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eunite Roadmap

Smart Adaptive Systems: State-of-the-art and challenging new applications and research areas

Edited by Kauko Leiviskä

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EUNITE, the European Network of Excellence on Intelligent Technologies for Smart Adaptive Systems is funded by the Inrormation Society Technologies Programme (IST) within the European Union's Fifth RTD Framework Programme

Foreword

EUNITE, the **Eu**ropean **N**etwork on **I**ntelligent **Te**chnologies for *Smart Adaptive Systems* started January 1st, 2001 with the following target setting:

a) "to join forces within the area of Intelligent Technologies for better understanding of the potential of hybrid systems and to provide guidelines for exploiting their practical implementations and particularly,
b) to foster synergies that contribute towards building *Smart Adaptive Systems* implemented in industry as well as in other sectors of the economy."

One of the main deliverables of EUNITE is the Roadmap. It was defined as follows: "to describe the state-of-the-art and the vision for the *Hybrid* and *Smart Adaptive Systems"*. This Roadmap should be considered in close connection with existing Roadmaps of Networks of Excellence in Intelligent Technologies (ERUDIT, NeuroNet, MLNet, Evonet, CoIL) and give decision makers and all workers of the area the insight as to where these technologies are going and what solution potential they include." It should reflect the global vision of the network, as an entity, on the development of technology, markets, education and the way to influence it. It should also point out research interest on finding solutions for important problems related to hybrid and adaptive systems and to significantly influence the quality of everyday life. What is also important, together with other documentation from EUNITE it should also provide a practical guideline for the non-expert that he can consult on what Intelligent Technology (or a combination of them) is appropriate for his problem.

Roadmap work was done in committees. Therefore, it is structured according to the committee structure and separate Roadmap contributions from RTD and IBA committees were done. This paper is a summary of the committee contributions.

Oulu, January 2004
Kauko Leiviskä

Executive Summary

EUNITE, the European Network on Intelligent Technologies for Smart Adaptive Systems had two targets, first, to join forces within the area of Intelligent Technologies for better understanding of the potential of hybrid systems and to provide guidelines for exploiting their practical implementations and particularly, to foster synergies that contribute towards building Smart Adaptive Systems implemented in industry as well as in other sectors of the economy.

One of the main deliverables of EUNITE is the Roadmap that was to describe the state-of-the-art and the vision for the Hybrid and Smart Adaptive Systems. It should reflect the global vision of the network, as an entity, on the development of technology, markets, education and the way to influence it. It should also point out research interest on finding solutions for important problems related to hybrid and adaptive systems and to significantly influence the quality of everyday life. This report is a summary of the Roadmap work, concentrating on the state-of-the-art and vision.

A smart system can be defined shortly as follows: “Smart system is aware of its state and operation and can predict what will happen to it. This knowledge can also lead to adaptation.” On the other hand, a Smart Adaptive System (SAS) has the following characteristics: “A SAS can (i) Adapt to a changing environment (ii) Adapt to a similar setting without explicitly being “ported” to it and (iii) Adapt to a new/unknown application.

The most existing applications of smart adaptive systems belong to the first level SAS. The increasing complexity and requirements for more self-managing options will mean the development towards the higher levels of SAS. Most practical applications take advantage of integrating two or more methods, neuro-fuzzy approach being, however, the one with the most worked-out theoretical background.

There are some common features in processes and systems that utilise SAS and IM:

- tighter quality requirements: high quality products and services, possibilities to customise the products depending on the customer.
- high throughput: high capacity requirements from the process, mass productisation, services offered to big audiences (e.g. in Internet) or to a high number of customers (traffic).
- increasing complexity: a high number of processes, mills, customers, products; services offered to high number of customers with varying customer profiles, needs and capabilities.
- capital intensive systems: high economical risk in production decisions.
- rapidly changing markets: needs to adapt to changing environment, customer needs, economical situation.
- safety critical applications: high technological risk in production and high requirements for reliability in offering services, fast/complicated processes, high economical risk in offering services, misuse, fraud.
- innovative companies/company imago
- market push: from technology companies/intelligent products.

Even though applications of integrated, hybrid systems are common, one of the major scientific challenges consists of providing integrated computational theories that can accommodate the wide range of intelligent systems. As their applications increase in numbers, there will also be a greater need for more sophisticated complexity control mechanisms. Research today pursues along several dimensions: integrating systems that support different capabilities, combining theories and methodologies that concern different facets of intelligence, and reconciling, accommodating and exploiting ideas from various disciplines. All of these dimensions also pose significant scientific and engineering challenges.

Three areas are essential in the development in production industries. Soft sensors are needed in difficult measurements and sensor fusion is one way to realise them. Intelligent monitoring is getting more and more important as the amount of information increases and the need for personalised interfaces rises. Performance and condition monitoring are also promising areas for (also higher) level SAS. Safety criticality is increasing importance when processes and system grow in size and in complexity.

In transportation, problems are seen in slow rate of applications. Promising research areas are in air and water transportation, as well as developing planning and evaluation tools.

Congestion control remains the challenging research topic in telecommunications. SAS has also a big role in the development of tailored, flexible multimedia systems that can follow user preferences and adjust their operations according to them. One important issue here is the representation and handling of the uncertainty that is conveyed in all the classification actions of user profiling and updating.

Sensor fusion, fault recovery and alarm handling require SAS in medical applications. Safety criticality is an important driver for the research and validation methods are needed. Huge data requires also new methods. Increasing number of eHealth applications also call for results from the abovementioned flexible multimedia.

SAS and hybrid intelligent systems will also be inherently included in our everyday actions. They will help in planning and learning our everyday tasks – house cleaning, cooking, shopping, answering the telephone and also in communicating with electronic information sources, mostly with Internet. They are also needed in keeping record and monitor one's personal "database", that is more or less distributed including medical history data, economic and insurance data, personal history consisting of photos, videos, etc. They are also reflected in the house one is living – controlling temperature and lightning together with security and alarming, not even to speak about entertainment. This all requires that the applications become more and more flexible and adaptive, i.e. self-managing; we cannot simple teach everyone to be a computer specialist.

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Appendix 1: List of Roadmap Materials
Appendix 2: List of Contributors

1 Introduction

The target setting for EUNITE, the **Eu**ropean **N**etwork on **I**ntelligent **Te**chnologies for *Smart Adaptive Systems*, was originally written in the following way[1]:

- "to join forces within the area of Intelligent Technologies for better understanding of the potential of hybrid systems and to provide guidelines for exploiting their practical implementations and particularly,
- to foster synergies that contribute towards building *Smart Adaptive Systems* implemented in industry as well as in other sectors of the economy."

The motivation for Smart Adaptive Systems was seen in the fact that while being powerful and contributing to increased efficiency of industrial processes, most solutions using intelligent technologies lack one important property: they are not *adaptive* (or not adaptive enough), when e.g. environmental conditions change. Hybrid Intelligent Systems have been increased in numbers, lately, but few theoretically sound methods exist which support the analysis and design of such systems. Usually, the design of systems of this nature is often characterised by ad hoc rules-of-thumb and extensive prototype testing. Also the question is to what extend these hybrid schemes improve the overall performance of the system and which combinations or architectures should have been chosen for optimal performance remains more or less unanswered.

One of the main deliverables of EUNITE is the Roadmap. It was defined in Annex 1 as follows: "to describe the state-of-the-art and the vision for the *Hybrid* and *Smart Adaptive Systems*". This Roadmap should be considered in close connection with existing Roadmaps of Networks of Excellence in Intelligent Technologies (ERUDIT, NeuroNet, MLNet, Evonet, CoIL) and give decision makers and all workers of the area the insight as to where these technologies are going and what solution potential they include." This version of Roadmap is written in this spirit

[1] Eunite Contract. Annex 1.

and more detailed discussions on Intelligent Technologies have been omitted.

Annex 1 defines roadmap objectives as follows:

- To reflect the global vision of the network, as an entity, on the development of technology, markets, education and the way to influence it.
- To focus research interest on finding solutions for important problems related to adaptive systems and to significantly influence the quality of everyday life
- To recommend for research, possible target areas and technological challenges.
- To analyse the business trends on a global scale with an outlook on the future scope and impact of the integration of Intelligent Technologies and the applications of Smart Adaptive Systems.
- To provide also a practical guideline for the non-expert that he can consult on what Intelligent Technology (or a combination of them) is appropriate for his problem.

The roadmap starts with the definition of the most essential terminology of the smart adaptive systems. Part of it was created during the Roadmap meetings and, naturally, different opinions still exist.

State-of-the-art and vision parts (Chapters 3 and 4) reflect EUNITE's committee structure and are mostly composed from the existing committee Roadmaps. Chapter 5 consists of short comments on other Roadmaps and relative work and Chapter 6 describes the penetration of Intelligent Systems and, especially, Smart Adaptive Systems, in different sectors of economy. Chapter 7 summarises the work.

There is also an html-version (to be updated more often) available from http://ntsat.oulu.fi together with the Committee Roadmaps.

2 Definitions

2.1 Comments on adaptive systems[2]

Sommerhoff (1950, pp 282-288)[3] gave one of the early descriptions of *adaptation*: “Speaking generally, it may be said that the notion of adaptation when applied to living nature refers to the widespread and striking *appropriateness*, which organic activities show in relation to the needs of the organism, and to the *effectiveness* with which organisms meet the demands made upon them by their environment. In the first place, the response must be to something, it must be evoked or called into being by some antecedent environmental event or state of affairs ... Secondly, the response can be called *appropriate* only in relation to the subsequent occurrence of some event or state of affairs towards the actual or probable occurrence of which we believe it to contribute effectively. This event or state of affairs is what is commonly regarded as the *goal* or *aim* of the response... In the third place, whether or not a given response is appropriate depends on the environmental circumstances which it meets and with which it comes to interact.”

This early formulation still contains most of the key aspects of adaptation and of what we understand as adaptive behaviour.

Ashby’s contribution is more distinct (1969, p 72)[4]: “... *adaptive behaviour* is equivalent to the behaviour of a stable system, the region of stability being the region of the phase-space in which all the essential variables lie within their normal limits.”

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[2] This part is based on Christer Carlsson’s working paper

[3]

[4] W.Ross Ashby, "Design for a Brain", Science Paperbacks, Chapman and Hall, London 1972.

Sagasti (1970, p 153)[5] builds on Ashby: "*Adaptation* – A system whose function it is to produce a class of entities Y is said to be *adaptive* if either of the two following conditions are satisfied:

- One or more modifications in the system's defining elements E (and/or relations R), which affect the system's potential production of Y, generate one or more changes in E (and/or R), such that the Y producing property of the system is preserved with at least the same level of efficiency. The initial structural modification(s) is (are) called *stimulus* and the subsequent ones *response* [structural adaptation].
- One or more modifications of the system's defining elements E and/or relations R generate a change in the function of the system, so that it will produce a different class of entities Y_1. These are more compatible with the new structure of the system in the sense that, after the initial modification of structure, the number of states of the system producing Y_1 becomes greater than the number of states producing Y. Therefore, after the stimulus, the efficiency of the system as a potential producer of Y_1 is greater than its efficiency as a potential producer of Y [functional adaptation].

There are four different forms of adaptation in Sagasti's classification:

- *External adaptation*, adaptive behaviour in the presence of a stimulus originated in its environment.
- *Internal adaptation*, adaptive behaviour in the presence of a disturbance located in the *object* of the system.
- *Darwinian adaptation*, adaptive behaviour when the response is directed towards modifying its *object*.
- *Singerian adaptation*, adaptive behaviour when the response is directed towards modifying its *environment*.

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[5] Fransisco Sagasti, "A Conceptual and Taxonomic Framework for the Analysis of Adaptive behaviour", General Systems, Vol. XV, 1970

Even if the early definitions of adaptation are from the 1950's and 60's they are still adequate today as can be seen from the description of the same phenomenon in the IIASA Adaptive Dynamics Network (ADN) program, which now is active. In this program, the adaptation of an ecological system is described in the following way: *the system is affecting its environment in order to induce desirable changes and then modifies its adaptive behaviour as a function of the input from environmental feedback loops*.

Control Engineering offers also a starting point in defining adaptive systems[6], when it defines adaptive controller simply as follows: "*An adaptive controller is a controller with adjustable parameters and a mechanism for adjusting the parameters*" Further on, Control Engineering applications are defined as:

- Gain scheduling, that adapts to known changes in the environment
- Model Reference Adaptive Control that adapts the system parameters so that it follows the model behaviour
- Self-Tuning Control that adapts the controller so that the system response remains optimal in the sense of an objective function.

We can carry knowledge about adaptive systems from control to other areas by analogy. An adaptive system is a rather well-defined concept within automatic control. Breakthroughs could occur by applying definitions, structures and theory to other areas such as management, transportation or healthcare. However, it should be remembered that Control Engineering methods are mostly concerned with *parameter adaptation* that is only one alternative when speaking about Intelligent Systems.

In Annex 1 an *Adaptive System* was considered in two senses:

- A system is *adaptive* if it can perform even in the presence of non-stationary environments that are reflected in significant smooth changes of the main characteristics in the data. Examples are

[6] Jantzen, EUNITE Kick-Off Symposium, Aachen, March 2001,

monitoring systems in the presence of tool wear, medical diagnostic systems in the presence of a changing population, or forecasting of dynamically changing time series.

- Another type of adaptivity is that required by systems that should be designed for one application class and must be transferred to several different instances of this application. Examples are monitoring or diagnostic systems that should run on different machines, which are of similar type but each having their individual characteristics. Adaptivity in this sense is closely related to reusability of models to minimise the efforts for development.

2.2 What are "Smart Adaptive Systems"?

"Smart" can be defined more or less as technologies included (fuzzy logic, neural networks, evolutionary computing, machine learning) because of "historical" reasons. Even the list of technologies is not complete. This chapter tries to define "smart" starting from the properties of the system. The chapter is more or less based on discussions in a Roadmap Meeting in Ipswich, September 15, 2001.

A short definition could be proposed:

"Smart system is aware of its state and operation and can predict what will happen to it. This knowledge can also lead to adaptation."

A more complete definition could be

"A smart system has a model of its own behaviour and not just a model of its environment. This means it does not only react to its environment, but it is also capable of predicting the repercussions of its own actions. It can predict how the environment will change and how that change will influence itself. It can use the results from its predictions to draw consequences for its own actions." [7]

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[7] "Smart" has also been defined as follows: "Generally speaking, if a machine does something that we think requires an intelligent person to do, we consider the machine to be smart." (Claude Doom, Get Smart, How Intelligent Technology Will Enhance Our World? CSC COM Consulting. 2002. See also Chapter 5.10)

There are several definitions for adaptive systems as written before. A short definition for the Smart Adaptive System comes from the draft of SAS Roadmap and from Anguita (2001)[8]:

“A SAS can:

- Adaptation to a changing environment
- Adaptation to a similar setting without explicitly being “ported” to it
- Adaptation to a new/unknown application.

The first level is the easiest form of adaptation and it concerns with systems that adapt their operation in changing environment by using their intelligence to recognise the changes and to react accordingly. The second level considers the change in the whole environment and the system’s ability to respond to it. The third level is the most demanding one and it requires tools to learn the system’s behaviour from very modest initial knowledge. It has been noted by Anguita (2001) that the boundaries between the three levels are very fuzzy: an environment can change in such a way to result in a completely different setting or even an entire new kind of problem to be solved..

How an adaptive system can become smart might be clarified by looking at an adaptive system for credit card fraud that would be able to detect new patterns in fraud it has never seen before. It would be able derive new actions that were not defined in advance. It would autonomously select and create an appropriate model for detecting new fraud patterns. In this sense it would also be capable of self-initialisation. This means that it can create an initial model for fraud detection and gradually improve it (it “grows” into the application).

The system would be generic in a sense that it can be ported to similar application areas without changing its internal structures and without

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[8] Anguita, D., (2001): Smart Adaptive Systems – State of the Art and Future Directions for Research. First EUNITE Annual Symposium, Tenerife, Spain, Dec. 13-14, 2001

adding functionality (second level SAS). According to the third level SAS, the effort of porting an adaptive system for credit card fraud detection to an area like insurance fraud detection would be restricted to specifying the terms of the new domain.

The system for credit card fraud detection would also be smart, if it can predict how fraud patterns and consumer behaviour could change depending on its actions and use this prediction to review and possibly modify its actions. For example, assume that there is a pattern that indicates fraud in 100% of the cases and causes the system to call the police in order to arrest the credit card user immediately. Further assume that due to change in consumer and fraud behaviour the system realises that the same pattern does not necessarily indicate fraud for every case. The system "knows" that informing the police when it is uncalled for would seriously offend a legitimate customer and could endanger business. Therefore the system would decide just to ask for a photo ID to verify the transaction and to deter fraud. The systems may have learned this kind of relationship from previous experience (i.e. police was called in non-fraud cases and subsequently business went down).

A simpler example could be given from Control Engineering: Adaptive system changes controller parameters so that the response always shows the required behaviour, e.g. 1:4 damping. A smart system knows the overshoot in is tolerated in some cases, but strictly forbidden in another. Smart adaptive system can also modify its operation or the control strategy and avoids the overshoot (for instance, because of safety reasons).

3 State-of-the-art

This chapter is more or less a summary of Committee Roadmaps, where also more detailed information is available.

3.1 Smart adaptive systems

Following text is based on Anguita's basic article (Footnote 8 before). Some editorial changes have been done.

Adaptation to a changing environment can be considered the basic characteristic of a smart system, and case studies collected during EUNITE's duration show that it is also easiest to achieve[9]. Perhaps the most advanced field on this topic is the broad area of Machine Learning (ML) where, as the name is proposing, the problem of adaptation through learning has been a core research issue for a long time. This is so true that some researchers suggest that ML systems are, in effect, Smart Adaptive Systems. ML covers both symbolic methods (decision trees and rules, etc.), sub-symbolic methods (neural networks, Bayesian networks, etc.) and has several connections with traditional statistics (discriminant analysis, regression analysis, cluster analysis, etc.).

Evolutionary Computation (EC) has started to address adaptation quite recently: examples are the adaptation of Genetic Algorithms to non-stationary environments, with adaptive and self-adaptive techniques, and the use of memory for storing good, partial solutions and reuse them later, when environmental changes occur. These evolving systems also often integrate other smart methods with EC.

Fuzzy Logic Systems have also been used in dynamical contexts: an example is the adaptation or evolution of rule-based models, treated as a learning process. Some applications combine traditional techniques with Fuzzy Logic to build adaptive control systems.

[9] For the case studies visit http://www.eunite.org or http://ntsat.oulu.fi. These case studies were collected in the beginning of EUNITE and the readers are encouraged to send their own proposals for case studies to the Editor.

In the field of Artificial Neural Networks (ANN), the problem of adaptation to a changing environment is well known and the term catastrophic interference has been commonly used to indicate it. Also a word of warning must be given concerning ANN. Most ANNs are built through the solution of an optimisation problem that finds the optimal weights and topology, according to a certain criterion. After this learning phase, the network is “freezed” and put to work. Unfortunately, using this approach, the behaviour of the network is completely defined by its learning phase and, even though the network shows good generalization capabilities, it cannot adapt if the environment changes. What is needed to call it SAS is to add smartness for the adaptation of ANN parameters or topology to reflect the changing environment. This definition for adaptive ANN has been used later in Chapter 3.6.

The adaptation to similar settings is a very interesting property that would avoid the explicit porting from one environment to another. Examples from ML that try to use a successful past solution and adapt it to a similar problem rely on the idea of reasoning by analogy. This is a principle that can be found in Case-Based Reasoning (CBR) systems applied to both simple and structured knowledge representations. A CBR system works along a cyclic process, retrieving the most similar cases, reusing the cases in the attempt to solve the problem, revising the proposed solution, if necessary, and retaining the new solution as a part of a new case.

Fuzzy Sets have also been used to build heuristics for solving classes of problems, and examples are reported where Fuzzy Sets are used for developing heuristic optimisation tools. Examples based on neural networks do not abound, however the subsymbolic approach of the ANN is a natural candidate for the embedding of neural computation on sensors and actuators.

The idea of a system that evolves by itself and finds autonomously the solution of a problem or suggests new ways to solve a problem (third level SAS) could appear visionary, at least. However, we could assign to this area the most of Data Mining research, as it tries to find new relations and information from a large variety of data. There is, however, some interesting and specific research in this area coming from both the ML and ANN field. If we relax the constraint of starting from zero knowledge, there are systems for knowledge revision and refinement: given an incomplete knowledge and a set of examples, they modify the knowledge to be consistent with the examples, therefore building new knowledge or, at least, improving the existing one.[10]

3.2 Integrated methods

The IM Committee concentrates on neuro-fuzzy systems, because it best fulfils the requirement for methodological integration. It must, however, be remembered that real-world applications almost always require a combination of several (intelligent) methods. Varying terminology is used and even the term "hybrid" is not so commonly used. The following text is modified from Detlef Nauck's original contribution.

The neuro-fuzzy technique is used to derive a fuzzy system from data. It can also start from fuzzy rules and enhance them by learning from examples. The exact implementation of the neuro-fuzzy model does not matter. It is possible to use a neural network to learn certain parameters of a fuzzy system, or to view a fuzzy system as a special neural network and to apply a learning algorithm directly to it. Learning algorithms are (usually) derived from neural network theory. The learning process is not knowledge-based, but data-driven.

Modern neuro-fuzzy systems are often represented as multi-layer feed-forward neural networks. ANFIS in probably the best known and it implements a Takagi-Sugeno fuzzy system in a network structure, and applies a mixture of the plain backpropagation and the least mean squares procedure to train the system. Mamdani-type fuzzy systems

[10] Anguita mentions also the Creativity Machine that aims at creating new knowledge from scratch. It is introduced by Thaler ("Virtual Input Phenomena", Neural Networks, 8, pp. 55-65, 1995).

usually require special learning algorithms because of non-differentiable functions included. Also other combinations are used, i.e. self-organising feature maps, fuzzy associative memories or just simply applying a learning procedure to define the parameters of the fuzzy system.

The status of the applications on Integrated Methods was already considered in the CoIL Roadmap[11]. Their research was based on a list of on-line bibliographies and they used as key words: neural, evolution, genetic algorithms, machine learning, fuzzy, case based reasoning, knowledge acquisition, data mining. The aim was to find publications that combined in their text at least two Intelligent Technologies. The overall picture was that this type of publications presented a period of hype during the mid 90's and since then, they declined.

Very low activity regarding applications of Integrated Methods was observed before 1990. The NN-EC integration in the late 80's refers to different methods of optimizing NN architectures: for example genetic algorithms were used to learn the appropriate set of weighted connections of a NN. Even earlier neuro-fuzzy systems were used in pattern recognition, inference systems, hardware implementations with neuro-fuzzy controllers and laboratory experiments. Machine Learning was used in some experiments with vector evaluated genetic algorithms.

During the period 1990-1995 evolutionary methods were used for auto-structuring Artificial Neural Networks and in general, Genetic Search methods were used for optimal representations of Neural Networks. Another application field was the optimization of Neural Controllers. Also Neural Networks and Genetic Algorithm were used to auto-design Fuzzy Systems. Simple combinations like the Fuzzy Perceptron, or Neuro-Fuzzy Controllers were very popular. Also there were examples of Neural Network driven FIS (Fuzzy Inference Systems) and Fuzzy-Neuro-GA Based Intelligent Robots.

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[11] G. Tselentis, M. van Someren, CoIL Technological Roadmap. See also Chapter 5.5.

After a period of active research a natural decline followed. However, some new applications came: Unsupervised Neural Networks for Fuzzy Clustering, Fuzzy Kohonen Neural Networks, Fuzzy Backpropagation Training of Neural Networks, Neural Fuzzy Agents for Profile Learning and Object Matching and Neuro-Fuzzy-Genetic Adaptive Control Systems. Majority of application references were related to FL-NN, mainly Neuro-Fuzzy controllers. But also FL-EC integration gave new applications, for example Genetic Evolution algorithms for membership functions and rules for fuzzy controllers, tuning of Fuzzy Controllers by means of Evolution Strategies etc.

During later years the interest of Integrated Methods has revived. Still the main interest stays in EC-NN and FL-NN and probably some more activity comes in ML-NN. Machine Learning seams to have some interactions with Neural Networks mainly in applications of data mining. CoIL Roadmap underlined that more research is needed on issues like optimum selection of methods together with benchmarking studies and theoretical work on the mathematical background of hybrid systems.

3.3 Production industry

This text is a summary of 2001 version of IBA A Roadmap written by Jukka Sivonen and Kauko Leiviskä[12]. Many industrial applications of intelligent methods, including fuzzy logic, neural networks, methods from machine learning, and evolutionary computing, have recently launched especially in cases were an explicit analytical model is difficult. In the following they are classified according to the usual control hierarchy starting from measurements (Software Sensors) and control systems, proceeding to diagnostics and quality control and ending to production scheduling.

Software Sensors are used in making the existing measurements more efficient or in replacing the non-existing measurements with software systems that form the measurements signals e.g. from other, existing

[12] http://ntsat.oulu.fi

measurements, laboratory analyses and a priori expert knowledge. Good example is the combining of information from several temperature or concentration measurements, e.g. from the blast furnace, to form a single measurement or the indication of the process state. Another possibility is to use process information to construct a Software Sensor for the non-existing quality measurement, e.g. in paper or biotechnical processes where on-line analysers are difficult to develop and expensive to install and maintain. Adaptation needs come from the necessity to correctly react to changing raw material quality, to different product specifications, or even to different processing alternatives. Systems easily gain the first level of adaptivity, but higher levels are more difficult. Portability is, however, important from the commercial point of view: generic solutions that guarantee long range of applications are needed.

Adaptive controllers must include two elements that make adaptation possible: detection system that reveals changes in process characteristics and the adaptation mechanism, which updates the controller parameters. Changes in process characteristics can be detected through on-line identification of the process model, or by assessment of the control response. Adaptation mechanisms rely on parameter estimates of the process model, e.g. gain, dead time and time constant. The choice of performance measures depends on the type of response the control system designer wishes to achieve. Alternative measures include overshoot, rise time, settling time, delay ratio, frequency of oscillations, gain and phase margins and various error signals.

Need for adaptive control comes from different sources. Changes in process conditions, raw materials, production rate or quality may require changes in control parameters. Multi-phase processes, i.e. fermenters, may require totally different models and control strategies for each phase. Here the moment when the phase change occurs is essential to know in order to make the change as smooth as possible. Multiple models, and adaptive strategies, are also needed in cases where there occur bigger changes in the state of the process.

Easiness of adaptivity depends on the control level – field controllers are generic tools that must apply to all possible applications, but the higher in control hierarchy we go, i.e. optimising controllers, the more difficult it comes to find generic solutions. Methods itself can be generic, but they need process knowledge to be successfully applied. This is especially applicable to rule-based systems.

The fault detection problem is, in principle, a classification problem that classifies the state of the process to normal or faulty. This is based on thresholds, feature selection and classification and trend analysis. Fault localisation starts from the symptoms generated in the previous stage and it either reports fault causes to the operator or starts automatically the corrective actions. In the first case, the importance of the man/machine interface must be emphasised. Actually this stage includes the defining of size, type, location and detection time of the fault in question.

Fault diagnosis is already a classical area for fuzzy logic applications. Compared with algorithmic-based fault diagnosis the biggest advantage is that fuzzy logic gives possibilities to follow human's way of diagnosing and to handle different information and knowledge in a more efficient way. Applications vary from troubleshooting of hydraulic and electronic systems using vibration analysis to revealing the slowly proceeding changes in process operation. A lot of technologies are used: neural networks, case-based reasoning, intelligent trend analysis, cluster analysis, etc.

Different methods are needed in data pre-processing. Vibration analysis uses spectral and correlation analysis to recognise the “fingerprints” of faults whereas regression analysis, moving averages or various trend indicators are used in revealing slowly developing faults. Especially for slow processes met in chemical, pulp and paper and biotechnical industries, temporal reasoning and trend analysis are very valuable tools to diagnose and control the process.

Changing process conditions together with changes in quality and production requirements lead to the need for adaptation. For instance, in surface quality testing of steel, change in the steel grade changes the patterns of single faults and it can also introduce totally new faults. This might require re-calibration of the camera system and training new patterns to the fault detection system. Very often the question is of the second level of adaptivity. The situation here is the same as in control: methods and algorithms are generic, but solutions include so much application-oriented features that the real third level adaptation is not usually possible.

Quality control within process industries is used both for registration of product quality as well as for direct feedback to the process control system. When product quality is used directly in the control of the process it is very important to have a measurement system that makes the quality figure available as fast as possible. Many quality control systems are based on computer vision. It is very interesting to note that Intelligent Methods are used extensively in almost all stages of computer vision process from sensing to scene interpretation. If the time delay is too long between taking a sample of the product and until the quality analysis is available, it is often necessary to base quality control on measurements, which are related to the product quality, i.e. Software Sensors. Also diagnostic information is used in many cases.

Quality control is very often based on modelling of relationships between continuous measurements and quality analyses. For processes, which are difficult to model mathematically, the techniques of neural nets, fuzzy logic and genetic algorithms are methods, which are likely to produce good results. Especially a combination of methods is a promising way to as good a quality control basis as possible.

If we look at quality control from SAS point of view, the question in several cases is of integrated, or hybrid, applications, where adaptivity plays a role in several levels: in sensor fusion at measurements level, on the field controller level, in supervisory controllers, in vision systems, in diagnosis. All comments given before are also valid here.

The short life cycles of customer products in modern electronics have brought along a new interesting case of adaptation. It is the need to adapt to the new product as fast as possible because short production series do not allow the collection of long history data. Usually it means the adaptation of the whole production starting from component selection and the board lay-out to intermediate and final acceptance testing and process control. Product organisation is a usual way to deal with this problem (mass productisation), but it has also given room to intelligent methods. They are used in “modelling“ the product histories and using these models to predict the quality performance of the new product.

The most applications in Production Industries represent the first level SAS. These applications will grow in number during next few years. Some use of the second level SAS could be charted within a short time horizon (5 years) and then CBR could show its power. The greatest hindrance for the third level SAS on-line comes from the safety aspects. It could, however, find usage in systems design and tune-up as an off-line engineering tool within a longer time horizon. Other possible applications are in Data Mining and Intelligent Process Analysis.

3.4 Transportation

This part is based on Jani Posio’s State-of-the-art report[13]. In past decades a variety of deterministic and stochastic models have been developed to solve problems encountered in complex traffic and transportation engineering processes. The models are developed in order to describe the real life phenomena as accurate as possible, even though many subjects in transportation engineering are often characterised as subjective, ambiguous and vague. Due to the fact that many of the problems of transportation engineering cannot be modelled with exact parameters and mathematical models, the fuzzy approach is found to be a promising method allowing the use of linguistic variables and subjective knowledge.

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[13] http://ntsat.oulu.fi

Forecasting traffic demand, trip distribution, route choice, assignment and modal split are traditional parts of traffic modelling. For all of these tasks, intelligent mechanisms are created. Fuzzy logic based self-learning systems have been tested for trip generation and distribution. Mode choice has been modelled with rules including passenger volumes and travel times and resulting an accessibility factor for a certain mode of transportation. Travel times and fuzzy rules are also applied to route choice and traffic assignment problems.

The *prediction* of traffic conditions is a vital component in an advanced traffic management and information system, and to make this prediction intelligent traffic simulation is needed. The prediction of the traffic conditions has been used in different ways, such as to influence travel behaviour, to estimate Origin-Destination matrix, to predict traffic flows and travel times and to reduce traffic congestion. Because of prediction problem, a lot of neural network applications exist.

Effective *classification* of the state of a transport system is very important for operating in an efficient way. For instance, there are systems for detecting traffic incidents and congestion. Statistical and neural classifiers are used to detect traffic operational problems on urban arterials. Fuzzy logic has also found use in detecting problems and anomalies in urban traffic and in performance evaluation.

In the same way as the traffic classification is very important in a good transport management application, the vehicle classification is, too. Within this problem area there are different types of vehicle classification problems, for instance: vehicle location identification, vehicle behaviour identification, and vehicle detection. Once again, neural networks are widely used.

Another problem area in transport management is *traffic control*. In this area there are different problems to be solved. (i) Traffic signal and lights control use (adaptive) fuzzy logic controllers and case-based reasoning, (ii) Traffic assignment takes advantage of fuzzy logic (also combined with evolutionary computing), case-based reasoning and nonlinear state feedback control that all form promising approaches for alleviating congestion. (iii) Scheduling that consists of organising transport services uses also fuzzy systems and (iv) Planning utilises case-based reasoning and genetic algorithms. There are also applications of fuzzy logic, intelligent agents, neuro-fuzzy methods and genetic algorithms for intersection and junction control.

In the traffic signal control, fuzzy control is found competitive at complicated real intersections where the use of traditional optimisation methods is problematic. In practice, for traffic safety reasons, uniformity is the goal the signal control strives to achieve. This goal sets limitations on both the cycle time and the phase arrangements. Hence, traffic signal control in practice is based on tailor-made solutions and adjustments made by the traffic planners. The modern programmable signal controllers with a great number of adjustable parameters are well suited to this process. For good results, both an experienced planner and fine-tuning in the field, are needed. Fuzzy control has proven to be successful in problems where the process can be controlled by an experienced human operator, but exact mathematical modelling of the problem is difficult or impossible. Thus, traffic signal control is a suitable task for fuzzy control.

Autonomous intelligent *cruise control* is one of the devices that has been introduced with the objective of increasing the capacity and improving the safety of existing highway system. Different problems solved in this problem area are, among others, route guidance & planning, autonomous driving and collision avoidance. There are also different solutions for driver assistance system. Neural networks, fuzzy logic and neuro-fuzzy systems exist together with more conventional solutions. Adaptivity and learning are necessary parts in vision-based systems for road following and navigation.

Different problems solved in *vehicle simulation* area are driver behaviour models, travel choice models and vehicle dynamics simulation. There are applications based on fuzzy logic, neural networks, and wavelets, but also several cases using conventional simulation techniques or hybrid modelling are met. *Vehicle design* area can be divided to transmission control, suspension design, steering control, traction control, acoustic optimisation, control of the intensity of headlights and condition monitoring of a diesel engine. There are also several applications for the control of anti-lock brake systems. Fuzzy logic, sometimes with adaptation, is used, but also the application of neural networks and integrated fuzzy neural system with genetic algorithms exist.

Other application areas for intelligent systems in the field of transportation are accident analysis and prevention, measuring the level of service and planning of the passenger and goods transportation. In all, fuzzy logic and other intelligent systems can be suited for transportation problems very widely, because the problems cannot be straight optimised, the reasons and/or the objectives are controversial and the phenomena cannot not be measured or predicted accurately. Fuzzy systems are applied in transportation investment selection and evaluation, which usually include several conflicting goals, like geographical location vs. market location and land use costs vs. labour costs. Using different weights for each variable, multicriteria analysis can be performed to evaluate cost-effective actions and investment locations.

3.5 Telecommunications

The overall theme of this problem area is the use of intelligent techniques, especially fuzzy logic, uncertainty reasoning, machine learning, neural networks, evolutionary computation, case-based reasoning and related technologies to problems in telecommunications network management, maintenance, and upgrading. This part is based on 2003 State-of-the-art report by K. Leiviskä[14].

Applications extend from queuing, buffer management, distributed access control, and load management to routing, call acceptance, policing, congestion mitigation, bandwidth allocation, channel assignment, network management, and quantitative performance

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[14] http://ntsat.oulu.fi

evaluation of networks. These applications may be divided into three areas — modeling and control, management and forecasting, and performance evaluation. Automated testing is also an area where intelligent methods are applied.

The use of fuzzy techniques to model *queuing* systems and in active queue management to support congestion control in Internet have been reported. Fuzzy logic has also been used in predicting future buffer conditions of the Internet TCP/IP traffic over ATM. Neural networks, fuzzy logic, and fractal schemes are also used in modeling packet data networks, and in access control.

Routing has offered several application possibilities for intelligent methods: Fuzzy logic is used in many routing applications for modeling and control; also adaptivity is needed. Neural network applications exist to the shortest path calculation in network routing: recurrent spatiotemporal and Hopfield networks and a combination of Hopfield network and genetic algorithm. When optimization is needed, Swarm Intelligence and Ant Colony algorithms are also used in routing, especially with satellite networks.

Fuzzy logic has been widely used for *traffic control* in ATM networks. Fuzzy logic is largely used in policing, and both in congestion and admission control. Fuzzy logic has also been used in call admission control for WCDMA systems. However, a couple of neural network applications for ATM exist: namely, predicting cell-loss-ratio at each switch and calculating bandwidth required to support multimedia traffic with multiple QoS requirements.

Fuzzy logic has found usage in bandwidth allocation and channel assignment and a neural network with swarm optimizer has also been used for the same purpose. Neural networks have been reported also in channel equalization: radial basis function network with sequential learning, recurrent neural networks and same together with extended Kalman filter have been mentioned.

Fault management, encompassing detection, diagnosis, and resolution, in telecommunication networks have been around for some time. In order to cope with constantly changing networks, intelligent adaptive technologies are essential to the success of fault management. Typical techniques used in fault management include fuzzy logic, neural networks, model based reasoning, case-based reasoning, and Bayesian belief networks. Reasoning under uncertainty approaches, such as the Dempster-Shafer theory of evidence, are often integrated into fault management components to enhance the ability to reason with transient or otherwise uncertain information.

Some intelligent approaches for intrusion detection in computer networks have been reported: fuzzy cognitive maps with fuzzy rule-bases and self-organizing maps.

Most adaptive applications represent the first level SAS. The increasing complexity of telecommunication systems will, however, make the development of higher level SAS a necessity already in the near future.

3.6 Human, medical and health care

The following text has been picked from the paper by Abbod et al. that includes a thorough state-of-the-art survey on medical applications.[15]

The main topics in this area can be classified into five fields (each of which can be further classified into subheadings) as follows: emergency and intensive care, general medicine, surgical medicine, pathology and medical imaging. The division could also be made according to functions like diagnosing, therapy and imaging.

There is one dominating reason for adaptive systems in medicine – as it relates to the human body, one is immediately faced with endemic problems of non-linearity and non-stationary – individual variations in patients. This means that the second level SAS is required in almost all applications. Even the third level SAS would be needed, but has not

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[15] M.F. Abbod, D.A. Linkens, M. Mahfouf and G. Dounias, Survey on the use of Smart and Adaptive Engineering Systems in Medicine. AI in Medicine.

been achieved this far. Further, the degree of complexity in physiological systems is very large. Consequently, researchers in a number of distinct areas have begun to address the analysis and synthesis of such systems through a combination of basic as well as applied techniques. Even more advanced types of adaptive system have characteristics as self-maintenance, adaptivity, information preservation, and spontaneous increase of complexity.

Intensive care applications are close to anaesthesia in their medical function, nevertheless, applications can be divided into blood pressure and respiration regulation, EEG monitoring and pain relief. Different solutions based on adaptive control exist. Neural networks are used with either adaptive capabilities or self-organizing maps. Also, neural networks with adaptive learning methods can be combined with other tools such as wavelets for extracting features of intracranial pressure (ICP) in the ICU units. Neuro-fuzzy adaptive systems comprising an adaptive fuzzy controller and a network-based predictor are used for controlling the mean arterial blood pressure of seriously ill patients. Neural networks have also been used in electrocardiogram (EGG) processing. Application of adaptive control algorithms combined with expert system techniques are used to maintain stable patient status within narrow physiological bounds despite large plant uncertainty.

Inside *general medicine*, most applications of adaptive systems are dedicated to neuromuscular stimulation, and adaptive control systems, adaptive neural network control systems, together with iterative learning control have been used. Also neuro-fuzzy systems with adaptive learning capabilities have been used in controlling selective functional neuromuscular stimulation (FNS). The designs integrate three approaches, artificial neural network modelling, fuzzy logical adaptation, and geometrical mapping.

Several methods are used to classify cardiac arrhythmias and EEG data: fuzzy adaptive resonance theory mapping (ARTMAP), combination of a fuzzy logic inference system with neural network adaptive learning, conventional ANFIS, and combinations of a wavelet transform and artificial neural networks. There are also applications of chaos theory and neuro-fuzzy network, forecasting of chaotic cardiovascular time series with an adaptive slope multi-layer perceptron neural network, and recurrent artificial neural networks. Also adaptive pacemakers have been developed.

Still on the field of general medicine, internal medicine is a classic field of research in computer-aided diagnosis, the most well known system being CADIAC-IV, a medical consultation system for internal medicine. The system combines fuzzy sets, fuzzy numbers and fuzzy logic. A wide selection of adaptive control methods has also been applied to simulation and optimisation of insulin therapy for diabetics and to artificial respiration.

Next main field is *surgical medicine*. Not many applications were found in the survey on the use of adaptive systems for surgical procedures, in contrast to the complementary field of anaesthesia. Controlling the blood pressure is one of the major fields to which adaptive control regimes have been applied. Methods are many: conventional adaptive control techniques, self-tuning control, generalised predictive control, combination of fuzzy logic and neural networks. In the field of muscle relaxation, gain scheduling control, self-organising fuzzy logic control, generalised predictive control and NARMAX models, self-tuning control and self-adapting model-based predictive control have been used.

Medical imaging and signal processing have benefited long from adaptive systems. There have been many reported applications of adaptive systems for signal processing that range from EEG, ECG, respiratory signals and gastric signals. Furthermore, the processing of biomedical signals (e.g. EEG, MEG, EMG, EOG, ECG) using adaptive intelligent techniques such as neural networks (sometimes with adaptive learning rate), and neuro-fuzzy systems have been implemented in many applications. Neural networks allow close matching of system properties without the requirement to know the underlying physical and mathematical equations that govern the system to be predicted. Dynamic networks with time-delays and recurrent loops are especially appropriate for time-series predictions.

Adaptive noise cancelling algorithms by FIR filters and neural networks are available.

List of methods used in medical imaging, mostly in MRI applications, is long: adaptive neural networks (with self-organising features, adaptive learning rate and momentum and vector quantisation), ANFIS, adaptive filter, adaptive fuzzy leader clustering, self-organizing neural network, fuzzy c-mean (FCM) classification algorithm, self-organizing principal components analysis, etc. An ultrasonic imaging system can also use adaptive filtering schemes for improving the picture quality. Nuclear imaging systems rely on photon detection as the basis of image formation. A wavelet-domain filter has been used in Poisson noise rejection. Neural networks (e.g. RBF) have been used in image restoration and visualization. Clustering algorithms have been used in image filtering and image decomposition and compression.

Looking at the three complementary areas of diagnosis, therapy and imaging, it seems that most applications in diagnosis are in general medicine, and intensive care and signal and image processing come very far away. Also in therapy applications general medicine is in the leading role, but surgical medicine comes very close to it. It is, of course, natural that most imaging applications are in signal and image processing area. It is surprising that there is practically no activity in the internal medicine even though expert systems were applied in this field at an early stage.

Following three major factors affecting the development of adaptive systems in medicine were found in the survey:

- Processing power: modelling and simulation will require ever-increasing processing power, particularly for developing ‘real-time’ applications. The continued development of single powerful machines and ‘farms’ of relatively simple and cheap processors will help to meet these needs.
- Output data handling: the amount of output from modelling and simulation is set to increase dramatically as is the amount of data acquired. There remains an urgent need to develop automated approaches for summarising and interpreting both output

measurements and the data itself. This means the need for improved analysis and visualisation software for complex systems.
- Software: The need exists for both novel, discipline-specific software development, and also for ‘off-the-shelf’ packages that can be applied easily to a broad range of problems.

3.7 Conclusions

The most existing applications of smart adaptive systems belong to the first level SAS. The increasing complexity and requirements for more self-managing options will mean the development to higher levels of SAS. Most practical applications take advantage of integrating two or more methods, neuro-fuzzy approach being, however, the one with the most worked-out theoretical background.

There are some common features in processes and systems that utilise SAS and IM:

- tighter quality requirements: high quality products and services, possibilities to customise the products depending on the customer.
- high throughput: high capacity requirements from the process, mass productisation, services offered to big audiences (e.g. in Internet) or to a high number of customers (traffic).
- increasing complexity: a high number of processes, mills, customers, products; services offered to high number of customers with varying customer profiles, needs and capabilities.
- capital intensive systems: high economical risk in production decisions.
- rapidly changing markets: needs to adapt to changing environment, customer needs, economical situation.
- safety critical applications: high technological risk in production and high requirements for reliability in offering services, fast/complicated processes, high economical risk in offering services, misuse, fraud.
- innovative companies/company imago
- market push: from technology companies/intelligent products.

In some areas, there is a general push to intelligent technologies in automation and consulting companies. However, the attitude of companies varies. Most automation companies are more or less selling results, not technologies as such. SAS have more a role of tools; they have been embedded in the system and concerned only if there is some doubt of the results. Companies depending on SAS as products are more actively marketing also this technology.

4 Challenging new applications and research areas

4.1 Integrated methods[16]

Rapid development in computer and sensor technology, not only used for highly specialised applications but being widespread and pervasive across a wide range of business and industry, has facilitated easy capture and storage of immense amounts of data. Examples of such data collection include medical history data in health care, financial data in banking, point of sale data in retail, plant monitoring data based on instant availability of various sensor readings in various industries, or airborne hyperspectral imaging data in natural resources identification to mention only a few. However, with an increasing computer power available at affordable prices and the availability of vast amount of data there is an increasing need for robust methods and systems, which can take advantage of all available information.

Much of the improvement of current intelligent systems stems from a long and tedious process of incremental improvement in existing approaches (i.e. neural networks, fuzzy systems, evolutionary computing techniques etc.). Extracting the best possible performance from known techniques requires more work of this kind, but exploration of new and combined approaches supplies additional opportunities. However, while a number of combined techniques have been very successful in certain application domains, they are usually constructed in an ad hoc manner.

Therefore, apart from the engineering challenge of building complex hybrid systems capable of accomplishing a wide range and mixture of tasks, one of the major scientific challenges consists of providing integrated computational theories that can accommodate the wide range of intellectual capabilities attributed to humans and assumed necessary for nonhuman intelligences. As the flexibility of the intelligent systems increases there will also be a greater need for more sophisticated complexity control mechanisms.

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[16] This text is based on the original version by Bogdan Gabrys.

Integration of intelligent technologies is today vigorously pursued along several dimensions: integrating systems that support different capabilities, combining theories and methodologies that concern different facets of intelligence, and reconciling, accommodating and exploiting ideas from various disciplines. All of these dimensions pose significant scientific and engineering challenges.

As the term hybrid (intelligent) systems is very broad it would be very difficult to cover all the possible combinations and aspects forming today's very dynamic research agenda of AI. Instead we will concentrate on highlighting some research directions and challenges facing researchers investigating generic intelligent hybrid architectures involving two or more core technologies from SC.

- *Neuro-fuzzy systems* are probably the most extensively researched combination of intelligent techniques with a number of demonstrated successes resulting from their complementary characteristics. The main motivation for such combination is the neural networks learning ability complimenting fuzzy systems' interpretability and ability to deal with uncertain and imprecise data. Some of the general issues currently investigated and likely to be investigated in a near future involve: the growing/shrinking structures where through learning new data can be accommodated in the process of on-line adaptation and optimisation of a rule base system represented in a network structure; generating interpretable models using inductive techniques which are related to a more general problem of interpretability vs. prediction accuracy; use of statistical resampling techniques in the process of neuro-fuzzy models generation; formal analysis of recurrent fuzzy models which could prove more appropriate for modelling dynamic systems than feedforward architectures.
- *Using evolutionary algorithms for optimisation of artificial neural networks.* One of the main drawbacks of conventional approaches to designing ANN is that their performance very much depends on the appropriate selection of the neural architecture (number of layers, neurons, activation functions and connection weights) and the learning algorithm. Evolutionary design of ANN can eliminate

the tedious trial and error work of manually designing an optimal network. Due to the number of parameters to be optimised this problem is far from trivial.

- *Evolutionary fuzzy systems.* Like optimising the parameters of ANN the evolutionary algorithms can be and have been used for the selection and optimisation of fuzzy systems parameters like membership functions, number of rules, fuzzy operators etc. One of the research challenges is to extend the use of evolutionary techniques for continuous adaptation of FS and ANN while in operation.
- *Neuro-fuzzy-evolutionary systems.* One of the potential problems with neuro-fuzzy approaches appears when some typical neural learning techniques are used and there is no guarantee that the learning algorithm will converge and the tuning of the fuzzy system will be successful. More general architectures are being developed which combine neural network learning algorithms with evolutionary optimisation to overcome this problem.

As correctly pointed out in[17] hybrid soft computing frameworks are relatively young, even compared to the individual constituent technologies, and a lot of research is required to understand their strengths and weaknesses. One such major weakness of most of the hybrid systems, as well as individual intelligent techniques, is that their successful performance heavily (sometimes critically) relies on a number of user-specified parameters. In order for such systems to be adopted as everyday tools by unskilled users the focus of the future research has to be on (semi-) automatic settings of such parameters (*self-configuring*). This is also required if such systems are to be fully adaptable to changing environments and operating conditions.

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[17] A. Abraham, "Intelligent Systems: Architectures and Perspectives", Recent Advances in Intelligent Paradigms and Applications, Abraham A., Jain L. and Kacprzyk J. (Eds.), Studies in Fuzziness and Soft Computing, Springer Verlag Germany, Chapter 1, pp. 1-35, Aug. 2002

Doyly ae al.[18], list some of more general and application based, representative long-term goals and challenges applicable in the context of integration and hybrid intelligent systems.

- Constructing efficient, uniformly transparent mechanisms for representing large amounts of knowledge and data, for translating among these representations, and for applying knowledge based inference, learning, and discovery mechanisms to information appearing in a variety of forms in extremely large scale knowledge and data repositories;
- Lessening the tension between speed and quality of action by continuing adaptation and extension of knowledge-based reasoning and learning techniques to real-time operation and control of complex real-world systems that involve hard deadlines;
- Making computers easier to use: more cooperative and customisable, with interfaces that employ natural languages and other modalities to communicate in familiar and convenient ways.

Examples of application related long term goals requiring hybrid intelligent systems:

- *Combining planning, learning, vision, touch, speech, and other senses in performing everyday tasks*, for example house cleaning, cooking, shopping, answering the telephone, making appointments and negotiating or bargaining with other agents for commodities and information;
- *Adaptively monitoring, selecting, tailoring and rewriting the contents of electronic information sources* (TV, faxes, newswires, the WWW) to inform one of news and events in accord with one's changing personal interests, plans, and purposes;
- *Recording, monitoring, and analysing one's medical history and condition* over one's entire lifetime, helping to explain and maintain treatment plans, to detect physician mistakes, and to guide interactions with healthcare providers;
- *Operating within a large scale distributed systems* to monitor and maintain the overall system operation, learning how to detect and defend against malicious external or internal attacks.

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[18] J. Doyle, T. Dean et al., "Strategic Directions in Artificial Intelligence", ACM Computing Surveys, vol. 28, no. 4, Dec. 1996

- *Constructing "do what I mean" capabilities* for household, educational, and industrial appliances, yielding machines that infer desires and intentions of the users and cooperate with them in achieving their aims.

4.2 Production industry

This part is based on IBA A Meeting held in Oulu on March 22, 2002. The target of the meeting was to identify potential applications for SAS in production industries: problems, methods, benefits and risks. The workshop included presentations on EUNITE, SAS and a structured view of applications of computational intelligence. Case studies of IBA D and IBA A were used to search for new applications by analogy.

Four main areas for future applications and research were recognised:

- sensors and measurements
- monitoring
- safety critical systems
- risks and problems

Sensors and measurements: There are difficulties on several areas in finding good measuring parameters and indicators. Measurements and parameters are often very application specific, what may represent a limitation to the portability of SAS. There is also a need for decentralized intelligence, otherwise there is too much data on the field bus. This emphasises the need for intelligent or soft sensors with, for instance, local processing capacity for, e.g. higher order statistics information.

Sensor fusion is important in several areas (rolling mills, blast furnaces, reheating furnaces, paper processes); e.g. finding out what's going on inside the steel sheet by combining noisy measurements (temperature). This kind of use of low cost measurements (temperature) for checking purposes is common in all areas of production. Noisy measurements are problematic meaning more or less averaged values and losing information. Information is also needed for maintenance. This might be in forms of distributions and confidence levels. In addition to noise also state changes exist and they tell a lot of process behaviour. Methods for state (and state change) indication are needed.

It should, however, be remembered that the sensor technology is a critical factor. Soft sensors are of a little use if the basic technology does not work. Soft sensors depend on original measurements; also their accuracy and reliability does.

Monitoring: Monitoring load in process industry is high; e.g. in pulp mills 10 000 control loops are monitored by 30 people. Adaptive and intelligent monitoring tools are needed, but actually no tools are available. There is also a need to keep display hierarchies as simple as possible.

Personalised interface systems are coming, but the suppliers are more or less relying on standardised display hierarchies. No general standard for interfaces exists and the suppliers will anyway have different ways to personalise. Whatever the technology, the systems should be transparent.

Overflow of alarms is still a problem (especially repeated alarms) and intelligent, adaptive systems would improve the situation. However, practical tools do not exist except simple masking. This offers good application possibilities to SAS and is also closely connected to personalised (intelligent) interfaces. All staff members do not need all possible information. Although it is possible that overflow of alarms can be generated, it is not always reasonable to remove these alarms by intelligent alarm handling as the responsibility is difficult to take. Better solution would be to try to detect problems in advance. Failure prevention with early warning will remove the overflow of alarms as well.

Indicators telling process status (and change in status) are needed (cf. web break sensitivity indicator). Systems are designed for normal operation and other states are not present in systems design nowadays. Status indicators can be combined to intelligent analysers and controllers and integrated into control hierarchies. Smart adaptive systems and integration of methods are essential tools in this case. Also some process vendors and designers are working with these questions. Special interfaces could be developed on the basis of different operating conditions (process state). These interfaces should be opened automatically when the intelligent analyser or diagnostic system has detected the state. The interface could also show those variables, which are considered to be important in the case, e.g. web break sensitivity indicator could provide this type of information in paper machines.

Performance monitoring is also a promising area. E.g. in pulp drying: the increase in production is increasing the risk for web breaks. A question is also how to change the operation in these cases. This is also a place for SAS.

Condition monitoring is going towards failure prevention. This means measurements that indicate sensitivity to failures and how to avoid break-downs by maintenance actions. In energy production adaptivity in many cases means also portability; same systems are used in several processes that are more or less of the same type.

Safety critical systems: Safety critical aspects were recognized as a central issue to many smart adaptive systems. In most applications, the highest level of adaptivity is not always desirable, what one strives for is the right level of adaptivity, that is the best compromise between the acceptable risk and the advantages provided by adaptivity. On-line adaptation can be a risk in varying operating conditions. Sometimes, it is safer to tune the control system in advance to different conditions. This will require multilayer control structures and a realistic dynamic simulator, which will also work on oscillatory conditions. Realistic dynamic simulation is a challenging task, but it can be done with data driven intelligent techniques. This approach has been in development of linguistic equation controllers in lime kiln and solar power plant applications.

New systems can make the applications more complicated; and can also bring along limiting factors. Legislation varies, e.g. in boiler houses all automation functions can nowadays be made by software in Finland, but not everywhere. The future vision seems to be that the development goes to monitoring systems to avoid emergencies and accidents instead of just diagnosing.

Problems and risks: Time is a limiting factor to the introduction of SAS, as for instance in the medical domain, where it can take up to 10 years between the workability of the system has been demonstrated and the broad acceptance by the medical community at large is achieved. The situation was found to be quite similar in many fields in industry.

New methods are very often used to solve the last 2% of the problem. Main effects are elsewhere. There is also a risk that more resources are needed with new systems in building and in maintenance. What tools are available? How to monitor the performance of new systems?

Need for adaptive systems is seen in all industries, all levels of automation. For instance, ramp-ups in electronics production is a new area where portability questions are critical. Faster, efficient ramp-ups bring direct savings. There are already experiences from test systems, because new products have different measurements and different specifications.

It is also frequently asked, what is the good level of adaptivity? Are there any criteria available? The answer seems to be no, even though algorithms have existed for 50 years.

Intelligent systems can be transformed into smart if the subsystems for all these tasks operate in a reliable way in their job. In this way, the system can be ported to similar settings and with some help to a new/unknown environment.

4.3 Transportation[19]

The continuing growth of traffic has caused a number of problems. Decreased traffic safety and environmental problems are perhaps the

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[19] This part is based on Jarkko Niittymäki's contribution.

most serious negative side effects of an increase in traffic. In general, traffic control is used to maximise the efficiency of existing traffic systems without new road construction, maintain safe traffic flows, minimise delays and hold-ups, and reduce air and noise pollution.

The use and study of the intelligent transportation are focused on road transport. The results gained from these studies have been promising: studies related to fuzzy logic in traffic forecasts, traffic control and vehicle/transportation scheduling have usually pointed out better performance than traditional methods used. However, many of the studies and experiments have been quite theoretical and limited, and more information is needed.

In the more uncommon areas of study, air and water traffic, results have also indicated the potential of intelligent applications. In future, it might be important to direct more research resources to these 'minor' areas of transportation: most of the transportation of goods and long distance passenger traffic are handled with these modes of transportation.

The main commercial potential of the intelligent transportation systems might be found from different transportation scheduling and planning systems, vehicle fleet management systems and multicriteria/expert systems of evaluation of competing investment plans and other financial decisions. The more traditional applications, traffic modelling and control, benefit more the society and public than the business world. Therefore the use and development of such systems are heavily dependent of public interests and funding.

Some statements of adaptive systems in the field of transportation are listed below as a summary.

- Adaptive systems are mostly studied and used in traffic control and traffic modelling.
- The real-life use of fuzzy systems is still small: some data analysis tools, prediction systems of future traffic and automated detection of congestion and accidents are based on fuzzy or other intelligent systems, but the use is often local and limited.

- In adaptive traffic control and traffic modelling, the intelligent applications should be taken into use more rapidly, in order to gain the benefits promised by various studies and experiments.
- The research should be directed to more comprehensive air and water transportation systems, as well as in developing planning and evaluation tools for decision-makers and traffic planners.
- Still, the research results lack some reliability due to the small scope and theoretical nature of the studies in general. This partially prevents applying the systems in real life.

4.4 Telecommunications and multimedia[20]

Intelligent methods are already used in automated testing and fault management in modern telecommunication networks. One of the major challenges of this research area is to cope with the accumulation of huge amount of alarm messages, even though several alarm correlation algorithms have been developed to pre-process overwhelming alarm messages. In order to cope with constantly changing networks, intelligent adaptive technologies are essential to the success of fault management. Massive data collected from alarm messages can also be used to discover useful rules or causes-effects relations among them. Future development in both automated testing and fault management will also address how the synergy of two or more artificial intelligent techniques will enhance the functionality of these systems in dynamic environments.

Intelligent methods have also been successfully used for solving control problems in packet-switching network architectures. The introduction of active networking adds a high degree of flexibility in customizing the network infrastructure and introducing new functionality. Therefore, there is a clear need for investigating the applicability of intelligent methods in this new networking environment, as well as the provisions of active networking technology that intelligent methods can exploit for improved operation.

[20] This part was originally written by Martin Spott and was later modified by Editor.

Network congestion control remains a critical and high priority issue. As the Internet grows rapidly it becomes clear that the existing congestion control solutions deployed in the Internet Transport Control Protocol (TCP) are increasingly becoming ineffective. The newly developed (also largely ad-hoc) strategies are also not proven to be robust and effective. Furthermore, the increased demand to use the Internet for time-sensitive voice and video applications necessitates the design and utilization of new congestion control algorithms and new architectures for the provision of quality of service, in some form. As a result, a number of researchers are now looking at alternative schemes such as AQM (Active Queue Management, e.g. RED-Random Early Detection and its variants) and other Internet architectures, such as DiffServ, to deliver QoS in TCP/IP networks. It is expected that Fuzzy Control will be useful in implementing effective DiffServ.

Soft Computing and Adaptive Systems are foreseen to play a major role in developing intelligent multimedia systems which permit effective browsing and visualisation of audiovisual information located in large, distributed, heterogeneous databases. Based on the fast and continuous explosion of multimedia content available through the internet and WWW, it has started to become clear among the research community, dealing with content-based image retrieval and browsing, semantic Web, and the emerging MPEG- 21 standard that the results to be obtained will not have the desired effectiveness, unless major focus is given to the semantic information level, which defines what most users desire to retrieve. Mapping, however, low level, subsymbolic descriptors of multimedia content to high level symbolic ones is in general, a very difficult, even impossible with the current state of technology, task. It is, however, expected that it will be tackled when dealing with specific application domains, taking into account:

- The nature of useful queries that users may issue. This is certainly only a portion of the general set of questions related to “content understanding”. Using all types of multimedia information, i.e., audio, visual and text, makes the task more tractable.
- The particular context determined by the profile of the user that issues the query.

To achieve this goal, the R&D Community has to blend the achievements in characterizing multimedia content – especially visual and acoustical one – with state of the art soft computing technologies in order to (i) offer unified semantic views to existing content sites, (ii) personalize those views according to the retained profile of individual users or specific user groups.

Current research and standardization activities in the area of multimedia content handling and indexing are driven by the work related to MPEG-4, MPEG-7 and the new MPEG-21 standards. This framework provides a formal syntax for attaching information of various detail and nature to the raw multimedia content. Description Schemes (DS's) are the containers of this information. Current efforts intend to evaluate the values of the DS's *dynamically,* in the sense that they should reflect the instantaneous *context* of queries, the latter being determined by the profile of the users. Soft computing can be used to achieve this behaviour, for constructing and learning the most appropriate associations for semantic extraction and interpretation.

Moreover, the large and expanding data volume of multimedia content may overwhelm users that attempt to browse through it. Recurrent refinement of users' queries may be necessary before reaching the desired content. This results in the increase of the search time, the overload of the serving system and the possible waste of bandwidth. Taking into account the different priorities/preferences of different users can beneficially reduce the scope of users' search, as well as settle a ranking in the presentation and visualization of the responses.

Mechanisms that keep track of users' preferences, project these preferences to appropriate indices of the archived content and adjust the responses to users' queries in a manner that "fits" to their priorities will become necessary for handling the above problems. Such mechanisms will rely on three major components, namely a *multimedia content classifier,* a *users' preferences tracking module* and a visualisation *filtering module.* The first will retain a semantic information structure for the available content and its components.

Users' preferences tracking module will monitor the choices of each user in order to trace his/her preferences. An important issue here is the representation and handling of the uncertainty that is conveyed in all the classification actions of user profiling and updating. The associated record, representing specific users' profiles, will be continuously updated using soft computing and relevance feedback adaptive techniques. Finally, the visualisation filtering module will rank the responses of the archives to specific user requests according to the relevance of their "information structure" to the "profile" of the user.

Access to the right information on the web is hampered by the sheer volume of data. Tim Berners-Lee, widely acknowledged as the "father of the web" has pointed out that this is mainly due to the data being *machine-readable* but not *machine-understandable*, and has proposed the Semantic Web. This allows relational knowledge to be encoded in web pages, enabling machines to use inference rules in retrieving and manipulating data. In turn, this will reduce the quantity of irrelevant data retrieved and increase the usefulness of the web. In this connection, it could also be worthwhile to refer to Halal and Moorhead[21]. Their vision on Intelligent Internet says that smart computers that learn and adapt will be available in a decade and that virtual robots and environments populate the web by 2010.

The need for web pages to include knowledge representation presents a tremendous opportunity for fuzzy researchers to demonstrate the power of soft inference in making useful, human-understandable, deductions from the semi-structured and sometimes contradictory information available on the web.

In order to deliver "relevant" information, we require knowledge about the content of a page, i.e. metadata. XML was created as a method of marking up documents and conveying the semantics - in the same way as HTML specifies the display properties of different pieces of text, XML can be used to convey a hierarchical relationship of data

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[21] www.TechCast.org

values. XML allows new tags to be defined, with a BNF grammar to determine the precise combinations of tags that are permitted. XML is becoming a de facto standard for electronic data interchange.

There is a need for fuzzification and matching of concepts. It is relatively easy to search within a database for a restaurant which is "*near*" to one's current location, or which has a menu on which "*most*" items are "*reasonably priced*" as these are numerical measures and fuzzy definitions can be produces for the italicised terms. It is much more difficult to search for a restaurant with a "*high quality* wine list" or which has "*a good range* of *spicy* vegetarian *main courses*".

Finally, we must bear in mind the available computing power and the need for practical implementations of systems. In order to prove the usefulness of fuzzy logic, examples are needed which are more efficient using fuzzy logic or which can't be done at all without fuzzy logic. It is essential that fuzzy extensions demonstrate performance improvements over “classical” techniques.

4.5 Human, Medical and Healthcare[22]

The driving forces for new developments in Medicine and Healthcare derive from new ideas and enhanced technologies. The slowing down forces for creating something new in this field come from problems with healthcare financing. The patient wants and expects from his practitioner best diagnosis and best treatment. But a generous delivery of all healthcare goods of all sorts to all patients goes far beyond the financial possibilities of a single person and of the community. In most cases there is no direct financial interaction between the consumer, the patient, and the provider, the medical system. Insurance companies, which are to some extend dependent on public and political authorities, interact financially between the consumer and the provider. The insurance companies allocate the costs of a new development to all patients, who may come under consideration to take advantage of the new development, and then they define cases for which they will pay. Such complicated mechanisms are first put in

[22] This part was contributed by Derek Linkens.

motion until a refinancing may start. Therefore the introduction of a new development in the healthcare sector is in general slow and uncertain. The initiators of a new development in medicine are most often academic persons. They may gain from a new idea for their personal scientific career, but are normally not financially affected in a direct way by the economic success or failure of the development they have initiated. The motivation to promote the economic aspect of a new device from the beginning is therefore low in medicine, in contrast to trade or industry. Furthermore, practitioners are sometimes very averse to replace established methods and behavior and show themselves in general very conservative in thinking. This may on the one hand protect patients from irresponsible injury and is therefore very good, but it contributes on the other hand to the delay of replacement of old habits and costumes by new methods.

The state-of-the art survey referred to in Section 3.5 sought to identify “white spots” in the medical sub-disciplines where intelligent technologies so far have little penetration.

Some tentative conclusions can be drawn from the results of the survey. Neurology, cardiology, surgery and anaesthesia, and radiology are well represented. In contrast, there is practically no activity in the areas of gynaecology, pathology and internal medicine. In the latter case this seems surprising, since expert systems were applied in this field at an early stage. Over the timescale of the survey there has been a general increase in activity since 1991. There was a peak in 1997, which gives a warning that interest and activity in adaptive systems may not have been consolidated. This provides a major challenge. In the individual sub-fields, there has been an increase over the period in cardiology and neurology applications. In respiratory medicine there has been a small increase, while in radiology there has been a significant increase. In surgery and anaesthesia there has been a steady output throughout the period of the survey.

There is a fairly even distribution in the theme of diagnosis. One would have expected contributions in internal medicine for this area. The theme of therapy is widely distributed through the sub-fields, which is not surprising because of the diverse nature of the specialisms. However, in adjacent areas of paediatrics and orthopaedics where therapy is particularly important, one would expect contributions to be possible. The theme of imaging has a very peaky distribution, possibly because other sub-fields are implicated within the area of radiological imaging. However, there is adjacency of concept for intelligent imaging in areas such as gynaecology and ophthalmology, which could benefit from the published work in radiology.

In terms of a "roadmap" for the theme of smart, adaptive systems the survey has demonstrated that there are certain "white spots" of medical specialisms, which could benefit from development in adjacent sub-fields. This accords with an equivalent survey of the use of fuzzy technology in medicine conducted within the European Network of Excellence ERUDIT and incorporated into its Roadmap. In addition the following needs were identified: non-accidental linkage between applications in special areas (systems scientists and engineers should have an important role here); a critical mass of focused clinicians to provide take-up of the technology; sufficient funding and career prospects for bioengineers to maintain impetus in developing the particular applications; globalisation of scare resources via journals, conferences and networking.

Nevertheless, some tentative statements may be made:

- Internal medicine, anaesthesia, radiology, electrophysiology, pharmacokinetics, and neuromedicine already use fuzzy logic methods to a considerable amount. They use fuzzy expert systems, fuzzy control, fuzzy signal and image processing, fuzzy modelling, and fuzzy neural simulation.
- No specific application has until now developed in the surgical disciplines, in dental medicine, for general practice and for nursing.
- Most of the regional defined medical disciplines participate from the methods developed or used in the neighbouring disciplines.
- Papers from the medical information basic sciences are appearing at a high rate. Innovations in these sectors will keep the development in the other sectors growing.

Obtaining reliable, cost-effective measurements from the human body remains a huge challenge for bioengineering. Even such routine transductions such as pressure and temperature present problems for continuous and non-invasive monitoring. For complex measurements such as EEG, EMG and EEG there remain the requirements for intelligent processing and storage. Data compression preferably at the monitoring point will avoid the massive data overload which is being produced in hospital PDMS (Hospital Data Management Systems) even when localised to smaller units as ICU (Intensive Care Units).

Sensor fusion requires hybrid intelligent techniques to optimise the information content from multiple sensors. In addition, adaptation will be required to encompass fault recovery under real-time operating conditions. The handling of huge numbers of alarms in hospital clinical conditions has been partially addressed in the past, but again it will require hybrid adaptive approaches to provide robust solutions to compress the decision vectors to a humanly-manageable dimension.

Safety criticality is vital in a hospital environment, and this poses major challenges to adaptivity and hybrid intelligence because of theoretical non-provability of convergence. Methodologies for adequate testing (cf. software validation methods) and audit trails are required. These and other factors were also addressed in the EUNITE Task Force on Safety Critical Systems.

A major explosion in bioinformatics data capability is being generated via modern gene expression array techniques. These are providing inpredented amounts of data, which will require intelligent techniques for feature extraction and data compression both for diagnosis, therapy advice and subsequent storage. The area is exciting with great scientific challenges, reflected in the establishment of a EUNITE Task Force on Gene Expression.

In the current context of Healthcare away from the hospital, the challenge within eHealth is to produce relevant technologies, which are Web-based. Ideally, this needs adaptive user-interfaces, as per multi-media in telecommunications. There is huge potential for XML-like and

HTML material for dissemination to the clinical community both for utilisation in patient care and for self-education and skills-updating.

In addition to clear destinations, a roadmap requires RELIABLE ROADS. Some features, which must be incorporated into the construction of such roads are as follows:

- Validation of techniques, including safety and security aspects.
- Evaluation, including costs/benefits analysis covering both end-user (patients) and the provider (healthcare structures).
- Litigation concerns, particularly those of the medical instrumentation manufacturing industry.
- Balance between technological PUSH and clinician PULL, requiring quality assurance, transparent usage, education (especially long-term) and sensitive vision/trust.

To facilitate navigation along reliable roads to clear destinations one also requires distinctive SIGNPOSTS. In the realm of biomedicine and its uptake of fuzzy and related technology the following issues will need to be addressed:

- Non-accidental linkages between applications in the specialist areas. Serendipity prevails at present, but does not need to, since the basic principles and implementation issues have already been developed.
- Critical mass of focused clinicians. This is necessary in each sub-area before any technique will be accepted into routine clinical practice.
- Bioengineers "sunset". Due to funding and career prospects, it is difficult for young research bioengineers to continue in the discipline long enough to see the critical mass of clinicians established in their specialist research topic. This discourages technology transfer.
- Globalisation is essential. There are a limited number of workers in this field world-wide, and hence to achieve penetration it is vital that there should be interchange between such groups. While this can be partially achieved via conference attendance etc., the role of

networks such as EUNITE could well be seminal in spreading the accumulated expertise.

- "Retired" wisdom. Much expertise is locked-up in researchers who have officially retired. Many of them would be only too willing to act as "signposts" to younger researchers for guidance and advice. EUNITE could well facilitate this in its specialist field better than in the Professional Institutions, which are mainly based in individual countries.
- Long gestation times must be expected in this discipline, where returns on investment may not be quick. Unlike industrial settings, the clinician is the manager/decision-maker at the "workface", rather than merely the operator who obeys commands. In this context, the mileage on the individual signposts may turn out to be larger than expected!

4.6 Conclusions

Even though applications integrated, hybrid systems are common, one of the major scientific challenges consists of providing integrated computational theories that can accommodate the wide range of intelligent systems. As their applications increase in numbers, there will also be a greater need for more sophisticated complexity control mechanisms. Research today pursues along several dimensions: integrating systems that support different capabilities, combining theories and methodologies that concern different facets of intelligence, and reconciling, accommodating and exploiting ideas from various disciplines. All of these dimensions also pose significant scientific and engineering challenges.

Three areas were found essential in the development in production industries. Soft sensors are needed in difficult measurements and sensor fusion is one way to realise them. Intelligent monitoring is getting more and more important as the amount of information increases and the need for personalised interfaces rises. Performance and condition monitoring were seen promising areas for (also higher) level SAS. Safety criticality is increasing importance when processes and system grow in size and in complexity.

In transportation, problems were seen in slow rate of applications. Promising research areas are in air and water transportation, as well as developing planning and evaluation tools.

Congestion control remains the challenging research topic in telecommunications. SAS has also a big role in the development of tailored, flexible multimedia systems that can follow user preferences and adjust their operations according to them. One important issue here is the representation and handling of the uncertainty that is conveyed in all the classification actions of user profiling and updating.

Sensor fusion, fault recovery and alarm handling require SAS in medical applications. Safety criticality is an important driver for the research and validation methods are needed. Huge data requires also new methods. Increasing number of eHealth applications also call for results from the above mentioned flexible multimedia.

SAS and hybrid intelligent systems will also be inherently included in our everyday actions. They will help in planning and learning our everyday tasks – house cleaning, cooking, shopping, answering the telephone and also in communicating with electronic information sources, mostly with Internet. They are also needed in keeping record and monitor one's personal "database", that is more or less distributed including medical history data, economic and insurance data, personal history consisting of photo, videos, etc. They are also reflected in the house one lives – controlling temperature and lightning together with security and alarming, not even to speak about entertainment. This all requires that the applications become more and more flexible and adaptive, i.e. self-managing; we cannot simple teach everyone to be a computer specialist.

5 Related work

There are several Networks of Excellence that do Roadmap work on their own areas. Some of them touch upon EUNITE. There are also some other organisations devoted to Roadmaps and, finally, some EUNITE Task Forces have contributed to this report.

5.1 AgentLink

AgentLink is a European NoE fostering activities on Agent-Based computing. Their Roadmap is from 2003 and it is downloadable at http://www.agentlink.org/roadmap/.

AgentLink Roadmap sets seven technological challenges for research and development over the next century. One of them is developing agent ability to adapt to changes in environment. The current research concerns mostly with reinforcement learning and evolutionary approaches. Applications are, however, few. Learning techniques for single agents are relatively well-advanced, but multi-agent learning is not. Issues like personalisation, distributed learning, hybrid learning, self-organisation, and run-time re-configuration and re-design will come in the future. Application areas where learning will receive more attention are communication, negotiation, planning and co-ordination, together with information and knowledge management.

5.2 Äly Roadmap

Äly[23] Roadmap is the product of the technology program with the same name that is financed by the Finnish National Technology Agency, Tekes. It concerns with the future trends and possibilities of intelligent automation systems; electronics production and automation being an important actor in the Finnish industry. The Roadmap is available at http://akseli.tekes.fi/Resource.phx/tivi/aly2000/roadmapluonnos.htx - unfortunately only in the Finnish language.

[23] “Äly” means “intelligence” in Finnish.

The Roadmap lists several areas for further development. Soft sensors with adaptivity and automatic calibration and diagnostics form one important area, as also the communication between sensors and the building of different sensor combinations. Methodological development is needed for signal processing and for the estimation of information quality and uncertainty. Also the actuators are becoming intelligent and one of the future challenges is the integration of intelligence in sensors, actuators and control.

Adaptivity is also a key word with user interfaces where human in the loop technologies need further research. Mobile interfaces are also changing the picture. All the information is not coming from the sensors, but the role of intra- or Internet is increasing requiring efficient search methods.

Advanced architectures for automation are seen as the key to further distribution, modularity, flexible configuration, and more efficient use of hardware and software components and software production. Agent technologies and semantic webs give new application tools. The role of standards will even increase.

On the modelling side, model-based control and diagnosis need further attention, as also automatic generation and tuning of models. Short production cycles and tailored products make also the integration of product and production design necessary (design-for-manufacturing).

5.3 ARTIST

ARTIST is an IST Network for Adaptive Real-Time Systems for Quality of Service Management. Their Roadmap is available at http://www.artist-embedded.org/. Embedded systems are, by nature, real-time and work in dynamic environments. So they have to be adaptive. In real-time operating systems scheduling is the most important mechanism affecting adaptivity. It offers several research areas in the future: overload handling, feedback-based scheduling using control theory, combined scheduling, and energy-aware scheduling in battery-powered devices.

Adaptive resource management is important in the middleware, especially in multimedia applications. This leads to the high utilisation of the system resources and enhances the system performance. The trend to highly distributed embedded systems has emphasised the importance of network communications, and the proper design of networks is a necessity in future systems. The report predicts the situation with programming languages, but the real-time specification of Java could change the situation.

5.4 CaberNet

CaberNet co-ordinates top-ranking European research in distributed and dependable computing systems architectures – Internet being the best-known example of large distributed networks. Dependability is defined as the property of the computer system that enables users to rely on the service provided. Their Roadmap consists of two parts: The state-of-the-art survey written by John Bates of Cambridge University (1998) and Vision of RTD contributed by several persons. The materials are available from http://www.newcastle.research.ec.org/cabernet/. The last update is 9 January 2004.

The visionary part has been composed by putting together the research projects of CaberNet partners. It is divided in 19 areas and only areas close to EUNITE are commented upon.

In network architectures two key challenges are seen: assuring pervasive connectivity and seamless roaming and converting today's data networks into "human networks". Smart and adaptive systems play a role in network management and security, and also in adapting to users needs. In operating systems, the trend is towards smart re-programmable devices that adapt to the users needs. A lot of research is directed to methods for protecting and assessing systems with respects to several kinds of faults and safety-critical systems. Research goes also to distributed computing systems that are extensible, can utilise the surrounding computing environment and adapt to changing configurations, utilising i.e. agent technology. Also mobile computing applications must rely on systems that are aware of their environment and own status (i.e. power situation) and act accordingly.

5.5 CoIL

CoIL comes from the words Computational Intelligence and Learning (CoIL) and it was a cluster of networks ERUDIT (Fuzzy Logic), EvoNet (Evolutionary Computing), MLNet (Machine Learning) and NeuroNet (Neural Networks). There 2001 Roadmap is available at http://www.dcs.napier.ac.uk/coil/. CoIL can be seen as the first attempt at European level to bring the areas of Computational Intelligence together for identifying issues in which complement each other and where collaboration based on this complementarity would be useful.

5.6 Embedded Systems Roadmap 2002

Embedded Systems Roadmap comes from STW Technology Foundation in the Netherlands and its public version is available from http://www.stw.nl/progress/ESroadmap/ESRversion1.pdf. It starts from the finding that the market size of embedded systems is about 100 times the desktop market, and new products usually include one to tens of separate embedded systems. Heterogeneity, a large variety of information sources, and integration of all kinds of technologies are characteristic for future embedded systems. In hardware/software design a major challenge is the designing of the right system at the right time, and getting new features faster to the market. This requires verification and validation of designs, and developments in testing activities.

5.7 ERUDIT

ERUDIT was one of four NoE's, which comprised the CoIL cluster. Their Roadmap is available at http://www.erudit.de/erudit/papers/. It presents a long list of areas where fuzzy solutions will play an important role in the future, including hybrid systems, fuzzy expert systems, fuzzy databases, search engines, high-level information sources, e-commerce, uncertainty management, human in the loop, and teaching.

5.8 EUD-Net

EUD-Net is a NoE concerned with empowering people to flexibly employ advanced information and communication technology, The December 2003 version of their Roadmap is available from http://giove.cnuce.cnr.it/EUD-NET/roadmap.htm.

End-User Development (EUD) means the active participation of end-users in the software development process. Users are carrying out tasks that are typically done by professional software developers. This means moving from easy-to-use systems to easy-to-develop interactive software systems. This means that the development of environments that allow people without particular programming skills to develop their own applications or to modify the existing ones.

EUD Roadmap focuses the future research to three areas: software architecture, interfaces and support for collaboration. The vision is that towards 2020, substantial adaptability has become a property of all newly developed software systems. Most people have skills on EUD and the adaptability is a big part in “Ambient Intelligence”. The Roadmap, however, concludes by notion that the road to this vision is still long.

5.9 EvoNet

EvoNet was one of four NoE’s, which comprised the CoIL cluster. Their 2002 Roadmap is available in the following Internet address http://evonet.dcs.napier.ac.uk/evoweb/files/meetings/roadmap-20021025.pdf. It concerns with five areas of applications for evolutionary computing, namely data mining, creativity, optimisation, bioinformatics and scheduling.

5.10 Get Smart

CSC's Leading Edge Forum has published a book considering how intelligent technologies will affect our living[24]. They define five attributes to what "smart" is and give a lot of examples in each category. They have put these five attributes shortly as follows: Adapting means modifying the behaviour to fit the environment. Sensing is bringing awareness to everyday things. Inferring concerns with drawing conclusions from rules and observations. Learning goes back to using experience to improve the performance. And finally, anticipating means thinking and reasoning about what to do next. The report also lists the main technologies available for each attribute.

5.11 IMTI Roadmaps

IMTI (Integrated Manufacturing Technology Initiative) has published a series of Roadmaps that are available at http://www.IMTI21.org. The Roadmap Intelligent Control for Continuous Processes presents a long list of potential application areas for intelligent methods: plug&play sensors, control system design, improved actuators, sensor data fusion, adaptable, model-driven control, mode-based failure prediction and mitigation, user-friendly human interfaces, controllers that learn, and plug&play enterprise control. These applications lead to considerable economic and other impact in the industry.

5.12 Monet

Monet is a NoE interested in promoting two Artificial Intelligence technologies – Model Based Systems and Qualitative Reasoning – into the commercial world. It is divided into four Task Groups: Automotive, Bio-Medical, Education and Training and Bridge (fault detection and diagnosis). They all have written separate Roadmaps that are available via Monet website at http://monet.aber.ac.uk:8080/monet/. These Roadmaps, all dated 30th June, 2003, are shortly commented upon in the following text.

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[24] Claude Doom, Get Smart, How Intelligent Technology Will Enhance Our World? CSC COM Consulting. 2002.

Automotive Technological Roadmap lists three main market drivers: Efficiency/environmental considerations, safety and customer satisfaction; together with three business drivers: increasing complexity (doubling of electronics in the vehicle), the decreasing development period for new models, and the need for cost reduction. Diagnosis applications will proceed from automatic generation of garage based diagnostics to automatic software test generation, on board repair and distributed diagnostic systems. Increasing care of emissions will lead to monitoring tools for efficiency and lower emissions and, finally, to automatic generation of emission reduction tools. Modelling tools need standardisation, automated modelling tools from data will be developed, and modelling of both driver and the environment is targeted to. Hybrid, integrated reasoning tools will be developed.

In bio-medical area two distinct modelling applications exist: modelling of biological and physiological systems and modelling of equipment and organisations. The former uses mostly control theory and the latter is nearer to model based approaches. The modelling of non-biological systems that interact with biomedical systems is seen as a growing area. This includes also the modelling of organisations and processes. In the future, the Roadmap sees a big issue in the integration of information extracted from data and its use in the improvement of the models. Also there is the need to improve learning tools. One of the major challenges is also in changing the attitudes – the bio-medical area is a conservative area.

There are several drivers in education and training as the Education and Training Roadmap puts it out. The environment is changing; project-orientated learning, on the job training, distance learning and life-long learning require new methods. Modelling is a good tool for learning and easy-to-use modelling environments are needed in the future together with interactive simulations and open source software. This requires also remarkable technology development during the next 10 years: To support the learning online, queriable help must be complemented by context-sensitive help, methods supporting coaching and collaborative model building and intelligent QR model building support. Automatic ways to test learning together learner modelling are required. Qualitative modelling and reasoning offer also tools for qualitative explanation of complex mathematical models and integrated QR-Math simulators.

Task Group Bridge is focused on bridging the gap between FDI (Fault Diagnosis & Identification – Engineering) and DX (Diagnosis – Computer Science & Artificial Intelligence) communities. Their Roadmap sees the main technological drivers in next then 10 years to be the integration of DX with FDI and accepting a common technological framework. It is also seen that systems are getting so complex that diagnosis must be taken into account already in the design stage. This is also the only way to get good models. Wireless communications, distributed diagnosis, embedding diagnosis with other control tasks, and automatic reconfiguration will be the trends of the future. One possible solution is that universities teach FDI and DX techniques together and DX techniques are also taught to engineers. This would increase mutual understanding and may also lead to technical support companies offering both technologies.

5.13 NEMI 2002 Roadmap

NEMI is the U.S. located roadmapping organisation that charts future opportunities and challenges for the electronics manufacturing industry. In addition to industrial needs, it also tries to influence the focus of university research and government investment in emerging technology. Their Roadmap is available in the web address http://www.nemi.org/roadmapping/. The Roadmap covers the whole field from business, legislation, and markets to technology. Getting closer to EUNITE areas, the report emphasises the need for developing simulation tools for many areas: optoelectronics and nano-electronics, thermal and electric modelling for embedded components and mixed-mode wireless chips.

5.14 NeuroNet

NeuroNet was one of four NoE's, which comprised the CoIL cluster. Their Roadmap is available in the following Internet address http://www.kcl.ac.uk/neuronet/about/roadmap/. It consists of State-of-the-Art survey, chapter on future prospects for neural networks written by several contributors and a chapter on best practices in applying neural networks.

5.15 Planet

PLANET is the European co-ordinating organisation for research and development in the field of AI Planning and Scheduling. They have seven Technical Coordination Units (TCU's) – Aerospace applications, Intelligent manufacturing, Knowledge engineering, On-line planning and scheduling, Planning and scheduling for the Web, Robot planning and Workflow management – that all do Roadmaps. More information is available from http://planet.dfki.de/TCUs/TCUs.html. Once again, only the topics close to EUNITE areas are commented upon.

Knowledge Engineering (KE) for Planning Roadmap points out some problems: There is little knowledge in creation, validation and maintenance of large domain models and also the evaluation of KE tools is problematic. More experience on matching planning technology and domain model should be gained. The people working on the field have different backgrounds. It is also realised that research is mostly dealing with toy problems and theory instead of real-life applications.

Some actions are also recommended: Research community should go more to the direction of applications and new tools and research methodologies should be surveyed. Existing experience should be used for inducing general methods, a common taxonomy and a classification system describing the characteristics of domains. Attempts to build integrated engineering environments for planning applications are encouraged.

The main objective of Planning and Scheduling (P&S) Roadmap is to show that P&S can give significant contributions to web technologies, and the web is also an effective testbed for P&S technologies. It defines three scenarios for P&S applications for web, where web is either a transparent media, a whole environment or a part of the environment for applications. The main research issues origin from the different between the web and conventional application environments. The research should concentrate on managing uncompletness, events, inconsistency and richer knowledge representations typical to the web. Also operators can change, appear and disappear, so do also services. More expressive and flexible models and task-oriented languages are needed. Research should also be directed to more technologically oriented topics as portability, interoperability, scalability and models for co-operative distributed planning. The importance of technology transfer, educational initiatives and standardisation is also pointed out.

The next generation robots are supposed to be more general than current ones: they must be able to work in changing or unknown environments, to improve their performance by adaptation, and to perform new tasks without long training sessions. The Research in Robot Planning Roadmap analyses the impact robot planning (or plan-based control) on the development of autonomous robots. In the near future, progress on following areas is expected: the development of plan languages, tighter integration of planning/reasoning and execution, development of temporal plan management capabilities, hybrid plan representation and reasoning systems, object recognition and manipulation tasks, general purpose plan libraries, and development for richer interaction of robots with people. Topics for the medium-term future include focusing on tasks in everyday activity, new planning techniques and better physical models. Examples of long-term future applications are autonomous spacecrafts and planetary rovers, robot companions (e.g. for elderly people), and robots performing complicated assembly tasks based on visual or verbal instructions.

5.16 ROADCON

ROADCON is an Accompanying Measure under IST aiming to develop a roadmap for the research and development of ICT for the construction industry. The roadmap is available at http://www.roadcon.org. Their vision for future systems includes total life cycle management, knowledge re-use, ambient access with ambient intelligence, model based ICT with context-awareness, automation, simulation and visualisation, flexible interoperability, performance driven processes, virtual collaborative teams, and adaptive systems that learn from their own use and user behaviour.

5.17 Task Force on Safety Critical Systems

The Task Force on Safety Critical Systems was a EUNITE Task Force started in September 2002. It formulated a Roadmap of EU funded projects with intelligent systems in safety-related applications. It operated via two workshops, a survey and a questionnaire to end-users. The final report is available at http://www.eunite.org/.

5.18 Best Practice Guidelines

One of the activities in EUNITE was to provide the users with Best Practice Guidelines to show how different methods can and should be applied. This was separated as a book project that will lead to publishing a book “Do smart adaptive systems exist? Best practice for selection and combination of intelligent methods” that is published by Springer in the Spring 2004. The book will put together the cumulated knowledge inside the Network and provide the reader with a good selection of application and review papers. More information is available at http://www.eunite.org/.

Appendix 1: List of Roadmap Materials

Document Name	Author(s)	Date
Smart Adaptive Systems – State of the Art and Future Directions for Research A review on interval methods for adaptive systems. Recent progress in the fields of universal learning algorithms and optimal search.	D. Anguita Vehi, J., Armengol, J., Mujica, L.E. Schmidhuber, J.	Dec. 2001 Sept. 2002 Sept. 2002
Intelligent Systems in Production Industries	J. Sivonen, K. Leiviskä	Dec. 2001, January 2003
Role of Intelligent Techniques in Transport Management – A Survey	J. Posio	June 2003
Applications in Telecommunications and multimedia	M. Spott K. Leiviskä	Dec. 2001 January 2003
Survey on the Use of Smart and Adaptive Engineering Systems in Medicine	M.F. Abbod, D.A. Linkens, M. Mahfouf, G. Dounias	June 2002
IBA E Contribution to the EUNITE Roadmap	C. Carlsson	July 2003
Measuring the Penetration of Intelligent Technologies in Medical Business	N.S. Thomaidis, G.D. Dounias	2003
Final Report of EUNITE Task Force on Safety Critical Systems	P.J.G. Lisboa	Sept. 2003
Case Studies	Several authors	2001
Survey on Teaching Intelligent Methods in Europe	M. Leiviskä	Dec. 2001
On-line bibliography survey on Smart Adaptive Systems	K. Leiviskä	Dec. 2002

Appendix 2. List of Contributors

Several persons have contributed the Roadmap during its preparation.

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The European Network on Intelligent Technologies for Smart Adaptive Systems

IST-2000-29207 - EUNITE

EUropean Network on Intelligent TEchnologies for Smart Adaptive Systems

To join forces within the area of Intelligent Technologies (i.e. neural networks, fuzzy systems, methods from machine learning, and evolutionary computing) for better understanding of the potential of hybrid systems and to provide guidelines for exploiting their practical implementations and particularly.

To foster synergies that contribute towards building Smart Adaptive Systems implemented in industry as well as in other sectors of the economy.