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Computational Intelligence: A Compendium

With 321 Figures and 67 Tables

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Preface

At this point in time, Computational Intelligence (CI) has yet to mature as a discipline in its own right. Accordingly, there is little consensus as to a precise definition of this emerging field. Nevertheless, most practitioners would include Artificial Neural Network (ANN), Fuzzy and evolutionary techniques (and perhaps others), and more especially *hybrids* of these (this will be expanded upon in Chap. 1.) Our emphasis in this Compendium is very much on *applied* methods – ones which have been tired-and-proven effective on real-world problems.

The 25 chapters have been grouped into the following ten themes (Parts):

I. Overview, Background
II. Data Preprocessing, Systems Integration & Visualization
III. Artificial Intelligence
IV. Logic and Reasoning
V. Ontology
VI. Intelligent Agents
VII. Fuzzy Systems
VIII. Artificial Neural Networks
IX. Evolutionary Approaches
X. DNA and Immunity-based Computing

This grouping is not the only one we could have used – indeed some chapters could have just as easily appeared in alternate Parts of the Handbook. For example, Lam & Lee's `iJADE` tourist guidance system could just as readily been grouped into Part-VI (Agents) as Part-V (Ontology); likewise, Fyfe's Topographic Maps would have fitted just as well into Part-VIII (ANNs), Ishibuchi et al. would have been just as equally well placed in either Part-VII or Part-IX, and Islam & Yao could have fitted equally well into Parts VIII or IX. Nevertheless, we have attempted to group together chapters with common foci.

Returning briefly to the question of real-world applications, Table 1 summarizes those covered in the chapters herein.

Table 1. Chapter methods and applications

Chapter	Method	Application(s)	Data set(s)
2	REDR; SOM; Mitra Multi-Scale	handwritten digits; yeast; synthetic	UCI KDD
3	SOM; GTM; HaToM; ToPE	data visualization	UCI-ML (algae; wine)
4	networked selfish agents; probabilistic cellular automata	self-maintenance/repair; 'internet being'	Denial-Of-Service & Traceroute websites
5	affective embodied agent	synthetic therapist; human behaviour change	—
6	paraconsistent annotated logic	pipeline safety process verification	—
7	Data-Oriented Parsing	Natural Language Processing; musical notation, physics problem solving	Penn Treebank; Essen Folksong Collection
8	Conceptual Graph Theory	ontologies: architectural design; air operations officer	—
9	mobile/GPS agents; ontologies	tourist guidance system	DAML; Protége
10	Agent-Based Modelling software	'Stupid' model	Santa Fe Institute artificial stock market
11	agents; Peer-to-Peer & cluster computing	resource allocation; communication; scheduling	—
12	multi-agents; dynamic clustering	sensor networks	—
13	agents; ANN; SVM; Evolutionary Comp.	computational economics; foreign exchange rates	SFI and AI-ECON artificial stock markets
14	reconciliation via optimization	fuzzy rule-based systems	—
15	Evolutionary multi-objective design	fuzzy rule-based classifiers	UCI-ML (breast; glass; heart; iris; wine)
16	ANNs; MAS	network bandwidth prediction	—
17	SOM; ViSOM; SOMN; kernel methods	vector quantization; image compression/ segmentation; text mining	UCI-ML (iris; yeast)
18	neural systems engineering	Blue Brain; SPINN; SpiNNaker	—
19	GenNt; CGA; FPGA	'artificial brain'; UXO robot	—
20	Evolutionary ANN ensembles	Credit Card; Diabetes; Heart Disease; Glass; Letter; Soybean; Breast Cancer	UCI-ML
21	genetic simulated annealing	graph colouring; bin packing; timetabling	DIMACS; Scholl & Klein; Falkenauer
22	Genetic Programming (GP)	modeling; the 'Humies'; image/signal processing; time series prediction; et al.	—

Table 1. (continued)

Chapter	Method	Application(s)	Data set(s)
23	Particle Swarm Optimization	finding origin; Rastrigin/ Schwefel functions; timetabling	—
24	DNA computing	multiple elevator scheduling	—
25	immunity-based computing	stable marriage problem; auto sensor diagnosis; noise neutralization	—

Chapters commence with an overview of the field in question, and conclude with a *Resources Appendix*. These resources cover key references (classic texts, survey articles, key papers), pertinent journals, professional societies/organizations and research groups, international conferences and workshops, and/or electronic/on-line material (with a particular emphasis on databases and Open Source software). Each chapter is thus complete unto itself for those readers wanting to explore just a single topic from the many on offer. In this mode, the Compendium could be used as a text for graduate programs in Artificial Intelligence, Intelligent Systems, Soft Computing, Computational Intelligence, and the like. The *Index* doubles as a Glossary of Terms (with acronyms shown in parentheses).

We have gathered together in a single volume chapters by leading experts in their respective fields – all of international repute, as evidenced (in part) by the following:

I. Learned Society Fellows: *IEEE* (Furber, Pedrycz, Yao); *Intl. Fuzzy Systems Association* (Pedrycz); *Royal Society* (Furber); *Royal Academy of Engineering* (Furber); *British Computer Society* (Furber); *Intl. Society for Genetic and Evolutionary Computation* (Koza, Langdon, Poli); *Institution of Engineers, Australia* (Jain)

II. Editors-in-Chief: *Computing and Information Systems* (Fyfe); *IEEE Trans. Evolutionary Computing* (Yao); *Information Sciences* (Pedrycz); *Intelligent Decision Technologies* (Jain); *Intl. J. Hybrid Intelligent Systems* (Jain); *Intl. J. Knowledge-based Intelligent Engineering Systems (Founding Editor)* (Jain); *Intl. J. Logic & Reasoning* (Nakamatsu); *Intl. J. Metaheuristics* (Mumford); *New Mathematics & Natural Computing* (Chen)

III. Associate/Area Editors: *Advances in Natural Computation* (Yao); *Computer and Information Systems* (Jain); *Evolutionary Computation* (Poli); *IEEE Computational Intelligence Magazine* (Ishibuchi); *IEEE Trans. Evolutionary Computation* (Ishibuchi); *IEEE Trans. Fuzzy Systems* (Ishibuchi, Pedrycz); *IEEE Trans. Knowledge and Data Engineering* (Wang); *IEEE Trans. Neural Networks* (Pedrycz, Wang); *IEEE Trans. Neural Networks* (Chen, Wang); *IEEE Trans. Systems, Man and*

Cybernetics (Ishibuchi, Jain, Pedrycz); *Intl. J. Advances in Fuzzy Systems* (Ishibuchi); *Intl. J. Applied Intelligence* (Hendtlass); *Intl. J. Computational Intelligence Research* (Ishibuchi, Poli); *Intl. J. Information Technology* (Chow); *Intl. J. Knowledge-based Intelligent Engineering Systems* (Ishida); *Intl. J. Metaheuristics* (Ishibuchi); *Intl. J. Pattern Recognition and Artificial Intelligence* (Jain); *J. Artificial Evolution and Applications* (McPhee); *J. Economic Research* (Chen); *J. Genetic Programming and Evolvable Machines* (Poli); *J. Intelligent and Fuzzy Systems* (Jain); *Mathware and Soft Computing* (Ishibuchi); *Neural Computing and Applications* (Jain); *Soft Computing J.* (Ishibuchi)

IV. Book Series Editors: *CRC Press (Intl. series on CI)* (Jain); *IGI (CI: Theory and Applications series)* (Fyfe, Jain); *Kluwer (Genetic Programming)* (Koza); *Springer (Advanced Information and Knowledge Processing)* (Jain)

V. Invited Keynote/Plenary Conference Speakers: Chen, deGaris, Fulcher, Fyfe, Ishida, Jain, Koza, Nakamatsu, Prokopenko, Wang, Yao

VI. Awards: *Royal Society Wolfson Research Merit Award* (Furber); *IET Faraday Medal* (Furber); *Queen's Award for Technology* (Furber); *Japanese Society for the Promotion of Science Prize* (Ishibuchi); *IEEE Donald G. Fink Prize Paper* (Yao); *AJB CEBIT Exhbition Award (Most Innovative Technology)* (Prokopenko); *Japanese Society for Artificial Intelligence Award* (Prokopenko); *Best Paper Awards* (Chow, Langdon, McPhee, Poli)

VII. Advisory Boards: *UK EPSRC Peer Review College* (Poli); *EU Expert Evaluator* (Poli)

Indeed, this Handbook is a truly international undertaking, with a total of 43 authors from 10 different countries contributing (9 in Australia; 19 in Asia; 11 in UK; and 4 in North America). All chapters were peer reviewed to ensure a uniformly high standard for the Handbook overall.

Next follows an overview of each Chapter.

In Part-I, Fulcher introduces fundamental Computational Intelligence concepts. This Introductory chapter is intended to serve both as background reading (tutorial) for students/newcomers to the field, as well as setting the scene/laying the groundwork for the more specialist chapters that follow.

A critical consideration with applying *any* CI approach to real-world problems is data pre-processing. Part-II begins with a chapter by Chow & Huang on Data Reduction for Pattern Recognition. They provide an overview of 'filter' and 'wrapper' methods, before focusing on their Representative Entropy Data Reduction (REDR) approach. In their discussion they cover not only *data reduction* but also *feature selection* – another key aspect of pre-processing.

Fyfe's concern in Chap. 3 is data visualization. He illustrates how the Self-Organizing Map, Generative and Harmonic Topographic Maps, and the

Topographic Product-of-Experts can all be effectively used on the UCI-ML algae and wine data sets.

Ishida adopts a game-theoretic approach to self-maintenance and repair in large-scale, complex systems such as the Internet – more specifically, 'selfish' agents and Probabilistic Cellular Automata. Emphasis is placed on the emergence of intelligent systems at the Nash Equilibrium in such networks. He concludes with speculation as to the conditions necessary for the emergence of a so-called 'Internet Being', in the context of such 'selfishware'.

Part-III covers conventional (traditional) AI, but from a slightly different perspective. In Chap. 5 Creed and Beale provide a fascinating insight into Emotional Intelligence and affective computing. They commence with a discussion of emotion theory, before introducing 'affective embodied' agents. The authors then demonstrate how such agents can be applied in the real world to engender behavioural change in humans, through the medium of a so-called 'simulated (artificial) therapist'.

Part-IV covers logic, reasoning and related approaches to CI. In Chap. 6 Nakamatsu provides a comprehensive discussion of various paraconsistent annotated logics, including his own extended vector-annotated logic program with strong negation – EVALPSN; defeasible reasoning proofs are also included. Nakamatsu then proceeds to show how EVALPSN can be applied to pipeline process safety verification, and by extension to pipeline process *order* safety verification (by way of before-after EVALPSN).

Bod uses the supervised, corpus-based probabilistic Data-Oriented Parsing approach to reveal the underlying structures in areas as diverse as Natural Language Processing, the melodic analysis of musical scores, and physics problem solving. A mechanism for determining the optimum parse tree is described, and the chapter concludes with an explanation of how DOP could be modified to support unsupervised learning.

Part-V of the Handbook covers ontology, which is often closely related to intelligent agents (Part-VI). In Chap. 8, Corbett takes the view that frameworks for intelligent systems are best represented by a combination of concept type hierarchy, canonical formation rules, conformity relations and subsumption. He illustrates the validity of this approach with regard to both architectural design and air operation officer ontologies, and concludes that his automated reasoning approach could be readily extended to the Semantic Web.

In Chap. 10, Lam and co-authors provide an account of an Intelligent Ontology Agent-based Tourist Guidance System, which they developed using the Intelligent Java Agent-based Development Environment (`iJADE`).

Part-VI is devoted to (intelligent) software agents. Standish commences with a comparative review in Chap. 11 of open source Agent-based Modelling

platforms, including a performance comparison on a simple pedagogical model (the so-called 'Stupid Model').

Zhang and co-authors follow in Chap. 11 with a discussion of their agent-based `SmartGRID` model – incorporating both Peer-to-Peer and clustering techniques – and which can yield improved resource allocation, as well as task communication and scheduling in agent grids operating in open environments. Piraveenan and co-authors are likewise interested in grids, but in their case scale-free sensor networks. They use a dynamic, decentralized MAS algorithm for predicting convergence times for cluster formation in such grids (networks).

Chen provides a comprehensive account of agent-based computational economics (ACE)in Chap. 13, with a particular focus on Genetic Algorithms. After introducing the cobweb and overlapping generations models, he describes several applications of ACE, including inflation, foreign exchange rate, and artificial stock markets.

Fuzzy Systems are the focus of Part-VII. Pedrycz commences with a discussion of the semantics and perception of fuzzy sets and fuzzy mapping. He proceeds to show that reconciliation of fuzzy set perception and granular mappings can be expressed in the form of an optimization pattern, which in turn can be subsequently applied to rule-based systems.

In Chap. 15, Ishibushi and co-authors discuss the principles underlying the evolutionary design of fuzzy classifiers, illustrating the effectiveness of their approach by way of data sets selected from the UCI-ML repository (breast cancer; glass; heart; iris; wine).

Part-VIII covers Artificial Neural Networks. Fu and co-authors commence by illustrating how supervised, feedforward networks (MLP/BP) can be used in the data mining of Quality-of-Service aware media grids.

Yin provides a comprehensive coverage of Kohonen's Self-Organizing Map and its more recent variants in Chap. 17. The performance of SOM, ViSOM, SOM Mixture Network and SOM kernel methods is compared on vector quantization, image compression and segmentation, density modelling, data visualization and text mining.

In Chap. 18, Furber & Temple provide an overview of neural systems engineering, namely the realization of ANNs in hardware form, rather than the more usual approach of software simulation. DeGaris follows in a similar vein, describing how Field Programmable Gate Arrays (FPGAs) can be used to build 'artificial brains'.

Evolutionary approaches to CI are the subject of Part-IX of the Handbook. Islam & Yao commence with an account of how ANN ensembles can be first evolved, then used as classifiers on representative data sets from the UCI-ML repository.

In Chap. 21 Mumford concerns herself with a so-called memetic EA – in the form of a Genetic Simulated Algorithm (GSA) – which she proceeds to demonstrate can be used to solve set partitioning problems (graph colouring, bin packing, timetabling).

Genetic Programming is the focus of the Chapter by Langdon and co-authors. An extensive coverage of basic principles is followed by descriptions of how to apply GPs in various application domains, including hints for the novice user ('tricks-of-the-trade', as it were). The Chapter rounds off with a section on theoretical aspects of GP. The authors include an extensive (420 item) reference list.

In Chap. 23, after providing an overview of the basic Particle Swarm Optimization algorithm, Hendtlass then proceeds to describe enhancements to handle multiple optima, niching and 'Waves of Swarm Particles', before outlining how one can minimize the computational cost of such algorithms. He illustrates the effectiveness of the PSO approach by way of finding the origin, solving Rostrigin's and Schwefel's functions, and timetabling.

In the last Part of the Handbook we cover CI approaches inspired by Nature, but which do not fall under the umbrella of ANNs, EAs or Fuzzy. Firstly, Watada provides an overview of DNA Computing, then proceeds to show how this can be successfully applied to the problem of scheduling the movements of a group of elevators in a high-rise building.

Chapter 25 is concerned with Immunity-based computing (IBC). After introducing the basic concepts, Ishida shows how IBC can be applied to automobile sensor diagnosis, noise neutralization, and the 'Stable Marriage Problem'. He concludes by proposing a general (immunity-based) problem solver.

One of your Editors (JF) formatted the Handbook, using `MikTex v2.4` and `WinEdit v5.4`. In this (considerable) endeavour we are indebted to the following for their assistance along the way: Professor Philip Ogunbona (for imparting 'the joy of LaTex'), Associate Professor Willy Susilo, Associate Professor Russell Standish, Professor Riccardo Poli, Dr. Bill Langdon, and Jia Tang for insight into the finer points of LaTex, as well as Nik Milosevic (for creation of .eps figures). Thanks are also due to Dr. Thomas Ditzinger, Senior Editor, and Heather King, Engineering Editorial, respectively at Springer-Verlag GmbH, as well as Srilatha Achuthan, Project Manager at SPi Technologies, Chennai.

We sincerely trust that you find much of interest in the ensuing pages.

Wollongong NSW, Australia — *John Fulcher*
Adelaide SA, Australia — *Lakhmi C. Jain*
September 2007

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