in a speech that will be recognized.

Our approach was to use already existing corpus of unigrams, bigrams, and trigrams, which was obtained through Hascheck, Croatian academic spellchecking web service [16][18]. Out of all the words found in Hascheck's large-scale n-gram database, we selected only the 15,000 most frequent words that cover over 75% of the Croatian word usage and added 396 words which appear in our training set because of phonetic reasons.

The complete vocabulary was used to extract all the bigrams and trigrams in which only those words occur. Because of immense initial numbers, only n-grams with frequencies ≥ 10 were selected (10^+ n-grams in Table I).

TABLE I. Basis for language modeling.

all unigrams	all bigrams	all trigrams	10^+ bigrams	10^+ trigrams
15,396	≈14e+6	≈64e+6	2,955,551	5,214,340

After the selection was made, only the trigrams (without their frequencies) have been passed on to the CMU language modeling toolkit (CMU LMTK), along with the transcriptions of all the recorded utterances.

This approach yielded good results, but since the frequencies of trigrams from Hascheck's database were completely ignored and all the trigrams were treated as equally likely, couple of problems emerged, one of which was a problem with the recognition of the starting word in testing utterances, being particularly troublesome for our system. This is not surprising since at the beginning of an utterance there is no context to rely on and every word had equal probability of being recognized as the correctly spoken starting word.

E. *Improving the Language Model*

Because of the problem mentioned above, it was necessary to address this problem by pondering trigrams in order to preserve some information about the frequency of each individual trigram. After initial testing, it was discovered that additional pondering could be useful.

Therefore, we also decided to ponder unigrams, hoping to improve our recognition results achieved so far. The ponderings of trigrams and subsequently unigrams were made roughly on logarithm scale according to their original frequencies. This choice, motivated by the data minimization needs, proved to yield much better results, both in recognition accuracy and utterance decoding response time.

IV. RESULTS

The speech database was divided into the training set (roughly 80% of the total number of recorded utterances) and the testing set (the rest of the recordings) by random partitioning of each speaker's recordings into two groups (training and testing subset) in the same ratio.

Four systems with different language models were tested: trigram model (not pondered) extracted from the 15,000 most frequent words in the Croatian language, trigram model extracted from recorded utterances, pondered unigram and trigram model extracted from the 15,000 most frequent words, and pondered unigram and trigram model extracted from the 15,000 most frequent words merged with the trigram model found in recorded utterances. Pondered n-grams were repeated in sentence style as many times as needed, i.e., according to their pondered frequencies, in order to satisfy CMU LMTK requirements.

Unsurprisingly, the best language model for the testing set described above was the one consisting only of the trigrams which were extracted from the recorded utterances. This model outperformed all the other models, which is expected because the model was biased by the word combinations found in recorded utterances, but its vocabulary would be too specific for arbitrary speech.

Recognition results are presented at Fig. 1 by corresponding values of word error rate (WER), the ratio between the number of inserted, deleted, and substituted words in test utterances, and sentence error rate (SER), the ratio of utterances in which at least one word was incorrectly recognized.

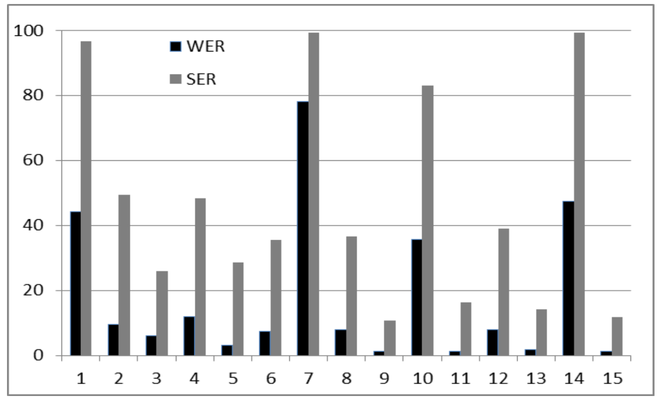


Figure 1. Speaker-dependent recognition results for the first testing set.

Presented results are achieved using large values of parameters for word combinations search and the computation needed to produce these results cannot be done in real-time (the speed of decoding an audio file was about 3xRT). We tried to use smaller values for those parameters and managed to get a system which can operate in real-time (the speed of decoding an audio file was roughly 1xRT), but the achieved WER results were fairly poor (about 65%).

The acoustic model generation for our final acoustic model lasted about 10 hours, while it took roughly an hour to create our biggest language model.

The whole computation/decoding were done in a virtual machine running Ubuntu 10.04 using VMware Workstation on a laptop with 4 GB RAM and 2.4 GHz processor.

Considering all 15 speakers in the first testing set, we obtained an average WER equal to 23.8%, and an average SER equal to 45.9%. The average results are heavily influenced by the utterances produced by speakers 1, 7, 10, and 14, whose recordings were done in extremely noisy conditions. Without them, the average WER would be 4.5%, and the average SER would be 28.6%. These recognition results are comparable to those presented in [4]. The measurements were performed with the number of Gaussian mixtures set to 8 and the number of senones set to 150 (default values).

Among other language models the last one, composed of pondered unigrams and trigrams containing 15,000 most frequent Croatian words and the utterances from the training set, has demonstrated to be the most accurate. Logarithmic pondering of n-grams and their conversion in sentences according to the pondered frequencies proved that our approach to language modeling through Hascheck's n-gram database was an appropriate choice for rapid LVCSR system prototyping.

Further testing was done by changing the number of Gaussian mixtures as well as the number of senones. The second test set was now built of 131 utterances freely composed of words from the dictionary, pronounced by a speaker whose voice is represented in the training set. The recognition results are presented in Table II.

Since the number of Gaussian mixtures can only be a power of 2, we tested powers of 2 between 8 and 64, while the number of senones remained at 150, except in one test scenario, when the tested value was 3000 (which was estimated by the CMU Sphinx toolkit as the best choice for our amount of training data).

The best result achieved for the number of Gaussian mixtures set to 8 and the number of senones set to 3000 is a consequence of the voice known to the system. For unknown voices, the best combination, according to our experience, is 32 Gaussian mixtures and 150 senones.

TABLE II. IMPACT OF THE KEY PARAMETERS ON THE RESULTS.

Combinations of the key parameters	**WER**	**SER**
8 Gaussian mixtures, 150 senones	28.4%	68.7%
16 Gaussian mixtures, 150 senones	24.4%	63.4%
32 Gaussian mixtures, 150 senones	21.8%	59.5%
64 Gaussian mixtures, 150 senones	19.7%	56.5%
8 Gaussian mixtures, 3000 senones	15.0%	49.6%

These results were confirmed by independent measurements performed according to the CMU Sphinx performance regression tests adapted to the Croatian language [19]. The main results are the following:

- Testing with known utterances from the training set gave WER of 7.83%;
- Testing with known utterances spoken by a speaker who was not in the training set gave WER of 10.82%;
- Testing with unknown utterances composed of words that are covered by our phonetic dictionary and spoken by a speaker who was not in the training set gave WER of 24.81%.

Unstressed monosyllabic words demonstrated to be the most problematic for correct recognition. For example, the Croatian number 5, whose pronunciation is “pet”, very similar to the pronunciation of the identically written English word, was almost regularly misdecoded.

V. FURTHER DEVELOPMENTS

As one direction of possible improvements, we tried to test the limits of our LVCSR system by increasing the number of words our system can recognize, and check the feasibility of using the larger system for speaker-independent speech recognition.

A. *Enlarging the Pronouncing Dictionary*

From Hascheck’s unigram database we took 130,160 most frequent Croatian words, which cover 95% of the Croatian word usage, as a basis for developing a large Croatian pronouncing dictionary. Those words were divided into three groups:

- Croatian non-name words;
- English words (mostly international names like Alexander, Mexico, Yamaha, etc.) contained in the CMU Sphinx pronouncing dictionary;
- All the other words.

Since the file with Croatian common (non-name) words contained 102,636 items, going through these words manually and writing them in the CMU Sphinx dictionary format would require a lot of time. Therefore, we made a short script in the Python programming language, which reads word by word from the input file containing Croatian words and writes those words in the CMU Sphinx dictionary format to the output file. Because of Croatian phonemic orthography, this was an easy task.

Generating Croatian pronouncing dictionary for English words (12,635 such words were found) proved to be a bit trickier. The English language contains many phonemes (“ah”, “iy”, “th”, and the like) which do not exist in the Croatian language. Therefore, we had to write a program which converts them into their Croatian counterparts, in a manner in which they would be pronounced by native Croatian speakers. The program was tuned by testing how the English words, being converted into Croatian phonetic system, are pronounced by HascheckVoice, Croatian academic speech synthesizer [20]. The final version of the program was applied to the English words found in the large Croatian dictionary, and this resolved the problem of their phonetic encoding.

Among other words (14,889 words in total) dominate name entities with South Slavic origin, which obey the same orthography as common (non-name) words. They were extracted and converted into the CMU Sphinx dictionary format in the same manner as common Croatian words. The remainder (3,102 words in total) had to be encoded manually. This was done in a few days.

All the dictionaries discussed in the next subsection are subsets of the large Croatian pronouncing dictionary with 130,160 entries.

B. *Generating Bigger Language Model*

After the initial success with 15,000 words covering 75% of the Croatian word usage, our goal was to develop a language model for 95% of the Croatian word usage. The intention was to repeat the steps used for generating the language model based upon 15,000 words on the new vocabulary size of 130,160 words, in order to produce a new language model for speech recognition purposes.

Since the size of n-gram files generated from 130,160 words was too big to handle, only n-grams with frequencies ≥ 10 were selected, which resulted in 4,158,737 bigrams and 15,686,105 trigrams. Selected trigrams were given as an input to the CMU LMTK.

 ISBN: 978-1-61208-310-0

Here is the point where the problems started. Generating the .arpa file using CMU LMTK needed a special flag for memory calculation because of the huge number of words.

After that, generating the .lm.DMP file used in Sphinx4 was aborted with error message saying that the number of unigrams exceeded 65,535. It was impossible to generate the binary file. More attempts to generate language model using unigrams and bigrams resulted in the same problem. Unfortunately, sphinx_lm_convert tool within the CMU LMTK does not allow more than 65,535 unigrams.

Due to the limitation on the number of unigrams to 65,535, and the complexity of the work required to change the source code of the CMU LMTK and the Sphinx4 library, which would allow us to work with bigger models, we restricted ourselves to the number of unigrams $\leq$ 65,535.

The next implementations of enlarged language models were based on dictionaries of 30,000 and 45,000 words, respectively. As with the previous model containing 15,000 words, we tested these models without any pondering, which resulted in the same issue of incorrect recognition of words at the start of utterances. In order to solve this problem, we pondered unigrams and trigrams logarithmically as before.

After testing such models, we concluded that with linear pondering of 10^+ unigrams, 10^+ bigrams without attestation in 10^+ trigrams, and 10^+ trigrams, we can get more accurate speech recognition than with the models of logarithmically pondered unigrams and trigrams. Development of linearly pondered language models is still in progress.

The CMU LMTK limits mean that we cannot achieve 95% coverage of Croatian word usage for now, but a coverage exceeding 85% seems easily feasible. Sometime in the future it might be necessary to develop systems able to work with larger dictionaries and language models. Until then, our efforts have to be focused on improving WERs in language models within the CMU Sphinx dictionary limits.

VI. CONCLUSION

The results of speech recognition for our ASR system using Sphinx4 are relatively good when compared to those reported for other Croatian systems so far, especially because we have a speaker-independent system, which can easily cope with large vocabularies. Although we have already achieved good results, there is still plenty of room for improvements, from lowering WER to increasing the size of vocabulary which the system can operate with. Encouraging results reached by the rapid prototyping approach can serve as a starting point for future development of Croatian LVCSR systems able to meet public needs.

Several tests confirmed that our initial hypothesis about recording audio files in acoustically imperfect conditions, according to the original intention of making our system more robust in a real-life application, was wrong. In the future, we intend to record the training data in good acoustical conditions, i.e., without too much noise. The noise can be added manually, when needed, afterwards. By doing that, we could keep the acoustic model "clean", which would ultimately enable our system to achieve WERs much lower than presented in the paper. We believe that the handicapping of our training set for acoustic modeling with too much noise was the main reason why our LVCSR system could not achieve WERs fewer than 20% on average.

REFERENCES

[1] A. W. Black et al., "TOUNGES: Rapid development of a speech-to-speech translation system," Proc. 2nd Int. Conf. on Human Language Technology Research, Morgan Kaufmann Publishers, 2002, pp. 183-186.

[2] Carnegie Mellon University (USA), Sphinx-4: A speech recognizer written entirely in the Java programming language, http://cmusphinx.sourceforge.net/sphinx4/, 15.07.2103.

[3] T. Tonžetić, Automatic speech recognition for Croatian language using Sphinx3 (in Croatian), M.S. Thesis, FER, Zagreb Univ., Croatia, 2005.

[4] S. Martinčić-Ipšić, M. Pobar, and I. Ipšić, "Croatian large vocabulary automatic speech recognition," Automatika, 2011, vol. 52, no. 2, pp. 147-157.

[5] Cambridge University (UK), HTK speech recognition toolkit, http://htk.eng.cam.ac.uk/, 16.07.2103.

[6] J. Vojtko, J. Kacur, and G. Rozinaj, "The training of Slovak speech recognition system based on Sphinx 4 for GSM networks," Proc. 49th Int. Conf. ELMAR, Zadar, Croatia, 2007, pp. 147-150.

[7] A. Janicki and D. Wawer, "Automatic speech recognition for Polish in a computer game interface," Proc. Federated Conference on Computer Science and Information Systems (FedCSIS 2011), September 2011, pp.711-716.

[8] X. Huang, A. Acero, and H.-W. Hon, "Spoken language processing," in Spoken Language Processing: A Guide to Theory, Algorithm and System Development, Prentice Hall, 2001.

[9] L. R. Rabiner and B. H. Juang, Fundamentals of Speech Recognition, Prentice Hall, 1993.

[10] J. P. Mallory and D. Q. Adams (eds.), Encyclopedia of Indo-European Culture, Fitzroy Dearborn Publishers, 1997.

[11] L. R. Rabiner and B. H. Juang, "An introduction to hidden Markov models," IEEE ASSP Magazine, January 1986, pp.4-15.

[12] M. Federico, "Bayesian estimation methods for n-gram language model adaptation," Proc. 4th Int. Conf. on Spoken Language Processing, Philadelphia, PA, USA, 1996, vol. 1, pp. 240-243.

[13] N. D. Warakagoda, A hybrid ANN-HMM ASR system with NN-based adaptive preprocessing, M.S. Thesis, Norges Tekniske Høgskole, Trondheim Univ., Norway, 1994.

[14] R. A. Cole et al. (eds.), Survey of the State of the Art in Human Language Technology, Cambridge Univ. Press, 1997.

[15] B. Dropuljić and D. Petrinović, "Development of acoustic model for Croatian language using HTK," Automatika, 2010, vol 51, no. 1, pp. 79-88.

[16] Š. Dembitz, B. Blašković, and G. Gledec, "Croatian language n-gram system," Frontiers in Artificial Intelligence and Applications, IOS Press, 2012, vol. 243, pp. 696-705.

[17] C. Manning and H. Schütze, Foundations of Statistical Natural Language Processing, MIT Press, 1999.

[18] Š. Dembitz, M. Randić, and G. Gledec, "Advantages of online spellchecking: a Croatian example," Software – Practice & Experience, 2011, vol. 41, no. 11, pp. 1203-1231.

[19] M. Radonić, Measuring word error rate in Croatian continuous speech recognition (in Croatian), B.S. Thesis, FER, Zagreb Univ., Croatia, 2013.

[20] FER, Zagreb Univ. (Croatia), HascheckVoice: The Croatian academic speech synthesizer, http://hascheck.tel.fer.hr/voice/, 16.07.2013.

 ISBN: 978-1-61208-310-0

2D-Packing Images on a Large Scale

Dominique Thiebaut
Dept. Computer Science
Smith College
Northampton, Ma 01063
Email: dthiebaut@smith.edu

***Abstract*—We present a new heuristic for 2D-packing of rectangles inside a rectangular area where the aesthetics of the resulting packing is amenable to generating large collages of photographs or images. The heuristic works by maintaining a sorted collection of vertical segments covering the area to be packed. The segments define the leftmost boundaries of rectangular and possibly overlapping areas that are yet to be covered. The use of this data structure allows for easily defining ahead of time arbitrary rectangular areas that the packing must avoid. The 2D-packing heuristic presented does not allow the rectangles to be rotated during the packing, but could easily be modified to implement this feature. The execution time of the present heuristic on various benchmark problems is on par with recently published research in this area, including some that do allow rotation of items while packing. Several examples of image packing are presented.**

Keywords*—*bin packing; rectangle packing; multi-threaded and parallel algorithms; heuristics; greedy algorithms; image collages.

I. Introduction

We present a new heuristic for placing two-dimensional rectangles in a rectangular surface. The heuristic keeps track of the empty area with a new data structure that allows for the natural packing around predefined rectangular areas where packing is forbidden, and the packing flows in a natural way around these "holes" without subdividing the original surface into smaller packing areas. The main application for this heuristic is to generate collages of large collections of images where some images are disproportionally larger than the others and positioned in key locations of the original surface. This feature could also be applied in domains where the original surface has defects over which packing is not to take place.

We are especially interested in avoiding packings that place the larger items concentrated on one side of the surface, and keep covering the remainder of the surface using decreasingly smaller items. These are not aesthetically pleasing packings.

This form of *2D-packing* is a special case of the *2D Orthogonal Packing Problem* (OPP-2) which consists in deciding whether a set of rectangular items can be placed, rotated or not, inside a rectangular surface without overlapping, and such that the uncovered surface area is minimized. In this paper we assume that all dimensions are expressed as integers, and that items cannot be rotated during the packing, which is important if the items are images. 2D-packing problems appear in many areas of manufacturing and technology, including lumber processing, glass cutting, sheet metal cutting, VLSI design, typesetting of newspaper pages, Web-page design or data visualization. Efficient solutions to this problem have direct implications for these industries [11].

Our algorithm packs thousands of items with a competitive efficiency, covering in the high 98 to 99% of the original surface for large collections of items. We provide solutions for several benchmark problems from the literature [5], [12], [14], and show that our heuristic in some cases generates tighter packings with less wasted space than previously published results, although running slower than the currently fastest solution [15].

To improve the aesthetics of the resulting packing, we use Huang and Chen's [13] surprising quasi-human approach borrowed from masons who pack patios by starting with the corners first, then borders, then inside these limits (also similar to the way one solves a jigsaw puzzle). Our algorithm departs from Huang and Chen's in that it implements a greedy localized best-fit first approach and uses a collection of vertical *lines* containing *segments*. Each vertical segment represents the leftmost side of rectangular area of empty space extending to the rightmost edge of the area to cover. The collection keep the lines ordered by their x-coordinate. All the segments in a line have the same x-coordinate and are ordered by their y-coordinate. Representing empty space in this fashion permits the easy and natural definition of rectangular areas that can be excluded from packing, which in turn offers two distinct advantages: the first is that some rectangular areas can be defined ahead of time as containing images positioned at key locations, and therefore should not be packed over. The second is that subsections of the area to pack can easily be delineated and given to other threads/processes to pack in parallel. Simple scheduling and load-balancing agents are required to allow such processes to exchange items as the packing progresses.

The impetus for this algorithm is to pack a large number of images, typically thousand to millions, in a rectangular surface of a given geometry to form large-scale *collages*. In such applications items are not rotated 90 degrees since they represent images. This type of packing is referred to as *nesting* [7].

II. Review of the Literature

Possibly because of its importance in many fabrication processes [11], different forms of 2D-packing have evolved and been studied quite extensively since Garey and Johnson categorized this class of problems as NP-hard [9]. It is hence a challenge to create a comprehensive review of the literature, as any 2-dimensional arranging of rectangular items in a rectangular surface can be characterized as packing. Burke,

 ISBN: 978-1-61208-310-0

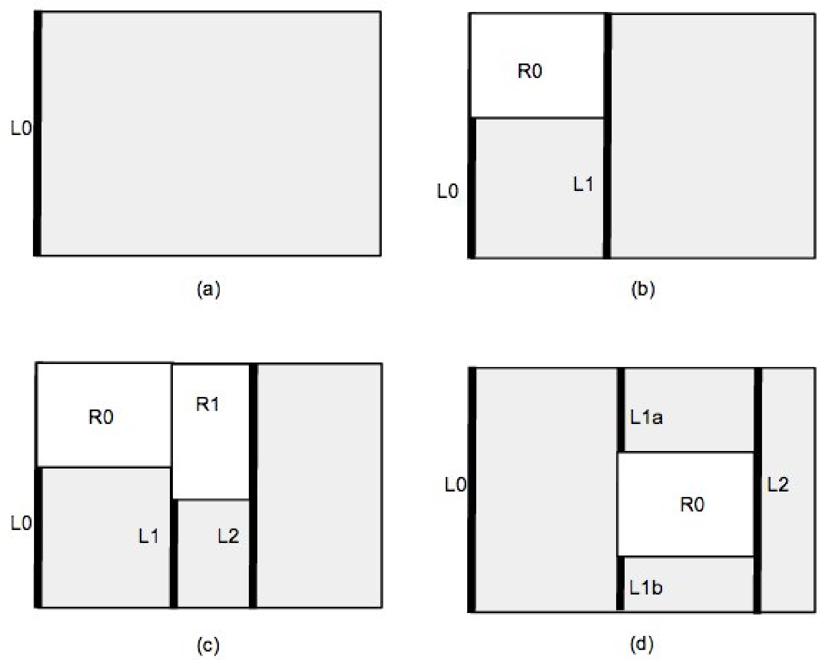


Fig. 1. The basic concept of the packing heuristic.

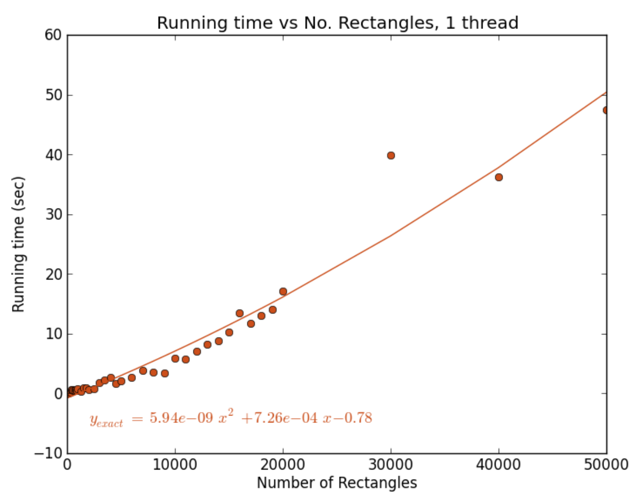


Fig. 2. Running times and regression fits for packings of 100 to 50,000 random rectangles on one core of a 3.5 GHz 64-bit AMD 8-core processor.

Kendall and Whitwell [5] and Verstichel, De Causmaecker, and Vanden Berghe [20] provide among the best encompassing surveys of the literature on 2D-packing and strip-packing research.

While exact solutions are non-polynomial in nature and slow, researchers have achieved optimal solutions for small problem sizes. Baldacci and Boschetti, for example, reports four know approaches to the particular problem of 2D orthogonal non-guillotine cutting problem [3], Beasley's optimal algorithm [4] probably being the one most often cited. Unfortunately such approaches work well on rather small problem sets. Baldacci and Boschetti, for example, report execution times in the order of tens of milliseconds to tens of seconds for problem sets of size less than 100 on a 2GHz Pentium processor.

Scientists from the theory and operations-research communities have also delved on 2D-packing and have generated close to optimal solutions [6], [8]. The *Bottom-Left* heuristic using rectangles sorted by decreasing width has been used in various situations yielding different asymptotic relative performance guarantees [1], [2], [19] [16]. Other approaches concentrate on local search methods and lead to good solutions in practice, although computationally expensive. *Genetic algorithms*, *tabu search*, *hill-climbing*, and *simulated annealing* [18] [17] are interesting techniques that have been detailed by Hopper and Turton [11] [12]. These meta-heuristics have heavy computational complexities and have been outperformed

 ISBN: 978-1-61208-310-0

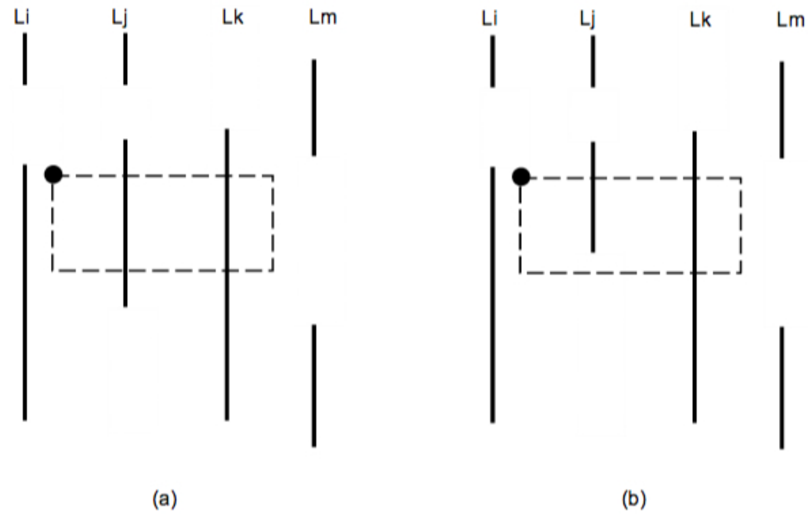


Fig. 3. Two examples of potential rectangle placements. In (a) the proposed location for the rectangle (shown in dashed line) is valid and will not intersect with other placed rectangles (not shown) because 1) its horizontal projection on the line L_i directly left of it is fulling included in a segment of L_i, and 2) its intersection with Lines L_j, L_k, and L_m is fully covered by segments of these lines. In (b) the proposed location for the rectangle is not valid, and will result in its overlapping with already placed rectangles since its intersection with Line L_j is not fully included in one of L_j's segments.

recently by simpler best-fit based approaches, including those of Hwang and Chen [13] [14], or Burke, Kendall and Whitwell [5]. Huang and Chen show that placement heuristics such as their *quasi-human* approach inspired by Chinese masons outperforms the meta-heuristics in minimizing uncovered surfaces in many cases, although requiring relatively long execution times. Burke et al. propose best-fit heuristic that is a close competitor in the minimization of the uncovered surface but with faster execution times.

Probably the fastest algorithm to date is that of Imahori and Yagiura [15] which is based on Burke et al.'s best-fit approach. Their algorithm is very efficient and requires linear space and $O(n \log n)$ time, and solves strip-packing problems where the height of the surface to pack can expand infinitely until all items are packed. They report execution times in the order of 10 seconds for problems of size 2^{20} items. Our application is slower, as our timing results show below, but provide a better qualitative aesthetic packing in a fixed size surface with similarly small wasted area. Because the time consuming operation of a collage of image is in the resizing and merging of images on the canvas which vastly surpasses our packing time by several orders of magnitude, the added value of the quality of the aesthetics of the packing makes our algorithm none-the-less attractive compared to the above cited faster contenders.

In the next section we present the algorithm, its basic data structure, and an important proposition that controls the packing and ensures the positioning of items without overlap. We follow with an analysis of the time and space complexities of our algorithm, and show that the algorithm uses linear space and requires at most O($N^3\log(N)^2$) time, although experimental results show closer to linear evolution of the execution times. This is due to the fact that the algorithm generally finds a rectangle to pack in the first few steps of the process, and the execution time is proportional mostly to the number of rectangles. Only the last few remaining rectangles take the longest amount of time to pack in the left over space. We compare our algorithm to several test cases taken from the literature in the benchmark section, and close with several examples illustrating how the algorithm operates. The conclusion section presents future research areas.

III. The Algorithm

A. Basic Data-Structures

The algorithm is a *greedy*, *localized best-fit* algorithm that finds the best fitting rectangles to pack closest to either one of the left side or top side of the surface. Figure 1 captures the essence of the algorithm and how it progresses.

The algorithm maintains ordered collections of vertical *segments* representing rectangular areas of empty space. Segments are vertical but could also be made horizontal without impeding the operation of the algorithm. These vertical segments can be thought of as the left-most height of a rectangle extending to the right-most edge of the surface to pack. Vertical segments with the same x-coordinate relative to the top-left corner of the surface to cover are kept in vertical *lines*. The algorithm's main data structure is thus a *collection* of lines ordered by their x-coordinates, each line itself a collection of segments, also ordered by their y-coordinates. The collections are selected to allow efficient *exact searching*, *approximate searching* returning the closest item to a given coordinate, *inserting* a new item (line or segment) while maintain the sorted order. *Red-black trees* [10] are good implementations for these collections.

The main property on which the algorithm relies to position a new rectangle on the surface without creating an overlap with already positioned rectangles is expressed by the following proposition:

 ISBN: 978-1-61208-310-0

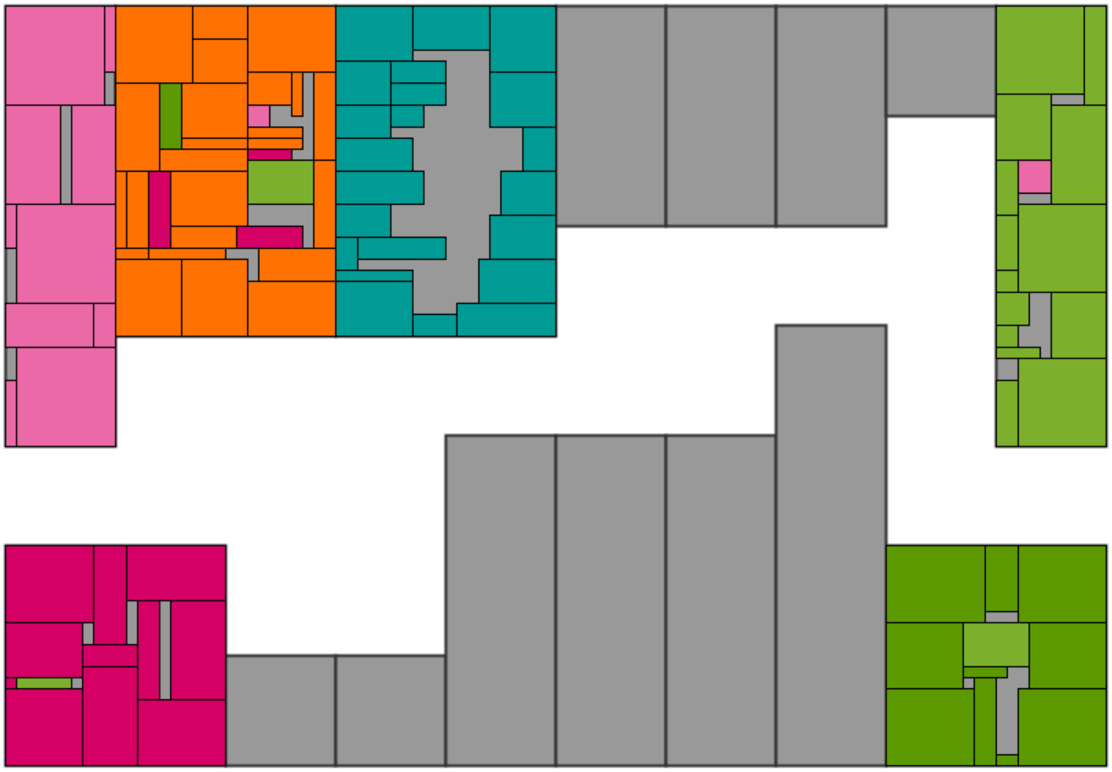


Fig. 4. The packing of 100 items in 16 objects as proposed by Hopper as the “M1a” case.

Proposition 1: A new rectangle can be positioned in the surface such that its top-left corner falls on the point of coordinates (x_{tl}, y_{tl}) and such that it will not intersect with already positioned rectangles if it satisfies two properties relative to the set of vertical lines:

1) Let L_{left} be the vertical line whose x-coordinate x_{left} is the floor of x_{tl}, i.e. the largest x such that $x <= x_{tl}$. In other words, L_{left} is the vertical line the closest to or touching the left side of the rectangle. For the rectangle to have a chance to fit at its present location, the horizontal projection of the rectangle on L_{left} must intersect with one of its segments that completely contains this projection.
2) The horizontal projection of the rectangle on *any* vertical line that intersects it must also be completely included in a segment of this line.

Figure 3 illustrates this proposition.

B. Basic Operation

The algorithm starts with two vertical lines, L_0 and L_∞. The first line originates at the top-left corner of the surface to cover, and contains a single segment whose length defines the full *height* of the surface to pack. L_∞ is a vertical line located at an x-coordinate equal to the width of the surface to pack. L_∞ contains no segments. It identifies the end of the area to pack. Any rectangle that extends past the end of the area to cover will cross L_∞, and because this one does not contain segment, the second part of the proposition above will reject the rectangle.

To simplify the description of the algorithm, we use the generic term *line* to refer to lines and segments. The algorithm packs from top to bottom and from left to right. Starting with the vertical line L_0 it finds the item R_0 with the largest height less than L_0. If several items have identical largest height, the algorithm picks the one with the largest perimeter and tests whether it can be positioned without overlapping any other already placed items. The algorithm tries three different locations: at the top of L_0, at the bottom of L_0, or at the centre of L_0. The item is positioned at the first location that offers no overlap, otherwise the next best-fitting item is tested, and so on.

The positioning of R_0 shortens L_0, as shown in Figure 1(b). A new line L_1 is added to the right of R_0 to indicate a new band of space to its right that is free for packing.

The goal is to place all larger items first and automatically the smaller ones find places in between the larger ones.

In Figure 1(c) the algorithm finds R_1 as the rectangle whose width is the largest less than L_1 and positions it against the left most part of L_1. Adding R_1 shortens L_1, indicating that all the space right of the now shorter L_1 is free for packing.

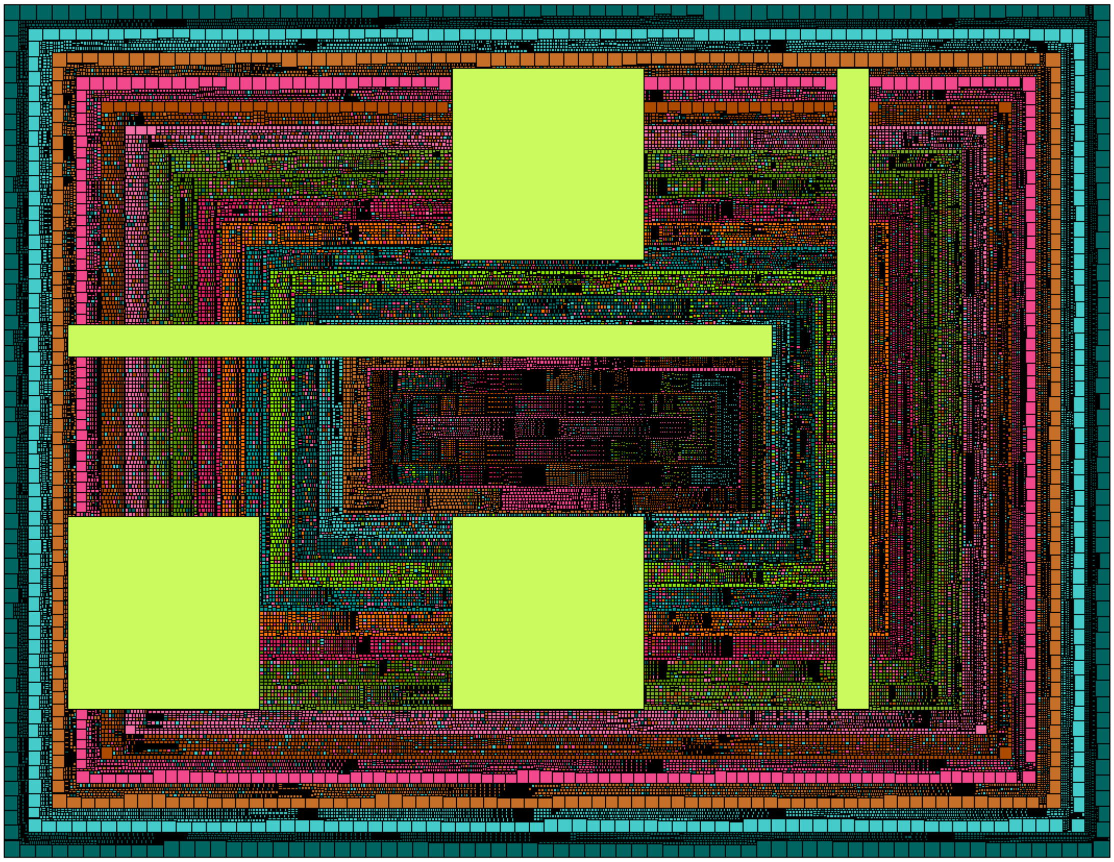


Fig. 5. The packing of 97,272 randomly generated items in a a rectangular surface. The application is multithreaded, each thread associated with a rectangular border. 5 large lime-green rectangles with different geometries are placed in various locations before the computation starts.

Again, a new line L_2 is added to delineate a band of empty space to the right of R_1.

We implement the data-structures for the lines as trees sorted on the line position relative to the top-left corner of the initial surface, so that a line or a group of lines perpendicular to particular length along the width or height of the original surface can be quickly found.

Note that in our context these line-based data-structures allow for the easy random positioning of rectangles in the surface before the packing starts, as illustrated in Figure 1(d) where a rectangle R_0 is placed first in the middle of the surface before the packing starts.

C. The Code and its Time and Space Complexities

We now proceed to evaluate the time complexity of our heuristic, whose algorithmic description is given in Algorithm 1. In it, N is the number of items to pack, $rects$ is the list of items to pack, VL the collection of vertical lines, and vl one such individual line.

Since N is the original number of items to pack, then clearly the size of VL is $O(N)$. Given a line vl of VL, we argue that the average number of segments it contains (exemplified by $L1a$ and $L1b$ in Figure 1) is O(N). The goal of the Loop starting at Line 3 is to pack all rectangles, and it will repeat N times, hence O(N). The combined time complexity of the loops at Lines 5 and 7 is O(N) because they touch at most all segments in all the lines, which is bounded by O(N). The time complexity of Line 16 is clearly O$(N \log N)$, although on the average the number of pairs to sort will be O$(\sqrt{N})$ rather than O$(N \log N)$. The loop starting at Line 17 processes at most O(N) pairs, and for each rectangle in it, must compare it to at most O(N) line vl. So it contributes O(N^2), which overpowers the sorting of the list. Therefore the combined complexity of the whole loop starting on Line 3 is O(N^3). Empirically, however, the algorithm evolves in nearly linear fashion as illustrated in Figure 2 where various selections of rectangles with randomly picked sizes are packed in a rectangular surface that is selected ahead of time to be of a given aspect ratio, and whose total area is 1/98% larger than the sum of all the items to pack. We found this approach the best for packing quickly the great majority, if not of all the items.

The space complexity is clearly O(N), since the packing of a new item in the surface introduces at most 2 new segments in the data structures.

D. Algorithmic Features

Our heuristic sports one feature that is key for our image-collage application: Rectangular areas in which packing is forbidden can easily be identified inside the main surface to

Fig. 6. The packing of 2,200 photos of various sizes and aspect-ratios, as many are cropped for artistic quality. The size of the photos is randomly picked by the algorithm. All the photos belong to this author.

be packed, either statically before starting the packing or even dynamically during run time. We refer to these areas as *empty zones*. This feature offers the user the option of positioning interesting images at key positions on the surface to be packed ahead of time. In other domains of application these could be areas with defects. Additionally, it allows parallel packing approaches where rectangular empty zones can be given out to new processes to pack in parallel, possibly shortening the execution time.

IV. Benchmarks

A set of benchmark cases used frequently in the literature are those of Hopper and Turton [12], and of Burke, Kendall and Whitwell [5]. For the sake of brevity we select a sample of representative cases and run our heuristic on each one. The computer used to run the test is one core of a 64-bit Ubuntu machine driven by a 3.5GHz AMD 8-core processor, with 16GB of ram. The heuristic is coded in Java. Note that all published results are on different types of computers, ranging from ageing memory-limited laptops to supped up desktops, all with different processor speed and memory capacities. To provide a more objective comparison, we make the following assumptions: *a*) all results reported in the literature corresponded to compiled applications that are all memory residents, *b*) they are the only workload running on the system, *c*) MIPS are linearly related to CPU frequency, and thus we scale the execution times of already published data reported by the ratio of their operating CPU frequencies to that of our processor (3.5GHz).

We follow the same procedure used by the researchers whose algorithms we compare ours to, and we run our application multiple times (in our case 30 times) on the same problem set and kept the best result.

Table I shows the scaled execution times of the various heuristics for problem sets taken from the literature. The times are those reported in the literature multiplied by a scaling factor equal to the 3.5GHz/*speed of processor*, where the processor is the one used by the researchers. For the Burke column, the speed of the processor is 850MHz. For the GRASP column, 2GHz, and for the 3-way column, 3GHz.

We observe that, as previously discovered [15] our packing efficiency improves as the number of items gets larger (in the thousand of items), which is the size of our domain of interest. The execution times of our heuristic are faster than those of Burke's best-fit, or of GRASP, and at most five times slower than the fast running 3-way best-fit of Imahori and Yagiur [15]. This difference might be attributed to either the choice of language used to code the algorithm, Java in our case, versus C for theirs, in our multithreaded approach–see the examples below–which adds a level of overhead, or possibly some inefficiency in the selection of slower data structures.

In the next section we show several packings generated by our heuristic.

 ISBN: 978-1-61208-310-0

TABLE I. PERFORMANCE COMPARISON TABLE

			Burke		GRASP		3-way		DT	
Case	No. items	optimal	diff.	time (s)	diff.	time (s)	diff.	time (s)	diff.	time (s)
N1	10	40	0	∼14.571	0	∼34.286	5	<0.009	0	0.05
N2	20	50	0	∼14.571	0	∼34.286	3	<0.009	6	<0.01
N3	30	50	1	∼14.571	1	∼34.286	4	<0.009	10	<0.01
N4	40	80	2	∼14.571	1	∼34.286	6	<0.009	49	<0.01
N5	50	100	3	∼14.571	2	∼34.286	4	<0.009	5	0.03
N6	60	100	2	∼14.571	1	∼34.286	2	<0.009	22	0.01
N7	70	100	4	∼14.571	1	∼34.286	7	<0.009	14	<0.01
N8	80	80	2	∼14.571	1	∼34.286	3	<0.009	23	<0.01
N9	100	150	2	∼14.571	1	∼34.286	13	<0.009	5	0.04
N10	200	150	2	∼14.571	1	∼34.286	2	0.01	10	0.03
N11	300	150	3	∼14.571	1	∼34.286	2	0.01	2	0.49
N12	500	300	6	∼14.571	3	∼34.286	5	0.02	7	0.07
N13	3152	960	4	∼14.571	3	∼34.286	4	0.20	5	0.927
C7-P1	196	240	4	∼14.571	4	∼34.286	6	<0.009	17	0.02
C7-P2	197	240	4	∼14.571	3	∼34.286	4	<0.009	41	0.02
C7-P3	196	240	5	∼14.571	3	∼34.286	5	<0.009	24	0.01

Algorithm 1 Simplified Packing Heuristic

```
N = dimension( rects )
VL = {L_0, L_∞}
while not VL.isempty() do
   success = false
   for all line ℓ in VL do
      list = { } // empty collection
      for all segment sl in ℓ do
         rect = rectangle in Rects with height closest to
         but less than sl
         if rect not null then
            list.add( Pair( rect, sl ) )
         end if
      end for
      if list.isempty() then
         continue
      end if
      sort list in decreasing order of ratio of rect.length to
      sl.length
      for all pair in list do
         rect, sl = pair.split()
         if rect fits in VL then
            pack rect at the top of sl
            update VL
            success = true
            break
         end if
      end for
      if success == true then
         break
      end if
   end for
   if Rects.isEmpty() then
      break
   end if
end while
```

V. PACKING EXAMPLES

In this section we provide several examples of packing under various conditions and constraints, some of them taken from the literature.

In Figure 4 we apply our heuristic to Hopper's *M1a case* [11] where 100 items must be packed into 16 different objects. Our algorithm also packs the objects, although this is not a requirement of the test. In this experiment our heuristic is multithreaded and several threads pack the different objects. A scheduler simply distributes the objects to separate threads, picking the largest object first and assigning it to a new thread implementing our packing heuristic. Then the scheduler picks the next largest object (in terms of its area) and assigns it to a new thread, and so on. The earliest starting threads are given a random sample of the items to pack. Threads that start last have to wait until earlier threads finish packing and return items that couldn't be packed. This automatically packs objects in such a way that as few objects as possible are packed, and some left empty, which may be desirable.

In Figure 5 the original surface is divided at run time into smaller surfaces, or *borders* one inside the other as the packing progresses, and individual threads are running the packing on individual borders. Here again the threads are given random samples of the original population of items and a load balancing scheme allows for the exchange of items between threads. This is represented by items with different colors. For example, the items associated with the first thread are all dark green, and some can be found in the light green, orange or pink borders as they are rejected by the first thread once it has packed the dark green band. Note that the utilization of the surface is 99.30%.

In Figure 5 we have placed five large items (yellow-green rectangles) on the surface before launching the packing algorithm. Notice how the heuristic naturally packs around these areas. Note also that as in Figures 4 and 5, we follow Huang and Chen's quasi-human approach [13] and pack corners and borders first before proceeding with the inside areas. Note that this modification of the algorithm fits completely with the natural properties of the heuristic, and enhances the visual aspect of the final packing.

VI. CONCLUSIONS

We have presented a new heuristic for packing or nesting two-dimensional images in a rectangular surface. The heuristic packs the items by creating a collection of segments that are maintained in two data structures, one for horizontal segments, and one for vertical segments. The segments represent the leftmost and topmost side of rectangular surfaces that extend to the edges of the original surface to pack. These data structures permit to test quickly whether a new item can be positioned in the surface without overlapping a previously placed item.

Our packing heuristic does not rotate items, but none-the-less compares favourably with other heuristics published in the literature that solve 2D-strip packing with rotation of items allowed.

The data structure used to maintain the empty areas lends itself well to positioning items in key places ahead of time, or in subdividing the original surface into multiple holes that can be either left empty, reserved for large size items, or assigned to separate processes that will pack in parallel. Such holes may contain defects (for example in a sheet of metal, or glass) that need to be avoided by the packing process. A forthcoming paper will explore scheduling and load-balancing approaches for speeding up the packing.

Because our domain of application is that of image collages, we have found that the the quasi-human approach of Huang and Chen, along with subdividing the surface into nested rectangular area significantly improves the aesthetic quality of the packing compared to most heuristic that privilege one side or corner and put all largest items there and finish packing with the smaller items at the opposite end.

REFERENCES

[1] B. S. Baker, D. J. Brown, and H. P. Katseff, "A 5/4 algorithm for two-dimensional packing," *Journal of Algorithms*, vol. 2, pp. 348–368, 1981.

[2] B. S. Baker, E. G. C. Jr., and R. L. Rivest, "Orthogonal packings in two dimensions," *SIAM Journal on Computing*, vol. 9, pp. 846–855, 1980.

[3] R. Baldacci and M. A. Boschetti, "A cutting-plane approach for the two-dimensional orthogonal non-guillotine cutting problem," *European Journal of Operational Research*, vol. 183, no. 3, pp. 1136–1149, 2007.

[4] J. Beasley, "An exact two-dimensional non-guillotine cutting tree search procedure," *Operations Research*, vol. 33, no. 1, pp. 49–64, January 1985.

[5] E. K. Burke, G. Kendall, and G. Whitwell, "A new placement heuristic for the orthogonal stock-cutting problem," *Oper. Res.*, vol. 52, no. 4, pp. 655–671, Aug. 2004.

[6] E. G. Coffman, M. R. Gazey, and D. S. Johnson, *Approximation algorithms for bin-packing an updated survey*. Springer-Verlag, 1984.

[7] R. D. Dietrich and S. J. Yakowitz, "A rule-based approach to the trim-loss problem," *International Journal of Production Research*, vol. 29, pp. 401–415, 1991.

[8] H. Dyckhoff, "Typology of cutting and packing problems," *European Journal of Operational Research*, vol. 44, pp. 145–159, 1990.

[9] M. R. Garey and D. S. Johnson, *Computers and Intractability: A Guide to the Theory of NP-Completeness*. New York: W. H. Freeman and Company, 1979.

[10] L. J. Guibas and R. Sedgewick, "A dichromatic framework for balanced trees," *Foundations of Computer Science, IEEE Annual Symposium on*, vol. 0, pp. 8–21, 1978.

[11] E. Hopper, "Two-dimensional packing utilising evolutionary algorithms and other meta-heuristic methods," Ph.D. dissertation, Cardiff University, United Kingdom, 2000.

[12] E. Hopper and B. C. H. Turton, "An empirical investigation of meta heuristic and heuristic algorithms for a 2d packing problem," *European Journal of Operational Research*, vol. 1, no. 128, pp. 34–57, 2000.

[13] W. Huang and D. Chen. (2008, July) Simulated annealing. [Online]. Available: http://cdn.intechopen.com/pdfs/4629/InTech-An_efficient_quasi_human_heuristic_algorithm_for_solving_the_rectangle_packing_problem.pdf

[14] W. Huang, D. Chen, and R. Xu, "A new heuristic algorithm for rectangle packing," *Computers and Operations Research*, vol. 34, no. 11, pp. 3270–3280, November 2007.

[15] S. Imahori and M. Yagiur, "The best-fit heuristic for the rectangular strip packing problem: An efficient implementation and the worst-case approximation ratio," *Comput. Oper. Res.*, vol. 37, no. 2, pp. 325–333, Feb. 2010.

[16] C. Kenyon and E. Remilia, "Approximate strip-packing," in *Proceedings of the 37th Annual Symposium on Foundations of Computer Science*, 1996, pp. 31–35.

[17] T. W. Leung, C. K. Chan, and M. Troutt, "Application of a mixed simulated annealing genetic algorithm heuristic for the two-dimensional orthogonal packing problem," *European Journal of Operational Research*, vol. 145, no. 3, pp. 530–542, March 2003.

[18] D. Liu and H. Teng, "An improved bl-algorithm for genetic algorithm of the orthogonal packing of rectangles," *European Journal of Operational Research*, vol. 112, no. 2, pp. 413–420, January 1999.

[19] D. Sleator, "A 2.5 times optimal algorithm for packing in two dimensions," *Information Processing Letter*, vol. 10, pp. 37–40, 1980.

[20] J. Verstichel, P. D. Causmaecker, and G. V. Berghe, "An improved best fit heuristic for the orthogonal strip packing problem," *International Transactions in Operational Research*, June 2013.

A Near Real-Time Color Stereo Matching Method for GPU

Naiyu Zhang, Hongjian Wang, Jean-Charles Créput, Julien Moreau and Yassine Ruichek
IRTES-SeT, Université de Technologie de Belfort-Montbéliard, Belfort, France
Email: {naiyu.zhang, hongjian.wang, jean-charles.creput, julien.moreau, yassine.ruichek}@utbm.fr

***Abstract*—This paper presents a near real-time stereo matching method with acceptable matching results. This method consists of three important steps: SAD-ALD cost measure, cost aggregation in adaptive window in cross-based support regions and a refinement step. These three steps are well organized to be adopted by the GPU's parallel architecture. The parallelism brought by GPU and CUDA implementations provides significant acceleration in running time. This method is tested on six pairs of images from Middlebury dataset, each possibly declined within different sizes. For each pair of images it can generate acceptable matching results in roughly less than 100 milliseconds. The method is also compared with three GPU-based methods and one CPU-based method on increasing size image pairs.**

Keywords - GPU; Real-Time Stereovision; SAD-ALD; Adaptive Window; CUDA.

I. INTRODUCTION

Stereo matching is one of the most extensively studied problems in computer vision. In years, people take their time into stereo matching algorithm designing for new achievements in the matching accuracy and the processing efficiency. Even with many algorithms introduced every year, the two concerns of accuracy and speed still tend to be contradictory in reported results: accurate stereo methods are usually time consuming. Some algorithms use large support windows for robust cost aggregation [1]–[3], and the disparity computation step is formulated as an energy minimization problem and solved with slow-converging optimizers [4]; In other studies, segmented image regions are used extensively as matching units [5], surface constraints [6], [7] or post-processing patches [8]. These techniques significantly improve the matching quality by paying considerable computation costs. As a result, people tend to look for new possibilities on Graphics Processing Unit (GPU) platforms. However, current accurate stereo algorithms employ some key techniques, which seem not to be suitable for parallel GPU architecture. As proved in [9]–[12], it will be tricky and cumbersome to directly take these techniques into GPU applications: large aggregation windows require extensive iterations over each pixel; some optimization, segmentation and post-processing methods require complex data structures and sequential processing. In spite of these difficulties, GPU is sill promising to fast stereo matching applications because of its powerful parallel computing ability. In fact, there already exist three GPU-based methods, namely, CostFilter [13], PlaneFitBP [12] and ADCensus [14] in the top 20 of Middlebury repository [15]. They all have near real-time performance. Trying to outperform them, we propose a brand new method, which also has near real-time performance, but simple computing components. It can naturally scale according to the image sizes. Our method is a correlation-based technique, which falls into the class of local dense stereo matching approaches. It includes the following key characters:

- SAD-ALD cost measure combining the adapted Sum of Absolute Differences (SAD) measure and the Arm-Length-Differences (ALD) measure. The usage of ALD is inspired by the similarity of the pixel's support region and that of its homologous pixel. This combined measure provides more accurate matching results than common aggregation methods.
- Improved cross-based regions for efficient cost aggregation. Proposed by Zhang *et al.* [16], the support regions are based on cross skeletons with accurate cross construction and cost aggregation by reusing middle-ranking disparity data.
- A simple refinement process with support region voting. This simple process proves to be quite effective with little time consuming.
- Efficient system implementation on GPU with Compute Unified Device Architecture (CUDA).

This paper is organised as follows. Section II presents the stereo-matching steps of the proposed method. Section III details the experiment carried out on a set of increasing size images from Middlebury dataset, with regard to both GPU and CPU methods. Section IV concludes the paper.

II. STEREO MATCHING STEPS

A. Adapted Matching Cost

The method is a local dense stereo matching method. It respects the very assumption that color information of the neighbors of a left pixel should be close to those of the same neighbors of its homologous right pixel in the right image. So, the matching costs are defined between the left pixel and the candidate right pixels in the corresponding line (epipolar line) in the right image. The cost is shifted over all possible pixels so that a matching cost between the left pixel and each candidate in the right image is obtained. By the aggregation of matching cost and the winner-takes-all method, the final disparity estimation is realized by selecting the candidate pixel with the lowest matching cost.

 ISBN: 978-1-61208-310-0

The SAD matching cost is adapted as (1).

$$SAD(x_l, y, d) = \begin{bmatrix} \frac{1}{4} & \frac{1}{2} & \frac{1}{4} \end{bmatrix} \times \begin{bmatrix} |I_{lR}(x_l, y) - I_{rR}(x_l - d, y)| \\ |I_{lG}(x_l, y) - I_{rG}(x_l - d, y)| \\ |I_{lB}(x_l, y) - I_{rB}(x_l - d, y)| \end{bmatrix} \quad (1)$$

In the formula, $|\cdot|$ is the absolute value, d is the spatial shift along the horizontal epipolar line (or we call it the disparity of the two pixels), and $|I_{li}(x_l, y) - I_{ri}(x_l - d, y)|_{(i=R,G,B)}$ are the absolute difference (AD) of three color components in the two chosen pixels. For the coefficient matrix of the three color components, we choose the $\begin{bmatrix} \frac{1}{4} & \frac{1}{2} & \frac{1}{4} \end{bmatrix}$ according to the Bayer Filter Mosaic [17], which uses twice as many green elements as red or blue to mimic the physiology of the human eye.

Since these pixels of horizontal lines with the same parity in left and right color images are characterized by the same three color components, we can reasonably assume that the color points of two homologous pixels are similar. Because the matching cost compares the color points of left and right pixels located on the same horizontal lines, they reach an extremum when the shift is equal to the disparity.

An assumption for matching cost aggregation is that a pixel and its homologous pixel should have the similar support region arm-length in vertical direction as shown in Fig. 1. This implies that the arm-length data can be used to enhance the matching results in most regions of the image pairs. So, we update the matching cost equation as (2),

$$MatchingCost(x_l, y, d) = SAD(x_l, y, d) + K \times \sum_j |AL_{lj}(x_l, y) - AL_{rj}(x_l - d, y)| \quad (2)$$
$$\text{where } j = (\textit{Up arm, Bottom arm})$$

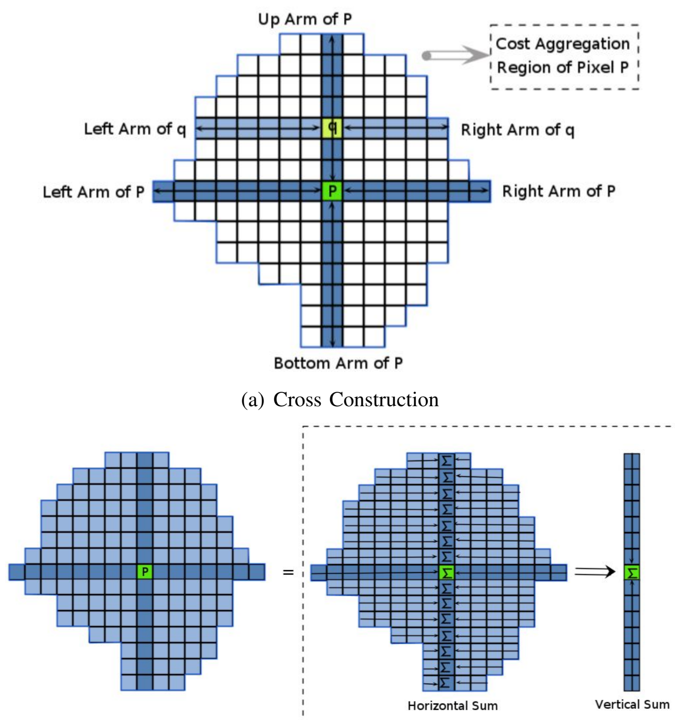
In the formula, $|AL_{lj}(x_l, y) - AL_{rj}(x_l - d, y)|$ is the difference of their arm-length (AL) in vertical direction, and the parameter K is a empirical preset value. The arm-length (AL) is equivalent to absolute difference of their coordinates in the same direction ($|x_p - x_{p'}|$ or $|y_p - y_{p'}|$ for pixel p and one of its endpoint pixel p', detail in Section *B*).

We find that this enhancement can evidently reduce the errors in most regions (the advantage degrades in those areas where both the color and the shape repeat).

B. Cross-based Cost Aggregation

In this step, each pixel's matching cost over its support region is aggregated, to reduce the matching ambiguities and noise, in the initial cost volume in order to pick out the best candidate pixel. As it is mentioned in the previous section, the matching method respects the very assumption that the color information of neighbors of a left pixel is close to those of the same neighbors of its homologous right pixel in the right image. Meanwhile, for matching cost aggregation, there is also two simple but effective assumptions, the first is the one that a pixel and its homologous pixel should have the similar support region arm-length in vertical direction, as shown in Fig. 1. For updating the matching cost equation, the second one is that neighboring pixels with similar colors should have similar disparities. Many well known cost aggregation methods have adopted this assumption such as segment support [6], adaptive weight [3], geodesic weight [1] and those proposed for GPU systems such as simplified adaptive weight techniques with 1D aggregation [11], [18] and color averaging [9], [12], either require too many segmentation operations, expensive iterations or lead to matching quality decrease owing to maladjustment of GPU's parallel architecture. Some other researchers have formulated the matching cost step as a cost filtering problem [13] and made the matching quality be well guaranteed by smoothing each cost slice with a guided filter.

Zhang *et al.* [16] have proposed a cross-based matching cost aggregation method. This method can be adopted to G-PU's parallel computation architecture and produce aggregated results comparable to the adaptive weight method but with less computation time. Moreover, this method constructs a support region for every pixel, which can provide supplemental information for later processing steps.



(a) Cross Construction

(b) Cost Aggregation

Fig. 1: Cross-based aggregation.

As it is shown in Fig. 1(a), cross-based aggregation is carried out by a two-step-process. In the first step, an upright cross in constructed for every pixel. The support region of a given pixel, such as p in the Fig. 1(a), is modeled by merging the horizontal arms of the pixels (such as the pixel q in Fig. 1(a)) lying on the vertical arms of pixel p. Generally, every pixel has four arms and the length of the arms is set by an endpoint pixel p' in the same direction that does not obey both the two following rules:

1) $D_c(p, p') < \sigma_{dc}$ and $D_c(p', p'') < \sigma_{dc}$, where $D_c(p, p') = max|I_i(p) - I_i(p')|_{(i=R,G,B)}$ is the color difference between the pixel p and the pixel p' , and p'' is the predecessor of p' lying between p and p' while σ_{dc} is a empirical preset threshold value.
2) $D_s(p, p') < \sigma_{ds}$, where $D_s(p, p') = |p - p'|$ is the spatial distance, which is equivalent to absolute difference of their coordinates in the same direction ($|x_p - x_{p'}|$ or $|y_p - y_{p'}|$) while the σ_{ds} is a empirical preset maximum length measured in pixels.

These two rules provide constraints in the four arm directions both on color similarity and arm length with parameter σ_{dc} and σ_{ds}. After the cross construction step, the support region for pixel p is modeled by merging the horizontal arms of all the pixels lying on p's vertical arms (as done for q for example in Fig. 1(a)). In the second step, shown in Fig. 1(b), the aggregated costs over all pixels are computed by firstly summing up the matching costs horizontally and secondly summing up these horizontal sum results vertically to get the final costs.

In some too textured regions, the color and the shape both repeat, which leads to degradation in matching results. We find that the reason for this degradation lies in the shape of aggregation support region. As seen in Fig. 1(a), we take the pixel at the end of pixel p's right arm as example, for this pixel, its up arm and bottom arm could be very short (less than 2 pixels), so, in the aggregation of its matching cost, there will be not enough information to achieve a unique minimum in the Winner-Takes-All processing, which leads to marching errors at this pixel. As a solution to this problem, we artificially enlarge the arms of a pixel to two pixels if its support region is too small, to make sure that the matching cost aggregation processing can have enough information for stereo matching. This operation provides a slight improvement in matching results in paying no computation time cost.

C. Simple Refinement

After the previous step, the disparity results of both the left image and the right image contain some outliers in certain regions that should be corrected by further operations. A simple refinement is carried out after detecting these outliers.

The outliers in the left image are detected with left-right consistency check: for a given pixel p, it is classified into outliers if this equation does not hold true: $\hat{d}_{Lp} = \hat{d}_{R(p-\hat{d}_{Lp})}$ where $\hat{d}_{Lp}$ is the estimated disparity for pixel p in the left image and $\hat{d}_{Rp}$ is the estimated disparity for pixel p in the right image.

These detected outliers are these errors that should be corrected. The most current accurate stereo matching algorithms use segmented regions for outlier handing [7], [8], which are not suitable for GPU architecture. Here, what we use is a simple voting refinement in reusing the support region information. We still take the pixel p in the left image as example, all the reliable disparities lying in its cross-based support region are sorted by their disparity values. The disparity value, which repeats the most (has the most votes), is denoted as $\hat{d'}_{Lp}$, its repeating frequency is denoted as $F_p(\hat{d'}_{Lp})$, the number of reliable pixels are denoted as S_p^r and the total number of pixels in its support region are denoted as S_p. The disparity value of outlier pixel p is then replaced with $\hat{d'}_{Lp}$ if these inequations hold true: $\frac{F_p(\hat{d'}_{Lp})}{S_p^r} > \sigma_F$, $\frac{S_p^r}{S_p} > \sigma_S$. If not, the p's disparity will be updated with nearest reliable disparity [19] in its support region.

These parameters are given in Table I, which will be kept constant in all the following experiments.

TABLE I: EXPERIMENT PARAMETERS.

K	σ_{dc}	σ_{ds}	σ_F	σ_S
1.12	12	10	0.4	0.55

III. EXPERIMENTS

A. Platform and CUDA Employments

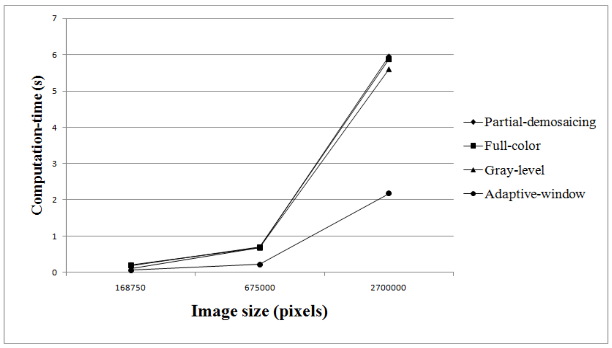
Our experiments are carried out both on CPU and GPU. For the CPU, it is a Intel(R) Core(TM)2 Duo CPU E8400, 3.00GHz, each of the two cores with a cache of 6144KB. The GPU used in the experiments is a GPU GeForce GTX 570 of NVIDIA. It has 15 multiprocessors of 32 cores, the total amount of global memory is 1280 Mb (constant memory 65536 Kb, shared memory per block 49152 Kb). The system, on which the experiment is evaluated, is Ubuntu 11.04, 32 bits.

The programming interface we used for parallel computation on GPU is the Compute Unified Device Architecture (CUDA). The parallel computation work is realized by a *kernel* function which is executed concurrently by multiple threads on data elements. All these threads are organized into a two level concepts: *grid* and *block*. A *kernel* has one *grid* which contains multiple *blocks*. Every *block* is formed of multiple threads. The dimension of *grid* and of *blocks* can be one-dimension, two-dimension or three-dimension. The performance of GPU with CUDA is closely related to thread organization and memory accesses, which should attract much attention according to various computation works and GPU platform. Based on our experimental platform, given an image of size $W \times H$, we briefly lay out the CUDA settings and the parameter values mentioned in our algorithm.

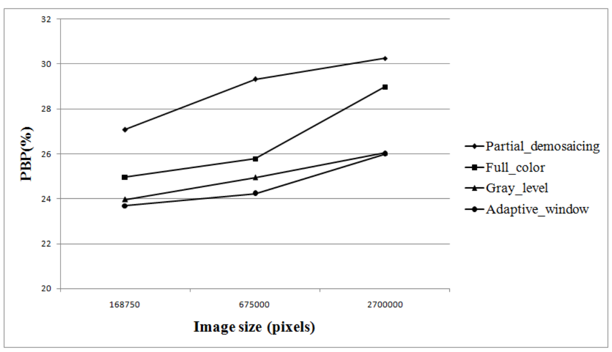
In our experiments, we use two-dimension *blocks* of size 16×16. Every thread takes care of one pixel at the three steps: matching cost computation, aggregation of the matching cost and refinement. So, for the $W \times H$ image, there are three grid each containing $W \times H$ threads distributed to the three matching steps and the size of *grid* is obtained by $\frac{W+16-1}{16} \times \frac{H+16-1}{16}$. In the cost computation step, a *grid* is created with $W \times H$ threads, every thread takes care of one pixel for the matching cost value computation at a set of given disparities. A logical 3D memory space will be employed to store matching costs obtained by this grid for the following steps.

TABLE II: COMPARATIVE EVALUATION ON THE FOUR MIDDLEBURY DATA SETS OF THREE DIFFERENT SIZES BY DIFFERENT GPU PROGRAMMING VERSIONS. 'COMPUTATION TIME (CT)' AND 'PERCENTAGE OF BAD PIXELS (PBP)' .

		Partial_Demosaiced		Full_Color		Gray_level		GPU_Ada	
Image	Size	PBP	CT (s)	PBP	CT (s)	PBP	CT (s)	PBP	CT (s)
Rocks1	Small size	28.76	0.214	25.81	0.191	24.58	0.146	24.28	0.068
	Half size	32.24	0.679	27.87	0.715	25.82	0.913	24.91	0.239
	Full size	37.06	5.811	31.20	5.717	28.93	8.235	28.40	2.275
Aloe	Small size	27.08	0.214	24.96	0.192	23.96	0.115	23.69	0.063
	Half size	29.33	0.698	25.78	0.697	24.94	0.68	24.22	0.217
	Full size	30.26	5.955	28.98	5.875	26.04	5.595	25.99	2.180
Cones	Small size	39.18	0.234	29.77	0.229	28.76	0.276	18.90	0.079
	Half size	46.98	2.123	37.36	1.548	36.91	3.024	35.26	0.812
	Full size	52.14	20.569	44.85	11.502	45.16	19.881	44.18	6.159
Teddy	Small size	45.27	0.23	32.23	0.23	29.86	0.284	23.67	0.112
	Half size	53.69	2.12	38.38	1.55	37.77	3.246	36.09	0.999
	Full size	57.36	27.09	46.58	11.51	47.37	24.922	45.98	6.783
Avg.		39.95	5.495	32.82	3.330	31.68	5.610	28.84	1.666



(a) Comparison on computation-time (s).



(b) PBP(%) comparison results.

Fig. 2: Comparison of the methods on the 'Aloe' image pair.

In the cost aggregation step, a second *grid* of size $W \times H$ is created, so that each pixel has one thread to take care of its matching cost aggregation and then the Winner-Takes-All processing aiming at a winner pixel from a set of candidate pixels, which will be the estimated disparity at the pixel. Here, data reuse with shared memory is considered in this step to reduce the accesses into the global memory space for saving time.

For the simple refinement, the platform does the executions concurrently on the estimated disparity images, a third *grid* of size $W \times H$ is employed to make sure that each pixel has one thread for its refinement processing.

B. Experimental Results

We test our method on the standard image pairs from the Middlebury datasets. Firstly, we take into the test these four pairs of three different sizes (measured in pixels):

- Small size: Rocks1: 425×370; Aloe: 427×370; Cones: 450×375; Teddy: 450×375
- Half size: Rocks1: 638×555; Aloe: 641×555; Cones: 900×750; Teddy: 900×750
- Full size: Rocks1: 1276×1110; Aloe: 1282×1110; Cones: 1800×1500; Teddy: 1800×1500

We first compare our method with three other methods that we implement also on GPU. These methods are the partial demosaicing matching method originally proposed by Halawana [20] and the classic fixed windows matching method, treating full color image and gray-level image separately. The results are shown in Table II. The PBP column reports the percentage of bad pixels, whereas the Computation Time (CT) column reports the computation time in seconds. We can verify that our adaptive method competes with the other ones on all these four pairs both in matching quality and in computation time, as it is shown in Fig. 2 more intuitively. Better performance comes from a new support region and different structure of computation, in comparing with the other methods. The other three methods use square window for cost aggregation. They always have the problem of adjusting the window size: small windows do not contain enough information to allow a correct matching or for a unique minimum in the matching cost, while at the opposite, too large aggregation windows may cover image regions containing pixels with different disparities, which violates the assumption of constant disparity inside the aggregation window. The upright cross support region used in this method has no such weakness. Here, the cost aggregation window could be well adjusted to make sure that only those useful pixels are covered, and it could be big enough to have sufficient information for a good

 ISBN: 978-1-61208-310-0

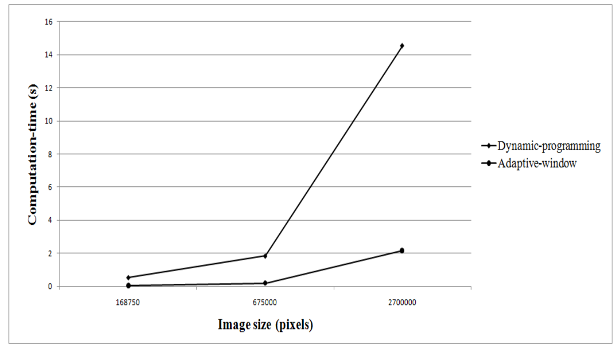
stereo matching result, which offers important contribution to matching quality. Meanwhile, the cost computation, the cost aggregation are organized into two different CUDA *girds*, each does a part of the stereovision work. This partition leads to less memory coalescence but better profit from GPU's massive mathematical capacity, feeding back a short running time. It is worth noting that near-real time computation is achieved for the small size images, since computing time may reduce to about less than 100 ms. Our method puts most of the data on the global memory space and carefully treats the coalescence of memory access with proper programming structures and adapted usage of cached memory space of GPU such as shared memory and texture memory for intermediary data, which makes our method be very extensible and scalable for large image pairs.

TABLE III: COMPARATIVE EVALUATION ON THE FOUR MIDDLEBURY DATA SETS OF THREE DIFFERENT SIZES BY DP AND OUR METHOD. 'COMPUTATION TIME (CT) ' AND 'PERCENTAGE OF BAD PIXELS (PBP)' .

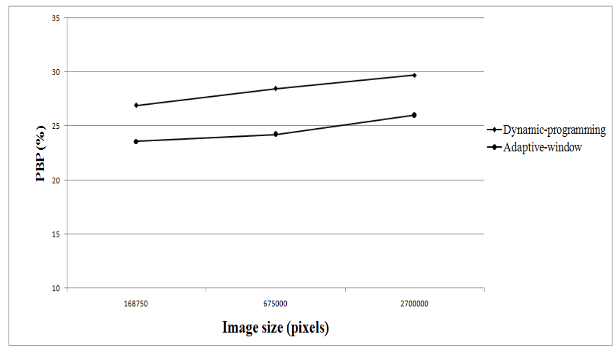
Image	Size	CPU_DP PBP	CPU_DP CT (s)	GPU_Ada PBP	GPU_Ada CT (s)
Rocks1	Small size	25.49	0.509	24.28	0.068
	Half size	27.71	1.811	24.91	0.239
	Full size	27.85	14.194	28.40	2.275
Aloe	Small size	26.90	0.544	23.69	0.063
	Half size	28.46	1.842	24.22	0.217
	Full size	29.72	14.534	25.99	2.180
Cones	Small size	21.57	0.583	18.90	0.079
	Half size	28.89	4.903	35.26	0.812
	Full size	35.32	37.736	44.18	6.159
Teddy	Small size	20.80	0.590	23.67	0.112
	Half size	27.95	4.881	36.09	0.999
	Full size	33.51	37.704	45.98	6.783
Avg.		27.85	9.986	28.84	1.666

We also compare our method with a standard Dynamic Programming (DP) matching method that we implement on CPU, and the results are presented in Table III, and in Fig. 3 more intuitively. These two methods can achieve similar matching quality but our method outperforms the dynamic-programming method in computation time with about five to ten times acceleration. On the four small size image pairs, the dynamic-programming method can finish its work in less than half a second, however, our system does have work done in 100 milliseconds.

Finally, some disparity results are presented in Fig. 4. These results concern the four images allowed in the Middlebury database for general comparison and ranking. These images are the small size images *Tsukuba*, *Venus*, *Teddy* and *Cones*. The ranking evaluations is shown in Fig. 5. Our method gives back the best results for the *Venus* image pair among the four image pairs. Generally speaking, the matching quality of the method is not very competitive in comparing to some other very sophisticated methods on CPU, especially for the *Tsukuba* image pair, in some regions of this image pair, near the shoulder or the lamp for example, the color is too dark and the color components' values are far out of the ordinary, which become as the noises to the matching method. Different from the methods on CPU, which take at least half a second to do the stereo matching, our method requires only 0.017 seconds for *Tsukuba* pair, 0.053 seconds for *Venus* pair, 0.079 seconds for *Cones* pair and 0.112 seconds for *Teddy* image pair.



(a) Comparison on computation-time (s).



(b) PBP(%) comparison results.

Fig. 3: Comparison to Dynamic Programming on 'Aloe' image pair.

IV. CONCLUSION

This paper presented a stereo matching method suitable to GPU's parallel architecture with good performance when looking at the trade-off between accuracy and computation time. The method is formed of three steps: SAD-ALD cost measure, cost aggregation in adaptive window in cross-based support regions and a refinement step to reduce the matching errors in the disparity results. Every step is well organized so that this method can be adopted efficiently by the GPU's parallel architecture. Experiment results show the accuracy and the efficiency of this method: this method can handle some pairs of images from Middlebury database within roughly 100 milliseconds with acceptable matching quality both in non-occluded regions and depth discontinuities. Furthermore, the approach scales well as the image size increases.

Although the running time is short, the implementation in real time is still a great challenge. As the cost aggregation step takes the biggest proportion of running time, looking for a more efficient way to further accelerate cost aggregation and finding out a set of robust experiment parameters to improve matching quality can be interesting topics for future studies.

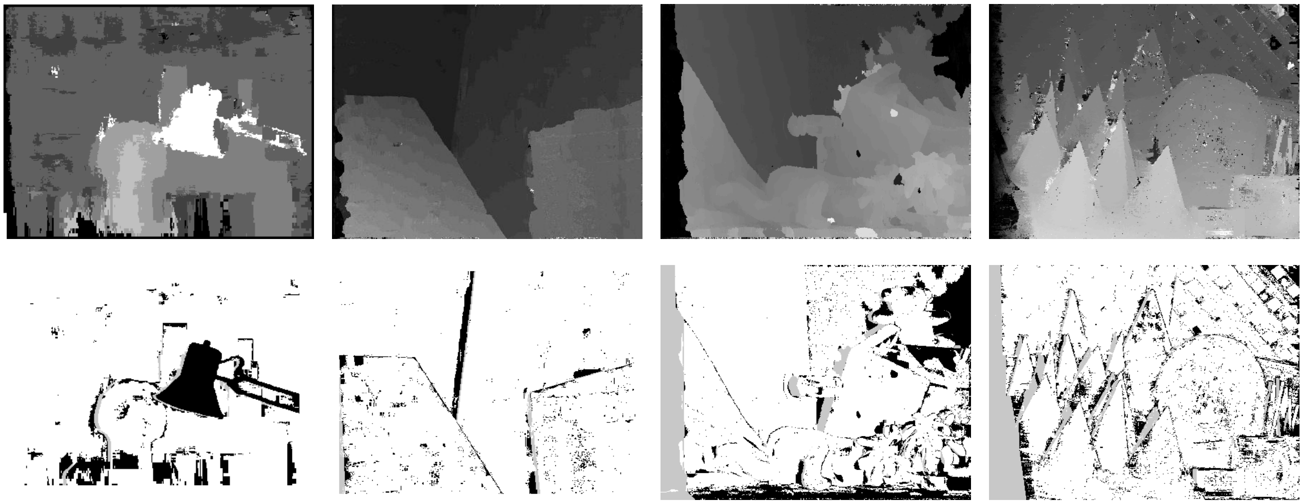


Fig. 4: Matching results for the four basic Middlebury image pairs: Estimated disparity map (first row) and disparity matching error maps (second row) with threshold 1 where the errors in unoccluded and occluded regions are marked in black and gray respectively.

Algorithm	Avg. Rank	Tsukuba ground truth			Venus ground truth			Teddy ground truth			Cones ground truth			Average Percent Bad Pixels
		nonocc	all	disc	nonocc	all	disc	nonocc	all	disc	nonocc	all	disc	
FW-DLR [129]	141.4	4.87 139	5.89 133	22.9 148	2.50 130	3.22 128	18.3 132	18.2 149	18.7 130	37.2 150	24.2 153	27.9 152	42.1 153	18.8
SO [1c]	142.9	5.08 141	7.22 145	12.2 113	9.44 150	10.9 150	21.9 139	19.9 151	28.2 153	26.3 135	13.0 147	22.8 150	22.3 141	16.6
MI-nonpara [85]	145.2	5.59 145	7.54 147	18.8 139	7.50 146	8.99 146	35.0 150	17.4 146	25.7 149	36.9 149	10.2 140	19.9 143	22.6 143	18.0
OUR METHOD	145.8	14.4 153	15.5 153	38.2 153	4.60 141	5.95 142	28.3 146	16.3 142	23.9 142	30.8 143	12.1 144	21.7 147	22.9 144	19.6
PhaseDiff [23]	146.2	4.89 140	7.11 143	16.3 131	8.34 149	9.76 149	26.0 144	20.0 152	28.0 152	29.0 141	19.8 152	28.5 153	27.5 149	18.8
STICA [16]	146.4	7.70 151	9.63 152	27.8 150	8.19 148	9.58 147	40.3 153	15.8 140	23.2 141	37.7 151	9.80 137	17.8 136	28.7 151	19.7
Rank+ASW [84]	146.5	6.51 149	8.43 149	19.7 141	10.5 152	12.0 152	32.7 148	15.7 139	24.1 144	32.8 145	14.1 148	23.1 151	21.7 140	18.4
LCDM+AdaptWgt [75]	146.8	5.98 148	7.84 148	22.2 146	14.5 153	15.4 153	35.9 151	20.8 153	27.3 151	38.3 152	8.90 134	17.2 135	20.0 137	19.5
Infection [10]	148.1	7.95 152	9.54 151	28.9 152	4.41 140	5.53 140	31.7 147	17.7 147	25.1 148	44.4 153	14.3 149	21.3 146	38.0 152	20.7

Fig. 5: The rankings in the Middlebury datasets with the error percentages in different regions.

REFERENCES

[1] A. Hosni, M. Gelautz, and C. Rheman, "Local stereo matching using geodesic support weights," *Proc ICIP*, pp. 2093–2096, 2009.

[2] F. Tombari, S. Mattoccia, and L. D. Stefano, "Segmentation-based adaptive support for accurate stereo correspondence," *Proc PSIVT*, pp. 427–438, 2007.

[3] K. J. Yoon and I. S. Kweon, "Adaptive support-weight approach for correspondence search," *IEEE TPAMI*, pp. 650–656, 2006.

[4] R. Szeliski and et al., "A comparative study of energy minimization methods for markov random fields with smoothness-based priors," *IEEE TPAMI*, pp. 1068–1080, 2008.

[5] Z. Wang and Z. Zheng, "A region based stereo matching algorithm using cooperative optimization," *Proc. CVPR*, pp. 1–8, 2008.

[6] A. Klaus, M. Sormann, and K. Karner, "Segment-based stereo matching using belief propagation and a self-adapting dissimilarity measure," *ICPR*, pp. 15–18, 2006.

[7] Q. Yang, L. Wang, R. Yang, H. Stewenius, and D. Nister, "Stereo matching with color-weighted correlation, hierarchical belief propagation and occlusion handling," *IEEE TPAMI*, pp. 492–504, 2009.

[8] H. Hirschmuller, "Stereo processing by semiglobal matching and mutual information," *IEEE TPAMI*, pp. 328–341, 2008.

[9] A. Hosni, M. Bleyer, and M. Gelautz, "Near real-time stereo with adaptive support weight approaches," *Proc. 3DPVT*, 2010.

[10] J. Liu and J. Sun, "Parallel graph-cuts by adaptive bottom-up merging," *Proc. CVPR*, pp. 2181 – 2188, 2010.

[11] Y. Wei, C. Tsuhan, F. Franz, and C. H. James, "High performance stereo vision designed for massively data parallel platforms," *IEEE TCSVT*, pp. 1–11, 2010.

[12] Q. Yang, C. Engels, and A. Akbarzadeh, "Near real-time stereo for weakly-textured scenes," *Proc. BMVC*, pp. 80–87, 2008.

[13] C. Rhemann, A. Hosni, M. Bleyer, C. Rother, and M. Gelautz, "Fast cost-volume filtering for visual correspondence and beyond," *Proc. CVPR*, 2011.

[14] X. X. Mei, " On building an accurate stereo matching system on graphics hardware," *GPUCV*, 2011.

[15] S. A. N. Brad Hiebert-Treuer and D. Scharstei, "2006 Stereo Datasets," *http://vision.middlebury.edu/stereo/data/scenes2006/*, [accessed: 2013-10-14].

[16] K. Zhang, J. Lu, and G. Lafruit, "Cross-based local stereo matching using orthogonal integral images," *IEEE TCSVT*, pp. 1073–1079, 2009.

[17] "Bayer filter," *http://en.wikipedia.org/wiki/Bayer_filter*, March 2012.

[18] X. Sun, X. Mei, S. Jiao, M. Zhou, and H. Wang, "Stereo matching with reliable disparity propagation," *Proc. 3DIMPVT*, pp. 132–139, 2011.

[19] D. Scharstein and R. Szeliski, "A taxonomy and evaluation of dense two- frame stereo correspondence algorithms," *International Journal of Computer Vision*, pp. 7–42, 2002.

[20] H. Halawana, "Partial demosaicing of CFA images for stereo matching," Ph.D. dissertation, Université de Lille 1, 2010.

Partial Demosaicing for Stereo Matching of CFA Images on GPU and CPU

Naiyu ZHANG, Jean-Charles CREPUT, Hongjian WANG, Cyril MEURIE and Yassine RUICHEK
IRTES-SET, University of Technology of Belfort-Monbeliard, Belfort, France
Email: {naiyu.zhang, jean-charles.creput, hongjian.wang, cyril.meurie, yassine.ruichek}@utbm.fr

***Abstract*—This paper presents a GPU implementation of a partial demosaicing scheme that is specially designed for stereo matching of CFA image. This method consists of three main techniques keys: the adapted matching cost for CFA image, the estimated Second color component based on Hamilton's estimate method and a robust cost aggregation window. Experiments are carried out to explore the performance for this method on GPU both at matching quality and matching efficiency, with comparison with version on CPU. The experiments on different size image pairs from Middlebury dataset show that this method can be substantially accelerated on GPU when the image size is large and has still space for improvements in performance.**

Keywords: ***GPU, Demaosaicing Stereovision, CFA Image, CUDA***

I. Introduction

In most implementation of stereo matching, such as in intelligent cars and integrated robot systems, color image pairs can be acquired by two types of cameras: the one equipped with three sensors associated with beam splitters and color filters providing the so-called full color images, of which each pixel is characterized in Red, Green and Blue levels, and the one equipped only with a single-sensor.

In the second case, the single-sensor can not provide a full color image directly but actually deliver a color filter array (CFA) image, of which every pixel is characterized by a single color component that can be one of the three color components: Red, Green and Blue. So, the missing color components has to be estimated at each pixel. This process of estimating the missing color components is usually referred to as CFA demosaicing and produces a demosaicing color image where every pixel is represented by an estimated color point [1]. This estimation step brings some artifacts in color density values, so, it is interesting to find one stereo matching directly based on CFA image.

As the demosaicing methods intend to produce demosaiced color images, they attempt to reduce the presence of color artifacts, such as the false colors ot zipper effects, by filtering the images [2]. So, some useful color information for stereo matching may be lost in the color demosaiced images. As a result, the demosaiced color image pairs stereo matching quality usually suffer either from color artifacts or from the alteration of color texture caused by demosaicing schemes.

The method that is used in this paper is an alternative solution to match pixels by analyzing directly the CFA images without reconstructing the full color image by demosaicing processing, but only estimating a second color component. The method is a local dense stereo matching method that was first proposed by Halawana [3]. Here, we study its potential for Graphics Processing Unit (GPU) implementation.

The following contents are organized in three parts. The Section II presents the partial demosaicing matching method including the estimation of the second color component and the adapted matching cost. The Section III describes the experiment platform and CUDA implantation. The Section IV details the experimental results. At the end is a conclusion.

II. Partial Demosaicing Matching Method

A. Second Color Component

The partial demosaicing matching method starts with the mosaiced CFA images. Here, the CFA images are those images obtained according to the Bayer color filter, each two-by-two submosaic contains 2 green, 1 blue and 1 red filter, each covering one pixel sensor and the mosaiced CFA image is the one whose pixel contains only one color component according to the Bayer color filter.

Different from the classic methods, which estimate all the missing color components for every pixel in the CFA images, the partial demosaicing method estimates only one color component, the Second Color Component (SCC), for every pixel. Here, the SCC is defined as the color component that is available in the same line. This means that SCC is the green color for all the red and blue pixels while for the green pixels the SCC is the red color component for even lines and the blue color component for odd lines. Summarized as (1).

$$SCC(x,y) = \begin{cases} \hat{G}(x,y) & \text{for red and blue pixels} \\ \hat{R}(x,y) & \text{for green pixels in even lines} \\ \hat{B}(x,y) & \text{for green pixels in odd lines} \end{cases} \quad (1)$$

B. Hamilton's Estimate Method

This method is an edge-adapted demosaicing method presented by Hamilton and Adams [4]. To select the interpolation direction, this method takes into account both gradient and Laplacian second-order values by using the green levels available at nearby pixels and red (or blue) samples located two apart.

We take the case GRG, as illustrated in Fig. 1, as example, to estimate the missing green level at the red pixels, this method uses the following algorithm:

a) Approximate the horizontal Δ^x and vertical Δ^y gradients thanks to absolute differences as (2).

b) Interpolate the green level as (3).

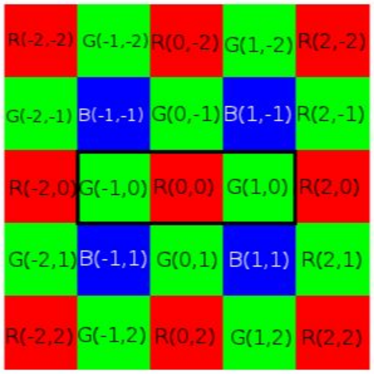


Fig. 1: Estimation of SCC in case of GRG.

$$\begin{cases} \Delta^x = |G_{-1,0} - G_{1,0}| + |2R - R_{-2,0} - R_{2,0}| \\ \Delta^y = |G_{0,-1} - G_{0,1}| + |2R - R_{0,-2} - R_{0,2}| \end{cases} \quad (2)$$

$$\hat{G} = \begin{cases} \frac{G_{-1,0}+G_{1,0}}{2} + \frac{2R-R_{-2,0}-R_{2,0}}{4} & \text{if } \Delta^x < \Delta^y \\ \frac{G_{0,-1}+G_{0,1}}{2} + \frac{2R-R_{0,-2}-R_{0,2}}{4} & \text{if } \Delta^x > \Delta^y \\ \frac{G_{-1,0}+G_{1,0}+G_{0,-1}+G_{0,1}}{4} & \\ \quad + \frac{4R-R_{-2,0}-R_{2,0}-R_{0,-2}-R_{0,2}}{8} & \text{if } \Delta^x = \Delta^y \end{cases} \quad (3)$$

Since this method well combines two color component data in partial derivate approximations by exploiting spectral correlation in the green plane estimation, the precision is well guaranteed.

Each pixel with coordinates (x, y) in the partially demosaiced color images is characterized by a two-dimensional partial color denoted $\hat{I}_{PA}$. As shown in (4), this partial color point is composed of the available color component and the estimated second color component.

$$\hat{I}_{PA}(x,y) = \begin{cases} (R(x,y), \hat{G}(x,y))^T & \text{if x is odd and y is even} \\ (\hat{R}(x,y), G(x,y))^T & \text{if x is even and y is even} \\ (\hat{G}(x,y), B(x,y))^T & \text{if x is even and y is odd} \\ (G(x,y), \hat{B}(x,y))^T & \text{if x is odd and y is odd} \end{cases} \quad (4)$$

C. Adapted Matching Cost

The method is a local dense stereo matching method also called window-based approach. It respects the very assumption that the color information of neighbors of a left pixel is close to those of the same neighbors of its homologous right pixel in the right image. So, the matching costs are defined between the window around the left pixel and the window around the candidate right pixels in the corresponding line (epipolar line) in the right image. The window is shifted over all possible pixels so that a matching cost between the left pixel and each candidate in the right image is obtained. By the Winner-Takes-All method, the final disparity estimation is realized by selecting the window with the lowest matching cost.

The matching cost, SSD (Sum of Squared Differences cost), is adapted as (5).

$$SSD^{\omega}(x_l, y, s) = \sum_{i=-\omega}^{\omega} \sum_{j=-\omega}^{\omega} \| \hat{I}_{lPA}(x_l + i, y + j) - \hat{I}_{rPA}(x_l + i - s, y + j) \|^2 \quad (5)$$

Where the $\| \bullet \|$ is the Euclidean norm. While s is the spatial shift along the horizontal epipolar line and ω the half-width of the $(2\omega + 1) \times (2\omega + 1)$ aggregation window.

Since these pixels of horizontal lines with the same parity in the left and right partially demosaiced color images are characterized by the same two color components, we can reasonably assume that the partial color points of two homologous pixels are similar. Because the partial costs compare the partial color points of left and right pixels located on the same horizontal lines, they reach an extremum when the shift is equal to the disparity.

III. Experiment

A. Experiment Platform and CUDA Implementation

We implement on GPU the partial demosaiced matching method of H. Halawana [3]. We use the well known Middlebury databases [5] to evaluate the method on both accuracy and computation time, as the image size grows. It is worth noting that the method was only implemented in a sequential computer (CPU) with no systematic evaluation of the trade-off between quality and computation time. The ten datasets used in our experiments are entitled *'Aloe', 'Bowling1', 'Cloth1', 'Flowerpots', 'Lampshade1', 'Midd1', 'Monopoly', 'Plastic', 'Rocks1'* and *'Wood1'*. All the datasets of 2 views are used here (full-size (width: 1240...1396, height: 1110), half-size (width: 620...698, height: 555), and third-size (width: 413...465, height: 370)) . In these datasets, the color stereo images are acquired by high resolution cameras equipped with one-single-sensor [6]. That's to say, the full color images are in fact color images that have been demosaiced by a specific chip integrated in the camera. They could contain artifacts caused by the demosaiced step. What's more, the work of applying a demosaicing step on CFA images, which have been generated by sampling color components from these previously demosaiced color images involves applying two successive demosaicing steps on the CFA images acquired by the camera. However, since Middlebury is the most frequently utilized database, an evaluation on this database will allow future comparative evaluation with new methods.

Our experiments are carried out both on CPU and GPU. For the CPU, we use a Intel(R) Core(TM)2 Duo CPU E8400 of 3.00GHz, with two cores having a cache of 6144KB. The GPU used in the experiments is a GPU GeForce GTX 570 of NVIDIA. It has 15 multiprocessors of 32 cores, GPU clock speed 1.54GHz, Memory clock rate 2000MHz, Memory Bus width 320 bits while the total amount of global memory is 1280 Mb (constant memory 65536 Kb, shared memory per

 ISBN: 978-1-61208-310-0

block 49152 Kb). The system, on which the experiment is evaluated is Ubuntu 11.04 32 bits.

The programming interface we used for parallel computation on GPU is the Compute Unified Device Architecture (CUDA). The parallel computation work is realized by a *kernel* function, which is executed concurrently by multiple threads on data elements. All these threads are organized into a two level concepts: *grid* and *block*. A *kernel* has one *grid*, which contains multiple *blocks*. Every *block* is formed of multiple threads. The dimension of *grid* and of *blocks* can be one-dimension, two-dimension or three-dimension. The performance of GPU with CUDA is closely related to thread organization and memory accesses, which should attract much attention according to various computation works and GPU platform. Based on our experiment platform, given an image of size $W \times H$ as example and briefly lay out the CUDA settings and the parameter values mentioned in our algorithm.

In our experiments, we use the two-dimension *blocks* of 16×16 size. Every thread takes care of one pixel and the size of *grid* is obtained by $\frac{W+16-1}{16} \times \frac{H+16-1}{16}$ for a given $W \times H$ image. In the SCC estimation step, a grid of $W \times H$ threads is created and each thread takes care of one pixel in the estimation, and the shared memory is employed to for fast memory access. For the matching cost computation, a grid of $W \times H$ threads is employed to compute the matching cost for every pixel at a set of given disparity and then pick out the best homologous candidate pixel by the Winner-Takes-All method, here, the main data is stored on Global memory space while the shared memory space is used to support the computation of matching cost and the comparison in WTA processing.

B. Experiment Process

The procedures on CPU and on GPU are almost the same.

As the datasets are all full color images, at the very beginning of the experiments, a simulation step for every pair of images is realized to obtain their CFA images needed by keeping only one of the three color components at every pixel. This work is done by GPU and by CPU separately . The whole evaluation is performed according to the spatial arrangement of the Bayers CFA. Then, for every CFA image, we do partial demosaicing step. Here, the partial demosaicing estimates only the missed Second Color Component (SCC) for every pixel by Hamilton's estimate method in the left image and in the right image. So, the left demosaiced color image and the right one are produced. The estimation method is the edge-adaptive demosaicing method proposed by Hamilton as presented in the precedent section.

The original full color image is shown in Fig. 2(a) and the left demosaiced color image using Hamiltons method is shown in Fig. 2(c). They look somewhat similar. However, zooming on the square areas outlined in these images as presented in Fig. 2(b) and Fig. 2(d), shows that textured areas are locally different.

Then the local stereo matching algorithm and the Winner-Takes-All method are taken into actions. In this step, as shown in Fig. 3 for every pixel in the left image, the method finds out its homologous pixel from a group of candidate pixels in the right image and compute their disparity s by computing the matching cost SSD, which is modified to adapt to the partial demosaiced color images.

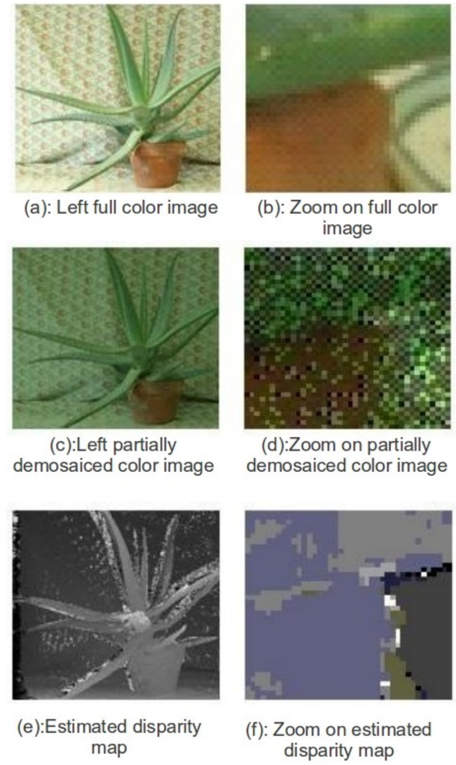


Fig. 2: 'Aloe' left image.

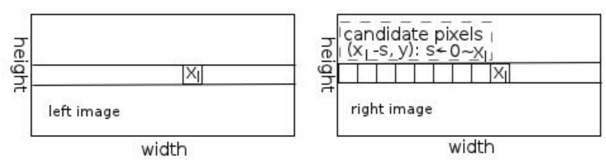


Fig. 3: matched pixel and its candidate ones in the right image.

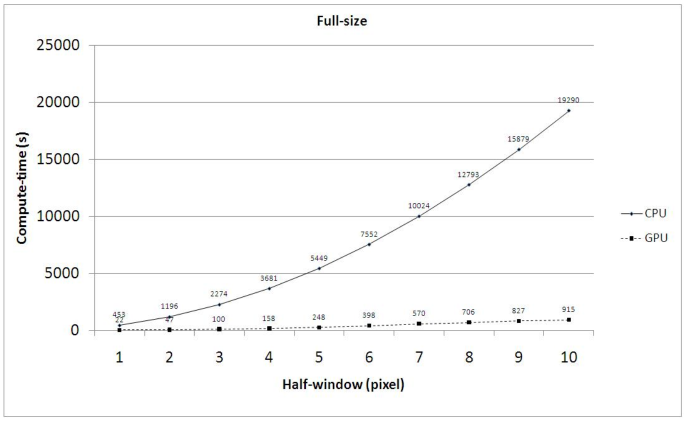
A matching is considered as valid when the absolute difference between the estimated disparity and the given benchmark $d_l^{\omega}(x_l, y)$ is lower or equal to δ, which is the disparity error tolerance. In the experiments we set this coefficient to 1.

At the end, a disparity map, as illustrated in Fig. 2(e), is estimated for each pair of image.

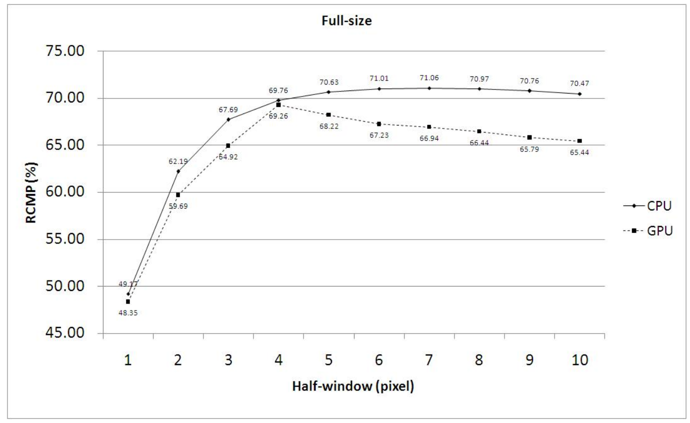
IV. Experimental Results and discuss

The experiment are executed on all the ten chosen datasets. Here, we take the 'Aloe' image group as an example. As it is shown in Fig. 4 that with the increase of the half-window, the computation time increases significantly. When the half-window is given as ω, for every pixel in the left image and for their every possible candidate pixel in the right image, we should compute a group of $(2\omega+1) \times (2\omega+1)$ pixels to obtain the matching cost. So, when the half-window ω increases, the

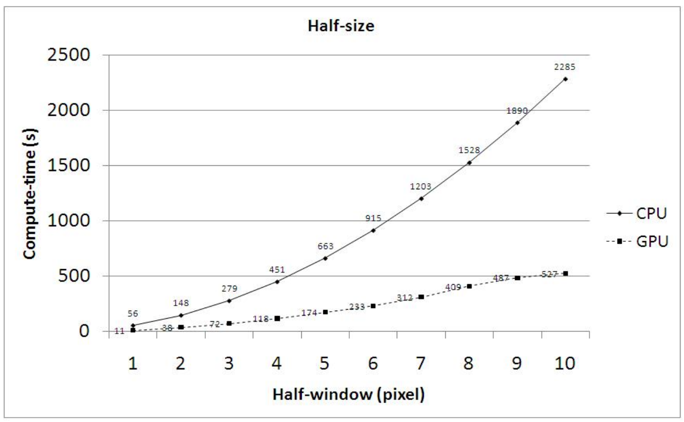
 ISBN: 978-1-61208-310-0



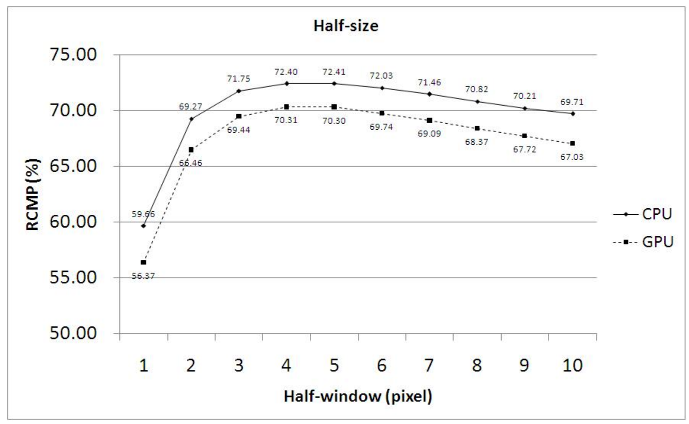
(a) Compute-time of GPU and CPU on full size datasets



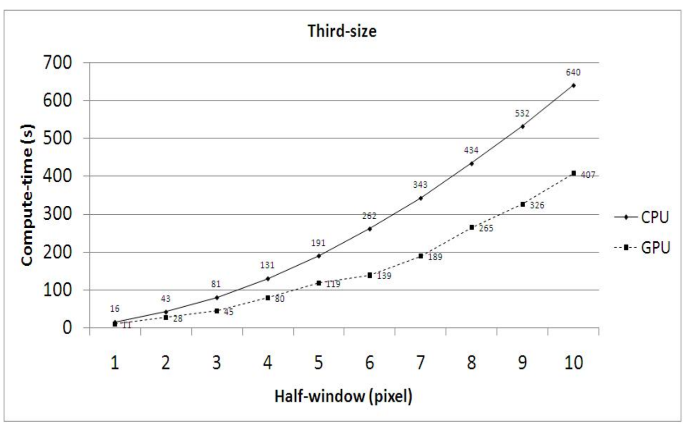
(b) RCMP of GPU and CPU on full size datasets



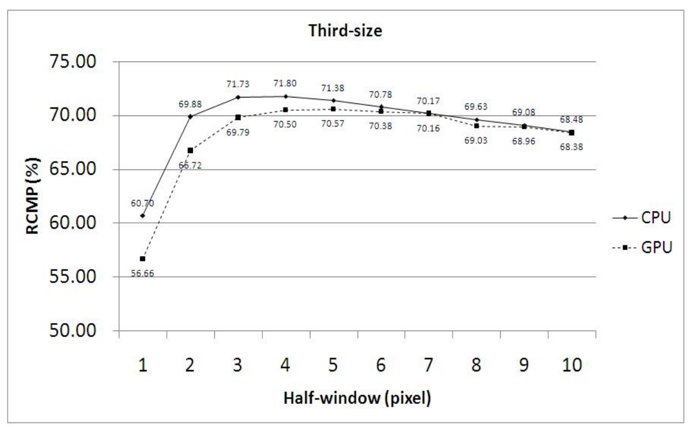
(c) Compute-time of GPU and CPU on half size datasets



(d) RCMP of GPU and CPU on half size datasets



(e) Compute-time of GPU and CPU on third size datasets



(f) RCMP of GPU and CPU on third size datasets

Fig. 4: Compute-time and rate of correctly matched pixels (RCMP) obtained with the adapted SSD computed on the full sizeAloe stereo image pair for δ set to 1.

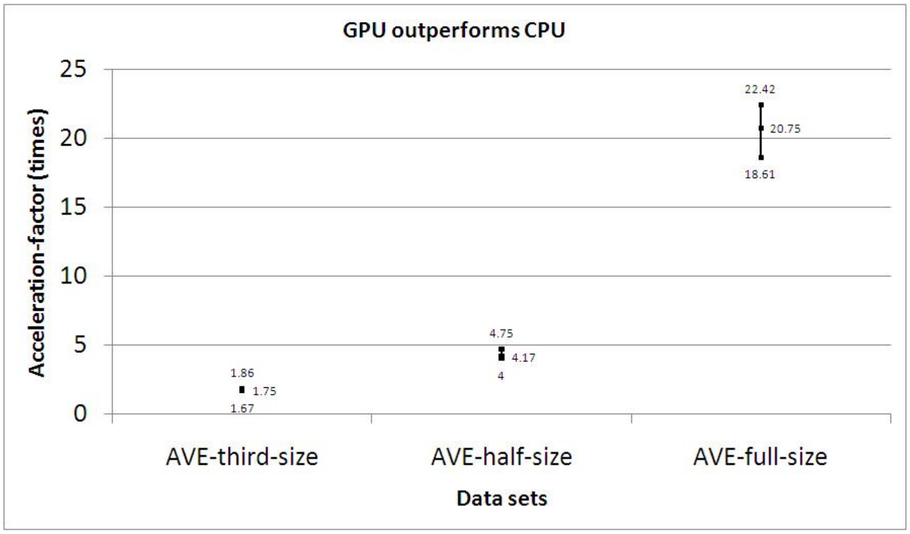


Fig. 5: GPU outperforms CPU in terms of computation time. The maximum, the minimum and the average acceleration factor obtained in the executions on 'Aloe' image pair based on half-window from 1 to 10 are marked. The acceleration increases along with the image dimensions.

TABLE I: COMPARATIVE EVALUATION ON THE FOUR MIDDLEBURY DATA SETS OF THE THREE DIFFERENT SIZES BY DIFFERENT GPU PROGRAMMING VERSION. 'COMPUTATION TIME (CT) ' AND 'PERCENTAGE OF BAD PIXELS (PBP)' .

Image	Size	Partial_Demosaiced		Full_Color		Gray_level	
		PBP	CT (s)	PBP	CT (s)	PBP	CT (s)
Rocks1	Third size	28.76	0.214	25.81	0.191	24.58	0.146
	Half size	32.24	0.679	27.87	0.715	25.82	0.913
	Full size	37.06	5.811	31.20	5.717	28.93	8.235
Aloe	Third size	27.08	0.214	24.96	0.192	23.96	0.115
	Half size	29.33	0.698	25.78	0.697	24.94	0.68
	Full size	30.26	5.955	28.98	5.875	26.04	5.595
Cones	Third size	39.18	0.234	29.77	0.229	28.76	0.276
	Half size	46.98	2.123	37.36	1.548	36.91	3.024
	Full size	52.14	20.569	44.85	11.502	45.16	19.881
Teddy	Third size	45.27	0.23	32.23	0.23	29.86	0.284
	Half size	53.69	2.12	38.38	1.55	37.77	3.246
	Full size	57.36	27.09	46.58	11.51	47.37	24.922
Avg.		39.95	5.495	32.82	3.330	31.68	5.610

computing complexity is a squared function of ω, which is a real challenge to the capacity of the processors.

Meanwhile, with the increase of the half-window, and so, the computation intensity, CPU's computation time increases more importantly than GPU's computation time. Moreover, as illustrated in Fig. 5, as the image dimensions augment, the acceleration factor obtained by using GPU has expanded from 1.75 to 20.75. This means that the GPU offers powerful computation capacity in intense computation thanks to the parallel organization of the *blocks* and the threads on GPU.

The performance of GPU is significantly influenced by the dimension of the image. The nearer to the complete load of the employed streaming multiprocessor on GPU, the higher performance we get.

The Ratio of Correctly Matched Pixel (RCMP) is the percentage of the well matched pixels in all the pixels of the image to be matched. As it is shown in Fig. 4, for 'Aloe ' image pair, the RCMP reaches the smooth peak when the half-window is between 4 and 8 (for those textureless image pairs, the half-window should be bigger to have their peak of RCMP). In fact, whatever the image type, the matching performance increases with aggregation window half-width. Small windows do not contain enough information to allow a correct matching. At the opposite, too large aggregation windows may cover image regions containing pixels with different disparities, which explains the decrease of matching

 ISBN: 978-1-61208-310-0

performance. Though on CPU and on GPU, all the single-precision floating-point computations follow the same accuracy standards. The accuracy-loss is more important on GPU owning to the accuracy problem of floating-point, that is why the results by CPU and that by GPU may have some deviations, especially when some cumulations in the computation exists. In our experiments, we use the floating point in the computation of matching cost with SSD and in the aggregation based on fixed support window, the deviation occurs at these computations, which can explain the tolerances between the RCMP by CPU and that by GPU shown in Fig. 4(b).

In addition, this method is also compared with the classic fixed windows matching methods (treating full color image and gray-level image separately) we used in former experiments, the results are shown in Table I. This method performs worse on all these four pairs both in matching quality and in computation time. That is because this method requires too many refers to the logical operations in the programming and too many branches in data treatments, which is the real weakness of GPU architecture. These branches and logical operations lead to great load on to the GPU system when loading data from the memory space and wastes GPU's CUDA cores, which are powerful in arithmetical operation, by making them do logical works.

V. CONCLUSION

This paper presents a GPU implementation of a partial demosaicing scheme specially designed for stereo matching of CFA image. By analyzing the CFA image directly, this method can handle the stereo matching works in case of single-CCD cameras usage. This method has three main techniques characters: the adapted matching cost for CFA image, the estimated Second color component based on Hamilton's estimate method, and the robust cost aggregation window. Experiments carried on show the performance of this method on GPU. The results show that this method can benefit from GPU's parallel architecture. The experiments also show that this method performs faster on GPU as the image size grows. Future improvements should come from a better setting of the memory arrangement in order to allow more coalescing accesses.

REFERENCES

[1] S. Battiato, M. Guarnera, G. Messina, and V. Tomaselli, "Recent patents on color demosaicing," *Recent Patents on Computer Science*, pp. 1(3):194–207, November 2008.

[2] Y. Yang, O. Losson, and L. Duvieubourg, "Quality evaluation of color demosaicing according to image resolution," *Proceedings of the 3rd International Conference on Signal-Image Technology & Internet-based Systems, pages 640–646,Shanghai Jiaotong University, China*, December 2007.

[3] H. Halawana, "Partial demosaicing of CFA images for stereo matching," Ph.D. dissertation, Université de Lille 1, 2010.

[4] J. Hamilton and J. Adams, "Adaptive color plan interpolation in single sensor color electronic camera," *US patent 5,629,734, to Eastman Kodak Co., Patent and Trademark Office, Washington D.C.*, May 1997.

[5] S. A. N. Brad Hiebert-Treuer and D. Scharstei, "2006 Stereo Datasets," *http://vision.middlebury.edu/stereo/data/scenes2006/*, Nov 2006.

[6] D. Scharstein and R. Szeliski, "A taxonomy and evaluation of dense two- frame stereo correspondence algorithms," *International Journal of Computer Vision, 47:7–42*, 2002.

 ISBN: 978-1-61208-310-0

CppSs – a C++ Library for Efficient Task Parallelism

Steffen Brinkmann and José Gracia
High Performance Computing Centre Stuttgart (HLRS)
University of Stuttgart
70550 Stuttgart, Germany
E-mail: {brinkmann,gracia}@hlrs.de

***Abstract*—We present the C++ library CppSs (C++ superscalar), which provides efficient task-parallelism without the need for special compilers or other software. Any C++ compiler that supports C++11 is sufficient. CppSs features different directionality clauses for defining data dependencies. While the variable argument lists of the taskified functions are evaluated at compile time, the resulting task dependencies are fixed by the runtime value of the arguments and are thus analysed at runtime. With CppSs, we provide task-parallelism using merely native C++.**

Keywords–high-performance computing; task parallelism; parallel libraries.

I. Introduction

Programming models implementing task-parallelism play a major role when preparing code for modern architectures with many cores per node and thousands of nodes per cluster. In high performance computing, a common approach for achieving the best parallel performance is to apply the message passing interface (MPI) [1] for inter-node communication and a shared-memory programming model for intra-node parallelisation. This way, the communication overhead of pure MPI applications can be overcome.

Shared memory models are also crucial when using single node computers as there are systems consisting of hundreds or even thousands of processing units accessing the same memory address space. These systems offer great parallelism to the developer. But utilising the processing units evenly, so that they can run efficiently, is a non-trivial task.

Many scientific applications are based on processing large amounts of data. Usually, the processing of this data can be split up and some of these chunks have to be executed in a well defined order while others are independent. This is the level on which task based programming models are employed. We will call the chunks of work to be processed tasks, while the appearances in the code (e.g., if they are implemented as functions, methods or subroutines) are going to be called task instances.

The dependencies between tasks can be stated explicitly by the programmer or inferred automatically by some kind of preprocessing of the code. In the case of fork-join-models (e.g. OpenMP [2]), all tasks after a "fork" are (potentially) parallel while code after the "join" and all consecutive forks depend on them. For example, in figure 1a), tasks 2, 3 and 4 can run in parallel, if sufficient processing units are available. Task 5 cannot be executed before all other tasks have finished. In programming models which support nesting (e.g. Cilk [3]), the dependencies can sometimes be derived from the placement of the calls (see Figure 1b)).

In many implementations of task based programming models, the data dependencies are specified explicitly by the programmer (e.g. SMPSs [4], OMPSs [5], StarPU [6] and XKAAPI [7]). This allows for more complex dependency graphs and therefore more possibilities to adjust the parallelisation to the code, the amount of data and the architecture. However, these implementations suffer from a number of disadvantages:

- The tasks and/or task instances and their dependencies have to be marked by special directives, usually within a `#pragma` in C or using special comments in Fortran. These use keywords and syntax which is not part of the actual language and which the programmer needs to learn.
- In order to compile the instrumented code, the programmer needs a special compiler or preprocessor. She depends on this additional software to be available on the desired platform, which is not generally the case.
- The need for special compilers also poses additional work to system administrators who will be asked by the programmer to install the specific compiler used in the application.
- The code of the programming model implementation itself becomes more difficult to maintain and usually at least one additional compile step is introduced when compiling the user code.

In order to avoid these inconveniences, we developed a pure C/C++ library, which allows functions to be marked as tasks and to execute them asynchronously. The programmer still needs to prepare the code looking for the parts feasible for parallelisation and separate them into functions. Also, it is still necessary to instrument the code with the CppSs API. But contrary to the implementations mentioned above, this is achieved using standard C++11 syntax instead of an "imposed" pragma language.

To execute the application serially, e.g. for debugging, the programmer can define the macro `NO_CPPSS`, which bypasses the creation of additional threads and converts the tasks instances into normal function calls.

In the following, we will illustrate the usage (Section II) and present the basic implementation of the library CppSs (Section III). Lastly, we will sum up our conclusions in Section IV.

 ISBN: 978-1-61208-310-0

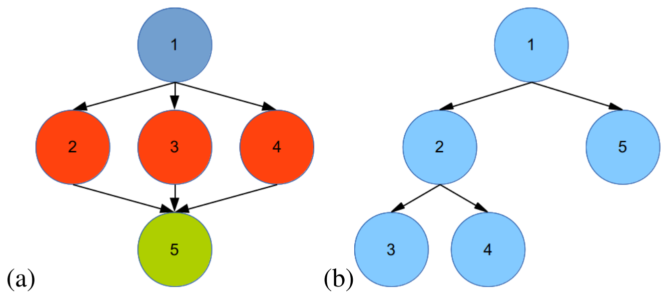


Fig. 1. (a) Example of fork-join-parallelism. After task 1 the execution thread is forked. (b) Example of nested parallelism. Task 1 spawns tasks 2 and 5. Before task 5 is created, task 3 and 4 are spawned, hence the numbering.

```
void func1(int *a1, double *a2, double *b)
{
        //...
}
auto func1_task = CppSs::MakeTask(func1,
                                  {INOUT,IN,OUT},
                                  "func1");
```

Fig. 2. Defining and taskifying a function. The return value is a functor, i.e., an object which overloads the parenthesis operator. Hence it can be "called" like a function.

II. CppSs - usage

CppSs is a library which compiles on any system with a working C++ compiler. The C++11 features necessary for CppSs are provided by the GNU compiler of version 4.6 or higher and the Intel compiler of version 13 or higher.

In order to use CppSs, the programmer only needs to include the header `CppSs.h` and link against the library `libcppss.so`. All of CppSs' application programming interface (API) functions are declared in the namespace `CppSs` to avoid overlap with other libraries' functions. In the following, the CppSs API is introduced presenting the declaration of tasks (Section II-A), the initialisation and finishing of the parallel execution (Section II-B) and setting barriers (Section II-C). Finally, we will give a minimal example putting everything together in Section II-D.

A. Declaring Tasks

Parallelisation with CppSs relies on functions with well defined directionality of their parameters. Loop parallelisation and anonymous code blocks are not supported.

To convert a function into a task, the programmer has to call the API function `MakeTask`, which takes the following parameters (see listing in Figure 2):

- a pointer to the function,
- an initialiser list containing directionality specifiers for each function parameter,
- (optional) a string with the function name for debugging purposes and
- (optional) a priority level, which is ignored in the present version. Future versions will provide one or more priority queues.

```
auto func_task = CppSs::MakeTask(func,
                                 {INOUT,IN,OUT},
                                 "func");
auto func_task = CPPSS_TASK(func,
                            {INOUT,IN,OUT});
CPPSS_TASKIFY(func,{INOUT,IN,OUT})
```

Fig. 3. Convenience macros for task declaration. These three lines translate into the same binary code. Hence only one of them should be used.

It is required that the arguments of the taskified function which are intended to cause dependencies are pointers. These can be used to access arrays, built-in types or any other data structure. However, potential overlap with other data structures is not detected. The directionality specifier must be one of `IN`, `OUT`, `INOUT`, `REDUCTION` or `PARAMETER`. The latter is used for arguments which are not to be interpreted as a potential dependency and must be of a built-in numerical type. The effect of each of the directionality specifiers are described in the following:

a) IN: The task treats this argument as input. It will not be executed until all task instantiations which were called before the function and which write to this argument (i.e. have an `OUT`, `INOUT` or `REDUCTION` specifier for the same argument value) have finished.

b) OUT: The task treats this argument as output. The content of the variable or array pointed to is (possibly) overwritten. This affects functions with an `IN` or `INOUT` specifier for the same argument value.

c) INOUT: The task intends to read from and write to this argument value. It will be dependent on the last task writing to this memory address. The following tasks reading from this memory address will be dependent on this task.

d) REDUCTION: Similar to `INOUT`. The task intends to read from and write to this argument value. In contrast to `INOUT`, the tasks with a `REDUCTION` clause will depend on other tasks with a `REDUCTION` clause on the same argument value.

e) PARAMETER: The argument is treated as a parameter. It will be ignored for the dependency analysis.

The return type of `MakeTask` is an internal template type, which includes the argument types of the taskified function, thus we recommend to use the C++11 keyword `auto`.

For convenience two macros were defined that wrap the call to `MakeTask`. The three calls in Figure 3 are equivalent.

B. Init and Finish

The next instrumentation to be inserted in the application code is calls to `Init` and `Finish`. These calls must be called before and after each task, respectively. While `Finish` takes no arguments, `Init` takes two optional arguments, namely

- the number of threads and
- the reporting level.

The number of threads must be any positive integer. If none is given, the default is 2. The reporting level must be

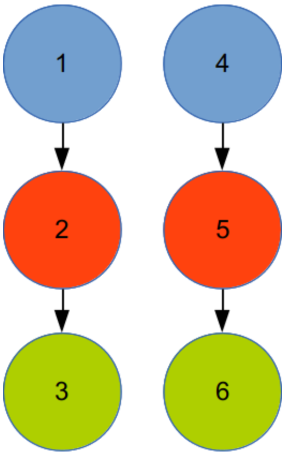


Fig. 4. Task dependency graph of the minimal example in listing in Figure 5. The blue nodes (1 and 4) represent task function `set_task`, the red nodes (2 and 5) `increment_task` and the green nodes (3 and 6) `output_task`.

one of `ERROR`, `WARNING`, `INFO` or `DEBUG`, which causes increasing amount of output. The default is `WARNING`.

`Init` will instantiate a runtime system which enables the queuing and asynchronous execution of tasks. The runtime will create one thread less than the number of threads specified in the call to `Init` as the main thread will also execute tasks. The threads will be constructed using the standard library `std::thread` class. This way portability is granted for each system which provides a C++11 compiler.

`Finish` will wait for all the tasks to be finished and destruct all threads, queues and the runtime.

C. Barriers

With the API function `Barrier` it is possible to halt the main execution thread, i.e. the code outside of tasks, until all tasks instantiated so far have finished. The call takes no arguments. The call to `Finish` contains a call to `Barrier`.

D. Minimal example

To sum up the API usage, we compile everything into a small example, shown in Figure 5. Internally, it produces the dependency graph shown in Figure 4 and prints the output shown in Figure 6.

III. CppSs - Implementation with Variadic Templates

The major design paradigm for CppSs was to avoid usage of external libraries. All code should be compilable with a standard C++ compiler. In order to achieve this goal, several features of C++11 were used, the most prominent one being variadic templates [8]. These are of central importance as the objects representing a task and an instance of a task are implemented as variadic templates, the function arguments of the taskified function being the template arguments. This is necessary because a function which the application programmer wants to taskify can have any number and type of arguments. These arguments are known at compile time, so an

```
#include <iostream>
#include "CppSs.h"

#define N_THREADS 2

void set(int *a, int b)
{
    (*a) = b;
}
CPPSS_TASKIFY(set,{OUT,PARAMETER})

void increment(int *a)
{
    ++(*a);
}
CPPSS_TASKIFY(increment,{INOUT})

void output(int *a)
{
    std::cout << (*a) << std::endl;
}
CPPSS_TASKIFY(output,{IN})

int main(void)
{
    int a[] = {1,11};

    CppSs::Init(N_THREADS,INFO);

    for (unsigned i=0; i < 2; ++i){
        set_task(&(a[i]), i);
        increment_task(&(a[0]));
        output_task(&(a[0]));
    }

    CppSs::Finish();

    return 0;
}
```

Fig. 5. Minimal complete example for CppSs. This code will produce a dependency graph as shown in Figure 4. The output will be similar to listing in Figure 6.

```
- 13:32:45.207 INFO:  ### CppSs::Init ###
- 13:32:45.207 INFO: adding worker: 1 of 2
- 13:32:45.207 INFO: Running on 2 threads.
1
2
- 13:32:45.207 INFO: Executed 6 tasks.
- 13:32:45.207 INFO:  ### CppSs::Finish ###
```

Fig. 6. Output from minimal example from listing in Figure 5.

implementation with variadic templates is the most efficient way to handle variable argument lists.

An excerpt of the `Task_functor` class declaration which stores the taskified function is shown in Figure 7.

In order to process the variable argument list at compile time, recursive template evaluation is necessary. For instance, the set of template functions used to retrieve the types of the task function arguments is shown in Figure 8.

IV. Conclusion

We developed a pure C/C++ library, which allows functions in C/C++ source code to be marked as tasks, specify their dependencies and to execute them asynchronously. Contrary

```
template<typename... ARGS>
class Task_functor : public Task_functor_base
{
    //...
    void (*m_f) (ARGS...);
}
```

Fig. 7. Excerpt from the class declaration of `Task_functor` which stores the taskified function. The member declaration shows the pointer to the actual function with a variable argument list.

```
template <typename fun, size_t i>
struct get_types_helper {
    static void get_types(
        std::vector<std::type_info const*> &types) {
         get_types_helper<fun, i-1>::get_types(types);
         types.push_back(&typeid(typename
            function_traits<fun>::template arg<i-1>::type));
    }
};

template <typename fun>
struct get_types_helper<fun,0> {
    static void get_types(
        std::vector<std::type_info const*> &types) {}
};

template <typename fun>
void get_types(std::vector<std::type_info const*> &types) {
    get_types_helper<fun, function_traits<fun>::nargs>::\
        get_types(types);
}
```

Fig. 8. Template functions to process argument types at compile time. A call to `get_types<function>(types)` will recursively get the type of each of `function`'s arguments and place their type in the array `types`.

to other similar task based programming models like OpenMP, SMPSs or OMPSs, no preprocessor directives are necessary and the instrumented code will compile with any compiler, which supports C++11 features such as variadic templates, smart pointers and initializer lists. The smallest versions that qualify of the GNU compiler collection (gcc) and the Intel C compiler (icc), both of which are widely available, are gcc 4.6 and icc 13.

The current version is capable of constructing the task dependency graph and execute the tasks asynchronously. Several directionality clauses are available.

The code was checked for correctness but has still to prove scalability in realistic scenarios. First performance tests showed more than three times faster execution when running on four cores compared with the serial version of the same algorithm. We believe that these results can be enhanced by revising the implementation of the queueing and dequeueing as well as the creation and destruction of task functor instances.

ACKNOWLEDGMENT

The authors acknowledge support by the H4H project funded by the German Federal Ministry for Education and Research (grant number 01IS10036B) within the ITEA2 framework (grant number 09011).

REFERENCES

[1] Message Passing Interface Forum (http://www.mpi-forum.org/) [retrieved: 09, 2013]. [Online]. Available: http://www.mpi-forum.org/

[2] OpenMP (http://openmp.org/wp/) [retrieved: 09, 2013]. [Online]. Available: http://openmp.org/wp/

[3] R. D. Blumofe, C. F. Joerg, B. C. Kuszmaul, C. E. Leiserson, K. H. Randall, and Y. Zhou, "Cilk: an efficient multithreaded runtime system," in *Proceedings of the fifth ACM SIGPLAN symposium on Principles and practice of parallel programming*, ser. PPOPP '95. New York, NY, USA: ACM, 1995, pp. 207–216. [Online]. Available: http://doi.acm.org/10.1145/209936.209958

[4] TEXT - Towards EXaflop applicaTions (http://www.project-text.eu) [retrieved: 09, 2013]. [Online]. Available: http://www.project-text.eu/

[5] The OmpSs Programming Model (http://pm.bsc.es/ompss) [retrieved: 09, 2013]. [Online]. Available: http://pm.bsc.es/ompss

[6] C. Augonnet, S. Thibault, R. Namyst, and P.-A. Wacrenier, *StarPU: A Unified Platform for Task Scheduling on Heterogeneous Multicore Architectures*, 2009.

[7] XKAAPI - Kernel for Adaptative, Asynchronous Parallel and Interactive programming (http://kaapi.gforge.inria.fr/) [retrieved: 09, 2013]. [Online]. Available: http://kaapi.gforge.inria.fr/

[8] D. Gregor and J. Järvi, "Variadic templates for C++0x," *Journal of Object Technology*, vol. 7, no. 2, p. 31–51, 02/2008 2008. [Online]. Available: http://www.jot.fm/issues/issue_2008_02/article2.pdf

An Evaluation of Partition Granularity in Exascale Parallel Simulations

Elvis S. Liu
IBM Research, Ireland and University College Dublin
Email: elvisliu@ie.ibm.com

***Abstract*—This paper is concerned with simulation technologies for the next generation high-performance computing systems that will operate at ExaFLOP (exascale). As the scale of computer simulations grows in terms of participants and simulated entities, using data filtering schemes to reduce the amount of data communication becomes increasingly important for exascale simulation systems. This paper presents a parallel data filtering algorithm, which divides the workload of filtering process across multiple processors. It also presents an evaluation on the optimal partition granularity of the parallel algorithm, which ensures an optimal use of computational resources in the simulation system.**

***Index Terms*—Exascale Simulation Systems, Interest Management, Data Distribution Management**

I. INTRODUCTION

In the coming years, we expect to reach a computational power equivalent to a thousandfold that of the current most powerful supercomputer. The next generation high-performance computing systems will achieve a computational power equivalent to ExaFLOPS (10^{18} floating point operations per second). Computational advances have opened the way for a growing number of computer simulation applications across many fields. However, exascale simulations also generate a substantial amount of data communication within the simulation systems.

The simplest data distribution approach for parallel or distributed simulations would be to have each host broadcast the data of each simulated entity (e.g., position of a vehicle) that it maintains. This might include, however, data that are not of interest to some receiving hosts. As the scale grows, providing scalable data distribution through filtering (referred to as "interest management") becomes one of the major design requirements of exascale simulation systems. The basic idea of interest management is simple: all participants of the simulation should only receive data that are of interest to them. This usually involves a process called "interest matching", which matches the "interest" between data senders and receivers. This process, however, may introduce considerable computational overhead. If the cost of interest management is too high, it would degrade the overall performance of the simulation. Over the years, numerous interest management schemes have been proposed, which sought to reduce the computational overhead and, at the same time, to maintain the high precision of data filtering. These schemes, however, are designed for serial processing which is supposed to be run on a single processor. As exascale simulations are executed on parallel or distributed systems, deploying the existing schemes on these systems would be unsuitable, and the performance cannot be guaranteed.

In our previous work [1], we presented the preliminary design of a parallel algorithm for interest management, which is suitable to deploy on multiprocessors. It facilitates workload sharing by dividing the simulated virtual worlds into a number of partitions (referred to as "zones") and distributing the interest matching process among multiple processors. In this paper, we present the theoretical background of this algorithm. We also present a performance evaluation of the algorithm, which focuses on finding the optimal granularity for the partitions.

The remainder of this paper is organised as follows. Section II briefly reviews the background and related work of zone-based interest management schemes and partition granularity. Section III presents the details of our parallel interest matching algorithm. Section IV evaluates the optimal partition granularity for our approach by experimental results. Finally, Section V concludes this paper and briefly describes our future work.

II. BACKGROUND AND RELATED WORK

This section briefly reviews the related work of zone-based interest management and granularity of zones.

A. Zone-based Filtering

Zone-based filtering schemes (various other terms have been used in the literature to describe this generic approach, most noticeably "cell-based", "grid-based", and "region-based") are perhaps the most widely used approaches for interest management. It has been studied extensively in many fields such as military simulations, commercial games, and academic simulation systems. Numerous schemes have been proposed throughout the years, which usually limit the participants' interactions and communications within a small number of space subdivisions, or zones. They typically partition the simulated virtual world into a number of zones with each zone containing a subset of entities. Participants in the simulation are connected to these zones in order to receive events and updates that are generated from them.

The seamless zone-based approach enables participants to specify an area of interest (AOI), in order to subscribe to multiple partitions. A typical AOI consists of a radius of zones where the participant is joining new zones at the leading edge and leaving old zones at the trailing edge as their avatar moves around the virtual world.

 ISBN: 978-1-61208-310-0

The primary advantage of using seamless zones is that they provide a "seamless" view of the virtual world. In other words, this approach has a better migration transparency - the participant would not see a "loading screen" when they join a new zone. Interest matching, however, is required for this approach. Whenever the AOI moves, the system needs to determine which zone(s) it overlaps. If the number of zones is constant, the computational complexity of the matching process would be $O(m)$ where m is the number of AOIs.

Zone-based schemes that adopt uniform partitioning [2], [3], [4] divide the virtual world into zones that are static, regular, have a uniform orientation, and have uniform adjacency. The most common shapes adopted by the existing approaches are rectangles, hexagons, and triangles.

The majority of nonuniform partitioning schemes employ hierarchical data structures such as binary space partitioning (BSP) trees [5], k-dimensional (k-d) trees [6], [7], and quadtrees [8], [9] for space partitioning. Unlike uniform partitioning, individual zones can be chosen freely and may be modified dynamically during runtime based on whatever is most convenient from the perspective of designing the individual zones themselves.

Furthermore, some systems that are compliant to High-Level Architecture (HLA) [10] also adopt this type of filtering schemes [11].

B. Granularity

Choosing a proper granularity is one of the major considerations for all zone-based schemes. For a static partitioning of the virtual world, a significant trade-off must be made. If the zones are large, each zone would contain a large number of virtual entities and thus the participants might receive a large amount of irrelevant data. On the other hand, if the zones are small, the number of zones as well as the number of multicast groups would become large, and therefore the entity movement between zones would be more frequent. This increases the chance of subscribing to and unsubscribing from multicast groups as the participants move around the virtual world, resulting in an increase in management overheads.

The hierarchy structures described in the previous subsection also suffer from the same problem but in a different form - a trade off must be made when choosing a proper granularity of the leaf nodes or a proper height of the hierarchy. Researchers such as Van Hook et al. [8] and Steed and Abou-Haidar [6] tried to maintain a balanced hierarchy by setting a maximum height or a population threshold. These are practical solutions, however, one should also consider the characteristic of the application, and the processing power and communication speed of the entire simulation system when choosing the optimal granularity.

A study presented in [11] argued that in a system with fast CPUs and slow communication network, the optimal zone size would be rather small. On the other hand, in a simulation system with slower CPUs and faster communication the optimal zone size would be rather large. Moreover, according to Rak and Van Hook [12], setting the zone size between 2 to 2.5km provides the optimal results in terms of filtering precision and multicast group join rates. These results are, however, entirely dependent on the simulation settings.

In this paper, we perform experimental evaluations on the optimal partition granularity of our parallel simulation system. The finding of the experiments is important as it allows the system to achieve and maintain an optimal use of resources.

III. Parallel Interest Matching Algorithm

This section describes a parallel interest matching algorithm which facilitates parallelism by distributing the workload of the matching process across multiprocessors. The algorithm divides the matching process into two phases. In the first phase it employs a spatial data structure called uniform subdivision to efficiently decompose the virtual space into a number of subdivisions. We define as work unit (WU) the interest matching process within a space subdivision. In the second phase, WUs are distributed across different processors and are processed concurrently.

For the sake of consistency, aura is hereafter referred to as "regions" as per the terminology of HLA.

A. Spatial Decomposition

Uniform subdivision is a common spatial data structure, which has long been used as a mean of rapid retrieval of geometric information. The idea of using hashing for subdivision directory was first described in an early article [13] and was later discussed more generally in [14]. This section presents the formal definitions of uniform subdivision, which leads to the discussion in the subsequent sections where they are used for hash indexing and rapid WU distribution.

Formally, the virtual space $\boldsymbol{S}$ can be defined as a multi-dimensional point set that contains all entities in the virtual world. Therefore, all update or subscription regions can be regarded as the subsets of $\boldsymbol{S}$.

Definition 1. Let $[SMIN_d, SMAX_d)$ be the boundary of a space $\boldsymbol{S}$ in d dimension, for $d = 1, 2, ..., n$.

$$\begin{aligned}\boldsymbol{S} =&\{(x_1, x_2, ..., x_n) \mid x_d \in \mathbb{R} \wedge SMIN_d \leq x_d < SMAX_d,\\ &\text{for } d = 1, 2, ..., n\}.\end{aligned}$$

Alternatively, $\boldsymbol{S}$ can be expressed as the Cartesian product of its one-dimensional boundaries.

Definition 2. Let $[SMIN_d, SMAX_d)$ be the boundary of a space $\boldsymbol{S}$ in d dimension, for $d = 1, 2, ..., n$.

$$\begin{aligned}\boldsymbol{S} =&[SMIN_1, SMAX_1) \times [SMIN_2, SMAX_2) \times ...\\ &\times [SMIN_n, SMAX_n)\\ =&\prod_{d=1}^{n}[SMIN_d, SMAX_d).\end{aligned}$$

The hashing approach requires decomposing $\boldsymbol{S}$ into uniform subdivisions. Each subdivision represents a slot in the hash

 ISBN: 978-1-61208-310-0

table, which is labelled by a multidimensional hash table index.

Definition 3. Let $[SMIN_d, SMAX_d)$ be the boundary of a space $\boldsymbol{S}$ in d dimension. The boundary can be uniformly divided into N_d sub-boundaries with unit length L_d, such that

$$L_d = \frac{SMAX_d - SMIN_d}{N_d}$$

$\forall N_d \in \mathbb{Z}^+$, $\forall L_d \in \mathbb{R}^+$, for $d = 1, 2, ..., n$.

Definition 4. Let $[SMIN_d, SMAX_d)$ be the boundary of a space in d dimension, for $d = 1, 2, ..., n$. The boundary is uniformly divided into N_d sub-boundaries with unit length L_d. The uniform subdivision $\boldsymbol{Z}$ of $\boldsymbol{S}$ is labelled by a multidimensional hash table index $(z_1, z_2, ..., z_n)$, such that

$$\begin{aligned} &\boldsymbol{Z}(z_1, z_2, ..., z_n) \\ =&\{(x_1, x_2, ..., x_n) \mid x_d \in \mathbb{R} \wedge SMIN_d + z_d L_d \le x_d \\ &< SMIN_d + (z_d + 1)L_d, \text{ for } d = 1, 2, ..., n\} \end{aligned}$$

for $z_d = 0, 1, ..., N_d - 1$.

Similar to all axis-aligned point sets, the uniform subdivision can be expressed as the Cartesian product of its one-dimensional boundaries, which is given in **Definition 5**.

Definition 5. Let $[SMIN_d, SMAX_d)$ be the boundary of a space in d dimension, for $d = 1, 2, ..., n$. The boundary is uniformly divided into N_d sub-boundaries with unit length L_d. The uniform subdivision $\boldsymbol{Z}$ of $\boldsymbol{S}$ can be defined as

$$\begin{aligned} &\boldsymbol{Z}(z_1, z_2, ..., z_n) \\ =&[SMIN_1 + z_1 L_1, SMIN_1 + (z_1 + 1)L_1) \\ &\times [SMIN_2 + z_2 L_2, SMIN_2 + (z_2 + 1)L_2) \\ &\times ... \\ &\times [SMIN_n + z_n L_n, SMIN_n + (z_n + 1)L_n) \\ =&\prod_{d=1}^{n} [SMIN_d + z_d L_d, SMIN_d + (z_d + 1)L_d) \end{aligned}$$

for $z_d = 0, 1, ..., N_d - 1$.

Theorem 1. Given a set of all hash table indices

$$\boldsymbol{HI} = \{(z_1, z_2, ..., z_n) \mid z_d = 0, 1, ..., N_d - 1 \wedge d = 1, 2, ..., n\}$$

where N_d is the number of subdivisions of space $\boldsymbol{S}$ in d dimension. Then, $\boldsymbol{S}$ can be expressed as the union of all uniform subdivisions, such that

$$\boldsymbol{S} = \bigcup_{k \in \boldsymbol{HI}} \boldsymbol{Z}(k).$$

Proof: By **Definition 2**, we derive

$$\begin{aligned} \boldsymbol{S} =&[SMIN_1, SMAX_1) \times [SMIN_2, SMAX_2) \times ... \\ &\times [SMIN_n, SMAX_n) \\ =&\bigcup_{z_1=0}^{N_1} [SMIN_1 + z_1 L_1, SMIN_1 + (z_1 + 1)L_1) \\ &\times \bigcup_{z_2=0}^{N_2} [SMIN_2 + z_2 L_2, SMIN_2 + (z_2 + 1)L_2) \\ &\times ... \\ &\times \bigcup_{z_n=0}^{N_n} [SMIN_n + z_n L_n, SMIN_n + (z_n + 1)L_n) \\ =&\bigcup_{k \in \boldsymbol{HI}} \boldsymbol{Z}(k). \end{aligned}$$

■

B. First Phase: Hashing

During the simulation, regions are hashed into the hash table. The algorithm uses the coordinate of a region's vertex as a hash key. Given a key k, a hash value $H(k)$ is computed, where $H()$ is the hash function. The hash value is an n-dimensional index, which can be matched with the index of a space subdivision, and therefore indicating that which subdivision the vertex lies in. Hence, the regions with hash key k are stored in slot $H(k)$. The hash function is given in **Definition 6**.

Definition 6. Let $[SMIN_d, SMAX_d)$ be the boundary of a space in d dimension, for $d = 1, 2, ..., n$. The boundary is uniformly divided into N_d sub-boundaries with unit length L_d. The hash function for transforming a key k_d into a hash value is defined as

$$H : \mathbb{R}^n \to \mathbb{Z}^n, H(k_d) = \lfloor \frac{k_d - SMIN_d}{L_d} \rfloor$$

There are two important properties of using a hash table for spatial decomposition. First, hash table collision means that regions in the same slot are potentially overlapped with each other; therefore, further investigation on their overlap status is required. This process is left to the second phase of the algorithm. Second, if a region lies in multiple space subdivisions, it would be hashed into all of them. The algorithm assumes that the size of region is much smaller than a space subdivision. Therefore, a region would exist in at most four slots in the two-dimensional space (at most eight slots in the three-dimensional space). This assumption ensures that the computational complexity of the hashing process would be bounded by a constant.

Figure 1 illustrates the basic concept of the spatial hashing for two-dimensional space. In the figure, region A is hashed into slot (0,1); region B is hashed into slots (0,0), (0,1), (1,0) and (1,1); region C is hashed into slots (1,1) and (1,2); region D is hashed into (1,0), (1,1), (2,0) and (2,1).

 ISBN: 978-1-61208-310-0

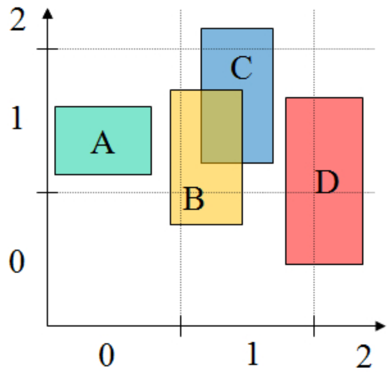


Fig. 1. Hashing for Space Subdivisions

The basic steps to construct a hash table are given in Algorithm 1. Note that if not all vertices of a region are hashed into the same slot, then the region exists in multiple subdivisions.

Algorithm 1: Algorithm for Hash Table Construction (Region)

Data: $\boldsymbol{S}$: a n-dimensional virtual space
Data: $\boldsymbol{Z}$: an uniform subdivision of $\boldsymbol{S}$
Data: k: a n-dimensional hash table index
Data: $\boldsymbol{R}$: a region
Data: v: a vertex of $\boldsymbol{R}$
Data: $H()$: a hash function
Data: $HashTable$: a hash table

begin
    Decompose $\boldsymbol{S}$ into a list of $\boldsymbol{Z}$;
    foreach $\boldsymbol{Z}$ **do**
        Determine the index k for $\boldsymbol{Z}$;
    end
    foreach k **do**
        $HashTable.AddSlot(k)$;
    end
    foreach $\boldsymbol{R}$ **do**
        foreach v *of* $\boldsymbol{R}$ **do**
            $HashTable.Slot[H(v)].AddRegion(\boldsymbol{R})$;
        end
    end
end

The hash table is constructed at the initialisation stage. During runtime, the position and size of regions may be frequently modified. Therefore, the algorithm needs to perform rehashing for the regions at every time-step. The complexity of this process is $O(n + m)$ where m is the number of subscription regions and n is the number of update regions.

C. Second Phase: Sorting

After the hashing stage, each slot of the hash table represents a WU which will be distributed across different processors. The algorithm then places the WUs on a task queue. Each processor fetches WUs from the queue and performs interest matching for the corresponding space subdivisions. Since only one processor has the authority to manage each space subdivision, there will be no ambiguous matching result. As discussed in [15], the task queue approach is desired for task distribution and provides very good load sharing for multiprocessors. When a processor finishes processing a WU, it would fetch another WU from the task queue immediately unless the queue is empty. Therefore, no processor would be idle until all WUs are fetched. The worst case happens only when all regions reside in a single space subdivision. In this situation, a single processor would be responsible for the matching of all of them.

The spatial decomposition approach essentially transforms the large-scale interest matching process into several individual sub-problems. When a WU is being processed, each processor carries out a matching process only for the regions within the WU. The matching process employs a sorting algorithm [1], which makes use of the concept of dimension reduction and is theoretically the most efficient serial algorithm for interest matching.

IV. Experimental Evaluation

This section presents the experimental evaluation on the optimal partition granularity of the parallel algorithm. Two sets of experiments were carried out to compare the performance of two approaches, namely:

1) Discrete interest matching by parallel algorithm (PDIM)
2) Space-time interest matching by parallel algorithm (PCIM)

PDIM [1] and PCIM [16] are the two parallel algorithms, which exploit parallelism by distributing the workload across multiple processors. The PDIM approach is designed for discrete interest matching approach, which performs interest matching at discrete time intervals, while the PCIM approach performs space-time interest matching approach, which perform space-time interest matching in order to capture more events in the simulation. The PCIM approach usually requires more computational effort than the PDIM approach.

A. Implementation and Experimental Set-ups

The two algorithms were implemented in C++. Message communication was constructed based on Open MPI protocols, such as $MPI\_Bcast()$, $MPI\_Send()$, and $MPI\_Recv()$; all processes were synchronised by the $MPI\_Barrier()$ call, which is a simple lock-step synchronisation protocol. The experiments were executed on the eScience Cluster at the Midland e-Science Centre. Each worker node has an Intel Xeon 3GHz 4-core processor with 2GB main memory. A Myrinet backplane is used to give 2+2Gbps programmable interconnection between the worker nodes.

The following set-up was used for the experiments.

- *Entity Distribution*: The entities are distributed randomly across the virtual space.
- *Entity Movement*: All entities move in a random direction and undergo linear translational motion.

 ISBN: 978-1-61208-310-0

- *Entity Speed*: The speed factor (SF) represents the average speed of the entities in proportion to its region length.
- *Number of Dimensions*: All simulations were performed in three-dimensional space.
- *Number of Regions* An update region and a subscription region were associated with each moving entity.
- *Execution Time Measurement*: Average execution time of the matching algorithms was measured over 10,000 timesteps.
- *Number of WUs*: The number of WUs is dependent on the granularity of spatial decomposition, which was assigned statically. The optimal granularity value was determined through experiments, which are presented in Section IV-B.
- *Number of Nodes*: All experiments of the parallel algorithms were run on 10 nodes.

B. Granularity of Spatial Decomposition

The spatial decomposition approach described in Section III-A requires an optimal granularity to achieve an optimal use of resources. This is similar to the virtual world partitioning problem as we have discussed in Section II-B. In this section, we present the results of a set of experiments that we have conducted to determine the optimal granularity of partitioning.

Since uniform subdivisions are employed for the parallel algorithm, the granularity of spatial decomposition is dependent on the number of sub-boundaries per dimension (denoted by N_d in **Definition 3**). We take $N_1 = N_2 = N_3$, which implies that each subdivision is a cube in shape. We measured the execution time of PDIM and PCIM, with N_d extending from 2 to 10. The number of entities was set to 20000 and the SF was set to 20.

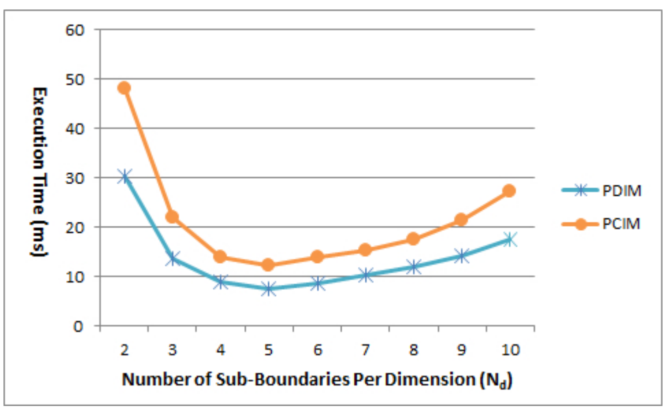


Fig. 2. Comparing the Execution Time of Parallel Interest Matching Approaches (Number of Sub-Boundaries varies)

The results are given in Figure 2. As we can see in the graph, there is some significant runtime overhead when N_d is equal to 2 (i.e., the number of WUs is equal to 8). This is due to the fact that the number of WUs is less than the number of nodes, which implies four physical cores would be idle at each time step of simulation, resulting in a poor utilisation of computational resources. However, if a large N_d is chosen, the size of job queue becomes large and thus overhead would be introduced due to the increase in the frequency of job queue access. According to results shown in Figure 2, we can conclude that, for the current experimental set-up, the optimal value of N_d for both PDIM and PCIM is 5.

V. Conclusions and Future Work

The interest management schemes enhance the scalability of the exascale simulation systems by filtering irrelevant data communication on the network. Over the years, many efficient filtering algorithms were proposed to speed up the interest matching process. However, they were designed for serial processing which is supposed to be run on a single processor. As the problem size grows, using these algorithms does not satisfy the scalability requirement of exascale simulations since the single processor may eventually become a bottleneck. In our previous work [1], we have presented the preliminary design of a parallel interest matching algorithm which is suitable to deploy on a multiprocessor computer. This algorithm partitions the simulated virtual world and distributes the interest management process across multiple processors. In this paper, we presented the detailed theoretical background of the parallel algorithm. We also presented an experimental evaluation on the optimal partition granularity of the proposed algorithm. Using the optimal granularity in future experiments would be the most efficient way to achieve and maintain an optimal use of resources in the simulation system.

Our future work will concentrate on evaluating the runtime efficiency of the parallel algorithm. We will test and compare its performance under different entity behaviors, number of nodes, and occupation density.

VI. Acknowledgment

This work was supported, in part, by Science Foundation Ireland grant 10/CE/I1855 to Lero - the Irish Software Engineering Research Centre (www.lero.ie).

References

[1] E. S. Liu and G. K. Theodoropoulos, "An Approach for Parallel Interest Matching in Distributed Virtual Environments," in *Proceedings of the 13th IEEE/ACM International Symposium on Distributed Simulation and Real Time Applications (DS-RT 2009)*, October 2009.

[2] D. J. Van Hook, S. J. Rak, and J. O. Calvin, "Approaches to Relevance Filtering," in *Proceedings of the 11th Workshop on Standards for the Interoperability of Distributed Simulations*, 1994, pp. 26–30.

[3] S. Srinivasan and B. R. D. Supinski, "Multicasting in DIS: A Unified Solution," in *Proceedings of the 1995 Electronic Conference on Scalability in Training Simulation (ELECSIM 1995)*, April-June 1995.

[4] M. R. Macedonia, M. J. Zyda, D. R. Pratt, D. P. Brutzman, and P. T. Barham, "Exploiting Reality with Multicast Groups: A Network Architecture for Large-scale Virtual Environments," in *Proceedings of the 1995 IEEE Virtual Reality Annual International Symposium (VRAIS '95)*, 1995, pp. 2–10.

[5] J. W. Barrus, R. C. Waters, and D. B. Anderson, "Locales and Beacons: Efficient and Precise Support For Large Multi-User Virtual Environments," in *Proceedings of IEEE 1996 Annual International Symposium on Virtual Reality (VRAIS '96)*, 1996, pp. 204–213.

[6] A. Steed and R. Abou-Haidar, "Partitioning Crowded Virtual Environments," in *Proceedings of the ACM Symposium on Virtual Reality Software and Technology (VRST) 2003*, 2003, pp. 7–14.

[7] S. Rieche, K. Wehrle, M. Fouquet, H. Niedermayer, L. Petrak, and G. Carle, "Peer-to-Peer-based Infrastructure Support for Massively Multiplayer Online Games," in *Proceedings of the 4th Annual IEEE Consumer Communications and Networking Conference (CCNC 2007)*, January 2007, pp. 763–767.

[8] D. J. Van Hook, S. J. Rak, and J. Calvin, "Approaches to RTI Implementation of HLA Data Distribution Management Services," in *Proceedings of the 15th Workshop on Standards for the Interoperability of Distributed Simulations*, 1997.

[9] K. Pan, X. Tang, W. Cai, S. Zhou, and H. Zheng, "Hierarchical interest management for distributed virtual environments," in *Proceedings of the 2013 ACM SIGSIM conference on Principles of advanced discrete simulation*, ser. SIGSIM-PADS '13, 2013, pp. 137–146.

[10] DMSO, "High Level Architecture Interface Specification Version 1.3," 1998.

[11] G. Tan, R. Ayani, Y. Zhang, and F. Moradi, "Grid-Based Data Management in Distributed Simulation," in *Proceedings of the 33rd Annual Simulation Symposium (SS 2000)*. Washington, DC , USA: IEEE Computer Society, April 2000.

[12] S. J. Rak and D. J. Van Hook, "Evaluation of Grid-Based Relevance Filtering for Multicast Group Assignment," in *Proceedings of the 14th DIS Workshop on Standards for the Interoperability of Distributed Simulations*, March 1996, pp. 739–747.

[13] M. Rabin, "Probabilistic algorithms," in *Algorithms and Complexity: New Direction and Recent Results*. New York: Academic Press Inc, 1976, pp. 21–39.

[14] J. L. Bentley and J. H. Friedman, "Data Structures for Range Searching," *ACM Computing Survey*, vol. 11, pp. 397–409, December 1979.

[15] S. P. Dandamudi and P. S. P. Cheng, "A Hierarchical Task Queue Organization for Shared-Memory Multiprocessor Systems," *IEEE Transactions on Parallel and Distributed Systems*, vol. 6, no. 1, pp. 1–16, 1995.

[16] E. S. Liu and G. Theodoropoulos, "A Continuous Matching Algorithm for Interest Management in Distributed Virtual Environments," in *Proceedings of the 24th ACM/IEEE/SCS Workshop on Principles of Advanced and Distributed Simulation (PADS 2010)*, May 2010.

Framework for Visual Analytics of Measurement Data

Paula Järvinen, Pekka Siltanen, Kari Rainio
VTT, PL 1000, 02044 VTT
Espoo, Finland
{paula.jarvinen, pekka.siltanen, kari.rainio}@vtt.fi

***Abstract*-Visual analytics is a recent research field for finding knowledge from data masses. It combines the strengths of automatic data processing, and the visual perception and analysis capabilities of the human user. This article represents a framework for analysis of measurement data with the help of visual analytics. The framework consists of a message service platform for collecting and unifying measurement data, and a visual analytics tool for analysis. The platform receives data from different types of measurement devices and transforms the data into unified format that applications can use through standard interfaces. With the visual analytics tool users can analyse the data coming from the platform. The tool shows data as interactive visualizations, both abstract and descriptive, and suggests analysis methods to the user. User performs reasoning by interpreting a series of consecutive visualizations. The framework frees the analyst from the time demanding data pre-processing and makes analysis possible without special skills and expertise in data analysis. A prototype application to demonstrate the framework is presented. Examples with real data show how explanations for building energy consumption can be reasoned with the help of the visual analytics tool.**

Keywords- visual analytics; measurement data management; information visualization

I. INTRODUCTION

Advances in sensor and data processing technology have extensively broadened the reach of measurement data. In industry, sensors monitor the state of machinery, environmental meters collect measurements from the environment, building automation systems store building information, and enterprises track the actions and behavior of consumers.

The accumulated data are expected to contain important knowledge that can be used to improve processes and support decision making. However, the collected data coming from different sources and forms requires a considerable amount of pre-processing; the relevant data must be recognized and extracted from the data sources, and noisy data has to be cleaned. Data values can be in non-comparable units that have to be harmonized. Before analysis and visualization data need to be transformed to specific data formats. The variety of data can be confusing to the user. Even a simple operational data base can contain dozens of data entities and each entity dozens of attributes. The analyst has to find the most meaningful properties and the right analysis methods.

Visual Analytics is a recent approach to finding knowledge from data masses [1-8]. It provides tools to support analytical reasoning. A visual analytic tool processes the raw data and shows the information in the form of abstract and interconnected visualizations. Users can then look for patterns, trends, anomalies, similarities and other relevant “nuggets of information” from the visualizations. Users can launch analysis, browse and navigate visualizations and highlight and select important areas for further study.

This article represents a framework for visual analytics of measurement data carried out as part of MMEA (Measurement, Monitoring, and Environmental Assessment) research programme under the Finnish Cluster for Energy and Environment (CLEEN). The framework consists of a message service platform that collects and pre-processes the measurement data, and a visual analytics tool for analysis. The framework provides a streamlined environment for analysis of measurement data where users reason by interpreting a series of consecutive visualizations. The tool combines both information visualization and descriptive visualizations of the monitored objects. A prototype is constructed to analyze energy consumption and indoor air quality measurements of office buildings in a research campus area in Finland.

The approach provides a novel general purpose data-analysis environment for measurement data. Data can originate from different kind of measurement devices as well as information systems such as data warehouses. Data are available in uniform format for analysis. Integration of a visual analytics tool to the platform provides an easy and comprehensive way to analyse data - no expertize in data analysis is required. Combining abstract and descriptive visualizations of measurement data is a novel approach in visual analytics.

The article is organized as follows. Visual analytics is introduced in Section II. The framework and the implementation method are presented in Section III. Section IV gives examples of how to reason with the help of the visual analytics tool. Section V ends the article with conclusions and discussion.

II. BACKGROUND

Visual analytics is defined as “the science of analytical reasoning facilitated by interactive visual interfaces” [1, 2].

 ISBN: 978-1-61208-310-0

It provides visual tools for finding insight from complex, conflicting and dynamic data to support analytical reasoning and decision making. The basic idea of visual analytics is to unite the strengths of automatic data analysis and the visual perception and analysis capabilities of the human user. Humans can easily recognize patterns, colour, shape, orientation and spatial position, detect changes and movement, and identify specific areas and items from visual presentations. Humans are good at reasoning and generating problem-solving heuristics [10]. Showing data and analysis results in the form of abstract visualizations is an efficient way to find insight from data [11]. Computers, on the other hand, have superior working memory and unlimited information processing capacity without cognitive biases [12]. The goal is to create systems that utilize human strengths while providing external aids to compensate for human weaknesses [2]. Visual analytics is especially focused on situations where huge amounts of data and the complexity of the problem make automatic reasoning impossible without human interaction.

Visual analytics is a multi-disciplinary research area, combining information visualization science, data mining, mathematical and statistical methods, data management, user interface techniques, human perception and cognition research. The area has several challenges, listed in [8] and [9], including management and integration of very large, diverse and variable quality of datasets.

The markets and research have produced a variety of visual analytics tools, including tools by major software houses, analysis and visualization environments, libraries, application-oriented tools, and technology-oriented tools. But, the use of visual analytic is not yet widespread. Market survey companies Frost & Sullivan, ReportLinker and Gartner Group have recently recognized the new field and made references to recommended application areas.

III. RESEARCH APPROACH

The research was implemented as constructive research, by

1. identifying the problems faced when using large amounts of measurement data to support reasoning based on the measurements,
2. creating a reasoning framework, combining the structural data model of the object monitored and the measurements,
3. building a prototype application to prove realistic implementation possibilities of the framework, and
4. testing the framework with real life reasoning examples.

A. *Identifying the problem*

Data quality is a well-known problem in data mining research [13]. The problem is partly caused by missing or erroneous measurements, as well as disparate data formats when combing data from several sources. In practical implementations, for example when comparing and estimating measurements (for example indoor temperatures, CO_2 values) from different buildings and from the surrounding environment, the data quality problem is faced immediately. Buildings have their own building automation systems, each storing the monitored data in different format. Things get even more complicated when the building monitoring data are combined with environmental measurements, such as outdoor temperatures or aerosol emissions that are again represented in different formats.

More problems are faced when trying to use the measurement data to support reasoning. Often the data are handled by facility management systems that reduce the data into simple performance indices and trend graphs. Even though the tools used by the data reasoning experts, such as R Statistical computing package [14] contain functions to import data from different sources, the task of transforming and importing the data is often the most time consuming task in the reasoning process. Also, the data analysis tools often have poor visualization capabilities, producing just static pictures for human viewing.

B. *Framework*

Fig. 1 shows the framework concept. Measurement data are collected from sensors and databases and delivered to applications through a message service platform in unified format. The format provides measurement data as simple data-timestamp –pairs accompanied with metadata. Our application, the visual analytics tool receives data from the platform and stores it into its own database. The database consists of time stamped measurement values, together with background data, properties of the monitored object and metadata of measurements. Data are stored in such a form that visualizations and analysis can be easily applied. Performance indices and other quantities are calculated from the data. In our experiments, building sensor measurements were used, but the data can be as well environmental data or human behavior data.

A set of pre-defined data analysis and visualization methods is coupled to the database. In our example, a set of analysis methods that is relevant for measurement data, such as finding correlations, trends, outliers, interesting subsets and clusters from data, is selected. When a new data set requires analysis, the data from the platform is loaded to the visual analytics tool database. The predefined analysis and visualization methods would be automatically available.

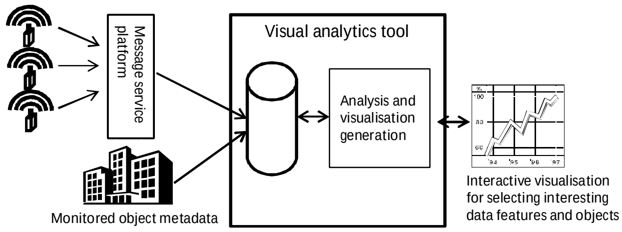


Figure 1. Framework concept.

All analysis show results in visual form and the visualizations are interactive. Visual reasoning is intensified

 ISBN: 978-1-61208-310-0

by combining descriptive models of the monitored object (e.g., maps, 3D models or product structures) with abstract visualizations. This approach is expected to strengthen the interpretation of the results and help users set the results into the right context.

During the reasoning process, the user selects variables from the database for analysis. The tool guides the user to choose the most suitable analysis and visualizations based on user's selections. For example, if user has selected power and water consumption measurements for analysis of a whole week, user is suggested calculation of correlations and scatterplots with regression lines and time series of correlations, to start with. Users can select data sets from the visualization for further analysis.

C. Visual analytics prototype

A web application was constructed using the framework. The monitored objects consist of office buildings of a research campus area in Finland. Measurements of power, reactive power, district heat and water used of each building, and environmental measurements including outdoor temperature and relative humidity were available, with measurement frequency measurement/hour. Indoor temperature, occupancy of people and CO2 measurements were available of one office building. In addition, the building gross volume, gross floor area and building age were available. A map of the campus area was used as descriptive visualization.

The user gets a visual user interface (Fig. 2), where the user can select monitored buildings and their properties for analysis. The buildings can be classified and visualized using different symbols or colors to help selecting.

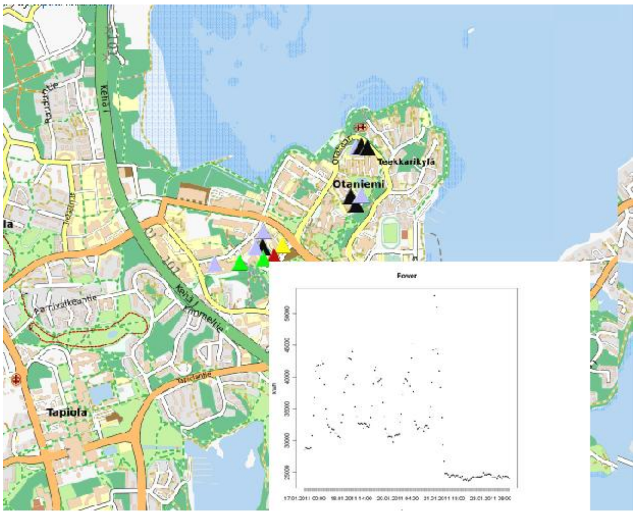


Figure 2: User interface.

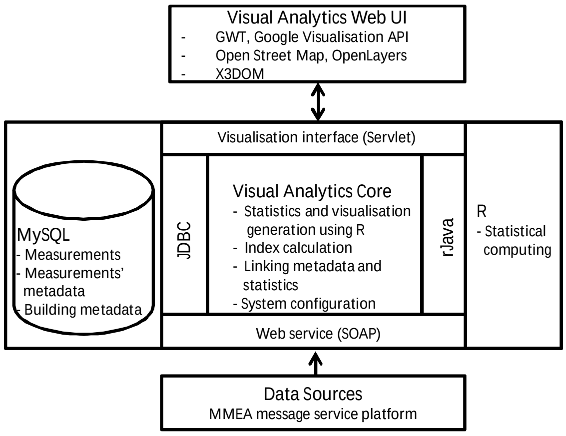


Figure 3. Prototype architecture.

An index for energy performance for each building is calculated. The set of visualizations and analysis methods include basic statistics (min, max, mean, standard deviation), histograms, time series with different time granularities (hour/day/week), clustering, correlations, scatterplots, linear regression, time series of correlations, autocorrelations and cross correlations.

D. Implementation details

The current prototype application uses a set of open source technologies for implementing the required features (Fig. 3). The user interface is implemented as a browser interface, showing the monitored buildings on Open Street Map environment. The user interactions and the visual markers representing the monitored building on the map are implemented using Openlayers JavaScript library. The building 3D geometry details can also be shown in the browser interface, by using X3DOM (X-Freedom) technology [15].

The MMEA message service platform takes care of collecting the data from different sensors and other measurement sources, as well as transforming the measurements to unified data representation. The measurements, together with measurement metadata and building properties from the Real estate information register maintained by Finnish Population Register Centre, are stored in the MySQL database.

Statistical computing is performed using R statistical library [14]. In the current prototype version, the graphics for example shown in Figure 2 are generated using R, too. However, in the future the R graphics will be replaced with more visually pleasing and interactive JavaScript visualizations, using JavaScript visualization packages such as Google Visualisation API.

Interfaces between MMEA Visual Analytics tool core and other components are implemented using standard technologies: browser server communication is implemented using REST servlets, database is connected to the core via JDBC, R statistical library is integrated to the core using rJava package, and data are received from message service platform using Web Service interface.

IV. EXAMPLE OF USING THE FRAMEWORK

The goal of the visual analytics tool is to help users find interesting phenomena and explanations to support decision making. It is performed by interpreting a series of consecutive visualizations. The principle is presented here by simple examples.

A. Data overview

Let us assume that a user is interested in the energy efficiency of the campus area buildings. First, the user gets an overview of the energy efficiency of the buildings on the map (Fig. 4). Different colours indicate the energy performance index values of each building, showing a rough estimate of energy performance of each building. User can click the buildings and get more details.

To get a better overview, the user wants to see the basic statistics and time series of all the buildings (Fig. 5). Figures show two interesting things: Most buildings have low energy performance index (i.e., low energy usage) but some have very high values. The time series show that energy usage on weekend, and on day and night differ a lot.

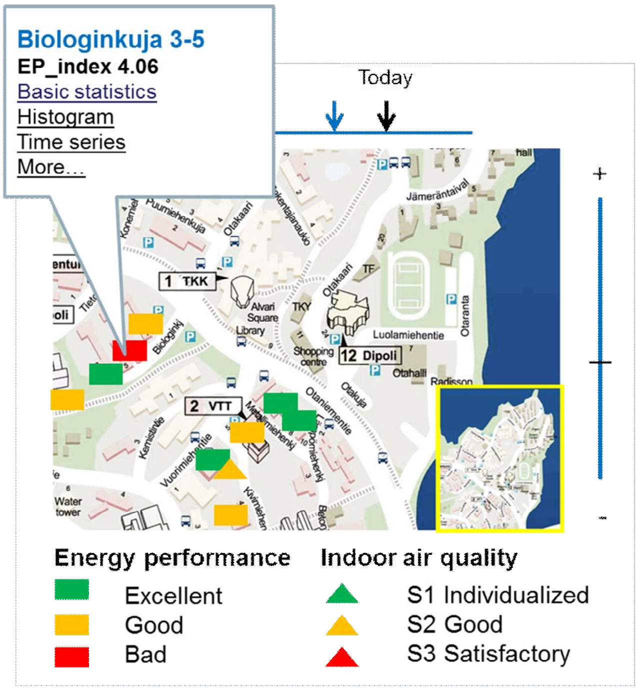


Figure 4. Overview.

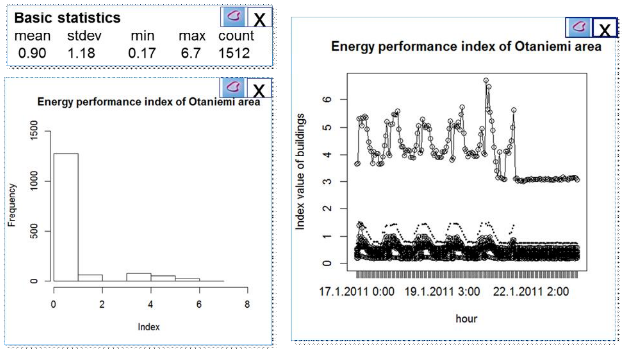


Figure 5. Basic statistics.

B. Finding explanations

Next, the user wants to find reasons for the big variances in the energy performance index values. User considers if the building age is behind the high energy performance values. A scatterplot with correlation coefficient value 0.43 and an ascending regression line give hint that there is some correlation between age and energy performance index (Fig. 6). The user can select an object from the scatterplot and see the corresponding buildings on the map. In the scatterplot user has paid attention to plots that indicate high index value and building age. The plots prove out to come from one building that is highlighted on the map. Similarly, user can study other background variables.

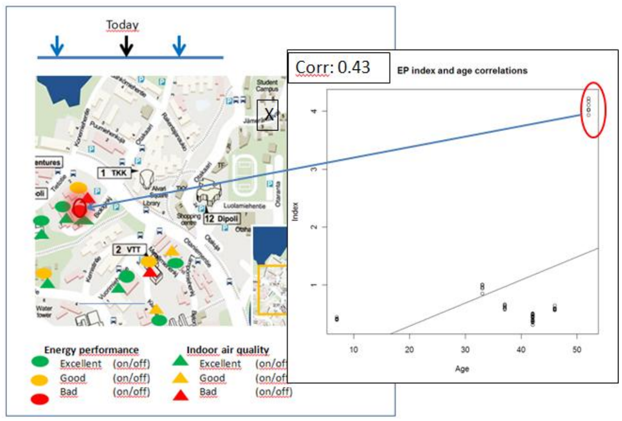


Figure 6. Correlation with age.

C. Exploring subsets

The user can also select data subsets of visualizations and perform analysis with subsets. In the example in Fig. 7, three clusters are formed based on the indices, and the statistics and details of one of the clusters are shown.

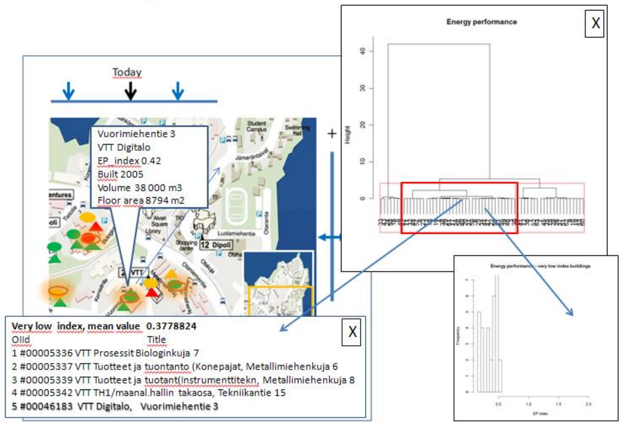


Figure 7. Analysis of subsets.

D. *Multivariate analysis*

The second example is about multivariate analysis. The example studies correlations between the energy performance index, district heat and water consumption (Fig. 8). The figures show that there is a strong correlation between district heat and energy performance. User wants to study more this correlation and produces a scatterplot. The plot shows an interesting pattern that the user wants to study more. It proves out to represent a specific building that is highlighted on the map.

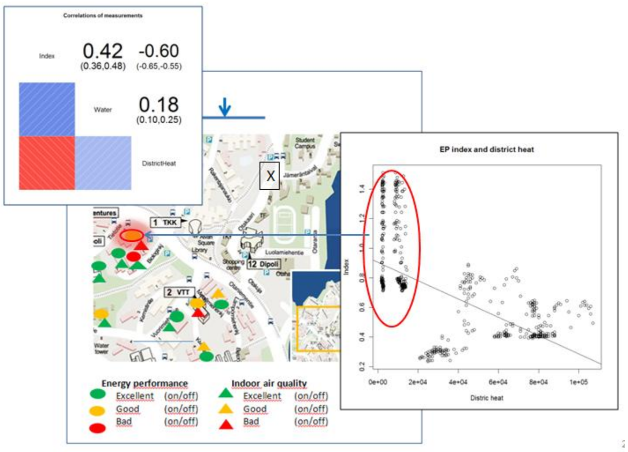


Figure 8. Multivariate analysis.

V. CONCLUSION AND FUTURE RESEARCH

A novel visual analytics based approach to tackle the information overload problem was introduced. It consists of a framework including a message platform and a visual analytics tool for experts and researchers to analyze measurement data. The approach was evaluated with identification and diagnostics of problems from building energy consumption.

The trials suggest that the framework provides solutions to the introduced data analysis problems. It provides a streamlined general-purpose environment for analysis of measurement data. Data are available from the message service platform in a standard form, avoiding the time demanding pre-processing. The analyst gets high quality data from the platform and can focus on the analysis task. Also the same pre-processed data are available to other applications, thus avoiding overlapping work.

Data analysis has been considered a job that requires special skills and expertise. With the suggested visual analytics tool the user needs no beforehand knowledge of data analysis or statistical methods. The complex analysis algorithms are hidden behind the user interface. The user only needs to select data, launch analysis from a pre-defined set of suitable analysis and interpret the results. Using abstract visualizations together with descriptive visualizations of the monitored objects intensifies the interpretation of the results. Thereby the data analysis can be performed by the domain expert, instead of a data analysis expert, as before.

Taking new datasets for analysis is straightforward. The data model of the tool, the user interface and the analysis methods are general purpose and can be applied as well as to environmental data or human behavior. Data coming from the message platform is ready for analysis after simple specifications. If new analysis methods are required, they can be easily taken into use from the R statistical package resources. The only time demanding tasks are adding the application specific calculations, such as performance indices, and adding the descriptive visualizations. The benefits of the framework are summarized in Table I.

TABLE I. BENEFITS OF MMEA PLATFORM.

•	General-purpose environment for analysis of measurement data.
•	Uniform data format for analysis, independent of individual data sources.
•	Data is pre-processed only once, proving high quality data for different kind of applications and saving overlapping work.
•	A general purpose data analysis tool for non-experts
•	Easy and comprehensive visualizations to reason and interpret data.
•	More analysis power by combining abstract and descriptive visualizations.

The current prototype does not contain a full set of interactive features. A real visual analytics application would enable making most of the interactions needed in reasoning by interacting with the visualizations generated by the system. Creating truly interactive visualizations in the browser environment is a challenge that will be tackled next. Another objective would be to develop further the user support in reasoning. At the moment the tool suggest analysis methods that are based on the qualities of the selected data. In addition to them knowledge of user actions and semantics could be utilized. The user could also discard obvious relationships to diminish the problem space. The third goal would be to study the usability of the solution: does the framework help users to utilize measurement data, find interesting phenomena and explanations, and improve decision making.

The framework described above enables linking the measurements into the object that is monitored: in examples above map based visualization of a set of buildings was used as a user interface to access the reasoning algorithms. Currently, the prototype supports map visualization and experimental 3D model visualization showing the monitored objects in the browser. In the future the visualizations of the monitored object will be further developed. Also, the prototype architecture enables embedding the visualizations to other user interfaces, such as aerial 3D model, allowing the user navigate in the 3D model instead of using the map user interface (Fig. 9).

ACKNOWLEDGEMENT

This work has been partly funded by the CLEEN Cluster for energy and environment, a company managing the Strategic Centre for Science, Technology and Innovation in the theme energy and environment, Tekes, the Finnish Funding Agency for Technology and Innovation, and VTT Technical Research Centre of Finland.

REFERENCES

[1] P. C. Wong and J. Thomas, Guest Editors' Introduction--Visual Analytics, IEEE Computer Graphics and Applications, vol 24 (5), Sep/Oct. 2004, pp. 20-21 4, No. PNNL-SA-41935.

[2] J. J. Thomas and K. A. Cook,. Illuminating the path: The research and development agenda for visual analytics. 1st ed. Los Alamitos, CA: IEEE Computer Society, 2005. ISBN 0769523234.

[3] D. Keim, F. Mansmann, J. Schneidewind and H. Ziegler, "Challenges in visual data analysis" Tenth International Conference on Information Visualization, London, UK IEEE, Jul. 2006, pp. 9.

[4] K. Cook, R. Earnshaw and J. Stasko. Guest editors' introduction: discovering the unexpected. Computer Graphics and Applications, IEEE, Vol. 27(5), 2007, pp. 15-19.

[5] P. C. Wong, "Visual analytics science and technology", Information Visualization, Vol. 6(1), 2007, pp. 1-2. ISSN 1473-8716. doi: 10.1057/palgrave.ivs.9500149.

[6] D. Keim, F.Mansmann, J. Schneidewind, J. Thomas and H. Ziegler, "Visual analytics: Scope and challenges".In Visual Data Mining. First edition ed. Heidelberg: Springer, 2008, pp. 76-90.

[7] M. Streit and 0. Bimber, "Visual analytics, Seeking the Unknown", Computer, vol 46(7), Jul 2013, pp 20-21.

[8] D. Keim, J. Kohlhammer, G. Ellis (eds.), "Mastering the information age: solving problems with visual analytics", First edition ed. Goslar, Germany: Eurographics assiociation, 2010.

[9] J-D. Fekete, "Visual analytics Infrastructure, From Data Management to Exploration", Computer, vol 46(7), Jul. 2013, pp 22-29.

[10] S. K. Card, J.D. Mackinlay and B. Shneiderman, Readings in information visualization: using vision to think. 1st ed. Morgan Kaufmann, 1999.

[11] C. Ware, Information visualization: perception for design.1st ed. Morgan Kaufmann, 2004.

[12] T. M. Green, W. Ribarsky and B. Fisher, "Visual analytics for complex concepts using a human cognition model", IEEE Symposium on Visual Analytics Science and Technology VAST'08, Colubmus, Ohio, USA, IEEE Computer Society, Oct.2008, pp. 91-98.

[13] E. Rahm, H.H Do "Data cleaning: Problems and current approaches", IEEE Data Engineering Bulletin 2000, Vol. 23, No. 4, pp. 3-13.

[14] W. N. Venables, D.M. Smith,. An introduction to R, 2012, (October 26 - last update). Available: http://cran.r-project.org/doc/manuals/R-intro.pdf [retrieved Oct. 2012].

[15] X3DOM home page. Available: http://www.x3dom.org/ [retrieved Nov 2013].

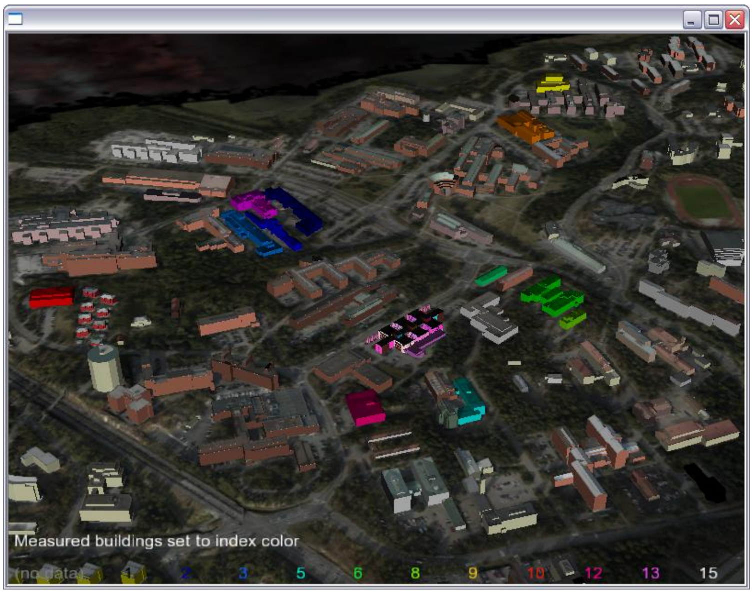


Figure 9. 3D model of the campus area with monitored buildings highlighted.

Sustainable Knowledge Resources Supporting Scientific Supercomputing for Archaeological and Geoscientific Information Systems

Claus-Peter Rückemann
Westfälische Wilhelms-Universität Münster (WWU),
Leibniz Universität Hannover,
North-German Supercomputing Alliance (HLRN), Germany
Email: ruckema@uni-muenster.de

***Abstract*—This paper presents the results from an implementation of long-term sustainable knowledge resources, which can be used for documentation, classification, and structuring as well as with scientific supercomputing resources for advanced information systems. The paper discusses the current implementation of information structures and object representations used with universal classification and computation algorithms for multi-disciplinary, dynamical knowledge discovery. It discusses practical examples from archaeology and geosciences disciplines, relying on the content, structure, and classification from the knowledge resources used with various case studies. The combination of universal knowledge resources and computational workflows based on High End Computing (HEC) resources and Universal Decimal Classification (UDC) allows for the goal of successful creation of long-term sustainable Integrated Information and Computing System components.**

Keywords*–Integrated Systems; Scientific Supercomputing; Sustainability; Knowledge Resources; Information Systems; UDC; Archaeology; Geosciences; High Performance Computing.

I. INTRODUCTION

The amount of data as well as the complexity of information keeps steadily increasing. The developments of the last decades have shown that for a continuous positive progress not only the efficiency must increase, the more, developments must be made long-term sustainable, too. As the knowledge gathered during generations should be considered the most important component to the overall success we need universal knowledge resources that can handle documentation as well as universal classification and structuring. The knowledge resources should not only be traditional collections as with digital libraries [1] and isolated content [2] but, despite any challenges be accessible with scientific supercomputing resources in order to create advanced information systems and implement and improve workflows and recommended operation [3], [4].

So, this decisively contributes to the goal of successful creation of long-term sustainable Integrated Information and Computing System components. The created features of the knowledge resources presented for the first time in this paper contain new practical concepts for information structures and object representations. The objects and derivatives, described in this paper, can be used with universal classification and computation algorithms for multi-disciplinary, dynamical knowledge discovery. This paper presents examples from archaeology and geosciences disciplines, resulting from practical case studies on structure and workflow modularisation, within the GEXI collaborations [5]. These are part of a multi-disciplinary knowledge structure. Further, the implementation of the knowledge objects is suitable to be used very flexibly with workflows on HEC resources, e.g., with Integrated Information and Computing System (IICS) components [6]. Multi-disciplinary knowledge resources are used to resemble and document of any information available. As the requirements for complexity can become arbitrary high, compute resources have to be used for any more advanced applications. Creating workflows based on the multi-disciplinary knowledge matrix therefore requires highly performant resources. The structure of the knowledge objects has to support the modularisation for application scenarios where the workflow has to allow highly efficient implementations itself. The applicability for parallelisation of the contributing algorithms with the complex knowledge trees has therefore been analysed with the case studies. The motivation for investigating in the efficiency and modularisation of the knowledge trees is the increased potential for drastical improvements of the Quality of Data (QoD) with the result matrix, which contributes to advanced cognition within the multi-disciplinary context.

This paper is organised as follows. Sections II and III introduce with sustainability and vitality of knowledge-based architectures and main issues of complexity. Sections IV and V present a practically used classification approach to the challenges. Sections VI and VII describe the new concept of object carousels, the discovery of "missing links", workflow, and computation demands. Sections VIII and IX discuss the lessons learned and summarise conclusions and future work.

II. SUSTAINABILITY AND VITALITY

Data mining is not only an analysis step of knowledge discovery in databases based on informatics but much more general in data pools. It is an inter-disciplinary as well as multi-disciplinary field of many sciences and computer science. It means discovering patterns in data pools using methods implementing statistics, classification, artificial intelligence, learning and many more based on knowledge resources. The process targets to extract information from knowledge resources and gaining content and context, e.g., based on structure and references, in order to prepare for further use. Sustainable long-term strategies have to combine operation, services, and especially the knowledge resources. With the

 ISBN: 978-1-61208-310-0

available systems components, we have Resources Oriented Architectures (ROA), Services Oriented Architectures (SOA), and "Knowledge Oriented Architectures" (KOA) in addition [7]. For long-term operation, all three must be obtained from the creation and operation. Considering the entirety of aspects necessary for a successful long-term change management with future information technology structures. Nevertheless, the KOA is the most important complement as it contains the highest percentage of the overall investments for the results and the data that may even not be reproducible later on.

III. Complex knowledge resources case

The knowledge resources created can integrate any object. These objects can be described with universal classification, handled with phonetic algorithms [8], [9], and can refer to external resources. The overall big data challenges, data intensive volume, variability, velocity and for future scenarios especially data vitality, meaning long-term documentation, usability, and accessibility can be handled in a scalable, modular way. Further, the components created are considered to become objects of sustainable knowledge resources, for long-term persistent big data vitality of documentation, processing, analysis, and evaluation. The created solution for long-term use meets a number of attributes, e.g., it should be generic, superior, adaptable, flexible, seminal sustainable. In summary, these combined vital features are called "eonic".

IV. Knowledge resources classification support

The operated knowledge resources, based on the LX Foundation Scientific Resources [8], incorporate UDC classification for any discipline and purpose, e.g., for knowledge discovery and workflows. Practical summarising excerpt subsets for specific disciplines are given in Tables I to II.

Table I. Archaeology knowledge resources classification.

UDC Code	*Description*
UDC902	Archaeology
UDC903	Prehistory. Prehistoric remains, artefacts, antiquities
UDC904	Cultural remains of historical times
UDC"63"	Archaeological, prehistoric, protohistoric periods, ages
UDC56	Palaeontology
UDC55	Earth Sciences. Geological sciences
UDC711.42	Kinds of town, locality, settlement
UDC720.32	Ancient architecture

Table II. Volcanoes knowledge resources classification.

UDC Code	*Description*
UDC532	Fluid mechanics in general.
UDC550.93	Geochronology. Geological dating. . . .
UDC551	General geology. Meteorology.
UDC551.1	General structure of the Earth
UDC551.2	Internal geodynamics (endogenous processes)
UDC551.21	Vulcanicity. Vulcanism. Volcanoes. Eruptive phenomena.
UDC551.23	Fumaroles. Solfataras. Geysers. Hot springs. Mofettes.
UDC551.24	Geotectonics
UDC551.26	Structural-formative zones and geological formations
UDC551.4	Geomorphology. Study of the Earth's physical forms
UDC551.44	Speleology. Caves. Fissures. Underground waters
UDC551.462	Submarine topography. Sea-floor features
UDC551.588	Influence of environment on climate
UDC551.7	Historical geology. Stratigraphy
UDC551.8	Palaeogeography
UDC552.2	General petrography. Classification of rocks

The UDC sets have been used with the presented computation. UDC [10] currently provides around 70000 entries in about 100 top classes, whereas the UDC Summary [11] provides a selection of more than 2000 classes. The multilingual support lists translations in fifty languages [12]. UDC classifications have been integrated with tens of thousands of knowledge objects [9] which are a base for each computation.

V. Coping with the challenges

A. Modular components for geoscientific applications

Complex geophysical exploration is an explicit big data problem. Data locality and data movements are of essential importance. Therefore, data handling does take longer a time than the compute intervals. Due to the short intervals for licensing and the high costs even the time efficiency has to be increased. This can be supported by parallel techniques [13]. In many multi-disciplinary cases, e.g., explicitely shown with the case studies [6], [8], the more with growing importance of evaluation processes, the task- and thread-parallelity has to be increased both. The data in geosciences and in associated natural sciences contains the most valuable information because many of these natural processes change in geological time intervals. Imaging for oil and gas is one of the most demanding tasks in computational sciences. It requires scale-out architectures, the processing and simulation are computation intensive as well as data intensive. The data provides long-term challenges on knowledge and resources to researchers and industry because of expenses on data collection and long-term usability.

B. Rising requirements on quantity and computation

As soon as even a selected subset of the available classification is integrated with a subset of detailed knowledge resources, the requirements for computing and interfaces are rising drastically. The increasing demands for advanced scientific computing are resulting from the huge number of relations within the knowledge resources as well as a consequence of the workflows, dynamical interaction, presentation, and visualisation of results. The conditions for the optimal computing architecture are defined by the application scenario, not by the knowledge resources themselves.

C. Quality for Quantity

For the discovery of a result matrix from a large quantity of data, additional high quality resources can be used for improving the quality of results deduced. The premise is that appropriate workflows and algorithms will be applied. The high quality knowledge resources have been used as "Quality for Quantity" (Q4Q), in order to build any additional missing references in the quantity data. With these HEC and discovery processes, big data means volume regarding storage, means variability regarding workflow processes, means velocity regarding instances, and vitality regarding knowledge resources.

VI. Object carousels

The organisation of the knowledge objects can be arbitrary complex. Many cases can be described in a simplified way like a mindmap, which has been used for introducing a new symbolic representation named "object carousels". The knowledge

 ISBN: 978-1-61208-310-0

objects build a kind of dynamical molecules. These molecules have connectors and references. These connectors can connect with other knowledge objects by computing references from any number of directions. The process reminds of rotating branches of trees, rings, and multi-dimensional objects for finding pluggable connections. The creation of object carousels does have the benefit, that knowledge discovery workflows can be implemented very scalable, using various algorithms for connecting trees. For example, full text references can be used between any carousels in order to compute a result matrix.

A. Object mapping

The mapping in Figure 1 shows an excerpt for the volcanology context on terrestrial volcanism calculated from the knowledge resources. These allow to calculate relations via flexible, user-defined algorithms.

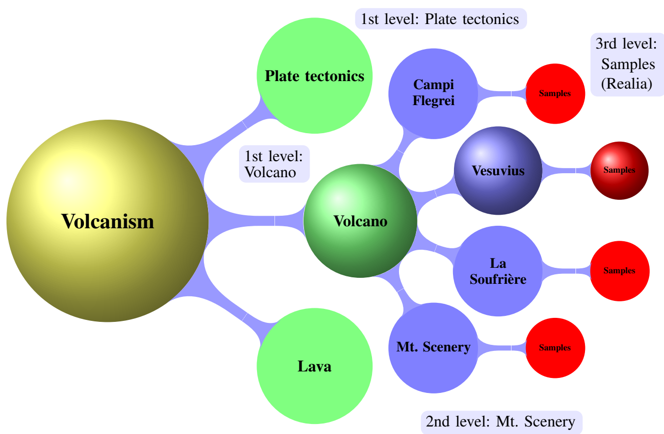


Figure 1. Object carousel for terrestrial "volcanism" context with subset of computed volcano references and examples of levels object relations.

The figure shows an excerpt of the direct relations by quality of relations and quality of objects. The colours visualise object groups or attributes within each figure. Any object or attribute can dock-in at any placed defined by the workflows, not depending on the grouping. Nevertheless, the decision within the workflow maybe assisted by the group information. The knowledge resources can contain objects and relations as well as classification entries. The case study example being the base for illustrating the different aspects in all the next sections follows a discovery path (3D), starting discovery on object and realia references in the volcanology dimension.

B. Information and object usage

In a non-promoted environment, a knowledge search engine showed significant requirements with up to over 500,000 application- and several million object-requests per day. The study on object usage from international public interest groups done in a time interval from 1994 to 2012 [5] revealed comparable large numbers of accesses and complexity. The object mapping is a basic part, whereas the algorithmic workflow for improving the quality can be as expendable as using every information available with each step recursively and iteratively. The computation share can increase to hours per discovery instance but computation can be done for any number of carousels in parallel. The KOA opens flexible support for task and process parallelity for using objects and object groups or clusters.

C. Case study views

Suitable views for volcanoes are: Type (of volcano, coarse categories), date on timeline, size (height). For craters respective views are: Type (of crater, fragmentary), date on timeline, size (diameter). An object carousel generated for volcano types, shows the knowledge resources groups (Figure 2).

Figure 2. Object carousel for volcano and type references computed for terrestrial volcanism, providing volcano type references.

An evaluation of the association that users have, showed that the criteria "date" and "location" are most prominent with objects if the workflow approaches from the "surface (of the earth)" view. Therefore, mapping and timelining will be the natural result.

D. Improving quality within the workflow

The resources, workflow, and classification are essential for a high level of usability quality of results. The elaborate workflow process for improving the quality of results when calculating a result matrix from a knowledge base is:

a) Calculate associator attributes and classes,
b) Compute on a base with large numbers of objects,
c) Evaluate detailed classification information,
d) Compute for a reduction of numbers of objects,
e) Create suggestions and recommendations.

The first computation block (b) is needed for considering more objects when applying the further steps afterwards. Here, the classification is essential for improving the quality for the respective selection process. The second computation block (d) is necessary for improving a selection process for the target audience or services. The selection processes can be significantly supported by high quality knowledge resources

(Q4Q), e.g., via the authored, classified, and audited content, with regular expression search, and phonetical algorithms.

E. Improving coverage: Dark data

In analogy to "dark matter" and "dark energy", there exists "dark information" and to an uncertain extent an unknown driving force in knowledge creation, even building "dark service" provided via "dark resources". Those information resources are not wider accessible and it is not known where the intention of gathering and creation. Anyway, this information must be considered for any holistic long-term concept as it provides an important factor for the overall knowledge and will stay in existance despite of any development. With the concept of long-term knowledge resources the information has been integrated in order to extend the base for any knowledge discovery. Considered methods for integration of resources are, e.g., references, description or caches. This further includes seamless updating of information, licensing of resources, dynamical use of data as well as provisioning of defined quality and reliability for sources and complements.

VII. Discovery of missing links

From the disciplines of humanities and archaeology, the directed tree spanning from settlements to used materials will show up with a practically defined depth. On the other hand, starting from natural sciences a directed tree spanning to materials associated with processes will deliver a natural sciences path. Along with the different paths, the genetic connectors of both carousels will show up with links from both directions. The connecting links, or short "connections" from the directed search do open new associations that can be used to discover the overall knowledge much deeper with new facets and quality, which provide multi-disciplinary links that have been missing in non-genetic discovery.

In general, any kind of tree path can be generated from the knowledge resources using a workflow and any number of carousels can be discovered for connections. The following example shows a simple two-carousel case (Figure 3). Computing the object carousels connections is shown for a historical city carousel and an environment object carousel. The trees show a subset of computed references computed by the workflow within the knowledge resources. The depth of the trees may by different for the computation. The connections are considered as soon as they lead to a defined conformity. In that case, defined conformity can mean comparable or identical. The example shows two trees, one from archaeology and one from natural sciences disciplines. For both, at a certain branch leading to object referring to stone material, which is shown by the highlighted red bullets.

A. Computing connections on modular objects

Figure 3 shows the principle used for computing connections with object carousels. It depicts one fitting branch, within archaeology and geosciences associated objects. Starting with the objects `Historical City` and `Environment` (identified by large golden bullets) and the linking objects "stone" the computed carousels show trees with a subset of references. The workflow attributes have been choosen to provide no tree depth restriction for computation. The two fitting connection lines within the object carousels of this example are highlighted in a three-dimensional representation: `Roman : Pompeji : Napoli : Architecture : Volcanic stone` and `Volcanology : Catastrophe : : Volcanic stone`. In the sample workflow the carousel connections are calculated via non-explicit references of comparable objects (red objects) from knowledge resources within trees. In addition, the red circle does mark those objects at the same depth level, including the fitting object term for historical city and environment `Volcanic stone`. The excerpt of associated multi-disciplinary branch level objects are `Limestone`, `Impact feature`, and `Climate change`.The method for creation of non-explicit references can be defined in the workflow. Here, full text mining and evaluation (red objects) has been used. For derivated associations additional objects can be computed and extracted in every branch as well as on all levels.

B. Connecting knowledge

Objects can be connected by various attributes. These may be attributes associated with content as well as with context. For example, relations for a volcano object can be connected and triggered by a large variety of attributes. Table III shows an excerpt of attributes and examples.

Table III. Attributes linking and triggering volcano objects and selected examples (excerpt).

Attribute	*Example in Archaeology/Geosciences*
`Time`	Events on timeline
`Location`	Volcano-impact-settlement locations
`Physics`	Earthquakes
`Chemistry`	Volcanic SO_2 ejection
`Geology`	Earth crust, petrography
`Catastrophes`	Volcanic eruptions, Tsunamis
`Etymology`	Phlegra, Vesuvius
`Cults, religions`	Volcano gods
`Artefacts`	Archaeological objects, "Pompeji" events
`Historic events`	Volcano, climate, economy, revolution

Relations can refer to any multi-disciplinary topic, building results from combination of information and generation of new objects and references, e.g., visualisations and views.

C. Flexible support for HEC and dynamical discovery

The KOA architecture is based on a flexible documentation and development architecture [9] and integrated with the case study implementations based on the Collaboration house framework for disciplines, services, and resources [8]. Building the tree paths as well as the discovery of connections in the carousels can be done in parallel, comparable to a modelling process. This way, while computing one tree it is possible to follow connections into other disciplines' branches interesting for a workflow. The task parallel processes can be computed to look ahead, dynamically discovering fitting relations. On the other hand it is possible to compute multiple trees and create intermediate result matrices, which can be used for building multi-disciplinary results. Referring objects for publicly available information can be integrated by dynamically building associations from the knowledge resources as has currently been done with search engine content, e.g., results from Google or other dynamical sources.

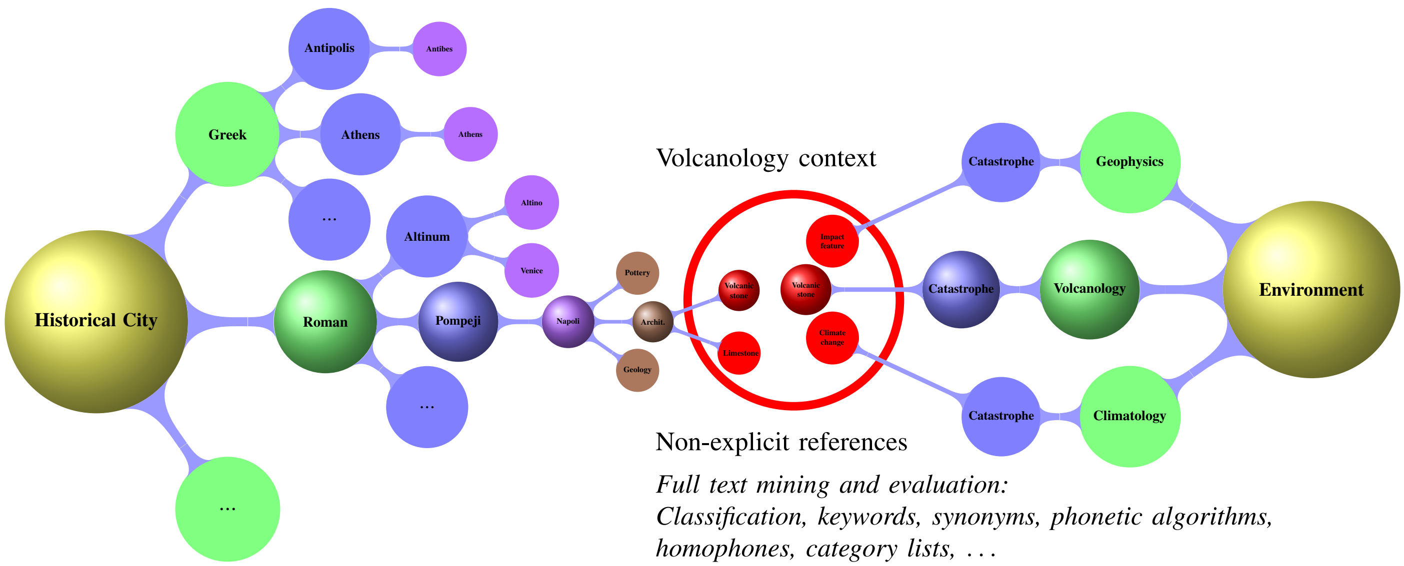


Figure 3. Computing object carousel connections: Historical city and environment object carousels showing trees with a subset of computed references. In this sample workflow the carousel links are calculated via non-explicit references of comparable objects (red) from knowledge resources within trees.

D. Workflow and computation demands

Table IV shows the resulting computation times (wall clock) for straight and broadened application qualities. Straight means calculating the result matrix directly from the plain data available, including ranking. Broadened means using full text, references, and available secondary context information, with a wide spectrum of topics. It is possible to flexibly support the knowledge discovery workflow by any number and kind of algorithms and communication. In this case classification, keywords, synonyms, phonetic algorithms, homophones, and category lists have been used.

Table IV. STRAIGHT AND BROADENED (SERIAL) APPLICATION QUALITIES AND COMPUTATION TIMES PER WORKFLOW INSTANCE AND REQUEST (RESTRICTED TO THREE INITIAL TERMS).

Item	*Straight*	*Broadened*
Number of terms (restricted for demo.)	3	3
Comparisons	≈ 90000	≈ 1090000
Selection processes	1540	16700
Intermediate results	420	5100
Final results (selected top 10)	10	10
Classification evaluation time share	3 s	30 s
Keyword extraction time share	2 s	4 s
Fulltext support time share	4 s	22 s
Reference support time share	1 s	3 s
Phonetic support time share	3 s	8 s
Instance computation time	3 s	120 s

The example demonstrates the principle and tendency. Starting a single workflow instance with a small number of 3 object terms (Figure 3), this statistically results in:

a) *Straight*: Retrieval followed by 90000 comparisons, delivers 30000 results, ranked to create a top 10.

b) *Broadened*: This requires an additional 1 million comparisons per term and some 10000 comparisons on more than one term as well as on subterms, it delivers 90000 results, which are ranked to create a top 10.

In an average of terms, b) results in 3 new top terms better reflecting the context, which means a significant improvement of the quality of the result matrix. As Table IV shows, when improving the quality, the compute time increases from about 3 seconds to 2 minutes. Over the time the resource usage increases by about a factor of 50. Due to the structure of the compute algorithms a part of the workflow processes can be done in parallel before the final result matrix is created. Other advanced workflow processes, e.g., those processes where all the intermediate results must be available before any decision on the next step can be done, have to be chained for the purpose of improving the quality. With parallel processing in the above example the overall time can be reduced to about 30 s on the same architecture if an increased number of resources is available. Increasing the number of comparisons by adding further sources for improving the quality of results increases the requirements on resources more than linear referring to the compute time. This is going ahead with a smaller amount of numerical improvement for the top results. The knowledge resources fully support this procedure. The broadened serial and task parallel (dual-core processors) application qualities per workflow instance and request are summarised in Table V.

Table V. BROADENED SERIAL AND PARALLEL APPLICATION QUALITIES PER WORKFLOW INSTANCE AND REQUEST (AS ABOVE).

Workflow Item	*Broadened Serial*	*Broadened Parallel*
Number of terms (restricted for demo.)	3	3
Parallel resources (nodes)	1	10
Instance computation time	120 s	20 s

The resulting computation times per instance can be efficiently reduced exploiting parallelity of resources. Modularising the knowledge resources into dynamical entity groups of objects is very efficient for a large number of requests and resources available. This is especially interesting for any wider economical and practical interactive use. The higher the complexity of the single, even non-linear, workflow is, the less efficient are todays resources architectures.

 ISBN: 978-1-61208-310-0

VIII. Discussion

Regarding the sustainability of the knowledge resources support it has been practical to consider three main aspects for creating sustainable KOA architectures.

1) *Scalability and efficiency:* The workflow process can be modularised and therefore can be implemented as scalable and parallelised algorithms.
2) *Discovery and content:* Big amounts of multi-disciplinary information will always have to consider inhomogeneous groups of information. With the described method the barrier between the inhomogeneous content, for example, between different disciplines can be overcome. The knowledge resources support structuring and modularising the workflows to a defined level. Any references that might not already exist explicitely in the knowledge resources can be suggested by a non-tree link. An example is, computing full text comparisons between the carousels from the available plain content of the knowledge resources.
3) *Universal multi-disciplinarity:* The knowledge resources allow any number of dimensional space. Besides that, the knowledge resources allow to use multi-disciplinary clustering of objects, e.g., clustering of stones for an archaeological view as well as for a petrographical view.

These features can be used for a flexible dynamically guided discovery. Besides the benefits of very flexible classification support, e.g., via UDC, expenses are that the creation and operation do require intensive work.

IX. Conclusion and future work

Structuring and classification with long-term knowledge resources and UDC support have successfully provided efficient and economic base for an integration of multi-disciplinary knowledge and IICS components, supporting archaeological and geoscientific information systems. With these, the solution is scalable, e.g., regarding references, resolution, and view arrangements. The concept can be transferred to numerous applications in a very flexible way. The overall results on object carousels and Q4Q workflows from the implementation and case studies are:

- The quality of data can be most efficiently improved at the knowledge resources components.
- The quantity of data can be increased by referencing and intelligent discovery workflow algorithms.
- The quantity of compute and storage resources is both tightly linked with the quality of data and the quantity of data and resources requirements.

The knowledge resources can be integrated into a steadily improving system architecture storing data for successful creation of sustainable workflow definitions, meaning that the result matrix of requests can be stored for future use and evaluation. This can be done in a non-incremental way, depending on the environment of communication, computation, and storage resources in order to provide an efficient solution. Separate snapshots of the knowledge resources allow to consider developments within time. Nevertheless, for service operation this can result in very high requirements for resources. With the presented object carousels an undefined number of practical workflows can be created on the knowledge resources. The object carousels concept is part of the “tooth system” for long-term documentation and algorithms and the exploitation of supercomputing resources for use with future IICS.

Acknowledgements

We are grateful to all national and international partners in the GEXI cooperations for the innovative constructive work. We thank the Science and High Performance Supercomputing Centre (SHPSC) for long-term support of collaborative research since 1997, including the GEXI developments and case studies on archaeological and geoscientific information systems. Thanks go to the scientific colleagues at the Institute for Legal Informatics (IRI), Leibniz Universität Hannover, and WWU Münster, as well as to the participants of the EULISP Programme for prolific discussion of scientific, legal, and technical aspects over the last years.

References

[1] “WDL, World Digital Library,” 2013, URL: http://www.wdl.org [accessed: 2013-05-12].

[2] “The Digital Archaeological Record (tDAR),” 2013, URL: http://www.tdar.org [accessed: 2013-07-10].

[3] Wissenschaftsrat, “Übergreifende Empfehlungen zu Informationsinfrastrukturen,” *Wissenschaftsrat, Deutschland, Drs. 10466-11, Berlin, 28.01.2011*, 2011, URL: http://www.wissenschaftsrat.de/download/archiv/10466-11.pdf [accessed: 2013-08-09].

[4] di Maio, P., “A Global Vision: Integrating Community Networks Knowledge,” *Community Wireless Symposium, European Community, EC Infoday, Barcelona, 5th October 2012*, 2012, URL: http://people.ac.upc.edu/leandro/misc/CAPS_Paola.pdf [accessed: 2013-08-10].

[5] “Geo Exploration and Information (GEXI),” 1996, 1999, 2010, 2013, URL: http://www.user.uni-hannover.de/cpr/x/rprojs/en/index.html#GEXI [accessed: 2013-05-26].

[6] C.-P. Rückemann, *Queueing Aspects of Integrated Information and Computing Systems in Geosciences and Natural Sciences*. InTech, 2011, pp. 1–26, Chapter 1, ISBN-13: 978-953-307-737-6, DOI: 10.5772/29337.

[7] “ROA, (Wikipedia),” 2013, URL: http://en.wikipedia.org/wiki/Resource-oriented_architecture [accessed: 2013-09-19].

[8] C.-P. Rückemann, “Enabling Dynamical Use of Integrated Systems and Scientific Supercomputing Resources for Archaeological Information Systems,” in *Proc. of The Int. Conf. on Advanced Communications and Computation (INFOCOMP 2012), October 21–26, 2012, Venice, Italy*. XPS, 2012, pp. 36–41, ISBN: 978-1-61208-226-4, URL: http://www.thinkmind.org/download.php?articleid=infocomp_2012_3_10_10012 [accessed: 2013-06-09].

[9] C.-P. Rückemann, “Advanced Scientific Computing and Multi-Disciplinary Documentation for Geosciences and Archaeology Information,” in *Proc. of The Int. Conf. on Advanced Geographic Information Systems, Applications, and Services (GEOProcessing 2013), February 24 – March 1, 2013, Nice, France*. XPS Press, 2013, pp. 81–88, ISSN: 2308-393X, ISBN: 978-1-61208-251-6, URL: http://www.thinkmind.org/download.php?articleid=geoprocessing_2013_4_10_30035 [accessed: 2013-05-26].

[10] “Universal Decimal Classification Consortium (UDCC),” 2013, URL: http://www.udcc.org [accessed: 2013-04-07].

[11] “Universal Decimal Classification Summary (UDCS),” 2013, URL: http://www.udcc.org/udcsummary/php/index.php [accessed: 2013-04-07].

[12] “Universal Decimal Classification Summary (UDCS) Translations,” 2013, URL: http://www.udcc.org/udcsummary/translation.htm [accessed: 2013-04-07].

[13] C.-P. Rückemann, “Application and High Performant Computation of Fresnel Sections,” in *Symp. on Adv. Comp. and Inf., Proc. of The 9th ICNAAM, Halkidiki, Greece, AIP Press*, vol. 1389, no. 1, 2011, pp. 1268–1271, ISBN: 978-0-7354-0956-9, URL: http://link.aip.org/link/?APCPCS/1389/1268/1 [accessed: 2013-07-07].

Ad Hoc Things Collaboration Based on Semantics of Things

Use case of Internet of Things

Marie Kim, Hyo-Chan Bang
IoT Convergence Department
ETRI
Daejeon, Korea republic of
mariekim@etri.re.kr, bangs@etri.re.kr

Abstract— **Internet of Things is everywhere, nowadays, in industrial fields, academic fields, and also in standardization fields. Most researches and products are about identification and connectivity aspects. If everything is connected and identified uniquely, then what can happen? This paper focuses on the usage of Internet of Things from a view point of personalized service provision by ad hoc things collaboration deployed by multiple providers. In this case, things are deployed without organized plans by multiple providers and shared among any users with appropriate permissions. Therefore, discovery, grouping, management and scheduling on things for collaboration are the main issues to resolve.**

Keywords-Internet of things; discovery; things; collaboration; semantics.

I. Introduction

Internet of Thing (IoT) has many different definitions [1][2] by different organizations. But, a common characteristic of Internet of things defined by different organizations is things-connectedness. In any case, everything should be connected to the Internet to communicate with other things.

There are many researches and standards regarding how to connect things to the internet. IETF Constrained Application Protocol (CoAP) [3] is an application layer messaging protocol to connect constrained things to the internet with a light RESTful framework. IETF 6LowPan [4] is a light IPv6 protocol for the constrained things to connect to the internet. A smart gateway [5] and a WoT Broker [6] are the gateways which bridge between different air protocol things (Bluetooth, IEEE802.11.4, WiFi) and web protocol things. Nowadays, many researches focus on Web of Things [4][6][7], which tries to connect things with web protocols. Meanwhile, Web of Objects (WoO) project [8] tries to build things manipulation environment based on Service Oriented Architecture (SoA)[9] philosophy.

When it comes to identification, identification requirements for IoT [10] are being analyzed and summarized now in ITU-T. In a web area, Uniform Resource Identifier (URI) is the identification scheme for all connected things. Until now, it is an open issue whether one powerful identification scheme prevails over the whole IoT things, or there just needs a smart interpreter or translator between different service/network area identification schemes.

This paper is organized as follows. Section II describes related works regarding things collaboration. Section III describes ad hoc things collaboration from a lifecycle management aspect.

II. Related Works

A. Common Open semantic USN Service platform (COMUS)

COMUS [11] is an open USN semantic service platform under developing by ETRI since 2010. Ubiquitous Sensor Network (USN) is focusing on sensors but deals with actuators also. One big characteristic of COMUS is that users send queries to COMUS to get needed sensor data with an abstract level query such as “get temperature values from room_number1”. Then, COMUS looks up the USN repository to get sensors’ identifiers located within a room_number1 and sends sensor data requests to those sensors. This is called as a dynamic logical sensor group management in ITU-T F.OpenUSN [12]. By using this mechanism, users do not need to know details of sensor networks.

B. Social Web of Things and Device Sociality

Convergence of sociality and things are the hottest IT trend nowadays and it is a very interesting and realistic model because there need ways to share connected things everywhere based on some permission mechanisms. Social web of things [5][7] and device sociality [13] approach a things-sharing issue with social networks. Paraimpu [7] provides a things-distribution mechanism based on a social network service and provides a social mashup editor to operate things which are allowed to use based on social relationships. So, users can share their things with friends and can build things-mashup easily. Meanwhile, device sociality aims at building and managing social relationships of personal devices by using human relationships obtained by social networking services. Multiple devices of one user can share data, application or more resources. Also, different devices of different users, but with human-friendship relationships can be shared among those users.

 ISBN: 978-1-61208-310-0

C. Other works

ISO/IEC 20005 (Information technology -- Sensor networks -- Services and interfaces supporting collaborative information processing in intelligent sensor networks) [14] is a standard about a node grouping for collaborative information processing. Actually, it does not include any logic or context but it defines related services and interfaces to manage a dynamic node group for collaborative information processing.

There were other approaches for collaborative application. Moon et al. [15] deals with collaborative application in VANETs (vehicular ad-hoc networks). While driving, if gasoline is running out of, then the vehicle initiates communication with other vehicles to get information about cheap and close gas stations. Then, other vehicles can give requested information to a requesting vehicle. The requester broadcasts queries to the certain amount of distance. Therefore, a size of an ad hoc group of vehicles can vary to the circumstance. And, members of a vehicle ad hoc group can vary where the broadcasting happens.

D. ThingsDoWeb

ThingsDoWeb is a dynamic things collaboration platform which is under developing by ETRI since 2013. It aims at providing environments where things collaborate with each other for seamless service provision. Things are identified by URI and communicate with each other by RESTful API. Things do web to collect information and to control other things for proving user-friendly seamless service without humans' intervention. To do that, *ThingsDoWeb* platform provides connectivity for all things and provides dynamic collaborative group management based on things' context (semantics of things) and users' preference. Ad hoc things collaboration based on semantics of things is one of the main research issues of *ThingsDoWeb* project.

III. AD HOC THINGS COLLABORATION BASED ON SEMANTICS OF THINGS

The everything-connectedness is the motto of IoT. Assuming that everything is connected, what can be done by using things? It necessarily brings up *services* which use multiple things to provide specific functions for human beings. When it comes to service provision, many cases require multiple things to provide target services what users want to receive. At this point, the important thing to be considered is which things should collaborate with others to serve the target services. This is the *thing discovery, selection and grouping issues* and it highly depends on the availability of things at the service time at the service spot. Especially, when we consider user's mobility, then available things are changed according to the location of users. Even though a user does not move, a thing can be out of order and a new thing can join to the given physical space.

Therefore, an available things list and things' status should be managed in real time and target service executors should manage and schedule things collaboration accordingly. This is the *management and scheduling on things issues*.

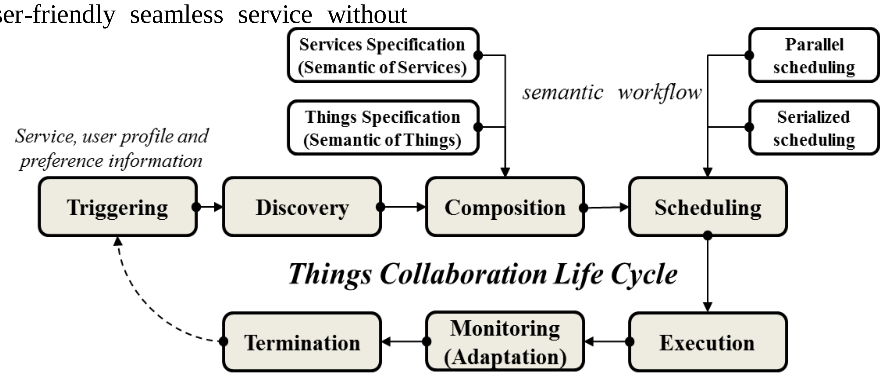


Figure 1. Ad hoc Things Collaboration Life Cycle.

Figure 1 depicts an ad hoc things collaboration life cycle. When target service initiation is triggered, first step is *discovery* of available things to use for the target services. When service triggering is initiated, target service information and user information need to be detected by using appropriate mechanism. Radio frequency identification [16] technology can be used to detect and identify user. Or, a newly designed things collaboration protocol can be used to detect target service information.

Then, based on detected information, things *discovery* should be performed. As a result of *discovery* process, an available things list is set up for the services. Then, next step is things *composition*. *Composition* (*ad hoc things collaboration space management*) includes *selection* and *grouping* of things and it should be performed based on the semantics of both services and things. Semantics of services is a specification of services which include service identifier, service location, service type, workflow, user's preference, etc. Semantics of things is a specification of things which include thing identifier, location, service type, device type, permission, etc. Next step is *scheduling*, which plans execution flow of things. Things can be operated in parallel or serialized. It depends on the semantics of services. Then, next step is execution of a composed service. During execution, status of each thing should be monitored and if certain thing's status is changed then service composition should be adapted accordingly. It is a *monitoring* step. Finally, when a user wants to stop services, then ad hoc things collaboration is terminated. It is a *termination* step.

A. Triggering

Ad hoc things collaboration can be triggered by users' manual click or can be triggered by intelligent things which recognize needs of users.

B. Discovery

Generally, discovery can be performed in two ways. One is a broadcast-based discovery, and the other is a registration-based discovery. In the case where collaborating things are restricted in a local domain, then both ways can be applied. But if things to collaborate with are in an open domain and scale of things are varying and large, then broadcast-based approach is not reasonable from the scalability and network traffic points of view. Figure 2 shows broadcast-based discovery and collaboration.

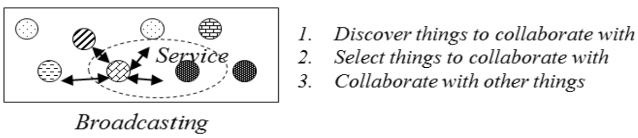


Figure 2. Broadcast-based discovery.

Figure 3 shows registration-based discovery. For service provision, within an open service domain, registration-based discovery may be a better choice than broadcast-based discovery. But, management of repository for a vast number of things is also a tricky problem. So, a DNS-like hierarchical management policy may be applied to keep consistency and an easy discovery.

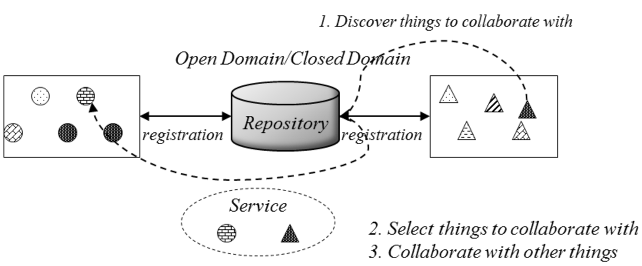


Figure 3. Registration-based discovery.

C. Composition

When it comes to *selection*, there need criteria for selecting members. Criteria for selecting things for target services are what functionalities are needed to perform services and what kinds of things users can use. Optionally users' preference on things can be an important factor.

Semantics of services is service specification and it includes service identifier, service name, service type, required service type list, workflow of services, associated things list, user's preferences, etc. Service specification gives the selection criteria such as a required service list which is provided by things and user's preference. Meanwhile, semantics of things is the thing specification. Thing specification includes thing identifier, thing name, access address, resource list (or supporting service type list), device type, owner, location, etc. Thing specification gives selection criteria such as a resource list, location, etc.

The definitions on things and services are very much arguable. In this paper, things are mapped into devices and devices provide multiple services. Figure 4 depicts the composition and relation between things and services.

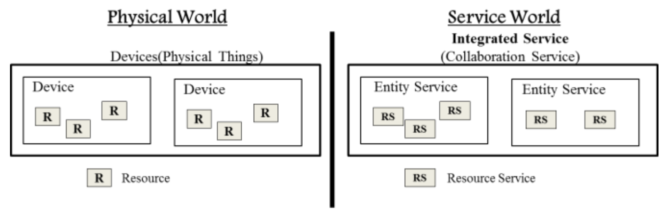


Figure 4. Things and services.

Table I shows a semantics of things (thing specification) and semantics of services (service specification) based on concepts of Figure 4.

TABLE I. TABLE A SEMANTICS OF THINGS AND SERVICES

Thing Specification	Service Specification
· thing identifier	· service identifier
· thing name	· service name
· access address	· required service type list
· resource list(=supporting service type list)	· workflow
	· associatedThings list
· deviceType	· user's preference
· owner	· location
· location	· service provider
· etc.	· etc.

D. Scheduling

A things collaboration execution schedule is determined by a coordinator. A coordinator can be preconfigured when things are deployed or a coordinator can be elected while operating based on a specific election algorithm. Both approaches have pros. and cons. But, from a practical point of view, a preconfigured coordinator is more reasonable than an elected coordinator. Figure 5 shows a role of collaboration coordinator.

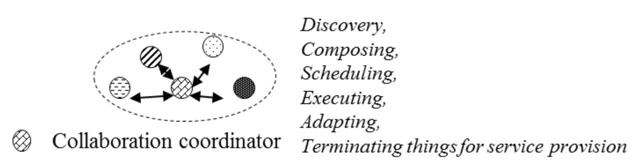


Figure 5. Collaboration coordinator.

E. Execution

Things collaboration can be executed in parallel or in serial. Figure 6 (a) shows a parallel execution case. Everything operates in parallel and this case can happen when a speaker, a player and a displayer operate together for a movie playing.

 ISBN: 978-1-61208-310-0

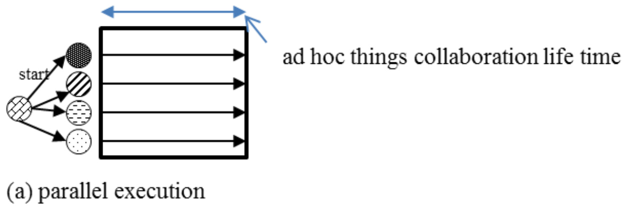


Figure 6. Collaboration execution in parallel.

In case of a serial execution, three modes are possible. First case is that a coordinator instructs each thing to start operation with an exact start time value and a duration time value optionally. Then each thing operates accordingly. The second case is that a coordinator sends each task to each thing. And then a coordinator instructs to the first things for start operation. After finishing operation, the thing triggers next thing's operation and so forth. The third case is that a coordinator transmits tasks to each thing. And then, a coordinator controls whole process. Everything should report its service termination to a coordinator, then a coordinator determines next thing to operate, and so forth.

Figure 7 shows serial execution cases. Case (a) means a collaboration coordinator instructs to each thing to operate with start time and duration time. Then each thing operates accordingly. In case of case (a), time synchronization among things is very much crucial. Case (b) means a collaboration coordinator transmits each thing with tasks at a time. Then each thing operates based on the specified task and after doing its task, each thing gives a notification to next thing and so forth. In this case, a coordinator specifies a workflow among things clearly and this information should be reflected into the things' tasks appropriately. Case (c) means each thing sends a finish notification to a collaboration coordinator after finishing its task, then a collaboration coordinator instruct to a next thing to do its task. This case is more flexible than the previous cases (a) and (b) from a point that when context or situation is changed during execution, a collaboration coordinator can react against the situation effectively.

Figure 7. Collaboration execution in serial.

F. Monitoring (Adaptation)

Ad hoc things collaboration space (members) is quite volatile because of things' unstable status and user's movement. Even though, services should be provided seamlessly in any situation. Therefore, monitoring on things is very important and when a thing (member of collaboration space) is out of order or away from a service area, then other candidate things should be ready for execution.

A collaboration coordinator should monitor the things' status and keep candidate things for any contingency. Figure 8 shows an ad hoc things collaboration space adaptation from the user's mobility and things' status change point of views.

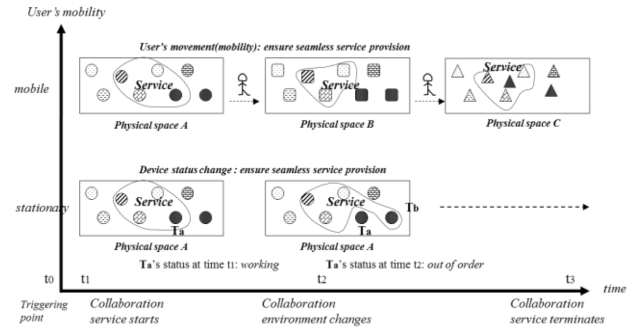


Figure 8. Ad hoc things collaboration space adaptation.

G. Termination

When collaboration service ends all things become released. Then each things change each occupancy status and a collaboration coordinator stops working.

IV. Conclusion

This paper describes ad hoc things collaboration lifecycle management and draft version of service specification and thing specification. It is in an early stage of design and implementation.

Furthermore, whole processes can be generalized as like SoA or Resource Oriented Architecture (RoA). Then, both of semantics of things or semantics of services can be refined clearly enough.

Even though this is in early stage, it is obvious that an ad hoc things collaboration technology is a key technology to empower Internet of Things or Web of Things. Based on the connectivity given by IoT or WoT, things can be operated more human friendly and that is a goal of ICT.

Acknowledgment

This work was supported by Electronics and Telecommunications Research Institute (ETRI) grant funded by the Korea government [**13ZC1130**, Development of USN/WoT Convergence Platform for Internet of Reality Service Provision].

References

[1] ITU-T Y.2060, "Overview of Internet of Things", June. 2012.

[2] "The Internet of Things 2012—New Horizons-Cluster Book," 2012. http://www.Internet-of-things-research.eu/pdf/IERC_Cluster_Book_2012_WEB.pdf. [accessed: 2013-09-15].

[3] Constrained Application Protocol (CoAP) draft-ietf-core-coap-17, May 2013.

[4] http://tools.ietf.org/wg/6lowpan/ [accessed: 2013-09-15].

[5] D. Guinard, "A Web of Things Application Architecture", PhD thesis, 2011.

[6] ITU-T Y.2063, "Framework of the web of things", July 2012.

[7] A. Pintus, D. Carboni, and A. Piras, "Paraipmpu: a Platform for a Social Web of Things," Proc. of WWW2012 Companion, Lyon, France, April 2012, pp. 401-404.

[8] http://www.web-of-objects.com/ [accessed: 2013-09-15].

[9] SOA Practitioners Guide Part 2: SOA Reference Architecture. 2006.

[10] ITU-T TD 149 (IoT-GSI), "Requirements and common characteristics of IoT identifier for IoT service", H.IoT-ID, September 2012.

[11] D.H Park, S.J. Kim and H.C. Bang, "Semantic open USN service platform architecture," Proc. of ICTC2012, Jeju, Korea (South), October 2012, pp.12-15.

[12] ITU-T TD145(IoT-GSI), "Requirements and functional architecture for open USN service platform", F.OpenUSN, September 2012.

[13] J. Moon, D. Kang, and C. Bae, "Design of Device Sociality Database for Zero-Configured Device Interaction," Proc. of MUE 2013. Seoul, Korea (South), May 2013, pp. 763-768.

[14] ISO/IEC 20005, "Information technology -- Sensor networks -- Services and interfaces supporting collaborative information processing in intelligent sensor networks", 2013.

[15] W. Woerndl and R. Eigner, "Collaborative, context-aware applications for inter-networked cars," Proc. of WETICE 2007, Paris, France, June 2007, pp. 180-185.

[16] Genesis of the Versatile RFID Tag. RFID Journal. Retrieved on 2013-08-16.

Adaptive Active Contours for the 3D Segmentation of Computed Tomography Images

Miguel Alemán-Flores and Luis Alvarez
Departamento de Informática y Sistemas
Universidad de Las Palmas de Gran Canaria
Las Palmas, Spain
Email: {maleman, lalvarez}@dis.ulpgc.es

***Abstract*—Computed Tomography is one of the most valuable modalities of medical imaging and is used in the diagnosis of a wide range of pathologies. In many cases, it is necessary to obtain a precise segmentation and a 3D visualization of certain organs, tissues, nodules or regions in the tomography. However, manual delimitation is a very time-consuming process and advanced applications are needed to perform this process automatically. Active contours intend to fit an initial approximation to the most relevant edges around the starting contour. Most approaches of active contours assume that all points in the initial approximation are close to the final solution and that similar conditions can be set to all the sections of the contour, which is frequently a false assumption. For that reason, we have developed a new approach, in which different terms are used and adapted according to the evolution of the contour. Balloon, regularizing and attraction terms are combined and extended to 3D, avoiding the need for a close initial approximation and reducing human intervention. Furthermore, a multiscale framework is added to tackle the heterogeneity of the images and the variability of the approximations. The combination of these terms allows obtaining a more precise segmentation of the tomography.**

Keywords*—*segmentation; computed tomography; active contours.

I. Introduction

Computed tomography (CT) is a medical imaging technique which generates tomographic images or slices from computer-processed X-rays. The cross-sectional images which are obtained can be used for diagnostic and therapeutic purposes. For an appropriate assessment of a radiological study, or for the extraction of certain measurements, the segmentation of the corresponding organs, tissues, or regions is frequently needed.

Different approaches have been proposed to perform this kind of segmentations, from graph-based algorithms [1] to atlas-based systems [2] and region-growing schemes [3]. Some methods are fully automated [4], some others require human intervention [5].

Active contours are a very useful tool for adjusting a contour to the edges in an image [6][7][8]. The basic idea underlying active contours consists in making a contour evolve locally according to certain features of the neighborhood of each contour point. Several problems arise when applying this technique to computed tomography. First, an initial approximation is required, but manual initialization is an extremely time-consuming task, since each 3D image consists of a large amount of 2D images. Second, these images present noise, heterogeneities and blurred edges, which makes it necessary to include additional terms to separate regions without clearly defined edges. Finally, local minima may stop the evolution on wrong edges.

Some variations have been proposed to tackle these problems in different types of images, but handling all of them is still a challenging task. Among these works, we can find some approaches applied to textured regions and areas without clearly defined edges, using region descriptors or statistical information [9][10][11][12][13]. If we focus on medical images, similar approaches using texture descriptors and statistical information have been applied in [14][15]. Active contours have also been used to deal with other kinds of problems, such as object tracking and motion estimation [16] or tensor images [17].

In this work, we propose a multistage approach in which human intervention has been considerably reduced. First, we filter the images by means of a 3D anisotropic filter. We adapt the ideas of the classical Perona-Malik equation [18] to the diffusion of computed tomographies. Afterward, an initial approximation is obtained from a single inner point of the region we want to segment by combining some terms in the active contours approach. These terms include balloon forces to expand the region, regularizing terms to smooth the contour and include small holes, and attraction terms to fit the contour to the edges. Finally, we introduce a multiscale framework to refine the segmentation and adapt it to the edges in the image. To tackle the problem of irregular edges and variable distance from the initial segmentation to the actual contour, this framework includes different scales in the attraction term, so that the diffusion depends on the magnitude of the gradient in the region. These multiscale active contours allow a better adaptation to the particular features of each area.

This paper is organized as follows: Section II introduces the underlying ideas of active contours and the classical approach used in their application. In Section III, the 3D anisotropic filtering is presented. The three types of morphological active contours (balloon, regularizing and attraction terms) which are combined in this work are presented in Section IV, whereas the multiscale approach used to improve the segmentation is explained in Section V. Section VI explains the post-processing of the 3D contour points to obtain the final volume and Section VII summarizes our main conclusions and future work.

 ISBN: 978-1-61208-310-0

II. Geodesic Active Contours

Geodesic active contours, also known as snakes, are based on the minimization of the following energy with respect to the contour C:

$$E_{gac}(C) = \int_C g_\sigma(C(s))\, ds, \tag{1}$$

where $C : [0, L] \to \mathbb{R}^2$, $L > 0$, is a rectifiable curve parameterized by arc-length s, and ds denotes the arc-length element. The function $g_\sigma(x, y)$ is used to stop the evolution of the snake when it approaches the edges. It is a smooth decreasing function of the modulus of the gradient of a regularized version of the image $I(x, y)$ on which the segmentation is performed, and acts as an edge detector. As in [7], we can use:

$$g_\sigma(I) = \frac{1}{\sqrt{1 + \alpha \|\nabla I_\sigma\|^2}}, \tag{2}$$

where I_σ represents the convolution of the original image I with a Gaussian kernel with standard deviation σ. The parameter α controls how contrasted the edges must be to stop the evolution. On the other hand, σ determines how much I is smoothed, so that increasing its value will blur the image, reducing noise but also details. To minimize the energy in (1), we can use a gradient descent curve evolution written as:

$$C_t = -\frac{\delta E_{gac}(C)}{\delta C}, \tag{3}$$

where $\frac{\delta E_{gac}(C)}{\delta C}$ represents the first variation of E_{gac}. Computing the first variation of E, we obtain (see [7]) the curve evolution equation:

$$C_t = (\kappa g_\sigma - \langle \nabla g_\sigma, \mathbf{n}\rangle)\mathbf{n}, \tag{4}$$

where κ denotes the curvature of C. To write the level set formulation of (4), we introduce a function $u(t, x, y)$ as an implicit representation of $C(t)$. Usually, to construct the initial snake $u(0, x, y)$, a set of points determining a parameterization of a polygon $P_0(\tilde{s}) = (x_0(\tilde{s}), y_0(\tilde{s}))$ are manually selected. Afterward, $u(0, x, y)$ is defined in such a way that $P_0(\tilde{s})$ corresponds to the zero level set of $u(0, x, y)$. In our case, instead of manually defining $P_0(\tilde{s})$ by means of several points outlining the contour, we apply the morphological snakes described in Section IV from a single inner point (manually selected by the user) and consider the curve $P_i(\tilde{s})$ obtained when finishing the process. This way, we can define $u(0, x, y)$ as the signed distance function to $P_i(\tilde{s})$ (positive inside, negative outside), or simply consider two different values for the inner and outer regions.

With this approach, the level set formulation of the geometric curve evolution in (4) is given by:

$$\frac{\partial u}{\partial t} = \|\nabla u\| \operatorname{div}\left(g_\sigma(I) \frac{\nabla u}{\|\nabla u\|}\right). \tag{5}$$

If we expand this equation, we obtain the following expression, in which the first term controls the smoothness of the contour and the second one makes the contour evolve toward the highest gradients:

$$\frac{\partial u}{\partial t} = g_\sigma(I) \|\nabla u\| \operatorname{div}\left(\frac{\nabla u}{\|\nabla u\|}\right) + \lambda \nabla u \nabla g_\sigma(I). \tag{6}$$

The parameter $\lambda > 0$ has been introduced to balance the contribution of both terms. If we increase the value of λ, the attraction term will have a higher contribution and the contour will try to fit to the highest gradients in the current configuration. On the other hand, decreasing its value will round the contour, making it tend to a more regular outline. When an initial approximation is available, geodesic active contours permit to improve the pre-segmentation, since the contour adapts to the minimum of the energy in (1). As mentioned above, this pre-segmentation must be relatively close to the real contour of the region to segment. Otherwise, the effect of the second term in (6) will not be enough to overcome the regularizing effect of the first term and, instead of approaching the real edges, the snake will be rounded and will tend to reduce.

From this general scheme of active contours, we propose a three-stage process to segment the computed tomography images. First, the tomography is filtered using an anisotropic 3D filter. Second, three types of morphological operations are combined to obtain an initial approximation of the contours. Finally, a multiscale scheme for active contours is introduced to refine the approximation and improve its accuracy.

III. Three-Dimensional Anisotropic Filtering

Balloon forces allow obtaining an initial approximation from a seed point, but they need a relatively homogeneous region to expand, in which irrelevant or spurious edges have been removed or reduced. With the aim of reducing noise, but preserving the edges, we first apply a 3D adaptation of Perona-Malik filtering [18]:

$$u_t = div\left(k\left(\|\nabla u\|\right)\nabla u\right), \tag{7}$$

where we use:

$$k(x) = e^{-\beta x}. \tag{8}$$

This kind of approaches, which diffuse the image but preserve the most important edges, are usually applied to single 2D images. However, as we deal with a series of uniformly spaced images, we can apply them in three dimensions, so that the noise reduction process also takes into account the neighbors in the previous and next images in the CT, i.e., the values at the same position in the neighboring images. Since the distance between two consecutive images may not be the same as the distance between the pixels within an image, different weights can be assigned to the neighbors in the different coordinates. This way, we filter the 3D image as a whole, and not each slice separately.

Depending on the similarity of the various elements in the 3D image, their contrast and texture, the value of β in (8) can be adapted, as well as the number of iterations in the following discrete approach:

 ISBN: 978-1-61208-310-0

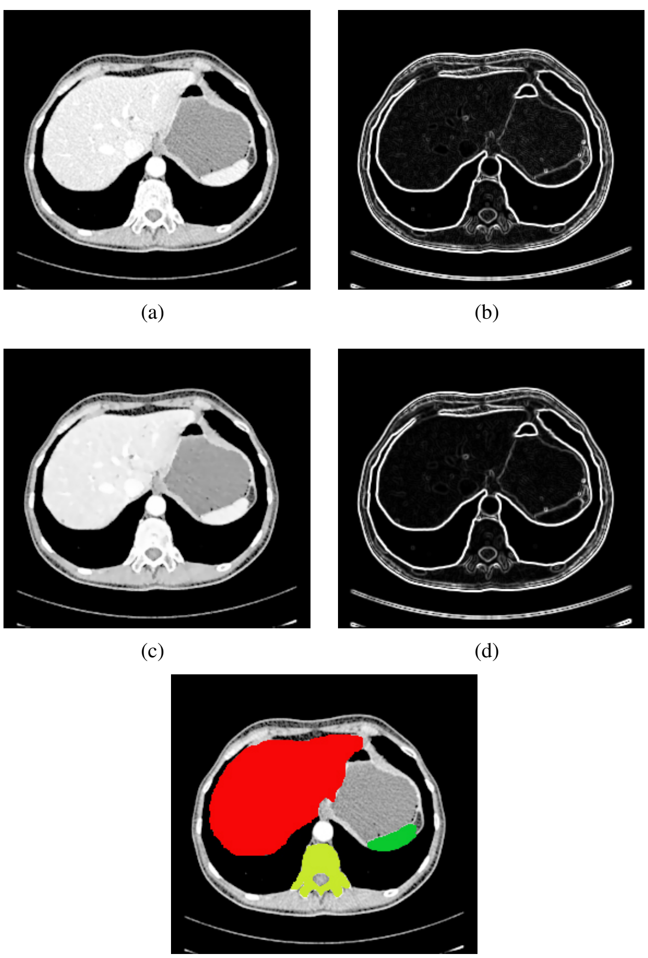
$$u_{i,j,k}^{n+1} = u_{i,j,k}^{n} + \frac{dt}{2\left(dh\right)^2} M\left(u_{i,j,k}^{n}\right), \quad (9)$$

where $M\left(u_{i,j,k}^{n}\right)$ is the result of convolving at each point (i, j, k) in the iteration n with the $3 \times 3 \times 3$ mask whose coefficients are:

$$\begin{aligned} C_{i+a,j,k} &= k_{i+a,j,k} + k_{i,j,k} \\ C_{i,j+a,k} &= k_{i,j+a,k} + k_{i,j,k} \\ C_{i,j,k+a} &= k_{i,j,k+a} + k_{i,j,k} \\ C_{i,j,k} &= -k_{i+1,j,k} - k_{i-1,j,k} - k_{i,j+1,k} \\ &-k_{i,j-1,k} - k_{i,j,k+1} - k_{i,j,k-1} - 6k_{i,j,k} \end{aligned} \quad (10)$$

and $a \in \{-1, 1\}$. The values of $k_{i,j,k}$ are obtained from (8) as follows:

$$k_{i,j,k} = e^{-\beta\|\nabla u\|_{i,j,k}}. \quad (11)$$



(a) (b) (c) (d) (e)

Figure 1. Image filtering: (a) sample slice of a CT, (b) gradient obtained from the original image, (c) result of the 3D anisotropic filter, (d) gradient obtained from the filtered image, (e) manually delimited regions corresponding to the liver (red), the spleen (green) and a vertebra (yellow).

An increase of β preserves more edges, but also noise. Therefore, its value must be adapted to the amount of noise present in the image and the relevance of the edges to be considered.

Figure 1 shows a slice of the result of applying this type of filter to a computed tomography of the abdominal region. As observed, the edges which are obtained from the filtered image are clearer, which makes them more suitable for a semi-automatic process. Noise and irrelevant edges have been reduced and the morphological snakes can act faster and more precisely to approach the actual edges.

IV. Morphological Snakes

The extraction of the initial approximation is one of the most important drawbacks of active contours. Manual delimitation is extremely time-consuming, even more when dealing with 3D images, as in our case. In particular, when working with large series of images in a computed tomography, it is almost unfeasible and hardly reproducible. As an example, in Figure 1(e), the regions corresponding to the liver, the spleen and a vertebra have manually been delimited. This corresponds to a single image from a large series of two-dimensional images contained in a three-dimensional CT scan. The use of region-growing algorithms is too risky when the limits are not clearly defined. This is the reason why, in order to obtain an initial pre-segmentation from a single point, we use a combination of different morphological operators based on [19][20]. These filters have been extended to three dimensions and applied considering the whole tomography. Instead of adopting the classical level-set approach with a range of values and a limit to separate the inner and outer regions, we work with only two values, so that the points are either inside or outside the snake according to a binary scheme.

In the first stage of the active contours, we use a balloon force which aims at growing from the initial seed while the magnitude of the gradient is lower than a certain threshold (we must be cautious with this threshold to avoid growing beyond the limits of the region we want to segment). This can be expressed with the following PDE:

$$\frac{\partial u}{\partial t} = g\left(I\right) v \left\|\nabla u\right\|, \quad (12)$$

where $g\left(I\right)$ is the stopping function described in (2). This PDE can be used for both, expanding or contracting contours, depending on the sign of v. In order to discretize this expression, we consider the dilation and erosion operators (D_d and E_d, where d stands for discrete) as follows:

$$u^{n+1}\left(x\right) = \begin{cases} D_d u^n\left(x\right) & \text{if } g\left(I\right)\left(x\right) \geq t \text{ and } v > 0 \\ E_d u^n\left(x\right) & \text{if } g\left(I\right)\left(x\right) \geq t \text{ and } v < 0 \\ u^n\left(x\right) & \text{otherwise} \end{cases} \quad (13)$$

where t is a threshold to determine when the evolution must be stopped. As our intention consists in expanding from the seed point, we make use of the first case, i.e., dilation.

However, balloon forces by themselves cannot provide precise and satisfactory contours. Therefore, when we have approached the edges and the magnitude of the gradient starts increasing, two more terms are introduced. One of them is a regularizing term which aims at smoothing the edges and filling the holes of the segmentation, avoiding an extremely irregular contour. This is obtained by controlling the curvature of the contour as follows:

$$\frac{\partial u}{\partial t} = g(I)\|\bigtriangledown u\|\left(div\left(\frac{\bigtriangledown u}{\|\bigtriangledown u\|}\right)\right). \quad (14)$$

In order to implement this kind of regularization, we consider the SI_d and IS_d operators:

$$\begin{aligned}(SI_d u)(x) &= \sup_{S\in B}\left(\inf_{y\in x+hS} u(y)\right)\\ (IS_d u)(x) &= \inf_{S\in B}\left(\sup_{y\in x+hS} u(y)\right)\end{aligned} \quad (15)$$

where sup is the supremum or least upper bound and inf is the infimum or greatest lower bound (h is a scale factor). The base B is a set of 9 planes (since we work with a 3D image, we deal with 9 planes instead of the 4 lines used in [19] and [20]), which cover all the possible planes within the neighborhood of the point which is being considered. The combination of both operators generates a smoother contour by performing erosion and dilation processes as follows:

$$u^{n+1}(x) = \begin{cases} (SI_d \circ IS_d u^n)(x) & \text{if } g(I)(x) \geq t \\ u^n(x) & \text{otherwise} \end{cases} \quad (16)$$

Finally, the third term is an attraction term, similar to that described in Section II (second term in (6)), although, in this case, the levels are only two, i.e., inside and outside the contour (1 or 0), and the condition to expand, contract, or remain constant depends on the product of the gradient of the current snake and that of the stopping function g:

$$\frac{\partial u}{\partial t} = \bigtriangledown g(I) \bigtriangledown u, \quad (17)$$

which is discretized as follows:

$$u^{n+1}(x) = \begin{cases} 1 & \text{if } \bigtriangledown u^n(x) \bigtriangledown g(I)(x) > 0 \\ & \text{and } g(I)(x) \geq t \\ 0 & \text{if } \bigtriangledown u^n(x) \bigtriangledown g(I)(x) < 0 \\ & \text{and } g(I)(x) \geq t \\ u^n(x) & \text{otherwise} \end{cases} \quad (18)$$

Since the first iterations are supposed to be quite far away from the final result, we start by applying only the balloon term to speed up the process, and then introduce the other two terms and combine all of them.

Figure 2 illustrates the result of applying these three types of snakes from a single point for the segmentation of the liver. Although it is a 3D segmentation, we show a single image as a sample. As observed, the segmentation is not completely satisfactory, since the balloon force has been stopped by the proximity of the edges, the smoothing term has rounded the contour and the attraction term has not been strong enough to fit the contour to the edges in all its segments. For this reason, the multiscale approach described in the next section has been introduced to refine the results.

Figure 2. Final contour obtained for the liver using the morphological snakes in an image belonging to a computed tomography.

V. Multiscale Active Contours

As explained in Section II, the value of σ determines how far the edges can be from the approximation to be reached. If the initial segmentation is too coarse, we need to use a high value of σ, but, as we approach the edges, it should be lower to prevent the contour from being too rounded and poorly defined. Using higher values in the first iterations and lower ones in the last steps works properly if the distance from the current approximation to the actual contour is homogeneous along the snake.

Since it is usual that some segments of the snake are far away from the actual contour, while others are already close to it, we use a multiscale implementation, considering higher values of σ in the most homogeneous regions and reducing it when the edges are nearby. This way, the scale varies not only across the iterations, but also from one region to another in the same iteration. However, it is computationally expensive to work simultaneously with a large number of different scales. Therefore, we use a combination of a reduced set of them in a single stopping/attraction term:

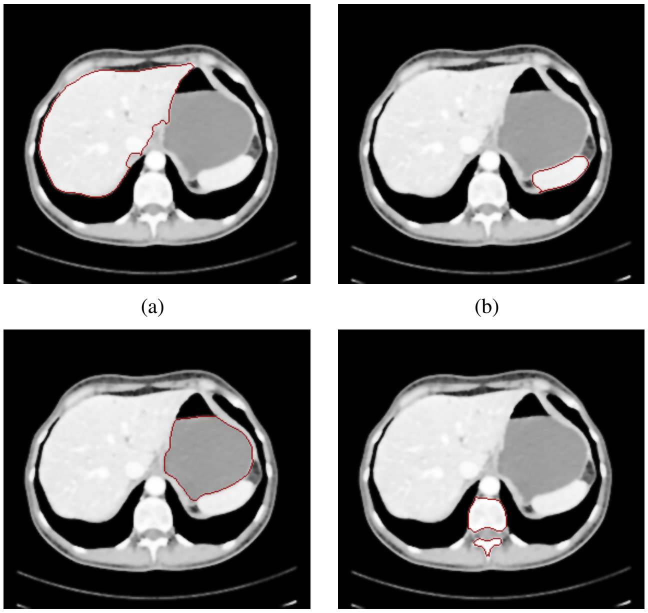
$$g(I) = \frac{1}{\sqrt{1 + \alpha \sum_{i=0}^{n}\left(w_n \|\nabla I_{\sigma_n}\|^2\right)}}, \quad (19)$$

where the weights w_n depend on the magnitude of the gradient computed on the smoothed image.

In fact, we use four scales and four blending functions which determine their weights, with the constraint that the sum of all of them is 1 for every gradient value. In the most homogeneous regions, large scales have a higher weight. Therefore, further edges can be reached and the probability of being stopped by a local minimum is reduced. When the magnitude of the gradient increases, the weight of the small scales is also increased. As a consequence, the contour can be refined according to the more detailed information.

Figure 3 shows how this approach improves the result of the segmentation of the liver, the spleen, the liquid in the stomach and a vertebra. Although the images which are shown

 ISBN: 978-1-61208-310-0



(a) (b) (c) (d)

Figure 3. Final contours for: (a) the liver, (b) the spleen, (c) the liquid in the stomach, and (d) a vertebra, obtained after using the multiscale approach.

correspond to a single slice, the process is carried out in the whole tomography, adapting the snake according to the edges in all the slices. As observed, the combination of different scales, which simultaneously contribute to adjust the contour, allows adapting the evolution of the snake to the particular features of each region, instead of trying to find global values for the entire 3D image.

VI. Three-dimensional Processing and Contour Combination

The case of computed tomographies is a special one, since the 3D images are a combination of 2D images and, not only may the distance between the slices be different to the distance between the pixels in each 2D image, but it may also vary from one scan to another.

As mentioned above, we try to minimize human intervention and, at the same time, accelerate the process as much as possible. To this aim, when the seed point is selected to apply the morphological snakes, it is advisable to choose it in one of the central slices, in order to reduce the distance to the furthest edges in the volume. However, the thresholds for these morphological snakes must be chosen carefully to prevent the expansion from flooding other regions.

The final segmentation is given by a set of 3D points, which belong to the planes determined by the slices in the tomography. Figure 4 illustrates some slices of the 3D segmentation of the liver obtained from a single point in a computed tomography. Since the active contours are applied in the 3D image, a single point allows reaching the edges in the whole tomography. The balloon forces provide an initial volume, which is later refined by using the attraction, smoothing and multiscale terms.

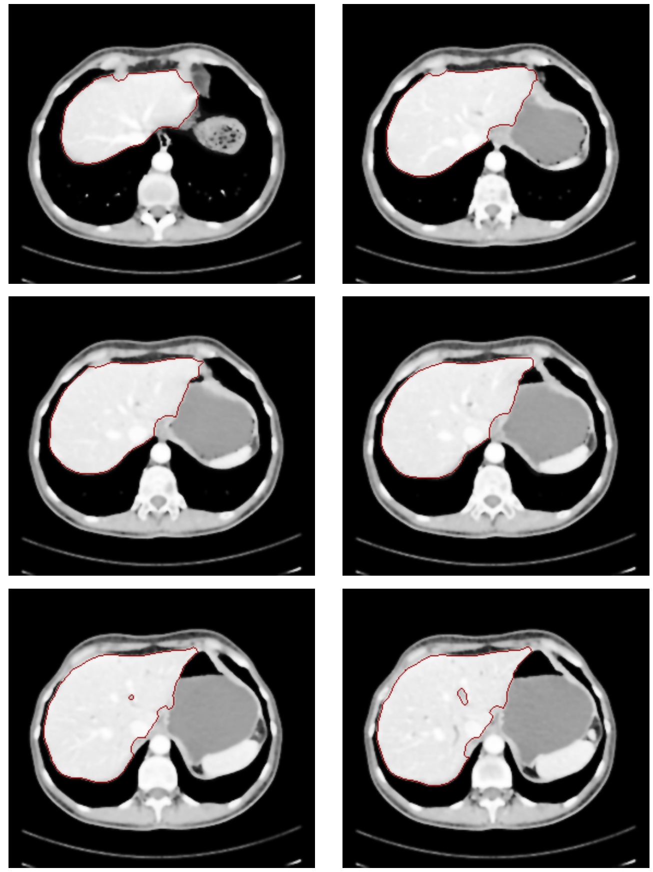


Figure 4. Final contours obtained for the liver in different slices of a computed tomography.

In order to represent the final segmentation in a more intuitive way, a triangulation process is applied by joining the 3D contour points. This allows building a 3D reconstruction of the region of interest and performing a further analysis when it is needed (e.g., measurements or shape analysis). Figure 5 illustrates the triangulation for a section of the liver. Figure 6 shows a 3D volume representation of the spleen.

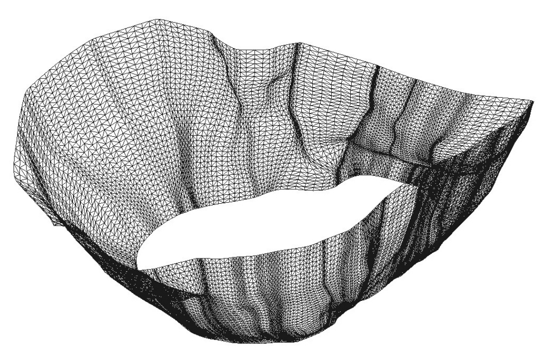


Figure 5. Triangulation of a section of the liver obtained from the 3D contour points.

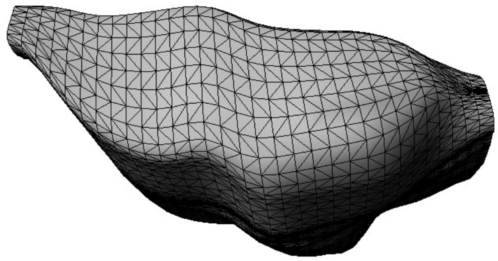


Figure 6. 3D representation of the spleen generated from the triangulation of the 3D segmentation.

As observed, introducing several scales in the active contours allows adapting the snake to the edges according to the rough and detailed information simultaneously, instead of predefining a single scale to work with.

VII. Conclusion and Future Work

In this paper, we have presented a method for obtaining a 3D segmentation of a region in a computed tomography by using an adaptive combination of different approaches for the active contours technique. Trying to tackle this problem with a single scheme would be very difficult, but adapting the contribution of the different terms to the needs of each stage and area allows obtaining quite satisfactory results. A combination of morphological operators, including balloon forces, regularizing filters and attraction terms, is used to extract a segmentation of the region of interest in a 3D image from a single seed point.

Furthermore, the use of different scales makes it possible to cope with those situations in which the contour is not uniformly close to the edges, accelerating the expansion in the most homogeneous regions and refining the contour when the final result is nearby. These multiscale active contours provide a framework to adapt the conditions of the snake to the particular area on which it is being computed. In this way, it is easier to deal with irregular edges and heterogeneous regions, since we make use of both, the coarse and the detailed information.

The results which have been obtained prove the efficiency of this approach and encourage its use for the semi-automatic analysis of medical images. The fact that the slices in the tomography are filtered and processed as a whole 3D image provides more consistent results and allows a further analysis for feature extraction, measurement or any other task which is required.

Future work includes accelerating the process and introducing some anatomical information which can help identify and distinguish the organs or tissues, as well as the application of this framework to the analysis of certain particular pathologies.

Acknowledgment

The authors would like to thank Dr. Patricia Alemán-Flores and Dr. Rafael Fuentes-Pavón from the Insular University Hospital of Gran Canaria for their collaboration in this research.

References

[1] L. Grady, "Random Walks for Image Segmentation," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 28, no. 11, 2006, pp. 1768-1783.

[2] T. Okada, K. Yokota, M. Hori, et al., "Construction of Hierarchical Multi-Organ Statistical Atlases and their Application to Multi-Organ Segmentation from CT Images," Proc. MICCAI (1), 2008, pp. 502-509.

[3] C. Couprie, L. J. Grady, L. Najman, and H. Talbot, "Power watersheds: A new image segmentation framework extending graph cuts, random walker and optimal spanning forest," Proc. ICCV, 2009, pp. 731-738.

[4] D. Kainmueller, T. Lange, and H. Lamecker, "Shape Constrained Automatic Segmentation of the Liver based on a Heuristic Intensity Model," Proc. MICCAI Workshop on 3D Segmentation in the Clinic: A Grand Challenge, 2007, pp. 109-116.

[5] A. Beck and V. Aurich, "HepaTux–A Semiautomatic Liver Segmentation System," Proc. MICCAI Workshop on 3D Segmentation in the Clinic: A Grand Challenge, 2007, pp. 225-233.

[6] V. Caselles, F. Catté, T. Coll, and F. Dibos, "A geometric model for active contours in image processing," Numerische Mathematik, vol. 66, 1993, pp. 1-31.

[7] V. Caselles, R. Kimmel, and G. Sapiro, "Geodesic Active Contours, International Journal of Computer Vision," vol. 22, no. 1, 1997, pp. 61-79.

[8] M. Kass, A. Witkin, and D. Terzopoulos, "Active Contour Models," Proc. 1st International Conference on Computer Vision, 1987, pp. 259-268.

[9] T. Brox and J. Weickert, "Level set based image segmentation with multiple regions," Pattern Recognition, Lecture Notes in Computer Science, vol. 3175, 2004, pp. 415-423.

[10] T. F. Chan, B. Y. Sandberg, and L. A. Vese, "Active contours without edges for vector-valued images," J. Visual Communication and Image Representation, vol. 11, no. 2, 2000, pp. 130-141.

[11] D. Cremers, F. Tischhäuser, J. Weickert, and C. Schnörr, "Diffusion Snakes: Introducing Statistical Shape Knowledge into the Mumford-Shah Functional," International Journal of Computer Vision, vol. 50, no. 3, 2002, pp. 295-313.

[12] N. Paragios and R. Deriche, "Geodesic active regions for supervised texture segmentation," Proc. Internationl Conference on Computer Vision, 1999.

[13] C. Sagiv, N. A. Sochen, and Y. Y. Zeevi, "Integrated active contours for texture segmentation," IEEE Transactions on Image Processing, vol. 15, no. 6, 2006, pp. 1633-1646.

[14] M. Alemán-Flores, L. Álvarez-León, and V. Caselles, "Texture-Oriented Anisotropic Filtering and Geodesic Active Contours in Breast Tumor Ultrasound Segmentation," Journal of Mathematical Imaging and Vision, vol. 28, no. 1, 2007, pp. 81-97.

[15] M. Hernández and A. F. Frangi, "Geodesic active regions using nonparametric statistical regional description and their application to aneurysm segmentation from cta," LNCS, vol. 3150, 2004, pp. 94-102.

[16] N. Paragios and R. Deriche, "Geodesic active contours and level sets for motion estimation and tracking," Computer Vision and Image Understanding, vol. 97, no. 3, 2005, pp. 259-282.

[17] C. Lenglet, J. Campbell, M. Descoteaux, et al., "Mathematical Methods for diffusion MRI processing," Neuroimage, vol. 45, no. 1, 2009, pp. 111-122.

[18] P. Perona and J. Malik, "Scale space and edge detection using anisotropic diffusion," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 12, 1990, pp. 629-639.

[19] L. Alvarez, L. Baumela, P. Márquez-Neila, and P. Henríquez, "A Real Time Morphological Snakes Algorithm," Image Processing On Line, 2012.

[20] L. Alvarez, L. Baumela, P. Henríquez, and P. Márquez-Neila, "Morphological snakes," Proc. CVPR, 2010, pp. 2197-2202.

Access Control for Sensitive Data in Hadoop Distributed File Systems

Yenumula B. Reddy
Department of Computer Science
Grambling State University, USA
email: ybreddy@gram.edu

Abstract—**User access limitations are very valuable in Hadoop distributed file systems to access sensitive and personal data. Even though the user has access to the database, the access limit check is very relevant at the time of MapReduce to control the user and to receive only permissible data. Data nodes do not enforce any access control on its access to the data blocks (read or write). Therefore, Kerberos ticket granting model for user login and user access permissions to MapReduce jobs do not limit the unauthorized data to obtain from the access granted database. In addition, to secure the data during processing, the authentication and authorization of data is required. The problems broadly include a) who will access the data, b) how it will be encrypted, and c) stability of data processing while the data are continuously growing. The current study includes the security mechanisms currently available in Hadoop systems, requirements of access control mechanisms, and change of access control depending upon the sensitivity of data.**

Keywords—Hadoop systems; access control; distributed file systems; MapReduce; network environment.

I. INTRODUCTION

The term big data is misleading in size and organization. Big data means exceeding the normal capacity and unmanageable with current available technologies. The data can be in the form of structured or unstructured category. It is large in the form of volume, variety, and velocity (increasing at any given time). In Defense organizations, big data can contain defense related documents that include text, images, and videos. The high sensitive data need to be analyzed and processed for real-time response. The initial designers of data models (hierarchical, relational, and the network) did not have an idea of volume of current data, type of data, and speed of growing. The Federal Government currently has a big challenge of managing big data volume compared to any other organization. The US health care system is expected to grow in size to yottabytes (10^{24} gigabytes) soon. Similarly, the Defense data will grow in size to yottabytes.

From 1960 to 2000, the storage, communication and processing time was very expensive. So, the concentration was storing the data and organizing the data using different data management techniques (indexed, index sequential, random, etc.). The recent developments made the storage, communication, and processing time very cheap. Therefore, corporations began storing all kinds of data (images, text, symbols, different languages, and various volume sizes) to meet the various types of emergencies. Thus, analysis and control of data has become unmanageable. The trend is built to elaborate models with more test data rather than simple models. The task in Defense organizations is to manage a large chunk of data sets, provide additional benefits like statistical data, and real-time answers to responsible officers. Therefore, threats to the database need to be identified sooner, so that the data can be protected. The query processing and threat detection must happen in real time and with lower cost.

After year 2000, the internet usage increased exponentially. The server and storage technology underwent many changes. Therefore, the distributed computing with many nodes was extremely difficult for many reasons such as distributed locking, data parallelism and distribution, load balancing, failure recovery, and network congestion. The big data revolution started after the release of “MapReduce: Simplified Data Processing on Large Clusters” in 2004 by Google. Soon, Google became the number one search engine. Next, Google released another paper “The Google File System”, which is a high-performance, widely available distributed file system that provides the storage layer for the MapReduce processing. The key advantage is ‘move processing to data’ rather than ‘moving the data to computer resources’.

The Hadoop project was developed in Java around these two papers and became a new paradigm [1, 3]. The system was adopted more in the DoD (Department of Defense) than in other agencies. The problem in Hadoop system design is lack of reusability of existing applications. The Apache Hadoop defines the new Java Application Programming Interfaces (API’s) for data access. This means the existing applications must be rewritten to access their big data in the Hadoop environment. Further, more work is needed to protect the data at source and at communication lines. Research is in progress in understanding the Hadoop system design, usage, and security status. Security can be improved at the source level using Honeypots database, and at communication level through protocol modifications.

Federated systems enable collaboration of multiple systems, networks, and organizations with different trust levels. Authentication and authorization procedures of a client must be kept separate from services. The deployment of federated security architecture was discussed in Windows Communication Foundation (WCF)

 ISBN: 978-1-61208-310-0

[1]. WCF provides support for building and deploying distributed systems that employ federated security. Domain/realm, federation, and security token service consist of primary security architecture of federated systems.

Traditional security is about protecting the resources within the boundary of the organization. The federated systems require the security specification for each function. Further, the federated systems change over time with new participants joining and they may not all be trusted. Therefore, individual protection domains are required for each entity. Boundary constraints are required depending upon the system. Therefore, monolithic security domain will not work in federated systems.

Existing federated security systems separates the client access, associated authentication and authorization procedures. As the federated systems are distributed, they need collaboration between networking, organizations and associated systems. Maintaining security among these is not an easy task, since multiple entities are involved. Security threat may be unavoidable from a variety of sources. Therefore, a high level coarse-grained security goals need to be specified in the requirements.

The rest of the paper discusses the review of research, security policies and proposed design. The recent developments in federated systems security are discussed in Section II. The proposed model is analyzed in Section III, and controlling the user access in Hadoop systems to the proposed model in Section IV. Section V provides the conclusions and suggestions for future research.

II. Recent Developments

Data reside in mobile devices, social media, cloud, and many static and dynamic storage media. IBM announced real-time security for big data environments that include data from mobile devices, social media, and cloud computing [2]. Tight coupling of the name space and block storage is possible by limiting the use of block storage directly. Further, IBM offers data masking to de-identify sensitive information as it moves into and out of big data systems. The implementation is limited to 60K tasks, but the next generation of Apache MapREduce supports 100K concurrent tasks [3]. In MapReduce, users specify the computation in terms of the map and a reduce function. The underlying scheme in MapReduce package automatically paralyzes the computation and schedules the parallel operations so that the task uses the network and computational facilities to perform the operations faster. An average of a hundred thousand MapReduce jobs are executed on Google clusters every day.

Halevy et al. [4] suggested that representing the data of large data sources with a nonparametric model is needed compared to summarizing parametric model because the large data sources hold a lot of details. The authors felt that choosing unsupervised learning on unlabeled data is more powerful than on labeled data. They pointed out that creating required data sets by automatically combining data from multiple tables is an active research area. Combining data from multiple tables with data from other sources, such as unstructured Web pages or Web search queries, is an important research problem.

User logs of search engines on query clustering, query expansion, and user generated query reformulations have attracted many researchers in recent years. Riezler et al. [5] studied the user queries and snippets of clicked results to train a machine translation model to bridge the “lexical gap” between query and document space. The authors claimed that the model has better results on contextual query expansion than other systems (based on term correlations). Further, dissecting the contribution of translation model and language model improved the search results. The improved search models include the combination of the correlation-based system, language-based system, and language model filter.

Queries without understanding the full complexity of schemas, source relationships, and query languages are another task of the research area. Talukdar et al. [6] presented a system in which non-expert user can create a new query templates and Web forms to be used by any user with related information needed. The proposed system works with the combination of user queries with keywords and sequence of associations used by the system. The system processes with multiple ranked queries, linking the matches to keywords. The query sets attached to Web form creates a particular query so that the user can input or fill in the blanks for search. The authors claimed that their approach is highly promising compared to other approaches for practical bioinformatics queries.

Thuraisingham [7] used federated database systems as cooperative, autonomous, heterogeneous, and distributed. The author discussed various types of security policies such as local, component, generic, export and federated. He further outlined the ways to generate and enforce the security policies. Jonsher and Dittrich [8] discussed the access control mechanisms to be applied at a global layer and showed how they can be mapped onto less powerful mechanisms of component database management systems. Tari and Fernadez [9] discussed the federated access control and secure access control in distributed object kernel for federated database systems. They proposed a unified security model aiming for the integration of existing access control models, such as mandatory access control and discretionary access control that could be imposed on local components. The authors introduced task agents within database agents to enforce the federated security policies using security procedures. The proposed idea may work better than existing procedures to secure the Hadoop systems with limitations. Geon and Qian [10] discussed the interoperation and security in a large database and recommended a security design. One of the proposals made by the authors is defining the interfaces to preserve the security. They suggested restricted access on direct and indirect access in these distributed systems. The suggestions may extend to honeypot databases. Ebmayr et al. [11] discussed the taxonomy of major design choices and access controls for federated database environments. Their work presents the main security mechanisms, authorization, and access control through simple examples.

Neuman [12] discussed the security in federated systems and reasons for failure. As the future technology is based on federated systems, it is necessary to understand the interactions and proper definition of security boundaries. Further, engineering, development and deployment must enforce these boundaries. Security and fail-recovery are very important in small or large data sets. The data recovery from failure was discussed by Gamble [13]. Big data policies and law enforcement in Hadoop systems was discussed by Oleskeer [14]. The research discussed the monitoring and user accountability, predictive policies, and the use of Hadoop systems by enforcement agencies.

Hadoop security was discussed in the reports [15-18]. Ravi's [15] comment on *Security for Big Data in Hadoop* is a two key solution that includes authentication and encryption. According to him, Kerberos file system has better protection to keep the intruders away from accessing the file system. Since the discipline is new, there has not been much research in Hadoop security. Chary et al. [16] presented security implementation in Hadoop systems. Their research discussed the security in distributed systems and current level of security in Hadoop systems. It also includes the client access for Hadoop cluster using Kerberos Protocol and authorization to access. O'Malley et al. [17-18] discussed the security in Hadoop design. They discussed the security threats from different user groups, Kerberos authentication system, role of delegation token in Kerberos and MapReduce implementation details. These papers discuss the encryption, limiting access to specific users by application, isolation between customers, and information protection. Their research further emphasizes the need for internal and external security for Hadoop systems.

Roy et al. [19] presented a prototype system called "Airavat", a MapReduce-based system which provides strong security and privacy guarantees for distributed computations of sensitive data. The authors provided a method to estimate the different parameters that should be used and tested on several different problems. Their proposed system has weak use cases, a complicated process in specifying the parameters, and is not efficient in general composition of MapReduce computations (the MapR function followed by another mapper). Some organizations raised critical questions on privacy and trust of the system.

III. PROPOSED MODEL

In this paper, a dependable security model is presented and explained how it differs from existing federated systems. Further, it discusses the difference between securities in federated systems and general distributed systems.

Hadoop system users are of four types. First, use of the facilities for storing, accessing, processing, and transferring the information; second, acquiring information (Google, for example) for research (to acquire knowledge for scientific purposes); third, accessing the globally stored information (including blogs) for current and future applications (research & business); and the fourth is hackers, who misuse the information or destroy sensitive information. The main purpose of security is to avoid unauthorized access and save the sensitive information from the intruders.

In federated systems, security is available through authorization and authentication. The authorization is provided using the Key Distributed System (KDS). Every federated user requires a security key to access the data. The client access in Hadoop high-level architecture has job tracker as well as task tracker. Once the client is authorized to access the data, the data will be processed on HDFS data nodes and package MapReduce will fuse the information as required by the client.

If a user from one business needs service in another business, a security token will be created to access the resources. The security token is the authorization to access and build the trust of the client. In Kerberos, the new delegation token is obtained with TokenID (as in (1)).

$$\text{TokenID} = \{\text{ownerID, renewerID, issueDate, maxDate, sequenceNumber}\} \quad (1)$$

Once the delegation token is obtained, it is valid for a day as a default or the token can be renewed for a week. Normally, the token is issued until the job is completed. The additional requirements for a job token are access limits and verification in MapR process. Access limits are the controls on stored information. The MapR module must verify the access rights of a user before filtering (reduce) and deliver the filtered response to the user query. The equation (1) is rewritten as (2) to incorporate the access rights of a user.

$$\text{TokenID} = \{\text{ownerIDc, renewerID, issueDate, maxDate, sequenceNumber, outputCheck}\} \quad (2)$$

where ownerIDc is the identification of user access rights and OutputCheck is verification of information after MapR function is performed. Formula (2) also helps in accessing blocks. Therefore, the OwnerIDc is formulated as in (3).

$$\text{ownerIDc} = \{\text{ownerID, accessLimit, keyID, expirationDate}\} \quad (3)$$

where ownerID is the right to use, accessLimit is the limitation of access to blocks or files (read/write/execute/update), and expirationDate is a valid time limit.

The access limits depend on types of files accessed by the client. For example, a nurse in the hospital can access patient information, unless it is restricted. The accessLimit keyword stops access to unauthorized information. Similarly, depending on the information, sensitive or clustered, the accessLimit keyword helps in securing the files.

In the federated security, the access limits are required within and outside the organization. Federated user jobs include job/task localization and shuffling the information. For example, in Yahoo, once the user is authenticated, the servlets check the authentication of the user to permit the operations. For example, in a hospital, a nurse is allowed to access the patient records. This should be limited to the type of user and permitted information. Similarly, for a doctor the limits apply to the medical records of the patient. These limits are designed in equation (2).

In federated databases, key management, access control, policy management, auditing, and distributed authentication are very important. The access control design changes depending on the environment and sensitivity of the information. Kerberos access control is available for the federated databases. Additional controls are required as introduced in (2) for sensitive data.

IV. CONTROLLING THE USER ACCESS TO DATABASES

Each ownerIDc is defined with a set of permissions to the database within or outside the organization for processing and retrieving information. Every user is tagged an access limit 'token' during login. If a login user is an intruder, the system must detect the access rights of the user (intruder) before permitting access to the database. The intruder is generally caught at login time or MapR time to retrieve unauthorized information. If an intruder is internal user and tries to access the unauthorized information, the intruder will be controlled with access limits to resources and further verified at MapReduce time. Consider the objective function G with a set of users (N), set of access rights (A), set of allowed resources in the database (D), and the response (U).

$$G = \{N, A, D, U\} \quad (4)$$

where

$n_i \in N$ (Set of users);

$a_i \in A$ (Set of access rights);

$d_i \in D$ (Set of allowed resources in the database);

$u_i \in U$ (The return result of the user query)

In the current research, the healthcare model is used for access control. For example, if a person is admitted to the emergency room, doctors can access the most up-to-date medical history and related information. This information helps the medical team to develop a personalized treatment plan while avoiding duplicate tests and procedures. It is assumed that a patient may be admitted to any hospital on the globe and patient's medical records are available on-line to the doctors to provide personalized treatment. Further, the access rights to patient's information are clearly defined to each person attending the patient.

The following assumptions, definitions, propositions, and theorems help us to generate the algorithms that control the unauthorized information.

- Every authenticated user n_i $(n_i \in N)$ will be provided a service token to a resource within its domain with a set of access types a_i. The limitation helps to control the user for resource access.
- For each service requested by the user, the system generates a set of access permissions to the resources. The services requested should not exceed the user limits. If the requested resources are outside the user boundaries, then the system alarms the security and denies the request.
- Hacker is a user that does not have any role in the system.
- An authorized user will be treated as hacker if the user tries to access unauthorized information. For example, the health care staff member will be treated as an intruder if the user accesses unauthorized data or misuses (printing and forwarding, for example) the authorized information.

Proposition 1: If user n_i possesses access types $\bigcup_{i=1,k} a_i$ where k is the access limit, then the user n_i gets permission to access the database only if $\bigcup_{i=1,k} a_i \in U$ (the results must match with access permission). That is accessed information and MapR result must satisfy the access rights.

Proposition 2: Given any two users n_i and n_j the operation $n_i \bigcap n_j \neq \phi$; where ϕ is null and $\neq$ represents 'different from' (not equals). That is, two users may have common access types. There are many examples using doctor and nurse combination.

- Two nurses working on a patient in different shifts have access to see the primary data about a patient (access to the data to collect or examine the type of medicine given at different times).
- A doctor and a nurse may have some common access rights on a patient.
- Two doctors in different shifts attending the patient have the same access rights.
- Two doctors working on a patient can have access to the previous data or data collected by the nurses.

Proposition 3: For any two users n_i and n_j the operation $n_i \bigcap n_j = \phi$; then the two users do not have any common access type. That is, they must be performing different operations on the resource (a doctor and a

 ISBN: 978-1-61208-310-0

cleaning person; a doctor and an accountant) or two different doctors do not have any common access rights.

Proposition 4: If user n_i possesses resources d_i and d_j with access types $\bigcup_{i=1,k} a_i$ and $\bigcup_{j=1,l} a_j$ respectively, then $\bigcup_{i=1,k} a_i \cap \bigcup_{j=1,l} a_j = \phi$, shows the user n_i do not have the same access types on both data sets d_i and d_j.

In other words, if user n_i has access types $\bigcup_{i=1,k} a_i \cap \bigcup_{j=1,l} a_j \neq \phi$ then the user n_i can have one or more common access rights between the two data sets. These cases are bound for close observation by security at the time of data consolidation by MapR; otherwise security threat will be alarmed.

Definition 1: The user with complete authorization access is called a super user (S). The super user 'S' possesses access rights of all users $S \supseteq \bigcup_{i=1,n} a_i$ where $\supseteq$ means contains. All accesses of super user on the database must be recorded.

Definition 2: The user that does not have any authorization is called hacker (h_i) and represented as H ($h_i \in H$) and $\forall H$ (hackers) the access rights $a_{ih} \mapsto d_i \equiv \phi$ is true; a_{ih} is access rights of the hackers, $\mapsto$ implication to, and $\equiv$ is equivalent to.

Proposition 5: If $Q(h_i, d_i)$ is a query placed by the hacker h_i on data source d_i simulating the user query $Q(n_i, d_i)$ then a mismatched query will be locked and alarmed the security.

Since the hacker could get the authorization and does not know the set of access rights a_i and access to permutable resources d_i, then the security takes control of the hacker and alarms the security manager. If an unauthorized user repeatedly accessing through a particular terminal, then the security system locks the terminal and user access to resources till the problem is resolved. Similar action will be taken for batch submission.
Furthermore, the query and assigned information is recorded as part of utility, and if the hacker poses the same query then the query and utility will be recorded for future intruder detection. For example, if h_i pretends as user n_i and try to access the information (that user n_i has permissions) then the system stamps on h_i as $h_i u_i$ (called hacker utility) and process as the hacker action.

Proposition 6: If an internal hacker tries to access unauthorized information then the system will alarm the warning to user and then send the internal security threat to security administrator.
Let internal hacker place a query $Q(In_i, d_i)$ on data source d_i simulating the user query $Q(n_i, d_i)$. A mismatched query will get information from security token service. Algorithm-1 helps to handle the internal hacker while trying to retrieve the information outside the user bounds.

__**Algorithm 1:**__

If $Q(n_i, d_i)$ matches the ownerIDc of TokenID, then the corresponding utility function u_i will be generated, else the query reflects as $Q(n_i, hd_i)$, where h is a hacker.

If the hacker is an internal user then

$hu_i \supseteq u_i + h^{'} d_i$ (u_i Internal user), alarms security manager about internal hacker.

If $Q(n_i, d_i) \subset u_i$ then exit;

else if $Q(n_i, d_i) \not\subset u_i \; \&\& Q(n_i, d_i) \cong hu_i$ then convert $Q(n_i, d_i)$ as $Q(n_i, hd_i)$ and generate $hu_i \supseteq u_i + h^{'} d_i$

Store the user utility hu_i that contains $u_i + h^{'} d_i$ and inform security and keep the counter (log) in alert for further attempts.
The Algorithm 1 helps to detect the hacker if the user tries to gain the information with unauthorized access from the database. The following query and Table I explains the unauthorized access to information.

If $Q(n_i, d_i) \equiv Q(hn_i, d_i) \not\subset u_i$ or $Q(hn_i, d_i) \approx hu_i$ then $Q(hn_i, d_i) = hu_i$, retrieve hu_i (utility from the Hacker alarm to database) and alarm security alert; where hu_i is available in log or identified as a new hacker and logged as new entry. The log is provided in Table I.

TABLE I. HACKER LOG AND ACTION

Hacker	Status	Result	Action
A	new	hu_i	New hacker, alarm
A	repeat	hu_i	Alarm and freeze

In general, if the hacker attempts to gain access to the database at different trimmings, the time attribute plays an important role to detect the hacker. Algorithm 1 is modified as Algorithm-2.

Algorithm-2

If $Q(n_i, t_i, d_i)$ is genuine and attempted during duty times then corresponding utility function u_i will be generated,

else the query reflects as $Q(n_i, t_j, hd_i)$ then user will get $hu_i \supseteq u_i + h^{'}d_i$ (where u_i is internal user information and $h^{'}d_i$ is the hacker alarm at time t_j).

If $Q(n_i, t_i, d_i) \subset u_i$ then exit (user access accepted)

else

if $(Q(n_i, t_j, d_i) \not\subset u_i) \& \&(Q(n_i, t_j, d_i) \cong hu_i)$

Convert $Q(n_i, t_j, d_i)$ as $Q(n_i, t_j, hd_i)$ and generate $hu_i \supseteq u_i + h^{'}d_i$ (alarm alert to Security manager)

Note: Store the user utility hu_i that contains $u_i + h^{'}d_i$ and alert security and keep the counter for further attempts.

If the hacker is external, then divert to the KDS. If the user hacks with authentication, then the time stamp will help to detect the hacker. For example,

If $Q(n_i, t_j, d_i) \equiv Q(hn_i, t_j, d_i) \not\subset u_i \;\; or \subseteq hu_i$ then $Q(hn_i, t_j, d_i) = hu_i$, retrieve hu_i, and alarm the security;

where hu_i is available in log or identified as a new hacker and logged as a new entry. Table II provides the log entries.

TABLE II. HACKER LOG AND DETECTION

Hacker	Status	Time	Result	Action
A	New, internal	Outside-bounds	hu_i	Detect as internal hacker and alarm
A	Repeated, internal	Within-bounds	hu_i	Check for presence of real user and alarm and find real user

Depending upon the security level, Algorithm-2 will be modified by adding the terminal type and log-on timings. Terminal type and time of access attributes along with access type attributes will protect the secret and top secret information.

Let us assume the hospital environment in the healthcare system. A doctor and nurse have common access to certain information (the doctor prescribes the medicine and the nurse is responsible for giving it to the patient). Then, the attributes patient id, type of medicine, and scheduled time medicine to be given to patient is accessible by the nurse. The same attributes are also accessible by the doctor. Therefore, the system security depends upon the merge and decomposition of two or more users.

Theorem 1: The security of the hospital system depends upon time and terminal type attributes but not on the merge and decomposition operators.

Let $u_{i,d}^{t}$ be the doctor user and $u_{i,n}^{t}$ be the nurse user at any time *t*. The decomposition of these attributes at time *t* is

$$u_{i,d}^{t} \cap u_{i,n}^{t} \neq \phi \;\; or \;\; u_{i,d}^{t} \cap u_{i,n}^{t1} \neq \phi \qquad (5)$$

The relation is true, since the duty timings are different. Similarly,

$$u_{i,d}^{t,\tau} \cap u_{i,n}^{t,\upsilon} \neq \phi \;\; or \;\; u_{i,d}^{t,\tau} \cap u_{i,n}^{t,\tau} = \phi \qquad (6)$$

where $\tau \; and \; \upsilon$ are terminal types and $u_{i,d}^{t,\tau} \cap u_{i,n}^{t1,\tau}$ shows the doctor and nurse on the same terminal at different times. For security purposes, the nurse is not allowed on the doctor's terminal, since the terminal is involved in access rights. We can show the similar operation for merge. This concludes that the merge and decompose operations provide the common and combined access types without compromising security.

Theorem 2: Any change in resource access will affect the utility (result of merge and decomposition operators).

The resource access changes will be done by the security authority through the Systems Administrator. The change in access rights in any user will affect the utility function and as a result the output of merge and decompose (in MapR process) operations change. The change reflects the presence of intruder. For example, if the nurse becomes head nurse (hn) then:

$$u_{i,d}^{t} \cap u_{i,n}^{t} \neq u_{i,d}^{t} \cap u_{i,hn}^{t} \, or \, u_{i,d}^{t} \cap u_{i,n}^{t1} \neq u_{i,d}^{t} \cap u_{i,hn}^{t1} \quad (7)$$

$$u_{i,hn}^{t} \cap u_{i,n}^{t} \neq \phi \;\; or \;\; u_{i,n}^{t1} \cap u_{i,hn}^{t1} \neq \phi \qquad (8)$$

$$u_{i,hn}^{t,\tau} \cap u_{i,n}^{t,\upsilon} \neq \phi \;\; or \;\; u_{i,hn}^{t,\tau} \cap u_{i,n}^{t,\tau} \neq \phi \qquad (9)$$

It shows that the head nurse has the access rights of a nurse and additional access permissions to resources. The change must reflect, otherwise security alarm alerts. The proposed system was implemented using CGI (Common Gateway Interface) framework in Python language (V2.6) for hospital environment. The program also uses HTML, JavaScript, AJAX and PHP for support. The database used is MySQL database and Hash security to encrypt the

 ISBN: 978-1-61208-310-0

password. The results were satisfactory. We are extending the work to Hadoop database (health care environment).

V. Conclusions and Future Efforts

The research was concentrated on security in Hadoop distributed file systems during access and MapReduce operations. The authentication access limits proposed in this paper ensure the limitations of user access to global data and avoids the unauthorized access to data. An objective function was created for the user access to the database and theoretical foundations were provided. The algorithms help to detect an intruder. The security model includes the access rights and resulting return value. The return value depends on the access permissions (Theorem 2).

The healthcare database is treated as a 'Big Database' (for global availability) because a patient may be admitted in the hospital of his/her choice (irrespective of place and time). The doctor on-duty needs to see the history of the patient to avoid unnecessary tests and provide personalized treatment. At the same time, the data are confidential. For example, news reporters are eager to collect information on a celebrity or an administrator (President, Senator, or movie actor, or any similar important person). Easy target is a hospital employee (nurse, for example). Some unauthorized doctors may be eager to know the sensitive data. In such cases, access rights restrict the unauthorized access to such data.

Future efforts of projects related to 'Federated Hadoop systems include the design, implementation and processing of data with security tags for sensitive data. Develop the algorithms with appropriate access rights to provide security to sensitive data within and outside organization is an important research problem.

Acknowledgements

The research work was supported by the Minority Leaders Program through contract number GRAM 11-S567-0017-02-C2. The author wishes to express appreciation to Dr. Connie Walton, Provost and Vice President, Academic Affairs, GSU for her continuous support. The author also wishes to appreciation to Prof. Rama, T, Dean of professional studies, GSU, for proof reading and corrections.

References

[1] Athontication, Microsoft Patterns & Practices, http://msdn.microsoft.com/en-us/library/ff649763.aspx 2012 [accessed: April 2013].

[2] "IBM Addresses Security Challenges of Big Data, Mobile and Cloud Computing", www.03.ibm.com/press/uk/en/pressrelease/39166.wss, ARMONK, N.Y., 18 Oct 2012 [accessed: April 2013].

[3] J. Dean and S. Ghemawat., "MapReduce: simplified data processing on large clusters", CACM 50th anniversary issue, Vol. 51, issue 1, Jan 2008, pp. 107-113.

[4] A. Halevy, P. Norvig and F. Pereira., "The Unreasonable Effectiveness of Data", IEEE Intelligent Syst., 2009, pp. 8-12.

[5] S. Riezler, Y. Liu and A. Vasserman,"Translating Queries into Snippets for Improved Query Expansion," Int. Conf. Computational Linguistics (Coling 08), 2008, pp. 737–744.

[6] P. P. Talukdar et al., "Learning to Create Data-Integrating Queries," Int. Conf. Very Large Databases (VLDB 08), Very Large Database Endowment, 2008, pp. 785–796.

[7] B. Thuraisingham, Security issues for federated database systems, Computers & Security, 13 (1994), pp. 509-525.

[8] D. Jonscher and K. R. Dittrich, An Approach for Building Secure Database Federations, VLDB '94 Proceedings of the 20th International Conference on Very Large Data Base, Morgan Kaufmann Publishers Inc. (1994), pp. 24-35.

[9] Z. Tari and G. Fernandez, "Security Enforcement in the DOK Federated Database System", Pierangela Samarati, Ravi S. Sandhu (Eds.): Database Security Volume X, Status and Prospects, IFIP TC11 / WG11.3 Tenth International Conference on Database Security, 22-24 July 1996, Como, Italy. IFIP Conference Proceedings 79 Chapman & Hall 1997, ISBN 0-412-80820-X, pp. 23-42.

[10] L. Gong and X. Qian, Computational issues in secure interoperation, IEEE Trans. on Software Engineering, vol. 22, 1996, pp. 43-52.

[11] W. Eßmayr, F. Kastner, G. Pernul, S. Preishuber and A. M. Tjoa, (1995) Access Controls for Federated Database Environments. Proc. Joint IFIP TC 6 and TC 11 Working Conf. on Comm. and Multimedia Security, Graz, Austria.

[12] C. Neuman, "Why Security fails in Federated Systems", University of Southern California, 7 March 2012, http://csse.usc.edu/csse/event/2012/ARR/presentations/20120307-neuman-csse.pdf [accessed: April 2013]

[13] G. Gamble, "Data Recovery Solutions", R3 Data Recovery, [accessed: October 2012].

[14] A. Olesker, "White paper: Big Data Solutions For Law Enforcement", June 2012, http://ctolabs.com/wp-content/uploads/2012/06/120627HadoopForLawEnforcement.pdf [accessed: January 2013].

[15] P. Ravi, "Security for Big Data in Hadoop", http://ravistechblog.wordpress.com/tag/Hadoop-security/, April 15, 2013 [Retrieved - April 2013].

[16] N. Char, K. M. Siddalinga and Rahman, "Security Implementation in Hadoop", http://search.iiit.ac.in/cloud/presentations/28.pdf [accessed: January 2013].

[17] O. O'Malle, K. Zhang, S. Radia, R. Marti and C. Harrell, "Hadoop Security Design", http://techcat.org/wp-content/uploads/2013/04/Hadoop-security-design.pdf, 2009, [accessed: March 2013].

[18] D. Das, O. O'Malley, S. Radia and K. Zhang, "Adding Security to Apache Hadoop", hortonworks report, http://www.Hortonworks.com [accessed March 2013]

[19] I. Roy Srinath, T.V. Setty, A. Kilzer, V. Shmatikov, and E. Witchel, "Airavat: Security and Privacy for MapReduce", 7th USENIX conference on Networked systems design and implementation (NSDI'10), 2010, Berkeley, CA.

Query Answering using User Feedback and Context Gathering for Web of Data

Takahiro Kawamura
Graduate School of Information Systems
University of Electro-Communications
Tokyo, Japan
e-mail: kawamura@ohsuga.is.uec.ac.jp

Akihiko Ohsuga
Graduate School of Information Systems
University of Electro-Communications
Tokyo, Japan
e-mail: akihiko@ohsuga.is.uec.ac.jp

***Abstract*—The 'Web of Data' is a growing trend for the creation of innovative services on the web. Thus, a search engine for the data is becoming important for promoting data-intensive services. However, full-text search is not suitable for data fragments, and formal query languages are difficult for ordinary users. Therefore, we propose a query answering system in natural language over the 'Web of Data'. We focus on mapping of question sentences to open-schema data, and data acquisition, and then propose improvement of accuracy based on user feedback and acquisition of new data by user context information. We also present 'Flower Voice', which is an environmental application of the query answering system for assisting with users' fieldwork and confirm the effectiveness.**

Keywords*—*Web of Data; Open Data; Query Answering System; Field; Plant.

I. Introduction

The 'Web of Data' is attracting attention for the creation of innovative service businesses, mainly in the areas of government, bioscience, and smart X projects [3], [7], [9], [15]. To promote the application of the data in a greater number of consumer services, it would be helpful to have a search function for the data that can reveal what kinds of data are available on the web. Especially if the data on the web forms Linked Open Data (LOD) that is the collection of interrelated datasets described in a triple language like Resource Description Framework (RDF) in Extensible Markup Language (XML) format, full-text search is not suitable for data fragments in the linked datasets. Moreover, it is difficult for ordinary users to perform searches using SPARQL Protocol and RDF Query Language (SPARQL). We therefore propose a query answering system for matching triples extracted from the user query sentence to triples $< Subject, Verb, Object >$ in the RDF. This also serves as a registration mechanism for user-generated triples.

This paper is organized as follows. Section 2 describes problems with and approaches to realizing the query answering service to the LOD. Section 3 proposes an application for this software, Flower Voice, which is a smartphone tool for searching for information and for logging agricultural work. We then present several examples of related work in Section 4, and finally conclude with intended future work in Section 5.

II. Related Work

In research on the query answering (QA) systems and databases, many attempts have been made to automatically translate from natural language queries to formal languages like Structured Query Language (SQL) and SPARQL in order to help the understanding of ordinary users and even basebase (DB) experts. Research also exists on outputting the queries and results into natural language sentences [22], [11]. Although it is difficult to apply full-text search to data fragments, as we pointed out in Section 1, there has been research on converting a keyword list to a logical query [14], [23], [25].

In this section, we focus on Linked (Open) Data as a data structure and SPARQL as a query language, and classify research on QA systems, which translate natural sentences into queries into two categories based on whether a deep or shallow linguistic analysis is needed.

One system that requires deep linguistic analysis is ORAKEL [4], [5]. It first translates a natural sentence into a syntax tree using Lexicalized Tree Adjoining Grammars, and then converts it to F-logic or SPARQL. Although it is able to translate while retaining a high degree of expressiveness, it also requires the original sentence to be precise and regular. [27] considers a QA system together with the design of a target ontology mainly for event information, and features handling of temporality and N-ary during the syntax tree creation. It assigns the words of the sentence to slots in a constraint called a *semantic description* defined by the ontology, and finally converts the semantic description to SPARQL recursively. However, it requires advance knowledge of the ontology structure.

In terms of the voice-controlled QA system for users, however, these approaches are problematic for practical use due to voice recognition errors, syntax errors in the original sentences, and triplification errors. Furthermore, if the DB is open, the assumption that the ontology schema is already given is also questionable. Approaches that use shallow linguistic analysis thus aim for portability and schema independence from the DB. Our proposed system falls into this category.

FREyA [6] was originally developed as a natural language interface for ontology search. It has many similarities with our system like matching the words from the sentence with Resources and Properties by using a string similarity measure and synonyms from WordNet and improvement of accuracy based on user feedback. However, it performs conversion of the sentence to a logical form using ontology-based constraints (without consideration of the syntax of the original sentence unlike the semantic description), assuming completeness of the ontology used in the DB. By contrast, DEQA [17] takes an approach called Template-Based SPARQL Query Generator [26]. It takes prepared templates of SPARQL queries and converts the sentence to fill the slots in the template (not the ontology constraint). Like our system, DEQA also applies to a specific domain (real estate search), and exhibits a certain degree of accuracy. PowerAqua [18], [19], [20] also originated as a natural language interface for ontology search and has similarities with our system such as a simple conversion to basic graph pattern called Query-Triples, matching of words from the sentence with Resources and Properties using a string similarity measure and synonyms from WordNet, and the use of user feedback. When used with the open data, PowerAqua also introduces heuristics according to the query context to prevent decreased throughput.

[21] serves as a useful reference for surveying QA systems. The system proposed in this paper is related to a number of works. However, it is distinguished by using a social approach, that is, improvement of accuracy and data acquisition through user participation by seamlessly combining the search query and registration statement. There are no similar work in terms of application to fieldwork (and Japanese sentences). Also, our system currently does not use the ontology, since our target source for the query is the LOD and we assume the open schema scenarios. The LOD schema is not regulated by any organization, and there may be several properties of the same meaning and a sudden addition of a new property. In addition, we assume searching over multiple LOD sets made by the different authors. Therefore, we do not rely on the ontology behind the LOD. However, the proper adaptation of the ontology is useful to interpret the semantics, and thus we will address this issue in the future.

Recently, well-known voice assistants such as Apple Siri and xBrainSoft Angie have been commercialized. Both offer high accuracy voice recognition functions and are good at certain typical tasks such as calling up handset capabilities and installed applications, which are easily identified from the query. In terms of the information search, these voice assistants correctly answer the question in cases that the information source is a well-structured web site such as Wikipedia. However, extracting the information from unstructured web sites often fails and they return the search engine results page (SERP), and thus the user needs to tap URLs from the list. Angie also provides a link to Facebook and a development kit. By comparison, our system focuses on the information search using the LOD as the knowledge source, and raises the accuracy using the user feedback.

Targeting smartphone applications in agriculture, Fujitsu Ltd. provides a recording system, in which the user can simply register the work type by buttons on the screen that have photos of cultivated plants. NEC Corp. also offers a machine-to-machine (M2M) service aimed at visualization of sensor information and support of farming diaries. Both systems address recording and visualization of work the same as Flower Voice, but our system contains a form of voice-controlled QA system for the open-schema data that takes a social approach by combining data recording with data viewing.

In terms of combination of the sensor and the semantics, the sensor data in semantic sensor network are annotated with semantic metadata to support for environmental monitoring and decision-making at the time of disaster. For example, SemSorGrid4Env [13] has been applied to flood emergency response planning. However, searching and reasoning is conducted on the collected semantic sensor data, whereas the sensor data in our system is connected to a broader range of the LOD DB. In social sensor research, social networking services and physical-presence awareness like Radio Frequency IDentification (RFID) and twitter with GPS data are integrated in order to encourage the collaboration and communication among users. For example, Live Social Semantics [24] was applied to academic conferences, and suggested new interests for attendees. Although the objectives are different, the architecture where face-to-face contact events obtained by RFID are connected to the social information is similar to our system. This will provide guidance for scaling up our system in the future.

III. PROBLEMS AND APPROACHES TO OPEN-SCHEMA DATA

In the classification of interactive systems, our QA service is in the same category as Siri, which is a DB-search QA system. However, Siri is more precisely a combination of a closed DB and open Web-search QA system, whereas our system is an ‘open’ DB-search QA system. Although the detailed architecture is described in the next section, the basic operation is to extract a triple such as subject, verb, and object from the query sentence by using morphological analysis and dependency parsing. Figure 1 shows a conversion from a dependency tree to a triple. Any query words (what, where, when, why, etc.) are then replaced with a variable and the LOD DB is searched. SPARQL is based on graph pattern matching, and this method corresponds to a basic graph pattern (one triple matching). At the data registration, if there is a Resource corresponding to the $Subject$ and a Property corresponding to the $Verb$ from the user statement, a triple, which has the $Object$ from the user statement as the Value is added to the DB.

Although DB-search QA systems without dialog control have a long history, there are at least the following two problems because the data schema is ‘open’.

A. Mapping of Query Sentence to LOD Schema

Although a mapping between the verb in the query sentence (in Japanese) and a Property in the LOD schema of the DB must be prepared in advance, both of them are unknown in the open-schema data (compared with a closed DB where the schema is given), so the score according to the mapping degree can not be predefined.

We therefore use a string similarity and a semantic similarity technique from the field of ontology alignment to map verbs to Properties, and attempt to improve the mapping based on user feedback. We first register a certain set of mappings {Verb (in Japanese), Property} as seeds in the Key-Value Store (KVS). If a verb is unregistered we then do the following:

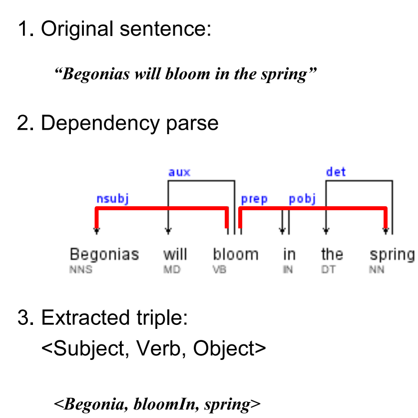


Figure 1: Conversion from dependency tree to triple.

(1) Expand the verb to its synonyms using Japanese WordNet ontology, and then calculate the Longest Common Substring (LCS) with the registered verbs to use as the similarity.
(2) Translate the new verb to English, and calculate the LCS of the English with the registered Properties.
(3) If we find a Resource that corresponds to a subject in the query sentence in the LOD, we then calculate the LCSs of the translated verbs with all the Properties belonging to the Resource, and create a ranking of possible mappings according to the combination of the above LCS values (Figure 2).
(4) The user feedback, which indicates which Property was actually viewed, is sent to the server, and the corresponding mapping of the new verb to the Property is registered in the KVS.
(5) Since the registered mappings are not necessarily correct, we recalculate the confidence value of the mapping based on the number of pieces of feedback, and update the ranking of the mapping to improve the N-best accuracy (refer to Section IV-D).

B. Acquisition and Expansion of LOD Data

Even for an open DB, it is not easy for an ordinary user to register new triples in the DB. We therefore provide an easy registration method that uses the same extraction mechanism as triples from statements.

We also provide an automatic registration method of the user context information to support of the data registration by the user. When the user registers a triple in the DB, the sensor data are automatically aggregated by using built-in sensors on the smartphone, and the context information related to the triple are inserted in the DB after the semantic conversion of the sensor data. Although Twitter is providing a function for attaching geographical information to tweets, this method is available with a greater variety of the context information. By using this method, the user can register not only the direct assertion, that is an object in the user statement, but also several background information at once. We describe examples of the sensor data and the corresponding context information in the next section. This is an approach to collect the necessary data from side effects of the user actions (the registration in this case), and corresponds to a typical method in the Human Computation mechanisms.

By contrast, we also attach the Twitter ID of the registrant to the data as the Creator in order to raise the feeling of contribution in the user who share the significance of building the 'Web of Data'. This is another method in the Human Computation mechanisms. These efforts further promote the social user participatory approach.

We have also been developing a semi-automatic LOD extraction mechanism from web pages for generic and specialized information; this mechanism uses Conditional Random Fields (CRF) to extract triples from blogs and tweets. As [29] shows, it has achieved a certain degree of extraction accuracy.

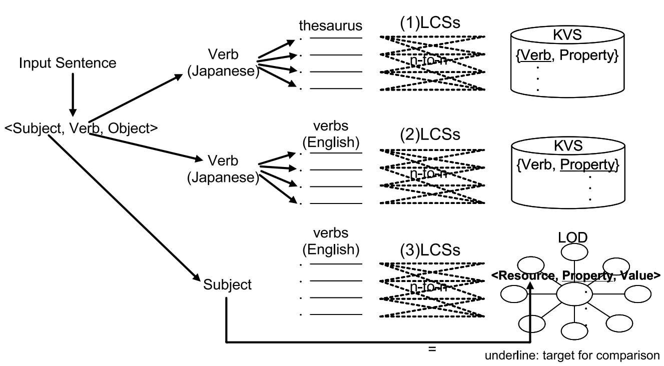


Figure 2: Calculation of LCS.

IV. Development of Applications for Fieldwork Support

This section shows the implementation of our service and an applications. The applications of QA systems include Interactive Voice Response, guide systems for tourists and facilities, car navigation systems, and game characters. However, these all basically use closed DBs and would not be the best match for an open DB. In addition, our system does not currently incorporate dialog control such as Finite-State Transducers (FST), so that problem-solving tasks such as product support are also difficult. We thus focus on searching for information as described in the previous sections and introduce the following applications.

1) General Information Retrieval
DBpedia [9] already stores more than one billion triples, and there are 31 billion triples on the web, so part of the information people are browsing in Wikipedia can be retrieved from LOD.
2) Recording and Searching Information for Fieldwork
Since the system allows user registration of information, the information relevant to a specific domain can be recorded and searched, including for agricultural and gardening work, elevator maintenance, factory inspection, camping and climbing, evacuation, and travel.
3) Information Storage and Mining Coupled with Twitter
If we focus on the information sharing, it is possible that when a user tweets using a certain hash tag (#), the tweet is automatically converted to a triple and registered in the LOD DB. Similarly, when the user submits a query using a hash tag, the answer is mined from the LOD DB, which stores a large amount of past tweets. This would be useful for the recording and sharing of word of mouth information and life log information.

Although the above (1) is our purpose mentioned in the introduction, we introduce an application of our QA system from the second perspective in the following section to evaluate the system in a limited domain, which is "Flower Voice" to answer a query regarding the agricultural, gardening work like disease and pest, fertilization, maintenance, etc.

A. Flower Voice

Urban greening and agriculture have been receiving growing attention due to the rise of environmental consciousness and growing interest in macrobiotics. However, the cultivation of greenery in a restricted urban space is not necessarily a simple matter. Beginners who have no gardening expertise have questions and get into trouble in several situations ranging from planting to harvesting. Although the user could employ

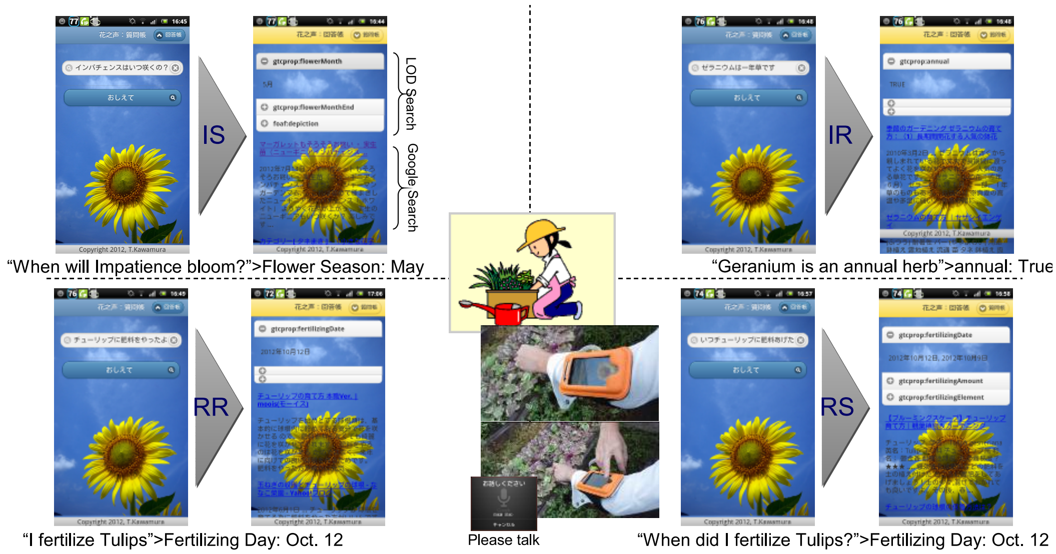


Figure 3: Overview of Flower Voice.

a professional gardening advisor to solve these problems, this would involve costs and may not be readily available in urban areas. Also this kind of work cannot be fully planned and the gardener needs to respond to the current status of the plants on site, since it highly depends on the surrounding environment. However, searching the Internet using a smartphone suffers from the disadvantages of inputting keywords and iteratively tapping and scrolling through SERP to find the answer. Therefore, we developed Flower Voice, which is a QA service for smartphones that answers questions regarding agricultural and gardening work. Moreover, we used a voice control, which is suitable for this work since users typically have dirty hands (and no need to be shy because no eyes and ears around). Furthermore, we provided a mechanism for registering the work of the user, since data logging is the basis of precision farming according to the Japanese Ministry of Agriculture. This is a tool for searching information and for logging by voice using smartphones for agricultural and gardening work. Figure 3 shows an overview of Flower Voice. It automatically classifies the speech intention (Question Type) of the user into the following four types (Answer Type is a literal, Uniform Resource Identifier (URI), or image).

1) Information Search (IS)
   Search for plant information in the LOD DB.
2) Information Registration (IR)
   Register new information for a plant that does not currently exist in the LOD DB or add information to an existing plant.
3) Record Registration (RR)
   Register and share records of daily work. Since data logging is important for the farming, it would be useful to add sensor information together with the registered record. However, the verbs that can be registered are limited to the predefined Properties in the DB (see the next section).
4) Record Search (RS)
   Search through records to remember previous work and view the work of other people.

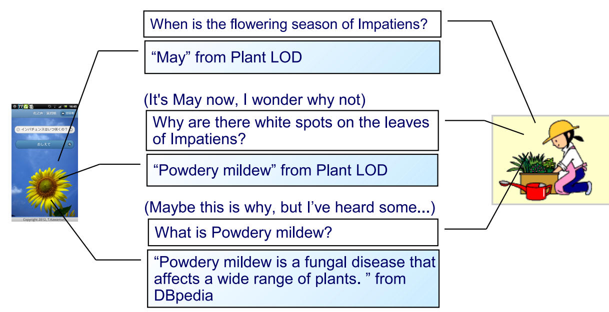


Figure 4: Chaining search.

The possible use cases are as follows.

1) Chaining Search: This is the case, in which Flower Voice continuously provides the pinpoint data that the user wants to know on site during the work (Figure 4).

2) Use of User Participation: This is the case where the user uses the registration mechanism to share a piece of data they learned about. This would be useful, for example, in environmental surveys (Figure 5 above) where users cooperatively investigate and report the specific environmental items such as rare species of plants that the users discovered, and building a knowledge community (Figure 5 below). The registered data are annotated with the Twitter ID of the registrant.

B. Plant LOD

The LOD used by Flower Voice is called Plant LOD, and consists of more than 10,000 Resources (species) under the Plant Class in DBpedia and 104 Japanese Resources that we have added. We have also added 37 Properties related to plant cultivation to the existing 300 Properties. In terms of the LOD Schemas for registering records, we prepared Properties mainly for recording dates of flowering, fertilizing, and harvesting. Figure 6 illustrates Plant LOD, which is an extension of the LOD used by Green-Thumb Camera [16], which was developed for introducing plants (greening design).

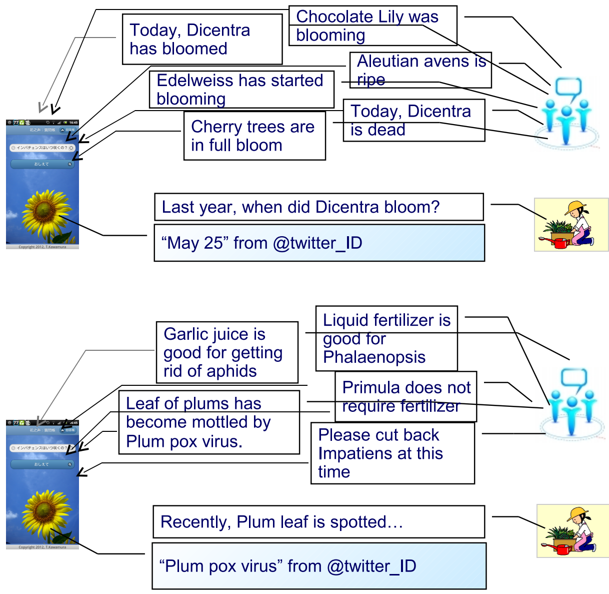


Figure 5: Use for environmental survey (above) and knowledge community (below).

Plant LOD is now stored and publicly available at Dydra.com.

C. System Architecture

Figure 7 shows the architecture of Flower Voice. The user can input a query sentence by Google voice recognition or keyboard. The system then accesses the Yahoo! API for Japanese morphological analysis to extract a triple using the built-in dependency parser, and generates a SPARQL query by filling in slots in a query template. The similar process also works for English sentences, although the morphological analyzer and dependency parser must be changed to, for example, Berkeley Parser [2]. The search results are received in XML format. After searching the {Verb, Property} mappings registered in Google Big Table and accessing the Microsoft Translator API and Japanese WordNet Ontology provided by the National Institute of Information and Communications Technology (NICT), the LCS values for each mapping are calculated as described in Section 2. The order of matching is firstly matching the $Subject$ against Resources by tracing ‘sameAs’ and ‘wikiPageRedirects’ links, and then searching for $Verb$ matches with the Properties of the Resources. A list of possible answers is then created from the pairs of Properties and Values with the highest LCS values. The number of answers in the list is set to three due to constraints on the client UI. The results of a Google search are also shown below in the client to clarify the advantages and limitations of the QA service by comparison. User feedback is obtained by opening and closing a collapsible area in the client, which gives a detailed look at the Value of the Property (but only the first click). During searches, feedback updates the confidence value of a registered mapping {Verb, Property} or registers a new mapping. During registration, the feedback has the role of indicating which of three Properties to which the $Object(Value)$ should be registered. The client UI displays the results. Text-to-speech has not been implemented yet.

In terms of the computational performance, this service is currently running on 1 CPU with 55.1 MBytes memory of Google App Engine 1.8.4, where 1 CPU corresponds to 1.0–1.2 GHz 2007 Opteron. Then, it needs almost 1 (sec) for retrieving a plant data from the LOD, but once loaded the data, it takes 0.05–0.3 (sec) for answering a query. However, it is difficult to compare the performance with other services, and thus evaluate the data accuracy and acquisition in the following sections.

TABLE I: MAPPING OF SENSOR AND CONTEXT INFORMATION.

Sensors	Context Info. that can be obtained
Clock	Date, Time
GPS	Location, Nearby POI
(Combination of the above two)	Weather, Temperature, Humidity
Illuminance	Space{Indoor, Outdoor}
Acceleration	Status{Moving, Stop}, Walking Time&Distance

The automatic registration method of the user context information is realized by the acquisition of sensor data and the semantic conversion based on the LOD Schema. The sensor data are obtained by JavaScript running on the smartphone, except for Osaifu-Keitai that is FeliCa (a specification of Near Field Communication) mobile payment. Table I shows examples of the sensor data and the corresponding context information. Note that although the clock and Osaifu-Keitai are not the sensors, these are included in the table for showing the mapping with the context information. Furthermore, Points of Interest (POI) and Weather are obtained by accessing Yahoo! Open Local Platform and Japan Meteorological Agency based on the Global Positioning System (GPS) information. The POIs specifies location names (buildings, companies, stations) around the location.

We prepared the LOD schemas (Properties) corresponding to the above context information, and once the sensor information is retrieved, we convert it to the property value with the designated data types like literal and interger that are predefined by the schemas. For example, when a user registers a triple describing “a flower has blossomed”, the sensor data for the location is converted to literal, one for the temperature is conveted to integer, and one for the space is translated to Indoor or Outdoor, respectively. Then, the context information such as **gtcprop:flowerAddress** (location), **gtcprop:flowerDateHighTemp** (highest temperature of the day), **gtcprop:flowerDateLowTemp** (lowest temperature of the day), **gtcprop:flowerSpace** (space of the flower) are automatically registered in the LOD DB.

We show the combinations of Properties registered by the user and the additional context information obtained by the sensors in Figure 8. In this figure, **gtcprop:flowerDate–Weather** means that the weather is registered with a flowering date. The links of the property and the context information can be easily changed according to the purpose of application. Flower Voice currently does not use the context information related to the user actions like number of steps, walking distance, walking time, etc. Therefore, there are unlinked contexts in the figure.

We have also added an advanced function for changing the LOD DB that is searched by the user input to a SPARQL endpoint as entered in an input field of the client UI, although

 ISBN: 978-1-61208-310-0

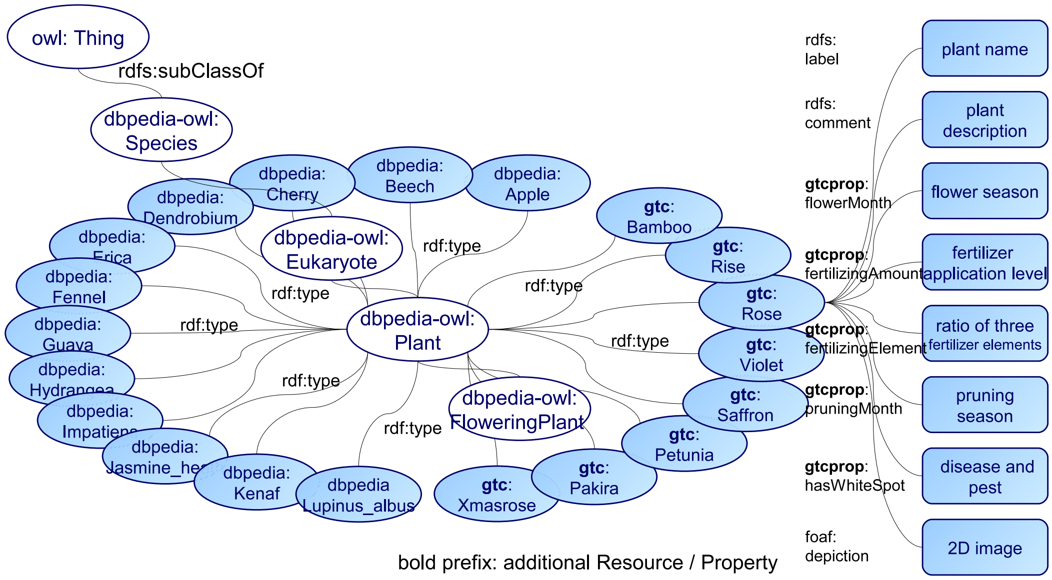


Figure 6: Plant LOD.

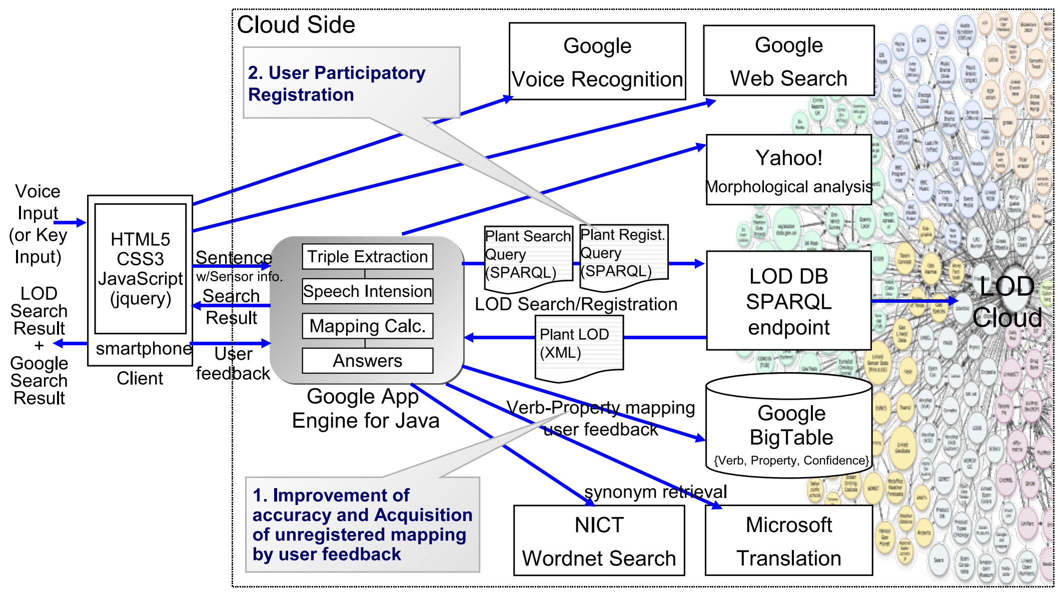


Figure 7: Mashup architecture.

the change is limited to searches. This is not compatible with all servers because the query is based on predefined templates and the results are received in XML format. Some servers also require attention to latency. Endpoints that have been confirmed include DBpedia Japanese [10], Data City SABAE [8], Yokohama Art LOD [28], etc. Users can also manually register {Verb, Property} mappings. If the Property that a user wants does not appear in the three answers, the user can input a {Verb, Property} mapping in an input field. The mapping is then registered in the KVS and will be searched by the next query. Although this function targets users who have some expertize dealing with LOD, we are expecting to discover unanticipated use cases when the system is open to users.

Flower Voice is available from our website (in Japanese) [12], and almost 500 users have used it with at least one query so far (Flower Voice won a Judges' Special Award in the LOD Challenge Japan 2012).

D. Evaluation of Accuracy Improvement

We conducted experiments on the current system to confirm the search accuracy, and how the accuracy is improved by the user feedback mechanism described in Section 2. Note that if a sentence is composed of more than two triples, it must be queried as separate single sentences. The intention of the speech, such as searching or registration, is classified by the existence of question words and the use of postpositional words, not by intonation. Sentences need to be literally described regardless of whether they are affirmative or interrogative.

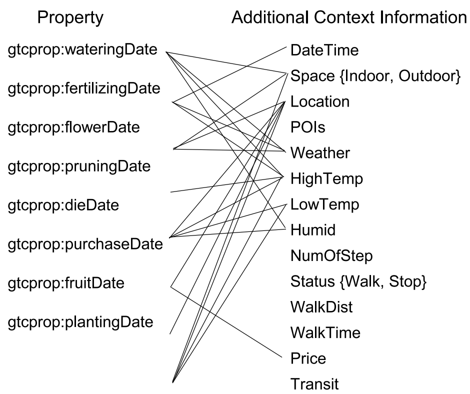


Figure 8: Properties and corresponding contexts.

TABLE II: ACCURACY OF SEARCH.

	False			True	
	no Res.	no Prop.	triplification error	1-best	3-best
1st Set (ave)	18.2%	0%	9.1%	54.5%	72.7%
2nd Set (ave)				72.7%	72.7%

In the experiment, we asked several experienced gardeners to select frequently asked questions from their daily work, and collected 99 query sentences (and the preferred answers). Although there were no duplicate sentences, sentences having the same meaning at the semantic level were included. We then randomly constructed 9 test sets consisting of 11 sentences each. We first evaluate one test set randomly selected, and give the correct feedback, which means registering {Verb, Property} mappings and updating the confidence value for one of the three answers for each query. We then proceed on to the next set. After evaluating the second test set, we clear the effects of the user feedback and repeated the above again from the first set. The difference of the accuracy between the first and the second set corresponds to the improvement by the user feedback. The results are shown in Table II. We assume that query sentences are correctly entered, since in practice Google Voice Recognition returns the possible results of the recognition, and the users can select the correct sentence in a dialog, or start over from speech.

In the table, “no Res.” means that there was no corresponding Resource (plant) in the Plant DB, and “no Prop.” means no Property corresponding to the Verb in the query sentence. “triplification error” indicates failure to extract a triple from the query sentence in case of a long complex question, etc. N-best accuracy is calculated by the following equation:

$$N - best\ precision = \frac{1}{|D_q|} \sum_{1 \leq k \leq N} r_k \qquad (1)$$

,where $|Dq|$ is the number of correct answers for query q, and r_k is an indicator function equaling 1 if the item at rank k is correct, zero otherwise. In the case of 3-best, the three answers are compared with the correct answer, and if any one of them is correct, then the result is regarded as correct.

TABLE III: EFFECTIVENESS OF ADDITIONAL CONTEXT.

False		True		
no Prop.	triplification error	success	num. of additional context	num. of useful context
0%	9.1%	90.9%	9.3 triples per registration	3.4 triples per registration

We found that approximately 20% of the queries were for unregistered plants, and the prepared Properties covered all of the queries. The current extraction mechanism is rule-based, and approximately 10% of the queries were not analyzed correctly. Although the queries are in a controlled natural language since the queries need to be literally described as single sentences, we found that 90% of questions are allowed in our system. We are planning to extend the rules and use CRF [29] for further improvement.

The N-best accuracy can be increased by providing more data such as Resources and Properties in the Plant LOD and {Verb, Property} mappings, and so the base accuracy of the first set is not particularly important. However, by comparing the results for the first set with the second one, we can confirm that the improvement of the accuracy was affected by the user feedback (note that the fact that 1-best accuracy equals 3-best accuracy means all the correct answers are in the first position, that is, they are among the first three positions).

We expect that the number of acquired {Verb, Property} mappings will form a saturation curve according to the number of trials that saturates to a domain-dependent value. In this domain, we found that an average of 0.09 new mappings were acquired per trial (query) from an initial 201 mappings in the DB. More detailed analysis will contribute to the bootstrap issue for applications in other domains.

E. Evaluation on Data Acquisition

We also conducted experiments on the current system to confirm the effectiveness of the context acquisition. In the experiment, we first collected 44 sentences for the registration from the experienced gardeners, and then registered them in the DB. We do not consider voice recognition errors as well as the previous experiment. We also assume that the user feedbacks that indicate Properties for registering the context information are correctly entered. The results are shown in Table III.

In the table, “no Prop.” means no Property corresponding to the Verb in the sentence. “triplification error” indicates failure to extract a triple from the query sentence. However, if there was no corresponding Resource (plant) in the Plant DB during the registration, the Resource is automatically created, and so “no Res.” does not happen in this experiment. Furthermore, “num. of additional context” means how many triples for the context information on average are automatically added with a triple that is successfully registered. Note that all the context information shown in Figure 8 are not necessarily obtained in practice because of the status and timing of the sensors. “num. of useful context” means the number of triples the experienced gardeners considered useful among all the additional context information. The followings are examples of the useful context information.

wateringDate–Location, HighTemp, Space: By this combination, useful data to analyze correlation with the watering period to the circumstances and seasons would be collected.

flowerDate, fruitDate, dieDate–Address, Weather, HighTemp, LowTemp, Space: By these combinations, usefull data regarding the process from flowering and fruiting to dying depending on weather change in each area would be collected.

pruningDate, flowerDate, fruitDate–Address, HighTemp, LowTemp: Correlation with flowering and fruiting to pruning can be investigated based on these data.

hasWhiteSpot–Humid: The risk of developing red spiders would be anticipated by drying in the planting space.

As a result, by automatically adding the context information as the side effects of the user registration, we confirmed that the useful triples have been increased 3.4 times more as the result. If these data are described in RDF and shared in the Cloud DB, then people who have several viewpoints can easily analyze from their own aspects.

V. Conclusion and Future Work

In this paper, we proposed a query answering service, which uses the LOD as a knowledge source to facilitate the spread of the data-intensive services. We then developed and evaluated an application for assisting with fieldwork. It also features the Human Computation mechanisms, namely, the improvement of accuracy based on user feedback and the acquisition of new data by user participation.

We have realized the method to register the context information converted from the sensor data in order to increase the new data in this paper. However, as lessons learnt from the application, we should also consider to use the context information for the searches. This means the refinement of the search results using subgraph matching based on user context. It would be useful to automatically select the necessary information based on the current and past situation of the user without explaining every detail. Also, we need to conduct the evaluation of accuracy with the LOD size, in general scalability of the system, and discuss the impact of the values gathered in the sense of how well does the system scale. In the future, we also intend to collect customer feedback on this application, and to apply the system to domains other than agriculture.

References

[1] Ars Technica, “”Siri, does anyone still use you?” Yes, says survey,” http://arstechnica.com/apple/2012/03/siri-does-anyone-still-use-you-yes-says-survey/[accessed: 2013-09-06].

[2] Berkeley Parser, https://code.google.com/p/berkeleyparser/[accessed: 2013-09-06].

[3] Bloomberg Businessweek Technology, “Q&A with Tim Berners-Lee,” http://www.businessweek.com/stories/2007-04-09/q-and-a-with-tim-berners-leebusinessweek-business-news-stock-\ market-and-financial-advice[accessed: 2013-09-06].

[4] P. Cimiano, “ORAKEL: A Natural Language Interface to an F-Logic Knowledge Base,” Proc. of 9th International Conference on Applications of Natural Language to Information Systems (NLDB), Jun. 2004, pp. 401-406.

[5] P. Cimiano, P. Haase, J. Heizmann, and M. Mantel, “Orakel: A portable natural language interface to knowledge bases,” Technical Report, University of Karlsruhe, March 2007, pp. 1-77.

[6] D. Damljanovic, M. Agatonovic, and H. Cunningham, “FREyA: an Interactive Way of Querying Linked Data using Natural Language,” Proc. of 1st Workshop on Question Answering over Linked Data (QALD-1), May 2011, pp. 125-138.

[7] DATA.gov, http://www.data.gov/[accessed: 2013-09-06].

[8] Data City SABAE, http://lod.ac/sabae/sparql[accessed: 2013-09-06].

[9] DBpedia, http://dbpedia.org[accessed: 2013-09-06].

[10] DBpedia Japanese, http://ja.dbpedia.org/sparql[accessed: 2013-09-06].

[11] B. Ell, D. Vrandecic, and E. Simperl, “SPARTIQULATION: Verbalizing SPARQL Queries,” Proc. of Interacting with Linked Data (ILD), May 2012, pp. 50-60.

[12] Flower Voice (in Japanese), http://www.ohsuga.is.uec.ac.jp/\~{}kawamura/fv.html[accessed: 2013-09-06].

[13] R. Garcia-Castro et al., “A Semantically Enabled Service Architecture for Mashups over Streaming and Stored Data,” Proc. of 8th Extended Semantic Web Conference (ESWC), May 2011, pp. 300-314.

[14] P. Haase, D. Herzig, M. Musen, and D. T. Tran, “Semantic Wiki Search,” Proc. of 6th European Semantic Web Conference (ESWC), May 2009, pp. 445-460.

[15] T. Heath, “The Web of Data,” Proc. of 9th Summer School on Ontology Engineering and the Semantic Web (SSSW), July 2012.

[16] T. Kawamura and A. Ohsuga, “Toward an ecosystem of LOD in the field: LOD content generation and its consuming service,” Proc. of 11th International Semantic Web Conference (ISWC), Nov. 2012, pp. 98-113.

[17] J. Lehmann et al., “DEQA: Deep Web Extraction for Question Answering,” Proc. of 11th International Semantic Web Conference (ISWC), Nov. 2012, pp. 131-147

[18] V. Lopez, E. Motta, and V. Uren, “PowerAqua: Fishing the Semantic Web,” Proc. of 3rd European Semantic Web Conference (ESWC), May 2006, pp. 393-410.

[19] V. Lopez, M. Sabou, V. Uren, and E. Motta, “Cross-Ontology Question Answering on the Semantic Web - an initial evaluation,” Proc. of 5th International Conference on Knowledge Capture (K-CAP), Sep. 2009, pp. 17-24.

[20] V. Lopez et al., “Scaling Up Question-Answering to Linked Data,” Proc. of 17th International Conference on Knowledge engineering and management by the masses (EKAW), Oct. 2010, pp. 193-210.

[21] V. Lopez, V. Uren, M. Sabou, and E. Motta, “Is question answering fit for the semantic web?,” A survey. Semantic Web J. Vol. 2, No. 2, July 2011, pp. 125-155.

[22] A. Simitsis and Y. E. Ioannidis, “DBMSs Should Talk Back Too,” Proc. of 4th biennial Conference on Innovative Data Systems Research (CIDR), Jan. 2009.

[23] S. Shekarpour et al., “Keyword-driven SPARQL Query Generation Leveraging Background Knowledge,” Proc. of International Conference on Web Intelligence (WI), Aug. 2011, pp. 203-210.

[24] M. Szomszor, C. Cattuto, W. V. Broeck, A. Barrat, and H. Alani, “Semantics, sensors, and the social web: The live social semantics experiments,” Proc. of 7th Extended Semantic Web Conference (ESWC), May 2010, pp. 196-210.

[25] D. T. Tran, H. Wang, and P. Haase, “Hermes: Data Web search on a pay-as-you-go integration infrastructure,” J. of Web Semantics Vol.7, No.3, Sep. 2009, pp. 189-203.

[26] C. Unger et al., “Template-based question answering over RDF data,” Proc. of 21st International Conference on World Wide Web Conference (WWW), April 2012, pp. 639-648.

[27] M. Wendt, M. Gerlach, and H. Duewiger, “Linguistic Modeling of Linked Open Data for Question Answering,” Proc. of Interacting with Linked Data (ILD), May 2012, pp. 75-86.

[28] Yokohama ART Search, http://archive.yafjp.org/test/inspection.php[accessed: 2013-09-06].

[29] T. M. Nguyen, T. Kawamura, Y. Tahara, and A. Ohsuga: “Building a Timeline Network for Evacuation in Earthquake Disaster”, Proc. of AAAI 2012 Workshop on Semantic Cities, July 2012, pp. 15-20.

A Novel Genetic Algorithm with Asexual Reproduction for the Maximum Lifetime Coverage Problem in Wireless Sensor Networks

Antonina Tretyakova
Polish-Japanese Institute of Information Technology
Koszykowa 86, 02-008 Warsaw, Poland
Email: antoninat@onet.pl

Franciszek Seredynski
Cardinal Stefan Wyszynski University in Warsaw
Dep. of Mathematics and Natural Science,
Woycickiego 1/3, 01-938 Warsaw, Poland
Email: fseredynski@gmail.com

***Abstract*—In this paper, we propose a novel evolutionary algorithm called Genetic Algorithm with Asexual Reproduction (GAwAR) to solve Maximum Lifetime Coverage (MLC) Problem in Wireless Sensor Networks (WSN). We use for GAwAR a binary coding of the problem, develop asexual operator of crossover and operator of mutation in which knowledge about MLC problem is incorporated, and apply deterministic selection. We compare the proposed algorithm with a standard Genetic Algorithm with elitist strategy. We show that the proposed GAwAR significantly outperforms the standard Genetic Algorithm.**

Keywords- Wireless Sensor Network; Maximum Lifetime Coverage Problem; Genetic Algorithms.

I. INTRODUCTION

WSN is a widely developing area of technology. They are getting involved in many spheres of human vital activities, such as military, healthcare, biomedicine, environment observation, etc. According to an application area different tasks are set before WSN, among which are monitoring environment, gathering data, transmission data to a sink, etc. Due to their tiny construction WSN nodes have limitations of energy power, computing power, sensing range, transmission distance and bandwidth. There are well-known optimization problems in the literature [1] [7] [9] related to WSN, among which are the sensor deployment problem, the coverage problem, the routing problem and the MLC problem, which will be the subject of this paper. One of the most important issues related to these problems is minimizing energy consumption in order to prolong the lifetime of WSN.

All these aforementioned problems are computationally difficult problems and belong to the class of NP-hard problems. Different solutions have been proposed to solve different variants of MLC problem. Among them are approximation algorithms [18] proposed for some variants of MLC problem, linear programming [11] [15] and different heuristics [17] [19] [20] [21]. Recently, a number of approaches based on application of evolutionary algorithms have been also proposed [2] [6] [23] to deliver approximate solutions.

Our recent study [10] comparing performance of genetic algorithms (GA), memetic algorithms and a local optimization scheme have shown that general solvers based on standard evolutionary schemes do not provide satisfactory solutions. Prevailing number of currently applied GAs to solve different problems are based on sexual reproduction, where two randomly selected individuals (solutions of a problem) create two offspring, which are a subject of selection and mutation. Some recent studies [22] have shown that succesfull evolutionary search may be conducted also by using asexual reproduction. Therefore, in this paper, we develop a novel evolutionary algorithm with asexual reproduction, where basic evolutionary operators such as selection and crossover are performed on single individuals. Additionally, we incorporate a specific knowlege about the problem into operators of crossover and mutation. We compare our approach with an approach based on a standard GA with sexual reproduction and elitist strategy incorporated into GA.

The remainder of the paper is organized as follows. The next section outlines MLC problem. In Section III, we introduce some preliminary notions. Section IV introduces our proposed greedy heuristic to solve MLC problem. In Section V, we describe two genetic algorithm - based solutions. Section VI contains results of experimental study of these algorithms. The conclusion is presented in the last section.

II. MAXIMUM LIFETIME COVERAGE PROBLEM STATEMENT

Let us consider a sensor network $S = \{s_1, \ldots, s_N\}$ consisting of N sensor nodes randomly distributed over a given *target field F*, a two-dimensional rectangular area of $W \times H\, m^2$. The target field F is uniformly divided on points of interest (POIs) with a step g (see Figure 1).

Sensors are responsible for detection of an intruder (a target point) and sending an alarm message to the sink node. A sensor is defined as a point of coordinates (x_s, y_s). All sensor nodes have the same sensing range R_s, communication range R_c and battery capacity *b*. The coverage model of a sensor node is assumed a disk model [9].

It is assumed that each sensor can work in two modes: *active mode* and *sleeping mode*. In active mode a sensor observes an area within its sensing range and can transmit or receive a signal.

 ISBN: 978-1-61208-310-0

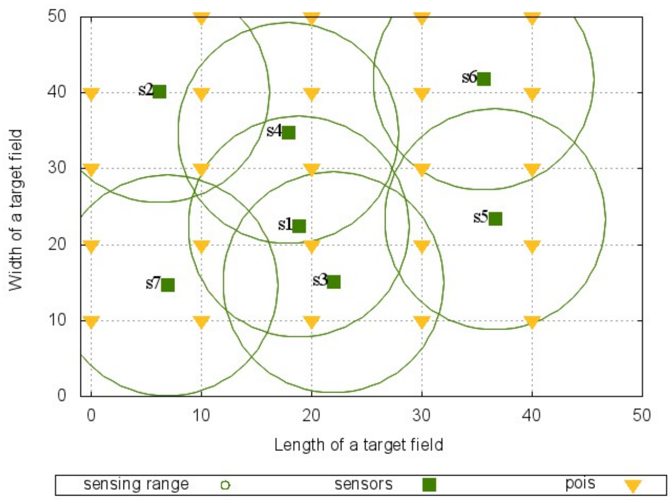


Figure 1. An example of sensor network deployed over the target field divided on POIs.

Below we give a number of definitions concerning the problem statement.

Definition1. A sensor $s(x_s, y_s)$ covers a POI *p(x, y)* denoted as POI_{obs} iff the Euclidean distance *d(s,p)* between them is less than the sensing range R_s.

Definition2. Coverage of a target field F at $i-th$ time period t_i denoted as $cov(i)$ is defined as a ratio of observed $POIs_{obs}$ by a network of active sensors S to all $POIs$, i.e.

$$cov(i) = \frac{|POIs|_{obs}}{|POIs|} \quad (1)$$

In this paper, a sensor is assumed to consume energy for monitoring area and it depends on its sensing range R_s. Considering a homogeneous sensor network, where all sensors have the same sensing range, the energy consumption per time interval is constant.

An objective in a point coverage problem is to cover a set of discrete points (targets), while an area coverage problem aims to cover the whole target field. In grid approaches, where the sensing field is uniformly divided on discrete points, called points of interest POIs [2] or targets, the area coverage problem can be considered as a point coverage problem. In this paper, we consider Maximum Lifetime Coverage Problem as a scheduling problem applied to WSN solving the point coverage problem regarding to prolongation the lifetime of WSN.

MLC has as objective to prolong lifetime of WSN by minimizing a number of redundant sensors during each time interval in order to minimize energy consumption. Lifetime of WSN is defined as a maximal number of consecutive time intervals, during which the coverage requirement is met, i.e.

$$Lifetime(q) = max\{m|(\forall i)i < m \quad cov(i) \geq q - \delta\} \quad (2)$$

Coverage requirement is given by a coverage degree k and a coverage ratio q, which means that at least q-th part with small declination δ of all targets is covered by at least k sensors. A point coverage problem with k coverage degree is denoted in literature as k-coverage problem. Further, we assume k to be equal to 1.

Maximum Lifetime Coverage Problem can be stated as follows:

- Given a set of numbers $POIs = \{1, 2, ..., P\}$, each element represents an ordinal number of a POI (a target), given a family of N subsets $S = \{S_1, S_2, ..., S_N\}$, where each element $S_i \subseteq POIs$, $i = 1, 2, ..., N$, is related to covered POIs by i-th sensor, and given an integer number b.
- Find a maximal number m of subsets $\{S'_1, S'_2, ..., S'_m\}$, where $S'_j \subseteq S$, such that the number of covered elements $| \cup_{S_i \in S'_j} S_i|$ meets the coverage ratio (Eq. 3) and each element S_i of the family S is included in b subsets $\{S'_{j_1}, S'_{j_2}, ..., S'_{j_b}\}$ (Eq. 4), i.e.

$$(\forall j)_{j=1,\dots,m} | \frac{| \cup_{S_i \subseteq S'_j} S_i|}{|POIs|} \geq q - \delta \quad (3)$$

$$(\forall i)(\exists j_1, ..., j_b) | S_i \in S'_{j_1}, ..., S_i \in S'_{j_m}, \quad (4)$$

where $i = 1, ..., N$ and $(\forall k)_{k=1,\dots,b} | 1 \leq j_k \leq m$

An objective of searching a maximal number m of subsets satisfying (3) is equivalent to lifetime maximization and corresponds to scheduling activities of sensor nodes. The last equation (4) corresponds to the battery capacity restriction.

In section IV, we present a heuristic to solve the MLC problem. Also we have taken into account the following assumptions:

- i-th subset S'_i represents the network of active sensors during the i-th time interval,
- duration of all time intervals are the same,
- a number b is predefined and corresponds to the battery capacity of a sensor node, so that initial battery capacity is sufficient for every sensor's activity during the b time intervals (rounds).

III. Preliminary notions

In this section, we describe a schedule solution representation and present classification of time intervals of WSN work according to coverage quality. For this purpose we introduce notions of $Redundant$, $Excellent$ and $Unsatisfactory$ $Subsequences$ (RS, ES and US). In Subsection 3.2, a volume of search space is evaluated.

A. Solution representation

A solution is encoded as an $T_{max} \times N$ table (further we call it as a *schedule* or a *schedule solution*), where T_{max} is predefined in time intervals meeting the following condition:

$$b < Lifetime(q) < T_{max} << N \times b, \quad (5)$$

where T_{max} should to be set greater than $Lifetime(q)$ (2). The upper bound $N \times b$ arises as a maximal number of different subsets, each of which consists of one element (such elements N) and, according to battery capacity requirement, can appear in the schedule b times.

In the schedule the parameter T_{max} is related to a number of columns. N is a number of sensors in the sensor network and concerning the number of rows in the schedule solution's table. A column of the schedule contains a network of active sensors during the certain time interval. Each row of the table is related to one of the sensors and represents its schedule of activity over all period of time T_{max}.

Binary coding is used, so that "1"s value corresponds to active state of a sensor, "0" corresponds to a sleeping state. Cells of the table are filled by "1"s and "0"s values in such a way that battery capacity restriction is met, i.e. each row of the table contains b ones and $T_{max} - b$ zeros. An exemplary schedule solution correspondingly to the network configuration from Figure 1 is depicted in Figure 2 (left).

A schedule solution is associated with a sequence of T_{max} numbers called a *coverage string*, i.e

$$coverage\ string = \{cov(1), ..., cov(T_{max})\}, \qquad (6)$$

where for every $i = 1, ..., T_{max}$ $cov(i)$ is counted according to (1) and $|POIs_{obs}| = |\cup_{j=1} POIs_{obs}(s_j)|$. These numbers represent a coverage of the target field during a corresponding time interval. For the individual from Figure 2 (left) correspondingly to WSN from Figure 1, the coverage string is the following {0.48, 0.36, 0.56, 0.24, 0.64, 0.0, 0.6}.

B. Solution space

Solution space contains all possible schedules and its volume depends on such parameters as a number of sensors N, battery capacity b and timeline division T_{max}. For a sensor a number of different schedules is equal to a number of different combinations of b ones and $T - b$ zeros. From combinatorics one can find that it is equal to $\frac{T_{max}!}{b!(T_{max}-b)!}$.

The volume of solution space for N sensors is presented by the following equation:

$$\frac{T_{max}!}{b!(T_{max} - b)!}^{N} \qquad (7)$$

For example, in the experiments we have WSN consisting of 100 sensors ($N = 100$), battery capacity b is equal to 15 and maximal number of intervals T_{max} is equal to 150, the search space in this case contains 148976491201904240^{100} elements.

C. Redundant, Excellent and Unsatisfactory Subsequences (RS, ES and US)

A searching process conducted by our proposed heuristics is based on the following classification of columns in a schedule. All columns of the schedule solution's table are divided on three groups called three subsequences:

1) *Redundant Subsequence (RS)*,
2) *Excellent Subsequence (ES)*,
3) *Unsatisfactory Subsequence (US)*.

Each subsequence groups time intervals such that a network of active sensors covers the target area with certain coverage ratio.

RS subsequence is introduced in order to reveal time intervals during which we potentially have redundant sensors and we wish to shift elements from *RS* into *ES*. *RS* is defined as a sequence of time intervals $\{i\}$, during which the coverage is greater than the coverage ratio q on at least δ, i.e.

$$cov(i) > q + 2\delta, \qquad (8)$$

where δ is a small value representing a predefined declination from coverage ratio q.

ES subsequence consists of time intervals $\{i\}$ in the schedule during which the coverage of the target field is within δ range from given coverage ratio q:

$$|cov(i) - \delta| \leq q + \delta \qquad (9)$$

We use *ES* as a mark of high quality of the schedule solution regarding to lifetime. In order to prolong the WSN's lifetime a number of elements in ES should be increased and their values should be less than elements included in *US*.

US subsequence is defined as time intervals $\{i\}$ in the schedule during which the coverage of the target field is less than the coverage ratio q on at least δ, i.e.

$$cov(i) < q \qquad (10)$$

Let us denote a number of elements in RS, ES and US as N_R, N_E and N_U respectevely.

IV. Genetic algorithm - based solution to MLC problem in WSN

Evolutionary approaches are based on improving the initial population of individuals (schedules) through repetitive application of selection, crossover and mutation operators. In this section we describe a solution based on Genetic algorithm (GA) approach, see Algorithm 1 in Figure 2. Individuals in a population are encoded as tables such as described in Section III.A. As fitness function Lifetime(q) (Equation 2) metric is used.

At the beginning a population of schedules is initialized in such a way that battery constraint is met, i.e. each row of the table is filled by b ones at random, the rest cells are filled by zeros. We use tournament selection scheme, where in each tornament between m randomly chosen individuals the winner goes to the next phase of reproduction. Further, selected individuals create offspring by applying the crossover operator with probability p_c. Their offspring are mutated with probability p_m and pass to the next generation. Lastly, the elitist strategy is applied, i.e. the best individual

 ISBN: 978-1-61208-310-0

Algorithm 1 GA

present an instance of WSN
present a grid target field
initialize a population P of N_p individuals (schedules)
compute fitness function
for i = 1 to G **do**
  tournament selection
  crossover
  mutation
  compute fitness function
  apply elitist strategy
end for
choose the best individual according to fitness function

Figure 2. Genetic Algorithm.

from the previous population goes to the next generation without changing, replacing the worst offspring.

These steps are repeated through G generations.

1) Representation: Individuals (or chromosomes) of a population are represented by solutions and encoded as described ones in Section III.A.

2) Fitness function: Individuals are evaluated according to fitness function introduced in Section II as Lifetime(q) metric (Equation 2).

3) Genetic operators: Genetic operators work in the following way.

Firstly, in a generation a tournament selection is applied. In each tournament m competitors participate. We use an elitist selection, where the best E individuals are copied to the population without changes.

In our algorithm crossover is an analogy of simple single-point crossover operator, which proceed in two steps. First, individuals of the newly reproduced population are mated at random. Second, each pair of schedules undergoes crossing over as follows: an integer position k along the rows of the tables is selected uniforly at random between 1 and a number of rows N less one [1, N-1]. Two new individuals are created by swapping all values in the rows between $k+1$ and N.

Binary mutation is used with probability p_m.

4) Correction of individuals: Under crossover operator application the battery capacity condition in offspring schedules is kept. But mutation can change a number of activity time interval of several sensors in a chromosome. Therefore, each individual is corrected in such a way that, in case of battery is overused the genes corresponding to the last active time intervals are zeroised. Otherwise, randomly chosen zero genes in the row related to the disturber sensor change their values to value one.

Algorithm 2 GAwAR

present WSN
present grid target field
initialize a population of N_p individuals (schedules)
compute fitness function
for i = 1 to G **do**
  for each individual **do**
    create by crossover an offspring from a single parent
    mutate offspring
    compute the fitness function of offspring
    select to a new population the better individual from the parent and its offspring
  end for
end for
The best schedule from the last generation is a solution of the algorithm

Figure 3. Genetic Algorithm with Asexual Reproduction.

V. A Novel Genetic Algorithm with Asexual Reproduction to MLC Problem in WSN

In this section, we propose an Genetic Algorithm with Asexual Reproduction (GAwAR) to solve MLC problem in WSN. Firstly, for a given WSN and grid target field a population of N_p individuals are generated. Solutions are encoded such as described in Section III.A. In evolutionary strategies in each generation an individual of the population produces an offspring by using a crossover operation, further it is mutated and deterministic selection applied to chose individuals for the next generation (see, Algorithm 2 in Figure 3).

A. Representation

Individuals of a population are represented by solutions and encoded as described in Section III.A.

B. Fitness function

Individuals are evaluated according to fitness function introduced in Section II as Lifetime(q) metric (Equation 2).

C. Genetic operators

Genetic operators work in the following way. In GAwAR crossover is a modification of two operators: inver-over and position-based crossover [5] [8] adopted to solve MLC problem. The crossover is executed on each single individual from the population and consists of the following two steps:

- searching pairs of values in the same row in two consecutive US columns, such that the first value of the pair (the value from the first US column) is equal to 0, and the second value of the pair is equal to 1;
- swap these values.

In another words, in the result the first selected column contains "1" in all cells, if at least one of the corresponding

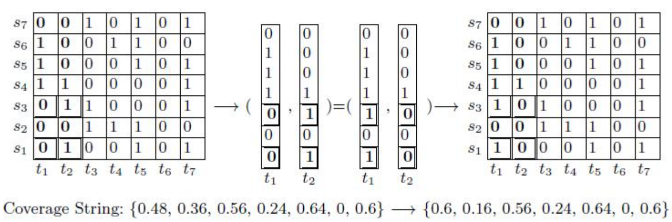


Figure 4. An example of a crossover in GAwAR.

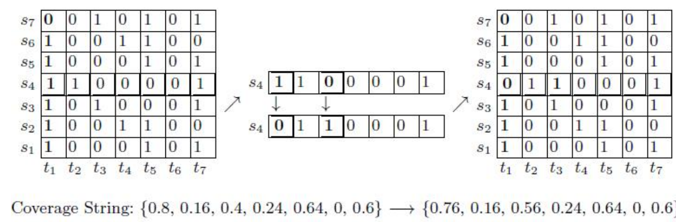


Figure 5. An example of a mutation in GAwAR.

cells has contained ”1”. The second column contains the rest of two values which was not used in the first one.

The aim of crossover is to shift several columns from US toward ES or RS.

An example of an offspring obtained by crossover is outlined in Figure 4. The schedule is constructed for a sensor network depicted in Figure 1 for seven consequtive time intervals. For coverage ratio q equal to 0.6 and coverage declination δ equal to 0.05, US consists of the four elements $\{1, 2, 4, 6\}$. As N_U=4, then the procedure repeats k or no more than 6 times. For instance, the initial schedule involves two columns corresponding to t_1 and t_2 time intervals. In the offspring solution two pairs related to sensors s_1 and s_3 in the two chosen columns change their values. Coverage strings of the parent and its offspring solutions are presented in the figure (left) and (right) respectevely.

The purpose of the crossover operator is to shift several columns from US toward ES or RS. But, during the evolution process, it may happen that, after applying crossover once, the chromosome does not improve its quality. Thus, we apply k-crossover operator, which is equivalent to use crossover k times to columns (1, 2), (1, 3), ..., (1, k+1) respectevely. k-crossover is executed on k pairs of columns from US consequently. In our example, after performing crossover for columns (1, 2) the operator will be continued for columns (1, 4) and (1, 6).

It is worth to notice that in the proposed algorithm crossover operator produces a single offspring from a single parent. This offspring will replace the parent if it is better or the parent will pass to the next generation. Therefore, at the beginning of evolution k is equal to 1. In the next generation k increases by 1 for the individual, if its fitness function value decreases.

Mutation is applied to each individual from the population. Mutation is based on reciprocal exchange of two gene's values in the individual. The first gene is taken from RS column with probability p_i:

$$p_i = \begin{cases} 0, & \text{if the } i-th \text{ gene in the column is equal to 0,} \\ \frac{1}{n_1}, & \text{if the } i-th \text{ gene in the column is equal to 1,} \end{cases}$$

where n_1 is a number ”1” genes in the column. Therefore, the first selected gene is equal to 1. The second mutated gene is taken as the first ”0” gene from US and from the same row as previous gene was. The selected genes swap their values. If there is no a gene with the value ”0” in US, mutation does not make any change in the chromosome.

Therefore, the first selected cell is equal to 1. The second selected cell is taken as the first ”0” cell from US and from the same row as previous cell was. The selected cells swap their values. If there is no a cell with the value ”0” in US, the parent solution coincides with its offspring.

Mutation is applied N_R times, once for each RS column.

An example of mutation is shown in Figure 5. A schedule constructed for a sensor network depicted in Figure 1 for seven consecutive time intervals. For coverage ratio q equal to 0.6 and coverage declination δ equal to 0.05, coverage string as follows $\{0.8, 0.16, 0.4, 0.24, 0.64, 0, 0.6\}$, where RS contains one element t_1. Therefore, mutation is executed once via changing the first column in the schedule. From the t_1 column with equal probabilities p_i = 0.16 for all cells of ”1”s values the one is taken, for an example the 4-th cell was selected. The chosen ”1” cell changes its value into ”0”, while the first ”0” cell of the corresponding row from US (in the picture such cell is from t_3 column) changes its value into opposite one. Coverage of the schedule for the first time interval (from the column t_1) decreases, while the coverage for the t_3 increases. Coverage string of the offspring solution becomes the following: $\{0.76, 0.16, 0.56, 0.24, 0.64, 0, 0.6\}$.

Lastly, deterministic selection is applied, where the best individual from each pair: a parent and its offspring passes to the next generation. These steps are repeated until stop condition is met. The best schedule from the last generation is a result of the algorithm.

VI. Experimental Results

In this section, we present some results of experimental study of the proposed algorithms.

The experimental study was conducted in two steps. Firstly, several experiments were made in order to estimate the best values for parameters of the algorithms. The next step of experiments was to compare these two algorithms with the best parameters sets.

For evaluating the solutions, we rely on our network simulator, written in Java. The experiments were run on standard PC computer with two cores 1.66GHz CPU and 1GB RAM.

 ISBN: 978-1-61208-310-0

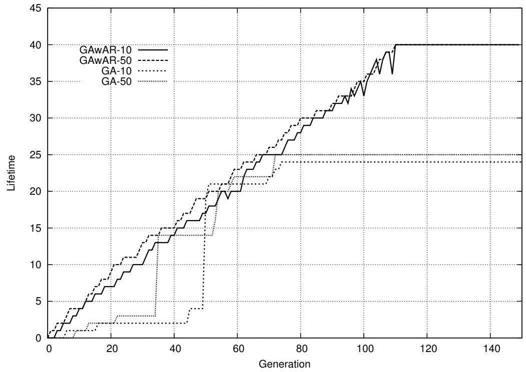


Figure 6. An examplary run for the best solution of algorithms: GAwAR-10, GAwAR-50, GA-10 and GA-50.

Sensors are randomly deployed over the target field F of dimensions $(L \times L)m^2$, where in all experiments we assume $L = 100$. POIs are uniformly distributed over the target field F in every g m, where $g = 20$.

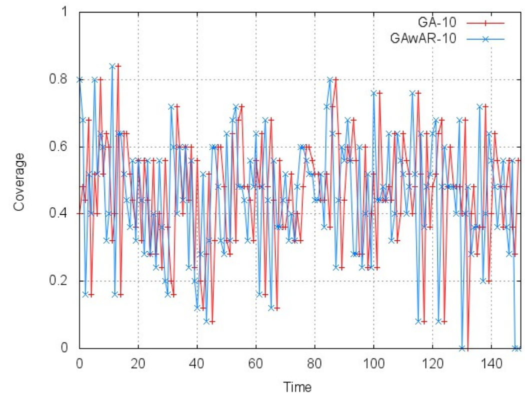
WSN consists of 100 sensors, sensing range R_s is equal to $20m$ and each node has a battery capacity $b = 10$. The size of an schedule solution is equal to $N \times T_{max}$, when $N = 100$ and $T_{max} = 150$. We consider that required coverage ratio is 90%, where q is equal to 0.91 and δ=0.01.

We assume two sizes of a population 10 and 50 individuals for each of considered algorithms, let us called them as GA-10, GA-50, GAwAR-10 and GAwAR-50 respectevely. The rest parameters: elite size is equal to 1, a number of competitors in a tournament m is equal to 2, crossover and mutation probabilities p_c and p_m are equal to 0.06 and 0.01. Evolution process of the algorithms is considered over 150 generations ($G = 150$).

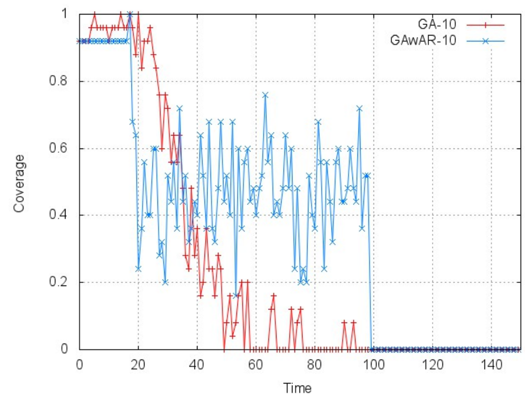
We run 5 times each of these algorithms: for five different randomly created WSN configurations. Exemplary runs with the best result for the first WSN instance of GA-10, GA-50, GAwAR-10 and GAwAR-50 are presented in Figure 6. Figure 7 presents the $CoverageString$ of the best solution obtained by GAwAR-10 and GA-10 for the first WSN instance in first (a), 50 (b), and the last (c) generation. The summarized results are presented in Table I. In the table from the left to right there are maximum, average with standard deviation values of Lifetime(0.9) obtained by each of the algorithms. The values in the two last column outlines a number of times a maximum solution by the algorithm was achieved and its average run time. Bold figures represent the best result for the WSN instance.

VII. Conclusion

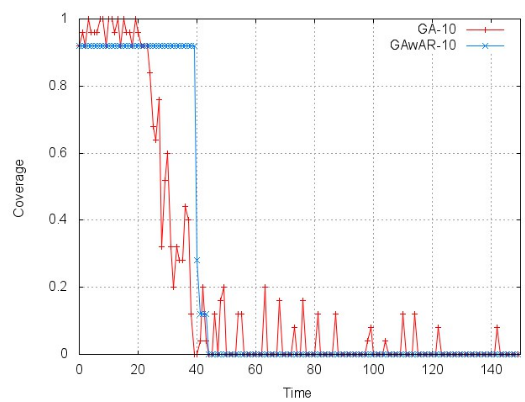
In this paper, we have proposed a novel evolutionary algorithm with asexual reproduction to solve MLC problem. Due to this approach it was possible to incorporate a specific knowledge about the problem into genetic operators of crossover and mutation. The performance of the proposed



(a)



(b)



(c)

Figure 7. CoverageString of the best solution obtained by GAwAR-10 and GA-10 in first (a), 50 (b) and the last (c) generation.

algorithm has been compared with one delivered by a standard GA. The preliminary results of experimental study of both algoritms have shown that the proposed GAwAR algorithm due to special design of its genetic operators significantly outperforms the standard GA-based approach, regarding to lifetime values and runnable time as well. The purpose of current and future studies is a more detailed study

Table I
LIFETIME(0.9): MAXIMAL, AVERAGE WITH STANDARD DEVIATION VALUES OF LIFETIME(0.9) AND NUMBER OF TIMES OF MAXIMUM ACHIEVED FOR GAWAR-10, GAWAR-50, GA-10 AND GA-50.

WSN	Algorithm	Max	Avg $\pm$ σ	Times of Max	T_{exec} [s]
Instance 1	GAwAR-10	**40**	38.8 $\pm$ 0.96	1	**21**
	GAwAR-50	**40**	**39.6 $\pm$ 0.24**	**3**	**111**
	GA-10	24	21.8 $\pm$ 1.46	1	39
	GA-50	25	23.4 $\pm$ 2.24	2	186
Instance 2	GAwAR-10	**33**	32.2 $\pm$ 0.56	2	**22**
	GAwAR-50	**33**	**32.6 $\pm$ 0.24**	**3**	**117**
	GA-10	19	18 $\pm$ 1.2	2	40
	GA-50	20	19 $\pm$ 0.4	1	231
Instance 3	GAwAR-10	**45**	42.8 $\pm$ 1.76	1	**22**
	GAwAR-50	**45**	**44 $\pm$ 0.8**	**2**	**127**
	GA-10	24	22.6 $\pm$ 1.04	1	36
	GA-50	26	23.8 $\pm$ 1.36	1	185
Instance 4	GAwAR-10	38	37.4 $\pm$ **0.24**	**2**	**23**
	GAwAR-50	**39**	**38 $\pm$ 0.4**	1	**122**
	GA-10	22	21.8 $\pm$ 0.16	4	39
	GA-50	23	22.2 $\pm$ 0.56	2	157
Instance 5	GAwAR-10	**55**	**53.2 $\pm$ 0.96**	1	**22**
	GAwAR-50	52	50.8 $\pm$ 0.96	2	**101**
	GA-10	31	29 $\pm$ 2	1	38
	GA-50	33	31.4 $\pm$ 1.04	1	162

of the proposed algorithm and using it for different variants of MLC problem.

ACKNOWLEDGMENT

The authors would like to thank the anonymous reviewers for their constructive comments and suggestions which improved the quality of the presentation.

REFERENCES

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, ”Wireless Sensor Networks: A Survey,” Computer Networks, vol. 38, No. 4, Mar. 2002, pp. 393-422.

[2] C. P. Chen, and et al, ”CoCMA: Energy-efficient coverage control in cluster-based wireless sensor networks using a memetic algorithm,” Sensors, June 2009, pp. 4918-4940.

[3] M. R. Garey and D. S. Johnson, Computers and intractability: a guide to the theory of NP-completeness, W.H. Freeman and Co, 1979.

[4] N. D. Georganas and D. Tian, ”A coverage-preserving node scheduling scheme for large wireless sensor networks,” WSNA ’02 Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications, 2002, pp. 32-41.

[5] D. E. Goldberg, Genetic algorithms in search, optimization, and machine learning, Addison-Wesley Pub,1989.

[6] S. Samarah, A. Boukerche and X. Fei, ”A bio-inspired coverage-aware scheduling scheme for wireless sensor networks,” Proc. IPDPS Workshops, 2010, pp. 1-8.

[7] B. Wang, Coverage Control in Sensor Network, Springer-Verlag, London, 2010.

[8] G. Tao and Z. Michalewicz, Inver-over Operator for the TSP, Proceedings of the 5th Parallel Problem Solving from Nature LNCS, 1998, pp. 803-812.

[9] B. Wang, ”Coverage Problems in Sensor Networks: A Survey,” ACM Comp. Serv., 43, 4, October 2011, pp. 32-85.

[10] A.Tretyakova and F. Seredynski, Application of Evolutionary Algorithms to Maximum Lifetime Coverage Problem in Wireless Sensor Networks, 27 IEEE International Parallel & Distributed Processing Symposium, NIDISC Workshop, Boston, USA, May 2013.

[11] M. Cardei, M. T. Thai, Y. Li, and W. Andwu, Energy-Efficient Target Coverage In Wireless Sensor Networks. In Proceedings of the IEEE Conference on Computer Communications (InfoCom), 2005, pp. 1976-1984.

[12] C. E. Jones, K. M. Sivalingam, P. Agrawal, and J. C. Chen, A survey of energy efficient network protocol(I), Wireless Networks, 7 (2001), pp. 343-358.

[13] J. Kahn, R. H. Katz, and K. Pister, Next Century Challenges: Mobile Networking for Smurt Dust, ACM MOBICOM Conference, Aug. 1999, pp. 271-278.

[14] X. Y. Li, P. J. Wan, and O. Frieder, Coverage in Wireless Ad-hoc Sensor Networks, IEEE Transactions on Computers, Vol 52 (2002), pp. 753-763.

[15] M. Cardei and D. Z. Du, Improving Wireless Sensor Network Lifetime through Power Aware Organization, ACM Wireless Networks, Vol 11, May 2005, No 3, pp. 333-340.

[16] S. Slijepcevic and M. Potkonjak, Power Efficient Organization of Wireless Sensor Networks, IEEE International Conference on Communications, Vol 2, June 2001, pp. 472-476.

[17] S. Mini, K. Siba, K. Udgata, and L. S. Sabat, M-Connected Coverage Problem inWireless Sensor Networks, ISRN Sensor Networks, Vol 2012.

[18] C. Liu and G. Cao, Distributed Critical Location Coverage in Wireless Sensor Networks with Lifetime Constraint, INFOCOM, 2012 Proceedings IEEE, pp. 1314-1322.

[19] L. Ding, W. Wu, J. Willson, L. Wu, Z. Lu, and W. Lee, Constant-Approximation for Target Coverage Problem in Wireless Sensor Networks INFOCOM, 2012 Proceedings IEEE, pp. 1584-1592.

[20] Y. Liu and W. Liang, Prolonging Network Lifetime for Target Coverage in Sensor Networks, Wireless Algorithms, Systems, and Applications LNCS, Vol 5258, 2008, pp. 212-223.

[21] T. Zhao and Q. Zhao, Lifetime Maximization Based on Coverage and Connectivity in Wireless Sensor Networks Journal of Signal Processing Systems, Vol 57, 2009, pp. 385-400.

[22] A. Simões and E. Costa, Using Genetic Algorithms with Sexual or Asexual Transposition: a Comparative Study, Evolutionary Computation, 2000, pp. 1196-1203.

[23] B. Sahoo, V. Ravu, and P. Patel, Observation on using Genetic Algorithm for Extending the Lifetime of Wireless Sensor Networks. IJCA Special Issue on 2nd National Conference-Computing, Communication and Sensor Network (CCSN), 2011, pp. 9-13.

 ISBN: 978-1-61208-310-0

Generating Domain-Restricted Resources for Web Interaction in Several Languages: Hindi, English and Spanish

Marta Gatius, Piyush Paliwal
Department of Computer Science
Technical University of Catalonia
Barcelona, Spain
e-mail:gatius@lsi.upc.edu, piyushpaliwal90@gmail.com

***Abstract*—The aim of our research is to develop domain-restricted resources for web interaction supporting different languages: English, Hindi and Spanish. Many practical natural language systems use linguistic resources adapted to a specific domain because the processing is faster and more robust against errors. Besides, those grammars can be adapted to the language used by different types of users. To facilitate the process of generating linguistic resources for each domain and language, we use ontologies representing the entities and relations in a specific domain. The use of domain ontologies also favors the integration of knowledge from several web sites. For developing the grammar rules for each domain and language, we use Grammar Framework, a powerful tool for writing multilingual grammars that supports several alphabets. Our work is focused on the generation of assisting the user when accessing the web in two different scenarios: searching for information on cultural events and searching for a new medical specialist.**

Keywords-multilingual web interfaces; domain ontologies; semantic grammars.

I. INTRODUCTION

As web is becoming more central to our daily activities, the need of web assistants adaptable to different types of users (different languages, ages, skills, and cultural sensitivity) increases. In this context, conversational systems guiding the user to access web information are becoming a good opportunity to enhance web usability.

The main challenge in conversational systems consists of understanding correctly the user's needs. To solve this problem, most practical conversational systems are adapted to a particular domain, thus limiting possible misunderstandings and errors. However, the cost of building the domain-restricted linguistic resources needed for processing the user interventions is high and they are difficult to adapt to a new domain. There are different approaches to face this problem, all requiring human intervention. Statistical techniques require big corpus, manually tagged. In knowledge-based approaches, conceptual and linguistic resources have to be developed by skilled professionals. Although several of the works on domain adaptation use in-domain training data to reduce the adaptation cost, most of these works are based on the use of domain conceptual models.

There are complex research communication systems that use general grammars to syntactically analyze user interventions and, from the results obtained perform semantic analysis, using conceptual domain-restricted knowledge. However, most practical conversational systems use semantic grammars adapted to a specific domain that perform syntactic and semantic analysis in parallel. The reason is that rules in semantic grammars correspond directly to the domain entities and relations, resulting in faster processing and more robust against errors. Besides, domain-restricted grammars are especially appropriate for multilingual systems because similar processing can be done for each language supported. Although domain-restricted grammars are easier to write and maintain than general grammars, they have to be build for each approach. The use of semantic-domain models may also be used to facilitate this task.

The use of a semantic model representing domain entities facilitates the obtaining of the domain-restricted resources needed for interpreting users needs. Furthermore, the semantic models in multilingual (and multimodal) systems provide a common semantic interpretation for different languages (and modes of interaction).

Domain knowledge can be represented in several semantic formalisms. Most used formalism to represent domain entities are database models, frames and ontologies. Database models are useful in applications using databases or web services and have been used in relevant works, such as the dialogue systems described by Polifroni et al. [1] and D'Haro et al. [2]. Frames and ontologies provide a more flexible way of representing domain concepts and have also been used in many interaction systems.

In ontologies, relations and preconditions between entities are defined, thus providing a richer conceptual representation. For this reason, they are very appropriate for complex systems, providing consistent generic processes, reusable for several domains, such as those described by Nesselrath and Porta [3] and Dzikovska et al. [4].

The use of ontologies also favours integration of knowledge sources of different types. Thus, ontologies are especially appropriate for communication systems integrating different types of knowledge, such as the dialogue system Smartweb (described by Sonntag et al. [5]), supporting several languages and modes of interaction and

 ISBN: 978-1-61208-310-0

the web assistant Active (described by Guzzoni et al. [6]), integrating language and active learning technologies.

Additionally, the organization of knowledge in ontologies in classes/subclasse helps with under/over specification phenomena and other simple inferences that may appear in communication in complex domains, such as the medical domain (as explained by Milward and M. Beveridge [7]).

In this paper, we present our work on the use of ontologies to generate the domain-restricted grammars needed for a web interface system supporting different languages: English, Hindi and Spanish.

This paper is organized as follows. Section II introduces our approach and Section III describes its application to two different scenarios: searching for cultural events and searching for a medical specialist. Conclusions and future work are given in the last section.

II. PROPOSED SOLUTION

The work described in this article is related to previous work on a dialogue system guiding the user when accessing web services, described in [8]. For that system, messages were generated using a general method, defined by J.A. Bateman et al. [9], based on a sintactico-semantic taxonomy that relates concepts and attributes in conceptual ontologies to the linguistic structures needed for their expression in several languages (Spanish, English and Catalan). Using this taxonomy grammars and sentences expressing queries and answers about the values of the conceptual attributes can be automatically generated, although they have to be manually supervised. The resulting sentences have been incorporated in the dialogue system with minor changes, however, the resulting grammars have not, because those grammars only recognized correctly a few sentences.

Manually defined grammars can support many more different forms of expressing domain terms, including abbreviations, mistakes, informal expressions, new terms and other forms difficult to represent in a formally. Besides, they can be adapted considering different types of users, different ages and different expertise levels.

Our current work is focused on the study of an appropriate representation of the conceptual and linguistic knowledge involved in communication to facilitate the manually creation of semantic grammars for new domains, new languages and new types of users. As in several of the works mentioned, we represent the general knowledge involved in several domains in reusable representation bases and the specific knowledge for each domain is incorporated manually. In our proposal, concepts appearing in several domains are represented in general ontologies and the linguistic knowledge associated with it in general grammar rules. Then, adapting the system to a new domain requires building the domain ontologies as well as the grammars rules related to this domain knowledge for each language.

Similar approaches have been followed in complex research dialogue systems supporting rich communication in different types of applications. The main difference is that our work was focused on assisting the user when accessing the web. The language supported by our system is limited to that used by the user when asking for information. Thus, the effort of generating the semantic grammar can be limited if first the user needs and expressions in the particular scenario are studied. Additionally, we have used a multilingual grammar environment, Grammatical Framework (GF), [10] specially appropriate for our approach. In GF grammars are represented in two separated modules: conceptual (abstract grammar) and syntactic (concrete grammar). The abstract grammar captures the semantics to be communicated and can be the same for all languages supported in a particular application. The concrete grammar component relates the abstract syntax to the linear strings representations and it is different for each language. This separation of grammars in two components therefore helps the human experts ease the generation of rules in each of the languages.

Following our proposal, the abstract grammars are defined considering the concepts in the domain ontologies. Then, the related rules in each concrete grammar are defined by the language experts.

The integration of the Hindi language with other languages is also an important difference from previous works on communication systems. Our proposed organization of knowledge in separated conceptual and linguistic knowledge and general and domain-specific has also facilitated work with language with a different organization and a different alphabet.

III. GENERATING DOMAIN-RESTRICTED GRAMMARS

Domain ontologies provide a formal organization of the conceptual knowledge appearing in user intervention when accessing web information in a particular domain. Thus, it can facilitate the integration of domain knowledge that appears in several web sites in different formats and languages. This formal representation of the domain knowledge facilitates the generation of linguistic resources needed for processing the user interventions and generating the system responses. This section describes the use of domain ontologies to generate semantic grammars needed for web interaction in English, Hindi and Spanish. Our proposal is based on a clear separation of general and domain-specific knowledge. General entities common to several domains (such as those related to time and space) are defined in an upper ontology. Grammars rules and vocabulary supporting the expressions related to those general conceptual entities are represented in a general grammar. General grammar also includes rules supporting expressions common to all scenarios (such as those expressing misunderstandings).

For each new scenario, we first study the user needs and the corpus of user's questions, if available. Then, the domain specific entities are described and related to those general entities in the upper ontology. Existing domain ontologies could also be integrated, when needed. For example, in the scenario the user is looking for a specialist an existing ontology describing parts of the body would be incorporated. In the final step, grammars supporting question and descriptions of the concepts in the domain ontologies are developed.

We had studied our proposal in two different scenarios where the user searches for practical information on the web. The first scenario we have studied is that of a user looking for a cultural event in the city. We selected this scenario because we already had previously collected a corpus of user interventions asking for information on cultural events. The second scenario we studied is that of a user searching for a specialist and we did not collect any corpus related to it. Next subsections describe the ontologies and grammars generated for two different scenarios.

A. Building the Domain Ontologies

In the first scenario we studied, the user wants to consult information on the cultural events that take place in the city. We consider the user may ask for information for a specific event (giving its name) or, alternatively, may ask for the events satisfying a specific description. There are many web sites giving information on cultural events. The central concept in those web sites is the same: a cultural event described by a set of attributes. Several of those attributes are the same in most web sites: title, venue, date and time. In some of those web sites additional information could also be given such us participants, price, age.

Figure 1 shows the description of the two entities involve in this scenario: **Event** and **Event-venue**. As can be seen, the concept **Event** is described by the attributes: **name**, **genre**, **at-venue**, **at_day** and **at_hour**. The concept **Event_venue** is described by two attributes: **venue** and **venue_zone**. These two domain concepts are related to the general concepts **Zone** and **Unit_Of_Time**.

In order to support most common user's questions in this domain we have defined the grammar rules supporting the consulting of the attribute values of the two concepts **Event** and **Event_venue**.

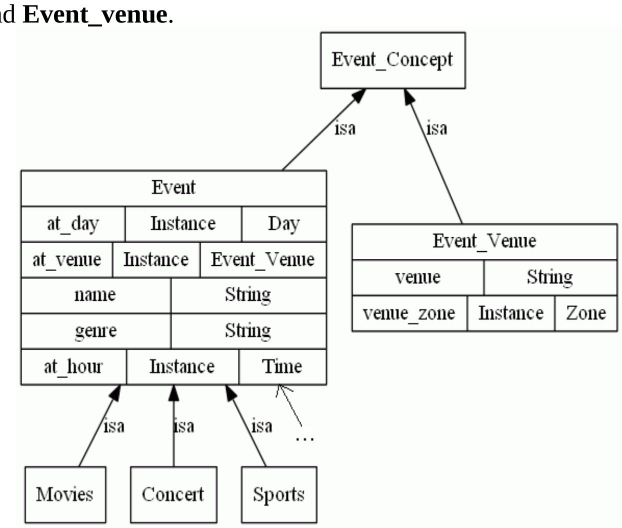


Figure 1. Conceptual knowledge in the Cultural Events domain.

We have considered a second scenario in a different domain: the health domain. In particular, we have considered the scenario in which the user accesses the web for searching information about a new medical specialist. In this scenario, most common user interventions will consist of giving information about his/her disease and asking for information about specialists.

There are different web sites containing practical information about medical specialists (i.e., the place where they visit and their schedule). In most of these web sites medical specializations and diseases are described using medical terms that could prove difficult for not experts. To solve this problem we have developed the semantic grammar needed for processing the questions asked by general public using non medical terms.

Figure 2 shows the concepts involved in the scenario of searching for a specialist. There are three top concepts: **Disease**, **Body_Parts** and **Medical_Resources**.**Medical Resources** is subclassified in three concepts: **Doctor**, **Equipment**, and **Others**. The main concept, **Doctor**, is described by a set of attributes: **name**, **specialist_type treat_of_body_part**, **visit_at_equipment**, **visit_at_day**, **visit_at_hour**. The concept **Body_Parts** has been included because one common way to ask for a specialist consists of giving the common name of the body part where a problem has been detected, as in the example *"I have stomachache, and I need a doctor"*. As shown in the Figure 2, the concepts in this domain have also been related to the general concepts **Zone** and **Unit_of_Time**. From this domain ontology, the abstract grammar is generated.

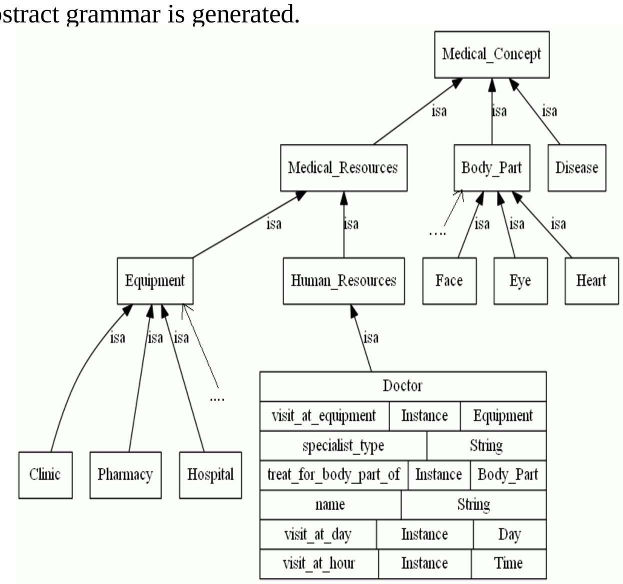


Figure 2. Conceptual knowledge in the health domain.

We have used Protégé, a knowledge-based framework to develop the ontologies.

B. Building the Grammars

As we mentioned in the introduction, we have used GF, an open-source environment for writing grammars in different languages. The main reason for using GF is that it supports languages using different alphabets, including Devanagari. However, because not all computers are configured to support Devanagari, we have also transliterated Hindi grammars to the Latin alphabet.

 ISBN: 978-1-61208-310-0

```
abstract EventDomain = {
flags startcat = Comment;
cat
  Comment; Day; Description; Event; Event_Info; Genre; Venue; Zone;
fun
   userComment : Description -> Comment;
   e_z_d : Event_Info -> Zone -> Day -> Description;
   e_v_d : Event_Info -> Venue -> Day -> Description;
   g_e : Genre -> Event -> Event_Info;
   movie : Event;
   concert : Event;
   sport : Event;
   musical : Genre;
   romantic : Genre;
   orchestic : Genre;
   auditori : Venue;
   city_hall : Venue;
   royal_play_ground : Venue;
   pz_catalunya : Zone;
   sants : Zone;
   friday : Day;
   saturday : Day;
}
```

Figure 3. The abstract grammar for the event domain.

```
concrete EventDomainEng of EventDomain = {
lincat
  Comment = {s : Str};
  Description = {s : Str};
  Event = {s : Str};
  Genre = {s : Str; b : boolean};
  Venue = {s : Str};
  Zone = {s : Str};
  Event_Info = {s : Str};
  Day = {s : Str};
lin
  userComment d = {s = d.s};
  e_z_d event_info zone day = {s = event_info.s ++ variants {"around"; "near"; "close to"}
                                   ++ zone.s ++ "on"++ day.s};
  e_v_d event_info venue day = {s = event_info.s ++ variants {"at"; "in" ++ variants {[];
                                    "the"}} ++ venue.s ++ "on"++day.s};
  g_e genre event = {s = give_info ++ det_a_an genre.b ++ genre.s ++ event.s};
  movie = {s = variants {"film"; "movie"}};
  concert = {s = "concert"};
  sport = {s = "sport"};
  musical = {s = "musical"; b = T};
  romantic = {s = "romantic"; b = T};
  orchestic = {s = "orchestic"; b = F};
  auditori = {s = "auditori"};
  city_hall = {s = "city hall"};
  royal_play_ground = {s = "royal play ground"};
  pz_catalunya = {s = "plaza catalunya"};
  sants = {s = "sants"};
  friday = {s = "friday"};
  saturday = {s = "saturday"};
param
  boolean = T | F;
oper
  give_info = variants {"i am looking for"; "can you find me";
       "i want to see"};
  det_a_an : boolean -> Str = \x -> case x of {
      T => "a";
      F => "an"
     };
}
```

Figure 4. The English concrete grammar for the event domain

```
concrete EventDomainHin of EventDomain = {

lincat
   Comment = {s : Str};
   Description = {s : Str};
   Event = {s : Str};
   Genre = {s : Str};
   Venue = {s : Str};
   Zone = {s : Str};
   Event_Info = {s : Str};
   Day = {s : Str};

lin
   userComment d = {s = d.s};
   e_z_d event_info zone day = {s = event_info.s ++ zone.s ++ "के पास" ++ day.s ++
                    "को" ++ give_info_end};
   e_v_d event_info venue day = {s = event_info.s ++ venue.s ++ ("में"|"पर") ++ day.s ++
                    "को" ++ give_info_end};
   g_e genre event = {s = give_info_start ++ genre.s ++ event.s};
   movie  = {s = variants {"फिल्म"; "चलचित्र"}};
   concert  = {s = "कार्यक्रम"};
   sport  = {s = "खेल"};
   musical  = {s = "संगीतिक"};
   romantic  = {s = "रोमांटिक"};
   orchestic  = {s = "नाटकीय"};
   auditori  = {s = "रंगभवन"};
   city_hall  = {s = "सिटी हॉल"};
   royal_play_ground  = {s = "रॉयल प्ले ग्राउंड"};
   pz_catalunya  = {s = "प्लाजा कातालुन्या"};
   sants  = {s = "संत"};

  friday  = {s = "शुक्रवार"};
  saturday  = {s = "शनिवार"};

oper
  give_info_start  = variants {"मे एक"};
  give_info_end  = variants {"देखना चाहता हु"};

}
```

Figure 5. Hindi concrete grammar for event domain

The use of GF also facilitates multilingual applications because all grammars are divided in two components: the abstract syntax component, a tree-like representation that captures the domain knowledge and the concrete syntax that relates the domain knowledge to the corresponding linear strings. We have defined the abstract syntax component (the same for all languages) using the domain representation in the ontology. Additional information obtained from the collected examples of sentences can also be included. Then, the concrete syntax for each language is obtained from the abstract syntax.

The general mechanism to define the abstract grammar from the ontology consists of representing ontology concepts and attributes appearing in the conversation as categories in the grammar (**cat**) and as the right part of one or more rules **(fun)**. There are two types of rules: syntactical rules (if the right side of the rule has more than one category), and lexical rules (if the right side of the rule has only one category). Instances and values of conceptual attributes were represented as lexical rules while syntact rules represent the combination of concepts appearing in user's interventions.

Figure 3 shows a fragment of the abstract grammar obtained from the ontology representing the cultural events entities. Fragments of the concrete grammars for English and Hindi are represented in Figure 4 and Figure 5, respectively. Notice that, even when the two languages are very different, the concrete grammars in both languages have the same organization because the abstract grammar is the same.

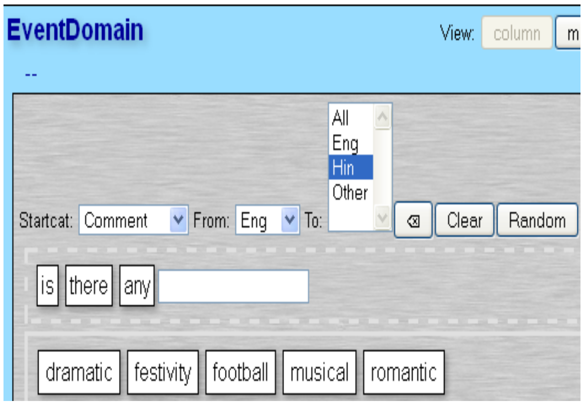


Figure 6. The system guides the user when building the query.

The GF environment supports another interesting functionality for assisting the user where building the query by presenting the next acceptable options on the screen when writing. When using this functionality, the errors when processing user interventions are minimized, resulting in a friendlier communication. Figure 6 shows how this functionality has been used to guide the user when using the grammars we have developed.

IV. CONCLUSION AND FUTURE WORK

In this paper, we describe the generation of domain-restricted grammars for a web interface supporting different languages: English, Hindi and Spanish. To facilitate the process of writing the grammars for different languages, we use domain ontologies. Grammars have been implemented in GF, an open-source environment for multilingual applications. Our work has focused on the language involved when assisting the user when accessing the web in two different scenarios: searching for cultural events and searching for a medical specialist.

The main goal of our work has been to find a general method to facilitate the generation of grammars that are easy to adapt to new languages, new domains and even new users (i.e. young people using informal languages including new words and mistakes).

We have tested the grammars developed by building a toy prototype integrating them, a set of canned system's responses and a small set of databases. Our goal has not been to construct a complete grammar. For this reason, evaluation to study how many sentences can be supported by the grammars has not been done. Instead, we have measured the reusability of grammar components (abstract and concrete rules) across domains and languages, finding high rates of reusability.

Our proposal also includes the semi-automatic generation of system responses by using a syntactic-semantic taxonomy. We have also started working on the adaptation of this taxonomy to the Hindi language, finding it simpler of what we expected. Future work will also include the definition of different types of users for the scenarios considered and the presentation of the results obtained in the most appropriate form for each type of user.

REFERENCES

[1] J. Polifroni, G. Chung and S. Seneff, "Towars the Automatic Generation of Mixed-Initiave Dialogue Systems from Web Contents," Proc. EUROSPEECH, 2003, pp. 193-195.

[2] L.F. D'Haro, R. Córdoba, J. M. Lucas, R. Barra-Chicote, and R. San-Segundo, "Speeding Up the Design of Dialogue Applications by Using Database Contents and Structure Information," Proc. SIGdial, 2009, pp. 160-169.

[3] R. Nesselrath and D. Porta, "Rapid Development of Multimodal Applications with Semantic Models," Proc. IJCAI Workshop on Knowledge and Reasoning in Practical Dialogue Systems, July, 2011, pp. 37-47.

[4] M. Dzikovska, J. F. Allen, and M. Swift, "Finding the balance between generic and domain-specific knowledge: a parser customization strategy," Proc. Workshop on Knowledge and Reasoning in Practical Dialogue Systems, 2003.

[5] D. Sonntag, R. Engel, G. Herzog, A. Pfalzgraf, N. Pfleger, M. Romanelli, and N. Reithinger. "SmartWeb handheld – multimodal interaction with ontological knowledge bases and semantic web services," AI for Human Computing, T.S.Huang et al. (Eds.): LNAI 4451, Springer, 2007, pp. 227-295.

[6] D. Guzzoni, C. Baur, and A. Cheyer, "Active: A unified platform for building intelligent web interaction assistants," Proc. IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology, 2006, pp. 417-420.

[7] D. Milward and M. Beveridge, "Ontology-Based Dialogue Systems," Proc. Knowledge and Reasoning in Practical Dialogue Systems, 2003, pp. 9-18.

[8] M. Gatius and M. Gonzalez,"Using Domain Ontologies for Improving the Adaptability and Collaborative Ability of a Web Dialogue System," International Journal of Computer Information Systems and Industrial Management Applications, V5, 2012, pp. 185-194.

[9] J.A. Bateman, B. Magnini, and F. Rinaldi, "The Generalized {Italian, German, English} Upper Model," Proc. ECAI Workshop on Implemented Ontologies, 1994.

[10] A. Ranta, Grammatical Framework: Programming with Multilingual Grammars, CSLI Publications, Stanford, 2011.

Complex Landscapes of Risk in Operations Systems Aspects of Modelling and Processing

Udo Inden

Cologne University
of Applied Sciences
Cologne, Germany
udo.inden@fh-koeln.de

Despina T. Meridou,
Maria-Eleftheria Ch. Papadopoulou,
Angelos-Christos G. Anadiotis

School of Electrical and Computer Engineering,
National Technical University of Athens
Athens, Greece
{dmeridou, marelpap, aca}@icbnet.ece.ntua.gr

Claus-Peter Rückemann

Leibniz Universität Hannover /
Westfälische Wilhelms-Universität,
Münster, Germany
ruckema@uni-muenster.de

***Abstract*— Large, dynamic landscapes of interdependent risks are potentially existential challenges to industry. Substantiated by an example out of a variety of concrete industrial cases, we discuss in this paper concepts of modelling and managing such landscapes in a new way. The starting-points of the concept are managerial responsibility, the propagation of risk along dependencies in complex operations' systems and resulting impacts, fundamental ambiguities of awareness, events' classification and mitigation of impacts. For solving these problems, we suggest semantic technologies and the programming paradigm of multi-agent systems that for this reason are to be leveraged by effective parallel computing.**

Keywords–Operations' Risk Management; Disambiguation; Semantic Technologies; High-End Computing.

I. INTRODUCTION: COMPLEX LANDSCAPES OF RISK

For the purpose of this paper we shall reduce the scope of *Risk Management* (RM) as it is described in ISO 31000 (2009) to is the task of managing the negative or positive impact of events under uncertainty [17]. The *Event Risk* (ER) is equal to a stochastically or statistically defined probability p, with $0 \leq p \leq 1$, where 1 and 0 represent certainty of occurrence or non-occurrence respectively.

In managerial contexts, the *relevance* of events is equal to its *Economic Expectation Value* (eEV), which is the product of event risk (p), impact (I, a monetary value) and awareness (A): eEV = p*I*A. Impacts may be positive or negative and will be experienced by at least one *victim* or *beneficiary*. We added the parameter of "awareness" to the model because it is an obvious prerequisite of managerial acting. So the awareness of a competitor's attack may be achieved too late. The factor of awareness again depends on factors like implicitness, ambiguity, ignorance, taboos, hubris or *unknown knowables and unknowables* [1] that may antagonize managerial effort. *Risk landscapes* (RL) develop from interacting risks and the value of p may be a function of other incidents: the risk of a denial of service attack depends on the probability to hijack a sufficiently large number of computers. That way, forward chaining of events is represented as risk of transit and negative impacts may be mitigated or eliminated by other events (consider noise cancellation) or meet a well prepared "victim". Accordingly, beneficiaries may not be that impressed by a price.

Time in Figure 1 passes from left to right with cones representing the universe of past and future events. Those to

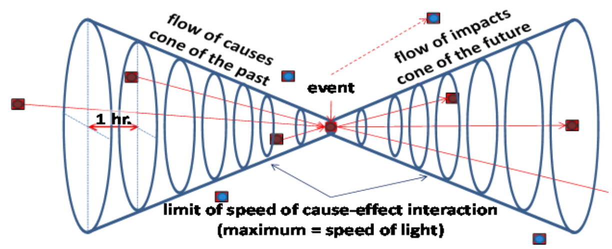


Figure 1. Cone of Cause-Effect Relations and Propagation.

the left are causes and those to the right effects of the one in the centre. Given a maximum speed of propagation events outside delimitations can neither be causes nor effects of the event in the focus. In managerial contexts, except in computer trading [3], propagation is determined by physical or organisational parameters of the system, not at least by the factor of awareness. Further the cause of an event matters. But when the event has arrived immediate managerial action needs to focus on appropriate response. The causes are subject of back-office analysis.

Hence, landscapes of risk are (possibly very large) sets of interacting cause-effect cones with a system-specific behaviour. It is "the set of all (possible) events in the managerial universe" [4]. Complexity emerges from variety and resolution of object and time, the chance that more and more variant objects become source or target of more and more variant events. This reduces the control of a system's behaviour: due to Ashby's Law of Requisite Variety [5], controllers need to dispose of as much Discretion to Act (DTA) as the controlled system – but it should be the right ones.

This paper explains an industrial use-case (Section II), the need and aspects of computing the model (Section III), a semantic model of a risk landscape (Section IV) and concluded by a section on current and future work.

II. THE ARUM SCENARIO

The *ARUM project* [6], a project in the 7th European Research Framework Program, aims at improving ramp-ups of small series of complex products, chiefly in aviation industry. Delays and costs' explosions of the Airbus A380 or Boeing B787 exemplify the problem [7]. Nightmares may develop from a component (e.g., a bracket later used for harnessing) showing a failure that has slipped through previous tests. To avoid "*extrinsic hazards that can result in compromises in the quality of engineering*" [1], production management is obliged to report failures. But only engineering is entitled to ascertain the failure and to decide conditions to continue work. Thus production is interrupted and solutions may change technology needing to revise previous assemblies. So delays may sum up to weeks and costs to Millions of euros.

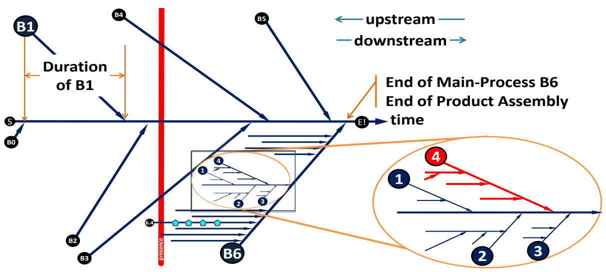


Figure 2. Diagram for Cause-Effect Analysis (fictitious example).

Landscapes of risk develop under such circumstances since at any time a variety of disruptions may occur at any node of operations. In short, the reasons are that competition pushes the technological envelops, that not all detail can be tested or that at some point in time capital intensity and small series enforce the start of production. After that immatureness of technology, resources, suppliers or processes are left to ramp-up management, now required to identify and clear up the nature of the problem, to assess impact, to select or in situ elaborate and to coordinate system-wide *policies* that mitigate impact. But although the defined technological and economical constraints may fail, they provide a reference that, as far as possible, is expected to be recovered. It also is an advantage that most aspects are transformed into monetary values.

The example of the faulty bracket mentioned above may lead to a formal declaration of '*non-conformity to design*' and by this withdraw many brackets of this type from production. If buffers are exhausted, the problem propagates along technical dependencies, the more the longer it takes to solve the problem. Figure 2 shows such dependencies in a *Fishbone Diagram* (a tool of Failure Effect and Mode Analysis [8]) matching the breakdown of work in a production system and relates to its *explosion of the bill of materials*. For this paper a time-line and a red line representing the present are added. The fictitious plant hosts lines B1 – B6, together delivering, e.g., an aircraft. Substructures are indicated for line B6 (bottom right). All assemblies finished in point B6 meet time constraints. The example of line B1 shows the duration of an assembly.

A station manager is expected to know "his" events' cones. So downstream, an NC-event that occurs in station 4 (marked in red) will disable the execution of subsequent work-orders in station 3 and following ones. Besides starting the NC-process, the station manager has only one obligation: mitigating negative impact by implementing a *policy* (pre-structured tactics). In in economic operations, this decision is driven by *economic relevance* (the eEV): Mitigating action is justified by exceeding a threshold of economic impact and policies need to provide adequate positive effect compared to the case of doing nothing.

In the case of the faulty brackets, a policy may be to implement an auxiliary solution, e.g. special cable ties, to be replaced later in time, but now applied in order to avoid far more expensive problems in station 3. However, further events may turn efficient policies into problems and so their effectiveness is to be tracked and changed: e.g., engineering needs more time and the problem propagates more than initially expected and planned. Alternatively, the policy may have to be suspended in order to save time and rework if station 3 is stopped for another reason, while the auxiliary solution is being implemented.

III. Efficient Handling of Landscapes of Risk

A. Managerial Concepts

A variety of use-cases from airports, airlines, inflight catering, large-scale technological ventures, or small series production show that even small operations systems can become very complex and not call for both, significantly improved planning capabilities and augmented awareness of system behaviour and the propagation of impact.

Effective policies are outcomes of operations' intelligence and deep knowledge about operations' behaviour like indicators of sensitivity or criticality. Policies may be an idea of proficient workers, step by step building a library of policies. Some are limited to a station or to a set of proceedings agreed between neighbour stations, others may refer to the main process or the whole factory. To ease rework policies may be considered in the design of the product. Some are documented or even certified, others may be used more informally.

In the simplest case an RL connects work-stations by sequential technical dependencies as indicated in Figure 2. But not all stations may be directly connected. A little more complicated model is shown in the Pert diagram [9] in Figure 3: a failure in station 6 may affect station 7 by stopping work in station 8 and shared resources may open another path of propagation.

Unplanned events with a serious impact switch the mode operations management from 'maintain standard operations' into 'manage an exception' with objectives different from standard proceedings. The background lies in the arguments of the formula eEV = p*I*A: If a substantial economic expectation value would have been identified already in planning, a proficient management would have planned for that contingency. If p or I are underestimated it arrives as unplanned event, and if A is (close to) 0 the event belongs to the class of *unknown knowables* [1].

While contingency buffers enable standard processes to breath, policies are temporarily implemented processes that exchange failing standard processes with the objective to recover (possibly improved) standard operations as soon as possible. Therefore the lifetime of policies is either limited to the time it needs to find and implement a solution recovering the initial or, if need be, a new standard or until a new event requires to change the policy.

ISBN: 978-1-61208-310-0

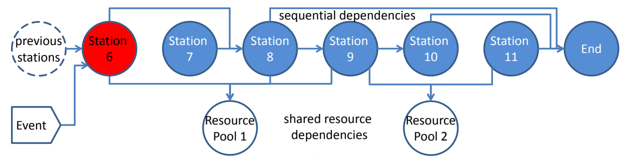


Figure 3. Pert-diagram of dependencies in Figure 2.

A policy has the planned impact to reduce a downside or to save an upside of the related unplanned event, both calculated from the eEV of the triggering event with p=1 and A=1 but still with an impact to be validated. As in real world the evaluation follows the way of propagation and, therefore, is calculated by the target stations until propagation is stopped. Considering first-level effects only, the impact of an unplanned event in station 6 in Figure 3 is equal to the sum of impacts in stations 7 to 11 and in the pools of resources (e.g., in terms of idleness).

As a process a policy employs resources and has costs. These resources may be (a) implemental ones like cable-ties that temporarily replace proper brackets for cables, or (b) contingency buffers that may even have been allocated to another purpose. The management of policies may use any discretion to act (DTA): In the cable-ties' example the chance to reduce rework was introduced as consequence of the actually negative event of failing operations in Station 3. In this way DTA belong to the 'fabric' of policies.

So the industrial cases have common demands: (a) to provide technology that supports back- and the front-office analysis and planning, and (b) to provide simulation-based training of managerial awareness of events.

With regard to the need for effective reasoning about the ambiguity of events, impacts and finally the value of policies, semantic technologies constitute the most promising approach and the integration of case-based, process-based and ontology-based reasoning. It should be noted that this concerns borders between conceptualisation strategies based on the (today most popular) root-concept of things on one side and on the root-concept of "process" (change) on the other side [13].

B. *Draft of a Multi-Agent Approach of Handling RLs*

Agent-based modelling and simulation (ABMS) provides means to handle RLs with thousands of geographically or organisationally distributed nodes. In the example, each node of the landscape, e.g., a work-station and its share in the work breakdown (fishbones in Figure 2 and resources assigned to it), pools of workers, inventories of resources etc. can be represented by one agent, or, if a deeper resolution of the network is required, further agents may represent elements of their substructures.

The choice of algorithms coding the behaviour of agents belongs to the core aspect of modelling. Examples are algorithms to check eligibility of resources to serve in a particular process (workers, tools or components need specified skills) or economic algorithms to minimize idle times. Methods will also control the behaviour of agents depending on constraints: e.g., agents of components of the product may be passive in a phase of transfer as one of many shipments (transport) or as one of many stock keeping units (storage) that temporarily are represented by one agent.

The impact of events and related activity is driven by communications between agents: affected by a statement of non-conformity (setting value of the attribute "eligible for" to zero) the withdrawal of respective resource(s) will cause a missing-resource event in the respective process, start evaluation of impact and activate mitigating action and respective implemental resources. The value of risk in this context may be defined by the responsible managers or calculated on the base of simulations and statistics.

But, also human factors and the variety or context sensitivity of latency times of organisations (slow decision procedures) or of IT-systems or material resources are to be modelled because each may substantially contribute to problems in synchronising activities and to disambiguate the character and control the impact of events.

The computational support of managing complex RLs calls for High-end or High-performance capacity, while however current multi-agent systems (MAS) are hardly designed for running under the conditions of present HPC/HEC environments and implementations, that again are less economic for applications imposing the burden of a high load of communication that is typical for MAS.

Technology arranging architecture and operations systems that provide high computational power and architectures of applications allowing high granularity and high adaptiveness to events are described in [14]: an example is the Repast HPC tool [16], offering both an editor for designing a multi-agent system and a platform organising and synchronizing interactions of agents in a way that is compatible to HEC/HPC environments.

To estimate the computational scale of simulating an RL, similarities to existing HEC applications deliver an idea: an architecture of a weather model with a number of interdependent geographic cells may compare to a network of interdependent cells of managerial responsibility (e.g., in a factory).

While the number of cells of the latter may be smaller, the variety of interactions is noticeably higher. And while weather models have clear inputs like temperature or humidity, managerial models may have to deal with the question "Is it the problem about humidity?". The phenomenon of immediate impact of human behaviour (awareness) implies that the disambiguation of events, of propagation, of building of patterns is not an input but an expected output of computing.

IV. A Semantic Model of Exception Management

A. *The Role of Ontologies in Operations' Risk Management*

Ontology is a formal specification of shared concepts within a domain and the relationships between those concepts and is used to improve communication between human beings and computers. With ontologies, a vocabulary capturing concepts that underlie knowledge of a specific domain can be defined [13]. For example, an ontology of a manufacturing domain would capture concepts describing seman-

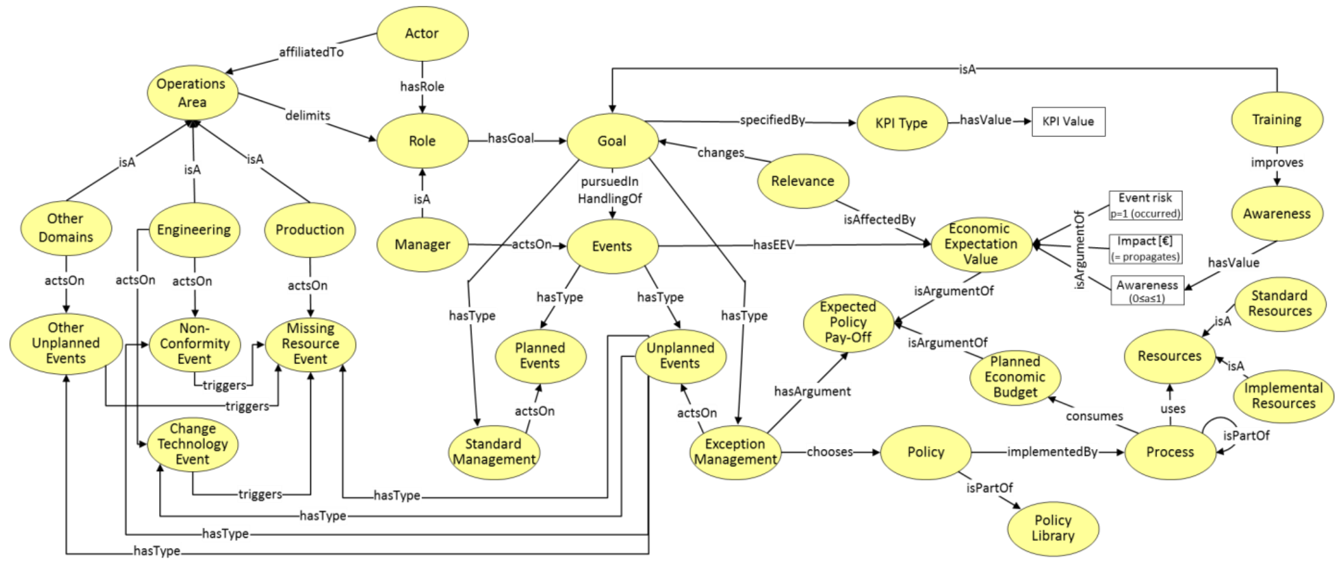


Figure 4. Ontology of Exception Management.

tically the existing production processes, the resources that are required for or the goals that need to be achieved by these processes. A risk exception management ontology, as the one presented in the lower section, should include the basic concepts of an unplanned event, the impact and risk values of this event, the management processes and policies applied in case of an exception, etc.

A major advantage offered by ontologies is the act of *Reasoning* or *Inference*. Reasoning is the process of deriving facts that are not explicitly stated in an ontology [14]. The process of inference can be achieved with a piece of software known as *Semantic Reasoner*. In the context of the RL of a factory, reasoning can be applied in order to identify the most appropriate policy to mitigate the impact of a negative unplanned event or to take advantage from the impact of a positive event that may follow a negative event. The reasoner should take into consideration the parameters of the context of the unplanned event, which include but are not limited to details of the work-order, the resources utilised during the process the event was raised, any other event that has preceded and the policies, if any, that were applied in order to mitigate the impact of this event.

Based on knowledge offered by the ontology, the need for the specification of a new policy, the application of an already existing one or even the re-evaluation of an already applied policy can be derived through the process of inference. In this manner, the semantic representation of policies in combination with the adoption of logic inference facilitates the control of a complex system, such as a manufacturing system, autonomously, thus, reducing human error.

Furthermore, a well-defined ontology can be used in combination with ontologies of different domains, providing the opportunity to build large-scale ontologies covering the concepts and the relations among them in a broader context. For example, in the semantic model presented in the lower section, the concept of time is planned to be expressed by means of a Time Ontology. Knowledge related to the engineering domain is planned to be modelled in an Engineering Ontology. Additionally, a unified ontology, providing a shared and reusable vocabulary, can be effectively used to govern the operational behaviour of multi-agent systems, where agents operate using knowledge from different domains. To sum up, the benefit of a unified semantic model is its flexibility, providing effective handling of heterogeneities, as well as its extensibility for additional semantic information, maintaining the Integrity of the Specifications

B. *Ontological Model of Exception Management*

In order to capture the aforementioned concepts, the ontological model shown in Figure 4 was created. When an event is raised, an instance of the *Event* class is created being either a *Planned Event* or an *Unplanned Event*. Each is associated with an *Economic Expectation Value*, which is formed by the *Event Risk* value, the *Impact* value and the *Awareness* value of the respective event. The latter may be improved by *Training*, which is a type of *Goal*. A *Goal* is assigned to a *Role* or a set of *Roles*, implemented by an *Actor*. Generally, a *Goal* is specified by a *KPI (Key Performance Indicator) Type*, which may be quantitative or qualitative, and is associated with a *KPI Value*. It is pursued within events handling by the responsible *Manager* and may be modified by *Relevance* of events due to the *Economic Expectation Value*.

Usually, a *Goal* may be either of type *Standard Management*, denoting an everyday production goal related to *Planned Events* handling, or *Exception Management*, representing the goal of dealing with an exception, referring to an *Unplanned Event*. Specifically, the *Exception Management* process, which may consist of one or more sub-processes, is responsible for choosing the appropriate *Policy*. A *Policy* may be explicitly elaborated and filed into a *Policy Library*. Implicit *Policies* are implemented during the exception handling process, in order to provide an intermediate solution

 ISBN: 978-1-61208-310-0

by reducing the impact of the unplanned event's propagation and mitigating the impact of waiting time, during which it is necessary to find and implement an enduring solution.

Furthermore, each *Policy* is implemented by a *Process*, which uses *Resources* that may be either *Standard*, i.e., resources that are used by default according to the type of the production process, or *Implemental*, *i*.e., complementary resources that are not included in the work-order but it is known that they are able to substitute the resource in question. The aforementioned process consumes the *Planned Economic Budget*, which is an argument of the *Expected Policy Pay-Off*, taking also into account the *Economic Expectation Value* of the unplanned event. Note that the eEV now is determined by the value of expected propagation, only because the event has occurred so that p=1 and since the work on finding a policy implies that awareness has the value a=1.

Additionally, an appropriate type of the *Operations Area* performs a number of actions on different types of events. To be more specific, the *Production* department is responsible for the *Missing Resource Events* handling and the *Engineering* department for either *Non-Conformity Events* or *Change Technology Events*. *Other Domains* of a manufacturing company have responsibility for decision-making in the context of *Other Unplanned Events*. All of these events are types of *Unplanned Events*. Irrespective of the reason, a *Missing Resource Event* is raised when a required resource is not available in planning of production or in life production. It may be triggered by a *Non-Conformity Event*, a *Change-Technology Event* or an *Other Unplanned Event*, referring to sources that are not explicitly elaborated in the model.

A *Non-Conformity (NC) Event* may lead to a *Missing Resource Event*, since at the moment a product is declared "non-conformant", it is no longer available for use during production processes. An *NC Event* is considered to have ended when the final solution has been applied, since any intermediate solution can only mitigate the propagation of the event. A *Technology Change Event*, which may also trigger a *Missing Resource Event*, implies that a change of the used technology has been defined by an engineer and has to be implemented in the production line. In addition, each *Operations Area* specifies the responsibility of a *Role*, which may reflect the right or the obligation an actor with a specific role may have to act or decide.

V. HEC AND HPC SUPPORT

With many modern and often dynamical and interactive application scenarios, the term "high performance" is covering demanding applications that are on the one hand compute- and on the other hand data-centric. It is a common understanding that parts of the respective scenarios will support the exploitation of parallelism for their implementation.

High End Computing (HEC) systems can range from a desktop computer, through clusters of servers and data centres up to high-end custom supercomputers. Resources can be physically close to each other, e.g., in a highly performant compute cluster, or the compute power can be distributed on a large number of computers as with most Grid and Cloud computing concepts. Mostly, these architectures are used for task-parallel problems in classical capacity computing.

High Performance Computing (HPC) systems are based on architectures with a large number of processors, for exploiting massive parallelism. Commonly used models are Massively Parallel Processing and Symmetric Multi-Processing, used with the concept of local islands. Due to physically shared memory usage and compute communication, the physical architectures with these HPC systems are different.

Handling of RM processes will therefore focus on distributed components. Due to the physically different structure of highly distributed and massively parallel resources, the following aspects can be considered.

In the case of HEC, e.g., Cloud Computing, these components can be system resources acting autonomously like servers, being connected by external network means, being the ideal resources for events processing at capacity level. HEC resources can provide efficient means for massively distributed tasks. The non-availability of resources can be handled on a job or task base.

In the case of HPC, e.g., common with Scientific Computing on Supercomputing resources, the components can be internal network resources only, compute nodes on the one hand, being controlled by a management network and software, and management nodes on the other hand. The communication intensive modelling especially for the overall results and visualisation as well as the pre- and post-processing for the models will be suitable for use of HPC resources. In order to optimise the efficiency and economic use of the HPC resources and minimising the effects of job size fragmentation these resources should be used for a defined class of suitable large tasks within the workflow. Available resources can be configured as distributed HPC resources within the network provided for the described systems. Software Defined Networks (SDN) can provide modular solutions for this purpose.

VI. DISCUSSION

On corporate level risk is addressed by Enterprise Risk Management providing the integrating structure of strategies and proceedings as approached by actuarial sciences addressing both risk in terms of insurance business and of real industry with a comparing idea. "A major challenge here is a more substantial and realistic description and modeling of the various complex dependence structures between risks showing up on all scales" [15]. To our research, related work focuses on stochastic models not addressing the ambiguity of scenes and therefore neither takes a semantic approach nor is able of discrete, event-driven simulation or control. Although our work is still in a very early stadium, the industrial use-cases provide confidence that the particular computational approach discussed above at least will add a promising strategy to risk management in real economy under exceptional circumstances.Conclusion and Future Work

For operation and management, it has shown appropriate to focus on the RM concept and service levels [11] [12]. Therefore, MR or CT Events and related processes can be

 ISBN: 978-1-61208-310-0

handled with less interference if services are defined and interfaces for the processes are created. This is especially important for the HEC, HPC, and communication resources required. For the HEC processes, this can be done on a service level Cloud base, whereas for the HPC resources available in research environments, this mostly will have to be assisted by service level agreement policies.

In both fields of semantic modelling and computation of industrial landscapes of risk, further work is to be done. One issue is that hybrid models require the integration of semantic conceptualisation with the mathematics of the neo-Bayesian school of probability [15]that significantly goes beyond the eEV-model used in this paper. Another aspect is that the relation between ontological and process-based reasoning (things and flows) may have to be revised [9].

ACKNOWLEDGMENTS

This work is partially supported by the EU FP7 Programme, in the frame of the ARUM project, Grant Agreement No. 31405.

REFERENCES

[1] R. Bea, "Approaches to achieve adequate quality and reliability," Technical report, University of California, Berkeley, 2006, [Online], http://ccrm.berkeley.edu/pdfs_papers/bea_pdfs/quality-and-reliability.pdf, [accessed: August, 2013].

[2] J. D. Norton, "Spacetime," [Online], http://www.pitt.edu/~jdnorton/teaching/HPS_0410/chapters/spacetime/, [accessed: August, 2013].

[3] N. Baumann, "Too fast to fail: is High-Speed Trading the next Wall Street disaster?," [Online], http://www.motherjones.com/politics/2013/02/high-frequency-trading-danger-risk-wall-street, [accessed: June, 2013].

[4] R. Sagaldo, "Events and Spacetime," [Online], http://www.phy.syr.edu/courses/modules/LIGHTCONE/events.html, [accessed: March, 2013].

[5] W. R. Ashby, "An introduction to Cybernetics," Chapman & Hall Ltd. London, pp. 206–212.

[6] ARUM: Adaptive production management, [Online]. http://www.arum-project.eu/, [accessed: August, 2013].

[7] U. Inden, N. Mehandjiev, L. Mönch, and P. Vrba, "Towards an Ontology for Small Series Production," Industrial Applications of Holonic and Multi-Agent Systems, Lecture Notes in Computer Science, Springer Berlin Heidelberg, 2013, pp 128-139, doi: 10.1007/978-3-642-40090-2_12.

[8] K. Ishikawa, "Introduction to Quality Control," 3A Corporation, 1990, ISBN: 4-906224-61-X.

[9] J. A. Rooke, L. Koskela, and D. Seymour, "Producing things or production flows? Ontological assumptions in the thinking of managers and professionals in construction," Construction Management and Economics, 25 (10), pp. 1077-1085.

[10] P. Leitão, U. Inden, and C.-P. Rückemann, "Parallelizing Multi-gent Systems for High Performance Computing," Proceedings of the International Conference on Advanced Communications and Computation (INFOCOMP 2013), November 17-22, Lisbon, Portugal, XPS Press, ISSN: 2308-3484, ISBN: 978-1-61208-310-0 (to appear).

[11] C.-P. Rückemann, "Enabling Dynamical Use of Integrated Systems and Scientific Supercomputing Resources for Archaeological Information Systems," Proceedings of the International Conference on Advanced Communications and Computation (INFOCOMP 2012), October 2012, Venice, Italy, XPS Press, pp. 36-41, ISBN:978-1-61208-226-4.

[12] C.-P. Rückemann, "Queueing Aspects of Integrated Information and Computing Systems in Geosciences and Natural Sciences," Advances in Data, Methods, Models and Their Applications in Geoscience, InTech, 2011, Chapter 1, pp. 1-26, ISBN-13: 978-953-307-737-6, doi:10.5772/29337.

[13] B. Chandrasekaran, J. R. Josephson, and V. R. Benjamins, "What are ontologies, and why do we need them?," Intelligent Systems and their Applications, IEEE, vol.14, no.1, Jan/Feb 1999, pp. 20-26, doi:10.1109/5254.747902.

[14] M. Obitko, "Translations between Ontologies in Multi-Agent Systems," Dissertation thesis, Department of Cybernetics, Czech Technical University, Prague, 2007.

[15] J. Neslehová and D. Pfeifer, "Modeling and generating dependent risk processes for IRM and DFA," Astin Bulletin, vol. 34, no. 2, 2004, pp. 333-360, doi:10.2143/AST.34.2.505147.

[16] N. Collier and M. North, "Repast HPC: A Platform for Large-scale Agent-based Modeling", Large-Scale Computing Techniques for Complex System Simulations, W. Dubitzky, K. Kurowski, and B. Schott (eds.), Wiley, 2011, pp. 81-110.

[17] ISO 31000:2009, Risk management -- Principles and guidelines, [Online], http://www.iso.org/iso/catalogue_detail?csnumber=43170, [accessed March, 2013]

GIS-based Hydrogeological Database and Analysis Tools

Violeta Velasco, Enric Vázquez-Suñè, Rotman Criollo
Mar Alcaraz, Alejandro Serrano, Alejandro García
Institute of Environmental Assessment and Water Research (IDAEA), CSIC,
Barcelona, Spain
violeta.velasco@upc.edu
enric.vazquez@idaea.csic.es

Isabel Tubau
Institut Geològic de Catalunya (IGC)
Barcelona, Spain
isabeltubau@hotmail.com
Radu Gogu and Dragos Gaitanaru
Technical University of Civil Engineering (UTCB)
Bucarest, Romania
radu.gogu@utcb.ro

***Abstract*—A software platform was developed to facilitate the development of 3D hydrogeological models. It is composed of a hydrogeological geospatial database and several sets of tools developed in a GIS environment. The geospatial database is used for the management of a great amount of different data types coming from different sources (geophysical, geological, hydrogeologicals, hydrological and others). The instruments enable us to create 3D geological models and allow further hydrogeological analysis. This platform offers interoperability with other external platforms.**

Keywords;GIS, geospatial database, groundwater

I. INTRODUCTION

Groundwater represents an important source of water; therefore, evaluating and predicting its availability and accessibility is one of the main tasks in Integrated Water Resources Management (IWRM) [2]. In an IWRM framework, the development of hydrogeological models is required in order to predict the impact of different land and water management. Moreover, all data required in modeling should be easily accessible to decision makers and modelers [3].

Models are a representation of the reality [6], but reality is elusive. A comprehensive hydrogeological model must use all kinds of information available such as geological, hydrometeorological, geographical, hydrochemical, hydrogeological and environmental information among other. Each aforementioned field complements the interpretation of the rest of the fields. For instance, a proper hydrochemical analysis allows us to reinterpret the geology, or a comprehensive geological analysis enables us to perform a proper hydraulic parameterization that can be complemented with pumping or tracer tests.

In practice, this interpretation task may face several difficulties: i) managing and integrating this vast amount of time and spatial data collected from diverse source and gathered in different formats [5], [25] and ii) the existence of gaps between data collection and modeling due to the necessity of a seamless integration between databases with raw data, databases with models data and models [19]. Moreover, the scarcity of comprehensive tools for the management of spatial-temporal dependent hydrogeological data, including all the information required for a wide range of groundwater modeling platforms (e.g. hydrochemical, geological and flow modeling) further complicates their interpretation.

Most common in practice software dealing with hydrogeological data are specifically designed to manage or interpret separately the different aspects involved in a groundwater analysis. For instance, GOCAD [12] is mainly used for 3D geological modeling whereas a comprehensive hydrochemical analysis can be performed by using AQUACHEM [1]. Other hydrogeological analysis such as aquifer tests interpretations can be easily managed using EPHEBO [9].

Geographical Information Systems (GIS) may serve as an efficient tool for interpreting and analyzing groundwater data [21], joining most of the aforementioned aspects in a single platform. However, some procedures are still missing refinements (e.g. detailed geological analysis, specific hydraulic tests management …).

In this context, a GIS-based platform has been developed. It is composed of a geospatial database and a set of toolbox that arranges all the available data into a coherent structure and provides support for its proper management, analysis and interpretation. Furthermore, it facilitates the pre- and post-processing of the hydrogeological data for modeling.

The presented work forms part of a wider on-going framework for the facilitation of detailed hydrogeological modeling that includes further hydrochemical and geological GIS–based analysis tools. These tools are described in [23] and [24]. Here, we describe new details of the hydrogeological database regarding to other hydrogeological data (e.g. heads measurements, hydraulic tests) and the innovative analysis tools orientated to the visualization and retrieval of these data.

These technologies were applied to some studies such as the metropolitan area of Barcelona (Spain) (e.g. [22]) and the urban area of Bucharest (Romania) (e.g. [14]).

The organization of the paper is as follows: First, Section II presents the design and functionalities of the geospatial database (subparagraph A) and the instruments developed in the GIS environment (subparagraph B). The main conclusions arising from the application of the software are presented in Section III.

II. GIS-BASED HYDROGEOLOGICAL PLATFORM

This software platform was designed taking into account the different tools and methodologies that the water managers use to evaluate, integrate and analyze the wide range of information for the construction of a hydrogeological model. Consequently, the following requirements were adopted during the design of the software platform: (1) A geospatial database with appropriate data store and management (HYDOR), (2) Data processing and analysis tools of geological and hydrogeological analysis in a GIS environment, (3) Interaction with external software for further analysis and (4) Post-processing.

A. The hydrogeological Geospatial database (HYDOR)

The geospatial database represents geospatial information based on the Personal Geodatabase structure provided by the ArcGIS (ESRI) concept. Its structure facilitates: 1) data standardization and harmonization; 2) the storage and management of large amount of spatial features and time-dependent data; and 3) the creation and the execution of simple queries.

In order to ensure the standardization and harmonization of the data, several libraries (e.g. list of lithology, type of wells) were created, taking into account standard guidelines (e.g. INSPIRE [15]). Additionally, schemas of some features have been directly imported from others sources such as O&M [16], OGCWaterM.L2.0 [17] or WFD [11] to assure correct future data exchanges.

The main components include geographical (e.g. Digital Terrain Model) , hydrological (e.g. river, lakes, wetlands), environmental (e.g. vulnerable or protected areas, soil uses), geological (e.g., boreholes lithological description, stratigraphic units, depth to bedrock), geotechnical (e.g. laboratory tests) , hydrochemical (physic-chemical parameters), hydrogeological (e.g. well descriptions, head measurements, extraction measurements), data coming from field tests such pumping tests, tracer tests or other in situ tests (CPT, diagraphy) and administrative features (e.g. water directives, entities).

The data derived from interpretation and modeling efforts are stored separately, thus allowing further interpretation.

A sketch of some of the components related to hydrogeological points of measurements and hydraulic field tests are shown in Figure 1.

B. GIS-based tools

The set of analysis tools were developed as an extension of ArcMap environment (ArcGIS; ESRI) [10]. They were created with ArcObjects, which is a developer kit for ArcGIS, based on Component Object Model (COM), and programmed in Visual Basic using the Visual Studio (Microsoft) environment.

They have been set up to manage, visualize, analyze and interpret the data stored in the spatial database. This set of tools is separated in three main modules represented by different toolbar termed HEROS, QUIMET and HYYH.

The first module (HEROS) allows the user to exploit the geological data stored and to facilitate the geological interpretation. Detailed stratigraphic columns of the selected boreholes can be generated using customized queries. Creating automatically a geological profile is further possible by displaying the boreholes lithological columns and the geophysical and geotechnical field-tests' results together with the defined stratigraphic units. Based on an interactive analysis environment, the user is able to analyze and to define the possible existing correlation surfaces, units, and faults. The obtained information represented by the geological units can be then converted within a 3D environment. Finally, employing the resulting geological model in support of the hydraulic parameterization for hydrogeological modeling is also possible (for further information see [23]).

The second module (QUIMET) is composed of a set of instruments for analysis that cover a wide range of methodologies for querying, interpreting and comparing groundwater quality parameters. They include, among others, chemical time-series analysis, ionic balance calculations, correlation of chemical parameters, and calculation of various common hydrogeochemical diagrams (e.g. Schöeller-Berkaloff, Piper, and Stiff). The GIS platform allows the generation of maps of the spatial distribution of several hydrogeochemical parameters and of the aforementioned specific hydrogeochemical diagrams. Moreover, it is also possible to perform a complete statistical analysis of the data including descriptive statistic univariate and bivariate analysis, the generation of correlation matrices of several components, calculation of correlation graphics, and so on [24].

The last module (HYYH) has been designed to analyze and visualize different hydrogeological measurements and hydraulic field tests results (see Fig 2).

Contour maps and further spatial operations of the depth or thickness of the aquifers could be generated using customized queries. Likewise piezometric maps can be created for the selected points and for the selected period of time with another command included in this toolbar.

Finally, multi-criteria query forms enable the user to analyze and visualize different data and interpretations derived from pumping and tracer tests.

All the results obtained by using the aforementioned toolbars can be further analyzed using other inbuilt tools of ArcGIS, such as the Geostatistical Analysis toolbox or Spatial Analysis Tools.

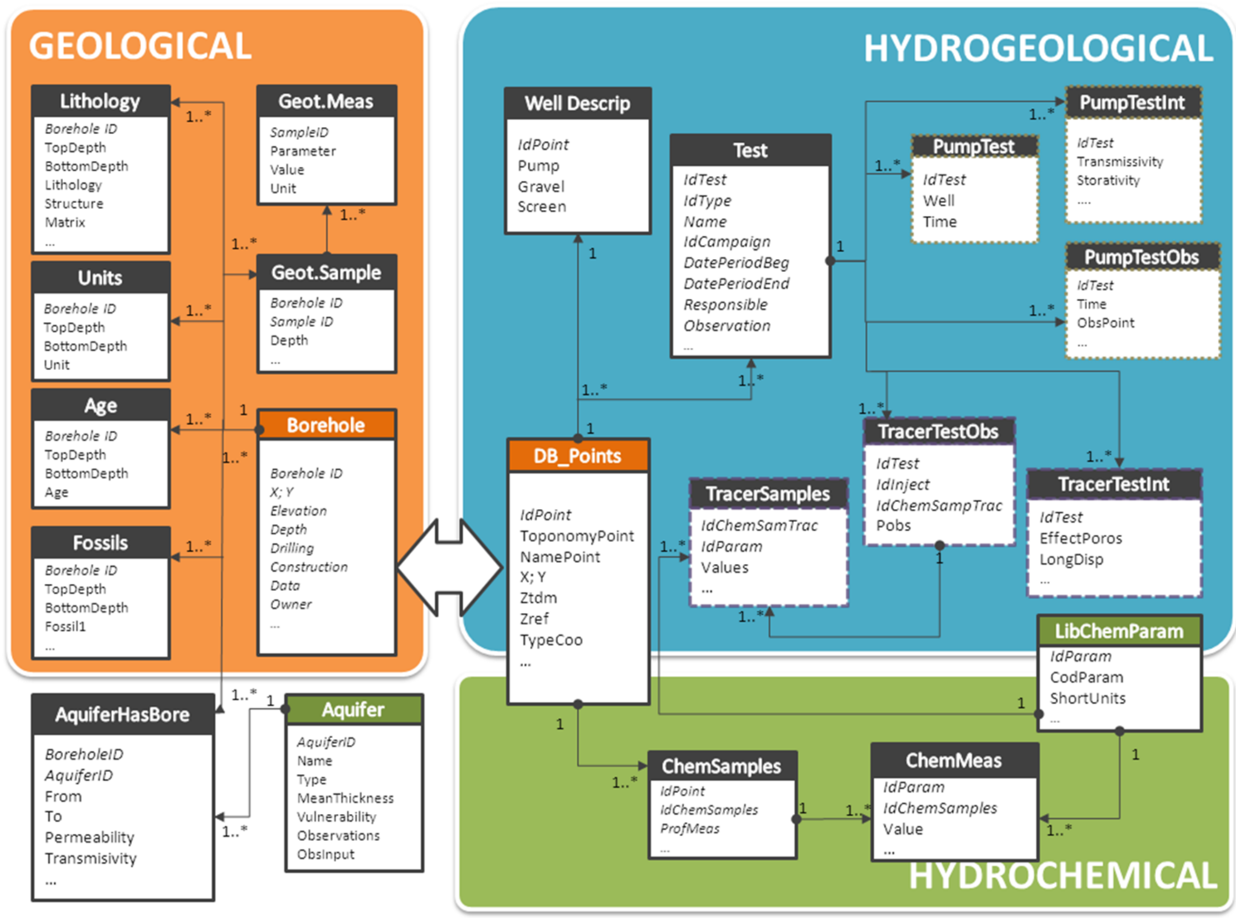


Figure 1: Simplified conceptual diagram representing the main contents in the hydrogeological database. The 1 and 1*.. represents the cardinality of the relationship between tables (further information of the database can be seen in [23]and [24]).

This software platform offers interoperability with external software for further analysis of the hydrogeological data, such as Hydrochemical modeling packages (e.g. EASYQUIM ; [8] and MIX; [4]), or codes designed to facilitate the hydraulic test interpretation (e.g. EPHEBO).Thus, the user pre-process the required spatial-temporal data in the same GIS environment and through the use of the export commands integrated in the different toolbars aforementioned, the results are transferred automatically through input/output predefined files.

III. CONCLUSION

The GIS-base software platform presented in this paper offers a user friendly GIS environment with a large variety of automatic tools developed specifically for the management and analysis of hydrogeological data to facilitate their integration and interpretation.

Despite the complexity of the internal structure of the database, the consultation and the introduction of the data is simple using the different query forms and instruments.

This software platform enables us to set up an updatable model database for further interpretations. Thus, each model study does not have to start from scratch.

The tools developed add a spatio-temporal analysis required to complete the analysis to other external platforms such as EASYQUIM or MIX. Moreover, with adequate adjustments this software platform could be readily linked to other programs such as PHREEQC [18], SGeMs [20], MODFLOW, and EASYBAL [7] considerably increasing the variety of hydrogeological calculations.

 ISBN: 978-1-61208-310-0

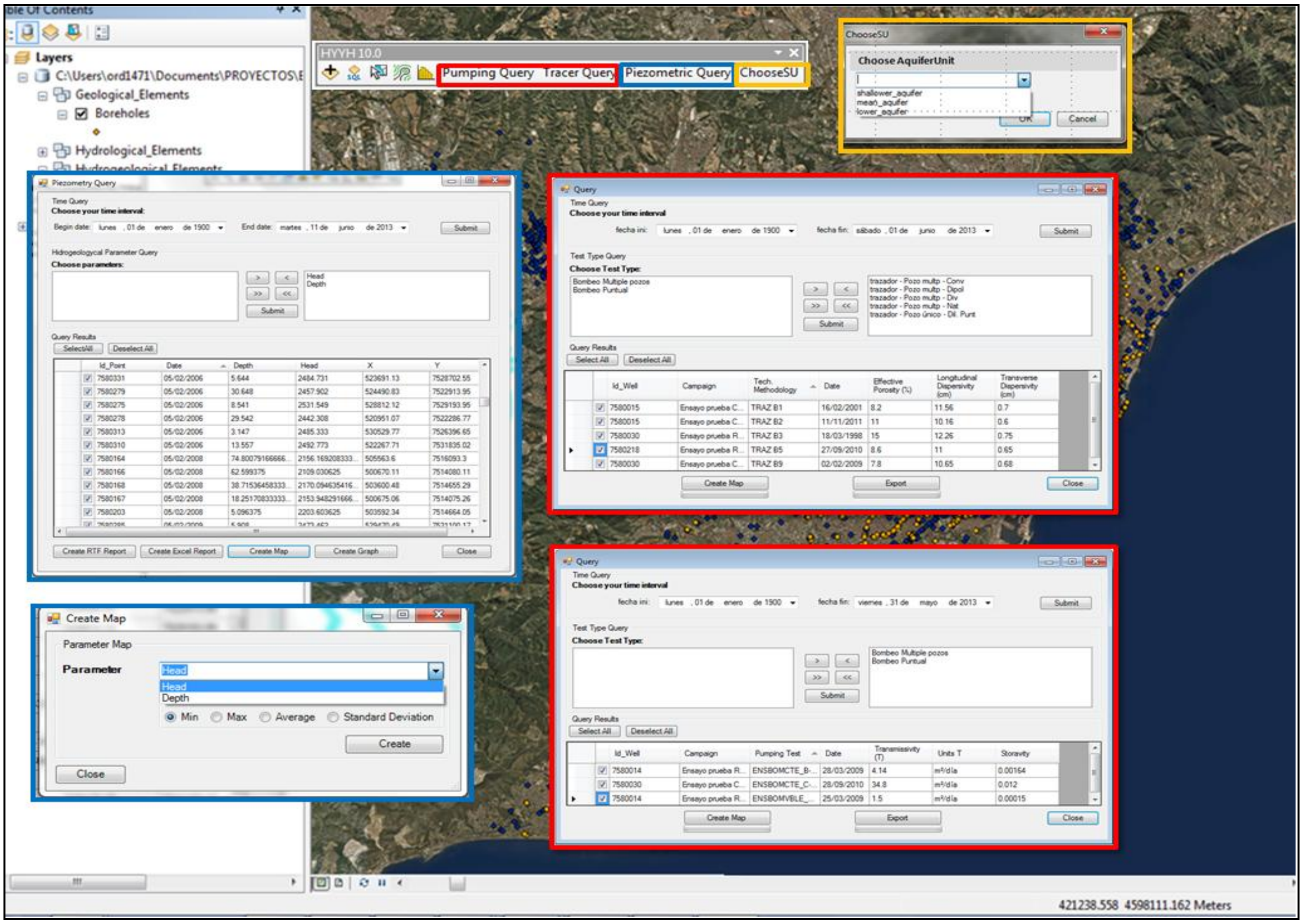


Figure 2:Toolbar HYYH integrated as an extension in ArcMap. It is composed of several commands: 1) inbuilt tools of ArcGIS (select, add data, statistical tools, etc) and three different multi-criteria query forms for interpreting hydrogeological analysis.

REFERENCES

[1] AQUACHEM (2013) Schlumberger Limited. Available at http://www.swstechnology.com. Accessed 09/07/2013.

[2] BarthelR. Sonneveld, B. Götzinger, J. Keyzer, M. Pande, S. Printz, A. Gaiser, T. (2008), Integrated assessment of groundwater resources in the Ouémé basin, Benin, West Africa. Physics and Chemistry of the Earth, 34, pp.236–250.

[3] Carrera-Hernández, J. Gaskin, S. (2008), The Basin of Mexico Hydrogeological Database (BMHDB): Implementation, queries and interaction with open source software. Environmental Modelling & Software, 23, pp.1271–1279.

[4] Carrera, J., Castillo, O., Vàzquez-Suñé, E., Sanchez-Vila, X., (2004), A methodology to compute mixing ratios with uncertain end members. Water Resources Research, vol. 40 (12), Art. w12101.

[5] Chesnaux, R., Lambert, M., Walter, J., Fillastre, U., Hay, M., Rouleau, A., Daigneault, R., (201), .Building a geodatabase for mapping hydrogeological features and 3D modeling of groundwater systems: Application to the Saguenay–Lac-St.-Jean region, Canada. Computers & Geosciences, 37(11), pp.1870–1882. doi:10.1016/j.cageo.2011.04.013.

[6] Cunge, J. A. (2003), Of data and models, Journal of hydroinformatics, pp.75–98.

[7] EASYBAL (2013) Hydrogeological group (GHS), Institute of Environmental Assessment and Water Research (IDAEA-CSIC) and Department of Geotechnical Engineering and Geosciences, Universitat Politècnica de Catalunya (UPC). Available at http://www.h2ogeo.upc.es.Accessed 18/07/2013.

[8] EASYQUIM (2013) Hydrogeological group (GHS) of Technical University of Catalonia (UPC) and Institute of Environmental Assessment and Water Research (IDAEA), CSIC, Barcelona, (Spain). Available at www.h2ogeo.upc.es. Accessed 03/06/2013.

[9] EPHEBO (2013). Hydrogeological group (GHS), Institute of Environmental Assessment and Water Research (IDAEA-CSIC) and Department of Geotechnical Engineering and Geosciences, Universitat Politècnica de Catalunya (UPC).Available at www.h2ogeo.upc.es. Accesed 18/07/2013.

[10] ESRI (2013) ArcGIS 10x Environmental Systems Research Institute, Redlands (United States). Available at http://www.esri.com/software/arcgis/arcgis-for-desktop. Accessed 03/06/2013.

[11] European Communities (2009) ,Guidance Document No: 22 Updated Guidance on Implementing the Geographical Information System (GIS) Elements of the EU Water policy, 192 pp, Available at: http://ec.europa.eu/environment/water/water-framework/facts_figures/guidance_docs_en.htm. Accesed 18/09/2013.

[12] Gocad (2011) gOcad research group ASGA. Available at: http://www.gocad.org. Accessed 18/09/2013.

[13] Gogu, R., Carabin, G., Hallet, V., Peters, V., & Dassargues, A. (2001). GIS-based hydrogeological databases and groundwater modelling. Hydrogeology Journal, 9(6), pp. 555–569. doi:10.1007/s10040-001-0167-3

[14] Gogu, R., Velasco, V., Vazquez-Suñè, E., Gaitanaru, D., Chitu, Z., Bica, I., (2011) .Sedimentary media analysis platform for groundwater modelling in urban areas. Adv Res Aquatic Environ 5, pp.489–496.

[15] INSPIRE (2013)Infrastructure for Spatial Information in Europe , D2.8.II.4 Data Specification on Geology – Draft Technical Guidelines. Available at: http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_GE_v3.0rc3.pdf. Accessed 18/09/2013.

[16] O&M (2013), D2.9 Guidelines for the use of Observations & Measurements and Sensor Web Enablement-related standards in INSPIRE Annex II and III data specification development. Available at: http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/D2.9_O&M_Guidelines_v2.0rc3.pdf .Accesed 18/09/2013.

[17] OGC® WaterML 2.0 (2012): Part 1- Timeseries.Available at: http://www.opengeospatial.org.Accessed 18/09/2013.

[18] Parkhurst, D.L., Appelo, C.A.J., (2013). Description of input and examples for PHREEQC version 3. A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: USGS Techniques and Methods, book 6, chap. A43, 497 pp.

[19] Refsgaard, Jens. Hojberg, Anker. Moller, Ingelise. Hansen, Martin. Sondergaard, V. (2010). Groundwater Modeling in Integrated Water Resources Management-Visions for 2020. Ground water, 48, pp.633–648.

[20] Remy, N., Boucher, A., Wu J., (2009). Applied geostatistic with SGems. Cambridge University Press, New York, United States of America.

[21] Strassberg G. (2005) A geographic data model for groundwater systems. Dissertation, University of Texas, Austin, pp 229.

[22] Velasco, V., Cabello, P., Vázquez-Suñè, E., López-Blanco, M., Ramos, E., & Tubau, I. (2012). A sequence stratigraphic based geological model for constraining hydrogeological modeling in the urbanized area of the Quaternary Besòs delta (NW Mediterranean coast , Spain), Geologica acta, 10, pp. 373–394. doi:10.1344/105.000001757.

[23] Velasco, V., Gogu, R., Vázquez-Suñè, E., Garriga, a., Ramos, E., Riera, J., & Alcaraz, M. (2012), The use of GIS-based 3D geological tools to improve hydrogeological models of sedimentary media in an urban environment. Environmental Earth Sciences. doi:10.1007/s12665-012-1898-2.

[24] Velasco ,V., Tubau, I., Vázquez-Suñè, E., Gaitanaru, D., Gogu ,R., Alcaraz, M., Serrano, A, Ayora, C., Sánchez-Vila, X., Fernàndez-Garcia, D., Fraile, F., Garrido T. GIS based Hydrochemical Analysis Tools (QUIMET), 7th Euregeo, Bologna, Italy, Vol 1, pp419-420, Juny 2012 .

[25] Wojda, P., & Brouyère, S. (2013). An object-oriented hydrogeological data model for groundwater projects. Environmental Modelling & Software, 43, pp 109–123. doi:10.1016/j.envsoft.2013.01.015.

Development of Database Structure and Indexing Technique for the Wireless Response System

Alhadi Klaib[1], Joan Lu[2]
Department of Informatics
University of Huddersfield
Huddersfield, UK
{[1]Alhadi.klaib,[2] j.lu}@hud.ac.uk

***Abstract*—The relevance of this paper to the topics of the conference is that this paper provides a contribution to the area of systems communications, since this paper participates in the improvement of the Wireless Response Systems (WRS). In more detail, the rapid development of computer and wireless technologies improves many aspects of daily life. The objective of this research is to develop a database for the WRS in order to gain an efficient, fast, and reliable database management system. Furthermore, this research proposes a generic database structure for the Wireless Response System. Moreover, it investigates and studies advanced database indexing techniques and then performs a comparison between them. Subsequently, this work makes an argument to find out the most appropriate indexing technique for the WRS. Consequently, this research has achieved a great deal of success and has met the objectives and aims. To conclude, a framework for the Wireless Response System database has been developed. Additionally, the B+ Tree and Hash indexing techniques have been examined successfully. Thus, it is found that the B+ Tree is a powerful technique for this particular system.**

Keywords-wireless response system; student response system; indexing techniques.

I. INTRODUCTION

Since mobile computing has grown rapidly in recent years, it has been involved in many life aspects such as e-commerce, e-education etc. The Student Response System (SRS) is an example of the e-education aspect. The SRS has improved the learning environment [1]. Moreover, the revolution in smart phone devices, Personal Digital Assistant (PDA) and other software development platforms has provided much support for the SRS. These devices have many advantages such as touch screens and Wi-Fi access which also gives them a great opportunity to be used as clickers [2]. The development of handheld devices has provided a motivation for developing the Wireless Response Systems (WRS) [3][4].

Database Management systems (DBMS) are widely used as a method for manipulating large datasets. Indexing technology is used by these systems to enable fast access to stored data. The index structures are additional files that provide alternative methods to access the data without affecting the physical placement of data on the disk. In fact, large databases need to be indexed to meet performance requirements [5][6].

Objectives and Aims: It is an attempt to enhance the WRS by proposing an appropriate generic architecture for the WRS database. This research concentrates on the development of an evolutionary scheme to support future improvement of the WRS and mobile computing technology in the education field. Subsequently, develop this proposal by using MySQL technology. The research will also investigate the possibility of implementing an appropriate advanced indexing technique for the WRS in order to gain an efficient and reliable system.

The remainder of this paper is structured as follows: Section II discusses related works. Section III defines database structure for the WRS as a case study. Section IV describes the methods and explains the implementation of the design. Section V shows the results and discusses them. Section VI concludes the work and recommends some future work.

II. LITERATURE REVIEW

A. *Student Response System :*

SRS has been used for many years, usually in large classes and lectures to increase the involvement of the student in the learning process. Traditionally, it began as a clicker device used to transfer student responses to the teacher or instructor as a receiver. The SRS has many different names such as clickers, personal response system, audience response system etc. The SRS has shown efficiency as a tool for improving the educational environment [7][8]. The EduMECCA SRS project was a part of the European funded Lifelong Learning Program. The aim of this project is to develop an easy to use SRS for iPod Touch and iPhone and PC. It is also to provide instructors and teachers with a new tool to improve the integration between the students and the teachers [7]. This SRS uses broadly tablet PCs and smart mobile devices, which can be connected to the internet, for collection of student responses [9]. There are some assessments and study cases that show how the SRS has contributed to improvement of the educational environment. For instance, the EduMECCA SRS tool was used by the University of Buckingham as a pilot study in a number of courses. The feedback shows that the WRS has a positive impact on student learning [9]. Another example is that an assessment of the effects of SRS on student learning and

 ISBN: 978-1-61208-310-0

attitudes over a number of courses at the Department of Biology, New Mexico State University shows that the use of SRS in classes had a positive effect on student performance in all biology courses [10].

B. Database Management System for the Wireless Response System

There are number of DBMS available such as:

1) Relational Database Management System: There are many types of Relational Database Management Systems (RDBMS) in the market such as My-SQL, Oracle, MS SQL server, MS Access. Additionally, many well-known firms use My-SQL for their systems, for instance YouTube, social networks, and Wikipedia [1].

2) Object-Relational Database Management System : it is similar to RDBMS. The difference is the Object-Relational Database Management System (ORDBMS) is based on supporting an object oriented database model such as class, objects, and inheritance. The objective of ORDBMS is to connect Entity Relationship with Object-Relational Mapping [3].

3) Object Database Management System: it is also called Object-Oriented Database. The Object Database Management System (ODBMS) is a kind of database that stores objects rather than data such as numbers, integers, and strings [1].

4) XML Database Management System: It is an advanced database technology which considers data as an XML format. The XML Database Management System (XDBMS) has the advantage that data can be queried in many different formats. There are mainly two kinds of XML database, namely XML Enabled and Native XML. XML has a great deal of advantages such as: efficiency, eliminating redundancy, fast, simple, strong, and object-oriented and relational [1][11].

The database technology for the WRS system was considered by the XDIR group at Huddersfield University [1]. It is an important step and it was proposed that using RDBMS is perhaps the most appropriate method [1].

C. Database Indexing Techniques:

The aim of database indexing is to improve the performance of the system. This goal can be achieved by making the retrieval of the data very fast. Therefore, indexing is a vital task to ensure a massive database is efficient and robust [3]. There are many indexing techniques. However, there is no indexing technique that is all-powerful and ideal for all types of queries. As far as classifications of indexing techniques are concerned, there are different kinds of classifications, each of which is based on particular criteria. Nevertheless, generally speaking, there are two kinds of indices, namely ordered indices and hash indices [5][12]. Ordered indices: this sort of index is based on a sorted ordering of data. Hash indices: such index is based on the values being distributed across a range of buckets [12]. Ordered Indices: we use index structure in order to get quick access to data. Each index structure is associated with a specific search key. A file may have a number of indexes [12].

1) Primary Index: in this kind of index we assume that data are sorted sequentially on a search key. These types of indices are developed for applications that request sequential and random access [12]. There are two types of ordered indices as follows. First, dense Indices is seen in every record of the file. The index record has a pointer to the first data record in the file/table/relation that has its search-key value; since it's a clustering index, all other records with that search-key value will be known to follow that record [12]. Second, sparse Indices: A sparse index holds index records only for some of the search-key values that are known. Sparse indices must be clustering – the sparse approach doesn't make sense for non-clustering indices.

2) Secondary Index: it provides a secondary way of accessing data. This data might be ordered, unordered, or hashed. B+ Tree indexes have been broadly used in data heavy systems to ease query retrieval. It is widely accepted due to height balanced tree [13]. In more detail, each path from the root of the tree to a leaf of the tree is the same length. Moreover, this indexing technique is the most widely used since it keeps its efficiency in the insertion and deletion data. B+ Tree indexes are an alternative to indexed-sequential files. The disadvantage of indexed-sequential files is that the performance degrades as the file grows, since many overflow blocks get produced. Periodic reorganization of the entire file is required. Advantage of B+ Tree index files are as follows: it automatically reorganizes itself with small, local, changes, in the face of insertions and deletions. Reorganization of the entire file is not required to maintain performance. The disadvantage of B+ Tree indexes is extra insertion and deletion overhead, space overhead. The advantages of B+–trees outweigh the disadvantages, and they are used extensively. Moreover, B Tree supports access concurrency, which is an important feature of the WRS. This maximizes access concurrency by multiple users [14][15][16].

Hash index: The disadvantage of sequential file indexing techniques is that there is a need to access the index structure to access the data or alternatively use a binary search. The consequence of this technique is more I/O operations. The hash index technique needs no such mechanism [12]. The hash index technique is another type of primary index file organization that is based on hashing, which provides very fast access to records under certain search conditions. This organization is usually called a hash file. The search condition must be an equality condition on a single field, called the hash field. In most cases, the hash field is also a key field of the file, in which case it is called the hash key [17]. The main advantage of hash tables over other table data structures is speed. This advantage is more apparent when the number of entries is large (thousands or more). Hash tables are particularly efficient when the maximum number

 ISBN: 978-1-61208-310-0

of entries can be predicted in advance, so that the bucket array can be allocated once with the optimum size and never resized. If the set of key-value pairs is fixed and known ahead of time (so insertions and deletions are not allowed), one may reduce the average lookup cost by a careful choice of the hash function, bucket table size, and internal data structures. In particular, one may be able to devise a hash function that is collision-free, or even perfect. In this case the keys need not be stored in the table [18].

D. *Comparison of B+ Tree and Hashing indexes:*

Selecting criteria for suitable comparison is a sophisticated task in many cases. Broadly speaking, there are four methods by which indexing techniques can be compared with respect to these criteria, namely direct argument, mathematical modelling, simulation, and experimentation [19]. Perhaps this research will just use the argument method as the research for selecting the most appropriate technique for the WRS [19][20].

Criteria of Comparison: there are many criteria by which index techniques can be compared, such as space requirement, CPU time, and memory requirement, overall speed etc. [19]. Perhaps we need to consider some of these criteria in case of addition, modification and deletion of records. Having studied the B+ Tree and Hashing indices, the results will be summarised in a couple of tables to show the advantages and disadvantages for each of these techniques. Table number I shows the advantages and disadvantages of the B+ Tree index technique [20][21][22]. Table number II illustrates the advantages and disadvantages of the Hash index technique [23].

III. CASE STUDY: DATABASE STRUCTURE FOR THE WIRLESS RESPONSE SYSTEM

Background: The WRS is being developed by the XDIR Research Group. This system is based on a wireless network environment by using the most recent smart phones and handheld devices [2]. The aim of the XDIR group is to develop an easy-to-use, efficient and fast system. Thus, this group proposed a prototype based on mobile devices [2]. There were found to be many advantages in this system such as: the system users do not always need an internet connection, and instead Wi-Fi can be sufficient for using the system. Moreover, mobile phone devices are a portable, easy to carry, and cost-effective tool compared with PCs [1].

Responding Relationship: there is a formula that defines the technique of the responding relationships as shown in (1) below [2].

$$SD= \sum qi \longleftrightarrow \sum rj \qquad (1)$$

Whereas SD is a subject domain, *qi* means a group of questions that respond to a group of responses in a particular session. *rj* stands for a particular response in a session [2].

TABLE I. ADVANTAGES AND DISADVANTAGES OF B+ TREE INDEX TECHNIQUE.

No	Advantages	Disadvantages
1	It automatically re-organizes itself with small, local, changes when insertions and deletions occur.	Extra insertion and deletion cause space overhead.
2	The overhead is acceptable as the cost of file reorganisation is avoided.	
3	Reorganization of entire file is not required to maintain performance	
4	B+–Tree is an alternative to indexed-sequential file.	
5	MySQL servers support B Tree index	
6	B Tree supports access concurrency	

TABLE II. ADVANTAGES AND DISADVANTAGES OF HASH INDEX TECHNIQUE.

No	Advantages	Disadvantages
1	Hash performance does not degrade with growth of file minimal space overhead	Hash index may be less efficient than B tree for particular string processing applications
2	Hash indexing is efficient when the maximum number of entries can be predicted in advance.	Hash tables may also be used as disk-based data structures and database indices, although B–trees are more popular in these applications
3	Fast for exact-match comparison	Hash is used only for = or <=> comparison
4	Whenever the indexed table is updated, the hash index is updated automatically.	Poor for looking for range of values
5	Search keys can be prefixed if the key can't be used to find rows.	Only whole search keys can be used to search for row, prefix of the key can't be used to find rows.
6		Hash index is stored in the main memory only.

Figure 1 shows a corresponding relationship between the questions and responses. As soon as *qi* has been generated by the system, some *rj's* will be hit back to *qi's*. At the same time a number of *rj's* will receive some qi's concurrently. As a result the system has to consider this relationship as many to many [2].

Since the WRS is based on the usage of mobile phone devices, and the communication method is wireless networking, the WRS should thus support a variety of sorts of both hardware and software mobile phones. Figure 1 illustrates the relationships between questions and responses. When a *qi* has been triggered by the system, a number of *rj's* will be hit back to *qi's*. Meanwhile, the number of *rj's* will receive a number of *qi's* at the same time [2].

Specifications and Features of the WRS:

A number of features and specifications need to be considered, which in some way are associated with the WRS database. Perhaps, some of these specifications are generic and will not be considered in this stage. The following specifications are the most important ones for the WRS:

- Concurrency: it is obvious that the nature of the WRS leads to heavy concurrent operations in the session's time.

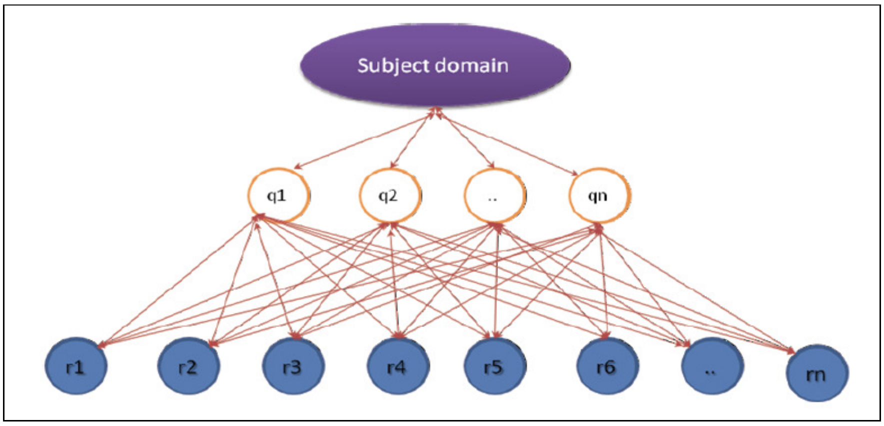


Figure 1. Logical relationship of wireless response system.

- Usability: the WRS is being developed to be simple to use and fast in storing and retrieving data [1].
- Scalability: the volume of the disk space needed for this system is crucial. Furthermore, the growth of the database files is also needs to be worked out.
- Extensibility: the numbers of queries in a certain time and to certain records of the database have to be figured out.
- Data types: the WRS is a sophisticated system that is supposed to support different kinds of data such as video, sound, picture, and text.
- Types of Queries: Different kinds of queries need different indexing techniques. For instance, some indexing techniques are good for exact-match comparisons; however, they are poor for queries that look for a range of values [24]. Therefore different queries scenarios need to be defined.
- Internationalization**:** the WRS is being developed to be an international system and can be used in different languages and different countries.
- Generalization**:** in this stage the WRS should be a generic system, so it can be used for different life aspects and the Mobile Exam System (MES) is an example [25][26][27].

IV. METHODS

A logical diagram was proposed for the WRS database. It is a generic framework for the WRS database. Basically, this framework includes three components, namely, disciplines, users, and results. Then, this framework was implemented using the appropriate technology which is MySQL. It is the most reliable and proper technology to implement this database and its relationships. Secondly, the current indexing techniques were studied and their advantages and disadvantages investigated. Thirdly, these techniques were compared in terms of the specifications and features of the WRS.

A. Database Design

It is assumed that the WRS needs a certain database management system in order to match the WRS's specifications. Figure 2 shows the proposed framework for the WRS database. As can be seen, the diagram has three components as follows: first of all, disciplines: this component includes all entities representing subjects and discipline materials. Second, users: this component includes all people that deal with the system such as teachers, students and administrators. Third and finally, results: this is the biggest and most sophisticated component which includes exam sessions and the relevant materials and marking. This design provides a clear and flexible scheme. Thus, it can be reformed in future for other systems.

B. Implmentation

The WRS database has been developed using MySQL by the phpMyAdmin**.** This database has sixteen entities (tables) so far. However, the work on it is still on-going and further development and enhancement are being considered. The diagram in Figure 3 provides a visual overview of the WRS database design and the relationships between the tables. Each table includes additional details on the columns (attributes).

V. RESULTS AND DISCUSSION

A. Results

An implementation of the database model for the WRS has been developed. This implementation is a generic scheme that can be adopted by other systems in future. The system is being integrated in the WRS by a researcher in the XDIR Group. It is being tested in order to find out any limitations. As far as the indexing technique is concerned, here is the comparison of B+ tree and Hash indexing techniques as follows:

Having considered the advantages and disadvantages for both indexing techniques, as well as the comparison of these techniques in Tables I, II and III, we are able to figure out the following results:

 ISBN: 978-1-61208-310-0

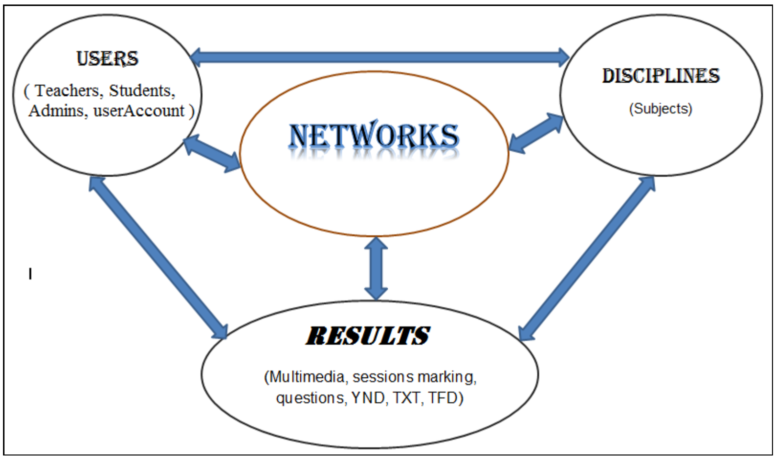


Figure 2. Generic Framework for WRS Database.

- Since WRS is a system that offers flexible and easy-to-use interfaces and functions, flexible and wide queries thus need to be accepted and accomplished. As a result, the B + tree indexing was selected to provide the required flexibility for broad queries.
- The WRS database is being developed by MySQL technology. Hence this technology supports both indexing techniques. B+ Tree is more flexible and suitable for WRS with wide queries support.
- The developed WRS database is a generic system, since the B+ tree indexing technique is intended for general purpose and is supported for different storage engines. Therefore, B+ tree would be the compatible technique for this system.
- In terms of types of queries, the WRS database is a generic and flexible system. Therefore, the indexing that will be used must be efficient for a varying range of queries, which in this case is the B+ Tree.

B. Discussion

The efficiency of WRS is crucial as this system needs to be fast and reliable in order to cope with its purposes such as MES. As a consequence, this research investigated the most powerful indexing techniques in order to achieve an efficient DBMS. Subsequently, a comparison among these techniques has been accomplished. As a result, this research proposes to use an indexing technique in order to achieve an efficient database system. The B+ Tree indexing technique is proposed to be the technique for the WRS as this is the most suitable one for this system.

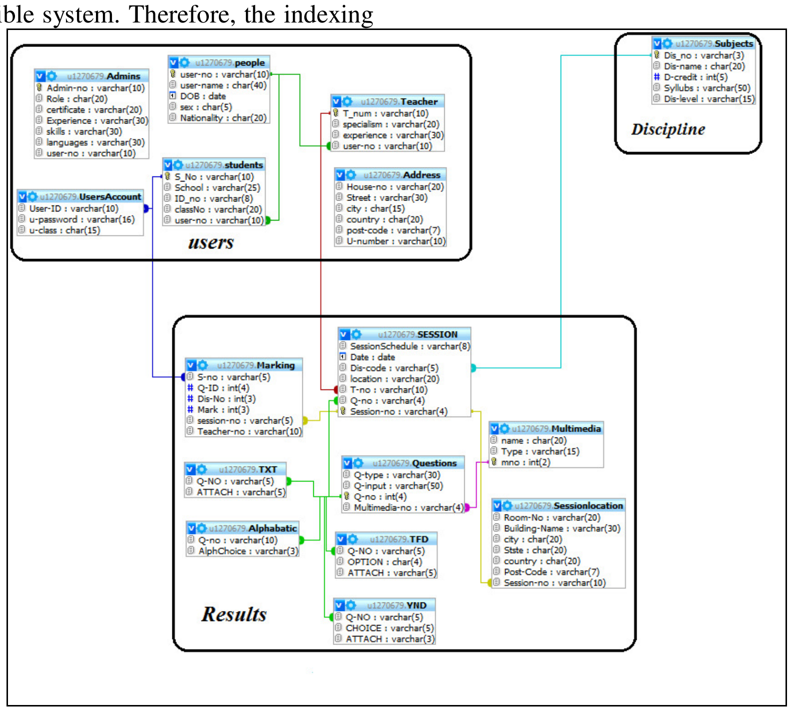


Figure 3. Database Structure of WRS.

TABLE III. A COMPARISON OF B+ TREE AND HASH INDEXING.

FEATURE OF WRS	B+ tree	Hash	Remarks
Keys of search and types of query.	Efficient for range of values (e.g., prefix)	Not efficient for range of values	B+ Tree preferred
Reorganization of data	It is updated automatically	It is updated automatically	Both are acceptable
Range of values	Supports queries for a wide range of values	Inefficient for range of values	B+ Tree preferred
Storage location		Only in main memory	B+ Tree preferred
ACCESS CONCURRENCY	SUPPORTS CONCURRENCY	Supports concurrency	BOTH ARE ACCEPTABLE

VI. CONCLUSION AND FUTURE WORK

A. *Conclusion*

This research proposes an indexing technique for the WRS database, in order to achieve fast and reliable system. It is found that the B+ Tree is a powerful technique in terms of the WRS specification, and it is a great deal to use it. Moreover, it has been developed and implemented a generic architecture for the WRS database that can be adapted by other relevant systems in future. In brief, this research has accomplished a solid base for building an efficient and reliable database system for the WRS.

B. *Future Work*

Further research and investigation need to be carried out. Furthermore, it is recommended to be in the following areas:

- Test the WRS database performance in order to confirm the indexing technique.
- Investigate the possibility of implementing XML technology in the WRS database in order to make it secure and reliable.

ACKNOWLEDGMENT

The authors thank Mr. **Wei Guo** and others from the XDIR Group at Huddersfield University for the help and discussion that they provided during this study.

REFERENCES

[1] J. Lu, A. Sundaram, and V. Arumugam, “Innovative Evaluation System – IESM: An Architecture for the Database Management System for Mobile Application,” The 2011 International Conference on Internet Computing, Las Vegas, USA, July 2011.

[2] J. Lu, Z. Meng, G. Lu, and J. B. Stav, “A New Approach in Improving Operational Efficiency of Wireless Response System,” IEEE 10th International Conference on Computer and Information Technology (CIT), 2010, pp. 2676-2683, ISBN 9781424475476.

[3] J. Lu, A. Sundaram, M. Zhaozong, V. Arumugam, and L. Gehao, “Mobile Exam System – MES: Architecture for Database Management,” The International Conference on Education & Learning in Mobile Age - CELMA, Lake District, UK, June 2011.

[4] P. Pocatilu, “Building Database-Powered Mobile Applications,” Informatica Economica, vol. 16, 2012, pp. 132-142.

[5] C. Zaniolo, Advanced database systems. San Francisco, CA: Morgan Kaufmann, 1997.

[6] T. M. Connolly and C. E. Begg, Database systems: a practical approach to design, implementation, and management. Boston, Mass: Addison-Wesley, 2010.

[7] F. o. T. Sør-Trøndelag University College. (2013). EduMECCA. Available: http://histproject.no/node/18 [retrieved: Aug. 2013]

[8] F. o. T. Sør-Trøndelag University College. (2013). What is a Student Response System (SRS). Available: http://histproject.no/node/77 [retrieved: Aug. 2013]

[9] H. Sellahewa, “Enhancing small group teaching and learning using online student response systems,” Higher Wducation Academy Higher Wducation Academy, 2012.

[10] R. W. Preszler, A. Dawe, C. B. Shuster, and M. Shuster, “Assessment of the Effects of Student Response Systems on Student Learning and Attitudes over a Broad Range of Biology Courses,” CBE—Life Sciences Education, vol. 6, Spring 2007, pp. 29–41.

[11] M. J. Young, Step by step XML. Redmond, Wash: Microsoft, 2000.

[12] A. Silberschatz, H. F. Korth, and S. Sudarshan, Database system concepts. New York: McGraw-Hill, 1997.

[13] E. Bertino, et al., Indexing techniques for advanced database systems (Advances in Database Systems), 1997.

[14] P. Lehman and s. Yao, “Efficient locking for concurrent operations on B-trees,” ACM Transactions on Database Systems (TODS), vol. 6, Dec. 1981, pp. 650-670.

[15] H. Umesh, M. Agarwal, P. Rastogi, S. Agrawal, S. Mittal, S. Jain, V. L. R. Madhurima, and D. S. Kushwaha, “A new novel indexing technique using a bit-tuple tree,” Recent Trends in Information, Telecommunication and Computing(ITC), Mar. 2010, pp. 224-226.

[16] t. f. e. Wikipedia. (2013). B-Tree. Available: https://en.wikipedia.org/wiki/B-tree#Access_concurrency [retrieved: Aug. 2013]

[17] R. Elmasri and S. Navathe, Fundamentals of database systems. Boston, Mass: Pearson Addison-Wesley, 2007.

[18] T. M. Connolly and C. E. Begg. Database solutions: a step-by-step guide to building databases. New York: Pearson Addison Wesley; 2004.

[19] J. Zobel, A. Moffat, and K. Ramamohanarao, “Guidelines for presentation and comparison of indexing techniques,” ACM SIGMOD Record, vol. 25, Sept. 1996, pp. 10-15.

[20] MySQL, Comparison of B-Tree and Hash Indexes, 2013 Available: http://dev.mysql.com/doc/refman/5.5/en/index-btree-hash.html [retrieved: Aug. 2013]

[21] K. Yat-Sang and D. Wood, “A New Method for Concurrency in B-Trees,” IEEE Transactions on Software Engineering, vol. SE-8, May 1982, pp. 211-222.

[22] MySQL. MySQL Customers [Online]. Available: http://www.mysql.com/customers/ [retrieved: Aug. 2013]

[23] Wikipedia tfe. Hash table 2013 Available from: http://en.wikipedia.org/wiki/Hash_table#Performance_analysis. [retrieved: Aug. 2013]

[24] M. Anca, P. Cerasela, and E. Cristi, “Indexing Strategies For Optimizing Queries On MySQL,” Annals of the University of Petrosani : Economics, 2010, pp. 201-214.

[25] T. Haapasalo, I. Jaluta, S. Sippu, and E. Soisalon-Soininen, “Concurrency control and recovery for multiversion database structures,” 2008, pp. 73-80.
[26] I. Jaluta, S. Sippu, and E. Soisalon-Soininen, “Concurrency control and recovery for balanced B-link trees,” The VLDB Journal, vol. 14, April 2005, pp. 257-277.
[27] I. Jaluta, S. Sippu, and E. Soisalon-Soininen, “B-tree concurrency control and recovery in page-server database systems,” ACM Transactions on Database Systems (TODS), vol. 31, Mar. 2006, pp. 82-132.

Hybrid Multistep Multiderivative Methods for the Schrödinger Equation and Related Problems

Ibraheem Alolyan
Chair of Actuarial and Applied Mathematics,
Department of Mathematics, College of Sciences,
King Saud University,
P. O. Box 2455, Riyadh 11451,
Saudi Arabia
Email: ialolyan@ksu.edu.sa

Theodore E. Simos
Department of Mathematics, College of Sciences,
King Saud University,
P. O. Box 2455, Riyadh 11451, Saudi Arabia
and
Laboratory of Computational Sciences,
Department of Informatics and Telecommunications,
Faculty of Economy, Management and Informatics,
University of Peloponnese,
GR-221 00 Tripolis, Greece
Email: tsimos.conf@gmail.com

***Abstract*—In this paper we will present a new methodology for the development of efficient hybrid multiderivative multistep methods for the approximate solution of the Schrödinger equation and related initial-value or boundary-value problems with solutions, which their behavior is periodical or oscillating. The main characteristics of this new methodology are (1) the vanishing of the phase-lag on its level of the hybrid multiderivative method and (2) the vanishing of the its derivatives on its level of the hybrid multiderivative method. We apply the new methodology on a four-step hybrid type multiderivative method. A comparative error and stability analysis will be presented for the new produced method. The new constructed method will finally be applied to the resonance problem of the Schrödinger equation in order to show its efficiency.**

Keywords*—Numerical solution, Schrödinger equation, multistep methods, hybrid methods, multiderivative methods, interval of periodicity, P-stability, phase-lag, phase-fitted, derivatives of the phase-lag

I. Introduction

The Schrödinger equation is a very important mathematical model in quantum mechanics, which describes how the quantum state of some physical system changes with time. This mathematical model was first formulated in late 1925, and published in 1926, by the Austrian physicist Erwin Schrödinger (see for details [1])

The numerical solution of the the radial time-independent Schrödinger equation and of the related initial-value or boundary-value problems with periodical and/or oscillating solutions is investigated in this paper.

The radial time independent Schrödinger equation :

$$q''(r) = [l(l+1)/r^2 + V(r) - k^2]q(r). \qquad (1)$$

is a boundary value problem. The one boundary condition is the following:

$$q(0) = 0 \qquad (2)$$

and the other boundary condition, for large values of r, determined by the physical conditions and parameters of the specific problem.

In order to have the completion of the above mentioned mathematical model, we have give the following definitions of the functions, quantities and parameters presented in Equation 1 :

1) The function $W(r) = l(l+1)/r^2 + V(r)$ is called *the effective potential*. This satisfies $W(x) \to 0$ as $x \to \infty$,
2) The quantity k^2 is a real number denoting *the energy*,
3) The quantity l is a given integer representing the *angular momentum*,
4) V is a given function, which denotes the *potential*.

The main purposes of this paper are (1) to introduce a new procedure in order to obtain efficient methods for the numerical solution of second order initial or boundary value problems of the form $q''(x) = f(x, q(x))$ with periodical and/or oscillating solutions and (2) to develop (based on the previous mentioned procedure) an efficient hybrid four-step multiderivative method.

II. Description of the Methodology

In Sciences and Engineering there are a significant number of real problems, which have models, which can be expressed as initial or boundary value problems of the above mentioned category (for example, the Schrödingers equation, Duffings equation, etc).

The new procedure for the development of efficient multiderivative multistep methods consists the following stages:

- The determination of the form of the hybrid multiderivative multistep method (i.e., method with more that one stage, higher order derivatives and more than one step)
- On each level of the hybrid multiderivative multistep method the vanishing of the phase-lag

 ISBN: 978-1-61208-310-0

- On each level of the hybrid multiderivative multistep method the vanishing of the derivatives of the derivatives (the order of the derivatives depends from the free parameters that the hybrid multiderivative multistep method has)
- The determination of how much more efficient are the new developed methods i.e., the investigation on how the vanishing of the phase-lag and its derivative affects the efficiency of the produced numerical methods
- The determination of how much more efficient are the new developed methods compared with those developed via the vanishing of the phase-lag and its derivatives in the whole of the method (and not on each stage).

Problems for which the algorithms presented in this paper are efficient for this approximate solution are:

1) problems with oscillating and / or periodical solutions,
2) problems in which the functions cos and sin are presented in their analytical solution,
3) problems in which combination of the functions cos and sin are presented in their analytical solution.

The aim and scope of the present research is the construction of a two-stage, four-step hybrid multiderivative method with the following properties:

1) the maximum possible algebraic order
2) the vanishing of the phase-lag on each stage of the method
3) the vanishing of the derivatives of the phase-lag on each stage of the method. The maximum order of the derivatives to be vanished is dependent on the free parameters which we have. The number of free parameters is dependent by the form of the hybrid two-stage, four-step multiderivative method

The satisfaction of the above purposes requires the computation of the phase-lag and its derivatives for the specific method. In [2] and [3], Simos and co-authors has proved a direct formula for the computation of the phase-lag for a $2\,n$-step method. We mention here that the computation of the derivatives of the phase-lag is based on the previously mentioned formula.

In order to investigate the efficiency of the new produced method, we will apply the following studies:

1) The local truncation of the new developed method will be compared with those of other methods of the same form (comparative error analysis),
2) The Stability (interval of periodicity) of the new obtained method will be determined and
3) Finally, the new produced method will be applied to the resonance problem of the radial time independent Schrödinger equation (see for more details [4]) and the results will be compared with those of other well known methods in the literature.

III. Study of the Phase-lag of Symmetric $2\,n$-step Methods

The general problem we face in the paper is the numerical solution of the the initial or boundary value problem of the form $q''(x) = f(x, q(x))$ via multistep multiderivative finite difference methods.

In order to investigate the above mentioned problem we apply the follow procedure

- We divide the interval of integration $[a, b]$ into $n + 1$ intervals $\{x_i\}_{i=0}^{n}$ of equal length. The length $h = |x_{i+1} - x_i|$ is called step-size of the integration.
- For the approximate solution of the above described problem we consider the general $2\,n$-step finite difference multistep multiderivative method of the form:

$$\sum_{i=-n}^{n} a_i\, q_{k+i} = h^2 \sum_{i=-n}^{n} b_i^j\, f^{(j)}\Big(x_{k+i}, q(x_{k+i})\Big), \quad j = 0, 1, \dots \tag{3}$$

where $f^{(j)}\Big(x_{k+i}, q(x_{k+i})\Big)$ is the derivative of j order of: $f\Big(x_{k+i}, q(x_{k+i})\Big)$ and $f^{(0)}\Big(x_{k+i}, q(x_{k+i})\Big) = f\Big(x_{k+i}, q(x_{k+i})\Big)$.
Using the integration step-size defined above, the method (Equation 3) is applied over the above mentioned integration area. In this paper we will study the specific category of methods (Equation 3), which are symmetric i.e., the category of methods for which: $a_i = a_{-i}$, $b_i = b_{-i}$, $i = -n(1)n$.
- We investigate now the phase-lag of the above mentioned method. The study demands the following procedure:
- In order to define the phase-lag for the above category of methods, we use the scalar test equation:

$$q'' = -\phi^2\, q \tag{4}$$

- If we apply a symmetric $2\,n$-step multiderivative method to the above test equation (Equation 4), the following difference equation is produced:

$$A_n(w)\, q_{k+n} + \ldots + A_1(w)\, q_{k+1} + A_0(w)\, q_k + \\ + A_1(w)\, q_{k-1} + \ldots + A_n(w)\, q_{k-n} = 0 \tag{5}$$

where $w = \phi\, h$, h is the step length and $A_0(w)$, $A_1(w), \ldots, A_n(w)$ are polynomials of $w = \phi\, h$.
- We note here that in our analysis the corresponding characteristic equation is also required. The characteristic equation of the difference equation (5) is given by:

$$A_n(w)\, \lambda^n + \ldots + A_1(w)\, \lambda + A_0(w) + \\ + A_1(w)\, \lambda^{-1} + \ldots + A_n(w)\, \lambda^{-n} = 0 \tag{6}$$

- The calculation of the phase-lag can be done via the following theorem which is proved by Simos and co-workers (see [2] and [3]):

 ISBN: 978-1-61208-310-0

Theorem 1: [2] and [3] The symmetric $2\,n$-step method with characteristic equation given by Equation 6 has phase-lag order q and phase-lag constant c given by:

$$-c\,w^{q+2} + O\left(w^{q+4}\right) = \frac{T_0}{T_1} \tag{7}$$

where

$$T_0 = 2\,A_n\,(w)\,\cos\,(n\,w) + \ldots + \\ +2\,A_j\,(w)\,\cos\,(j\,w) + \ldots + A_0\,(w) \tag{8}$$

$$T_1 = 2\,n^2\,A_n\,(w) + \ldots + \\ +2\,j^2\,A_j\,(w) + \ldots + 2\,A_1\,(w) \tag{9}$$

where the polynomials $A_0(w)$, $A_1(w), \ldots$, $A_n(w)$ are given above (see Equation 5 and Equation 6).

Remark 1: It is easy to see that from the above formulae Equations 7, 8 and 9 we can compute the phase-lag of any symmetric $2\,n$-step multiderivative method.

IV. The New Algorithm

The construction of a hybrid type symmetric four-step multiderivative method for the numerical solution of problems of the form $p'' = f\,(x, p)$ is presented in this section.

Consider the method:

$$\begin{aligned}\hat{p}_{n+2} &= c_0\,p_{n+1} + c_0\,p_{n-1} - p_{n-2} + \\ &+h^2\left(a_0\,p''_{n+1} + a_1\,p''_n + a_0\,p''_{n-1}\right) + \\ &+h^4\left(b_0\,p^{(4)}_{n+1} + b_1\,p^{(4)}_n + b_0\,p^{(4)}_{n-1}\right) \\ p_{n+2} - c_1\,p_{n+1} &- c_1\,p_{n-1} + p_{n-2} = \\ &= h^2\left[a_4\,\left(\hat{p}''_{n+2} + p''_{n-2}\right) + \right. \\ &\left. +a_3\,\left(p''_{n+1} + p''_{n-1}\right) + a_2\,p''_n\right] + \\ &+h^4\left[b_4\,\left(\hat{p}^{(4)}_{n+2} + p^{(4)}_{n-2}\right) + \right. \\ &\left. +b_3\,\left(p^{(4)}_{n+1} + p^{(4)}_{n-1}\right) + b_2\,p^{(4)}_n\right]\end{aligned} \tag{10}$$

Notations for the above mentioned general family of methods :

- We define as free parameters the coefficients a_j, $j = 0(1)4$ and b_i, $i = 0(1)4$.
- The step size of the integration is defined as h.
- n is the number of steps,
- The approximation of the solution on the point x_n is presented as p_n
- $x_n = x_0 + n\,h$ and
- x_0 is the initial value point.

A. First Layer of the Hybrid Method

Our study begins from the first method of the above mentioned hybrid scheme:

$$\begin{aligned}p_{n+2} &- c_0\,p_{n+1} - c_0\,p_{n-1} + p_{n-2} = \\ &= h^2\left(a_0\,p''_{n+1} + a_1\,p''_n + a_0\,p''_{n-1}\right) + \\ &+h^4\left(b_0\,p^{(4)}_{n+1} + b_1\,p^{(4)}_n + b_0\,p^{(4)}_{n-1}\right)\end{aligned} \tag{11}$$

Applying the method given by Equation 11 to the test equation (4), we obtain the difference equation (5) with $n = 2$. We note that $A_j\,(w)$, $j = 0,\,1,\,2$ are given by:

$$A_2\,(w) = 1,\; A_1\,(w) = -c_0 + w^2\,a_0 - w^4\,b_0, \\ A_0\,(w) = w^2\,a_1 - w^4\,b_1 \tag{12}$$

We demand the above scheme to have the phase-lag vanished. Based on the formula given by Equation 7 (for $n = 2$) and taking into account the formulae given by the Equations 12, we obtain the following equation:

$$\mathrm{Phase-Lag} = \frac{1}{2}\,\frac{T_2}{-4 + c_0 - w^2\,a_0 + w^4\,b_0} = 0 \tag{13}$$

where

$$\begin{aligned}T_2 &= -4\,\left(\cos\,(w)\right)^2 + 2 \\ &+\; 2\,\cos\,(w)\,c_0 - 2\,\cos\,(w)\,w^2\,a_0 \\ &+\; 2\,\cos\,(w)\,w^4\,b_0 - w^2\,a_1 + w^4\,b_1\end{aligned} \tag{14}$$

Remark 2: Equations for the first, second etc derivatives of the phase-lag can be produced. In order to define the maximum number of the available equations of the previous type, we must check the free parameters of the algorithm. In our case and since we have five parameters $\left(c_0,\,a_0,\,a_1\,b_0,\,b_1\right)$, we can produce four more equations for the vanishing of the first, second, third and fourth derivatives of the phase-lag.

Remark 3: The definition of the free parameters of the scheme, i.e., the parameters $\left(c_0,\,a_0,\,a_1\,b_0,\,b_1\right)$, can be done solving the system of equations produced by the requirement of the vanishing of the phase-lag and its derivatives.

B. Second Layer of the Hybrid Method

Our study is continued now to the second layer of the proposed method (10) :

$$q_{n+2} - c_1\, p_{n+1} - c_1\, p_{n-1} + p_{n-2} = \\ = h^2 \Big[a_4\, \left(p''_{n+2} + p''_{n-2}\right) + \\ + a_3\, \left(p''_{n+1} + p''_{n-1}\right) + a_2\, p''_n \Big] + \\ + h^4 \Big[b_4\, \left(\hat{p}^{(4)}_{n+2} + p^{(4)}_{n-2}\right) + \\ + b_3\, \left(p^{(4)}_{n+1} + p^{(4)}_{n-1}\right) + b_2\, p^{(4)}_n \Big] \qquad (15)$$

Applying now the second layer (15) to the test equation (4) (following the methodology described in the previous section for the first layer of the hybrid method), we obtain the difference equation (5) with $n = 2$ and $A_j\,(w)\,, \quad j = 0,\, 1,\, 2$ given by:

$$\begin{aligned} A_2\,(w) &= 1 + w^2\, a_4 + w^4\, b_4, \\ A_1\,(w) &= -c_1 + w^2\, a_3 - w^4\, b_3 \\ A_0\,(w) &= w^2\, a_2 - w^4\, b_2 \end{aligned} \qquad (16)$$

We require now the above algorithm to have the phase-lag vanished. We again base our investigation on the formula given by Equation 7 (for $n = 2$) and we take into account the formulae given by Equations 16. Based on this the following equation holds:

$$\text{Phase} - \text{Lag} = \frac{1}{2}\,\frac{T_3}{T_4} = 0 \qquad (17)$$

where

$$\begin{aligned} T_3 &= 4\,(\cos{(w)})^2\, \Big(-4\,w^2\, a_4 \\ &+ 4\,w^4\, b_4 - 1\Big) + 2\,\cos{(w)}\, \Big(-w^2\, a_3 \\ &+ w^4\, b_3 + c_1\Big) + w^4 \Big(-2\,b_4 + b_2\Big) \\ &+ w^2 \Big(2\,a_4 - a_2\Big) + 2 \qquad (18) \\ T_4 &= -4 + c_1 - w^2\, \Big(a_3 + 4\,a_4\Big) \\ &+ w^4\, \Big(b_3 + 4\,b_4\Big) \qquad (19) \end{aligned}$$

Remark 4: Equations for the first, second etc derivatives of the phase-lag can be also obtained. In order to define the maximum number of the available equations of the previous type, we must check the free parameters of the algorithm. In our case and since we have seven parameters

$$c_1,\, a_j,\, j = 2(1)4\, b_i,\, i = 2(1)4, \qquad (20)$$

we can produce six more equations for the vanishing of the first, second, third, fourth, fifth and sixth derivatives of the phase-lag.

Remark 5: The definition of the free parameters of the scheme, i.e., the parameters

$$c_1,\, a_j,\, j = 2(1)4\, b_i,\, i = 2(1)4, \qquad (21)$$

can be done solving the system of equations produced by the requirement of the vanishing of the phase-lag and its derivatives.

Based on the above developments several methods can be obtained.

Remark 6: If we demand our hybrid multiderivative four-step method of the form (10) to have vanished the phase-lag and its first derivative, then the formulae (13), (17) have to be satisfied and also the corresponding formulae for the first derivatives. In order the above relations to be satisfied we must have at least four free parameters. We can choose four from the twelve free parameters of the scheme in order the above request to be satisfied on each layer of the hybrid method.

Remark 7: If we demand our hybrid multiderivative four-step method of the form (10) to have vanished the phase-lag and its first and second derivatives, then the formulae (13), (17) have to be satisfied and also the corresponding formulae for the first and second derivatives. In order the above relations to be satisfied we must have at least six free parameters. We can choose six from the twelve free parameters of the scheme in order the above request to be satisfied on each layer of the hybrid method

The steps we have to follow for the development of the new hybrid four-step multiderivative method are:

- Decision of the form of the method we wish to have (this is based on the mathematical model of the problem. If, for example, we have a problem with oscillating behavior of the solution, the we must have a method with vanished the phase-lag and as much as we can derivatives of the phase-lag)
- Development of the equations, which satisfy the above
- Solution of the system of equations and determination of the free parameters of the method
- Analysis of the produced method: local truncation error analysis, stability analysis.
- Finally, application of the obtained method to several well known problems in order to test the efficiency of the new algorithms.

V. Evaluation

The new proposed methods have the following characteristics :

1) High algebraic order
2) Vanishing of the phase-lag on each stage of the method
3) Vanishing of the derivatives of the phase-lag on each stage of the method

Based on the above characteristics, the new proposed method can be efficiently to any second order initial or boundary value problem with oscillating solutions.

VI. Conclusion

A new methodology for the construction of effective hybrid multiderivative multistep methods for the approximate solution of the Schrödinger equation and related problems with periodical or oscillating solutions is presented in this paper. It is mentioned that the important parts of this new methodology are (i) the vanishing of the phase-lag on its level of the hybrid multiderivative method and (ii) the vanishing of the its derivatives on its level of the hybrid multiderivative method. As an example, we applied the new methodology on a four-step hybrid type multiderivative method. From the numerical results produced from the application of this new developed four-step hybrid type multiderivative method to the resonance problem of the Schrödinger equation it is easy for one to see the efficiency of the new methodology.

Acknowledgment

The authors would like to thank the "Distinguished Scientists Fellowship Program" of the King Saud University for the support of their participation in the INFOCOMP 2013.

References

[1] L.D. Landau and E.M. Lifshits, *Quantum Mechanics. Nonrelativistic Theory [in Russian]*, Nauka, Moscow, 1974.

[2] A. Konguetsof and T. E. Simos, A Generator of Hybrid Symmetric Four-Step Methods for the Numerical Solution of the Schrödinger Equation, Journal of Computational and Applied Mathematics, **158(1)**, 2003, pp. 93-106.

[3] T. E. Simos and P. S. Williams, A finite difference method for the numerical solution of the Schrödinger equation, Journal of Computational and Applied Mathematics **79**, 1997, pp. 189-205.

[4] Ibraheem Alolyan and T. E. Simos, A new four-step Runge-Kutta type method with vanished phase-lag and its first, second and third derivatives for the numerical solution of the Schrödinger equation, Journal of Mathematical Chemistry, 2013, **51(5)** pp. 1418-1445.

A New RSSI-based Centroid Localization Algorithm by Use of Virtual Reference Tags

Hua Long[1,2], Joan Lu[1], Qiang Xu[1]
[1]School of Computing and Engineering, University of Huddersfield, Huddersfield, UK
[2]Faculty of Information and Automation, Kunming University of Science and Technology, Kunming, Yunnan, P. R. China
1670931890@qq.com; {j.lu,q.xu2}@hud.ac.uk

Qian Lei
Faculty of Information and Automation, Kunming University of Science and Technology, Kunming, Yunnan, P. R. China
1670931890@qq.com

***Abstract*—A good design of node location is critical for efficient and effective wireless communications. This paper presents an improved algorithm, in order to solve the low localization accuracy caused by traditional centroid algorithm. The improved algorithm combined with VIRE system and traditional centroid algorithm. The VIRE algorithm is introduced and the signal propagation model is utilized to construct virtual reference tags in the location area. Simulation shows that this further developed algorithm has further improved the accuracy of positioning up to 35.12% compared to the traditional centroid algorithm. It is concluded that this algorithm can further improve the locating accuracy in comparison with the original centroid algorithm.**

Keywords–VIRE algorithm; Virtual reference tags; RSS; Centroid algorithm.

I. INTRODUCTION

Node localization is one of the core technologies in Wireless Sensor Network (WSN) [1]. Currently, the localization algorithm of wireless sensor network can be divided into two categories: the distance-independence [2] and distance-dependence [3].

The common positioning algorithms of distance-independence are centroid algorithm and Approximate Point-In-triangulation Test (APIT) [4, 5]. Bulusu et al. [4] introduced a node positioning technology-centroid algorithm that has a lower computational complexity than that of the trilateration [5]. The positioning algorithm, such as Received Signal Strength Indicator (RSSI), of distance-dependence has better accuracy, but the survival of the network is stronger when the unknown node has not had a high positioning accuracy.

In order to improve the accuracy of centroid localization, this paper proposes a modified algorithm similar to the Virtual Reference Elimination (VIRE) algorithm [6]. This modified algorithm uses the signal propagation model [7] to construct the Received Signal Strength Indicator (RSSI) [8] information of virtual reference tags in location area and locates the object using traditional centroid algorithm. The VIRE realizes accurate position using a linear interpolation algorithm with adding a grid virtual reference tags based on the LANDMARC [9] algorithm.

To reduce the redundant calculation of VIRE algorithm, Shi et al. [10] used Subregion Selection (SRS) mechanism to reduce the interpolation area, and a nonlinear interpolation algorithm to calculate the RSSI values of virtual reference tags. Nevertheless, the location accuracy is affected by dividing areas [10].

To solve the above problem, this paper proposes an improved algorithm that combines with VIRE system and the original centroid algorithm according to the VIRE algorithm and the RSSI information of virtual reference tags that are established by signal transmission model in the location area. The simulation results show that the algorithm can further improve the locating accuracy without any additional hardware overhead in comparison with the original centroid algorithm.

The rest of the paper will be organized as follows. Section II will describe RSSI location, VIRE disposing and transmission model of wireless signal. Section III will describe the detailed research approach. Section IV will describe the experiments and error analysis. Finally, Section V will draw the conclusion and future work.

II. RELATED WORK

A. *Ranging methods*

According to the physical medium, there are four popularly ranging methods in the signal communications of sensor systems: 1) the RSSI (Received Signal Strength Indicator) [8], 2) the TOA (Time Of Arrival) [11], 3) the TDOA (Time Difference Of Arrival) [12], and 4) the AOA (Angle Of Arrival) [13]. The performance comparison of four ranging methods is shown in Table I.

 ISBN: 978-1-61208-310-0

TABLE I. THE COMPARISON OF RANGING METHOD BASED ON DISTANCE

Ranging method	Measuring distance	Hardware costs	Measurement Accuracy
RSSI	TOA	TDOA	AOA
>100m	>100m	10m	Short
Low	High	High	High
Low	High	High	High

Ranging method	Additional hardware	Transmission medium
RSSI	TOA	TDOA
AOA	Not need	GPS devices
Ultrasonic receiving apparatus	Antenna array	Electromagnetic
Electromagnetic	Ultrasonic wave, Electromagnetic	Ultrasonic wave, Electromagnetic

The TOA algorithm requires GPS-assisted equipment, which is not used in the indoor environment [16]. Ultrasonic transmission distance is limited, which is usually less than 10 meters, affected by angle, temperature, and obstructions [17]. The AOA is reliable only in the line of sight signal dominant circumstances [18]. It follows that these limitations of three positioning methods lead to an extreme difficulty in dealing with the complex indoor environments. The RSSI-based ranging method has the advantages of long transmission distance, lower cost, lower power consumption, easy node hardware, small size, and light weight [19]. However, the positioning accuracy of RSSI based methods is low, as it can only be used as a rough ranging method [19]. Thus, its positioning accuracy must be improved by an adjunct way.

B. Transmission model of wireless signal

The Received Signal Strength Indictor (RSSI) converts the loss during the process of transmission according to the signal intensity of transmitting and node received [14]. In the indoor location, the RSSI ranging signal propagation model can be simplified as (1) in consideration of environmental, cost, location accuracy requirements and other factors:

$$RSSI = -(10 n_1 \log_{10} d + k_1) \quad (1)$$

wherein, n_1 is the signal attenuation factor that is from 2 to 4; d is the distance of reference node and object node; k_1 is the measured RSSI of one meter, with the unit of dBm.

III. RESEARCH APPROACH

The approach is designed in two phases: first, the system structure and the algorithm based on virtual tags; second, the realization of algorithm in VIRE system.

A. System structure and algorithm based on virtual tags

1) Construction of VIRE system (VIRE disposing)

'Virtual Reference Elimination' (VIRE) is introduced in [6]. In the VIRE, instead of deploying many real reference RFID tags, the concept of virtual reference tags is provided as denser reference coverage in the sensing areas.

The distribution of VIRE reader R_i and reference tags, T_a, T_b, T_c and T_d are shown in Figure 1 with relationship, $a,b,c,d \in N^+$. The object tags are in the range of specified area. The core of VIRE method is related to 4 reference tags as a unit grid: N1xN1, shown in Figure 2.

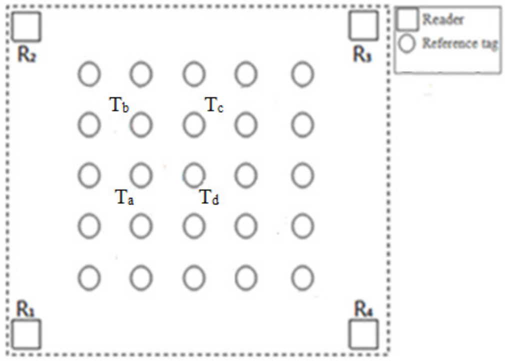


Figure 1. The distribution of VIRE readers and tags

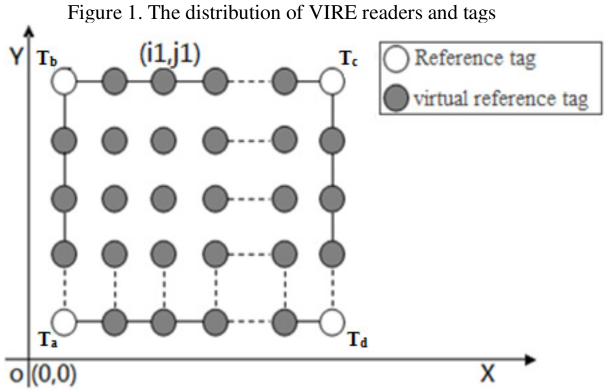


Figure 2. The distribution of virtual reference tags

Under the condition of known values of reference tags' position and density, the field strength of virtual reference tags in both horizontal and vertical directions is calculated by (2) and (3):

$$E_{Ri}(t,b) = E_{Ri}(a,b) + t \times \frac{E_{Ri}(a+N1,b) - E_{Ri}(a,b)}{N_1} \quad (2)$$

$$E_{Ri}(u,y) = E_{Ri}(a,y) + u \times \frac{E_{Ri}(a,b+N1) - E_{Ri}(a,b)}{N_1} \quad (3)$$

wherein, E_{Ri} is RSSI value of reference tag located at the coordinate (i, j) for the R_i reader. The values of parameters are $a = \lfloor i / N1 \rfloor$, $b = \lfloor j / N1 \rfloor$, t is known and located at *x* axis as the interval of object virtual reference tag, and u is known and located at *y* axis as the interval of object virtual reference tag.

Under the conditions of known values of the field intensity of reference tags and virtual reference tags, LANDMARC algorithm is normally used to select a certain threshold for solving the nearest reference tag weights, in order to obtain positioning results [10].

According to the VIRE system, this paper gives a further development of the positioning method.

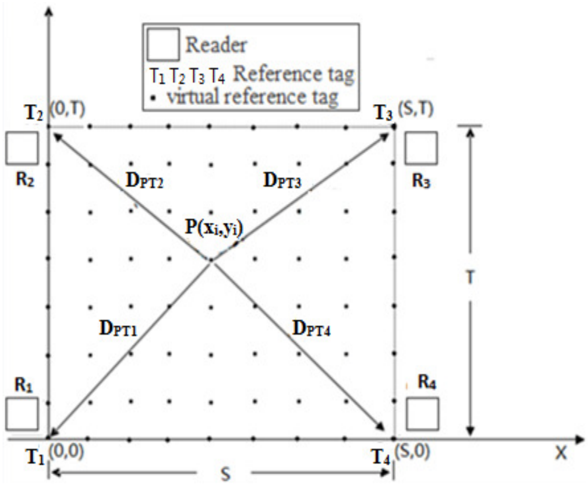


Figure 3. The definition of virtual reference tags area

The positioning system is for a two-dimensional plane. The location area has a size of S×T, where reference tags are the four vertices of the region, and the coordinates are $T_1(0,0)$, $T_2(0,T)$, $T_3(S,T)$, $T_4(0,S)$. Four readers are placed on those vertices, as shown in Figure 3.

Assuming the Coordinate of virtual reference tag D is (x_i, y_j), the Euclidean distance between D and reference tags T_i are:

$$
\begin{aligned}
D_{PT_1} &= \sqrt{x_i^2 + y_i^2} \\
D_{PT_2} &= \sqrt{x_i^2 + (y_i - T)^2} \\
D_{PT_3} &= \sqrt{(x_i - S)^2 + (y_i - T)^2} \\
D_{PT_4} &= \sqrt{(x_i - S)^2 + y_i^2}
\end{aligned} \tag{4}
$$

According to above (4), the tables are established for the four reference tags shown in Table II below.

TABLE II. VIRTUAL REFERENCE TAGS RSSI FOR REFERENCE TAGS

Distance of virtual reference Tags to the reference tags	RSSI value of virtual reference Tags relative to the reference tags
D_{PT_1}	$RSSI_{PT_1}$
D_{PT_2}	$RSSI_{PT_2}$
D_{PT_3}	$RSSI_{PT_3}$
D_{PT_4}	$RSSI_{PT_4}$

There are $(N1+1)^2 - 4$ data in the table.

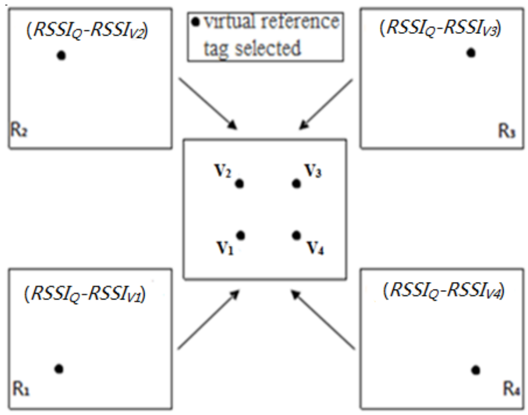


Figure 4. Process of selection of virtual reference tags

2) The selection of virtual tags

An object node is located at $Q(x_q, y_q)$, the RSSI values will be read by readers at four corners. A comparison was carried out with the virtual reference tags'RSSI from readers. The virtual reference tags that are nearest distance between $Q(x_q, y_q)$ are selected according to the following algorism.

IF $RSSI_Q > 0$
THEN
for i=1 to $(N1+1)^2 - 4$
do $Value_i = |RSSI_Q - RSSI_{V_i}|$
ELSE
Return (min Value$_i$*)*
Return i
end
End

The four virtual reference tags are selected in Figure 4 as below.

$$V_1(x_{v_1}, y_{v_1}), V_2(x_{v_2}, y_{v_2}), V_3(x_{v_3}, y_{v_3}), V_4(x_{v_4}, y_{v_4})$$

B. The realization of algorithm in VIRE system

1) Traditional centroid algorithm

According to the traditional centroid algorithm, the four virtual reference tags are selected to form an enclosed area that is the estimated area of the object node [12]. By (5), the estimate coordinates of object node can be calculated.

$$
\begin{cases}
x_q = \frac{1}{4}(x_{v_1} + x_{v_2} + x_{v_3} + x_{v_4}) \\
y_q = \frac{1}{4}(y_{v_1} + y_{v_2} + y_{v_3} + y_{v_4})
\end{cases} \tag{5}
$$

 ISBN: 978-1-61208-310-0

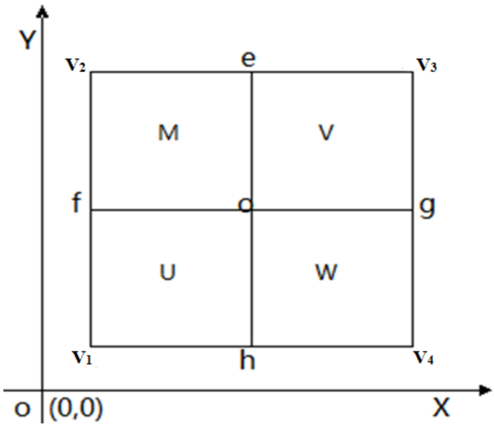


Figure 5. The schematic diagram of the renewed centroid algorithm

2) Renewed centroid algorithm

Through narrowing down the testing area, a key improvement of centroid algorithm in positioning accuracy is described as follows.

According to the geometric relationship, in Figure 5, the coordinates: e, f, g, h, and o, are defined in the following relationships of (6), (7), (8), (9) and (10):

$$x_e = \frac{1}{2}(x_{v_2} + x_{v_3}) \qquad y_e = \frac{1}{2}(y_{v_2} + y_{v_3}) \tag{6}$$

$$x_f = \frac{1}{2}(x_{v_1} + x_{v_2}) \qquad y_f = \frac{1}{2}(y_{v_1} + y_{v_2}) \tag{7}$$

$$x_g = \frac{1}{2}(x_{v3} + x_{v_4}) \qquad y_e = \frac{1}{2}(y_{v_3} + y_{v_4}) \tag{8}$$

$$x_h = \frac{1}{2}(x_{v_1} + x_{v_4}) \qquad y_h = \frac{1}{2}(y_{v_1} + y_{v_4}) \tag{9}$$

$$x_o = \frac{1}{4}(x_{v_1} + x_{v_2} + x_{v_3} + x_{v_4}) \qquad y_o = \frac{1}{4}(y_{v_1} + y_{v_2} + y_{v_3} + y_{v_4}) \tag{10}$$

The process of the renewed algorithm is as shown in Table III.

TABLE III. PROCESS OF THE RENEWED ALGORITHM

Conditions of judgment	Estimation region	Estimation of the object node's coordinate (x_{test}, y_{test})
When Δ_1 is Less than $\Delta_2 \Delta_3 \Delta_4$	In the region of U	The centroid of U: $\frac{1}{4}(V_1 + f + o + h)$
When Δ_2 is Less than $\Delta_1 \Delta_3 \Delta_4$	In the region of M	The centroid of M: $\frac{1}{4}(V_2 + f + o + e)$
When Δ_3 is Less than $\Delta_1 \Delta_2 \Delta_4$	In the region of V	The centroid of V: $\frac{1}{4}(V_3 + e + o + g)$
When Δ_4 is Less than $\Delta_1 \Delta_2 \Delta_3$	In the region of W	The centroid of W: $\frac{1}{4}(V_4 + g + o + h)$
When $\Delta_1 = \Delta_2$,and is Less than$\Delta_3 \Delta_4$	In the segment of fo	The midpoint of fo: $\frac{1}{2}(f + o)$
When $\Delta_3 = \Delta_4$,and is Less than$\Delta_1 \Delta_2$	In the segment of go	The midpoint of go: $\frac{1}{2}(g + o)$
When $\Delta_2 = \Delta_3$,and is Less than$\Delta_1 \Delta_4$	In the segment of eo	The midpoint of eo: $\frac{1}{2}(e + o)$
When $\Delta_1 = \Delta_4$,and is Less than$\Delta_2 \Delta_3$	In the segment of ho	The midpoint of ho: $\frac{1}{2}(h + o)$

IV. THE SIMULATION AND ERROR ANALYSIS

In the simulation experiment, Matlab7.6.0 software is used. There are two indicators of size set up and the positioning accuracy is set as the evaluation criteria, when the positioning precision, scale, network coverage rate, and power consumption are often used as the evaluation index in the WSN. In the simulation experiment, the WSN area is set that the S and T are equal to 90. The reference tags are located at the four vertices of this area and uniformly distributed. The positioning error of the object nodes is defined in (11):

$$AverageError = \frac{\sqrt{(x_q - x_{real})^2 + (y_q - y_{real})^2}}{s_1} \qquad (11)$$

Wherein, s_1 is the times of the Simulation.

A. *Searching the optimum number of the virtual reference tags*

As shown in Table IV, ten object nodes' RSSI are from the reader R_i, where i is shown as 1, 2, 3, 4.

TABLE IV OBJECT NODES'S RSSI

unit(dBm)	Object node1	Object node2	Object node3	Object node4	Object node5	Object node6	Object node7	Object node8	Object node9	Object node10
Reader R_1	-72.5	-72.9	-70.6	-68.2	-72.4	-74.2	-76	-75.7	-78.9	-83.5
Reader R_2	-72.3	-72.2	-72.8	-71.4	-71.8	-72.4	-76.7	-68	-73.2	-68.6
Reader R_3	-73.2	-71.1	-75.8	-73.2	-65.1	-66.2	-60.8	-67.2	-66	-50.5
Reader R_4	-72.4	-72.4	-71.5	-72.2	-70.9	-72.2	-72.6	-67.8	-66.2	-68.1

When the number of the virtual reference tags increases, the error in comparison with the two algorithms are illustrated in Figures 6 and 7.

Figure 6 shows that there is no obvious change between the two algorithms, if the number of the virtual reference tags is above 121 and the 90/N2 is greater than 10. The best performance shows that the number of the virtual reference tags is 49 when 90/N2 is equal to 6. It follows that the renewed centroid algorithm could further improve the accuracy compared with the traditional centroid algorithm.

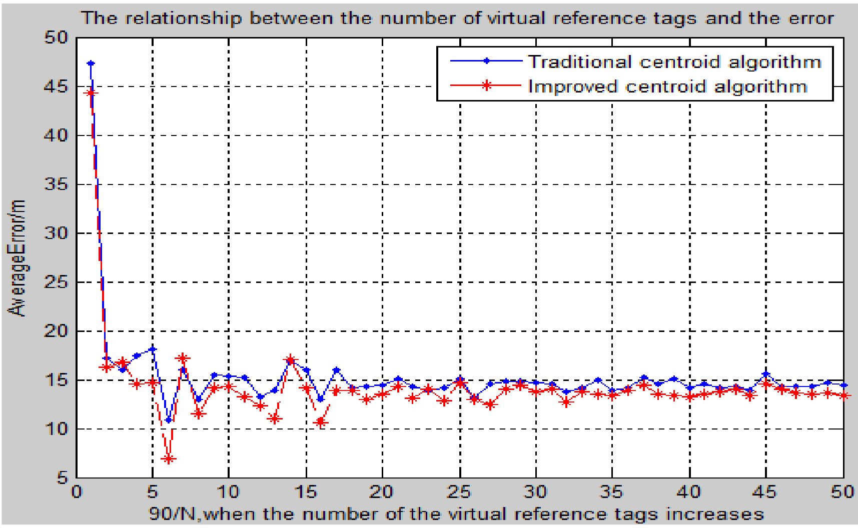


Figure 6. The difference between two algorithms

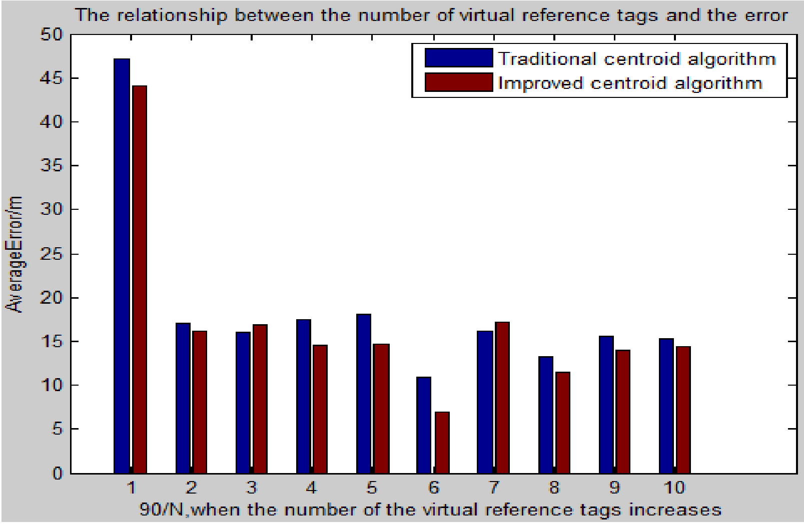


Figure 7. The error comparison of two algorithms when the number of the virtual reference tags increases

B. Comparison of the two algorithms when the number of virtual reference tags is 49

Figure 8 shows that the results are obtained by (5) from the test for 100 times. It is clear that the renewed centroid algorithm gets a further improved localization accuracy compared with the traditional one.

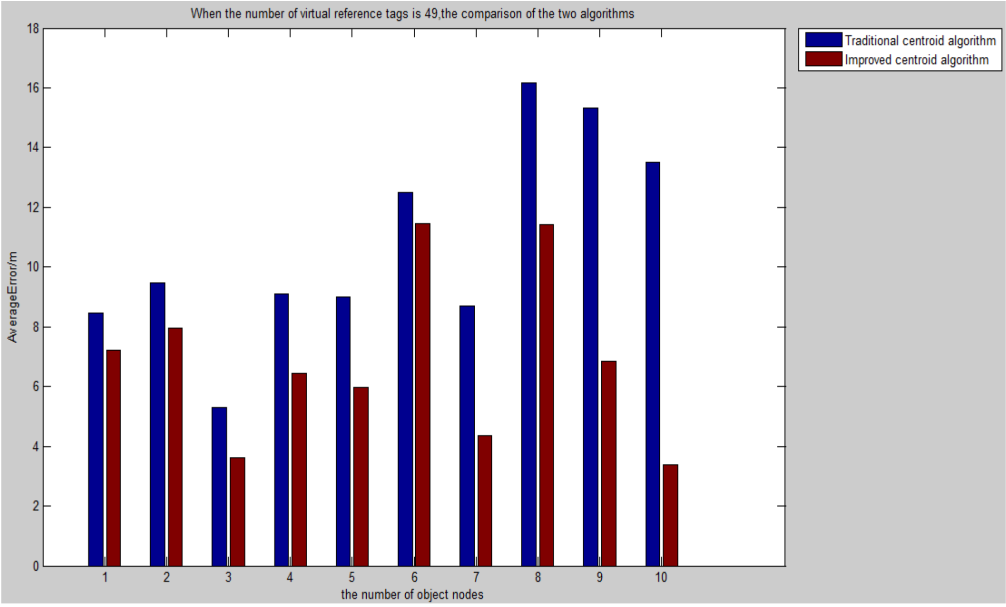


Figure 8. The comparison of the two algorithms

C. Error analysis

For the virtual reference tags, they may not be able to choose four ones near the object node, or four virtual reference tags are repeatedly chosen, as it may lead to excessive error(s). In the radio propagation model, the signal is disturbed by the external environment instead of being transmitted in free space. Through repeated measurements and the statistical average value, some error can be reduced, although the further improvement is still needed.

V. CONCLUSION AND FUTURE WORK

A. Achievements

One of the hot topics in WSN is localization of the object node. The paper proposes an improved centroid algorithm combined with the VIRE system. The algorithm is simple. The positioning accuracy of the object nodes has been improved significantly in comparison with the traditional centroid algorithm. This new algorithm can be used to solve the problem of the low localization accuracy of the traditional centroid algorithm.

B. Future work

However, there are still some shortcomings existing in the positioning methods. On one hand, the signal propagation model applicable to non-free-space conditions needs further research. On the other hand, the selection methods of the virtual reference tags need further optimization so as to further improve the positioning accuracy.

Acknowledgement: authors thank Dr Sawsaa's feedback and proof reading for the final version of the paper.

REFERENCES

[1] S. K. Low, H. A. Nguyen, and H. Guo, Optimization of sensor node locations in a WSN[C]//Fourth International Conference on Natural Computation. 2008, pp. 286-290.

[2] G. Mao, B. Fidan, and B. D. O. Anderson, "Wireless sensor network localization techniques," Comput. Netw., vol. 51, pp. 2529–2553, 2007.

[3] C. Liu, H. Jiang, and D. Wang, Range-based node localization algorithm for wireless sensor network using Unitary Matrix pencil[C]//Test and Measurement, 2009, ICTM'09, International Conference on. IEEE, 2009, vol. 2, pp. 128-132.

[4] N. Bulusu, J. Heidemann, and D. Estrin, GPS-less low-cost outdoor localization for very small devices [J], Personal Communications, IEEE, 2000, vol. 7(5), pp. 28-34.

[5] D. Moore, J. Leonard, and D. Rus, Robust Distributed Network Localization with Noisy Range Measurements[C]. Proceedings of the 2nd International Conference on Embedded Networked Sensor Systems, Baltimore, USA, 2004: 50-61.

[6] Z. Yiyang and L. Yunhao, VIRE: Active RFID-based localization using virtual reference elimination[C], XiAn, 2007 International Conference on Parallel Processing, 2007, pp. 56-63.

[7] M. Srivastava, D. Culler, and D. Estrin, Guest editors' introduction: overview of sensor networks [J], Computer, 2004, vol. 37(8), pp. 41-49.

[8] L. Girod, V. Bychovskiy, J. Elson, and D. Estrin, Locating Tiny Sensors in Time and Space: A Case Study, [C]//Proceedings of the 2002 IEEE International Conference on Computer Design: VLSI in Computers and Processors. Freiburg, IEEE, 2002, pp. 214-219.

[9] M. N. Lionel, Y. H. Liu, and Y. C. Lau, LANDMARC: Indoor location sensing using active RFID [J], Wireless Networks, 2004, vol. 10(6), pp. 70l-7l0.

[10] W. Shi, L. Liu, Y. Ju, G. Yan, and G. An Efficient Indoor Location Algorithm Based on RFID Technology, [C]//Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on. IEEE, 2010, pp. 1-5.

[11] J. Caffery, A new approach to the geometry of TOA location [C]//IEEE VTC2000 Fall September 24—28, Boston, USA, 2000, pp. 1943—1949.

[12] J. Yoon, J W. Kim, W. Y. Lee, and D. S. Eom, A TDOA-based localization using precise time-synchronization[C], Advanced Communication Technology (ICACT), 2012 14th International Conference on, IEEE, 2012, pp. 1266-1271.

[13] J. Zhou, H. Zhang, and L. Mo, Two-dimension localization of passive RFID tags using AOA estimation, [C]//Instrumentation and Measurement Technology Conference (I2MTC), 2011 IEEE, 2011, pp. 1-5.

[14] L.M. Sun, J.Z. Li, and Y. Chen, WSNs [M], Tsinghua University Press, 2005, pp. 135-155.

[15] H. Shi, A new weighted centroid localization algorithm based on RSSI, [C]//Information and Automation (ICIA), 2012 International Conference on. IEEE, 2012, pp. 137-141.

[16] N. Saiedeh and O. M. Razavi, GPS-less indoor construction location sensing, original research article, Automation in Construction, vol. 28, December 2012, pp. 128-136

[17] X. Guangzhen, P. Yang, and L. He, Estimation of diffraction effect in ultrasonic attenuation by through-transmission substitution technique, original research article, Ultrasonics, April 2013, vol. 53, Issue 4, pp. 825-830

[18] M. Dakkak, A. Nakib, B. Daachi, P. Siarry, and J. Lemoine, Indoor localization method based on RTT and AOA using coordinates clustering, original research article, Computer Networks, 1 June 2011, vol. 55, Issue 8, pp. 1794-1803

[19] W. Huanhuan, J. Wang, and R. Liu, A Novel Ranging Method Based on RSSI, original research article, Energy Procedia, 2011, vol. 12, pp. 230-235.

An Integrated SDN Architecture for Applications Relying on Huge, Geographically Dispersed Datasets

Andy Georgi
Technische Universität Dresden
E-Mail: Andy.Georgi@tu-dresden.de

Reinhard G. Budich
Max Planck Institute for Meteorology
E-Mail: Reinhard.Budich@zmaw.de

Yvonne Meeres
Max Planck Institute for Meteorology
E-Mail: Yvonne.Meeres@zmaw.de

Rolf Sperber
Embrace HPC-Network Consulting
E-Mail: Rolf.Sperber@embrace-net.de

Hubert Hérenger
T-Systems Solutions for Research GmbH
E-Mail: Hubert.Herenger@t-systems-sfr.com

***Abstract*—The target of our effort is the definition of a dynamic network architecture meeting the requirements of applications competing for reliable high performance network resources. These applications have different requirements regarding reliability, bandwidth, latency, predictability, quality, reliable lead time and allocatability. At a designated instance in time a virtual network has to be defined automatically for a limited period of time, based on an existing physical network infrastructure, which implements the requirements of an application. We suggest an *integrated Software Defined Network* (SDN) architecture providing highly customizable functionalities required for efficient data transfer. It consists of a service interface towards the application and an open network interface towards the physical infrastructure. Control and forwarding plane are separated for better scalability. This type of architecture allows to negotiate the reservation of network resources involving multiple applications with different requirement profiles within multi-domain environments.**

Keywords – Software Defined Networking, Huge Data, Network Architecture

I. Introduction

In fields like climate research, astronomy and high energy physics, international collaboration is standard today. Consequently, mass data have to be transported between compute and storage sites. Federation techniques consolidate the view on dispersed datasets, however they do not transport them. Mass data applications relying on multi-site datasets require networks with highest possible bandwidth and additional features, such as low latency and low latency variation at a dedicated instance of time for a period of time.

Applications taking advantage of distributed computing rely on highest possible bandwidth and lowest possible delay and delay variation for short periods of time. Both types of applications should be able to utilize the same network without mutual interference. Current developments like the Open Flow standard [17] and the Network Service Interface (NSI) [21] suite are a step towards fully automated virtual network provisioning. The NSI activities bridge the gap between application and network while OpenFlow standardizes the communication between controller and network element.

In this paper, we introduce an integrated multi-domain SDN architecture, in which network control is decoupled from forwarding and directly programmable by open interfaces between different layers. In Section II some approaches targeting similar objectives are evaluated. Our architecture as well as an automated network configuration process arbitrating between the concurrent applications competing for network resources is described in Section III. Finally, we summarize our approach in Section IV.

II. Related work

Approaches to provide application-oriented sustained network services on demand already exist. Also, protocols for traffic engineering and optimization were specified. For both, some examples are given in this section, together with the reason they don't gain acceptance.

A. Network service architectures

ITU-T G. 805 03/2000 [1] describes a technology independent functional architecture of a transport network. At the time the standard was written it provided a set of functional architecture recommendations for the prevailing network transport technologies. However, because of the agnostic character of G.805 it is valid for all types of current transport technology and future implementations to come. Multi layer networking and multi layer control plane interworking are not considered.

GMPLS [16] is a generalization of IP/MPLS for layer 1 transport services. It was initially defined to enable dynamic restoration in transport networks. In the course of the VIOLA project [14] UNI-Client and UNI-Server interworking was implemented between the transport layer and an IP/MPLS layer. This way bandwidth requirement from the IP/MPLS layer could be communicated to the transport layer.

The common Network Information Service Schema Specification (cNIS) activities [15] by Geant2 community are targeted at supplying domain related network information to the application layer regardless of the network layers present in the respective domains. Inter domain exchange of information is part of the service. The cNIS activities are vital for the NSI definition.

G.805 abstracts from hardware related description of transport networks, GMPLS defines cross network layer interworking and cNIS finally makes the networking layer transparent for the application layer. The missing link is a control interface between the application and the network.

B. SDN architectures

We also evaluated other SDN approaches like e.g. [5], [6], [7], [8] or [20]. Thereby we recognized three main deficiencies:
1) Single-domain solutions only ([5], [8])

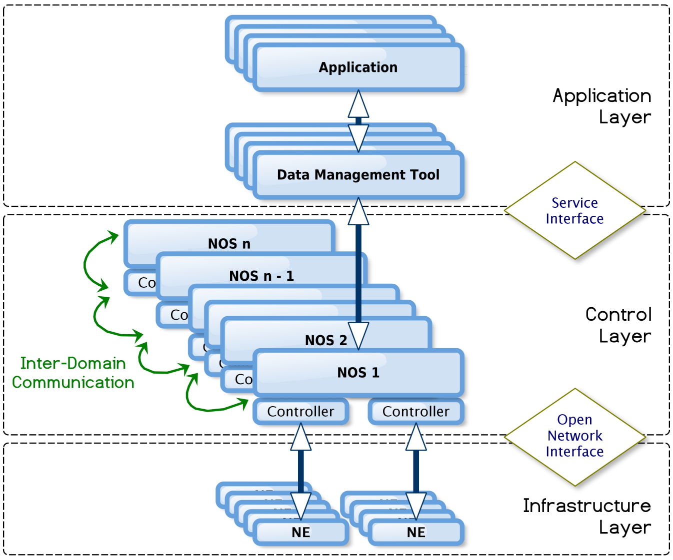


Fig. 1: Integrated SDN architecture overview

2) Based on a specific protocol like OpenFlow ([6], [8])
3) Missing consideration of the application layer ([7], [20]).
Hence, our architecture described in the following section will support end-to-end negotiation of network resources, depending on the requirements of the application. Thereby, applications are implemented by the end user and not equatable to network functions. Communication partners can be located within different domains and the infrastructure is not limited to a single protocol.

III. Integrated SDN Architecture

To provide application-oriented network services, we suggest an architecture consisting of three layers, depicted in Figure 1. The infrastructure layer defined by the network providers and hardware vendors is usually characterized by a vast heterogeneity. It lays at the bottom of our architecture. The control layer in the middle abstracts from the infrastructure layer and prevents direct user access to the hardware. At the top level sits the application layer representing the users view on this network architecture.

Interoperability between these layers enables an application- and user-oriented network infrastructure. To achieve this, additional communication protocols have to be specified providing the required functionality. Therefore, we introduce an Open Network Interface (ONI) between infrastructure and control layer as well as a Service Interface (SI) with an appropriate connection service protocol between control and application layer.

In the following, we describe the layers and the intermediate communication protocols in more detail and give an example of a communication process within this architecture.

A. Layer description

In the following sections we describe the three layers of the introduced architecture. The application layer representing the users view, the control layer as intermediary between application and network hardware, and the infrastructure layer, consisting of the network elements and their interconnects.

TABLE I: Time to Transport 1 TB and 1 PB of Data from one Climate Center to Another [9]

Transfer Rate	*Time to Transport Data of Size* 1 TB	1 PB
10 Mbps	9.7 days	27.20 years
50 Mbps	1.94 days	5.44 years
100 Mbps	23.3 hours	2.72 years
1 Gbps	2.28 hours	97.1 days
10 Gbps	13.65 minutes	9.7 days
100 Gbps	81.9 seconds	23.3 hours

1) Application Layer: The activities in data management rely on fast, broadband, reliable networks. At the moment, intercontinental network speeds are limited to 40 Gb/s [4]. The project *Advanced North Atlantic 100G Pilot* (ANA100G) tries to reach the 100 Gb/s barrier [10] On the other hand, practical experience shows, that the opportunistic networks (WANs) available today do not offer enough reliability, predictability and speed per cost necessary for the applications from the "Data Tsunami".

The international *Coupled Model Inter-comparison Project* (CMIP) [3] conducts sets of co-ordinated experiments with numerical climate models to compare them against each other. This comparison of climate models serves as the basis for the *Assessment Reports*, on which the Nobel Laureate *International Panel on Climate Change* (IPCC) bases its recommendations for policy makers.

Numerical Climate Models regularly utilise to a high percentage high performance computers like those to be found in the TOP500 list [22]. They also swamp these computers with data volumes at the bleeding edge of the most current technologies available (for an overview of some of the problems see e.g. [13]). As the name of the project suggests (Coupled Model Inter-*comparison* Project), these data need to be compared. Since the models and their data are situated at different places, they have to be transported. Or the applications that compare the data have to be available near to the data – unfortunately practical experience shows that it is much easier to organise data near to applications than applications near to data, see e.g. the results of the German C3-Grid initiative [11].

The climate modeling community agreed upon sub-setting the data to a volume of about 1,5 PB, containing only those data most relevant for the comparison, and to make these data available in five centers world-wide for easier access and replication [3]. ESnet says: "The fastest we could hope to move only 1 PB of data from PCMDI to one of the RCA data centers is essentially one day at 100 Gbps, whereas with a peak of 10 Gbps, it would take almost 1.5 weeks." An estimation of the speeds following the ESnet can be found in Table I, whereas the last row – the 100 Gbps – are not reached yet, but only addressed in the ANA100G project [10]. The fact that many network lines outward bound from centers seem rather underutilised does not contradict this observation: Burst-wise utilisation is common-place, people try to get their job done, but the unreliability of the connections and the fact that the slowest part of the complete connection limits the transfer speed, make life of the users difficult: Maintaining constantly high data transfer speeds is near to impossible today.

If we interpret current negotiations about CMIP6, the future edition of CMIP, correctly, it can be expected that the data volumes will be 1 to 2 orders of magnitude higher than in CMIP5, with the intercontinental network speeds staying about the same. With respect to the architecture of the application layer it can be expected that the available system (ESGF) will be stabilized and possibly extended by a federated file system. The situation for the CMIP5 data: Until now the scientists have to search through a data jungle by clicking through web portals, looking at folders on different servers or using scripts. With neither of these methods all data can be accessed. E.g. the scriptbundle called synchro-data [19] can access only the data available with the new ESGF login method, not with the old one, and requires a special port which is then locked. Two users at one time can't download from the same machine at the same time. Again: many networks seem to be underutilised, but not because the scientists don't need their data, but because retrieving them is intransparent. The scientists want to know how to get the data and how long the transfer takes.

A data management tool hides this data access complexity. It informs about the expected time constraints and offers reserving mechanisms. In contrast to the current tools it offers a feedback about the transfer – a very essential but missing feature. This new functionality is offered by lower SDN layers to the application layer.

A totally different, but also very demanding application for the network is state-of-the-art turbine development as it is performed at DLR (*German Aerospace Centre*). It requires a multitude of different process chains to be completed. Such process chains typically consist of different simulation tools such as CFD and CSM solvers, which are executed in a specific collaborative order. The data is needed "just in time": At DLR different clusters of different sizes and configurations are available at geographically distributed locations. Optimal resource usage implies high flexibility in where to run jobs. In order to avoid necessity of moving data to a selected resource in order to be able to run a job it is desirable to provide reliable and fast access to all data from all different resources and locations. This is not "Big Data" application but it urges the network to be prioritized.

Thus we have the climate application which needs high bandwidth for a long time and can manage interruptions, and the turbine application which needs prioritization to receive the data as fast as possible. These two applications do not cumber each other and are a good example for challenging our SDN architecture.

2) Control Layer: Our control layer, depicted in Figure 2, consists of two main components – the Network Operating System (NOS) on the application side and one or more Controllers on the side of the infrastructure. The communication between the upper and lower layer is realized by a north- and southbound API. Additionally the NOS module within the control layer needs an interface for inter-domain communication to enable multi-domain interoperability.

The NOS we introduce operates similar to typical operating systems. Within its domain it interacts as an intermediary between applications and network hardware, to avoid direct access to the network hardware and to hide unnecessary information. This increases the security on the one hand and enables the possibility to virtualize the network on the other hand. Therefore, the integrated Broker compares the requirements – transmitted through the northbound API – with the available network resources – which can be requested through the southbound API – and instructs the reservation if available resources meet the requirements. Negotiation between application layer and network layer should be possible. The requesting application receives only a partial graph, which can be a direct link with the corresponding characteristics between ingress and egress at the end.

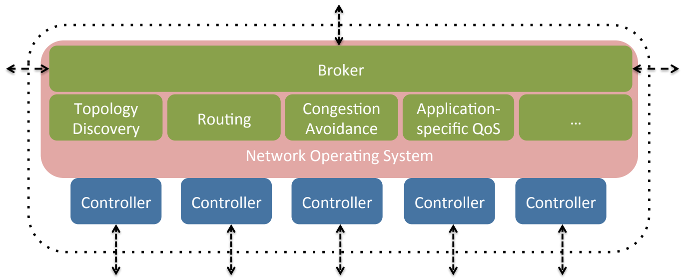


Fig. 2: Single domain control layer overview

Besides the virtualization our approach also takes traffic engineering into account. Link state information can be updated periodically or requested on demand via the southbound API. This way, weighted graphs are composed for the entire domain, in which the weights can represent any link parameter – like bandwidth, latency, utilization or costs – or any combination of them. Based on these graphs the route is optimized w.r.t. the requirements of the applications. Link parameters should not change during transmission. However, if a change is inevitable, the network resources dedicated to a certain application should be adapted within feasible bounds.

Real time communication is another feature which can be implemented within this network architecture. Especially with respect to large data volumes the transfer completion time is often more important than the entire transfer time. Knowing this point in time allows more efficient resource planning which can result in reduction of costs. This functionality is enabled by allowing reservations of network resources for specific periods of time. The reservations for specific flows are managed by the Broker, which has a global view on the entire domain. Thereby, overcommitment can be avoided and start and end points of the data transfer can be guaranteed.

All described features are necessary to transfer the amounts of data described in Section III-A1 efficiently through a shared multi-user network. Many different algorithms and other features exist, which can be realized by this architecture. So, we encapsulate these functionalities in different modules, which can be added, replaced or removed during runtime without interruption, similar to loadable kernel modules. Thereby, every domain can optimize its control layer for its requirements as long as the interoperability is still guaranteed.

To enable the described functionality between multiple domains, an inter-domain communication is required. Those incoming and outgoing requests are also handled by the Broker and will be processed similar to intra-domain requests. Therefore, external and internal request messages may only differ in the source tag which determines the security group classification and the consequential permissions of the service requestor.

Beside the loadable kernel modules and the Broker we

 ISBN: 978-1-61208-310-0

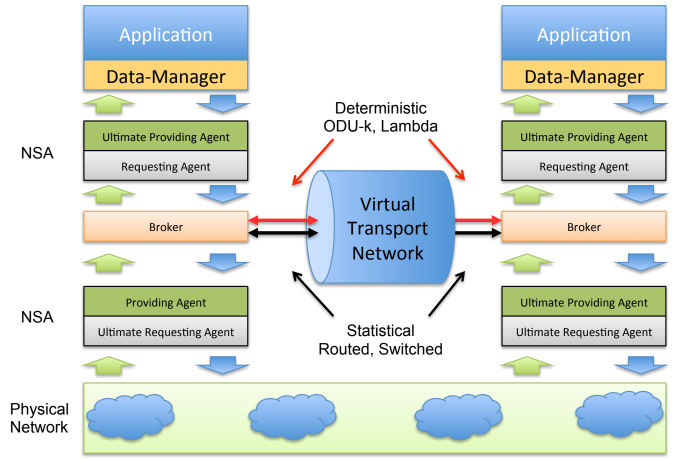


Fig. 3: Deterministic and statistically multiplexed transport

suggest to encapsulate the Controller as executive unit. Controllers implement the interface to the network infrastructure and perform requests or reservations, instructed by the Broker. Since this can result in a bottleneck depending on the number of requests and the domain size, we recommend to use more than one Controller. Thereby the separation from the NOS enables scalability by varying the number of Controllers depending on the network size and work load. An additional aspect which motivates for separation of NOS and Controller are the heterogeneous interfaces we expect to be provided by the network hardware vendors. To enable compatibility, at least one Controller for every network interface implementation has to be provided. The integration is mainly realized by the hardware vendors, similar to hardware drivers in conventional operating systems. Hence the encapsulation of the Controllers guarantees scalability and interoperability in our proposed architecture.

In summary the control layer we introduce provides required functionalities – like network virtualization, adaptive routing or real time communication – for the application layer, to enable an efficient transfer of big data volumes. The layer is highly customizable by integrating the functionality within loadable kernel modules which can be added, substituted or removed on demand. Additionally we took into account scalability and compatibility of an heterogenous infrastructure by encapsulating the Controllers as executive units.

3) Network Layer: In data networks there is a hierarchy of deterministic transport and statistical multiplexing. Deterministic transport can be utilized for client-to-client communication and as a transport layer for, e.g., routed services. The Broker instance shown in Figure 3 arbitrates between the requirements of multiple applications and available network services. Based on requirements communicated by the Network Service Agent (NSA), it will decide if the requested capacity will be provided on a deterministic or routed path.

Multi domain networks suffer from a lack of homogeneity. This in turn requires abstraction that allows for a unified network description language. The Network Description Language (NDL), introduced in [12], is a modular set of schemata. The topology schema describes devices and interactions between them on a single layer. The layer schema takes into account the existence of multiple layers and interactions between these layers. Capabilities of network devices are described in the capability schema and domain schemata have to deal with different domains and in consequence with administrative entities and services linked to these entities. Finally the physical schema describes the physical aspects of network elements. This set of schemata defines the ontology of network functionality.

TABLE II: SERVICE INTERFACE PRIMITIVES

Primitive	*Description*
RESERVE	The **requesting agent** (RA) requests the **providing agent** (PA) to reserve network resources
PROVISION	The RA requests the PA to provision network resources according to the previous reserve request. Depending on actually available resources the provision request may differ from the reserve request.
RELEASE	The RA requests the PA to de-provision resources without removing the reservation
ACTIVATE	The RA requests the PA to activate provisioned resources
TERMINATE	The RA request the PA to release provisioned resources and terminate the reservation
FORCED END	PA notifies RA that a reservation has been terminated
QUERY	Can be used as a status polling mechanism between RA and PA

Since most applications rely on resources from different domains, information about services and capabilities of these domains will have to be interpreted and coordinated. An application and its related data management is attached to a single domain. All information from external domains should be gathered here and communicated to the data manager to enable negotiation.

B. *Communication Interfaces*

Interoperability between the layers introduced in Section III-A requires information exchange. Therefore, interfaces have to be defined, which enable communication in both directions. To achieve compatibility, open interface standards are preferred. The following sections describe general requirements for service and network interfaces.

1) Open Service Interface (OSI): The northbound interface of the control layer communicates with the application layer, the southbound interface with the network layer. Since there is a multitude of network domains, horizontal communication is mandatory to enable federated network services based on a virtual multi domain network. Therefore both, application and control layer, implement embedded Network Service Agents (NSA) which are connected by a service interface. The application NSA is called requesting, the control layer NSA providing agent. Multiple services can be handled by a single NSA, in fact, as many as there are available on the end to end infrastructure. The requesting agent communicates only with the local NOS, information from other network domains is gathered and provided by the remote home domain NOS.

Because the NSA has no authority about local or remote resources, any kind of resource management is realized by the NOS in conjunction with the controller. Flexibility regarding to the introduction of new network services is enabled by the modularity of the OSI and NSA concept.

The OSI connection protocol communicates requirements to the providing agent and consists of 6 primitives, listed in Table II. These requirements have to be mapped on the corresponding QoS properties – sustained bandwidth, latency

 ISBN: 978-1-61208-310-0

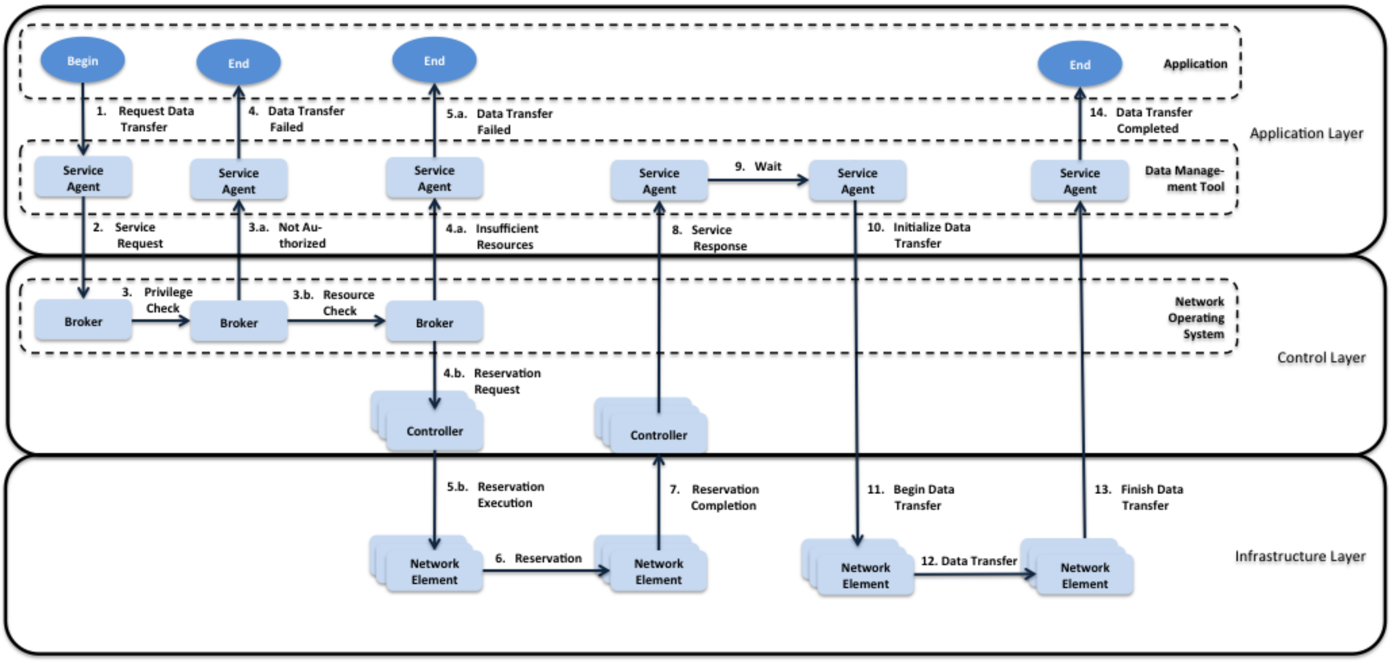


Fig. 4: Communication process within an integrated SDN architecture

and maximum latency variation. Furthermore the dedicated instance of time a certain transmission should start is communicated. The providing agent either answers with a complete confirmation or starts negotiating with the requesting agent. Once a service is confirmed there will be no further negotiations or limitations.

2) Open Network Interface (ONI): Current network elements implement control and forwarding plane on the same closed platform. Decoupling this control functionalities from the infrastructure, requires a protocol to exchange information between these two layers. This section describes the functions, required to implement the features described in Section III-A2.

An efficient placement of data flows requires a global view on the underlaying infrastructure. Therefore the position of all network elements within a domain and their connection between themselves has to be announced to the control layer. This can be implemented by an initialization message during the startup of a network element and a link discovery protocol like LLDP [2]. Once a network element and its connections is known, state changes are noticed implicitly as soon as a data flow can not be routed anymore. In this case the link is removed from the topology graph until the node is back and sends the initialization message.

Once the underlaying network topology is identified, link characteristics like bandwidth, latency or cost have to be communicated to the control layer during the initialization phase. These mostly static properties are stored together with source and destination of a link and are used to build a weighted graph for data transfers if requested.

Next to these properties, there are more varying link state informations like utilization, message rate or number of flows. Updating these values on every change would cause an immense overhead. Therefore these informations are requested periodically by the Controller and only reported to the NOS as soon as values exceed predefined thresholds. The controller can request these informations explicitly by a message, or implicitly as soon as a data transfer is completed.

Additionally to the upward directed information flow the ONI has to implement the reservation requests from the Control Layer to the network elements. These reservation requests can be combined with a period of time during which they are valid. If the reservation observance can be handled by the network elements only, the requests have to be transmitted. If not, the control layer has to add the reservation at the beginning and remove it at the end. This causes more overhead, but leaves the control function within the dedicated layer.

As described, the main objective of the ONI is to provide information about the infrastructure for the control layer to enable efficient traffic engineering. To reduce the emerging overhead, information should be updated implicitly on occurring events which already require a communication. Additionally the executive commands instructed by the control layer have to be transmitted to the network elements by the ONI.

C. Communication process

Specified requirements for data transfers can not be satisfied in any case, e.g., if the request exceeds available capacities. To ensure a data transfer anyway and independent from the current utilization, we recommend to partition the available capacity. One part for best-effort transfers, the other one for optimized SDN communications. This way, rejected data transfer requests can use conventional communication protocols. Also for small data sets the best-effort transfer might be the better path. Since the conventional best-effort communication is known, we confine the description in this section to the optimized SDN communication.

Figure 4 depicts the chronological sequence of a demand-oriented communication within the introduced SDN architecture. Thereby the application communicates its requirements

 ISBN: 978-1-61208-310-0

to the data management tool first. The integrated service agent determines the network services which are required to satisfy the request. Subsequently the agent can apply for these services by forwarding the request to the Broker of the Control Layer.

As described in section III-A2 the Broker verifies incoming requests. If the requestor is not authorized to use these services or if there are not enough resources to fulfill the request, the transfer fails and the application is informed by the service agent. At this point, a new request with different requirements can be initiated. This process can be repeated until both sides accept the conditions. The negotiation phase can also be implemented transparent to applications within the data management tool. This way the application defines tolerable ranges for the requested network parameters instead of single values. If both sides can not agree on a parameter set, the application has to transfer the data by using the conventional best-effort path.

If the request is valid the Broker initializes the reservation process and instructs all required Controllers to distribute the reservation to all participating network elements. Once all reservation confirmations arrived at the Controller, the Service Agent can be informed about the conditions of the requested transfer. At the communicated start point the data transfer can be initialized and accomplished. From the application's point of view, the following transfer does not differ from the conventional communication process, except that the infrastructure behaves like negotiated in the initialization phase.

As Figure 4 and the description of the communication process show, the overhead increases due to the initialization phase. Therefore the optimized data path is only recommended for elephant flows, where the transfer time is much higher than the startup time. In this case the overhead to define an optimized environment is worthwhile. However, small flows may still use the conventional data path.

IV. Conclusion

Our integrated SDN architecture enables concurrent applications competing for network resources, to define virtual networks that satisfy their respective requirements providing efficient network usage and reliable data transfers. We introduced the elements necessary for an end-to-end negotiation of network resources between multiple domains and without any limitation to specific protocols. The authors of this paper already introduced a first SDN prototype on the ISC'13 [18], based on a 400 Gbits demonstrator between the *Center for Information Services and High Performance Computing* (ZIH) in Dresden and the *Rechenzentrum Garching* (RZG).

References

[1] ITU-T Recommendation G.805: Generic functional architecture of transport networks. Technical report, International Telecommunication Union, Mar. 2000.

[2] IEEE Standard for Local and Metropolitan Area Networks– Station and Media Access Control Connectivity Discovery. *IEEE Std 802.1AB-2009 (Revision of IEEE Std 802.1AB-2005)*, pages 1–204, 2005.

[3] CLIVAR Exchanges - Special Issue: WCRP Coupled Model Intercomparison Project - Phase 5 - CMIP5. Project report, May 2011.

[4] Alcatel-Lucent. Alcatel-lucent upgrades cable system linking japan and california, January 21 2013. Retrieved April 26th, 2013, from http://www3.alcatel-lucent.com.

[5] Big Switch Networks. The Open SDN Architecture. Technical report, Big Switch Networks, Inc., 2012.

[6] N. Blefari-Melazzi, A. Detti, G. Morabito, S. Salsano, and L. Veltri. Information centric networking over sdn and openflow: Architectural aspects and experiments on the ofelia testbed. *CoRR*, abs/1301.5933, 2013.

[7] M. Casado, T. Koponen, S. Shenker, and A. Tootoonchian. Fabric: a retrospective on evolving sdn. In *Proceedings of the first workshop on Hot topics in software defined networks*, HotSDN '12, pages 85–90, New York, NY, USA, 2012. ACM.

[8] O. M. E. Committee. Software-Defined Networking: The New Norm for Networks. Technical report, Open Networking Foundation, April 2012.

[9] Energy Sciences Network ESnet. BER Science Network Requirements; Report of the Biological and Environmental Research. LBNL report LBNL-4089E, Network Requirements Workshop, April 29-30 2010.

[10] Energy Sciences Network ESnet. ESnet Partners with North American, European Research Networks in Pilot to Create First 100 Gbps Research Link Across Atlantic, April 24 2013. Retrieved April 26th, 2013, from http://esnetupdates.wordpress.com.

[11] C. Grimme and A. Papaspyrou. Cooperative negotiation and scheduling of scientific workflows in the collaborative climate community data and processing grid. *Future Generation Computer Systems*, 25:301–307, 2009. Publication status: Published.

[12] P. Grosso, A. Brown, A. Cedeyn, F. Dijkstra, J. van der Ham, A. Patil, P. Primet, M. Swany, and J. Zurawski. Network topology descriptions in hybrid networks, March 2010.

[13] N. Hemsoth. 20 lessons enterprise cios can learn from supercomputing. *datanami*, November 2012. http://www.datanami.com/datanami/2012-11-12/20_lessons_enterprise_big_data_buffs_can_learn_from_supercomputing.html.

[14] P. Kaufmann. *Gesamtdarstellung des VIOLA-Projektes (Vertically integrated optical testbed for large applications in DFN)*. DFN-Verein, 2007.

[15] M. Labedzki, C. Mazurek, A. Patil, and M. Wolski. common network information service - modelling and interacting with a real life network, 2009.

[16] E. Mannie. Generalized Multi-Protocol Label Switching (GMPLS) Architecture. RFC 3945 (Proposed Standard), October 2004.

[17] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner. Openflow: enabling innovation in campus networks. *SIGCOMM Comput. Commun. Rev.*, 38(2):69–74, Mar. 2008.

[18] R. Budich, A. Georgi, J. Müller and R. Sperber. International Supercomputing Conference 2013, June 2013.

[19] J. Raciazek. *synchro-data script bundle*. Technical documentation. http://dods.ipsl.jussieu.fr/jripsl/synchro_data.

[20] B. Raghavan, M. Casado, T. Koponen, S. Ratnasamy, A. Ghodsi, and S. Shenker. Software-defined internet architecture: decoupling architecture from infrastructure. In *Proceedings of the 11th ACM Workshop on Hot Topics in Networks*, HotNets-XI, pages 43–48, New York, NY, USA, 2012. ACM.

[21] G. Roberts, T. Kudoh, I. Monga, J. Sobieski, and J. MacAuley. NSI Connection Service Protocol v1.1, 2012.

[22] Top500. Top 500 Supercomputer Sites. http://www.top500.org/, 2013.

User Centered Approach Identifying Mobile Device Application

Malgorzata Pankowska
Information Systems Department
University of Economics
Katowice, Poland
pank@ue.katowice.pl

***Abstract*— Nowadays, people widely utilize mobile devices e.g., smart phones and tablets into their daily lives. Educational institutions for years have developed the wireless networking environments, providing students with flexibility of accessing the educational resources and creating the opportunities for downloading the academic publications and course materials at a desired time and location. The paper aims to reveal the purpose of usage of mobile devices by the university students as well as to illustrate by case study on SAP Business One academic course the benefits of Bring Your Own Device (BYOD) approach at universities.**

Keywords-mobile devices; m-education; BYOD; user centered approach.

I. INTRODUCTION

Mobility is not only the most important market and technological trend within information and communication technology (ICT) as Krogstie argues [13], but first of all the most typical characteristics of contemporary life style. Literature studies mostly focus on clarification and explanation of construction of mobile devices, investigation of the technological issues, research on mobile information systems influence on the business organization, and on implementation and evolution of mobile information systems. Starting the research on mobile information system development requires to explain the theoretical background. Beyond that, certain novelty in research results is required as well as the applied methodology should be explained.

The paper consists of three parts. The first part covers explanation of theoretical background of methodologies applied for research of end user behaviour in their work with mobile devices and mobile enterprise information systems. The second part includes discussion on application of mobile devices in different socio-economic domains: healthcare, marketing, business, banking, education and public administration. Next, the short survey research results are discussed on new media and mobile devices usage by university students. The fourth part of the papers comprises a case study on opportunities to apply bring your own device (BYOD) strategy to support university computerized infrastructure.

II. RESEARCH METHODOLOGIES FOR MOBILE DEVICES MANAGEMENT

During the last years, the Internet and mobile technologies have changed people's life, work and communication. The evolution has made it possible to have access to information and software applications anytime and anywhere. There are three trends connected with mobile technologies that are driving economy: user centered innovation development, new mobile devices innovation and new infrastructure innovation [12]. The concept of user centered innovation ranges from innovations created by the user to user direct involvement in the innovation process. There are a couple of methodologies for research realization on the mobile devices' acceptance and deployment by users.

User centered mobile device innovation implies that companies are striving to deliver innovations that generate user value or user experience unmatched by the competitors. These methods require an understanding of user needs and user values as well as the ability to translate these into unique products and experiences. The methods for research on user acceptance of mobile devices are as follows: user experience, user centric management, and user experience design.

A. User Centered Development Process

User centered development process is a product development process focusing on usability throughout the entire development process and further throughout the product life cycle. The key principles of the approach are as follows: user focus, active user involvement, evolutionary system development, simple design representation, prototyping, evaluation of user in a context, holistic design, process customization [11]. The purpose of user centered development (UCD) is to develop products with a high degree of usability. The user becomes the centre of focus on the usability goals, environment, tasks and workflows [7]. Design methods of UCD approach include prototyping and participatory design. Among the evaluation methods, there are usability inspection methods, and user testing methods such as laboratory and field tests. Major issues considered in this approach cover the expertise regarding users' own work, sustainable innovation opportunities, and the linking of the work practices, technology and the work environment context [18].

B. User Centric Management

User centric management (UCM) is a philosophy and an approach to business management that puts users first in all decision making. The approach is realized to ensure frictionless, easy and intuitive interactions between the company and its stakeholders [16]. For example, the business organizations are under strong influence of user critique provided online, therefore they carefully analyze their website content and distribute only what is not harmful for them. They create a certain environment for users to increase their personal satisfaction and software usability.

C. User Experience

The concept of user experience is understood as the subjective relationship between user and application or daily use technical devices. It goes beyond the usability of the application or device, focusing on the personal outcome that the user gets from interacting with the application or device while performing a task [9]. In Human Computer Interaction (HCI), the term designing for experience is about considering the user, the task and the context when designing a computer application [8]. Usually, projects have a larger context that the users understand and Information Communication Technology (ICT) people integrate into their planning. This context is the project's ecosystem and it includes the environment they are working within the company culture, the general type of work they all will be engaged in and the people with whom they interact within the roles and responsibilities. According to Beccari and Oliveira, the user experience orientation concentrates on a project’s goals, but not just to attain effectiveness, efficiency and satisfaction, but to enhance the entire experience and emotions resulting from the use of a product, system or service [5]. For example, user experience in games is evaluated using a variety of concepts, i.e., immersion, fun, presence, involvement, engagement, playability and entertainment. Bernhaupt noticed that user experience includes a look on all the qualitative experience a user is making while interacting with a product, and the emotions made during interacting with a special type of product, i.e., mobile phones [6].

III. MOBILE DEVICES' APPLICATION REVIEW

According to McGrane research, [15] 86% of smart phones owners say they use their phone while watching television. The numbers are even higher for tablet owners. 71% of smart phone users say they are searching for more information on their mobile device after seeing an advertisement on TV, in print, or online [15].

The e-business is constantly changed into mobile (m-business) . Mobile business is the best where the consumer is driven by a sense of urgency, and when they need to have their goods and services immediately for upcoming functions and events, although the consumer must wait for delivering material product. User with the same device is able to communicate over a wireless network and view office documents at the same time. In today's mobile commerce paradigm, when users are empowered by mobile solutions, a number of benefits emerge: increased employee productivity, faster response times to business changes, streamlined business processes, improved customer satisfaction, and increased competitive advantage [10]. M-commerce enables users to access the Internet without the need to find a place to plug in through the cable connection. People can buy and sell goods and services through wireless handheld devices and they are able to receive updated information concerning for instance the flight time on the way to the airport. M-banking is a very successful extension to Internet banking [3, 10]. The customers' benefits come from the use of mobile devices for online payments through e-cash. Mobile users withdraw daily news, i.e., stock quotes, weather information, entertainment, sports scores from their mobile devices. The mobile operators and service providers have access to several types of advertising information, therefore, with the cooperation with advertisers, they are able to distribute personalized advertisements to the prospective customers. This approach demands an acceptance of message recipients.

Generally, mobile marketing is used in connection with other marketing events, i.e., campaigns on television, in printed journals or on the web portals. This is referred to as integrated marketing. Nowadays, integration of mobile marketing with social networks sites is an effective approach to increase brand awareness and loyalty. Social networking supports building brand awareness and loyalty, and creates the Internet image of the company, but the mobile devices and mobile applications radically speed up the activities. Known as next-generation technology, mobile enterprise systems can either be enterprise system extended to support process mobility or separate mobile applications on mobile devices integrated with existing enterprise systems. The mobile enterprise systems require the further re-engineering of business processes as well as development of special repositories for temporal data storing on mobile devices. Mobile enterprise system technologies combined with other technologies such as bar code, GPS (Global Positioning System) and Radio Frequency Identification (RFID) can offer a substantial efficiency and cost-effectiveness improvements. In the same way, supply chain management and procurement management processes benefit from mobile devices and mobile applications. The main characteristic of a mobile business process is the mobility of human and physical resourses involved in the process. Mobile devices allow to track goods delivery and movements of vehicles. According to Alag, the application of m-business can be distinguished as global use in outdoor settings in interorganizational logistics chains, or local usage e.g., in hospitals, libraries, universities or hypermarkets [1].

M-healthcare enables connecting medical devices to mobile phones and permits the patient data to be transmitted to remote clinics healthcare systems for further processing [4]. Some of the mobile applications that are downloaded to patient handsets can provide answers to medical questions without necessary connecting to a remote clinical centre, therefore patients and their relatives can self-control automatically and only occasionally contact the hospitals. Mobile devices are not only simple voice communication devices. They are a medium to create on demand voice, music, text, video and image communications [19].

IV. BYOD Strategy Benefits and Weaknesses

During the development of mobile devices and services, the consideration of market offers plays an important role. Inadequate market orientation is the main reason of failures in the development of mobile services. However, the business considering enterprise wide process mobility requires a mobility strategy. The mobility strategy should guide operations and technology employees through the process redesign, application design, and implementation of the mobile enterprises systems. Alag argues that mobility strategies depend on factors, such as the business nature, strategic goals, need for process mobility, existing IT infrastructure and financial budgets [1]. Mobility strategies are unique for enterprises and cover many important problems e.g., risk and expected benefits of mobile devices usage, BYOD approach implementation. For instance, making decisions and quantifying risks about mobile devices is hard without good investigation of the mobile devices' usage in a business organization. Some organizations permit end user to take care of device management but some may want more protection. Anyhow, the business organization should be able to track, monitor, and control mobile network usage for business purposes. For example, if any of the users work with critical and unique data, they should consider using a backup and recovery solution. BYOD is a recent idea to exploit the personal communication devices for the work-related tasks. Although, some business organizations have for years provided smart phones, laptops and tablet computers to employees, nowadays, personally-owned mobile devices are permitted to access the organization's networks and data. The obvious advantage for the enterprise is cost savings achieved by not having to purchase these employee-owned devices. According to the Forrsights Workforce Employee Survey, Q4 2011 in North America and European Union countries 57% of users choose work devices themselves and spend their own money. For the netbooks, it is 51%, for tablets it is 48%, for laptops it is 41%, but for PC desktops it is only 16%.

The BYOD-specific security and control issues are as follows: protection of sensitive data and intellectual property, protection of networks to which BYOD devices connect, responsibility and accountability for the device and information contained on it, removal of the data in case of the device loss, malware protection, ensuring that employee-owned devices are properly backed up at all times [14]. Silva presented findings that 77% of responding business professionals said that the use of mobile devices in the workplace is important to achieving business goals, but simultaneously, 76% of respondents believe that mobile devices introduce a serious risk [17]. The survey revealed that only 39% of the devices have security controls to mitigate the risk and nearly 59% of respondents admitted to malware infections over the last 12 months of unsecured laptops, smart phones, and tablets. Business organizations, particularly in government, health care and defence face new legal questions: ownership of devices, buying the device, ownership of the information on the device. There is no clear answer, therefore the companies should consider the context, in which their employees' devices are used and if the employees' use of the devices for work purposes is very limited and concerns non-critical information, then BYOD strategy can make sense and it adds convenience at a predictable cost. However, the companies have several classes of users and have to choose a different provisioning and cost strategy for each separately.

V. m-Education

Soon, computer laboratories will not need to be supported by desktop computers, instead there is an opportunity to use private mobile devices to connect through Internet to servers and utilize business applications. However, wide implementation of mobile education is still a challenge. Some of the problems are mobile service costs, the need to change attitudes and institutions' policy against using electronic devices [19]. Development of mobile learning is driven by an opportunity, necessity, innovativeness and perceived weaknesses of e-learning. Nowadays, private enterprises and government sponsored programs and educational institutions are in a key position to find new ways to emphasize the role of m-learning and focus on user experience for further m-learning system development. M-learning means also the change of learning process paradigm. M-learning is not simply a direct extension of e-learning. So, what may work perfectly well in traditional education or even in e-learning system, may not fit the dynamic mobile environment. M-learning seems to support individual learning in the special context. Glossaries, dictionaries, phrasebooks, learning tips, examples, games and other learning aids are important in m-learning. M-learners within a community share ideas, stories, opinions or ratings, and utilize the student-to-student and student-to-teacher interactions. Mobile devices allow for the realization of education process in a particular socio-natural context, where teachers are able to explain more precisely the course topics during field works. For instance, students can learn biology in the forest. M-grading and m-testing are also possible with mobile phones. For example, during a course in the big university hall a concrete questions are randomly sent to the particular, chosen students who are obliged to answer within a few seconds. Teachers can provide feedback via Short Message Service (SMS) or other means regarding homework assignments or test scores to a group of students. However, it can be stressful for teachers, who are obliged to answer students anytime and anywhere. In some cases, mobile learning is seen as an adjunct to more traditional learning or e-learning. For example, students call together for group projects or entertainment events. The use of the small screen of mobile device for animations, graphs, equations perhaps is trendy, and the graphical user interface makes course materials more appealing to students. There are some considerations for defining m-learning systems compared to the traditional e-learning system. Some important issues are as follows: 1) understanding which mobile systems model is to be used 2) controlling the access of student data on mobile devices and 3) the profile of the

 ISBN: 978-1-61208-310-0

student. For the designing of m-learning system, student must be at the design centre. Some business software development companies support e/m-learning providing business application online. For instance, SAP realizes SAP Business One and SAP ERP courses online. Students have access to remote server from their own private notebooks. In computer laboratories students used to utilize the university desktops, but more and more frequently they prefer to work on their own personal notebook. They are able to create their own data bases and realize all business transactions. Their data is secured, each student receives individual login and password for their own private access to the SAP Business One applications. So, students have access to the applications wherever they are at school, university open spaces and corridors in buildings. They can work at home, and they do not need to have special software license, but rather login and password to access the Internet. The unlimited number of students can take part in the provided online course materials. When asked what they considered to be new and innovative about their experience of m-learning, students talked about the following qualitative advantages: availability of data and applications, flexibility, portability, easy navigation and intuitiveness of SAP Business One, efficiency of m-course provision in comparison with the traditional learning, comfortability, communication possibility and the sense of being in control. For years, the same two options (i.e., PC versus notebook) were offered to teachers. They can provide courses directly from university desktops or change to their own notebook. For some of them, teaching directly from personal notebook is more comfortable and safe. It allows teachers to keep all data files under control.

VI. Research on Mobile Device Usage by Students

So far, some research has been done on factors influencing mobile technologies successful implementation. According to Amberg et al., for a systematic research process there is a need for a comprehensive, complete and disjunctive classification of factors influencing mobile services. Although, in literature there are some detailed approaches identifying concrete factors, generally the factors can be divided into four groups: structure (who?) process (how?) outcomes (for what?) and market (what?) [2]. The structure dimension describes the required input factors for the mobile service development. So, there is the need to answer who is the recipient of the service or mobile device. In this research, the university students are the recipients of mobile services and devices. The process dimension represents the required processes during the product lifecycle. There is a question of how or in what processes or procedures students use the mobile devices. In this research, work, entertainment and education are the basic processes of mobile devices' usage. The outcome of a mobile service and device can be divided into procedural outcome and impact of the outcome. In this research, the usage of mobile devices is to increase knowledge resource or to develop social relationships. The procedural outcome can be evaluated at the end of the service provision. The impact of the mobile service and mobile devices has a long term character. This is significantly determined by the end-user's acceptance. The fourth, market dimension covers services and devices vendors, their brands and concrete products. However, these issues are out of the scope of this research.

It is generally believed that the rapid development of mobile technologies as well as the increase of mobile solutions for students call for a user-centered research to develop further applications. Therefore, the research is focused on analysis of students behaviour and students attitudes towards mobile devices. The short questionnaire was distributed during the first lecture at the beginning of the semester, after the presentation of the course curricula among the students of Logistics Information Systems, Business Information Systems and Corporate Architecture courses at the University of Economics in Katowice, Poland. 114 students answered the questionnaire. They accepted the questionnaire as important for the evaluation of their competencies to use mobile devices in learning processes as well as in other activities. Generally, the students' tasks can be categorized based on the areas that can be affected by mobile technologies. So, there are three categories of students' tasks: information tasks, interaction tasks, and planning tasks [2]. Although, each category of tasks has specific requirements in terms of mobile support and there is a need to fit mobile technologies characteristics with the requirements in terms of content, processing, and device portability, this research considers which devices are used for learning, occupational works and for social communication.

The first question in the survey concerns the issue of what devices and technologies are utilized by the students. The answers are included in Table 1.

TABLE I. Technologies and Mobile Devices Used by Students

Technology and Device	**Purpose of usage**			
	Learning	***Occupation***	***Social Relations***	***No use***
stationary phone	2[a]	31	41	50
mobile phone	35	60	103	9
smart phone	30	27	57	56
iPod	3	0	3	109
iPad	6	3	8	106
notebook	76	55	72	33
netbook	23	18	24	83
desktop computer	49	37	50	44
tablet	11	6	14	93
GPSdevice	1	32	38	52
RFID device	0	6	2	108
automatic personal identification	2	7	1	106
biometric identification	2	5	2	106

a. number of positive answers, index applies to all numbers in Table

In Table 1, the number of positive answers are included. So, mobile phones (103 positive answers) and notebooks (72 positive answers) are the most popular devices for social relations development as well as for learning and for occupational work. Young people, i.e., students reject stationary phones for mobile phones and smart phones. The devices for automatic identification and biometric identification are still not very popular, although new passports are supported by the biometric identification of the owner. They still use desktop computers for learning, because at university laboratories there are desktop computers available, and only part of them prefer to use their own computers. However, 54% of surveyed students have answered they use their own mobile devices for occupational works, 89% of the students use owned devices in learning processes at university. Only 34% of students declared that they prefer to access the Internet from only one device. 76% of the students use different mobile devices for different purposes. 46% of the surveyed students believe that access to Internet from only one device is realized more quickly than access from more than one. Nearly the same percent of students believes that access to Internet from one device is more efficient (48% of students) and more secure (55% of students). Figure 1 presents percentages of students who use the devices in comparison with the percent of students who do not use the mobile devices and technologies.

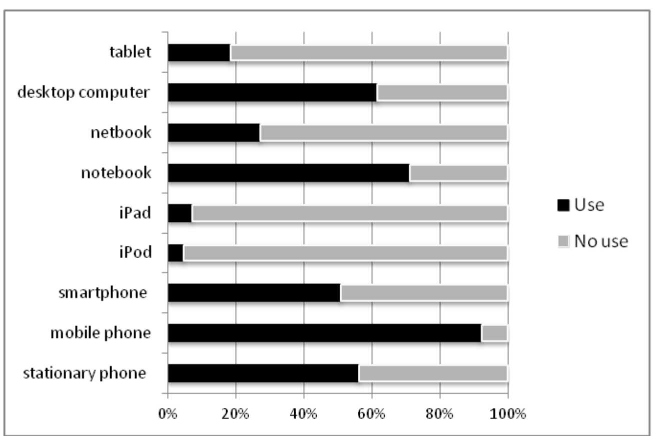


Figure 1. Percent of students using the mobile devices.

The second part of the survey concerns the popularity of social media, social network portals and communication software among students and use of the technologies for learning support, occupational work support and for social communication, maintaining contacts with friends and families or generally, for social relations development. The survey results are presented in Table 2 and Figure 2. Email and SMS are the most popular communication forms. All the surveyed students use them. The email is called "killer application" and it is treated as the basic communication form between university faculty staff and students. It should be noted that Facebook is also very popular in contrast with LinkedIn and Where Are You Now? (WAYN). Twitter is widely used in other countries and by politicians, but not by students in Poland. Recommender systems are implemented, but they are not widely approved by students. They have own preferences, instead of using the suggested products. Although, sometimes students are not conscious that they behave according to recommendations.

TABLE II. COMMUNICATION SOFTWARE AND SOCIAL MEDIA USAGE

Social media & communication software	**Purpose of usage**			
	Learning	***Occupation***	***Social Relations***	***No use***
email	102[a]	82	108	0
SMS	69	60	112	0
chat room	50	33	76	28
Skype	28	9	94	31
Facebook	54	18	105	18
YouTube	51	13	81	7
Twitter	1	2	5	107
WAYN	0	0	0	114
LinkedIn	0	6	8	102
recommender system	4	3	6	103
price comparison portals	13	18	46	43
GoogleMaps	44	49	66	14
Wikipedia	84	29	26	13
discussion fora	52	21	47	33
blogs	16	6	37	66
open e-book repositories	54	13	13	51
open e-publication	76	20	22	26

a. number of positive answers, index applies to all numbers in Table

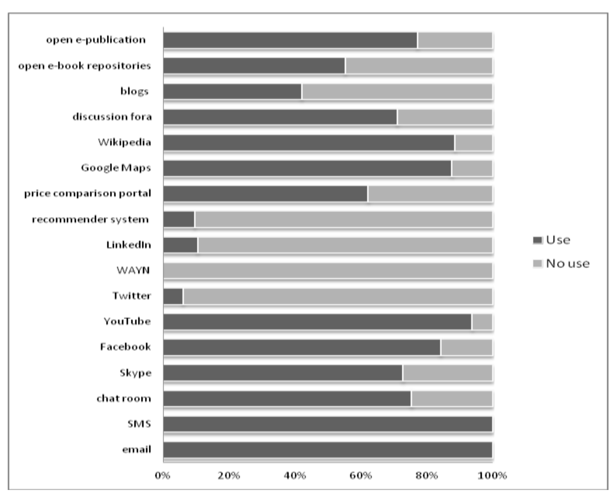


Figure 2. Percent of students using new media.

It should be noticed that students readily support their educational processes as well as their occupational works by knowledge from open repositories. Reading e-publication is more comfortable than reading printed materials. The research results are very similar to the effects received by Wojcik [20]. There is also the tendency visible to reduce usage of desktop computers and stationary telephones in favour of laptops and mobile devices.

VII. CONCLUSION

The paper was to show the university students' attitudes towards mobile devices and new media. Students as consumers of mobile devices have been found to rely on market information when evaluating innovations. Irrationally high price is the main reason of low usage of iPods and iPads. Students simply cannot afford these overpriced pieces. However, the increase of demand for the devices is expected to bring the price reduction. Students do not perceive application of RFID and biometric identification in their life, although biometric passwords are now widely implemented. Simply, students in survey process do not think about the opportunities to apply biometrics in daily use. Students are rather conservative and need time for the verification of usefulness of Twitter, blogs and recommender systems. Usability of some new media is bigger for private social communication than for business, as it is in the case of Skype, Facebook, Google Maps and YouTube. Further research would cover analysis of environment, client and organizational factors influencing student behaviour in this user centered approach. The group of environmental factors will cover market issues, infrastructure, culture and skills. Organizational factors will comprise relevant prior experience in e-learning, willingness to explore the potential of the Internet and mobile devices. Client factors cover convenience of purchasing, prices and quality of the products, security and level of maintenance service.

ACKNOWLEDGMENT

This research was conducted as part of the Prosumption project at University of Economics in Katowice. The project is supported by the National Centre of Science, grant number NN 115410040.

REFERENCES

[1] H.S. Alag, "Business Process Mobility," in Handbook of Research in Mobile Business: Technical, Methodological, and Social Perspectives, Volume1, B.Unhelkar, Ed. Idea Group Reference, Hershey, 2006, pp.583-601.

[2] M. Amberg, J. Wehrmann, and R. Zimmer, "Factors influencing the design of mobile services," in Mobile Information Systems, E. Lawrence, B. Pernici, J. Krogstie, Eds. Springer NY 2005, pp. 199-213.

[3] A. Ayadi and Ch. Ammi, "Strategic Perspectives in Mobile Banking: Technology, Value Creation and Developing Factors," Handbook of Research in Mobile Business: Technical, Methodological, and Social Perspectives, Volume 1, B. Unhelkar, Ed. Idea Group Reference, Hershey, 2006, pp.420-429.

[4] A. Bamigboye, "Mobile Healthcare: Challenges and Opportunities," in Mobile Technology Consumption Opportunities and Challenges, B.L. Ciaramitaro, Ed. Information Science Reference, Hershey, 2012, pp.77-98.

[5] M.N. Beccari and T.L. Oliveira, "A Philosophical Approach about User Experience Methodology," in Design, User Experience and Usability, Theory, Methods, Tools and Practice, A. Marcus, Ed. Springer, Heidelberg, 2011, pp. 13-22.

[6] R. Bernhaupt, "User Experience Evaluation in Entertainment," in Evaluating User Experience in Games, Concepts and Methods, R. Bernhaupt, Ed. Springer-Verlag, London, 2010, pp. 3-10.

[7] H. Beyer, User-Centered Agile Methods. Morgan & Claypool Publishers, Boston, 2010.

[8] B. Buxton, Sketching User Experiences. Morgan Kaufmann, San Francisco, CA, 2007.

[9] E.H. Calvillo-Gamez, P. Cairns, and A.L. Cox, "Assessing the Core Elements of the Gaming Experience, " in Evaluating User Experince in Games, Concepts and Methods, R. Bernhaupt, Ed. Springer, London, 2010, pp. 47-72.

[10] N. Godbole, "Relating Mobile Computing to Mobile Commerce," in Handbook of Research in Mobile Business: Technical, Methodological, and Social Perspectives, Volume1, B. Unhelkar, Ed. Idea Group Reference, Hershey, 2006, pp.463-486.

[11] J. Gulliksen, B. Goransson, I. Boivie, J. Persson, S. Blomkvist, and A. Cajander, A. "Key principles for user-centered systems design", in Human-centered software engineering - integrating usability in the software development lifecycle, A. Seffah, J. Gulliksen, M.C. Desmarais, Eds. Springer, Berlin, 2005, pp. 17-37.

[12] C. Ihlstrom Eriksson, and J. Svensson, "A User Centered Innovation Approach Identifyin Key User Values for the E-Newspaper," in Developing Technologies in E-Services, Self-Services, and Mobile Communication, New Concepts, A. Scupola A. Ed. Information Science Reference, Hershey, 2011, pp.146 -185.

[13] J. Krogstie, "Requirement Engineering for Mobile Information Systems", 2001, http://www.ido.ntnu.no/~krogstie/publications/2001/REFSQ01/draft.pdf, retrieved August 2013.

[14] N. Kelson and J. Kalwerisky, "Bring Your Own Device (BYOD)," Security Audit/Assurance Program, ISACA, 2012, http://www.isaca.org/BYOD-AP, retrieved May 2013.

[15] K. McGrane, Content Strategy for mobile, A Book Apart, New York, 2012.

[16] A. Shapiro, Users not Customers, Penquin Books Ltd. London, 2011.

[17] P. Silva, "BYOD 2.0: Moving Beyond MDM," http://www.f5.com, March 8.2012, retrieved May 2013.

[18] B. Torpel, A. Voss, M. Hartswood, and R. Procter, "Participatory Design: Issues and Approaches in Dynamic Constallations of Use, Design and Research," in Configuring User-Designer Relations, A. Voss, M. Hartswood, R. Procter, M. Rouncefield, R.S. Slack, M. Buscher, Eds. Springer Verlag London, 2009, pp. 13-30.

[19] A. Velokovsky and S. Shammas, "Mobile Education," in Mobile Technology Consumption Opportunities and Challenges, B.L. Ciaramitaro, Ed. Information Science Reference, Hershey, 2012, pp. 16-32.

[20] J. Wojcik, "Attitudes of Polish students towards Web 2.0 technology," in Creativity Support Systems, Methods and Applications, H. Sroka, S. Stanek and M. Pankowska, Eds. University of Economics, Katowice, 2012, pp.119-131.

 ISBN: 978-1-61208-310-0