Information Fusion

from Databases, Sensors and Simulations

Annual Report 2006

IN PARTNERSHIP WITH THE
Knowledge Foundation

UNIVERSITY OF SKÖVDE

Information Fusion

from Databases, Sensors and Simulations

Annual Report 2006

Technical Report HS-IKI-TR-07-007
December 2007

Sten F. Andler (Ed.), Program Director (sten.f.andler@his.se)
Marcus Brohede (Ed.), Program Administrator (marcus.brohede@his.se)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

www.infofusion.se

Part I Activity Report

The activity report is a statement of the development of the research program 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 University of Skövde has established an Information Fusion Research Program (***infofusion***), based on the research profile funded by the Knowledge Foundation in the area of "Information Fusion from Databases, Sensors and Simulations". The research program is vital 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, says Leif Larsson.

Our ambition is to build 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. Among other things, the advisory board makes sure that the research question of each project is well formulated. 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 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?

2 National and international competitive situation of the research program

The research program will achieve 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, we are confident that internationally highly competitive research will result.

2.1 International competitiveness today

The groups participating in the program have strong publication records. In 2006, the second year of operation of the Information Fusion

Research Program, we had six publications accepted to the 9th International Conference on Information Fusion in Florence, Italy, and a total of 26 publications. Several of the research leaders were also invited to speak at international conferences and workshops.

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 Rode 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.

Prof. Sang H. Son teaching at the ARTES summer school.

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.

A large number of smaller international conferences and workshops were also organized by the participating groups, e.g., RTiS 2005 – *Real-Time in Sweden Conference*, EJC 2004 – *European-Japanese Conference on Information Modelling and Knowledge Bases*, Bioinformatics 2001 – *International Conference of the Society for Bioinformatics in the Nordic countries*.

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 (in September 2006) 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 – 2008, 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.

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.

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

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.

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 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. Starting from spring 2005, Bachelors and Masters level students are offered the opportunity to complete a final year project in information fusion.

Starting in fall 2005, two PhD courses are offered, Systems Thinking and Information Fusion.

The 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.

The information fusion course was given twice during 2006 (the first round ended in spring and the second in winter). Eleven PhD students participated in the first round. In the second round, ten Master students and four PhD students participated. An important difference between the two rounds is that in the first round most lectures were given by invited speakers and in the second round most lectures were given by members of the Information Fusion Research Program (most of them students who took the previous course). The information fusion course will be given for Master and PhD students again in the fall of 2007.

Apart from the two rounds of the information fusion course, a course called "Advanced topics in information fusion" was also given with ten participating PhD students. The 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 course modules in the area of Information Fusion. The first such module was developed in 2006 and made available to the Masters program in Computer Science as well as the other Masters programs. Additional Masters level course modules will be developed in 2007.

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 are 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 *(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.

Atlas Copco Tools *(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 *(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.

Electrolux Major Appliances *(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, Skovde is in the business of 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)*

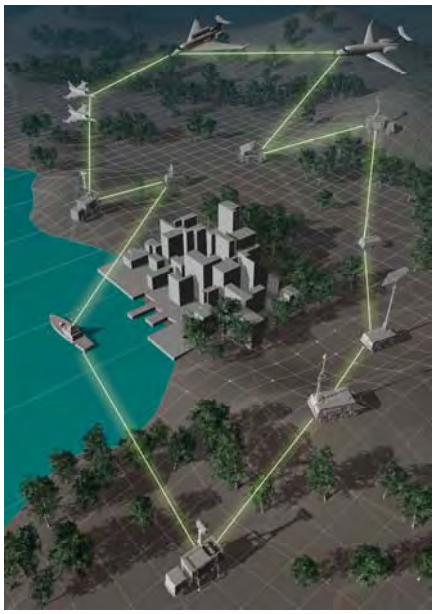
InNetics AB was founded in 2002 and is continuing the development of advanced modeling and analysis software tools for the pharmaceutical industry originally initiated by MathCore. InNetics supplies its state-of-the-art solutions in modeling and simulation into the pharmaceutical industry in close cooperation 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

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 costumers 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

Agroväst Livsmedel AB *(precision agriculture)*

Precision Agriculture Sweden (POS) is a project financed by Agroväst with the over all 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 *(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 *(systems development)*

The cooperation with Skövde university 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 Skövde university.

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 *(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 *(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 Skovde 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 Skovde 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 Skovde, 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 Skovde 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 Skovde 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 long¬standing relationship with the University of Skovde 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 Högskolan i 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 Mkr 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 kind.

***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 bioscenario 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 ambition for the program is that the major portion of the Knowledge Foundation funding be used to attract new faculty (professor and two post-docs) and a number of new Ph.D. students.

During 2005, 9 new Ph.D. students were hired, and 2 more were identified to be hired in 2006. The process of recruiting a professor and two post-docs, which started in 2005, was successfully finished in 2006, resulting in two post-docs starting in the spring and fall of 2006 respectively and the professor in January 2007. 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 pa1-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.

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. 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.

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 2006 and identifies some specific activities for 2007 and onwards.

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 20 scientific publications, including journal publications that normally have a long lead time, have already appeared. Some were published already in 2004, well before 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.
- 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.
- 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 work-shops with companies and cooperation partners to foster new collaborations as well as to market the University of Skövde and the City of Skövde.

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. Penetration 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 a good penetration 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 better 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 the next year (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. Partly this serves to create more awareness about the research program within the companies, and partly to show benefits of their participation, in order to increase the internal support and to create an atmosphere that may results 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 results from the Information Fusion Research Program that are suitable for commercialization. This serves to address commercialization opportunities and research activities concurrently, for instance definition of suitable commercialization schemes. 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. Partly this serves to explore and create opportunities for strengthening the research program through associated projects, but in particular to broaden the industrial base in the view of continuation after 2011.

It should be noted here that many of the above-mentioned activities have already been started; however, these items are mentioned as activities that 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 a conference related to Information Fusion. This would ideally be the International Conference on Information Fusion (FUSION), but conferences related to the subject areas within the application scenarios, obviously with a special session or workshop on Information Fusion, are also considered.
- Continuous refinement of the external information and marketing through identification of specific target groups within the external target group. An example here could be targeting youth; the research program can form a showcase for increasing the interest for science and technology. Whilst the program itself can appeal to youth with specific interests for areas such as IT, manufacturing, biology/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.

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:

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, the recruitment is now 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 project called My-car, carried out within Infofusion, is an incentive from the car 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 a project within the field of Cognition. Professor Tom Ziemke is the leader of the project called 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

The Information Fusion Research program is hosting 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.

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 2006), was held in Florence, Italy, during July of 2006, in which 15 Infofusion research faculty and graduate students participated, both through paper presentation, poster sessions and, most importantly, the Information Fusion Research program was presented to the entire conference audience, consisting of around 300 participants from around the world. The upcoming conference, the 10th International Conference on Information Fusion (Fusion 2007) will be held in Québec City, Canada, and the plan is to participate and present ongoing research work in the field of information fusion at the conference.

Several Infofusion faculty members also participated in the EU-organized IST conference in Helsinki, during 2006. The purpose of participation was many-fold; exposure to technical sessions, network session, partner meetings, and presentation of the Information Fusion Research Program. Many new scientific contacts were made which now have led to initial discussions about research applications for EU grants with the Seventh Framework Program.

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.

The Information Fusion Research Program participants in a seminar on how to write a successful application.

Information about ongoing research in the Information Fusion Research Program is regularly distributed to various 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 and the year 2005, 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 still relatively young and has not yet appeared frequently among the general public in all types of popular science publications. However, it is our belief that it will naturally improve when the program starts to produce concrete results.
- Funding agencies have been identified as a specific target group, instead of being part of the general public. 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.
- The Information Fusion Research Program paid extra attention to the launch of EU's Seventh Framework Program during the spring and fall of 2006. The information and marketing activities included a number of seminars on what the Framework Program contains, on writing a successful application, on the opportunities for SME's to participate etc. We are now moving further in this direction, with a specific aim on how the Information Fusion Research Program can prepare for a possible participation in EU Seventh Framework Program.

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 the year

As the program is newly started, all projects are new for the first year. Descriptions of the projects and their research questions can be found in Appendix E.

The following 3 projects were started in 2006:

- Manufacturing (mfg)
  - 2006-03-01: mfg1
  - 2006-04-01: mfg2
- Precision Agriculture (pa)
  - 2006-01-01: pa1

An additional 3 projects will be started in 2007:

- Ground Situation Awareness (gsa)
  - Future project: gsa4
- Manufacturing (mfg)
  - Future project: mfg3
- Precision Agriculture (pa)
  - Future project: pa2

One project will be ended in 2007:

- Bioinformatics (bio)
  - 2004-03-01-2007-02-28: bio4

One project will be ended in 2008:

- Systems Development (sd)
  - 2005-04-01 – 2008-03-31: sd1

10.3 Summary of all projects carried out so far

No projects have been completed as yet. The current status and the results of each project so far can be found in Appendix E.

Prior to 2006, 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 and all partner companies
- Ground Situation Awareness (gsa)
  - gsa1a: Saab Microwave Systems
  - gsa1b: Saab Microwave Systems
  - gsa2: Saab Microwave Systems
  - gsa3: Saab Microwave Systems
- Bioinformatics (bio)

  - bio1: Cellartis, Sahlgrenska
  - bio2: Arexis
  - bio3: Lexware Labs
  - bio4: Arexis, InNetics
- Retail Sector (rs)
  - rs1: ICA Handlarna, University of Borås
  - rs2: ICA Handlarna, University of Borås, Ericsson AB (not in program)
- Manufacturing (mfg)
  - mfg1: Volvo Powertrain, Electrolux, Delfoi
  - mfg2: Euromation
- Precision Agriculture (pa)
  - pa1: AgroVäst
- Systems Development (sd)
  - sd1: Enea Systems, Atlas Copco Tools, Saab Microwave Systems

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

2006

1 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

2 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

3 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

4 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

2005

5 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

2006

6 Gamalielsson, J., Nilsson, P., and Olsson, B. (2006) A GO-based Method for Assessing the Biological Plausibility of Regulatory Hypotheses. In Alexandrov, V. N., van Albada, G. D., Sloot, M. A., and Dongarra, J. (eds.), *Proceedings of ICCS 2006: 6th International Conference on Computational Science*, LNCS 3992: 879-886. Springer-Verlag.

7 Blais, C L., Gustavsson, P M and Turnitsa, C. “A strategy for Ontology Research for the Coalition Battle Management Language (C-BML) Product Development Group", *Fall Simulation Interoperability Workshop (Fall SIW)*, September 10-15, 2006, Orlando, FL., USA. pp. 531-541. ISBN: 1-930638-45. 06-SIW-003.

8 Olsson, B., Gawronska, B., and Erlendsson, B. (2006) Deriving pathway maps

from text analysis using a grammar-based approach. *Journal of Bioinformatics and Computational Biology, 4(2):* 483-502.(eds.), /Proceedings of ICCS 2006: 6th International *Conference on Computational Science, LNCS 3992*: 879-886. Springer-Verlag.

9 Blais, C L, Gustavson, P., Gustavsson, P.M. and Reichenthal, S. (2006). "An Architecture for Demonstrating the Interplay of Emerging SISO Standards". *Fall Simulation Interoperability Workshop (FallSIW),* September 10-15, 2006, Orlando, FL., USA. pp. 11-23. ISBN: 1-930638-45-0. 06-SIW-069.

10 Synnergren, J., Giesler, T. L., Adak, S., Tandon, R., Noaksson, K., Lindahl, A., Nilsson, P., Nelson, D., Olsson, B., Englund, M. CO, Abbot, S., Sartipy, P. (2006). Differentiating human embryonic stem cells express a unique housekeeping gene signature. *Stem Cells*, 25: 473-480.

11 De Vin, LJ, Lagerström, H & Brade, D. (2006). Verification, Validation and Accreditation for Manufacturing Simulation, *FAIM 2006,* Limerick, Ireland, 327-334.

12 Sundberg, M., Ng, AHC, Adolfsson, J. & De Vin, LJ. (2006). Simulation Supported Service and Maintenance in Manufacturing, *Proceedings IMC23,* Jordanstown, UK, pp 559-566, 2006.

13 Bäckstrand, G, De Vin, LJ., Högberg, D & Case, K. (2006). Attention, Interpreting, Decision-Making and Acting in Manual Assembly, *Proceedings IMC23,* Jordanstown, UK, pp 165-172, 2006.

14 Dahlbom, A. & Niklasson, L. (2006) Goal-directed hierarchical dynamic scripting for RTS games. *In Proceedings of the Second Artificial Intelligence and Interactive Didgital Entertainment Conference (AIIDE-06),* pp. 21-28. AAAI Press, Menlo Park, CA

15 Dahlbom, A. & Niklasson, L. (2006) Goal-directed hierarchical dynamic scripting for RTS games. Accepted as a poster presentation at the *SAIS 2006 workshop* in Umeå.

16 Dura, E., Erlendsson, B., Gawronska, B., and Olsson, B. (2006) Towards Information Fusion in Pathway Evaluation: Encoding of Relations in Bomedical Texts. *In proceedings of 9th International Conference on Information Fusion,* Florence, 10-13 July 2006, pp., 240-247. ISBN: 0-9721844-6-5 (CD).

17 Gustavsson, P.M. and Brax, C. (2006) An Agent Architecture for Multi-Hypothesis Intention Simulation: An Ontology Driven Interoperability Architecture. *The 10th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI) 2006,* July 16-19 in Florida US.

18 Gustavsson P.M. (Saab/University of Skövde), Blais C. (Naval Post Graduate School) and Turnitsa C. (Old Dominion University) (2006). A Strategy for Ontology Research for the Coalition Battle Management Language (C-BML) Product Development Group. *Fall Simulation Interoperability Workshop(Fall SIW),* 10-15, September 2006, Orlando, FL, US, pp 531-541, ISBN 1-930638-45-0 06F-SIW-003.

19 15 Gustavsson P. M.(Saab/University of Skövde) Blais C.(Naval Post Graduate School), Gustavson P (SimVentions) and Reichenthal (Boeing) (2006). An Architecture for Demonstrating the Interplay of Emerging SISO standards. *Fall Simulation Interoperability Workshop (FallSIW),* 10-15 September, Orlando, FL, US, pp 11-23, ISBN 1-930638-45-0 06F-SIW-069.

20 Gustavsson, P. M. (Ericsson/University of Skövde) and Lagervik, C. (Ericsson/University of Skövde) (2006). A System Theoretical Approach to Situation Awareness and its Application. *11th Interbational Command and Control Research and Technology Symposium (ICCRTS)* 26-28 September 2006, Cambridge, UK.

21 Gustavsson, P.M (Ericsson/University of Skövde), Planstedt, T. (Ericsson), Brax, C. (Ericsson/University of Skövde) (2006). The Road Towards Multi-Hypothesis Intention Simulation Agents Architecture - Fractal Information Fusion Modeling. Accepted for poster presentation at the *SAIS workshop 2006* in Umeå and for publication in the associated workshop proceedings.

22 Gustavsson, P.M. (HiS/Ericsson), Wemmergård, J. (Swedish Defence Material Administration) and Norstedt Larsson, M. (Ericsson), (2006). Expanding the Management Language Smorgordsbord - Towards Standardization of Crisis Management Language (CML). *The Spring Simulation Interoperability Workshop,* Huntsville, Alabama, 2-7 april 2006.

23 Lagervik, C. (Ericsson/University of Skövde) Norstedt-Larsson, M. (Ericsson)

Gustavsson, P.M. (Ericsson/University of Skövde) (2006). A System Theoretical Approach to Situation Awareness, A Holistic View of Purposeful Elements. Accepted for poster presentation at the *SAIS workshop 2006* in Umeå and for publication in the associated workshop proceedings.

24 Johansson, F. and Falkman, G. (2006). Implementation and integration of a Bayesian Network for prediction of tactical intention into a ground target simulator. *Proceedings of the 9th International Conference on Information Fusion, Florence, Italy,* 10-13 July, 2006. ISBN: 0-9721844-6-5.

25 Lagervik, C. (Ericsson/University of Skövde) Norstedt-Larsson, M. (Ericsson) Gustavsson, P.M. (Ericsson/University of Skövde) (to appear) A System Theoretical Approach to Situation Awareness, A Holistic View of Purposeful Elements. *Accepted for publication and presentation at the 9th International Conference on Information Fusion, Florence,* 10-13 July 2006. ISBN:0-9721844-6-5 (CD).

26 Loefstroem, T., Koenig, R., Johansson, U., Niklasson, L., Strand, M and Ziemke, T. (to appear) Benefits of Relating the Retail Domain to Information Fusion. In Proceedings of the *9th International Conference on Information Fusion.* IEEE ISIF, Florence, 10-13 July 2006 ISBN: 0-9721844-6-5.

27 Nilsson, M. and Ziemke, T. (2006) Rethinking level 5: Distributed Cognition and Information Fusion. *Accepted for publication and presentation at the 9th International Conference on Information Fusion, Florence,* 10-13 July 2006,IEEE ISIF, ISBN 0-9721844-6-5, IEEE Catalog No. 06EX1311C.

28 Olsson, B., Gawronska, B., and Erlendsson, B. (2006) Deriving pathway maps from text analysis using a grammar-based approach. *Journal of Bioinformatics and Computational Biology, 4(2)*: 483-502.

29 Tiberg, J. (Vehco), Brax, C. (Ericsson/University of Skövde), Gustavsson, P.M. (Ericsson/University of Skövde) (to appear) Towards Hypothesis Evaluation in Command and Control Systems. *Proceedings of SAIS 2006, The 23rd Anuual Workshop of the Swedish Artificial Intelligence Society,* Umeå, Sweden, May 10-12, 2006. pp. 97-102. ISSN: 0348-0542.

2005

30 Dahlstedt, Å. and Persson, A. (2005) 5 Requirements Interdependencies: State of the Art and Future Challenges. *In Aurum, A. and Wohlin, C.(Eds) Engineering and Managing Sofware Requirements. Springer-Verlag, Berlin Heidelberg,* ISBN-10 3-540-25043-3, ISBN-13 978-3-540-25043-2, pp. 95-116

31 De Vin, L.J., Lagerström, H. & Brade, D. (2005) Verification, Validation and Accreditation – Lessons from the Defence Sector, *Proc 2nd IWSMSL Conf*, Dublin, Ireland

32 Alenljung, B. & Persson, A. (2005) Decision-making from the decision-maker's perspective: A framework for analysing decision situations. *Proc 4th Int'l Conf on Business Informatics Research* (BIR 2005), 3-4 October 2005, Skövde, Sweden, pp. 13-22

33 Alenljung, B. & Persson, A. (2005) Decision-making activities in the requirements engineering decision processes: A case study. In *Proc 14th Int'l Conf on Information Systems Development* (ISD 2005), 15-17 August 2005, Karlstad, Sweden

34 Alenljung, B. & Persson, A. (2005) Factors that affect requirements engineers in their decision situations: A case study. In: E. Kamsties, V. Gervasi & P. Sawyer (Eds.) *Proc 11th Int'l Workshop on Requirements Engineering: Foundation for Software Quality* (REFSQ'05)/, 13-14 June 2005, Porto, Portugal

35 Andler, S.F., Niklasson, L., Olsson, B., Persson, A., Planstedt, T., de Vin, L., Wangler, B. and Ziemke, T. (2005) Information Fusion from Databases, Sensors and Simulations. *Proc 29th Annual NASA/IEEE Software Engineering Workshop,* 6-7 April 2005, IEEE Computer Society Press. URL: sel.gsfc.nasa.gov/website/29ieee.htm.

36 De Vin, L.J, Andler, S.F, Ng, A.H.C, Moore, P.R, Pu, J and Wong, B.C.B (2005) Information Fusion: What can the Manufacturing Sector Learn from the Defence Industry? *Proc IMC-22 Conf,* Tallaght, Ireland, Sept 2005, pp. 363-371.

37 De Vin, L., Ng, A.H.C., Oscarsson, J. and Andler, S.F. (2005) Information Fusion for Simulation Based Decision Support in Manufacturing. *Proc FAIM 2005*, 18-20 July 2005, Bilbao, Spain, pp. 136-144.

38 Gawronska, B. and Erlendsson, B. (2005) Syntactic, semantic and referential

patterns in biomedical texts: towards in-depth understanding. *Proc NLUCS-2005*, with 24-25 May 2005, Miami, USA.

39 Gawronska, B., Erlendsson, B. and Olsson, B. Tracking biological relations in texts: a Referent Grammar based approach. *Proceedings of the workshop 'Biomedical Ontologies and Text Processing, 4th European Conference on Computational Biology (ECCB05), Madrid, Spain*, September 2005, pp 15-22.

40 Gustavsson, P. M., Karlsson, G. S, Brax, C., Planstedt, T. and Björk, Å. (2005) Service Oriented Simulations Concept. *Proc SimTecT-05 Conf*, Sydney, Australia, 9-12 May 2005, pp 233-238.

41 Gustavsson, P.M. and Planstedt, T. (2005) The Road Towards Multi-Hypothesis Intention Simulation Agents Architecture - Fractal Information Fusion Model Chapter. Poster presentation. In *Proc 2005 Winter Simulation Conf* (WSC '05). Orlando, FL, USA, Dec 4-7, 2005.

42 Johansson, U., König, R. and Niklasson, L., (2005), Automatically Balancing Accuracy and Comprehensibility in Predictive Modeling, *Proc 8th Int'l Conf Information Fusion*, CD-ROM, IEEE Catalog Number: 05EX1120C, ISBN: 0-7803-9287-6, 2005.

43 Olsson, B., Gawronska, B. and Erlendsson, B. (2005) Deriving pathway maps from automated text analysis: a grammar-based approach. *Proceedings of the International Moscow Conference on Computational Molecular Biology*, Moscow, Russia, July 18-21, pp. 268-270

44 Olsson, B., Nilsson, P. Gawronska, B., Niklasson, L., Ziemke, T., Andler, S.F. (2005) An Information Fusion Approach to Controlling Complexity in Bioinformatics Research. *Proc 2005 IEEE Computational Systems Bioinformatics Conf, Workshop on "Controlling Complexity"*, Stanford University, California, Aug 8-12 2005

2004

45 Gawronska, B, Olsson, B and de Vin, L. (2004) Natural Language Technology In Multi-Source Information Fusion. *Proc Int'l IPSI-2004k Conf*, Kopaonik, Serbia, April 2004. ISBN 86-7466-117-3.

46 Gawronska, B., Torstensson, N., Erlendsson, B. (2004) Defining and Classifying Space Builders for Information Extraction. *Proceedings of NLUCS (Natural Language Understanding and Cognitive Science), Porto, Portugal*, April 2004, pp 15-27

47 Gawronska, B. (2004) Towards In-Depth Understanding of Biomedical Texts. *Proc Int'l IPSI-2004 Conf*, Stockholm, September 2004. CD ISBN 86-7466-117-3.

48 De Vin, L. J., Oscarsson, J., Ng, A., Jägstam, M. and Karlsson, T. (2004) Manufacturing simulation: good practice, pitfalls, and advanced applications. *Proc IMC21 Conf*, Limerick, Ireland, September 2004, pp. 156-163.

49 Johansson, U., Niklasson, L. and König, R. (2004) Accuracy vs. comprehensibility in data mining models. In *Proc 7th Int'l Conf on Information Fusion*, Stockholm, Sweden, pp 295-300.

50 Strand, M. and Wangler, B. (2004) Incorporating external data into data warehouses - problems identified and contextualized. In *Proc 7th Int'l Conf on Information Fusion*, Stockholm, Sweden, pp 288-294.

51 Warston, H. and Persson, H. (2004) Ground surveillance and fusion of ground target sensor data in a network based defense. In *Proc 7th Int'l Conf on Information Fusion*, Stockholm, Sweden, pp 1195-1201.

12.4 Technical reports

The university does not have an internal report series and therefore, internal reports are distributed as private communication or as seminar presentations. However, within the manufacturing scenario the possibility of using the Lappeenranta University report series as a parallel channel for publishing internal reports is being explored.

12.5 Miscellaneous

52 Dahlstedt, Å. and Persson, A. (2005) 5 Requirements Interdependencies: State of the Art and Future Challenges. In Aurum, A. and Wohlin, C. (Eds) *Engineering and Managing Software Requirements*. Springer-Verlag, Berlin Heidelberg, ISBN-10 3-540-25043-3, ISBN-13 978-3-540-25043-2, pp. 95-116

13 Patents filed and/or granted during the year

In this 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 Infofusion research program, in the role as scenario and/or project leader, advisor, etc. There were 5 other staff at the university with Infofusion 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 studing at 80% progress rate. In addition, 9 Senior PhD students, funded by the university or other sources have joined Infofusion, as well as one industrial PhD student.

In total, 20 staff were working at the university with 22 PhD students, for a total of 42 persons. There were 74 participants from industry, for a grand total of 116 positions.

.

Pragram administrator Camilla Andersson.

In 2006, additional funding from the Knowledge Foundation is used to hire one full professor (starting in January 2007), two post-docs, and two more graduate students. In addition, senior researchers and PhD students are being added, funded by the university. Additional industry participants are being added as projects are ramping up, including one adjunct professor and two industrial PhD students.

New personnel in 2006

During 2006 the research program filled 14 positions. The new personnel during 2006 were:

Joeri van Laere
Post-doc in computer science/information fusion: common goals

Henrik Boström
Professor in computer science/ information fusion

Klas Hedenberg
Adjunkt in electronics: information fusion/precision agriculture

Stefan Eriksson
Adjunkt in electronics: information fusion/precision agriculture

Ronnie Johansson
Post-doc in computer science/information fusion – common goals

Tehseen Aslam
PhD student in automation/information fusion: manufacturing

Lina Nolin
PhD student in soil science/information fusion: precision agriculture

Per Hilletofth
Adjunkt in logistics: information fusion/ manufacturing

Olli-Pekka Hilmola
Professor in logistics: information fusion/ manufacturing

Sandor Ujvari
Assistant Professor in logistics: information fusion/manufacturing

Thomas Lezama
Assistant Professor in automation: information fusion/manufacturing

Amos Ng
Assistant Professor in automation: information fusion/manufacturing

Mattias Strand
Assistant Professor in computer science: information fusion/retail

Tarja Susi
Assistant Professor in computer science: information fusion/common goals

15 A calendar of communication activities during the year

For a summary of events that took place in 2006, please see Appendix B, Information and marketing activities 2006/2005. Many of these events have been reported on in the newsletters that, apart from publication on the website, have been distributed to a mailing list of participants and other interested people. More

detailed information can be found in the respective newsletters on www.infofusion.se

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.

Anita Andler project leader for Fusion as Vision

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.

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 a 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 Technolgy. 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, i.a. 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 Technolgy. 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.

Leif Larsson

Appendix B Information and marketing activities 2006/2005

B.1 Web information

The Infofusion website at www.infofusion.se (or www.his.se/infofusion) contains documents and information about the Information Fusion Research Program. It can easily be accessed from the University's main website. The Infofusion 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.2 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.3 Popular scientific publications

The university's popular scientific magazine "Perspectives"

The popular science magazine Perspectives of University of Skövde writes about the Information Fusion Research program in each issue. The magazine publishes approximately three issues a year. Since the magazine targets a predominantly Swedish speaking audience – general public as well as staff and students, the Perspectives magazine is written in Swedish.

Publications in Perspectives during 2005 and 2006 featuring the Information Fusion Research Program were the following:

- Nr. 3, 2006
  - Agroväst utvecklar lantbruksnäringen.
- Nr. 2, 2006
  - Nya pusselbitar till Cellartis forskning
- Nr. 1, 2006
  - Mervärde genom samverkan Informationsfusion nationellt och globalt.
- Nr. 3, 2005
  - Systemperspektivet lyfts fram
- Nr. 2, 2005
  - Information om RTiS 2005 konferensen
  - Forskningsprofilen inom informationsfusion
- Nr. 1, 2005
  - KK-stiftelsens satsning på forskningsprofilen informationsfusion vid Högskolan i Skövde
  - Forskningsprofilen inom informationsfusion

B.4 Media contacts and exposure

University's press relations

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.

News addressing Infofusion and its research during 2006 and 2005 at the University's news website were the following:

2006

18 December	IST konferens i Finland
12 December	Stort intresse för EU:s sjunde ramprograms delområde för småföretagare.
29 November	Infofusions novembermöte
4 December	Ytterligare forskningsmiljoner

	till Högskolan i Skövde.
2 November	Doktorandträff fylld med föreläsningar och kamp.
25 October	Infofusions doktorander bjöds på aktivitetsdag.
11 October	Direktör från NASA besöker Högskolan.
17 October	Högskolan arrangerar prestige-full produktionskonferens.
9 October	Högskolan får EU-miljoner till produktionstekniskforskning.
29 September	Nytänkande kring frågan kris-hantering.
29 August	Workshop om krisövningar.
9 August	Högskolan deltog i video-konferens med Stanford.
15 June	Högskolan medverkar i Euro-SIW.
7 June	Stanford Univeristy besöker Högskolan i Skövde.
9 June	Katastrofövning på Skövde kommun.
28 April	Högskolan besökte Stanford University.
16 March	Högskolans forskare deltar i kommunens krisövning.

2005

20 December	Forskningsprofil i Informa-tionsfusions första formella träff sedan starten.
22 November	Doktorandkurser inom Information Fusion.
31 October	Beviljad finansiering för krisberedskapsprojekt.
25 April	NEWS-möte på Högskolan.
6 April	100 000 kronor till Högskolan.
26 Januari	Företagsavtal skrivs för KK-profilen informationsfusion.

Press

During 2006 and 2005 the Information Fusion Research Program laid a solid ground and started its research; therefore the outside media exposure has been somewhat limited given that concrete results have not yet been established. We are, however, expecting the media exposure to increase during 2007. The following gives examples of contact during 2006 and 2005.

2006

10 October	”Forskning om framtidens biltillverkning kommer till Skövde” Västgötabladet.
10 October	”EU-miljoner till Högskolan” Skaraborgs Allehanda.
10 October	”Forskning om framtidens bil-tillverkning kommer till Skövde” Falköpingstidning.
9 October	”EU-miljoner till forskning om unik biltillverkning” SVT Västnytt.
9 October	”EU-miljoner till Högskolan” Sveriges Radio P4.
17 September	”Inbyggnads- och realtids-forskningen i centrum vid SNART seminariet och ARTES sommarskola. www.artes.uu.se
22 May	”Skövde klarade katastrofen” Skövde Nyheter.
31 March	”Glöm Databasen” Computer Sweden.
17 March	“Hårt tryck under krisövning” Skaraborgs Allehanda.
9 January	”Allt fler av Leos landsmän lockas till Sverige” Skövde Nyheter.
7 January	”Trångbodda flyttar till Sverige” Västgötabladet.

Forskning om framtidens bil-tillverkning kommer till Skövde

Av PER CLAESSON
2006-??-??

SKÖVDE: Forskning på Högskolan i Skövde kommer att påverka hur framtidens bilar tillverkas. Högskolan i Skövde är en part i projektet my-Car, som fått ett stiere EU-bidrag.

Fyra eller fem forskare kommer att arbeta med projektet under fem års tid.

– Initiativet kommer från bilindustrin, nämligen Volvo Technology som är koordinator för projektet, Ford, Daimler Chrysler och Fiat, säger professor Leo de Vin på Högskolan i Skövde.

My-car går ut på att utveckla nya principer för flexibel montering av bilar. Bakgrunden är att kunder i allt högre utsträckning vill ha kundanpassade bilar. Fortsätter denna trend kommer varje bil som tillverkas i framtiden att vara unik och tillverkas för en specifik kund. Denna utveckling vill EU-projektet möta.

– Det är att sätt att framförhållt stärka europeisk bilindustri i ett flexibelt modern kundanpassade bilar utan att effektivitetens blir sänkdrs, säger Leo de Vin.

Bilar beställnpassas nyckfet i dag, men problemet är enligt Leo de Vin just att kostnaden för anpassningen är för stor.

För Högskolan i Skövdes del är EU-bidraget fyl miljoner kronor under att femårsperiod. Fyra till fem forskare kommer att jobba helt eller delvis med projektet. Arbetet i projektet kan pågå i maj i år, men först nu är alla detaljer kring bidraget klart.

Fem länsnätet är med i projektet totalt. Från Sverige är det Högskolan i Skövde och Chalmers tekniska högskola.

– Bilindustrin har hjälpt in 30 utvalda samarbetspartner och att Högskolan i Skövde är med är grunnla redan en stor ära i sig, säger Leo de Vin.

De övriga medverkande aktörerna är bland annat maskinbolagnen, mjukvaruleverantörer och consulentgårvetanförer.

Stor forskningsgrupp

Att den lilla högskolan i Skövde valts ut av jättarna inom bilindustrin till att ingå i detta projekt förklarar man på högskolan med att tydligt forskningsfältet. Den aktuella forskningsgruppen har arbetat med produktionsmonitoring i cirka tä det och det en av de största forskningsgrupper inom produktionsinnovering som finns. Som andra framgångsfaktorer räknas tillgång och pågående simuleringsprojekt samt också gien i samarbete med industrin.

– När konsortiet skrev projektansökan bidrog vi bland annat med idéer som har sitt ursprung i forskningsgrupperna. Informationsfusion, säger Leo de Vin.

Leo de Vin tror att vissa resultat av forskningen kan komma att börja utvecklas av bilindustrin redan under projektets gång, men att genombrottet framförallt sker efter projektetsslut.

Det lokala näringslivet i Skövde kan också komma att medverka i projekten.

– Vi diskuterar möjligheten att bygga en demonstrator i Skövde, säger Leo de Vin.

Brunn föreskissandlagning skulle i sådd bunna bli på Kuromalmt Industry i Skövde.

Högskolans rektor är nyckfet glad över att hans lärosäte ingår i projektet.

– Att detta i EU-projekt och länsnätet med svensk bilindustri står högt på vår prioriteringslista, säger Leif Larsson.

Världskonferens till Skövde

Leo de Vin har i dagarna också fått klartecken om att Högskolan i Skövde får arrangera en internationell konferens om produktionsteknik och flexibel automatisering. Att Skövde får denna uppgiftt har ingen direkt koppling till my-Car, men konferens lägger ta ra varandra.

Konferensnamn heter Flexible Automation and Intelligent Manufacturing (FAIM) och har arrangerats årligen i 1 ärs tid.

Bilbas och Länsnätet har varit de se nasste vårdskärarna och nästa är arrangerna konferensen i Philadelphia. Det har aldrig tidigare arrangerats i Sverri ge.

– Den kommer att sätta Skövde pa kartan för produktionsteknik. Intern tionellt sett, säger Leo de Vin.

EU – 150 beräknar vänta kommna till konferensen.

– De kommer framst från Europa och USA, men i princip från hela världen säger Leo de Vin.

Flexibel montering. På Högskolan i Skövde pågår forskning kring montering av bilar och särskilt hur monteringen ska kunna anpassas efter varje enskild kunds önskemål. Högskolan har som del i projektet my-Car beviljats 3,6 miljoner kronor från EU att forska för.

ERIK VON BRAUCHITSCH/SCANFO

Future car research establishes in Skövde

2005

December	IF Advisory Board meets at the University of Skövde (host).
October	Executive Committee (host) meets Johan Mårtensson, Johan Schubert, Pontus Hörling, Per Svenson and Anders Törne from Swedish Defence Research Agency (FOI).
October	KK:s kunskapsdialog där det diskuterades kring kommunikation, samverkan och hur information om forskning sprids, participating.
September	Seminar on Crisis management Games, Försvarshögskolan, Stockholm (participating)
September	Venture Cup presentation at University of Skövde.
August	Presentation of Information Fusion Research Program at ARTES summer school in Skövde.

May	Presentation of Information Fusion Research Program at AI Society Industry Day in Västerås.
April	Presentation of Information Fusion Research Program at AI Society meeting.
April	Presentation of "Information Fusion from Databases, Sensors and Simulations - a Research Program in Cooperation with Industry" at NASA Goddard Space Flight Center.
March	Kick-off with NFFP where Saab Microwave Systems, Saab and Volvo participated. SMW talked about the Information Fusion Research Program in their presentation.
March	Parts of the Executive Committee visits SaabSystems in Jakobsberg, Sweden in order to create contacts between University of Skövde, Information Fusion Research Program and SaabSystems.

2004

September	Invited overview presentation and paper about the Information Fusion Research Research Program at the VINNOVA Workshop on Intelligent Sensor Networks, Stockholm.
June	Network meeting of ATC (Automation Technology Cluster of West Sweden).
March	Study visit by ISA (Invest in Sweden Agency) to Skövde.
February	Visit to the FOI Stockholm Information Fusion Group at the Swedish Defence Research Agency (FOI), Stockholm.

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.

December	Information Fusion Workshop at the University of Skövde (host).
September	Internal Information Fusion seminar for research groups Mechatronic design, Automation engineering, Integrated product development, Logistics.
June	Seminar on Verification and validation of simulation models at University of Skövde.
May	Seminar at University of Skövde by Harold W. (Bud) Lawson called "Life Cycle Management of Information and Information Systems". An introduction to the course Systems Thinking and its Application.
February	Seminar about safety in Stockholm, Sweden, Tomas Planstedt.
February	Presentation by Leo de Vin about the program at a workshop in Lund arranged by "Single Fuel Concept" on "condition based service and maintenance for ground vehicles and aircraft".

17 August	“NASA på besök i Skaraborg” Falköpings Tidning.
16 August	Inslag om Forskningsveckan, intervju med Michael G. Hinchey och Sten F. Andler TV4 Skaraborg.
5 August	”Tio lediga tjänster till Högskolans nya program” Skaraborgs Allehanda.
5 July	”Forskning om Informationsfusion attraherar näringslivet” KK-bladet.
2 April	“Skövdeprojekt presenteras för NASA” Skövde Nyheter.
27 January	”Pengaregn över Högskolan”.

B.5 Miscellaneous

Monthly newsletters

The Information Fusion Research Program produces monthly newsletters that are 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. These areas serve to increase the visibility of the program for the external visitors, internal staff and students. During the later part of 2006 Fusion as Vision started the competition “The best ideas for the IF lab", the competition was open for everyone working within the research program. The purpose of the competition was to get everyone involved in the new IF-lab and to solicit proposals on how to make the environment interesting, exciting and highly usable. Two proposals were awarded. The IF lab will be completed and ready to be opened in spring 2007.

Executive Committee meetings

The executive committee has regular meetings, documented by minutes. The committee had 25 meetings in 2006 and expects to have around 15 meetings in 2007.

Infofusion Program Meeting

The first in a series of regular Infofusion program meetings was held on 16 Nov 2006. The purpose of the 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.

B.6 Courses, Seminars and Conferences

Courses

During 2005 and 2006 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.

2006

(Start 26 September)
Information Fusion
A graduate course (5 points) and workshop, also offered as an MSc course.
Organizer: The University of Skövde
Invited Speakers: Dr. Pontus Svensson (FOI) , Mike Hinchey and more
Lecturers: Ronnie Johansson, Sten F Andler.

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

(Start 26 April)
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.

2005

(Start 16 December)
Introduction to Information Fusion.
Industrial lectures.
Organizer: University of Skövde, project Fusion as Vison.
Invited Speaker: Dr. Pontus Svensson FOI

(Start 6 September)
Systems Thinking
A graduate course called Systems Thinking and its applications (5 points) was open to students

from the graduate schools CUGS and ARTES.
Organizer: Univeristy of Skövde
Lecturer: Dr Harold “Bud” Lawson.

Conferences

The University of Skövde has participated in several relevant conferences:

2006

21 - 23 November
- IST, Information Society Technology conference 2006. Helsinki, Finland.

11 - 15 September
- HCI 2007. Human Computer Interaction conference, London, England.

20 - 23 September
- International Conference on Information Systems in Sustainable Agricultural, Agro environment and Food technology. Volos, Greece.

3 - 6 September
- IEEE’s MFI. International Conference on Multisensor Fusion and integration for intelligent systems. Heidelberg, Germany.

14 -18 August
- IEEE’s ICECCS, International Conference on Engineering and complex computer systems, Stanford University, California, USA.

Michael G Hinchey and Sten F Andler at the ICECCS Conference.

9 August
- Video conference with Stanford University, SCIL, Stanford Center for Innovations in Learning.

10 - 13 July
- FUSION 2006, 9th International Conference on Information Fusion. University of Skövde sent 15 participants. Florence, Italy.

2 - 7 July
- IPMU 2006. 11th Conference on information processing and management of uncertainty in knowledge based systems. Paris, France.

Dan Gilbert and Bob Smith from Stanford University were talking with Högskolan through video.

2005

1 - 4 November
- Sensor Fusion Europe. Barcelona, Spain.

11-15 September
- ICANN 2005. International conference on artificial neutral networks. Warsaw, Poland.

16 - 17 August
- Real-Time in Sweden (RTiS 2005). Organized by Infofusion/DRTS research group.

25 - 29 July
- FUSION 2005. 8th International conference on information fusion. Philadelphia, USA.

16 - 17 July
- Focus Innovation 2005. Göteborg, Sweden. Invited speaker.

April
- IPSN 2005. International conference on information processing in sensor networks. Los Angeles, USA.

31 March
- Implementation of precision agriculture. Uppsala, Sweden.

17 February
- Intelligent products. Ottawa, Canada.

Seminars

During 2005 and 2006 the Information Fusion Research program has been hosting several different seminars at the University of Skövde. The project Fusion as Vision is a project running pararel with the Information Fusion Research program founded by Sparbanks-stiftelsen Alfa. Its main focus is the support the activities in the Information Fusion Research Program.

2006

18 December
Professor Stefan Arnborg from CSC/Nada, KTH held a seminar in “On Bayesian tracking of extended objects and target groups”.

28 November
Fusion as Vision invited the research program and SME’s to listen to Gunnar Sandberg VINNOVA as he talked about the Seventh Framework Program.

14 November
Professor Hans Hansson had a seminar on “How to write a successful application”.

Gunnar Sandberg presented the 7th Framework Program

26 October
Fusion as Vision invited Johan Lindberg from VINNOVA to talk about the IST program.

25 October
Fusion as Vision arranged a seminar in rhetoric and how it could be used in writing a successful application. Speaker was award winning Lena Andersson.

17 October
Dr Michael G. Hinchey from NASA Goddard Space Flight Center came to the University of Skövde to talk about “Autonomic Computing – 99% (biological) inspiration”.

16 October
Associate Professor Henrik Boström had the seminar in “learning from experience”.

14 June
Professor Sang H. Son from University of Virginia held a seminar in “Real-time processing data streams – the relation of sensor fusion to real-time database systems”.

24 May
Associate Professor Sverker Sikström from Lund University had a seminar in “Information Fusion and measuring values of concepts: Application to ethnicity and gender”.

12 May
Post-Doc Ronnie Johansson held a seminar in “Large-scale information acquisition for data and information fusion”.

8 May
Associate Professor Henrik Boström had the seminar “On the role of machine learning in information fusion research”.

27 April
Marcus Brohede had a seminar in “Bounded recovery in distributed discrete real-time simulations”.

Juha Alatalo standing next to the University’s President Leif Larsson

26 April
PD Dr. –Ing habil. R. Ingo Schmitt had a seminar in “Integration of database and retrieval systems for information fusion.

2 March
Juha Alatalo from VINNOVA presented the 7th Framework Program.

2005

June
A seminar on “Verification and validation of simulation models” at the University of Skövde.

9 May
Professor Harold “Bud” Lawson had a seminar in "Life Cycle Management of Information and Information Systems".

February
Seminar about Safety in Stockholm, Sweden. Speaker was Thomas Planstedt, Saab Microwave Systems.

B.7 Invitations, visits and presentations

Scholarships for information events, travel, conferences etc.

During 2006 over seven Information Fusion Travel Grants were awarded to individuals within the research program. The grants were funded within the project titled Fusion as Vision, which has the main purpose of ensuring the exposure of infofusion results, mobility, etc.

The purpose of the scholarships is for the individuals to represent and market the research program. The following graduate students were designated to represent the program at different events:

Alexander Karlsson
Alexander Karlsson participated in "The Society for Imprecise Probability: Theories and Applications", The Second SIPTA Summer School on Imprecise Probabilities. It was held in Madrid, Spain, July 24-28 2006 and consisted of five days of lectures and exercises, providing input valuable to Mr Karlsson and his future research. There were discussions with other researchers providing many new ideas about "uncertainty issues" related to information fusion.

Marcus Brohede
Marcus Brohede went to the University of Virginia, USA, on a four month visiting scholarship. During this time he continued his research within the Common Goals and Infrastructure project by conducting an experiment aimed at providing results for his thesis on Distributed Real-time Simulations.

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

Maria Nilsson
Maria Nilsson participated in the Information Fusion Conference (Fusion 2006) in Florence, Italy to present her paper "Distributed Cognition and Information Fusion". She also travelled to the Human Computer Interaction conference (HCI 2007) in London, England to participate in a doctorial consortium at the HCI Conference.

Maria Riveiro
The International Conference on Information Fusion provided a suitable platform to gain insights into various research works in the field and to meet experts. It also allowed Miss Riveiro to establish valuable contacts to other researchers on an international basis. Valuable discussions took place at the Conference that might lead to future co-operation.

Anders Dahlbom
Anders Dahlbom is a relatively new PhD student within the Information Fusion Research Program. The main task during the past year has been for him to establish a solid foundation for developing a research proposal and research question. An excellent opportunity for guiding this work was provided at the international conference on Information Fusion 2006, Florence. It gave Mr Dahlbom an overview and insights into important problems within the domain.


Participants at FUSION 2006. Florence, Italy. Picture taken by Maria Riveiro.

Lina Nolin
Lina Nolin participated in the International Conference on Information Systems in Sustainable Agricultural, Agro environment and Food technology in Volos, Greece, September 20-23 2006. The purpose of her participation in the conference was to get general conference experience, to meet people in the same research field, to learn more about Crop Modeling, Precision Agriculture, Sensors, GPS and Wireless Technology and to present a poster about her own research project and the connections to the Information Fusion Research Program at the University of Skövde.

Christoffer Brax


Christoffer Brax presents the poster "A System Theoretical Approach to Situation Awareness and its Application", at FUSION 2006.

FUSION 2006 gave Christoffer Brax an excellent opportunity to get an overview of the main topics in the Information Fusion Research area. Since he is in the process of specifying his research problem, the conference gave him an insight in the work done in the area of anomaly detection.

Workshops and seminars

Workshops and seminars are organized for the research program and its industry partners, as well as for interested external parties.

2006

26 April
PD Dr.-Ing. R. habil. R. Ingo Schmitt from the University of Magdeburg, Germany held a workshop within the field of Integration od database and retrieval systems for information Fusion.

2005

14-15 December
A workshop on Information Fusion was held for all participants in the Information Fusion Research Program.

February
Presentation by Leo de Vin about the program at a workshop in Lund, arranged by “Single Fuel Concept” on “condition based service and maintenance for ground vehicles and aircraft”.

Presentations

The Information Fusion Research Program has been presented in several different arrangements, locally, nationally and internationally.

2006

21 – 23 November
Information Society Technology Conference (IST 2006), Finland.

20 – 23 September
International Conference on Information Systems in Sustainable Agriculture, Agro environment and Food technology.

The Information Fusion Research program had a presentation at the IEEE Conference. Here Michael G. Hinchey welcomes the participants.

15 – 17 August
IEEE International Conference on Engineering of Complex Computer Systems.

9 August
Video conference with Stanford University. Selected people from the research program had a presentation of the Information Fusion Research Program through video link with Stanford University.

10 – 13 July
The information Fusion Research Program and six technical papers were presented at The 9th International Conference on Information Fusion (FUSION 2006), Florence, Italy.

19 – 21 June
The Information Fusion Research program was presented at the EuroSIW trade fair of 2006.

2005

12 September
Venture Cup presentation.

18 - 20 July
Leo de Vin held a presentation at FAIM 2005.

16 June
Sten F Andler held an invited presentation at Fokus Innovation 2005 in the "In Search of Excellence".

6 April
Sten F Andler held an invited presentation of the Information Fusion Program at NASA.

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 activites:

	Expenses 2005	Expenses 2006	Budget 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**	

Appendix D Foundations of Information Fusion

This appendix contains three papers. 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 [ref]). 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.L., 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

On the Definition of Information Fusion as a Field of Research

Henrik Boström, Sten F. Andler, Marcus Brohede, Ronnie Johansson, Alexander Karlsson, Joeri van Laere, Lars Niklasson, Maria Nilsson, Anne Persson, Tom Ziemke

School of Humanities and Informatics
University of Skövde
541 28 Skövde, Sweden
henrik.bostrom@his.se

HS-IKI-TR-07-006

Abstract – A more precise definition of the field of information fusion can be of benefit to researchers within the field, who may use such a definition when motivating their own work and evaluating the contribution of others. Moreover, it can enable researchers and practitioners outside the field to more easily relate their own work to the field and more easily understand the scope of the techniques and methods developed in the field. Previous definitions of information fusion are reviewed from that perspective, including definitions of data and sensor fusion, and their appropriateness as definitions for the entire research field are discussed. Based on strengths and weaknesses of existing definitions, a novel definition is proposed, which is argued to effectively fulfill the requirements that can be put on a definition of information fusion as a field of research.

Keywords: information fusion, definition

1 Introduction

During the last decade a substantial amount of research has been dedicated to problems concerning how to combine – or fuse – data from multiple sources in order to support decision making. Traditionally there has been a focus on fusing online sensor data, but more recent work also considers other sources, such as databases, simulations, ontologies, text documents, the web, and even humans. The research has addressed both human decision makers, who are supported by the underlying fusion systems, and automated decision making without human intervention.

The term *information fusion* has become a well-established name for the research field concerned with this type of problems, which is not least reflected in the names of the annual international conference on information fusion, and the two journals *Information Fusion – an International Journal on Multi-Sensor, Multi-Source Information Fusion*, and *Journal of Advances in Information Fusion*. However, as important as having such an informative name of the field is to have a definition that clearly states the main research problems of the field.

A precise definition may be important for practitioners whose interest in applying techniques developed in the field may increase with a better understanding of the type of problems addressed by these techniques. Furthermore, such a definition would also allow researchers outside the area to more easily relate their own research to the field of information fusion, and thereby allow for a higher degree of cross-fertilization between the different fields. It should be stressed that equally important to being able to conclude that something is indeed a contribution to the field, is being able to determine what is *not* a contribution – a too loose definition would allow the inclusion of only vaguely related topics, with minor relevance to the field as a whole. Hence, such a definition could clearly also play an important role for researchers already inside the field, who have to motivate the relevance of their own work as well as evaluate the contributions of others to the area.

In this paper, we review previous definitions of information fusion, also including definitions of *data and sensor fusion*, which sometimes are considered to be special cases of, and sometimes synonyms for, information fusion [1]. Based on the limitations of these when it comes to defining the field of research, we suggest a novel definition, which is more inclusive in some respects compared to several of the earlier definitions, but at the same time can be used to more clearly conclude what is not considered to be a contribution to the field of research.

Our motivation for this work is twofold and can be broken down into a 'global' and a 'local' component. The first one is that with this conference celebrating its tenth

JDL
- an overview[1]

Gunnar Buason and Lars Niklasson
School of Humanities and Informatics, University of Skövde
Box 408, 541 28 Skövde, Sweden
gunnar.buason@his.se, lars.niklasson@his.se

[1] This is a shorter version of Buason, G. and Niklasson, L (2004) *NFFP3+ Concepts and Method,* http://www.ida.his.se/~lars/PUBLICATIONS/NFFP3-concepts.pdf

Fusion and the JDL model

The Joint Directors Laboratories (JDL) model (see Figure 1) was established in 1986 as an effort to establish a terminology related to data fusion (Llinas & Hall, 1998; Hall & Llinas, 2001). The model was designed to be a functional model opposed to, for instance, the Observer-Orient-Decide-Act (OODA)[2] model which is a process model (Steinberg & Bowman, 2001; Hall & McMullen, 2004). The difference is that a functional model only *defines* the functions of the model but does not state anything about the *interactions* within the model. A process model, however, *specifies the interaction* among the functions in a system. In this context, the JDL model has been useful to associate processes to the refinement of "objects", "situations", "threats" and "processes". With regards to the terminology in Svensson (2003) Level 0 and Level 1 can be considered to be sensor fusion processes while the upper levels refer to information fusion processes.

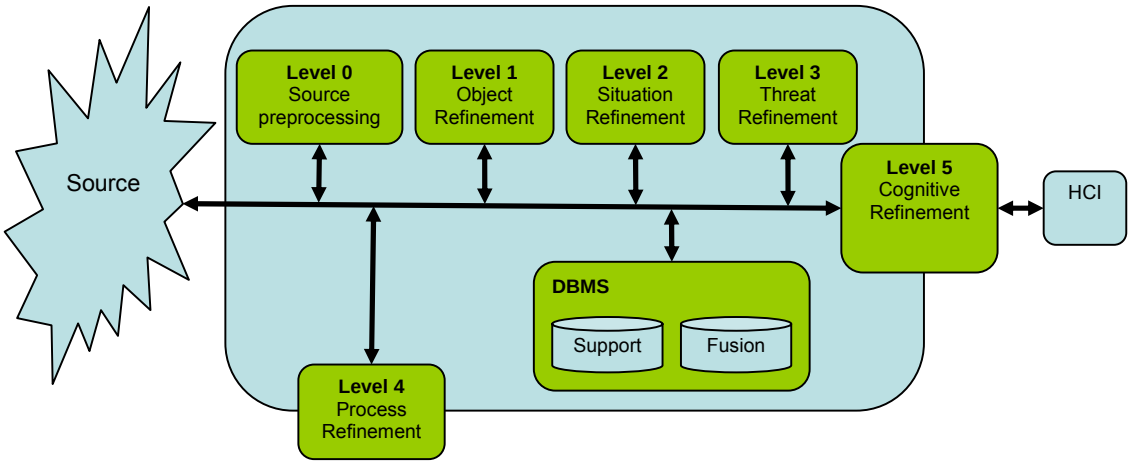


Figure 1 The Joint Directors of Laboratories data fusion model (Adapted from Hall & McMullen, 2004)

Level 0 - Source preprocessing

Level 0 focuses on preprocessing the data for the other levels. This is performed in order to not overwhelm the system with raw data. This preprocessing is usually performed at the specific sensor and is therefore individual to each sensor (Hall & McMullen, 2004).

Level 1 – Object refinement

Level 1 has been primarily of focus in the research community and numerous techniques have been investigated in order to achieve fusion at this level. Here data, e.g. from level 0, is fused to determine the position, velocity, attributes, characteristics, and identity of an observation. According to the taxonomy in Hall and McMullen there are four main categories of functions within level 2.

The first is *data alignment* where data from different sources are aligned, both spatially and temporally. This can also include other types of data manipulation/conversion in order to compare data from different sources (e.g. units conversion).

[2] For more info see: http://www.webster-dictionary.org/definition/Military%20Strategy%20%28John%20Boyd%29

The second category is *data/object correlation*. Here the problem of interest is to associate a number of observations from one or more sources to a single observation. The general model to solve this is by setting up a number of hypothesis that could explain the data, the hypothesis are then evaluated using some form of quantitative measurement such as probabilistic metrics, similarity measures, distance calculations, and likelihood functions.

The third category of functions focuses on *estimations of position and velocity*. Here the focus is on trying to track an object and predict its next position using a state vector. An estimation problem must be defined by specifying the state vector, observation equations, and equations of motion among other things.

The fourth category focuses on estimating the *identity of an observation*. Techniques used for identity fusion range from well-known statistical-based methods such as classical inference, Bayesian methods and Dempster-Shafer methods, to techniques in pattern recognition, e.g. templating, cluster algorithms, neural networks, or knowledge based techniques.

It is important to realize that despite the above categorization of functions, they are closely related to one another and usually complement each other in order to achieve fused results. For example, positional information can be of value for establishing identity of an observation and vice versa. In addition, the estimation of identity is closely related to Level 2 as both use pattern recognition techniques.

Level 2 – Situation refinement

Level 2 involves refining our estimates and understanding of a situation. It focuses on understanding the relationships among observations, their relationship to the environment and aggregation of, both in time and space, in order to be able to infer more abstract reasoning. The level is decomposed into four categories of functions, object aggregation, event and activity aggregation, contextual interpretation, multi-perspective assessment. Further, the functions therein are included.

Object aggregation considers aggregating objects in time and space, i.e. Level 1 identifies a single object and on Level 2 we try to understand the relation among a number of objects.

Event and activity aggregation is another type of reasoning about situations, where events and activities are analyzed in time, i.e. a certain action may require a number of events and a number of (seemingly unrelated) events may lead to a certain action.

The third category of functions refers to being able to reason about the *context of observations*. That is, the environment and weather can constrain observations in different ways, for example a car is most likely to use a bridge to cross a river and a snow storm might prevent traffic.

The fourth category is a rather military point of view where in order to understand a situation one must be able to see the situation from *different perspectives*, e.g. both a neutral point of view, own point of view and from the adversarial point of view. Hall and McMullen (2004) however state that this can also be transferred to other areas, e.g.

failure conditions of an airplane is considered from a different point of view if the plane is on the ground or in the air.

Level 3 – Threat refinement

The JDL introduces Level 3 for processing of threat refinement, i.e. to understand the consequences of certain actions with regards to the current situation. An example of this is to predict when machinery might break down based on running it in certain operating conditions. The key functions identified by Hall and McMullen are aggregation and estimation of force capabilities, prediction of enemy indent, identification of threat opportunities, estimation of implications, and multi-perspective assessment. The functions here bear a strong resemblance to the functions of Level 2 except that on Level 3 the focus is on prediction, i.e. understanding future relationships and predicting the effect of certain events and actions.

Level 4 – Process refinement

Hall and McMullen define Level 4 as a meta-process. The process monitors the data fusion process and tries to optimize the process by controlling the sensor resources in order to achieve improved fused results.

Basically the purpose of sensor management is to optimize fusion performance by managing the sensor resources. It can therefore be considered as a decision making task, taking viewpoint from decision theory, determining the most appropriate sensor action to be taken in order to achieve maximum utility. According to Xiong and Svensson (2003) the problems within this area fall into three categories, namely sensor deployment (where to place the sensors in an optimal manner), sensor behaviour assignment (adapt to a dynamically changing situation), and sensor coordination (coordinating numerous, perhaps, heterogeneous sensors).

Level 5 – Cognitive refinement

According to Hall & McMullen human-computer interaction (HCI) research in the fusion domain has mainly considered interaction between the user and a geographical information display (based on a geographical information system) through menus and dialogs. However, the current research interest in this area is growing, and techniques such as gesture recognition and natural language interaction are currently of interest. Hall & McMullen further point out a new research area, referred to as *cognitive aids*. This area focuses on developing different end user aids, in order to avoid, for example, cognitive biases or to draw focus of attention to a certain subject.

Summary

The above discussion has focused on the levels of the JDL, see also figure 2 where more detail about functions and algorithms is given for each level. This, however, is not nearly a complete list of the functions/algorithms that are required (or can be used) for performing fusion. Hall and McMullen state that supplementary support functions may account for as much as 80% of the total software in a data fusion system. Examples of such functions are numerical libraries including different types of statistical algorithms and models, data alignment including algorithms for coordinate and time-based

transformations, data preprocessing including signal, image and test processing and database management including storage and retrieval approaches.

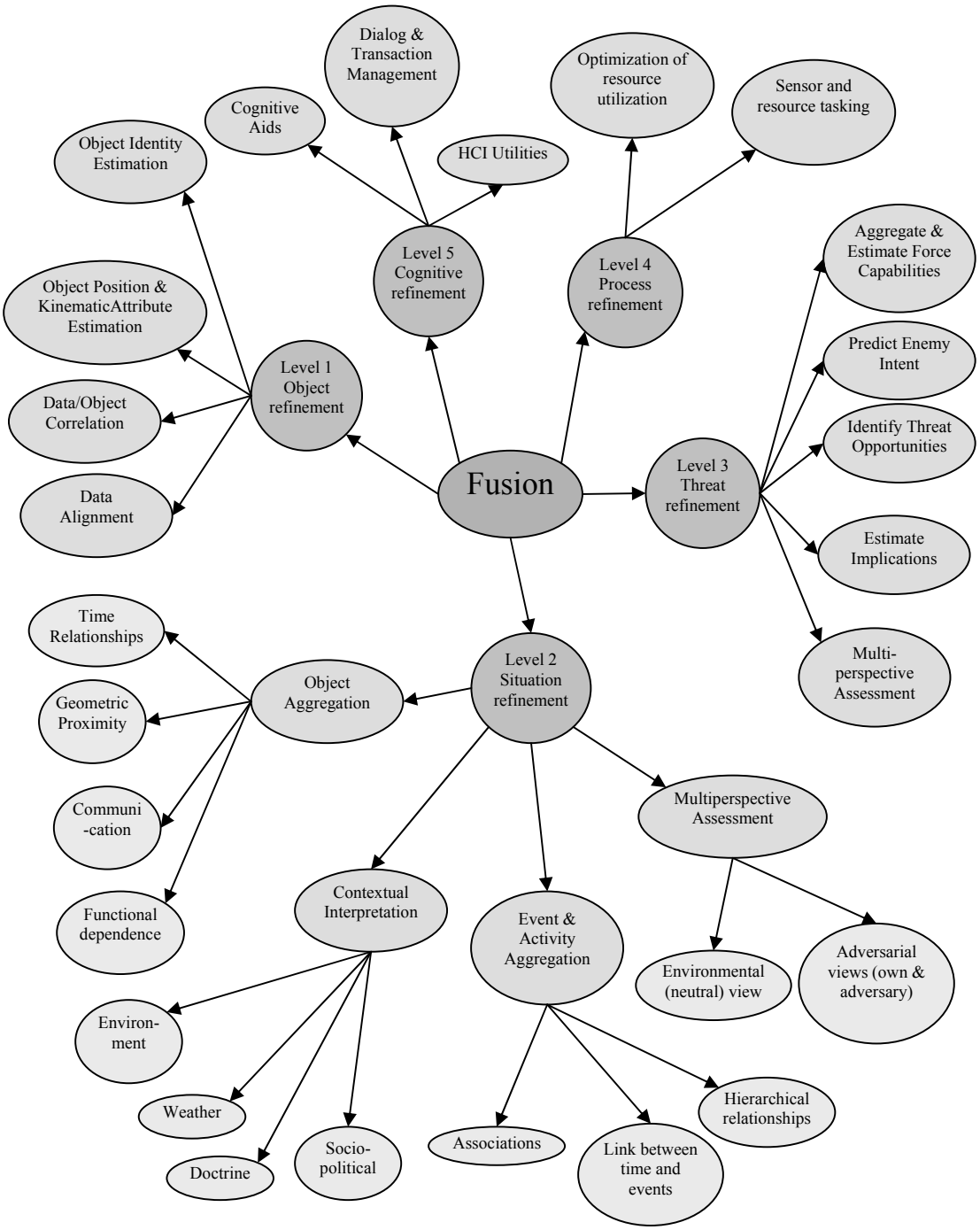


Figure 2 Functional decomposition of the JDL model based on taxonomy from Hall and McMullen (2004). Based on the five levels of the JDL model (excluding level 0) different functions (or category of functions) are identified. We choose to include only a further decomposition of level 2 functions.

References[3]

Hall, D. & Llinas, J. (2001) *Handbook of multisensor data fusion*. CRC Press.

Hall, D. & McMullen, S.A.H. (2004) *Mathematical techniques in multisensor data fusion*. Artech House.

Llinas, J. & Hall, D.L. (1998) An introduction to multi-sensor data fusion. In: *Proceedings of the 1998 IEEE International Symposium on Circuits and Systems (ISCAS 1998)* (pp. 537-540). 31 May – 3 June, 1998. Monterey, CA, USA.

Steinberg, A. N. & Bowman, C. L. (2001) Revisions to the JDL data fusion model. In: D. L. Hall & J. Llinas (Eds.), *Handbook of multisensor data fusion*. CRC Press Inc., Boca Raton, Florida, USA.

Svensson, P. (2003) Technical survey and forecast for information fusion. In: *RTO IST Symposium on Military Data and Information Fusion*. 20-22 October, 2003, Prague, Czech Republic, RTO-MP-IST-040.

[3] All references are stored locally (except for books) as PDF documents at http://www.ida.his.se/~buag/nffp3+/viewer.php. To access the references a login name and a password is required. Please contact Gunnar Buason (gunnar.buason@his.se) to gain access to the references.

A Unified Situation Analysis Model for Human and Machine Situation Awareness

Lars Niklasson[1], Maria Riveiro[1], Fredrik Johansson[1], Anders Dahlbom[1], Göran Falkman[1], Tom Ziemke[1], Christoffer Brax[1,2], Thomas Kronhamn[2], Martin Smedberg[2], Håkan Warston[2], Per M. Gustavsson[1,2]

[1]School of Humanities and Informatics, University of Skövde, Skövde, Sweden
[firstname.lastname]@his.se

[2]Product Development, Saab Microwave Systems, Gothenburg, Sweden
[firstname.lastname]@saabgroup.com

Abstract: The use of technology to assist human decision making is not a novel idea. However, we argue that there is a need for a unified model which synthesizes and extends existing models. In this paper, we give two perspectives on situation analysis: a technological perspective and a human perspective. These two perspectives are merged into a unified situation analysis model for semi-automatic, automatic and manual decision support $(SAM)^2$.

1 Introduction

At a high level of abstraction decision making can be seen part of an iterative process. Before a decision maker can decide what to do, the relevant information needs to be observed and analyzed in order for the decision maker to become aware of how the observations relate to each other and influence potential decisions. This part of the process is often referred to as *situation analysis* which results in *situation awareness* (e.g., [Ro01]), in the following termed SA and SAW respectively. When a decision maker is aware of the current situation or its future implications it can be quite straight forward to actually decide on which action to take. After an action is performed, the situation is analyzed to evaluate if the chosen action had the desired effect.

The result from this analysis process, which depending on the task can range from single entity identification to prioritized lists of available actions, is reported to the decision maker as decision support. For most complex tasks fully automated SA is not possible with today's technology. Instead, integration between machine and human analysis is needed. The literature does not supply a unified model for SA, integrating both technical and human analysis. Nor is SAW fully incorporated into models commonly used for constructing technical systems. In this paper, we present a unified SA model for generating human and machine SAW. We call this model $(SAM)^2$ (Situation Analysis Model for Semi-automatic, Automatic and Manual decision support) as it can be applied to automatic and manual SA as well as to analysis integrating both of these, referred to as semi-automatic analysis. This latter type of SA is important since it will allow exploitation of both human and machine strengths.

Appendix E Scenario and project summaries

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

Each of the scenarios is followed by a one-page summary of each project within the scenario. The scenarios themselves are not actual projects, but serve as an umbrella for the projects within it.

Scenario: IF cgi – Common goals & infrastructure

Information fusion theory, methods and infrastructure

Tom Ziemke, Professor, Sten Andler, Professor, Henrik Boström, Professor (from 2007)
Joeri van Laere, Postdoc, Ronnie Johansson, Postdoc, Tarja Susi, PhD
PhD Students: Maria Nilsson, Alexander Karlsson, Marcus Brohede

Skövde Cognition & Artificial Intelligence Lab (SCAI) &
Distributed Real-Time Systems Research Group (DRTS) &
Information Systems Research Group (IS)
University of Skövde, PO Box 408, SE-54128 Skövde, Sweden

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, and (b) 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). 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 data 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 develop the following three elements, corresponding to three projects, which capture the *use* of information fusion, its *functionality*, and its *technological realization* respectively: (**cgi1**) 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**) generic *methods, algorithms and tools* for the use in modeling and implementing information fusion processes and systems; and (**cgi 3**) 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

We believe that these 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 (such as the JDL model) 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. (cf. next section).

Highlights in 2006

Recruitment: Two postdocs have been recruited (Johansson, van Laere) and have joined the program/scenario from May and December 2006 respectively. One new professor (Boström) has been recruited, who will start in January 2007 and will be involved in all CGI projects.

Program Synergies: The PhD course *"Information fusion"* has been given twice, in the second instantiation as a combined PhD masters course (altogether 14 PhD students, 10 masters students) as well as a second PhD course on *"Advanced topics in information fusion"*. IF project leader meetings have been held a couple of times per term. IF program meetings, intended to bring together all researchers in the IF program, have been started (coordinated by the postdocs); ten new meetings are planned for the spring.

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 *all* application projects, and thus to some degree will involve all research groups and all industrial partners, at least indirectly.

Approach

The general approach is to use all application scenarios as case studies and/or input sources and at the same time feed back to all scenarios/projects the relevant general knowledge, insights gained, etc. Project cgi1, for example, will involve case studies of the different requirements for information fusion and decision support in the different application scenarios/projects 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, project cgi2 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

The CGI projects play a key role in the research program in gathering knowledge, experience, etc. from the different application scenarios/projects, developing generic theories, models, and methods, and facilitating knowledge transfer between application domains.

Results achieved in project

Program Activities: The IF research program has been presented externally at several events, such as the *Fusion 2006* conference in Florence and in a networking session at *IST 2006* FP7 event in Helsinki, as well as at/for several universities, institutes and companies, incl. SAAB, Swedish Defence College, NASA, Wuhan Technical University, (Wuhan, China), AIST research institute (Tsukuba, Japan), and Denki University (Tokyo). Courses and regular information meetings have been held program-internally (cf. above).

Research: The research results are discussed in the three CGI project summaries.

Related work

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

Growth Potential for scenario

Start: 1 Nov 2005 (5 yrs) ***Project: IF cgi1 framework***

Information Fusion and Decision Support: Cognitive and Organizational Factors

Tom Ziemke, Professor (tom.ziemke@his.se)
Henrik Boström, Professor (henrik.bostrom@his.se) (from 2007)
Joeri van Laere, Postdoc (joeri.laere@his.se)
Tarja Susi, PhD (tarja.susi@his.se)
Maria Nilsson, PhD Student (maria.nilsson@his.se)

Skövde Cognition & Artificial Intelligence Lab (SCAI),
Information Systems Research Group (IS)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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. Using an existing framework/taxonomy of IF user interaction (which is, however, mostly limited to military decision making) as a starting point, the users' interaction with IF systems in different application domains will be analyzed through interviews and case studies to understand the different 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:

- Which 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?
- Which 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/decision makers and application contexts?

Relevance to Information Fusion

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

Highlights in 2006

One newly recruited postdoc (van Laere) and another senior researcher (Susi) have joined the project very recently (working on the project 50% and 10% respectively) and complement the existing competence with their respective backgrounds in organization theory/coordination and cognitive science, decision making/situation awareness.

Since both van Laere and Susi are also working in a project on the coordination of different actors in crisis management, led by van Laere and funded by the Swedish Emergency Management Agency (SEMA, Krisberedskapsmyndigheten), the cgi1 project has now also established close connections to that project and will profit from that in the understanding of organizational factors in and requirement for information fusion systems.

The PhD student (Nilsson) has presented her work, taking a situated/distributed cognition perspective in a talk/paper on JDL level 5 at the *Fusion 2006* conference in Florence (Nilsson & Ziemke, 2006). She has also presented her work at a doctoral consortium workshop at the *Human-Computer Interaction* (HCI 2006) conference in London (Nilsson, 2006), received useful feedback from a panel of leading senior HCI researchers, and subsequently has been invited to write a 500-800 word summary of her PhD research for the HCI magazine *Interfaces* (cf. Results).

The newly recruited professor (Boström) will also be involved in the project from January 2007).

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.

Scientific

The project is carried out in cooperation with all application scenarios, and thus to some degree will involve all research groups in the IF research program.

Approach

The general approach is to, at least initially, use all application scenarios as case studies/input sources to get a picture of different IF system user situations and requirements. Using Blasch & Plano's JDL User Model framework/taxonomy [1] (which is, however, mostly limited to military decision making) as a starting point, the users' use of and interaction with IF systems in the different application domains will be analyzed through interviews and case studies to understand the different requirements for information fusion and decision support in the different application scenarios/projects. 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 *infofusion* 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

An initial literature survey has been carried out as part of the PhD student's research proposal, and contacts with all projects have been established in order to be able to get input through interviews and case studies in all applications domains/scenarios. Initial interviews have been carried out during spring 2006. Nilsson, van Laere and Ziemke have also been involved in discussions of JDL and situation awareness terminology with researchers in the ground situation awareness scenario. Potential synergies between the cgi1 project and the abovementioned crisis management project have also been discussed.

The PhD student (Nilsson) has also already collected 23 PhD student course credits/weeks and finished about 80% of her research proposal (corresponding to the first 20 credits/weeks of the PhD thesis).

Some first publications/manuscripts have been produced:

- Nilsson & Ziemke (2006). Rethinking level 5: Distributed Cognition and Information Fusion. In: *Proceedings of the 9th International Conference on Information Fusion*. IEEE ISIF, ISBN 0-9721844-6-5.
- Nilsson (2006). Rethinking HCI for Information Fusion and Decision Support. In: *Proceedings of HCI 2006*, vol. 2, pp. 225-227. ISSN 1470-5559.
- Nilsson (in progress). Information Fusion: a new requirement for future effective decision making? (working title). *Interfaces*, to appear in 2007.
- Nilsson (in progress). Research proposal, to be finalized in early 2007 (about 50 pages).
- Nilsson (in progress). The Future of Information Fusion: Information Fusion Systems in the light of Decision Support Systems. Draft paper for possible submission to *Fusion 2007*.

Related work

Although it is acknowledged that information fusion systems are intended to support human decision makers, there is a lack of studies which focuses on cognitive and organizational factors in an information fusion context. In 2000 an addition to the JDL model in the form of a level 5 was suggested by Hall, Hall and Tate [2] which explicitly accounts for functions associated with human-computer interaction. They argued that we need to remove the "*HCI bottleneck*" i.e. the fact that HCI interfaces tend to become a bottleneck which prohibits humans from using their extensive pattern recognition and analytical skills to infer the information presented. Level 5 typically includes both cognitive and HCI issues, but is commonly referred to as "*Level 5: cognitive refinements"* [2]. Blansch and Plano [3] suggested an extension to the above in 2002 by re-labelling the level as "Level 5: User Refinements" and creating the *JDL-User model*. The goal of the modified level is to extend the human capabilities. This provides an interesting base for further studies and will in this project be extended to take into account more explicitly organizational factors as well as non-military decision making contexts.

[1] Blasch & Plano. Level 5: user refinements to aid the fusion process. *Proceedings of Multisensor, Multisource Information fusion: Archetetures, Algorithms, and Applications, SPIE* vol 5099, 288-297, 2003.

[2] 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.

[3] Blasch & Plano. JDL Level 5 fusion model: User refinements issues and application in group tracking. *SPIE* vol 4729, *Aerosense*. 270-279, 2002.

Start: 1 Nov 2005 (5 yrs)

Project: IF cgi2 methods

Generic Methods, Algorithms and Tools

Sten F. Andler, Professor (sten.f.andler@his.se)
Ronnie Johansson, PhD (ronnie.johansson@his.se)
Alexander Karlsson, PhD Student (alexander.karlsson@his.se)

Distributed Real-Time Systems Research Group (DRTS)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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, 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). 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 contribute 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/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 information fusion domain 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 to a large extent been an uncharted research field. Most attempts that address this problem are quite similar and almost exclusively belong to the military domain.

High-level information fusion is usually tightly coupled with decisions (automatic or by a decision maker). It is therefore important that also high-level information fusion algorithms and methods are *robust* and *reliable.* In fact one can consider these two concepts (similar to Svensson [1]) as preconditions for a trustworthy information fusion system and "fusion-based decision-making".

Specifically, the following research questions can be raised concerning robustness and reliability:

- What are the requirements on generic algorithms and methods for high-level information fusion to ensure robustness and reliability?
- How should situations and their corresponding possible impacts be represented for different application domains?
- How can uncertain domain knowledge and data from the past (databases), present (sensors), and future (simulations) be used in generic high-level information fusion algorithms and methods, for the purpose of increased robustness and reliability?
- How can one evaluate generic high-level information fusion methods and algorithms with respect to robustness and reliability?

Relevance to Information Fusion

We believe that 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 (such as the JDL model) 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 reliability and robustness, we believe that the research questions are of fundamental importance for fusion-based decision-making.

Highlights in 2006

An important highlight is a research proposal report where the more focused research questions are presented.

Another important highlight is an extended cooperation with the precision agriculture scenario, which resulted in new valuable contacts with the Swedish University of Agricultural Sciences (SLU). Several discussions with SLU have led to an increased understanding of different ways in which information fusion may be used in the precision agriculture domain.

Other important highlights of 2006 are:

- Dr. Ronnie Johansson (PhD The Royal Institute of Technology) with specialization in information fusion, new Post-doc and co-supervisor for Alexander Karlsson (AK)
- AK attended the second SIPTA (The Society for Imprecise Probability: Theories and Applications) summer school, Madrid, Spain
- AK admitted to CUGS (Swedish National Graduate School in Computer Science)
- AK admitted to ARTES (A network for Real-Time research and graduate education)
- AK attended ARTES summer school, Nässlingen, Sweden,
- Project members attended the 9th international conference on information fusion, Florence, Italy

Cooperation

The CGI projects are carried out in cooperation with *all* application projects, and thus to some degree involve all research groups and all industrial partners, more or less directly.

Industrial

As a result of the direct collaboration with the precision agriculture and ground situation awareness scenarios, cooperation has been established with the industrial partners Agroväst and Saab Microwave Systems.

Scientific

An extended cooperation with the precision agriculture scenario has led to several contacts within the Swedish University of Agricultural Sciences (SLU).

Approach

The general approach is to use all application scenarios as case studies and/or 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.

More specifically, the military domain, precision agriculture and manufacturing have been identified as particularly interesting domains for our work in high-level information fusion. These scenarios are all part of the Infofusion program, which enables for demonstration and proof-of–concept implementation of robust and reliable high-level information fusion algorithms and methods. Also, we believe that this versatile mixture of application domains further emphasizes the generic aspect of the research questions.

Contribution to *infofusion* goals

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

An important contribution is to depict how to account for robustness and reliability in high-level information fusion in different application domains and thus contribute to the increased generalization of information fusion. This contribution is also of great importance to all scenarios where fusion-based decision-making is needed.

Results achieved in project

An important result is a research proposal report, expected to be completed in 2006, where more focused research questions are presented. The research proposal is planned to be a basis for a “work-in-progress" publication. The main expected outcomes of the work are contributions to a revised, generic version of the JDL information fusion model and a toolbox of generic, robust, and reliable high-level information fusion formalisms and algorithms.

Related work

Svensson [1] has addressed the issue of high-level information fusion in conjunction with reliability and robustness and declared that very few articles depict this problem. He further argues for the importance of “reliability-demonstration” of high-level information fusion algorithms and methods in order to enable for trustworthiness.

Several articles propose Bayesian networks (BNs) for high-level information fusion (e.g., Das et al.). However, these papers seldom address the issue of robustness and reliability (exceptions exist, e.g., Pavlin et al.) and the BNs are usually not applied to a realistic practical problem. Furthermore, these articles only argue for BNs as a high-level information fusion method within a military context. A serious deficiency is that BNs do not support imprecision in probabilities, which is of fundamental importance when an insufficient amount of information is available or beliefs incomplete (Cozman).

Other approaches to high-level information fusion often rely on a combination of different methods [1]. The results of such combinations are usually difficult to assess from a robustness and reliability perspective.

[1] Svensson, P.: On reliability and trustworthiness of high-level fusion-based decision support systems: Basic concepts and possible formal methodologies, in *Proc. 9th Int’l Conference on Information Fusion*, 2006

Start: 1 Apr 2005 (3 yrs) ***Project: IF cgi3 infrastructure***

Using Active Real-Time Database Functionality as an Infrastructure for Information Fusion

Sten F. Andler, Professor (sten.f.andler@his.se)
Ronnie Johansson (ronnie.johansson@his.se)
Marcus Brohede, PhD student (marcus.brohede@his.se)

Distributed Real-Time Systems Research Group (DRTS)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 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. 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 2006

The PhD student presented his thesis proposal titled "*Bounded recovery in distributed discrete real-time simulations*".

Meeting with researchers from SLU to form a group that intends to investigate how information fusion can improve agriculture. 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. One part of particular interest is the potential use of wireless sensor networks (WSN) for sensing in the field and real-time simulations for improving the decision on fertilizer amounts.

During a four month period the PhD student went to the University of Virginia (UVA), USA, to work in the real-time systems group. He started a project that aimed at using our proposed infrastructure in the medical domain. The project looked on how real-time simulation could improve the vital data for a doctor, nurse or a first responder decision. In this way the three tiers of information fusion could be tied together to form another proof of concept application. One important outcome of this visit was the design of an experiment where real data from humans was collected and used to demonstrate the use of our infrastructure. A paper that describes this project and its results is about to be submitted to a conference. During this time good connections were founded and potential future joint projects were discussed, e.g., due to the mature knowledge in building WSN the real-time systems group at UVA could be an asset when designing and building the agriculture demonstrator mentioned above.

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.

Scientific

The CGI projects will be carried out in cooperation with *all* application projects, and thus to some degree will involve all research groups and all industrial partners, at least indirectly.

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

A PhD student was already on board when the research program started expected to complete his doctoral dissertation in 2007.

Initial experiments show good indications that the methods can be successfully applied. For example, a paper describing the use of our proposed database infrastructure as an infrastructure for distributed real-time simulations was submitted and accepted to the Simulation Interoperability Workshop (SIW) 2005.

A thesis proposal was written and presented in January 2006. The document also became a technical report at the University of Skövde, HS-IKI-TR-06-008.

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.

Goldsman & 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.

Scenario: IF gsa - Ground Situation Awareness

Information fusion for Ground Situation Awareness

Lars Niklasson, Prof., Tom Ziemke, Prof., Göran Falkman, PhD,
Håkan Warston, PhD, Thorbjörn Johansson, PhD, Martin Smedberg, PhD,
Thomas Kronhamn, MSc, Tomas Planstedt, BSc
Industrial PhD Students: Per Gustavsson, Christoffer Brax
PhD Students: Maria Riveiro, Anders Dahlbom, Fredrik Johansson

Skövde Cognition and Artificial Intelligence Lab (SCAI)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 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?

An overall research question for the scenario is how to synthesize the common definitions of the area into a framework valid for all the subprojects within the scenario. The framework need to incorporate 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. The framework will also need to iron out some inconsistencies within the common definitions.

A central problem within situation awareness is how to automatically fuse sensor generated target information (position, type, etc.) and context information (weather, geographical topology, etc.) with historical information (e.g. tracking of movements or previous doctrines) 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'. Another interesting aspect is to investigate if and how impact assessment can influence situation assessment. The domain is also characterized by the presence of a large number of objects and the need for dealing with uncertainty.

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. Two subprojects will focus on the development of methods and algorithms for *impact assessment*. They will focus on the usefulness of different automatic induction methods from the artificial intelligence area (Genetic Algorithms, Neural Networks, ID3, etc.) for hypothesis generation. This includes developing methods and algorithms for hypothesis generation and testing, but also how to break down an impact assessment into critical situations. These can then be used as triggers for detecting if a threat or opportunity is imminent. 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.

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 2006

During 2006 the scenario has developed a common framework for situation awareness. This framework incorporates definitions for both machine and human situation awareness. It also incorporates all the subprojects of the scenario. This work will result in a publication common to all of the PhD projects.

During 2006 a number of internal seminars were conducted. A 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).

The scenario evaluated two scenario generators during 2006 (Virtual forces and Stage). This evaluation showed that Stage could be a common platform for generating data for several subprojects.

The students have participated in a number of courses, both at he University of Skövde and at other universities.

Projects within scenario IF gsa

IF gsa1 algorithms
IF gsa2 visualization
IF gsa3 hypotheses

Industrial cooperation

Two companies are involved today, Saab Microwave System and Exensor Technology. Saab has during 2006 purchased Ericsson Microwave Systems, During 2006 representatives from both the old Ericsson Microwave Systems and University of Skövde have met with representatives from Saab in order to introduce the research program within the Saab organization. The cooperation with Exensor Technology has so far been limited, since the preliminary plan to utilize an industrial PhD at Exensor failed. Plans have bee initiated to set up a project with Exensor during 2007. This project will involve a postdoctoral student. Other companies within the defence industry are also potential partners.

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.

Milestones for 2007

- An infrastructure for generating data for the subprojects will be purchased and installed.

It will probably be passed on the Stage software.

- The PhDs are currently in the process of writing a paper suggesting a new approach to information fusion. This approach includes both manual and automatic processes. The intention is to publish a paper at the Information Fusion conference 2007.
- The PhDs have started on their Research Proposals (i.e., a description of the problem area, including a background literature survey) during 2006. The original plan to finish all of these by November 2006 has been somewhat delayed since they all have participated in somewhat more extensive course work than planned. The revised plan is that all PhDs should have finished thir RP by the first half of 2007.
- The PhDs should start on a Thesis Proposal (i.e., a description of the research problem and hypothesis) by the first quarter of 2007. These TPs should be finished by December 2007..

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.

Start: 1 Nov 2005 (5 yrs) ***Project: IF gsa1a algorithms***

Algorithms and methods for automated ground-situation analysis through Information Fusion of sensor, database, and predicted information.

Lars Niklasson, Professor (lars.niklasson@his.se)
Anders Dahlbom, PhD Student (anders.dahlbom@his.se)

Skövde Cognition & Artificial Intelligence Lab (SCAI),
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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. The task for a decision maker is to obtain SA by perceiving information, comprehending its meaning, and projecting its impacts into the future, in such a way as to make feasible decisions. The aspects of SA are all concerned with analysing the information by various means, e.g. performing ground-situation analysis. 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. This in turn, could lead to incorrect SA, leading to bad decisions, and in the extreme, human casualties. This problem, also known as information overload, needs to be addressed.

In order to alleviate for this problem, various aspects of the original awareness might need to be removed from the decision maker by automating some of the tasks originally handled manually, and instead accomplishing the tasks with automatic or semi-automatic decision support tools that have the ability to cater for the increased complexity. Completely automating some tasks can however lead to a loss of SA as the decision maker does not need to address the issues coupled to the specific tasks anymore. This motivates the interest for automating the task of analysing ground-situation information to various degrees depending on the task, but at the same time sustaining some form of SA in the processes. The starting point for this project reside at the lower end of this problem, by investigating how *Information Fusion* can be used to create automatic tools for ground-situation analysis, implicitly containing various degrees of SA.

Research Question

Processes for situation assessment have the main purpose of finding relations amongst entities in the information flow under consideration. Relations can range from proximity in attribute space between homogenous entities, to asymmetric relations amongst heterogeneous entities such as buildings and tanks, and to other types of relations possibly defined in some ontology or similar. The processes that are needed might also need to anticipate relations that are not obvious in the current flow of information, but which are based on previous knowledge together with the new information. Due to the enormous complexity entailed in the problem domain, constructing algorithms and methods for automating situation assessment is imperative.

Fully automating some tasks may indeed allow for more complex tasks to be handled by semi-automatic and manual processes, which in turn can allow for new abilities being developed. This as new kinds of information might become available through more complex processing. It can also be important to move the SA needed for the tasks handled automatically, into the processes such as to avoid the potential problem of information overload.

The long-term goal in this project is to investigate if and how automated processes for situation assessment, sustaining the SA needed for specified tasks, could allow for new capabilities to be developed.

Relevance to Information Fusion

Investigating algorithms and methods for automated situation assessment is highly relevant for information fusion, as understanding the relations amongst the various pieces of information is vital for making decisions. Considering the huge amounts of information that needs to be processed, achieving automation can be a key for obtaining new abilities.

Maintaining SA can however also be of utmost importance when constructing automatic processes, as there might be situations where there is no decision maker available to make the final considerations of what to do.

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 2006

From previously only considering the elements to investigate and how to investigate them (various aspects of clustering), a research question is now

being developed that intends to address a well-defined and previously unexplored problem.

Initial results have been obtained when working on simulated data in a coastal surveillance scenario, in which the task is to automate the process of detecting abnormal behaviours at varying levels of complexity.

Two tools for generating and simulating ground-situation scenarios have been evaluated together with the other projects within the GSA scenario: VR-Forces and Stage.

Discussions concerning collaboration have been initiated with other research institutes working in adjacent, but highly relevant, areas.

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.

Exensor is a company specialized in short-range surveillance equipment. The interest from Exensor is to further their knowledge concerning how to fuse information from spatially separated sets of surveillance equipment.

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. We also intend to initiate collaboration with the information fusion project at De Montfort University, UK.

Approach

A number of scenarios have been identified and are being developed, in collaboration with the related projects and industrial partners, in order to develop algorithms and methods for information fusion at various levels of abstraction. The scenarios range from border-control to full-scale war, and are being developed in that order with the intent to gradually increase the complexity of the information being processed. The information that is processed is also 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.

The approach for reaching the long-term goal in this project will be to investigate how to automate various tasks suitable for automation in the various scenarios that are being developed. It will first be investigated how to automatically perform situation assessment on fully certain data which is completely available. The problem is then extended by introducing uncertainty and by investigating how the algorithms and methods can be used online. Even more complexity is then added by also trying to include relations based on anticipated information.

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, but we will also contribute to the theoretical framework.

Results achieved in project

Initial project specifications and delimitations have been initiated. The writing of a research proposal has been initiated and is scheduled to be completed in the first quarter of 2007. A couple of sub-projects have also been initiated in relation to modules in Information Fusion, Advanced Topics in Information Fusion, Machine Learning and Inference, and Data Mining and Knowledge Discovery.

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

Related work

Ensley's work on *Situation Awareness* (SA) is highly related to this project. Adams' work concerning automated SA in unmanned vehicles is also of great interest as other automated processes (as those investigated in this project) might also need to provide some form of SA.

Work related to *Situation Assessment* is highly relevant, as that is the main focus 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 highly interesting. Work on *Situation Analysis* (similar to, but more general than situation assessment) by for example Maupin & Jousselme, or Kettani & Roy, is also of great interest for this project.

Start: 1 Jan 2006 (5 yrs) ***Project: IF gsa1b algorithms***

Information Fusion for anomaly detection.

Lars Niklasson, Professor (lars.niklasson@his.se)
Christoffer Brax, PhD Student (christoffer.brax@his.se)

Skövde Cognition & Artificial Intelligence Lab (SCAI),
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 todays and tomorrows 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 filer 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. On key part in the identification is to incorporate data form a number of sources, i.e. databases, different kinds of sensors and simulations.

Highlights in 2006

In cooperation with the ground situation awareness group we have constructed a common framework for Situation Awareness based on a number of other models. The purpose with this model is to relate the different projects to each other and get a clear view about how the projects relates to other work in the field of information fusion.

The research question has been refined and is now more focused on the problem. Other highlights this year are three paper publications and the evaluation of two tools for scenario generation (VR-Forces and STAGE).

In cooperation with Saab Microwave Systems and the other GSA projects we have defined three scenarios that can be used to discuss specific and general problems and issues in the GSA projects. The other part of the cooperation has been the SAIDA (Situation Awareness using Intelligent Detection of Anomalies) project which focuses on evaluating algorithms for anomaly detection.

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 and attended a situation awareness workshop with Saab, Ericsson, Volvo and the University of Halmstad.

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. One possibility is to relate our approach with national and international ISTAR projects, which appear to have a focus closer to the sensor level.

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.

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 “Towards Hypothesis Evaluation in Command and Control Systems” was presented at the SAIS Workshop in Umeå, Sweden. The paper evaluates artificial neural networks and Bayesian networks for prediction of enemy course of action. The results were that in most of the cases the artificial neural networks had better performance than the Bayesian networks. Another paper was presented as a poster at SAIS. It described an architecture for an information fusion system and was entitled “The Road Towards Multi-Hypothesis Intention Simulation Agents Architecture - Fractal Information Fusion Modeling”. The third paper published was “An Agent Architecture for Multi-Hypothesis Intention Simulation: An Ontology Driven Interoperabilty Architecture”, the paper was presented at The 10th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI), Orlando.

The report from the evaluation of scenario generation tools was completed.

We also got some initial results from the experiments in the SAIDA project where an algorithm for adaptive resource allocation vector quantization was evaluated in the coastal control scenario. The evaluation showed some promising results both for detecting anomalies in basic object behavior and for making an abstract representation of the data.

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),
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

Ground situation analysis is characterised by large amounts of information that typically need be 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, e.g. mobile displays of limited size or resolution. 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 can fused situation analysis information be presented to a user/decision-maker in such a way that it can be assessed and used in a semi-automatic fashion to effectively support decision-making in situations characterized by information overload and time pressure?

This includes issues such as:

- Visualization of uncertainty, reliability of available data and/or alternative future developments of the current situation
- Different levels of abstraction or granularity (in time and space)
- Interactivity of visualization, depending on the user's needs (e.g. trust or experience)
- Interdependence of visualization needs and available resources

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 2006

Most of 2006 has been devoted to: (a) clarifying the use of and the exact relation between situation awareness and JDL terminology (supposed to result in the publication of a joint position paper), and (b) a joint project on anomaly detection in collaboration with all GSA projects (SAIDA - Situation Awareness using Intelligent Detection of Anomalies; the visualization part of this work has been on using self-organizing maps for low-dimensionality visualization of complex, high-dimensional data). The PhD student (Riveiro) has already collected 27 PhD student course credits/weeks and finished about 80% of her research proposal (corresponding to the first 20 credits/weeks of the PhD thesis).

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, usually 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. Possible collaborations have been discussed with several other groups, including the Swedish Agricultural University, Skara.

Approach

A number of concrete scenarios, military and civilian, will be developed, in close cooperation with the other GSA projects, in order to initially investigate the above research issues in several concrete case studies.

A number of initial scenarios have been specified in collaboration with SAAB Microwave

Systems (including border control and surveillance of sea scenarios). Simulation data has been generated/provided by SAAB and has been used by the GSA PhD students in the abovementioned initial SAID project.

Contribution to *infofusion* 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 (cgi1) that looks at the cognitive (and organizational) 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. Since then a literature review on information fusion visualization has been carried out. 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 starting points and case scenarios.

An initial joint project (SAIDA) has been carried out (with relatively little focus on visualization, but providing a number of initial ideas). 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 is supposed to result in the publication of a joint position paper.

Two tools for generating and simulating ground-situation scenarios have been evaluated together with the other projects within the GSA scenario (VR-Forces, Stage).

Related work

The most relevant related work is the work of Anne Bisantz [1] on the visualization of uncertainty. This project will test/start from some of the ideas developed by Bisantz, but will additionally also 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, Breton and Paradis presented in [2] 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 [3].

A brief overview on visual and graphical interfaces for Information Fusion can be found in [4, chap. 9, pp. 320-324].

[1] 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.

[2] 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, Ivan Kadar; Ed.

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

[4] Hall, D., McMullen, S. A. H. (Eds.), 2004. Mathematical Techniques in Multisensor Data Fusion, 2nd Edition. Artech House, Inc., Norwood, MA.

Start: 1 November 2006 (5 years) ***Project: IF gsa3 hypotheses***

Information Fusion for Impact Assessment in the Domain of Ground Situation Awareness

Göran Falkman, PhD (goran.falkman@his.se)
Fredrik Johansson, PhD Student (fredrik.johansson@his.se)

Skövde Cognition and Artificial Intelligence Research Lab (SCAI),
University of Skövde, P.O. Box 408, SE-541 28 Skövde, Sweden

Superior situation awareness and decision superiority are important concepts in tomorrows 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 drowning in heterogeneous data or information, they need decision support systems to help with the computationally hard inference making task.

A good candidate for the basis of such a decision support system is the family of graphical models, since they are grounded on the well-founded concept of probability theory, represent information in a way that people can be able to grasp and understand and since they are computational efficient.

The project addresses the question of how to provide computer support to the military decision maker by developing guidelines on when to use a specific graphical model, and when to use a certain technique for solving an impact assessment problem. Initial work shows how a very general Bayesian network can be used for prediction of the enemy's short-term tactical intention in a ground combat scenario. It also shows the possibility to integrate such a Bayesian network into a ground target simulator in order to address the often hard problem of how to come up with the conditional probability distributions. Problems such as how to tailor-made a general Bayesian network into more situation specific networks and how to generate hypotheses are identified.

Research Question

The threats against our society have changed during the last years. Armed forces all around the world are now facing threats and tasks other than just to defend the nation against invasions or armed aggressions. In such new tasks (e.g., riot control), it is very important to get an understanding of the situation – known as situation awareness, since it is often unclear who is friendly and who is foe, and also hard to know the capabilities of the opponent. The uncertainty regarding the opponent and its capabilities is very different compared to the situation during the cold war, which make it hard to follow predefined doctrines nowadays. Instead, the use of dynamic solutions is the key to meet the unknown threats of the future. This puts high demands on making quick and good decisions based on the decision maker's view of the current situation and the way the situation will evolve in the future.

To achieve situation awareness and to make the right decisions are anything but trivial tasks for the human decision maker. These situations are complex in nature and the available information will always be uncertain to a high degree. Often the objective is to predict some abstract state of entities or between entities and the environment To infer these states is hard for humans since many possible hypotheses regarding an entity's state 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.

Relevance to Information Fusion

In the field of data 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. Lower levels of data fusion typically consist of fusion of multi-sensor data to determine characteristics of an entity. Higher levels of data fusion, commonly known as 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.

Data and information fusion have been put forward as the core technology underlying decision support systems for situations with large amounts of real-time information. The data fusion process have been researched for a long time and are quite well understood, but when it comes to information fusion, the research is more immature, with numerous prototypes but only a few operational systems.

Probabilistic reasoning, i.e., methods based on the well-founded concept of probability theory, is well-understood methods of representing uncertain knowledge and to reason under uncertainty. Most systems for probabilistic inference are built upon

Bayes' theorem, which makes it possible to update the probability for a hypothesis being true when new data arrives. Drawbacks with these methods are that they demand quantitative probabilities to be defined, and that hypotheses have to be mutually exhaustive, i.e. all possible hypotheses have to be modeled.

Graphical models combine probability theory with graph theory. They represent information in a way people often are able to grasp and understand, which make it easier for the users to trust the inferences and to model the problem domain. They also enable efficient inference algorithms. Bayesian networks is a well known family of graphical models, but also techniques such as hidden Markov models and Kalman filters can be seen as special cases of graphical models. Individual graphical models have earlier been used for specific information fusion problems, but there is no research on the use of techniques from the family of graphical models for impact assessment problems in general.

Highlights in 2006

In cooperation with the other projects within the GSA scenario and SAAB Microwave Systems, methods and algorithms for anomaly detection have been studied within the SAIDA (Situation Awareness using Intelligent Detection of Anomalies) project. This includes an investigation of how an adaptive resource allocation vector quantization network could be used for unsupervised detection of anomalies in a border and coastal surveillance scenario, as well as an implementation of an anomaly detector based on a Self-Organizing Map and a Gaussian Mixture Model.

The project has also been involved in the testing and evaluation of two systems for the generation and simulation of ground situation scenarios: VR-Forces and STAGE.

Cooperation

Industrial

This project is in collaboration between SAAB Microwave Systems AB (formerly Ericsson Microwave Systems AB), Göteborg, and the University of Skövde, as a part of the Information Fusion Research Program. Another industrial partner that will be linked to the project is Exensor AB, Lund.

Scientific

This project is a part of the Ground Situation Awareness (GSA) 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.

Approach

The first step is to investigate what kind of graphical model techniques that are appropriate for different impact assessment problems and what models that have been used earlier. This includes: (i) identify common properties and problems with the use of graphical model techniques for impact assessment; (ii) find, adapt and develop methods and algorithms for dealing with the identified problems; (iii) create guidelines for which graphical model, and what methods and algorithms to use for a specific scenario or situation.

The second step is the implementation of specific graphical models for making inferences in military decision support systems. For getting access to realistic synthetic training and test data, scenario generation systems, such as STAGE and VR Forces, will be used. This step includes: (i) identify and construct appropriate scenarios for training and testing; (ii) implement a graphical model for inference making, based on the earlier developed guidelines, methods and algorithms; (iii) test and evaluate the implemented system together with domain experts.

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, and especially impact assessment. The project also contributes to the evolvement of models for describing information fusion processes and functions, e.g., the JDL model and the OODA loop.

We also expect to contribute to the work on developing ground target simulators for use in strategic analysis, which gives the project a commercial potential.

Results achieved in project

A paper entitled “Implementation and integration of a Bayesian Network for prediction of tactical intention into a ground target simulator” has been accepted and presented on the 9th International Conference on Information Fusion. The paper suggests a topology of a Bayesian network for prediction of the enemy’s courses of action, and addresses the problem of how to find appropriate prior distributions for the Bayesian network, by integrating a data collecting tool into a ground target simulator.

A research proposal entitled “Inference Making Using Graphical Models for Improved Ground Situation Awareness” will be put forward before the end of 2006.

Related work

This project is related both to the use of different kinds of graphical models for impact assessment problems, and to more general work on graphical models, e.g. inference algorithms and model learning. Related work of the first kind is the problem of modeling enemy intent, which has been studied in a number of papers by Santos Jr. *et al.*, and Suzić’s work on plan recognition using Bayesian networks.

When it comes to related work of the second kind, some examples are the work of Heckerman, Lauritzen, Neapolitan and Pearl.

Scenario: IF bio - Bioinformatics

An Information Fusion Approach to Understanding Complex Biological Systems

Patric Nilsson, Associate Professor; Björn Olsson, Associate Professor; Barbara Gawronska, Professor; Elzbieta Dura, PhD
PhD Students; Jane Synnergren, Elie Järnmark, Jonas Gamalielsson, Kim Laurio

University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

The goal of the research in the bioinformatics scenario is to develop and apply information fusion 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, which are currently beginning a larger research collaboration under the heading "systems biology". The scenario includes four projects which involve four PhD students. Two of the students are fully financed within the Information Fusion (IF) profile and all four students are expected to complete their degrees within the time-frame of the profile. In addition, one new senior researcher has been recruited.

Research Question

The general goal in the bioinformatics scenario is to develop and apply information fusion 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, there are four related research questions being addressed in the projects within this scenario:

1) *Can the application of an information fusion approach enhance our understanding of how the differentiation of stem cells into different cell types is controlled by gene regulation?* This question is 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 information fusion-based approaches for mathematical modelling be developed and applied to the modelling of the regulatory mechanisms involved in lipid-digestion?* This question is addressed in project **IF bio2 lipids**, where the aim is to fuse information from biological experiments, databases and simulations to derive a model of lipid digestion. Further, this model will be 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 information fusion?* This question is addressed in project **IF bio 3 extract**, where natural language processing techniques are being adapted to the domain of biomedical literature and integrated with data mining techniques in order to form an integrated part of an information fusion process.

4) *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?* This question is being addressed in project **IF bio 4 ModPharm**, where various algorithms are being developed which fuse data from different biological experiments with previous knowledge (stored in databases) to derive sets of biologically plausible hypotheses to be used in the design of further biological experiments.

Relevance to Information Fusion

The research and development on 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 economically costly, and it 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 information fusion approaches, as well as for the development of new information fusion 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 information fusion is useful for

integration of the various data sets and analysis methods, and that it helps us to reach new insights into the biological systems being studied. The scenario is thereby both a test-bed for existing information fusion methods and an arena for development of new methods.

Highlights in 2006

- Two journal articles published: one in *Stem Cells* and one in the *Journal of Bioinformatics and Computational Biology*.
- Conference papers published in the proceedings of the conferences Fusion 2006, BGRS 2006, DILS'06 and ICSS 2006.
- Posters presented at the conferences Bioinformatics 2006 and ICSSR 2006.
- Initial biological experiments completed in **IF bio 1 cells**, followed by application of information fusion techniques to identify reference genes and putative key regulatory genes.
- Initial mathematical models built in project **IF bio 2 lipids**, which will in the next steps of the project be used as basis for the design of experiments to obtain large scale gene expression profiling data.
- Text analysis technique successfully extended and adapted to biomedical domain in project **IF bio3 extract**.
- Two new methods for information fusion to support the pharmaceutical development process developed in project **IF bio4 modPharm**.
- New collaboration with research group at Fraunhofer-Chalmers Institute for Industrial Mathematics established.

Projects within scenario IF bio

IF bio1 cells

IF bio2 lipids

IF bio3 info extract

IF bio4 modPharm

Industrial cooperation

Four companies are involved today: Biovitrum AB, Cellartis AB, Lexware labs, and InNetics AB. The roles of Biovitrum and Cellartis are to provide experimental data from model systems, assist with biomedical expertise, and to provide the biomedical research context in which our information fusion methods are being evaluated. Lexware and InNetics are both software companies and therefore have an interest in potentially developing tools based on the new methods and algorithms that result from the projects in this scenario. Other companies within the biotechnology industry are potential partners.

Scientific cooperation

In the project IF bio1 cells, collaboration takes place with the research group of professor Anders Lindahl, at Sahlgrenska Akademien and Göteborg University. In the project IF bio4 ModPharm, collaboration has been initiated with the group of Mats Jirstrand at the foundation Fraunhofer-Chalmers Center for Industrial Mathematics. Systems biology is an emerging field in molecular biology. In Sweden systems biology research is mainly concentrated to Göteborg and Skövde. At this point initial contacts have been made with the systems biology research group at Göteborg University. 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 information fusion 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.

Contribution to *infofusion* goals

The scenario mainly contributes with new algorithms and methods and a set of highly relevant application problems for information fusion 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 information fusion, for example by making tools for automated text analysis available for all participating projects.

Results achieved in project

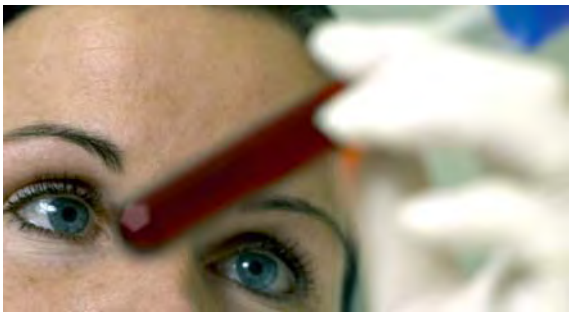
Two PhD students were already active (in project IF bio4 ModPharm) when the scenario started, and two more PhD students started their research on 1st July 2005.

In project **IF bio1 cells** the first stage has been 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 documented in a manuscript which was accepted for publication 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. The identified sets of genes provide clues for the design of follow-up experiments, thus contributing to the process refinement, as described in level 4 of the JDL IF model. The goal of process refinement is to optimize the collection of additional data in such a way that the most appropriate experiments are done and the maximum utility is obtained, in terms of new insights into the behaviour of the system. In this project, given the high costs of the biological experiments, it is vitally important to optimize the information fusion process by selecting the most informative input.

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 provides the basis for a first publication which is planned to be 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 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 will also be addressed by using a complementary *in vitro* model system (using specific cell types), which will result in data sets that must be analyzed in an integrative manner, which again provides a situation where an information fusion approach will be extremely useful.

In project **IF bio3 extract** the initial work has consisted in 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, which were detailed in a paper presented at the Fusion 2006 conference, showed the potential of the algorithm in this domain and identified the most important issues to deal with in the continued tuning of the method. 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 the representation formalism in the Kyoto Encyclopedia of Genes and Genomes, with the aim of providing an output that is both meaningful and easy to evaluate for the biologist. This prototype system was described in a paper presented at the international workshop DILS 2006 and a more detailed evaluation was presented in an article published in *Journal of Bioinformatics and Computational Biology*. Additional components of the prototype system which were added in the latter publication included named entity recognition, syntactic and semantic analysis, and identification of foreground text paragraphs.



The project **IF bio 4 modPharm** has so far resulted in the development of three new methods for data mining in the biomedical domain, which all involve aspects of information fusion. 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). The third new method that has 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 information fusion, and follow-up experiments. The new method has been described in a manuscript that is currently under review for the conference EvoBio 2007.

Related work

It can be argued that bioinformatics is an ideal domain for the application of information fusion approaches, since it is a very common situation in bioinformatics research that an analysis must be done 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. Despite this, it is quite rare that the concept of information fusion is explicitly adopted by bioinformaticians and it can fairly be said that the awareness of information fusion is very low in this research community. Therefore, there are not many examples of authors who actually use the term "information fusion" in the context of bioinformatics. In the following, however, we will give a few examples.

Kasturi and Acharya (2004; *Bioinformatics* vol. 21, p. 423-429) addressed the problem that microarray gene expression data – although very useful - has its limitations, and that improved statistical significance of the findings can be achieved if the microarray data is complemented by additional information, such as promoter sequences of genes and DNA binding motifs, annotation data based on gene ontologies, or location data. To allow inference from such diverse data sets, the authors devised a fusion algorithm based on the unsupervised SOM clustering method. In the proposed algorithm, each data set is considered a category, and a weighting scheme is used to allow adjustment of the degree of influence for each category. Since categories represent data in different formats, a distance function is defined individually for each category. Hence, different data types do not need to be combined into a single feature vector, and the problem of normalization between data types is avoided. Kasturi and Acharya evaluated the approach using yeast as a model system, and fused data sets including gene expression data that had been aggregated from multiple microarray experiments on budding yeast, a set of known transcription factors extracted from the TRANSFAC database, and the frequencies of occurrence of their binding motifs in the upstream regions of the genes. The results demonstrated that the combined clustering found more biologically relevant clusters than when using just a single data source as input.

A more general approach was presented by Lanckriet *et al*. (2004; *Bioinformatics* vol. 20, p. 2626-2635), who proposed a framework based on kernel functions for integrating and drawing inferences from diverse biological data sets. One advantage of this approach is that the theoretical framework of kernel methods provides efficient algorithms for combining functions derived from different types of data in a way that minimizes a statistical loss function. As noted by Lanckriet *et al*. the various data sets that are typically available in a bioinformatics scenario provide different and partially independent views of the molecular machinery being studied, and it can therefore be expected that combining these complementary pieces of information will enhance the total information about the biological system being studied. In their evaluation, the authors defined seven kernel matrices representing information derived from three different types of data. Four of these matrices represented protein sequence data, two represented protein-protein interaction data, and one microarray gene expression data. For the sequence data, the information that had been derived from the primary data represented three different measures of sequence homology (derived by three different sequence alignment algorithms) and transmembrane region prediction data (derived by a Fourier transform analysis of a hydrophobicity profile of the sequence). To perform fusion over the seven different kernel matrices, a convex optimization method named semidefinite programming was used to find a linear discriminant in feature space with maximal distance between the classes. Using data from yeast, Lanckriet *et al*. demonstrated that significantly better classification results were obtained, compared to the same algorithm trained on any of the individual data sets in isolation. The generality of the approach was demonstrated by the development of a library of kernel functions for common biological data types.

Troyanska *et al*. (2003; *PNAS* vol. 100, p. 8348-8353) proposed a Bayesian approach for combining heterogeneous data sources in gene function prediction, while also addressing the problem of varying accuracies of different data sources (a notorious problem in biological research). The proposed method allows the combination of multiple data sources as well as expert knowledge about the relative accuracy of each source.

Other examples of information fusion approaches developed in bioinformatics include the method based on pseudoinverse projection by Alter and Golub (2004; *PNAS* vol. 101, p. 16577-16582), the data integration tool POINTILLIST that offers a number of different integration techniques and was successfully applied for the integration of 18 different data sets to derive a network model of galactose utilization in yeast (Hwang *et al*. (2005; *PNAS* vol. 102, p. 17296-17307), and the Bayesian network-based method used in the bioPIXIE tool developed by Myers *et al*. (2005; *Genome Biology* 6: R114).

Currently, there seems to be a lack of methods that also involve integration of a feedback loop, which is an issue that will be addressed in the projects in the bioinformatics scenario of the information fusion research profile.

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 information fusion-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 information fusion 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 information fusion-based bioinformatic techniques to study the developmental pathways of endometrial cancer tumours.

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

Björn Olsson, Associate Professor (bjorn.olsson@his.se)
Jane Synnergren, PhD Student (jane.synnergren@his.se)

Bioinformatics and Systems Biology Research Groups,
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 project aims to apply an Information Fusion (IF) approach to various types of experimental data in order 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.*

Research Question

The main question being addressed is: *Can the application of an information fusion approach enhance our understanding of how the differentiation of stem cells into different cell types is controlled by gene regulation?*. In the early stages of the project the focus is on 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, integration of inferences from different data sources, and the use of analysis results to make decisions on the design of 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 2006

- Establishment of reference genes to be used in the following experiments.
- Acceptance of the first manuscript for publication in the journal *Stem Cells*, which is ranked as the world's leading journal in the field of stem cell research (impact factor 6.1).
- Presentation of the project by a poster at ISSCR 2006 – the annual meeting of the International Society for Stem Cell Research.
- Candidate genes putatively responsible for differentiation into heart muscle cells identified by fusing microarray data from experiments using two different protocols for cell differentiation.

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 of 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. The aim is to apply and adapt 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 can 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) here translate

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. 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.

Contribution to *infofusion* goals

The main contribution is that the project will show how the concept of information fusion is useful in a bioinformatics scenario. This will be 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 can 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 also evaluated the stability of this novel set of reference genes in publicly available gene expression data from other hESC microarray studies, which confirmed a substantial proportion of the novel genes. Our results suggest that hESCs have a unique signature of reference genes, which can be used as controls in microarray analysis of differentiation. The results are being published in the following journal article:

Synnergren, J., Giesler, T.L., Adak, S., Tandon, R., Noaksson, K., Lindahl, A. Nilsson, P., Nelson, D., Olsson, B., Englund, M.C.O., Abbot, S., Sartipy, P. (2006) Human embryonic stem cells express a unique housekeeping gene signature. *Stem Cells* (volume and page number to appear)

The next 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. When the first protocol is used there are beating areas of cells in parts of the culture colonies after 1-2 weeks, while no beating cells can be seen when cells are differentiated according to the second protocol. This is an excellent situation for comparing gene activity between the two differentiation approaches where the desired property of the phenotype is seen in one of the populations, and it facilitates identification of the relevant objects, i.e. the genes that influence the differentiation process.

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 reveaed 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. This provides clues for the design of follow-up experiments, thus contributing to process refinement, as described in level 4 of the JDL model. The goal of process refinement is to optimize the collection of additional data in such a way that the most appropriate experiments are done and the maximum utility is obtained, in terms of new insights into the behaviour of the system. In this project, given the high costs of the biological experiments, it is vitally important to optimize the information fusion process by selecting the most informative input.

The interesting results also prompted us to plan another gene expression experiment of purified beating cell colonies which will be completed in December 2006. The beating cells are also being monitored both at the protein level and at the electrophysiological level. An IF approach is useful to integrate data from all these different sources into a common understanding of gene activity. The conclusions drawn from the integrated analysis will be represented in a graphical model to aid understanding of the system. This corresponds to level 5 in the JDL model, cognitive refinement, which concerns user interaction. Time permitting; a quantitative model may also be implemented. Such models allow the user to test hypotheses by *in silico* experiments, where the influence of different parameter settings can be tested by simulation.

Related work

Since the concept of information fusion has not yet received widespread attention in bioinformatics, there are not many examples of related work. However, the method for fusing heterogeneous microarray data using multivariate regression proposed by Gilks *et al*. (2005; *Bioinformatics*, vol. 21, p. ii137-ii143) is highly relevant, as we are facing the problem of fusing microarray data generated in different laboritories using different experimental platforms. Also, for development of graphical models of the pathways being studied, we consider using a software for bioinformatical information fusion, such as POINTILLIST (Hwang *et al*., 2005; *PNAS*, vol. 102, p. 17296-17301), or to develop improved software based on our own ideas.

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.

Patric Nilsson, Associate Professor (patric.nilsson@his.se)
Mikael Ejdebäck, Assistant Professor (mikael.ejdeback@his.se)
Mikael Harlén, Assistant Professor (mikael.harlen@his.se)
Elie Järnmark, PhD Student (elie.jarnmark@his.se)

Molecular Systems Biology Research Group,
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

This project is in 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 will be adopted 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 will 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?

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.

Highlights in 2006

Based on published data, and data obtained from own experiments, a tentative mathematical model has been developed in order to capture the flow of long-chain fatty acids from the intestinal lumen to the assembly of chylomicrons (small fatty particles) inside the enterocytes. Experimentally, we have tried to identify the key players involved in regulation of this process by using quantitative real-time PCR. Feeding and re-feeding experiments in a mouse model system have been undertaken and intestinal samples were collected at different time points. This data set constitute a minor milestone in the project as it provides valuable time course data for the development of a more robust mathematical model. The insight from these studies provides the basis for future and more extensive large scale experiments and the development of at least two unique experimental model systems.

Cooperation

Industrial

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

Scientific

This project is 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 is adopted to fuse information from biological databases, simulations and gene expression profiles to synergistically increase our knowledge.

Approach

The first objective is to document and validate two animal models, a mouse model and a pig model. These models will 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 will provide mechanistic and molecular details. A second objective is 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.

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

- Established time course data of key players in the regulation of long-chain fatty acid metabolism. 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 2007.
- 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 system 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 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 used to study the uptake of specific fatty acids by enterocytes.

Related work

<to be added>

Start: 1 Apr 2005 (5 yrs)

Project: IF bio3 info extract

Text Mining and Text Analysis as a Tool in Information Fusion

Barbara Gawronska, Professor (barbara.gawronska@his.se)
Elzbieta Dura (elzbieta.dura@his.se)

Computational Linguistics Research Group,
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 2006

- A large corpus of biomedical texts (Stem Cell Corpus), consisting of 40 millions words, has been collected, tagged, and made available for searching by different statistical measures (T-score, Z-score, MI, maximum MI, Chi-square test, etc.)
- A general English tagger (Stanford Tagger) has been evaluated with respect to the biological corpus. The conclusion was that - for high precision extraction – a more specialized tagger is needed. The special - purpose tagger, that includes domain-specific recognition of names of genes, proteins, and biological relations, has been implemented and tested
- A syntactic parser prototype has been implemented and tested. Currently, the work on implementing the Prolog prototype in C# is going on
- An algorithm for dividing scientific abstracts into background and foreground part has been developed, tested, and evaluated. The success rate is over 92%
- A publication in an international journal: Olsson, B., Gawronska, B., and Erlendsson, B. (2006) Deriving pathway maps from text analysis using a grammar-based approach. *Journal of Bioinformatics and Computational Biology*, 4(2): 483-502
- The work on the project has been presented at a number of conferences and meetings.

Cooperation

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

Scientific: The Graduate School in Language Technology (GSLT) is financing two PhD students. 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. Recently, research cooperation with the Faculty of Science at UNAM (Mexico) has been established, and a common workshop has been scheduled for summer/fall 2007.

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 *infofusion* 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., Erlendsson, B., Gawronska, B., and Olsson, B. Towards Information Fusion in Pathway Evaluation: Encoding Relations in Biomedical Texts. *Proceedings of FUSION 2006*, Florence, Italy, July 2006, we show the results of large corpus investigations and compare general English to the language of biology/bioinformatics/ biomedicine. In: Olsson, B., Gawronska, B., and Erlendsson, B. Deriving pathway maps from text analysis using a grammar-based approach (Leser, U., Naumann, F., and Eckman, B. (eds.), *Data Integration in the Life Science.* Third International Workshop, DILS 2006, Proceedings. Berlin/ Heidelberg/New York: Springer, 50-65) and Gawronska, B. , Erlendsson, B. and Olsson, B. Towards an Automated Analysis of Biomedical Abstracts. *Journal of Bioinformatics and Computational Biology*, 4(2): 483-502, we present the work on morphological analysis, named entity recognition, syntactic and semantic analysis, and identification of foreground text paragraphs. Currently, we work on a systematic presentation of term extraction from corpora by means of statistical methods. Up to now, we can state that:

- While noun parts of general lexicons are useful, verb lexicons should be designed with respect to the specialized text domain
- A grammar-based approach is more promising than statistical approaches to text understanding
- Statistical measures are more useful for term extraction than for text understanding
- Different statistical measures perform differently in the task of term extraction; for example, Mutual Information Ratio returns mainly English terms, like *stem cell* or *growth factor*, while Chi-square test is useful for recognition of Latin terms and names of complex chemical substances, like *fibrosum centrale*, *chordae tendinae*, *erythrina cristagalli* etc.

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,
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

This project is 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 is 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 so far include three new methods for model-based data mining. One of these methods has been presented at the 2006 International Conference on Computational Science and has also resulted in a provisional patent granted by the US Patent Office. The other two methods are currently in the process of being published in two new manuscripts.

Research Question

The main research question in this project is: *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 is 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 requires 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 concerns 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 being 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 2006

- A method that had previously been developed within the project was presented at the conference ICCS 2006 (*International Conference on Computational Science*) in Reading, UK, and the paper was published in the conference proceedings.
- Two additional new methods were developed during 2006.
- Three posters detailing results of the project were presented at the conference *Bioinformatics* 2006, in Århus Denmark.
- One new manuscript was submitted to the conference EvoBio 2007 and another is in preparation (to be submitted to *International Journal of Bioinformatics Research and Applications*).

Cooperation

The project is a collaboration between University of Skövde, Biovitrum AB and InNetics AB. During the project, we have also established collaboration with the Fraunhofer-Chalmers Research Centre for Industrial Mathematics (FCC). Biovitrum contributes experimental data, biological expertise and example research questions, while InNetics and FCC contribute implementation support.

Approach

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

Contribution to *infofusion* goals

The contribution to the IF research program is mainly related to the development of algorithms and methods for information fusion processes. These methods are 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

So far the project has resulted in the development of three 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 presented in the following publication:

Gamalielsson, J., Nilsson, P. and Olsson, B. (2006). A GO-based Method for Assessing the Biological Plausibility of Regulatory Hypotheses. In Alexandrov, V. N., van Albada, G. D., Sloot, M.A. and Dongarra, J. (eds.), *Proceedings of ICCS 2006: 6th International Conference on Computational Science*, LNCS 3992: 879-886. Springer-Verlag.

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 has been named GOSAP (Gene Ontology-based Semantic Alignment of biological Pathways). The aim in this case is 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 GOSAP method is being described in a manuscript which is currently in preparation for submittal to *International Journal of Bioinformatics Research and Applications*.

The third new method that has 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. The new method has been described in a manuscript that is currently under review for the conference EvoBio 2007.

Related work

The GOTEM method uses ideas from the semantic similarity measures developed by Lin (1998; *Proc. ICML*, p. 296-304), Jiang and Conrath (1997; *Proc. ROCLING X*; p. 19-33) and Resnik (1999; *J. Artificial Intell. Res.*; vol. 11, p. 95-130) when calculating term similarity using the annotation terms that have been systematized in the Gene Ontology (Ashburner *et al.*, 2000; *Nat. Genetics*, vol. 25, p. 25-29). These techniques are also used in the GOSAP method, in combination with an adapted version of the alignment algorithm for biological sequences originally proposed by Smith and Waterman (1981; *J. Mol. Biol.*, vol. 147, p. 195-197). The aim of the GOSAP method, i.e. to provide a tool for information fusion by alignment of biological pathways from different species, has also been addressed by Pinter *et al*. (2005; *Bioinformatics*, vol. 21, p. 3401-3408), Koyotürk *et al.* (2004; *Bioinformatics*, vol. 20, p. i200-i207), Dandekar *et al*. (1999; *Biochem. J.*, vol. 343, p. 115-124), Ogata *et al*. (2000; *Nucl. Acids Res.*, vol. 28, p. 4021-4028) and Kelley *et al*. (2003; *PNAS*, vol. 100, p. 11394-11399), although none of these authors considered using the GO annotation combined with a semantic similarity measure, so that any type of gene product can be handled (rather than only, for example enzymes, as in the work of Pinter *et al.*)

Scenario: IF rs - Retail Sector

Information fusion for informed decision support

Lars Niklasson, Professor, Henrik Boström, Professor, Mattias Strand, PhD
PhD Students: Rikard König, Tuve Löfström

Skövde Cognition & Artificial Intelligence Lab (SCAI)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

This scenario contains two projects in collaboration with 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 identity 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. 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 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 2006

During 2006 the cooperation with ICA has intensified. The original organisation within ICA for the projects vanished as a result of an internal reorganisation 2005-2006. The ambition during 2006 has been to find other interested parties within ICA for the projects. This has been achieved late 2006.

Two 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).

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. Since the launch of the program, Ericsson AB (not involved in the information fusion program) has shown an interest in this project, specifically the behavioural patterns project. The forecasting project is relevant for many companies.

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 form 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.

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 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 bee 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 has been submitted to Fusion 2006.

Milestones 2007

- The PhDs will formalise two application projects in corporation with representatives of ICA Handlarna.
- The projects will start to deliver results, which will form the basis for enriched project specifications.
- One of the PhDs will receive a new main supervisor, the new IF professor.
- The work on identifying customer patterns will focus on: (a) identifying groups or segments of customers, based on a data-driven analysis of the sales data from ICA (Q1-2 2007),

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 or 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.

Growth potential for scenario

The problem of fusing information from various heterogeneous sources in order to identify interesting situations, for instance that a customer is about to become non-customer, is a general one. Several other companies have expressed an interest in this problem. The most promising potential for growth for this scenario is that ICA and Högskolan has agreed to be part of a larger EU-project focussing on similar problems, but within other application domains. If this project becomes reality, and if our suggested participation actually becomes reality, the scenario would benefit greatly. The planned consortium is composed of 4 partners (Czech Technical University - Czech Rep., Institute Josef Stefan - Slovenia, Semantic Systems - Spain, University of Skövde - Sweden) and 2-3 end users (research institute in biomedical sciences, company from retail sector and/or precision agriculture).

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)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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. Two types of forecasts are necessary; a short term forecast (one to three days a head) to support replenishment functions in a specific store and long term forecasts (ten to fourteen weeks a head) to support 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 variating 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 is to use non-linear techniques, specifically artificial neural networks (ANN), in order to increase the accuracy of the produced forecasts. We use ensemble method to combine forecast from different techniques to increase the performance and robustness of the model and to calculate predictions probabilities. If we can establish that this type of algorithm has better performance than the traditionally used linear algorithms, we will extend the algorithms by incorporating additional sales effecting information and human expert knowledge.

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 2006

We have shown that non linear techniques such as artificial neural networks and decision trees and especial ensembles of these techniques clearly outperform the standard linear techniques that are used today.

Two studies on probability prediction, for ensembles and for Genetic Programming, have shown promising result. These studies will hopefully result in one or two publication in the beginning of 2007.

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

As the performance of the current forecasts was unknown an initial study was required. The study was performed to evaluate the minimum performance of different linear and non linear techniques. Only small set of basic parameters were used in these experiments. These results are going to bee used as a benchmark minimum result in future studies.

In the coming studies the focus will be on ensemble methods as the initial studies showed that they lead to increased accuracy and robustness. Ensembles techniques also make it possible to calculate forecast probabilities. One goal is to adapt the standard algorithms that are used for weather forecasting to better suit the characteristics of the current domain. When we have found a robust method for creating accurate forecast models the next step is to fuse the models with human knowledge. The fusion will not only focus on the actual forecast but also on probability forecasting.

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 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 bee used for benchmarking in coming studies involving evaluation of parameter selections and deign 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.

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 of course 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: IF rs2 data mining***

Information fusion for identifying patterns in customer/sales data

Tom Ziemke, Professor (tom.ziemke@his.se), Henrik Boström, Professor (from 2007)
Tuve Löfström, PhD Student (tuve.lofstrom@hb.se)
Mattias Strand, PhD (mattias.strand@his.se)

Skövde Cognition & Artificial Intelligence Lab (SCAI)
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

This project is carried out in collaboration between the University of Skövde, the University of Borås and ICA Handlarna AB, one of the major retail organisations in Sweden. The project goal is to utilize information fusion techniques in the identification of relevant behavioural patterns in large sets of customer/sales data, i.e. detecting, or ideally predicting, when customers are changing their behaviour, e.g. when food customers also become non-food customers, or when customers are about to end their customer relation with ICA Handlarna AB. Our starting point is to use artificial neural networks to perform bottom-up analyses/clustering of the data in order to identify the different segments/groups that a customer belongs to (to different degrees). An initial hypothesis is that the customers' 'movement' in such an abstract parameter/state space could be usefully tracked with information fusion techniques similar to those used in the surveillance of geographical spaces.

Research Question

The main research question for this project is: How can techniques from information fusion and data mining be applied and combined in:

1. the identification of relevant patterns of customer behaviour in large sets of customer/sales data,
2. the tracking of such patterns/behaviours over time and their analysis, and
3. the support of proactive decision-making and action in customer relationship management (CRM)?

The background for these questions is that the retail sector is, due to an increased competition, in need of more accurate tools for tracking the development of customers' behaviour over time, e.g. to identify customers that may end the business relation. This includes both more advanced algorithms and the ability to include additional variables/indicators. Being able to identify early on critical signals would allow ICA to become more pro-active in their initiatives in customer relationship management (CRM). In addition, a thorough analysis of the customers and their buying-behaviours may also help ICA in developing customer groups or segments in a bottom-up manner, which is currently only possible to a very limited degree (e.g. not taking into account membership in several groups).

Relevance to Information Fusion

The project also provides an interesting case study of how techniques developed in more traditional information fusion research concerned with tracking, analysing and predicting the movement of objects in some surveilled geographical space over time can be transferred to and utilized in the tracking, analysis and prediction of customers and their behaviours in some abstract customer profile space. Some first ideas on this have been presented in a position paper presented at *Fusion 2006* (Löfström et al., 2006).

Highlights in 2006

The research questions have been specified in more detail, based on discussion with ICA and the results of an initial data analysis study. A literature study on the relevant data mining and information fusion techniques has been carried out and a literature study on the relevant business context, i.e analysis of customer behaviour/segmentation, has been initialized. A position paper has been presented at the *Fusion 2006* conference (Löfström, König, Johansson, Niklasson, Strand & Ziemke (2006). Benefits of Relating the Retail D*omain to Information Fusion.* In: *Proceedings of the 9th International Conference on Information Fusion*. IEEE ISIF, ISBN 0-9721844-6-5).

The newly recruited professor, Henrik Boström, will join the project and take over as project leader and main supervisor for the PhD student from January 2007.

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 unversities). Apart from collaboration with several projects in the IF research

program, no other/outside scientific partners are involved at this point.

Approach

Since the segmentation of the customers is to be data-driven, the initial work encompassed becoming familiar with ICA's customer data, e.g., sales data, but also to develop the skills in applying ICA's internal tools for analysing the data. In addition, the initial work has been aimed at trying to identify different groups/segments (e.g. non-food customers).

The coming studies are mainly going to focus on the following goals:

- Identifying groups or segments of customers, based on a data-driven analysis of the sales data from ICA.
- Comparing data from different stores, in order to verify that the groups or segments are generic.
- Identifying indicators for customers about to leave ICA and developing an "early-warning"-system, which automatically notifies ICA that they need to become pro-active.

Contribution to *infofusion* goals

The contribution to the IF Research program will be twofold: (1) the integration/evaluation of data mining techniques into/from an IF perspective, (2) an extension/application of the JDL IF model in a novel domain where so far IF is rarely used (cf. above).

Results achieved in project

- An initial analysis and evaluation of the sales data for a particular location (Alingsås) and with a specific focus on non-food customers and products.
- A position paper arguing for an IF perspective on the above issues has been presented at the *Fusion 2006* conference (Löfström, König, Johansson, Niklasson, Strand & Ziemke (2006). Benefits of Relating the Retail D*omain to Information Fusion.* In: *Proceedings of the 9th International Conference on Information Fusion*. IEEE ISIF, ISBN 0-9721844-6-5).
- An initial study has been performed on data from a limited set of customers. The results helped to specify in more detail the different research questions to address, in which order to address them, and which data will be required in future studies. The initial focus on non-food customers has after recent discussions with ICA more or less been dropped.

Related work

Research about dynamic segmentation is interesting to this project, since dynamic segmentation deals with segmentation over time.

Clustering algorithms, and especially soft clustering and Self Organizing Maps (SOMs), are techniques that could be used in this project to group customers. SOMs could be used to map customers to a 2D or 3D representation illustrating behaviours over time. Another approach might be to use Generative Topographic Mappings, GTM, for the same purpose.

Clustering and tracking algorithms are potentially interesting later in the project to track changes in behaviour over time.

The most important difference between dynamic segmentation and the approach we intend to use is the techniques we intend to apply. The intention is to build a topological map over the customer behaviors and then transform the problem into an artificial tracking problem, where the customers trajectories through the topological map are defined and analysed.

Scenario: IF mfg – Manufacturing

Simulation-based information fusion for manufacturing decision support

Professor Leo J De Vin (leo.devin@his.se), Professor Olli-Pekka Hilmola, Dr Sandor Ujvari, Dr Amos Ng, Dr Thomas Karlsson, Dr Mats Jägstam
PhD students: Tehseem Aslam, Per Hilletofth, (Vacant)

School of Technology and Society
University of Skövde, P.O. Box 408, SE-541 28 Skövde, Sweden

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

They 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 question 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 troupes 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 de 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.

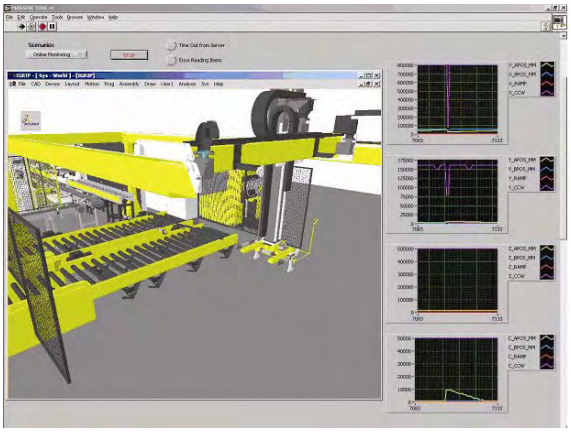


Figure 1: Example of User Interface

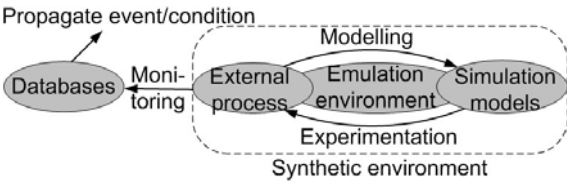


Figure 2: Massive interaction model

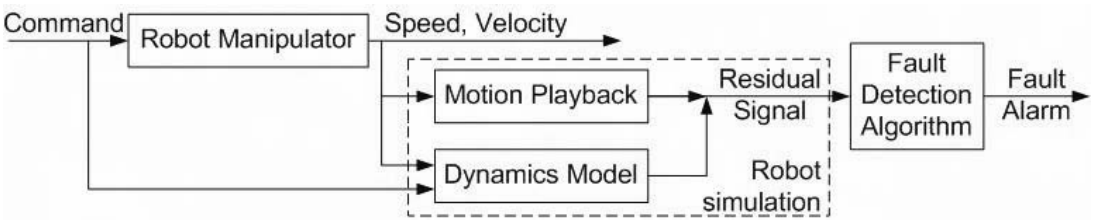


Figure 3: Fault Alarm generation based on analysis of residual signal

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 Jan Oscarsson (external, MVV), Tehseen Aslam (PhD student)

Centre for Intelligent Automation (CIA),
University of Skövde, P.O. Box 408, SE-541 28 Skövde, Sweden

In principle, OEMs in 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). OEMs, often striving after lean operations whilst at the same time needing to be agile, have traditionally passed the agility problem on to their 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 the OEM 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 use only information from a limited number of sources (often only one, for instance a company’s ERP system), do not address the planning problem from a holistic standpoint, and do not take system variations and variations in reliability of the various information sources 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 will 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 *Infofusion* 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.

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

Olli-Pekka Hilmola, Professor
Per Hilletofth, PhD student
Sandor Ujvari, PhD

Logistics Group
School of Technology and Society
University of Skövde, P.O. Box 408, SE-541 28 Skövde, Sweden

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. The project is carried out in close cooperation with the first project in the Manufacturing Scenario which has a stronger sensor fusion approach to maintenance operations.

Research Question

Production supporting and maintenance focused companies are subject to a rapidly changing business environment strongly influenced by the Forrester Effect (also known as Bullwhip effect). 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 firm 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 2006

Participation in Research Courses, thorough case-study conducted at Euromaint, the clear definition of the project plan.

Closer co-operation between the two research groups involved in this scenario resulted in an internal research seminar on October 31st.

Cooperation

Industrial

This project is carried out in collaboration with Euromaint Industry AB (former Euromation), a machine builder with an increasing focus on machine system service & maintenance.

Scientific

The project works as a catalyst fostering increased cooperation between research groups within the University of Skövde. Both groups have international scientific cooperation.

Approach

The first 3-6 months has been used to identify the specific project scope and to carry out empirical research of maintenance management including industrial case studies. The application of Multi Agent system modeling will take place in the following 6 month period. After evaluation a IF-prototype for operative use is expected to be developed and tested.

Contribution to *Infofusion* 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 well with active involvement and support from the industrial partner. The first part to identify specific project scope and the first empirical research part will be completed within a few months.

Envisaged start: January 2007 (3 years +) ***Project: IF mfg3 foundry***

Information Fusion for Holistic Process Analysis in the foundry industry

Dr Amos Ng, Dr Thomas Karlsson, Dr Mats Jägstam, TBA (PhD Student), Professor Leo de Vin

Centre for Intelligent Automation
University of Skövde, P.O. Box 408, SE-541 28 Skövde, Sweden

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.

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 Gjuteriföreningen, 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 unseen 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 *Infofusion* 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

Expected output will be 2 papers/year, one PhD, and a system for Holistic Process Analysis of complex manufacturing processes. Results to date are the definition of the industrial problem and a suitable approach; a more detailed research plan will be defined when a PhD student has been appointed (recruitment process ongoing to date).

Related Work

Related work is carried out at Gjuteriföreningen 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

Bo Magnusson, PhD, Bo Stenberg, Associate Professor, Mats Söderström, PhD
PhD Student: Lina Nolin

University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 2006

The main focus in 2006 has been on defining the scientific content of the scenario, participating in conferences and PhD courses.

Three PhD Students started during the year 2006 and one was already on board at this time.

Three new projects are being proposed in the precision agriculture scenario. These projects are only in the initial phase, meaning formulating research questions and establishing a platform for the research group.

Projects within scenario IF pa

IF pa1 prec agricult

Three additional projects are proposed to join the precision agriculture scenario during 2007.

Cooperation

Industrial

Participating companies are in AgroVäst AB.

Scientific

The projects are cooperating with both other scenarios within the Infofusion 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, four 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 *infofusion* 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 pa1 prec agricult***

Information fusion in precision agriculture for optimized real-time nitrogen application

Bo Magnusson, PhD (Bo.Magnusson@his.se)
Bo Stenberg, Associate Professor (Bo.Stenberg@mv.slu.se)
Mats Söderström, PhD (Mats.Soderstrom@mv.slu.se)
Lina Nolin, PhD Student (lina.nolin@his.se)

Precision Agriculture - Ecology Group,
University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 Infofusion 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 2006

- Participation at the International Conference on Information Systems in Sustainable Agriculture, Agroenvironment and Food Technology, 20-22 September, Volos, Greece.
- Poster presentation at the NJF (Nordic Association of Agricultural Scientists) seminar Precision Technology in Crop Production, Implementation and Benefits, 7-8 November, Lillehammer, Norway.
- Initiation of cooperation projects with other IF scenarios, mainly within the CGI (Common goals and infrastructure) and GSA (Ground Situation Awareness).
- Initiation of cooperation projects about sensor networks with Halmstad University.
- Initial literature survey was started.

Cooperation

Industrial

Mats Emilsson is contact person at AgroVäst AB. Collaboration with Anders Andersson and Knud Nissen at AgroVäst AB.

Scientific

Henrik Eckersten, Professor at the Department of Crop Production Ecology, SLU, is assistant supervisor.

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.

A collaboration project, named *Risk Analysis for Precision Agriculture with Information Fusion*, was discussed and initiated together with Alexander Karlsson within the CGI (Common goals and infrastructure) scenario. The project aim at, using real-time data and background data for a cultivated field, make risk analysis on weather forecasts etc.

An initial literature study, aiming at giving the direction for further work, was started.

Related work

This project will be in close collaboration with another on-going project within PA at the University of Skövde, carried out by the PhD Student Simon Wetterlind. That project is focused on forecasting pest insect population developments based on census and sensor data. Despite, or due to, different perspectives on PA, the two projects will be able to take advantage of each other.

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

University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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.

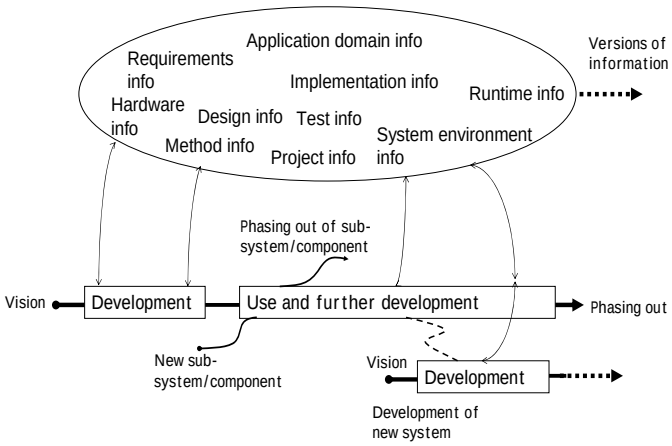


Figure 1: The system life cycle

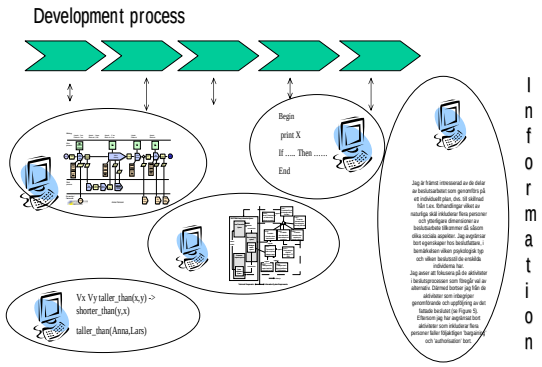


Figure 2: Examples of information types in the systems/software development process

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.

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.

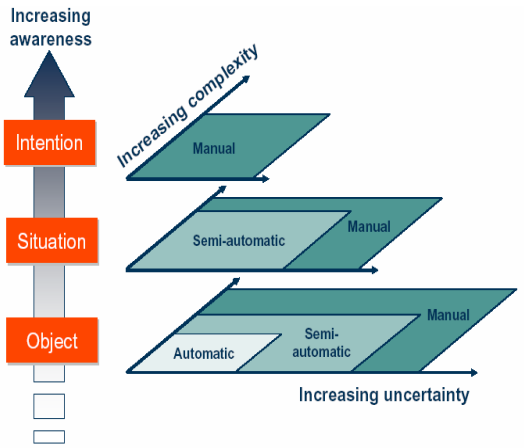


Figure 3: Awareness, complexity and uncertainty

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 2006

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

Research in this scenario has shown that there should be potential for developing this strand of IF research considerably. Our current understanding of the decision-making problems and the need for decision-support tools in the area of systems development supports this. At present, the industry partners in the scenario are companies that develop software. Such companies seldom develop their own tools to support the software development process. This means that the future development of this scenario is dependent on collaboration with companies that develop software engineering tools. We perceive that IF methods could be incorporated in such tools in order to support decision-making activities in the software development process. Such contacts will be sought during 2007.

Start: 1 Apr 2005 (3 yrs) ***Project: IF sd1 infokrat***

Information Management for Requirements and Testing in Software Development

Anne Persson, PhD (anne.persson@his.se)
Beatrice Alenljung, PhD Student (beatrice.alenljung@his.se)
Åsa G. Dahlstedt, PhD Student (asa.dahlstedt@his.se)
Mats Grindal, PhD Student (mats.grindal@his.se)

University of Skövde, P.O. Box 408, SE-54128 Skövde, Sweden

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 takes a first step towards investigating the potential for using information fusion to support decision-making in systems/software development. It does 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 2006

The most productive aspect of the project has been the active involvement of industrial partners in the project. We have also been successful when it comes to publication.

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 investigate 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

Appendix F Sponsors and partners

Note: In June 2005, Euromation AB was acquired by EuroMaint AB, and is now called EuroMaint Industry AB. In August 2005, Arexis AB was acquired by Biovitrum AB.

Partners and Sponsors

IN PARTNERSHIP WITH THE Knowledge Foundation

Grevillis FOND

Gothia Science Park
Teknikparken vid Högskolan i Skövde

Sparbanksstiftelsen Alfa

Bioinformatics

Lexware® Labs

Arexis

Invetics

cellartis

Ground Situation Awareness

SAAB

EXENSOR
Awareness Assured

Manufacturing

Precision Agriculture

Retail Sector

Systems Development

Appendix G Personnel in 2006

Senior researchers at the university (roles: scenario and/or project leader, advisor, etc.)

Scenario leader	Name	% active	Type	Project leader
	Barbara Gawronska	5%	Professor	bio3
	Benkt Wangler	5%	Professor	
gsa, rs	Lars Niklasson	35%	Professor	gsa1, rs1
mfg	Leo De Vin	15%	Professor	mfg1
adm	Sten F Andler	50%	Professor	cgi2, cgi3, adm
cgi	Tom Ziemke	35%	Professor	cgi1, gsa2, rs2
	Olli-Pekka Hilmola	5%	Professor	
	Björn Olsson	35%	Assoc Prof	bio1, bio4
bio	Patric Nilsson	30%	Assoc Prof	bio2
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%	Postdoc	
	Ronnie Johansson	50%	Postdoc	
Total number:	15			

Other staff at the university (roles: information, marketing, and administration)

	Anita Andler	40%	Other staff
	Camilla Andersson	50%	Other staff
	Eva-Lisa Svensson	30%	Other staff
	Jill Elmshorn	70%	Other staff
	Marcus Brohede	15%	Other staff
Total number:	5		

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%)
New 2006	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%)
New 2006	Tehseen Aslam	80%	PhD student	KK funded (75 of 80%)
	Tuve Löfström	55%	PhD student	KK funded (50 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	
New 2006	Per Hilletofth	50%	PhD student	
New 2006	Klas Hedenberg	50%	PhD student	
New 2006	Stefan Ericson	50%	PhD student	
	Per Gustavsson	50%	Ind PhD stud	**HS/SMW**

Total number: 9

Total number of PhD students 22

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 Muños		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 2006

Information Fusion Research Program ***infofusion***

Financial report 2006 Total income

Intäkter (kr)	Budget för projekt i profilen	Bokförda intäkter perioden (1) (2) 20060101 - 20061231	Bokförda intäkter perioden (1) 20050401 - 20051231	Bokförda intäkter ackumulerat (1) 20050401 - 20061231
Bidrag från KK-stiftelsen	6 200 000	6 200 000	3 700 000	9 900 000
Bidrag från deltagande företag	9 086 000	8 846 000	5 718 000	14 564 000
Bidrag från HS	6 747 000	6 491 774	3 612 872	10 104 646
Summa intäkter i kronor	**22 033 000**	**21 537 774**	**13 030 872**	**34 568 646**

Intäkter (kr)	Budget för associerade projekt	Bokförda intäkter perioden (1) 20060101 - 20061231	Bokförda intäkter perioden (1) 20050401 - 20051231	Bokförda intäkter ackumulerat (1) 20050401 - 20061231
Bidrag från KK (Modpharm)	630 000	630 000	1 260 000	1 890 000
Bidrag från bl a Alfastiftelsen	0	0	50 000	1 632 885
Summa intäkter i kronor	**630 000**	**630 000**	**1 310 000**	**1 940 000**

Totala intäkter i kronor	**22 663 000**	**22 167 774**	**14 340 872**	**36 508 646**

(1) Bidrag som lämnats i annan form än kontanta bidrag skall här räknas om till kronor i enlighet med företagens principer för interndebitering

(2) Bidrag från KK-stiftelsen inkom 07-02-09 och 07-02-20

Information Fusion Research Program ***infofusion***

Financial report 2006 Total expenses

Kostnader (kr)	Budget			Bokförda kostnader (korrigerade) 20060101 - 20061231		
	HS	**KK**	**Totalt**	**HS**	**KK**	**Totalt**
Lönekostnader (inkl.arbetsgivaravg.)	4 718 182	4 361 315	9 079 497	4 539 702	3 214 832	7 754 534
Övriga kostnader	471 818	436 131	907 949	453 970	321 483	775 453
Summa kostnader	**5 190 000**	**4 797 446**	**9 987 446**	**4 993 672**	**3 536 315**	**8 529 987**
Högskolepålägg 21%	1 089 900	1 007 464	2 097 364	1 048 671	742 626	1 791 297
Inst.pålägg 9 %	467 100	431 770	898 870	449 431	318 268	767 699
Summa före moms	**6 747 000**	**6 236 680**	**12 983 680**	**6 491 774**	**4 597 209**	**11 088 983**
Högskolemoms		542 320	542 320		496 000	496 000
Summa kostnader	**6 747 000**	**6 779 000**	**13 526 000**	**6 491 774**	**5 093 209**	**11 584 983**

Kommentar: Högskolemoms i kolumnen bokförda kostnader 2006 gäller medel rekvirerade för 2006 men bokförda 2007

Kostnader (kr)	Bokförda kostnader 20050401 - 20051231			Bokförda kostnader ackumulerat 20050401 - 20061231		
	HS	**KK**	**Totalt**	**HS**	**KK**	**Totalt**
Lönekostnader (inkl.arbetsgivaravg.)	2 526 484	1 224 412	3 750 896	7 066 186	4 439 244	11 505 430
Övriga kostnader	252 649	122 441	375 090	706 619	443 924	1 150 543
Summa kostnader	**2 779 133**	**1 346 853**	**4 125 986**	**7 772 805**	**4 883 168**	**12 655 973**
Högskolepålägg 21%	583 618	282 839	866 457	1 632 289	1 025 465	2 657 754
Inst.pålägg 9 %	250 122	121 217	371 339	699 553	439 485	1 139 038
Summa före moms	**3 612 873**	**1 750 909**	**5 363 782**	**10 104 647**	**6 348 118**	**16 452 765**
Högskolemoms	0	296 000	296 000	0	792 000	792 000
Summa kostnader	**3 612 873**	**1 750 909**	**5 363 782**	**10 104 647**	**6 844 118**	**16 948 765**

Kommentar: Högskolemoms i kolumnen bokförda kostnader 2005 gäller medel rekvirerade för 2005 men bokförda 2006

Financial report 2006 — Project expenses

Kostnader (kr) inklusive overhead(*)	Projektbudget 2006 för projekt i profilen			Bokförda kostnader (korrigerade) 20060101 - 20061231			Differens	
	HS	KK profil	Totalt	HS	KK profil	Totalt	HS	KK profil
IF cgi1 framework	494 000	940 000	1 434 000	266 130	445 843	711 973	-227 870	-494 157
IF cgi2 methods	254 000	940 000	1 194 000	262 524	658 056	920 580	8 524	-281 944
IF cgi3 infrastructure	596 000	386 000	982 000	324 668	162 596	487 264	-271 332	-223 404
IF gsa1 algorithms	297 000	520 000	817 000	227 764	455 801	683 565	-69 236	-64 199
IF gsa2 visualization	194 000	520 000	714 000	198 848	415 522	614 370	4 848	-104 478
IF gsa3 hypotheses	459 000	520 000	979 000	488 927	407 666	896 593	29 927	-112 334
IF bio1 cells	351 000	513 000	864 000	376 094	489 478	865 572	25 094	-23 522
IF bio2 lipids	442 000	513 000	955 000	362 230	362 404	724 634	-79 770	-150 596
IF bio3 info extract	522 000	0	522 000	406 561	0	406 561	-115 439	0
IF rs1 prognoses	171 000	272 000	443 000	195 145	273 002	468 147	24 145	1 002
IF rs2 data mining	164 000	272 000	436 000	167 471	270 641	438 112	3 471	-1 359
IF mfg1 manufacturing	278 000	488 000	766 000	148 297	371 950	520 247	-129 703	-116 050
IF mfg2 manufacturing	0	0	0	238 808	0	238 808	238 808	0
IF pa1 prec agricult	773 000	391 000	1 164 000	856 198	280 919	1 137 117	83 198	-110 081
IF sd1 infokrat	424 000	504 000	928 000	455 090	499 331	954 421	31 090	-4 669
IF adm1 mgmt/activities	1 328 000	0	1 328 000	1 517 019	0	1 517 019	189 019	0
Summa kostnader i kronor	**6 747 000**	**6 779 000**	**13 526 000**	**6 491 774**	**5 093 209**	**11 584 983**	**-255 226**	**-1 685 791**

Kostnader (kr)	Projektbudget 2006 för associerade projekt			Bokförda kostnader (korrigerade) 20060101 - 20061231			Differens	
	HS	Externt	Totalt	HS	Externt	Totalt	HS	KK profil
IF bio4 modPharm	0	709 649	709 649	0	823 832	823 832	0	114 183
assoc1 Fusion som vision	0	698 506	698 506	0	608 459	608 459	0	-90 047
Summa kostnader i kronor	**0**	**1 408 155**	**1 408 155**	**0**	**1 432 291**	**1 432 291**	**0**	**24 136**
Totalt kostnader i kr	**6 747 000**	**8 187 155**	**14 934 155**	**6 491 774**	**6 525 500**	**13 017 274**	**-255 226**	**-1 661 655**

(*) Projektbudget och kostnader är angivna inklusive högskolepålägg 21% och institutionspålägg 9% (motsvarande avdrag 23%)

Information Fusion Research Program ***infofusion***

Financial report 2006 — Corrections

Kostnader (kr) inklusive overhead(*)	Bokförda kostnader perioden 20060101 - 20061231			Korrigering gällande 2005		Korrigering gällande 2006		Bokförda kostnader (korrigerade) 20060101 - 20061231		
	HS	KK profil	Totalt	HS	KK profil	HS	KK profil	HS	KK profil	Totalt
IF cgi1 framework	278 967	445 843	724 810	126 646		113 809		266 130	445 843	711 973
IF cgi2 methods	356 392	658 056	1 014 448	104 520		10 652		262 524	658 056	920 580
IF cgi3 infrastructure	146 400	375 683	522 083	52 260		230 528	-213 087	324 668	162 596	487 264
IF gsa1 algorithms	198 890	455 801	654 691	183 901		212 775		227 764	455 801	683 565
IF gsa2 visualization	245 062	415 522	660 584	97 288		51 074		198 848	415 522	614 370
IF gsa3 hypotheses	502 878	407 666	910 544	256 147		242 196		488 927	407 666	896 593
IF bio1 cells	344 591	663 250	1 007 841	90 653	61 796	122 156	-111 976	376 094	489 478	865 572
IF bio2 lipids	493 770	362 404	856 174	131 540				362 230	362 404	724 634
IF bio3 info extract	376 308	337 754	714 062	293 696	-31 864	323 949	-369 618	406 561	0	406 561
IF rs1 prognoses	241 289	280 052	521 341	17 391	-17 391	-28 753	-24 441	195 145	273 002	468 147
IF rs2 data mining	160 462	277 650	438 112	17 391	-17 391	24 400	-24 400	167 471	270 641	438 112
IF mfg1 manufacturing	428 942	371 950	800 892	41 837		-238 808		148 297	371 950	520 247
IF mfg2 manufacturing	0	0	0	0		238 808		238 808	0	238 808
IF pa1 prec agricult	1 170 198	280 919	1 451 117	314 000				856 198	280 919	1 137 117
IF sd1 infokrat	131 960	820 841	952 801	-318 407	360 969	4 723	39 459	455 090	499 331	954 421
IF adm1 mgmt/activities	1 096 826	105 567	1 202 393	-148 728		271 465	-105 567	1 517 019	0	1 517 019
Summa kostnader i kronor	**6 172 935**	**6 258 958**	**12 431 893**	**1 260 135**	**356 119**	**1 578 974**	**-809 630**	**6 491 774**	**5 093 209**	**11 584 983**

Kostnader (kr) inklusive overhead(*)	Bokförda kostnader perioden 20060101 - 20061231			Korrigering gällande 2005		Korrigering gällande 2006		Bokförda kostnader (korrigerade) 20060101 - 20061231		
	HS	Externt	Totalt	HS	Externt	HS	Externt	HS	Externt	Totalt
IF bio4 modPharm		823 832	823 832					0	823 832	823 832
IF assoc1 Fusion som vision		608 459	608 459					0	608 459	608 459
Summa kostnader i kronor	**0**	**1 432 291**	**1 432 291**	**0**	**0**	**0**	**0**	**0**	**1 432 291**	**1 432 291**
Totalt kostnader i kr	**6 172 935**	**7 691 249**	**13 864 184**	**1 260 135**	**356 119**	**1 578 974**	**-809 630**	**6 491 774**	**6 525 500**	**13 017 274**

(*) Projektbudget och kostnader är angivna inklusive högskolepålägg 21% och institutionspålägg 9% (motsvarande avdrag 23%)

OH-faktor:	1,3

Appendix I Company contributions by company

Company contributions 2006: Commitment vs. financial report (1 quarter in year 1 and 3 quarters in year 2)

Company	Year 1 commitment				Year 2 commitment				2006 commitment (25% year 1, 75% year 2)				2006 financial report				Diff			
	cash	labor	equip	total	cash	labor	equip	total	cash	labor	equip	total	cash	labor	equip	total	cash	labor	equip	total
AgroVäst AB	0	550	250	**800**	0	550	250	**800**	0	550	250	800	0	550	242	**793**	0	0	-8	-7
Arexis AB	0	100	300	**400**	0	100	300	**400**	0	100	300	400	0	20	300	**320**	0	-80	0	-80
Atlas Copco Tools AB	0	250	24	**274**	0	251	24	**275**	0	251	24	275	0	264	18	**283**	0	14	-6	8
Cellartis AB	0	330	320	**650**	0	330	320	**650**	0	330	320	650	0	558	320	**878**	0	228	0	228
DELFOI Sweden AB	0	40	50	**90**	0	100	75	**175**	0	85	69	154	0	0	0	**0**	0	-85	-69	-154
Electrolux Major Appliances Euro	0	0	0	**0**	0	500	100	**600**	0	375	75	450	0	1150	0	**1150**	0	775	-75	700
Enea Services Stockholm AB	0	482	0	**482**	0	489	0	**489**	0	487	0	487	0	174	9	**182**	0	-314	9	-305
Enea Software AB	0	35	200	**235**	0	35	200	**235**	0	35	200	235	0	34	150	**184**	0	-1	-50	-51
EuroMaint AB	0	24	0	**24**	0	96	100	**196**	0	78	75	153	0	12	120	**132**	0	-66	45	-21
Exensor Technology AB	0	263	0	**263**	0	525	0	**525**	0	460	0	460	0	0	0	**0**	0	-460	0	-460
ICA Sweden AB	0	504	70	**574**	0	504	70	**574**	0	504	70	574	0	333	30	**363**	0	-171	-40	-211
InNetics AB	0	0	0	**0**	0	0	0	**0**	0	0	0	0	0	0	0	**0**	0	0	0	0
LexWare Labs AB	0	368	790	**1158**	0	299	700	**999**	0	316	723	1039	0	658	338	**996**	0	342	-385	-43
Saab Microwave Systems, sd	0	440	0	**440**	0	550	0	**550**	0	523	0	523	0	607	0	**607**	0	85	0	85
Saab Microwave Systems, gsa	0	1560	350	**1910**	0	2705	350	**3055**	0	2419	350	2769	0	2863	49	**2912**	0	444	-301	143
Volvo Powertrain	0	50	50	**100**	0	75	50	**125**	0	69	50	119	0	47	0	**47**	0	-22	-50	-72
Total	**0**	**4996**	**2404**	**7400**	**0**	**7109**	**2539**	**9648**	**0**	**6581**	**2505**	**9086**	**0**	**7269**	**1577**	**8846**	**0**	**689**	**-929**	**-240**
			chk	**7400**			chk	**9648**			chk	**9086**			chk	**8846**			chk	**-240**

Appendix J Plan for development of the research program

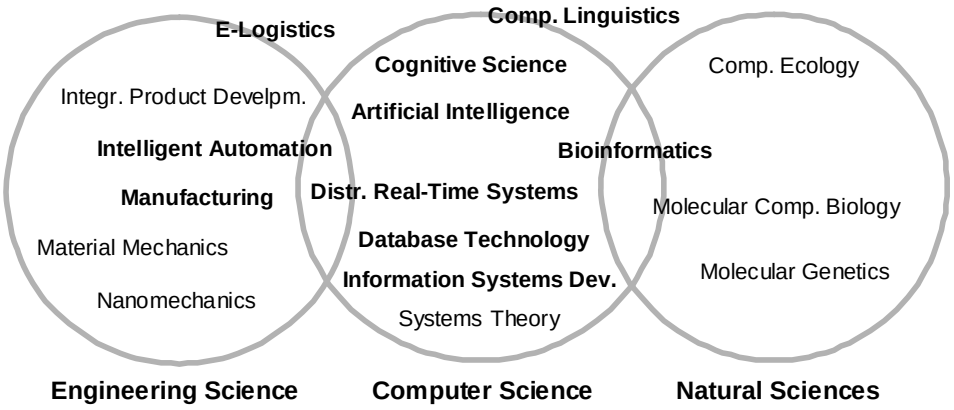


Figure: The Technology area –research groups and their relations to disciplines

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 sceanrio/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.