Mircea Negoita, Daniel Neagu, Vasile Palade

Computational Intelligence: Engineering of Hybrid Systems

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Computational Intelligence: Engineering of Hybrid Systems

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To erudite professor and scholar Severin Bumbaru

To our lovely and patient wives Doina Negoita,
Daniela Neagu and Dana Palade

Invited Preface

It is my great pleasure to introduce to you this excellent book on computational intelligence written by three well-known researchers: Mircea Gh. Negoita of New Zealand, and Ciprian Daniel Neagu and Vasile Palade of Great Britain. The authors have published extensively in the area of computational intelligence and the book benefits greatly from their experience.

Computational intelligence is a very broad term meaning different things to different people. However, recent creation of the Computational Intelligence Society, by the Institute of Electric and Electronic Engineers (IEEE), and the scope of journals it publishes, enables us to roughly define computational intelligence as one encompassing neural networks, fuzzy systems, evolutionary computation, their variants and hybrids.

It is the hybrid approaches, combining several methodologies that are paid special attention in the book. Many indicators show that such hybrid intelligent systems are one of the fastest growing fields that attract hundreds of researchers and practitioners. It comes as no surprise that hybrid approaches are required on dealing with real-world problems since (artificial) intelligence cannot be accomplished by any single methodology alone. There are many views on human intelligence as well, and it can also be seen as a hybrid of several types of "intelligence".

It is the view of the authors that hybrid intelligent systems are more than just the three broad areas mentioned above. Consequently, they also cover knowledge extraction and fusion, and novel areas such as DNA computing, Artificial Immune Systems and Evolvable Hardware.

The book presents in a thorough way almost an entire range of hybrid intelligent systems, and what is very important for practitioners, it also provides several real-life, working, implementations of hybrid systems.

The book probably is the first attempt to provide the basis for hybrid intelligent systems through clear and well-organized way of presenting the fundamentals of key methods. As a result the book can serve as a valuable introduction to hybrid intelligent systems, and as a guide of how to use them for solving real problems. As such it has a good chance of becoming one of the most cited references in the area.

I am convinced that the book will play an important role in pursuing further developments and applications of hybrid intelligent systems methods.

The authors well deserve congratulations for their excellent work, and I commend to the readers the volume that is an important addition to the literature of computational intelligence.

University of Colorado at Denver
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Krzysztof Cios

Preface

The *Soft Computing* framework or *Computational Intelligence* with its large variety of efficient applications is hugely fascinating. Problems in engineering, computational science and the physical and biological sciences are using the increasingly sophisticated methods of *Computational Intelligence*. Because of the high interdisciplinary requirements featuring most real-world applications, no bridge exists between the different stand alone *Intelligent Technologies*, namely Fuzzy Systems, Neural Networks, Evolutionary Algorithms, DNA Computing, Artificial Immune Systems and Knowledge Based Systems. The concomitant increase in dialogue and interconnection between the *Intelligent Technologies* has led to *Computational Intelligence* and its practical implementation – the *Hybrid Intelligent Systems*. The idea of writing a book on this topic first crossed my mind in 1996, and I am really happy that the book is finally complete.

Initially I thought this book would be of real help to my gifted students at the Department of Applied Electronics and at the Department of Automatics in the Faculty of Electrical Engineering and Navy of the University "Dunarea de Jos" Galati, Romania. New ideas and suggestions regarding the final structure of the book were obtained from students attending my course on Intelligent Multi-Agent Hybrid Systems at Wellington Institute of Technology, New Zealand. They were really pleased to become familiar with *the Intelligent Technologies* and with some typical competitive software, such as Neural Network Professional II Plus and Soft Computing Genetic Tool. Their interest in this area gave me the stimulus to finish the book. My intention was to be helpful to the students, not to exempt them from intellectual effort, but to put as much illustrative information as possible into the book. The purpose was to create *a very clear image* of what *Computational Intelligence* is in general terms, and to convince them that *Hybrid Intelligent Systems* are really nothing else but the engineering implementation of *Computational Intelligence.*

The purpose of this book is to illustrate the current needs and to emphasize the future needs for the interaction between various *Intelligent Technologies*. The team writing this book did this firstly by encouraging the ways that *Intelligent Technologies* may be applied in those areas where they are already traditional, as well as pointing towards new and innovative areas of application involving emergent technologies such as DNA Computing, Artificial Immune Systems and Evolvable Hardware. Secondly, to help encourage other disciplines to engage in a dialogue with practitioners of *Hybrid Intelligent Systems* engineering, outlining their problems in accessing these new methods in the engineering of *Hybrid Intelligent Systems,* and also suggesting innovative developments within the area itself.

An important concept in my university teaching/research work was that a student must be convinced at an early professional stage that there is an interdisciplinary aspect in the development of technology. Students require not only a knowledge/skills base, but also the methodology for implementing real world applications under interdisciplinary conditions. Nowadays this is available not only to recent graduates, but also to other practitioners (engineers, scientific researchers and academic staff) whatever their background and area of interest may be. Thus the progress of *Hybrid Intelligent Systems* within the framework of *Computational Intelligence* was discussed from an application – engineering point of view, rather than from a cognitive science or philosophic view point. In our book we have not detailed all aspects of the *Computational Intelligence* framework as viewed by its founder L. A. Zadeh. The second feature of this book is a discussion of the interactive aspects of different *Intelligent Technologie*s which have lead to both the evolution and practical interactions of *Hybrid Intelligent Systems.*

Special attention (separate book chapters) is given to the interaction of the I*ntelligent Technologies* with DNA Computing, Artificial Immune Systems and with the most spectacular emergent technology – **E***volvabl*e **H***ard***W***are* (*EHW*). *EHW* has opened a revolutionary era in technology and in the social life development of humans by its radical impact on engineering design and automation. A dream of humanity has become reality: *EHW* has transferred the adaptivity of a system from software to hardware. A significant time-saving path is used from a design to a real world application of intelligent hardware. Differences no longer exist between the design and adaptation involving *EHW*-based machines having behavioural computational intelligence. Electronic engineering has been fundamentally changed by using *EHW* custom-design technologies instead of solder based manufacturing.

Chapter 1 is an introduction to *Computational Intelligence* and *Hybrid Intelligent Systems*, including their terminology and classification.

Chapter 2 presents a major application of *Hybrid Intelligent Systems* – fault diagnosis, and is focused mainly on neural-fuzzy methods.

Chapter 3 describes theoretical aspects of the main neural-fuzzy techniques for the design of *Hybrid Intelligent Systems*, but hybrid intelligent systems combining connectionist and symbolic features are also presented.

Chapter 4 focuses on the strictly fuzzy approach of neural networks, and presents some interactive fuzzy operators in order to extract connectionistrepresented knowledge using the concept of f-duality. The methodologies are tested on simple and traditional case studies.

Chapter 5 is an introduction to modular networks in fuzzy systems. This provides new insights into the integration of explicit and implicit knowledge in a connectionist representation.

Chapter 6 is focussed on application aspects of *Hybrid Intelligent Systems* engineering. The main application areas of *Hybrid Intelligent Systems* are mentioned. Some special original applications are introduced. *NEIKeS* (**N***eural* **E***xplicit* and **I***mplicit* **K***nowledge* Based **S***ystem*) is an original Fuzzy Knowledge-Based System for the prediction of air quality. *WITNeSS* (**W***ellington* **I***nstitute of* **T***echnology* **N***ovel* **E***xpert* **S***tudent* **S***upport*) is an intelligent tutoring system. Two applications of *VLGGA* (**V***ariable* **L***ength* **G***enotype* **G***enetic* **A***lgorithm*) – a special non-standard *GA* – are introduced in the form of two hybrid intelligent optimisation methods which have wide applicability.

The most recent trends in the development of *Hybrid Intelligent Systems* are presented in *Chap. 7.* These applications rely on the hybridization techniques of DNA Computing and Artificial Immune Systems.

Chapter 8 emphasizes the massive role played by Evolutionary Computation in the implementation of *Computational Intelligenc*e. A large range of GA based *Hybrid Intelligent Systems* are introduced, with applications in Fuzzy information processing, and Neural Networks design and optimization. The role of *Hybrid Intelligent Systems* in the design of high performance GA is illustrated. A special part of this chapter is reserved for GA based *Hybrid Intelligent Systems* in EHW implementation.

Most sections include useful suggestions for the practical design and development of further applications. All three authors agree that although this book is a primer, it is not useful to only students. This book has practical value for both those new to the discipline and also for those who are already practitioners in the area.

The common research work with my research team colleagues while I was at the University of Galati, Romania – Dr. Ciprian Daniel Neagu (Bradford University, UK) and Prof. Vasile Padae (Oxford University, UK) – constitutes the foundation for this book. Some of the results in their PhD theses are introduced in this book. The time which I spent abroad both as a visiting professor and as a visiting researcher at Dortmund University (Germany), at York University (Toronto, Canada), at RWTH (Aachen, Germany), and the permanent connection and exchange of ideas with colleagues from abroad, were of great value in obtaining the original results that are presented here. Some common research developments with my brilliant former research team-mates (Alexandru Agapie, Florin Fagarasan, Marius Giuclea and Dan Mihaila) from National Institute for Research and Development in Microtechnologies (IMT) in Bucharest, and also some very recent results of international scientific cooperation with Dr. Dragos Arotaritei from Aalborg Univesity (Esbjerg, Denmark) are integrated into some sub-chapters.

I have just one regret regarding this book: Prof. Edmond Nicolau, world renowned as one of the co-founders of modern cybernetics, former Director in World Organization of Cybernetics and Systems, a pioneer of scientific research in Neural Networks, my PhD supervisor and scientific mentor passed away before this book was finished.

A decisive element for finally completing the book was the environment and research conditions I met at Wellington Institute of Technology (WelTec), Wellington, New Zealand. Special thanks are due to Dr. Linda Sissons, WelTec CEO and to Denford McDonald, WelTec Council Chairman, for understanding the important role of *Computational Intelligence* in economic development and for giving me their full support in my work as the Director of Centre for Computational Intelligence at WelTec.

The emotional feelings involving the completion of this book which I have written in New Zealand – together with my best research colleagues – were that I never forget my native country – *Romania*, but I deeply love my adoptive country – *New Zealand*.

The whole team of authors is grateful for the understanding and permanent support of Springer Verlag Publishing House throughout the writing of this book. We would also like to acknowledge our special appreciation for the hard work done by David Pritchard, my research team colleague at WelTec Centre for Computational Intelligence, and, being a native English language speaker, for finally "brushing" the camera-ready manuscript. Special acknowledgments must be addressed to Professor Nikolaos Avouris and the Human Computing Interaction Group of the University of Patras, Greece, where the prototype for the air quality prediction system NEIKeS has been developed. Also we acknowledge the support of the EU FP5 RTN project IMAGETOX, Professor Giuseppina Gini, Dr. Emilio Benfenati and Dr. Mark Cronin for the collaborative research training network the prortotype of the system NIKE for Predictive Toxicology has been developed.

Wellington, New Zealand
January 2005

Mircea Gh. Negoita
Daniel Neagu
Vasile Palade

Contents

List of Acronymes

A	**A***denine (a* **DNA** *base)*
AI	**A***rtificial* **I***ntelligence*
aiNet	**A***rtificial* **I***mmune* **Net***work*
AIS	**A***rtificial* **I***mmune* **S***ystems*
AL	**A*ggregative*** **L***ayer*
AN	**A***daptive* **N***etworks*
ANN	**A***rtificial* **N***eural* **N***etworks*
ANFIS	**A***daptive* **N***euro-***F***uzzy* **I***nference* **S***ystems*
BCA	***B***-**c***ell* **A***lgorithm*
BPNN	**B***ack* **P***ropagation* **N***eural* **N***etworks*
C	**C***ytosine*
CAI	**C***onexionist* **A***rtificial* **I***ntelligence*
CI	**C***omputational* **I***ntelligence*
CRI	**C***ompositional* **R***ule of* **I***nference*
CRF	**C***ombine the* **R***ules* **F***irst*
CSP	**C***onnectionist* **S***ymbol* **P***rocessing*
CMSE-OLC	**C***onstrained* **M***ean-***S***quared* **E***rror-***O***ptimal* **L***inear* **C***ombination* **A***lgorithm*
CSM	**C***oncept* **S***upport* **M***ethod*
CWP	**C***omputing with* **W***ords and* **P***erceptions*
DCPS	**D***istributed* **C***onnectionist* **P***roduction* **S***ystem*
DDS	**D***istributed* **D***atabase* **S***ystem*
DFRBS	**D***iscrete* **F***uzzy* **R***ule* **B***ased* **S***ystem*
DNA	**D***eoxyribo***N***ucleic* **A***cid*
DNA-AIS	*Hybridization between* **D***eoxyribo***N***ucleic* **A***cid systems and* **A***rtificial* **I***mmune* **S***ystems*
DNA-FS	*Hybridization of* **D***eoxyribo***N***ucleic* **A***cid techniques and* **F***uzzy* **S***ystems*
DNA-NN	*Hybridization of* **D***eoxyribo***N***ucleic* **A***cid techniques and* **N***eural* **N***etwork techniques*
DNA-GA	*Hybridization of* **D***eoxyribo***N***ucleic* **A***cid techniques and* **G***enetic* **A***lgorithms*
DPGA	**D***ynamic* **P***arameter* **G***enetic* **A***lgorithm*
EA	***E****volutionary* **A***lgorithms*

EC	**E***volutionary* **C***omputation*
EC-AIS	*Hybridization between* **E***volutionary* **C***omputation techniques and* **A***rtificial* **I***mmune* **S***ystems*
EHW	**E***volvable* ***H****ard***W***are*
EHW-AIS	*Hybridization between* **E***volvable* ***H****ard***W***are and* **A***rtificial* **I***mmune* **S***ystems*
EK	**E***xpert* **K***nowledge*
EKM	**E***xplicit* **K***nowledge* **M***odule*
EMSE-OLC	**E***stimated* **M***ean-***S***quared* **E***rror-***O***ptimal* **L***inear* **C***ombination* **A***lgorithm*
EP	**E***volutionary* **P***rogramming*
ES	**E***xpert* **S***ystems*
FAS	**F***uzzy* **A***dditive* **S***ystem – as described by TSK rules*
FGA	**F***uzzy* **G***enetic* **A***lgorithms*
FPAA	**F***ield* **P***rogrammable* **A***nalogue* **A***rrays*
FPGA	**F***ield* **P***rogrammable* **G***ate* **A***rrays*
FS	**F***uzzy* **S***ystems*
FS-AIS	*Hybridization between* **F***uzzy* **S***ystems and* **A***rtificial* **I***mmune* **S***ystems*
FCM	**F***uzzy-***c***-***M***eans algorithm*
FDI	**F***ault* **D***etection and* **I***solation*
FEM	**F***ire* **E***ach* **M***odule*
FIS	**F***uzzy* **I***nference* **S***ystem*
FNN	**F***uzzy* **N***eural* **N***etwork*
FRBS	**F***uzzy* **R***ule-***B***ased* **S***ystems*
FR	**F***uzzy* **R***ule*
FRF	**F***ire the* **R***ules* **F***irst*
FSM	**F***inite* **S***tate* **M***achine*
G	**G***uanine*
GA	**G***enetic* **A***lgorithms*
GA-FS	**G***enetic* **A***lgorithms hybridization with* **F***uzzy* **S***ystems*
GA NN	**G***enetic* **A***lgorithms hybridization with* **N***eural* **N***etworks*
GA-NN-FS HIS	***G****enetic* ***A****lgorithms-***N***eural* **N***etworks-***F***uzzy* **S***ystems relied* **H***ybrid* **I***ntelligent* **S***ystem*
GMP	**G***eneralized* **M***odus* **P***onens*
GP	***G****enetic* **P***rogramming*
GSO	**G***lobal* **S***election* **O***perator*
HFNN	**H***ybrid* ***F****uzzy* **N***eural* **N***etwork*
HIS	**H***ybrid* **I***ntelligent* **S***ystem*
HME	**H***ierarchical* **M***ixtures of* **E***xperts*
HNN	**H***ybrid* **N***eural* **N***etwork*
HNS	**H***ybrid* **N***eural* **S***ystem*
HTN	**H***igh* **T***reshold* **N***euron*

IKM	**I***mplicit* **K***nowledge* **M***odule*
HIS	**H***ybrid* **I***ntelligent* ***S****ystem*
IP	**I***nternet* **P***rotocol*
IT	**I***ntelligent* **T***echnologies*
ITS	**I***ntelligent* **T***utoring* **S***ystem*
KBANN	**K***nowledge-****B****ased* ***A****rtificial* **N***eural* **N***etworks*
KBES	**K***nowledge-***B***ased* **E***xpert* **S***ysyem*
KBS	**K***nowledge-***B***ased* **S***ystem*
KDD	**K***nowledge* **D***iscovery in* **D***atabases*
K-MCA	**K**-**M***eans* **C***lustering* **A***lgorithm*
LMS	**L***east* **M***ean* **S***quares (Widrow) algorithm*
LOP	**L***ogarithmic* **O***pinion* **P***ool*
LSE	**L***east-***S***quares* **E***stimator*
LTN	**L***ow* **T***reshold* **N***euron*
MAPI	**M***atching,* **A***ggregation,* **P***rojection,* **I***nverse* **F***uzzification*
MAX	*fuzzy* **max***im opearor*
MC	**M***olecular* ***C****omputing*
MF	**M***embership* **F***unction*
MIMO	**M***ulti-***I***nput* **M***ulti-***O***utput*
MIN	*fuzzy* **min***im opearor*
MILA	**M***ultilevel* **I***mmune* **A***lgorithm*
MISO	**M***ulti-***I***nput* **S***ingle-***O***utput*
MLP	**M***ulti-***L***ayer* **P***erceptron*
MPNN	**M***ulti***P***urpose* **N***eural* **N***etwork*
MSE	**M***ean-***S***quared* **E***rror*
MSE-OLC	**M***ean-***S***quared* **E***rror-***O***ptimal* **L***inear* **C***ombination algorithm*
MultiNN Prom	**Multi***ple* **N***eural* **N***etwork Based System for* **Prom***oter Recognition*
N	**N***eural (neural component of an HIS)*
NN	**N***eural* **N***etwork*
NES	**N***eural* **E***xpert* **S***ystems*
NEIKeS	**N***eural* **E***xplicit and* **I***mplicit* **K***nowledge-based* **S***ystem*
NGA	**G***enetic* **A***lgorithm of* **N***agoya type*
NKB	**N***eural* **K***nowledge* **B***ase*
NNR	**N***earest-***N***eighbour* **R***ule*
NN-FS HIS	**N***eural* **N***etwork –* **F***uzzy* **S***ystems based* **H***ybrid* **I***ntelligent* ***S****ystem*
NRFC	**N***ew* **F***uzzy* **R***easoning* **F***uzzy* **C***ontrollers*
NSP	**N***euronal* **S***ymbol* **P***rocessing*
OLC	**O***ptimal* **L***inear* **C***ombination*
OLS	**O***rthogonal* **L***east-***S***quares algorithm*
PI	**P***roportional* **I***ntegral*
PPX	**P***recedence* **P***reserving* **C***rossover*

PPS	**P**recedence **P**reserving **M**utation
PRODUCT	*fuzzy* **prod**uct *operator*
QSAR	***Q****uantitative* ***S****tructure-****A****ctivity* ***R****elationship*
RAFNN	***R***ecurrent ***A***rtificial **N**eural **N**etwork with **F**uzzy ***N***umbers
RAINN	***R****esource limited* **A***rtificial* **I***mmune* **N***etwork*
RBFN	**R***adial* **B***asis* **F***unction* **N***etworks*
RBS	**R***ule-***B***ased* **S***ystems*
RHIS	**R***obust* (**S***oft* **C***omputing*) **H***ybrid* **I***ntelligent* **S***ystems*
RLS	**R***ecursive* **L***east-***S***quares algorithm*
RLSE	**R***ecursive* **L***east-***S***quares* **E***rror*
RNN	**R***ule* **N***eural* ***N****etwork*
RRS	**R***elative* **R***ule* **S***trength*
S	*Symbolic (symbolic component of an HIS)*
SAI	**S***ymbolic* **A***rtificial* **I***ntelligence*
SAR	***S****tructure-****A****ctivity* ***R****elationship*
SC	**S***oft* **C***omputuing*
SGA	**S***imple* **G***enetic Algorithm*
SGN	**S***upervised-***t***rained* **G***ating* **N***etwork*
SO	**S***tudent* **O***bject*
SOM	**S***elf* **O***rganizing* **M***aps (Kohonen Neural Networks)*
T	**T***hymine*
TNGS	**T***heory of* **N***euronal* **G***roup* **S***election*
TP	**T***riangular* **P***artition*
TPE	**T***riangular* **E***quidistant* **P***artition*
TPh	**T**riangular **P**artition with Variable Length (**h**yperbolic sements)
UGN	**U***nsupervised-trained* **G***ating* **N***etwork*
U MSE-OLC	**U***nconstrained* **M***ean-****S****quared* **E***rror-***O***ptimal* **L***inear* **C***ombination algorithm*
VLGGA	**V***ariable* **L***ength* **G***enotype* **G***enetic* **A***lgorithm*
WITNeSS	**W***ellington* **I***nstitute of* **T***echnology* **N***ovel* **E***xpert* **S***tudent* **S***upport*
XOR	***EX****clusive* **or** *operator*