

Annual report 2002

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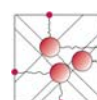
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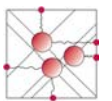
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Preface

There is an enormous difference in behavior between humans and computers. People can manage many intelligent tasks, like recognition of images and sounds, even when they are obscured by noise, and they can plan actions in the absence of complete knowledge. Computers are very poor at these tasks, but outperform humans on pure number crunching.

SNN's research program on adaptive intelligence addresses the question how we can incorporate learning mechanisms in modern computers. Improving our understanding of effective and efficient learning methods 1) is important to better understand the functioning of the brain and 2) has a technological spin-off in numerous artificial intelligence applications, such as robotic systems, expert systems, artificial vision, agents and data mining. In order to achieve intelligent behavior in machines, novel methods for learning must be developed and these methods must be assessed in concrete applications.

These methods are of great practical importance for industry. Information processes in companies and public organizations become more and more complex and problems arise to manage these processes in an efficient and effective manner. At the same time, due to the advances in information technology, far more data are available which could in principle be used to improve business processes.

We are proud to present SNN's annual report 2002 which gives an overview of our achievements in 2002. In section 3 we give a short introduction on adaptive intelligence and give some concrete examples of SNN research results that are used in practice. In section 4, the activities in 2002 of the research groups that participate in SNN are described in detail.

Bert Kappen
Stan Gielen



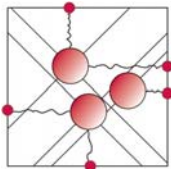
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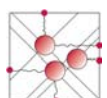
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Contacts

SNN had collaborations with the following companies and organisations in 2002

Akzo, Intervet	Almende
ATO-DLO	Aurus Kennis- en Trainingsystemen
Bolesian	BrandmarC
BSL	Buma Stemra
CAP Gemini Ernst & Young Nederland B.V.	Collexis
Centraal Bureau voor Statistiek Heerlen	Centurion Security BV
CLB	CMG
Coda Music Technology	De Telegraaf
DSM	EADS
Eagle Vision BV	ECN
Emagic Soft- und Hardware GmbH	Eurocontrol
Fujitec Co. Ltd.	GE Bayer Silicones
GreenVision	Groeneveld Group
Hogeschool voor de Kunsten	IBM Watson Center New York
ING	Kennis Centrum Papier en Karton
KiQ	Korg Italy
KPN	Midesa
NATO	NATO C3 Agency
Noldus Information Technology BV	OPG Groothandel BV
Pfizer BV	Philips
Philips Research and Corning Inc.	Philips Research Labs
Post Kogeko Transport Group	Rand Corporation
Rijkswaterstaat	Sappi
Schiphol	Schuitema NV
SHELL EPT/RF	SIEMENS
Siemens CAD, USA	Simplex
SKF Engineering & Research Centre B.V.	SMART Research BV
SNS	SoundPalette
SUN Microsystems Nederland B.V.	Syngenta Seeds B.V.
Technische Unie	Thales Communications BV
TNO	TNO-FEL
TNO-TPD	Tomandandy Music Inc
Torex-Hiscom BV	Tweehuysen Consultancy BV
UMC Maastricht	UMC Nijmegen
UMC Utrecht	Unilever
Unilever Research	URV Vlaardingen
Vendex	Vos Logistics
Yamaha Corporation	

SNN Research is funded in part by: European community, Japanese Ministry of International Trade and Industry (MITI), Technology Foundation (STW, NWO), Prinses Beatrix Fonds.



SNN as an organization

SNN is a national consortium of 6 university research groups in the field of adaptive intelligence and is coordinated from Nijmegen. Criteria for membership are scientific excellence and proven transfer of research to industry.

SNN is a not-for-profit foundation that was founded in 1989 as one of the SPIN (Ministry of Economic Affairs) initiatives. The statutes of SNN define the goal of SNN as follows 1) to coordinate research into neural networks, 2) to explore new fields of industrial application, and 3) to stimulate knowledge transfer to industry.

SNN is one of the leading research institutes in this field world-wide.

Platform adaptive intelligence

SNN forms a national platform for adaptive intelligence, which is sponsored by STW. The aims of the platform are to stimulate research on adaptive methods in the Netherlands and to stimulate transfer of knowledge to industry. See also www.snn.kun.nl/nederland. Activities of the platform are:

Research networks

To initiate joint research with the SNN members and industry in national or international context. As an example, SNN Nijmegen and SNN Amsterdam participated for 10 years in the Japanese Real World Computing Partnership (RWCP). In this project 20 large Japanese companies and 4 non Japanese research institutes participated (see fig. 1).

Call for proposals

Since 1995, SNN organizes together with STW every two years a call for proposals on the field of adaptive intelligence. The calls of 1996, 1998 and 2000 approved 5 projects each. The total allocated budget is approximately 2.5 MEuro for each call. The call of 2002 resulted in 16 proposals of which an expected 40 % will be granted in the summer of 2003.

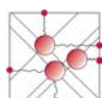
Meetings

SNN organizes academic meetings (national and international) and symposia for knowledge transfer to industry. Past meetings include ICANN in 1993, Europe's main conference on neural networks. In 1995, SNN's third conference "Neural Networks: Artificial Intelligence and Industrial Applications" showed several case studies of real working neural network applications. In 1997 SNN's conference "Neural Networks: Best Practice in Europe" showed several case studies of real working neural network applications. In 2000 and 2002, SNN co-organized the symposia "Learning solutions" in collaboration with STW. The symposia gave an overview of research and successful applications of neural networks in The Netherlands.

Forthcoming meetings are:

Learning solutions

A national meeting where researchers on adaptive intelligence meet industry (October 22, 2003)



BNAIC

The Belgium-Netherlands AI Conference which is the main conference in this field in the Benelux (October 2003).

Theme days

Adaptive intelligence theme days in collaboration with the national research schools IPA, SIKS and ASCI.

Courses

SNN regularly organizes several courses in the field of adaptive intelligence, together with the Graduate schools ASCI, SIKS and IPA . The courses are intended for PhD students and researchers from industry. In 1999 and 2001, the course Advanced Issues in Neurocomputing was organized in collaboration with ASCI.

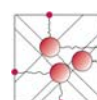
Forthcoming courses are:

- Advanced Issues in Neurocomputing (with ASCI, April 2003)
- Advanced Pattern recognition (with ASCI, April 2003)
- Pattern Recognition System Design (with ASCI, October 2003)
- Computational Intelligence (with SIKS, October 2003)



Figure 1
Visitors and IAS-robot at the RWCP symposium





2 Achievements

What is adaptive intelligence?

The human brain is one of the biggest mysteries of nature, and the way the brain achieves its intelligence is not well understood. One important difference between humans and the current generation of computers is our ability to learn from examples and to adapt our behavior to novel situations.

Neural networks are computer programs that imitate intelligence, using the principles of the brain. Neural networks are able to learn from data and are useful when the task is ill understood in terms of quantitative rules, but when sufficient data are available to train the network. Early neural networks were criticized because they lacked accuracy estimates for their predictions. The modern view is that neural network learning is best viewed as a statistical estimation task, which solves this shortcoming.

Using data only, however, will not always produce the best solution. Better solutions are often obtained through a combination with explicit (human expert) domain knowledge. *Bayesian statistics* offer an elegant formalism to combine learning and explicit modeling. This way to integrate adaptive methods with expert knowledge for modeling intelligent behavior is called *adaptive intelligence*.

History

The fields of neural networks and artificial intelligence started after the second world war. This was at the same time then the first digital computers were built. Important contributors to the early development of the modern computer, such as Alan Turing and John von Neumann, also were greatly interested in the mysteries of the brain.

Early generations of neural networks, the perceptrons, demonstrated the learning abilities in digital and analogue computers. One of the most impressive demonstrations was the checkers program built by Arthur Samuel in the 1960's. This program learned to beat his creator and ended as the number 4 on the national ranking in the USA. The program was demonstrated on national TV and caused a great commotion.

Multi-layered perceptrons in the 1980's much extended the learning capabilities of neural networks. Due to the ever increasing computer speed, it also became possible to build many impressive applications of neural networks that are used by companies all over the world.

In the 1990's the neural networks and statistical communities joined forces. In particular in the NIPS community (Neural Information Processing Systems), which is the leading conference in the field, much work was done to integrate the neural and statistical approaches. The result is that by describing neural networks in the language of Bayesian statistics, one can combine the strong modeling characteristics of neural networks with the reliability and confidence estimates provided by statistics. The resulting generation of neural networks was recognized by industry as a reliable and powerful tool, which is evident from the number of patent applications in this field (see fig. 2).

Another approach to artificial intelligence was to treat the problem as an

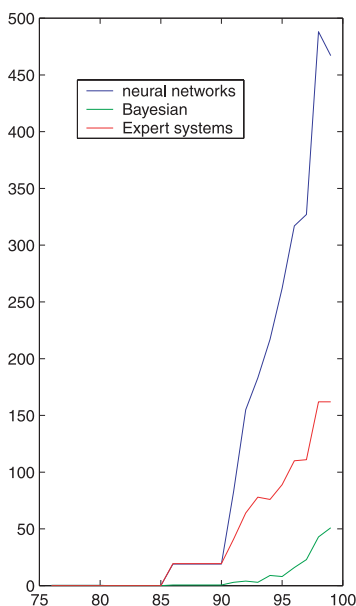
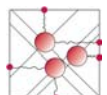


Figure 2 Neural network (top line), Bayesian statistics (middle line) and expert system (bottom line) patents per year (75 means 1975 and 00 means 2000)



optimization problem. Early examples of this approach are the chess computers and the mathematical theorem provers. On small problems, these approaches gave spectacular results, convincing many people that artificial intelligence was within reach. However, it turned out that the proposed algorithms scaled very badly with increasing problem size. The formal study of the complexity of optimization problems was pioneered by Cook and Karp. It turned out that optimization problems come in two flavors: easy ones and hard ones. The hard problems require computation time and/or memory that scales exponentially with the problem size. The easy problems only require resources that scale polynomially with the problem size. It comes as no surprise that many AI problems turned out to be hard. Thus, the fact that a program can find a solution in principle does not mean that the program contains any of the mechanisms needed to find it in practice.

It was realized that the brute force approach of combinatorial optimization is infeasible for many AI problems. Another drawback of the brute force approach is that programs often contained little or no knowledge of their subject matter and operated by simple syntactic manipulation. A typical story occurred in early machine translation efforts, which were generously funded by the National Research Council in an attempt to speed up the translation of Russian scientific papers in the wake of the Sputnik launch in 1957. It was thought initially that simple syntactic transformation based on the grammars of Russian and English, and word replacement using an electronic dictionary, would suffice to preserve the meaning of sentences. In fact, translation requires understanding of the subject matter, as is exemplified in the famous example "the spirit is willing but the flesh is weak" that was retranslated into "the vodka is good but the meat is rotten". In 1966 all US government funding for academic translation projects was cancelled.

In order to proceed, it was proposed in the 1970's to explicitly use the knowledge of human experts to help the optimization problem to become tractable. As one of the first examples of this approach, Edward Shortliffe and Bruce Buchanan wrote MYCIN in 1972, an expert system to diagnose infectious blood diseases

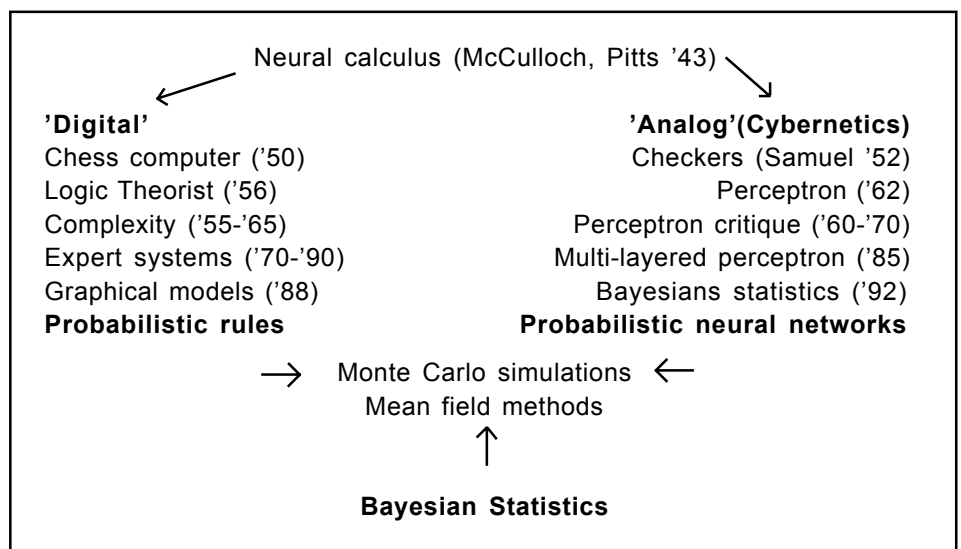


Figure 3
A brief history of AI, showing the digital branch of symbolic AI and the analog branch of learning methods. The digital branch has led to probabilistic rule based systems, also known as graphical models. The modern approach to neural networks is to describe them in terms of Bayesian statistics. Since the 1990, these fields are integrating more and more.



and to recommend antibiotics, with dosage adjusted for patient's body weight. To use explicit rules for modeling is cumbersome. Rules have many exceptions and it requires many rules and much effort on the part of the modeler and the human expert to cover all cases. For instance, the rule 'Birds fly' is often true, but not for penguins. Instead of listing all exceptions explicitly, one can use probabilities to summarize all the exceptions. Thus the probabilistic rule becomes '95% of the birds fly'. The remaining 5% may contain many exotic species, but one does not list them explicitly. The modern generation of expert systems is based on probability theory.

Thus, after 50 years of leading a separate life, we have now reached a stage in research where both branches of AI, the neural or learning branch and the 'symbolic'/rule based branch, both use probability theory to describe their models. This makes it now possible to construct solutions that integrate learning and 'rules'. (Bayesian) statistics provide the third ingredient, making it possible to quantify the accuracy and significance of the model predictions. The probabilistic approach is also called Bayesian statistics. This way to integrate adaptive methods with expert knowledge for modeling intelligent behavior is called *adaptive intelligence*.

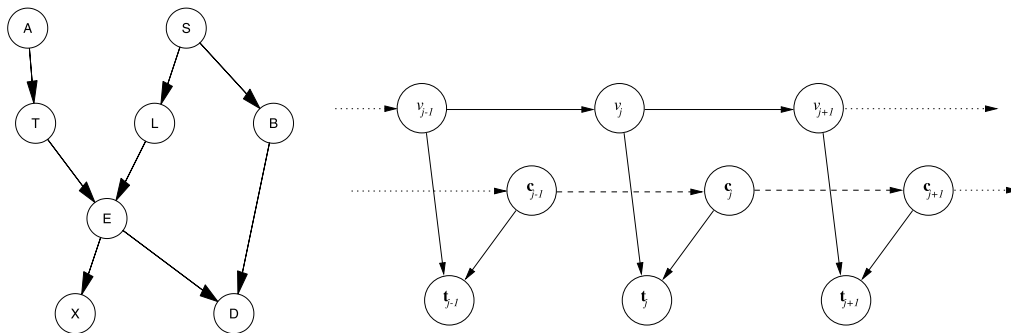


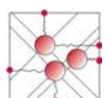
Figure 4 Left: A small medical diagnostic model. The network contains three diagnoses: tuberculosis (T), lung cancer (L) and bronchitis (B). The probability of tuberculosis is increased when the patient has recently visited Asia (A). The probability of lung cancer and bronchitis are increased by smoking (S). The diseases in turn alter the probabilities of symptoms such as dyspnoea (D) or an X-ray scan (X). Right: Graphical models can also be used to model relations through time. Large numbers of observations (measurements) may be related through time using a small number of unobserved (hidden) dynamical variables.

The Bayesian approach

The Bayesian approach to modeling is to describe the world as a probability distribution over the variables in the domain. The dependence between the variables can be graphically described (see Figure 4). For this reason, these probability models are also known as *graphical models*.

Unlike many other methods, the Bayesian approach gives a principled procedure to integrate learning from data and expert knowledge. Typically, the expert will be able to draw the graphical model, defining which variables depend on which other variables. Data or additional text-book knowledge can then be used to provide the numerical values of the probabilities.

Once the model has been defined, one can compute the probability of any of the variables in the model, given some evidence about the value of some other variables. This computation is called inference.



Examples of successful applications

We will illustrate the concepts of Bayesian statistics in some typical examples from SNN's research: newspaper prediction, medical diagnosis and adaptive strategies in commercial games, trading systems and logistics. These examples have been chosen to illustrate the broad spectrum of the possible applications that can be made with adaptive intelligence.

Predicting newspaper sales

Department of Biophysics, University of Nijmegen

Partner: De Telegraaf, SMART Research B.V.

The sales of newspapers is affected by many factors, such as news content, events, season and weather. Prediction of future sales requires an integrated approach that takes all these factors into account. We showed that by doing so, the knowledge embedded in historical data can be turned into money. A commercial product called JED (Just Enough Delivery) has been operational at "De Telegraaf" since 1997.

Single-copy sales strongly fluctuate. The better one can predict the fluctuations, the better the distribution, and thus the higher the revenues. In the dynamic markets of newspaper sales, it is important to have a prediction system that learns and adapts itself to the latest changes.

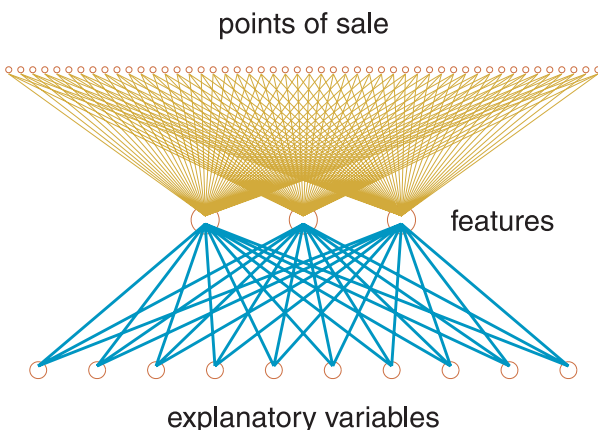


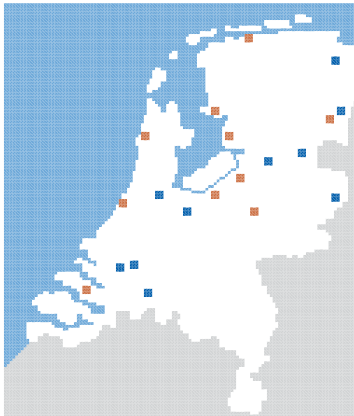
Figure 5

The neural architecture has a layered structure of processing units (neurons). The explanatory (or input) variables could be sales figures, seasonal figures, weather information, major events, etc. that go into the JED system. The network then determines which information is relevant and extracts these data to predict the number of sales for each outlet or newsstand.

A neural network is such a learning system, based on ideas from neurobiology. The input layer encodes the currently available information. This information is passed on through layers of "hidden" units to the output layer. Each output of the neural network corresponds to the sales of a particular outlet (or newsstand). Input variables can include any type of relevant information that helps to predict the future sales.

JED learns from the historical sales figures in the past how to tune the deliveries in the future. The parameters of the network model are optimized to give the closest fit between the observed sales figures and the sales figures generated by the network on historical data. The hidden units form a kind of bottleneck and extract the most important information for prediction. In this way, the neural network discovers autonomously which variables are the most important, i.e.





which variables mainly affect future sales. An important aspects of the learning procedure is the demand that the individual prediction tasks ‘learn from each other’. In this way, each learning task has effectively more data than when learned in isolation. As a result, one can include more explanatory variables as inputs to the model, and improve the prediction performance.

Learning is done “on-line” which means that the network is adapted, every day in the case of De Telegraaf, to maintain good performance despite changes in the market. The system has been operational at De Telegraaf since 1997 and outperforms their previous system, which was based on a classical, but already quite sophisticated statistical method.

For more information see also: <http://www.smart-research.nl/products/jed> and <http://www.snn.kun.nl/nijmegen/paper>.

Figure 6

The neural network discovers that the sales of some outlets situated along the coast and in other recreational areas (red squares) respond positively to good weather; the sales of some outlets situated in downtown areas of bigger cities (blue squares) respond negatively to good.

Medical diagnosis

Department of Biophysics, University of Nijmegen

Funded by STW

Partner: DIGD, UMCU

Promedas is a medical patient-specific Decision Support System (DSS) based on graphical probabilistic models. Promedas aims to improve the quality and efficiency of health care, while reducing its costs at the same time.

Modern-day medical diagnosis is a very complex process, requiring accurate patient data, a profound understanding of the medical literature and many years of clinical experience. Often, a clear-cut diagnosis cannot be made and several alternatives must be considered. As a result of this uncertainty, the decisions made by different physicians at different stages of the diagnostic process do not always agree and lack “rationalization”.

We are developing a medical diagnostic Decision Support System (DSS), called Promedas. The DSS is a computer program that contains all relevant knowledge about a certain medical (sub)domain and generates patient specific diagnostic advice in the form of a list of likely diagnoses and suggestions for additional laboratory tests that are expected to be particularly informative to establish or rule out any of the diagnoses considered.

Promedas is based on medical expert knowledge, acquired from the literature by the medical specialists in our project team. The acquired knowledge is stored in a database, in such a way that extension and maintenance of the expert knowledge is facilitated. Currently, the database contains over 6000 records. From (parts of) this database, the graphical model and an interface for Promedas are automatically compiled. Our current models contain 100-500 variables. We use Bayesian inference to compute the probability of all diagnoses in the model given the patient data. A key technical innovation is the use of advanced approximate inference methods which allow Bayesian inference to be applied to large problem instances (patent submitted).

The system is intended to support diagnosis making in the setting of the outpatient clinic and for educational purposes. Its target-users are general internists, super

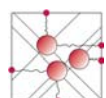


Figure 7

The Promedas advice page displays the differential diagnosis (upper left); the entered data (lower left); the proposed additional tests with respect to a selected diagnosis (upper right); and the effect of the possible outcomes of the selected test to the selected diagnosis, together with the probability of these possible outcomes (lower right).

The screenshot shows the Promedas software interface. The title bar reads "Promedas". The main window is divided into several sections:

- Diagnostic Categories (D):** A list of conditions with their probabilities:
 - 90% familial hypercholesterolemia homozygotes
 - 26% familial hypercholesterolemia heterozygotes
 - 26% polygenic hypercholesterolemia
 - 26% familial defective apo b 100** (highlighted)
 - 24% cigarette smoking
 - 18% familial combined hyperlipidemia
 - 9% obesity
 - 4% hypothyroidism
- Test Proposals (T) for: "familial defective apo b 100"**: A table listing tests and their associated values:

Info (0.100)	Test
83	apo b-100 gene mutation at amino acid 3500
70	apolipoprotein b (g/l)
45	first-degree family members: atherosclerosis premature
38	ratio low - density lipoprotein cholesterol (calculated) to ...
18	triglycerides (mmol/l)
16	first-degree family members: hypercholesterolemia
15	high - density lipoprotein cholesterol (mmol/l)
6	xanthomas achilles tendons
6	xanthomas extensor tendons of the knuckles
2	xanthomas tuberosus
- Test Information for: "first-degree family members: atherosclerosis premature"**:
 - sensitivity 0.696
 - specificity 0.999
 - A table showing the relationship between test results and diagnosis probabilities:

	TRUE	FALSE	prior
true	1	0	0.186
false	0.1	0.9	0.814
prior	0.267	0.733	
- Test Value Table:**

Test	Value
<input checked="" type="checkbox"/> xanthomas tendon	true
<input checked="" type="checkbox"/> cholesterol total (mmol/l)	13.0

specialists (i.e. endocrinologists, rheumatologists), interns and residents, medical students and others working in the hospital environment.

It is clear, that the benefits of a successful DSS for internal medicine are far reaching. All medical specialists will appreciate it because it can give valuable information support for those patients that suffer from a disease outside his or her own super-specialization. It will result in an improved and more rationalized diagnostic process, as well as higher efficiency and cost-effectiveness. See also http://www.snn.kun.nl/nijmegen/medical_diagnosis and <http://www.snn.kun.nl/nijmegen/promedas>.

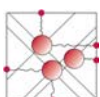
Many problems in computation vision can be formulated as inference problems, where the image acts as external evidence from which we need to infer unobserved properties, such as for instance object identity. Some parts of an image contain valuable information while other parts, contain almost no information. Such vision problems are intractable but are well suited for the cluster variation method. It has been used for instance to estimate high resolution images from low resolution images and to explain perceived transparency from edge information. This topic is investigated by several research groups world wide, and also companies such as Intel, who foresee applications in real-time vision.

Adaptive intelligence in commercial games

Institute for Knowledge and Agent Technology (IKAT)

The rapidly growing commercial-game industry is interested in the development of adaptive-intelligence techniques to improve the perceived intelligence of opponents. The challenge is to maximize the quality of the adaptive performance given the limited resources (e.g., processing time and capacity).

In commercial computer games such as Quake, Civilization or Baldurs Gate, the human player is confronted with one or more virtual opponents. In these games, opponents commonly behave according to pre-defined scripts that



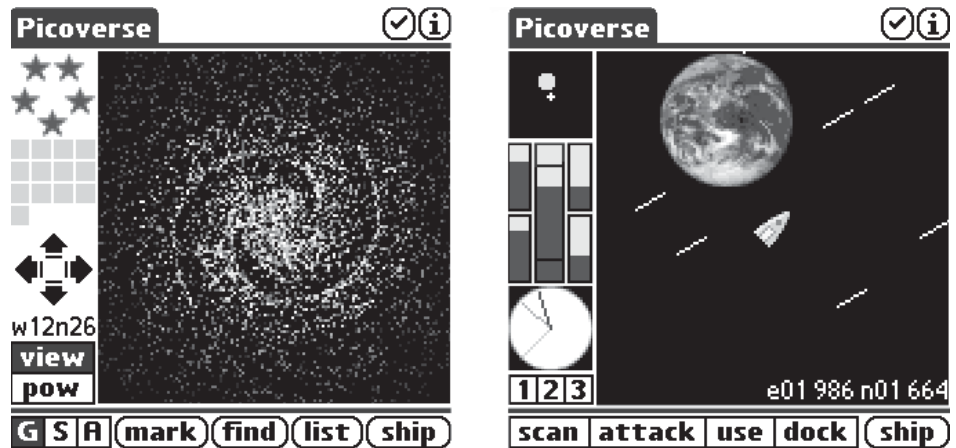


Figure 8
Two screenshots of the Palm game Space Trader

specify what actions are to be executed under what circumstances. The inability of the scripted opponents to adapt to, for instance, changing strategies of the human player limits the perceived challenge and attractiveness of the game.

In 2002, IKAT started to perform research on adaptive-computation techniques to improve the intelligence of opponents in commercial computer games. Our initial research focuses on learning in (virtual) competitions between adaptive and scripted opponents. The results indicate that the application of learning techniques in adaptive opponents gives rise to quite unexpected strategies. In particular, the approach helps to uncover mistakes in the scripts controlling the opponents. Current and future research addresses the adaptive acquisition of appropriate sequences of decisions. The results of the research will be incorporated in commercial games such as the future version of the Palm game Space Trader that is being developed at IKAT.

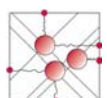
(More details about adaptive intelligence in commercial games can be found at <http://www.cs.unimaas.nl/p.spronck/>.)

Autonomous Systems of Trade Agents in E-Commerce (ASTA)

CWI, Amsterdam

Partners: TNO, ING KPN

The Trade Agents project (“Autonomous Systems of Trade Agents in E-Commerce”) concerns research on systems of trading software agents in electronic commerce. Partners in the project are CWI, TNO, ING and KPN, and the project is funded by the Telematics Institute. The major line of the CWI research in this project, in cooperation with the partners, addresses the development of models and algorithmic software solutions for new business applications that are based on interacting software agents, where the individual agents are owned and controlled by different, autonomous market parties. Specific examples of these research lines include market mechanisms, dynamic pricing, negotiation, bidding and buying, and (fast) profiling in e-business. Our focus is on the evolutionary simulation and development of trade agent systems; the development of adaptive, learning trade agents; and the creation of new e-business concepts.



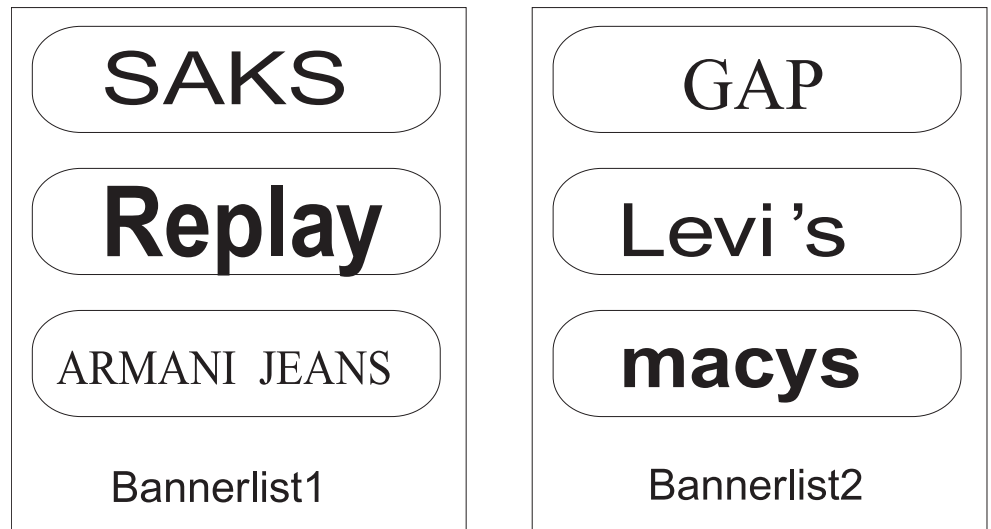


Figure 9
 The winning agents display their advertisement to the customer, where the attention space is sufficiently large to display three banners. Two lists of stores are shown for 2 types of consumers (both searching for jeans).

A new e-business concept we developed is that of an adaptive, distributed recommendation system, that could be used for recommending products in an electronic shopping mall, the targeting of web-banners and other resource allocation problems. The problem in recommending is that the amount of attention space available for recommending suppliers to consumers is typically limited (if only by the attention span of the consumer). To solve the problem of determining what when to recommend to who, we developed a competitive market-based recommendation mechanism (based on adaptive software agents) for efficiently allocating the “consumer attention space”, or banners. A patent application was filed (together with TNO Telecom) for this system.

In our approach, agents get information about a consumer’s interest. Subsequently, each agent bids in an auction for the momentary attention of that consumer. Winning agents may display their advertisement or banner in the available attention space to the consumer.

Successive auctions allow agents to rapidly adapt their bidding strategy to focus on consumers interested in their offerings. The feasibility of this system, for a variety of customer behavior models, was demonstrated by evolutionary simulation (as in agent-based computational economics, ACE). More information on this application can be found on the website: www.cwi.nl/projects/ASTA. Other activities within the project focus on finding bundles of products that create extra value for a customer, algorithms for dynamic pricing, and methods for fast profiling of customer “types”.

Distributed Engine for Advanced Logistics (DEAL)

CWI, Amsterdam

Funded: E.E.T. program (Economy, Ecology, and Technology) via Novem

Partners: Almende, Erasmus University, Free University, Vos Logistics, Post Kogeko Transport Group, and Groeneveld Groep.



The project concerns research on advancing the efficiency in operational logistics. The fundamental research within the CWI contribution to DEAL focuses on the development of robust, distributed Multi-Agent Systems (MASs), for usage in the logistics of the transportation sector. In the current work, market-mechanisms are used in the form of online, decentralized auctions, where agents (representing trucks) bid for cargo in a Multi-Agent System logistics setting. Appropriate, adaptive bidding strategies were then studied, which are novel for such a large-scale setting.

One novel agent-based logistical setting researched is a system where agents have the opportunity to unilaterally *decommit* from contracts. Sandholm *et al.* have shown formally that by incorporating this decommitment option, the degree of efficiency of the reached agreements can increase as agents can escape from premature deals by adjusting their contracts.

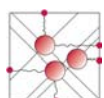
In a series of computer experiments for the above transportation settings, we showed that significant increases in performance (profit) can be realized by a company with agents that are allowed to decommit loads. As a necessary precondition, decommitment is only a clearly superior strategy if an agent (truck) is close to the limit of its capacity. This is a new, general result for agents capable of handling simultaneous tasks. Furthermore, the increase in performance for the (abstract) model of the transportation sector can be seen as a lower bound for expected increased performance in practice. This claim was substantiated through experiments that show that the relative impact of a decommitment strategy increases with the complexity of the world (joint work by P.J. 't Hoen, D.D.B. van Bragt and J.A. La Poutré).

Parallel to this research, CWI cooperates with the partners within the DEAL project to test the ideas and results from this research in real-world situations. Vice versa, the problems and ideas from real-world logistics provide important further input for research directions.



Figure 10

A large fraction of trucks on the road are actually empty, forming a great opportunity for improving efficiency and reducing environmental damage via advanced logistics.



3 Research results

3 A

Intelligent Autonomous Systems Group, University of Amsterdam

The Intelligent Autonomous Systems (IAS) group is part of the Informatics Institute of the University of Amsterdam. The group consists of 20 members including staff, postdocs, Ph.D. student and support. Together with TNO-FEL and TNOTPD, the IAS group forms a 'center of expertise' in the field of public safety. Here the projects are described which are concerned with learning and probabilistic methods.

Bayesian Robotics and perception

Our daily environment is getting more and more intelligent because of smart sensors, processing techniques and actuators. Characteristic for such real-world applications is that sensor data are noisy and models of state and action are inaccurate or unknown. This calls for adaptive methods, which are able to learn accurate models and are used to make optimal actions for those systems.

The Intelligent Autonomous Systems (IAS) group develops a theoretical understanding and computing methods for autonomous systems, including methods for sensor data processing, reasoning, learning and distributed systems. The focus is on systems which operate in a real world, such as surveillance and safety systems, service robots, intelligent cars and multi-vehicle systems.

Learning and adaptivity are essential in such systems because the real world in which they live is partly unknown and is subject to changes. Take for example a personal robot which has to operate in an intelligent house. Such a system will, after is has been unpacked by the owner, not immediately know the structure of the house, nor the identity of the persons in the family. It will have to learn the environment, the users, and many other things such as the concepts by which it is instructed, or the best way to collaborate with other agents. These, and many other scientific questions and applications, are the kind of problems we work on.

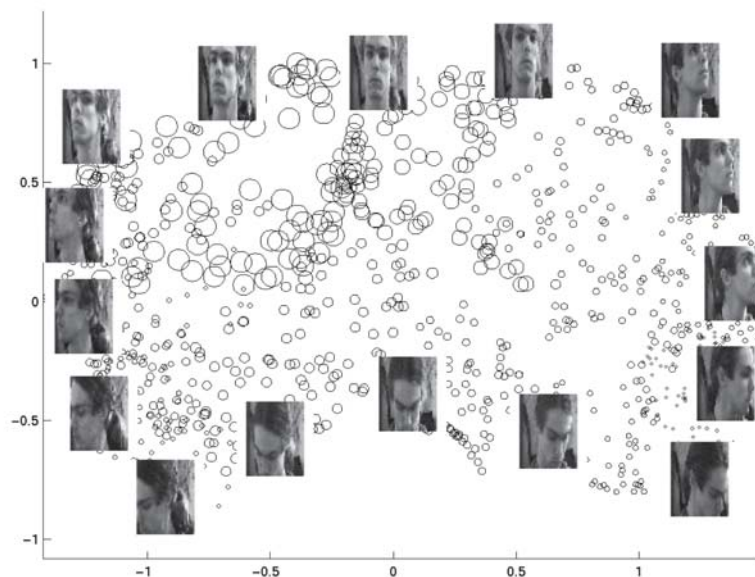
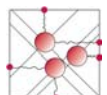


Figure 11
A data set of a face under different viewing angles projected to a 2D representation. A model like this can be used for face recognition on the basis of multiple views of a face.



Adaptive methods, in combination with Bayesian belief updates, are powerful solutions to many of the modeling and decision making tasks for systems which operate in a real world. An important line of research in the IAS group concerns the modeling of sensoric data. Typical sensor data are high dimensional and noisy, while the underlying process generating this data may have a lower dimension.

For example, all images of a face looking in two different directions (see Figure 11) can be considered as noisy points lying on a 2D-dimensional manifold embedded in the space of high-dimensional measurements. We studied methods that map high dimensional data to a low dimensional space that preserves the structure of the data. The approach in our research is a combination of several local linear mappings. A probabilistic framework allows us to find appropriate locations for the local linear maps and the regions for which they are responsible. We developed powerful methods with low computational complexity for such nonlinear projections. An accurate low dimensional representation is important for visualization but also for fast recognition.

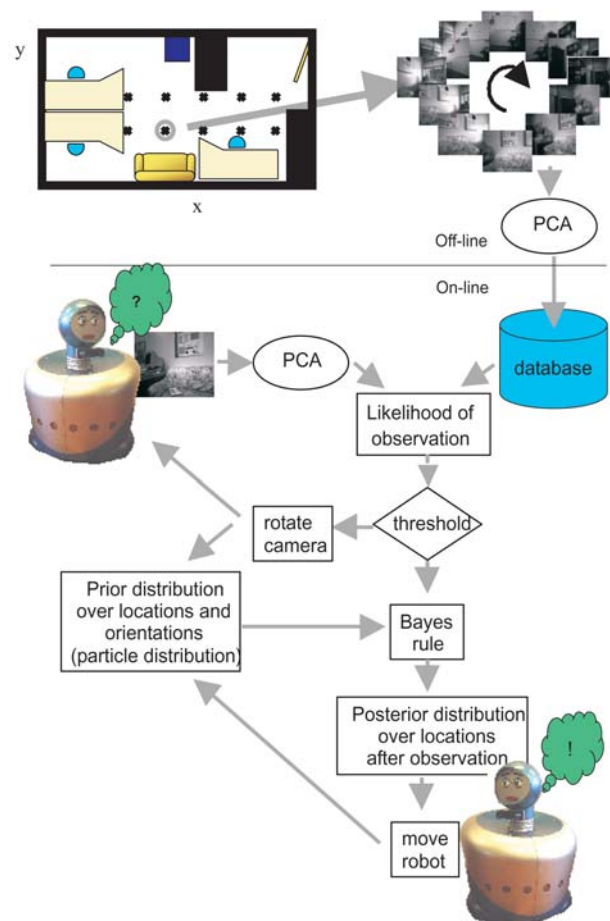


Figure 12

The method used by the Philips 'Lino' to estimate its position. An 'appearance' model of the environment is made in an off-line training. After a movement of the robot the belief in its position is updated on the basis of a new observation.



Another important line of research are the Bayesian methods which we use to estimate the state of the system from sensor data. We were very successful in an application where the position of a personal robot system has to be estimated while it navigates indoors. This project was carried out in collaboration with Philips Research (see Figure 12). Recently we also developed Bayesian methods for tracking the locations of humans walking in a building in a distributed surveillance system.

Autonomous systems take decisions on the basis of their state, or state estimate. For real systems the state is often only *partially observable*. For instance, visual objects may be observed differently because of noise in the sensors. Or partial observability can be related to an inherent property of the environment referred to as *perceptual aliasing*: different states may produce identical perceptions to the agent at different time steps. For example, two identical doors along a corridor will look exactly the same to the eyes of a human or the camera of a mobile robot, no matter how accurate each sensor system is. We study the effect of this partial observability for *multi agent systems*, which have to coordinate their actions to achieve a common goal.

Personal robot in an intelligent environment

Future 'personal' robots should be able to learn a representation of the world in which they operate autonomously. We develop probabilistic methods for environment learning, robot localization and navigation. The work is funded by Ministry of Economic Affairs and is carried out within a European (ITEA) project 'Ambience', in collaboration with Philips Research.

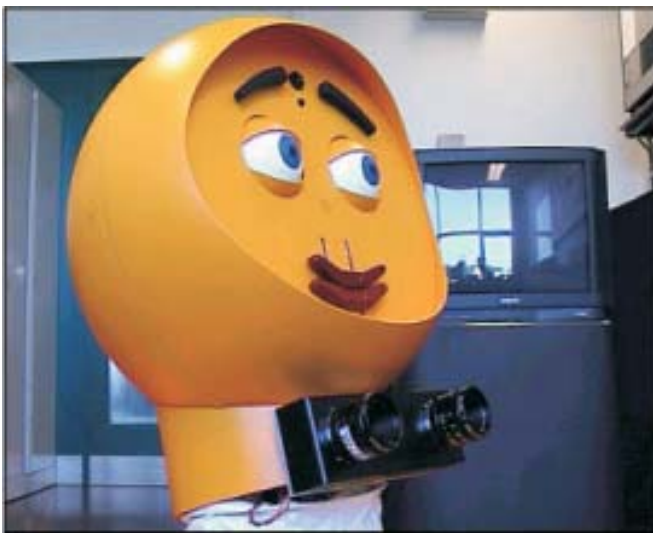
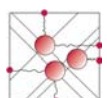


Figure 13
The personal robot developed in the AMBIENCE project.

Classification of radar range profiles

In this project we develop methods to automatically recognize aircrafts by examining how they reflect radar waves. On the basis of simulated data we estimated a model of the point scatterers for each class. These models were successfully used to classify real radar profiles. The project was funded by TNO-FEL.



Tools for non-linear data analysis

We study methods that map high dimensional data to a low dimensional space that preserves the structure of the data (i.e. it keeps nearby points nearby). Such methods are of interest for data visualization, where one needs to map data to two-dimensional coordinates, and for regression, inter- and extrapolation tasks, where it is helpful to map the data to a low dimensional space. Robust and fast methods have been developed. The project is a collaboration with the Pattern Recognition Group of the TU Delft and is funded by STW.

Probabilistic models for distributed surveillance

Surveillance systems often need to track a moving object through larger areas or buildings. In case the camera's (or other sensors) do not overlap, the system is faced with the problem whether an object observed with a camera at some time is the same object as observed by some other camera some time ago. To deal with the uncertainty we use probabilistic networks. These methods are able to model the belief in target trajectories. Hidden Markov models can be seen as a special class. At the moment we adapt probabilistic methods developed for traffic surveillance to indoor tracking problems. An experimental set-up is built, see figure 14. The project is funded by STW.

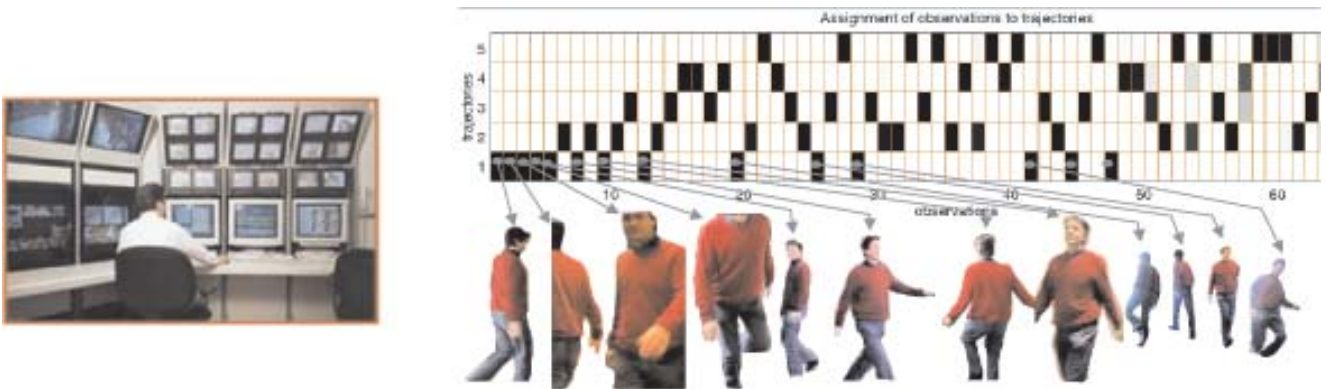


Figure 14

In a surveillance task humans have to be tracked across camera's. The right image shows the images that are considered to belong to the same object from the total set of images of objects captured by different cameras in a building. Note that despite the large differences in illumination conditions the found identities are correct.

Omni directional vision

We studied the use of an 'omni-directional' vision system for robot applications. While traversing the environment, images are captured. We developed a robust method for making a spatial reconstruction of the environment from the images. Based on correspondences between images we were able to reconstruct the driven trajectory simultaneously. This project was started with funding from RWCP. The work is continued partly within the project 'concept learning'.

Learning concepts in real world embodied agents

Service robots, personal assistance and other intelligent computers which operate in the real world inhabited by humans, deal with problems of interacting in a 'natural' way with humans about their environment. In this project we develop



novel learning methods that can be used for concept formation in a human-robot interaction. Our agent is a mobile robot equipped with omni-directional vision and it categorizes visual inputs into concepts related to target locations and places in the environment. We use an hierarchical architecture that allows the robot to learn about concepts at different abstraction levels from “move forward 3 centimeters” to “go to the robot lab”.

Distributed user modeling for personalized exploring recommender systems

This newly started collaboration with the Department of Social Science Informatics (SWI) of the UvA aims at assisting human users by estimating their interests and predicting their future behavior. We use an adaptive web site as test application. User models are formed and estimated based on the interactions with the site and a recommender system uses these models to guide users faster to the content of their interest.

Multi agent coordination

A distinguishing feature of a multi agent system is the fact that the decision making of the agents is distributed. This means that there is no central agent that decides what each agent must do at each time step. Instead, each agent is to a certain extent ‘responsible’ for its own decision. In order for the agents to be able to take their actions in a distributed fashion, appropriate coordination mechanisms must be additionally developed. Coordination can be viewed as the process that ensures that the individual decisions of the agents result in jointly optimal decisions for the group. In our group we study such coordination mechanisms when a large number of cooperative agents are involved. In this case the agents are assumed to form a team and through this team they make joint plans and pursue common goals. Robot soccer is such an example, where a group of robots attempt to score goals against an opponent team. We have extended coordination graphs to the case where the state is continuous and communication among agents is forbidden.

An example of a coordination graph on the simulated robot soccer is shown in Figure 15.

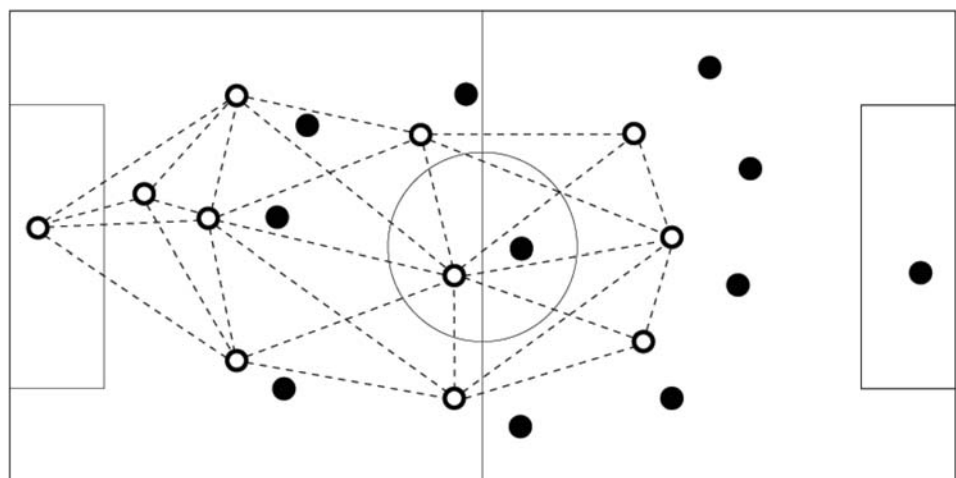
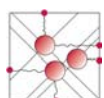


Figure 15
A coordination graph applied on robot soccer.



3B

Department of Biophysics, University of Nijmegen

The SNN Nijmegen research group is part of the physics faculty of the university of Nijmegen. The group currently consists of 14 people, consisting of senior staff, post-doctoral fellows, PhD students and programmers and is headed by Stan Gielen and Bert Kappen. The group conducts research on adaptive methods and their applications.

In 2002, we obtained concrete research results in three areas: medical diagnosis, prediction of newspaper sales and medication adjustment. The first two topics are described in section 3. The latter is described below. In addition, we briefly describe our ongoing research topics. For more information, consult the SNN web site www.snn.kun.nl/nijmegen.

Medication adjustment

Patients with Parkinson's disease receive Levodopa to alleviate the symptoms of Parkinson's Disease (PD). However, long-term use of levodopa frequently causes involuntary movements (dyskinesia), which can be prevented by adjusting the dose of levodopa at the proper times each day. However, determining the proper dose requires continuous monitoring of the patient's movements for a period of about a week, which is impossible for practical reasons. Therefore, the aim of this project was to develop a neural network, which uses accelerometers at the wrist, upper arm, legs and trunk to measure movements of the patients for an object, automatic detection and classification of dyskinesia. The main problem is to distinguish involuntary movements from normal voluntary movements in daily life activities. The neural network gave an excellent performance (about 97 % correct), which is a huge improvement upon existing methods, which did not exceed a performance of 75% correct. Moreover, the information stored in the neural network could be used to interpret the combination of movement parameters, which contribute to a distinction between dyskinesia and normal movements. This is important to understand the role of the basal ganglia, which are affected in PD, in the coordination of movements. The system is now ready for commercial marketing.

Other research projects

SNN Nijmegen is engaged in many other applications and basic research. Many of the basic research projects are funded by the Technology Foundation (STW). Other projects are short-term and are done on a commercial basis through SNN's spin-off company SMART Research.

Basic research projects

Efficient inference

A serious drawback of Bayesian inference is that it is intractable, meaning that computation time and memory requirement scale exponentially with the problem size. We are engaged in the development of novel approximate inference algorithms that allow fast large scale application. Two patents are submitted in 2002. This work is funded by the a STW Pionier grant.

Sales forecasting

Prediction of sales can be done on the level of individual products or on aggregated levels. Although more detailed prediction is desired, lack of data requires aggregation. This project designs automatic methods for aggregation that optimize prediction



given the available data. The project is done in collaboration with the TUE and is funded by STW.

Genetic linkage analysis

Localization of genes involved in a genetic disease is a promising real world application for Bayesian inference. Currently available software can however only handle relatively small problems and simple disease models. In this project we assess the validity of our approximate inference methods for this application. This research is done in collaboration with the department of antropogenetics of the KUN and is funded by STW.

Music perception

When music is performed, expressive timing and tempo changes causes deviations from exact timing implied by the score notation. Music recognition (understanding what is being played) requires to model timing deviations from a strict mechanical template. We use HiddenMarkov Models with both discrete and continuous variables to model the score and tempo through time, respectively. With our methods it is possible to generate notations from performed music in real time. This research is done in collaboration with the NICI MMM group and is funded by STW.

Data mining

To find the most useful information in large data sets requires a complex interplay between what is suggested by the data (learning) and what is known by the domain expert (rules). We are developing a tool that supports this difficult process. The tool proposes (partial) graphical structures between variables as suggested by the data. These structures can be accepted, rejected or edited by the human domain expert. This research is funded by STW.

Research projects in collaboration with industry are:

Newspaper prediction

JED is a commercial product for prediction and optimal distribution of newspapers. It has been sold to De Telegraaf and to Midesa, the distributor of the newspaper Público in Portugal.

Retail prediction.

We performed a market basket analysis for C1000; Prediction of consumer demand and algorithm development for Ahold; Prediction of personnel demand for Vendex; Prediction of weather dependence for Riedel.

Financial modeling

Credit risk management model for Simplex CA in Hongkong.

Product failure diagnosis.

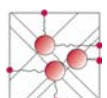
Based on the Promedas technology, an expert system was built to support diagnosis of bearing malfunctioning for SKF. This system is operational through SKF intra-net world-wide.

Agriculture.

Quality prediction of seeds based on visual features for Syngenta.

Process monitoring

With the Kenniscentrum Papier en Karton we are building tools for visualization the high-dimensional sensor data of a paper production process. The aim is to optimize control and to prevent failure such as paper break.



The group is engaged in theoretical and applied research on optimization and search using evolutionary and genetic paradigms. Current projects are on the topics Evolutionary approaches to optimization; Self-adaptive software; Data mining; DNA computing; Optimization and search for Drug design; The group consists of 9 researchers.

Solving difficult optimization problems

In practice, there is a large number of difficult optimization problems. These problems are typically characterized by properties such as non linearity's, multi modality (i.e., existence of many local optima), large dimensionality, discontinuities, or noise. Inspired by the success of organic evolution, searching a combinatorial space of vast size (DNA-sequences of up to 4 billion symbols from a 4-letter alphabet C,A,G,T), evolutionary algorithms try to imitate this process on a computer to evolve high-quality solutions. Evolutionary algorithms are search and optimization algorithms gleaned from the model of organic evolution, involving concepts such as a population, recombination, mutation, and selection operators. In a variety of practical applications and large experimental comparisons, evolutionary algorithms have demonstrated that they are well suited for a certain niche of application tasks, because of their capabilities to

- effectively combine properties of global and local search procedures, e.g. by exploiting the population structure and hybridizations with other methods,
- adapt their strategy parameters to the properties of the actual problem,
- make intermediate solutions available all the time during the course of the optimization run,
- seed the optimization run by using already existing knowledge about promising regions of the search space, and
- adapt to changing objective function topologies on-line during the optimization process.

Self-adaptivity is one of the key discoveries in the field of evolutionary computation, originally invented in the framework of the so-called evolution strategies.

The concept enables the algorithm to dynamically adapt to the problem characteristics and even to cope with changing environmental conditions - as they occur in unforeseeable ways in many real-world business applications.

In evolution strategies, self-adaptivity is generated by means of an evolutionary search process that operates on the solutions generated by the method, as well as on the evolution strategy's parameters and configuration, i.e., components of the algorithm itself. This concept therefore enables the algorithm to adapt itself to varying conditions of its environment, which is a desirable property for software in general. Therefore, a deeper understanding of the principles underlying self adaptation is desirable and will have an influence to fields outside evolutionary computation as well.

Genetic Programming complements the self-adaptive principles of evolution



strategies from the automatic programming point of view. Genetic Programming is a label for that set of Evolutionary Algorithms which, for the purpose of quality evaluation, represent a potential solution to a decision problem as a computer program. The quality of a located potential solution is calculated from the behavior the representing program exhibits during its training on data modeling the given problem.

Ultimately, we focus on a phenomenon we call antipoetic programming, i.e., the emergence of self-maintaining algorithms in a noisy working memory which exhibit problem-oriented behavior.

Data mining tool Daisy

Data mining is concerned with the analysis of large amounts of data. Usually these data are gathered in some automated fashion, for instance in the case of market basket analysis. In Leiden we have a special interest in the application of techniques from adaptive intelligence, such as neural networks and evolutionary programming. The main goal of data mining is to extract (possibly unanticipated) information from the data. Interesting topics are classification, including clustering and prediction. We are particularly interested in association rules: these rules try to find statically significant if-then rules in large datasets. The rules can be used to understand what is happening, and provide, e.g., the management with proper information about business processes such as purchase behavior. In many cases the programs find their own route through the problem space, but for most applications it turns out to be important to have human guidance during the process. Human experts are always necessary to raise the questions - and to interpret the answers.

During the BTS-Project 'Data Integration and Data Mining (BTS98040) a prototype Data Conversion and Data Mining Tool called 'Daisy' was developed. It uses parsing techniques to convert and integrate legacy data systems into modern data warehouses. Further, these data warehouses are used by the tool for data analysis and mining using statistical and evolutionary algorithms. Results can be visualized in table form and higher dimensional graphs.

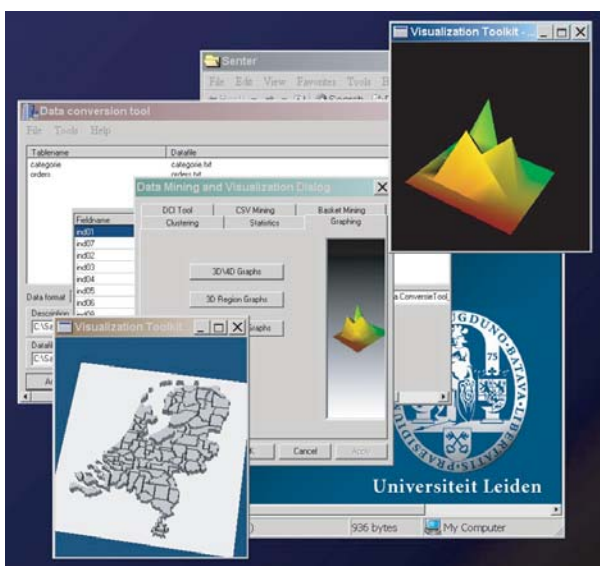
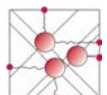


Figure 16
Screenshot of the Daisy tool



From Sequence to Function

G protein-coupled receptors (GPCRs) are the target of the majority of today's medicines. These receptors are membrane-bound proteins that serve as anchor points for hormones and neurotransmitters. Given their importance it is remarkable that we know relatively little about their actual 3D structure. This knowledge gap frustrates the traditional triad in protein research, i.e., that sequence determines structure and structure determines function. The aim is to use adaptive intelligence techniques to efficiently search in vast search spaces - such as the human genome - to the field of drug target validation. In particular, the work aims at using these methods for directly linking receptor sequence with receptor function, thereby avoiding the difficult structural element mentioned above. This project is funded by NWO.

Data Mining on semi-structured data

Semi-structured data arises when the source or the environment does not impose a rigid structure on the data and when data is combined from several heterogeneous sources. Examples include the WorldWideWeb and bioinformatics databases; the situation also occurs in data warehousing. Unlike (nearly) unstructured raw data such as image and sound, semi-structured data has some structure: objects share (parts of) their structure. Most data mining algorithms are not designed for semi structured data and should at least be adapted in order to deal with such data. The objective of the project is to do research on foundations of efficient and effective mining algorithms with a focus on tree- and graph-structured data.

Evolutionary DNA Computing

Molecular computing studies the use of molecules that store and transmit information in living cells for attacking various computational problems. DNA may be suitable for dealing with optimization problems which require huge search spaces but relatively simple operations. In order to solve problems of realistic sizes, laboratory procedures must become both less error-prone and much faster. The latter is being achieved by increased automation and miniaturization in molecular biology, including advanced liquid handling robots, DNA arraying techniques and single molecule detection. Errors are harder to avoid, since many biochemical procedures are intrinsically noisy. We "attack these errors using adaptive intelligence techniques, using evolutionary computing in which errors can be used as a mutation mechanism. This project is funded by NWO.

Evolutionary Algorithms in Physics

Many problems in physics depend in a complex way on a large number of parameters. Such problems can often be studied by using an evolutionary approach. Here the response of the system of interest is studied in a closed loop that is controlled by an evolutionary algorithm. The algorithm manipulates the parameters and tries to determine the optimum combination of parameters for achieving a goal defined at the start of the experiment. We learn about the underlying physics by interpreting the set of parameters determined by the evolutionary algorithm, rather than by performing experiments with controlled variations of these parameters. We apply this approach to experiments on the interaction of intense shaped femtosecond laser pulses with molecules and

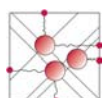


clusters, where the number of independently tunable parameters describing the laser pulse shape can be as high as 640. This project is in cooperation with the AMOLF institute.

Evolutionary Algorithms in industry

A rich diversity of practical optimization problems with industrial relevance are solved very successfully today by means of evolutionary computation techniques. Often, traditional technologies fail to tackle such problems, because of difficulties caused by non linearity's, discontinuities, stochastic perturbations, numerical instabilities and dynamical properties of the objective function. Moreover, the search spaces can be mixed (integer / float) or even of varying dimensionality. We use our in-depth expertise on solving real-world optimization problems, including applications as diverse as:

1. dynamic traffic light and elevator control optimization (Rijkswaterstaat, Fujitec Co., Ltd.),
2. dynamic scheduling of airplanes for landing (Schiphol),
3. optical filter optimization, including aspects of robust design (Philips Research and Corning, Inc.),
4. design optimization in aerospace, automobile, chemical and food industry (EADS, GE Bayer Silicones, Unilever),
5. optimization applications in telecommunication (SIEMENS),
6. discrete optimization involving e.g. scheduling and constraint satisfaction problems (GE Bayer Silicones, Unilever).



3D

Pattern Recognition Group, Delft Technical University

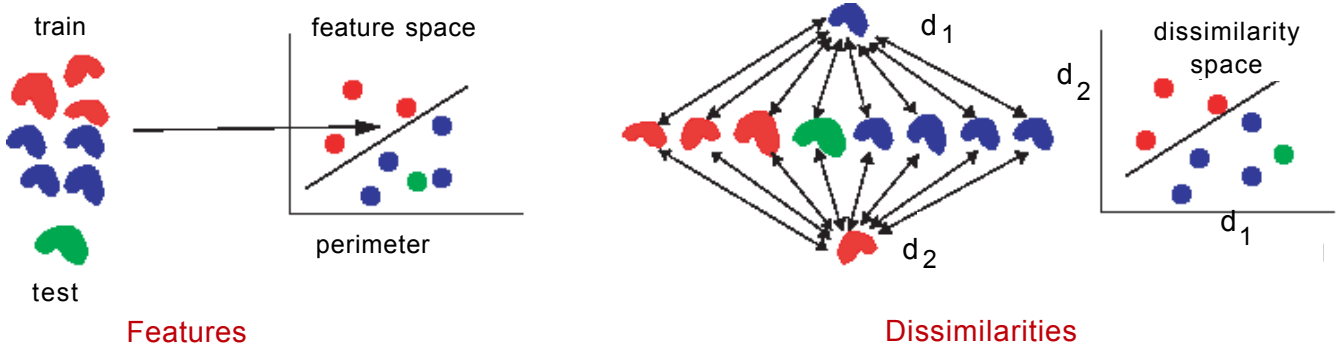
The topic of statistical pattern recognition has been studied for more than 30 years within the Delft Pattern Recognition Group. Since 1988 this research has been focused on an understanding of neural network classifiers and a comparison with traditional classification techniques. Recently, methods for novelty detection and combining classifiers have been studied. In addition the question of how real world objects can be optimally represented for recognition purposes receives more and more attention. As the research is focused on sensor based applications observing natural scenes it is called Sensory Pattern Analysis. Current projects are machine diagnostics; non-linear data analysis; multi-spectral image segmentation. The group consists of 8 researchers.

The first question to be answered in each pattern recognition application is: how do we represent a real world object or phenomenon in a computer, in such a way that we can learn from a set of examples of these objects. If a pattern has to be found we want to know more than just a database of objects. The pattern, to be found in this database, has to give us insight in what is common, what is characteristic, what are interesting features for describing the objects and how to detect whether a new object belongs to a previously defined pattern class.

Various representations are studied. Which one to choose is heavily dependent on the expert knowledge of the user who wants to find the patterns in his data. If he is able to define good features, i.e. characteristic attributes or measurements, then they should certainly be chosen for representation. We found, however, that in many applications, including the traditional pattern classification problem of optical character recognition (OCR) other representations, like the use of dissimilarities, may show significant improvements. In this case the user has to define a distance measure between objects. Also in other applications like the recognition of spectra, dissimilarity measures are very useful.

Very often a set of examples is not representative in the statistical sense. E.g., if we want to study the normality of the behavior of a car, or a collection of medical data, we may have access to various examples, but only rarely the distribution of these examples agrees with their probabilities of occurrence in reality. It is possible that there is a relatively small set of examples of the

Figure 17
The traditional feature based representation (left) and the new proposed dissimilaritybased representation (right).



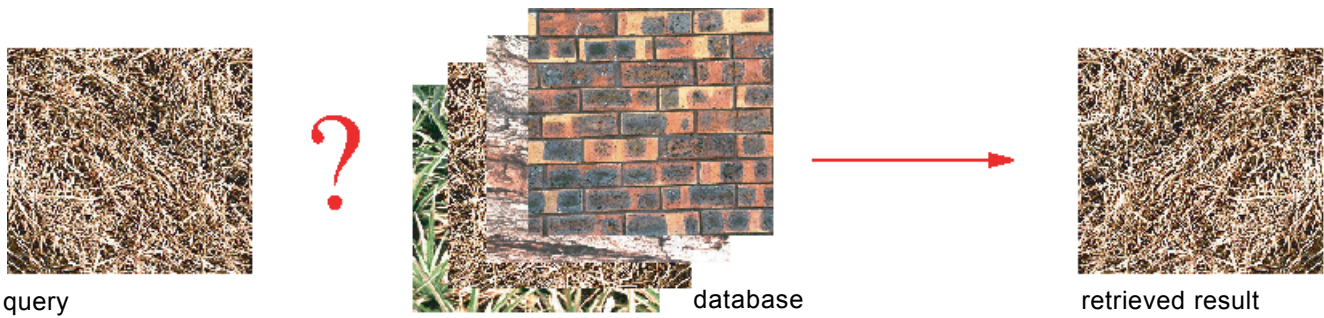


Figure 18
Image database retrieval by query image

average case (why should there be more, they are very alike), while typical, but improbable pathological cases have too many examples in the dataset. It is also possible that we have just examples of normal behavior and no or very few examples of abnormal cases, a common situation for patient monitoring in a hospital. We found a good, robust solution for these pattern recognition problems, using the technique of so-called one-class classifiers.

We studied two interesting applications of one-class classifiers: image database retrieval and demining. In image database retrieval, the patterns detected in a query image are used to 'classify' the database and images with strong hits are selected. In this case it is very clear that no statistics in the query image are valid for the database.

In the demining problem one needs to detect personnel mines hidden in the soil, even when no good examples of them are given. So a description of the soil is learned (using infrared imaging) and an alarm is generated if an object is detected that does not fulfill the known pattern. In this example also the technique of active learning is important. Objects with an unknown pattern, like a fruit juice tin, generate an alarm at the first instance. Its pattern may be learned and after a few other instances it is not unknown any more and no alarms are made.

In an application study on animal behavior we successfully applied nonlinear data analysis techniques that make use of the fact that, in spite of the complexity

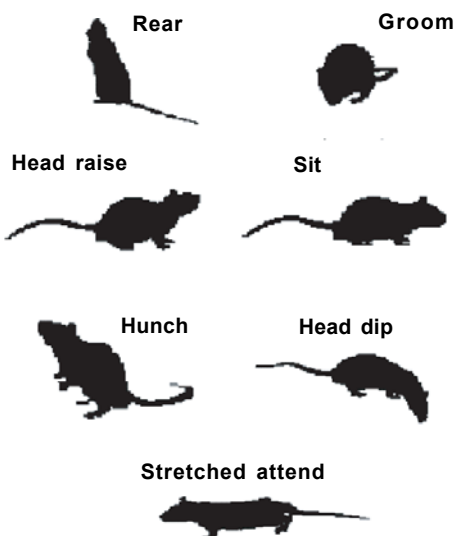
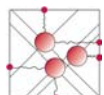


Figure 19
Some of the behavioral classes to be distinguished



of the pattern of a moving animal, its evolution in time has intrinsically a one-dimensional structure: Time is just one-dimensional, so a continuous series of pictures follows a one-dimensional path. Also in other applications, the use of the inherent structure in the observations is fruitful. In a study of tumor detection in lungs and mouth techniques for using the continuous connections of the wavelength in auto fluorescence spectra are developed.

In a project on hyper spectral imaging we combined spectral and spatial connectivity in the data to enable a fast and cheap segmentation. Projects on learning and adaptive intelligence in the Delft Pattern Recognition Group, see also <http://www.ph.tn.tudelft.nl/Research/neural/>

Dissimilarity-based Pattern Recognition

For learning purposes, objects are usually represented by features. Defining welldiscriminating features for a given task, is not trivial, and sometimes not even possible. An alternative is a representation built by using the concept of dissimilarity (distance). An object is then characterized in a relative way, i.e. by its dissimilarities to a set of prototypes. The use of dissimilarities is especially appealing when features can hardly be defined in a natural manner, e.g. when some particular characteristics of objects or measurements, like curves or shapes are considered. The use of dissimilarities, built directly on measurements, e.g. based on template matching, is then of interest.

One-class classification

Three types of one-class classifiers are distinguished, (1) the density estimators, (2) the boundary estimators (the support vector data description is considered a boundary method) or (3) the reconstruction methods. The choice depends on the distribution, on its type, as well as on whether it is well represented by the dataset or not. When the data is representative for the distribution, density methods will perform well (also assuming reasonable sample sizes). In the case of an unknown outlier distribution, the density methods completely fail and the boundary methods are to be preferred. Finally, when the generating model behind the data is known (or approximated with reasonable precision), it is usually better to use this model and apply a reconstruction model to detect outliers.

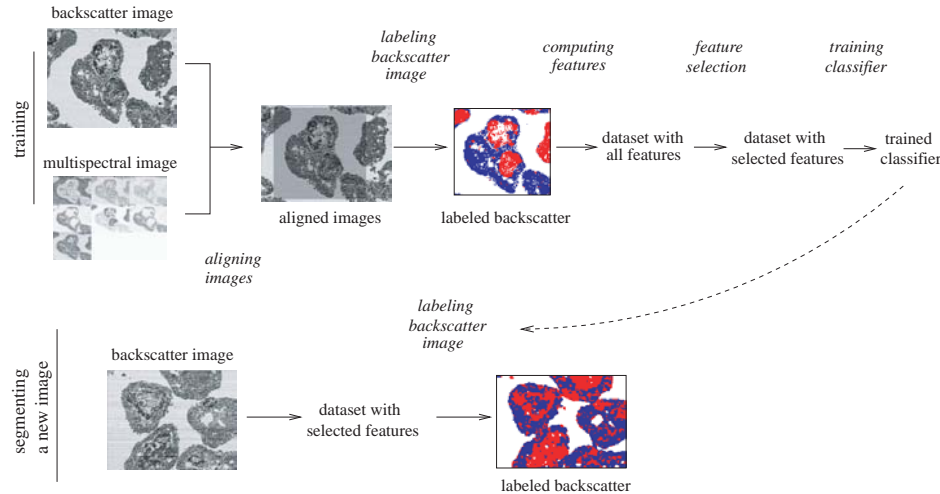


Figure 20
The automatic segmentation of cheap backscatter electron-microscope images (below) as trained by expensive multi-spectral images (top)



The foundations for the one-class classifier approach are studied and its use will be illustrated by some applications.

Improving endoscopic detection of lung cancer using auto fluorescence spectroscopy analyzed by a neural network

The aim of the project is to improve endoscopic detection of lung cancer by combining the high sensitivity of endoscopic fluorescence imaging with the excellent specificity of auto fluorescence spectroscopy analyzed by neural network. So, lesions will be detected with fluorescence imaging, spectroscopic information is obtained from each lesion and the selection of the malignant ones is found by neural networks.

Tools for nonlinear data analysis

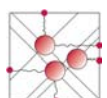
Current computerized measurement systems and data acquisition systems deliver a huge amount of data. Because sensors are often measuring on the same physical phenomenon, the intrinsic dimensionality of the data will in many cases be lower than the dimensionality of the data itself and only depend on the degrees of freedom of the observed phenomenon. If the dimensionality of the measurement space is not reduced correspondingly by some mapping, the outcomes of any analysis of the measurements may suffer from an increased noise resulting from more sensor signals, instead of taking advantage of the increased information or resolution. Feature extraction thereby becomes more and more important in relation with increasing sensor capabilities. However, standard analysis packages are often limited to linear projections, while the data not necessarily resides on a linear manifold. We study this problem in relation with a specific application in animal behavior observation.

Multi-spectral and hyper spectral image segmentation

A hyper spectral image offers full spectral information in each pixel of the image. Different parts of the spectra offer different information of the underlying spatial structures. This project concentrates on the case that the observed spectra are noisy (e.g. when obtained by electron microscopes) and the structural knowledge has to be derived from a series of objects from the same physical origin (e.g. a number of particles obtained by the same chemical or physical procedure). In this situation it is necessary to fuse statistical, spatial and spectral information. This is the more challenging as the spectra are given in their raw, almost continuous representation. It is aimed to constitute a software toolbox that enables an analyst to interact with series of hyperspectral images in such a way that the three mentioned information sources and his expert knowledge may be combined into the final analysis and physical description of the observed spatial structures.

Industrial Pattern Recognition Courses and Software

Two highly interactive, one week courses for small groups (4-10 participants) are frequently organized. See <http://www.ph.tn.tudelft.nl/Courses/PR/>. W Pattern Recognition System Design: applications and the overall design of a system. W Advanced Pattern Recognition: in depth discussion of modern pattern recognition techniques like support vector machines, one-class classifiers and dissimilarity representations. The main software tool for these courses, PRTools, is commercially available. See <http://www.ph.tn.tudelft.nl/prtools/>.



3E

Institute for Knowledge and Agent Technology (IKAT), University Maastricht

IKAT's research is organized in five main research groups: agent technology, neural networks and adaptive behavior, search and games, public services and knowledge management. Neuro-computational and machine learning methods are mainly employed in the neural networks and adaptive behavior group, and to a lesser extent in the agent technology and search and games groups. Current projects in this group are recognition of paintings; communication and behavior in multi-robot systems. The group consists of 6 researchers.

EIDETIC

The EIDETIC project is concerned with content-based image retrieval. The project is a collaboration of the Delft University of Technology, the Technical University Eindhoven, the Catholic University of Nijmegen, and the University Maastricht. The EIDETIC research at IKAT focuses on the automatic detection of object classes using advanced pre-processing and support vector machines. (See <http://www.cs.unimaas.nl/~postma/Token2000> for more details.) The EIDETIC project is funded by NWO as part of the Accessibility and Knowledge Retrieval in the Netherlands 2000 (ToKeN2000) program. ToKeN2000 is an interdisciplinary research program in which cognitive and computer science focus on fundamental problems of interaction between a human user and a knowledge and information system.

Adaptive Robots

The research on adaptive robots is concerned with the application of neural-network and evolutionary-computation techniques to (real and simulated) robots placed in a realistic environment. In the project we have investigated the evolutionary development of complex behaviors in neural-network controlled robots. In particular, we study how and to what extent various forms of memory enhance the adaptive behavior of the robots. (See <http://www.cs.unimaas.nl/~postma> for more details.) Part of the research on adaptive robots is funded by NOW's Cognition program.

Multi-Agent Diagnosis

In the Multi-Agent Diagnosis project, IKAT collaborates with the Delft University of Technology, the University Utrecht and the Dutch National Aerospace Laboratory (NLR). The project aims (1) at analyzing the complexity of multi agent diagnosis in case (possibly inconsistent) knowledge is distributed over the agents, and (2) at developing protocols for efficiently establishing diagnoses. (See <http://www.cs.unimaas.nl/~roos> for more details) The Multi-Agent Diagnosis project is funded by STW.

Interoperability: agents learning ontology mappings

Interoperability: agents learning ontology mappings In the interoperability project, we investigate how agents can learn a mapping between their idiosyncratic ontology's without using domain knowledge. For instance, two agents may represent addresses of the same person in different ways. The learning method is inspired by language games that enable agents to learn a common ontology through communication. The method requires that a small number of the instances of corresponding concepts (e.g., the names in the address) in the two ontology's denote the same entity in the world. Through the application of adaptive information retrieval techniques pairs of instances denoting the same entity are detected. The instances are mapped



onto each other by generating associations between attributes of concepts. (See <http://www.cs.unimaas.nl/~roosfor> for more details.) Part of the interoperability project is funded by NWO.

Learning in games

Two research projects apply adaptive intelligence to board games. The first project investigates the application of machine-learning techniques to the game of Go. In the second project, neural networks are applied for enhancing search decisions in the game of chess. (See <http://www.cs.unimaas.nl/~uiterwyk/cg.htm> for more details.) Both learning in games projects are funded by NWO.

Machine learning for Law

In a number projects, applications of adaptive intelligence for Law Enforcement and the Judicial System are investigated and developed. Below we mention two examples. (See <http://www.cs.unimaas.nl/~verbeek/> for an overview of relevant publications.)

Data mining and criminal investigation

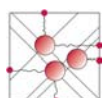
The project data mining and criminal investigation has been carried out within the framework of the national program Information Technology and Law (ITeR) (<http://www.nwo.nl/iter>). The research takes into account the privacy and criminal procedural limitations that need to be set with respect to the use of data-mining techniques. Criminal investigation authorities need to know these limitations when operating within the framework of the criminal investigation task. In the study we examine the meaning of the existing legislation for the data-mining process and deal with the question which aspects of the current legislation need to be revised. We depart from the present legal viewpoints.

NORMA+

To reinforce the activities of the Advisory Board Open Borders (Advies Commissie Open Grenzen; ACOG) the Department of International Police Cooperation of the Dutch Home Office (www.bzk.nl) granted financial support to a research proposal investigating the existing legislation in Belgium and Germany on the (im)possibilities of linking computer networks held by the police and on the cross-border use of multimedia databases. The NORMA+ project is a sequel to the NORMA project, published as issue 19 of the ITeR series under the title Politie en Intranet. The granting of subsidies was based on the program for cross-border police cooperation (GROS). The research on Machine Learning for Law is funded by European and national institutions.

Machine learning for Health Care

Two of IKAT's research projects focus on the application of machine learning to health care. The first project is performed in close cooperation with the Faculty of Health Sciences of the University Maastricht. A data warehouse has been developed for the regional registration database of Huisarts praktijken. Advanced machine-learning techniques are applied to the database to discover novel relations among registered diseases and complaints. The second project is performed in close collaboration with the Department of Pathology of the Atrium Hospital in Heerlen. The aim of the project is to apply machine-learning techniques for automatic analysis of flow cytometric measurement of tumors to generate consistent advise for therapy. Both projects are performed together with the MEMIC of the University Maastricht. The flow cytometric-analysis project is funded by the Atrium Hospital in Heerlen.



3F

Evolutionary Systems and Applied Algorithmics; CWI, Amsterdam

The CWI group SEN4 is part of the software engineering cluster of the Netherlands Center for Mathematics and Computer Science (CWI). The group currently consists of 9 people, including senior staff, post-doctoral fellows and PhD students. The group is headed by Han La Poutré, and is concerned with research on a range of aspects in adaptive agent systems.

The activities of the group are focused on research intelligent adaptive agent systems, where an important part of the work is concerned with bridging the gap between fundamental research and applications via joint projects with industry and technological institutes. For more information, consult the SEN4 website: <http://www.cwi.nl/sen4>.

Intelligent Adaptive Agent Systems

Many processes in society are best described as the interaction of (semi-) independent entities, *agents*, where these agents adapt their behavior to that of other agents and to the rewards and penalties their actions entail. The same descriptions also apply to many business practices, and even to models of Intelligence: the collective actions and behavior of individual, interacting and interdependent “agents” together produce desired or suitable outcomes. In a business, this result may be the correct functioning of a supply chain through the concerted actions of the parties involved; in an intelligent system, this result may be a recommendation of a product to a customer (see below). Insights into the functioning and design-constraints of effective agent-systems are thus important to areas ranging from (business) economics and social studies to cognition and machine learning.

In computer science, agent-based systems can be simulated or build using the concept of “software agents”, where pieces of adaptive software represent real (human) agents. Using the paradigm of software agent systems, many interesting questions can be researched, from the smallest scale of designing algorithms that make individual software agents “smart” (adaptive), to the design of multi-agent systems for new forms of business procedures and/or automation of existing ones, to the largest scale of the study of simulated agents systems and the influence of social or economic factors on their collective behavior (Agent-based Computational Economics).

In the Intelligent Adaptive Agent Systems research, all these scales are addressed, where for the adaptive “internals” of software agents machine learning techniques are developed, ranging from traditional discrete algorithms and finite state machines, to advanced “biologically inspired” methods like neural networks and evolutionary algorithms. The design of efficient systems of agents to collectively perform particular tasks highly depends on the proper *incentive structures*: the way individual agents interact with the outside world – and how they learn from it – has to be structured such that all agents contribute to the common cause.

Here, we borrow from the economics fields of *game theory* and *mechanism design*, using for instance *market mechanisms*. In *market-based programming*,



a system of agents is setup such that the individual agents compete in a market for a scarce resource, like the right to change the temperature in a part of a building. If properly setup, the collective of agents can then learn to participate in the market such that a situation is reached where all agents achieve their goal as best they can (and the inhabitants of the building are best served with a suitable temperature). Some of the practical applications of Adaptive Agent Systems we are described in section 3: a financial news service developed in cooperation with ING and TNO and a system for efficient distribution of cargo transport on the road.

CIM: Cybernetic Incident Management.

CIM, funded as a CIC “doorbraak”-project (CIC: “Competing with ICT Competences”), aims to improve the coordination of relieve efforts in disaster management using software techniques. Partners in the project are Almende, Delft University of Technology, Free University, Group4Falck, and CMotions. The project will start for SEN4 by the end of 2003.

EESEM – Evolutionary Exploration Systems for Electronic Markets.

Funded by NWO, this research is done in cooperation with Eindhoven University of Technology.

FREA – Fundamental Research on Economic Agents and on Evolutionary Algorithms.

Research-topics in this basic research line concern constraint satisfaction using both classical techniques and evolutionary computation, the development of algorithms for real-life negotiations involving multiple parties with different preferences for different issues and bargaining strategies which change over time. Such a dynamic environment (with imperfect information) was studied with a multi population evolutionary algorithm (EA). The FREA project also contributed to the more fundamental aspects of the DEAL and ASTA projects.

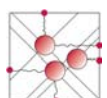
FRNN – Fundamental Research on Neural Networks.

Fundamental research was performed in the area of Spiking Neural Networks, novel and promising area within the field of neural networks that aims at creating more powerful neural networks based on our increasing understanding of how the real neural networks of the brain work. Examples include research on the development of Reinforcement Learning rules for spiking neural networks.

Within the ASTA project, FRNN research was incorporated for using neural networks in an on-line learning agent-system, where the neural network calculates bids in an auction.

FS – Financial Systems.

This projects researches pricing of complex financial derivatives. The use of certain techniques from high energy physics, in particular the formulation of pricing problems in such a way that numeraire invariance’s becomes manifest, has led to significant simplifications in the theory. Cooperation’s with financial institutions consider practical applications of this work, as well as potential future directions.



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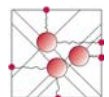
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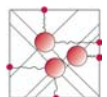
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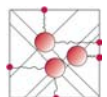
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