RTD - IM Executive Summary

Reporting period: 01.01.2001 - 31.12.2003

1. Achievements

The Research Theory and Development - Integration of Methods Committee, as a complementary and collaborative committee to RTD-SAS, has been very active within EUNITE, contributing to a variety of important areas. There are 10 nodes within RTD IM committee which have participated in various activities organised by the committee and within various task forces relevant to the RTD IM committee scope. These are:

• Bournemouth University, UK	Bogdan Gabrys
• BTexaCT, UK	Detlef Nauck
• Univesitat Magdeburg, Germany	Rudolf Kruse
• University of Coimbra, Portugal	Antonio Dourado Correia
• University of Paisley, UK	Colin Fyfe
• University of Aberdeen, UK	George McCoghill
• University Paul Sabatier, France	Didier Dubois
• ADIC, Spain	J.R. Dorronsoro
• CSIS Spanish Council for Scientific Research, Spain	Maria C. Garcia Alegre
• National Technical University of Athens, Greece	Spyros Tzafestas

Also very active and deserving of special thanks are Andreas Nuernberger (Univesitat Magdeburg, Germany) and Silvia Galichet (University Paul Sabatier, France) for their various contributions of research materials and participation in the organisation of the events and meetings.

Major achievements that members of RTD-IM committee have contributed to include:

- *"Do Smart Adaptive Systems Exist? - Best practice for selection and combination of intelligent methods" book.* This contributed, multi-author book to be published by the Springer in a series on "Fuzziness and Soft Computing" represents a major undertaking and achievement of RTD-IM who are the coordinators of the project. The book is intended as a reference and a guide summarising and focusing on best practices when using intelligent techniques and building systems requiring a degree of adaptation and intelligence. It is therefore not intended as a collection of the most recent research results (which is a common characteristic of most edited volumes) but a practical guide for experts from other areas and industrial users who are interested in building solutions to their problems using intelligent techniques. One of the main issues covered is an attempt to answer the question of how to select and/or combine suitable intelligent techniques from a large pool of potential solutions. Another attractive feature of the book is that it brings together experts from neural network, fuzzy, machine learning, evolutionary and hybrid systems communities who will provide their views on how these different intelligent technologies have contributed and will contribute to creation of smart adaptive systems of the future.
- *Special Issues of International Journals.* As part of the activities focusing on providing a common platform to discuss and exchange research results and to disseminate the scientific results via publications RTD-IM have prepared and published 2 special issues of international journals which resulted from EUNITE conferences and workshops on Hybrid Methods for Adaptive Systems organised in 2001 and 2002. The first special issue was published in the journal of Fuzzy Sets and Systems (to appear in 2004) and the second in the International Journal of Approximate Reasoning (vol. 35, 2004). Both issues have focused on the integration of methods and hybrid systems.
- *The EUNITE Roadmap document*. RTD-IM committee members contributed in many ways to the EUNITE roadmap document. The focus was on providing material related to the hybrid intelligent methods with combinations of two or more individual intelligent technologies like neural networks, fuzzy systems, evolutionary computing and machine learning which were originally envisaged as being encompassed within EUNITE. Due to their prominence and the best fulfilment for methodological integration neuro-fuzzy techniques have been discussed and covered in the greatest detail. The roadmap document with contributions concerning the state-of-the-art and highlights of future directions from different committees represents a major contribution to both experts and newcomers to the filed of smart adaptive systems.

- *The Bibliographical Database Entries for Hybrid Systems.* RTD-IM have contributed, managed and maintained the entries in the hybrid systems category of the EUNITE bibliographical database set up and managed by RTD-SAS. The search for the entries in this category have been primarily focused on finding survey/overview papers and books most relevant to the RTD-IM committee scope of activities and providing further extensive reference lists for an interested reader to follow. These entries have also been supplemented by a number of research papers published in 4 successful workshops on Hybrid Methods for Adaptive Systems (see below) which are available in EUNITE conference proceedings, 2 special issues of international journals and a book concerning the best practice in selection and combination of intelligent methods mentioned above.
- *RTD IM Research Theory and Development Meetings.* A number of national and international conferences, workshops and meetings have been organised by the members of RTD IM. 4 main events were the annual workshops on Hybrid Methods for Adaptive Systems which have attracted submissions from members of EUNITE Network of Excellence as well as wider European and International research communities. These successful workshops have also been supplemented by high calibre invited speakers delivering talks on hybrid intelligent techniques and their applications in a variety of domains. Apart from attracting distinguished speakers, the financial contributions of RTD-IM have been directed towards encouraging young researchers in early stages of their careers to participate in organised events. All the meetings have been organised with an idea to provide a common platform to discuss and exchange research results and to define common terminology related to the general theme of integration of methods and hybrid systems.
- *Computational Intelligence Shop.* It has recently been estimated that we are producing 1.5 Exobytes of data annually. In other words, humans are producing more information every three years than was produced during the whole of our species' previous history. Yet this presents a problem in that we require to develop means for extracting information from these vast data stores. However it is extremely unlikely that there will be a silver bullet which will solve all problems in this area: both the nature of the tasks and the types of data are simply too diverse. A tool which is liable to be good for forecasting time series is unlikely to be useful for automatic clustering of visual images; a tool for text classification will be useless for automatic speech transcription; a tool for mining associations in a large database is not one which could be used for optimising robotic movement. The *Computational Intelligence Shop* (CIS) has been proposed as a virtual organisation built round a set of web pages which would allow: a) practitioners (or companies or organisations) to anonymously post or upload problems based on difficult information extraction problems. Such problems may be generic or specific to a particular data set; all problems would be posted with criteria for acceptable solutions. All problems would attract a financial reward and be given a time scale within which solutions must be provided; b) scientists and researchers around the world to view the problems and the price which would be paid by the practitioner's organisation to them for the best solution posted by the scientists and researchers for this problem. This information would allow the researchers to assess whether they have a tool which could solve the problem and whether they would be interested in posting a solution to the problem.
- *Other activities - Participation in Task Forces.* RTD-IM members have contributed to many other activities organised by other committees and led or have been involved in a number of task forces including User *Adaptive Search Interfaces, Taxonomy, State-of-the-art of Rule Based Systems, Intelligent Technologies for Gene Expression Based Individualised Medicine*, summer schools, supplying case studies, etc. The networking activities facilitated within EUNITE have also led to forming new research collaborations between many participating RTD IM nodes which can be regarded as one of very important achievements of both EUNITE and the committee itself.

2. Integration of Methods - Current Status

One of the more promising approaches to constructing smart adaptive systems is based on intelligent technologies including artificial neural networks, fuzzy systems, belief networks, methods from machine learning, parts of learning theory and evolutionary computing which have been especially successful in applications where input-output data can be collected but the underlying physical model is unknown. The incorporation of intelligent technologies has been used in the conception and design of complex systems in which analytical and expert systems techniques are used in *combination*. Viewed from a much broader perspective, the above mentioned intelligent technologies are constituents

of a vigorously developing research area called soft computing (SC) (the terms computational intelligence and hybrid intelligent systems are also frequently used). It is believed that the most important factor that underlies the marked increase in machine intelligence nowadays is the use of soft computing to mimic the ability of the human mind to effectively employ modes of reasoning that are approximate rather than exact. Unlike traditional hard computing based on precision, certainty, and rigor, soft computing is tolerant of imprecision, uncertainty and partial truth. The primary aim of soft computing is to exploit such tolerance to achieve tractability, robustness, a high level of machine intelligence, and a low cost in practical applications. Although the fundamental inspirations for each of the constituent intelligent technologies are quite different, they share the common ability to improve the intelligence of systems working in an uncertain, imprecise and noisy environment, and since they are complementary rather than competitive, it is frequently advantageous to employ them in *combination* rather than exclusively.

This realisation has also been reflected in various European initiatives, which have concentrated on bringing together communities working with and potentially benefiting from the intelligent technologies. The identification of the potential benefits from *integration of intelligent methods* within four thematic networks of excellence for machine learning (MLNet), neural networks (NeuroNet), fuzzy logic (Erudit) and evolutionary computing (EvoNet) initially led to conception of the cluster on Computational Intelligence and Learning (CoIL) and subsequent launch of EUNITE.

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 in this summary 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. These are:

- Neuro-fuzzy systems. 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 is related to a more general problem of interpretability v. 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. Similarly to 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 is that when some typical neural learning techniques are used 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.

3. Integration of methods - Future Challenges

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.

Hybrid soft computing frameworks are relatively young, even comparing 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) rely 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. This is also required if such systems are to be fully adaptable to changing environments and operating conditions.

Before finishing let us, following recent publication on strategic directions in AI, list some of more general and application based, representative long term goals and challenges applicable in the context of *integration* and *hybrid* intelligent systems.

Long term goals and challenges with respect to integration of intelligent methods:

- 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 analyzing 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.

- 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. Do Smart Adaptive Systems Exist?

Though there have been very exciting developments in the field of hybrid intelligent systems and some successes have been reported it has to be said that they represent cases which are, at best, adaptive to levels 1 (Adapting to a changing environment) and 2 (Adapting to a similar setting) as defined for EUNITE purposes of distinguishing between different *smart adaptive systems*. It is clear and can be seen from the existing trends that a road to more intelligent/smart systems is through development of integrated/hybrid approaches which have already proven to be more flexible and powerful than individual intelligent paradigms. These hybrid techniques have now moved from the research laboratories into a real world applications and are very likely to have an immense impact on our world as amply illustrated in the recent CSC’s Leading Edge Forum report entitled “Get Smart: How Intelligent Technology Will Enhance Our World”. However, it has to be said that, as for today, a truly intelligent/smart systems as defined by the requirements of the level 3 (Adapting to solve a new problem) certainly DO NOT EXIST.

5. Some events and outcomes in RTD IM area

- Hybrid Method for Adaptive Systems (HMAS'2001) workshop, a part of *EUNITE'2001 Conference,* (4 sessions) Tenerife, Spain, December 2001
- Hybrid Method for Adaptive Systems (HMAS'2002) workshop, a part of *EUNITE'2002 Conference,* (4 sessions) Albufeira, Portugal, September 2002
- Hybrid Method for Adaptive Systems (HMAS'2003) workshop, a part of *EUNITE'2003 Conference*, (4 sessions) Oulu, Finland, July 2003
- Adaptive Multimedia Retrieval (AMR 2003) workshop, a part German Conference on Artificial Intelligence (KI 2003), (5 sessions), Hamburg, Germany, September 2003
- To be held: Hybrid Method for Adaptive Systems (HMAS'2004) workshop, a part of *EUNITE'2004 Conference*, Aachen, Germany, June 2004
- To be held: Adaptive Multimedia Retrieval (AMR 2004) workshop, a part ECAI 2004, Spain, August 2004
- A special issue of the *Fuzzy Sets and Systems* journal on *Hybrid Methods for Adaptive Systems*, Nauck, D. (ed.), in press, 2004
- A special issue of the *International Journal of Approximate Reasoning* entitled *Selected Issue on Integration of Methods and Hybrid Systems*, Gabrys, B. (ed.). , vol.35, no. 3, pp. 1-2, 2004
- A book entitled "*Do Smart Adaptive Systems Exist? - Best Practice for Selection and Combination of Intelligent Methods*", Gabrys, B., K. Leiviska and J. Strackeljan (eds.). To be published in the Springer series on "Studies in Fuzziness and Soft Computing", in preparation, 2004