Intellectual Biography 2026

Dr Brian R. Gaines

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1 Synopsis

Brian R. Gaines was born in Cheltenham, U.K., on October 25 1940. In 1959 he was awarded a State Scholarship to study Mathematics at Trinity College, Cambridge, and obtained a B.A. degree in 1963. He then took a second B.A. degree in Psychology, and did research on the human adaptive controller, receiving his M.A. and Ph.D. from Cambridge in 1967 and 1972, respectively. He was appointed Lecturer in the Department of Electrical Engineering Science, University of Essex, from September 1967, Senior Lecturer in 1969, Reader in 1971, and Professor in Computer Engineering and Chairman of Department in 1975.

He consulted for the National Enterprise Board on re-structuring Monotype Corporation, became the Technical Director and Deputy Chief Executive of Monotype Holdings Ltd in 1978. In 1980 Dr Gaines left Monotype to form Cadre Systems in order to develop a range of image communications systems. In August 1982 he moved to Toronto to establish Cadre Information Transfer Systems Inc. with developmental funding from the Canadian Government, and Inforite Corporation in the USA as a joint venture with Toppan-Moore of Japan. He also took up positions as adjunct Professor of Industrial Engineering at the University of Toronto and of Computer Science at the University of Calgary. In 1984 he was appointed Professor of Computer Science at York University.

In 1985 he moved to Calgary to take up the Izaak Walton Killam Memorial Chair at the University of Calgary. At Calgary he established the Knowledge Science Institute, an inter-disciplinary center for the study and development of knowledge-based systems. In 1988 he also became Director of the Software Research and Development Group at the University, a center primarily concerned with the support of industry. In 1997 he was appointed Dean of Graduate Studies and Associate Vice President (Research), and in 1998 also became Acting Associate Vice President (Academic and Planning) and Coordinator Strategic Transformation. In 2000 he retired and became Professor Emeritus at the University of Calgary. In 2004 he was appointed Adjunct Professor of Computer Science at the University of Victoria.

He was adviser to the Chief Scientist on the Computer Research and Development Committee of the Department of Health and Social Security. He represented NSERC on the Ministry of State for Science and Technology Inter-Agency Committee on Strategic Planning for Information Technology. He has been Chairman of the NSERC Industrial Engineering Grant Selection Committee. He is a member of the Alberta Science and Research Authority. He has directed research contracts with the Ministry of Defence, Ministry of Technology, Department of Health and Social Security, National Research and Development Council, Employment and Immigration Canada, and various industrial bodies, and has been a consultant to several industrial

companies, including ITT, Plessey, George Kent, Moore Corporation and New York Stock Exchange. He has been a founder Director of a number of companies, and was Technical Director of Questel Ltd, and Micro Computer Systems Ltd., a computer manufacturing subsidiary of Brown Boveri Kent. He has been responsible for a number of commercial computer designs, and holds some 15 patents on digital systems including that for stochastic computing systems.

Dr Gaines was founder of the *International Journal of Man-Machine Studies* in 1968 and *Knowledge Acquisition* in 1988, and was executive editor of both journals from their inceptions until 2005. He is on the editorial board of the *International Journal of General Systems, Systems Research*, *Journal of Fuzzy Sets and Systems, International Journal of Intelligent Systems, Expert Systems: Research and Applications, Expert Systems with Applications*, *Journal of Intelligent Information Systems* and *Knowledge-Based Systems*. He is founder and co-chairman of the three series of annual Knowledge Acquisition Workshops, that in North America sponsored by AAAI, in Europe sponsored by various European professional associations, and on the Pacific Rim sponsored by various Japanese and Australian professional associations. He is author of over 450 technical papers on topics including stochastic computing, digital differential analyzers, computer architecture, software engineering, databases, language implementation, human factors in computing, machine learning, adaptive control, algebraic system theory, automata theory, system identification, computational theoretical and philosophical logic, fuzzy systems, expert systems, knowledge acquisition, technological forecasting, information technology industry, socio-technical impact of information technology, the role and creation of expertise in society, portfolio management, printing systems and factory automation.

Dr Gaines is or has been a Chartered Engineer, a Chartered Psychologist, a Fellow of the Institution of Electrical Engineers, the British Computer Society and the British Psychological Society. He is or has been a member of: Society of Manufacturing Engineers; Association for Computing Machinery; Association for Symbolic Logic; British Society for the Philosophy of Science; Experimental Psychology Society; Institute of Electrical and Electronics Engineers; Mind Association; and Philosophy of Science Association. He has been President of the Society for General Systems Research.

His prime current research interests are in the areas of: the socio-economic dynamics of scholarship, knowledge production and dissemination, science and technology in human civilization through the ages; the nature, acquisition and transfer of knowledge and its computational support; foundations of logic; software engineering for heterogeneous systems; object-oriented architectures for high-performance knowledge modeling, representation and processing systems; and knowledge-based system applications in manufacturing, the professions, sciences and humanities.

2 Curriculum Vitae

2.1 Personal

Brian Ronald Gaines

Born Cheltenham, Gloucester, UK, 25th October 1940

2.2 Career

1951-59	Shooters Hill Grammar School
1959	State Scholarship
1959-60	Standard Telephones & Cables Semiconductor Division, Footscray
1960-63	Trinity College, Cambridge—Mathematics & Theoretical Physics
1960-67	Dept Experimental Psychology—Electronics Assistant, Richard Gregory
1962-66	Intern, Learning Machines Project, ITT Standard Telecommunications Laboratories, Harlow
1963	BA—Senior Optime (2(i)), Mathematics Tripos
1963-64	Trinity College, Cambridge—Natural Science Tripos Part II—awarded 2(i) in Psychology
1964-67	Trinity College, Cambridge—research under Ministry of Defence contract into control and learning systems
1966-68	Consultant and Project Leader for advanced computer and control systems, ITT Standard Telecommunications Laboratories, Harlow
1967	MA (Cantab)
1967-69	Lecturer, Department of Electrical Engineering Science, Essex University
1968-71	Consultant on computers and systems engineering to ITT (Europe)
1969-71	Senior Lecturer, Department of EES, Essex University
1969-72	Technical Director & Consultant on interactive computing to Questel Ltd.
1969-75	Technical Director & computer designer for Micro Computer Systems Ltd., a subsidiary of Brown Boveri Kent.
1971-75	Reader, Department of EES, Essex University
1971-74	Founder Director, Educational Technology Unit, Essex University
1971-75	Member, Computer Consultative Council of Computer Board for Universities and Research Councils
1971-75	Member, IEE Professional Group E2 on Computer Design
1972	PhD (Cantab), The Human Adaptive Controller
1975-78	Chairman, Department of EES, Essex University
1975-78	Professor of Computer Engineering, Department of EES, Essex University
1976-78	Member, Advisory Committee to Chief Scientist, Department of Health and Social Security
1976-78	Chief Scientist's Representative, Computer Research & Development Committee, Department of Health and Social Security
1976-78	Outside Member, Computer Technical Committee, Department of Health and Social Security
1978	Chartered Engineer
1978-80	Technical Director, City Computer Systems Ltd.

1978-82 Chairman, G W Information Transfer Systems
1978-81 Technical Director & Deputy Chief Executive, Monotype Holdings Ltd, & Deputy Chairman, Monotype Corporation
1978-80 Visiting Professor, Department of EES, Essex University
1978-82 Member, Board of Society for General Systems Research
1979-80 President, Society for General Systems Research
1980-82 Managing Director, City Computer Systems
1980-82 Member, Board of International Federation for Systems Research
1981-82 Managing Director, Cadre Systems Ltd.
1981-85 Technical Director, Cadre Information Transfer Systems Inc., Canada
1982-84 President, Inforite Corporation, USA, joint venture between CITS, Canada, and Toppan-Moore, Japan
1983-88 Adjunct Professor of Industrial Engineering, University of Toronto
1983-85 Adjunct Professor of Computer Science, University of Calgary
1984-85 Professor of Computer Science, York University, Toronto
1985-98 Izaak Walton Killam Memorial Research Professor, University of Calgary
1985-99 Professor of Computer Science, University of Calgary
1985-90 Adjunct Professor of Psychology, University of Calgary
1985-99 Director, Knowledge Science Institute, University of Calgary
1985-86 Chairman Executive Committee, Department of Industrial Engineering, University of Toronto
1985-88 Member, Industrial Engineering Grant Selection Committee, National Science and Engineering Research Council
1987-88 Chairman, Industrial Engineering Grant Selection Committee, National Science and Engineering Research Council
1987-91 Member, Ministry of State for Science and Technology Inter-Agency Committee on Strategic Planning for Information Technology
1988-05 Director, Software Research and Development Group, University of Calgary
1988- Chartered Psychologist
1991-96 Graduate Director, Department of Computer Science, University of Calgary
1991-99 Member, Graduate Council, University of Calgary
1993-97 Adjunct Professor of Mechanical Engineering, University of Calgary
1993-94 Chair, Graduate Policy Committee, University of Calgary
1994-95 Chair, Informatics Committee, University of Calgary
1995-96 Chair, Graduate Policy Committee, University of Calgary
1995-96 Appeals Facilitator, Faculty of Graduate Studies, University of Calgary
1997-00 Member Alberta Science and Research Authority
1997-99 Dean, Faculty of Graduate Studies, University of Calgary
1997-99 Associate Vice President (Research), University of Calgary
1997-01 Member, Deans' Council, University of Calgary
1997-01 Member, President's Executive Advisory Council, University of Calgary
1997 Chair, Research and Graduate Studies Task Force, University of Calgary

1998-99 Acting Associate Vice President (Academic and Planning), University of Calgary
1998-01 Member, Vice President (Academic) Advisory Group, University of Calgary
1998-01 Member, Vice President (Research) Advisory Group, University of Calgary
1998-99 Coordinator Strategic Transformation Task Force, University of Calgary
1998-00 Member, Scholarships and Fellowships Committee, National Science and Engineering Research Council
1998-99 Chair, Information Resources and Technology Committee, Committee, University of Calgary
1999-02 Chair, Post-Degree Continuous Learning Task Force, University of Calgary
1999-00 Member, iCORE Review Committee, Alberta Science and Research Authority
2000 Retired from University of Calgary, appointed Professor Emeritus
2004-21 Adjunct Professor in Computer Science, University of Victoria

2.3 Editorships

1966-04 Founder and Editor in Chief of *International Journal of Man-Machine Studies* (later renamed *International Journal of Human-Computer Studies*)
1968-80 Associate Editor *Automatica*, Journal of the International Federation for Automatic Control
1976- Member, Editorial Board of *International Journal of General Systems*
1976- Member, Editorial Board of *International Journal of Fuzzy Sets and Systems*
1977- Member, Advisory Board for *Frontiers in Systems Science* Series, Martinus Nijhoff
1977-80 Member, Editorial Board of *Annals of Systems Research*
1979- Founder & Executive Editor of *Computers & People* book series, Academic Press
1980- Member, Editorial Board of *International Journal of Systems, Measurement and Decisions*
1983- Member, Editorial Board of *Systems Research*, Journal of International Federation for Systems Research
1984-89 Editor-in-Chief, *Future Computer Systems*
1985- Member, Editorial Board of *International Journal of Intelligent Systems*
1985-92 Member, Editorial Board of *Journal of Approximate Reasoning*
1985- Member, Editorial Board of *Expert Systems: Research and Applications*
1986- Founder & Executive Editor of *Knowledge Acquisition* book series, Academic Press
1989- Founder & Executive Editor of *Knowledge Acquisition* (later merged with *International Journal of Human-Computer Studies*)
1989- Member, Editorial Board of *Expert Systems with Applications*
1992- Member, Editorial Board of *Journal of Intelligent Information Systems*

1992- Member, Editorial Board of *Knowledge-Based Systems*

2.4 Professional Society Membership

Fellow, Institute of Electrical Engineers
Fellow, British Computer Society
Fellow, British Psychological Society
Senior Member, Society of Manufacturing Engineers
Member, Institute for Electrical & Electronics Engineers
Member, Association for Computing Machinery
Member, Experimental Psychology Society
Member, Association for Symbolic Logic
Member, Association for Computational Linguistics
Member, Society for General Systems Research
Member, British Society for Philosophy of Science
Member, Philosophy of Science Association
Member, Association for Library and Information Science
Member, World Future Society

2.5 Patents

Fifteen full and provisional patents held in the fields of: optical movement detectors, automatic training systems, message switching systems, stochastic computers, incremental digital computers, direction finders, teaching machines and computer memory systems.

2.6 Research Grants and Contracts

Adaptive Training: 1964-67: Contract from Ministry of Defence, £7,000 for research into automatic training systems.

Computer-aided Instruction: 1968-70 (joint with J.L.Gedye): Contract from the National Research & Development Council, £28,000 for research into, and development of, low-cost, multi-user interactive computer systems.

Adaptive Training: 1968-71: Contract from Ministry of Defence, £18,000 for research into automatic training systems and human decision making.

Patient Monitoring: 1970-72: Contract from Department of Health, £18,000 for research into, and development of, computer-based intensive care, patient monitoring systems.

Automated Assessment: 1970-72 (joint with J.L.Gedye): Contract from Questel Ltd., £20,000 for research into, and development of, computer-based systems for automated psychological assessment

Hospital Administration: 1973-76 (joint with J.L.Gedye): Contract from Regional Hospital Board, £2,500 a year for support of staff at University, some £50,000 for computer system developed at University and implemented at Southend Hospital in 1974. This project was one of the only two out of eighty hospital computing initiatives funded by the Ministry of Health that was rated as successful by the Auditor General of the British Goverment.

Electronics Centre: 1975-78: Grant from Wolfson Foundation, £30,000 to set up an Electronics Centre to provide research and development services to local industry.

Universal Emulators: 1976-79: Contract from Advanced Computer Techniques Project, £23,000 for research into, and development of, microcomputers capable of efficient emulation of a wide range of computers.

Pattern Recognition: 1982-85: Contract from Industrial Research Assistance Program, Ottawa, $700,000 for development of Telidon terminals incorporating hand-written character recognition.

Expert Systems: 1984-85: NSERC Individual Operating Grant, $27,000 for "Industrial expert systems—modeling, encoding and applications to industrial engineering".

Expert Systems and Flexible Manufacturing: 1984-87: (Principal Investigator, joint with H.Kolodny, N.Moray, I.B.Turksen) NSERC Strategic Grant, $156,000 for "Management of new industrial technology".

Expert Systems: 1985-87: NSERC Individual Operating Grant, $135,000 for "Knowledge engineering for expert systems and its applications".

Expert Systems: 1985-86: (Principal Investigator, joint with M.L.G.Shaw) NSERC Equipment Grant, $38,000 for Lisp machine for "Knowledge engineering for expert systems and its applications".

Killam Endowment: 1985-90: Chair Operating Grant, $40,000 a year.

Knowledge Engineering 1987-91: (Principal Investigator, joint with L.Katz, M.L.G.Shaw, J.Vickers) Immigration and Employment Canada contract, $1,010,000 for "Knowledge engineering project".

Expert Systems: 1988-91: NSERC Individual Operating Grant, $150,000 for "Knowledge engineering for expert systems and its applications".

Distributed Systems: 1988-91: (as SRDG Director representing Department of Computer Science) NSERC Infrastructure Grant, $250,000 for "Distributed Systems".

Intelligent Networking: 1988: Apollo Computer Inc, $504,000 for "Knowledge-Based Support of Heterogeneous Networks".

Knowledge-Based Systems: 1989-90: (Principal Investigator, joint with M.L.G.Shaw & I.H.Witten) NSERC Equipment Grant, $53,000 for extensions to Apollo network for "Knowledge-based systems".

Knowledge-Based Systems: 1990-91: (Principal Investigator, joint with M.L.G.Shaw & I.H.Witten) NSERC Equipment Grant, $26,000 for extensions to Apollo network for "Knowledge-based systems".

Open Systems: 1989-90: Open Systems Foundation Research Grant, US$5,000 for a study of the conceptual structure of the Motif interface.

Distributed Systems: 1991-1994: (as SRDG Director representing Department of Computer Science) NSERC Infrastructure Grant, $264,000 for "Distributed Systems".

Expert Systems: 1991-94: NSERC Individual Operating Grant, $135,000 for "Knowledge engineering for expert systems and its applications".

Intelligent Manufacturing Systems: 1993-94: (with D.H.Norrie) Industry Canada, $100,000 to participate in international Intelligent Manufacturing Systems research program.

Distributed Systems: 1994-1998: (as SRDG Director representing Department of Computer Science) NSERC Infrastructure Grant, $198,000 for "Distributed Systems".

Knowledge Support Systems: 1994-98: NSERC Individual Research Grant, $148,000 for "Networked multimedia scholarly collaboration".

Collaborative Networking: 1995: (Principal Investigator, joint with M.L.G.Shaw) NSERC Equipment Grant, $37,000 for multimedia conferencing equipment to support distributed collaborative research.

Knowledge Support Systems: 1998-02: NSERC Individual Research Grant, $148,000 for "Networked multimedia scholarly collaboration".

2.7 Teaching Experience

Taught undergraduate and postgraduate courses in: control systems, computer architecture, special-purpose computer engineering, digital communications, pattern recognition, database systems, human factors in engineering, real-time system design, microprocessor applications, artificial intelligence, language processors, future computing systems, cognitive science, advanced logic, computational logic, decision support systems, knowledge engineering, technological forecasting, and research methods in software engineering.

Overall responsibility for all computer courses in Department of Electrical Engineering and for Computer Engineering Degree course.

Whilst Chairman, responsible for re-structuring the four degree courses in the Department on a modular basis and for proposals for a 4-year degree scheme.

Member, Open University Course Team for preparation of second-level course, tm221, The Digital Computer. Author of first unit and associated radio and television programs.

Established and directed a doctoral program with some 30 students for the Department of Computer Science at the University of Calgary.

Established and managed a program of workplace training for Employment and Immigration Canada targeted on retraining professionals.

Have given seminars widely at all levels from general public and pre-university through to international professional conferences on a wide variety of topics ranging from policy issues to detailed technical expositions

2.8 Administrative Experience

Served on a wide variety of committees within the academic Department at Essex responsible for areas such as curriculum development, resource allocation, and staff-student liaison.

Responsible for setting up the Educational Technology Unit at Essex with five technicians providing central services including film-making, photography and CCTV.

Served on wide variety of committees within the University structure including Faculty Board, Student Progress, Student Discipline, Trade Union Liaison and Senate.

Chaired the Department, Departmental committees, and a number of major University committees including Computing Centre and Trade Union negotiations. Have chaired a range of professional body committees including major conference organizations.

Extensive experience of government committees and large national committee structures at policy level.

Extensive experience of financial negotiations within University, at national level, and in a variety of commercial situations, particularly in USA, Canada, China and Japan. Extensive experience of planning, financing, establishing and staffing a wide range of academic and commercial projects.

At University of Calgary, Director Knowledge Science Institute, Director Software Research and Development Group, Graduate Director Department of Computer science, Chair University Graduate Policy Committee, Chair University Informatics Committee.

Established and managed an international network of some 500 researchers in knowledge-based systems meeting through three annual conference series in North America, Europe and Japan/Australia.

Established and managed collaborative support systems and procedures for a consortium of 31 university and industry organizations internationally as a test case for a program of research on Intelligent Manufacturing Systems.

Managed a consortium of 170 researchers across 35 institutions in Canada to develop a proposal for a National Centre of Excellence in Technology-Based Learning.

Dean of Graduate Studies, Associate Vice-President Research, Associate Vice-President Academic, Coordinator of Strategic Transformation, and Chair of a number of task forces at University of Calgary.

2.9 Industrial Experience

Year with Standard Telephones & Cables (STC) semiconductor division on device fabrication before University. Developed planar transistor fabrication and epitaxial growth of GaAs.

Undergraduate vacations at STC and at ITT Standard Telecommunications Laboratories (STL), Harlow, with Dr J. H. Andreae on Learning Systems.

Consultant and Project Leader at STL whilst a postgraduate. Invented, developed and patented stochastic computer for STL. Also worked with various ITT companies: SRT in Stockholm on radar computers and auto-tracking—designed central processor unit manufactured by them; STK in Oslo on navigation systems—designed digital Decca navigator for them; LMT in Paris on message switching systems; LCT in Paris on flight simulation; STC in London on navigational aids—developed digital direction finder for them.

Took over Andreae's projects and staff when he left and ran team of 5 engineers on ITT-funded research on navigational aids and ACTP-funded research on digital control. Became consultant to ITT(Europe) and travelled extensively to ITT locations in France, Belgium, Norway and Sweden, consulting on computer systems and design.

Wide range of industrial consultancy whilst at Essex for ITT, Plessey, Questel, George Kent, Micro-Computer Systems, and Laurie Milbank. Designed MINIC range of computers for Micro-Computer Systems used extensively in machine-tool control. Designed AIMS interpretive programming language used by Arbat Ltd. for banking systems world-wide.

Established Electronics Centre at the University of Essex to provide low-cost consultancy to local industry and obtained Wolfson Foundation support for it. Developed computer dealing system for brokers, Laurie Milbank, in Stock Exchange in 1972 and set up a company in collaboration with Dr White, City Computer Systems (CCS) in 1979 to offer such systems to other brokers. CCS was taken over by the National Enterprise Board (NEB) when it re-structured Monotype.

Developed videotex dissemination and page makeup systems for G W Information Transfer Systems in 1979 in which a combination of cable TV teletex and interactive viewdata was used.

Consulted for NEB on re-structuring of Monotype Corporation and was asked by them to join Monotype Holdings Ltd. as full-time Deputy Chief Executive and Group Technical Director in 1979. In this capacity responsible for a wide range of activities: Managing Director of Monotype International, the phototypesetting division for 6 months, and then responsible for the control of this division; responsible for launch of Monotype products in USA and China; responsible for formation of Advanced Development Group in Science Park at Cambridge; responsible for development of system for editing and phototypesetting Chinese; responsible for developments in laser phototypesetters, editing terminals and computer-based text processing systems. The experience of bringing Monotype back to profitability complemented previous experience in founding new companies.

Consultant for Moore Corporation Corporate Development in Canada from late 1980 on product development programme and advanced printing systems. Set up Cadre Systems in 1981 in the UK to act as a focal point for joint development programmes with Moore Corporation and developed page makeup system, graphic computer for image output, and hand-character recognition terminal for data acquisition at source from business forms. Sold interests in this company in 1983.

Set up Cadre Information Transfer Systems in 1981 in Canada to establish an office of the future business in conjunction with the Moore Corporation. Moved to Toronto in 1982 to operate CITS and obtained $700,000 support from the Canadian Government to develop image processing systems for the office. Sold this company to Toppan-Moore in 1985.

Set up Inforite Corporation in the USA in 1982 as a joint venture with Toppan-Moore, a subsidiary of Toppan Printing in Japan and the Moore Corporation in Canada, in order to establish an office image processing company in the USA for distribution of systems developed by Cadre and manufactured by Toppan-Moore or CITS. Sold this company to Toppan-Moore in 1985.

Set up Centre for Person-Computer Studies in Canada in 1983 to provide on-going consultancy on advanced computing systems and human factors to a wide variety of organizations including: New York Stock Exchange, Tokyo Stock Exchange, Alberta

Research Council, Defence Institute of Civil and Environmental Medicine, Lehigh Press and Cairn Capital.

2.10 Main Areas of Research

Personal research activities include:

—Computer system design and application, particularly the interaction of hardware and software in system design for ease of ongoing development and overall system reliability;

—Special-purpose computer design for low-cost or high-complexity applications, including stochastic computers, analog/digital hybrids, graphic computers, database systems and knowledge-processing systems;

—Person-computer systems engineering, particularly the interaction between users who are not computer-oriented and database systems, and programming interactive dialog;

—Expert system development and application to management, administrative, and production functions;

—Knowledge acquisition and representation system theory, development and application;

—Hypermedia system development and application to skills training and information management;

—Digital journal and book publication, technologies extending the medium, and its impact on scholarship and knowledge dissemination.

—Social implications of developments in information technology, particularly microprocessors and communication networks affecting the office and home environments;

—Economic and social infrastructure of generations of computing systems, their development impact and future trends;

—Algebraic system theory and its application to system modeling, stability and control, and to computer architecture and protection structures;

—Systematic acceleration of scientific research through computer support of collaboration among distributed research groups;

—Technology-based learning, collaborative learning and distance and workplace delivery of education;

—Modeling and forecasting the information highway and other ‘convergence’ phenomena;

—The history and philosophy of science and its role in the evolution of human civilization;

—The foundations of logic and mathematics and their roles in scholarly disciplines;

—The evolution of scholarship from the earliest recorded time to the present, its cultural and economic role in society, and its support through institutions and technology.

Have supervised a wide range of PhD and MSc projects in topics including: pattern recognition; stochastic computing; incremental computers; emulation; chemical simulation; automated design; human perception; speech recognition; textual analysis; naive user characterization; human controller modeling; analogical reasoning; ray

tracing; process migration; group writing; human factors in virtual reality systems; deductive databases; class libraries for parallel processing.

3 Project Areas

My broad interests since 1955 have been in the nature of knowledge, its extension through observation, modeling and application, and the limitations to this. This has led to interests in knowledge technologies: at a hardware level electronics and computers; at a formal level philosophy, logic and mathematics; at a human level psychology, sociology and economics; at a computational level knowledge-based systems; and at an applied level information systems. I have been particularly interested in the role of technology in supporting knowledge processes, and in the impact both of technology on society and of society on technology. These interests have involved university, goverment and industrial research, and resulted in publications on a diverse range of topics. In retirement, these interests have broadened to include the history and dynamics of ideas and civilizations.

The notes below organize my research projects into a number of major projects in chronological order that are outlined and linked to published works.

3.2 Adaptive Training of Human Operators

For my doctoral research at Cambridge (1964-1967) I had a contract from the Ministry of Defence to study the adaptive training of airline pilots which was extended when I moved to Essex. I built a small hybrid computer and used this to simulate a tracking task similar to those involved in controlling a high-performance vehicle. As well as human experiments I also developed theoretical foundations for the work at a number of different levels ranging from the abstract, through the systemic to the concrete tracking situation. I also simulated the complete system on a digital computer and investigated the training schemes using machine learning algorithms as 'subjects'.

My current interest in this work is in the theoretical studies that form the foundations for a general theory of control systems with only partial models and changing dynamics.

The practical work is summarized in No.21, the educational implications in No.36, modeling implications in No.29, and theoretical foundations in Nos.35 & 41. Other papers are Nos.2, 5, 6, 9, 16, 24, 26, 238.

3.3 Learning Systems

In parallel with the work on human learning I worked in ITT's UK research laboratories on machine learning algorithms in conjunction with John Andreae (1963-1966). We developed a number of general purpose learning strategies and simulated these in a variety of control situations. In my case this triggered off later research on system identification at both abstract and concrete levels. The concepts generated in this work have become of current importance in research on knowledge acquisition.

My current interests in this area are and concerned with the abstract systemic limitations on knowledge acquisition and system identification, and on the practical possibilities of automatic knowledge acquisition in expert systems. I have developed statistically well-founded inductive algorithms that are now in widespread use, reported in Nos. 251 and 323, and also developed models of social learning in societies of agents, 364, 397.

The main description of the early work is No.8. Others are 1, 3, 7, 23, 30, 49, & 66, 252, 257, 307, 317, 342, 361, 366, 379, 382, 385, 392, 397, 408.

3.4 The Stochastic Computer

I developed a new form of computer at ITT Europe Research Laboratories in 1965 as part of our learning machines research and called it a "stochastic computer." The concept was to enable a digital logic system to operate in an analog mode by using the probability of occurrence of a logic level to encode a value. I patented several versions of the computer for ITT and built a working prototype.

The stochastic computer did not become a major technology initially because of the lack of suitable high-speed logic elements. It has been used in instrumentation and studied as a model of some operations in the human brain, and there has been continuing major activity worldwide on research and development in stochastic computing, particularly in the UK, France, USA and Japan. The Proceedings of the 1st International Symposium on Stochastic Computing, Toulouse, November 1978 provide an early study of the state of the art, and many recent developments have been reported at IEEE conferences.

I predicted in the 1960s that the availability of optical logic systems having gates based on photon pair interactions would be necessary for significant activity in this area. Research on stochastic computing architectures such as Boltzmann machines suggested that the topic was becoming of wider interest and

in recent years stochastic computing has been shown to have major advantages even with current technologies in applications such as image processing. It has become a significant area of engineering research again in recent years/

The main publication summarizing my stochastic computing research is No.27 that has become a standard citation in recent literature. Other papers are Nos.4, 10, 11, 15, 17, 25 & 214. I have also digitized my early stochastic computer design documents and patents and made them available on the web.

3.5 The Phase Computer

In looking at applications of the stochastic computer for ITT I found that hybrid DDA systems could be applied to speed up and reduce in cost a number of systems such as tracking radars and navigational aids. I developed such a system in 1966, terming it a phase computer because of its mode of operation and it was used primarily in navigational aids.

The main paper on this work is No.20. Others are Nos.13, 14, 18, 19, 22, 28, 31.

3.6 Digital Computer Design

In ITT I consulted on the processor design for a number of general-purpose computers for use in air-traffic control in Sweden and message-switching in France. When I left ITT I decided to design my own ultra-minicomputer using the small 8-bit core stores that had then become available (1968) for use in visual displays. This was the MINIC computer which was manufactured by Microcomputer Systems, a company in the George Kent Group, and used largely in machine tool control. I designed it as an 8-bit machine with a 48-bit wide microprogram with extensions definable by the user. The hardware design was modular around a single system bus.

I had a number of government contracts at Essex to develop systems around the MINIC computer including a mass spectrometry system and the fist computer-based intensive care unit patient monitoring system in use for some years at University College Hospital. I also had contracts to develop various other machine architectures, notably a universal emulator machine which could operate as a PDP8, Nova 1200, PDP11 and a number of other machines. I also developed for George Kent a replacement machine, MINIC S, which was descriptor organized and designed to be efficient in an Algol 68 runtime environment. A prototype was built and both operating system and high-level languages developed but the development was discontinued when Brown Boveri took over Kent. I have continuing interests in computer design, notably for AI and image processing applications, and in using silicon compilers to implement the systems in VLSI technology.

The descriptor machine is described in Nos.39 & 44. Others are Nos.33, 38, 42, & 93. I have also digitized the MINIC and MINIC-S design documents and manuals and made them available on the web.

3.7 Interactive Systems

I moved to Essex in 1967 to set up a man-machine systems laboratory with John Gedye. We undertook a number of medical and commercial system developments together and, finding that in the mid 1960s there was little software support for interactive system developments, I designed a programming language Basys. This had extensive string-handling facilities, long integer arithmetic for accounting purposes, and close control of communications protocols. I implemented it for a number of machines including the PDP8, PDP10 and PDP11. It became heavily used commercially for medical, banking and stock exchange applications and later versions emphasized modularity with local variables, segmentation, and full Brooker-Morris compiler-compiler string functions.

My interest in symbolic interpreters continues as a tool for writing interactive systems and dialog shells. Basys was widely used for many years primarily for banking and stock exchange systems.

The main technical reference is No.82. A survey of the system developments is 50. Others are 12, 32, 37, 62, 63 & 70. I have also digitized the manuals for various dialects of Basys and made them available on th web.

3.8 Stock Exchange Systems

One area of particular interest for developing interactive systems has been the London Stock Exchange where I installed a system for gilt-edged stock dealers in 1972. The system was very effective and a number of systems based on it have been installed since. City Computer Systems Ltd. in the UK continues this work and I continue to consult for them on new designs. This has been a good testbed for evaluating a number of concepts in interactive system design.

When I came to North America I was appointed a consultant to the New York Stock Exchange on advanced technologies and their implications for exchange operations. I worked with the Tokyo, London and New York stock exchanges on linked information systems with a view to eventual automated exchanges on a world-wide basis.

The London systems are described in 116. Other papers are 40, 62, 77, 83, 85, & 88.

3.9 Dialog Engineering

As part of the work on interactive systems I became interested in treating the programming of person-computer dialog as a software engineering problem. I developed a set of rules for programming dialog 1974, at first pragmatically and then later with increasing psychological and systemic foundations.

Further developments include modeling dialog engineering in terms of a human protocol similar in concept to network protocols for equipment. Later papers provide a framework for writing dialog shells ranging in style from formal dialog and menus through natural language and icon/windows. In particular, the OSI virtual circuits notions have been integrated with a layered model of human-computer interaction.

The most extensive summary of the work is No.125. The human protocol is No.121. Dialog shell design is No.159. The layered model is 242. Applications to expert systems are in 297. Major surveys are 180 & 181. Others are Nos.76, 89, 103, 132, 155, 157, 158, 164, 166, 167, 173, 185, 233 & 237.

3.10 Stochastic and Fuzzy Logics

I have always been interested in knowledge acquisition, decision making and control under uncertainty. This has led to a deep interest in the foundations of probability theory that has had spin-offs in the stochastic computer development and learning machine work. I have looked for situations where probabilistic phenomena are necessary to system function and have modelled probabilistic reasoning as a multi-valued logic system. Thus I also took an interest in the development of fuzzy reasoning when it arose and have been concerned to set it in a historical framework and relate it to classical multi-valued logics and probability theory.

This work resulted in recent publications showing that a single logic of uncertainty underlying both probability and fuzzy logics may be used to derive most of the results used in practical applications.

The relationship between stochastic automata and recursive functions in some applications is in No.34. The common features of stochastic and fuzzy logics are in No.52 and most recently in No.135. The relationship of fuzzy logic with other systems is in No.64. Other papers are Nos.43, 48, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 69, 80, 122, 124, 134, 148, 194 & 200.

3.11 Stochastic and General System Identification

As part of my work on human modeling and machine learning I become very interested in the problem of identifying the structure of the process underlying the behavior of an observed stochastic system. In 1975 I became convinced that this problem had never been solved and went to the USA to visit Joe Goguen and Michael Arbib, who had worked on the problem for deterministic systems, to obtain their assessment. In that year I published the first paper to give a full solution to the problem and went on to generalize it to a variety of system types and problems. The algorithms were implemented as computer programs and used with a variety of test and natural data.

This work continues as a major interest and I am in touch with groups around the world working on aspects of the problem. I also inverted the direction of development to use the solution of the identification problem to define axioms for probability and other logics of uncertainty.

No.53 shows the nature and No.47 gives the solution to the sequential stochastic system identification problem. No.67 generalizes it extensively. Others are No.61, 72, 73, 75, 86, 87, 96 & 147.

3.12 Foundations of Computing

I have long been interested in the systemic foundations of computing. What is a computer? What is programming? What is a structured system? This has led to a number of studies that fit loosely together under this heading. I have found category theory a useful tool in modeling virtual machine hierarchies and modal logic a good tool for modeling protection systems. I have used Popper's theory of 3 worlds a basis for modeling the role of computers in society, and have found nonstandard logics applicable to problems of database security and access.

The work on protection and that on analogy categories both found application by others to human systems and I became interested in foundational models that encompasses the complete system

including people and computers. In particular I assimilated Petri net theory into the systemic framework I had already developed for stochastic system modeling to encompass indeterminate systems.

The development of analogy categories as models of virtual machine hierarchies threads through Nos.18, 46 & 118. Modeling of protection with modal logics is No.66. A 3 worlds model of computers in society is in No.84. Computers as a new medium is No.128. Nonstandard logics in database systems is No.94. Others are Nos.45, 71, 79, 90, 91, 107 & 145.

3.13 Printing/Image Systems & Office Automation

In 1978 I went on secondment for two years to Monotype Corporation and became very interested in typography and the role of computers in printing systems. I developed the first system for photo-typesetting Chinese and installed it in Beijing and Shanghai in 1979. I also toured parts of China lecturing on computer technology for the Asia foundation and became involved in internal planning of their semiconductor and computer industries.

I developed a forms makeup system for Moore Corporation shortly before leaving the UK. I also developed algorithms for a typographic computer to drive laser printers and typesetters at high speed and low cost and suitable for implementation in VLSI technology. Coupled with my previous work in the Stock Exchange this has led to a general interest in office automation. In Canada I have received funding from the government to develop a Telidon input pad using hand character recognition. I was particularly interested in computing system operating in languages with unusual scripts such as Devanagari and Kanji, and worked with Toppan Printing in Japan on some of the problems. The technology developed has been commercialized for signature collection and handwriting recognition is now a routine feature of many computer systems.

The Chinese system development is described in No.100 and its extension to other languages and office automation in No.126. Digital handwriting is No.146. Others are Nos.106, 108, 110, 111, 119 & 131.

3.14 Individuals and Organizations

Using personal construct psychology it has been possible to take account of the normative social influences upon the individual and formulate a model of individuals, organizations and the dynamics of their relationships. The full development of this, its incorporation in computer models, and the practical application of these to societal and economic modeling became a major research activity in collaboration with Mildred Shaw. One outcome was interactive computer systems incorporating inter-personal skills found in those who readily establish effective human relationships.

This work has been of particular significance in the approach I have taken to setting up industrial and commercial organizations. The approach is one of global constraint through setting up a working framework for a team rather than detailed individual management. It has been very effective in product development and is being tested in more general organizational areas. Eventually it should be possible to give a general formulation of goal-directed project management.

We also developed methodologies and tools to model social processes at the knowledge level. This became the basis for a new line of research on group decision support systems.

No.98 describes the computer analysis of personal construct systems. The first formulation of societal modeling is in No.104. No.210 gives a logical analysis of accountability and impact assessment. The methodologies and tools are detailed in 345. No.314 gives an overall model of the human species as a distributed, anticipatory system. No.302 describes the group decision support system. Others are Nos.92, 99, 102, 109, 112, 113, 114, 115, 117, 120, 123, 129, 136, 140, 149, 201, 281, 299, 312, 316, 324, 325, 348, 362, 364, 446, 447.

3.15 Knowledge Acquisition and Transfer

In the 1980s I became interested in the development and application of expert systems from both theoretical and practical points of view. My work on non-standard logics and system theory proved relevant to the foundations of knowledge engineering for expert systems. The industrial applications of these systems has changed the basic operations of many industries. I collaborated with a number of industrial and government groups world-wide in setting up expert system projects, and working on the theoretical and empirical foundations of such systems.

Techniques were developed in collaboration with Mildred Shaw for the automatic transfer of knowledge from experts to expert system shells using interactive interviewing. The research became increasingly collaborative as we developed a network of users of our programs world-wide and integrated them with a number of systems developed by others. With the advent of the World Wide

Web the technology was extended in 1994 to multiple-user interactive knowledge modelling systems accessible over the Internet and intranets. The WebGrid system was widely recognized as a major advance in interactive applications on the web and I was invited to give a tutorial on porting applications to the web at the first WWW conference in 1995 (390). We have maintained and extended the technology over the years and is still still being used in successfully in a wide range of organizations for the development of knowledge management systems and for research on human knowledge processes.

No.133 describes an experiment in knowledge engineering for business accounting and 212 surveys our knowledge engineering techniques. Nos.256 and 267 describe the techniques for working with multiple experts. Others are Nos.139, 141, 143, 148, 150, 151, 153, 160, 161, 165, 168, 169, 170, 172, 175, 176, 177, 178, 179, 183, 185, 189, 195, 196, 198, 202, 204, 205, 206, 209, 213, 217, 221, 222, 224, 226, 227, 231, 234, 236, 239, 243, 246, 255, 258, 259, 261, 263, 269, 270, 328, 333, 334, 337, 339, 344, 346, 347, 349, 383, 384, 388, 389, 399, 401.

3.16 Expert System Applications

I have become initiated a number of projects on the development of expert systems for specific applications. I obtained strategic grant funding from NSERC for a project to develop a Technology Management System for managing the design, introduction and operation of flexible , 386, 387acturing systems. This project took place in the Department of Industrial Engineering at the University of Toronto, and involved the integration of expert systems, simulation and database techniques. The significance of this work was recognized internationally with the invitation to devote a complete session to it at AUTOFACT'86 in Detroit 1986.

I continued this work in conjunction with colleagues in the Department of Mechanical Engineering at the University of Calgary. This has resulted in object-oriented models of various aspects of design and , 405acturing processes.

No.189 and 367 summarize the manufacturing applications. Others are Nos.186 & 197, 203, 225, 249, 260, 289, 363, 409, 413.

3.17 Fifth Generation Systems

The Japanese fifth generation computer development program was of immense personal interest because it ties together the many strands of my own activities, from vlsi circuits and computer architecture to automatic programming, machine learning and knowledge representation. I established strong links with the research group at ICOT in Tokyo, and with corresponding Alvey projects in the UK and Esprit projects in Europe.

I gave a numbers of seminars to university and industry on the nature of fifth generation developments, their technical, economic and social foundations and impact, and developed an operational model of trends in computing in relation to other high-technology disciplines.

No.138 analyses the economic and social infrastructure of fifth generation systems, No.152 surveys the technical foundations, and No.184 gives a model of the development of generations. Others are Nos.130, 144, 154, 156, 163, 171, 174, 187, 188, 199, 329.

3.18 Sixth Generation Systems—Knowledge Science

The Japanese proposals for research in knowledge science, the so-called sixth generation computer development program, was again of great personal interest as it focused on cross-disciplinary aspects of intelligence in neurology, logic, psychology and linguistics. In particular it was supportive of my own efforts to establish an institute for research on knowledge science. I organized two sessions at the IEEE SMC Conference in 1986 concerned with knowledge science and consulted to MITI in Japan on the structure and impact.

No.182 is the first publication in the West of a review of the Japanese proposals. Nos.193 give models of developments in sixth generation technologies and No.211 is a major survey. Others include 275.

3.19 Modeling the Knowledge Economy

In order to model and forecast the impact of information technology on the economy and society, I have developed a number of models of the foundations and infrastructure of information technology. The BRETAM tiered learning curve model has been widely applied to a number of industries and technologies. Recently I have developed a simulation model of the way in which expertise forms in society, and a quantitative measure of the value of knowledge.

No.184 presents the BRETAM model, No.247 the expertise formation model, and Nos.251 and 323 a measure of the value of knowledge. No.457 brings the model up to date as of 2013. Others are 168, 190, 215, 218, 252, 264, 293, 300, 326, 329, 402.

3.20 Heterogeneous Systems Integration

The complexity of modern information systems is such that complete control over systems design is becoming impossible for major applications. It is becoming necessary to integrate systems from diverse sources, including those already in place. This problem of heterogeneous integration can be analyzed theoretically in such a way as to make design, development, implementation and maintenance very much more effective. I developed theoretical models that have become part of the 'open systems' literature, and also illustrated the potential of heterogeneous integration in some widely used practical systems.

These principles have been applied to the development of a number of practical systems based on heterogeneous integration and involving collaboration with institutions such as the GMD in Bonn, and companies such as Neuron Data

No.271 presents the integration issues and model, and Nos.263 and 290 illustrate applications. Others are 184, 207, 216, 220, 239,240,241, 254, 277, 278, 288, 292, 340.

3.21 Knowledge Support Systems

Computer-based systems may be seen as tools supporting human knowledge processes. This viewpoint allows expert systems and hypermedia to be seen as the latest developments in a wide range of knowledge support systems. I have been developing this approach as a design principle for a next generation of knowledge-based systems.

I have also used this approach in applied system developments such as hypermedia systems for sports coaching in collaboration with colleagues in Physical Education at the University of Calgary, and in the development of systems offering integrated hypermedia, knowledge acquisition and expert systems.

In order to access the existing knowledge support processes of the scientific community a project on scientific collaboration over networks was developed, focused initially on joint writing of papers. Experiments were also conducted on making the conceptual modeling tools available to groups over local networks and Internet

No. 291 develops the concept of a knowledge support system and 250 gives a theoretical framework. Nos. 229 and 230 describe the coaching application. No. 265 describes the integrated knowledge support system. Nos.301 and 322 describe conceptual modeling over networks. No.321 describes the group writing system. Others are 208, 219, 223, 228, 240, 243, 244, 245, 252, 265, 266, 272, 274, 276, 282, 283, 294, 295, 298, 308, 309, 310, 311, 318, 330, 335, 336, 353, 357, 358, 360, 364, 368, 369, 376, 377, 399, 400, 401.

3.22 Knowledge Representation

Knowledge representation theory and techmology is now at a stage where it is feasible to develop knowledge representation servers on a par with floating-point arithmetic units and numeric libraries, as software (and perhaps ultimately hardware) modules with well-defined functionality and fast, reliable performance. As with arithmetic units, such servers by no means solve all the problems of a particular application domain, but they do greatly reduce the burden of system development, allowing effort to be focused on the specifics of particular systems rather than on what should be general utilities. Much of my recent research has been focused on the design and implementation of such servers, and their application in knowledge acquisition and hypermedia systems.

In particular modules have been developed to integrate rules with exceptions in the server operation and to provide a visual language for knowledge entry and editing. The implementation of the server and support systems as an object-oriented class library has also become significant in its own right.

No. 285 develops the concept of a knowledge representation server. No.287 develops cognitive and logical foundations. No. 286 describes knowledge acquisition applications. No.304 details the knowledge representation server research. No.305 describes rule integration. No.313 describes the visual language. Nos.307, 356 and 369 describe the object-oriented implementation. Others are 279, 280, 296, 303, 319, 327, 331, 350, 355.

3.23 Digital Scholarship, Publication and Knowledge Dissemination

I have been involved over the past 50 years with a number of attempts to use digital networks as a publication medium complementing existing books and journals. In the past these have had little impact but the technologies of digital publication and networking are now at a stage where they are making major changes in knowledge dissemination. This became a major research interest and I have written an extensive survey of the role of journals in scholarship, given a detailed analysis of the technologies necessary to effective digital journals, and surveyed the impact of the Internet on scholarly practice to date (351). In parallel with this I developed digital journal and book publication technology, such as a word processor with versioning for collaborative writing (352), that also supports multi-media, hypertext and embedded knowledge structures.

We published a paper in December 1992 using this technology to create a document which, in printed form, is a conventional conference paper, but, in electronic form, is the actual knowledge base being described in the paper (343). This enables a knowledge base and its documentation to be treated as a unified entity. It also opened up new opportunities for publishing scholarly material in an operational form.

Papers on this theme are Nos.320, 332, 338, 354, 359, 371, 372, 373, 374, 375, 391, 398, 403, 409, 412, 415, 450.

3.24 General Systems Theory

Most of my remaining abstract interests can be subsumed under the heading of general systems theory. I am interested in the problems of observation, modeling, decision, action and control in their most general forms, and the synthesis of this work to form a generic coherent systems theory.

Papers on this theme are Nos.74, 81, 95, 101, 105, 127, 137, 142, 162, 322.

3.25 Surveys and Future Developments

I have become increasingly involved in presenting survey material in the areas of computer technology, artificial intelligence and human factors, both to specialist computer audiences and also in more general contexts such as energy and agriculture. I expect this trend to increase as computer technology passes performance thresholds that make it increasingly impinge on all aspects of society.

I have developed a model of the evolution of information technology as a tiered structure of learning curves and applied it many IT industries as well as the phenomena of convergence between information and communication technologies. My paper for the journal *Technological Forecasting and Social Change* (426) summarizing this work was awarded a $1,000 prize as best paper for 1998. The most recent update of the forecasting model is 458.

Human-computer interface research is surveyed in No.164, 158 & 181, fifth generation in No.152, world-wide research in information technology in Nos.211 and 275, and knowledge acquisition in No.273. Others are 65, 78, 89, 90, 91, 93, 97, 106, 110, 130, 138, 139, 144, 161, 173, 174, 182, 190, 232, 235, 253, 268, 273, 275, 284, 315.

3.26 Journals and Book Series

In 1969 John Gedye and I founded the *International Journal of Man-Machine Studies* and I have been executive editor since. IJMMS now publishes monthly and has become well-established as the leader in inter-disciplinary studies between computing and psychology, particularly human-computer interaction and, more recently, expert systems. In 1979 I set up a *Computers and People* book series for Academic Press in order to publish longer works that would not fit into IJMMS. This also has become well established and I see a continuing role for it in promoting standards and scholarship in human factors in computer systems.

In 1983 I was approached by Maruzen, the leading book publishers in Japan, and Oxford University Press to advise them on establishing a new journal on the future of computing covering policy, strategy and the broader issues of technological change. *Future Computing Systems* commences publication in 1985 with Hajime Karatsu of Matsushita and myself as joint Editors-in-Chief. Dr Karatsu was a major driving force in setting up the Fifth Generation Development project, and his colleagues Dr Fuchi, Director of ICOT, and Professors Nagao and Aiso, formed the Japanese Editorial Board.

In 1988 I started a second book series with Academic Press on *Knowledge-Based Systems* which has now published four volumes edited by John Boose and myself, and has a number of monographs commissioned from leading researchers in artificial intelligence. In 1989 I started a second journal with

Academic Press on *Knowledge Acquisition* which has already achieved wide circulation and a good reputation.

I also have major interests in a number of other journals where I am on the editorial board, primarily in artificial intelligence, expert systems, general systems and mathematical systems theory.

3.27 Knowledge Acquisition Workshops

In 1986 John Boose and I founded a series of international workshops entitled *Knowledge Acquisition for Knowledge-Based Systems*. They have attracted world-class researchers in knowledge-based systems internationally and established a very high reputation for excellence. The workshops have been kept to a small size of some 40 people, and refereeing standards are high with reject rates of about 70%. We are now running three series of annual workshops: a North American series with meetings in Banff in 1986, 1987, 1988, 1989, 1990 and 1991, and plans through to 1993; a European series with meetings in the UK in 1987, Germany in 1988, France in 1989, Holland in 1990, Scotland in 1991, Heidelberg in 1992, Toulouse in 1993 and plans though to 1994; and a Pacific Rim series with meetings in Japan in 1990, Australia in 1991, Japan in 1992 and Korea in 1993.

These meetings have had a major impact on progress in knowledge-based system research and resulted in a number of books and a large number of journal articles. The Proceedings of all the meetings have been kept in print and are in wide demand. A world-wide community of cooperating researchers has been built and is developing into a very effective research network. We published a quarterly newsletter (funded by Boeing Computer Services) with a circulation of over 1,500.

The three series of Knowledge Acquisition Workshops have continued to the present day although I am no longer involved in there organization or content and have become major fora for technical aspects of semantic web research. In 2013 I was the keynote speaker for the 25th anniversary meeting in Banff.

3.28 Knowledge Engineering Training Project

There has been a major problem in making effective use of knowledge technologies in industry through the lack of trained personnel. In 1987 the opportunity arose to develop a training course for knowledge engineers and implement it for ten full-time people a year. This has been very effective in those on the course have not only benefited in themselves but have also made major contributions to research projects in various Departments and Faculties in the University. In particular, research projects have been initiated with these resources that would not otherwise have been funded initially but where the results have been sufficient to generate publications and specific funding. Those trained on the courses have responded well to both the formal teaching material and the work experience through involvement in research, and have in general found employment utilizing their new knowledge. A new project is being developed to capture the training material and make it widely available.

3.29 Knowledge Science Institute

In 1983 I developed a proposal for a Knowledge Science Institute that would be concerned with the study of the impact of knowledge technologies on the knowledge processes of society. The concept was to attempt to model the knowledge economy, quantify the notion of knowledge itself, and study the impact of knowledge technology on a variety of disciplines. In particular I was interested in the possibility of the systematic acceleration of scientific research through the application of effective knowledge technology.

My appointment to an endowed research chair at the University of Calgary gave me an opportunity to establish a *Knowledge Science Institute* as a distributed network of collaborating researchers. This has involved interdisciplinary projects within the University enabling me to study the impact of knowledge technology on widely varying disciplines. It has involved establishing an international network of researchers with similar interests, in the USA, Japan, Australia, Germany, France, the UK, Austria and Finland. It has involved establishing three series of international workshops on knowledge acquisition.

Most of the outcomes from the Knowledge Science Institute activities are reported under specific headings above. My goals were to develop what we had already achieved into a model that might be followed by other institutions, to consolidate the experience and results into a series of books on knowledge technology and the knowledge economy, and to extend and strengthen the existing network.

3.30 Software Engineering

I have been involved in practical software engineering throughout my career, writing modular numerical analysis and statistical packages for the Cambridge Titan whilst an undergraduate, developing operating systems, programming languages, interpreters, compilers and libraries for the

various computers I designed and used in my laboratories, and developing category-theoretic foundations for modular virtual machine architectures that made correct implementations of complex architectures feasible.

When my colleague Mildred Shaw was appointed Industrial Software Engineering Chair at the University of Calgary I collaborated with her in establishing graduate programs in software engineering and making modern software engineering techniques more accessible to industrial communities. This also led to a number of publications about both the teaching and the research.

No. 380, 393, 416, 420, 430, 433, 435, 437, 438, 439, 440, 441.

3.31 Retirement Projects

I planned in retirement to take the opportunity to read in much greater breadth and depth than had been possible during my career and to complete various projects that had always been of major interest to me, notably to track the history of scholarship as the production, testing, recording and dissemination of ideas from the earliest recorded era of cuneiform in Babylonian civilization through to the present era and its projection into the future. Digital libraries have made it possible to access most of the worlds' literature and undertake scholarly research on a scale never previously possible. I have focused on the evolution of knowledge production in general and that of logic as a significant example with which I am already familiar.

The main outcome to date has been to develop new foundations for computational logic that address the mismatch between first-order predicate calculus with its strong ontological presuppositions and the need for logical systems appropriate to computational linguistics and other human-related disciplines. A logical framework has been developed that supports the inferential and representational structures needed for ontological modelling, and can be incrementally strengthened in a principled and controlled fashion to introduce further structures as needed to model individuals, relations, nonmonotonic reasoning, and so on. The framework has been implemented as an inference engine integrated with our existing knowledge modelling tools and is being documented as a tool for introductory and advanced logic courses and for applications in a number of disciplines, notably linguistics and philosophy. The current tools have been made freely available to the academic community and we plan to port the implementation to a modern open-source framework (probably Node.js, TypeScript, et al) to make it easier for colleagues to extend and support the existing tools and integrate them with their own systems.

The main publications to date are 453, 454, 458 and 461.

4 Books, journal & conference publications and technical reports

77a: Gupta, M.M., Saridis, G.N. & Gaines, B.R., Eds. (1977). *Fuzzy Automata and Decision Processes* New York: North-Holland.

79a: Gaines, B.R., Ed. (1980). *General Systems 1979.* Louisville, Kentucky, Society for General Systems Research.

81a: Mamdani, E.H. & Gaines, B.R., Eds. (1981). *Fuzzy Reasoning and its Applications*. London:Academic Press.

84a: Zimmermann, H.J., Zadeh, L.A. & Gaines, B.R., Eds. (1984). *Fuzzy Sets and Decision Analysis*. Amsterdam:North-Holland.

84b: Gaines, B.R. & Shaw, M.L.G. (1984). *The Art of Computer Conversation*. Englewood Cliffs, New Jersey, Prentice-Hall.

88a: Gaines, B.R. & Boose, J.H., Eds. (1988). *Knowledge Acquisition for Knowledge-Based Systems*. London, Academic Press.

88b: Boose, J.H. & Gaines, B.R., Eds. (1988). *Knowledge Acquisition Tools for Expert Systems*. London, Academic Press.

90a: Gaines, B.R. & Boose, J.H., Eds. (1990). *Machine Learning and Uncertain Reasoning*. London, Academic Press.

90b: Boose, J.H. & Gaines, B.R., Eds. (1990). *The Foundations of Knowledge Acquisition*. London, Academic Press.

90c: Wielinga, B., Boose, J.H. & Gaines, B.R., Schreiber, G., van Someren, M., Eds. (1990). *Current Trends in Knowledge Acquisition*. Amsterdam, IOS.

90d: Motoda, H., Mizoguchi, R., Boose, J.H. & Gaines, B.R., Eds. (1990) *Knowledge Acquisition for Knowledge-Based Systems.* Tokyo: Ohmsha.

93a: Wetter, T., Althoff, K.D., Boose, J., Gaines, B., Linster, M. & Schmalhofer, F., Eds. (1993) *EKAW'92: Current Developments in Knowledge Acquisition*. Berlin: Springer.

99b:. Aussenac, N., Boy, G., Gaines, B., Linster, M., Ganascia, J.G. & Kodratoff, Y., Eds. (1993) *EKAW'93: Knowledge Acquisition for Knowledge-Based Systems*. Berlin: Springer.

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65a: Gaines, B.R. (1965). Automated feedback trainers for perceptual-motor skills. *Technical Report No.1*, Ministry of Defence Contract 70/JAN/9577, 1-19 (February). University of Cambridge, Cambridge, UK: Psychological Laboratory.

65b:. Gaines, B.R. & Andreae, J.H. (1965). Nonlinear simplifications of the general control problem. *United Kingdom Automation Council Symposium on Advances in Automatic Control* (April). Nottingham.

65c: Gaines, B.R. (1965). A stochastic analog computer. *Standard Telecommunication Laboratories Internal Memorandum,* 1-10 (December).

65d: Gaines, B.R. (1965). Discontinuities in tracking strategies. *Internal Memorandum*, 1-2 (November).

66a: Gaines, B.R. (1966). The evaluation and control of human skills. *Colloquium on Human Operator Studies*, 1-8 (January). London: Institution of Electrical Engineers.

66b: Andreae, J.H. & Gaines, B.R. (1966). An introductory description of the STeLLA learning machine. *Standard Telecommunication Laboratories Technical Memorandum* No.556, 1-14 (August).

66c: Gaines, B.R. & Andreae, J.H. (1966). A learning machine in the context of the general control problem. *Proceedings of the 3rd Congress of the International Federation for Automatic Control*. London: Butterworths.

67a: Gaines, B.R. (1967). Teaching machines for perceptual-motor skills. Unwin, D. & Leedham, J., Eds. *Aspects of Educational Technology*. pp. 337-358. London: Methuen.

67b: Gaines, B.R. (1967). Stochastic computing. *Spring Joint Computer Conference*, 30, 149-156. Atlantic City: AFIPS.

67c: Gaines, B.R. (1967). Techniques of identification with the stochastic computer. *Proceedings IFAC Symposium on The Problems of Identification in Automatic Control Systems*, 1-10. Prague.

67d: Gedye, J.L. & Gaines, B.R. (1967). Medical applications of programmable audio-visual displays. *Proceedings of 7th International Conference on Medical & Biological Engineering*, 226. Stockholm.

67e: Gaines, B.R. & Joyce, P.L. (1967). Phase Computers. *Proceedings of 5th Congress of International Association for Analog Computation*, 48-57. Lausanne.

67f: Gaines, B.R. (1967). The place of incremental techniques in future computer systems. *Colloquium on Integrated Circuits & Logical Design*, 1-2 (November). London: Institution of Electrical Engineers.

67g: Gaines, B.R. (1967). Stochastic computer thrives on noise. *Electronics*, 72-79 (July).

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