Oppivien ja älykkäiden järjestelmien sovellukset 1994–1999

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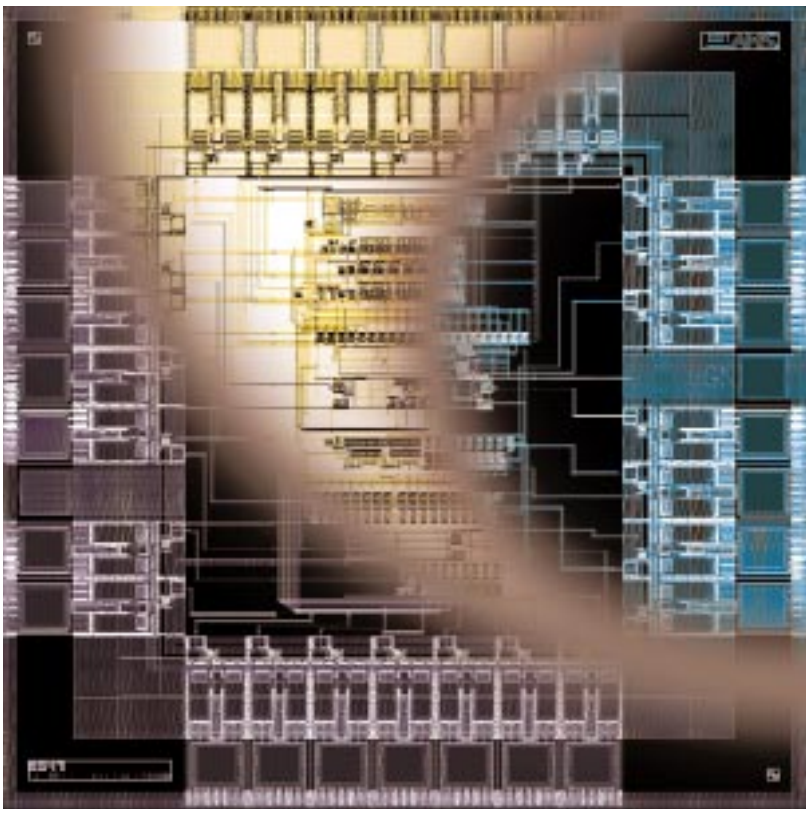
Teknologiaohjelmaraportti 20/2000 | Arviointiraportti



TEKES

Oppivien ja älykkäiden järjestelmien sovellukset 1994–1999

Adaptive and intelligent systems applications

Arviointiraportti
Evaluation Report

Piero P. Bonissone
Juhani Sarparanta

National Technology Agency

Teknologiaohjelmaraportti / Technology Programme Report 20/2000
Helsinki 2000

Kilpailukykyä teknologiasta

Tekes tarjoaa rahoitusta ja asiantuntijapalveluja kansainvälisesti kilpailukykyisten tuotteiden ja tuotantomenetelmien kehittämiseen. Tekesillä on vuosittain käytettävissä avustuksina ja lainoina runsaat kaksi miljardia markkaa teknologian kehityshankkeisiin.

Teknologiaohjelmien avulla maahamme luodaan uutta teknologiaosaamista yritysten, tutkimuslaitosten ja korkeakoulujen yhteistyönä. Ohjelmien tavoitteena on nostaa teknologista kilpailukykyämme tulevaisuuden keskeisillä teollisuuden toimialoilla. Tällä hetkellä Tekesillä on käynnissä noin 60 teknologiaohjelmaa.

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Esipuhe

Oppivien ja älykkäiden järjestelmien sovellusten teknologiaohjelman keskeisenä sisältönä oli neuroverkkojen, sumean logiikan ja geneettisten algoritmien sovellukset eri teollisuusalojen, kaupan ja rahoitustoiminnan sekä lääketieteen ongelmissa. Ohjelman yleisenä tavoitteena oli kehittää tutkimuslaitosten ja yritysten yhteistyönä liiketoiminnallisesti kannattavia oppivien ja älykkäiden järjestelmien sovelluksia erilaisissa tuotteissa ja tuotantoprosesseissa etenkin sellaisissa ongelmissa, joita perinteisillä menetelmillä on vaikea ratkaista. Tavoitteena oli luoda ja edelleen kehittää kansainvälisesti huipputason osaamista. Teknologiaohjelma sisälsi sekä yritysten ja tutkimuslaitosten yhteistyössä toteuttamia teollisuusvetoisia hankkeita että tutkimuslaitosten yhteishankkeita.

Teknologiaohjelmasta laadittiin väliarviointi 1996. Sen perusteella ohjelmaa laajennettiin ja pidennettiin. Ohjelma päättyi vuoden 2000 alussa ja päättymisen yhteydessä käynnistettiin loppuarviointi. Loppuarviointi koostuu kahdesta osasta. Tutkimuslaitosten projektien arvioinnissa kiinnitettiin huomiota yhteistyön ja verkottumisen kehitykseen sekä projektien tuloksiin. Tätä analysoi tri Piero P. Bonissone General Electricin tutkimuskeskuksesta. Hän sijoitti teknologiaohjelman tutkimusalueet soft computing -alan kehitystrendeihin ja vertasi tutkimuksen tasoa kansainvälisesti. Tri Bonissonen osuus on englanninkielinen. Teollisuusvetoisissa projekteissa painopisteenä oli ohjelman taloudellisen merkityksen ja vaikutusten arviointi suomalaisen teollisuuden kannalta. Tähän paneutui toimitusjohtaja Juhani Sarparanta Oy Chester Ltdstä. Yhteenveto ja suositukset (Executive Summary) on arvioitsijoiden yhdessä laatima.

Tekes warmly thanks the evaluators for the thorough and in-depth analysis of the technology programme, as well as program manager Ossi Taipale, project managers and other interviewed persons for their contribution. We wish the evaluation and its conclusions will serve the participants in building the future.

Tekes

Executive Summary

Arguably, one of the most significant achievements obtained from the Adaptive and Intelligent Systems Applications Program is the development of a large number of experts in the field of Soft Computing (SC). The number of specialists trained within this program has already exceeded critical mass. In the future, these experts will be able to capitalize on the experiences derived from this program and offer these methods and solutions to the Finnish industry in the large.

The results of this program have already validated the effectiveness of these methods. This is especially noticeable when processing large and (to some extent) incorrect data, collected from real production lines. This is a natural application for Soft Computing, one of most promising emerging technologies in Computer Science and Computer Engineering. SC provides complementary reasoning and searching methods that allow us to combine domain knowledge and empirical data to develop flexible computing tools and solve complex problems.

Overall, the level of complexity of the applications addressed in the program was high enough to exercise the technologies and testing their robustness, while insuring that at least some of these projects had a successful transition to the industrial/commercial partners that participated in the program.

The *Adaptive and Intelligent Systems Applications Program* has definitely achieved its overall goal. The cooperation between research institutes and industries is evidenced by a total of 60 joint projects and 18 transition paths (at different stages).

The research results are equally remarkable and the best projects in the program exhibit world-class quality. They compare very well with the work of other researchers in the field. The diffusion of the research, measured by the number of publications and degrees earned, is equally impressive. The five research projects have produced a total of 140 publications: 1 book, 15 book chapters, 22 journal articles, and 102 conference papers. Furthermore, we believe that the best way to distribute this information is to train professional people in developing and applying these technologies. This goal has also been achieved, given that 46 degrees have been conferred (or are in preparation): 6 Doctorates, 8 Licenciate, and 32 Masters.

The content of the program has been versatile covering many areas of business applications. Two years' extension in the program's duration was absolutely necessary for achieving these results. During this extension period, the results and financial benefits obtained were significant and offered the companies applying them a considerable competitive edge. The program's cost/benefit ratio is clearly positive, even if many projects are not yet willing to estimate financial benefits.

The program has been of great value also for participating Universities and Research Institutes giving their researchers the experience and credibility needed to obtain financing for research and education of this new data processing area.

Critical issues

When we established the metrics for evaluating the research results, we suggested three criteria: research diffusion, research excellence, and participation in EC projects. Perhaps the only evaluation criterion that has not been equally satisfied is the third one, i.e.; the number of EC projects derived from this program. Rather than being an issue of quality, this might be more an issue of timing with the EC procurement cycle. This criterion should be emphasized more in the next phase of this program, so that better results can be achieved.

Another issue to consider is how to construct a successful transition path from the universities/research institutes to the participating industries. This problem typically does not have a standard solution, and requires customized approaches. While a research project might have a follow-up pilot program, this does not necessarily mean that the program is ready for industrial use. A successful technology transition path requires that the receiving partners commit internal resources to all aspects of the transition, including the testing of the software in an industrial setting, and the education and training of its own personnel.

Recommendations: Programmatic Issues

As we noted above, the best way to distribute the results of this program is by training the professional people involved in the application of these technologies. In this kind of research, whose results are mainly computer programs, it is essential to distribute this expertise among all the people participating in the projects, to ensure the feasibility of the programs and their potential commercialization.

We would expect that, in about a year, when most of the development programs and testing periods will be completed, the participating companies will be more willing to provide us with information related to the success of these projects and their transitions. At that point, we should publish a follow-up report detailing the results of the technology program and their impact on the participating companies.

Recommendations: Research Issues

The research portfolio is well balanced, covering the four components of Soft Computing (SC). In this current phase of the program, we would have liked to see a greater effort in applications of evolutionary computing (EC), since the two current attempts at using EC are rather mundane. In the future, we would also like to see an *explicit effort* at studying and developing *hybrid* soft computing systems.

Currently, most of the applications in the *Adaptive and Intelligent Systems Applications Program* rely on a single SC component. However, the main reason for Soft Computing popularity is the *synergy* derived from its components. SC's main characteristic is its intrinsic capability to create *hybrid systems* that are based on a *loose* or *tight* integration of these technologies. This integration provides us with complementary reasoning and searching methods that allows us to combine domain knowledge and empirical data to develop flexible computing tools and solve complex problems.

The future appears to hold a lot of promise for the novel use and combinations of SC applications. The circle of SC's related technologies will probably widen beyond its current constituents. The push for low-cost solutions combined with the need for intelligent tools will result in the deployment of hybrid systems that efficiently integrate reasoning and search techniques. We believe that the Adaptive and Intelligent Systems Applications Program has already established the first step toward this future and needs to continue along the suggested path.

Piero P. Bonissone
Juhani Sarparanta

Contents

I Final Evaluation of Research Projects

1 Evaluation Task

1.1 Program Structure

The Adaptive and Intelligent Systems Applications Program consists of five research projects:

- Intelligent Methods for Processing and Exploration of Signal and Systems (IMPRESS)
- DYHA
- TOOLMET 2
- Probabilistic Modeling and Stochastic Optimization (PROMISE)
- NESUMED II and COMPSOFT

The first two years of this program were devoted to the development of technologies, while the last two years, which are evaluated in this report, were focused on the use of these technologies in a wide gamut of applications.

The projects comprising the Adaptive and Intelligent Systems Applications Program address a portfolio of applications. Some of them have a short-term horizon, leading to immediate productivity payoffs and new product developments, while other applications are more speculative in nature and have the potential for great long-term benefits. Overall the level of complexity of the applications was high enough to exercise the technologies and testing their robustness, while insuring that at least some of these projects had a successful transition to the industrial/commercial partners that participated in the program.

1.2 Evaluation Criteria

The projects will be evaluated along two main criteria: **1) Co-operation and networking**, and **2) Research results**.

The detailed evaluation criteria for co-operation and networking are:

1. *Co-operative* structures and number of projects between the research institutes and the companies (measured by the number of joint projects with the companies)
2. *Accumulation* of expertise on adaptive and intelligent systems in the companies (measured by evidence of technology transfers to the companies)

The detailed evaluation criteria for research results are:

1. *Diffusion* of research results into applications, number of new applications. Diffusion will be measured by the number of papers published, degrees earned, patents filed, and follow-up contracts.
2. *Research excellence* and its comparison to the international level, as expressed by publications. Excellence will be judged by novelty, usefulness, potential for generalization of the application and by a comparison with other similar applications published in the literature
3. *EC projects* and other *international co-operation*. The number of projects and their impacts will measure this criterion.

1.3 Structure of the Report

First, we will describe each individual research projects and its components and provide an evaluation for each of them. Then we will look at the comprehensive scope of the research program, its underlying technologies and its applications. These projects use most of the techniques that comprise the field of Soft Computing: Probabilistic and Fuzzy Reasoning, Neural and Evolutionary Computation. In our summary, we will compare the program's contributions with state-of-the-art technology and applications development. Finally we will provide our joint conclusions and recommendations.

2 Review of the Five Projects Comprising the AISA Program

2.1 Intelligent Methods for Processing and Exploration of Signal and Systems (IMPRESS) Research Project

Project Leader
Prof. Erkki Oja, HUT

Structure and Goals

This project's overall goal was to increase the co-operation between research institutes and companies, while maintaining high quality of research. To this end, the project organizers subdivided the projects into nine sub-projects. They also formed a consortium of twenty-seven government/industrial partners to provide data and a technology transition path to the various research institutes.

IMPRESS focused on the application of Neural Networks (NN) and learning to processing, coding, feature extraction, detection, classification, analysis, modeling of signals, images, sets of measurements, and textual documents stemming from various sources and processes. These efforts resulted in the development of prototype systems for testing and demonstration of the underlying technologies, using the data and domain expertise available from the 27 partners.

Results

This was a large-scale project, with a high number of participants (eight research institutes and twenty-seven partners). Nevertheless, the project was managed extremely well, and obtained excellent results, achieving the above stated goals. The

Table 1. Description of IMPRESS Sub-Projects.

Project	Project Leader	Project Volume	
		[FINM (k)]	[person -months]
IMPRESS	Prof. Erkki Oja, HUT		
1. Adaptive Real-Time Image Analysis (ARTA)	Dr. Jorma Laaksonen	1000	44
2. Data Mining and Analysis Using Self-Organizing Map (DM & SOM)	Prof. Olli Simula	1190	62
3. Data Fusion and Neural Networks in Complex Models (DF & NN)	Jouko Lampinen	1750	80
4. Optical Characterization of Microstructures (OCM)	Dr. Jyrki Saarinen	455	26
5. Intelligent Signal Processing (ISP)	Prof. Jukka Saarinen	3100	140
6. Nonlinear Disturbance Analysis (NLDA)	M.Sc. Heimo Ihalainen	500	22
7. Analysis of Annual Reports by Advanced NNs Methods (AAR)	Prof. Ari Visa	1200	44
8. DAEMON: Data Analysis and Representation by NNs	Prof. Pasi Koikkalainen	1000	50
9. Spatio-Temporal NNs for Solving Time-Dependent Prob. (ATNN)	Prof. Juha Roning	1500	44
Total IMPRESS		**11,695**	**512**

Table 2. IMPRESS Co-operation & Networking Efforts.

Project	**Co-operation & Networking**	
	# Joint Projects with Companies	Tech Transfer to Companies
IMPRESS		
1. ARTA	**2**	prototypes, dev proj
2. DM & SOM	7	prototypes, MATLAB Toolbox
3. DF & NN	6	-
4. OCM	2	-
5. ISP	4	-
6. NLDA	1	collab. with KCL-WEDGE (software)
7. AAR	2	-
8. DAEMON	5	NDA S/W
9. ATN	2	Polar Electro and Nokia Mobile Phones
Total	**31**	**6**

Table 3. IMPRESS Research Results.

Project	**Research Results Diffusion**											**Research**
	Papers				Total	Norm.	Patent	Degrees			Follow-up	Research
	Books	Book Chapter	Jour-nals	Conf./ TR/etc.	Papers	Papers /pm	Pen-ding	PH.D	Master	Licenc.	devel. proj.	Excellence
IMPRESS												
1. ARTA	-	**3**	1	10	**14**	**32 %**		1	1	-	**2**	HIGH
2. DM & SOM	-	**4**	**5**	**5**	**14**	**23 %**			1	1		HIGH
3. DF & NN	-	-	-	-	0	**0 %**			3		2	HIGH
4. OCM	-	-	3	3	**6**	**23 %**			1	1		HIGH
5. ISP	-	-	2	14	**16**	**11 %**	1	2	5		1	HIGH
6. NLDA	-	-	-	1	1	**5 %**		-	-	-		LOW
7. AAR	-	-	-	4	4	**9 %**			2			HIGH
8. DAEMON	-	1	-	8	9	**18 %**			2			HIGH
9. ATN	-	-	-	5	5	**11 %**	1					HIGH
Total		**8**	**11**	**50**	**69**		**2**	**3**	**15**	2	5	HIGH

list of IMPRESS Sub-projects is shown in Table 1, while the evaluation of this project according to the established criteria is provided in tables 2 and 3. IMPRESS originated a total of three EC projects (one with DF &NN and two with DAEMON).

We will now provide a succinct description of the nine sub-projects that form the IMPRESS program.

IMPRESS Sub-project 1:
Adaptive Real-Time Image Analysis

Project Leader
Dr. Jorma Laaksonen (44 person-months)

Research Organizations
Helsinki University of Technology (CIS Dept.)

Companies
ABB Pulp and Paper,
Nokia Research Center

Goals: Application of Machine Vision and Neural Networks in real-time image analysis to two industrial problems: 1) *Visual fault analysis of running paper web* and *2) On-line recognition of handwritten characters for palm-sized computers.*

1) Visual fault analysis of running paper web (with ABB Pulp and Paper). The goal of this project was the detection and classification of optically detectable defects of running paper webs. The solution is based on SOM and feature extractions (shape, texture, and gray levels). The high speed of the Web and the resolution required for the visual analysis, impose a time frame of 50 ns to decide on each image pixel. A pipeline architecture handles this problem. The classification uses unsupervised image segmentation based on Self-Organizing maps (SOMs) and statistics to develop a two-class segmentation. An unknown sample is classified as a defect if it is different enough from prototypical fault-free samples. SOMs are used to estimate prototypes.

2) On-line recognition of handwritten characters (with Nokia Research Center). This project addresses the adaptation of individual prototypes or adaptive committees of static classifiers to learn and adapt to new writing styles for use in palm-sized computers. The final accuracy had to be comparable with human readers (96%), with no restriction on writing style or language. The solution had to operate in real-time while accounting for the noisy environment.

The solution was based on the following steps:
- *Feature Extraction:* Symbol strings, thickened strokes, Karhunen-Loeve transformation
- *Classification*: Dynamic Time Warping (DTW), Local Subspace Classification
- *Committees* of classifiers: based on Dynamically Expanding Context (DEC) rules
- *Adaptation*: Learning Vector Quantization, etc.

Current classifiers are all based on the same DTW algorithms and produce errors that are too dependent. The real difference in this project is provided by an adaptation mechanism (using Learning Vector Quantization) that improves the recognition of the handwritten characters, decreasing the error rate by 5-10%.

Results of IMPRESS Sub-Project 1
- Prototypes constructed in software, implemented and tested.
- Transition with product development projects started in participating companies.
- 14 Publications and 2 Degrees earned

IMPRESS Sub-project 2:
Data Mining and Analysis Using Self-Organizing Map (SOMs)

Project Leader
Prof. Olli Simula (62 person-months)

Research Organizations
Helsinki University of Technology (CIS Dept.)

Companies
UPM-Kymmene/Wisaforest Oy Jaakko Poyry Consulting Oy; Metsateho Oy, Rautaruukki, Raahe Steel, Outokumpu Polarit Oy, Fundia Wire Oy Ab, Imatra Steel Oy Ab

Goals: Application of SOM to analyze and monitor industrial processes, such as forest and steel industry.

SOMs were applied to the forest industry, to visualize cluster pulp and papers mills of the world, and continuous pulp digester data. SOMs were also applied to hot rolled strip to visualize defects in the continuous casting of steel. The goal was the detection of ruptures/break-through from thermo-couplers. The use of SOMs as visualization and data browsing tool allows the operator to perform correlation of variables by inspection (false coloring

images is used to indicate different clusters). The overall goal of this sub-project, illustrated by the two applications to forest and steel industry, was to gain information on processes that cannot be analytically modeled due to the lack of necessary process measurements.

Results of IMPRESS Sub-Project 2

The use of SOMs made it possible to investigate the behavior of the processes leading to possible process control and optimization. The results of this project were:

- Development of prototypes constructed in software
- Developed SOM Toolbox for Matlab
- Additional minor programs for participating industrial companies: Visualization, analysis of continuous pulp digester; steel production line (Rautaruukki Strip Products); Harvester data (Metsateho).
- 14 Publications and 2 Degrees earned.

IMPRESS Sub-Project 3: **Data Fusion and Neural Networks in Complex Models**

Project Leader

Dr. Jouko Lampinen (80 person-months)

Research Organizations

Helsinki University of Technology (Lab Computational Eng., Dept. Of Mathematics, Lab. Of Metallurgy)

Companies

Vaisala Ltd., Soil and Water Ltd., Kouvola Region Federations of Municipalities, Finnish Metal Industry Consortium

Goals: Mixture of applications, ranging from planning with Geographical Information Systems (GIS), satellite images, wind speed modeling, and steel production. The unifying theoretical framework for this mixture of applications was the use of statistical modeling and estimation. A large portion of this research was deemed so useful to the co-sponsoring companies that much of a reporting information was kept private, at their request, to protect their competitive advantage.

1) Planning with Geographical Information Systems (GIS). The objective of this project was to develop a computational model of consumer behavior in the choice of stores. The study, based on store sales, profiles, and locations, road networks, and other geographical data was aimed to design common infrastructure and/or determine optimal locations. The model parameter estimation used Bayesian models with Markov Chain Monte-Carlo random sampling. The model was cross-validated with predicted sales over the years. The methodology used in this project could be applied to many other potential users. In the public sector it would apply to town planning, traffic minimization, and service analysis. In the private sector it could be used for competition analysis, determination of the utility of store clusters, etc.

2) Statistical inverse method to recover wind speed on different altitudes from observed Doppler spectra. Monostatic wind radar using unmodulated continuous wave have a very narrow band signal and do not provide any altitude information in the Doppler spectrum. This project solved this problem by developing an inverse model using a Bayesian algorithm, whose solution was approximated using Gibbs sampling, Metropolis-Hasting and Hybrid Monte-Carlo methods. No publications are available due to confidentiality issues, at the request of the co-sponsoring company.

3) IKONOS satellite data. The main goal was the segmentation and classification of satellite images to recover building and road information to infer population and traffic information. This was successful in spite of using a rather crude image resolution (1 mt.) The best results to detect building were obtained using Neural Networks with parallel edge requirements, achieving an accuracy of 75%. Roads were extracted using line filters and road characteristics.

Results of IMPRESS Sub-Project 3

- Publications: Confidentiality with industrial partner hindered publications on wind inverse model
- Master theses: 3
- Follow-up developments with selected partners.

IMPRESS Sub-Project 4:
Optical Characterization of Micro-structures (HUT, Comp. Eng. Dept.)

Project Leader
Dr. Jyrki Saarinen (26 person-months)

Research Organizations
Helsinki University of Technology
(Materials Physics Lab.)

Companies
Terapixel Oy, Planar Systems, Inc.

Goals: Apply neural networks as statistical tools in optical scatterometry, a highly non-linear problem that is quite suitable for a NN approach. Optical scatterometry is a non-destructive technique in which the scattered intensity distribution of a coherent laser beam from a regular microstructure is measured, and the structure is characterized from the measurements.

Results of IMPRESS Sub-Project 4
- Seven publications (including a Licentiate and a Master Thesis)
- Numerical results showing nano-level accuracy in the measurement of micro-structured plates.

IMPRESS Sub-Project 5:
Intelligent Signal Processing

Project Leader
Prof. Jukka Saarinen (140 person-months)

Research Organizations
Tampere University of Technology
(Signal Processing Lab.)

Companies
Nokia Research Center, Nokia Mobile Phones, Oy Imix Ab, Patria Finavitec Systems.

Goals: Apply neural networks techniques to speech recognition (spoken digits), speech coding, bar-code recognition (from digital images), channel equalization (for mobile telephones), image interpolation, enhancement of digital X-ray images, and passive detection of moving targets (helicopter and underwater acoustic detection).

Results of IMPRESS Sub-Project 5
- Sixteen publications
- Excellent results in speech recognition for voice dialing with mobile phones, including speaker adaptation. The training process used Finnish digit strings, all major dialects, men and women, and two environments (clean: 20 db, and car: 1.7 db). This work was done in conjunction with Nokia Research Center.
- Very good results in channel equalization, done with Nokia Mobile Telephone, and other applications.

IMPRESS Sub-Project 6:
Nonlinear Disturbance Analysis (Tampere University of Technology)

Project Leader
M Sc. Heimo Ihalainen (22 person-months)

Research Organizations
Tampere University of Technology
(Measurement and Information Tech.)

Companies
KCL Development Oy.

Goals: Application of linear and non-linear methods to the detection of abnormal process behavior and the analysis of the sources of process variations. When a process behaves differently, we want to identify the reasons for the odd process behavior and distinguish between those reasons and their consequences. When a process exhibits variations, we want to identify and compare the sources of such variation.

Results of IMPRESS Sub-Project 6
- Some traditional linear techniques, such as Principal Component Analysis and partial least square (PLS), and one non-linear technique Self-Organizing Maps (SOM) were used in the analysis of process data for paper production, with normal results.
- One conference publication

IMPRESS Sub-Project 7:
Analysis of Annual Reports by Advanced NNs Methods - Dept. Information Science, Lappeenranta University of Technology

Project Leader
Prof. Ari Visa (44 person-months)

Research Organizations
Lappeenranta University of Technology (Dept. of Information Science), Abo Academi University (Lab. Information Systems)

Companies
Ramse Consulting Oy, Teollisuuden Voima Oy

Goals: Find any correlation between the text part and the corresponding economical figures of annual reports. A time-series of the economical figures of the companies was used as a reference.

Results of IMPRESS Sub-Project 7
- The proposed solution is based on multilevel hierarchies of SOMs and on a special language-independent encoding of words.
- Four publications (and four more pending)

IMPRESS Sub-Project 8:
DAEMON: Data Analysis and Representation by NNs

Project Leader
Prof. Pasi Koikkalainen (50 person-months)

Research Organizations
University of Jyväskylä (Dept. of Mathematical Information Tech.),

Companies
Sonera Oyj, Greenwin Oy, Visipoint Oy, Kuopio, Savon Liitto and Ministry of the Environment

Goals: ***1) Document Matching:*** use Neural Data Analysis (NDA), a software tool developed in the previous Stella project, to find similar documents from a database of ~100,000 reports describing data network fault diagnostics. ***2) Air Quality Prediction:*** estimate and monitor the development of urban air quality based on weather service information.

Results of IMPRESS Sub-Project 8
- Developed search engine for diagnostic reports (for Sonera), which classify documents based on their contextual similarity. Search is language-independent, allowing mixture of English and Finnish.
- Built prototype software for air quality prediction. Tested with data from Kuopio, Imatra, Stockholm, and Singapore.
- 9 publications (1 book chapter and 8 conference proceedings)
- 2-3 doctoral thesis partially supported by this project
- Two EC projects derived from this project: Appetise and Erudit.
- Commercial product for a new founded company, Visipoint Oy that uses NDA for environmental technology applications

IMPRESS Sub-Project 9:
Spatio-Temporal NNs for Solving Time-Dependent Probability (Dept. of Electrical Engineering, University of Oulu)

Project Leader
Prof. Juha Roning (44 person-months)

Research Organizations
University of Oulu (Computer Eng. Lab.),
VTT Electronics

Companies
Polar Electro Oy, Nokia Mobile Phones

Goals: Develop signal process methods based on NN and adaptive computing for applications in telecommunications and medical measurement. Two applications were targeted by this project: ***1) self-management of health/quality of life***; ***2) Improvement of quality of speech signals in digital audio devices.***

Results of IMPRESS Sub-Project 9
- Health Self-management: developed software prototype for aerobic fitness classification using

a combination of feature extractions, fuzzy pre-classifiers and NN classifiers.
- Quality of Speech Improvement: developed adaptive digital filtering techniques to remove interference with EM caused by TDMA standard base transmitter (affecting microphone and headphones).
- Implemented a novel separation method for periodic signals to remove interference in microphone digital signal. A patent is been filed for this adaptive separation method.
- Developed adaptive algorithm to reduce interference in headphones analog signal.
- 6 publications, 1 patent pending

2.2 DYHA Research Project

Project leader
Jari Hämäläinen

Structure and Goals

This project's overall goal was to develop application of Neural Networks, fuzzy logic, Wiener-NN models and others SC methodologies to model, simulate, and control industrial processes. Six major sub-project comprise this program: 1) Neural Networks for Thermodynamic Properties; 2) Monitor and validation of Control for Biotechnological and Food Process; 3)Intelligent Visualization of Dynamic Process Data; 4) Intelligent control of Switched-Mode Power Supplies; 5) Neuro-Fuzzy Applications for On-Line Weight Determination of a Moving Loader; 6) Intelligent Control of Harvester Head.

Results: The list of DYHA Sub-projects is shown in Table 4, while the evaluation of this project according to the established criteria is provided in tables 5 and 6. DYHA did not originate any EC project.

DYHA Sub-project 1:
Neural Networks for Thermodynamic Properties

Project Leader
Dr. Jari Hämäläinen and Reijo Lilja
(18 person-months)

Research Organizations
VTT Automation, Technical Research Center of Finland (VTT)

Companies
Fortum Engineering Ltd.

Table 4. Description of DYHA Sub-Projects.

	Project Leader	Project Volume	
		[FINM (k)]	[person -months]
DYHA	Dr. Jari Hämäläinen (VTT)		
1. Neural Networks for Thermodynamic Properties (NNTP)	Dr. Jari Hämäläinen (VTT)	1000	18
2. Monitor & Validation of Control for Biotech. & Food Processes (M&V)	D.Tech Arto Visala (HUT)	925	**39**
3. Intelligent Visualization of Dynamic Process Data (IVDPD)	Prof. H.Koivo; Jari Seppälä (TUT)	752	21
4. Intelligent Control of Switched-Mode Power Supplies (ICS-MPS)	Prof. H. Koivo; Kai Zenger (HUT)	1052	**42**
5. NF Applic.:On-Line Weight Determ.of a Moving Loader (NF OWD)	Prof. Heikki Koivo (HUT)	230	8
6. Intelligent Control and Diagnostics of Harvester Head (IC & D)	Prof. Heikki Koivo (HUT)	394	14
Total DYHA		**4353**	**142**

Table 5. DYHA Co-operation & Networking Efforts.

	Co-operation & Networking	
	# Joint Projects with Companies	Tech Transfer to Companies
DYHA		
1. NNTP	1	Incorporated in APROS 5.02
2. M&V	3	Roal will continue
3. IVDPD	2	developer -prototype
4. ICS-MPS	1	follow-up
5. NF OWD	1	follow-up
6. IC & D	1	follow-up
Total DYHA	**9**	**6**

Table 6. DYHA Research Results.

	Research Results Diffusion											Research
	Papers				Total	Norm.	Patent	Degrees			Follow-up	Research
	Books	Book Chapter	Jour-nals	Conf./ TR/etc.	Papers	Papers /pm	Pen-ding	PH.D	Master	Licenc.	devel. proj.	Excellence
DYHA												
1. NNTP	-	-	-	1	**1**	**6%**		-	-	-		HIGH
2. M&V	-	-	1	4	**5**	**13%**		-	1	-	1 (Roal)	HIGH
3. IVDPD	-	-	1	-	**1**	**5%**		1	-	1		MEDIUM
4. ICS-MPS	-	-	-	8	**8**	**19%**		-	-	1		HIGH
5. NF OWD	-	-	-	-	**0**	**0%**	1	-	1	-		HIGH
6. IC & D	-	-	-	-	**0**	**0%**	-	-	-	-		HIGH
Total DYHA	0	0	2	13	**15**	**11%**	1	1	2	2	1	HIGH

Goals: This project provides a fast method to calculate the thermodynamic properties of substances. These properties are needed in numerical simulation of industrial processes for control, design, and operator training. The resulting methodology was first applied to the description of temperatures, pressures, densities, and mass fractions of different components of air-H_2O mixture.

Results of DYHA Sub-Project 1

A total of 33 NN models were developed for different phases of H_2O, air, and their mixtures and were incorporated into APROS 5.02, a general purpose dynamic process simulation package. This project can be easily adapted to model the thermodynamic properties of other substances. This potential for generalization makes this project results quite useful. The run-time of the models is three orders of magnitude faster than conventional iterative methods based on table interpolations, and is fast enough for dynamic simulation.

DYHA Sub-project 2:
Monitoring and Validation of Control for Biotechnology and Food Processes

Project Leader
D. Tech Arto Visala (39 person-months)

Research Organizations
Automation Technology Lab. (HUT)

Companies
Roal Oy, Cultor Oy, and Systecon Oy

Goals: Develop a methodology to model autonomous systems (like batch processes) by using Wiener-Neural Networks with output feedback or state feedback.

Results of DYHA Sub-Project 2
This method was used to model the columns of an industrial sequential ion-exclusive chromatography separation process. The models work well as a predictor (within the scope of the training data) but not as well as a simulator of the whole separation process. More recently this approach was successfully applied to the modeling of fermentation processes, such as Tricoderma and Aspergillus.

DYHA Sub-project 3:
Intelligent Visualization of Dynamic Process Data

Project Leader
Prof. Heikki Koivo and Jari Seppala
(21 person-months)

Research Organizations
Automation and Control Institute,
Tampere University of Technology

Companies
UPM-Kymmene Oyj; Metso Oyj

Goals: Develop a visualization system to preprocess the measurement data, collected from complex industrial processes, and display them to the process operators.

Results of DYHA Sub-Project 3
- Developed a prototype for paper mills, comprised of a simple user interface and visualization tool. The visualization system is not for the end user but for the developer of an application based on the collected data.
- 3 publications

DYHA Sub-project 4:
Intelligent Control of Switched-Mode Power Supplies

Prof. Heikki Koivo; Idirsi Gadoura, Kai Zenger (42 person-months)

Research Organizations
Control Engineering Lab, Helsinki University of Technology

Companies
Efore Oyj

Goals: Develop an intelligent control for a DC-DC converter that can transform DC voltages into a desired level with very little losses. This digital solution should replace the current analog controllers of output voltage.

Results of DYHA Sub-Project 4
- Modeled basic DC-DC converter topology (Buck)
- Developed and analyzed different intelligent control algorithms. Compared them with the traditional approaches, using simulated benchmarks. The testing was recently extended by the use of a test bench consisting of a real switching power supply, connected to a DSP (with A/D and D/A)
- Eight publications

DYHA Sub-project 5:
Neuro-Fuzzy Application for On-Line Weight Determination of a Moving Loader

Project Leader
Prof. Heikki Koivo (8 person-months)

Research Organizations
Automation and Control Institute, Tampere Univ. of Technology

Companies
Sandvick Tamrock

Goals: Develop a NN or fuzzy logic based model to determine the payload in the bucket of a loader, while the machine is moving. This weight estimation can be used to determine the material flow coming out of a mine.

Results of DYHA Sub-Project 5
- Developed accurate NN weight estimator, based on measurements of hydraulic pressure in the boom lifting cylinder, slope angles, boom position, temperature of hydraulic oil, and pressure signal.
- Problems that need to be resolved to transition the algorithm: requirements for large size training data, and calibration issues.
- Patent application

DYHA Sub-project 6:
Intelligent Control and Diagnostics of Harvester Head

Project Leader
Prof. Heikki Koivo (14 person-months)

Research Organizations
Automation and Control Institute,
Tampere University of Technology

Companies
Plustech

Goals: Develop robust feeding control for the harvester head, improving positioning accuracy, and increasing feeding rate, while avoiding damage to the bark. Investigate fault diagnostics of harvester head to detect common faults in instrumentations, and identify gradually alarming faults

Results of DYHA Sub-Project 6
- Implemented an accurate simulator of the harvester head, including the head's dynamic behavior. The simulator, which can be used to test new control or diagnostic algorithms, has been transitioned to Plustech.
- Developed a new control for stem feeding, which adapts to changes in log mass and to the presence of strong branches. The new controller results in smoother accelerations and breaking actions.
- Developed diagnostics algorithm, using the simulator as test-bench, to detect failures modes or incipient failures
- Transition path to Plustech, who will continue the development of this project

2.3 TOOLMET 2 Research Project

Project Leader
Kauko Leiviskä

Structure and Goals

This project has two sub-projects, MODIPRO and PROPOS, as shown in Table 7. The evaluation of these projects according to the established criteria is provided in tables 8 and 9. TOOLMET 2 did not originate any EC project. However it created one international project (Plataforma Solar Almeria). Furthermore, this project has fostered working relationships and established international co-operations with several institutions: 1) IFMA (Institut Francais de Mechanique Avancee)/Clermont Ferrent in the area of SPC and intelligent methods (student/researcher exchange); 2) University of Rome "Tor Vergata" in the area of hardware applications of linguistic equations; 3) University of Dortmund, (Prof. Kiendl), in the combination of linguistic equations and fuzzy systems; 4) MIT/ Aachen, in developing connections between linguistic equations and Data Engine.

Table 7. Description of TOOLMET 2 Sub-Projects.

	Project Leader	**Project Volume**	
		[FINM (k)]	[person -months]
TOOLMET 2	Prof. Kauko Leiviskä		
1. MODIPRO	DI Esko Juuso (Oulu)	2100	98
2. PROPOS	Jorma Hintikka (VTT Elect.)	2200	55
Total TOOLMET 2		**4300**	**153**

Table 8. TOOLMET 2 Cooperation Efforts.

	Co-operation & Networking	
	# Joint Projects with Companies	Tech Transfer to Companies
TOOLMET 2		
1. MODIPRO	3	X-Ray inspection used. 2 more prototypes
2. PROPOS	4	Xfer S/w to Kaski Tech
Total TOOLMET 2	**7**	**5**

Table 9. TOOLMET 2 Research Results.

	Research Results Diffusion											**Research**
	Papers				Total	Norm.	Patent	Degrees			Follow-up	Research
	Books	Book Chapter	Jour-nals	Conf./ TR/etc.	Papers	Papers /pm	Pen-ding	PH.D	Master	Licenc.	devel. proj.	Excellence
TOOLMET 2												
1. MODIPRO		1	1	13	**15**	**15%**	-		3	3	yes	HIGH
2. PROPOS	-	-	-	3	**3**	**5%**	-		2		yes	MEDIUM
Total TOOLMET		1	1	16	**18**	**12%**	-		**5**	**3**	2	Med-High

TOOLMET 2 Sub-Project 1: **MODIPRO**

Project Leader
Prof. Esko Juuso (98 person-months)

Research Organizations
Control Engineering Lab, University of Oulu

Companies
ABB Pulp and Paper, Valmet Oyj Paper Machines, Nokia Access Systems Oy

Goals: Develop reasoning methods combining different sources of knowledge, such as fuzzy systems and expert systems. These methods are applied to four industrial case studies: 1) Intelligent cooking liquor analyzer (ABB Pulp and Paper); 2) Web break sensitivity indicator (Valmet, Paper machines); 3) Expert Systems for X-Ray inspection (Nokia Access Systems); 4) Quality Forecasting Tools (Nokia).

Results of TOOLMET 2 Sub-Project 1

- Developed the Linguistic Equation (LE) approach, a unified method for developing and tuning adaptive fuzzy systems.
- Integrated the LE approach with case-based reasoning, and successfully tested in the paper web break sensitivity indicator.
- Incorporated the LE approach in the production of the X ray inspection system, achieving a noticeable reduction in false alarms (40-50% less).
- The Linguistic Equations approach has also been used in lime kiln control (UPM Pietarsaari mills, Finland), in the control of Solar Power Plant (Plataforma Solar de Almeria, Spain), and in product demand forecasting (Nokia Networks, Finland).
- Future applications of this technology are: Product design in pharmaceutics industry (2000-2001); Control of digester, washing and oxygen delignification (2000-2002); Fault diagnosis of converter room and continuous casting (1999-2001).

TOOLMET 2 Sub-Project 2: **PROPOS - Applying Optimization Methods for Production Planning in Steel and Electronic Manufacturing**

Project Leader
Prof. Jorma Hintikka (55 person-months)

Research Organizations
VTT Elektroniikka

Companies
Outokumpu Polarit Oy, Salcomp Oy, Kaski Tech Oy and Rautaruukki Steel

Goals: Develop and test optimization techniques for production planning in electronic and steel manufacturing.

Results of TOOLMET 2 Sub-Project 3

- Developed an optimization software prototype based on a combination of stochastic local search with linear programming, heuristics and tabu search. Prototype tested in electronic manufacturing (Salcomp), leading to a more efficient material handling process. A similar prototype, using linear program for preliminary allocation, genetic algorithms for robustness, and local search at the end of the schedule, was tested for steel manufacturing production planning.
- VTT and KASKI Tech Oy will further refine this prototype to extend it to new applications
- 3 publications

2.4 PROMISE Research Project

Project Leader
Henry Tirri

Structure and Goals

This project is divided into three sub-projects: UH-PROMISE, HUT-PROMISE, and VTT-PROMISE. The first sub-project addresses key issues in *probabilistic modeling and stochastic optimization*. In probabilistic modeling, the main problem is to develop a computational efficient method to apply Bayesian networks and finite mixture models to real-world problems. In stochastic optimization, the goal is to perform empirical studies and compare methods such as simulated annealing and Genetic Algorithms.

The second sub-project deals with the integration of background knowledge in network modeling. In particular, the project focuses on the development of Bayesian methods for combining knowledge and data. The third sub-project is aimed at developing inventory control methods for supply chains. In particular the project focuses on demand forecasting and purchasing optimization.

The list of Promise sub-projects is shown in Table 10, while the evaluation of this project according to the established criteria is provided in tables 11 and 12. The researchers of this project have established a large number of international collaborations with NASA, UCL (London), and CWI (Amsterdam). They are also active participants in two European research networks (NeuroCOLT and HSSS).

Table 10. Description of PROMISE Sub-Projects.

	Project Leader	**Project Volume**	
		[FINM (k)]	[person -months]
PROMISE	Prof. Henry Tirri (UH)		
1. Probalistic Modeling and Stockhastic Optimization (PM & SO)	Dr. Petri Myllymäki (UH)	2650	105
2. Using Background Knowledge in Neural Modeling (BK in NM)	Prof. Jouko Lampinen (HUT)	1750	80
3. Intelligent Inventory Control (IIC)	Lic. Tech. Ilkka Karanka (VTT)	2750	70
Total PROMISE		**7150**	**255**

Table 11. PROMISE Co-operation Efforts.

	Co-operation & Networking	
	# Joint Projects with Companies	Tech Transfer to Companies
PROMISE		
1. PM & SO (UH)	5	BAYDA software
2. BK in NM (HUT)	4	-
3. IIC (VTT)	**3**	**-**
Total	**12**	1

Table 12. PROMISE Research Diffusion and Research Excellence.

	Research Results Diffusion											**Research**
	Papers				Total	Norm.	Patent	Degrees			Follow-up	Research
	Books	Book Chapter	Jour-nals	Conf./ TR	Papers	Papers /pm	Pen-ding	PH.D	Master	Licenc.	devel. proj.	Excellence
PROMISE												
1. PM & SO (UH)	1	4	3	13	**21**	**20%**		docent	3			HIGH
2. BK in NM (HUT)	-	-	1	12	**13**	**16%**			4			HIGH
3. IIC (VTT)	-	-	-	2	**2**	**3%**			3			Medium
Total	1	4	4	27	**36**	**14%**		**1**	**10**			HIGH

PROMISE Sub-Project 1:
Probabilistic Modeling and Stochastic Optimization (HU)

Project Leader
Dr. Petri Myllymäki (105 person-months)

Research Organizations
University of Helsinki

Companies
TietoEnator, Kone, BayesIt, Nokia and Kibron

Goals: 1) Develop computationally efficient methods for building and applying probabilistic models, e.g. Bayesian Networks and finite mixture models. 2) Perform empirical studies of simulated annealing, genetic algorithms and other stochastic search methods in complex problem domains.

Results of PROMISE Sub-Project 1

- Obtained strong theoretical results in Bayesian Networks, concerning model selection with respect to the predictive performance of the chosen models. These results were validated by tests with real-world data sets.
- Empirical comparison of stochastic optimization methods led to a novel version of simulated annealing, with an automatic cooling schedule that improves overall performance.
- Successful transitions of project results to commercial products: a) TietoEnator has incorporated the optimization algorithms developed by this project in the intelligent container packing software that determines packing structure and container requirements for customized shipment; b) StoraEnso is using this software package extensively; c) BayesIT, a spin-off software company, is developing a commercial data analysis and visualization product based on the probabilistic modeling methods generated by this project.
- 21 publications; 1 software package (BAYDA) for data analysis in classification domains
- 3 EC project proposals

PROMISE Sub-Project 2:
Using Background Knowledge in Neural Modeling - (HUT)

Project Leader
Jouko Lampinen (80 person-months)

Research Organizations
Helsinki University of Technology
(Lab. Of Computational Engineering)

Companies
Ahlstrom Pumps Ltd., Lohja Rudus Ltd., OWC – Omni Weight Control Ltd., Taipale Eng. Ltd.

Goals: Develop methods for using background knowledge in neural modeling. This project focused on the use of Bayesian methods for choosing the correct NN model complexity, and tools for analyzing the confidence of the resulting models.

Results of PROMISE Sub-Project 2

- Developed methods for Bayesian analysis of neural networks and a novel approach for statistical inverse methods.
- Successfully applied these methods to the inverse problem in process tomography (EIT for Ahlstrom Pumps), the estimation of load by measuring strains in supporting system (weight measurement for Omni Weight), the modeling of quality parameters in concrete industry (Lohja Rudus), and forest scene analysis (separating trees from background for inventory estimation)
- 13 publications (1 journal + 12 conferences proceedings)

PROMISE Sub-Project 3:
Intelligent Inventory Control (IC)

Project Leader
Ilkka Karanka (70 person-months)

Research Organizations
Technical Research Center of Finland
(VTT Information Technology)

Companies
Valio, Kesko and ICL Data.

Goals: Development of intelligent inventory control methods, with a particular focus on demand forecasting for the supply chain and on the optimization of purchase levels.

Results of PROMISE Sub-Project 3

- Built prototype for Valio, incorporating forecasting, automatic model building and data base, and user interface. In test runs the prototype provides a better forecast than the old methods in 88% of the products. The prototype was built mostly in Java (with C, C++ for interface with external components, such as SPSS, and LINPACK)
- Publications: 3 conference papers been submitted
- Practical use: Valio has not decided yet whether to use the prototype, while Kesko is still considering it.

2.5 NESUMED II Research Project

Project Leader
Jari Forsström

Structure and Goals

This project has two sub-projects, NESUMED-II and IIS:COMPSOFT. Both projects cover data analysis techniques. The first one deals with medical data analysis, while the second one focuses on process control data analysis in the forest industry.

Results: The list of NESUMED-II + COMPSOFT sub-projects is shown in Table 13, while the evaluation of this project according to the established criteria is provided in tables 14 and 15. NESUMED did not originate any EC projects, but it organized one international workshop to secure quality of medical software.

NESUMED II Sub-Project 1:
Nesumed II Medical Decision Support System

Project Leader
M.D. Jari Forsström (61 person-months)

Research Organizations
Medical Information Research Center in Turku, University of Turku (Dept of CS).

Table 13. Description of NESUMED-II + COMSOFT Sub-Projects.

	Project Leader	**Project Volume**	
		[FINM (k)]	[person -months]
NESUMED II + IIS: COMSOFT			
Nesumed	Jari Forsström	1150	40
Compsoft	Patrick Eklund	590	21
Total		1740	**61**

Table 14. NESUMED-II + COMSOFT Co-operation Efforts.

	Co-operation & Networking	
	# Joint Projects with Companies	Tech Transfer to Companies
NESUMED II + IIS: COMSOFT		
Nesumed	-	-
Compsoft	1	-
Total	**1**	0

Table 15. NESUMED-II + COMSOFT Research Diffusion and Research Excellence.

	Research Results Diffusion											Research
	Papers				Total	Norm.	Patent	Degrees			Follow-up	Research
	Books	Book Chapter	Jour-nals	Conf./ TR/etc.	Papers	Papers /pm	Pen-ding	PH.D	Master	Licenc.	devel. proj.	Excellence
NESUMED II + IIS: COMSOFT												
Nesumed	-	2	1	3	**6**	**15%**		1				HIGH
Compsoft	0	2	1	3	**6**	**29%**				1		MEDIUM
Total	**0**	**4**	**2**	**6**	**12**	**20%**		**1**	**0**	**1**		Med-High

Companies
Harkatie Health Care Center (Lieto), Wallac Oy (Turku) and Leiras Oy (Turku).

Goals: The goal of this project was to apply neural networks to a variety of medical diagnostic problems. The first application was to calculate the risk of Down's Syndrome from biochemical screening data of the mothers. The second application was the screening of prostate cancer screening based on antigen (PSA). The third one was the recognition of trabecular elements in radiographs to estimate different stages of osteoporosis.

Results of NESUMED II Sub-Project 1
The Down's Syndrome application used Artificial Neural networks to develop a classifier using as inputs the gestational age, maternal weight, and maternal age. The results were good but not significantly different than traditional Gaussian models. The lack of confidence interval was an additional problem caused by this approach.

The Prostate Cancer Screening based on antigen was analyzed by a variety of tools (ANN, neuro-fuzzy algorithms, etc.). However, the data collected (1000 cases) were not sufficient to successfully train the models.

The osteoporosis application was more successful. It used:

1) *Directional filtering*: Gabor wavelets to suppress orientation outside scope
2) *Detection* and validation of trabecules (done with specific heuristics) - very good for monitoring changes
3) Accurate *segmentation* of trabecules using deformable contours
4) Osteoporosis stages linked to lower density and spacing, since loss of bone mineral and deterioration of micro-structure characterize this disease

This study is very promising and should be continued. Future work should be a comparison of X-ray of proximal femur images with Singh Index, which shows systematic erosion of trabecular structures.

NESUMED II Sub-Project 2:
Intelligent Information Systems: Computing Methods and Software Development (IIS:COMPSOFT)

Project Leader
Prof. Patrik Eklund (21 person-months)

Research Organizations
Umea University (CS Dept.), Abo Academi University

Companies
Valmet Oy, UPM

Goals: Support the development of web break indicators for paper machines. The ultimate goal was to create a software infrastructure to replicate the Break Indicator process for other lines, machines, and for different longitudinal positions.

Results of NESUMED II Sub-Project 2
These efforts lead to the development of data analysis methodologies and software to provide such functionality. The data analysis efforts were based on production data obtained from Valmet during 1995-97. A prototype to illustrate this capability was built in Visual Basic. The prototype is well documented and has all the necessary real-time connections to be installed in the process. However, the system has not been transitioned yet to Valmet.

2.6 Summary Of AISA Program Evaluation

We have reviewed the five research projects that form the Adaptive and Intelligent Systems Applications Program. In their scope, they span the entire field of Soft Computing, one of the most promising emerging in Computer Science and Computer Engineering. To properly evaluate the contributions of these five research projects, we need to establish a framework for SC, within which we can position them.

We will start by defining Soft Computing and its components, and then by locating the output of the five research projects in this context. Finally, we will provide our comments, and recommendations for the overall AISA program.

3 Soft Computing

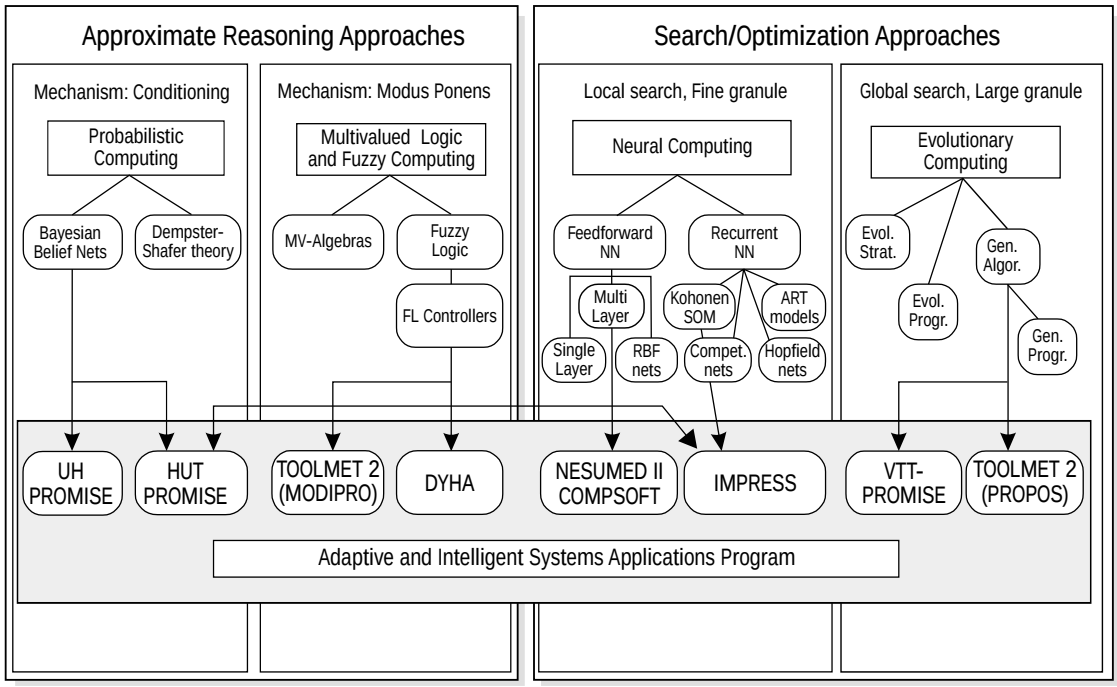


Figure 1. Soft Computing Components and Hybrid Systems.

Soft computing (SC) is a term originally coined by Zadeh in 1994 [1] to denote systems that "… exploit the tolerance for imprecision, uncertainty, and partial truth to achieve tractability, robustness, low solution cost, and better rapport with reality." Soft computing is "*an association of computing methodologies that includes as its principal members fuzzy logic (FL), neuro-computing (NC), evolutionary computing (EC) and probabilistic computing (PC)*" [2]. Figure 1 illustrates a taxonomy of SC components. Extensive coverage of this topic can be found in references [3-4].

3.1 SC Components and Taxonomy

3.1.1 Fuzzy Computing

In 1965 Zadeh proposed a complete theory of fuzzy sets (and its isomorphic fuzzy logic) that allowed us to represent and manipulate ill-defined concepts [5]. In a narrow sense, fuzzy logic could be considered a fuzzification of Lukasiewicz Aleph-1 multiple-valued logic [6]. In the broader sense, however, this narrow interpretation represents only one of FL's four facets [7]. More specif-

ically, FL has a logical facet, derived from its multiple-valued logic genealogy; a set-theoretic facet, stemming from the representation of sets with ill-defined boundaries; a relational facet, focused on the representation and use of fuzzy relations; and an epistemic facet, covering the use of FL to fuzzy knowledge based systems and data bases. A comprehensive review of fuzzy logic and fuzzy computing can be found in [8].

Fuzzy logic gives us a language, with syntax and local semantics, in which we can translate qualitative knowledge about the problem to be solved. In particular, FL allows us to use linguistic variables to model dynamic systems. These variables take fuzzy values that are characterized by a label (a sentence generated from the syntax) and a meaning (a membership function determined by a local semantic procedure). The meaning of a linguistic variable may be interpreted as an elastic constraint on its value. These constraints are propagated by fuzzy inference operations, based on the *generalized modus-ponens*. This reasoning mechanism, with its interpolation properties, gives FL a robustness with respect to variations in the system's parameters, disturbances, etc., which is one of FL's main characteristics.

3.1.2 Probabilistic Computing

Rather than retracing the history of probability, we will focus on the development of probabilistic computing (PC) and illustrate the way it complements fuzzy computing. As depicted in Figure 1, we can divide probabilistic computing into two classes: single-valued and interval-valued systems.

Bayesian belief networks (BBNs), based on the original work of Bayes [9], are typical examples of single-valued probabilistic reasoning systems. They started with approximate methods used in first-generation expert systems, such as MYCIN's confirmation theory [10] and PROSPECTOR's modified Bayesian rule [11], and evolved into formal methods for propagating probability values over networks [12-13]. In general, probabilistic reasoning systems have exponential complexity, when we need to compute the joint probability distributions for *all* the variables used in a model. Before the advent of BBNs, it was customary to avoid such computational problems by making unrealistic, global assumptions of conditional independence. By using BBNs we can decrease this complexity by encoding domain knowledge as structural information: the presence or lack of conditional dependency between two variables is indicated by the presence or lack of a link connecting the nodes representing such variables in the network topology. For specialized topologies (trees, poly-trees, directed acyclic graphs), efficient propagation algorithms have been proposed by Kim and Pearl [14]. However, the complexity of multiple–connected BBNs is still exponential in the number of nodes of the largest sub-graph. When graph decomposition is not possible, we resort to approximate methods, such as clustering and bounding conditioning, and simulation techniques, such as logic samplings and Markov simulations.

Dempster-Shafer (DS) systems are a typical example of interval-valued probabilistic reasoning systems. They provide lower and upper probability bounds instead of a single value as in most BBN cases. The DS theory was developed independently by Dempster [15] and Shafer [16]. Dempster proposed a calculus for dealing with interval-valued probabilities induced by multiple-valued mappings. Shafer, on the other hand, started from an axiomatic approach and defined a calculus of belief functions. His purpose was to compute the credibility (degree of belief) of statements made by different sources, taking into account the sources' reliability. Although they started from different semantics, both calculi were identical.

Probabilistic computing provides a way to evaluate the outcome of systems affected by randomness (or other types of probabilistic uncertainty). PC's basic inferential mechanism - conditioning - allows us to modify previous estimates of the system's outcome based on new evidence.

3.1.3 Neural Computing

The genealogy of neural networks (NN) goes back to 1943, when McCulloch and Pitts showed that a

network of binary decision units (BDNs) could implement any logical function [17]. Building upon this concept, Rosenblatt proposed a one-layer feedforward network, called a *perceptron*, and demonstrated that it could be trained to classify patterns [18-20]. Minsky and Papert [21] proved that single-layer perceptrons could only provide linear partitions of the decision space. As such they were not capable of separating nonlinear or non-convex regions. This caused the NN community to focus its efforts on the development of multilayer NNs that could overcome these limitations. The training of these networks, however, was still problematic. Finally, the introduction of backpropagation (BP), independently developed by Werbos [22], Parker [23], and LeCun [24], provided a sound theoretical way to train multi-layered, feed-forward networks with nonlinear activation functions. In 1989, Hornik et al. proved that a three-layer NN (with one input layer, one hidden layer of squashing units, and one output layer of linear units) was a universal functional approximator [25].

Topologically, NNs are divided into *feedforward* and *recurrent* networks. The feedforward networks include single- and multiple-layer *perceptrons*, as well as radial basis functions (RBF) networks [26]. The recurrent networks cover competitive networks, self-organizing maps (SOMs) [27], Hopfield nets [28], and adaptive resonance theory (ART) models [29]. While feed-forward NNs are used in supervised mode, recurrent NNs are typically geared toward unsupervised learning, associative memory, and self-organization. In the context of this paper, we will only consider feed-forward NNs. A comprehensive current review of neuro-computing can be found in [30].

Feedforward multilayer NNs are computational structures that can be trained to learn patterns from examples. They are composed of a network of processing units or neurons. Each neuron performs a weighted sum of its input, using the resulting sum as the argument of a non-linear activation function. Originally the activation functions were sharp thresholds (or Heavyside) functions, which evolved to piecewise linear saturation functions, to differentiable saturation functions (or sigmoids), and to Gaussian functions (for RBFs). By using a training set that samples the relation between inputs and outputs, and a learning method that trains their weight vector to minimize a quadratic error function, neural networks offer the capabilities of a supervised learning algorithm that performs fine-granule local optimization.

3.1.4 Evolutionary Computing

Evolutionary computing (EC) algorithms exhibit an *adaptive* behavior that allows them to handle non-linear, high dimensional problems without requiring differentiability or explicit knowledge of the problem structure. As a result, these algorithms are very robust to time-varying behavior, even though they may exhibit low speed of convergence. EC covers many important families of stochastic algorithms, including *evolutionary strategies* (ES), proposed by Rechenberg [31] and Schwefel [32], *evolutionary programming* (EP), introduced by Fogel [33-34], and g*enetic algorithms* (GAs), based on the work of Fraser [35], Bremermann [36], Reed et al. [37], and Holland [38-40], which contain as a subset *genetic programming* (GP), introduced by Koza [41].

As noted by D. Fogel [42], ES, EP, and GAs share many common traits: "…Each maintains a population of trial solutions, imposes random changes to those solutions, and incorporates selection to determine which solutions to maintain in future generations..." Fogel also notes that "… GAs emphasize models of genetic operators as observed in nature, such as crossing-over, inversion, and point mutation, and apply these to abstracted chromosomes…" while ES and EP "… emphasize mutational transformations that maintain behavioral linkage between each parent and its offspring."

Finally, we would like to remark that EC components have increasingly shared their typical traits: ES have added recombination operators similar to GAs, while GAs have been extended by the use of real-number-encoded chromosomes, adaptive mutation rates, and additive mutation operators [43].

3.2 Soft Computing Taxonomy

The common denominator of these technologies is their departure from classical reasoning and modeling approaches that are usually based on Boolean logic, analytical models, crisp classifications, and deterministic search. In ideal problem formulations, the systems to be modeled or controlled are described by complete and precise information. In these cases, formal reasoning systems, such as theorem provers, can be used to attach binary truth-values to statements that describe the state or behavior of the physical system.

When we solve real-world problems, we realize that such systems are typically ill defined, difficult to model, and possess large solution spaces. In these cases, precise models are impractical, too expensive, or non-existent. To generate the appropriate solution, we must leverage two kinds of resources: *problem domain knowledge* of the process or product and *field data* that characterize the behavior of the system. The relevant available domain knowledge is typically a combination of first principles and empirical knowledge, and is usually incomplete and sometimes erroneous. The available data are typically a collection of input-output measurements, representing instances of the system's behavior, and may be incomplete and noisy.

We can observe from Figure 1 that the two main approaches in soft computing are *knowledge-driven* reasoning systems (such as probabilistic and fuzzy computing) and *data-driven* search and optimization approaches (such as neuro and evolutionary computing). This taxonomy, however, is soft in nature, given the existence of many hybrid systems that span across more than one field.

3.3 SC Solutions

The alternative approaches to SC are the traditional knowledge-driven reasoning systems and the data-driven systems. The fundamental problem of these classical approaches lies in representing and integrating uncertain, imprecise knowledge in data-driven methods or in making use of somewhat unreliable data in a knowledge-driven approach.

Although it would be presumptuous to claim that soft computing *solves* this problem, it is reasonable to affirm that SC provides a different paradigm in terms of representation and methodologies, which facilitates these integration attempts. For instance, in classical control theory the problem of developing models is decomposed into system identification and parameter estimation. Usually the former is used to determine the order of the differential equations and the latter determines its coefficients. Hence, in this traditional approach we have *model = structure + parameters*. This equation does not change with the advent of soft computing. However, we now have a much richer repertoire to represent the structure, to tune the parameters, and to iterate this process. It is understood that the search method used to find the parameter values is an important and implicit part of the above equation, which needs to be chosen carefully for efficient model construction.

4 The Adaptive and Intelligent Systems Applications Program and Soft Computing

The Adaptive and Intelligent Systems Applications Program covers a large area of Soft Computing, as illustrated in Figure 1. IMPRESS is state-of-the-art research in Neural Networks. DYHA and TOOLMET 2 (MODIPRO) have produced remarkable fuzzy logic applications. UH- and HUT-PROMISE are at the forefront of Probabilistic (Bayesian) research. A little more mundane are the applications of Genetic Algorithms in TOOLMET 2 (PROPOS) and VTT-PROMISE. Finally, NESUMED II has investigated the use of Statistics and neural networks to develop medical DSS. The breadth of the program is comparable with the depth of the results achieved by most of five projects.

1) IMPRESS, the largest research project of this program, has developed state-of-the-art applications of neural networks, especially in the use of unsupervised NN (SOMs). This project, which consists of nine sub-projects, is definitely at the forefront of its field. Equally impressive the number of degrees earned by young researchers working on this program (3 PhD, 2 Licenciate, 15 Master degrees.)

The *Adaptive real-time image analysis* sub-project, documented by a large number of papers [44-45], has produced excellent results in applying machine vision and neural networks to visual fault diagnosis of a running paper web in a paper machine and on-line handwritten text recognition for palm-sized computers. These results represent an improvement over existing solutions as documented in references [46-47].

The second sub-project, *Data mining and analysis using the SOM*, is also a stellar example of research excellence [48]. This is not surprising, given the progeny of this technology [27]. This sub-project resulted in over sixteen papers and a software package. The results described are of the same quality as the one illustrated in previous applications by other researchers [49-50].

The third sub-project, *Data fusion and neural networks in complex models*, improves upon existing results in estimation of wind speed on different altitudes [51-52], spatial model for consumer behavior [53], and satellite image analysis [54]. Especially noteworthy are the results obtained in wind speed estimation based on Doppler spectra data.

The fourth sub-project, *Optical characterization of microstructures*, has led to the successful application of NN to the complex problem of optical scatterometry. The results, described in [55-56] show that the surface parameters of micro-structured plates were predicted with nanometer-level accuracy by using a multilayer perceptron NN. These results are state-of-the-art, as compared with those achieved by other techniques [57-58].

The fifth sub-project, *Intelligent signal processing*, addressed speech recognition, speech coding, image interpolation, channel equalization, enhancement of digital X-ray images, and passive detection of moving targets. This resulted in more than sixteen publications [59-60], whose quality is comparable with some of the best references in the field [61-65].

The sixth sub-project, *Nonlinear disturbance analysis*, describes the results of an experiment in detection of abnormal process behavior. PCA and SOMs are used to analyze the data from a paper mill. The results are not particularly significant [66]. While there are no comparable references, the use of SOMs to visualize process changes can also be found in [67].

The seventh sub-project, *Analysis of annual reports by advanced NN methods,* is documented by four papers, with [68] been the most representative publication. The nature of this work is still preliminary but the underlying approach is quite novel and promising. A survey of this particular problem can be found in reference [69].

The eighth sub-project, *Data analysis and representation by NN (DAEMON),* described by nine papers – see, for instance, [70] - is a good example of how to leverage previously developed software tools (NDA) to produce good results with a modest incremental budget. References [71-72] illustrate background information and alternative approaches, respectively.

The ninth sub-project, *Development of spatio-temporal NN for solving time-dependent problems,* is described by six papers, - see [73] as a representative publication illustrating this research effort. References [74-76] provide the readers with a description of comparable related research approaches.

2) DYHA, the second largest project in this program, has also achieved its goals. This program, comprised by six sub-projects, has produced remarkable results in applying neural networks and fuzzy logic to a broad variety of problems. A total of six degrees (1 PhD. 2 Licenciate, 2 Master) have been earned by participants to this project.

The first project, *Neural Networks for Thermodynamic Properties,* has developed a methodology to model the thermodynamic properties of mixtures of air and water. This effort is described by one publication. The NN models generated by this project have been incorporated in APROS, a general-purpose dynamic process simulation program.

The second project, *Monitoring and validation of control for biotechnological and food process,* is described by six papers – see, for instance [77]. The methodology developed by this project use Wiener-neural networks with feedback to model autonomous systems, like batch processes. This effort improves upon previous work done by the principal investigator [78], and is rooted on the work of M. Nazmul Karim, who demonstrated the use of many NN based estimation techniques for bioprocesses in 1992 [79]. His work was also based on Hammerstein model [80].

The third project, *Intelligent visualization of dynamic process data,* addresses the visualization of dynamic multidimensional data collected from complex industrial processes, such as paper mills. The project, described by three publications, has led to the construction of a prototype with a simple user interface and visualization.

The fourth project, *Intelligent control of switched-mode power supplies,* has developed a comprehensive solution to the problem of creating DC-DC converters that can transform DC voltages into a desired level with very little losses. This approach is an alternative to the analog component based solutions – see references [81-85]. Different intelligent control algorithms have been developed, analyzed, and compared with the traditional approaches, using simulated benchmarks. The testing has recently been extended by the use of a test bench consisting of a real switching power supply, connected to a DSP. The successful results of these comparisons were described in eight publications and in a Licenciate Thesis [86].

The fifth project, *Neuro-fuzzy application for on-line weight determination of a moving loader,* has developed an innovative approach for determining the payload in the bucket of a loader, while the machine is moving. This result has led to the filing of a patent application.

The sixth project, *Intelligent control and diagnostic of a harvester head,* is at the forefront of the research with harvesters, a topic that is not well explored yet. Related modeling work, limited to the modeling of the harvester boom can be found in references [87-88]. Related work on fault diagnosis, of hydraulic motors, rooted on a model-based approach, can be found in references [89-94]. The work sponsored by this program, on the other hand, is focused on the harvester head and is based on a logic reasoning approach to perform its diagnostics. The results obtained from this project compare favorably with the existing state of the art described by the above-mentioned references. In

particular, the diagnostic algorithm developed for the header head will remove the need for using additional instrumentation.

3) TOOLMET 2, the third project, is comprised of two sub-projects that address model-based diagnostics for process analysis and the optimization of production planning. This project has been quite successful in establishing several international collaborations with other research institutions.

The first project, *Model-based Diagnostics Process analysis (MODIPRO),* has developed an interesting approach to develop reasoning methods combining different sources of knowledge, such as fuzzy systems and expert systems. Particularly promising is the integration of case-based reasoning with the linguistic equations approach, which was used in the Web break sensitivity indicator. The linguistic equations approach is a very versatile tool, and it has also been used in intelligent cooking liquor analyzer, in lime kiln control, in the control of solar power plant, and in product demand forecasting. This project is extensively described by more than fifteen publications – see for instance [95].

The second project, *PROPOS,* has applied optimization techniques to production planning in electronic and steel manufacturing. The current system uses a combination of stochastic local search with linear programming, heuristics, and tabu search. Preliminary results are promising, but further refinements are needed. A good reference for related work – an approach using genetic algorithms - can be found in [96].

4) PROMISE, the fourth project of this program, is pushing the research envelope in Probabilistic Reasoning and Optimization.

UH-PROMISE has proven to be a very prolific project, generating over twenty excellent publications on probabilistic (Bayesian) models and stochastic optimization [97-99]. These results have been embodied into BAYDA, a Java software package for data analysis in classification domains. The research covers information-theoretic approaches (MDL/MML) to predictive modeling, case-based reasoning, stochastic optimization, and Bayesian networks applied to supervised learning, learning with incomplete data and feature selection. The output of this project is truly world-class research, and it compares very well with the work of other researchers in this field such as the research group at Microsoft [100-107].

HUT-PROMISE has studied methods for using background knowledge in neural network modeling [108] and has developed a fast and accurate solution for the inverse problem in electrical impedance tomography [109]. The proposed solution is considerably better and faster than the state of the art solution to this problem [110-111].

Finally VTT-PROMISE addresses the problem of intelligent inventory control, with a particular focus on demand forecasting in the supply chain. The results of this project are described in a two publications. More importantly, however a Java-based software system has been developed and applied successfully to Valio's products.

5) NESUMED II + IIS:COMPSOFT, the last project of this program, is a combination of two very different projects.

The first one, *NESUMED II*, based on the primary investigators' prior work [112], explored the use of neural networks in a variety of medical diagnostic problems. Three publications document the application of NN to Down's Syndrome screening and prostate cancer screening based on antigen (PSA). However, the most promising application is the recognition of trabecular elements in radiographs to estimate different stages of osteoporosis. Although at an early stage, this application seems to be extremely promising and should be continued.

The second one, *IIS:COMPSOFT*, focused on the creation of a software infrastructure to support the development of web break indicators for paper machines [113]. A prototype to illustrate this capability was built in Visual Basic, but the transition to the partnering company, Valmet Inc., has yet to occur. .

5 Summary

The *Adaptive and Intelligent Systems Applications Program* has definitely achieved its overall goal. The cooperation between research institutes and industries is evidenced by a total of 60 joint projects and 18 transition paths (at different stages).

The research results are equally remarkable and the best projects in the program exhibit world-class quality. They compare very well with the work of other researchers in the field. The diffusion of the research, measured by the number of publications and degrees earned, is equally impressive. The five research projects have produced a total of 140 publications: 1 book, 15 book chapters, 22 journal articles, and 102 conference papers. Considering that the total number of person-months in the program is roughly 1,123, the average number of papers per person-month is 0.12. In other words, for every person in the program one paper was written every 8 months. This simple statistics is almost uniformly distributed across the five research projects, showing a general commitment to the diffusion of the research results. Furthermore, we believe that the best way to distribute this information is to train professional people in developing and applying these technologies. This goal has also been achieved, given that 46 degrees have been conferred (or are in preparation): 6 Doctorates, 8 Licenciate, and 32 Masters.

Critical issues

When we established the metrics for evaluating the research results, we suggested three criteria: research diffusion, research excellence, and participation in EC projects. Perhaps the only evaluation criterion that has not been equally satisfied is the third one, i.e., the number of EC projects derived from this program. Rather than being an issue of quality, this might be more an issue of timing with the EC procurement cycle. This criterion should be emphasized more in the next phase of this program, so that better results can be achieved.

Another issue to consider is how to construct a successful transition path from the universities/research institutes to the participating industries. This problem typically does not have a standard solution, and requires customized approaches. While a research project might have a follow-up pilot program, this does not necessarily mean that the program is ready for industrial use. A successful technology transition path requires that the receiving partners commit internal resources to all aspects of the transition, including the testing of the software in an industrial setting, and the education and training of its own personnel.

Recommendations: Programmatic Issues

As we noted above, the best way to distribute the results of this program is by training the professional people involved in the application of these technologies. In this kind of research, whose results are mainly computer programs, it is essential to distribute this expertise among all the people participating in the projects, to ensure the feasibility of the programs and their potential commercialization.

We would expect that, in about a year, when most of the development programs and testing periods will be completed, the participating companies will be more willing to provide us with information related to the success of these projects and their transitions. At that point, we should publish a follow-up report detailing the results of the technology program and their impact on the participating companies.

Recommendations: Research Issues

The research portfolio is well balanced, covering the four components of Soft Computing (SC). In this current phase of the program, we would have liked to see a greater effort in applications of evolutionary computing (EC), since the two current attempts at using EC are rather mundane. In the future, we would also like to see an *explicit effort* at studying and developing *hybrid* soft computing systems.

Currently, most of the applications in the *Adaptive and Intelligent Systems Applications Program* rely on a single SC component. However, the main reason for Soft Computing popularity is the *synergy* derived from its components. SC's main characteristic is its intrinsic capability to create *hybrid systems* that are based on a *loose* or *tight* integration of these technologies. This integration provides us with complementary reasoning and searching methods that allows us to combine domain knowledge and empirical data to develop flexible computing tools and solve complex problems.

Soft computing is having an impact on many industrial and commercial operations, from scheduling to predictive modeling and control. It provides us with alternative approaches to traditional knowledge-driven reasoning systems or pure data-driven systems and it overcomes their shortcomings by synthesizing a number of complementary reasoning and searching methods over a large spectrum of problem domains. These systems leverage the tolerance for imprecision, uncertainty, and incompleteness, which is intrinsic to the problems to be solved, and generate tractable, low-cost, robust solutions to such problems. The synergy derived from these hybrid systems stems from the relative ease with which we can translate problem domain knowledge into initial model structures whose parameters are further tuned by local or global search methods. This is a form of complementary or *tight* hybridization. Apart from this type of hybridization, there is a type of model fusion or *loose* hybridization that does not combine features of the methodologies themselves, but only their results. Its primary motivation is to increase reliability rather than to make model construction easier.

For example, to tune *knowledge-derived models* we first translate domain knowledge into an initial structure and parameters and then use global or local data search to tune the parameters. To control or limit search by using prior knowledge we first use global or local search to derive the models (structure + parameters), we embed knowledge in operators to improve global search, and we translate domain knowledge into a controller to manage the solution convergence and quality of the search algorithm.

The payoff of this conjunctive use of techniques tends to be a more accurate and robust solution than a solution derived from the use of any single technique alone. This synergy comes at comparatively little expense because typically the methods do not try to solve the same problem in parallel but they do it in a mutually complementary fashion. Another way to say this is that the model needs a structure and parameters, and a search method to discover them, and no single technique should be expected to be the best for all problems. Another advantage to the hybridization of techniques is that it is easier to think of alternative solutions to the same problem. If there are several possibilities for the structure and the search methods, many more pairings of technologies are possible, and problem solving becomes easier. A step in further improving system performance is the exploitation of parallel systems. These systems may be designed to rely to the maximum amount on non-overlapping data and use different techniques to arrive at their conclusions. In *information fusion*, the outputs of these heterogeneous models will be compared, contrasted, and aggregated, as seen in our last application.

The future appears to hold a lot of promise for the novel use and combinations of SC applications. The circle of SC's related technologies will probably widen beyond its current constituents. The push for low-cost solutions combined with the need for intelligent tools will result in the deployment of hybrid systems that efficiently integrate reasoning and search techniques. We believe that the Adaptive and Intelligent Systems Applications Program has already established the first step toward this future and needs to continue along the suggested path.

II Taloudellisten tulosten ja vaikutusten arviointi suomalaisen teollisuuden näkökulmasta

1 Arvioinnin toteutus

Teknologiaohjelman taloudellisten tulosten ja vaikuttavuuden arvioimiseksi lähetettiin 1.3.–31.3. välisenä aikana 2. vaiheen 70 projektin talouselämän vastuuhenkilölle kysymyslista. Siinä pyrittiin kartoittamaan projektin syntyä, taloudellista arvoa, saatavia hyötyjä, jatkonäkymiä ja yhteistyökuvioita henkilöresursseineen. Suurelle osalle jouduttiin soittamaan vastauksen saamiseksi, jossa yhteydessä suoritettiin täydentäviä haastatteluja. Korkeakoulujen tai tutkimuslaitosten vetämien tutkimusohjelmien 2. vaiheen projekteihin osallistuneita yrityksien tai organisaatioiden edustajia on 52 ja yrityskohtaisista projekteista vastuussa olleita henkilöitä 18. Vastaus saatiin 57 henkilöltä. Kyselyn saaneista viisi katsoi jääneensä niin ulkopuoliseksi, ettei voinut vastata, ja kahteen ei saatu yhteyttä.

2 Vastausten ja haastattelujen tulokset

2.1 Teknologiaohjelman merkitys

Teknologiaohjelman merkityksen tarkastelu haastattelujen valossa tehdään yleisen vaikutelman lisäksi tarkemmin jakamalla haastateltavien yritykset neljään ryhmään:

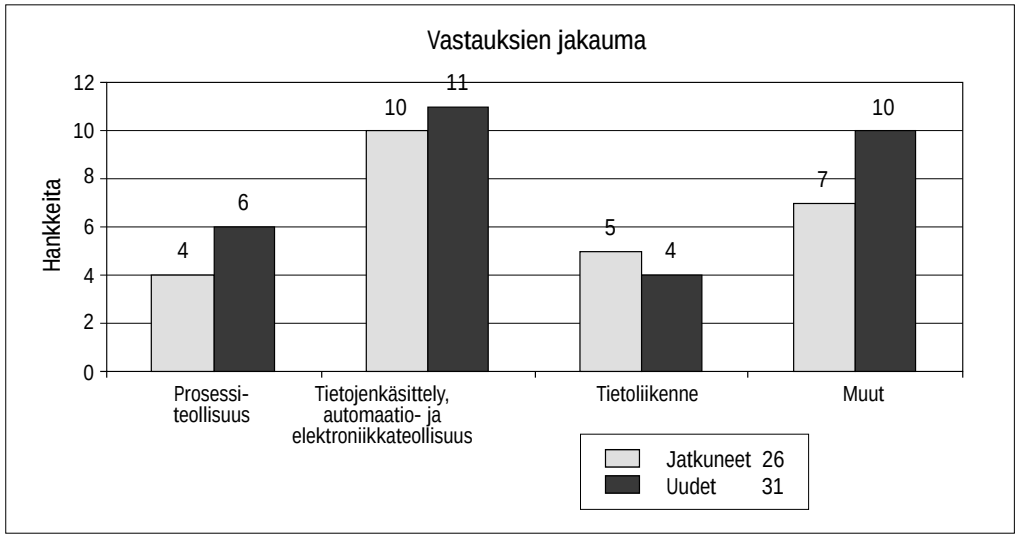
1. Prosessiteollisuus
2. Tietojenkäsittely, automaatio- ja elektroniikkateollisuus
3. Tietoliikenne
4. Muut (mm. koneiden valmistus, terveydenhoito, konsultointi, tukkukauppa)

Haastateltavien jakaantuminen eri ryhmien kesken on esitetty kaaviossa 1. Siitä käy ilmi myös se, että teknologiaohjelman ensimmäisestä vaiheesta jatkuneet ja uudet hankkeet jakaantuvat varsin tasaisesti. Lisäksi on arvioitu ohjelman merkitystä tutkimuslaitosten ja korkeakoulujen osalta.

2.1.1 Yleisvaikutelma

Paria poikkeusta lukuun ottamatta kaikki haastatellut olivat joko erittäin tyytyväisiä tai tyytyväisiä ohjelmassa saatuihin tuloksiin vaikkakin työ oli vielä kesken suurimmassa osassa projekteja. Syyt keskeneräisyyteen olivat moninaisia:

- projekti löytyi vasta toiseen vaiheeseen
- suuryrityksiltä vaadittu tutkimuksellisuus, jolloin käytännön sovellutukset tulevat myöhemmin
- testien keskeneräisyys tai estyminen ohjelmasta riippumattomista syistä, kuten muutokset organisaatiossa tai tuotantoprosessissa, kausittainen käyttö esimerkiksi budjetoinnin yhteydessä tai peräkkäisten kausien vertailuvaatimus)
- tutkijoilta kesken oleva ohjelmien viimeistely
- pilottisovelluksen soveltumattomuus sellaisenaan kaupalliseen käyttöön.



Kaavio 1. Vastauksien jakauma.

Merkillepantavaa on se, että vaikka muutama haastateltava on esittänyt melko voimakastakin kritiikkiä itse tutkimustyön tuloksista ja tekotavasta, aiotaan yhteistyötä kuitenkin jatkaa.

Taloudellista hyötyä uusien tuotteiden tai uusien tuotepiirteiden muodossa taikka toisaalta parannusta prosessiin arvioi haastatelluista 85 %, mikä on hämmästyttävän korkea luku huomioiden tutkimusohjelman luonne.

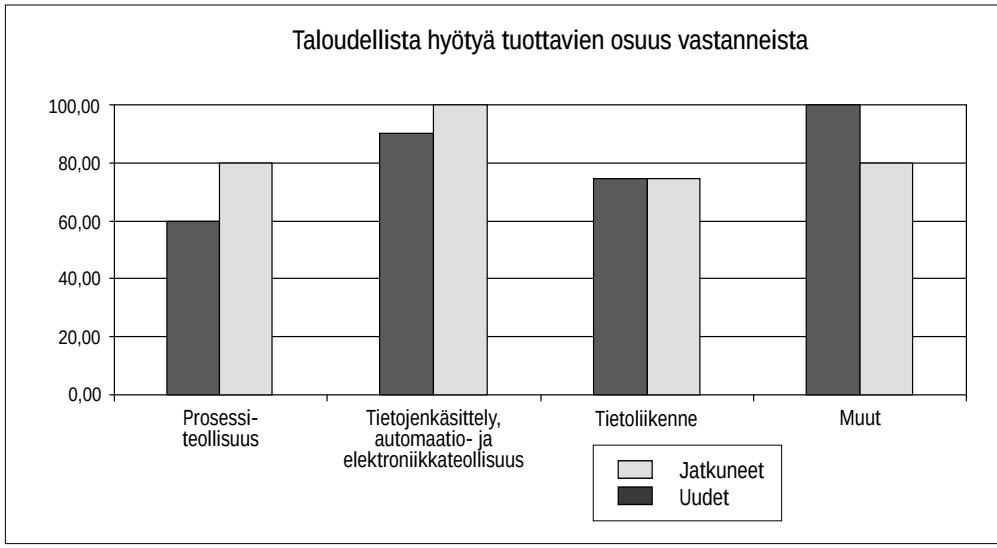
Systemaattista eroa ensimmäisestä vaiheesta jatkuneiden ja uusien hankkeiden välillä ei ole (kaavio 2), mikä näyttäisi olevan ristiriidassa sen väittämän kanssa, että vasta toiseen vaiheeseen löydettiin oikeat projektit. Tämä selittyy osittain projektien keskeneräisyydellä ja osittain sillä, että myös jatkuneissa hankkeissa itse projekti lopullisessa muodossa on alkanut vasta toisessa vaiheessa taikka sen ohjelmaa on tarkennettu.

Haastattelujen suorittamista ovat vaikeuttaneet yritysten myynnit ja muut uudelleen organisoinnit, joiden seurauksena alkuperäisiä projektihenkilöitä ei ole onnistuttu enää tavoittamaan. on myös jäänyt kesken hankkeita arviolta kahdesta viiteen.

2.1.2 Prosessiteollisuus

Taloudellista hyötyä tuottavien hankkeiden suhteellinen lukumäärä on prosessiteollisuudessa pienin, 75 %. Tätä voidaan selittää sillä, että prosessit ovat suhteellisen hyvin tunnettuja ja valvomo- ja säätöratkaisut kehitetty perinteisillä menetelmillä toimiviksi. Kun ohjelman hankkeissa on näiden rinnalle yritetty neurolaskennan ja sumean säädön keinoin saada parempia ratkaisuja, on muutamissa tapauksissa tuloksena ollut jo ennestään tiedossa olleita ”totuuksia”. Erityisenä ongelmana on esiin noussut perinteisellä tavalla kerättyjen mittaustietojen ja muun datan käyttökelpoisuus ja siirto älykkäiden ja oppivien järjestelmien soveltajille. Ohjelman aikana on asia tiedostettu ja siitä on tehty erillinen raportti.

Vaikeuksista huolimatta myös tässä ryhmässä oltiin osallistumiseen yleensä tyytyväisiä. Hyöty on saatu siitä, että yrityksen teknisellä henkilöstöllä on ollut tilaisuus perehtyä neurolaskennan ja sumean säädön metodiikkaan. Useissa yrityksissä on hankkeen puitteissa järjestetty koulutustilaisuuksia suhteellisen suurillekin ryhmille (10–30 henkilöä). Tässä yhteydessä on valmistusprosessia tutkittu uudella tavalla tai tuotteisiin on etsitty uusia piirteitä.



Kaavio 2. Taloudellista hyötyä tuottavien osuus vastauksista.

2.1.3 Tietojenkäsittely, automaatio- ja elektroniikkateollisuus

Tutkimusohjelman luonteen mukaisesti tämän ryhmän osuus on suurin, mutta ei dominoiva. Taloudellista hyötyä tuottavien suhteellinen osuus on tässä ryhmässä korkein, peräti 90–100 %. Muista ryhmistä poiketen rahallinen tulos myös uusien projektien osalta on hyvä, jopa kaksinkertainen jatkuneihin projekteihin verrattuna.

Ryhmä sisältää useita pieniä ohjelmistotaloja, jotka pyrkivät kehittämillään ohjelmistopaketeilla kansainvälisille markkinoille. Osa on päässyt tai pääsemässä yhteistyöhön kansainvälisten suuryritysten kanssa, osa pitää kilpailusyistä hyvin matalaa profiilia.

2.1.4 Tietoliikenneteollisuus

Tietoliikenneteollisuuden osallistuminen teknologiaohjelmaan on ollut merkittävän runsasta. Hankkeet on koettu poikkeuksetta onnistuneiksi ja ovat johtaneet teknologian käyttöönottoon tai jatkokehitykseen. Uutta teknologiaa on hankkeissa sovellettu liiketoiminnan eri alueille hämmästyttävän laajasti, mikä on oiva osoitus hermoverkkolaskennan sovellutusten laaja-alaisuudesta.

2.1.5 Muut

Muut-ryhmään sisältyy useita toimialoja, joiden suuri määrä osoittaa tutkimusohjelman laaja-alaisuutta sovellutusten suhteen. Oppivien ja älykkäiden järjestelmien soveltuvuutta on tutkittu mm. koneenrakennuksen, lääketieteen, ympäristöteknologian ja kaupan piirissä. Taloudellista tulosta tuottavien lukumäärä ei tässä ryhmässä oleellisesti poikkea keskiarvosta, mikä on hyvä osoitus neurolaskennan ja sumean säädön soveltuvuudesta eri toimialoille. Voidaankin väittää tämän tutkimusohjelman tulosten perusteella, että kilpailukyvyn säilyttäminen tulevaisuudessa edellyttää näiden menetelmien soveltamista ainakin sellaisilla toimialoilla, joilla joudutaan käsittelemään suuria tietomääriä.

2.1.6 Korkeakoulut ja tutkimuslaitokset

Teknologiaohjelman merkitys korkeakouluille ja tutkimuslaitoksille on ollut suoritettujen haastattelujen perusteella hyvin hyödyllinen. Se on antanut uskottavuutta tutkijoille, jotka ovat suunnitelleet aiheeseen liittyvää tutkimusta ja ohjelman kannustamana on perustettu ainakin pari uutta tutkimusryhmää, toinen Helsingin yliopistoon ja toinen VTT:lle.

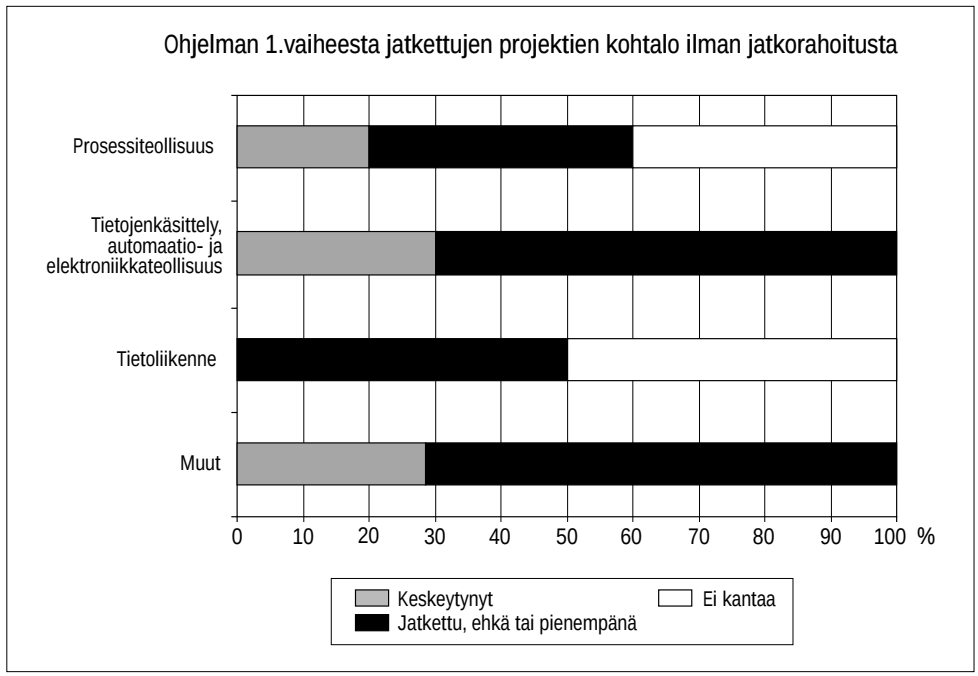
Ohjelman seurauksena tulee talouselämälle hyötyä haastateltujen arvion perusteella monella tavalla:

- opetuksen tason nousu opetusohjelmien sisällön tarkistuksen seurauksena
- vanhempien tutkijoiden motivaation parantuminen teollisuuden tarjoamien reaalisovellutusten ansiosta
- harjoitustöiden tason nousu samasta syystä
- tutkijoiden välisen tietojen vaihdon huomattava lisääntyminen
- tutkimuskohteen tarkentamisen tärkeys
- tutkimustyön moni-ilmeisyyden ymmärtämisen kasvaminen
- talouselämästä saatavan datan oikeellisuuden arvon ymmärtäminen
- tutkijoiden asiantuntemuksen lisääntyminen.

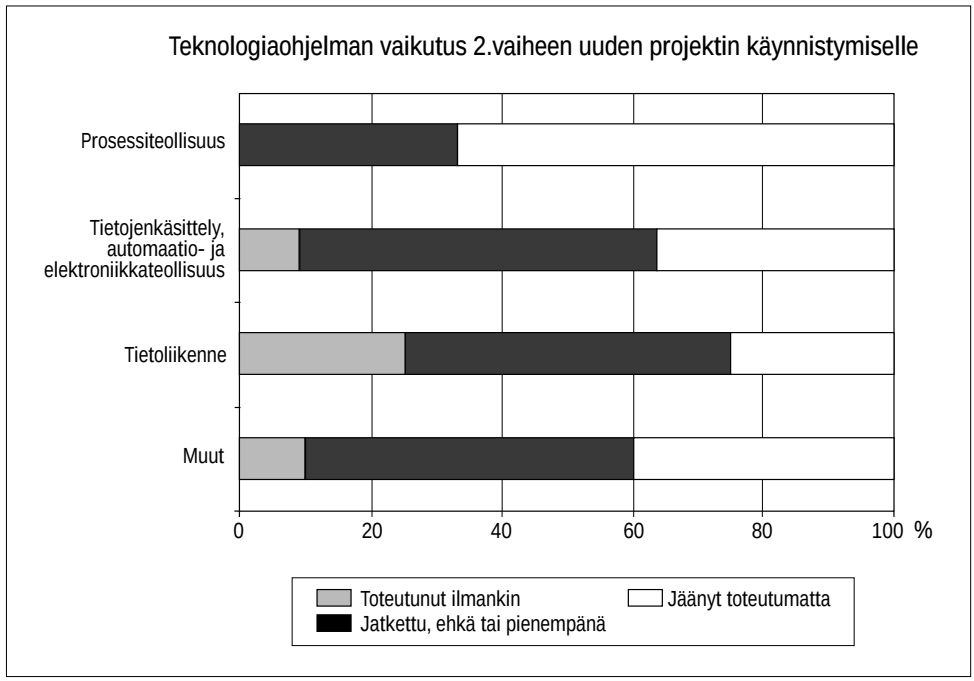
Teknologiaohjelman vaikutuksena arvioidaan 100–200 opiskelijan suunnanneen opiskeluaan normaalin ohjelmoinnin sijasta jollekin teknologiaohjelman kattavasti sisältämien Soft Computing (SC) nimellä tunnettujen menetelmien osa-alueista.

2.2 Tutkimusohjelman toisen vaiheen merkitys

Teknologiaohjelman toisen vaiheen merkitystä kartoitettiin kysymällä alkuvaiheessa aloitettujen projektien kohtaloa ilman ohjelman tarjoamaa jatkorahoitusta. Prosessiteollisuuden ja tietoliikenteen ryhmissä noin puolet jätti vastaamatta tähän kohtaan. Vastanneista 20–30 % arvioi projektiensa jääneen kesken ilman 2. vaihetta lukuun ottamatta tietoliikennettä, jossa kaikkien vastanneiden projektit olisivat jatkuneet ainakin jossain muo-



Kaavio 3. Ohjelman ensimmäisestä vaiheesta jatkettujen projektien kohtalo ilman jatkorahoitusta.



Kaavio 4. Teknologiaohjelman vaikutus toisen vaiheen uuden projektin käynnistymiselle

dossa, kaavio 3. Lopuissa jatko olisi ollut epävarmaa tai hankkeen tavoitteita olisi madallettu.

Kysyttäessä toisen vaiheen projektien käynnistymistä ilman ohjelman tarjoamia puitteita, vain kol-

men arvioitiin toteutuvan joka tapauksessa. Ehkä tai pienemmin tavoittein toteutuvia arvioitiin 40–60 %:ssa vastauksista, kaavio 4. Prosessiteollisuuden ryhmässä arvioitiin peräti 60 % vastauksista projektin jääneen kokonaan toteutumatta, muissa 25–40 %.

Vaikka näiden vastausten tulkintaan sisältyy eniten epävarmuutta eikä niistä selviä yhteys rahalliseen tai muuhun hyötyyn, on niiden perusteella todettavissa teknologiaohjelman toisen vaiheen tärkeys koko ohjelman onnistumisen kannalta.

2.3 Taloudelliset hyödyt

Taloudelliset hyödyt vuosille 2001–2005 on saatu lisäämällä ilmoitettuihin kustannussäästöihin sellaisten yhtiöiden liikevoittoarviona 10 %, jotka ovat ilmoittaneet liikevaihdon kasvavan tulosten seurauksena. Liikevaihdon mahdollisen lisäyksen osalta useat eivät vielä ole valmiita esittämään mitään lukua ja vaikeinta on ollut arvioida liikevaihdon kasvua tulevina vuosina. Vuonna 2001 on arvioitu liikevaihdon kuitenkin kasvavan yhteensä 65 mmk:lla.

Teknologiaohjelman taloudelliset hyödyt jatkovaiheen osalta painottuvatkin selvästi kustannussäästöjen puolelle ja tietoliikenteeseen, jossa on jo nähtävissä varsin merkittäviä rahallisia tuloksia, kaavio 5.

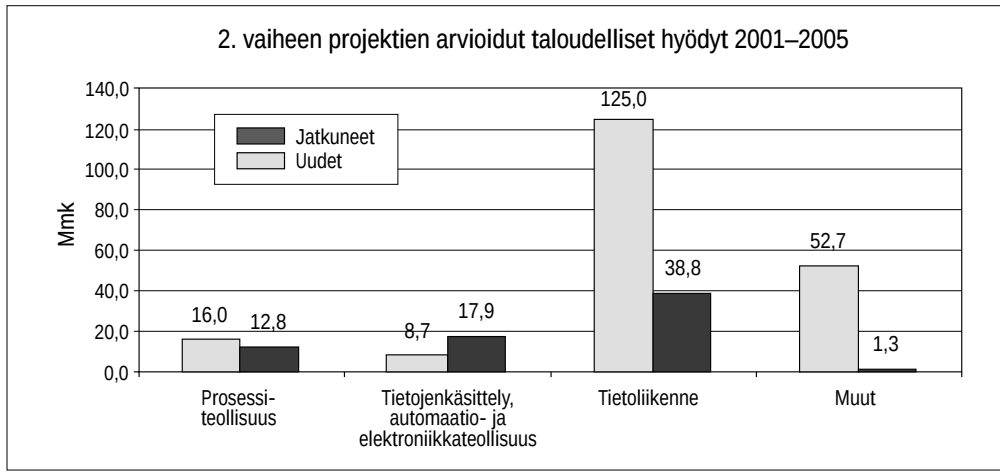
Koko teknologiaohjelman taloudelliseksi hyödyksi vastanneiden osalta saadaan 370 mmk laskemalla yhteen jatko-ohjelman vuosille 2001–2005 arvioidut 270 mmk ja väliarvioinnissa 1. vaiheen vuosille 1996–2000 saadut n. 50 mmk ja olettamalla viimemainittujen jatkuvan samansuuruisina vuosille 2001–2005.

Useissa hankkeissa on arvioitu kehitetyn menetelmän tai lisäpiirteen niiden tuleville ostajille tuottamia hyötyjä, joiden yhteisarvo näyttäisi liikkuvan myös sadoissa miljoonissa markoissa. Nämä seuraavan kertaluokan hyödyt tukevat usein myös ympäristöystävällistä kehitystä, kuten

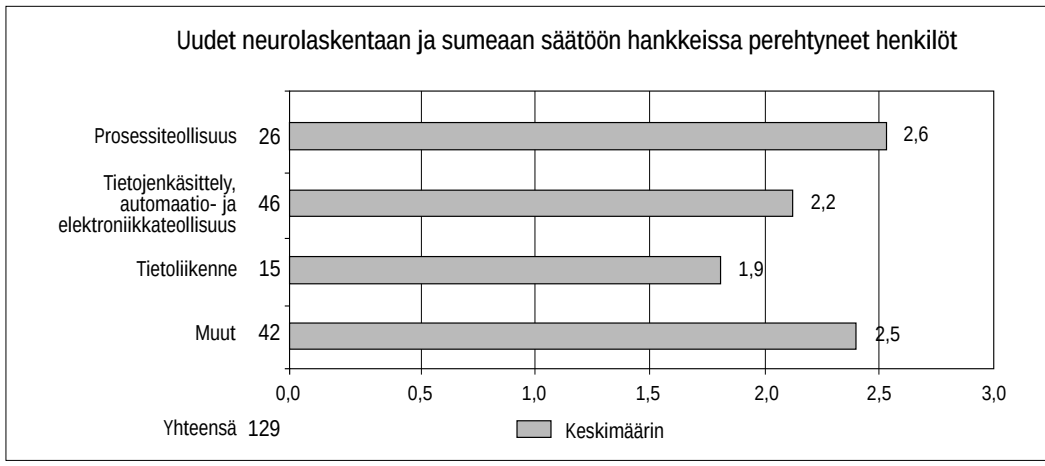
- raaka-aineiden tehokkaampi hyödyntäminen
- energian käytön väheneminen
- jätteiden väheneminen.

2.4 Soft Computing -menetelmiin tutustuneet henkilöt

Hankkeissa on ollut yritysten osalta keskimäärin 2,3 sellaista henkilöä, jotka ovat tutustuneet käytettyihin menetelmiin syvällisemmin teknologiaohjelman 2. vaiheessa, kaavio 6. Yhteensä yrityksissä on tällaisia henkilöitä 129. Lisäksi muutamissa suuryrityksissä on hankkeen yhteydessä järjestetyssä koulutustilaisuudessa aiheeseen tutustunut yhteensä 63 henkilöä. Kun lasketaan yhteen 1. vaiheen 50 henkilöä ja opiskelijoiden lisäyksen ar-



Kaavio 5. 2. Vaiheen projektien arvioidut taloudelliset hyödyt 2001-2005.



Kaavio 6. Uudet neurolaskentaan ja sumeaan säätöön hankkeissa perehtyneet henkilöt.

viona 150, saadaan SC-menetelmiin ohjelman vaikutuksesta perehtyneiden yhteismääräksi 290. Kun vielä korkeakouluissa ja tutkimuslaitoksissa on osa projekteihin osallistuneista uusia soveltajia, voidaan hyvällä syyllä sanoa henkilöiden lukumäärän ylittävän 300.

2.5 Yhteistyökontaktit eri osapuolten kesken

Uusien yhteistyökontaktien syntymistä kysyttiin erikseen

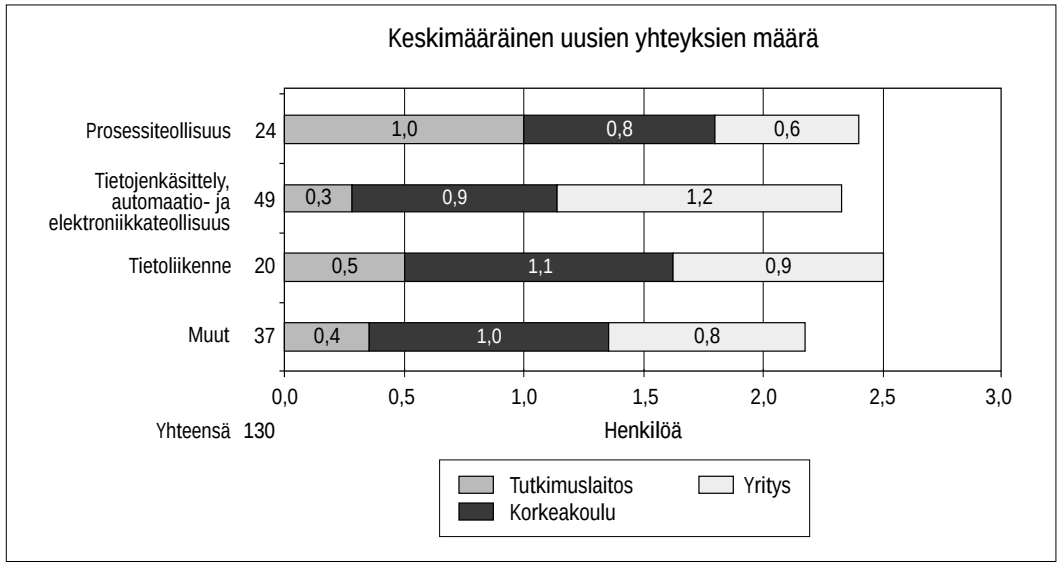
- tutkimuslaitoksiin (26)
- korkeakouluihin ja (52)
- toisiin yrityksiin (50)

Teknologiaohjelman toisessa vaiheessa syntyneiden yhteistyökontaktien määrä oli keskimäärin 2,3uutta kontaktia, yhteismäärältään 130 (kaavio 7). Luku ei anna oikeata kuvaa yhteistyön kokonaismäärästä, koska osalla hankkeeseen osallistuneista oli yhteistyö alkanut jo aiemmin. Annettujen vastausten ja haastattelujen perusteella voidaan arvioida hankkeiden kokonaismäärästä noin puolen perustuvan aikaisempaan yhteistyöhön, jolloin yhteistyökontaktien kokonaismääräksi saadaan noin 160.

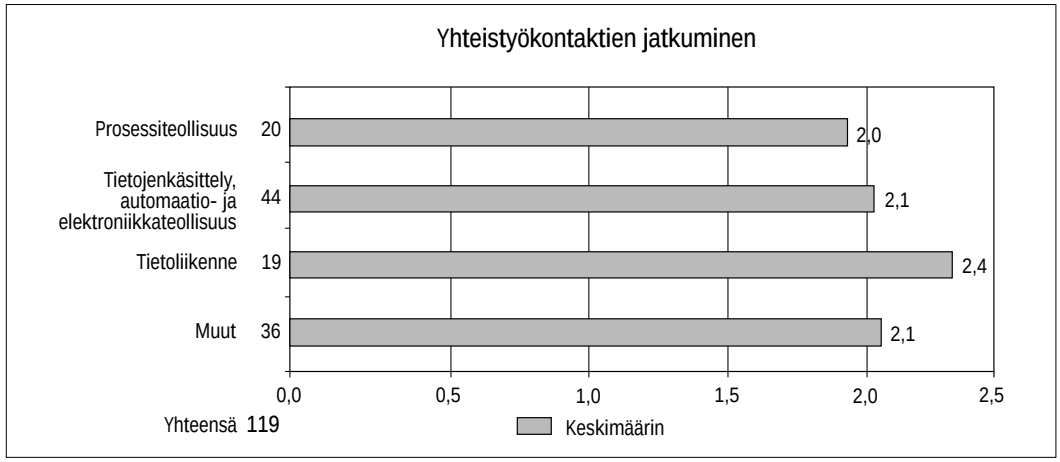
Kontaktien määrä korkeakouluihin ja toisiin yrityksiin oli kaikissa yritysryhmissä keskimäärin samaa 2,3 suuruusluokkaa, mutta tutkimuslaitoskontaktien (VTT) suhteellinen määrä oli prosessiteollisuudessa selvästi suurin ja ylitti korkeakoulujen ja toisten yritysten osuuden, kun se muissa ryhmissä jäi alle puoleen näistä.

Yhteistyön arvioidaan jatkuvan 119 osapuolen kanssa (kaavio 8), mikä vastaa niinkin korkeaa osuutta kuin 75 %. Luku saattaa sisältää kuitenkin laajemman aihepiirin kuin SC-menetelmät.

Kun toisaalta yhteistyön voidaan olettaa edelleen jatkuvan jo aikaisemmin alkaneen (30) kanssa, on teknologiaohjelman vaikutuksena syntyneiden uusien ja edelleen jatkuvien yhteistyökontaktien määrä SC-menetelmien osalta noin 90, mikä edustaa 55 % onnistumisastetta. Kun yhteistyön aihe jatkossakin on mitä ilmeisimmin sama, on syytä uskoa teknologiaohjelman kantavan hedelmää vielä pitkään.



Kaavio 7. Keskimääräinen uusien yhteyksien määrä.



Kaavio 8. Yhteistyön jatkuminen.

3 Yhteenveto

Ohjelmaa pidettiin erittäin tarpeellisena ja ajankohdaltaan oikein osuneena. Muutamaa poikkeusta lukuun ottamatta arvioitiin, että tutkimushanke olisi ilman ohjelman kaltaista yhteistyömuotoa joko jäänyt toteutumatta, toteutunut vaatimattomimmin tavoittein tai siirtynyt myöhempään ajankohtaan.

Ohjelmasta on tehty väliarviointi 1996 koskien aikajaksoa 1994–1997. Vertailtaessa haastateltavien mielipiteitä ja kokemuksia ohjelman merkityksestä nyt ja lähes neljä vuotta sitten, voidaan todeta väliarvioinnissa esitetyt keskeiset arviot edelleen voimassa oleviksi. Tässä arvioinnissa on keskitytty varsinaisesti ohjelman jatko-osan tulosten ja vaikutusten selvittämiseen.

Ohjelman jakaminen kahteen toisistaan erotettuun jaksoon on todettu erittäin onnistuneeksi. Ohjelmassa käytettyjen menetelmien uutuudesta johtuen alkujakson todettiin menneen aiheeseen tutustumiseen ja jopa väärien asioiden tekemiseen. Monessa tapauksessa vasta ohjelman toiseen vaiheeseen on löydetty joko sopivat ongelmat ratkaistaviksi ja/tai oikeat pilottikohteet.

Taloudelliset tulokset tämänhetkisten arvioiden mukaan osoittavat, että ohjelmaan sijoitetut varat tulevat seuraavan viiden vuoden aikana takaisin yrityksien parantuneena tuloksena, vaikka varsinkin suuremmilla yrityksillä tulosten kaupallistaminen on selvästi kesken. Tämä johtuu osittain siitä, että halutaan riittävästi käyttökokemuksia ennen lopullisen kaupallisen version tekemistä, mutta myös siitä, että näiltä yrityksiltä vaadittiin ehtona osallistumiselle riittävää tutkimuksellisuutta, jolloin varsinainen tuotekehitys joudutaan tekemään ohjelman jälkeen.

Ohjelmistojen kaupallisen viimeistelyn vaikeutta osoittaa se, että sellaisten projektien, joihin pilottikohteiden lisäksi oli löydetty kaupallinen hyödyntäjäehdokas, suhteellisen suuresta määrästä huolimatta tulokset ja myös niiden odotukset ovat varsin laihoja ainakin toistaiseksi. Osaan onnistuneen pilottivaiheen ohittaneista projekteista kaupallistajaa etsitään edelleen, koska asian uutuudesta johtuen kaikkiin ei Suomesta löydy sopivaa. Ohjelman koko kestoaikana onkin jo perustettu yli kymmenen uutta yritystä hyödyntämään saatuja tuloksia kaupallisesti.

Ohjelmalla koettiin olevan suurta merkitystä myös tutkimuslaitosten ja korkeakoulujen piirissä. Saadun rahoituksen lisäksi ohjelman kannustamana on perustettu uusia tutkimusryhmiä ja korkeakoulujen opetuksen tason todetaan nousseen teollisuudesta saatujen hyvien pilottikohteiden seurauksena, jolloin teoriaa on päästy soveltamaan oikeiden ongelmien ratkaisuun.

Väliarvioinnissa esitetty tavoite kriittisen massan syntymisestä neurolaskentaan ja sumeaan säätöön perehtyneiden henkilöiden määrästä näyttää toteutuneen suurelta osin teknologiaohjelman vaikutuksesta.

References

[1] L. A. Zadeh, "Fuzzy Logic and Soft Computing: Issues, Contentions and Perspectives" *Proceedings. of IIZUKA'94: Third Int. Conf. on Fuzzy Logic, Neural Nets and Soft Computing*, pp. 1-2, Iizuka, Japan, 1994.

[2] L. A. Zadeh, "Some reflection on soft computing, granular computing and their roles in the conception, design and utilization of information/intelligent systems", *Soft Computing A Fusion of Foundations, Methodologies and Applications*, vol. 2, no. 1, pp. 23-25, 1998.

[3] P. Bonissone, "Soft Computing: the Convergence of Emerging Reasoning Technologies, *Soft Computing A Fusion of Foundations, Methodologies and Applications*, vol. 1, no. 1, pp. 6-18, 1997.

[4] P. Bonissone, Y-T Chen, K. Goebel, and P. Khedkar, "Hybrid Soft Computing Systems: Industrial and Commercial Applications" by, *Proceedings of the IEEE*, 87(9): 1641-1667, 1999.

[5] L. A. Zadeh, "Fuzzy sets" *Information and Control*, vol. 8, pp.338-353, 1965.

[6] J. Lukasiewicz, *Elementy Logiki Matematycznej [Elements of Mathematical Logic]*, Warsaw, Poland: Panstowowe Wydawinctow Naukowe, 1929.

[7] L.A. Zadeh, "Foreword," in *Handbook of Fuzzy Computation*, E.H. Ruspini, P.P. Bonissone, and W. Pedycz, Eds., Bristol, UK: Institute of Physics, 1998.

[8] E.H. Ruspini, P.P. Bonissone, and W. Pedycz, *Handbook of Fuzzy Computation*, Bristol, UK: Institute of Physics, 1998.

[9] T. Bayes, "An essay towards solving a problem in the doctrine of chances," *Philosophical Trans. of the Royal Society of London*, vol. 53, pp. 370-418, 1763. Facsimile reproduction with commentary by E.C. Molina in "Facsimiles of Two Papers by Bayes" E. Deming, Washington, D.C., 1940, New York, 1963. Also reprinted with commentary by G.A. Barnard in *Biometrika*, vol. 25, pp. 293—215, 1970.

[10] E. Shortliffe and B. Buchanan, "A Model of Inexact Reasoning in Medicine," *Mathematical Biosciences*, vol. 23, pp. 351-379, 1975.

[11] R. Duda, P. Hart, and N. Nilsson, "Subjective Bayesian Methods for Rule-Based Inference Systems," in *Proc. AFIPS* vol.45, pp. 1075-1082, New York, NY: AFIPS Press, 1976.

[12] J. Pearl, "Reverend Bayes on Inference Engines: a Distributed Hierarchical Approach," in *Proc. 2nd Natl. Conf. on Artificial Intelligence*, pp. 133-136, Menlo Park, CA: AAAI, 1982.

[13] J. Pearl, *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference*, San Mateo, CA: Morgan-Kaufmann, 1988.

[14] J. Kim and J. Pearl, "A Computational Model for Causal and Diagnostic Reasoning in Inference Engines", in *Proc. Eighth Int. Joint Conf. on Artificial Intelligence*, pp. 190-193, Karlsruhe, Germany, 1983.

[15] A. P. Dempster, "Upper and lower probabilities induced by a multivalued mapping," *Annals of Mathematical Statistics*, vol. 38, pp. 325-339, 1967.

[16] G. Shafer, *A Mathematical Theory of Evidence*. Princeton, NJ: Princeton University Press, 1976.

[17] W.S. McCulloch and W. Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity," *Bull Math Biophysics*, vol. 5, pp. 115-133, 1943.

[18] F. Rosenblatt, "The perceptron, a Perceiving and Recognizing Automaton," Project PARA, Cornell Aeronautical Lab. Rep., no. 85-640-1, Buffalo, NY, 1957.

[19] F. Rosenblatt, "Two theorems of statistical separability in the perceptron," in *Proc. Mechanization of Thought Processes*, pp. 421-456, Symposium held at the National Physical Laboratory, HM Stationary Office, London, 1959.

[20] F. Rosenblatt, *Principle of Neurodynamics: Perceptron and the theory of Brain Mechanisms*, Washington, DC: Spartan Books, 1962.

[21] M. Minsky and S. Papert, *Perceptrons*, Boston, MA: MIT Press, 1969.

[22] P. Werbos, *Beyond Regression: New Tools for Predictions and Analysis in the Behavioral Science*. Ph.D. thesis, Harvard University, Cambridge, MA, 1974.

[23] D. Parker, "Learning Logic," Tech. Report TR-47, Center for Computational Research in Economics and Management Science, MIT, Cambridge, MA, 1985.

[24] Y. LeCun, “Une procedure d’apprentissage pour reseau a seuil symetrique,” *Cognitiva*, 85, pp. 599-604, CESTA, Paris, France, 1985.

[25] K. Hornick, M. Stinchcombe, and H. White, “Multilayer feedforward networks are universal approximators,” *Neural Networks*, vol. 2, pp. 359-366, 1989.

[26] J. Moody and C. Darken, “Fast learning in networks of locally tuned processing units,” *Neural Computation*, vol. 1, pp. 281-294, 1989.

[27] T. Kohonen, “Self-Organized Formation of Topologically Correct Feature Maps,” *Biological Cybernetics*, vol. 43, pp. 59-69, 1982.

[28] J. Hopfield, “Neural Networks and Physical Systems with Emergent Collective Computational Abilities,” *Proc. Acad. Sci.*, vol. 79, pp. 2554-2558, 1982.

[29] A. Carpenter and S. Grossberg, “A Massively parallel architecture for a self-organizing neural pattern recognition machine,” *Computer, Vision, Graphics, and Image Processing*, vol. 37, pp. 54-115, 1983.

[30] E. Fiesler, and R. Beale, *Handbook of Neural Computation*, Bristol, UK: Institute of Physics, and New York, NY: Oxford University Press, 1997.

[31] I. Rechenberg, “Cybernetic Solution Path of an Experimental Problem,” *Royal Aircraft Establishment*, Library Translation no. 1122, 1965.

[32] H-P. Schwefel, Kybernetische Evolution als Strategie der Experimentellen Forschung in der Stromungstechnik, Diploma Thesis Technical University of Berlin, Germany, 1965.

[33] L.J. Fogel, “Autonomous Automata,” *Industrial Research*, vol. 4, pp. 14-19, 1962.

[34] L.J. Fogel, A.J. Owens, and M.J. Walsh, *Artificial Intelligence through Simulated Evolution*, New York, NY: John Wiley, 1966.

[35] A.S. Fraser, “Simulation of Genetic Systems by Automatic Digital Computers. I. Introduction,” *Australian J. of Biological Sci.*, Vol 10, pp. 484-491, 1957.

[36] H. Bremermann, “The Evolution of Intelligence. The Nervous System as a Model of its Environment,” Technical Report no. 1 Contract no. 477(17), Dept. of Mathematics, University of Washington, Seattle, 1958.

[37] J. Reed, R. Tooms, and N. Baricelli, “Simulation of Biological Evolution and Machine Learning,” *J. Theo. Biol.*, vol. 17, pp. 319-342, 1967.

[38] J.H. Holland, “Outline of a Logical Theory of Adaptive Systems,” *J. ACM*, vol. 9, pp. 297-314, 1962.

[39] J.H. Holland, “Nonlinear Environments Permitting Efficient Adaptation,” *Computer and Information Science IIs*, New York, NY: Academic Press, 1967.

[40] J.H. Holland, *Adaptation in Natural and Artificial Systems*, Cambridge, MA: MIT Press, 1975.

[41] J. Koza, *Genetic Programming: On the Programming of Computers by Means of Natural Selection*, Cambridge, MA: MIT Press, 1992.

[42] D.B. Fogel, *Evolutionary Computation*. New York, NY: IEEE Press, 1995.

[43] T. Back, D.B. Fogel, and Z. Michalewicz, *Handbook of Evolutionary Computation*, Bristol, UK: Institute of Physics, and New York, NY: Oxford University Press, 1997.

[44] J. Iivarinen, K. Heikkinen, J. Rauhamaa, P. Vuorimaa, and A. Visa, “A Defect Detection Schema for Web Surface Inspection”, to appear in *International Journal of Pattern Recognition and Artificial Intelligence*, 2000.

[45] J. Laaksonen, V. Vuori, M. Aksela, E. Oja, and J. Kangas, “Experiments with Adaptation Method in On-Line Recognition of Isolated Latin Characters”, to appear in a book edited by N. Murshed, 2000.

[46] J. C. Badger, “An automatic web inspection system with advanced defect detection and classification capabilities”, in *Proc. of 1992 Nonwovens Conference*, pp. 69-80, Marco Island, Florida, May 10-14 1992,

[47] X. Li and D.-Y. Yeung, “On-Line Handwritten Alphanumeric Character Recognition Using Dominant Points in Strokes”, *Pattern Recognition*, 30(1):31-44, 1997.

[48] O. Simula, J. Ahola, E. Alhoniemi, J. Himberg, and J. Vesanto, “Self-Organizing Maps in Analysis of Large-Scale Industrial Systems”, *Kohonen Maps* (E. Oja, and S. Kaski eds.), Elsevier, 1999.

[49] T. Kohonen, E. Oja, O. Simula, A. Visa, J. Kangas, “Engineering applications of the self-organizing map”, Proceedings of the IEEE 84 (10), 1996.

[50] T. Tanaka, H. Endo, N. Kamada, S. Naito, H. Kominami, “Trouble forecasting system by multi-neural network on continuous casting process of steel production”, in *Proceedings of International Conference on Artificial Neural Networks (ICANN’91)*, pp. 835-840, 1991

[51] A.G. Gorelik and V.VC. Sterlyadkin, “Doppler Tomography in Radar Meteorology, Izvestiya” *Atmospheric and Oceanic Physics*, Vol. 26(1) 1990.

[52] V. V. Sterlyadkin, “Doppler correlation reconstruction of velocity field”, *Atmospheric and Oceanic Physics*, Vol. 30(5), April 1995.

[53] M. Bierlaire, L. Tsippy, “On the overspecification of multinomial and nested logit models due to alternative specific constants”, *Transportation Science*, 31(4)

[54] J.A. Shufelt, Performance evaluation and analysis of monocular building extraction from aerial imagery, *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 21:311-326, 1999.

[55] I. Kallioniemi, J. Saarinen, E. Oja, “Optical Scatterometry of subwavelength diffraction gratings: neural network approach”, *Applied Optics*, 37, 1998.

[56] I. Kallioniemi, J. Saarinen, E. Oja, “Characterization of diffraction grating in a rigorous domain with optical scatterometry : hierarchical neural network model”, *Applied Optics*, 38, 1999.

[57] J. R. McNeil et al., “Scatterometry applied to microelectronics processing. 1, Scatterometry applied to microelectronics processing. 2", *Solid State Technology*, 36, pages 29-32 and 53-56, 1993.

[58] C. J. Raymond et al, “Multi-parameter CD measurements using scatterometry”, *Proceedins of SPIE*, Vol. 2725, pages 698-709, 1996.

[59] A. Kantsila, M. Lehtokangas, and J. Saarinen, “Burst Adaptive Equalization of Binary Data”, *Journal of Intelligent Systems*, 9(2), 1999.

[60] P. Salmela, M. Lehtokangas, and J. Saarinen, “Neural Network based Digit Recognition System in Voice Dialing in Noisy Environments”, *Int. Journal of Information Science*, to appear, 2000.

[61] N. Morgan and H. Bourlard, “Neural Networks for Statistical Recognition of Continuous Speech,” *Proceedings of the IEEE*, 83(5): 741-770, May 1995.

[62] W.B. Kleijn, “Waveform interpolation for speech coding and synthesis,” *in Speech Coding and Synthesis* (W.B. Kleijn and K.K. Paliwal, eds.), pp.175-208, Elsevier Science B.V., 1995.

[63] G. J. Gibson, S. Siu and C. F. N. Cowan, “The application of nonlinear structures to the reconstruction of binary signals”, *IEEE Transactions on Signal Processing*, 39(8): 225-232, 1991.

[64] A H. Baydush, J E. Bowsher, J K. Laading, C E. Floyd Jr., “Improved Bayesian Image Estimation for Digital Chest Radiography”, *Medical Physics* 24: 539-545, April 1997.

[65] Hemminger T.L. and Pao Y-H., “Detection and Classification of Underwater Acoustic Transients Using Neural Networks,” *IEEE Transactions on Neural Networks*, 5(5):712-718, September 1994.

[66] P. Kumpulainen, H. Ihalainen, and R. Ritala, “Multivariate Disturbance Analysis”, *XV IMEKO World Congress*, Osaka, June 1999.

[67] Esa Alhoniemi, Jaakko Hollmén, Olli Simula and Juha Vesanto, “Process Monitoring and Modeling using the Self-Organizing Map”, *Integrated Computer Aided Engineering*, 6(1):1-14, 1999, http://www.cis.hut.fi/projects/ide/publications/papers/jicae.zip

[68] A. Visa, J. Toibvanen, B. Back, and H. Vanharanta, “Towards text Understanding - Comparison of Text Documents by Sentence Map”, *Proc. EUFIT-99*, Aachen, Germany, September 1999.

[69] D. Mladenic, J.S. Institute, “Text-Learning and Related Intelligent Agents: A Survey”, IEEE Intelligent Systems& Their Applications, 14(4): 44-54, July/August 1999.

[70] P. Koikkalainen, “Tree structured Self Organizing Maps”, *Kohonen Maps*, 121-130, E. Oja, and S. Kaski (eds.) Elsevier, 1999.

[71] T. Kohonen; *Self-Organizing Maps*, (Chapters 5 and 7) 2nd Ed., Springer, 1997.

[72] M.W. Berry and M. Browne, *Understanding Search Engines: Mathematical Modeling and Text Retrieval*, (Chapters 1 and 9) SIAM Book Series: Software, Environments, and Tools, 1999.

[73] K. Vainamo, T. Makikallio, M. Tulppo, J. Roning, “A Neuro-Fuzzy Approach to Aerobic Fitness Classification: a multistructure solution to the context-sensitive feature selection problem”, IEEE WCCI, 797-802, Anchorage, Alaska, 1998.

[74] Turjanmaa, V., Tuomisto, M., Fredrikson, M., Kalli, S. and Uusitalo A., “Blood pressure and heart rate variability and reactivity as related to daily activities in normotensive men measured with 24-h intra-aerial recording”, *Journal of Hypertension*, 9(7):665-673, 1991.

[75] S. Gregory Furno and Willis J. Tompkins, “A Learning Filter for Removing Noise Interference”, *IEEE Transactions on Biomedical Engineering*, BME-39(4):234-235, 1983.

[76] P. Heinone, T. Saramaki, J.Malmivuo, Y. Neuvo, “Periodic Interference Rejection Using Coherent Sampling and Waveform Estimation”,. *IEEE*

Transactions on Circuits and Systems,. CAS-31 (5): 438-446, 1984.

[77] A. Visala, "Identification of Wiener-MLP with Feedback NOE-Model with Extended Kalman Filter". *World Congress on Computational, Intelligence (IJCNN 98), Anchorage AK, May 98.*

[78] A. Visala A., H. Pitkänen, and A. Halme, "Wiener-type SOM- and MLP-classifiers for recognition of the dynamic modes". In *Artificial Neural Networks ICANN'97, 7th International Conference*, Lausanne, Switzerland, Oct. 1997.

[79] M.N.Karim, and S.L. Rivera, "Artificial Neural Networks in Bioprocess State Estimation", *Biochemical Engineering and Biotechnology* 46, pages 1-33, 1992

[80] H. Al-Duwaish, and M.N. Karim, "A New Method for the Indentification of Hammerstein Model", *Automatica*, 33(10):1871-1875, 1997.

[81] Y. Duan, and H. Jin, "Digital Controller Design for Switchmode Power Converters", *Proc. of APEC'99*, pp. 967-973.

[82] C.C. Hang, K. J. Åström, and W. K. Ho, "Refinements of the Ziegler-Nichols tuning formula", *IEE Proceedings-D*, Vol. 138, No. 2, March 1991, pp. 111-118.

[83] P. Mattavelli, L. Rossetto, G. Spiazzi, and P. Tenti, "General-Purpose Fuzzy Controller for DC-DC Converters", *IEEE Trans. Power Electronics*, Vol. 12, No 1, pp. 79-86, January 1997.

[84] R.D. Middlebrook, "Small-Signal Modeling of Pulse-Width Modulated Switched-Mode Power Converters", *Proc. of the IEEE*, Vol. 76, No 4, pp. 343-354, April 1988.

[85] F.H. Wang, and C. Q. Lee, "Comparison of Fuzzy Logic and Current- Mode Control Techniques in Buck, Boost, and Buck/Boost Converters",*IEEE Power Electronics Specialists Conference*, Vol. 2, pp. 1079-1085, 1995.

[86] Gadoura, I. "Design of Intelligent Controllers, for Switching-Mode Power Supplies", Licenciate Thesis Helsinki University of Technology, Control Engineering Lab., October 1999.

[87] Papadopoulos, Frenette, Mu, and Gonthier, "On the modeling and control of an experimental harvester machine manipulator", Proceedings IEEE International Conference on Intelligent Robots and Systems, pages 1832-1837, v 3, Sep 7-11, 1997.

[88] Papadopoulos, and Sarkar, "Dynamics of an articulated forestry machine and its applications", Proceedings IEEE International Conference on Robotics and Automation, v 1, p 323-328, Apr 20-25, 1997.

[89] D. Yu, and D.N. Shields, "Bilinear fault detection observer", *Automatica*, v 32, n 11, p 1597-1602, Nov 1996.

[90] D.N. Shields, S.Ashton and S.Daley, "Fault Detection, Supervision and Safety for Technical Processes", in *A Nonlinear Observer Approach: Experience with Hydraulic System*, Ron J. Patton and Jie Chen (eds.), pages 504-509, IFAC, UK, 1997.

[91] D. Yu, D.N. Shields, and J.L. Mahtani, "Nonlinear fault detection method for a hydraulic system", *IEE Conference Publication*, v 2, n 389, pages 1318-1322, Mar 21-24, 1994.

[92] P. Frank, X. Ding, and J. Wochnik, "Model based fault detection in diesel-hydraulically driven industrial trucks", Proceedings of the *American Control Conference*, pages 1528-1533, v 2, Jun 26-28, 1991.

[93] J. Watton, and Ki-Soo Kwon, "Neural network modeling of fluid power control systems using internal state variables", *Mechatronics*, 6, pages 817-8277, Oct, 1996.

[94] D.J. Creber, and J. Watton, "Fluid power component and sensor diagnostics using an expert system shell", *SAE Technical Paper Series*, Sep. 10-13,1990.

[95] E.K. Juuso, "Fuzzy Control in Process Industry: The Linguistic Equation Approach", *Fuzzy Algorithms for Control, International Series in Intelligent Technologies*, Verbruggen, Zimmerman, and Babuska (eds.), pages 243-300, Kluwer, Boston, 1999.

[96] Lin S-C. "A genetic algorithm-based scheduling system for dynamic job shop scheduling problems". Ph.D. thesis, Michigan State University, Department of Electrical Engineering, (1997).

[97] P. Kontkanen, J. Lahtinen, P. Myllymaki, T. Silander, and H. Tirri., "Supervided Model Based Visualization of high-dimensional data", to appear in *Intelligent Data Analysis*, 2000.

[98] P. Kontkanen, P. Myllymaki, T. Silander, H. Tirri, and P. Grunwald, "On predictive distributions and Bayesian networks", *Statistics and Computing*, 10, 39-54, 2000.

[99] P. Kontkanen, P. Myllymaki, T. Silander, and H. Tirri, "On the Accuracy of Stochastic Complexity Approximations", in *Casual Models and Intelligent Data Management*, A. Gammerman (ed.), 120-136, 1999.

[100] P. Grunwald, The Minimum Description Length Principle and Reasoning under Uncertainty. Ph.D. thesis, ILLC Dissertation Series DS 1998-03. Http://robotics.stanford.edu/~grunwald/thesispage.html

[101] J.Rissanen, “Hypothesis Selection and Testing by the MDL Principle”, *Computer Journal* 42(4) 1999. http://www3.oup.co.uk/computer_journal/hdb/Volume_42/Issue_04/

[102] CS.Wallace, D.Dowe: Minimum Message Length and Kolmogorov Complexity", *Computer Journal* 42(4) 1999. Http://www3.oup.co.uk/computer_journal/hdb/Volume_42/Issue_04/

[103] Heckerman, D. and Geiger, D. and Chickering, D.M., Learning Bayesian Networks: The Combination of Knowledge and Statistical Data, *Machine Learning*, 20(3), pp. 197-24, 1995. Ftp://ftp.research.microsoft.com/pub/dtg/david/tr-94-09.ps

[104] N. Friedman, D. Geiger, and M. Goldszmidt. Bayesian Network Classifiers", *Machine Learning* 29:131-163, 1997. Http://www.cs.huji.ac.il/~nir/Papers/FrGG1.ps

[105] D.M. Chickering, and D. Heckerman, D., “Efficient approximations for the marginal likelihood of incomplete data given a Bayesian network”, in *Proceedings of the 12th Conference on Uncertainty in Artificial Intelligence*, Horvitz, E. and Jensen (Eds.), 158-168, F. Morgan Kaufmann Publishers, 1996. Ftp://ftp.research.microsoft.com/pub/tr/TR-96-08.PS

[106] P. Langley, P. and S. Sage, S. “Induction of selective Bayesian Classifiers”, *Proceedings of the Tenth Conference on Uncertainty in Artificial Intelligence*, pp. 399-406, 1994. Seattle, WA: Morgan Kaufmann. http://www.isle.org/~langley/papers/select.uai94.ps.gz

[107] A. Juels and M. Wattenberg, “Hillclimbing as a Baseline Method for the Evaluation of Stochastic Optimization Algorithms”, in *Advances in Neural Information Processing Systems*, S. Touretzky et al., (Eds.) 8, pp 430-436, MIT Press, 1995. http://cs-tr.cs.berkeley.edu/Dienst/UI/2.0/Describe/ncstrl.ucb%2fcsd-94-834

[108] J. Lampinen, A. Vehtari, and K. Leinonen, “Using Bayesian neural networks to solve the inverse problem in electrical impedance tomography”, in Proc. 11th Scandinavian Conference on Image Analysis SCIA’99, pp 87-93, 1999.

[109] A. Vehtari, and J. Lampinen, “Bayesian neural networks: Case studies in industrial applications”, in *Soft Computing in Industrial Applications*, Susuki, Roy,Ovaska, Furuhashim, end Dote (eds.), Springer-Verlag, 1999.

[110] D. Husmeier, W. D. Penny, and S. J. Roberts, “An empirical evaluation of Bayesian sampling with hybrid Monte Carlo for training neural network classifiers”, *Neural Networks*, 12(4-5):677-705, 1999. Http://www.ee.ic.ac.uk/research/neural/dirkh/publications/NN3.ps

[111] M. Vauhkonen, J.P. Kaipio, E. Somersalo and P.A. Karjalainen, “Electrical Impedance Tomography with Basis Constraints”, *Inverse Problems*,13(2), pp. 523-530, 1997.

[112] J. Forsstrom and K. Dalton, “Artificial Neural Networks for Decision Support in Clinical Medicine”, *Annals of Medicine* ,27, pp. 509-517, 1995.

[113] P. Eklund, T. Riissanen, “Software Development for web break risk indication”, *2000 TAPPI PCE&I*, March 26-30, 2000, Williamsburg VA.

Appendix

Curriculum Vitae

Piero P. Bonissone
BS in EE/ME from the University of Mexico City (1975), MS in EECS and MS in ME from UC Berkeley, (1976, 1978) and PhD in EECS from UC Berkeley (1979).

A computer scientist at the General Electric Corporate Research and Development Center since 1979, Dr. Bonissone has carried out research and projects in Artificial intelligence, expert systems, simulation, fuzzy sets, and interactive graphics. He led the development team for Diesel Electric Locomotive Troubleshooting Aid (DELTA), an expert system to help maintenance technicians in troubleshooting diesel electric locomotives. He was the principal investigator in a five-year research program on Reasoning with Incomplete and Uncertain Information, as part of the Knowledge Based Systems Technology Base in DARPA's Strategic Computing Program. He was responsible for the development of the Situation Assessment Module in the first phase of DARPA's Pilot's Associate Project (Lockheed team).

He led the development of the Reasoning with Uncertainty Module (RUM), and PRIMO, two GE proprietary expert system tools for plausible reasoning. Dr. Bonissone has led many projects in Fuzzy Logic Control ranging from the control of turbo-shaft engines to the use of Fuzzy Logic in dishwashers, locomotives, and power supplies. He has also developed case-based and fuzzy-neural systems to accurately estimate the value of single-family residential properties when used as mortgage collaterals. In 1990 he developed CARS (Combined Approximate Reasoning Systems), a case-based reasoning tool integrated with PRIMO, and applied to military transportation planning problems. He has been a member of DARPA's Planning and Scheduling Initiative Executive Committee with responsibilities as Co-chair of the Initiative's Visionary Demonstration. He was also Technical Coordinator for the Initiative's 1993 Integrated Feasibility Demonstration. Recently he has led a Soft Computing (SC) group at GE CRD in the development of SC application to diagnostics and prognostics of processes and products.

In 1986, he received the King-Sun Fu Award from the North American Fuzzy Information Processing Society for his contributions to the field of fuzzy sets and approximate reasoning. In 1989 he received the Dushman Award from GE CRD for his work on reasoning with uncertainty. In 1993 he received the Coolidge Fellowship Award from GE CRD for overall technical accomplishments. In 1996 he became a Fellow of the American Association for Artificial Intelligence (AAAI). In 1999 he received the Dushman Award from GE CRD for his work on medical equipment diagnostics.

Dr. Bonissone is an Adjunct Professor of ECSE Dept. at the Rensselaer Polytechnic Institute (RPI), Troy, NY, since 1982. Since 1993 he has been the Editor-in-Chief of

the International Journal of Approximate Reasoning (North-Holland Publishing Company). He co-edited the book *Expert Systems in Structural Safety Assessment*' (Springer-Verlag 1989), *Uncertainty in Artificial Intelligence 6* (North-Holland 1991), and *Uncertainty in Artificial Intelligence 7* (Morgan Kaufmann 1991). He is also one of the three Editors-in-Chief of the *Handbook of Fuzzy Computation* (Institute of Physics Publishing).

Dr. Bonissone was the program chairman of NAFIPS II, an international conference on approximate reasoning and expert systems. He was also the Program Chairman of the 1990 Conference on Uncertainty in Artificial Intelligence and the General Chair of the 1991 Conference on Uncertainty in Artificial Intelligence. He was an ACM Lecturer for 1994 and 1995. In 1993 he was the Program Chair of the IEEE Second International Conference on Fuzzy Systems (FUZZ-IEEE'93). In 1994 he was the Conference Chair of FUZZ-IEEE'94. Since 1993 he has been Vice-President Finances for the IEEE Neural Network Council.

He published more than one hundred articles in the area of expert systems, approximate reasoning, fuzzy sets, pattern recognition, decision analysis, and soft computing. He received eleven patents from the U.S. Patent Office for his work on reasoning with uncertainty and fuzzy control.

Juhani Sarparanta
DI (1962) TKK Sähkötekniikan säätö- ja vahvavirtatekniikan opintosuunnat

Hän on toiminut liikkeenjohdon ja ohjelmoinnin konsulttina vuodesta 1992, osakkaana kahdessa yhtiössä Oy Chester Ltd. ja Sarpacon Oy. Hän on erikoistunut korkean teknologian pienyritysten konsultointiin ja sulautettuihin ohjelmistoihin. Lisäksi on ollut paikallisten yritysten konsultointia Venäjällä ja Puolassa.

Aikaisemmin hän on toiminut lähes 30 vuotta eri tehtävissä Nokia Oy:ssä vuodesta 1964 alkaen: aluksi suunnittelijana ja suunnittelupäällikkönä teollisuuselektroniikan kehitys- ja koordinointitehtävissä, myöhemmin osastopäällikkönä johtaen tietokoneteknologian soveltamista automaatioon vuodesta 1968 lähtien. Hän oli mukana kehittämässä myös suomalaista tietokoneteollisuutta ja toimi tietokoneiden markkinointi- ja projektinjohtotehtävissä sekä näitä ja tietoliikennettä koskevan teollisuuspolitiikan koordinoinnissa Nokia Elektroniikan johtoryhmän jäsenenä. Vuodesta 1979 lähtien hän toimi Nokian useiden tytär- ja osakkuusyhtiöiden toimitusjohtajana.

Tekesin teknologiaohjelmaraportteja

20/2000	Oppivien ja älykkäiden järjestelmien sovellukset 1994–1999, Adaptive and intelligent systems applications. Arviointiraportti, Evaluation Report, 2000, 54 s.
19/2000	Finnsteel-teknologiaohjelma. Loppuraportti. 2000. 57 s.
18/2000	Adaptive and Intelligent Systems Applications 1994–1999. Final Report. 2000, 182 p.
17/2000	Nanotechnology Research Programme 1997–1999. Final Report. 2000
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7/2000	Pakkausalan teknologiaohjelma 1994–1999. Loppuraportti ja arviointi. 2000, 39 s. Annukka Leppänen-Turkula, Mai Anttila, Jorma Hämäläinen, Terhen Järvi-Kääriäinen
6/2000	Harvennuspuun tuotelähtöinen jalostusketju HARJU 1996–1998. Loppu-raportti. 2000, 51 s. Kaarlo Rieppo
5/2000	R&D Programmes in Electronics and Telecommunication – ETX, TLX, INWITE and Telectronics. Mid-term evaluation. 2000, 94 p. Ahti Salo, Kaveh Pahlavan, Jukka-Pekka Salmenkaita
4/2000	Improving Product Development Efficiency in Manufacturing Industries 1996–1999. Evaluation report. 2000. Steven Eppinger, Hannu Syntera

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