GENERAL PRINCIPLES AND PURPOSES OF COMPUTATIONAL INTELLIGENCE

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Contents

Summary

This article reviews basic ideas and a common scientific perception of computational intelligence (CI) with its relationship to other system sciences and cybernetics. Also it describes a CI position in the overall body of artificial and biological intelligence.

Although the term of CI has been widely used for quite a long time with steadily increasing amount of research and practical applications, there is no anonymously accepted definition. This article considers CI as integrity of theories, applying methods and models analogous to those demonstrated by biological intelligent systems in problem solving and decision making. Among such theories are artificial neural networks, genetic algorithms and evolutionary computation, fuzzy and adaptive systems, approximate reasoning and learning, simulated annealing. As most of these methodologies have their own articles allocated, a lot of cross-references are expected to arise. On the other hand, this article maintains a more general level of discussion, paying a particular attention to relations between different CI components and examples of their integration.

The article starts with a short presentation of CI as a synergetic structure of different methodologies and describes main principles of the selection of models and methods

selection and their combination. It gives a brief report of the CI historical development, the current situation and main research and industrial activities in the area. It explains shortly various parts, however, concentrating mainly on their commonalties and distinguished features. CI components are treated as being complementary rather than competitive research fields. Interaction between different sub-field methodologies in solving practical problems is described. Advantages of their combined employment are pointed out. Bibliography is included.

1. Introduction

Although the term of CI has been widely used for quite a long time with steadily increasing amount of research and applications, there is no anonymously accepted definition. CI can mean many things to different people and various techniques are considered as belonging to CI. Behind the approaches could be seen different communities, traditionally applying various methodologies and criteria of their evaluation and having some lack of understanding and sometimes even some misunderstanding of each other methods. To make things even more complicated, there exist a lot of variations even within one approach, and different concepts may have the same name in different reports, while the same things could be called distinctly by different researchers. Such a situation can be partly explained by the two following reasons: CI is a shifting phenomenon, changing its study domain in time but staying young forever, on one hand, and CI is a distributed phenomenon, the algorithmic study of processes in every field of enquiry. All of these features impose an extra burden on any attempt to describe the field of CI. This article attempts to present and describe a diversity of views, however, giving interpretations, which are considered to be the most popular among the research community at the present time and the most appropriate for this publication. Note that none of the views considered below is meant to be particularly controversial. Rather, they complement each other in some aspects. The standard way how to distinguish different theories and views is by naming the constituents of a particular methodologies. This way is explored in the following text as well.

2. Definition and Understanding of Computational Intelligence

The first view of CI considers it as a replacement term for artificial intelligence (AI) as well. In this very wide interpretation, CI represents the branch of science and engineering concerned with making computers behave like humans. The term of AI was coined in 1956 by J. McCarthy at the Massachusetts Institute of Technology (USA). Since then two complementary views of AI have been developed: one as an engineering discipline dealing with the creation of intelligent machines, the other as an empirical science concerned with the computational modeling of human intelligence. The first branch is a part of computer science and engineering, aimed at programming computers to behave intelligently. The second branch is a part of cognitive science, aimed at simulating with computers the actual processes applied by humans in their intelligent behavior. Within this domain the computer is a tool for modeling theories of human intelligence. When the field was young, these two views were seldom distinguished. However, by the present time a substantial divide has opened up, with the former view dominating modern AI and the latter view characterizing much of modern cognitive science. For this reason the more neutral term of "computational intelligence" has been adopted by many researchers, as both communities are attacking the problem of understanding intelligence in computational terms.

The field of AI (or CI in a wide interpretation as we will apply it in this section) is concerned both with modeling human (in many references it is called natural or biological) intelligence and with solving complex problems not solvable by simple or analytical procedures. For instance, a major, long-range goal of CI is the construction of an intelligent robot, one capable of perceiving, acting, comprehending, reasoning, and learning in complex environments. Among other goals one can find the following:

- Automatic Programming - the task of describing what a program should do and having the CI system 'write' the program.
- Natural Language Processing (NLP) - processing and understanding human ("natural") language, also known as computational linguistics.
- Knowledge Engineering/Representation - turning what we know about a particular domain into a form in which a computer can understand it - *see Cybernetics and the Integration of Knowledge.*
- Planning - given a set of actions, a goal state, and a present state, deciding which actions must be taken so that the present state is turned into the goal state.
- Search - the finding of a path from a start state to a goal state (similar to planning, yet different)
- Machine Learning - creating of systems that are able to learn from their experience.
- Visual Pattern Recognition - developing the ability to reproduce the human sense of sight automatically.
- Speech Recognition - conversing of speech into text.
- The great variety of CI techniques have been developed and applied over the history for solving the problems mentioned above. Some of these methodologies are:
- Automatic Reasoning - most human reasoning occurs in task/domains with uncertain, ill-defined and incomplete knowledge. Reasoning in such domains requires techniques such as use of default, probabilistic, and non-monotonic logics.
- Bayesian Networks - a technique of structuring and interferencing with probabilistic information.
- Neural Networks (NN) or Artificial Neural Networks (ANN) - the study of programs that function in a manner similar to how animal brains do. The two terms NN and ANN are frequently used interchangeably. They simulate a highly interconnected, parallel computational structure with many relatively simple individual processing elements. - *see. Neural Networks* for more detail
- Fuzzy Logic (FL) - is the logic of approximate reasoning. Fuzzy logic comprises operations on fuzzy sets including equality, containment, complementation, intersection and union, and is a generalization of conventional (two-valued, or "crisp") logic - Evolutionary Computation comprises machine learning optimization and classification paradigms based on mechanisms of evolution such as biological genetics and natural selection. The evolutionary computation field includes genetic algorithms, evolutionary programming, genetic programming, and evolution strategies. Most widely used in applications are genetic algorithms.

Genetic algorithms are search algorithms that incorporate natural evolution mechanisms including crossover, mutation and survival of the fittest. GA paradigms work on populations of individuals, rather than on single data points or vectors. They are more often used for optimisation, but also for classification. Evolutionary programming algorithms are similar to genetic algorithms, but do not incorporate crossover. Rather, they rely on survival of the fittest and mutation.

- Problem solving and search - a fundamental technique in CI is to encode a problem as a state space in which solutions are goal states in that space. Thus, problem solving can be viewed as state space search. To search large, combinatorial state spaces, knowledge (e.g. heuristics) and planning are required.
- Simulated Annealing (SA) - a technique which can be applied to any minimization or learning process based on successive update steps (either random or deterministic) where the update step length is proportional to an arbitrarily set parameter which can play the role of a temperature. Then, in analogy with the annealing of metals, the temperature is made high in the early stages of the process for faster minimization or learning, then is reduced for greater stability - *see Simulated Annealing.*

CI problems (speech recognition, NLP, vision, automatic programming, knowledge representation, etc.) can be paired with techniques (NN, search, Bayesian nets, production systems, etc.) to make distinctions such as search-based NLP vs. NN NLP vs. Statistical /Probabilistic NLP. Then one can combine techniques, such as using neural networks to guide search. And one can combine problems, such as posing that knowledge representation and language are equivalent.

3. Goals of Computational Intelligence and their Accomplishment to date

Speaking in very general terms, the goal of CI is developing methods, which allow producing thinking machines that can solve problems. One may note that this statement does not limit the choice of those problems by any way. On the contrary, complex problems, which are not typically attempted by computers, should be considered first of all. In 1958 Newell and Simon predicted that computers would by 1970 be capable of composing classical music, discovering important new mathematical theorems, playing chess at grandmaster level, and understanding and translating spoken language. Although these predictions were overly optimistic, they did represent a set of focused goals for the field of CI. What has been achieved so far? Quite a bit of progress has been made, that can be illustrated with the following examples:

- Deployed speech dialog systems by firms like IBM, Dragon and Lernout&Hauspie
- Applications of expert systems/case-based reasoning, for example a computerized Leukemia diagnosis system did a better job checking for blood disorders than human experts.
- Computer translation for Environment Canada: software developed in the 1970s translated natural language weather forecasts between English and French.
- Deep Blue, the first computer system, which has beaten the human chess champion G.Kasparov.
- Intelligent (employing fuzzy, neural and their combinations techniques) systems to control the whole range of the household devices available on the market.

One persistent 'problem' in evaluating the achievements of CI is that often as soon as a CI technique truly succeeds, in the minds of many it ceases to be AI, becoming something else entirely. For example, when Deep Blue defeated Kasparov, there were many who said Deep Blue was not CI, since after all it was just a brute force parallel minimax search. It can be explained partly by the absence of a standard understanding of what intelligence is and how it should be evaluated. However, there exist some methods, the most famous is the so-called Turing test. Alan Turing, one of the founders of computer science, made the claim that by the year 2000, computers would be able to pass the Turing test at a reasonably sophisticated level. Turing test is passed if an independent observer being presented with the results of solving a complex problem is not able to judge if the solution has been achieved by a human or a computer. In particular, that the average interrogator would not be able to identify the computer correctly more than 70 per cent of the times after a five minute conversation.

4. Goals for Future Research

Such goals have to represent great challenges for CI and expect to produce amazing results when achieved. In particular, they should satisfy to the following conditions:

(a) Represent collaborative community effort: It must span several sub-fields of CI, requiring some degree of collaboration between CI researchers of different specialties. The idea is to help unify the fragmented areas with a common purpose or purposes.
(b) Has high society impact: It must address important problems of widespread interest. Solving the problem must matter to many people. This will help motivate and excite researchers, and justify the field to outsiders.
(c) Has short horizon for progress: It must be possible to have incremental progress and not be an all or nothing problem. For example, problems where we can reasonably expect to make significant measurable progress over the next 10 years or so.
(d) Drive Basic Research: It should involve more than just applying current technology, but should drive basic research and the development of new technology (possibly in completely new directions).

The examples of such problems could be found in different fields. Ones, which a CI community has already intensively been working on, are:

– Knowbots/Infobots or Web agents and intelligent help desks, which require research and development of unified NLP, information retrieval, reasoning, intelligent user interfaces.
– Autonomous Vehicles, which require research and development of unified robotics, machine vision, machine learning, intelligent control, planning.
– Machine Translation, which require research and development of unified NLP, knowledge representation, speech understanding, speech synthesis.
– Intelligent Homes and Services, which require research and development in intelligent control and information systems

5. Other Views of Computational Intelligence

The second view of CI is based on the definition of this term, put forward by J. Bezdek in 1994. He proposed the narrowest definition, in which he contrasts three ABC's of intelligence: artificial, biological, and computational. In the strictest sense, CI depends on numerical data supplied by manufacturers and does not rely on knowledge. Artificial intelligence, on the other hand, uses what Bezdek called "knowledge tidbits". Heuristically constructed AI systems, such as expert systems, is an example. His understanding of CI and relationship between components of CI systems is summarised in Figure 1, where both natural and artificial intelligence components are considered. Bezdek described the three levels (A, B, and C) as being three very different levels of system complexity, with complexity increasing from left to right and bottom to top. In the figure, NN refers to neural networks, PR to pattern recognition and I to intelligence. CI thus refers to numeric, or computational, intelligence. The distances between the nodes are skewed to show disparities between terms they represent. Thus, for example, the distinction between computational neural networks (CNNs) and computational pattern recognition (CPR) is less than that between biological neural networks (BNNs) and biological pattern recognition (BPR).

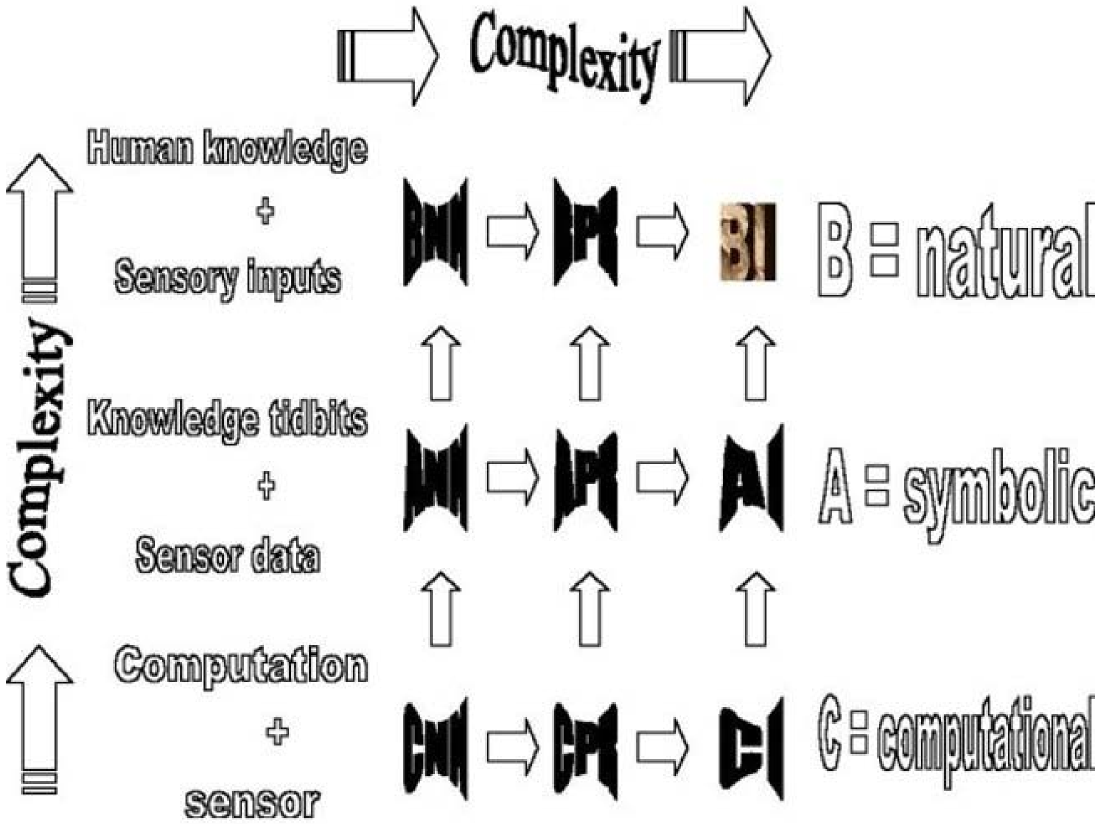

Figure 1. Definition of computational intelligence according to J. Bezdek.

In Bezdek's scheme, then, the top layer represents biological intelligence and the two lower layers represent machine intelligence. As he pointed out, the model presented in the figure is limited to systems used for pattern recognition; there are many alternatives to CNNs appropriate as inputs to CPR. Additionally, he pointed out that there are many kinds of CPR, including deterministic fuzzy and statistical models, some of which do not have biological equivalents. Finally, he suggested that the relationship between nodes at the ends of any arrow is that the node at the tai of the arrow is a subset of the node at the head of the arrow. Thus, CNN is a subset of CPR which is a subset of Cl; and Cl is a subset of AI, which is a subset of BI.

This definition was criticized by R.C. Eberhart who pointed out the following problems:

- the dichotomy of functions (nodes) along biological versus computational lines,
- the statement that some computational models do not have biological equivalents,
- the characterization of a node as a subset of subsequent nodes.

Eberhart's main point is that intelligence exists, and that intelligence is manifested in both artificial and natural systems, and sometimes in hybrids of the two. It does no matter what produces the intelligence. Further, all computational models must have biological analogies, since humans conceived, designed, developed and tested them. We can make only something, what we know. In 1994 he defined CI as a methodology involving computing that exhibits an ability to learn and/or to deal with or adapt to new situations. Such a system is perceived to possess one or more attributes of reasoning, such as generalization, discovery, association and abstraction. CI systems usually comprise hybrids of paradigms such as ANN, FL systems and evolutionary computation systems, augmented with knowledge elements. CI systems are often designed to mimic one or more aspects of the biological intelligence systems.

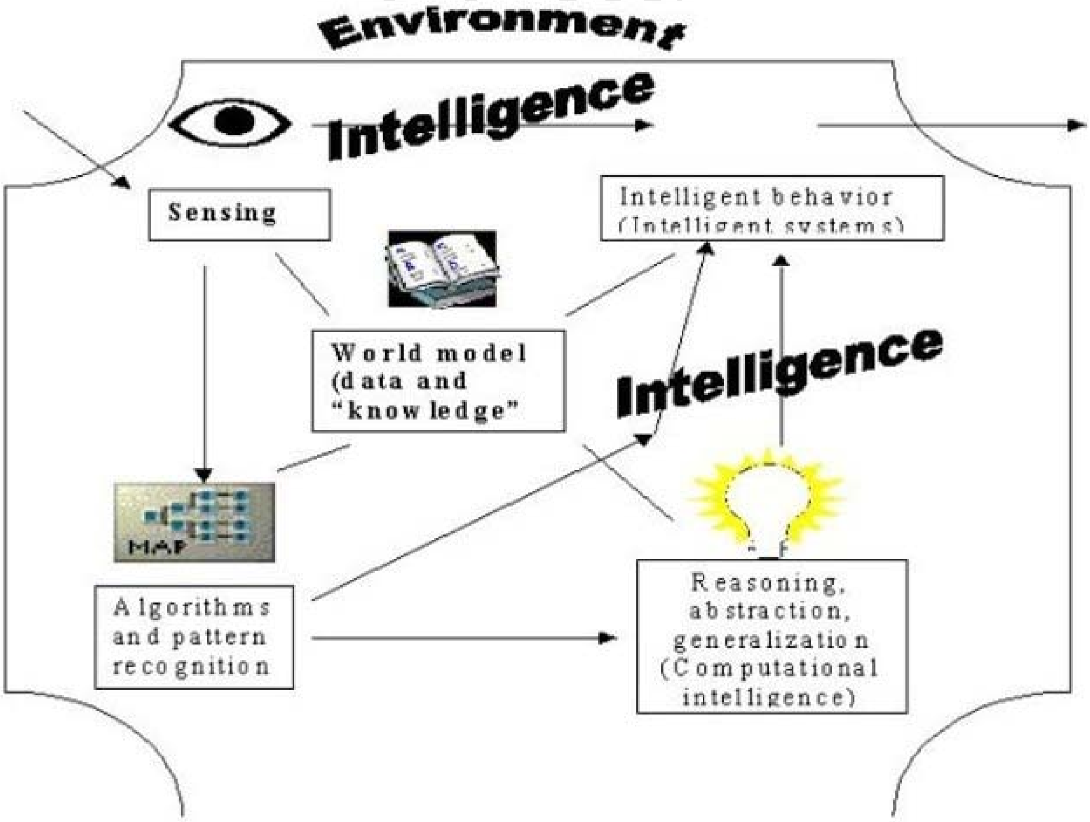

Figure 2. Definition of computational intelligence according to R.C. Eberhart.

The relationships among the components of intelligent systems are, as suggested by Eberhart, represented by Figure 2. Analogous to Bezdek's analysis, the emphasis is on pattern recognition. Other functions are needed to make the figure more complete.
The inputs to the system can be sensory inputs in the case of biological systems or a computer keyboard, etc. Then outputs of the intelligent behavior nod to the environment are communications to, and actions upon, the environment. If there is no action that affects the environment, there is no intelligent behavior. One arrow goes directly from sensing to intelligent behavior; another from algorithms and pattern recognition to intelligent behavior. These are meant to represent processes, which include reflex actions related to safety and survival, such as person's actions when touching a hot stove. There may be a better way to represent such processes, but the representation is meant to emphasize that, in general, nodes at the tails of arrows are not subsets of those at the heads, and that all nodes can provide input to the intelligent behavior node.

The diagram in Figure 2 is simplistic, but it is meant to convey the Eberhart's belief that there should be no distinction between artificial and natural intelligence. A system simply possesses one or more of the attributes shown in the Figure 2, and the actions on and communications to the environment are intelligent to some degree, depending upon the system attributes. As represented, CI is buried deeply within the core of the system, be it biological or machine. It is perhaps the furthest from the interface with the environment (also *see Biological and Computational Intelligence*)

Further explanation of this understanding was provided by T. Fukuda who considered the CI as a way, which aims to construct intelligence from the viewpoints of biology, evolution and self organization. Cl tries to construct intelligence by internal description, while classical AI tries to construct intelligence by external (explicit) description. Therefore, information and knowledge of a system in Cl should be learned or acquired by it.

The claimed advantage of such understanding of CI is that it is very constructive and stimulates the development of the CI techniques and exciting new analytical tools. Further development of the area has been concentrated on the constructive side, considering CI as a synergism of paradigms or techniques. Among those selected are, first of all, ANN, FL systems and EP. This approach gives a narrower understanding of CI in comparison with the first one presented above.

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http://webopedia.internet.com/TERM/a/artificial_intelligence.htmlhttp://webopedia.internet.com/TERM/a/artificial_intelligence.html

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Professional associations specializing in CI.

ASSOCIATION FOR COMPUTING MACHINERY (ACM)

ACM, 1515 Broadway, New York, NY 10036. ACM, PO Box 12105, Church St. Station, New York, NY 10257 USA, Member Services, 11 West 42nd Street, New York, NY 10036 USA, 800-342-6626 (212-626-0500), 212-869-7440. Fax 212-944-1318., Email: acm_help@acm.org, acmhelp@acmvm.bitnet.

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c/o AISB Executive Officer, School of Cognitive Science, University of Sussex, Brighton BN1 9QH, UK. Tel: +44-0-273-678448 Fax: +44-0-273-671320, Email: aisb@cogs.susx.ac.uk

AMERICAN ASSOCIATION FOR ARTIFICIAL INTELLIGENCE (AAAI)

AAAI, 445 Burgess Drive, Menlo Park, CA 94025., phone 415-328-3123, fax 415-328-4457, info@aaai.org, membership@aaai.org, URL: http://www.aaai.org

ASSOCIATION FOR COMPUTATION AL LINGUISTICS (ACL)

Natural language processing research and applications., PO Box 6090, Somerset, NJ 08875 USA, email: acl@cs.columbia.edu., http://www.aclweb.org/

COGNITIVE SCIENCE SOCIETY

Write to Alan Lesgold, Secretary/Treasurer, Cognitive Science Society, LRDC, University of Pittsburgh, 3939 O'Hara Street, Pittsburgh, PA 15260, USA fax 1-412-624-9149, email: al+@pitt.edu.

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INNS Membership, Suite 300, 1250 24th Street, NW, Washington, DC 20037 USA, Email: 70712.3265@compuserve.com, 202-466-4667, fax 202-466-2888., INNS Membership, P.O. Box 491166, Ft. Washington, MD 20749

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Prof. Philippe Smets, University of Brussels, IRIDIA, 50 av., F. Roosevelt, CP 194/6, 1050 Brussels, Belgium.

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Berkeley Initiative in Soft Computing (BISC) BISC Administrator: Frank Hoffmann, Ph.D. Email: fhoffman@cs.berkeley.edu

Biographical Sketch

Leonid Reznik was born in St. Petersburg, Russia. He received his first degree in Electrical/Electronics Engineering (with Honors) in computer control systems from St. Petersburg Institute of Aircraft Instrumentation (1978) and a Ph.D. degree in Engineering from St. Petersburg University of Technology, Russia (1983). He was awarded with the academic title of Senior Researcher in Measuring and Information Systems in 1987.

Since his graduation Dr. Reznik has been employed in both industry and academia. His research and industrial projects have involved research and development of computer based information, measurement and control systems. He worked as a computer programmer and a commercial project manager in the area of industrial information systems as well as a lecturer in computing and control. Currently he is working as a Senior Lecturer at the School of Communications and Informatics, Victoria University, Melbourne, Australia. He has strong research interest in computational intelligence development and system modeling and design. Fuzzy systems and especially fuzzy controller design, is currently his main research area. He is leading of the collaborative research group, which investigates different fuzzy technology applications ranging from home climate microprocessor control to tourism forecasting and other business applications. Dr. Reznik is the author of the textbook "Fuzzy Controllers" (Newnes-Butterworth-Heinemann, Oxford, UK, 1997), adopted for teaching by many universities around the world, and a co-editor of the volume "Fuzzy System design: Social and Engineering Applications" (Physica Verlag, Heidelberg, Germany, 1998). His biography has been selected and included into 15th (1998), 16th (1999) and Millennium (2000) Editions of Marquis "Who's Who in the World", USA as well as the 27th (1999) and 28th Editions of the Dictionary of international Biography, IBC, Cambridge, UK, and a special volume "Outstanding People of the 20th Century".