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Information
Fusion
from Databases,
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Simulations

Annual
Report
2007

University of Skövde · Sweden

IN PARTNERSHIP WITH THE

Knowledge Foundation



Information Fusion

from Databases, Sensors and Simulations

Annual Report 2007

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Executive Summary

The Infofusion Annual Report 2007 contains a financial and activity report for 2007, as well as an operating plan for 2008, for the Information Fusion Research Program at the University of Skövde. The research Program is based on a funding grant from the Swedish Knowledge Foundation, “2003/0104 Information Fusion from Databases, Sensors and Simulations”. The grant is for MSEK 36 over 6 years, and is matched by commitments of MSEK 54 from 14 industry partners and MSEK 29 from the University, for a total of MSEK 119 from 1 April 2005 to 31 March 2011.

The financial report for 2007 is found in Part II and Appendix H-I, while a description of the Infofusion and its activities in 2007 can be found in the remainder of the report. The activity reports for 2007 of all the scenarios and projects in the Infofusion research program, as well as the operating plan for 2008 is found in Appendix E, titled “Scenario and Project Summaries”. Some highlights from the scenario and project results are found below.

Personnel changes

In January of 2007, Professor Henrik Boström joined the Information Fusion Research Program, as Program Co-Director and Scenario Leader for Common Goals and Infrastructure. We were also very pleased to appoint two Adjunct Professors to the Research Program, namely Thomas Kronhamn and Håkan Warston of Saab AB. We also recruited a new Ph.D. student for the Manufacturing Scenario, Catarina Dudas. Another Ph.D. student, Johan Olby, joined the Common Goals and Infrastructure Scenario but unfortunately left us for a position in industry in December 2007.

Mats Grindal and Ulf Johansson graduated from the Infofusion program with a PhD degree in 2007. Beatrice Alenljung submitted her PhD thesis in 2007, to be defended in 2008.

Papers

We are happy to report over 20 publications in journals and conferences in 2007, including six (6) papers to Fusion 2007 in Québec City, Canada.

Mid-Term Evaluation

During 2007 (June through December) a mid-term evaluation of Infofusion was performed for the Knowledge Foundation by Inno Scandinavia AB. The result of this evaluation is available on the Foundation’s web page as well as our own web page. The evaluators found the Information Fusion Research Program to be a well working research community with good potential for growth and future funding. They also found a few areas where improvement could be made. The executive committee has acted on this and is currently taking measures to further improve the research program.

Infofusion Advisory Board

The international Information Fusion expertise on the Infofusion Advisory Board has been extended adding a new member, Dr. James Llinas, Executive Director, Center for Multisource Information Fusion (CMIF), University at Buffalo, NY, USA. He replaces Prof. Hans Björnsson, who has returned to California and resigned from the Advisory Board in 2007.

Dr. Llinas brings over 30 years of experience in multisource information processing and data fusion technology to his research, teaching, and business development activities. He is an internationally-recognized expert in sensor, data, and information fusion, co-authored the first integrated book on Multisensor Data Fusion, and has lectured internationally for about 20 years on this topic. He is co-editor of the recently-published “Handbook of Multisensor Data Fusion”. Dr. Llinas is a Technical Advisor to the Defense Department’s Joint Directors of Laboratories Data Fusion Group, the only US DoD technology oversight group for Data Fusion, a position he has held for over 15 years. Dr. Llinas was awarded the definitive US defense community award from the Data Fusion community, the Joe Mignona Award, in 1999. In addition, reflecting his international interests and stature, Dr. Llinas was voted as the first President of the International Society for Information Fusion in 1998. Dr. Llinas created the concept for and is Executive Director for the “Center for Multisource Information Fusion” located at the State University of New York at Buffalo. This first-of-its-kind, University-based research

has received sponsorship from a broad base of defense and industrial R&D organizations, and is conducting basic research in Distributed Situational Estimation, Distributed Learning, and in Correlation Science, among other programs. [<http://www.infofusion.buffalo.edu/>]

Members of the Infofusion Advisory Board

- Stefan Arnborg, Professor, Royal Institute of Technology, Stockholm
- Kent Eriksson, Manager Process and Materials R&D, Volvo Powertrain
- Noël Holmgren, Vice Rector, Professor, University of Skövde
- Wolfgang Koch, Head of Sensor Networks and Data Fusion, FGAN-FKIE, Germany
- Anders Jonsson, Adjunct Professor, SLU
- James Llinas, Executive Director, Center for Multisource Information Fusion (CMIF), University at Buffalo, NY, USA
- Anders Malmjö, Research and Education Council Chair, Professor, University of Skövde
- Johan Norén, Vice President Research, Development & IT, Ericsson Microwave Systems, Gothenburg

Infofusion Executive Committee

All scenario leaders are now members of the Infofusion Executive Committee (IFEC) and two industry representatives have been added for a total of 9 voting members. In addition, all Infofusion project Leaders (IFPL) and industry contacts are invited to be present at all IFEC meetings.

Members of the Infofusion Executive Committee

- Sten F Andler (Infofusion Program Director, IFEC Chairman)
- Henrik Boström (Infofusion Program Co-director, CGI Scenario Leader)
- Lars Niklasson (GSA and RS Scenario Leader)
- Björn Olsson (BIO Scenario Leader)
- Leo J de Vin (MFG Scenario Leader)
- Bo Magnusson (PA Scenario Leader)
- Tomas Planstedt (Industry Representative, Saab AB)
- Kent Eriksson (Industry Representative, Volvo Powertrain AB)
- Jan-Olof Lundgren (Industry Representative, Euromaint Industry AB)
- Marcus Brohede (Infofusion Program Administrator)

Strategic Business Plan

In response to a request made at the follow-up meeting in December 2007 of the mid-term evaluation, Infofusion is now (in 2008) developing a Strategic Business Plan for 2009 and beyond. An initial sketch for the business plan and development plan will be presented at the Spring 2008 Infofusion Advisory Board meeting (IFAB 15-16 May 2008) and the plan is to be finalized at Fall 2008 Infofusion Advisory Board meeting (in Oct/Nov 2008). The Strategic Business Plan will be made part of the Infofusion Annual Report 2008, as an appendix, to replace the current Appendix titled “Plan for development of the research program”, which describes the current development plan for Infofusion, and the Appendix titled “Strategy for development of the university”, which indicates that the Information Fusion Research program is considered central to the research strategy of the University of Skövde.

An important part of the plan is to identify and involve our Strategic Partners, with a strategic goal of establishing a competence center in High-Level Information Fusion. A major strategic application area of the competence center is likely to be Military as well as Civil Security, but other civilian applications such as pharmaceuticals, manufacturing, retail and precision agriculture may prove to be equally important if sufficient interest can be demonstrated by our national industry partners. Work is also underway on forming a European network on high-level information fusion, involving many of our strategic partners in the European arena. Internationally, an increased involvement is also seen with activities of the International Society of Information Fusion (ISIF), where Infofusion took a seat on the Board of Directors of ISIF (2008 – 2010) in an election that took place in December 2007.

An important part of the business plan is identifying options for funding – such as funding for a graduate school in information fusion or an industrial graduate school, funding for a center of

excellence in high-level information fusion, or funding for focused programs on certain scenarios in the information fusion research program.

Annual Report on the web

A downsized version of annual report for 2007 will be made public on the Infofusion web site as a Technical Report (as in 2005, 2006), consisting of the following parts:

- Part I: Financial Report and Activity Report for 2007
- Part II: Description of Infofusion Goals, Scenarios and Projects (including all scenario and project summaries)

After the Fall 2008 IFAB meeting we will also make available the following report:

- Strategic Business Plan for 2009 and Beyond (in Fall 2008)

All annual reports and publications (subject to copyright limitations) will be made available on the web as well as a CD-ROM. All publications will be listed by year, with abstracts and hyperlinks to PDF files where available or URL:s to appropriate publications.

Scenarios and projects in Infofusion

Infofusion is composed of seven scenarios; one common goals scenario and six application scenarios. Each scenario serves as an umbrella (not a project in itself) for the projects within the corresponding research area.

- Scenario Common Goals and Infrastructure (cgi) – Information fusion theory, methods and infrastructure
 - Project cgi1: Information Fusion and Decision Support: Cognitive and Organizational Factors
 - Project cgi2: Generic Methods, Algorithms and Tools
 - Project cgi3: Using Active Real-Time Database Functionality as an Infrastructure for Information Fusion
- Scenario Ground Situation Awareness (gsa) – Information fusion for Ground Situation Awareness
 - Project gsa1a: Template-based situation recognition for ground-situation awareness
 - Project gsa1b: Information fusion algorithms for anomaly detection
 - Project gsa2: Information Visualization for Ground Situation Awareness
 - Project gsa3: Information Fusion for Threat Analysis in the Domain of Ground Situation Awareness
- Scenario Bioinformatics (bio) – An IF Approach to Understanding Complex Biological Systems
 - Project bio1: An Information Fusion Approach to Identify Genes and Molecular Pathways Critical for Differentiation of Human Embryonic Stem Cells
 - Project bio2: An Information Fusion Approach to Understanding Complex Biological Systems – a Systems Biology view of lipid digestion and absorption
 - Project bio3: Text Mining and Text Analysis as a Tool in Information Fusion
 - Project bio4: Model-based Data Mining as Support for Pharmaceutical Research Focused on Disease Models and Drug Discovery
- Scenario Retail Sector (rs) – Information fusion for informed decision support
 - Project rs1: Information fusion for improved predictive quality in domains with high information uncertainty
 - Project rs2: Information fusion for identifying patterns in customer and sales data
- Scenario Manufacturing (mfg) – Simulation-based information fusion for manufacturing decision support
 - Project mfg1: Prediction and reduction of bull whip effects in supply networks - a holistic approach Relevance to information fusion

- Project mfg2: Decision support in service related maintenance Relevance to Information Fusion
- Project mfg3: Information Fusion for Holistic Process Analysis in the foundry industry
- Scenario Precision Agriculture (pa) – Information fusion in precision agriculture
 - Project pa1: Information fusion in precision agriculture for optimized real-time nitrogen application
- Scenario Systems Development (sd) – Information fusion in the systems development process
 - Project sd1: Information Management for Requirements and Testing in Software Development

Highlights from the scenario and project results

Highlights of the Common Goals & Infrastructure Scenario

A new course on “*Intelligent data analysis*” was given for the first time in fall 2007, with participation of six Ph.D. students from the research program. The PhD course “*Information fusion*” was given for a third time in fall 2007.

A one-year master's program in information fusion, starting in fall 2008, was developed and established at University of Skövde. A grant was obtained from the Swedish Knowledge Foundation for developing a two-year Master's program in information fusion. External partners are SAAB Microwave Systems and the Swedish Defence Research Agency (FOI).

Skövde Workshop on Information Fusion Topics (SWIFT) was organized for the first time, during three days in April 2007 and with more than 60 participants in total. The workshop included invited talks by Peter Willett (University of Sheffield), Ulf Norinder (AstraZeneca), Stavri Nikolov (University of Bristol), Pontus Svenson (FOI), Johan Schubert (FOI), Michael Hinchey (Loyola College), and Galina Rogova (State University of New York at Buffalo), as well as presentations from researchers and Ph.D. students from the research program.

IF program meetings, intended to bring together all researchers and external partners in the IF program, were held 15 times during the year. Typically, at each occasion, one scenario presents ongoing work. Research: The research highlights are specified in the three cgi project summaries.

Nilsson has performed two case studies to get more insight in the use of information fusion systems in practice. In cooperation with SAAB Systems a maritime surveillance application was studied (JDL-level-1). The Swedish Defense Research Institute (FOI) invited members of the project to study a prototype of an impact matrix (JDL-level-2). These case studies have resulted in 2 papers to be presented at Fusion 2008. Laere and Susi have participated in the organization and analysis of three municipal crisis management exercises where the relation between information management and decision making is central, and which as such can serve as an input for the theoretical framework under development.

Alexander Karlsson visited the Center for Multi-source Information Fusion, University at Buffalo (State University of New York), during one month in the fall.

An evidential reasoning toolbox “pyBelief”, has been developed by Dr. Ronnie Johansson. The toolbox has been used both in teaching and in scientific work.

Meetings with SLU have continued. Today, precision agriculture (PA) uses a lot of sensors to enable sound decisions on for example amount of fertilizer to dispense on a field. PA also has a lot of historic data on for example the yields of previous years. Therefore, this application qualifies as a proof of concept. They have given input to the development of our wireless sensor networks (WSN) testbed, in particular for sensing in the field for which they also suggested that we interfaced sensors from their domain, e.g., conductivity sensors. In 2007 strategic funds was received to build a wireless sensor network testbed. This project was aided by senior researcher PhD Leo Selavo, a contact established at UVA. Leo was a research associate at UVA during the periods when we had PhD students visit UVA. An application for support for cooperation with database and sensor network experts in India and China was submitted to the Swedish Research Council (Vetenskapsrådet). Funding was provided and a workshop for all participants is being prepared for autumn 2008.

Highlights of the Ground Situation Awareness Scenario

During 2007 the scenario further developed the common framework for situation awareness. This framework incorporates definitions for both machine and human situation awareness. During 2007 a number of internal

seminars were conducted. An external seminar together with another research program was also conducted. This seminar had about fifteen presentations from both the Information Fusion program (Skövde) as well as the Embedded Systems program (Halmstad).

Two of the student projects have been given access to real data. The results that the projects have delivered on this data have generated a lot of internal interest within our industrial partner, SAAB. SAAB Systems have contacted us in order to investigate the possibility to incorporate a new industrial PhD student, working on anomaly detection. The scenario has representatives in an EU expert group on Situation Awareness. This group will contribute to the development of research calls within FP7.

So far the project has resulted in seven publications in international scientific press. One of the projects has been closely related to the internal work within SAAB on anomaly detection. Another project has been presented for another internal SAAB group, which now has invited the PhD student to work on real data and compare the result with those of the group.

Throughout the year, the projects have been involved in regular meetings (every 2nd week) with SMW and the other projects in the scenario. These meetings have, according to SMW, spawned many internal projects at SMW with the intent of commercializing research results.

The work on specifying and implementing test scenarios have proceeded as scheduled. The Stage Scenario tool was purchased and is now being used for construction of test data.

In cooperation with Saab Microwave Systems we have performed a project on anomaly detection in video data. In the project two algorithms for modeling normalcy was evaluated with data from a real-world situation. The proposed algorithms were able to find most of the anomalies presented to the system. Anomalies used in the project were for example: people running in areas where people usually walk, pick pocketing and snatching.

In cooperation with Saab Microwave Systems and the other GSA projects we have defined a camp protection scenario with a number of event chains. The idea is to use this scenario as a base when generating data for experiments and algorithm development.

Riveiro finished her research proposal in June 2007 and has authored or co-authored a number of publications in 2007.

Between the GSA projects a common understanding of the use of and the exact relation between situation awareness and JDL terminology has been developed and published in SDF2007. Regarding the visualization of uncertainty, two publications summarize the work carried out regarding the theoretical evaluation of different methods. Currently, a scenario using a simulation tool, Stage, is being developed. The scenario will be used to test visual analytics methods and techniques that can be applicable in information fusion.

The studies of methods and algorithms for anomaly detection have continued within SAIDA (Situation Awareness using Intelligent Detection of Anomalies), in cooperation with the other projects within the GSA scenario and Saab Microwave Systems. This has resulted in two publications on unsupervised detection of anomalies in a coastal surveillance scenario, where the first was presented at the International Conference on Intelligent Sensors, Sensor Networks and Information Processing 2007 (Melbourne, Australia), and the second will be presented at the 10th Scandinavian Conference on Artificial Intelligence (Stockholm, Sweden).

Highlights from the Bioinformatics Scenario

Two journal articles were published (in *Journal of Biotechnology* and in *International Journal of Bioinformatics Research and Applications*), and conference papers were published in the proceedings of the conferences SMC 2007, MCCMB 2007, EvoComp 2007 and BIRD 2007.

Initial biological experiments were completed in project bio1, followed by application of IF techniques to identify reference genes and putative key regulatory genes. Project bio2 was terminated during the year. Text analysis technique successfully extended and adapted to biomedical domain in project bio3. Project bio4 was completed. New project bio5 (SimSoft) was initiated in collaboration with researchers at Fraunhofer- Chalmers Institute for Industrial Mathematics established and the industry partner InNetics AB.

Three companies are involved: Cellartis AB, Lexware labs, and InNetics AB. The role of Cellartis is to provide experimental data from model systems, assist with biomedical expertise, and to provide the biomedical research context in which our IF methods are being evaluated. Lexware and InNetics are software companies and therefore interested in developing tools based on the new methods and algorithms that result from the projects in this

scenario. Other companies within the biomedical and biotechnology industry are potential partners.

The first stage of the bio1 project was to establish reliable reference genes to be used as controls in the subsequent experiments. The second stage in the project addressed the question of finding genes important for coaxing hESCs to differentiate towards cardiomyocytes. To bring structure into the IF processes in this project we examined the usability of the JDL data fusion model in bioinformatics in general and in stem cell differentiation in particular. By using this model we believe that we more easily can identify IF problems in our problem domain. It is highly probable that we can utilize algorithms and methods already developed for a typical IF problem for solving similar problems in the bioinformatic domain. In our on-going work we have also tried to use this model as a framework for categorization of fusion-related functions.

In project bio2 the initial analysis of experimental time-course data identified some of the key players in the regulation of long-chain fatty acid metabolism. An experimental system for measuring gene expression in enterocytes of the mouse small intestine was developed. This method is based on isolation of transcript from intestinal enterocytes and quantitative real-time PCR. Based on the data obtained from these experiments, a comprehensive model has been developed in order to capture the flow of lipids from the intestinal lumen to the assembly of chylomicrons and high density lipoproteins (HDL) inside the enterocytes. Experimentally, we have tried to identify the key players involved in regulation of this process by using feeding and re-feeding experiments in a mouse model system and intestinal samples were collected at different time points. This data set constituted a minor milestone in the project as it provided valuable time course data for the development of a more robust mathematical model. The insight from these studies provided the basis for future and more extensive large scale experiments and the development of at least two unique experimental model systems.

The long-term goal of the research in project bio3 is to incorporate linguistic text analysis into a system for evaluation of biological pathways based on information fusion. The initial work consisted of adapting a grammar-based algorithm for automated text analysis to the biomedical domain. During 2007, we initiated an effort to integrate the text analysis system with the pathway alignment algorithms developed in project bio 4.

A large corpus of biomedical texts collected in 2006 has been divided into specific subdomains (human genetics, animal genetics, and cancer research). The corpus is available for searching by different statistical measures (T-score, Zscore, MI, maximum MI, Chi-square test, etc.) at <http://bergelmir.iki.his.se/culler> • the prototype tagger and parser for deep text analysis developed in 2006 has been implemented in C++ and tested • a book chapter documenting the work on information extraction from biological texts has been accepted for publication • The work on the project has been presented at a number of conferences, seminars, and meetings.

The project bio4 (ModPharm) was a three year project running from March 2004 to March 2007. The project resulted in the development of three new methods for data mining in the biomedical domain, which all involve aspects of IF. The method GOSAP was described in an article published in the *International Journal of Bioinformatics Research and Applications*. The method EGOSAP was presented at the Moscow Conference of Computational Molecular Biology and published in the conference proceedings. A method for improvement of path diagrams was presented at the *European Conference on Evolutionary Computation, Machine Learning and Data Mining*, and published in the conference proceedings.

Highlights from the Retail Sector Scenario

Two overall projects have been identified (and funded internally). One of the projects involves utilizing information fusion to achieve better prognoses and fuse prognoses to generate an early warning system to detected deviations from what is predicted. The other project involves extracting behavioral patterns from stored data (i.e., different customer groups). The latter of these projects has during 2007 been given access to a large body of relevant data to experiment on. This was indeed a highlight during the year. The other project has during the year focused on developing the tools needed to analyze the data as it becomes available. Some data has been made available, but it needs to be extended somewhat before it can be used. During 2007 a new steering group was organized for the scenario. This group has had regular meetings during the year, and decided to organize an internal workshop for relevant decision makers within ICA during 2008. The intention with the workshop is to initialize some projects involving ICA personnel as well as personnel from the research program.

Three publications have been presented in relation to the rs1 project during 2007. One article shows how to enhance probability estimation for ensembles by modifying and using a technique employed in the weather forecasting domain. The two other articles regard rule extraction based on genetic programming. They show that more than one accuracy measure can be successfully be optimized and how the inherent nondeterministic property of genetic programming can be utilized to produce better probability estimation for the extracted model. These articles are important for the project as we believe in a solution where a final comprehensible model is extracted from an opaque predictive model. In our case the opaque model would be produced by fusing an ensemble with

knowledge of a human expert. During 2008 we hope to further increase the accuracy of our ensembles by using more relevant data. We also plan to perform live case studies with ICA to further evaluate the proposed techniques.

The research questions to be focused on in the rs2 project have been narrowed down to the study of aggregation strategies for customer segmentation. An extensive study has been performed on data that has been collected at ICA Handlarna AB, consisting of all available transaction data for a period of 18 months for 10 000 households, which accounts for approximately 12 000 individual card holders (i.e., enlisted customers that receive some special offers, and in return the company can register all transactions and tie them to a particular card). Several different aggregation strategies have been compared for predicting customer segment membership, together with strategies for fusing features and classifiers obtained from these aggregations. The topic of diversity, which is of importance when fusing multiple classifiers, has been extensively explored, and results from these studies have been presented at the Fusion and IJCNN conferences in 2007, and will be further presented at upcoming PAKDD and IJCNN conferences in 2008. Main conclusions from these studies are that most diversity measures do not correlate well with test set accuracy, and although some measures show promising results, it turns out to be extremely hard to utilize them effectively in ensemble creation. A straightforward combination of all trained models turns out to work well for almost all problems.

Highlights from the Manufacturing Scenario

In essence, this scenario and its projects got properly underway early 2006. This was due to the fact that most of the cooperating companies were involved in closely related projects such as Massive and SimPlan that ended December 2005, and preferred to complete these projects before engaging fully in the IF research program. As a result, the scenario description in the 2005 annual report was rather tentative; in essence only one project was relatively well defined.

The project mfg1 that was defined fairly loosely has been defined more clearly. The project with Electrolux is running in close association with their P21 project; a major initiative aiming at substantial cost reduction through a holistic supply chain approach. Closer co-operation between the two research groups involved in this scenario resulted in an internal research seminar on October 31st. Recruitment of PhD student Tehseen Aslam was formalized. Results up to date are the definition of the industrial problem and the research plan for the PhD student. So far the project has produced 2 conference papers and a thorough mapping of Electrolux internal demand and supply processes. This mapping has revealed the complexity of the internal processes and therefore, it has been decided to focus on the Electrolux plant itself, at least in the next few years. The reason for this is twofold. Firstly, the hypothesis regarding the suitability of agent-based simulation can be adequately tested by just studying the Electrolux plant. Secondly, including external suppliers implies problems regarding availability, format and reliability of manufacturing data. Although this is an interesting problem in its own right, it would not contribute to the testing of the hypothesis to investigate this problem at this stage.

Project mfg2 takes a starting point from an applied and relevant problem in logistics. The nature of the problem is illusive with much data and information available, and many modeling approaches have been suggested (e.g. in operations management). This leads to the belief that information fusion is a realistic approach for this problem: i) to fuse information from data-bases, ii) utilize real-time when available, iii) and make future predictions based on existing knowledge. Participation in Graduate Courses, and the evaluation and purchase of Multi Agent-Modeling software has been carried out.

One more project has been defined and established with Volvo Powertrain (mfg3). Holistic Process Analysis (HPA) of a cascade of production steps is an intricate problem; in this case particularly as it involves both continuous processes and discrete part operations. It is, for instance, difficult to perform an impact analysis of parameters in the foundry process on machining processes and throughput times with the use of conventional methods.

Volvo Powertrain has announced to increase their level of participation following the definition of the mfg3 project. Unfortunately, Delfoi had to put their participation on ice, due to changes in personnel including MD. This is compensated by an increase of effort by Volvo Powertrain

Publications: 3 journal papers accepted (one already published), 6 conference papers published. Various presentations of the IF research program, such as at the SMSN (Swedish Manufacturing Simulation Network) seminar in Skövde and at the kick-off for the Industrial Graduate School CAPE in Trollhättan.

A Related European project "My-Car" with participation from University of Skövde has been started.

Organization of the FAIM2008 conference (Flexible Automation and Intelligent Manufacturing) was granted to

University of Skövde; an IF special track or associated IF workshop is planned.

Highlights from the Precision Agriculture Scenario

This scenario intends to improve equipments in precision agriculture, i.e. in image analysis and algorithms for vision supported navigation of robots and in automated fertilizer application. In all these areas, fusing information and the OODA (Observe- Orient-Decide-Act)–loop is crucial in the processes taking place.

The main focus in 2007 was based on the literature survey, a few models were chosen with respect to time step, complexity and availability, to undergo the evaluation. During the evaluation work in fall 2007, some insights were revealed about the input data set needed; leading to that the continuing evaluation work in spring 2008 uses extended input data.

Highlights from the Systems Development Scenario

The problem area has several characteristics that indicate the relevance of investigating whether or not information fusion techniques could support the decision-making process and improve the predictability of decision outcomes. The results of this project potentially opens new applications for IF methods and technology.

Mats Grindal successfully defended his PhD thesis “Handling Combinatorial Explosion in Software Testing” in March. Beatrice Alenljung submitted her PhD thesis “Envisioning a Future Decision support System for Requirements Engineering: A Holistic and Human-centred Perspective” to be defended in 2008.

Infusion – In Collaboration with Industry

Part I Activity Report

The activity report is a statement of the development of the research program in 2007 with respect to the following aspects:

- 1) Scientific quality and the relation to the expressed university profile
- 2) National and international competitive situation of the research program
- 3) University collaboration and opportunities for cooperation
- 4) Influence on graduate and undergraduate and graduate education
- 5) Industrial relevance
- 6) Commercial motivation of participating companies
- 7) Growth potential for the research program
- 8) Opportunity for continued funding
- 9) Information and marketing activities
 - a. Workshop
 - b. Press exposure
 - c. Guest lectures and courses
- 10) Scenarios and projects
 - a. Scenarios
 - b. New / ongoing / finished projects during the year
 - c. Summary of all projects carried out so far
- 11) Company and other partners for each project during the year
- 12) Publications
 - a. International journal with referee procedure
 - b. Theses
 - c. Conference contributions
 - d. Internal reports
 - e. Other
- 13) Patents filed and/or granted during the year
- 14) Personnel
- 15) A calendar of communication activities during the year

1 Scientific quality and the relation to the expressed university profile

The Information Fusion Research Program (*infusion*) at University of Skövde is based on a research profile grant from the Swedish Knowledge Foundation for “Information Fusion from Databases, Sensors and Simulations”. The research program is paramount for the further development of industry and society in a complex world of information and focuses on a research area of high industrial relevance. The research program fits well into the strategic plan of the University (see Appendix A), says the President of the University, Leif Larsson:

– The research direction towards Information Fusion is central for the further development of the University. Most of the research activities at the University are at the core of information fusion or closely related to it, either at the technical level (development of systems) or at the application level (the use of information fusion systems for decision support). A research profile in this area is viable, and crucial to the further development of the research environment at the University.

We have established ourselves as an internationally renowned center for information fusion studies. The research program is led by Professor Sten F. Andler, as Program Director, in close cooperation with an Executive Committee and an Advisory Board.



Prof. Sten F Andler, director of the Information Fusion Research Program

The scientific quality of the projects in the research program is evaluated by the Advisory Board at their meeting twice a year. The Spring Meeting focuses on the results and achievements of the previous year, while the Fall Meeting focuses on the action plan for the

coming year. The complete list of scenario descriptions (umbrellas for a set of projects including statements of related work) and project summaries (including a statement of research question, industry collaboration and expected results) can be found in Appendix E.

The research field of the program can be defined in the following way: “Information fusion is the study of efficient methods for automatically or semi-automatically transforming information from different sources and different points in time into a representation that provides effective support for human or automated decision making.” (See Appendix 4 for information on a paper that motivates and discusses this definition.)

The overall research questions that are targeted by the program are:

- Can we develop a common theory and framework to describe information fusion processes in such a way that the framework can be used in various application areas?
- Can we develop generic algorithms and methods that allow fusion of information from multiple sources and with different temporal scope (including simulated future states) to be used in several different application areas?
- Can we find a common set of requirements on information fusion systems in the application areas of our partner companies that can be fulfilled by a toolbox and suitable information fusion infrastructure?

1.1 Mid-Term Evaluation

During 2007, a mid-term evaluation was conducted on all research programs recently funded by the Knowledge Foundation. The evaluation was done by an external firm, Inno Scandinavia AB. The result of this evaluation is available on the Foundation’s web page as well as our own web page.

The evaluators found the Information Fusion Research Program to be a well working research community with good potential for growth and future funding. They also found a few areas where improvement could be made.

The executive committee has acted on the recommendations of the evaluation team and has taken measures to further improve the research program.

2 National and international competitive situation of the research program

The research program achieves international competitiveness by high-quality research, by being visible in the international research community, and by being a leading European center for information fusion research. The participating researchers and groups are internationally competitive. By these groups joining forces in the research program, internationally highly competitive research results are achieved.

2.1 International competitiveness today

The groups participating in the program have strong publication records. In 2007, the third year of operation of the Information Fusion Research Program, we had 6 publications accepted to the 10th International Conference on Information Fusion in Québec City, Canada, and a total of 22 publications. Several of the research leaders were also invited to speak at international conferences and workshops.



Johan Schubert, FOI, gives an invited presentation at SWIFT 2007.

The University has a long tradition of cooperation with international academic partners, both in education and research. Examples of such cooperation include:

- *Joint-location Ph.D. programs.* Currently, 16 Ph.D. students from Skövde are registered at foreign universities, among them 3 in De Montfort, 4 in Exeter, 1 in Westminster, 2 in Limerick, 1 in Leiden, 2 in Rhode Island, and 2 in New South Wales, Australia. Through these collaborations, 8 Ph.D. graduates have received their degrees from Exeter, 4 from Sheffield, and 6 from De Montfort.

- *Joint-location faculty.* The research groups participating in the program have well-developed research collaborations with faculty that are part-time employed at Skövde (usually on a 25% basis) and take very active part in our research. This includes professors Ajit Narayanan (Exeter, UK), Jeff Offutt (George Mason University), and Sang H. Son (University of Virginia), as well as senior lecturers Brian Lings (Exeter, UK), Philip Moore (De Montfort University, UK) and Keith Case (Loughborough University, UK). To date, over 40 co-authored publications have resulted from these collaborations.

The University of Skövde has always been very active in organizing international conferences and has succeeded to an extent that is unique for a small Swedish university. The participating researchers are also active in scientific and program committees on many international conferences hosted elsewhere. For example, several of the researchers in the Information Fusion Research Program have been on the 2004, 2005, 2006 and 2007 program committees of the *International Conference on Information Fusion*.

International visibility is also achieved by serving on committees and editorial boards. Examples of such current activities taking place include appointments as Editor and Acting Editor-in-chief of *Connection Science – Journal of Neurocomputing, AI and Cognitive Research*; member of the editorial board of the *Innovations in Systems & Software Engineering* journal (ISSE); editorial board member for IEEE Press series on *Engineering of Complex Computer Systems*; member of the Executive Committee of the IEEE Technical Committee on *Complexity in Computing* and Guest Editor of special issues for several journals, such as *Autonomous Robots*, *Artificial Intelligence Review*, and *Cognitive Systems Research*.

Apart from international contacts and visibility in research, the University is teaching international Masters Programs of high quality. There are currently four international Masters Programs relevant to the Information Fusion Research Program: in Computer Science, Bioinformatics, Mechatronics and Intelligent Automation. These programs attract highly motivated students from all over the world, who perform high-quality research in their dissertation projects. Historically, over 40 % of

the dissertation projects in the Computer Science Masters Program have resulted in peer-reviewed publications. Several dissertations have received awards for “Best Masters Thesis”.

When looking at the competitive situation of the research program in the manufacturing research community, it would be fair to say that the research program has a strong position. This is underpinned by the relatively large number of information fusion related papers published at manufacturing research conferences and in peer reviewed scientific journals. With the exception of sensor/data fusion, the concept of information fusion for decision support is not widespread in the manufacturing research community and the leading role of the researchers in the information fusion research program in promoting information fusion is acknowledged by many, for instance by Professor Gunnar Sohlenius, Past President of CIRP. Participation in the my-Car project, which was on an invitation basis by four major European OEM car manufacturers, is another indicator for the strong position of the research program. Furthermore, a bid to organize FAIM 2008 has been successful.

2.2 Future international competitiveness

The program is well-positioned to become a leading center for information fusion research in Europe. Also, as described in Appendix J, the area covered by the program is very central to the research strategy of the University as a whole, and will therefore be strongly supported by the University Board.

Several of the industrial partners participating in the program work on the international arena. This means that results generated within the program will have the potential not only to be acknowledged by the international academic community, but also by the international industrial community. The program supports this by being based on a balance between theory development and practical applications of information fusion.

The international collaborations already established (as described above) lead to opportunities for wider collaborations in information fusion to strengthen the program even further. For example, De Montfort University has recently been allocated large funds (GBP 6 million) for research in Network

Centric Warfare, which is of great relevance for the program.

The European Security Research Advisory Board (ESRAB) has identified a number of areas where Information Fusion is highly important, for instance for *Border security*. ESRAB also acknowledges the importance of the information fusion for *Protection against terrorism and organised crime*, as well as for Critical infrastructure protection and *Restoring security in case of a crisis*.

The term information fusion for decision support in precision agriculture is not widely used within the research area, although some aspects of this concept are an issue within some research programs. There is a pronounced need for finding suitable methods to optimize variable fertilizing using crop-reading sensors in addition to traditional means. However, the idea of combining sensor output with soil-and-crop growth interaction models and data bases has not been investigated yet, why the scenario has potential to take a front position, national and international, in this research area.

3 University collaboration and opportunities for cooperation

Collaboration with the CUGS National Graduate School in Computer Science

CUGS is a national computer science graduate school, commissioned by the Swedish government and the board of education. The scientific scope of CUGS includes central parts of the core computer science and engineering. CUGS puts an emphasis on programming languages, algorithms, software engineering, also including related areas of autonomous systems, real-time systems, embedded systems, knowledge-based systems and artificial intelligence.

University of Skövde participates in CUGS and receives funding for Modules in Distributed Real-Time Systems (2001 - 2006, three PhD students), Reactive Mechanisms (2003 - 2008, one PhD student), and Information Fusion (2006 - 2009, two PhD students). The students participate in national courses and graduate conferences, and the faculty participates by giving national courses and being available in a network of advisors.



Dr. Roland Grönroos and Prof. Paul Pettersson of ARTES++ with Dr. Mike Hinchey of NASA and Prof. Sten F Andler.

Collaboration with the ARTES Graduate School and the SNART Association

ARTES is a national Swedish strategic research initiative in Real-Time Systems supported by the Swedish Foundation for Strategic Research (SSF). ARTES forms a network of academic and industrial groups, with the ambition to strengthen the Real-Time Systems competence nationwide. The main focus of ARTES is on graduate education and cooperation between industry and academia. ARTES is organized as a research program at Uppsala University.

University of Skövde participates in ARTES with two ARTES++ Real-Time Graduate Students, who have obtained special grants from ARTES for course and mobility activities, and a number of ARTES Real-Time Graduate Students. All the Real-Time Graduate Students have priority admittance to ARTES courses and other common activities within ARTES, and access to the network of advisors and industry mentors. We also participate by giving national courses related to real-time systems, such as Systems Thinking and Distributed Real-Time Database Systems. Both of these courses are related to Information Fusion.

The ARTES program formally ended in 2007, with a final conference planned for early 2008, but collaboration between partners will continue in the SNART organization (Swedish National Real Time Association).

Cooperation with the Industrial Research School RAP

The area in which RAP operates, namely intelligent robotics, automation and process control can be related to information fusion. Research areas such as unmanned intelligent vehicles or cooperating robots can be relevant to information fusion, especially when it comes to process control and information processing.

An example can be flocking UAVs for surveillance tasks. Since the university participates in RAP, it is obvious to exploit synergistic effects through treating some of the RAP projects as associated projects. This implies potential cooperation with the universities in Örebro, Mälardalen and Halmstad.

Virtual Manufacturing

In the area of virtual manufacturing, the university participates in an industrial research school CAPE. Whilst virtual manufacturing (or manufacturing simulation) in itself is not based on information fusion, simulation applications can be a building block for information fusion. Furthermore, some of the research questions emanating from the virtual manufacturing arena can be treated as information fusion problems. Projects addressing such questions can be treated as associated projects, which implies cooperation with universities in Gothenburg (Chalmers), Trollhättan, and Jönköping.

The university also has a tight cooperation with De Montfort University, UK in the area of virtual manufacturing. This cooperation goes back to the mid-nineties and the universities have jointly participated in several EU projects such as VIR-ENG and ARMMS. The universities have more recently also exchanged some results in nationally funded projects, for the university of Skövde this was the MASSIVE project. De Montfort University as carrying out research in synthetic environments (mixed reality/virtuality systems) which is an area with relevance to information fusion.

The university will participate in the EU integrated project my-Car. This project deals with adaptive assembly of vehicles, in particular with the self-adaptive assembly plant which is a plant that can address customized vehicles through individualized product routing and cooperating robots. Predicting and preparing required assembly operations through virtual engineering is seen as a potential technology enabler; the my-Car DOW explicitly mentions the role of information fusion in this respect. Through my-Car the university will cooperate not only with major European automotive OEMs and their associated industrial sector, but also with universities in Karlsruhe, Patras, Gothenburg (Chalmers), Saarland and Turin.

The researchers in the manufacturing scenario

have succeeded in expanding their network of industrial and academic research partners since the start of the research program. Examples are participation in the industrial graduate schools CAPE and RAP, and participation in various projects within the Swedish MERA program. There are also a number of initiatives within the framework of cooperation in research and education between the universities in Örebro, Halmstad and Skövde. We have also had a visiting researcher from Chile which may result in more intensive future collaboration. Our participation in my-Car means a further expansion of our network and this offers possibilities to become more active on the European research arena.

Precision Agriculture

The projects within precision agriculture are collaborating with other scenarios within the IF program and with outside scientific partners, such as the Division of Precision Agriculture, the Department of Crop Production Ecology, SLU (Swedish University of Agricultural Sciences), and Halmstad University, regarding crop growth models and sensors for controlling potato fungus disease. These collaborations have potential to expand and to identify additional common research projects. A contact of more industrial character is already established with POS (Precision Farming Sweden), a network of farmers, researchers and other practitioners. This opens for cooperation with POS participants, such as Swedish Farmers' Co-operative, Swedish Institute of Agricultural and Environmental Engineering (JTI), as well as Yara in Sweden and Denmark.

Collaboration with Örebro University in Modeling and Simulation

The University is collaborating with the University of Örebro to establish a research school in Modeling and Simulation. This effort is done in close collaboration with industry. Within this project there will be very good opportunities to attract industrial PhDs, since the collaborating industry has offered to finance some 10 industrial PhDs. The program should strive to get some of these.

Collaboration with Örebro University and Halmstad University in Information Technology

University of Skövde is collaborating with the University of Örebro and Halmstad University to establish a graduate school in Information

Technology. The graduate school will include all IT PhD students in the three universities, for a total of approx. 80 PhD students and 40 faculty.

Collaboration with ETIS

Some of the participating researchers are also involved with the establishment of Edutainment and Training Initiative Sweden (ETIS), which is a project to establish a knowledge and competence center within Serious Gaming for Education and Training. This initiative is very relevant for the Information Fusion program. The plan is to have the center up and running 2007. Since this is a joint effort between industry, academia and public organizations, it should offer many opportunities to establish new collaborative projects.

Cooperation with industry and organizations

The University has intensified its efforts to cooperate with industry and organizations. The University currently cooperates in research and graduate education with about 30 companies. The cooperation is primarily in the form of projects, but also donations that finance professors and graduate students.

The research platform in Mechatronic Systems has resulted in increased external cooperation, primarily with Volvo Powertrain, Euromaint Industry, Electrolux, Delfoi, Volvo Cars Engine, AP&T, B4Industry, Arla and the Industrial District of Skaraborg. This cooperation has resulted in two projects funded by the Knowledge Foundation, *Massive* (2002/0242) and *SimPlan* (2992/0243). These projects initially overlap with the program, which means that there is a natural transition from the research platform to the research program.

The same applies to the research platform in Learning Systems, which has resulted in a project in Bioinformatics, funded by the Knowledge Foundation for 2004-2006. There is also an application for an information fusion project within the *National Aeronautics Research Program*, aiming to integrate sensor information from various sources to achieve ground-situation awareness. Situation awareness is central to the interest of Saab Microwave Systems in the program.

The focus on information technology at the

University of Skövde has resulted in local establishment of several companies with a focus on technology development. One example is Saab Microwave Systems, with its main office in Gothenburg: In 1998 the company opened a branch office for software development in Skövde in order to get closer to the competence of the University. Saab Microwave Systems is an important part of the information fusion program development, which further increases the regional ability to attract additional companies with focus on technology development.

The importance of the University to the development of the local industrial region is increased by Gothia Science Park. The Technology Park is located on the University Campus, with a mission to support commercialization of results and ideas generated at the University. The applied nature of the research program increases opportunities for research collaboration with industry and organizations, including the recruitment of additional graduate students funded by industry, making local industry more knowledge intensive and diverse in nature.

4 Influence on graduate and undergraduate education

Several activities are carried out with the purpose of using the results from the research program in developing undergraduate and graduate education. Bachelors and Masters level students are offered the opportunity to complete a final year project in information fusion, and PhD courses are offered in Systems Thinking and Information Fusion. These information fusion courses have provided the students of the research program with an opportunity to meet interact and explore various parts of the information fusion field.



Ph.D Students in the Information Fusion Research Program.

The information fusion course was given for Master and PhD students again in the fall of 2007, as well as the course called "Advanced topics in information fusion". The latter course mainly contained student presentations of interesting research articles, but also guest lectures and optional individual student projects.

The University offers Masters level programs in Computer Science, Cognitive Science, Bioinformatics, and Automation that have been extended to include one or more of the course modules in the area of Information Fusion. Additional Masters level course modules have been developed in 2007.

The Information fusion research program applied for a grant from the Swedish Knowledge foundation to develop a two-year Master's program in Information Fusion. The group will cooperate with industrial partners, initially Saab Microwave Systems and the Swedish Defence Research Agency (FOI). This is a co-production to ensure the industrial relevance of the education.

5 Industrial relevance

Industrial relevance of the Information Fusion Research Program is illustrated with statements by the partner companies.

Agroväst Livsmedel AB (precision agriculture)

Agroväst Livsmedel AB often seeks partnerships where our money is used as seed money. The best is if all partners involved can get more out of their investment together than you would have been able to alone. You can have better results and also draw more attention to the project than you would be able to on your own.

Arexis AB (Biovitrum) (bioinformatics)

Arexis' idea of business starts with the concept of "forward genetics", which after translation from biology to English means that the consequences of a certain unknown gene and its function is highlighted and leads to the identification of the gene itself. The approach taken by Arexis is to use experimental genetics to create a range of manifestations of the disease of interest (by displaying different phenotypes in genetically defined animal models), which allows the genes responsible to

be identified with greater precision than by conventional approaches. Arexis' goal is to develop therapies that treat the cause of disease and not only the symptoms of disease.

In order to identify a "disease gene", different kinds of data, e.g. genotype and phenotype data, from the genome of study has to be functionally linked (or fused), by use of statistical algorithms. To enable the storage of large amounts of genetic data in a structured way, Arexis has developed and implemented a database application that supports genetic studies (International patent application PCT/IB01 /01883 published as WO 02/17207, US patent application US 10/086,788 published as US 2002/0187496, International patent application PCT/IB02/01998 published as WO 03/073352). This software also allows the researcher to extract, compare and analyze relevant data sets, in order to narrow down disease-linked chromosomal regions as much as possible.

Arexis was bought by Biovitrum AB in 2006. Biovitrum felt that information fusion was not aligned with their research and as a result choose not to continue the collaboration with the research program. They formally exited the research program 2007-11-30. A majority of Biovitrum's funding commitment is covered by an increase from InNetics AB.

Atlas Copco Tools AB *(systems development)*

Atlas Copco is market leader in the market of assembly tools for industrial use, mainly in the automotive industry. To develop products for these markets we need to work in a global perspective, consolidating different product requirements and priorities to get clear goals for our product development. We work in a very competitive environment where it is crucial for us to have strong and even unique sales points.

To be able to succeed with this, i.e. to have a long term effective product planning, we need to work in a broad way with our development, including concept and product development and also very active product maintenance during the products life cycle. Another very important part for us is to be able to, with minimal effort, develop customer specials.

We have identified that a proactive and integrated way of working with information about our customers businesses and product

requirements is essential for us to succeed with all this over time.

Cellartis AB (bioinformatics)

For small companies such as Cellartis AB, it is difficult to host all kinds of expertise in house, which makes it necessary to seek strategic alliances. Partnerships can be formed both with academic groups and other companies in order to facilitate product development.

Delfoi Sweden AB (manufacturing)

Delfoi develops markets and supports Digital manufacturing solutions and related consulting and integration services which enable companies to speed up and streamline their product creation and product delivery processes. With Delfoi products and services, companies can integrate and automate engineering to execution process, which will lead to shorter time-to-market, faster ramp-up, more agile demand adaptation and - most importantly - better profitability. Obviously, the ability to provide customers with tools and methods that enable them to achieve this is a key competitive element.

Delfoi Sweden AB left the research program by the end of 2007.

Electrolux Major Appliances AB *(manufacturing)*

Electrolux Home Products co-operates with University of Skövde in research, especially with its research group in Intelligent Automation (CIA), for example in areas such as virtual product- and production development, manufacturing simulation and modular manufacturing equipment. Examples of successful projects are dAISy (Vinnova) and SimPlan (KK-Stiftelsen).

Enea Services Stockholm AB (systems development)

Enea Services Stockholm AB (ESS) is a subsidiary of Enea AB. ESS assists its customers in the development of products and systems where the demands on usability and reliability are especially high by providing solutions, consultant services and training throughout the whole life cycle of the products. ESS currently boasts the most experienced test organization with the broadest range available in Sweden today. Important fields of practice of ESS are medical technology, industrial automation, automotive, telecommunications,

public authorities and government agencies.

Enea Software AB (common goals and infrastructure)

Enea Software AB offers products and services for embedded real-time systems to customers who develop products in this area. Enea delivers the basic functions through software, concepts, and services. They can also take the functional and maintenance responsibility for the entire life cycle of customer products.

Enea's real-time technology for embedded systems is world leading and a de facto standard in the communication product arena. Our company is seen as one of the most innovative in the business. The customers often build very complex products. This puts a high demand on the system software that connects the micro chip to all the software that makes up the product, and a need for handling complex information from many sources.

Euromaint Industry AB (manufacturing)

Euromaint Industry AB, Skövde is in the business to design and refine production processes, and develop, design, manufacture and maintain production equipment.

The operation focuses on the engineering industry and encompasses maintenance services, component servicing and production engineering, as well as the development and manufacture of production equipment.

In this business, high quality and speedy service to customers is a key competition factor. The ability to supply not just the manufacturing equipment itself but to offer a suite of tools that will enable the customer to utilize the equipment in an efficient and effective way is more and more becoming a must. This means that advanced methods and tools that enable fusion of different information sources for supporting service & maintenance and in some sense production engineering, become even more important.

Exensor Technology AB (ground situation awareness)

Exensor Technology AB is a well-established high-tech company which focuses on ground sensors and ground sensor systems. We develop systems covering the entire chain from gathering information (sensors) via transfer of information (transmission) to presentation and or logging into other systems (interface).

Exensor's interest in the research program in

information fusion is the development of architectures and algorithms for information fusion for ground situation awareness. In this area information fusion can be identified at various levels. Exensor's competence and products includes the data fusion (or sensor fusion) aspect. The UMRA (Intelligence Multi-sensor Radio) is an identification system that uses two sensor probes each one containing an acoustic, a seismic and a magnetic transducer. The UMRA can be used to identify soldiers, cars, trucks, light or heavy combat vehicles and helicopters. The key aspect of such a system is naturally the fusion algorithms. Ground situation awareness poses the challenge to combine information from different sensor systems (e.g. UMRA, ground based or air based radar systems, surveillance information, etc) in order to achieve full understanding on the situation at ground level.

ICA AB (retail sector)

ICA's purpose for involvement in the information fusion platform is to explore opportunities that emerge from the fact that ICA gathers data and information from various internal sources. It is highly interesting to explore how this internal information could and should be fused with information from external sources e.g. weather information or information on competitor's advertising strategies, to generate the best possible decision support for both planning and marketing.

InNetics AB (bioinformatics)

InNetics AB was founded in 2002 and is continuing the development of advanced modeling and analysis software tools for the pharmaceutical industry originally initiated by MathCore. InNetics supplies its state-of-the-art solutions in modeling and simulation into the pharmaceutical industry in close cooperation with Fraunhofer-Chalmers Centre for Industrial Mathematics (FCC). The resulting product - PathwayLab - is an application for in silico modeling and simulation of biological processes. The aim is to enable researchers to increase their understanding of disease relevant biological mechanisms and their implications for e.g. target validation and prioritization

InNetics AB increased their commitment from 2008 and onwards.

Lexware Labs AB (bioinformatics)

Participation in the information fusion research program at the University of Skövde furthers goals of two types: providing feedback for our products and opening up for new domains of use. A good example of pursuing the first goal is letting students engage into learning tasks supported by our tools, tasks which are either determined by the teacher or self-invented. Both types of use contribute with valuable comments such as shortcomings of an interface, as well as postulates for adding desired functionalities.

Saab AB, Saab Microwave Systems (ground situation awareness & systems development)

Saab is a high-technology company that offers world-leading system solutions, services and products in defence, aviation, space and civil security. Saab has technology for a changing world.



Futuristic image on collaboration to achieve ground situation awareness

Saab Microwave Systems is a business unit within Saab AB, specializing in complete sensor solutions for information superiority. The importance of sensors is increasing. The ability to react rapidly and accurately to any threat is vital on the modern battlefield as well as in other crises. Combinations of radar sensors can provide total visibility 24 hours a day, in any weather.

Saab Microwave Systems is a leading provider of Radar Systems encompassing advanced airborne, ground-based and naval radar, as well as an extensive range of services. Providing customers and partners with information superiority is the basis for the products and solutions developed. If you are first to know, you can be first to act.

With more than 50 years of experience in radar development we are today a world-leading competence-center for microwave and antenna

technology. Over the years more than 3000 sensors have been delivered worldwide and today our products are operational in more than 30 countries.

Saab Microwave Systems is also well positioned to meet the increased demand for information technology and communication networks, primarily built on civilian technology, for military and other governmental customers. In close cooperation with other Saab units we provide a unique competence to support the strategic change and technology shift that is denominated the Networked based defence.

Volvo Powertrain AB (manufacturing)

Volvo Powertrain is an in-house supplier of automotive drive line components to the different business areas inside the Volvo Group. Manufacturing of these components take place in Sweden, Brazil, France and the USA. The company holds a world leading market position in the segment of 9-18 L displacement heavy duty diesel engines and also a very strong market position in heavy duty transmission volumes.

At the site in Skövde most of the Volvo Group need of heavy duty diesel engines is manufactured. The processes included for this manufacturing are casting, machining and assembling. Running this production is a complex task, with a variety of influencing parameters. Quite often it also involves interaction between these parameters. Factors to keep under control, to optimize or to maximize performance for are, among others, incoming, intermediate and final product quality, logistics, production rate, production flexibility, production equipment status, information quality to operators, environmental aspects, etc. Use of suitable sensors for different processes and intelligent handling of collected and merged data is of extremely high importance to satisfy the demands on a well working and controlled process.

6 Commercial motivation of participating companies

The commercial motivation of participating companies for participating in the Information Fusion Research Program is illustrated with excerpts from statements by the partner companies. The full texts of all letters of intent are found in the profile proposal filed in 2004.



Logotypes of our partner companies during 2007.

Agroväst Livsmedel AB *(precision agriculture)*

Precision Agriculture Sweden (POS) is a project financed by Agroväst with the overall aim to develop tools and strategies for better utilization of inputs such as fertilizers and pesticides in agriculture. By adjusting the inputs according to within fields variations of crop demand and soil characteristics inputs are applied where they best fill their purpose. This will gain the profit of the farm and reduce risks for negative impact on the environment. Through the participation in the Information Fusion Project at Skövde University we hope to improve the decision support for variable N-fertilizer application in real-time. On economical and environmental grounds, with respect to robustness, speed and precision, fusion of information from soil and crop sensors, model simulations and databases of varying spatial resolution should provide reliable decision support in precision agriculture.

Arexis AB (Biovitrum AB) *(bioinformatics)*

The typical disease model is the result of many man-years of research in which the molecular components of the disease process are pinpointed. One of the keys to success in this process is the ability to represent the disease model and its constituent knowledge in such a way that it helps the researchers involved to share a clear understanding of the current knowledge about the disease process. Another of the keys to success is the availability of bioinformatics and data mining tools to support the refinement of the disease model by inferring new information from the mining of both public and proprietary data sources.

Bioinformatics is an integral part of the modern

pharmaceutical R&D process and could be described as the application of various software tools to organize and analyze biological data and thereby derive new tentative knowledge in the form of experimentally testable hypotheses. Highly related to bioinformatics, computational biology is more focused on building models of biological systems, so that hypotheses can be tested by simulation. Computational biology therefore complements experimental molecular biology by providing another approach for testing hypotheses derived by applying bioinformatics and data mining tools to biological data. To illustrate the abundance of bioinformatic tools, data and databases it can be mentioned, for example, that the ExPASy molecular biology server lists 150 publicly and freely available tools and over 600 databases, some of which contain millions of records (e.g. Genbank contains almost 30 million DNA sequences, which corresponds to about 30 billion nucleotides).

Atlas Copco Tools AB *(systems development)*

The cooperation with University of Skövde and also within the companies in our group in this program gives us a direct access to best practice and relevant experience for managing information about our customers businesses and use of products for our business and product development. We will develop and adjust our processes based on the experiences and conclusions that come from this work and also spread the knowledge within our development staff. Doing this, we also share our industrial perspective and experiences with the project team and the University of Skövde.

Cellartis AB (bioinformatics)

The current collaboration gives Cellartis AB the opportunity to access the bioinformatics expertise of University of Skövde. This is a valuable contribution to the research and development activities of the company. The present project aims to increase the knowledge of gene expression profiles for different stem cell populations, which is an important research area for Cellartis AB. This will increase the understanding of the differentiation process from immature stem cells to mature specialized cells and contribute to a decrease in time and cost for the development of future products. In addition, data valuable also for the research community is generated through the joint activities of the company and the academia.

Delfoi Sweden AB (manufacturing)

The research program "information fusion from databases, sensors and simulations", in particular the theme "simulation-based production planning and maintenance" is highly relevant to us in the context of developing tools and methods for simulation-based lifecycle support of manufacturing systems. We are already now involved in joint projects with University of Skövde within the area of simulation-based planning and service- and maintenance, namely the KKS supported "Massive" and "SimPlan" projects. We see the above-mentioned theme within the program as a natural continuation of these projects.

Electrolux Major Appliances AB (manufacturing)

The sponsoring from Electrolux Home Products is related to co-operation in future research projects with Electrolux as industrial partner and is expected to be MSEK 2-3 during this period, mainly through offering an industrially relevant research & development environment including equipment, human resources, and a manufacturing environment in general. The purpose of this sponsoring is to offer the University the possibility to carry out industrially relevant research with the aid of state-of-the-art manufacturing equipment, and also to support our own future development.

Enea Services Stockholm AB (systems development)

Since Jan 1st 2000 ES together with the University of Skövde and the KK foundation are co-financing one industrial PhD student within the program for industrial PhD students at new Universities. Our experiences from this cooperation with the University of Skövde are very good. The major benefit we can point at is that the PhD student has been a catalyst in transferring knowledge from academia to our consultants, which in turn has increased their competitiveness. Further one of our training programs offered to our customers is a direct result of this knowledge transfer.

The research program in information fusion at the University of Skövde, in particular the work directed towards decision support and presentation of complex information structures, summarizes many of the problems we help our customers to solve. Thus, we expect involvement in the research conducted at the University of Skövde to strengthen the core

competence of our consultants even further. A second important argument for participating in this research program is the potential for new business cases. Such business cases may arise both directly from contacts with other participating companies and indirectly through the exposure ES gets from participating in the program. An additional potential benefit with our involvement in this project is an expansion of the services we offer to our customers.

ES strongly supports the program in information fusion from databases, sensors, and simulations, and intends to continue collaboration with the University of Skövde as part of the research program.

Enea Software AB (common goals and infrastructure)

Enea Software AB (formerly as Enea Embedded Technology, Enea Data and Enea OSE Systems) has had a longstanding relationship with the University of Skövde in the joint NUTEK-funded effort to develop an architecture and later prototype for distributed active real-time database systems, known as DeeDS. We want to support the proposed exploration of infrastructures for information fusion, in particular the role of such a distributed active database system that could be used as part of our supporting software, within the research program in Information Fusion from Databases, Sensors, and Simulations.

Euromaint Industry AB (manufacturing)

The research program "information fusion from databases, sensors and simulations", in particular the theme "information fusion in the areas of advanced maintenance and industrial (service) logistic" and/or "simulation-based production engineering/planning and maintenance" is highly relevant to us in the context of improving customer service. Based on previous real life experience and for example, a joint project with University of Skövde called "Massive project" we have seen the above-mentioned theme within the program as a natural continuation for joint investigations and research. Furthermore, participation in the program will enable us to improve our technical competence on a continuous basis and through the IF-profile ease the idea and information exchange and synergies that obvious exist between the different scenario projects.

We envisage to participate in projects within the theme "simulation-based production

planning and maintenance". The program is expected to run initially from 2005 to 2010, and we expect to contribute the equivalent of approximately 1 MSEK during this period.

Exensor Technology AB
(ground situation awareness)

Exensor will initially focus on projects involving development of algorithms for information fusion at the sensor level, but will also take an active part in projects involving fusion at the system level. The ambition is to extend our current system with person identification capacity, and to incorporate this into a system of systems for total ground awareness. This would mean that ground situation awareness could include vehicles as well as personnel, a scenario that would be of extreme importance in a conflict situation.

This will be a central idea within the net centric form of defense that Sweden is developing. We believe that the program, with its industrial and academic partners, will allow an excellent opportunity to develop systems which will allow the fusion of information from different systems and vendors.

ICA AB (retail sector)

New opportunities emerge from the fact that ICA gathers data and information from various internal sources, e.g. customer's individual purchases and advertising information. New techniques are required to refine and combine the data and information to discover new valuable information. Examples of this include identification of customer groups with similar purchase patterns, which could be used for individually styled marketing; new opportunities also emerge when external sources, e.g. weather information or information on competitor's advertising strategies, are incorporated into ICA's internal information and used to decide about, and estimate the outcome of, ICA's own advertising.

InNetics AB (bioinformatics)

InNetics will participate in bioinformatics projects to develop a model-based information fusion approach to support the drug development process. InNetics' goal is to provide pathway modeling tools where a range of different modeling and analysis features can be applied. In addition to the analysis tools we see a specific need to have different kinds of

data mining tools that work in the same framework as the modeling and simulation tools, thereby providing the most convenient way to build the knowledge going into the models. The development of such a framework needs to be done in close collaboration with the end user dealing with the needs of information fusion that is the reality in the pharmaceutical research today. InNetics will act as the software developer and integrator of the methods and algorithms developed in the project. InNetics will also provide expertise in modeling as well as tools for the project. In this project the software PathwayLab will be developed to support the special requirements that are needed for incorporating PathwayLab into the framework. The main things to add to PathwayLab are methods and algorithms for parameter estimation in biochemical reaction network models given time series measurement data of various kinds.

Lexware Labs AB (bioinformatics)

Biomedicine is an example of a wide domain opening for natural language processing tools developed by Lexware Labs. Here it is obvious that researchers, be it at a university or a pharmaceutical company, require special tools for extracting information from a constantly growing number of new research articles - plain browsing is not an option when billions of articles need to be looked through. Researchers are thus the target group of our product. Our participation in the bioinformatics scenario of the information fusion research program helps us to develop our information extraction tool Lexware Culler into a specialized tool for biomedical text corpora.

Saab AB, Saab Microwave Systems
(ground situation awareness & systems development)

The role for the Swedish Armed Forces, Saab Microwave Systems main customer, will change in the coming years. In the future their tasks will change not only to encompass military responsibilities on Swedish territory but will also include support to civilian authorities during crises and international peace keeping missions. During the last years Swedish authorities have initiated major technological, methodical and operational changes to develop a new concept of operation called Networked Based Defense, (NBD). The adjustment to the NBD doctrine will take many years and will pose major technological and

conceptual problems to be solved and the entire Swedish defense industry will be involved in this work for years to come.

However, the ideas about network based command and control infrastructures are not exclusive to the military realm. Governments in several countries around the world pursue similar ideas about network centric cooperation between civilian authorities in the case of emergency situations. Hence, there is a potential major worldwide market for such information and communication systems for the Swedish industry if the technological and methodological challenges proposed by NBD can be solved.

Volvo Powertrain AB (manufacturing)

Successful work for improving performance will have a significant economical impact due to the high production volumes.

Volvo Powertrain expects by participating in the Information Fusion program to benefit from the following areas, in order to increase the commercial input to their business:

- getting better knowledge of techniques for data handling
- decrease rejects
- gain competitive precedence
- optimization of production
- extended cooperation with academic researchers

7 Growth potential for the research program

The Information Fusion Research Program is based on the research conducted within a number of existing research groups at the University. The ambition has been to recruit a number of new researchers and graduate students within the area of information fusion, including the establishment of the first Swedish chair in Information Fusion and to create a research group around this position. The total funding for the program is almost MSEK 120, with MSEK 36 from the Knowledge Foundation, MSEK 54 as industrial support from participating companies and MSEK 29 from internal university funding. The major portion of the Knowledge Foundation funding is used to fund new faculty (professor and two post-docs) and a number of new Ph.D. students.

During 2007, a professor in Information Fusion

and two adjunct professors were added to the program, as well as one Ph.D. student. Previously, two post-docs and 2 Ph.D. students were hired in 2006, and 9 new Ph.D. students in 2005.

The University funding is used to support existing faculty and Ph.D. students, often funded in part by other project grants. The industrial support is in part used to fund several industrial Ph.D. students and adjunct professors, but primarily to support researchers and developers within participating companies.

We have identified a number of factors that ensure the long-term development of the program:

- The program is at the core of the University's research focus and will play an important role in further development of the University. This ensures that the internal institutional bodies responsible for quality assessment and control of research funds actively contribute to the program development.
- Current research and research infrastructure at the University is solid and offer good opportunities for development, providing a good basis for further development and expansion of the research conducted today.
- The program is complemented by a number of funded application projects. This ensures that the program can exploit results from a number of concrete projects from the onset, in order to support the overall research vision.
- The Swedish armed forces are currently making a transition from an invasion-centered to a net-centric defense structure. Information fusion will play a vital role in this transition. The planning horizon for this transition is the year 2020, which means that the horizon for civilian applications should be even longer, as the Swedish armed forces and defense industry often are leaders in technology development.
- The University has established cooperation, with important key individuals in the armed forces and defense industry, within the area of Modeling and Simulation for Decision Support. A letter of intent has been signed with Saab Microwave Systems

and commanders of local army regiments (the 4th armored tank regiment, the 3rd cavalry regiment, the 2nd transport and logistics regiment), and with a simulation facility for ground force combat. This special interest group contains representatives for the research program and important information fusion application areas.

Manufacturing scenario

It has been indicated from within the manufacturing research community that the use of information fusion is a novel idea for this sector. Professor Gunnar Sohlenius (KTH) for instance wrote in 2006:

“Previous and ongoing research at the Centre for Intelligent Automation at University of Skövde has highlighted the potential use of simulation as a decision support tool in different manufacturing life-cycle phases. (...) The use of information fusion to integrate the use of historical data, current status/signals and future estimates with the aim of providing improved decision support is one interesting novel element in this approach.”

It should be mentioned here that not only industrial manufacturing companies can benefit from the information fusion research, but also other companies/organizations such as health care providers and the service sector, or in more general, organizations that face similar issues as the manufacturing industry.

The groups participating in the manufacturing scenario are also heavily involved in the formation of a new research environment called “Virtual Systems”. Here, there is an excellent potential for synchronization and synergistic collaboration with a center of “Modeling and Simulation” as currently being studied by Örebro University. Tommy Hansson from Volvo Technology wrote to us that the establishment of such a research center in virtual systems sounded like a highly interesting initiative and that he was eager to discuss possibilities for future collaboration with such a center.

Precision agriculture scenario

The expected outcome of the IF pal-project (techniques and principles for real-time variable nitrogen dose) could be expanded and adapted for other measures within agriculture as well, e.g. other fertilizers (such as phosphorous and

potassium), pesticides etc. Not only traditional agriculture, but also golf courses, forestry and vineyards could be potential application areas. Future collaboration partners could be the JTI (Swedish Institute of Agricultural and Environmental Engineering) and SMHI (Swedish Meteorological and Hydrological Institute) for developing routines for data management, weather statistics and forecast models. Furthermore, central partners in this scenario would be the manufactures of fertilizers, tractors, sensors (the Yara Company) and of other machines and hand devices used by farmers for fertilizing purposes. Similarly, other scenarios within the IF program would be important potential partners regarding visualization, data fusion models, user perspective, and trust in the systems.

Common goals and infrastructure

In conjunction with the growth of existing and new application areas for information fusion, the benefit of transferring acquired knowledge across different application areas is expected to grow substantially. This will put new requirements on formal frameworks and terminology for analyzing these scenarios, as well as demands for new algorithms and infrastructure. Hence, the growth potential for the common goals and infrastructure scenario is highly dependent of the growth of the application areas. The common goals and infrastructure scenario is also expected to be very important for the other scenarios from a scientific point of view by providing support for scientific methodology and the formulation of research problems, ensuring that they indeed contribute to the field of information fusion and not only to the areas of application.

Strategic funds and travel grants

During 2007 a total of nearly 450 000SEK were received in strategic funds and travel grants. These funds are included in the contribution made by the University.

Common goals and infrastructure (cgi) received funds to establish a testbed for wireless sensor networks, which forms a key platform for many information fusion applications. The testbed was developed with help from Dr. Leo Selavo from University of Latvia.

Funds were also received to enable usage of software called Stage. Stage is advanced simulation software that has helped researchers in the ground situation awareness (gsa) scenario

generate data.

The retail scenario (rs) received funds to develop increased collaboration with AstraZeneca AB.



Maria Nilsson, PhD Student in the common goals and infrastructure scenario, received a travel grant

8 Opportunity for continued funding

The Information Fusion Research Program is the result of integrating activities within two research platforms, *Learning Systems* and *Mechatronic Systems*, previously established at the University of Skövde with funding from the Knowledge Foundation, with other fusion-related research activities. The platforms were invaluable in establishing important research directions within the central research focus of the University, i.e. the development of advanced information technological systems. The research platforms also contributed to an increase in research volume and the number of external contacts.

The University of Skövde has a joint Faculty of Technology between the universities of Skövde, Halmstad and Örebro. This faculty in practice means that we have obtained the right to issue PhD degrees, formally under the responsibility of the Faculty of Medicine, Natural Science and Technology, University of Örebro. The Information Fusion Research Program strengthens research directions towards a new focus in harmony with the current central research focus of the University. It is therefore likely that the research program will be able to extend the university funds for the program.

We have identified a number of projects that address the overall research vision and the industrial relevance of the program. Some of them are funded by other sources and are in progress, and can therefore be used to obtain

early results. There will be excellent opportunities to identify additional projects that fit within the program during its lifespan. The research program has excellent opportunities to attract additional external funding for activities that complement the program research, including EU funding in FP7. Another approach to radically increase the research volume of the program is to fund participating projects on a reciprocal basis, i.e. if an information fusion project has funding for a participant from another source, then the program could match this by funding another participant.

The University of Skövde has identified the need to expand the infrastructure supporting its research. The plan is to build a new building co-located with Gothia Science Park. The ambition is to house most of the applied research within these new facilities. This will basically mean three new opportunities for information fusion:

- An opportunity to create a common environment for all the research projects within IF.
- An opportunity to make the IF research more visible since it is located to a designated area.
- Close relation to companies with a high need for R&D collaboration.
- Increased spin-off and patenting opportunities

9 Information and marketing activities

The internal and external interest for the Information Fusion Research Program, as described in Section 9.1 and Appendix B, is an indicator for the effectiveness of the information & marketing strategy of the program as summarized in Section 9.2. Sections 9.3 to 9.5 detail how communication issues have been handled during 2007 and identifies a number of future activities.

9.1 Communication effectiveness

While a listing of information and marketing activities is useful in itself, an estimate of the *effectiveness* of the activities is a more useful instrument. In this respect, there are some major indicators that the information strategy as implemented so far has been highly effective:

- A large number of high profile companies and organizations have contacted the University about direct participation in the research program or about indirect participation through associated projects. Examples include NASA, FMV (procurement agency for the Swedish Defense), FOI (Swedish Defense Research Agency), Saab AeroSystems, Saab Systems, SaabTech, Volvo Technology (resulted in an invitation to join an EU IP bid related to the manufacturing scenario now entering the final selection stage). In particular, interest from AgroVäst during the application process resulted in the definition of an additional application scenario within the research program, namely "Precision Agriculture". Furthermore, interest from AnalyCen resulted in participation in the industrial research school RAP, also funded by The Knowledge Foundation and Swedish industry, and interest from KBM (the Swedish Emergency Management Agency) has resulted in a substantial stipend for a postdoctoral fellow.
- Interest from the media: Media such as newspapers, radio stations and television channels have shown a sharply increased interest in reporting about the research program and its associated activities.

An unprecedented high response from Sweden and abroad to advertised job vacancies also indicates that "the message has come through" about this major research initiative.

Considerable impact has also been made in the scientific community. Over 70 scientific publications have appeared, including journal and conference publications (see Chapter 12). A few of these were published in the year ahead of the formal start of the research program. Several of these publications have been "invited contributions" or have been selected for special journal issues. This underlines the effectiveness of the information strategy within the research community. The high production of research papers at such an early stage may look remarkable at first sight, but in essence, it just underpins the fact that Information Fusion is the common denominator for the core of research undertaken at the University of Skövde. It also demonstrates that faculty and research students show faith and commitment to make this research program a success and that the establishment of the program is a source of inspiration for those participating as

well as for other research groups.



Partner company rollups

International attention to the research program is underpinned by invitations to join various EU applications (ongoing as well as projected bids), but also through invitations to act as external experts for research funding agencies. As an example, Professor De Vin has become a member of the EPSRC Peer Review College, which is a group of experts that assesses project applications for a research agency that annually allocates 500M GBP (7000 MSEK) in research funding.

9.2 Summary of the Information Strategy

Aims and goals

The overall aim of the information strategy is to have a thorough plan for the dissemination of information about the research program. Information distributed internally serves to facilitate communication within the program, to facilitate synergy between projects/scenarios, and to stimulate the generation of new ideas. Information distributed externally serves to inform other organizations and the public about the research program as well as to market it as a research partner and source of innovations. An important goal of the external information is to create awareness about the fact that the University of Skövde performs high quality research in a strong research environment and is focused on dissemination of information on ongoing research in Information Fusion to all of society, academic organizations and industry, nationally as well as internationally.

Marketing material and target groups

The information strategy has an internal target group as well as an external. The internal target

group includes the research program participants and relevant members of their organizations. The external target group includes the international research community, Swedish industry and research funding agencies, as well as society at large and the public sector.

According to the contract between the University of Skövde and the Knowledge Foundation the main goals of the internal information are to:

- Gain support for the research program and projects within the participating organizations.
- Disseminate project results, including detailed information about developed solutions and methods.
- Co-ordinate projects and achieve synergy effects between projects that are carried out within the framework of the funded research profile, and between those projects and associated projects (projects with some relevance for, but not conducted within the funded profile).
- Inform about planned activities.
- Get feedback about the research program and ongoing projects, and get ideas for new projects.

This list has been extended with the following goals:

- To encourage researchers in the research program to explore opportunities for research leading to innovations.
- To show role models of spin-off enterprises formed from other research profiles funded by the Knowledge Foundation or from other research environments in Sweden and internationally.
- To inform about support channels/schemes for patentable research and business development.
- To create a platform for intensive dialogue with industry that (i) leads to discussions that help to improve industrial relevance of our study programs and (ii) ensures that industry highlights the cooperation with the university in their internal and external information and marketing.

The main goals of the external information are to:

- Disseminate information about the research program, projects, partners, etc.
- Disseminate information about results of the

projects to potential users.

- Disseminate information about research highlights to the general public.
- Highlight the scientific questions addressed in the research program and the projects.
- Disseminate scientific findings.
- Inform of potential opportunities for establishing spin-off enterprises
- Highlight opportunities for research and graduate studies at the University of Skövde.
- Highlight opportunities for cooperation between industry and the university within the research program or as associated projects with other forms of external funding.
- Increase opportunities for mobility between academy and industry, nationally as well as internationally.
- Market the University of Skövde as a university with a strong and thriving research environment.

An important activity here is to disseminate generalized research program and project results with the purpose to create new contacts for future collaborations both national and international, in particular to increase the opportunity for research collaborations within the EU.

The internal information also aims to:

- Contribute to information about future activities
- Gather feedback about the research program and its projects and ideas about new projects
- Generally distribute information and knowledge about the research program in order to give the University a good image both national and international
- Create marketing materials for use by program participants and design special web information
- Arrange seminars, conferences and workshops with companies and cooperation partners to foster new collaborations as well as to market the University of Skövde and the City of Skövde.
- Inform program participants of opportunities for future funding.

9.3 Implementation of the information strategy

Essentially, the external target group is the ultimate and most important target group. However, in order to reach the external target group in an efficient and effective way,

information distribution to the internal target group is an absolute necessity. Dissemination of awareness and knowledge about the Information Fusion Research Program into the internal organization increases the contact surface area with the external target group; furthermore it increases the quality of information to the external target group.

In order to achieve good dissemination of information into the internal organization, a variety of internal target groups have been exposed to the Information Fusion Research Program through presentations, seminars, courses and other channels (web, folders, news items). The Executive Committee has not only addressed operational issues such as budgets, recruitment and contracts during their meetings, but has also discussed research content in the various scenarios as well as the contributions from these scenarios to the overall goals and vision of the research program. As a result, members of the Executive Committee have a holistic view of the research program as well as a detailed insight into the various scenarios. This means an increased flexibility to respond to invitations for discussions, to deliver presentations, answer questions from the media, as well as the capability to identify potential research partners/opportunities related to the various application scenarios. We have recently formed a Project Leader Group to achieve more efficient and effective coordination and synergy between the participating projects and to instill the holistic view on all the participants. Furthermore, the Information Fusion Research Program has been a recurring item on the agenda whenever meetings have been carried out between representatives from the University of Skövde and external target groups.

Regarding specific information and marketing activities for 2007, four types of activities are of particular interest:

- Dissemination of information and results within the companies that participate in the Information Fusion Research Program. This creates more awareness about the research program within the companies and shows the benefits of their participation, in order to increase the internal support and to create an atmosphere that may result in new ideas for joint research.
- Targeting other funding agencies with information about the research program, with the aim to increase awareness about the program and to promote the University of

Skövde as a strong research environment in the area of Information Fusion. The purpose of this is to create a dialogue to facilitate the identification of funding schemes suitable for strengthening the research program and for enabling continuation of the program as a self-sustainable research environment after 2011.

- Regular dialogue seminars with Gothia Science Park, in order to identify research results from the Information Fusion Research Program that are suitable for commercialization. This process addresses opportunities for commercialization and research activities concurrently, for instance the definition of suitable commercialization approaches. Such dialogue seminars are a meeting place for researchers and business coaches.
- Active information exchange and dialogue with companies currently not participating in the Information Fusion Research Program. This serves to explore and create opportunities for strengthening the research program through associated projects, and in particular to broaden the industrial base in the view of continuation after 2011.

Many of the above-mentioned activities deserve particular attention in the coming 1-2 years, in addition to continuation of the other activities as carried out so far.

In a longer perspective, the following activities are seen as important:

- Planning to organize and host a conference related to Information Fusion. This would ideally be the International Conference on Information Fusion in 2010 (Fusion 2010). Other conferences related to the subject areas within the application scenarios, preferably with a special session or workshop on Information Fusion, are also considered.
- Continuous refinement of the external information and marketing by identification of specific target groups within the external target group. An example here could be the targeting of youth; the research program can form a showcase for increasing the interest for science and technology, while the program itself can appeal to youth with specific interests for areas such as IT, manufacturing, biology and medicine, agriculture/environment, retail, and defense. The fact that a single research program has such a *variety* of application areas should be

highlighted to show that studying science and technology subjects opens up a wide spectrum of exciting career opportunities.

- Recruiting of new people to the research program, in order to do undergo graduate studies, to do research in one or more of the many projects, and to invent new solutions in collaboration with industry.

9.4 Actual vs. planned information/marketing activities

After comparing the implemented information and marketing activities with the initial information strategy, we reach the following conclusions:



Anita Andler, project leader for the Fusion as Vision project

Communication with the general public

The primary channel for communication with the general public and target groups has been the web. The infofusion website has been used extensively, for instance through newsletters and news items. The local and national press and the University's research magazine "Perspectives" (in Swedish "Perspektiv") have also been used widely.

The Information Fusion Research Program has also been exposed to the general public when recruiting new personnel. During 2006 over 15 positions were filled with PhD students, post-docs and professors, and in 2007 the recruitment of the planned research staff was completed.

The Information Fusion Research Program has been highlighted in the popular scientific newspaper "Computer Sweden" and several other published articles have appeared in newspapers of various types. On several

occasions, Infofusion events and visitors have been featured on local television.

Communication with industry

The Information Fusion Research program has arranged a number of seminars and workshops where industry was invited. Communication has been carried out with the participating companies as well as external companies, companies not directly involved in the Information Fusion Research program. The external companies have been invited for visits, seminars and presentations. The Information Fusion Research Program has also been presented at large number of meetings addressing Information Fusion, as well as other meetings with topics related to information fusion.

The exposure in trade journals has been somewhat limited; however we are expecting a change as projects mature and research starts to produce solid results.

An EU-funded project called "my-Car", carried out within Infofusion, is an incentive from the automobile industry; Volvo Technology (who coordinates the project), Ford, Daimler Chrysler and Fiat. The project will be running for 5 years and Professor Leo De Vin at the University of Skövde is one of the 16 selected copartners to be working on the project. My-car is working on developing new ways to assembling so that the process can adjust itself to the cars that are being built.

The University of Skövde also coordinates an EU-funded project within the field of Cognition. Professor Tom Ziemke is the leader of a large project titled ICEA ("Integrating Cognition, Emotion and Autonomy"). The project is working on developing robots that in the future can interact with their surroundings and evaluate different actions.

Communication within the research community

In 2007, the Information Fusion Research program intensified the planning for the hosting of the Flexible Automation and Intelligent Manufacture Conference (FAIM2008) in June 2008 at University of Skövde. The conference includes a special session on information fusion. In collaboration with Göteborg & Co, we are preparing a bid to organize the FUSION 2010 conference, an event normally attracting approximately 300 participants.



Participants in the Information Fusion Research Program brainstorming during coffee break.

Furthermore, the Information Fusion Research faculty and Ph.D. students actively participate in conferences related to information fusion both nationally and internationally. A major International Conference on Information Fusion (Fusion 2007) was held in Québec City, Canada, during July of 2007, in which several Infusion research faculty and graduate students participated and presented ongoing research work in the field of information fusion.

Several Infusion faculty members have participated in various EU-organized meetings during 2007. Many new scientific contacts have been for initial discussions about research applications for EU grants with the Seventh Framework Program.



Prof. Sten F. Andler and prof. Sang H. Son discussing in a social setting.

Internal communication

The internal communication of the research program has been implemented largely according to the original plan. The impact has been more extensive than originally anticipated. The internal support for the Information Fusion Research Program is demonstrated by the fact that the University's research magazine "Perspectives" includes at least one article

related to Information Fusion in each issue. The research magazine is distributed throughout the university, to research colleagues and university administration as well as the university board, in addition to the general public as previously mentioned. It is important to note that research groups not participating in the research program find inspiration from the Information Fusion Research Program.

Information about ongoing research in the Information Fusion Research Program is regularly distributed to a number of target groups, internally and externally. Companies participating in the program receive continuous updates on the progress. Research groups nationally and internationally receive updated information on event and activities taking place in the research program. The Advisory Board, Executive Committee, Project Leader Group, and Administration of the research program are also provided with information about the latest developments.

9.5 Summary

When reviewing the Information Fusion Research Program's information and marketing activities during the last year, we can make following observations:

- The information strategy of the Information Fusion Research Program has been implemented enthusiastically and with great eagerness from everyone involved. The effectiveness of the information and marketing activities is clearly demonstrated by the fact that external organizations and individuals can easily find their way to the Information Fusion Research program, as well as by the internal support, both at the participating companies and at the University.
- The Information Fusion Research Program is maturing and has appeared among the general public in popular science publications. It is our belief that more such publications will naturally appear as the program produces concrete results.
- Funding agencies have been identified as a specific target group. This group receives specific information, both through formal channels and informal contacts. The Information Fusion Research program has also recognized young people as another specific target group.

- Commercialization is often the Achilles heel in academic research projects due to relatively late attention in the projects to commercialization aspects. In order to avoid this problem, a frequent dialogue takes place with Gothia Science Park, the technology park at University of Skövde. In order to further encourage technology transfer and spin-off, Venture Cup has been invited to the University of Skövde with a purpose of showing the way from idea to product and/or service.
- We are moving forward in the direction of preparing the Information Fusion Research Program for participation in the EU Seventh Framework Program. A number of EU FP7 applications (five) were prepared in 2007 to be submitted in early 2008.

10 Scenarios and projects

10.1 Scenarios

The scenarios and common goals of the Information Fusion Research Program have been briefly introduced. Detailed descriptions of the scenarios and the projects carried out within the umbrella of each scenario are found in Appendix E.

10.2 New / ongoing /finished projects during 2007

As the program has matured and is close to midterm, some projects have finished and new ones have been started or are about to start. Descriptions of the projects and their research questions can be found in Appendix E.

The following new project was started in 2007:

- Manufacturing (mfg)
 - mfg3: Foundry

An additional project will be started in 2008:

- Bioinformatics (bio)
 - bio5: Future project

Three projects were ended in 2007:

- Systems Development (sd)
 - sd1: 2005-04-01 – 2007-12-31
- Bioinformatics (bio)
 - bio2: 2005-04-01-2007-11-30
 - bio4: 2004-03-01-2007-02-28

10.3 Summary of all projects carried out so far

Three (3) projects have been completed so far. The current status and the results of each project so far can be found in Appendix E.

Prior to 2007, the following 13 projects were started in 2005:

- Common Goals and Infrastructure (cgi)
 - 2005-11-01: cgi1 cgi2 cgi3
- Ground Situation Awareness (gsa)
 - 2005-11-01: gsa1a/b gsa2 gsa3
- Bioinformatics (bio)
 - 2005-04-01: bio1 bio2 bio3
- Retail Sector (rs)
 - 2005-04-01: rs1 rs2
- Systems Development (sd)
 - 2005-04-01: sd1

Prior to the start of the research program, the following project was started in 2004:

- Bioinformatics (bio)
 - 2004-03-01: bio4

11 Company and other partners for each project during the year

The following partner companies were involved with each of the projects listed as follows:

- Common Goals and Infrastructure (cgi)
 - cgi1: All partner companies
 - cgi2: All partner companies
 - cgi3: Enea Software AB, Exensor, Agroväst and Saab AB
- Ground Situation Awareness (gsa)
 - gsa1a: Saab AB, Saab Microwave Systems AB
 - gsa1b: Saab AB, Saab Microwave Systems AB
 - gsa2: Saab AB, Saab Microwave Systems AB
 - gsa3: Saab AB, Saab Microwave Systems AB
- Bioinformatics (bio)
 - bio1: Cellartis AB, Sahlgrenska
 - bio2: Arexis AB (Biovitrum AB)
 - bio3: Lexware Labs AB
 - bio4: Arexis, InNetics
- Retail Sector (rs)
 - rs1: ICA Sweden AB, University of Borås
 - rs2: ICA Sweden AB, University of Borås, Ericsson AB (not in program)
- Manufacturing (mfg)

- mfg1: Electrolux Major Appliances AB, Delfoi AB
- mfg2: Euromation Industry AB
- mfg3: Volvo Powertrain AB
- Precision Agriculture (pa)
 - pa1: AgroVäst Livsmedel AB
- Systems Development (sd)
 - sd1: Enea Systems Stockholm AB, Atlas Copco Tools AB, Saab AB, Saab Microwave Systems AB



Prof. Sten F. Andler talking about the partner companies.

For more detail, please see descriptions of the projects and their partner companies in Appendix E. For a complete list of partner logotypes, please see Appendix F.

12 Publications so far

Publications so far (with dates) in the following categories:

12.1 Refereed international journals

2007

1 De Vin, LJ., Andler, SF., Ng, AHC, Moore, PR, Pu J., & Wong, BCB., (2007) Information Fusion for Decision Support in Manufacturing: Studies from the Defense Sector, Accepted for publication by *International Journal of Advanced Manufacturing Technology*

2006

2 LJ De Vin, AHC Ng, J Oscarsson & SF Andler, Information Fusion for Simulation Based Decision Support in Manufacturing, *FAIM 2005 Special Issue of Robotics and*

Computer Integrated Manufacture, 2006, Vol 22, 429-436

3 Johansson, U., Löfström, T., König, R. and Niklasson, L. (2006) Why Not Use an Oracle When You Got One? *Neural Information Processing - Letters and Reviews*, Vol. 10, No 8-9: 227-236, 2006.

2005

4 Gawronska, B. Information Extraction from Texts: Adapting a System for Summarization of News Reports to the Domain of Bioinformatics. The IPSI BgD Transactions on Advanced Research, *Issues in Computer Science and Engineering*, Vol 1 No 1 (ISSN 1820-4511), pp.20-28.

2004

5 De Vin, L. J., Ng, A. H. C. and Oscarsson, J. (2004) Simulation Based Decision Support for Manufacturing System Life Cycle Management. *Journal of Advanced Manufacturing Systems*, Volume 3 Number 2, December 2004, pp 115-128.

12.2 Theses

2007

6 Grindal, M. (2007) *Handling Combinatorial Explosion in Software Testing*. Thesis Dissertation no 1073, Department of Computer and Information Science, University of Linköping. ISBN 978-91-87515-74-9. ISSN 0345-7524.

7 Johansson, U. (2007) *Obtaining Accurate and Comprehensible Data Mining Models: An Evolutionary Approach*, Thesis Dissertation no 1086, Department of Computer and Information Science, University of Linköping, ISBN: 978-91-85715-34-3, ISSN: 0345-7524

2005

8 Alenljung, B. (2005) *Decision-making in the Requirements Engineering Process: A Human-centred Approach*. Licentiate Thesis, Department of Computer and Information Science, Linköping University, Sweden, Thesis No. 1204

12.3 Conference publications

2007

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13 Patents filed and/or granted during the year

In this relatively early stage of the program, no patents have been applied for.

14 Personnel

A complete list of research program personnel during the year is found in Appendix G.

There are 15 senior researchers at the university involved in the Infusion research program, in

the role as scenario and/or project leader, advisor, etc. There were 4 other staff at the university with Infusion roles of information, marketing, and administration. These were all funded by the university or other sources.

Funding from the Knowledge Foundation has been used to hire 13 new PhD students studying at 80% progress rate. In addition, 10 Senior PhD students, funded by the university or other sources have joined Infusion, as well as one industrial PhD student.

In total, 19 staff members were working at the university with 23 PhD students, for a total of 42 persons. There were 74 participants from industry, for a grand total of 116 positions.

New PhD degrees in 2007

Mats Grindal and Ulf Johansson graduated with a PhD degree in 2007. Beatrice Alenljung submitted her PhD thesis in 2007, to be defended in 2008.

New personnel in 2007

During 2007 the research program accepted two adjunct professors, Thomas Kronhamn and Håkan Warston, and hired one PhD student, Catarina Dudas.

Prof. Thomas Kronhamn is a senior researcher at Saab Microwave Systems AB, Sweden. He is a Specialist in Target Tracking and Data Fusion at the Expert level.

Prof. Håkan Warston is a senior researcher at Saab Microwave Systems AB, Sweden

Catarina Dudas joined on September 1 the foundry project (mfg3) within the manufacturing scenario.

Dr. Ronnie Johansson (previously recruited) was hired on a two-year position as Post-Doctoral Fellow.

15 A calendar of communication activities during the year

For a summary of events that took place in 2007, please see Appendix B, Information and marketing activities 2007. Many of these events have been reported on in email newsletters and news items on the web, www.infusion.se.

Infusion – In Collaboration with Industry

Part II Financial Report

The activity report is a statement of the development of the research program with respect to the following aspects:

- 1) Summary of contributions from the Knowledge Foundation, partner companies, and other sources
- 2) Summary of expenses by category over all projects
- 3) Summary of all expenses by project

Attached to the financial report is an excerpt of the bookkeeping of each company regarding the research program.

1 Summary of contributions from sponsors and partners

A summary of contributions from the Knowledge Foundation, partner companies, and other sources is submitted in Appendix H. The contributions from partner companies as well as from university of Skövde meet and exceed the commitments made to the program. In addition to the contributions from the Knowledge Foundation for the funded research profile, there is also a contribution from the Knowledge Foundation for the separately funded project ModPharm.

Special grants from the Swedish Savings Bank Foundation Alfa (Sparbanksstiftelsen Alfa) and the Grevilli Fund (Grevillis Fond) support information and marketing activities for the Information Fusion Research Program through the Fusion as Vision project.



*Marcus Brohede, Information Fusion
Administrator and PhD Student.*

1.1 Company contributions by company

As can be seen by the summary of company contributions listed in Appendix I, some companies are slightly below their previous commitments at this time, usually due to a later start of the project than anticipated. This is compensated by other companies reporting much higher contributions than they have committed to. As a result, actual contributions are somewhat over MSEK 8,8 compared to total commitments of approx. MSEK 9,1.

2 Summary of expenses by category over all projects

A summary over all projects of expenses by category is submitted in Appendix H, after the summary of contributions from the Knowledge Foundation, partner companies, and other sources.

3 Summary of all expenses by project

A summary of all expenses by project is submitted in Appendix H, after the summary over all projects of expenses by category.

Infofusion – In Collaboration with Industry
Part III Appendices

Appendix A Strategy for development of the university

Leif Larsson, President
University of Skövde

Memorandum
Date: 2007-04-23

File nr.: HS 2007/136-60

Research, education and collaboration with society

1 Background

This memorandum contains descriptions presenting the strategies for research, education and collaboration with society at the University of Skövde, with an emphasis on research and graduate education.

2 The overall vision 2012

The University of Skövde formally established a vision for 2012 during 2006. This vision states that by 2012, the university:

- offers focused study programs at the basic level which are in demand by students as well as future employers,
- offers study programs at the MSc and PhD levels which are closely related to the research conducted at the university,
- plays a leading role in the development of the surrounding society.

For each of these goals, a number of strategies have been identified.

3 Research vision and strategies

The University of Skövde shares VINNOVA's notion about the role of research. The role of research in the technological development of society will be highly evident over the coming years and the central role of research universities as a societal institution will not diminish during the coming decades (ref: VINNFORSK – VINNOVA's proposal for an improved commercialization and an increasing growth in research funding at universities, 2003). Based on this notion the University of Skövde has formulated an overall vision for its research, a set of concrete goals for the period 2005-2008 and a number of strategies to reach these goals.

3.1 The research vision at the University

The University must offer research environments capable of attracting and keeping important key individuals. The research environments must encourage research

collaboration and create opportunities for unusual meetings between applied research and basic research as well as between the different research environments, thus making the University a forerunner when it comes to establishing unique research collaborations. Research must be useful to society, characterized by openness and curiosity, and deal with tomorrow's challenges.

The direction of conducted research must stimulate cross-disciplinary collaborations, supported by infra-structural processes. The University has already taken an important step in this direction through identification of the technology area as connecting disciplines such as engineering and computer science with important areas of natural sciences, humanities and social sciences. A Faculty of Technology was established between the universities of Skövde, Halmstad and Örebro in January 2006. This means that we now have a much greater possibility to influence the research education, since we are directly involved in its planning and execution.

The goal for all research is to be useful to society. It means that results from research must be made available to the University, the scientific community and society as a whole. This applies not only to the type of research that is generally considered applied research, but also to basic research. Results from applied research must supply new ideas for development of new methods and techniques. Results from basic research must supply increased sophistication, new knowledge and understanding. However, the most central mechanism for the usefulness of research to society is the development of competence taking place in a research environment coupled with the mobility of personnel characterizing such an environment.

3.2 Goals and strategies

The University has established a set of goals for the period 2005-2008 in order to reach the

overall research vision.

The research conducted at the University must be of high quality measured by international standards. It must deal with issues relevant to the values set forth by the scientific community and the community outside the University. Produced knowledge must be made available to various types of recipients and should, where suitable, be available for use for developing theories, methods and techniques.

Concretely this means that, during the above-mentioned period the University will:

- develop 3-5 so called strong research environments, which should constitute good environments for research students in the sense that they have both depth and width.
- increase research connection to undergraduate education
- increase the volume of research
- increase the number of contacts with society in general

The University will utilize a number of concrete strategies in order to reach these goals, see below.

3.2.1 Concentration of research into a few strong research environments

Research is needed in order to produce new knowledge. The University has a strategy to most efficiently utilize available resources in order to maintain high international standards in produced knowledge. This is done by focusing research on a limited number of strong and, to the University, central *research environments* (i.e. focused research directions that are characterized by high quality and a critical mass of research faculty on different levels and research students). The ambition within these research environments is to establish a scientifically creative and competitive environment with critical mass of professors, associated professors and lecturers deeply involved in research, Ph.D. students and Masters students. These research environments are therefore prioritized from a funding viewpoint. A major part of the University's fixed research funding from the Government will be allocated to these environments. The premise is that a research environment must be able to compete within the international scientific community, considering the quality of the scientific results and the researchers that

these environments produce.

The Faculty Board of Research and Education and the University Management evaluate proposals for new research environments as well as discontinuation of environments. Processes for establishing research environments and regular quality assessments are already defined and applied on a regular basis. These processes focus on the abilities of the research environment to offer a creative and high quality research environment, within one relevant area for the University. Here we also find natural connections to the University's undergraduate education; for example, there is a requirement that a research environment must offer Masters education, which can build a foundation for continued graduate education within the research environment. This is done for the purpose of offering the students natural and convenient continued education after completed Bachelor degrees and also with the goal of ensuring a good recruiting base of Ph.D. students to the research environment.

The University has decided not to only concentrate its efforts on research depth when creating research environments, but also to establish breadth within the environments, by building the research environments on the existence of 5-6 related research groups. This facilitates education and research to be performed as cross-disciplinary collaboration between the different research groups. Systems biology is one example of such an ongoing cross-disciplinary research environment where molecular biology and bioinformatics work in collaboration.

It is vital for all research efforts to focus on a small number of research environments at the University. These research efforts also need to be organized within a framework of different research environments, according to appropriate strategic and quality assessments. Research that does not meet the requirements and conditions set forth for a research environment, but still supports the University profile, may apply for funding from sources available for strategic research. This applies to research that is under development with the goal of becoming one of the University's research environments and research that is limited in its scope but still considered important for the University.

During 2006 criteria and processes for

establishment, quality assessment and termination of the research environments were established by the University Board. It also established the first two strong research environments December 2006, namely Systems Biology and Information Technology.

As stated earlier the research environments should supply a good environment for PhD students. One vital aspect is therefore the availability of challenging research projects and programs. Through these projects and programs the students get to work on application oriented projects. The Information Fusion program is vital for both of the established environments, since it houses projects within both system biology and information technology. It will also be important for the development of an additional environment within Virtual Systems. The Information Fusion research program therefore is at the core of the research conducted at the University, and a vital instrument to develop research education.

3.2.2 The establishment of our own graduate education

Graduate education serves two purposes. It generates new knowledge among the Ph.D. students in collaboration with their respective thesis advisors and possible project partners, and it provides the Ph.D. students the opportunities to spread their newly acquired knowledge outside the University - through publications of their findings to society and other institutions of higher education. One of the most important mechanisms for succeeding in making use of acquired knowledge is the mobility of personnel that graduate education provides. A new Ph.D. student imports influences and ideas to the University and researchers getting their graduate degrees provide influences and ideas to society outside the University. Thus, graduate education becomes a natural strategy to reach the research goals of the University. Today there are approximately 90 Ph.D. students involved in graduate studies at the University of Skövde. Approximately 20 percent of these are enrolled at foreign universities and the remainder at Swedish universities, e.g. The Royal Institute of Technology, (KTH), University of Linköping and Chalmers University of Technology (CTH). The advisors to the majority of the Ph.D. students are located at the University of Skövde.

It is crucial to obtain the right to grant the Ph.D.

degree in order to fully utilize all opportunities that graduate education provides. Therefore, University of Skövde has submitted an application to the Swedish Government to obtain the right to establish a *Faculty of Technology*. The research direction described in the application has its focus placed on development of advanced information technology systems and models, which include most of the research environments established at the University. Such a graduate education profile would greatly contribute to the existing information technology research profile. Furthermore, it increases the collaboration between research environments - through establishment of cross-disciplinary graduate educational programs. The University's judgment is that the Government, due to current governmental monetary constraints, will delay the evaluation of our application. The University has therefore initialized collaboration with University of Halmstad and University of Örebro, of which the latter has the right to issue PhD diploma within the area of Engineering and Technology. This collaboration has now resulted in a joint board for working with issues concerning research and research education. Currently then University of Skövde has nine PhDs enrolled within the collaboration.

3.2.3 Increased research volume

Funds allocated by the Government to the University of Skövde have during the past few years increased by 97%, from approx. MSEK 13 in 1999 to approx. MSEK 25.6 in 2006. The externally funded research has increased by 500% - from approx. MSEK 5 to approx. MSEK 30. The goal is an annual research volume of MSEK 90 by 2008, of which at least 50% should be funded through external funding sources. As a lead in the ambition to establish a *Faculty of Technology* at the University, efforts have already been made and work intensified in an attempt to increase the extent of the externally funded research. The direction of the technically oriented research at the University is well suited to carry out applied research and thus provides excellent opportunities to attract external funding agencies, provided that quality requirements are met. The results of these efforts are starting to show. For instance did the externally funded research increase with 65% between 2005 and 2006.

The University also has established a research program in *information fusion*. Initially, this

research program will be run during 2005-2010, partially funded by the Knowledge Foundation, within the framework of its investment in the research profile. The research program is based on two research platforms previously funded by the Knowledge Foundation, one on learning systems and one on mechatronic systems. The program will be of vital importance in the University's investment in establishing a *Faculty of Technology*. The program links above-mentioned platforms and makes the establishment of cross-disciplinary research and graduate education programs possible. As information fusion requires a number of different competences, e.g. competence in information systems development, database systems, real-time systems, man-machine interaction, and decision support systems, it can be applied within a large number of areas, such as bioinformatics, automation, mechatronics, network-based warfare systems and simulation.

4 Strategies for undergraduate education

4.1 Increased volume of undergraduate education

During the past decade the University has experienced an annual increase of about 300 students. The number of students in 2003 was 6,800 or 4,105 full-time equivalents. For 2005 these numbers were about 8,000 and 4,225. The University's goal is to continue with the same rate of increase over the next few years. In order to reach this goal, the University will increase its investments in educational programs at Masters Level, Network University programs, professional educational programs focusing on profession, continued education and the supply of independent courses.

4.2 More frequent quality assessment of undergraduate education

In January 2003 the University established the Faculty Board of Research and Education. The role of the Faculty Board is to coordinate the University's educational activities. Furthermore, the Faculty Board is responsible to act as quality assurance for undergraduate education and research. The Faculty Board has the overall responsibility for the content of all educational programs. It also plays an extremely important role in the evaluation of research conducted at the University.

4.3 Increased connection between research and education

One of the research goals is to distribute the newly acquired knowledge within and outside the University. According to the Higher Education Act the universities must conduct undergraduate education that rests on scientific or artistic ground. It is therefore of great importance that the research conducted is related to the undergraduate education offered by the institutions of higher education. An important strategic mandate is to demand that Masters education be carried out within a research environment in order for it to be established. This has two goals. One is to distribute the results from research but also methodology to students on undergraduate educational level. The second is to increase the opportunities for recruitment of Ph.D. students. This close connection between undergraduate education and research has the effect that final year projects on the Bachelor and Masters levels often become part of a research project.

The fact that Masters education is closely connected with research is demonstrated by the fact that many Masters theses are published in international scientific journals. The University has, the past years, increased the number of Masters programs and has a goal to drastically increase the number of Masters students over the coming years.

A major part of the ongoing research and graduate education at the University of Skövde, in collaboration with other higher education institutions, is performed within the *development of advanced systems and models related to information technology, where the abilities, limitations, and needs of humans play a central role.*

This direction has a close relation to the major part of the basic education offered at the University. In order to adhere to the Higher Education Act and in order to reach the research goals, the strategy of the University is to solely conduct research and graduate education closely related to the areas where the University offers undergraduate education. The processes set up for the establishment and follow-up of the research environments act as a guarantor.

The University also strives to expose its research in undergraduate education, e.g. by encouraging professors to teach courses at

undergraduate level. The Faculty Board of Research and Education makes sure that each graduate student completing their Ph.D. degree will give a popular scientific lecture on the subject of their Ph.D. theses.

Increased connection between undergraduate education and research requires that the University is able to protect and develop its technical research profile and to ensure that new research environments are established in central areas of undergraduate education outside the technology area. An increased scope of research allows the exploration of new cross-disciplinary areas. A Faculty of Technology is a condition for this.

5 Contacts with society

The Governing Board of the University has confirmed that the region surrounding University of Skövde covers the entire West Gotaland Region. The University is fully involved in the process of determining the role it will play in the West Gotaland Region.

5.1 Increased collaboration with universities in the region

New universities in the region (Borås, Trollhättan-Uddevalla and Halmstad) have initiated collaboration within education and research. The ambition is to identify areas where collaboration can take place. This applies to areas where several universities have the competence required and to areas where one university could be the major provider of competence to the others.

The University of Skövde has joined forces with the universities of Halmstad and Örebro to form a joint faculty for research and research education within the area of Technology. For legal reasons this faculty is formally associated to the University of Örebro, which is the only university of the three that currently have the right to issue PhD diplomas. The three parties have, however, formed a joint section board, which, in practice, will govern the research education within the research area. This collaboration has also resulted in additional projects focusing on research and research education.

5.2 Research

The University has a great deal of experience in disseminating research results to the scientific community. Approx. 80 scientific publications

were published within the technology area in international scientific press in 2002. In 2005, 172 scientific papers were published. The University is also experienced in arranging international scientific conferences. The Faculty Board of Research and Education also publishes a popular scientific magazine.

The University is also experienced in disseminating results to the industrial society. This is mainly proven by the fact that the University has conducted research and graduate education. The result was collaboration with external partners in various types of industrially applied projects. To this should be added collaboration with Gothia Science Park, located centrally at the University Campus. This collaboration has resulted in an educational program in entrepreneurship which is managed by the science park and the University in collaboration. The result is the establishment of a number of spin-off companies. These are, however, mainly a result of ideas from students who graduated from the University and not a result of commercialization of research results.

During 2005-2008 the University has the ambition to increase the possibilities for researchers to commercialize their results through the establishment of new spin-off enterprises. The collaboration with Gothia Science Park will increase in order to reach this goal. The University and the science park already have a close collaboration for expanding the number of available offices in the science park. A clear goal is to create a scientific environment that fosters collaboration among the companies, the researchers and the graduate students. Furthermore, the University has the ambition to investigate opportunities that might arise from establishing a holding company, an opportunity that was only recently offered to Swedish universities, mainly regarding seed money, ownership etc.

In order to further increase the network of contacts with society outside the academia, the University will create positions for a number of adjunct professors with experience from both the industrial and the cultural part of society.

(signed)

Leif Larsson

President, University of Skövde

Appendix B Information and marketing activities 2007

B.1 Calendar of Events

Below is a summary of some major activities in the research program. News items are continually published at the University's internal, Infofusion website: <http://www.his.se/infofusion/news>. The University's Press relations group handles external press-related materials.

1 Jan 2007 - Henrik Boström joins as new Professor in Information Fusion

Henrik Boström is a new Professor in the Information Fusion Program. He was formerly Associate Professor at KTH/SU, Department of Computer and Systems Sciences, Laboratory for Data Mining and Decision Analysis.

An article featuring our new Professor Henrik Boström was published on 2007-01-19 in the local news paper Skövde Nyheter [in Swedish]

12 Jan 2007 – First Infofusion Executive Committee Meeting of 2007

Infofusion Executive Committee meetings are held once a month during the year, except in the summer.

25 Jan 2007 – First Infofusion Program Meeting of 2007

Infofusion Program meetings are held once a month during the year, except in the summer. Scenario and project meetings of the Common Goals and Infrastructure scenario are also held once per month

26-27 Feb 2007 – ETIS Seminar on Serious Gaming

Edutainment and Training Initiative Sweden seminar: Interoperability and Serious Gaming - Enablers for the Next Generation Training Systems, hosted by University of Skövde

12 March 2007 – Mats Grindal PhD Defense

Mats Grindal is the first "industrial" PhD of University of Skövde.

Thesis topic: Handling Combinatorial Explosion in Software Testing

Mats is a Testing Engineer at Enea Services, Stockholm.

14-15 March 2007 – Invited talk by Sten F

Andler at Fusion Forum workshop

Sten F Andler was invited by the PReVENT/ProFusion2 Consortium to attend the 2nd Fusion Forum Workshop at DELPHI Paris Office, to make a presentation on the Infofusion program.

16 March 2007 - Invited talk by Björn Olsson at Biomolecular workshop

Björn Olsson was invited to give a talk on "Biomolecular network inference by information fusion" in the workshop "Data and Knowledge Based Biomolecular Network Reconstruction" in Jena, Germany.

21 March 2007 - NFFP Program Seminar

Sten F Andler was invited to the Swedish National Aeronautics Research Program, held in the Volvo Aero Auditorium, Trollhättan, Sweden

16-18 April 2007- SWIFT 2007

The Information Fusion program organized the Skövde Workshop on Information Fusion Topics (SWIFT 2007) for the first time. This year we had several prominent people as invited speakers, among them Stavri Nikolov, Galina Rogova, Peter Willett, and Mike Hinchey. We felt that the workshop was a success and plan for this to be an annual event. Read more on the workshop homepage. <http://www.his.se/infofusion/swift2007>

19 April 2007 – Presentation of Infofusion to Örebro University Faculty Board

Sten F Andler presented Infofusion to the Engineering Section of the Faculty Board at Örebro University.

8 May 8 2007 - Midterm evaluation initial meeting

On May 8th, members of the executive board and advisory board had an initial meeting with the Knowledge foundation and the consultants that will carry out the midterm evaluation.

14 May 2007 - Per Gustavsson appointed George Mason University Affiliate Faculty

Per Gustavsson was appointed as George Mason University Affiliate Faculty in the Volgenau School of Information Technology and Engineering, George Mason University (GMU). Per comments: "This is a penta-helix -- beneficial for me as a researcher and for the

University of Skövde, George Mason University, Saab and the Swedish Defence Material Administration."

1 June 2007 - Ulf Johansson's PhD Thesis Defense

Title: Obtaining Accurate and Comprehensible Data Mining Models – An Evolutionary Approach

Opponent: Professor Thorsteinn Rögnvaldsson, Högskolan i Halmstad/Örebro Universitet

7-8 June 2007 - Mid-term evaluation interviews

The evaluation process is started with individual interviews with selected participants in the program. The evaluating firm has made the selection from the categories: executive/advisory board, PhD students, senior researchers, and external partners/companies.

11-14 June 2007 – Visit by Dr. James Llinas

We had the pleasure to welcome Dr. James Llinas from the University at Buffalo (State University of New York) for a one-week visit. Prof. Llinas is one of the most renowned researchers in the field of information fusion and is the Executive Director of the Center for Multisource Information Fusion (CMIF), <http://www.infofusion.buffalo.edu/>.

During his stay, Prof. Llinas was able to learn about our research program and give his opinion on our research direction and advice for further progress. In addition to an interesting talk on University of Buffalo and CMIF, Prof. Llinas' schedule during the week included individual research discussions with representatives for some of our projects; a discussion workshop where interesting and urgent topics for the research community were treated; and participation in our regular research meeting. Opportunities for future collaboration and further visits were also discussed.

9-12 July 2007 - Fusion 2007 in Quebec, Canada

6 papers with authors from the research program were accepted to the FUSION 2007 conference (<http://www.fusion2007.org/>).

14 Sept 2007 – Briefing at Saab AB

Briefing at Saab Microwave Systems, Skövde, on Security Arena Lindholmen by Project manager of Secure Port Operation (SEPO) and contact person, EU FP7 - Security Theme.

21 Sept 2007 – Meeting at Lindholmen Science Park, Security Arena

Meeting to discuss activities at Lindholmen Science Park with Bo Norrhem, Director, in particular the Security Arena and possible collaboration.

26 Sept 2007 - Mid-term evaluation report complete

The mid-term evaluation report is complete and is made available to program participants

27 Sept 2007 - The 3rd German Workshop SDF 2007

Presentation of Ground Situation Awareness paper in workshop on Sensor Data Fusion: Trends, Solutions, Applications.

28 Sept 2007 – The University of Skövde explores new research building

The University Board at University of Skövde explores plans of a new research building that will be shared with the Gothia Science Park. Continued planning for the building is approved.

1 Oct 2007 – Anne Persson promoted to Professor of Computer Science

Prof. Anne Persson, who is a participant in the Information Fusion Research Program, is the first female Professor “produced in Skövde”.

12 Oct 2007 – University celebrates 30th Anniversary and installs new professors

Among professors installed are Henrik Boström, Thomas Kronhamn, and Anne Person of the Infofusion Research Program. Thomas Kronhamn was appointed Adjunct Professor in the Information Fusion on 1 December 2006, and is a Specialist in Target Tracking and Data Fusion at the Expert level with Saab Microwave Systems AB, Sweden.

24 Oct 2007 - The Fall 2007 Infofusion Advisory Board meeting

Topics of the Fall Meeting were the Mid-Term Evaluation report and project presentations. A new format for the meeting was introduced, where all of the project presentations were made by the PhD students in the projects, followed by feed-back from the Advisory Board and the audience of the well-attended presentations.

30-31 Oct 2007 – Leo Selavo visit

Professor Leo Selavo, University of Latvia,

visited to give seminar and discuss collaboration with the Wireless Sensor Network (WSN) Testbed project

7 Nov 2007 - Mid-term evaluation meeting in Stockholm

A final meeting with the evaluators and Knowledge Foundation officials was held in Stockholm to discuss the evaluation procedure. Participants were Sten F Andler, Lars Niklasson, Tomas Planstedt, Stefan Arnborg, and Henrik Boström.

8 Nov 2007 – SACS Conference on Civil Security

The Swedish Association of Civil Security (SACS) arranged this conference on Civil Security to discuss experience related to collaboration with the Department of Homeland Security (DHS), USA. Among the speakers were representatives of the Swedish Government, DHS, Swedish industry, funding agencies, and the US Embassy.

7 Dec 2007 – The University Board at University of Skövde approves new research building

The Information Fusion Research Program will be among other application-oriented research activities at the University of Skövde that will move into a new research building that will be shared with the Gothia Science Park. The University Board approved the project to be started in 2008 for a move-in date of October 2009.

12 Dec 2007 - Mid-term evaluation feed-back

A feed-back meeting with the Knowledge Foundation CEO and Program Administrator was held with University and Infusion program management. Challenges common to all funded profiles as well as challenges specific to Infusion were discussed.

14 Dec 2007 – Final Infusion Executive Committee Meeting of 2007

Reflections on the successful Mid-Term Evaluation and the specific challenges presented.

B.2 Web information

The Infusion website at www.infusion.se (or www.his.se/infusion) contains documents and information about the Information Fusion Research Program. It can easily be accessed from the University's main website. The Infusion website features news and

information as well as background information about the profile and ongoing projects.



The website of the Information Fusion Research Program

B.3 Scientific publications

The research faculty monitors published materials on the overall development of ongoing research in the field of information fusion and related research, but also studies publications in trade journals, magazine, and other types of media.

All publications are listed at the university website and are also distributed to the project partners. Publications in scientific journals and conferences are listed in Section 12.

B.4 Press – News items

University's press relations

Taking advantage of the opportunities offered by editorial coverage in the press, or on TV and radio, brings a number of benefits. These media reach large audiences. Moreover, the credibility of the messages is enhanced by a public perception of editors' impartiality.

The University of Skövde publishes news-related information at the University's website; news about research, development, external funding, visits, invited speakers etc. The news is published daily at www.his.se/nyheter. Those involved in the Infusion research program, the University's press relations group and the research administrative staff have been active in working with external press with the purpose of providing information about the ongoing research work and activities in the program to the society.

Media coverage – external press

Dissemination of information to society on research issues has during the past few years become increasingly important. During 2007 a number of research activities were highlighted in the external press.

One important step in the future development and strengthening of the Infusion research program was featured in the press;

- *Henrik Boström joins as new Professor in Information Fusion.* Henrik was formerly Associate Professor at KTH/SU, Department of Computer and Systems Sciences, Laboratory for Data Mining and Decision Analysis, now joining the University and the Infusion research group.

Serious gaming has during the past become of importance in the information fusion research area. A conference held at the University of Skövde in February titled ETIS – Edutainment and Training Initiative Sweden - attracted the attention of the local news media.

The University of Skövde hosted a workshop “SWIFT2007” attracting a number of scientifically well-known and prominent research faculty was featured in the media as well.

Furthermore, the press features the following; the University appoints its first female professor;

- *Anne Persson promoted to Professor of Computer Science* who is a participant in the Information Fusion Research Program, is the first female Professor “produced in Skövde”.

The University celebrated its 30th anniversary – an important milestone in its development. The press highlights;

-*University celebrates 30th Anniversary and installs new professors.*

Among professors installed are Henrik Boström, Thomas Kronhamn, and Anne Person of the Infusion Research Program. Thomas Kronhamn was appointed Adjunct Professor in the Information Fusion. He is a Specialist in Target Tracking and Data Fusion at the Expert level with Saab Microwave Systems AB, Sweden. The appointment of Thomas Kronhamn strengthens the academic and industrial collaboration and brings new angles to the Infusion research program.

The importance of strengthening the ties between academia and industry was featured in the news media when the University of Skövde produces its first industrial PhD, funded by the Knowledge Foundation. The press highlights;

- *Mats Grindal PhD Defense* - Mats Grindal is the first “industrial” PhD of University of Skövde. Mats’ thesis topic was on “Handling Combinatorial Explosion in Software Testing”. Mats is a Testing Engineer at Enea Services, Stockholm.

An important milestone and a crucial decision were made during 2007 to allow the future expansion of the University of Skövde. The media;

- *The University Board at University of Skövde approves new research building.*

The Information Fusion Research Program will be among other application-oriented research activities at the University of Skövde that will move into a new research building that will be shared with the Gothia Science Park. The University Board approved the project to be started in 2008 for a move-in date of October 2009.

International attention was gained through the election of Prof. Sten F. Andler to new member of the Board of Directors for ISIF – International Society of Information Fusion, a world-wide organization with a mission to advocate the advancement of the profession of FUSION technologies, to propose approaches for solving real-world information fusion problems, recognize emerging technologies and to foster information transfer. This appointment allows the University’s Infusion program to play an important role in the future development of the information fusion research arena.

It is our intension to make every attempt to increase the external media exposure during the coming 3-year period of the research program and beyond.

Media coverage – internal press

The University website is intended to serve as the gateway through which the University may introduce its wide range of leading-edge research activities to the international academic community, industry, government, for potential collaborations purposes.

This website was constructed with the faculty, staff and students in mind. It is intended to be an internal communications vehicle to

promulgate the latest strategic research developments, to show highlights of current research activities, to disseminate research performance information and statistics, to publicize research funding opportunities and procedures, and to announce schemes for outstanding research performance. However, it may also serve as a gateway for those outside, industry, potential future collaborators, and society at large, interested in the activities taking place at the University.

Media coverage of workshops and seminars

Workshops and seminars are being organized for the research program and project partners, as well as for interested external parties. Established partner networks are used as channels for invitations. Workshops, seminars and collaboration days have been arranged either at industry sites or at the University.

SWIFT 2007

The Information Fusion program organized the Skövde Workshop on Information Fusion Topics (SWIFT 2007) for the first time. The objective of the workshop was to gather program participants and key representatives from research and industry in the field of information fusion to discuss the latest developments. The workshop program included a number of sessions focusing on some of the application fields in the information fusion research program.



Participants gathering for one of the sessions at Swift 2007.

Several prominent invited speakers, among them Professors Stavri Nikolov, Galina Rogova, Peter Willett, and Mike Hinchey attended the workshop. The workshop was a success and there is a plan for this to be an annual event. The workshop homepage: <http://www.his.se/infusion/swift2007>

The event was highlighted in the University internal website.



Dr. Pontus Svenson from Swedish Defence Research (FOI) receives a gift from Project Assistant Jill Elmshorn after a talk at Swift 2007.

ETIS Seminar on Serious Gaming

A workshop on Serious Gaming, ETIS, was organized by the University during the year. Information about the workshop was widely spread through both internal and external channels. ETIS is an initiative taken by the University of Skövde, in collaboration with a number of partners; Räddningsverket Skövde, Markstridsskolan Skövde, Försvarets Materielverk Karlsborg, Skövde Kommun, Gothia Innovation, Lockpick Entertainment, Saab Microwave Systems and Volvo Competence center. The focus is on creating a market for serious games and training simulators and services connected to it. The seminar attracted experts from George Mason University (GMU), Fairfax, Virginia and Old Dominion University (ODU), Norfolk, Virginia and University of Central Florida (UCF) to discuss components which support the next generation training systems, namely interoperability and serious gaming. The workshop was featured both externally in the local media as well as widely spread through the University's website.

2nd Fusion Forum workshop

Both University of Skövde internal press as well as dissemination of information through the workshop organizer was made in connection with the 2nd Fusion Forum Workshop to which Professor Sten F Andler was invited by the PReVENT/ProFusion2 Consortium. The 2nd Fusion Forum Workshop at DELPHI Paris Office invited Prof. Andler to make a presentation on the Infusion program.

The 3rd German Workshop SDF 2007

Internal coverage at the University of Skövde as well as through the various research channels used by the conference organizer in Germany was used to make the workshop well attended. At the workshop a presentation of Ground Situation Awareness, one of the Infusion scenarios, was presented. The title of the paper in the workshop on Sensor Data Fusion was: "Trends, Solutions, Applications".

Invited talk by Björn Olsson at Biomolecular workshop

The invited talk by Björn Olsson on "Biomolecular network inference by information fusion" in the workshop "Data and Knowledge Based Biomolecular Network Reconstruction" in Jena, Germany was highlighted in the University's local website as well as through the channels used by the University of Jena faculty. The workshop was well attended and got wide international exposure.

NFFP Program Seminar

The invited talk by Sten F Andler at the Swedish National Aeronautics Research Program, held in the Volvo Aero Auditorium, Trollhättan, Sweden was mainly covered by the internal website at both Volvo and the University of Skövde.

B.5 Courses, Seminars and Conferences

Courses

During 2007 a number of courses were offered in order to broaden and deepen the knowledge of the members of the Information Fusion Research Program from within and outside the academic community, nationally and internationally.

Information Fusion

A graduate course (5 points) and workshop, also offered as an MSc course.

Organizer: The University of Skövde

Invited Speakers: Dr. Pontus Svenson (FOI), Prof. Mike Hinchey etc

Lecturers: Dr. Ronnie Johansson, Prof. Sten F Andler.

Advanced Topics in Information Fusion

The PhD course "Advanced Topics in

Information Fusion, 3 + 2 points" is a seminar course with invited seminars and student presentations. A 2 point project is optional. The course "Information Fusion, 5 points" is an additional prerequisite for the project part.



Dr. Ronnie Johansson, one of the speakers at the Information Fusion course.

Conferences and seminars

During the year members of the Infusion research community have participated in several relevant conferences both nationally and internationally. We have also hosted a number of research conferences and seminars. These are highlighted in the section "Calendar of events" and are also indicated in the summary of paper publications, most of which have been presented at conferences and through seminars.

The marketing of activities and supporting the dissemination of information in the Infusion research program are supported by a project titled "Fusion as vision" which runs parallel with the Infusion research program. The project is funded by the Sparbanksstiftelsen Alfa. The main purpose of the project is to help spreading the information of the events in the program and to support in the briefing of the same to a wide audience, both research audience but the society as well.

B.6 Invitations, visits and presentations

Scholarships for information events, travel, conferences etc.

During 2007 eight Information Fusion Travel Grants were awarded to individuals within the research program. The grants were funded within the project titled Fusion as Vision as mentioned above, which has the main purpose

of ensuring the exposure of infofusion results and to support mobility as well.

The purpose of the scholarships is for the individuals to represent and market the research program. The media coverage for the scholarships and travel grants were mainly handled through internal press. Following are examples of graduate students who were designated to represent the program at different events;



Mr. Mathiason spent much of time at the Olsson Hall, where the Computer Science Department is situated.

Gunnar Mathiason

Gunnar Mathiason went to the University of Virginia, USA, on a more than four months long visiting scholarship funded by CUGS. During this time he continued his research and spent a lot of time talking to his co-supervisor Prof. Sang H. Son. He also promoted the Information Fusion Research Program at George Mason University together with Per M. Gustavsson, who also is a researcher in the program.

Alexander Karlsson

PhD student Alexander Karlsson met a number of researchers at Center for Multisource Information Fusion (CMIF), located in the state of New York at University at Buffalo. During his 4 week long visit he discussed IF-topics of common interest, e.g., high-level information fusion, uncertainty management, and imprecise probability. CMIF is one of the leading research centers within the information fusion (IF) community, with well-known and renowned researchers in the field. In particular, he had interesting discussions with Professor Llinas and they primarily discussed the concept of imprecise probability and its relation to decision effectiveness.

Visits and visitors

Several international visits were made by research faculty in the Infofusion research program. The University of Skövde also hosted a number of international visits by research

faculty at prominent universities. Such visits were, for example, a visit by Dr. James Llinas from the University of Buffalo (State University of New York). Professor Llinas is one of the most renowned researchers in the field of information fusion and is the Executive Director of the Center for Multisource Information Fusion (CMIF):

<http://www.infofusion.buffalo.edu/>

Visits were also made by Prof. Alejandro Buchmann, University of Darmstadt, Department of Computer Science, one of the leading universities in Germany. Professor Buchmann has an extensive background in the development of new solutions for the integrated management of data.

Furthermore, a visit was made by Dr. Jorgen Hansson, Carnegie-Mellon University, SEI, Pittsburgh, PA, USA, and Prof. S. Son, University of Virginia, USA. Both visitors have an outstanding background in the information fusion area and research areas closely related to it. The Director for the Infofusion Research Program has active research collaboration with Prof. Son since a few years back in time whereby visits of this nature are mainly to strengthen the collaboration and to find new approaches in the joint work.



View of North Campus from Baird Point, University of Buffalo.

Presentations

The Information Fusion Research Program has been presented in several different arrangements, locally, nationally and internationally. These are highlighted, on one hand, in the calendar of events indicating invited talks, and on the other hand, in the summary of workshops and conferences where the ongoing research work in the Infofusion research program was presented. Presentations of ongoing work was also carried out in connection with each visit taking place at the

university as well as in connection with visits to external sites, visits to collaboration partners, participation in briefings etc.

B.7 Miscellaneous

Monthly newsletters

The Information Fusion Research Program produces monthly newsletters published on the Infofusion website; the previously published newsletters are archived and also accessible from the website. If you wish to receive the newsletters you can subscribe to it by sending an e-mail to info@infofusion.se

Designated facilities for Information fusion

The Information Fusion Research Program has a number of designated areas that provide exposure to the research program, such as an Infofusion Lab, an Infofusion conference room and Infofusion administrative offices. The Infofusion conference facilities and lab area are now basically operational. These areas serve to increase the visibility of the program for the external visitors, internal staff and students.

Executive Committee meetings

The executive committee has regular meetings, documented by minutes. The committee had 13 meetings 2007. The minutes are accessible on our internal web pages.

Infofusion Program Meetings

The purpose of the Infofusion Program Meetings is to bring researchers of the Information Fusion Research Program together to share information and discuss common research issues. The meetings are open to all participants in the research program. Program meeting organizers are post-docs Ronnie Johansson and Joeri van Laere. During 2007 these meetings have continued and we have had a number of meetings. During the fall 2007 we started to have themes for our meetings. The idea was to let each of our scenarios host a meeting and bring the rest of the research program up to speed on the individual scenario's progress.

Briefings

A number of briefings with various partners and potential future collaborators were held during the year. The purpose of the briefings is to provide up-to-date information about the status of the Infofusion research program and to simultaneously look at project ideas and joint work. Briefings were held, among others at the following research environments; Saab AB, Security Arena Lindholmen, Volvo Aero, Örebro University, etc.

Project "Fusion as vision"

To support the marketing and dissemination of the information and activities in the Infofusion research program the project *Fusion as Vision* is a project running parallel with the Information Fusion Research program. The project is funded by Sparbanksstiftelsen Alfa. Its main focus is the support the information and marketing activities in the Information Fusion Research Program.

RCP – Regional Contact Point elected

During the year a number of RCP:s – Regional Contact Point – were appointed in Sweden. The election was made through the Regional Governor (Landshövding) for each region. For the region Västra Götaland, Anita Andler, at the University of Skövde, was elected to represent the region on issues pertaining to EU's 7FP. The purpose of the role as an RCP is to provide EU-related information to industry, especially aimed at regional SMEs to support their future participation in the 7FP. These supporting activities may also include industry/SMEs in the field of information fusion and related areas of research and development.

Appendix C Information and marketing budget

This appendix contains a preliminary estimate of the portion of the budget for the Information Fusion Research program that is used for

information and marketing activities of various kinds.

Financial Report — Fusion as Vision

Expenses/budget for information and marketing activities:

	Expenses 2005	Expenses 2006	Expenses* 2007	Accumuated 2005-2007
1. Personnel costs				
Salary	203 407	203 926	170 000	577 334
Social costs	101 704	96 786	82 455	280 945
PERSONELL COSTS	305 111	300 713	252 455	858 279
2. Courses and Seminars	44 000	23 650	5 931	73 581
3. Cost of material & web	50 330	4 145	1 000	55 475
4. Travel costs	8 500	111 816	28 043	148 359
5. Representation	20 000	28 299	7 138	55 437
OTHER COSTS	122 830	167 909	42 112	332 851
SUBTOTAL	427 941	468 622	294 567	1 191 130
6. Overhead (30 %)	128 382	139 837	88 370	356 589
TOTAL COSTS	556 323	608 459	382 937	1 547 719
7. TAX (8,7 %)	48 400	52 936	33 316	134 652
SUM TOTAL COSTS	604 723	661 395	416 253	1 682 371
INCOME	1 632 885	0	0	1 632 885
REMAINDER	1 028 162	366 767	-49 486	

* Estimate of expenses based on budget 2007

Appendix D Foundations of Information Fusion

This appendix highlights three papers that define our view of Information Fusion. The first paper [1] presents a novel definition of information fusion as a field of research, which provides a foundation for assessing the contribution of work in the research program to the field as a whole. The second paper [2] gives a brief overview of the Joint Directors Laboratories (JDL) model of Information Fusion, as an introduction to several of the concepts used in the summaries of scenarios and projects in the Information Fusion Research Program. Finally, the third paper [3] presents a situation analysis model combining some of the existing concepts within information fusion: the JDL model, the OODA loop (Observe, Orient, Decide, and Act), and Endsley's definition of situation awareness.

The Information Fusion Research Program intends to set up a discussion forum for its members. Since the members are distributed, both within the University and outside (including the members at the University College of Borås and the industrial partners), a web-based discussion forum is anticipated to be beneficial for the information exchange. Typically, questions and answers can be raised and debated between our regular program meetings. We are, therefore, investigating such a discussion forum for the program members.

There are many terms and definitions in use in the information fusion field, due to its interdisciplinary nature and its use in diverse application domains. Hence, it should also be beneficial to maintain a common website for adding and modifying terms. Wiki is a technology that provides this kind of functionality (an excellent example of a Wiki application is the famous Wikipedia on-line dictionary site [4]). Initially, such a site could be used internally only, but as the dictionary matures, it should also be useful for the information fusion community as a whole as a means to achieve a common nomenclature.

References

- [1] H. Boström, S.F. Andler, M. Brohede, R. Johansson, A. Karlsson, J. v.Laere, L. Niklasson, M. Nilsson, A. Persson, and T. Ziemke (2007). On the Definition of Information Fusion as a Field of Research, Technical Report, HS-IKI-TR-07-006, University of Skövde, Sweden.
- [2] Buason, G. and Niklasson, L. (2004) JDL – an overview. Condensed version of Buason, G. and Niklasson, L (2004) NFFP3+ Concepts and Method,
- [3] Niklasson, L., Riveiro, M., Johansson, F., Dahlbom, A., Falkman, G., Ziemke, T., Brax, C., Kronhamn, T., Smedberg, M., Warston, H. and Gustavsson P.M., (2007) A Unified Situation Analysis Model for Human and Machine Situation Awareness, Lecture Notes in Informatics, pp 105 – 110, Köllen Druck+Verlag GmbH, Bonn ISBN 978-3-88579-206-1
- [4] Wikipedia, the free encyclopedia. URL: <http://en.wikipedia.org/wiki/Wikipedia>

Appendix E Scenario and project summaries

This appendix contains summary descriptions of the common goals scenario and each of the six application scenarios of the Information Fusion Research Program:

- Common Goals and Infrastructure (cgi)
- Ground Situation Awareness (gsa)
- Bioinformatics (bio)
- Retail Sector (rs)
- Manufacturing (mfg)
- Precision Agriculture (pa)
- Systems Development (sd)

Each of the scenario summaries is followed by a two-page summary of each project within the scenario. The scenarios serve as an umbrella for the projects within each of the research areas.

Scenario: IF cgi – Common goals & infrastructure

Information fusion theory, methods and infrastructure

**Prof. Sten Andler, Prof. Henrik Boström, Prof. Anne Persson, Prof. Tom Ziemke,
Ph.D. Ronnie Johansson, Ph.D. Joeri van Laere, Ph.D. Jonas Mellin, Ph.D. Tarja Susi,
PhD Students: Marcus Brohede, Alexander Karlsson, Maria Nilsson**

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In cooperation with the specific application scenarios and projects in the information fusion research program, these central projects aim to establish a *common framework for information fusion* and to capture the *generic aspects* of information fusion processes *across different levels and domains*, addressing (a) the embedding of information fusion systems in the context of *decision support* for collective decision processes in organizations or groups, individual human decision making, automatic decision making, and the interdependencies of these different types of decision processes, (b) the development of generic methods, algorithms and tools for use in modeling and implementing specific information fusion processes and systems, and (c) the possible technological realizations and platforms underlying information fusion systems which, depending of the nature of the decision processes supported, might need to support, for example, information fusion in distributed, network-based systems (e.g. sensor networks) and might face real-time processing demands (e.g., where fast decisions are required). Consequently, the cgi projects will span practically all the levels of the revised JDL information fusion model, from the cognitive/user refinements level (including human-machine interaction and organizational aspects) to sensor fusion at the lowest level, and try to capture the interrelations between these levels, and thus also contribute to the further development of the JDL model itself (or alternative models). More specifically, the scenario aims to contribute to the following three areas, corresponding to three projects, focusing on the *use* of information fusion, its *functionality*, and its *technological realization* respectively: **cgi1 framework**, which aims for developing a theoretical framework capturing the nature of information fusion as decision support, i.e., what the organizational and cognitive demands and constraints are that different types of information fusion systems have to face, **cgi2 methods**, which aims for developing generic methods, algorithms and tools for use in modeling and implementing information fusion processes and systems, and **cgi3 infrastructure**, which aims for developing a technological infrastructure for the implementation of information fusion systems that supports the requirements of different application scenarios.

Research Question

The central questions for the cgi projects are the following: Which are the overlaps and differences between the different application domains/scenarios in the information fusion research program, and how can they be integrated in a common framework for information fusion? Which generalizations are possible, i.e., what is domain-specific and what is generic, and which aspects (insights, experiences, methods, algorithms, etc.) can be transferred between domains? The specific research questions are elaborated in more detail in the three cgi project summaries.

Relevance to Information Fusion

The cgi projects are important, firstly, for the integration of the different activities in the IF research program, and, secondly, for a wider distribution of information fusion theories, methods, and models to a broader range of application domains.

It is important to note that the cgi scenario not only addresses research issues, but also the creation and exploitation of synergies between the different

scenarios and projects in the information fusion research program through common program meetings, project leader meetings, PhD courses, etc.

Highlights in 2007

Recruitment: Professor Henrik Boström joined the research program in January 2007. He took over as co-director of the research program and as scenario leader for common goals and infrastructure (IF cgi). He also became project leader and main supervisor for one Ph.D. student in the retail scenario (IF rs), and main supervisor for one Ph.D. student in the manufacturing scenario (IF mfg).

Program synergies: A new course on “*Intelligent data analysis*” was given for the first time in fall 2007, with participation of six Ph.D. students from the research program. The PhD course “*Information fusion*” was given for a third time in fall 2007.

A one-year master's program in information fusion, starting in fall 2008, was developed and established at University of Skövde. An application to a call from Swedish Knowledge Foundation was approved regarding support for a project for developing a two-year master's program in information fusion.

External partners in the project, which starts in spring 2008, are SAAB Microwave Systems and Swedish Defence Research Agency (FOI).

Skövde Workshop on Information Fusion Topics (SWIFT) was organized for the first time, during three days in April 2007 and with more than 60 participants in total. The workshop included invited talks by Peter Willett (University of Sheffield), Ulf Norinder (AstraZeneca), Stavri Nikolov (University of Bristol), Pontus Svenson (FOI), Johan Schubert (FOI), Michael Hinchey (Loyola College), and Galina Rogova (State University of New York at Buffalo), as well as presentations from researchers and Ph.D. students from the research program.

IF program meetings, intended to bring together all researchers and external partners in the IF program, were held 15 times during the year. Typically, at each occasion, one scenario presents ongoing work.

Research: The research highlights are specified in the three cgi project summaries.

Projects within scenario IF cgi

- IF cgi1 framework
- IF cgi2 methods
- IF cgi3 infrastructure

Industrial & scientific cooperation

The cgi projects are carried out in cooperation with the application projects, and thus to some degree will involve all research groups and all industrial partners, at least indirectly. Besides partners formally associated with the research program, extensive collaboration has been undertaken with researchers at AstraZeneca, Swedish Defence Research Agency (FOI), SAAB, Swedish Emergency Management Agency and University College of Borås. A strategic project, funded by the University of Skövde, was executed during fall 2007 to strengthen the cooperation between the university, AstraZeneca and University College of Borås.

Approach

The general approach is to use all application scenarios as case studies and input sources and at the same time feed back to all scenarios relevant general knowledge and gained insights. The cgi1 project, for example, involves case studies of the different requirements for information fusion and decision support in the different application scenarios and should result in the identification of different types of *information fusion systems and processes*, different types of *users, cognitive and organizational demands*, and a common *terminology* applicable across different domains of use. Similarly, the cgi2 project is based on demands and techniques of the applied projects and should assimilate, generalize and integrate different models and techniques from the specific projects in order to develop *generic methods and algorithms* that support effective and efficient development of

information fusion systems in different application domains.

Contribution to *infofusion* goals

The cgi scenario plays a key role in the research program in gathering knowledge and experience from the different application scenarios, developing generic theories, models, and methods, and facilitating knowledge transfer between application domains.

Results achieved

Research: The research results are presented in the three cgi project summaries.

Program activities:

Regular program meetings have been organized bi-weekly during spring and fall.

The Skövde Workshop on Information Fusion Topics (SWIFT) was organized in April 2007.

Courses on information fusion and intelligent data analysis have been held for Ph.D. students and students on the advanced level.

A one-year master's program in information fusion has been developed.

Related work

This varies between the projects and is therefore stated in the three cgi project summaries.

Growth potential

Together with AstraZeneca and University College of Borås, a project application has been submitted to Vinnova on information fusion for drug discovery by modeling molecular properties through combining multiple sources of molecular information. This and other planned projects are expected to further strengthen the research collaboration within information fusion between University of Skövde, University College of Borås and AstraZeneca. This collaboration is expected to provide an excellent platform for getting access to industry relevant problems and non-synthetic data as well as to domain experts within the pharmaceutical industry.

The two-year master's program in information fusion, which is planned to start in fall 2009, will provide a long-term basis for recruiting Ph.D. students as well as for disseminating knowledge about information fusion theory, methods and techniques to the industry through students and through the planned co-production with industry of the master's program.

Start: 1 Nov 2005 (5 yrs)

Project: IF cgi framework**Information Fusion and Decision Support:
Cognitive and Organizational Factors**Joeri van Laere, PhD (joeri.laere@his.se)Maria Nilsson, PhD Student (maria.nilsson@his.se)Tarja Susi, PhD (tarja.susi@his.se)Henrik Boström, Professor (henrik.bostrom@his.se)Anne Persson, Professor (anne.persson@his.se)Tom Ziemke, Professor (tom.ziemke@his.se)

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This project investigates the embedding of information fusion systems in the context of *decision support* for collective decision processes in organizations or groups, individual human decision making, automatic decision making, and the interdependencies of these different types of decision processes. Hence, the project is mostly concerned with “level 5” (*cognitive refinements*) in the revised JDL model, and it aims to develop a *theoretical framework* capturing the nature of information fusion as decision support, i.e. what the organizational and cognitive demands and constraints are that different types of information fusion systems have to face. The general approach is to apply theories and insights from distributed cognition and organization science in different case studies to understand requirements for information fusion and decision support. This should result in the identification of different types of *information fusion systems and processes*, different types of *users, cognitive and organizational demands*, and a common *terminology* applicable across different domains of use.

Research Question

The general research question in this project is to understand the human-computer interaction issues as well as the organizational and cognitive constraints and requirements that IF systems face when used in the support of individual and group decision making. This includes:

- What are the relevant organizational issues for different application scenarios, e.g. how are IF systems embedded in larger IF processes such as decision-making in groups and organizations?
- What are the relevant cognitive or psychological factors for decision makers relying on information fusion systems (e.g. trust in IF systems) for different types of users and decision makers and application contexts?

Relevance to Information Fusion

As several authors have pointed out an efficient interaction between IF systems and their users, i.e. the decision-makers they support, is absolutely crucial in many applications. This project will help to identify and understand the varying constraints and requirements in different application domains.

Highlights in 2007

Nilsson has performed two case studies to get more insight in the use of information fusion systems in practice. In cooperation with SAAB Systems a maritime surveillance application was studied (JDL-level-1). The Swedish Defense

Research Institute (FOI) invited members of the project to study a prototype of an impact matrix (JDL-level-2). These case studies have resulted in 2 papers to be presented at Fusion 2008.

Laere and Susi have participated in the organization and analysis of three municipal crisis management exercises where the relation between information management and decision making is central, and which as such can serve as an input for the theoretical framework under development.

Members of the project presented two papers at the Fusion 2007 conference in Quebec, Canada.

From July 2007 the post-doc Joeri van Laere has become project leader for the project.

Initial contacts with other scenarios have been established to perform case studies under 2008.

Cooperation**Industrial**

This project does not involve industrial partners directly, but will be carried out in cooperation with *all* application scenarios, and thus to some degree will involve all industrial partners, at least indirectly. Additional industrial contacts have been developed as in the case of SAAB Systems and FOI .

Scientific

The project is carried out in cooperation with *all* application scenarios. Therefore it will to some degree involve all research groups in the IF research program.

Approach

The general approach is to use all application scenarios as case studies and input sources to get a picture of different IF system user situations and requirements. The users' use of and interaction with IF systems in the different application domains will be analyzed by applying theories and insights from distributed cognition and organization science. Primary research methods are interviews and case studies to understand the different requirements for information fusion and decision support in the different application scenarios. This should result in the identification of different types of *information fusion systems and processes*, different types of *users, cognitive and organizational demands*, and a common *terminology* applicable across different domains of use.

Contribution to infusion goals

The project is an essential part of the IF research program's common goals, and will contribute to understanding the cognitive and organizational constraints on the use of IF systems in decision support in different application domains.

Results achieved in project

The main findings of the project thus far are:

- 1) IF has traditionally had a technical focus, thereby picturing the decision maker as a passive end user. In practice, operators and decision makers are actively interacting with fusion technology and contributing to the fusion process, rather than only consuming the output. As such, there is a need for models to be able to describe this rich interaction between humans and machines.
- 2) Although addressed in commonly used models like the JDL model, Endsley's model of situation awareness and the 1996 version of the OODA loop, information fusion research seldom discusses how preconceptions, assumptions, cultural traditions and worldviews impact or limit what information actually is fused and how it is fused. Therefore fusion systems may be unaware that they are producing a biased view of reality rather than ground truth.
- 3) There are few studies of information fusion systems in use, most only discuss prototypes.

Our project will contribute to information fusion by addressing the first two issues in the development of the theoretical framework and by aiming to perform more user studies, within or outside the Infusion profile in Skövde in the coming years. For 2008 several possible studies have been discussed with Infusion scenarios as well as with outside parties.

In 2007, 5 publications have been produced:

- Laere, Nilsson & Ziemke (2007). Implications of Weickian perspective on decision making for information fusion research and practice. *Proceedings of the 10th International Conference on Information Fusion*

- Nilsson & Ziemke (2007). Information Fusion: a decision support perspective. In: *Proceedings of the 10th International Conference on Information Fusion*.
- Nilsson (2007). Information Fusion: a new requirement for effective decision making? *Interfaces 70*.
- Nilsson (2007). Information fusion and human decision making: extending the concept of decision support. *Technical Report:HS-IKI-TR-07-002* (PhD research proposal)
- Boström, Andler, Brohede, Johansson, Karlsson, van Laere, Niklasson, Nilsson, Persson & Ziemke (2007). On the Definition of Information Fusion as a Field of Research. *Technical Report:HS-IKI-TR-07-006*

Furthermore we are working on the following publications to be published/submitted in 2008:

- Nilsson, Laere, Ziemke, Berggren & Kylesten. A user study of the *Impact matrix*, a fusion based decision support for enhanced situation awareness. Accepted for Fusion 2008.
- Nilsson, Laere, Ziemke & Edlund. Extracting rules from expert operators to support situation awareness in maritime surveillance. Accepted for Fusion 2008.
- Nilsson, Riveiro & Ziemke. Investigating Human computer interaction issues in information fusion based decision support. Submitted to Nordic CHI 2008.
- Nilsson, Laere, Susi & Ziemke. A distributed cognition perspective on the active role of users in information fusion. Draft article to be submitted to the Information fusion journal.

Related work

Our work is related to the 'JDL-level-5' discussion initiated by Hall, Hall and Tate [1] and Blasch and Plano [2]. In a recent literature overview Hall et al [3] conclude that none of the models currently available covers the entire scope required by a situation assessment domain, e.g. from data gathering, information fusion, information presentation and cognitive sense making to decision making. This serves as a challenge for our project.

- [1] Hall, Hall & Tate. Removing the HCI Bottleneck: How the Human Computer Interaction (HCI) affects the performance of Data Fusion System. In: Hall D. L & Llinas J (eds.), *Handbook of Multisensor data fusion*, CRC Press, Florida, USA 2001.
- [2] Blasch & Plano. JDL Level 5 fusion model: User refinements issues and application in group tracking. *SPIE vol 4729, Aerosense*. 270-279, 2002.
- [3] D. Hall, B. Hellar, J. Llinas, and M. McNeese, Assessing the JDL Model: a survey and analysis of decision and cognitive process models and comparison with the JDL model, presented at the National symposium of sensor fusion 2007.

Start: 1 Nov 2005 (5 yrs)

Project: IF cgi2 methods**Generic Methods, Algorithms and Tools**

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In cooperation with the specific applied scenarios and projects, this central project aims to capture the *generic aspects* of information fusion processes *across different levels and application domains*, addressing the possible technological realizations and platforms underlying information fusion systems which, depending of the nature of the decision processes supported, might need to support, for example, information fusion in distributed, network-based systems (e.g. sensor networks) and might face real-time processing demands (e.g. where fast decisions are required). Consequently, the project spans several levels of the revised JDL information fusion model, from the process refinement level (including sensor management) to sensor data fusion at the lowest level, and tries to capture the interrelations between these levels, and thus also contributes to the further development of the JDL model (or versions thereof) itself. More specifically, this project aims to capture the *functionality* of information fusion and its *technological realization* by developing *generic methods, algorithms and tools* for the use in modeling and implementing information fusion processes and systems. This project is carried out in close interaction with the cgi1 framework and cgi3 infrastructure projects.

Research Question

The central question for the cgi projects is to identify the overlaps and differences between the different application domains and scenarios, and to clarify which generalizations are possible, i.e., what is domain-specific and what is generic, and which aspects (insights, experiences, methods, algorithms, etc.) can be transferred between domains.

Most research in the field of information fusion has addressed the problems involved in low-level information fusion, e.g., target tracking with multi-sensor fusion. However, *high-level information fusion*, i.e., level 2 – *situation assessment* and level 3 – *impact assessment*, has been a relatively uncharted research field.

High-level information fusion is usually tightly coupled with decisions. It is therefore important that also high-level information fusion algorithms and methods are *dependable*. In fact one can consider dependability as a precondition for trustworthy “fusion-based decision-making”.

Specifically, we raise the following research questions concerning high-level information fusion:

- How can one evaluate generic high-level information fusion methods and algorithms with respect to dependability?
- What are the requirements on generic methods and algorithms for high-level information fusion to ensure dependability?
- How will different belief representations and fusion methods affect decision making?
- How can domain knowledge and data from the past (e.g., databases), present (e.g., sensors), and future (e.g., simulations) be

used in generic high-level information fusion methods and algorithms, for the purpose of increased dependability?

Relevance to Information Fusion

This project is important, firstly, for the integration of the different activities in the IF research program, and, secondly, for a wider distribution of information fusion theories, methods, and models to a broader range of application domains. Also, since there has been little attention given to the problem of high-level information fusion in conjunction with dependability, the research questions are of fundamental importance for trustworthy fusion-based decision-making.

Highlights in 2007

- Professor Henrik Boström joined the project in January 2007.
- Alexander Karlsson visited the Center for Multi-source Information Fusion, University at Buffalo (State University of New York), during one month in the fall.

Cooperation**Industrial**

This project is carried out in cooperation with virtually *all* application projects, and thus to some degree involves all research groups and all industrial partners, more or less directly. A strategic project, funded by the University of Skövde, was executed during fall 2007 to strengthen the cooperation between the university, AstraZeneca and University College of Borås.

Scientific

The cooperation between the project and the retail and manufacturing scenarios has been extended through the new professor, who also is project leader and main supervisor for one Ph.D. student in the retail scenario (IF rs), and main supervisor for one Ph.D. student in the manufacturing scenario (IF mfg). An extended cooperation with the precision agriculture scenario has led to several contacts within the Swedish University of Agricultural Sciences (SLU). Workshops and discussions with the Bioinformatics scenario have also been held concerning graph fusion. Furthermore, a project with a member of the ground situation awareness scenario is ongoing.

Approach

The general approach is to use all application scenarios as case studies and input sources. The project will naturally be based on the demands and techniques of the applied projects and should assimilate, generalize and integrate different models and techniques from the specific projects in order to develop *generic models and solutions*, based on a *common formal/computational framework and terminology*, that support efficient development of information fusion systems in different applications domains.

Contribution to *infofusion* goals

This project plays a central role in gathering knowledge and experience from the different application scenarios, in developing generic methods, algorithms and tools, as well as in facilitating knowledge transfer between application domains. The main expected contribution from this project is to depict how one can account for dependability in high-level information fusion in different application domains.

Results achieved in project

The results for 2007 include the following:

- Evidential reasoning toolbox “pyBelief”, has been developed by Dr. Ronnie Johansson. The toolbox has been used both in teaching and in scientific work.

The following articles were published within the project:

- Karlsson, A., “Generic robust and reliable high-level information fusion - algorithms and methods”, In: "Workshop on Information Technology" proceedings from workshop in Skövde, Sweden, April 2-3, 2007, Tech. report IDE0727, Halmstad University, Gaspes, V., editor, 103-109
- Karlsson, A. “Dependable and generic high-level information fusion - methods and algorithms for uncertainty management”, Tech. report HS-IKI-TR-07-

003 School of Humanities and Informatics, University of Skövde, 2007

- Karlsson, A., Johansson, R., & Andler, S.F. “Imprecise Probability as an Approach to Improved Dependability in High-Level Information Fusion”, Proc. of the Intl Workshop on Interval/Probabilistic Uncertainty and Non-Classical Logics, 2008
- Boström H., “Estimating Class Probabilities in Random Forests”, Proc. of the Sixth Intl. Conf. on Machine Learning and Applications, IEEE Computer Society, (2007) pp. 211-216
- Boström H., “Feature vs. Classifier Fusion for Predictive Data Mining – a Case Study in Pesticide Classification”, Proc. of the 10th Intl. Conf. on Information Fusion (2007)
- Boström H., “Maximizing the Area under the ROC Curve with Decision Lists and Rule Sets”, Proc. of the SIAM Intl. Conf. on Data Mining (2007) 27-34 (ISBN: 978-0-898716-30-6)
- Deegalla S. and Boström H., “Classification of Microarrays with kNN: Comparison of Dimensionality Reduction Methods”, Proc. of the 8th Intl. Conf. on Intelligent Data Engineering and Automated Learning, LNCS 4881, Springer-Verlag, Berlin Heidelberg (2007) pp. 800–809

Related work

Most research concerning high-level information fusion has utilized precise Bayesian theory or some variant of evidential theory. In order to fuse information from different sources, methods like *Bayesian networks* or *combination rules* have been proposed and utilized. However, different types of belief representations and combination rules have seldom been compared against each other from a dependability perspective. Since high-level information fusion aims at enabling for better decisions, this essentially amounts to evaluate how different belief representations and combination rules affect decision making. One rare comparative work is (Aughenbaugh, 2006) who makes one comparison for a specific engineering problem, but general comparisons are still lacking. A thorough study of combination rules is provided in (Polikar, 2006), but is limited to certain types of belief representations. .

- (Aughenbaugh, 2006) “The value of using imprecise probabilities in engineering design,” Journal of Mechanical Design, vol. 128, pp. 969–979, 2006.
- (Polikar, 2006) “Ensemble based systems in decision making,” IEEE Circuits and systems magazine, vol. 6, no. 3, pp. 21–45, 2006.

Start: 1 Apr 2005 (3 yrs)

Project: IF cgi3 infrastructure**Using Active Real-Time Database Functionality as an Infrastructure for Information Fusion****Prof. Sten F. Andler, Professor (sten.f.andler@his.se)****PhD Ronnie Johansson (ronnie.johansson@his.se)****PhD Jonas Mellin (jonas.mellin@his.se)****PhD Student Marcus Brohede (marcus.brohede@his.se)****PhD Student Gunnar Mathiason (gunnar.mathiason@his.se)****MSc Johan Olby (johan.olby@his.se)**Distributed Real-Time Systems Research Group (DRTS)
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In cooperation with the specific applied scenarios and projects, this central project addresses the possible technological realizations and platforms underlying information fusion systems which, depending of the nature of the decision processes supported, might need to support, for example, data fusion in distributed, network-based systems (e.g. sensor networks) and might face real-time processing demands (e.g. where fast decisions are required). More specifically, this project aims to capture the *technological realization* of information fusion by developing a *technological infrastructure* for the implementation of information fusion systems that supports the requirements of different application scenarios. This project is carried out in close interaction with the cgi2 project Generic Methods, Algorithms and Tools.

Research Question

To serve as an infrastructure for information fusion applications, we argue that requirements such as *heterogeneity*, *distribution*, and *scalability* must be addressed. Data have temporal attributes that must be handled and many information fusion applications are also real-time systems, i.e., deadlines must be kept. Finally, *robustness* is also a requirement for many information fusion applications; fault tolerance and uncertainty management must be available in any candidate infrastructure. To address these requirements, we look to technologies such as databases, real-time and distributed systems. For instance, can a distributed active real-time database be used as an infrastructure for information fusion applications with real-time requirements?

Relevance to Information Fusion

Handling vast amounts of complex information from databases, sensors and simulations requires database support for information storage and retrieval as an important part of the infrastructure for information fusion.

The decision-making affects physical processes in real-time decision support applications. The fusion of information must not only be semantically correct and consistent in the database, it must also satisfy time constraints. If simulation is used to predict the behavior of the system in response to a specific parameter choice or action, the simulation must return results in bounded time.

Highlights in 2007

The activities and objectives of the project were presented to the rest of the research program.

Discussions with representatives for some of the other program scenarios concerning infrastructure issues were performed and a questionnaire concerning application-specific requirements for infrastructure support was given to all scenarios.

The meetings with SLU continued. Today, precision agriculture (PA) uses a lot of sensors to enable sound decisions on for example amount of fertilizer to dispense on a field. PA also has a lot of historic data on for example the yields of previous years. Therefore, this application qualifies as a proof of concept. They have given input to the development of our wireless sensor networks (WSN) testbed, in particular for sensing in the field for which they also suggested that we interfaced sensors from their domain, e.g., conductivity sensors.

Cooperation**Industrial**

The infrastructure project is carried out in cooperation with Enea Embedded Systems, a developer and supplier of a real-time operating system and database.

We also have cooperation with Exensor AB who is currently developing a new sensor for identifying land based vehicles.

Agroväst AB and Saab Microwave Systems AB are also partners with whom we have collaborated with during 2007.

Scientific

During 2007, members of the project met and discussed infrastructure issues with several of the other scenarios to determine the requirements pertaining to the different scenarios.

We have also worked with researchers from the University of Virginia (UVa) and the University of Latvia. Prof. Sang Son, UVa, is co-advisor of our PhD students and PhD Leo Selavo, University of Latvia, was technical advisor when purchasing our wireless sensor network testbed.

Approach

Since information sources are developed and maintained by people in different groups and organizations distributed physically and logically, on heterogeneous hardware and software, issues concerning the distribution of data and simulations are relevant.

The information fusion process involves monitoring and responding to system state and events, such as complex sequences of events or specific data states in the database that trigger the computation of refined information. An infrastructure that supports such reactive behavior, using rules to specify active functionality, allows these processes to be described independently of specific application code.

Contribution to *infofusion* goals

This project plays a central role in gathering knowledge, experience, etc. from the different application scenarios/projects, developing generic methods, algorithms and tools, and facilitating knowledge transfer between application domains.

The main expected outcomes are a suitable technological infrastructure with support for a toolbox of generic methods and algorithms. These results will be evaluated in practice as applicable to the different application domains, and scientifically by being published and presented in relevant IF journals and conferences.

Results achieved in project

In 2007 strategic funds was received to build a wireless sensor network testbed. This project was aided by senior researcher PhD Leo Selavo, a contact established at UVA. Leo was a research associate at UVA during the periods when we had PhD students visit UVA.

An application for support for cooperation with database and sensor network experts in India and China was submitted to the Swedish Research Council (Vetenskapsrådet). Funding was provided and a workshop for all participants is being prepared for autumn 2008.

Related work

Ghosh et al. (1994) has developed a prototype infrastructure called PORTS (Parallel Optimistic

Real-Time Simulation) that use an optimistic synchronization protocol together with continuous calculation of GVT. PORTS is said to be tightly coupled systems, i.e., distributed simulations that are connected through a network is not suitable.

Wang, Turner, Low & Gan (2004) describes an optimistic synchronization architecture for HLA simulations. It fails to address fault tolerance, i.e., the RTI is still a single point of failure. The architecture provides a way for implicit state saving to simplify for simulation engineers, i.e., they should not need to think of state saving and doing rollbacks.

Goldsmann & Withers (1990) describe a way to run replicas with different parameters in order to foresee how a production cell reacts to different control settings. In their approach, rare events with high impact on the simulation, e.g., failure of an important machine, are removed. They argue that occurrence of high impact events probably changes control settings radically and therefore should be treated as input parameters.

Knop & Sunderam (1994) describe a parallel software system called ACES that supports heterogeneous network based cluster computing. In particular, with a toolkit called EcliPSe, which is used as an upper layer in this ACES architecture, target replication-based simulations. They use a checkpoint-rollback mechanism that periodically saves data. However, it is unclear if data is saved to one or several nodes. Also, there is no mentioning of supporting real-time requirements.

Antony (1995) describes the design of a database manager which simultaneously stores both semantic and spatial data. This design may simplify access of data in traditional information fusion applications from the defense domain where information often is geographical. The work does not, however, address information fusion related issues such as uncertainty representations and system distribution.

Scenario: IF gsa - Ground Situation Awareness

Information fusion for Ground Situation Awareness

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The overall goal of the Information Fusion program is to supply theory, techniques and tools for exploiting the synergy in the information provided by heterogeneous sources and thereby support decision making. The research within the ground situation awareness scenario is focused on processes for situation analysis, i.e., processes which examine a situation, its elements, and their relations, to provide and maintain a state of situation awareness, for a decision maker. This includes both automatic and semi-automatic fusion processes for analyzing the current situation as well as the projection of its impact on future situations. The overall plan for this scenario is to focus on three main problem areas, namely *algorithms and methods for situation assessment*, *impact assessment* and *information visualization*. These problem areas will be addressed by three PhD-students (fully funded by the KK-foundation) who are expected to finish within the contract period for the Information Fusion Research Program (2005-2011). The problems will also be addressed by two additional industrial PhD-students (funded by Saab Microwave Systems AB) who also will finish within the contract period. In addition to this, another eight people (from both industry and academia) will work on these problems. The expected outcome of the research conducted within the scenario is theories and methods for Information Fusion. The usefulness of theories and methods will be demonstrated by results from applying prototypes and demonstrators to a number of military scenarios relating to ground level combat.

Research Questions

This scenario will focus on three main problem areas; i) which methods and algorithms are best suited for various aspects of situation assessment, ii) which methods are best suited for information visualization of situation awareness information, and iii) which methods and algorithms are best suited for impact assessment?

A starting point for the scenario has been to synthesize the common definitions of the area into a framework valid for all the subprojects within the scenario. The framework incorporates situation awareness at different levels of abstraction, the OODA-loop, as well as the boundaries between automatic, semi-automatic and manual decision making. Traditionally situation awareness has been a mental process, but we see the need to also include automatic (machine) processes, in order to achieve the goals of the information fusion program.

A central problem within situation awareness is how to automatically fuse sensor generated target information (speed, heading, position, type, etc.) and context information (geographical topology, relations to other objects, etc.) with historical information (tracking of movements, previous doctrines, etc.) as well as manually generated information (e.g., intelligence information). Two subprojects will therefore focus on development of automatic methods and algorithms for *situation assessment*. Of special interest is to study how temporal relations can be exploited to achieve 'normal-situation' assessment, including deviations

from what is to be considered 'normal'. This is evaluated in an anomaly detection setting.

Another interesting aspect is to investigate if and how impact and object assessments can influence situation assessment. This is needed in order to recognize certain situations (e.g. intrusion) and follow how they develop over time. Of special interest here is to combine predefined coarse descriptions of the situations of interest with the incoming sensor data.

For some situations it is not enough to assess the current situation, one also need to assess the impact of a set of possible actions, both own and opponent's, in order to decide which actions to take. One subproject will focus on the development of methods and algorithms for *impact assessment*. It will focus on the usefulness of different automatic induction methods from the artificial intelligence area (Bayesian networks, Genetic Algorithms, Neural Networks, ID3, etc.) for hypothesis generation. This includes developing methods and algorithms for hypothesis generation and testing. At this level of abstraction much of the assessment is traditionally made by humans. In order to automate parts of these processes, methods for extracting the assessment is called for. One of the subprojects will therefore focus on the use of graphical models.

The problem of human-computer interaction is present at all levels of abstraction of situation awareness. The problem domain is characterized by the need for rapid decision making and the presence of many different sources of information. This means that a part of the problem is to focus human

attention to the most important pieces of information. It is also common that a particular situation can be viewed from different perspectives (e.g., information about targets with respect to their geographical position, fuel situation, capability, etc.) depending on which role the user of the system has. A subproject will therefore focus on development of methods for *information visualization*. It will focus on how to present situation analysis information to a user in such a way that the user effectively can assess the information and fuse it in a semi-automatic fashion.

A related problem is to disseminate the basis for a decision to those parties affected by it. One subproject is concerned with disseminating Commanders Intent to subordinates in such a way that they can act in a way that allows them to exploit opportunities which do not violate the intention of their supreme commander.

Relevance to Information Fusion

This scenario is at the core of the Information Fusion program. The scenario will not only develop demonstrators to show the usefulness of information fusion, it will also contribute to the development of the theoretical framework of information fusion.

The Swedish armed forces are going through a major change by adopting a network centric warfare organisation. To succeed with this quest, it is vital that the organisation has the right tools for decision support at all levels. These tools are not available today.

Highlights in 2007

During 2007 the scenario further developed the common framework for situation awareness. This framework incorporates definitions for both machine and human situation awareness.

During 2007 a number of internal seminars were conducted. An external seminar together with another research program was also conducted. This seminar had about fifteen presentations from both the Information Fusion program (Skövde) as well as the Embedded Systems program (Halmstad).

Two of the student projects have been given access to real data. The results that the projects have delivered on this data have generated a lot of internal interest within our industrial partner, SAAB.

SAAB Systems have contacted us in order to investigate the possibility to incorporate a new industrial PhD student, working on anomaly detection.

The scenario has representatives in an EU expert group on Situation Awareness. This group will contribute to the development of research calls within FP7.

During 2007 Exensor technology left the scenario in order to develop cooperation with another scenario, within the area of sensor networks.

Projects within scenario IF gsa

- IF gsa1 algorithms
- IF gsa2 visualization
- IF gsa3 hypotheses

Industrial cooperation

One company is involved today, Saab Microwave System. Discussions have been initiated with another Saab company, namely Saab Systems. The interest is to incorporate a new PhD who will work in complementing areas to the already existing PhDs

Scientific cooperation

Research within this area is conducted by several national and international bodies, e.g. FOI, NADA, University of De Montfort. At this point initial contacts have been made with these parties. Several involved people participate in military projects. The potential for extending this involvement is large.

In addition to this, initial contacts have been taken with researchers from the University of Halmstad, who also are involved in a KK-foundation supported research program. The common problem of generating an accurate situation picture will be addressed. This includes analysis at various levels of abstraction.

Approach

Five PhD projects have been identified so far. These projects will make up the core of the scenario. A scenario steering committee has been established. The committee has phone meetings every other week and meets with the PhD students every other week.

The five projects will all utilize a number of common sub scenarios. Three scenarios have so far been identified; an invasion scenario, a rapid deployment scenario defending an air base for a United Nations effort, and a rapid deployment scenario including border and surface surveillance.

A sixth potential project has been identified during 2006. This project will be finalised during the first quarter of 2007.

Contribution to *infofusion* goals

The scenario will not only contribute with algorithms and methods. It will also be a vital part of the development of the theoretic framework. It has during 2006 developed a common framework for all the projects within the scenario. This view will be rather easy to extend to the common goals. To a minor degree, the scenario will contribute to the infrastructure aspect of information fusion.

Results achieved in project

Three PhD students started 1 Nov 2005 and one started 1 Jan 2006. One already was on board when the project started.

So far the project has so far resulted in seven publications in international scientific press.

One of the projects has been closely related to the internal work within SAAB on anomaly detection. Another project has been presented for another internal SAAB group, which now has invited the PhD student to work on real data and compare the result with those of the group.

Milestones for 2008

- For 2007 an infrastructure for generating data for the subprojects was purchased and installed. It turned out that it was not as easy as anticipated to incorporate information about geographical objects (e.g. shore lines). For 2008 we anticipate to use other sources of data.
- We anticipate a number of papers (between 3 and 5) to be accepted for publication at FUSION 2008. In addition to this we anticipate another 3-5 papers to be published elsewhere.
- All of the PhD projects will during 2008 focus on more practical aspect of the projects by conducting projects involving real or simulated data.

Related work

Within ground situation awareness much attention has been focused on level 1 of the JDL model. The *research* has mainly focused on developing algorithms for *data alignment*, *data/object correlation* and *estimations of position and velocity*. Another problem that has received attention has been to establish the *identity of an observation*.

The current state of the art research is focusing on level 2 of the JDL model, i.e. to construct algorithms for exploiting/detecting relationships between a number of objects, and often their relation to a given context. Algorithms typically deal with some sort of reduction of uninteresting data and information, both for computational and cognitive reasons. Techniques for this include clustering techniques (primarily for reduction purposes) and agent based techniques (primarily for detection of some “interesting” feature). The proposed PhD projects within this scenario are focussed at these types of problems, and are therefore within the core of the current state of the art research.

Several papers have been published on variants of the JDL model. There is, however a need for further development, especially to incorporate both manual and automatic processes into a situational awareness framework. It is the intention fo the scenario to develop such a framework.

Growth potential for the scenario

The European Security Research Advisory Board (ESRAB) has (September 2006) identified a number of areas where Information Fusion, in general, and situation awareness, in particular, is highly important. Situation awareness is for instance highlighted as a important function for *Border*

security. Since one of the scenarios used to demonstrate the usefulness of our approach is anomaly detection for border surveillance, it is anticipated that the scenario can contribute to such a degree that it will be an interesting partner for other European initiatives within this area.

ESRAB also acknowledges the importance of the function of Situation awareness for *Protection against terrorism and organised crime*, as well as for Critical infrastructure protection and *Restoring security in case of a crisis*. Aspects of these areas naturally tie in with anomaly detection, so there are great potential to undertake new project within these areas.

ESRIF (European Security Research and Innovation Forum) has initiated a working group (WG7) focusing on Situation Awareness. Since the scenario is represented in this group it will have an opportunity to be part of shaping future research programs within FP7.

FOI, SAAB and The University of Skövde has initiated discussions on a national research program for both the military and civilian domains of security research. Here the ground situation awareness scenario will be at the core of this colloboration.

Start: 1 Nov 2005 (5 yrs)

Project: IF gsa1a algorithms**Template-based situation recognition for ground-situation awareness**

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Ground-situation analysis is characterised by ever increasing amounts of information. More specifically, the information can contain numerous objects, be of different types, be available at varying frequencies, and last but not least it can be uncertain. The overall goal of ground-situation analysis is to enhance the situation awareness (SA) of decision makers and to allow for the development of new capabilities for the armed forces, as well as for civilian authorities. From a military perspective, the amount of data stemming from: sensors, intelligence reports, doctrines, etc., increase rapidly on a daily basis. New capabilities might also put new requirements on the information that is needed, and together, these two facts drastically increase the amount and complexity of the information that needs to be considered by a decision maker. More information can however lead to incorrect SA, possibly leading to bad decisions, which in the extreme can lead to human casualties. This problem is also commonly known as information overload and needs to be addressed. This is where information fusion plays a central role, as it attempts to produce information of higher value by *fusing* many pieces.

Information fusion for ground-situation analysis can at a high level be divided in three different categories based on the degree of active involvement of operators: (1) manual analysis, (2) semi-automatic analysis and (3) automatic analysis. In this project we focus on automatic support functions where the operator is not an active component of the fusion process, but only seen as a user of information.

Research Question

To construct a general system for understanding the current situation is a too broad topic to be considered for automation. There are simply too many possible explanations. However, an interesting support function would be to have a capability of recognising if something in particular is possibly occurring, i.e. matching the current input stream with a priori defined templates of interesting situations (where interesting vary depending on the task of the operator and the purpose of the system).

Situation Recognition

To allow for situation recognition to be conducted, we first need to establish relevant symbols for reasoning. What are the basic elements in our situation templates and how do we infer these elements from data. Once these symbols have been established, we can consider a set of possible actions (or events) $A = \{a_1, a_2, \dots, a_n\}$ that can be inferred from our object level data. Now, consider a set of templates $T = \{t_1, t_2, \dots, t_3\}$ that we have defined as interesting. Each template consists of one or more partially ordered actions. During operation, a sequence s (possibly many simultaneous) of actions can be inferred from data and the problem we face is to establish some form of degree d that depicts how well each template matches the sequence s or any sub-sequence s' therein. Depict a hypothesis space $H = \{h_1, h_2, \dots, h_n\}$ where each hypothesis is formed as a triplet (t_i, s', d) . This hypothesis space would possibly grow exponentially for each new action that can be inferred. A number of interesting research questions can now be established:

1. How should we represent templates? Should they include only actions/events or do we also need to

consider different state spaces?

2. How can we efficiently manage the hypothesis space to be suitable for online use?

As we all know, the world is a highly dynamic environment and it is therefore of great interest to investigate solutions that are adaptable, either by themselves or with input from experts and decision makers. This gives rise to two additional questions:

3. How can we generalize/specialize our templates to match the current flow of information?
4. Can we identify any other opportunities for adaptation in such a framework?

Relevance to Information Fusion

Situation assessment is usually depicted to be concerned with estimating relations between various entities. These relations may span from simple similarity measures to more elaborate relations that include for example organizational constraints. To be aware of something however demands more than knowing which relations that hold. It can also require that we reason around what these relations actually mean. This is where situation recognition fits in. It aids in tracking situations over time with the intent of identifying situations that in advance have been classified or marked as interesting. The step after recognizing a situation, naturally, would be to "assess" or estimate the impact of this on our own interests, i.e. impact and threat assessment

The importance of minimizing information overload is also closely connected to the goal of stepping inside your opponents OODA-loop (Observe, Orient, Decide and Act). Another important aspect is however also that the hypothesis space for later impact assessment could become smaller, which is imperative for efficient processing.

Highlights in 2007

Throughout the year, the project has been involved in regular meetings (every 2nd week) with SMW and the other projects in the scenario. These meetings have, according to SMW, spawned many internal projects at SMW with the intent of commercialising research results.

The work on specifying and implementing test scenarios have proceeded as scheduled. The Stage Scenario tool was purchased and is now being used for construction of test data.

Presentations have been held at Fusion07, SAIS07 and SDF07 regarding trajectory clustering in the maritime domain (see results achieved). Also worth mentioning is the participation at the Skövde Workshop on Information Fusion Topics (SWIFT).

Discussions concerning potential collaborations with other projects within the research program have continued during 2007.

Cooperation

Industrial

Saab Microwave Systems AB (SMW) is a company specialized in radar equipment and information networks. The interest from SMW in this project is to further their understanding and services from low-level target specific tools, to an abstraction of the ground-situation in military warfare, as well as during civilian operations. SMW is a part of the Saab Group which also has other branches of which some are concerned with Command & Control (C2) systems, which also is a highly relevant topic in this project.

Scientific

This project is a part of the Ground Situation Awareness scenario where a number of related projects have been defined. Related projects are conducted by the Swedish Defense Research Agency as well as the Swedish Defense. We intend to identify potential collaborative projects.

Approach

A number of scenarios have been identified and are being developed, in collaboration with the related projects and industrial partners. The scenarios range from border-control to full-scale war, and are being developed in that order with the intent of gradually increasing the complexity of the information being processed. The information that is processed is initially considered to be completely certain, e.g. ground-truth, but with an increasing level of uncertainty being included throughout the project to account for the uncertainty of sensing in reality.

Additional initial assumptions in this project are that (1) there are only combatants in the input stream and (2) we have perfect blue-force tracking. These assumptions allow us to only consider adversaries in our initial investigations on situation recognition. Our intent is to gradually remove these assumptions too, in order to resemble reality to a higher degree.

The approach for reaching the long-term goals in this project will be to first handle basic situations, after which more complex situations can be recognized. The main problem is to find algorithms for efficient management of the hypothesis space. Finally, we also intend to investigate how we can adjust our coarse descriptions of what to find, with respect to the current input information.

Contribution to *infofusion* goals

The contribution to the Information Fusion Research Program will mainly be related to the development of algorithms, representations and methods for information fusion processes, or to be more specific, adaptive algorithms for top-down driven recognition of previously established “interesting” situations. We will also contribute to the theoretical framework.

Results achieved in project

During 2007 a paper that investigates the suitability of an algorithm for trajectory clustering in the maritime domain have been presented at the 10th International Conference on Information Fusion (Fusion07). The paper addresses issues related to unsupervised learning and representation of normal behaviour in a costal surveillance scenario.

The project has also, together with the other projects in the ground-situation awareness scenario, contributed on a paper regarding situation analysis and awareness at the Sensor Data Fusion (SDF07) session of Informatik'07 in Bremen, Germany.

A paper describing an AI-based approach for opponent intelligence in real-time gaming has been published and presented at the second international conference on Artificial Intelligence in Interactive Digital Entertainment (AIIDE-06). The paper is concerned with learning and decision making in virtual entities.

Related work

Work related to *Situation Assessment* is highly relevant, as that is the main focus area of this project. The main problem for situation assessment is to infer relations amongst different pieces of information. Hence, the work of A.K. Jain concerning Clustering is highly relevant. Other types of relations can however also be interesting, and in order to find these in complex sets of information the use of *Ontologies* can be fruitful. Therefore, work by Kokar & Matheus, Lambert, Wallenius, Boury-Brisset, and many others, also becomes interesting. Work on *Situation Analysis* (similar to, but more general than situation assessment) by for example Maupin & Joussemme, or Kettani & Roy, is also of great interest for this project.

Work on plan-recognition by for example Gratch & Mao, Carberry, Mulder & Voorbraak and Katuz is also relevant for this project, although with slightly less weight put on actually inferring intent and goals, but to instead recognise if the current situation matches any previously defined interesting patterns for situations – *situation recognition*.

Start: 1 Jan 2006 (5 yrs)

Project: IF gsa1b algorithms**Information fusion algorithms for anomaly detection.**

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Establishing of common operational pictures (COP) is a key to success in achieving information superiority. Situation awareness in a specific area or domain generally requires a complete understanding of all the activities in the surrounding environment. The area of interest may contain a large amount of manoeuvring objects, which generate a huge amount of data collected over time. The vast majority of tracking and surveillance data are associated with routine events and they represent an ambient background which is of no interest to the operator. The concept of anomaly detection, high-lightening unusual behaviours, reduces the information load on the operator and increases the operational efficiency of the system.

Anomaly detection approaches build models of data considered as being normal and then attempts to detect deviations from the normal model in the observed data. Those events considered unusual can be flagged as alerts to cue the human operator. The unusual behaviour, or anomaly, can be anything between a single event, represented by the current state of the object in relation to its environment, through more long-term behaviours described by a specific sequence or set of events.

Research Question

Situation Awareness (SA) is one of the most important aspects for today's and tomorrow's decision makers. Regardless of if the domain is military or civilian the need to be "aware" of the situation is vital to get the advantage over the adversary. SA is therefore a cornerstone to reach information superiority.

In a ground situation scenario there are a large number of objects that have to be detected, tracked and communicated. A Command and Control (C2) system is often used to manage the objects and present them to the decision maker. When the number of objects increases, problems arise for the decision maker. It's hard to get an overview of the situation and to see what's important when the system floods the decision maker with information.

To decrease the amount of information that is presented some kind of filtering is needed. There are numerous techniques to filter the information, for example filtering can be applied on time, space or both. Another way of filtering is to only show information that in some way not is regarded as "normal".

There are several problems to consider with this approach. First we must realize that we deal with very complex situations. With this we mean many objects, many object types, uncertain data (for example due to incomplete sensor coverage) and unknown relations between objects. We also have to consider when in time we have to detect interesting situations. Most preferable is to predict them *before* they actually happen. This is of course very hard to do compared to detecting them *when* they happen, or *after* they have happened.

Additional problems are how to define what's normal, i.e. how to model normal and abnormal

behavior of single objects, and how to model the relations between objects and between objects and the environment. We also need a method to find anomalies in the objects behavior with respect to the models.

Relevance to Information Fusion

Helping to ease the problem with information overload on the user of a decision support system is essential. In this project this is done by focusing on identifying objects that are potentially important based on their behavior and the relation to the environment. One key part in the identification is to incorporate data from a number of sources, i.e. databases, different kinds of sensors and simulations.

Highlights in 2007

In cooperation with Saab Microwave Systems we have performed a project on anomaly detection in video data. In the project two algorithms for modeling normalcy was evaluated with data from a real-world situation. The proposed algorithms were able to find most of the anomalies presented to the system. Anomalies used in the project were for example: people running in areas where people usually walk, pick pocketing and snatching.

In cooperation with Saab Microwave Systems and the other GSA projects we have defined a camp protection scenario with a number of event chains. The idea is to use this scenario as a base when generating data for experiments and algorithm development.

Cooperation

Industrial

This project is in collaboration between Saab Microwave Systems AB and the University of Skövde, as a part of the Information Fusion

Research Program. We have also had meetings with Saab Systems to establish new collaborations.

Scientific

This project is a part of the Ground Situation Awareness (GSA) scenario where a number of related projects has been defined. Related projects are conducted by the Swedish Defense Research Agency as well as the Swedish Defense. We intend identify potential collaborative projects.

Approach

The first objective is to construct a simple simulation environment. This environment will then be used to model a scenario for border control defined by Saab Microwave Systems. Later on we are going to use more advanced scenario generation tools to be able to model the behavior of the objects with a greater detail.

The simulation environment will then be used as a test bed for evaluation of different algorithms for anomaly detection and different ways of modeling normal and abnormal behavior of the objects. We will also use the simulation environment to evaluate performance measurers. The initial simulations will focus on rather simplistic behaviors over time, involving few objects with rather predictable behavior and marginal uncertainty.

The next objective is to extend the algorithms to deal with more unpredictable and complex behavior, including behavior with respect to the behavior of other objects and environmental parameters.

The simulation environment will be used in conjunction with real-world data recorded from various sensor systems.

Contribution to *infofusion* goals

The contribution to the Information Fusion Research program will be mainly be related to the development of algorithms and methods for information fusion processes. We also anticipate contributing to the theoretical framework, since the project involves a case study related to the JDL model. The project also has a commercial potential.

Results achieved in project

A paper called "Finding behavioral anomalies in public areas using video surveillance data" was submitted to the Fusion'08 conference.

Related work

Bomberger et al's work on Associative Learning of Vessel Motion Patterns is closely related to this work. They try to model behavior patterns among vessels. The models are used to find anomalous behavior among the vessels and to predict future vessel locations. The prediction can be used to alert on possible future situations when the vessels behave anomalous. Other related research are the work from Portnoy et al. have done experiments with unsupervised anomaly detection and Kraiman et al. that have worked on a system for automated

anomaly detection processor. There are also a lot of related work done in other areas with detections of novelties, faults, surprises, deviants, temporal change, aberrant behavior and outliers.

Start: 1 Nov 2005 (5 yrs)

Project: IF gsa2 visualization**Information Visualization for Ground Situation Awareness****Tom Ziemke, Professor (tom.ziemke@his.se)****Göran Falkman, PhD (goran.falkman@his.se)****Maria Riveiro, PhD Student (maria.riveiro@his.se)**Skövde Cognition & Artificial Intelligence Lab (SCAI),
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Ground situation analysis is characterised by large amounts of information that typically need to be handled not only by machines, but also visualized for human decision-makers, who typically are under time pressure. Hence, this project mainly concerns the situation level of the JDL model, and in particular the human-computer-interaction aspect. The problem to be studied includes how to present situation analysis information to a user/decision-maker in such a way that it can be effectively assessed and fused in a semi-automatic fashion. The problem domain is typically characterized by the need for rapid decision making and the presence of many different sources of information. This means that a part of the problem is to focus attention on the most important pieces of information. It is also common that a particular situation can be viewed from different perspectives (e.g., information about targets with respect to their geographical position, fuel situation, capability, etc.) depending on which role the user of the system has. The focus of this project is to investigate how semi-automatic means for information fusion can be integrated with automatic means in a resource effective way. This is particularly important when there are limitations on the visualization resources. A further goal is to compare and contrast the effects of availability of different resources in a command center and in the field.

Research Question

The general research question to be studied is how fused situation analysis information can be presented to a user in such a way that it can be assessed and used in a semi-automatic fashion to effectively support decision-making. This includes issues such as:

- Study and development of interaction methods that allow the involvement of the user in the fusion process, data exploration and knowledge discovery (e.g. how to input user's knowledge or experience into the system)
- Visualization of large data sets: patterns, trends, changes over time, outliers, exceptions, anomalies, relationships, correlations, clusters, groups, context, etc.
- Visualization of uncertainty, reliability, completeness and quality of information
- Visualize different levels of abstraction or granularity (in time and space)

Relevance to Information Fusion

Visualization of fused information for human decision-makers is a crucial component of application domains like the ones studied here, where critical decisions need to be taken by humans, often under time pressure. Military applications in a network-centric warfare scenario are a typical example, but this also applies to many types of civilian operations, e.g. dealing with different types of catastrophes.

Highlights in 2007

The PhD student (Riveiro) has finished her research proposal in June 2007 (corresponding to the first 20 credits/weeks of the PhD thesis). She has collected 33p PhD student course credits and 9p more will be finished in the near future. The following is a list of articles published during 2007:

Riveiro, M. 2007. Evaluation of Uncertainty Visualization Techniques for Information Fusion. *Proceedings of the 10th International Conference on Information Fusion*, Québec, Canada, July 9–12, 2007, pp. 1-8.

Riveiro, M. 2007. Cognitive Evaluation of Uncertainty Visualization Methods for Decision Making. *Symposium on Applied Perception in Graphics & Visualization (APGV 2007)*, Tübingen, Germany, July 25-27, pp. 133. ACM SIGGRAPH.

Niklasson, L., Riveiro, M., Johansson, F., Dahlbom, A., Falkman, G., Ziemke, T., Brax, C., Kronhamn, T., Smedberg, M., Warston, H. and Gustavsson, P. 2007. A Unified Situation Analysis Model for Human and Machine Situation Awareness. *Proceedings of the 3rd German Workshop on Sensor Data Fusion: Trends, Solutions, Applications (SDF 2007)*, Bremen, Germany, September 27, 2007.

The PhD student has attended the Fusion 2007 Conference and the APGV Symposium and presented there her work.

Cooperation

Industrial: like the other projects in the GSA scenario, this project is carried out in cooperation with SAAB Microwave Systems AB. Joint meetings are held very regularly, every second week.

Scientific: this project is part of the Ground Situation Awareness scenario where a number of related projects have been defined which will be carried out in close collaboration.

Approach

A number of concrete scenarios, military and civilian, had been developed, in close cooperation with SAAB Microwave Systems (including border control, surveillance of sea areas and intrusion in a military camp). The simulated data is used to test data mining and visualization techniques.

Contribution to *infusion* goals

This project will be able to contribute to the IF research program's common goals by furthering our understanding of the requirements and possibilities of interactive, user- and situation-dependent information fusion visualization at different levels of abstraction. Thus this project will contribute in particular to the common-goals framework project (cg1) that looks at the cognitive constraints on information fusion and its use in decision support, but also indirectly to several other projects in which visualization of fused information for decision-makers is a crucial element.

Results achieved in project

The PhD student started 1 Nov 2005. Regular (bi-weekly) meetings with the industrial partner and with the other projects in the GSA scenario have been held in order to define common research issues and case scenarios. Riveiro's research proposal has been completed in June 2007.

Between the GSA projects a common understanding of the use of and the exact relation between situation awareness and JDL terminology has been developed and published in SDF2007. Regarding the visualization of uncertainty, two publications summarize the work carried out regarding the theoretical evaluation of different methods (*Fusion 2007* and *APGV 2007*).

Preliminary results from the joint project SAIDA (initiated in 2006) have been summarized in three publications (accepted for oral presentation in *SCAI 2008*, Stockholm, and submitted to *Fusion 2008*, Cologne and the *Intl. Conference on Information Visualization*, London, 2008).

Currently, a scenario using a simulation tool, Stage, is being developed. The scenario will be used to test visual analytics methods and techniques that can be applicable in information fusion.

Related work

Exploring, analyzing and finding the relevant information in vast amounts of multidimensional sensor data is a complex task. Data mining techniques can filter and extract valuable patterns. The need to tightly include the human in the exploration process is recognized by many authors (e.g. [1] and [2]). *Visual data mining* focuses on integrating the user in the knowledge discovery process using effective and efficient visualization techniques and interaction capabilities. A classification of visual data mining methods regarding data type, visualization technique and the interaction/distortion technique can be found in [1].

Significant examples of the use of data mining and data visualization can be found in [2].

An emerging research area in the past years is visual analytics. *Visual analytics* is defined as analytical reasoning supported by highly interactive visual interfaces [3]. Contributions in this area integrate information visualization, interaction and computational analysis in order to transform massive data into knowledge. A relevant publication describing the scope of visual analytics is [5]. When the data analyzed is space related, models, methods and tools presented in geovisual analytics [4] are worth considering.

Regarding the visualization of uncertainty the most relevant related work in information fusion was presented by Anne Bisantz in [6]. This project will additionally focus on interactivity of visualization, i.e. giving users the possibility of adapting the mode of visualization actively rather than being passive recipients of visual displays.

Roy et al. presented in [7] a command decision support interface prototype for investigations in computer based situation awareness (SA) and decision support. This project will as well apply recent developments in information display technology to the problem of enhancing SA [8].

[1] D. A. Keim. Information visualization and visual data mining. *IEEE Transactions on Visualization and Computer Graphics*, 7(1):1-8, 2002.

[2] U. Fayyad, G. G. Grinstein, and A. Wierse, Eds., *Information visualization in data mining and knowledge discovery*. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc., 2002.

[3] J. Thomas and K. Cook, Eds., *Illuminating the Path: The Research and Development Agenda for Visual Analytics*. Los Alamitos, CA: IEEE Computer Society, 2005. [Online]. Available: <http://nvac.pnl.gov/agenda.stm>

[4] G. Andrienko, N. Andrienko, P. Jankowski, D. Keim, M. Kraak, A. MacEachren, and S. Wrobel. Geovisual analytics for spatial decision support setting the research agenda," *Journal of Geographical Information Science*, vol. 21, no. 8, pp. 839-857, 2007.

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[6] Bisantz, A. M., R. Finger, Y. Seong and J. Llinas. (1999) *Human Performance and Data Fusion Based Decision Aids*. Proceedings of the FUSION '99 Conference, July, Sunnyvale, 2, 918-925.

[7] Roy, J., Breton R. and Paradis, S. (2001) *Human-computer interface for the study of information fusion concepts in situation analysis and command decision support systems*. Proc. SPIE, 4380, 361-372, Signal Processing, Sensor Fusion, and Target Recognition X, I. Kadar; Ed.

[8] Endsley, M.R. (1995) *Toward a Theory of Situation Awareness in Dynamic Systems*. *Human Factors Journal*, 37(1), 32-64.

Start: 1 November 2006 (5 years)

Project: IF gsa3 hypotheses

Information Fusion for Threat Analysis in the Domain of Ground Situation Awareness

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Superior situation awareness and decision superiority are important concepts in tomorrow's network based defense. To achieve high-level situation awareness, the military decision-makers have to be able to project the current situation into the future, also known as impact assessment. In order for this projection to be sound, it demands processing of all available data. Since military decision-makers often are overwhelmed by the amount and complexity of data, they need decision support systems to help with the computationally hard inference-making task.

This project addresses the high-level information fusion problem of threat analysis, which mainly consists of threat evaluation and weapons allocation. Threat evaluation is an area with a quite small amount of publicly available research results. Weapons allocation has been studied more thoroughly, especially within the field of operations research. However, initial work on threat evaluation shows that in order to compare different threat evaluation algorithms, the following weapons allocation process is of importance.

Research Question

To achieve situation awareness and to make the right decisions are anything but trivial tasks for the human decision-maker. Military situations are complex in nature and the available information will always be uncertain to a high degree. Often the objective is to predict the state of entities or relations between entities and the environment. To infer these states and relations is hard, since many possible hypotheses regarding the future may be consistent with given data and information. Moreover, since new data and information arrive in real-time, new hypotheses must continuously be formed and tested.

Hence, there is a need for dynamic decision support systems, which, in real-time, help the decision-maker with acquiring important information from various sources, combine the uncertain information pieces, form plausible hypotheses, make inferences regarding the present and future situation and to create a situation picture that the decision-maker can use to achieve improved situation awareness and to make the right decisions.

Threat Analysis

Consider a tactical situation where we have a set of defended assets $\mathbf{A} = \{A_1, \dots, A_n\}$ that we are interested in to protect (e.g., friendly forces, bridges, and power plants). There is also a set of air targets $\mathbf{T} = \{T_1, \dots, T_m\}$, which have been detected in the surveillance area. Now, the problem is to, for each target-defended asset pair (T_i, A_j) , where $T_i \in \mathbf{T}$ and $A_j \in \mathbf{A}$, assign a threat value, i.e., to define a function $f: \mathbf{T} \times \mathbf{A} \rightarrow [0, 1]$, assuming threat values between 0 (lowest possible threat value) and 1 (highest possible threat value). Based on the calculated threat values we would like to create a prioritized threat list, going from the most severe threat to the least. This prioritized threat list can later on be used as a basis

for deciding how friendly weapon systems should be allocated to the targets.

From this definition of threat analysis a number of interesting questions follows:

1. What parameters should be the input to the threat value function f ?
2. What should f look like, i.e., what kinds of algorithms are appropriate for threat evaluation?
3. What are the characteristics of different threat value functions and how can algorithms be compared to each other?

Relevance to Information Fusion

In information fusion, one tries to combine data from multiple sources in order to make inferences that may not be possible to do from a single source alone. Low-level fusion typically consists of fusion of multi-sensor data to determine characteristics of an entity. High-level information fusion include situation assessment, i.e., automated reasoning to refine our estimate of a situation, and impact assessment, i.e., projection of the current situation into the future to define alternative hypotheses regarding possible threats or future conditions.

Low-level fusion has been researched for a long time and is quite well understood, but when it comes to high-level information fusion, the research is more immature, with numerous prototypes but only a few operational systems.

Threat evaluation is a part of threat analysis, which in an information fusion context is a central part of impact assessment in the well-known Joint Directories of Laboratories (JDL) data fusion model. Even though threat evaluation obviously is important, few papers have been written on the topic, especially when it comes to systems for automatic or semi-automatic threat evaluation. Threat evaluation is a prerequisite for weapons allocation, a process in which the decision-maker decides on which weapon

system that should be assigned to a certain target. Threat evaluation can also be used to support intelligent sensor management, by allocating more sensor resources to targets with high threat values.

Highlights in 2007

The studies of methods and algorithms for anomaly detection have continued within SAIDA (Situation Awareness using Intelligent Detection of Anomalies), in cooperation with the other projects within the GSA scenario and Saab Microwave Systems. This has resulted in two publications on unsupervised detection of anomalies in a coastal surveillance scenario, where the first was presented at the International Conference on Intelligent Sensors, Sensor Networks and Information Processing 2007 (Melbourne, Australia), and the second will be presented at the 10th Scandinavian Conference on Artificial Intelligence (Stockholm, Sweden).

The project has also been involved in the specification and construction of test scenarios using the STAGE Scenario tool.

Other things worth mentioning are the participation at the Skövde Workshop on Information Fusion Topics (Sweden), a presentation at the Sensor Data Fusion workshop in Bremen (Germany), and participation at the 2nd Advanced Data Analysis and Modeling Summer School (Madrid, Spain).

Cooperation

Industrial

This project is in collaboration between SAAB Microwave Systems AB, Göteborg, and the University of Skövde, as a part of the Information Fusion Research Program.

Scientific

This project is a part of the Ground Situation Awareness (GSA) scenario where five related projects have been defined. Related projects are conducted by the Swedish Defense Research Agency as well as the Swedish Defense.

Approach

In our work in threat analysis, we started out with a literature study on what parameters that have been suggested for threat evaluation, and what kind of algorithms that have been suggested. From this study, we developed a precise description of the threat evaluation problem. The study also resulted in implementations of two threat evaluation systems, based on a Bayesian network and fuzzy inference rules, respectively. Initial comparisons between the two approaches have been made, both on a theoretical and empirical basis. However, we have concluded that in order to make better comparisons, implementation of a weapons allocation system is needed. Study and implementation of the weapons allocation process will be the next step in our work.

Another idea is to make a hybrid of the two approaches to threat evaluation implemented so far, i.e., Bayesian networks and fuzzy logic. One way to

achieve such a hybrid is to create an ensemble of the two approaches, while another is to try to incorporate the use of fuzzy sets in the Bayesian network approach. Reasons for such an approach are to make the construction of the conditional probability tables easier, as well as making the output from the Bayesian network smoother.

Contribution to *infofusion* Goals

The contribution to the Information Fusion Research program will mainly be related to the development of algorithms and methods for information fusion processes. Examples of this can be seen in project collaboration with CGI 2 and GSA 2. The project has also contributed to the development of a situation analysis model for human and machine situation awareness.

Results Achieved in Project

A paper entitled "Implementation and integration of a Bayesian Network for prediction of tactical intention into a ground target simulator" was presented at FUSION 2006. The paper suggests a topology of a Bayesian network for prediction of enemy intent, and addresses the problem of how to find appropriate prior distributions for the Bayesian network. A paper entitled "Detection of vessel anomalies – a Bayesian network approach" was presented at ISSNIP 2007. The same problem is solved using Self-Organizing Maps in the paper "Supporting Maritime Situation Awareness Using Self Organizing Maps and Gaussian Mixture Models". This paper will be presented at SCAI 2008. We have also participated in the work and preparation of "A Unified Situation Analysis Model for Human and Machine Situation Awareness", presented at the SDF 2007 workshop. Additionally, two papers on threat evaluation have been submitted to FUSION 2008 and MDAI 2008.

Related Work

Liebhaber and Feher (2002) have investigated how experienced U.S. Navy officers perform threat evaluation on air targets. Their research indicated that humans use templates for such assessments. In their study a number of important parameters for threat evaluation can be found.

In Okello and Thoms (2003), a Bayesian network based algorithm using target state estimates for evaluation of the threat posed by a target on a defended asset is presented. Another graphical model is implemented by Benavoli *et al.* (2007). In their approach, an evidential network (i.e., a valuation-based network using belief functions) is used to represent and reason about threat in the context of air surveillance. A threat evaluation system using fuzzy inference rules is described by Liang (2006). To our knowledge, it does not exist any work where a comparison between Bayesian networks and fuzzy inference rules has been done, from a threat evaluation perspective.

Scenario: IF bio - Bioinformatics
**An IF Approach to
 Understanding Complex Biological Systems**

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The goal of the research in the bioinformatics scenario is to develop and apply information fusion (IF) methods in an applied research scenario where the aim is to increase our understanding of the role of genes in diseases and thereby facilitate the research on new drugs to treat or cure these diseases. A systems biology approach is adopted to fuse information from biological databases, simulations and gene expression profiles to synergistically increase our knowledge. Computational linguistics techniques are used as an additional resource in analyzing and fusing biological data. This scenario brings together research in the bioinformatics, molecular biology and computational linguistics research groups, in a larger research collaboration under the heading "systems biology". The scenario includes four projects which involve five senior researchers, one post-doc and one PhD student. The student is fully financed within the IF (IF) profile and expected to complete the degree within the time-frame of the profile. Three industry partners are involved in the scenario, including two software-oriented companies (InNnetics AB and Lexware AB) and one biotech company (Cellartis AB) specialising in stem cell applications.

Research Question

The general goal in the bioinformatics scenario is to develop and apply IF methods for bioinformatics and systems biology. The scientific area in which the methods are applied and evaluated concerns the role of genes in diseases and the gathering of knowledge which enables future development of new pharmaceutical drugs to treat and cure diseases. Within this general area, five related research questions are being (or have been, in two cases) addressed in the projects in this scenario:

- 1) *Can the application of an IF approach enhance our understanding of how the differentiation of stem cells into different cell types is controlled by gene regulation?* This question is being addressed in the project **IF bio1 cells**, where the hypothesis underlying the research is that IF is useful for integrative analysis of data from many different biological experiments and for designing follow-up experiments to test specific biological hypotheses.
- 2) *Can IF-based approaches for mathematical modelling be developed and applied to the modelling of the regulatory mechanisms involved in lipid-digestion?* This question was addressed in **IF bio2 lipids**, where the aim was to fuse information from biological experiments, databases and simulations to derive a model of lipid digestion. The model was used as a basis for designing experiments on a candidate treatment to correct nutritional problems related to lipid digestion and absorption.
- 3) *Can information extraction by automated text analysis be integrated as part of a method for biomedical IF?* This question is being addressed in **IF bio 3 extract**, where natural language processing techniques are adapted to the biomedical literature

domain and integrated with data mining techniques in order to form an integrated part of an IF process.

4) *Can IF methods and algorithms support the research process for development of drug targets and for drug discovery in a pharmaceutical R&D company?* This question was addressed in **IF bio 4 ModPharm**, where various algorithms were developed to fuse data from different biological experiments with previous knowledge (stored in databases), and thereby to derive sets of biologically plausible hypotheses to be used in the design of further biological experiments.

5) *Can IF methods and algorithms be used to simulate and understand the behavior of biological systems?* This question is being addressed in **IF bio 5 simSoft**, where new modules and methods are being added to an existing software (PathwayLab) to enhance its ability to integrate data from different abstraction levels of different biologic processes.

Relevance to Information Fusion

The research and development of new therapeutics carried out both in academia and by biotechnology and pharmaceutical industry is of immense importance for our health and well-being. This research process is, however, extremely time consuming and costly, and requires the organization and analysis of huge amounts of data from various experiments. Hence, this is potentially a very fruitful new area for application of IF approaches, as well as for the development of new IF methods. In the projects carried out within this scenario, we are developing and applying such methods as automated information retrieval and information extraction from scientific text, data mining in experimental data sets and biological databases, mathematical and

statistical modeling, and several others, in order to support the large-scale analysis of genes, proteins and metabolic and regulatory pathways. The aim is to show that IF is useful for integration of the various data sets and analysis methods, and that it helps us to reach new insights about the biological systems being studied. The scenario is thereby both a test-bed for existing IF methods and an arena for development of new methods.

Highlights in 2007

- Two journal articles published (in *Journal of Biotechnology* and in *International Journal of Bioinformatics Research and Applications*).
- Conference papers published in the proceedings of the conferences SMC 2007, MCCMB 2007, EvoComp 2007 and BIRD 2007.
- Poster presented at the conference ICSSR 2007.
- Initial biological experiments completed in **IF bio 1 cells**, followed by application of IF techniques to identify reference genes and putative key regulatory genes.
- Termination of project **IF bio 2 lipids**.
- Text analysis technique successfully extended and adapted to biomedical domain in project **IF bio3 extract**.
- Project **IF bio4 modPharm** completed.
- New project IF bio SimSoft initiated in collaboration with researchers at Fraunhofer-Chalmers Institute for Industrial Mathematics established and the industry partner InNetics AB.

Projects within scenario IF bio

IF bio1 cells
 IF bio3 info extract
 IF bio 5 SimSoft

Industrial cooperation

Three companies are involved: Cellartis AB, Lexware labs, and InNetics AB. The role of Cellartis is to provide experimental data from model systems, assist with biomedical expertise, and to provide the biomedical research context in which our IF methods are being evaluated. Lexware and InNetics are software companies and therefore interested in developing tools based on the new methods and algorithms that result from the projects in this scenario. Other companies within the biomedical and biotechnology industry are potential partners.

Scientific cooperation

In **IF bio1 cells**, collaboration takes place with the research group of professor Anders Lindahl, at Sahlgrenska Akademien and Göteborg University. During the now completed project IF bio4 modPharm, collaboration was initiated with the group of Mats Jirstrand at the foundation Fraunhofer-Chalmers Center for Industrial Mathematics, which has now resulted in the new project IF bio5 simSoft. In addition, strategic alliances have been established in order to generate

large scale gene expression profiles based on different animal model systems.

Approach

A highly novel aspect of this scenario is that the concept of IF is applied in the domain of biomedical research. This is done by developing new data mining algorithms which integrate various forms of experimental data, and which are also integrated with other forms of data mining algorithms. A key aspect is also that background knowledge from the domain is being considered in the data mining process. Furthermore, the results of the analysis are conceptualised in the form of models, which are used to guide the design of further biological experiments, so that a feedback loop is created. With the new project IF bio 5 SimSoft a larger effort is also initiated in developing methods for modelling, including parameter estimation techniques tuned to the peculiarities of biomedical data.

Contribution to infofusion goals

The scenario mainly contributes with new algorithms and methods and a set of highly relevant application problems for IF in the biomedical domain. To some extent, it also contributes to the development of the theoretic framework. In addition, the scenario may also contribute to the infrastructure aspect of IF, for example by making tools for automated text analysis available for all participating projects.

Results achieved in project

In project **IF bio1 cells** the first stage was to establish reliable reference genes to be used as controls in the subsequent experiments. Since the results suggested that hESCs have a unique signature of reference genes, which can be used as controls in microarray analysis of differentiation, the findings were considered of general interest, and were therefore published in the internationally top-ranked journal *Stem Cells*. The next stage in the project addressed the question of finding genes important for coaxing hESCs to differentiate towards cardiomyocytes, which was addressed by applying data mining techniques to analyse gene expression data collected from cells differentiated under two different protocols. This analysis resulted in identification of a set of 500 heart-related genes, which were subsequently clustered to identify groups of genes with similar gene expression patterns. We published these results in *Journal of Biotechnology*. The results also provide clues for the design of follow-up experiments, thus contributing to process refinement, as described in level 4 of the JDL model. To bring structure into the IF processes in this project we examined the usability of the JDL data fusion model in bioinformatics in general and in stem cell differentiation in particular. Inspired by Steinberg and co-workers who have tried to make the JDL model more general and less focused on military applications, we made a mapping of the

model to our domain. The results from this work were presented at the *Conference on Systems, Man and Cybernetics*. In our on-going work we have also tried to use this model as a framework for categorization of fusion-related functions.

In project **IF bio2 lipids** the initial analysis of experimental time-course data identified some of the key players in the regulation of long-chain fatty acid metabolism. This unique data set facilitates an analysis aimed at disentangling most of the conflicting data published in the field so far, and it provided the basis for a manuscript which was submitted during the spring of 2007. Subsequently, a tentative mathematical model of long-chain fatty acid metabolism was developed by fusing in-house experimental data with data that had already been published. The derived mathematical model was used as a basis for designing two experimental model systems aiming to monitor the flow of long-chain fatty acids from the intestinal lumen to the enterocytes. The same scientific question was also addressed by using a complementary *in vitro* model system (using specific cell types), which resulted in data sets that must be analyzed in an integrative manner, which again provides a situation where an IF approach is extremely useful.

In **IF bio3 extract** the initial work consisted of adapting a grammar-based algorithm for automated text analysis to the biomedical domain. The first step was to evaluate the ability of the existing algorithm to handle biomedical texts by applying it on a large corpus of texts from PubMed. The results were detailed in a paper presented at the Fusion 2006 conference. Work was also done on complementing the text analysis system in such a way that it can produce pathway maps showing the relations between biological objects which have been derived from the text analysis. A prototype system was implemented that outputs pathway maps corresponding to an established representation formalism, thus providing an output that is both meaningful and easy to evaluate for the biologist. This prototype system was presented at the international workshop DILS 2006 and in an article in *Journal of Bioinformatics and Computational Biology*. During 2007, we initiated an effort to integrate the text analysis system with the pathway alignment algorithms developed in IF bio 4 modPharm. The aim is that a user of the integrated system should be able to apply text analysis to corpora for two related organisms, and use comparative pathway analysis to refine the sets of inferred pathways

The project **IF bio 4 modPharm** was a three-year project running from March 2004 to March 2007. The project resulted in the development of three new methods for data mining in the biomedical domain, which all involve aspects of IF. The method GOTEM (Gene Ontology-based regulatory TEMplates) is a tool that enables the researcher in a data mining situation to distinguish biologically plausible data mining results from non-plausible

ones. Here, the IF aspect is that the method allows systematic fusion of experimental data with background knowledge. The GOTEM method was described in a paper presented at the conference ICCS 2006, and was also the subject of a provisional patent granted by the US Patent Office. The second new method, GOSAP (Gene Ontology-based Semantic Alignment of biological Pathways), is used to align biological pathways from different species to find evolutionarily preserved similarities between regulatory, metabolic and other biological pathways, across different species. The fusion process in this case involves five different data sources (two pathway databases, two sets of gene annotations and the Gene Ontology hierarchy of annotation terms). GOSAP was described in an article published in *International Journal of Bioinformatics Research and Applications*. The third new method that resulted from the project uses a combination of statistical path analysis, parameter fitting by hill-climbing and an evolutionary algorithm to search for pathway diagrams, using two different data sources as input. This method forms part of a feedback loop that includes biological experiments, data mining, data and IF, and follow-up experiments. The method was described in a paper presented at the conference MCCMB 2007.

Related work

It can be argued that bioinformatics is an ideal domain for the application of IF approaches, since it is a very common situation in bioinformatics research that an analysis must be based on heterogeneous sets of data derived by different experimental techniques, and often reflecting different aspects of the system that is being studied. It is also common that the analysis results in models or hypotheses that are used as a basis for designing new experiments. During 2007, we have written a review paper covering a broad spectrum of examples of IF methods in bioinformatics, and submitted the manuscript to the conference Fusion 2008.

Growth Potential for Scenario

The bioinformatics IF scenario coincides quite well with the establishment of systems biology as one of the core research areas which are being prioritized by the University. The participation of the bioinformatics group in the systems biology environment opens many opportunities for closer collaborations with our colleagues from biomedicine, molecular biology and ecology, and facilitates access to their datasets and research questions, which provides important application examples for IF-based bioinformatics. Also the collaborations with the partner companies have a potential for growth, and discussions are currently going on with one of the companies regarding a concrete proposal for expansion of their involvement in the programme. In general, formation fusion is a useful approach in many bioinformatic application areas besides those where we are currently engaged. One

example is the application of bioinformatics in cancer genetics, where we currently have collaborations outside of the IF profile and where there is a great potential for application of IF techniques, since there is often a need for combining data from different experiments and of different types (for example data on the genetic background, various forms of clinical data, risk factor data, follow-up data recorded during treatment, etc). We have recently initiated discussions on a possible expansion of the scenario which would involve researchers in biomedicine and a partner hospital and/or company, with the goal of applying IF-based bioinformatic techniques to study the developmental pathways of endometrial cancer tumours.

Publications from the scenario

- Dura, Gawronska, Erlendsson and Olsson (2006) Towards IF in Pathway Evaluation: Encoding of Biological Relations in Research Articles. *Proceedings of the 9th International Conference on IF (FUSION 2006)*.
- Gamalielsson, Nilsson and Olsson (2006) A GO-based Method for Assessing the Biological Plausibility of Regulatory Hypotheses. *Proceedings of ICCS 2006: 6th International Conference on Computational Science*, LNCS 3992: 879-886. Springer-Verlag.
- Gamalielsson and Olsson (in press) GOSAP: Gene Ontology-based Semantic Alignment of Biological Pathways. *International Journal of Bioinformatics Research and Applications*, 4(2).
- Gamalielsson and Olsson (2007) EGOSAP: Evolutionary Gene Ontology-Based Semantic Alignment of Biological Pathways. *Proceedings of the Moscow Conference on Computational Molecular Biology*.
- Gawronska, Erlendsson and Olsson (2005) Tracking biological relations in texts: a Referent Grammar based approach. *Proceedings of the workshop 'Biomedical Ontologies and Text Processing,' at the 4th European Conference on Computational Biology (ECCB05)*, 15-22.
- Gawronska, Erlendsson and Olsson (2006) Towards an Automated Analysis of Biomedical Abstracts. *Proceedings of the 3rd International Workshop on Data Integration in the Life Sciences*.
- Gawronska, Olsson and De Vin (2004) Natural Language Technology in Multi-Source IF. In *Proceedings of the International IPSI-2004k Conference*.
- Laurio, Gamalielsson, Svensson, Jirstrand and Olsson (2007) Evolutionary search for improved path diagrams. *Evolutionary Computation, Machine Learning and Data Mining in Bioinformatics, 5th European Conference*. LNCS 4447: 114-121. Springer-Verlag.
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- Olsson, Gawronska, Erlendsson, Lindlöf and Dura (2006) Automated text analysis of biomedical abstracts applied to the extraction of signaling pathways involved in plant cold-adaptation. *Proceedings of the Fifth International Conference on Bioinformatics of Genome Regulation and Structure*, vol. 3, 296-299.
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- Synnergren, Adak, Englund, Giesler, Noaksson, Lindahl, Nilsson, Nelson, Abbot, Olsson and Sartipy (2008) Cardiomyogenic gene expression profiling of differentiating human embryonic stem cells. *Journal of Biotechnology*, 134: 162-170.
- Synnergren, Gamalielsson and Olsson (2007) Mapping of the JDL Data Fusion Model to Bioinformatics. *Proceedings of Systems, Man and Cybernetics 2007*. p. 1506-1511. IEEE Press.
- Synnergren, Giesler, Adak, Tandon, Noaksson, Lindahl, Nilsson, Nelson, Olsson, Englund, Abbot and Sartipy (2007) Differentiating human embryonic stem cells express a unique housekeeping gene signature. *Stem Cells*, 25: 473-480.
- Synnergren, Åkesson, Dahlenborg, Ameen, Steel, Lindahl, Olsson and Sartipy (to appear) Molecular signature of cardiomyocyte clusters derived from human embryonic stem cells. *Stem Cells*.

Start: 1 Apr 2005 (5 yrs)

Project: IF bio1 cells***An Information Fusion Approach to Identify Genes and Molecular Pathways Critical for Differentiation of Human Embryonic Stem Cells***

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This project is a collaboration between University of Skövde and Cellartis AB, a company specialized in human embryonic stem cell technologies. The company provides the human embryonic stem cell (hESC) lines, laboratory facilities and wet-lab experimental results that are used in the project. The main focus of the project is to apply an Information Fusion (IF) approach to various types of experimental data to identify genes involved in molecular pathways important for directing hESCs into various specialized cell types and to use results from the data analysis as a basis when making decisions on the design of new experiments. To understand the on-going activity in a cell it is critical to monitor the cell at different molecular levels. Large amounts of data from different abstraction levels are being generated and the challenge is to merge these data into a common understanding of the molecular activities in the cell. Gene expression profiles from hESCs in different differentiation stages are being analysed to identify significantly over- and under-expressed genes, with the purpose of finding genes that are crucial for directing stem cells into specialized cell types. The first stage of the project focused on identifying reliable reference genes for this particular cell type. This has been carried out successfully and results are documented in a manuscript, which was recently accepted for publication in the journal *Stem Cells*. At present the major efforts in the project are concentrated on finding key genes responsible for deciding the fate of the cells at various stages during differentiation towards functional cell types such as cardiomyocytes and hepatocytes. This requires results from repeated extensive experiments and some of these were conducted and analyzed during 2007. Interesting results from the analysis were published in two articles (in *Journal of Biotechnology* and *Stem Cells*).

Research Question

The main question being addressed is *Can the application of an IF approach enhance our understanding of how the differentiation of stem cells into different cell types is controlled by gene regulation?* During this project we concentrate the work to two functional cell types, cardiomyocytes and hepatocytes. The long-term goal, however, is to develop general methods for identifying genes critical in the stem cell differentiation process. The envisioned method includes biological experiments, data mining, integrating inferences from different data sources, and using analysis results to design follow-up experiments.

Relevance to Information Fusion

The project extends the application of the JDL IF model to the domain of bioinformatics. Of relevance to the IF research program is also that new algorithms and methods are developed for IF processes suitable for integration of data from different abstraction levels of the cell, and for using the results of the analysis when making decisions on the design of follow-up experiments.

Highlights in 2007

- Acceptance of second manuscript for publication in *Journal of Biotechnology*.
- Mapping of the JDL data fusion model to bioinformatics, which was presented in a paper at

the *Conference on Systems Man and Cybernetic*, Oct 7-10 2007 in Montreal, Canada.

- An oral presentation as well as a poster presentation of the project at *The Heart-Repair meeting* – an EU project in the 6th frame program.
- Presentation of the project by a poster at ISSCR 2007 – the annual meeting of the International Society for Stem Cell Research.
- Identification of the *human-cardiac EGF* pathway as up-regulated in our datasets, which demonstrated that this pathway is activated during differentiation towards the cardiac lineage. We presented these results at the *First International Symposium on Human Embryonic Stem Cell Research* in February 2008.
- Genetic characterization of cardiomyocytes (one type of heart muscle cells) derived from human embryonic stem cells using gene expression data, real-time RT-PCR data, data from immunohistochemistry and annotational data from various databases.
- Submission of a third journal manuscript for publication in *Stem Cells*.

Cooperation

The project is a collaboration between University of Skövde and Cellartis AB (co-financing industrial partner). Collaborations have also been established with Sahlgrenska Akademien (supervision of the PhD student) and General Electric Healthcare Inc. (access to microarray experiments). Through the collaboration partners of Cellartis we have also

established contacts with a number of universities and research groups both nationally (Karolinska Institutet, KI) and internationally that have both experience and interest in stem cell differentiation.

Approach

The phenotype of a cell is dependent on the protein production in the cell, which in turn is dependent on the mRNA transcription. All these three levels must therefore be monitored to gain an understanding of their dependencies, i.e. how stimulation at the transcriptional level affects the resulting phenotype. We have applied and adapted the JDL IF model to this domain as a supporting model of merging the information. Most of the activities included in the JDL IF model could be identified in the project. For example, the questions of what objects we have in this domain (object refinement) and how the relationships between observations can be understood (situation refinement) were translated into the questions of which genes and proteins are involved in the differentiation process and how these interact and regulate the expression of each other. For example, it is vitally important in this project to identify transcription factor proteins which regulate the transcription of their target genes. By screening the promoter regions of co-expressed genes for common binding sites we have identified 27 putative binding sites that may be involved in cardiomyocyte differentiation. By combining data from the Transfac database, we have identified several important proteins that bind to these sites. A full understanding of stem cell differentiation involves identification of several hundreds of genes and proteins, which form complex patterns of interaction in various regulatory pathways. Examination of cell samples harvested under different stages in the differentiation process resulted in putative sets of genes important at various time points during development of cardiomyocytes. Examples of such genes are MYH6, MYH7, SMPX, TNNI1, and PLN. Interestingly, these genes show 2000-3000 times higher expression in cardiomyocyte-like cells than in undifferentiated stem cells, and are therefore defined as marker genes in cardiomyocytes.

Contribution to *infusion* goals

The main contribution is that the project shows how the concept of information fusion is useful in a bioinformatics scenario. This is being done by applying and adapting the JDL IF model to this domain as a supporting model for how to handle the numerous data sources used in the project. Most of the levels and activities of the JDL IF model could be identified in the project.

Results achieved in project

The first stage of the project was to establish reliable reference genes to be used as controls in the subsequent experiments. This was necessary since we are entering new ground in this project, where the reference genes that are “traditionally” used in

microarray gene expression studies may not be useful. For this purpose, an extensive microarray data set was generated and in the analysis we were able to identify a novel set of reference genes that are stably expressed in undifferentiated and early differentiated hESCs. We published our results from this stage in the journal *Stem Cells* (Synnergren et al., 2007).

The second stage in the project addressed the question of finding genes important for coaxing hESCs to differentiate towards cardiomyocytes. This corresponds to level 1 in the JDL IF model, i.e. the identification of relevant objects in the domain. Microarray data from hESCs that were differentiated using two different protocols were investigated. Data from three different time points during the maturation process were sampled for each protocol. The relevant objects identified by this analysis consist of approximately 500 heart-related genes, which were selected for intrinsic analysis. The genes were clustered to identify groups with similar gene expression patterns, which revealed sets of genes with very interesting expression patterns, e.g. groups that were up-regulated when using the protocol which gave beating colonies of cells and down-regulated when using the other protocol. We published these results in *Journal of Biotechnology* (Synnergren et al., 2008). The results also provide clues for the design of follow-up experiments, thus contributing to process refinement, as described in level 4 of the JDL model.

To bring structure into the IF processes in this project we examined the usability of the JDL data fusion model in bioinformatics in general and in stem cell differentiation in particular. Inspired by Steinberg and co-workers who have tried to make the JDL model more general and less focused on military applications, we made a mapping of the model to our domain. By using this model we believe that we more easily can identify IF problems in our problem domain. It is highly probable that we can utilize algorithms and methods already developed for a typical IF problem for solving similar problems in the bioinformatic domain. For each level in the model we have identified relevant bioinformatics problems that could be characterized according to each category in the model. Our conclusion from this work is that the model is general enough to apply to problems within the bioinformatics domain. The results from this work were presented at the *Conference on Systems, Man and Cybernetics*. In our on-going work we have also tried to use this model as a framework for categorization of fusion-related functions.

Related work

To place our own approach into context and compare with others, we have written and submitted a review of IF methods in bioinformatics. The manuscript is currently being reviewed for the FUSION 2008 conference.

Start: 1 Jul 2005 (5 yrs)

Project: IF bio2 lipids***An Information Fusion Approach to Understanding Complex Biological Systems – a Systems Biology view of lipid digestion and absorption.***

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This project was a collaboration between University of Skövde and Arexis AB, which is a pharmaceutical company specializing in developing new and effective therapeutics in the areas of metabolism and inflammation. An information fusion approach was proposed to increase our understanding of the role of genes in diseases in order to increase the ability to produce new drugs to treat or cure diseases associated with pancreatic insufficiency. Quantitative and qualitative data from large scale gene expression profiles was collected to be fused with information available in different biological databases and then used in mathematical models to provide not only a mechanistic explanation at the molecular level but also a comprehensive understanding at the physiological level of lipid digestion and absorption.

Research Question

Can we develop and implement methods for mathematical modeling and information fusion of lipid digestion and absorption as an aid to investigate the biological operability of bile-salt stimulated (BSSL)-replacement therapy to correct nutritional problems?

valuable time course data for the development of a more robust mathematical model. The insight from these studies provided the basis for future and more extensive large scale experiments and the development of at least two unique experimental model systems.

Relevance to Information Fusion

The development of new effective drugs and therapeutics is a time consuming and costly project. Hence, there is a need for new approaches which enable researcher to shorten the time it takes from drug discovery to market penetration of the drug. An information fusion based approach is fruitful tool to accomplish this objective. The importance of this project is also highlighted by the need for more effective therapeutics against pancreatic insufficiency.

Cooperation**Industrial**

This project was a collaboration between Arexis AB and the University of Skövde, as a part of the Information Fusion Research Program. During the time period of this project, Arexis AB was acquired by Biovitrum who terminated their engagement in the project.

Scientific

This project was a part of the Bioinformatics scenario where a number of related projects have been defined. Related projects are conducted by Cellartis AB as well as Lexware AB. The goal of the research in the bioinformatics scenario is to increase our understanding of the role of genes in diseases in order to increase the ability to produce new drugs to treat or cure these diseases. A systems biology approach was planned to be adopted to fuse information from biological databases, simulations and gene expression profiles to synergistically increase our knowledge.

Highlights

An experimental system for measuring gene expression in enterocytes of the mouse small intestine have been developed. This method is based on isolation of transcript from intestinal enterocytes and quantitative real-time PCR.

Based on the data obtained from these experiments, a comprehensive model has been developed in order to capture the flow of lipids from the intestinal lumen to the assembly of chylomicrons and high density lipoproteins (HDL) inside the enterocytes. Experimentally, we have tried to identify the key players involved in regulation of this process by using feeding and re-feeding experiments in a mouse model system and intestinal samples were collected at different time points. This data set constituted a minor milestone in the project as it provided

Approach

The first objective was to document and validate two animal models, a mouse model and a pig model. These models would constitute the basis for generating quantitative and qualitative large scale

gene expression profiling data in a time-dependent manner.

Qualitative and quantitative data from large scale gene expression profiling experiments provided mechanistic and molecular details. A second objective was to fuse these data with information available in different biological databases and use the fuse data in mathematical models in order to be able to identify and explain regulatory mechanisms involved in lipid digestion.

Such an understanding is fundamental and a key issue to establishing the clinical effect of recombinant BSSL versus a negative control but also to benchmark recombinant BSSL against competitive therapeutics on the market.

As the research activities of the partner, Arexis AB, was terminated by Biovitrum all objectives in this study could not be reached.

Contribution to *infofusion* goals

The contribution to the Information Fusion Research program was proposed to be mainly related to the development of algorithms and methods for information fusion processes. We also anticipated contributing to the theoretical framework, since the project involves a case study related to the JDL model. The project also had a commercial potential.

Results achieved in project

- Established gene expression time course data of key players in lipid absorption in the small intestine. This data set is unique as it emerges from purified enterocytes and not from whole tissue biopsies and has the potential to disentangle most of conflicting data published in the field so far. The data provides the basis for a first publication which is planned to be submitted during spring 2008.
- A tentative mathematical model of long-chain fatty acid metabolism has been developed based on our own data and data already published. The primary objective of this model is to understand how different key players contribute, individually or together, to the formation of chylomicrons. A further goal is to identify new actors involved in this process.
- Design of two experimental model systems aiming to monitor the flow of long-chain fatty acids from the intestinal lumen to the enterocytes. In one of the experiments, we will use a closed *in vivo* (using whole tissue) intestinal model system to measure transport of specific radiolabeled fatty acids into the enterocytes. This is a key issue that needs to be solved in order to understand

the role of the regulators involved in the formation of chylomicrons. The same scientific question will be addressed by using a complementary *in vitro* (using specific cell types) model system. Also in these experiments, radiolabeled fatty acids will be used to study the uptake of specific fatty acids by enterocytes.

Start: 1 Apr 2005 (5 yrs)

Project: IF bio3 info extract***Text Mining and Text Analysis as a Tool in Information Fusion***

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This project is a collaboration between University of Skövde and LexwareLabs AB, a company specialized in programming for logistics, information retrieval, information extraction, and language technology. The company provides large corpora, corpus building tools, and concordance tools that are used in the project. The long-term goal of the project is to contribute to Information Fusion (IF) in the domain of biology, biomedicine, and bioinformatics by providing a toolkit for domain-specific literature search. The results of text analysis will be compatible with the format of data representation in international pathway databases, and thus enable more extensive and more detailed data mining. This will facilitate decisions on the design of new experiments. The first stage of the project included a corpus-based comparison between general English and the specialized language of biomedicine, comparing different part-of-speech taggers with respect to their efficiency in processing biological texts, and development of domain-specific versions of a tagger and a syntactic parser. The results have been documented in several publications and presented at international conferences.

Research Question

What are the main syntactic, lexical, and textual differences between Language for General Purpose (LGP) and Language for Special Purpose (LSP), in this case, the language of biology and biomedicine? How should language technology tools for LGP be modified for the purpose of LSP-processing?. Which techniques are most suitable for term extraction from large specialized corpora? How should the results of linguistic analysis be transformed into representations that are compatible with object and relation representations in biological databases?

Relevance to Information Fusion

The long-term goal of the research is to incorporate linguistic text analysis into a system for evaluation of biological pathways based on information fusion. Relations extracted from biomedical texts are thought to be compared with pathways encoded in existing specialized databases. In this way, the biologist conclusions regarding the plausibility and/or novelty of a certain relation between genes, proteins etc. would be supported by fused information from biological databases and biological literature. The main assumption underlying the research is that this decision support cannot be successful, unless the information encoded in natural language texts is taken into consideration in the fusion process that generates the decision support.

Highlights in 2007

- A large corpus of biomedical texts collected in 2006 has been divided into specific subdomains (human genetics, animal genetics, cancer research. The corpus is available for searching by different statistical measures (T-score, Z-score, MI, maximum MI, Chi-square test, etc.) at <http://bergelmir.iki.his.se/culler>
- the prototype tagger and parser for deep text analysis developed in 2006 has been implemented in C++ and tested
- a book chapter documenting the work on information extraction from biological texts has been accepted for publication
- The work on the project has been presented at a number of conferences, seminars, and meetings.

Cooperation

Industrial: The project is collaboration between University of Skövde and LexwareLabs AB (co-financing industrial partner).

Scientific: Contacts are established with departments of bioinformatics in Göteborg and Uppsala. We also have a continuous cooperation with the System Biology Research Group in Skövde. Furthermore, we are a part of the Gene Discovery Network (a cooperation between Skövde, Göteborg, and Uppsala)

Approach

The language study is goal-oriented and usage-based. We investigate real language data using very large corpora and different statistical measures. On

this basis, and on the basis of our knowledge of theoretical linguistics, we design, implement, and evaluate specialized tools for term extractions, intelligent text search, and text-to-graph-conversion.

Contribution to *infusion* goals

The main contribution lies in that the project will show how the information coded in natural language texts can be extracted, formalized, and employed for the purpose of Information Fusion along with the information stored in specialized databases. The methods for specialized natural language processing will, as we hope, not be restricted to bioinformatics; we also aim on a general methodology for adapting LGP-tools to different technical and scientific domains.

Results achieved in project

In: Dura, E. and Gawronska, B. (2007) *Novelty Extraction from Special and Parallel Corpora*. In: Proceedings of 3rd Language & Technology Conference 2007, 305-309. Adam Mickiewicz University, Poznan, Poland. ISBN 978-83-7177-407-2 we show how domain specific terms and novel terms can be extracted from large corpora and utilized in domain-specific dictionaries and ontologies. In Gawronska, B. (to appear): *Objects and relations in the world of microbiology: information extraction from biological texts* the problem of syntactic and semantic ambiguity is addressed, and algorithms for resolving certain cases of ambiguity are proposed. We also present and discuss the current implementation of the syntactic analyser. For the time being we can conclude that:

- a rule-based information extraction system relying on syntactic and semantic knowledge can in fact be quite fast and robust approaches to text understanding
- general linguistic knowledge should, be combined with corpus studies during the development of the system
- it is important to gain knowledge about the language of a particular domain and gather most frequent collocational and syntactic patterns from a domain-specific corpus.

Related work

Information overload in the field of bioinformatics is a generally acknowledged difficulty, discussed in scientific literature. Many serious attempts to overcome it, are in progress. A very informative survey of the area is presented in Hirschman et al. 2002: Accomplishment and challenges in literature data mining for biology. In *Bioinformatics*, Vol. 18(12):1553-1561.

The large medical literature databases MedLine and PubMed provide access to electronic medical lexicons, encyclopaedias, document retrieval systems, and a limited possibility of automatic

query answering. Still, there are several serious problems to cope with, especially the shortage of integration tools. Specialized databases and literature are available in electronic form, but there are not enough tools for fusion of information coming from these sources. There is also a need for developing an ontology of different kinds of relationship. Several authors, e.g. Pustejovsky, Ding, and Park, stress the need of employing grammatical and semantic analysis in processing of biological texts. Statistical text retrieval and text mining devices can inform the researcher that there seems to be some relation between e.g. a gene and a disease, but in most cases they do not specify what kind of relation it is. Systems like MedScan and GENIES aim at more sophisticated relation extraction, but there is a need of incorporating more linguistic knowledge to avoid wrong term segmentation and inadequate sentence interpretation.

Start: 1 Mar 2004 (3 yrs)

Project: IF bio4 modPharm**Model-based Data Mining as Support for Pharmaceutical Research Focused on Disease Models and Drug Discovery****Björn Olsson, Associate Professor (bjorn.olsson@his.se)****Patric Nilsson, Associate Professor (patric.nilsson@his.se)****Kim Laurio, PhD Student (kim.laurio@his.se)****Jonas Gamalielsson, PhD student (jonas.gamalielsson@his.se)**Bioinformatics and Systems Biology Research Groups,
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This project was a collaboration between University of Skövde, Biovitrum AB and InNetics AB. These partner companies specialize in pharmaceutical drug development and software for molecular modelling, respectively. The purpose of the project was to develop and refine model-based data mining techniques that can support the knowledge discovery process in the study of disease biology. In particular there is a need for new and improved techniques for the integration and utilization of already existing knowledge, in the form of experimentally verified facts and hypothetical models about biological processes, to improve the researcher's ability to judge the significance and relevance of findings, both from experimental and theoretical studies. The results of the project included four new methods for model-based data mining. One of these methods was presented at the 2006 International Conference on Computational Science and also resulted in a provisional patent granted by the US Patent Office. The other three methods were published in a journal article and two conference papers. The project started in March 2004, had funding for three years, and ended in March 2007, in accordance with the plan.

Research Question

The main research question in this project was: *Can information fusion methods and algorithms support the research process for development of drug targets and for drug discovery in a pharmaceutical R&D company?* The model-based approach adopted in the project was a data mining process that makes use of already existing knowledge (i.e. models of the biological system under study) to guide the data mining process. This required the development of algorithms that can fuse information derived from experimental data with information encoded in the models representing previous knowledge.

Relevance to Information Fusion

The project concerned the development of new algorithms, which can be seen as examples of the usefulness of the IF concept in the domain of bioinformatics. Some of the methods that were developed are also quite general, and can be applied outside the area of bioinformatics, thus contributing to one of the common goals of the research profile, i.e. the goal of developing new algorithms for IF.

Highlights in 2007

- The method GOSAP was described in an article published in the *International Journal of Bioinformatics Research and Applications*.
- The method EGOSAP was presented at the Moscow Conference of Computational Molecular Biology and published in the conference proceedings.

- An method for improvement of path diagrams was presented at the *European Conference on Evolutionary Computation, Machine Learning and Data Mining*, and published in the conference proceedings.

Cooperation

The project was a collaboration between University of Skövde, Biovitrum AB and InNetics AB. Biovitrum contributed experimental data, biological expertise and example research questions, while InNetics and contributed implementation support. During the project, we also established a new collaboration with the Fraunhofer-Chalmers Research Centre for Industrial Mathematics (FCC), which lead to development of the project IF bio5 simSoft.

Approach

The research question was addressed by developing and evaluating new information fusion algorithms. These algorithms were tested on experimental data supplied by the partner company Biovitrum AB. Also the utility of the new methods in pharmaceutical drug development was evaluated in the context of Biovitrum projects.

Contribution to infusion goals

The contribution to the IF research program was mainly related to the development of algorithms and methods for information fusion processes. These methods were developed in the context of bioinformatics applications, but have nevertheless in some cases general applicability also in other

domains. The concrete methods are described in the section “Results achieved in project”.

Results achieved in project

The project resulted in the development of four new methods, as described in the following.

The first method, named GOTEM (Gene Ontology-based regulatory TEMplates), is meant to be a tool for the researcher in a data mining scenario for distinguishing biologically plausible data mining results from non-plausible ones. The information fusion aspect of this work is that it provides a method for systematically combining experimental data (such as microarray gene expression data) with background knowledge (encoded in the form of Gene Ontology annotation). The practical usage of the method is that a researcher can first apply any data mining technique to derive a set of candidate regulatory pathways from a set of experimental data, and thereafter apply the GOTEM method to rank the derived candidate pathways according to their degree of biological plausibility. The GOTEM method was also the subject of a provisional patent named *Biological plausibility determination utilizing the matching of regulatory hypotheses to templates*, which granted by the US Patent Office in March 2005 (US60/594,234).

Using the GOTEM method in the drug development research process, the user can more efficiently than previously reduce a set of regulatory hypotheses to a set containing the most biologically interesting hypotheses. This reduced - and more relevant - set of hypotheses can be used to refine a model representing the current knowledge of a disease-related regulatory pathway, thus creating an updated model which in turn can be used to suggest additional biological experiments. In the project, which started in 2004, i.e. earlier than the Information fusion profile, this concept of iterative data mining has been termed Model-based data mining, MBDM. Since the MBDM process involves both the use of multiple data sources and a feedback loop, the MBDM concept essentially describes an information fusion process.

The second new method developed in the project was named GOSAP (Gene Ontology-based Semantic Alignment of biological Pathways). The aim in this case was to develop tools for aligning biological pathways from different species. Such a tool makes it possible for researchers to find evolutionarily preserved similarities between regulatory, metabolic and other biological pathways, across different species. Like GOTEM, the method is based on utilizing the Gene Ontology hierarchy of annotation terms as a means for calculating semantic similarity between related biological objects (gene products). Since GOSAP is used for aligning pathways from two species, the fusion process in this case involves five different data sources, i.e. two pathway databases (one for each species), two sets of gene annotations (again, one for each species),

and the Gene Ontology hierarchy of annotation terms.

The third method that we developed, EGOSAP (*Evolutionary Gene Ontology-Based Semantic Alignment of Biological Pathways*), aimed to evaluate data mining results consisting of a group of genes rather than a network. This type of result is often obtained for example from differential analysis of gene expression data. It is of interest to understand how the genes in such a group relate to known biological networks. In methods proposed in previous work, a mapping is often done by exact matching of genes, with the aim to understand how the identified group of genes relate to the known network. EVOSAP is a more powerful method since it uses our ideas of generalization using semantic classification of genes, in combination with an evolutionary search for optimal mappings. The semantically optimal mappings of paths obtained by the algorithm allows the user to identify similarities and differences, with respect to the known networks.

The fourth new method that resulted from the project uses a combination of statistical path analysis, parameter fitting by hill-climbing and an evolutionary algorithm to search for pathway diagrams, using two data sources as input: a microarray gene expression data set, and a database of pathway motifs, representing elements of typical pathway topologies. The aim of the method is not to find completely correct pathway diagrams (the complexity of the underlying biology and the dimensionality of the search space prohibits that), but rather to suggest relevant hypotheses for testing in follow-up experiments. Thus, this method forms part of a feedback loop that includes biological experiments, data mining, fusion of information, and follow-up experiments.

Publications

Gamalielsson and Olsson (in press) GOSAP: Gene Ontology-based Semantic Alignment of Biological Pathways. *International Journal of Bioinformatics Research and Applications*, 4(2).

Gamalielsson and Olsson (2007) EGOSAP: Evolutionary Gene Ontology-Based Semantic Alignment of Biological Pathways. In *Proceedings of MCCMB 2007*.

Laurio, Gamalielsson, Svensson, Jirstrand, and Olsson (2007) Evolutionary search for improved path diagrams. In *Evolutionary Computation, Machine Learning and Data Mining in Bioinformatics, 5th European Conference*. LNCS 4447: 114-121. Springer-Verlag.

Gamalielsson, Nilsson and Olsson (2006) A GO-based Method for Assessing the Biological Plausibility of Regulatory Hypotheses. In *Proceedings of ICCS 2006: 6th International Conference on Computational Science*, LNCS 3992: 879-886. Springer-Verlag.

Information fusion for informed decision support

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This scenario contains two projects in collaboration with our industrial partner ICA, one related to data mining and one related to fusion algorithms. This means that the scenario has the potential to study the integration of these two types of processes, where the former is closely related to hypothesis creation (discovery), and the latter to hypothesis validation (generalisation and validation). The starting point for the two projects are i) to use the vast amount of customer and purchase information available as a result of the extensive use of customer cards, and ii) to extend the information used in forecasting by incorporating information about external sales affecting events. Both of these projects are interesting from an information fusion aspect since they can be used as reference projects regarding to what degree the JDL model can be applied outside the military domain. It is quite natural to view some of the data driven data mining processes (e.g., to form customer groups from purchase patterns) as a form of situation analysis. Similarly, the inductive processes of sales forecasting could be used to identify threats or possibilities. Examples of this include the bottom-up identification of behavioural patterns to identify individual purchase patterns, e.g., when customers are about to become non-customers or when they are about, or could be influenced, to change purchase patterns.

Research Question

Several interesting research questions can be identified:

1. Can information fusion, based on non-linear techniques and new information sources, enhance the accuracy of sales forecasts for products in the retail sector?
2. How can sales data be fused with additional information in the identification of relevant patterns of customer behaviour in large sets of customer/sales data, and the tracking of such patterns/behaviors over time (similar to situation pictures in the JDL model)?
3. To what degree is the JDL model applicable in the retail sector?

Relevance to Information Fusion

The commonly used approach to perform forecasts within the retail sector is to rely on linear forecasts. The need to incorporate additional, i.e., external, sales affecting information in the forecasts is evident since the sector needs to minimize costs, e.g. the security stocks needed to handle poor accuracy in the forecasting. This can be compared to situation analysis.

The potential to use the vast amount of information recorded for individual customers is large. The main potential is to allow new analysis and situation awareness that allows for new possibilities, e.g., change the top-down aggregations of product groups and customer groups to a bottom-up data-driven approach. The main hindrance for fully exploiting this potential is the sensitivity of customer relations.



Highlights in 2007

Two overall projects have been identified (and funded internally). One of the projects involves utilizing information fusion to achieve better prognoses and fuse prognoses to generate an early warning system to detected deviations from what is predicted. The other project involves extracting behavioural patterns from stored data (i.e., different customer groups). The latter of these projects has during 2007 been given access to a large body of relevant data to experiment on. This was indeed a highlight during the year. The other project has during the year focussed on developing the tools needed to analyse the data as it becomes available. Some data has been made available, but it needs to be extended somewhat before it can be used.

During 2007 a new steering group was organised for the scenario. This group has had regular meetings during the year, and decided to organise an internal workshop for relevant decision makers within ICA during 2008. The intention with the workshop is to initialise some projects involving ICA personnel as well as personnel from the research program.

Projects within scenario IF rs

IF rs1 prognosis

IF rs2 data mining

Industrial cooperation

This project is in collaboration between ICA Handlarnas AB, the University of Skövde and the University of Borås, as a part of the information Fusion Research Program. The potential for additional industrial cooperation appears good since the forecasting relevant for many companies. However, the highest priority is to get the project well and truly integrated into ICAs own organisation.

Scientific cooperation

Several potential partners for collaboration can be identified, e.g. Swedish Institute for Computer Science which is involved in similar projects in the same domain.

Approach

Two projects have been specified. One deals with sales forecasting and the other with data mining. The two projects will start at a fairly application oriented level and increase the complexity level. The projects will run in parallel and be analysed from a more general perspective, including their relation to each other and the JDL model. A project organisation for the scenario has been established. This includes an overall scenario reference group and two individual projects, with additional project leader.

The approach so far has been to work on historical data generated by ICA. The approach from 2008 is to start new projects involving personnel from ICA as well as more up to date data.

Contribution to *infusion* goals

The contribution to the Information Fusion Research program will be mainly be related to the development of algorithms and methods for information fusion processes. We also anticipate to contribute to the theoretical framework, since the project can be related to the all levels of the JDL model. The retail sector scenario can be used to investigate if the JDL model also can be related to other domains than the purely military.

Results achieved in project

One initial study in the forecasting project has produced results that are going to be used for benchmarking in coming studies involving evaluation of parameter selections and design choices.

A continuation of the initial study has been specified. This continuation does not only study the fusion process close to the sensory level (here point of sales systems), but also include incorporation of additional sales affecting information. The idea is to, as a first step, incorporate advertising information within the prediction process. This will be achieved by incorporating prior advertising information.

A first paper presenting an information fusion perspective on the above projects and discussing the generalizability/applicability of the JDL model was accepted for presentation at Information Fusion 2006. A follow-up paper was accepted for the 2007 Information Fusion conference. A third and fourth has been submitted for 2008. In addition to this, two papers have been published and presented at *The 2007 international conference on data mining* and CEC Singapore

Milestones 2008

- An internal seminar will be held at ICA

- Both PhD students will complete their licentiate theses.
- Projects will be initiated in collaboration with ICA.

Related work

The projects currently mainly deal with applications of known non-linear techniques (e.g., neural networks) on traditional forecast problems and bottom-up identification of behavioral patterns. Many commercial toolboxes contain algorithms for these problems, but there are few systematic methods for utilizing the capacity of these techniques within the retail domain. The current projects should therefore be seen as a starting point (benchmark) for future research. We regard this as vital in order to gain credibility for the suggested techniques. Some aspects of these projects deal with state of the art techniques, e.g., the design of ensemble techniques fusing the results of several different techniques (e.g., neural networks, regression models, etc.).

However, the domain shares a number of characteristics of the military domain, e.g., the need for external (heterogeneous) sources, the need to detect “interesting” behavioral patterns for products and customers, the need to deal with uncertainty, etc. We therefore anticipate that the future research should contribute to the state of the art with respect to algorithm construction and method development.

When it comes to the identification of customer categories and behavior patterns, the state of the art and practice at ICA is to do this ‘top-down’, i.e. based on human expertise and ‘common sense’ (e.g. families with small children are considered a relevant category), which is known to have limitations (e.g. when it comes to multi-category membership) and not well suited for tracking/predicting of behavioral patterns over time. Bottom-up identification of such categories/patterns through neural nets, clustering techniques, etc. is considered a promising alternative approach.

Start: 1 Apr 2005 (5 yrs)

Project: IF rs1 prognosis**Information fusion for improved predictive quality in domains with high information uncertainty****Lars Niklasson, Professor (lars.niklasson@his.se), Rikard König, PhD Student (rikard.konig@hb.se), Mattias Strand, PhD (mattias.strand@his.se)**Skövde Cognition & Artificial Intelligence Lab (SCAI)
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This project is in collaboration between the University of Skövde, University of Borås and ICA Handlarnas AB, one of the major retail organisations in Sweden. The project goal is to enhance the performance of ICAs decision support system for sales forecasting, by utilizing various forms of information fusion. The main focus will be on long term forecasts (ten to fourteen weeks a head) to support campaign and strategic planning.

The retail domain suffers from an ever changing environment with a high degree of uncertainty. The customers shopping behaviour changes over time due to factors such as season, weather, marketing campaigns and lifestyle trends. In some cases the information is partial known i.e. (own marketing campaigns) but will still contain a high degree off uncertainty as unknown factors (competitors campaigns, weather, TV-shows) also influence the customers and therefore the effect off the campaign.

The problems described above sets several demands of a successful decision support system. First it has to be able to fuse data from several different systems and forecasts made by different techniques. Both the data and the forecasts will contain elements with a varying degree of uncertainty which has to be handled in some way. The system also has to be able to incorporate new information runtime to be able to support timely action upon sudden drastic environmental changes; the information could come from a system or a human expert. It is also necessary to facilitate an early warning of a forecast breakdown and to give an accurate prediction of the forecast certainty, to support stock level optimization.

Our starting point was to use non-linear techniques, specifically artificial neural networks (ANN), in order to increase the accuracy of the produced forecasts. We used ensemble method to combine forecast from different techniques to increase the performance and robustness of the model and to calculate predictions probabilities. Experiments showed that ensemble methods are significantly better compared to traditional methods but still lack a sufficient accuracy to facilitate a fully automated system. Possible reasons for the unsatisfactory performance are that all relevant data cannot always be presented in a structured manner, that all data is not always available at production time or that a drastic environmental change could have occurred. These factors could more easily be handled by a human expert which suggests a support system where a predictive model is fused with forecasts or rules produced by a human forecaster. Theory also recommends that the fusion process is best done mechanically and that the final model needs to be comprehensible to some degree to be accepted and used by a decision maker.

Research Question

We have identified the following main research questions for this project:

1. Can information fusion, based on non-linear techniques, enhance the usability of ICAs decision support systems?
2. How can we concurrently fuse new information with the current knowledge of a decision support system?
3. How do we concurrently incorporate human knowledge into a decision support system?
4. How should a decision support system be designed to be able to predict forecast uncertainty and breakdowns?

Relevance for Information Fusion

All levels in the JDL-model are related to the retail scenario but this project mainly focus on level two (situation refinement) and level three (threat refinement).

ICA has access to large amount of data but has problems with how utilize the data to maximize the knowledge of the relationships between the objects (products and customers). At level two of the JDL model, ICAs main problem is high complexity due to a huge number of individual objects (customers, purchases, products etc.). An example is how to identify the behaviour of different products and group them based on campaign- or seasonal sensitivity etc. A variation is to fuse individual customers buying behaviour into a typical behaviour for a certain group of customers, to better be able to tailor customer specific campaigns.

Level three is better described as predicting the result of a certain action in a specific situation. A concrete example at this level is to predict the impact on sales of different marketing campaigns which are dependent of the current situation, the campaign and competitors actions.

The OODA-loop is also relevant for the project as the typical work process of marketing campaigns iterates all steps of the loop continuously. The current situation (product behaviour, stocks etc) has to known before a campaign can be planned. When

the current situation and campaign plan is available predictions of the sales impact are generated and the inventory levels can be planned accordingly. Finally the prediction model is evaluated weekly to facilitate correction of stock levels and early warning of model breakdown.

Highlights in 2007

Three publications have been presented in relation to this project during 2007. One article shows how to enhance probability estimation for ensembles by modifying and using a technique employed in the weather forecasting domain. The two other articles regard rule extraction based on genetic programming. They show that more than one accuracy measure can be successfully be optimized and how the inherent nondeterministic property of genetic programming can be utilized to produce better probability estimation for the extracted model. These articles are important for the project as we believe in a solution where a final comprehensible model is extracted from an opaque predictive model. In our case the opaque model would be produced by fusing an ensemble with knowledge of a human expert.

During 2008 we hope to further increase the accuracy of our ensembles by using more relevant data. We also plan to perform live case studies with ICA to further evaluate the proposed techniques.

Cooperation

Industrial

This project is in collaboration between ICA handlarna AB, the University of Skövde and the University of Borås, as a part of the information Fusion Research Program.

Scientific

Several potential partners for collaboration can be identified, e.g. Swedish Institute for Computer Science which is involved in similar projects with in the same domain.

Approach

In the coming studies we will focus on increasing the usability of ensembles. This will be done by increasing their accuracy by fusing them with expert forecasts or rules and by increasing the comprehensibility of the models by rule extraction based on genetic programming. The fusion will not only focus on the actual forecast but also on the probability of the forecasts.

Contribution to infusion goals

The contribution to the Information Fusion Research program will be mainly be related to the development of algorithms and methods for information fusion processes. We also anticipate to contribute to the theoretical framework, since the project can be related to the all levels of the JDL

model. The retail sector scenario can be used to investigate if the JDL model also can be related to other domains than the purely military.

Results achieved in project

An initial study has produced results that are going to be used for benchmarking in coming studies involving evaluation of parameter selections and design choices.

Another result is the importance of a good error measure. ICA has currently no policy for measuring forecast performance. A few different error measures as been evaluated but no single measure can currently be recommended.

The studies also show that non linear techniques as ANN and different ensembles of techniques archives a higher accuracy even on a small set of basic parameters then linear techniques. ANN and ensembles even outperforms linear techniques which has used a more advanced parameter set.

Ensemble-MOS methods have also shown to very useful for forecast probability estimation. An adaptation of the current standard algorithm for MOS has been made which yields better result for datasets with the characteristics of the retail domain.

Rule extraction based on genetic programming seems to be a very promising technique for producing accurate comprehensible models. Genetic programming facilitates optimization of more than one performance measures (including comprehensibility) and a possibility to tailor the representation of the extracted model to the taste of the decision maker.

Related work

Previous work on ensembles methods are of course of the highest interest for this study as initial experiments has shown that ensemble techniques achieve the highest level of performance in the current domain.

Statistical post-processing of ensemble forecasts based on historical verification data (i.e. ensemble-MOS methods) is the standard way of doing probability forecast and is therefore also an interesting area. Most of the research concerning ensemble-MOS methods is done in the domain of weather forecasting.

Another important area is previous work in the retail domain. Most studies have focused on Box-Jenkins ARIMA models and multivariate regression which makes it natural to use these techniques for comparisons. It should also be useful do study the methods used for data preprocessing and result evaluation in these studies.

Start: 1 Apr 2005 (5 yrs)

Project: Information fusion for identifying patterns in customer and sales data**Information fusion for identifying patterns in customer and sales data****Henrik Boström, Professor (henrik.bostrom@his.se)****Tuve Löfström, PhD Student (tuve.lofstrom@hb.se)**Skövde Cognition & Artificial Intelligence Lab (SCAI)
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This project is carried out in collaboration between the University of Skövde, the University College of Borås and ICA Handlarna AB, one of the major retail organizations in Sweden. The project goal is to utilize information fusion techniques in the identification of customer segments, providing ICA Handlarna AB with effective support for direct marketing. The underlying hypothesis is that the expected buying behavior of customers can be identified through analysis of previous buys, i.e., point-of-sale (POS) data. The POS data that are continuously collected at ICA Handlarna AB, are very detailed and require aggregation for efficient and effective handling. Different types of aggregation, such as summing amount and frequency over time periods and grouping items based on product hierarchies, and their effect on predictive performance are investigated as well as different strategies for fusing features and models obtained from such aggregations. A long-term goal of the project is to utilize the aggregation strategies not only for customer segmentation but for predicting whether the customer behavior is about to change.

Research Question

In many situations it is not possible to analyze all available data to provide effective decision support under given time and resource constraints, e.g. due to limits on computational power, as well as particular requirements of the employed analysis methods. The retail sector is one area in which such situations are frequently occurring. One of the most characteristic features of today's retail businesses is the huge amount of point-of-sale (POS) data gathered continuously. The POS data is usually very detailed, where each transaction (i.e., when a customer pays for an item) is represented with detailed information on each item included in the purchase. Hence, significant computational power is required to perform any systematic analysis on raw data. Furthermore, the employed analysis techniques have specific prerequisites on the format of the data they can handle. These prerequisites are often rather constraining and mean that data must be reduced into tables where each instance (e.g., customer) is represented by one row, and where the columns correspond to features of the instances. Another issue concerns the dimensionality of the analysis task: often no or only very weak correlations can be detected between variables characterizing single purchase items and some target variable (e.g., customer segment), making it difficult to separate out the true signal from noise.

One way of addressing the problem of having too large data sets to allow for efficient and effective analysis is to aggregate the data in some way before the analysis, e.g., by summing all purchases over a period. Depending on what is aggregated and how the actual aggregation is performed, there is an obvious risk that crucial information is lost.

The way in which aggregation is undertaken leads to different amounts of information and to different possible ways of utilizing the information.

Several important aspects have to be considered when aggregating the data: how much the customers have bought in different item groups, how many items they have bought and so on. Different levels in the item group hierarchy can be utilized during the aggregation. Since it would be practically impossible to consider each and every item, a tradeoff between the need for details and what is possible to handle is needed.

The main research question for this project is to study how customer segmentation can be improved by utilizing various kinds of aggregation strategies, including strategies that fuse features or models that result from employing any of the individual aggregation strategies. A long-term goal of the project is to utilize the aggregation strategies not only for customer segmentation but for predicting whether the behavior is about to change.

Relevance to Information Fusion

The topic of aggregation is central in information fusion, cf. situation assessment (level 2) in the JDL model, as is the long term goal of predicting future behavior of the customers, cf. impact assessment (level 3) in the JDL model. The project is expected to increase the understanding of what impact different aggregation strategies may have on predictive performance and contribute with novel aggregation strategies that are based on fusing features and models obtained from using the individual aggregation strategies.

Highlights in 2007

The newly recruited professor, Henrik Boström, joined the project and took over as project leader and main supervisor for the PhD student in January 2007.

The research questions to be focused on in the project have been narrowed down to the study of aggregation strategies for customer segmentation.

An extensive study has been performed on data that has been collected at ICA Handlarna AB, consisting of all available transaction data for a period of 18 months for 10 000 households, which accounts for approximately 12 000 individual card holders (i.e., enlisted customers that receive some special offers, and in return the company can register all transactions and tie them to a particular card). Several different aggregation strategies have been compared for predicting customer segment membership, together with strategies for fusing features and classifiers obtained from these aggregations.

The topic of diversity, which is of importance when fusing multiple classifiers, has been extensively explored, and results from these studies have been presented at the Fusion and IJCNN conferences in 2007, and will be further presented at upcoming PAKDD and IJCNN conferences in 2008. Main conclusions from these studies are that most diversity measures do not correlate well with test set accuracy, and although some measures show promising results, it turns out to be extremely hard to utilize them effectively in ensemble creation. A straightforward combination of all trained models turns out to work well for almost all problems.

Cooperation

Industrial

This project is carried out in collaboration between ICA Handlarna AB, the University of Skövde and the University of Borås, as a part of the IF research program.

Scientific

The Universities of Skövde and Borås are collaborating in this project (the PhD student is partly employed at both universities). Apart from collaboration with several projects in the IF research program, no other/outside scientific partners are involved at this point.

Approach

Empirical investigations of what effect different choices of aggregation strategy and levels in item hierarchies have on the resulting analysis are undertaken. The effects of fusing the results of such analyses are furthermore investigated. All data for the studies are collected at ICA AB, and further background information on these, as well as suitable test scenarios are obtained from close collaboration with domain experts and database administrators at the company.

Contribution to *infusion* goals

The contributions to the IF Research program are threefold: (1) the integration and evaluation of data mining techniques into and from an IF perspective, (2) an increased understanding of diversity measures for classification, and (3) new strategies for fusing multiple aggregations.

Results achieved in project

- Johansson U., Löfström T. and Niklasson L. "The Importance of Diversity in Neural Network Ensembles - An Empirical Investigation", the 2007 International Joint Conference on Neural Networks, IEEE Press (2007)
- Löfström T., Johansson U. and Niklasson L., "Empirically Investigating the Importance of Diversity", the 10th International Conference on Information Fusion (2007)
- Löfström T., Johansson U. and Niklasson L., "Evaluating Standard Techniques for Implicit Diversity", the 2008 Pacific-Asia Conference on Knowledge Discovery and Data Mining, Springer Verlag (to appear)
- Johansson U., König R. Löfström T. and Niklasson L., "Increasing Rule Extraction Accuracy by Post-processing Gp Trees", the 2008 IEEE Congress on Evolutionary Computation, IEEE Press (to appear)
- Löfström T., Johansson U. and Boström H., "The Problem with Ranking Ensembles Based on Training or Validation Performance", the 2008 International Joint Conference on Neural Networks, IEEE Press (to appear)
- Johansson U., Sönströd C., Löfström T. and Boström H., "Chipper - A Novel Algorithm for Concept Description", the 10th Scandinavian Conference on Artificial Intelligence, IOS Press (to appear)

Related work

Behavior-based segmentation aims at discovering customers exhibiting similar purchase behavior. A lot of different aspects could additionally be included in the current study of customer behavior. For instance, a retailer could distinguish between light and heavy consumers of a product or product category, stock-up shoppers versus top-up shoppers, lunch-time shoppers vs. evening shoppers, or weekday shoppers vs. weekend shoppers, etc., see e.g., T. Brijs et al., "Using shopping baskets to cluster supermarket shoppers," Conference Notes of the 12th Annual Advanced Research Techniques Forum (2001) pp. 24–27. There are also several alternative ways of grouping the purchase items, e.g., the products may be divided into groups based on *penetration* i.e., percentage of households that purchase the category), and *frequency*, i.e., average number of times per year category is purchased, see e.g., S.K. Dhar, S.J. Hoch, and N. Kumar, "Effective category management depends on the role of the category?," Journal of Retailing, vol. 77, 2001, pp. 165-184.

Scenario: IF mfg – Manufacturing **Simulation-based information fusion for manufacturing decision support**

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The goal of the research in the manufacturing scenario is to extract information about manufacturing facilities in a way that allows improved decision support for planning of operations and maintenance of manufacturing facilities. This involves the identification, extraction and fusion of relevant information from the manufacturing system and/or simulation, and other sources. In some situations, more or less automatic extraction and fusion of information is of interest whereas in other cases, the information fusion is more human centric.

Research Question

The overall research question within this scenario is how manufacturing activities can be supported by IF. Manufacturing systems and supply-demand networks are sufficiently complex that the effective and efficient operation of these, including support functions such as service and maintenance, require adequate decision support systems. The scenario encompasses three industrial cases with essentially the same question: "What information (type and amount) has to be presented how and when to the decision maker?". This immediately results in a number of derived questions such as "which IF tools and techniques are useful?" or "how much of the IF process must (can) be automatic and how much human centric?".

Relevance to Information Fusion

This scenario is application/problem oriented, but all projects within the scenario deal with the problem of synergistically combining information from a variety of sources and presenting the results of this fusion process in such a way that it supports the making of decisions that are better, more robust or can be made faster ("window of opportunity"). As an example, a production planner who receives a phone call from one of the company's salespersons "I can sell X products of type Y to company Z, but we need to start dispatching them on Tuesday - can we do that?" is dealing with exactly the same type of problem as a field commander observing enemy troops movements; an emerging situation needs to be addressed with limited resources whilst the time for decision making and acting is limited.

In this scenario, there are a number of IF related research challenges such as:

- Identification and extraction of relevant information (but not more) from manufacturing system and/or simulation, and other sources
- Automatic extraction and fusion of information, depending on problem/scenario

- Identification and use of tacit knowledge and other "hard to find / get at" sources
- Problems related to semi-autonomy (how? how much? when?)
- Identification of major/minor events/conditions, when should events/conditions be propagated to decision level?

Highlights in 2006

In essence, this scenario and its projects got properly underway early 2006. This was due to the fact that most of the cooperating companies were involved in closely related projects such as Massive and SimPlan that ended December 2005, and preferred to complete these projects before engaging fully in the IF research program. As a result, the scenario description in the 2005 annual report was rather tentative; in essence only one project was relatively well defined.

Main highlights have been:

- The project mfg1 that was defined fairly loosely has been defined more clearly. One more project has been defined and established with Volvo Powertrain (mfg3).
- Unfortunately, Delfoi had to put their participation on ice, due to changes in personnel including MD. This is compensated by an increase of effort by Volvo Powertrain (see below)
- Volvo Powertrain has announced to increase their level of participation following the definition of the mfg3 project.
- The project with Electrolux is running in close association with their P21 project; a major initiative aiming at substantial cost reduction through a holistic supply chain approach.
- Closer co-operation between the two research groups involved in this scenario resulted in an internal research seminar on October 31st.
- Recruitment of PhD student Tehseen Aslam was formalized.

- Publications: 3 journal papers accepted (one already published), 6 conference papers published. Various presentations of the IF research program, such as at the SMSN (Swedish Manufacturing Simulation Network) seminar in Skövde and at the kick-off for the Industrial Graduate School CAPE in Trollhättan.
- Related European project "My-Car" with participation from University of Skövde started.
- Organization of FAIM2008 conference (Flexible Automation and Intelligent Manufacturing) granted to University of Skövde; an IF special track or associated IF workshop is planned.

Projects within scenario IF mfg

There are three projects in this scenario that each addressing complex industrial problems in a holistic way and that together address a closely linked chain.

1. Mfg 1: Prediction of variations and reduction of bull whip effects in supply networks - a holistic approach.
2. Mfg 2: Allocation of service & maintenance resources.
3. Mfg3: Information Fusion for holistic process analysis (HPA) in the foundry industry.

Industrial & scientific cooperation

Each of the three projects has at least one industrial partner. In all the cases, the project descriptions are rooted in genuine industrial problems as the industrial partners have taken the lead in defining the problem.

Cooperation takes place with amongst others Gjuteriföreningen, De Montfort University in Leicester (UK) and Deusto University in Bilbao (Spain) as described in more detail in the project summaries.

An associated project is dealing with cognitive aspects in manual assembly of heavy duty diesel engines. Our partners in this project are Volvo Powertrain, Loughborough University (UK), and the research group in Human Centred product Development. An industrial PhD student is studying the problem of attention levels in mixed model assembly; one hypothesis is that triggers can be used to start an OODA loop, the result of which is a reduction of assembly errors.

Approach

For the first two projects, agent-based discrete event simulation is seen as a technology that in principle can deliver a solution. Discrete event simulation is also seen as offering a partial solution in the HPA problem (third project), but in this case in combination with data mining and soft computing techniques.

Contribution to *infofusion* goals

The scenario provides an application area that is complementary to the other scenarios; this in itself is important as one of the strengths of the IF research program is a holistic instead of application specific approach to IF.

More specifically, this scenario contributes through:

- providing a test-bed for tools, algorithms etcetera developed in other scenarios
- developing or enhancing IF tools or components that may be used in other scenarios
- contributing to the development of more generic IF theory
- presenting examples of tactile benefits of using IF
- promoting the use of IF and creating awareness about IF in the international manufacturing research community

Results achieved in the scenario

One of the main results achieved in the scenario is the specification of the projects that are each rooted in a genuine industrial problem.

Another result is the completion of the Massive project that, although not started as an IF project in 2003, has many elements of IF. The main results are summarized at the end of this document.

Related work

Industrial applications of Information Fusion (IF) in manufacturing are almost without exception limited to sensor fusion. In most of these cases, this involves physical sensors, sometimes in combination with databases or archives [1, 2]. The majority of applications are related to detection or prediction of tool wear, tool failure, spindle bearing condition and so on [3]; in short these applications are limited to some features of individual machines. An exception to this is research related to navigation of mobile robots. Industrial applications of this research are, at present, mainly limited to fairly simple problems such as obstacle detection and avoidance and free navigation over a short distance in well-known and structured environments. An example of research on robot navigation in industrial environments is reported on in [4].

Despite the potential use of IF on machine system level or even plant level and supply-demand network level in manufacturing [5, 6], most applications of IF in manufacturing are as mentioned limited to features of single machines. Exceptions can possibly be found in the form of the Massive project [7] that provides enabling technologies for machine system service support and in the upcoming EU project my-Car that proposes some IF applications for the establishment

of the self-adaptive assembly plant. For the interested reader, the Massive project is summarized under “Previous Project: Massive”.

1. BV Dasarathy (2000) Industrial applications of multi-source information fusion, Proc IEEE int conf on industrial technology, Vol2 pp5-11
2. Madan R N, Rao N S V (1999) Special issue on information/decision fusion with engineering applications, Journal of The Franklin Institute-Engineering and Applied Mathematics 336 (2), 199-204
3. BV Dasarathy (2003) Information fusion as a tool in condition monitoring. Information Fusion, Vol 4/2, June 2003, pp 71-73
4. L Khammari, K Hedenberg & LJ De Vin (2005) Change Detection Algorithms for Vision Based Mobile Platforms, Mechatronics 2004, Turkey, 251-258.
5. LJ De Vin, AHC Ng, J Oscarsson & SF Andler (2005) Information Fusion for Simulation Based Decision Support in Manufacturing, FAIM 2005, Bilbao, Spain, 135-144
6. LJ De Vin, SF Andler, AHC Ng, PR Moore, J Pu & BCB Wong, Information Fusion for Decision Support in Manufacturing: Studies from the Defense Sector, accepted for publication by International Journal of Advanced Manufacturing Technology
7. LJ De Vin, AHC Ng & J Oscarsson (2004) Simulation Based Decision Support for Manufacturing System Life Cycle Management, Journal of Advanced Manufacturing Systems, Vol 3 No 2, 115-128

Previous Project: Massive

The Massive project carried out by the Centre for Intelligent Automation at the University of Skövde partly parallel with the Infofusion research program studied simulation based service & maintenance support in order to allow remote on-line monitoring of manufacturing machinery as well as off-line analysis using historical data. This is achieved by connecting the simulation model (the tool used is a 3-D graphical simulation pack for Computer Aided Robotics called Igrip) with the physical manufacturing system in such a way that the execution of the physical system drives the simulation model. The user can thus monitor the equipment using the Igrip animation whilst simultaneously viewing selected signals (non-animated signals such as current, torque and so on). This is shown in Figure 1. Alternatively, the user can use data from the database and analyze the operation of the system using media players such as

slow motion, rewind whilst selecting different signals of interest to unravel the cause of a machine failure. In essence, what is created in Massive is a “synthetic environment” which is similar to the interaction model used in Infofusion (Figure 2). In terms of the JDL model, the lower level fusion is automatic (Figure 3) whilst the higher level is “manual” which is in accordance with the human centric nature of the JDL model [8].

The kernel of MSSS is essentially a remote data acquisition and analysis system. An advanced data acquisition, pre-processing and management framework is the foundation for all other functions. The data acquisition system can be configured remotely so that specified parameters, machine process variables and signals can be acquired in prescribed time intervals and sampling rates. Configurations for routine periodic data logging can also be selected for day-to-day monitoring. Configuration of the data acquisition components is enabled through XML Web services using the user interface functions provided by the Scenario Manager.

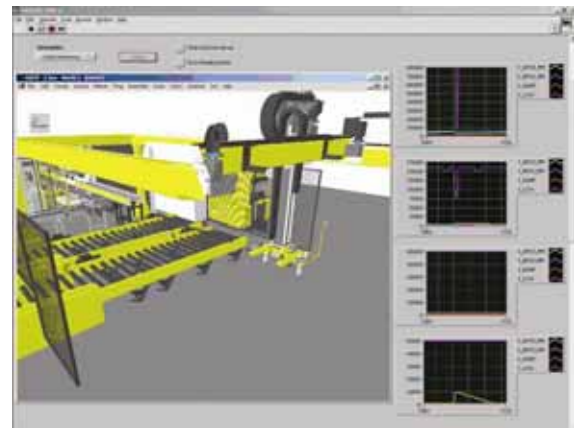


Figure 1: Example of User Interface

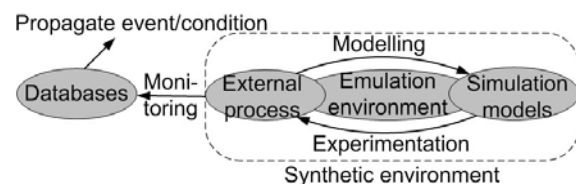


Figure 2: Massive interaction model

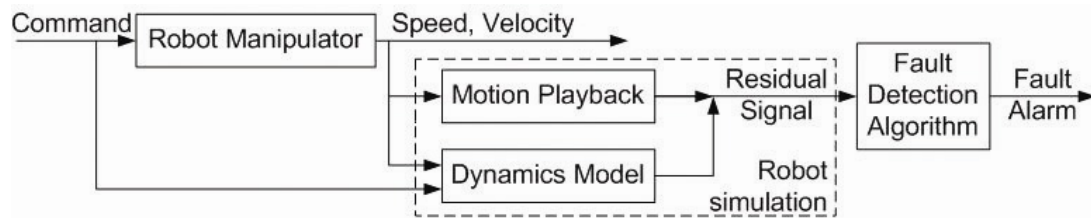


Figure 3: Fault Alarm generation based on analysis of residual signal

8. Llinas, J., Bowman, C., Rogova, G., Steinberg, A., Waltz, E., White, F., 2004, Revisiting the JDL Data Fusion Model II, Proceedings of Fusion 2004, Stockholm, 1218-1230

Growth Potential for scenario

With the exception of data fusion (from databases and/or sensors), the area of information fusion is not very well developed within the manufacturing industry. However, the manufacturing industry is increasingly becoming aware of the potential of information fusion as a decision support tool. This means that there is an excellent potential to start new projects with a focus on information fusion, or in which elements of information fusion are used. The recently started EU project my-Car is a living example of this. The research groups within the scenario have become active in industrial graduate schools (such as RAP and CAPE) and are active within the MERA program, and this has increased the base of collaboration partners. Furthermore, there is a potential to extend the work to business areas that face issues related to those in the manufacturing industry, for instance healthcare providers and the service sector.

Start: Summer 2006 (5 years)

Project: IF mfg1 supply networks**Prediction and reduction of bull whip effects in supply networks
- a holistic approach****Professor Leo J de Vin, Dr Amos Ng, Tehseen Aslam (PhD student)**Centre for Intelligent Automation (CIA),
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In principle, the manufacturing industry have always had to face fluctuations in demand, with perhaps some incidental exceptions when demand exceeded world-wide production capacity (which today is rarely the case). Final assembly companies and departments, often striving after lean operations whilst at the same time needing to be agile, have traditionally passed the agility problem on to their external or internal suppliers. Today, there is an increasing awareness that this essentially results in local suboptimisations. In the research community as well as in industry, there is consensus that the problem of fluctuating demand needs to be addressed in a holistic manner in order to achieve responses that are both efficient and effective for the supply network as a whole. Typically, a supply network is subject to knock-on effects; small variations in demand (output from the market) result in somewhat larger variations for final assembly which in turn result in larger variations for the suppliers. The aim of this project within the Manufacturing Scenario of the Information Fusion Research Programme is to develop a method to predict and address demand fluctuations in a holistic manner. Agent based simulation is seen as one of the tools that could be part of the information fusion platform that is required for being able to address this intricate problem. The principle industrial partner is Electrolux Home Products in Mariestad, but at later stages of the project, selected suppliers will be involved.

Research Question

Optimizing the manufacturing operations in a single plant is a complex and intricate problem; even more so the management of a supply-demand network which typically incorporates a number of stakeholders with partly overlapping but also conflicting interests. A particular problem here is the propagation of small disturbances across the manufacturing chain, often resulting in the so-called bullwhip effect (meaning large variations for, for instance, suppliers). The research question is: "How can this bullwhip effect be eliminated or at least contained within acceptable limits, using a holistic approach based on information fusion?"

Relevance to information fusion

Efficient and effective operation of manufacturing systems is of key importance to Swedish industry to maintain a competitive advantage over low-wage countries. Typically, the stakeholders tend to have a limited focus which results in sub-optimization; this in turn jeopardizes the economic viability of the whole supply network in the long run. Thus, a holistic approach is needed to remedy this situation. In essence, a supply network is a system with several sub-systems that are complex in itself, and optimization of the operations in such a network requires a synergistic use of historical performance data, current status information, and demand predictions, as well as a tool to assess the impact of decisions or demand fluctuations on the overall system performance. Such a tool would thus enable decisions makers to form a "situation awareness" first, followed by an impact assessment of

alternative decisions. Conventional planning systems do not address the planning problem from a holistic standpoint, and do not take system variations into account. Designing and implementing a decision support system that does not have these shortcomings makes the project relevant to information fusion.

Cooperation**Industrial**

The main industrial partner is the Mariestad Plant of Electrolux Home Product Operations. At a later stage, selected suppliers to the Mariestad Plant might be involved in the project.

Scientific

The project will aim at fostering synergistic effects within the IF research program but also cross-fertilization with other projects such as Optimist, MY-CAR, MERA, Insikt and the industrial research schools RAP and CAPE. At the joint research seminar on Oct 31, clear links with project in the Logistics group have been identified. Dr Esther Alvarez from Deusto University in Bilbao and her group are working on a similar project.

Approach

The first 2 years will be used to analyze the operations at the Electrolux plant; for instance identification of planning restrictions that may be either "hard" restrictions such as bottlenecks or "soft" restrictions that are a result of current practice. In addition to this, the way in which demand fluctuations are prognosticated and handled will be

analyzed. After this first stage, the research will be extended to include selected suppliers.

The current hypothesis is that agent-based simulation is a very promising tool for holistic analysis, planning and optimization of complex supply-demand networks. However, this tool needs to be supplemented with techniques such as data mining and prognostic tools. Furthermore, prerequisites for using the tool need to be clarified.

Contribution to *Infusion* goals

Optimization of complex system where historical performance data, current status and demand predictions need to be addressed in a holistic manner obviously is a relevant IF problem. What makes this project particularly interesting is that the stakeholders are autonomous with very clear-cut own interests; yet their aggregate overall performance is central to the survival of the network as a whole and many stakeholders individually.

Results achieved in the project

One PhD and at least 10 scientific papers is the envisaged scientific production in this project. Results up to date are the definition of the industrial problem and the research plan for the PhD student. So far the project has produced 2 conference papers and a thorough mapping of Electrolux internal demand and supply processes. This mapping has revealed the complexity of the internal processes and therefore, it has been decided to focus on the Electrolux plant itself, at least in the next few years. The reason for this is twofold Firstly, the hypothesis regarding the suitability of agent-based simulation can be adequately tested by just studying the Electrolux plant. Secondly, including external suppliers implies problems regarding availability, format and reliability of manufacturing data. Although this is an interesting problem in its own right, it would not contribute to the testing of the hypothesis to investigate this problem at this stage.

Related work

Related work is carried out within the scenario in the sense that MAS (Multi-Agent Systems) is proposed as a tool in one of the other projects; the application problem however is different.

Related work is also carried out at the Department of Industrial and Systems Engineering at the University at Buffalo. They do research in the field of supply chains and substantial research in the field of information fusion (James Llinas) and these areas have been combined in at least one PhD project.

Some work at Oregon State University also is related but there, the work on information fusion and that on supply chains seem (currently) still relatively disparate.

Start: 1 April 2006 (5 yrs)

Project: IF mfg2 logistics**Decision support in service related maintenance**

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This project is carried out in collaboration between the Logistics Group and Centre for Intelligent Automation at the University of Skövde, and Euromaint Industry AB, a major production service organization in Sweden. The project goal is to make use of information fusion techniques for improved decision support in managing maintenance service operations. The starting point is to use Multi-Agent systems to model and simulate different scenarios, based on a thorough empirical study.

Research Question

Production supporting and maintenance focused companies are subject to a rapidly changing business environment. Additionally, since these types of companies are essentially service-based, their operations need to be well-balanced in terms of utilization rate of resources vs. service rate towards customers. In a highly competitive environment this balance becomes even more important, neither to loose customers nor to underutilize resources. This leads to the research question: How can IF advance decision making in the operation of service-related maintenance? Specifically the use of Multi-Agent System will be studied in a service-related maintenance organization, both for modeling and simulation, and for data mining applications.

Relevance to Information Fusion

This project takes a starting point from an applied and relevant problem. The nature of the problem is illusive with much data and information available, and many modeling approaches have been suggested (e.g. in operations management). This leads to the belief that information fusion is a realistic approach for this problem: i) to fuse information from data-bases, ii) utilize real-time when available, iii) and make future predictions based on existing knowledge.

Highlights in 2007

Participation in Research Courses, hypothesis testing concerning Forrester Effect, Weather Forecast related surge in service demand, geographic and periodical variations in demand. The evaluation and purchase of Multi Agent-Modeling software has been carried out.

Cooperation**Industrial**

This project is carried out in collaboration with Euromaint Industry AB, a machine builder with an increasing focus on machine system service & maintenance.

Scientific

Cooperation has taken place within the scenario, also an increasing involvement from CGI.

Approach

The first empirical material has been analyzed and formed a base for development of a fusion-model. Based on this, additional research questions have emerged, which need addressing. A more detailed empirical data gathering is required, and more thorough data analysis is needed. The final aim of this project is to evaluation an IF-prototype for operative use.

Contribution to Infusion goals

This project is envisaged to contribute to IF theory, both through own specific contributions to knowledge and through providing a different context of application for the theory. More specifically, the problem of deploying limited manufacturing resources in an optimal and/or robust manner has many similarities with general problem statements for a number of applications. As a result, it is expected that this project will deliver joint results, thus contributing to the overall program.

Results achieved in project

Work has progressed with active involvement and support from the industrial partner. A conference article has been published at Swedish Production Symposium.

Envisaged start: January 2007 (3 years +) **Project: IF mfg3 foundry**

Information Fusion for Holistic Process Analysis in the foundry industry

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The foundry process (casting) is amongst the oldest manufacturing technologies in the world. However, at the same time, it is a complex process where many variables play a role including human centric issues such as craftsmanship and tacit knowledge. In modern manufacturing, it is imperative that manufacturing processes have a predictable output. This becomes even more important when the output from one process is input for another process, as typically, small variations in one process may have severe knock-on effects in subsequent processes (so-called bull whip effect). Car engine manufacturing is a typical example of such a process; casting is followed by NC machining. The aim of this project within the Manufacturing Scenario of the Information Fusion Research Programme is to develop simulation based diagnostic and prognostic methods and tools to arrive at a predictable output. The industrial partner is Volvo Powertrain in Skövde.

Research Question

The aim of this research project is to investigate how a foundry plant in automotive industry, which contains both continuous processes (casting) and discrete parts operations (such as machining), can be improved in terms of capacity and quality by fusing information from process databases, process controllers, shop floor control systems and multidisciplinary simulation. The leading research question thus becomes: What (in terms of information, data, and knowledge) is needed for a holistic optimization of casting and machining processes and how (in terms of algorithms, fusion techniques, and platforms) can we achieve this?

Relevance to Information Fusion

Holistic Process Analysis (HPA) of a cascade of production steps is an intricate problem; in this case particularly as it involves both continuous processes and discrete part operations. It is, for instance, difficult to perform an impact analysis of parameters in the foundry process on machining processes and throughput times with the use of conventional methods. In order to predict the effects of parameters and actions in the foundry process on overall system performance, a combination of co-simulation, data mining and soft computing techniques is proposed, with information sources being databases, process models, sensors, and humans (for instance, tacit knowledge).

Cooperation

Industrial

The main industrial partner in this project is Volvo Powertrain, Skövde. Their motivation for actively participating in this project is rooted in the general need for Swedish industry to control and predict their processes: Efficient and effective operation of manufacturing systems is of key importance to

Swedish industry to maintain a competitive advantage over low-wage countries. In case of outsourcing of manufacturing activities, associated activities such as design, R&D and eventually the service sector will move as well. Thus, control of manufacturing processes in such a way that they yield a stable and predictable high quality output is imperative for Swedish industry. The main goal for Volvo Powertrain is to work in a pro-active manner in the future.

Scientific

The project will foster synergistic effects within the IF research program; but also cross-fertilization with other projects such as Optimist and the industrial research schools CAPE. We are also involved in a PhD project on simulation based minimization of environmental impact of foundry processes involving Swerea Swecast AB, DMU and GSP.

Approach

Current data mining techniques can be very useful in developing local prediction models for a process using continuous (discrete-time) data saved in the database. The generalization capability will then allow the model to be used to estimate the process performance when novel data are applied. However, it is impossible to develop such a prediction model when huge number of variables and the discrete part flows have to be taken into account simultaneously to provide accurate analysis on the system level (e.g. overall system throughput). On the other hand, the current practice of using discrete-event simulation (DES) for system-level analysis relies heavily on input data analysis on existing process data to give data distribution on for instance cycle times. This lack of generalization would limit the capability of DES to consider the effects of altering process parameters, which is necessary for advanced analysis and system optimization. Therefore, the proposed project aims to address this problem by using a synthesis of continuous simulation and DES

methods (i.e. multidisciplinary simulation) as well as data mining techniques, within the framework of information fusion from database, sensors and simulation, to facilitate variability reduction and/or optimization of system parameters in a foundry plant.

Contribution to *Infusion* goals

This project will provide IF implementations and a test bed for IF tools developed in other projects. In particular, the combination of continuous and discrete processes is of particular interest.

Results achieved in the project

One PhD student was appointed on 1:st of September 2007. Expected number of papers will be 2 / year, and a system for Holistic Process Analysis of complex manufacturing processes. The first results are the definition of the industrial problem and a suitable approach.

A pre-study of the data mining approach to predict the process outcome in terms of quality of the cast product was performed in the end of the year. Different mining algorithms were tested as well as several software solutions. The main result of this study was to explore the current data in the database and realizing the insufficiency of the data. Noting this; we need further data and data sources to be included. In order to get a reasonable overall picture the next step is to perform a mapping of the process.

Related Work

Related work is carried out at Swerea Swecast AB in a PhD project regarding prediction of environmental impact of foundry processes with the use of discrete event simulation (DES).

Other related work is carried out at Otto-von-Guericke-University, Magdeburg, in the field of information fusion for casting design. This work focuses on the process and on work scheduling, and thus has an off-line nature and is more limited in scope with regards to processes.

Scenario: IF pa – Precision Agriculture**Information fusion in precision agriculture**

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The overall goal of this scenario is to develop decision support for real-time control of agricultural equipment in the field, for example to control the amount of fertilizer, pesticides or watering used in crop production, based on fusing of sensor data (such as the current water and nitrogen content in the crop), database information (such as soil condition, environment-sensitive areas, previous harvest results, rainfall, previous fertilizing) and model-based simulation (such as future effect of fertilizer, effect of projected rainfall or reasonable deviation).

Research Question

The central question in this scenario is how decision support in agriculture (e.g. for weed/pest insects control or fertilizing) can be improved by involving information fusion strategies.

Relevance to Information Fusion

This scenario intends to improve equipments in precision agriculture, i.e. in image analysis and algorithms for vision supported navigation of robots and in automated fertilizer application. In all these areas, fusing information and the OODA (Observe-Orient-Decide-Act)-loop is crucial in the processes taking place.

Highlights in 2007

The main focus in 2007 was based on the literature survey, a few models were chosen with respect to time step, complexity and availability, to undergo the evaluation. During the evaluation work in fall -07, some insights were revealed about the input data set needed, leading to that the continuing evaluation work in spring -08 uses extended input data.

Projects within scenario IF pa

IF pa1 prec agricult

Cooperation**Industrial**

Participating companies are in AgroVäst AB.

Scientific

The projects are cooperating with both other scenarios within the Infusion program but also with outside scientific partners, such as the

Department of Crop Production Ecology, SLU, and Halmstad University.

Approach

The PA-scenario includes, at the moment, two projects. The projects have different directions of applying information fusion in precision agriculture. The different project groups will carry out the research work separately but in close collaboration with each other, since the projects have many issues in common.

Contribution to infusion goals

All projects in this scenario expect to contribute with experiences and expended knowledge within their subject field that can be applied and utilized within the information fusion field. The projects are expected to give contributions within the areas of e.g. visualization, infrastructure development, theoretical frameworks, algorithms and methods.

Growth potential for scenario

The expected outcome of the IF pa1-project (techniques and principles for real-time variable nitrogen dose) could be developed and adapted for other measures within agriculture as well, e.g. other fertilizers (such as phosphorous and potassium) and pesticides. Not only traditionally agriculture, but also golf courses, forestry and vineyards could be potential application areas. Future collaboration partners could be the JTI (Swedish Institute of Agricultural and Environmental Engineering) and SMHI (Swedish Meteorological and Hydrological Institute) for developing routines for data management, weather statistics and forecast models.

Furthermore, central partners in this scenario would be the manufactures of fertilizers, tractors, sensors (the Yara company) and of other machines and hand devices used by farmers for fertilizing purposes. Similarly, other scenarios within the IF program would be important potential partners regarding visualization, data fusion models and user perspective and trust on the systems.

Start: 1 Jan 2006 (5 yrs)

Project: IF pal prec agricult

Information fusion in precision agriculture for optimized real-time nitrogen application

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This project is in collaboration with the Division of Precision Agriculture at SLU (Swedish University of Agricultural Sciences). An IF approach will be applied, since the purpose of this project is to develop an interface between various data sources and models to be used on-the-go as well as to work with adaptation and assessment of the application of such models. This will also include the identification and evaluation of relevant data sources with a potential to function as input data in such systems. The work will be carried out as a PhD project aiming at optimal application of supplementary nitrogen (N) fertilizers according to within-field differences in demand and risk for losses assessed by real-time modelling of data from sensors and databases. Thus, the project will form basis for advanced and practical solutions in applied precision agriculture.

Research Question

How can interfaces between sensor data, model simulations and databases – providing real-time data and background information of varying spatial resolution – be fused and make decision support regarding variable N-fertilizer application in real-time, on economical and environmental grounds, with respect to robustness, speed and precision?

Relevance to Information Fusion

This project will deal with the entire spectrum of the Infusion Program vision; the process of gathering relevant information (e.g. soil properties and nitrogen content in crop), fusing different information sources (databases and N-sensor) and interpreting the data (in model simulations) to result in real-time decision-making (at the time for fertilizing in field).

Highlights in 2007

- Participation at the ECPA (European Conference on Precision Agriculture), 3-6 June 2007, Greece.
- Participation at the POS (Precisionsodling Sverige) workshop, 12 November 2007, Skövde.
- Continuing discussions with the CGI (Common goals and infrastructure) scenario about a cooperation project.
- The initial literature survey (Introduction to Soil Science Research, 7.5 credits) was completed.
- A PhD-course in Philosophy of Science, 4.5 credits, was completed.

Cooperation

Industrial

Mats Emilsson is contact person at AgroVäst AB. For coming work, it is also likely that collaboration

will be started with Knud Nissen, Lantmännen Lantbruk.

Scientific

Collaboration projects have been discussed and initiated both within and outside the IF program. Within the IF program, discussions have been made mainly with the CGI scenario. Outside the IF program collaborations have been initiated with Johanna Wetterlind, PhD-student at Division of Precision Agriculture, SLU Skara, and with Anders Larsolle, Department of Energy and Technology, SLU Uppsala.

Approach

Research objects are to:

- identify and validate relevant data sources and models that can interact with N-sensor measurements in real-time for economical and environmental optimization of N fertilizing,
- develop interfaces between background models and real-time data for precision agriculture to facilitate variable application,
- investigate how the relationship between analytical accuracy and spatial resolution in background data influence accuracy and resolution of the real-time model.

Contribution to *infofusion* goals

By aiming at a framework for applying *information fusion to optimize nitrogen application in agriculture in real-time*, this project is expected to contribute to *improvements of theory, techniques and tools for decision-support* for this specific purpose, but also for the common goals of IF in general. The outputs are expected to relate mainly to

(1) infrastructure and process development and (2) human-machine interaction and visualization.

Results achieved in project

One PhD-student started in January 2006. The definition of the problem was formulated and contacts, both scientific and industrial, were established. Much time was spent on following PhD-courses and starting up the literature survey.

In 2007 as the initial literature survey (“Possible tools for site-specific nitrogen management in precision agriculture”) was completed, the research question was deepened and the focus was on evaluating crop growth models with regard to potential use in precision agriculture. Based on the literature survey, a few models were chosen with respect to time step, complexity and availability, to undergo the evaluation. During the evaluation work in fall -07, some insights were revealed about the input data set needed, leading to that the continuing evaluation work in spring -08 uses extended input data.

Related work

The project has potential to be in collaboration with another on-going project using a crop model for fertilizer predictions, mainly carried out by Anders Larsolle, Department of Energy and Technology at, SLU, Uppsala. Another PhD-project, carried out by Simon Wetterlind at the University of Skövde, is focused on forecasting pest insect population developments based on census and sensor data and this is also a potential collaboration partner.



Scenario: IF sd – Systems development

Information fusion in the systems development process

Anne Persson, PhD

PhD Students: Beatrice Alenljung, Åsa G. Dahlstedt

Industrial PhD Student: Mats Grindal

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The goal of this scenario is improving information and decision quality in the systems development process by fusing simulation of decision outcome with complex information generated in the different stages of the systems/software development process, across the entire life cycle of a system and across several development tools. The vision is the creation of an integrated systems development workbench. that builds on an information fusion platform. The flexibility of such a system, relying on many different types and sources of information, puts special emphasis on issues like requirements specification and validation, e.g. in fuzzy and volatile domains, as well as adequate testing methods for such domains.

The scenario involves one senior researcher and three existing PhD students. Two of the PhD students write their theses in the area of decision support in requirements engineering and the third PhD student focuses on testing. In this scenario we bring together researchers that traditionally do not collaborate which is intended to bring new insights into common problems, in particular with regard to supporting decision-making in the different phases of system/software development.

Industry interest in this scenario has led to the formation of a project for fusion of requirements and test information that addresses improved information and decision quality. It does so by working towards integrating these activities in the system/software development process through sharing of information.



Research Question

For this scenario, we have not defined a detailed research question, since we are exploring new grounds as described in the following text. The general question we ask is: *What is the potential for using information fusion as a means of improving decision-making in the systems and software development process?*

Given that the outcome of the project in the scenario points towards a positive answer to this question, we will formulate more detailed research questions for future research.

The systems life cycle is to a large extent an information management process, which deals with a large variety of information types (Figure 1). The process also has to deal with a number of versions of this information that pertain to different phases in the systems life cycle.

This information takes different forms, such as e.g. graphical models, formal textual specifications and natural language text specifications (as suggested in Figure 2). The information is stored using a number of different media. Some is stored in software engineering tools that often do not

communicate with each other, and some is stored as spreadsheet or word processor files.

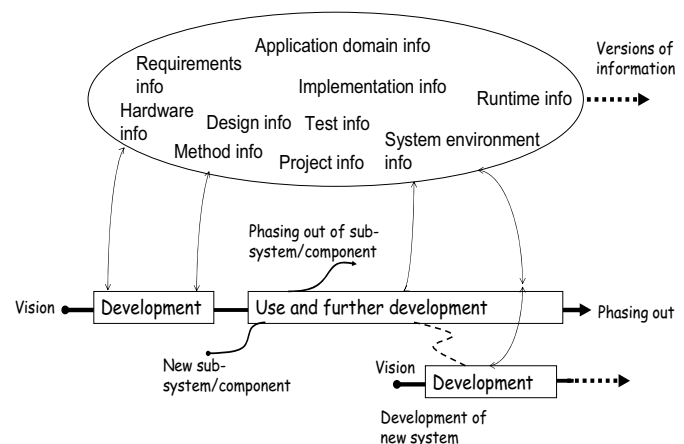


Figure 1: The system life cycle

In addition to this, the systems/software development process is a decision-driven process, where decisions are continuously and concurrently made by a large number of actors who play various roles in the development process.

In summary, the information that is managed throughout the system/software development process is fragmented and takes many different forms. Hence, is inherently difficult to provide a

coherent view of the information or some portion of the information that can function as basis for decisions. In fact, it is more or less impossible to make a high quality impact analysis and fully understand the implications of a decision. This poses a serious threat to software quality and also to the productivity of the development process.

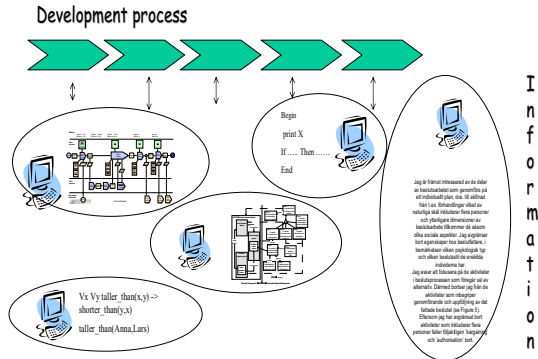


Figure 2: Examples of information types in the systems/software development process

Relevance to Information Fusion

The problem described above has several characteristics that indicate the relevance of investigating whether or not information fusion techniques could support the decision-making process and improve the predictability of decision outcomes:

1. Decisions are based on complex information
2. The information takes many forms and is stored using different media.
3. The decision-making process is typically manual and relies heavily on the personal skills of the decision-maker.

With reference to figure 3, inspired by the JDL model, the level of awareness with regard to overview of the situation needs to be raised, as indicated in the left side of the picture. Doing that without a higher degree of automation, as indicated in the right side of the picture, is inherently difficult in this domain. Automation is needed for collecting, processing, and presenting complex information.

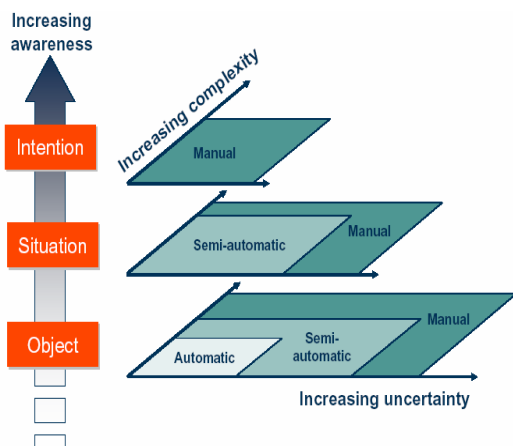


Figure 3: Awareness, complexity and uncertainty

We perceive the most difficult problem to be:

1. Extraction and processing of data from graphical models and from sources such as natural language texts and spreadsheets. Extracting the semantics from graphical models is a particular challenge. For natural language texts, computational linguistics techniques could be a potential route ahead (see scenario IF bio – Bioinformatics).
2. Visualization of complex data in a view that for a certain problem describes the “situation” at hand. In this scenario a particular challenge is to find illustrative means of visualization. One issue here is e.g. to define the “objects” that are to be visualized.

Finally, we once again emphasize the explorative nature of this scenario. We explore the potential for using IF techniques to improve decision-making in systems development/software engineering. On the basis of our findings more concrete IF research questions will be formulated. This means that when it comes to concrete use of methods and techniques for information fusion, this scenario is at the very beginning.

Highlights in 2007

Since there is only one project in the scenario, we refer to the project summary for IF sd1 Information Management for Requirements and Testing in Software Development.

Projects within scenario IF sd

There is only one project in this scenario: IF sd1 Information Management for Requirements and Testing in Software Development. Therefore, we refer to the project summary of IF sd1 as concerns:

- industrial and scientific cooperation,
- approach,
- contribution to IF goals,
- results achieved, and
- related work.

Growth potential for scenario

We consider the idea of information fusion in the domain of systems/software development to be a novel and fruitful one.

The research included in the project plan of the project in the scenario has been completed, although there is still some calendar time left. We find that the idea behind the project is still promising, but in order to proceed to the next level other partner companies than the ones currently involved have to be sought. Suitable partners would be tool developers/vendors and so far we have had no success in attracting such partners to be involved in the research program.

A decision has, therefore, been made to make this scenario inactive in the research program from December 31, 2007, while opportunities for continuing this line of research are investigated.

Start: 1 Apr 2005 (3 yrs)

Project: IF sdl infokrat**Information Management for Requirements and Testing
in Software Development**

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Systems/software development is a process that heavily involves complex decision-making and information management. A large number of actors/decision-makers are dependent on the ability of “making sense” of information that is fragmented in various tools and documents. Despite this, effective and efficient decision support hardly exists. This project has taken a first step towards investigating the potential for using information fusion to support decision-making in systems/software development. It has done so by focusing on the requirements engineering and testing phases in the development process.

Research Question

The research question of the scenario is: *What is the potential for using information fusion as a means of improving decision-making in the systems and software development process?*

The complexity of the systems and software development process motivates to focus on some critical activities in the process. A large body of research points to requirements engineering as being perhaps the most critical activity for successful systems and software development. The mirror image of this activity is systems and software testing. Software is tested against requirements. Therefore, the project has chosen to focus on these two dependent activities and their interaction.

The project vision is to improve precision and requirements fulfillment in software and to decrease the lead-time in the development process. More specifically, the research questions are:

1. How can the computer supported fusion of information from different phases of the systems and software development process be increased, particularly when it comes to requirements information and test information?
2. How can integration of tools and fusion of requirements and test information improve decision-making in requirements engineering and testing?
3. How can the fusion of information support synergy between requirements engineering and enable continuous refinement of the information?

Relevance to Information Fusion

This project takes an initial step towards the research question formulated for the systems and software development scenario. The results of this project potentially opens new applications for IF methods and technology.

Highlights in 2007

Mats Grindal successfully defended his PhD thesis “Handling Combinatorial Explosion in Software Testing” in March. Submitted her PhD thesis “Envisioning a Future Decision support System for Requirements Engineering: A Holistic and Human-centred Perspective” and successfully defended it in February 2008.

Cooperation**Industrial**

This project is in collaboration between the University of Skövde, Enea Systems AB, Atlas Copco Tools AB and Ericsson Microwave Systems AB as part of the Information Fusion program.

Scientific

The project involves Professor Sture Hägglund and PhD Pär Carlshamre, Linköping University, taking the role of co supervisors of PhD theses.

Approach

The project has the following main activities:

1. Requirements on requirements information

This activity investigates how software requirements as well as the information about the requirements should be specified and documented in order to support decision-making in the requirements engineering process and effective development of test cases as well as enable a higher degree of automation. The results of this activity include:

- R1. A description of the decision-making processes in requirements engineering where requirements are used as input to decisions, and
- R2. A description of the need of requirements information and traceability mechanisms that exist in testing.

2. Tool evaluation

This activity compares a number of commercial requirements management tools with regard to their ability to fulfill the need for requirements

information that testers and requirements engineers have when it comes to decision-making. Particular attention is paid to how the tools visualize complex information in support of decision-making, e.g. in development of test cases and impact analysis in connection to requirements change. The results of this activity include:

R3. An evaluation of a number of commercial requirements management tools based on a number of developed criteria.

3. Development of methods and tools

This activity enhances methods and tools for refinement of requirements information to test information, in support of test case development. The following tasks are involved:

- Enhance and evaluate methods and tools for fusion of requirements and test information.
- Develop a method for development of test cases, based on the information that was integrated.

The results of this activity include:

R4. A method for fusion of relevant requirements and test information

R5. A number of evaluation methods that support decisions concerning a suitable combination strategy for the testing. Suitability is evaluated with regard to the requirements concerned and available resources

R6. A number of instances of implementing the evaluation methods.

4. Analysis of results

This activity involves a thorough analysis of the results and an evaluation of the results against scenario and IF common goals. Based on evaluation results, new research questions are formulated.

Contribution to *infusion* goals

The project discovers and describes work methods in requirements engineering through evaluation of requirements management tools from a decision-making perspective and through development of methods and tools from developing test-cases based on information stored in requirements tools. Through this work the researchers will gain new knowledge about the nature and the challenges of decision-making in this area. This will be one of the contributions to evaluating whether or not systems/software development is a potential application area for information fusion techniques. The knowledge and experiences from this project will also, together with knowledge from other application areas in the research programme, form valuable input to an enhanced understanding for the application of IF in various domains.

With regard to specific common goals projects, the project is mainly related to the IF cgil framework, Information Fusion and Decision support: Cognitive and Organizational Factors. One specific contribution to this framework is the description of the nature of decision-making in requirements engineering. Further on, the inclusion of computational linguistics techniques could potentially be interesting for testing in this domain.

The results of the project have potential for being commercially interesting, in particular for developers of support tools for software development.

Results achieved in project

Work has progressed well with active involvement and support from the industrial partners.

The progress of project results are as follows:

R1. Completed
R2. Completed
R3. Completed
R4. Completed
R5. Completed
R6. Completed

We consider the idea of information fusion in the domain of systems/software development to be a novel one. After almost three years of working with this problem we are still convinced that it is novel. When it comes to decision-making in requirements engineering very little research has been done. A few papers have been published but they mainly point to the challenges. No solutions are proposed, which is one of the main contributions of Beatrice Alenljung's thesis. She proposes characteristics and design strategies to support decision-making in requirements engineering that will require information fusion techniques to be effectively implemented.

The research included in the project plan has been completed, although there is still some calendar time left. We find that the idea behind the project is still promising, but in order to proceed to the next level other partner companies than the ones currently involved have to be sought. Suitable partners would be tool developers/vendors.

A decision has, therefore, been made to make this scenario inactive in the research program from December 31, 2007, while opportunities for continuing this line of research are investigated.

Appendix F Sponsors and partners

IN PARTNERSHIP WITH THE
Knowledge Foundation ><

Grevillia
FOND



Gothia Science Park
Teknikparken vid Högskolan i Skövde



Sparbanksstiftelsen
Alfa

Bioinformatics

Lexware® Labs

Arexis



cellartis

Ground Situation Awareness



SAAB

EXENSOR
Awareness Assured

Manufacturing



Precision Agriculture



Retail Sector



Systems Development



Appendix G Personnel in 2007

sd	Anne Persson	10%	Asst Prof	sd1
pa	Bo Magnusson	15%	Asst Prof	pa1
	Elzbieta Dura	50%	Asst Prof	
	Göran Falkman	15%	Asst Prof	gsa3
	Mikael Ejdebäck	10%	Asst Prof	
	Mikael Harlen	5%	Asst Prof	
	Tarja Susi	8%	Asst Prof	
	Mattias Strand	16%	Asst Prof	
	Amos Ng	10%	Asst Prof	
	Thomas Lezama	10%	Asst Prof	
	Sandor Ujvari	5%	Asst Prof	mfg2
	Joeri van Laere	5%	Post-doc	
	Ronnie Johansson	50%	Post-doc	
	Thomas Kronhamn	20%	Adjunct Prof	Saab AB
	Håkan Warston	21%	Adjunct Prof	Saab AB
Total number:	15			

Other staff at the university (roles: information, marketing, administration, and financial statements)

	Anita Andler	40%	Other staff
	Camilla Andersson	50%	Other staff
	Jill Elmshorn	70%	Other staff
	Marcus Brohede	15%	Other staff
Total number:	4		

PhD students, funded by the Knowledge Foundation

	Alexander Karlsson	80%	PhD student	KK funded (80%)
	Anders Dahlbom	80%	PhD student	KK funded (80%)
	Elie Järnmark	80%	PhD student	KK funded (80%)
	Fredrik Johansson	80%	PhD student	KK funded (80%)
	Jane Synnergren	80%	PhD student	KK funded (80%)
	Lina Nolin	80%	PhD student	KK funded (60 of 80%)
	Maria Nilsson	80%	PhD student	KK funded (80%)
	Maria Riveiro	80%	PhD student	KK funded (80%)
	Beatrice Alenljung	60%	Sr PhD stud	KK funded (60%)
	Mats Grindal	20%	Ind PhD stud	KK funded (20 of 60%)
	Rickard König	55%	PhD student	KK funded (50 of 80%)
	Tuve Löfström	55%	PhD student	KK funded (50 of 80%)
New 2007	Catarina Dudas	80%	PhD student	KK funded (75 of 80%)

Total number: 13

Senior PhD students, funded by the university or other sources

	Åsa Dahlstedt	50%	Sr PhD stud	
	Jonas Gamalielsson	30%	Sr PhD stud	
	Kim Laurio	40%	Sr PhD stud	
	Marcus Brohede	40%	Sr PhD stud	
	Simon Wetterlind	80%	Sr PhD stud	
	Per Hilletoft	50%	PhD student	
	Klas Hedenberg	50%	PhD student	
	Stefan Ericson	50%	PhD student	
	Per Gustavsson	50%	Ind PhD stud	University of Skövde/
	Tehseen Aslam	80%	PhD student	Saab AB

Total number: 10

Total number of PhD students 23

Industry participants

Knud Nissen		Industry	AgroVäst AB
Mats Söderström		Industry	AgroVäst AB
Sofia Delin		Industry	AgroVäst AB
Thomas Svensson		Contact person	Arexis AB
Janne Lundberg	10%	Contact person	Atlas Copco Tools AB
Daniel Berggren	5%	Industry	Atlas Copco Tools AB
Arne Muñoz		Industry	Atlas Copco Tools AB
Petter Björquist	4%	Contact person	Cellartis AB
Johan Hyllner	5%	Industry	Cellartis AB
Karin Noaksson	25%	Industry	Cellartis AB
Karina Moya	9%	Industry	Cellartis AB
Mats Lundwall	4%	Industry	Cellartis AB
Mikael Englund	14%	Industry	Cellartis AB
Peter Sartipy	22%	Industry	Cellartis AB
Ulrika Törn	10%	Industry	Cellartis AB
Fredrik Wessberg	20%	Industry	Cellartis AB
Marie Renström	15%	Industry	Cellartis AB
Petter Hjelmqvist		Contact person	Electrolux Major Appliances
Bert G Levefelt		Industry	Electrolux Major Appliances
Anders P Johansson		Industry	Electrolux Major Appliances
Stefan Ryd		Industry	Electrolux Major Appliances
Paul Hughes		Industry	Electrolux Major Appliances
Malin Kvarnud		Industry	Electrolux Major Appliances
Björn Ekeberg		Industry	Electrolux Major Appliances
Peter Bäckebo		Industry	Electrolux Major Appliances
Henrik Frisk		Industry	Electrolux Major Appliances
Micael Wästefors		Industry	Electrolux Major Appliances
Anders Magnusson		Industry	Electrolux Major Appliances
Bengt Esplund		Industry	Electrolux Major Appliances
Horst Raupach		Industry	Electrolux Major Appliances
Emma Bodemyr		Industry	Electrolux Major Appliances
Tommy Olsson		Industry	Electrolux Major Appliances
Fredrik Adamsson		Industry	Electrolux Major Appliances
Zoher Bharmal		Industry	Electrolux Major Appliances
Jan Eklund		Industry	Electrolux Major Appliances
Christer Lindgren		Industry	Electrolux Major Appliances
Ulf Andersson		Industry	Electrolux Major Appliances
Rickard Modigh		Industry	Electrolux Major Appliances
Andreas Sjöberg		Industry	Electrolux Major Appliances
Subtotal:	39		

Stefan Balazs		Industry	EuroMaint Industry AB
Thomas Kanestad		Contact person	ICA Sverige AB
Christer Orrebrink		Industry	ICA Sverige AB
Charlotta Svarfvar		Contact person	ICA Sverige AB
Carina Pettersson		Industry	ICA Sverige AB
Jonas Gunnarsson		Industry	ICA Sverige AB
Anders Livchitz		Industry	ICA Sverige AB
Regina Essal		Industry	ICA Sverige AB
David Holmstrand		Industry	ICA Sverige AB
Annica Carlsson		Industry	ICA Sverige AB
Christer Nyman		Industry	ICA Sverige AB
Elzbieta Dura	20%	Contact person	LexWare Labs AB
Maciej Drejak	5%	Industry	LexWare Labs AB
Marek Drejak	15%	Industry	LexWare Labs AB
Tomas Planstedt	14%	Contact person	SMW, gsa
Håkan Warston	20%	Industry	SMW, gsa
Martin Smedberg	32%	Industry	SMW, gsa
Thomas Kronhamn	21%	Industry	SMW, gsa
Christoffer Brax	80%	Industry	SMW, gsa
Per Scherman		Contact person	SMW, sd
Kent M Eriksson		Contact person	Volvo Powertrain
Anders Holm		Industry	Volvo Powertrain
Johan Ekengård		Industry	Volvo Powertrain
Subtotal:	35		
Total number of people at University of Skövde			42
Total number of people at partner companies			74
Total number of people involved in 2006			116

Appendix H Financial report 2007

Contents

Financial report

Signature page

Budget for 2008

Information Fusion Research Program
Financial report 2007

infofusion
Total income

Intäkter (kr)	Budget för projekt i profilen	Bokförda intäkter perioden (1) 20070101 - 20071231	Bokförda intäkter perioden (1) 20060101 - 20061231	Bokförda intäkter perioden (1) 20050401 - 20051231	Bokförda intäkter ackumulerat (1) 20050401 - 20071231
Bidrag från KK-stiftelsen	7 375 000	7 000 000	6 200 000	3 700 000	16 900 000
Bidrag från deltagande företag	10 844 250	8 236 553	8 846 000	5 718 000	22 800 553
Bidrag från HS (2)	8 974 000	7 552 179	6 491 774	3 612 872	17 656 825
Summa intäkter i kronor	27 193 250	22 788 732	21 537 774	13 030 872	57 357 378

Intäkter (kr)	Budget för associerade projekt	Bokförda intäkter perioden (1) 20070101 - 20071231	Bokförda intäkter perioden (1) 20060101 - 20061231	Bokförda intäkter perioden (1) 20050401 - 20051231	Bokförda intäkter ackumulerat (1) 20050401 - 20071231
Bidrag från KK (Modpharm)	0	0	1 260 000	0	1 260 000
Bidrag från bl a Alfastiftelsen (3)	0	0	50 000	1 632 885	1 682 885
Summa intäkter i kronor	0	0	1 310 000	1 632 885	2 942 885

Totala intäkter i kronor	27 193 250	22 788 732	22 847 774	14 663 757	60 300 263
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(1) Bidrag som lämnats i annan form än kontanta bidrag skall här räknas om till kronor i enlighet med företagets principer för interndebitering

(2) Bidraget från HS inkluderar strategiska medel och resebidrag (449 440kr)

(3) Bidrag från Alfastiftelsen och Grevillifond till Fusion som Vision

Information Fusion Research Program
Financial report 2007

infofusion
Total expenses

Kostnader (kr)	Budget			Bokförda kostnader (korrigerade) 20070101 - 20071231		
	HS	KK	Totalt	HS	KK	Totalt
Lönekostnader (inkl.arbetsgivaravg.)	6 275 525	4 744 755	11 020 280	5 281 245	3 918 734	9 199 979
Övriga kostnader (1)	627 552	474 476	1 102 028	528 124	391 873	919 997
Summa kostnader	6 903 077	5 219 231	12 122 308	5 809 369	4 310 607	10 119 976
Högskolepålägg 21%	1 449 646	1 096 038	2 545 684	1 219 967	905 227	2 125 194
Inst.pålägg 9 %	621 277	469 731	1 091 008	522 843	387 955	910 798
Summa före moms	8 974 000	6 785 000	15 759 000	7 552 179	5 603 789	13 155 968
Högskolemoms		590 000	590 000		487 286	487 286
Summa kostnader	8 974 000	7 375 000	16 349 000	7 552 179	6 091 075	13 643 254

Kostnader (kr)	Differens mot budget 2007			Bokförda kostnader ackumulerat 20050401 - 20071231		
	HS	KK	Totalt	HS	KK	Totalt
Lönekostnader (inkl.arbetsgivaravg.)	-994 280	-826 021	-1 820 301	12 347 430	8 321 943	20 669 373
Övriga kostnader	-99 428	-82 603	-182 031	1 234 743	832 194	2 066 937
Summa kostnader	-1 093 708	-908 624	-2 002 332	13 582 173	9 154 137	22 736 310
Högskolepålägg 21%	-229 679	-190 811	-420 490	2 852 257	1 922 369	1 704 704
Inst.pålägg 9 %	-98 434	-81 776	-180 210	1 222 396	823 872	730 588
Summa före moms	-1 421 821	-1 181 211	-2 603 032	17 656 826	11 900 378	29 557 204
Högskolemoms	0	-102 714	-102 714	0	1 034 815	1 034 815
Summa kostnader	-1 421 821	-1 283 925	-2 705 746	17 656 826	12 935 193	30 592 019

(1) Övriga kostnader är baserade på ett schablonpåslag om 10% på lönekostnader

Financial report 2007

Project expenses

Kostnader (kr) inklusive overhead(*)	Projektbudget 2007 för projekt i profilen			Bokförda kostnader 20070101 - 20071231			Differens	
	HS	KK profil	Totalt	HS	KK profil	Totalt	HS	KK profil
IF cgi1 framework	619 000	1 126 000	1 745 000	421 727	1 011 636	1 433 363	-197 273	-114 364
IF cgi2 methods	301 000	1 124 000	1 425 000	288 314	918 876	1 207 190	-12 686	-205 124
IF cgi3 infrastructure	765 000	537 000	1 302 000	598 790	325 357	924 146	-166 210	-211 643
IF gsa1 algorithms	444 000	520 000	964 000	393 519	502 311	895 830	-50 481	-17 689
IF gsa2 visualization	268 000	520 000	788 000	289 458	455 486	744 945	21 458	-64 514
IF gsa3 hypotheses	467 000	520 000	987 000	546 331	424 650	970 981	79 331	-95 350
IF bio1 cells	364 000	524 000	888 000	395 388	495 385	890 773	31 388	-28 615
IF bio2 lipids	480 000	524 000	1 004 000	568 627	382 838	951 465	88 627	-141 162
IF bio3 info extract	278 000	0	278 000	306 703	0	306 703	28 703	0
IF rs1 prognoses	193 000	272 000	465 000	179 698	274 002	453 699	-13 302	2 002
IF rs2 data mining	164 000	272 000	436 000	108 520	308 947	417 466	-55 480	36 947
IF mfg1 manufacturing	478 000	203 000	681 000	408 804	154 216	563 020	-69 196	-48 784
IF mfg2 manufacturing	424 000	0	424 000	335 705	0	335 705	-88 295	0
IF mfg3 manufacturing	48 000	203 000	251 000	50 128	142 085	192 213	2 128	-60 915
IF pal prec agricult	1 599 000	389 000	1 988 000	1 081 188	280 631	1 361 818	-517 812	-108 369
IF sd1 infokrat	657 000	641 000	1 298 000	457 466	414 732	872 198	-199 534	-226 268
IF adm1 mgmt/activities (**)	1 425 000	0	1 425 000	1 121 816	-76	1 121 740	-303 184	-76
Summa kostnader i kronor	8 974 000	7 375 000	16 349 000	7 552 179	6 091 075	13 643 254	-1 421 821	-1 283 925

Kostnader (kr)	Projektbudget 2007 för associerade projekt			Bokförda kostnader (korrigerade) 20070101 - 20071231			Differens	
	HS	Externt	Totalt	HS	Externt	Totalt	HS	Externt
IF bio4 modPharm	0	42 385	42 385	0	42 385	42 385	0	0
assoc1 Fusion som vision	0	416 253	416 253	0	416 253	416 253	0	0
Summa kostnader i kronor	0	458 638	458 638	0	458 638	458 638	0	0
Totalt kostnader i kr	8 974 000	7 833 638	16 807 638	7 552 179	6 549 713	14 101 892	-1 421 821	-1 283 925

(*) Projektbudget och kostnader är angivna inklusive högskolepålägg 24% och institutionspålägg 11% (motsvarande avdrag 26%)

(**) Detta inkluderar kostnader för Sensor Networks Testbed (62 660kr)

Kostnader (kr) inklusive overhead(1)	Bokförda kostnader perioden 20070101 - 20071231			Korrigerig gällande 2007 (2)			Bokförda kostnader (korrigerade) 2007		
	HS	KK profil	Totalt	HS	KK profil	Totalt	HS	KK profil	Totalt
IF cgi1 framework	421 727	1 011 636	1 433 363				421 727	1 011 636	1 433 363
IF cgi2 methods	288 314	918 876	1 207 190				288 314	918 876	1 207 190
IF cgi3 infrastructure	598 790	325 357	924 146				598 790	325 357	924 146
IF gsa1 algorithms	393 519	502 311	895 830				393 519	502 311	895 830
IF gsa2 visualization	222 660	455 486	678 146				289 458	455 486	744 945
IF gsa3 hypotheses	420 254	424 650	844 904				546 331	424 650	970 981
IF bio1 cells	395 388	495 385	890 773				395 388	495 385	890 773
IF bio2 lipids	568 627	382 838	951 465				568 627	382 838	951 465
IF bio3 info extract	306 703	0	306 703				306 703	0	306 703
IF rs1 prognoses	179 698	274 002	453 699				179 698	274 002	453 699
IF rs2 data mining	108 520	308 947	417 466				108 520	308 947	417 466
IF mfg1 manufacturing	-156 870	675 158	518 289	565 674	-520 943	44 731	408 804	154 216	563 020
IF mfg2 manufacturing	255 400	0	255 400	80 305		80 305	335 705	0	335 705
IF mfg3 manufacturing	0	0	0	50 128	142 085	192 213	50 128	142 085	192 213
IF pa1 prec agricult	1 081 188	280 631	1 361 818				1 081 188	280 631	1 361 818
IF sd1 infokrat	457 466	414 732	872 198				457 466	414 732	872 198
IF adm1 mgmt/activities	1 121 816	-76	1 121 740				1 121 816	-76	1 121 740
Summa kostnader i kronor	6 663 198	6 469 933	13 133 130	696 107	-378 858	317 250	7 552 179	6 091 075	13 643 254

Kostnader (kr) inklusive overhead(*)	Bokförda kostnader perioden 20070101 - 20071231			Korrigerig gällande 2007		Bokförda kostnader (korrigerade) 20070101 - 20071231		
	HS	Externt	Totalt	HS	Externt	HS	Externt	Totalt
IF bio4 modPharm			0			0	0	0
IF assoc1 Fusion som vision			0			0	0	0
Summa kostnader i kronor	0	0	0	0	0	0	0	0
Totalt kostnader i kr	6 663 198	6 469 933	13 133 130	696 107	-378 858	7 552 179	6 091 075	13 643 254

(1) Projektbudget och kostnader är angivna inklusive högskolepålägg 21% och institutionspålägg 9% (motsvarande avdrag 23%)

(2) Korrigeringen gäller lönekostnader för personal som blivit konterade på fel kostnadsbärare

**Information Fusion Research Program
Financial report 2007**

***infofusion*
Signatures**

Stefan Axelsson
Redovisningsansvarig

Sten F Andler
Programdirektör

Johan Norén
Referensgruppens ordförande

Information Fusion Research Program

Budget for 2008 - passed by Infofusion Executive Committee on 21 Dec 2007

Annual budgets and allocations 2005 - 2011

infusion Annual budgets and allocations (KSEK)
Infusion 2005 - 2011

	KK	HS			
		HS tot	IKI	IVN	ITS
2005	2 206	3 569	2 913	446	210
2006	6 779	7 687	5 165	1 269	1 253
2007	7 375	9 364	6 029	1 341	1 994
2008	6 223	8 161	4 939	1 300	1 922
2009	5 976	8 416	4 871	1 566	1 980
2010	3 830	8 416	4 912	1 482	2 022
2011	310	2 022	1 191	449	382
Total	32 700	47 635	30 019	7 852	9 764

IF cgi	cgi1		cgi2		cgi3		Scenario total	
	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)
IKI								
2005	130	147	130	112	0	121	260	380
2006	765	372	765	254	210	474	1 740	1 100
2007	893	497	891	301	303	643	2 087	1 441
2008	851	639	804	296	214	662	1 869	1 596
2009	680	658	828	304	185	684	1 692	1 646
2010	510	678	510	314	73	649	1 093	1 640
2011	37	175	0	81	19	0	56	255
IKI total	3 867	3 165	3 928	1 661	1 003	3 233	8 797	8 059
ITS								
2005	0	0	0	0	0	91	0	91
2006	175	0	0	0	88	122	263	122
2007	233	0	0	0	117	122	350	122
2008	255	0	0	0	46	0	301	0
2009	66	0	0	0	43	0	109	0
2010	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0
ITS total	729	0	0	0	294	335	1 023	335
IVN								
2005	0	91	0	0	0	0	0	91
2006	0	122	175	0	88	0	263	122
2007	0	122	233	0	117	0	350	122
2008	0	0	208	0	108	0	316	0
2009	0	0	214	0	111	0	325	0
2010	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0
IVN total	0	335	830	0	424	0	1 254	335
object total	4 596	3 500	4 758	1 661	1 721	3 568	11 074	8 729
Checksum	4 665	3 361	4 656	1 646	1 729	3 617	11 050	8 624

IF gsa	gsa1		gsa2		gsa3		gsa4		Total	
	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)
2005	130	223	130	101	130	144	0	0	390	468
2006	520	297	520	194	520	459	0	223	1 560	1 173
2007	520	444	520	268	520	467	0	383	1 560	1 562
2008	459	432	459	202	459	481	0	0	1 377	1 116
2009	473	445	473	208	473	281	0	0	1 419	935
2010	365	458	365	215	365	290	0	0	1 096	963
2011	0	118	0	55	0	75	0	0	0	248
IKI total	2 467	2 417	2 467	1 244	2 467	2 197	0	606	7 402	6 464
object total	2 467	2 417	2 467	1 244	2 467	2 197	0	606	7 402	6 464
Checksum	2 600	2 409	2 600	1 435	2 600	1 874	0	1 563	7 800	7 281

IF bio	bio1		bio2		bio3		bio4		Total	
	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)
IKI										
2005	385	263	0	0	0	392	0	0	385	655
2006	513	351	0	0	0	522	0	0	513	873
2007	524	364	0	0	0	278	0	0	524	642
2008	0	0	0	0	0	237	0	0	0	237
2009	0	0	0	0	0	244	0	0	0	244
2010	0	0	0	0	0	252	0	0	0	252
2011	0	0	0	0	0	65	0	0	0	65
IKI total	1 422	978	0	0	0	1 990	0	0	2 600	4 132
IVN										
2005	0	0	385	331	0	0	0	0	385	331
2006	0	0	513	442	0	0	0	0	513	442
2007	0	0	524	480	0	0	0	0	524	480
2008	511	264	515	432	0	0	0	106	1 026	802
2009	526	267	530	441	0	0	0	109	1 056	817
2010	135	270	546	449	0	0	0	112	682	832
2011	0	187	141	233	0	0	0	29	141	449
IVN total	1 172	988	3 154	2 808	0	0	0	356	4 326	4 152
object total	2 594	1 966	3 154	2 808	0	1 990	0	356	6 926	8 284
Checksum	2 600	2 161	2 600	2 812	0	1 971	0	5 200	6 944	6 944

IF rs	rs1		rs2		Total	
	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)
2005	204	76	204	71	408	147
2006	272	171	272	164	544	335
2007	272	193	272	171	544	364
2008	287	187	287	165	574	353
2009	296	193	296	170	591	363
2010	76	176	76	153	152	329
2011	0	43	0	37	0	81
IKI total	1 407	1 040	1 407	932	2 813	1 972
oject total	1 407	1 040	1 407	932	2 813	1 972
Checksum	1 360	1 019	1 360	915	2 720	1 934

IF mfg	mfg1		mfg2		mfg3		Total	
	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)
2005	0	51	0	0	0	0	0	51
2006	488	278	0	318	0	0	488	596
2007	203	478	0	424	203	48	406	950
2008	0	522	0	455	416	28	416	1 005
2009	0	538	0	468	429	29	429	1 035
2010	0	554	0	482	442	29	442	1 066
2011	0	17	0	124	114	8	114	149
ITS total	691	2 438	0	2 272	1 604	141	2 295	4 851
oject total	691	2 438	0	2 272	1 604	141	2 295	4 851
Checksum	691	2 517	0	2 122	1 785	426	2 476	5 065

IF pa	pa1		pa2		pa3		pa4		Total	
	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)	KK (24)	HS (23)
2005	0	24							0	24
2006	391	705							391	705
2007	389	739							389	739
2008	344	268	0	230	0	0	0	0	344	498
2009	355	276	0	473	0	0	0	0	355	749
2010	365	284	0	365	0	0	0	0	365	650
2011	0	0	0	0	0	0	0	0	0	0
IVN total	1 844	2 297	0	1 068	0	0	0	0	1 844	3 365
2005	0	17							0	17
2006	0	467							0	467
2007	0	860							0	860
2008	0	0	0	0	0	430	0	425	0	854
2009	0	0	0	0	0	443	0	438	0	880
2010	0	0	0	0	0	446	0	444	0	890
2011	0	0	0	0	0	107	0	109	0	216
ITS total	0	1 344	0	0	0	1 425	0	1 415	0	4 185
oject total	1 844	3 641	0	1 068	0	1 425	0	1 415	1 844	7 549
Checksum	1 946	7 679							1 946	7 679

IF sd	sd1		Total	
	KK (24)	HS (23)	KK (24)	HS (23)
2005	378	318	378	318
2006	504	424	504	424
2007	641	657	641	657
2008	0	0	0	0
2009	0	0	0	0
2010	0	0	0	0
2011	0	0	0	0
IKI total	1 523	1 399	1 523	1 399
oject total	1 818	1 564	1 818	1 564
Checksum	1 818	1 564	1 818	1 564

IF adm	adm1		Total	
	KK (24)	HS (23)	KK (24)	HS (23)
2005	0	945	0	945
2006	0	1 260	0	1 260
2007	0	1 363	0	1 363
2008	0	1 637	0	1 637
2009	0	1 682	0	1 682
2010	0	1 728	0	1 728
2011	0	543	0	543
IKI total	0	9 158	0	9 158
2005	0	51	0	51
2006	0	68	0	68
2007	0	62	0	62
2008	0	63	0	63
2009	0	65	0	65
2010	0	67	0	67
2011	0	17	0	17
ITS total	0	393	0	393
oject total	0	9 551	0	9 551
Checksum	0	8 380	0	8 380

Appendix J Plan for development of the research program

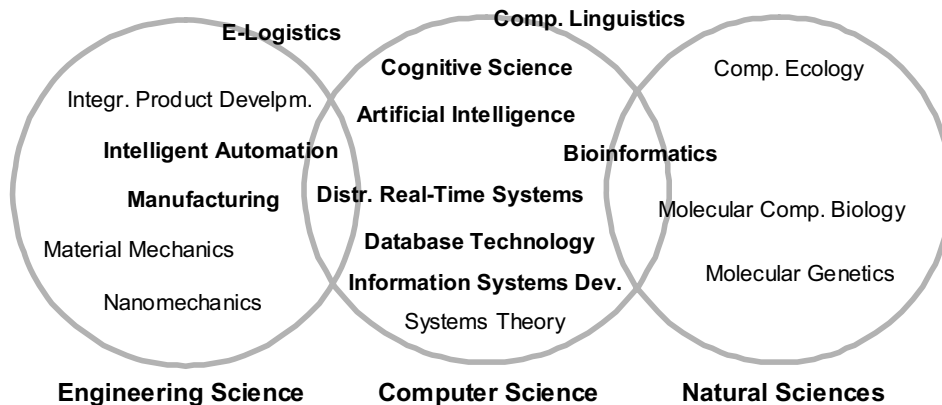


Figure: The Technology area –research groups and their relations to disciplines

The research within the Information Fusion Research Program constitutes a large proportion of the overall research conducted within the technology area at the University of Skövde; creating bridges between several central research groups (see Figure).

The research program covers different application areas of information fusion, for example intelligent automation and manufacturing, bioinformatics and health care. Technology areas important to information fusion are artificial intelligence (fusion algorithms and decision support) information systems development (methodological questions for software development) simulation and distributed real-time and database systems (infrastructures for information systems). The program also covers related theoretical areas such as cognitive science, and has the opportunity to consult with competent researchers from other areas of research closely connected to aspects of information fusion, e.g. computer linguistics, human-computer interaction, decision-making and e-logistics. The program will play a very important role in the development of 3-5 so called *strong research environments* (i.e., environments suitable for research education, which means that they should have both breadth and depth) at the University of Skövde.

J.1 The main research focus of the University of Skövde

The research conducted at the University of Skövde is mainly focused on development of advanced models and systems for information technology, where human constraints and needs are central. The research aims to develop computer-based models for technical and social systems, and for the understanding of natural systems. The demands of the application area must be integrated into and influence the entire development process and this is of central importance when developing such systems. Furthermore, the development process and subsequently the system must take into account human user constraints and abilities.

The research has depth within the relevant areas of computer science and within the application areas. Different sub-areas are integrated in such a way that they contribute to the overall vision of the profile.

J.2 Infrastructure that supports the Research Program

This section highlights the essential parts of University's infrastructure that support the information fusion research program.

Graduate education

The University of Skövde has carried out graduate education since the mid-nineties. The Ph.D. students are currently enrolled at fifteen different universities, but conduct studies in Skövde. A majority have

their supervisors located at the university in Skövde. Currently, there are efforts to create a graduate education program that is shared by all Ph.D. students at the University. An important step in this direction has been an agreement between the universities of Skövde, Halmstad and Örebro to form a joint faculty of technology. The first two Ph.D. students enrolled within this cooperation, were information fusion Ph.D.s

Critical mass

During the early stages of the development of the University, research efforts took place mainly within the areas of computer science and automation. The research environments within these areas have matured and now contain a combination of senior and junior research faculty involved in both research and graduate education. This has proven to be important for the long-term development of the individual research groups. Since there is a close and natural connection between undergraduate education and research, it has been easy to recruit motivated and skilled graduate students.

The main research focus of the University can be classified as both broad and deep. Several research areas are interrelated, which has been invaluable when defining an overall research focus within information technology, connecting several sub-areas. The depth is manifested in that the research groups within the main research focus have a critical mass of researchers, in total around 50 faculty with a Ph.D. degree and Ph.D. students, currently around 75, at various levels of progress. Research efforts of the professors and students in 2005 summed to 76 Full-time-equivalents (FTEs) (16 for professors and 60 for Ph.D. students), compared to 66.5 (16.2 for professors and 50.3 for Ph.D. students) in 2002. 172 scientific papers were published in 2005, compared to 80 in 2002 (as highlighted in the application for the research profile).

Library

Advanced facilities to search, value and retrieve information are important for all higher education, both undergraduate and graduate. The University library has developed its role to become a social, cultural and intellectual environment and meeting point over the disciplinary boundaries of the research. The library also constitutes a pedagogical resource that serves an educational role of developing the students' skills in handling and evaluating information sources. More than 2000 students at all levels participate in some form of education in information competence on a yearly basis.

The development of the library follows the development of the University. The library has currently around 110,000 titles, about 400 printed journals and 5,100 electronic journals. The funds allocated to the library in 2005 constituted 3.4 % of the total University budget, compared to 3.5 % in 2002.

Research laboratories and equipment

Several special labs are available. Some of these are important to the technology area, e.g., labs for computer science, distributed real-time systems, human-computer interaction, and biosciences. Furthermore, there are labs for automation, electronics, mechanical engineering, and product development. The need for specialized labs will increase when the University obtains the right to issue Ph.D. degrees. This need can be met on the existing Campus.

J.3 Recruiting researchers and graduate students

A number of new researchers and graduate students must be recruited to the research program. There are two options for recruitment of graduate students, namely recruitment from within the University or external recruitment. The University of Skövde offers several undergraduate study programs within its research focus.

A conscious and long-term plan to ensure a high level of formal competence has resulted in a high ratio of researchers with a Ph.D. degree. Around 50% of the teaching staff at the University of Skövde currently hold a Ph.D. degree, and around 50 researchers in technology hold a Ph.D. degree. Around two thirds of the researchers live within a 50 km radius of the University, indicating that they have a long-term interest in developing the University.

Besides the offer of a stimulating research environment at the University, the geographical location of

Skövde increases the chances of recruiting faculty and students to the program. Sweden's two largest cities, Stockholm and Gothenburg, are located within two-hour commuting time. Employees of the University can choose to live in a larger city, e.g. Gothenburg with approx. 500,000 inhabitants, within one-hour commuting time, or close-by in a small town, e.g. Skövde with approx. 50,000 inhabitants and close access to nature.

J.4 Obtaining further funding

See section 8) Opportunity for continued funding.

J.5 Plan for 2007 – 2010

An important task for the program has been to establish a suitable organization for its management. This is especially important owing to the interdisciplinary nature of the program and the fact that a large number of research groups and companies are participating. It is essential that program activities are interlinked in such a way as to contribute to the overall research vision of the program.

The research program must serve four purposes:

1. Generate substantial research results that develop the overall research vision.
2. Generate important research results with industrial relevance so that participating industrial partners will continue their participation after 2010.
3. Develop activities that improve the ability to recruit students and faculty to the program
4. Provide a basis and infrastructure for graduate education

Organization

The Information Fusion Research Program is led by a Program Director and an Executive Committee, consisting of the program director and co-director, two additional scenario/project leaders and an industry representative. The Executive Committee handles the operational, day-to-day, issues of the program. The Executive Committee establishes research projects, graduate education and undergraduate study programs across the research groups in the program and across department boundaries.

The progress and direction of the research program is overseen by an Advisory Board that decide the program research direction and ensure that the program progresses towards the goals of the overall research vision by allocating funds to appropriate projects. The Advisory Board consists of 8 members with representatives from academia and industry. The Advisory Board meets twice each year, with research project leaders invited to some sessions.

The quality of all academic research and education is also monitored by the Faculty Board of Research and Education at the University of Skövde.

Some key operational choices that increase the impact of the program research and help obtain program goals are:

- Collaboration with national and international universities of all sizes
- Integrated research activities with regional and national industry
- Industrial relevance and close coupling to education, in particular M.Sc. studies as a recruiting path to Ph.D. studies
- Natural integration with Gothia Science Park
- Innovation, spin-off, industrial presence and participation
- Dissemination in academic forums as well as in industry and society

Listed below are the research groups participating in the initial stages of the program, including research group leaders. It should be noted that most of the existing participating faculty and students are funded from other sources, which allows new funding to be used to extend the program with new personnel.

Artificial Intelligence Research Group

Lars Niklasson, group leader

Bioinformatics Group

Björn Olsson, group leader

Center for Intelligent Automation

Leo De Vin, group leader

Cognitive Research Group

Tom Ziemke, group leader

Database Technology Group

Mikael Berndtsson, acting group leader

Distributed Real-Time Systems Research Group

Sten F. Andler, group/program leader

Information Fusion Common Goals and Infrastructure Scenario

Henrik Boström, scenario leader

Information Systems Engineering Research Group

Anne Persson, group leader

Molecular biology

Patric Nilsson, group leader

Three of these groups have contributed to the previously funded Learning Systems research platform: the Artificial Intelligence Research Group, the Cognitive Research Group and the Bioinformatics Group. One of the groups contributed to the Mechatronic Systems research platform: the Center for Intelligent Automation.

Activities

The implementation of a suitable research organization serves the purpose of developing the overall research vision of the program. The three goals of the research vision are considered key activities within the program. Participating researchers are required to actively contribute to at least one such key activity, in addition to one application-oriented activity.

Projects

A number of closely cooperating research projects is an important tool for generating good research results. Researchers in the program are expected to participate in projects that contribute to the overall program vision, and to projects in application areas. External partners, companies and organizations, are expected to *actively* participate in the projects, e.g., by participating in the formulation of problem definitions or by supplying personnel for active project participation. There will be a natural driving force for the participating groups to define projects, in cooperation with external partners and in line with the program vision.

Program participants are expected to participate in a joint program meeting once or twice annually. At this meeting, that may be held at a participating company site or at the University, the contribution of participating projects to the overall vision will be presented and discussed, one way of fulfilling the important goal of knowledge transfer

**Information Fusion Research Program
Annual Report 2007**

infofusion

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Referensgruppens ordförande

***infofusion* – Information Fusion Research Program**



HÖGSKOLAN I BORÅS



Gothia Science Park
Teknikparken vid Högskolan i Skövde

