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Intelligent Systems and Soft Computing

Prospects, Tools and Applications

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Preface

Building intelligent machines has been mankind's dream for decades. There have been many discussions on, and much written about, the impact of machine intelligence on society. Science fiction movies have portrayed both the brighter and the darker aspects of being surrounded on all sides by artificial systems with more intelligence than humans. Building such intelligent machines is, and will remain for the foreseeable future, a dream. The collection of papers that makes up this book, explore the prospects of incorporating intelligent behaviour into software systems. It outlines many promising directions, and describes possible tools and applications for intelligent systems in the near future.

Much effort, time, and money have been spent in the last 50 years in understanding the nature of human intelligence. Why? So that artificial systems can be built that act and work as intelligently as humans. While the realisation of an intelligent machine that is as clever as a human is as yet a technical impossibility, and in some people's view undesirable, we cannot ignore the fact that people nowadays are demanding (intelligent) systems that are useful and can complement their physical or cognitive capabilities. This demand is leading to the creation of a large and lucrative market in intelligent systems, which is naturally spawning the associated information technology industries for building these systems.

The *raison d'être* for this volume is to bring together, within a single publication, a collection of papers describing recent advances in intelligent systems and soft computing, with particular focus on applications. The book is unique in the way it concentrates on building intelligent software systems by combining methods from diverse disciplines, such as fuzzy set theory, neuroscience, agent technology, knowledge discovery, and symbolic artificial intelligence (AI). Traditionally, AI has been trying to solve human-centred problems, such as natural language understanding, speech recognition, and common-sense reasoning. On the other hand, soft computing has been applied successfully in the areas of pattern recognition, function approximation, clustering, and automatic control. The papers in this book explore the possibility and opportunity of bringing these two areas closer together. The first section focuses on future directions and includes contributions from some of the most eminent academics in the fields. The second section aims to provide the reader with an overview of recently developed software tools to aid researchers and practitioners in building flexible intelligent systems. The final section describes a number of developed applications that utilise the theoretical results and software tools described in the first two sections. We hope that the particular combination of the three sections will ensure that the book appeals to a wide audience, ranging from industrial researchers to academic scholars.

February 2000

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Acknowledgements

The authors of the papers are the *sine qua non* of the endeavour of creating an edited volume. We are deeply grateful to them and we do apologise if they found us demanding; hopefully it has enhanced the quality of the volume. Our thanks go also to the many reviewers, particularly to David Djian, Kwok Ching Tsui, and Wayne Wobcke. Finally, we wish to acknowledge Graham Davies and David Griffiths of the BT Group Technology Programme for their continuous support of the Soft Computing programme.

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Introduction

In October 1998 we at BT's intelligent systems research group organised a workshop at Adastral Park with the aim of setting up a forum for discussion about new paradigms for building intelligent systems. The feedback from the workshop was extremely encouraging to the extent that we decided to gather together the contributions of the participants. This book is the result of our efforts. Its subject is how to build intelligent systems – systems that can make intelligent decisions in complex situations. The book does not aim to explain what intelligent systems are or should be (as this has been the subject of many recent publications including an edited volume containing a number of contributions from authors represented in this volume entitled Software Agents and Soft Computing [1]), but it tries to offer academics and industrialists a way forward for engineering intelligent systems.

This volume extends and builds upon some of the papers which appeared in BT Technology Journal Vol. 16, No. 3. It is divided into three sections: prospects, tools and applications. The first section includes articles from some of the most prominent academics of our era about future perspectives and new areas of research that will help us in our long search for the nature of intelligence and intelligent systems. The ultimate goal of understanding intelligence is to build artificial systems that behave intelligently and so the second section is devoted to tools that utilise new algorithms and software languages to enable us to build such systems. In the last section a number of papers present recently developed prototypical systems that, by utilising intelligent techniques, will in our view increasingly play a vital role in our lives, fulfilling our information and communication needs in the years to come.

From a technical point of view our aim of compiling this volume has been to build upon the existing work based on well-known symbolic artificial intelligence (AI) by introducing hybrid techniques that borrow from the soft computing paradigm when there is a good reason to do so. Our aim is to demonstrate that such hybrid approaches enable us to provide robust, adaptive and easy-to-interact-with systems that work for, alongside, or on behalf of humans.

1 Motivation

Early attempts at building systems with comparable cognitive capability to the human brain, even in limited domains, have not been as successful as predicted. The problems of knowledge representation, common-sense reasoning, real-time problem solving, vision, speech and language processing have not as yet yielded to classical AI techniques. More research is needed and is being carried out mainly by academia in the areas of pattern recognition, logical representation, search, inference, learning from experience, planning, ontology and epistemology. Despite the difficulties, AI has been successfully applied in areas such as expert systems, classification, planning, scheduling, game playing and robotics.

For the past half century the AI community has aimed to build artefacts that could compete with human level intelligence on various tasks. An alternative view for building intelligent systems is the tool metaphor in which the human is seen as a skilled craft-person with the system trying to provide the tools that fit the capabilities of the user and the task to be performed. In this view, the focus is on systems that can augment the cognitive capabilities of humans, i.e. a human-machine symbiosis or *Human-Centred Intelligent System* (HCIS). HCIS are different in many respects from traditional AI systems in that they do not compete with, or try to match, human level intelligence. Rather, they assist humans in performing cognitive tasks such that the combination of the human and the system has a greater cognitive capacity than each on its own [2].

Looking at the world from a different perspective it can be seen that it is constantly growing in complexity. This complexity manifests itself today, for example, in the form of information overload. In a normal business environment we face an ever growing stream of information from such channels as e-mail, telecommunication devices, Internet-based services, etc. At home with digital, terrestrial and satellite TV we experience a similar situation where we have the choice of hundreds of TV channels. On the one hand, most of this information is useless for us, and on the other hand it becomes more and more difficult to find important information. Intelligent systems can help us cope with this complexity. These are systems that act on our behalf by filtering unnecessary information, dealing with unwanted communication, anticipating and learning our reactions and preferences, actively searching for relevant information for us, scheduling our tasks the way we would, etc.

Symbolic AI techniques mainly do not take uncertainty, imprecision and vagueness into account – even more, they try to avoid them at all cost. This approach consequently leads to systems that require to model all possible states and exceptions resulting in highly complex systems that cannot run in real time on today's computers.

Humans deal with complexity by simplification. Precise representations have a good chance of being wrong or inapplicable most of the time. Furthermore such representations are very brittle and cannot tolerate the small variations or uncertainty that are present in all but a handful of real problems. Simplified rules, and representations that are vague, apply to a whole range of situations, at least to some extent.

Furthermore, precision carries a cost, which is often too prohibitive for real-world problems. By tolerating uncertainty and imprecision we can drastically reduce the complexity of a system. Instead of conceiving rules for every possible precise situation we use vague rules which do not distinguish between similar states.

By building systems that deliberately exploit the tolerance for uncertainty and imprecision in certain situations, we can develop robust intelligent solutions with less cost and effort, two critically important factors in constructing real-world applications.

By assuming the tool-oriented view of HCIS we can concentrate on solving sub-tasks fast and are able to accelerate application development. The main focus in the development of such systems lies on:

- robustness, i.e. applicability under uncertain and vague conditions,
- adaptability, i.e. learning from experience and human intervention,
- autonomy, i.e. acting on behalf of a user without direct intervention, and
- multi-modal interfaces, i.e. making use of human communication channels like vision, speech, and understanding natural language.

In our view soft computing is ideally suited to handle uncertainty, vagueness and learning problems within HCIS.

2 Rationale: Soft Computing

The term *soft computing* was coined by Lotfi A. Zadeh to describe a collection of methodologies that aim to exploit the tolerance for imprecision and uncertainty to achieve tractability, robustness and low solution cost [3, 4]. Zadeh sees fuzzy logic, neural computation and probabilistic reasoning as the main constituents of soft computing, the latter subsuming genetic algorithms, belief networks, chaotic systems and parts of learning theory.

Fuzzy logic is mainly concerned with imprecision, vagueness and approximate reasoning, neural computation with (sub-symbolic) learning and probabilistic reasoning with uncertainty.

According to Bonissone [5] soft computing techniques are drawn together by 'their departure from classical reasoning and modelling approaches that are usually based on Boolean logic, crisp classification and deterministic search.'

Zadeh has selected the term *soft* computing to distinguish the above-mentioned methodologies from traditional *hard* computing which is based on precision, certainty and rigor. Soft computing draws from the idea that precision and certainty carry a cost and that computation, reasoning and decision making should exploit the tolerance for imprecision and uncertainty wherever possible [3].

There are usually trade-offs between precision and robustness and precision and simplicity. If we aim for a very precise system, slight modifications in the input can lead to drastic changes in the system's behaviour. This effect is known as *brittleness* in classical symbolic expert systems. In addition, precision can often only be reached by very complex systems. Complexity, however, can prevent a system from working in real time and a lack of simplicity prevents user-friendliness.

By applying fuzzy systems, for example, a considerable reduction in complexity can be reached. Instead of a large number of individual values, a few fuzzy sets are used to describe a domain. This leads to data compression (granulation), because we refrain from explicitly distinguishing similar values. In addition we can let adjacent fuzzy sets overlap such that slight changes in the input values will not lead to drastically different system outputs.

The performance of soft computing solutions must therefore not only be measured by its precision but also by its simplicity, user-friendliness, robustness, overall cost, etc.

Another important aspect of soft computing is that the mentioned methodologies complement each other. For example, combinations between neural networks and fuzzy systems – so-called neuro-fuzzy systems – are a very well researched area [6, 7]. A neuro-fuzzy system aims at learning a fuzzy system from data, thus combining learning aspects and vagueness handling.

As important as soft computing techniques in the design of HCIS may be, we are convinced that soft computing cannot replace AI. It is important to use both paradigms in building solutions. The Intelligent Assistant that is presented in Section 3 is an example for such a strategy.

3 Outline

The first section of this book contains contributions of well-known researchers from the soft computing community who provide their views of future development in this area.

The second section discusses three well-known tools for soft computing. NEFCLASS-J is an open-source software for learning fuzzy classifiers, FRIL is a commercial system that combines soft computing and AI methodologies and Data Engine™is a commercial data analysis tool with a focus on soft computing techniques.

The third section contains several contributions on the Intelligent Assistant (IA) that was developed within the BT Laboratories at Adastral Park. The IA consists of a suite of integrated assistants that helps the user with communication, information and time management. The assistants use both AI and soft computing techniques to maintain a user model and to learn user preferences.

Section 1 – Prospects

L.A. Zadeh – From Computing with Numbers to Computing with Words – From Manipulation of Measurements to Manipulation of Perceptions – Computing, in its usual sense, is centred on manipulation of numbers and symbols. In contrast, computing with words, or CW for short, is a methodology in which the objects of computation are words and propositions drawn from a natural language, e.g. *small, large, far, heavy, not very likely, the price of gas is low and declining, Berkeley is near San Francisco, CA, it is very unlikely that there will be a significant increase in the price of oil in the near future,* etc. Computing with words (CW) is inspired by the remarkable human capability to perform a wide variety of physical and mental tasks without any measurements and any computations. Familiar examples of such tasks are parking a car, driving in heavy traffic, playing golf, riding a bicycle, understanding speech, and summarizing a story. Underlying this remarkable capability is the brain's crucial ability to manipulate perceptions – perceptions of distance, size, weight, colour, speed, time, direction, force, number, truth, likelihood, and other characteristics of physical and mental objects. Manipulation of perceptions plays a key role in human recognition, decision and execution processes. As a methodology, computing with words provides a foundation for a computational theory of perceptions – a theory which may have an important bearing on how humans make – and machines might make – perception-based rational decisions in an environment of imprecision, uncertainty and partial truth.

J.G. Taylor – Bringing AI and Soft Computing Together – The problem of reconciling what appear as two completely different computing styles, those of AI and of soft computing, is considered in terms of modern brain research. After a brief but general discussion of soft computing relevant to the analysis of the brain, this contribution gives an introduction to neural networks as a modelling framework with which to approach brain processing. The author develops a framework to describe how object perception can arise in the brain and considers how that can help reconcile the two different styles of computing.

J.F. Baldwin – Future Directions for Soft Computing – This paper discusses possible future directions of research for soft computing in the context of artificial intelligence and knowledge engineering. The author uses a voting model semantics to develop ideas for a mass assignment theory which provides means of moving from the case of crisp sets to that of fuzzy sets. The use of fuzzy sets provides better interpolation, greater knowledge compression and less dependence on the effects of noisy data than if only crisp sets are used. The benefits are illustrated in the areas of decision trees, probabilistic fuzzy logic type rules and Bayesian nets.

R. Kruse, C. Borgelt and D. Nauck – Problems and Prospects in Fuzzy Data Analysis – In meeting the challenges that resulted from the explosion of collected, stored, and transferred data, *Knowledge Discovery in Databases,* or *Data Mining,* has emerged as a new research area. However, the approaches studied in this area have mainly been oriented at highly structured and precise data. In addition, the goal to obtain understandable results is often neglected. Therefore the authors suggest concentrating on *Information Mining*, i.e. the analysis of heterogeneous information sources with the prominent aim of producing comprehensible results. Since the aim of fuzzy technology has always been to model linguistic information and to achieve understandable solutions, it is expected to play an important role in information mining.

E.H. Mamdani, A.G. Sichanie and J. Pitt – Soft Agent Computing – Soft agent computing (SAC) draws together the ideas of soft computing with the agent paradigm. This paper considers several issues of fusing these areas from the perspective of agent characteristics and agent architectures. The authors present different abstraction layers of a SAC architecture and describe a practical SAC system based on the beliefs-desires-intention model.

Section 2 – Tools

D. Nauck and R. Kruse – NEFCLASS-J – A Java-based Soft Computing Tool – Neuro-fuzzy classification systems offer a means to obtain fuzzy classification rules by a learning algorithm. It is usually no problem to find a suitable fuzzy classifier by learning from data; however, it can be hard to obtain a classifier that can be interpreted conveniently. There is usually a trade-off between accuracy and readability. NEFCLASS-J is a Java based tool that aims at learning comprehensible fuzzy classifiers. It provides automatic strategies for pruning rules and variables from a trained classifier to enhance its interpretability. NEFCLASS-J is freely available via the Internet at http://www.neuro-fuzzy.de.

T.P. Martin and J.F. Baldwin – Soft Computing for Intelligent Knowledge-based Systems – Knowledge-based systems are founded in the idea that knowledge should be declarative, so that it can be easily read, understood, and altered by a human user as well as by a machine. Logic fulfils these criteria, and logic programming has been widely used for implementing knowledge-based systems. One major shortcoming of logic programming is the lack of a mechanism to deal with the uncertainty inherent in many knowledge-based systems. Soft computing is a key technology for the management of uncertainty. This contribution outlines some of the issues related to the area of soft computing in knowledge-based systems, and suggests some simple problems to test the capabilities of software. FRIL is discussed as an implementation language for knowledge-based systems involving uncertainty, and some of its applications are outlined.

C. Borgelt and H. Timm – Advanced Fuzzy Clustering and Decision Tree Plug-Ins for DataEngine™ – Although a large variety of data analysis tools is available on the market today, none of them is perfect; they all have their strengths and weaknesses. In such a situation it is important that a user can enhance the capabilities of a data analysis tool by his or her own favourite methods in order to compensate shortcomings of the shipped version. However, only few commercial products offer such a possibility. A rare exception is DataEngine™, which is provided with a well-documented interface for user-defined function blocks (plug-ins). In this paper the authors describe three plug-ins they implemented for this well-known tool: an *advanced fuzzy clustering plug-in* that extends the fuzzy c-means algorithm (which is a built-in feature of DataEngine™) by other, more flexible algorithms, a *decision tree classifier plug-in* that overcomes the serious drawback that DataEngine™ lacks a native module for this highly important technique, and finally a *naive Bayes classifier plug-in* that makes available an old and time-tested statistical classification method.

Section 3 – Applications

B. Azvine, D. Djian, K.C. Tsui and W. Wobcke – The Intelligent Assistant: An Overview – The Intelligent Assistant (IA) is an integrated system of intelligent software agents that helps the user with communication, information and time management. The IA includes specialist assistants for e-mail prioritisation and telephone call filtering (communication management), Web search and Yellow Pages lookup (information management), and calendar scheduling (time management). Each such assistant is designed to have a model of the user and a learning module for acquiring user preferences. In addition, the IA includes a toolbar providing a graphical interface to the system, a multi-modal interface for accepting spoken commands and tracking the user's activity, and a coordinator responsible for managing communication from the system to the user and for initiating system activities on the user's behalf. A primary design objective of the IA is that its operation is as transparent as possible, to enable the user to control the system as far as is practicable without incurring a heavy overhead when creating and modifying the system's behaviour. Hence each specialist assistant is designed to represent its user model in a way that is intuitively understandable to non-technical users, and is configured to adaptively modify its user model through time to accommodate the user's changing preferences. However, in contrast to adaptive interface agents built under the behaviour-based paradigm, the assistants in the IA embrace complex AI representations and machine learning techniques to accomplish more sophisticated behaviour.

A. De Roek, U. Kruschwitz, P. Scott, S. Steel, R. Turner and N. Webb – The YPA – An Assistant for Classified Directory Enquiries – The YPA is a directory enquiring system which allows a user to access advertiser information in classified directories. It converts semi-structured data in the Yellow Pages®machine readable classified directories into a set of indices appropriate to the domain and task, and converts natural language queries into filled slot and filler structures appropriate for the queries in the domain. The generation of answers requires a domain independent query construction step, connecting the indices and the slot and fillers. The YPA illustrates an unusual but useful intermediate point between information retrieval and knowledge representation.

K.C. Tsui and B. Azvine – An Intelligent Multi-modal Interface – Research in human/computer interaction has primarily focused on natural language, text, speech and vision in isolation. A number of recent research projects have studied the integration of such modalities. The rationale is that many inherent ambiguities in single modes of communication can be resolved if extra information is available. This contribution discusses issues related to designing and building a multi-modal system. The main characteristics of such a system are that it can process input and output from conventional as well as new channels. Examples of multi-modal systems are the *Smart Work Manager* and the *Intelligent Assistant*. Main components of the two systems described here are the reasoner, the speech system, the non-intrusive neural network based gaze-tracking system, the user presence detector and the integration platforms.

D. Djian – Communication Management – Nowadays, office workers receive an increasing number of communications, mainly through e-mail and telephone. If not handled correctly, these can lead to a communication overload. This paper describes a system which helps a user to manage interruptions from incoming communications. It is based on a generic hierarchical priority model using causal probabilistic networks and taking into account the context of an interruption. The model was implemented in an e-mail and a telephone assistant. These assistants can learn the user's preference in a non-obtrusive manner and we show experimental results of successful adaptation to changing user's needs.

W. Wobcke – Time Management in the Intelligent Assistant – In this contribution, the author discusses in detail issues related to time management in the IA. There are two distinct types of time management relevant to the IA: that concerning the user's management of his or her own time, and that concerning the coordination of actions performed by the various specialist assistants in the system (which affects the overall effectiveness of the system from the user's point of view). To aid the user in managing his or her own time, the IA includes a *Diary Assistant* which acts as a scheduler of tasks with the aim of satisfying the user's combined preferences for start times, durations and deadlines. The Diary Assistant offers ease of use by allowing preferences for a task to be specified using natural language terms such as *morning*, *afternoon*, *early morning* and *around 11:00*, which are interpreted by the system using fuzzy functions. To manage the system's time, the IA has a special *Coordinator* for regulating the communication from the system to the user and for planning system tasks. The Coordinator is the only component of the IA capable of scheduling the future actions of the assistants, and incorporates a novel agent architecture based on ideas from reactive scheduling called IRSA (*Intelligent Reactive Scheduling Architecture*). The Coordinator constructs and maintains the system's schedule of tasks using information about the user's schedule obtained from the Diary Assistant.

S. Case, J.F. Baldwin and T.P. Martin – Mood Recognition from Facial Expressions – Facial expressions are an important source of information for human interaction. Therefore, it would be desirable if computers were able to use this information to interact more naturally with the user. However, facial expressions are not always unambiguously interpreted even by competent humans. Consequently, soft computing techniques in which interpretations are given some belief value would seem appropriate. This contribution describes how the mass assignment approach to constructing fuzzy sets from probability distributions has been applied to the low-level classification of pixels into facial feature classes based on their colour.

N.R. Taylor – Modelling Preferred Work Plans – Temporal sequence storage and generation is important during our everyday lives. The sequences of actions that we perform to accomplish tasks are learnt as schemata and are then used in planning solutions. Hence for planning schemata are required to be set up. This contribution describes a system based on a neural network architecture that learns to plan a user's work schedule.

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References

1. Nwana H. S. and Azarmi N., Eds.: 'Software Agents and Soft Computing'. No. 1198 in Lecture Notes in Computer Science. Berlin, Springer-Verlag (1997).
2. Azvine B. and Wobcke W.: 'Human-centred intelligent systems and soft computing'. BT Technology Journal, Vol. 16(3), pp. 125–133 (1998).
3. Zadeh L. A.: 'Fuzzy logic, neural networks and soft computing'. Comm. ACM, Vol. 37(3), pp. 77–84 (1994).
4. Zadeh L. A.: 'Soft computing and fuzzy logic'. IEEE Software, Vol. 11(6), pp. 48–56 (1994).
5. Bonissone P. P.: 'Soft computing: The convergence of emerging reasoning technologies'. Soft Computing, Vol. 1(1), pp. 6–18 (1997).
6. Jang J.-S., Sun C. and Mizutani E.: 'Neuro Fuzzy and Soft Computing'. Upper Saddle River, NJ, Prentice Hall (1997).
7. Nauck D., Klawonn F. and Kruse R.: 'Foundations of Neuro-Fuzzy Systems'. Chichester, Wiley (1997).