Preface

Soft Computing has proved its capability in handling real life complexities, such as imprecision, uncertainty, and vagueness. This emerging computing paradigm contains a combination of methodologies including Fuzzy Logic, Neural Networks, Evolutionary Computation, Probabilistic Computing, and Machine Learning to address the growing challenges. The increasing popularity of the paradigm is clearly visible in a number of international conferences and numerous journals in the area.

The World Conference on Soft Computing has entered its sixth year (WSC6) and is devoted to Industrial Applications. We are very proud to present you this book containing the WSC6 conference papers. The application area of soft computing is wide; our book presents advances in fuzzy, neural and evolutionary computing techniques, and their applications in real life systems. The book deals with a wide range of applications, such as intelligent control, 3-D agents, multimedia and Internet, as well as reasoning and intelligent behavior. This book also presents new frontiers of soft computing.

WSC6, a truly international conference, included 70 papers from 28 countries: 17 from America, 20 from Asia and 33 from Europe. Approximately 400 people from 58 countries registered for the conference. *Soft Computing and Industry—Recent Applications* is divided into seven chapters including the keynote papers, and applications in intelligent control, classification problems, optimization, image and signal processing, agents, multimedia and Internet, prediction, design and diagnosis, and finally a number of new paradigms. Thus, the book presents a nice balance between recent advances in soft computing techniques and their applications in industry. The Best Paper Award of WSC6 was given to "Finite Element Mesh Adaptation via Time Series Prediction Using Neural Networks," by Larry Manevitz, Akram Bitar, and Dan Givoli.

And finally, the WSC6 conference was dedicated to the memory of Professor Francisco Varela, who passed away in May 2001. He was an intended invited author for the conference. We pray for his eternal peace.

Cyberspace
25.03.2002

Rajkumar Roy
Mario Köppen
Seppo Ovaska
Takeshi Furuhashi
Frank Hoffmann

WSC6 Organization

General Chair
Mario Köppen, Fraunhofer IPK Berlin, Germany
International Co-Chairs
Nikhil R. Pal, Indian Statistical Institute, India
Javier Ruiz-del-Solar, Universidad de Chile, Chile
Scientific Chair
Seppo J. Ovaska, Helsinki University of Technology, Finland
Technical Programme Chair
Rajkumar Roy, Cranfield University, UK
Publication Chair
Frank Hoffmann, Royal Institute of Technology, Sweden
Online Chair
Yukinori Suzuki, Muroran Institute of Technology, Japan
Online Tutorial Chair
Takeshi Furuhashi, Nagoya University, Japan
Virtual Exhibition Chair
Janos Abonyi, University of Veszprem, Hungary
Best Paper Award Chair
Katrin Franke, Fraunhofer IPK Berlin, Germany
Social Programme Chair
Bertram Nickolay, Fraunhofer IPK Berlin, Germany

International Scientific Board

F. Abbatista, Italy
A. Asano, Japan
B.de Baets, Belgium
R. Baeza-Yates, Chile
H.H. Bothe, Denmark
S. Cagnoni, Italy
C.A. Coello Coello, Mexico
P. Culverhouse, UK
A. Duffy, UK
M. Embrechts, USA
T. Fukuda, Japan
J. Gero, Australia
E. Goodman, USA
I.B. Gurevich, Russia
P. Hajela, USA
K. Hameyer, Belgium
A. König, Germany
V. Kurkova, Czechia
V. Kvasnicka, Slowakia
W. Langdon, UK
K.M. Lee, Korea
W.M. Lippe, Germany
Z. Michalewicz, USA
V.V. Mottl, Russia
Z. Nakao, Japan
W. Pedrycz, Canada
D T Pham, UK
G. Raidl, Austria
A. Roy, USA
A. Satyadas, USA
L. Schomaker, The Netherlands
U. Seiffert, Australia
Y.G. Smetanin, Russia
A. Soria-Frisch, Germany
J. Tanskanen, Finland
H. Tizhoosh, Canada
O. Unold, Poland
V.B. Valkovsky, Russia
H.M. Voigt, Germany
L. Vuurpijl, The Netherlands

WSC6 Conference Chair's Message

The "6th On-line Conference on Soft Computing in Industrial Applications" has opened its gates. From September 10 to 24, registered participants will have the opportunity to follow and discuss the about 60 on-line presentations of authors from all over the world, and also to use all other conference facilities.
The WSC conference is already in its sixth round now. Starting off from a small workshop held on Nagoya University on Evolutionary Computation in 1994, it has grown up to a regular scientific event gaining more and more international attention. In 1999, there were two "real" conferences held in conjunction with the WSC4 conference, one in Finland and one in Japan. At the end of those conferences, the foundation of the "World Federation of Soft Computing" was announced. This was done in order to have a reliable background organization behind future WSC conferences. Now, the WFSC is also in its third year, and has gained much interest among researchers and other scientific organizations from all over the world.
Sometimes, on-line conferencing is considered an opposite to a "real conference". However, the formal way of conference organization has much changed. WSC now has more in common with traditional conferences than someone might think. It has become usual for nearly all conferences to provide Call-for-papers electronically, to have its own homepage, to advice authors to submit papers via email or web interface, and even to pay the registration fee on-line. So, what makes WSC unique at all? The answer is easy: you will have *instant* access to all the contributions, and thus you may find an overview of newest soft computing research from nearly 30 countries all over the world. You can meet your colleagues via the discussion boards in the WSC6 sessions, and found a base for future cooperations, hopefully accompanied by a personal meeting with your colleague in the near future.
On behalf of all organizers I want to express my thanks to all who have contributed to WSC6: thanks to all authors, who have considered WSC6 a suitable place to present their scientific work to an international audience; thanks to all who have helped with the organization of WSC6, be it distributing the Call-for-paper, be it technical support in script programming, logo design, file conversion or testing; thanks to the sponsors of this event; and, last but not least a special thanks to all members of the Scientific Board for their great help and valuable comments with reviewing the submitted papers.
We hope that you will enjoy the conference. Feel free to explore our small webspace and to use all features that it offers. It is our pleasure to provide the facilities, but it is up to you to make the conference vital and a success. And, what we also very hope is that you overcome the only drawback of an on-line conferences: that you will also *personally* meet many of your "virtual" colleagues in the near future.

Mario Köppen
WSC6 Chair

WSC6 Conference Co-Chair's Message

Since the early days of Artificial Intelligence scientists and engineers have been searching for new computational paradigms capable of solving real-world problems efficiently. Soft-Computing (SC) is one of such paradigms that has emerged in the recent past as a collection of several models of computation which work synergetically and provide the capability of flexible information processing. The principal constituents of SC are fuzzy logic, neural networks, evolutionary computing, probabilistic reasoning, chaotic theory and parts of machine learning theory. SC is more than a melange of these disciplines, it is a partnership in which each of the partners contributes a distinct methodology for addressing problems in its domain. In this perspective, these disciplines are complementary more than competitive.

SC technologies are currently attracting a great deal of attention and have already found a number of practical applications ranging from industrial process control, fault diagnosis and smart appliances to speech recognition, image processing and biometric systems. In this context, the "Online World Conferences on Soft Computing in Industrial Applications" give excellent opportunities to present the last advances and applications in this field. These conferences take place every year at the Internet, with an increasing number of attendants. It is our very pleasure to inaugurate the WSC6, the 6th Online World Conference on Soft Computing in Industrial Applications.

Please enjoy all the articles, summary papers and tutorials. The conference can not be a success without your active participation!

Javier Ruiz-del-Solar
WSC Co-Chair

WSC6 Conference Co-Chair's Message

Dear Colleagues:
Welcome to the 6th Online World Conference on Soft Computing in Industrial Applications, September 10-24, 2001 organized by the World Federation of Soft Computing. It is our conviction that this conference will be a great success through active participation from all over the globe.

We have got an excellent response from all over the world, in particular, we have received submissions from 27 different countries including USA, Brazil, India, Finland, Spain, UK, Italy, Japan and many others. Each paper has gone through a rigorous review process and based on the review reports we have finally selected 62 quality papers. This has become possible only because many researchers have taken the pain of doing the so called "thank-less" job of reviewing the manuscripts. The reviewers deserve our very special thanks for this and we give the same and express our gratefulness to them.

The distinguished plenary presenters deserve sincere appreciation for squeezing out some of their valuable time from their busy schedule for the conference. We take this opportunity also to acknowledge our authors without whose contributiond, the conference would not have been a reality.

Thanks are due to all others who have helped us in different capacities in different stages of the evolution of the conference.

Finally, we are grateful to WFSC for entrusting us with this job and we hope that we all will have a very fruitful conference.

Dr. Nikhil R. Pal
WSC Co-Chair

WSC6 Conference Honorary Chair's Message

Welcome to what promises to be a special on-line treat, the 6th Online World Conference on Soft Computing in Industrial Applications (WSC 6). Researchers and practitioners from around the globe have gathered virtually for fourteen days of exchange of the latest results from both research labs and the real world in the growing field of soft computing.

It is triply satisfying for me to be asked to be the honorary chair of WSC 6. First, as a sword-carrying member of the genetic algorithms and evolutionary computing battalion of the soft computing revolution, I am proud to be a soldier in the fight for the relaxed computational techniques that make up the arsenal of soft computing that are now having and will continue to have great impact on industrial applications around the world.

Second, much ballyhoo has surrounded the internet revolution, but much of our scientific and technological exchange continues to take place the old-fashioned way, through expensive in-person conferences, requiring outrageously priced airplane tickets to destinations halfway around the planet. The WSC conference was an early and aggressive innovator in trying to reduce the transaction costs of scientific-technological exchange by harnessing the magic of the web. Each year the website and the online offerings become more sophisticated as presenters find new ways to exploit the differences between virtual and actual conference presence. I am pleased to be asked to be the symbolic leader of such an innovative, groundbreaking activity and the many people who have made it possible.

Third, I myself have served the community as chair of a major organization (the International Society of Genetic and Evolutionary Computational, www.isgec.org) and as chair of two major conferences, the Fifth International Conference on Genetic Algorithms (ICGA 5, co-chair with Dave Schaffer) held in Champaign, IL in 1993, and the 1999 Genetic and Evolutionary Computation Conference (GECCO-99) held in Orlando, FL. I have also served on many conference committees and have held a number of time-consuming chairmanships. Thus, I know first hand the amount of work that it takes to put on a major conference. Moreover, I know that the "magic" of the web, while it reduces costs for the participants, actually increases preparation time and the complexity of conference organization for the organizers. I am therefore especially grateful to have been asked to be *honorary* chairman of WSC 6 and not the real thing. This way I can reap a disproportionate amount of the glory while shouldering almost none of the actual work.

On that humorous (?) note, I would like to turn serious and thank the organizers for their Herculean efforts in bringing off another WSC to the benefit of our increasingly united soft-computing community of researchers and practitioners. Special thanks are due to Mario Köppen, conference chair. My original contact regarding the conference was with him, and he has gently guided me to fulfill my duties as honorary chair every step of the way. I would like to close by thanking and listing the entire organization of WSC 6 and its many sponsors.

Through the power of hypertext, you can e-mail anyone of the chairs of the conference from within these welcoming remarks. I would urge you to do so. All conferences depend on feedback for improvement, and perhaps you have glitches to report or suggestions for better or new things to do. Conference chairs welcome this kind of constructive criticism, but I also urge you to report on the things that you liked and to express your gratitude. None of the people listed are paid for their efforts, but they have given freely and graciously of their time just the same. Please join me in thanking them for sharing their time and creativity to put on such a marvel of our internet age.

I declare WSC 6 open and wish everyone a stimulating fortnight.

Sincerely,

David E. Goldberg
Honorary Chair WSC 6

WFSC Chair's Message

As the Chair of World Federation of Soft Computing it is my great pleasure to welcome all participants of the 6th On-line World Conference on Soft Computing in Industrial Applications (WSC6) in the Cyberspace. The conference is the third of WSC series sponsored by WFSC.

Since we started the cyber-conference in 1996, this series has been expanded and received wider support from the researchers in the field of soft computing. The conferences have removed the financial burden from the authors and participants, and thus have attracted good quality papers from all over the world. The registered participants have also represented academia and industries from many countries around the world. The conferences have established a new way of publishing technical papers and discussing papers in greater detail. The organizers of WSC1 – WSC3 decided to expand the activities and make the 'Web based technical discussion and publishing' more popular. The 'World Federation on Soft Computing (WFSC)', which is a virtual society for active researchers in the field has been established since 1999.

The aim of the Federation is to promote 'Soft Computing' across the world. The Federation is promoting all other organizations in this area and evangelizing the concept of 'virtual discussion and publishing'. This Federation is now publishing the Journal of Applied Soft Computing (ASOC) in collaboration with Elsevier. The papers will be published on Elsevier Science Web Site as soon as they are accepted, which enables authors to publish their work FAST and readers get the latest work in Soft Computing on their desktop. A free hardcopy of volume will be available to authors by the end of the year.

The authors of excellent papers of WSC6 will be invited to submit revised and extended versions to the ASOC Journal.

I am convinced that you will enjoy the cyber-conference on the internet!

Takeshi Furuhashi
Chair of WFSC

Keynote of the WSC6 Honorary Chair

A Meditation on the Application of Soft Computing and Its Future[1]

David E. Goldberg

Illinois Genetic Algorithms Laboratory
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801 USA
deg@uiuc.edu

It is an honor for me to give a keynote address to the attendees of 6th Online World Conference on Soft Computing in Industrial Applications (WSC 6). The rise of soft computing (SC) is reflected in the continuing success of this online gathering and the high level of interest in this year's conference. Indeed, the symposium organizers should be congratulated on having assembled such a diverse collection of interesting and useful papers, but as I scan the web site, I can't help wonder about the larger lessons of this conference for the field and its future. In the remainder, I reflect on the rise of SC, wonder whether SC will ultimately be successful in influencing the course of human events, and then briefly discuss perhaps the single most important requirement for SC systems of the future.

The rise of SC. Soft computing has been on the rise whether viewed individually from the perspective of its bedrock constituents—neural computation, fuzzy systems, and genetic and evolutionary computation (GEC)—or from the perspective of joint activities such as this one. In my own discipline, genetic and evolutionary computation, a recent on-line listing contained exactly 32 workshops, symposia, and conferences between now (September 2001) and next September. In other words, one could do nothing but traipse around the world and attend GEC-related events every other week of the year if one was so inclined, and this growing popularity is remarkable. Not long ago there was only one GEC conference, the first International Conference on Genetic Algorithms (1985), and all of about 60 people attended. By way of contrast, this past July the Genetic and Evolutionary Computation Conference (GECCO) in San Francisco drew 583 attendees, so the growth in both numbers of events and attendees per event has been substantial.

Is SC successful? But our success in numbers—our success in talking amongst ourselves—has not yet translated to having influence in the most prestigious

[1] Portions of this talk are adapted from a foreword to the Proceedings of the 2000 International Symposium on Computational Intelligence in Slovakia.

academic departments, organizations, and industries. With rare exception, these positions are still held by those who grew up with hard computation or artificial intelligence as their guiding technology. This situation reminds me of a story told of the German physicist Max Planck. A friend approached him and asked him how the acceptance of the new physics was going. The great man is reputed to have said, "Fine, lots of funerals." Our situation is simultaneously similar and dissimilar to that of the new physics. A substantial mind makeover is required to accept the differences in philosophy and outlook of SC versus the earlier paradigms of traditional computation and artificial intelligence, but the time rate of discovery of new knowledge is no longer well matched to the funeral rate of earlier thinkers.

Of course I should be quick to point out that I am not suggesting that this problem is one we should actively try to solve through an increase in the number of homicides or unexplained accidental deaths. But it *is* an interesting question for the survival of the field, as we must imagine a pathway to both intellectual and political success if the field of soft computing and its constituent disciplines are to survive and continue to influence the course of human events.

Certainly, the growth of the field is itself a remarkable fact given the relatively low levels of corporate and governmental support driving our study. Ours is an insurgency led by passionate researchers, and we should not underestimate the power of passion in the promotion of important ideas. But the pathway to wider acceptance takes more than passionate commitment, and I believe the pathway for widespread SC ascendance is presenting itself to us in the form of (1) scalable results, (2) with practical import, using (3) *little* or *facetwise* models or theory.

Scalable results. The AI winter following the bust of the expert systems bubble in the 1980s was the result of systems that worked well in the pilot stages, but were too *brittle* as they were tried on larger, real-world systems. SC, as a rule, has been more concerned with results that scale well from its very inception, and fielded SC systems continue to grow and prosper; we have not yet "hit the wall" on the growth of these systems in practice.

My own research in GEC has largely concentrated on such efforts, and I am pleased today to announce publicly for the first time the completion of a new book on the subject, entitled *The Design of Innovation: Lessons from and for Competent Genetic Algorithms*. The book will soon be available as part of the Kluwer International Series on Genetic Algorithms and Evolutionary Computation (http://www.wkap.nl/series.htm/GENA). The take-home message of this monograph is that (1) design methodology matters, (2) *facetwise* or *little* models are necessary and sufficient to the design of complex algorithms that scale, and (3) competent algorithms *can* be designed that solve large, difficult classes of problems that matter.

Practicalilty. Moreover, it seems to me that SC has been tied more closely to practice from its beginnings with real problems tackled earlier and more often. Early AI was characterized by the solution of "blocks world" types of problems, but early fuzzy, neural, and genetic systems have been solving complex simulation, optimization, and control problems for some time, and the trend seems likely to continue.

Additionally, these early and continued ties to practice have promoted explicit concern with efficiency enhancement. In the case of scalable GEC, well-designed algorithms give accurate, reliable results on hard problems in subquadratic time; however, if one is working on a large-scale problem—say one with a thousand decision variables—the square of 1000 is 1,000,000. A million function evaluations means long waiting times if no other steps are taken. In other words, the design of competent algorithms takes us from intractability to tractability. Efficiency enhancement takes us from tractability to practicality.

In our lab, we study four facets of GA efficiency enhancement:
1. Parallelization
2. Time continuation
3. Evaluation relaxation
4. Hybridization

Each of these is important, and principled results are available in each facet. For a sampling of what is possible and a roadmap to success, see Erick Cantu-Paz's recent monograph Efficient and Accurate Parallel Genetic Algorithms. Similar results are coming and are available across the landscape of SC.

Little or economic models. Additionally, the growth of SC has been accompanied by a concomitant interest in applicable theory or what I have called *little models* or *facetwise models*. Where early AI seemed content with the firewall that exists in the computer science curriculum between the rigor of algorithm theory on the one hand and fielded systems on the other, SC seeks out scaling laws, bounding theories, or equations that are only complex enough to advance the state of SC design. Some may decry the loss of rigor this suggests, but I view it as an advantage of SC, plain and simple, and elsewhere[2] I discuss this view in more depth. Simply stated, the use of *scaling laws* is extraordinarily helpful in the design of complex SC systems. The Wright brothers[3] used lift coefficients and drag coefficients to build Flyer I, but they did not use the Navier-Stokes equations. Likewise, we must use models to design complex SC systems, but the models must be simple enough to be tractable in design usage at the same time they are sufficiently predictive to answer the design questions that arise.

The coming integration in our SC future. These three factors, I believe, bode well for the future of our field. As more people come to the party, it is essential

---

[2] See my paper "The Race, the Hurdle, and the Sweet Spot" available as IlliGAL 98007, http://www-illigal.ge.uiuc.edu/techreps.php3 or read the forthcoming monograph *The Design of Innovation,* http://www.wkap.nl/series.htm/GENA.

[3] Gary Bradshaw's writing and presenting on the Wright brothers has influenced me greatly. His web site *To Fly is Everything,* http://hawaii.psychology.msstate.edu/invent/air_main.shtml,

that our systems scale well, are practical, and are guided by solid and appropriately complex theories or models. Many of the papers of this on-line conference reflect these values, and better understanding and articulation of SC's competitive advantage in the marketplace of ideas can only help future researchers and practitioners to accentuate these matters in their own work. But as we turn to the future, one observation about the conference stands out above others. In many of the papers, the constituent technologies co-mingle comfortably and are integrated seamlessly to bring out the best in each technology. This, I believe, is our collective future.

Individually the constituent methods of soft computing are powerful. Each has a driving metaphor, a driving logic, and a driving base of successful application, but the future of our field lies in the *integration* of the best of the constituent technologies. Some of this drama is being played out today on the web pages of this very conference through simple *combinations* of neural-fuzzy, neuro-genetic, fuzzy-genetic, or fuzzy-neuro-genetic systems, but the careful integration of our methods into autonomously intelligent systems goes beyond simple combinations. Subtle integration of the abstraction power of fuzzy systems, the associative powers of neurocomputing, and the innovating power of genetic systems requires a design sophistication beyond our current means and a better sense of economy of hybridization than has been recognized heretofore. Some of these matters are now receiving attention, and their study will grow. Nonetheless, the integration of the constituent technologies into powerful competent systems is off on a not-too-distant horizon. This conference represents a few more steps toward that now-visible goal, and I urge the conference contributors and attendees to join together to hasten the day when that goal shall be reached.

Dedication

The scientific routes of Francisco Varela (1946-2001)

Juan Carlos Letelier

Facultad de Ciencias
Universidad de Chile
(letelier@uchile.cl)

Francisco Varela's life as a scientist was not an ordinary experience... some of the most interesting problems addressed in Biology during the last century referred to him. His scientific work developed in such "classical" areas as the electronic microscopy of the eye of the honeybee, as well as in more advanced areas, which in his case were many and varied: the nature of living organization, the neurobiology of mind phenomena, the vertebrate vision, immunology.

A brief summary

Francisco Varela attended the German school in Santiago and later entered the Medical School of the Universidad Católica de Chile. It was obvious very soon that his interests went well beyond the ordinary practice of medicine. Pushed by two of his teachers, Joaquín Luco and Juan de Dios Vial he changed to the Facultad de Ciencias, recently created at the Universidad de Chile. The fact that Varela was an excellent student coupled with the help of Daniel Yudelevich, made him win a scholarship for a Ph.D. offered by Harvard to the Facultad de Ciencias. He obtained his Ph.D. at relativistic speed (**1**) returning to Chile in 1970 as an assistant professor at the Facultad de Ciencias. In October 1973 he escaped being held at the Estadio Nacional by the military (a sports stadium turned into a concentration camp), leaving the country in a hurry for Costa Rica, where he was hired as a teacher at the Biology Department of the Universidad de San Jose. After a few months and just when he was being offered the position of head of the Department, he left for the United States where he worked between 1975 and 1980 at the University of Colorado and NYU. In 1980, surprising everybody and to the great gratitude of many young students, one of which was I; he returned to the Facultad de Ciencias in Chile and worked there until 1984. In 1985 he went to Germany thanks to a Von Humboldt fellowship, landing finally in Paris in 1986. In 1988 the Centre National de la Recherche Scientifique (CNRS) named him Director of Research. He held this position until his death in May 2001.

A taste for formality

Francisco Varela had a special love for mathematics, and the more theoretical and complex the better. His work in biomathematics was focused on three areas: harmonic analysis (**2**) which he used to understand some of the properties of the visual system, non-linear dynamics (**3**) that he used for his work in electroencephalography in order to make a space-temporal quantification of the electroencephalogram (**4**), and the third area was his attempt to formalize biological organization. In order to tackle this highly complex problem he used theoretical artillery proportional to the problem itself: he used the indicational calculus created by Spencer- Brown (**5**) trying to make a mathematical formulation of autopoietical systems. Unfortunately for all those interested in theoretical Biology, this attempt did not have the expected success, and Varela himself later looked for other approaches to this problem. With his usual partner in these theoretical adventures, mathematician Jorge Soto Andrade, he explored the use of the theory of categories to understand the intrinsic *fuite en avant* that the circular organization of the biological metabolism implies (**6**).

Autopoiesis

Francisco Varela's name will always be linked to the theory of the nature of living organization, known as autopoiesis, and to another giant of Biology in Chile, Humberto Maturana. The small "red book" **De Máquinas y Seres Vivos** (**7**) published at the Editorial Universitaria in the convulsed years of 1972-1973 triggered a deep conceptual change which will take a long time to reach its climax. A simple inspection in the Internet shows how the concept of autopoiesis, which states that the most important feature of living beings is the circular organization of their metabolism, is like a snowball that keeps growing as the number of supporters and the fields of application increase (**8**). As it usually happens the field where this idea originated, Biology, has been the most reluctant to adopt its analytical method and questions. With no fear of making a mistake it can be said that the concept of autopoiesis is the scientific idea originated in Chile that has had the greatest repercussion abroad. Varela used this work as a stepping stone for many other problems in Biology related to autonomy (**9**) and the nervous system (**10**). As Varela himself explains in the preface to the second Spanish edition of **De Máquinas y Seres Vivos** (1996) the concept of autopoiesis was used (and abused of) as a metaphor in many fields very different from Biology and the phenomena for which the concept was created. Varela never felt at easy with these metaphors; nevertheless he continued his research in this field. In the last ten years, in fact, he had reassumed the theoretical and experimental work in this area. In relation to the theory, he had redone the original simulations of the protobio (the computer model of a minimal autopoietic system) (**11**) in a more modern environment (**12**) than the historic and missed IBM 360 of the Facultad de Ciencias Físicas y Matemáticas, in which the original simulations were performed in 1973. He also participated in algebraic theories of autopoietic systems to recognize shapes (**13**), fully entering the field of artificial life with these publications (**14**). In the experimental aspect he collaborated with Luisi in biogenesis experiences evoking the classical experiments of Fox and Oparin (**15**). For those interested in working in the field of simulation, formalization and synthesis *di novo* of living beings it must be pointed out that Varela considered this an extremely difficult problem as it required a new way of thinking and of doing science.

Enaction

It is not advisable to read **De Máquinas y Seres Vivos** (published in English as **Biology of Cognition** in 1980) lightly, as the concept of structural coupling, that is, the characteristics of living beings are congruent with the world that contains them, is not easy to understand. Varela developed the concept of Enaction (**16**) to help clarify the concept of structural coupling applied to living beings with a nervous system. In one sentence enaction is a concept related to Von-Uexkull's *Umwelt,* Piaget's *evolutive epistemology* and the *structural coupling* of the autopoiesis. In enactive cognition the "objects" are generated by the behavior of the organisms (**17**). This point of view may seem too constructivist and a heresy if one believes that science is about "objective" objects that are independent of the observer. It is obvious that Varela did not believe this, he had a constructivist view of the reality surrounding us. Slowly these ideas have been gaining support especially in the field of robotics, where for practical reasons, and not because of epistemological reasoning, it has been discovered that the concept of "situated intelligence" applies to the construction of really autonomous agents (robots). The concept of situated intelligence is directly related to the notion of *Umwelt*, and it is related to enaction and structural coupling. It is for this reason that Varela published several papers on robots and how they can be made intrinsically intelligent (**17**).

The nervous system understood by neuronal synchronies

Francisco Varela 30 years of research in Neurobiology show a constant underlying principle: the nervous system can be understood as the operation of populations of neurons that are mainly coupled among themselves, and only faintly coupled to external stimuli. In fact already in his Master's Degree thesis, in 1967, Varela studied how the properties of the receptive fields were explained by the coupled action of excitation and inhibition in the frog's visual system (**18**). Varela not only never ceased to consider the operation of the visual system from a systemic and population point of view but he also continuously searched theoretical and experimental methods to prove this. The research work he carried out with Humberto Maturana in the early '80s on the avian visual system (**19**) fully convinced him that the recording techniques involving one (or just a few) neurons had a fundamental flaw. To complete this presentation it is important to point out that during his stay in New York Varela together with A. Toro did research on human EEG (**20**), developing the concept of *perceptual framing*. This concept would later be very important in Varela's work in France. Between 1982 and 1984 lacking specialized hardware and using analog filters from old ***Flash Gordon*** films, he worked with Michel Gho improving the concept of framing (**20**). The possibility of using other technologies for neurophysiologic registration is one of the reasons he left Chile to go to Europe in 1984. He first worked with Wolf Singer, one of the icons of neurophysiology of the visual system, on the influence of the visual cortex on the nucleus geniculatus lateralis. They tackled a problem that still today is a mystery: what is the function of the descendant cortico-thalamic pathway? (**21**). Francisco Varela later told me that that year was fundamental in his life as a scientist. It was then that he decided to accept an offer to work in France, and also in Wolf Singer he had found an excellent partner in relation to his ideas on correlation and synchrony in neuronal ensembles.

The immune system as a closed system

In Paris, Varela began the publication of a series of papers on a reinterpretation of the immune system. Broadening reflections already made by Nelson Vaz in 1978 (**22**) he considered the immune system not as an army that defends the body against foreign elements but as a series of cell populations that confer operational coherence to the multicellular autopoietic systems. Essentially he applied in the field of immunology the concept of operational closure, a central concept in autopoiesis and cognitive biology, and some of the tools used in models of the nervous system (**23**). This new interpretation gained great popularity when A. Coutinho, an important immunologist, converted himself to this new approach with Varela (**24**).

Neuronal ensembles

In Paris, his neurophysiological studies had a slow start, in relation to the great vigor shown in the last five years. Together with Adrián Palacios and Serge Neuenschwander they publish several papers on the visual system of the pigeon (**25**). Especially relevant to what would come later was the study on the synchrony of the neuronal responses in the tectum of the pigeon (**26**). This paper contains in embryonic form all the theoretical ideas that were later implemented by Varela and collaborators in the study of human electroencephalography. In 1994 Varela's group begins to be familiar with multichannel electroencephalography. This is a highly competitive field and many groups work in it. One of Varela's contributions was precisely his mathematical-theoretical approach to EEG signals, using the new techniques of non-linear dynamic systems and of time-frequency analysis that physicists had developed ten years before to study time series and chaos (**27**). Initially the work was slow and they had to assemble several bricks of the building. But their systematic work begun to render results at a great speed in 1998 (**28**), when they were able to predict epileptic seizures several minutes in advance. Varela's contribution in this field is not only methodological, that is generating the correct application of concepts of nonlinear analysis to EEG signals (ideas such as embedding dimension or the correlation dimension). Another important contribution is the generation of a comprehensible theoretical background on the operation of neuronal ensembles (**29**)

Biology of the self

The study of consciousness and mind phenomena. Francisco Varela never forgot that the real reason of studying the nervous system is to understand "higher" phenomena such as *consciousness* and the nature of the *self*. Most neurobiologists believe these subjects lie beyond empirical science; but Varela always worked to show it is possible to "make science" with these vague entities. Already in 1971 he published some ideas on the nature of what we call consciousness (**30**). In the last 10 years, this subject became absolutely central in his interests. With Evan

Thompson he published a series of papers (**31**) and he also became editor of the Journal of Consciousness Studies. Considering how important this last stage was to Varela I will try to explain how this interest originated. It is common in Psychophysics to use perceptions that cause illusions. Each illusion is a configuration of visual stimuli that may generate in whoever is watching it (Observer X) at least two contradictory perceptions. Generally an external experimenter, using arguments that lie outside the dominion of the visual configuration of Observer X, can classify these perceptions assigning one "correct" and one "wrong" perception. When Observer X manages to see the "wrong" configuration it is only Observer X who has the experience. In theory there is no one else in the whole universe that can have that experience, in that time and place. That is, X has something that for western science is inaccessible as it is a unique and private phenomenon to which the external experimenter has no access and that will only exist for an instant in a fragmentary way. In other words, the "wrong" perception only exists for one person and this perception exists outside the phenomenical world of the experimenter. ¿Can one make science with such an ethereal situation? Varela believed it was possible, but a Biology of "the self" had to be founded, a Biology that considered relevant the experiences when the observer himself experiences them (**32**). The conviction that the internal environment is fundamental, made him publish a description of his illness and subsequent liver transplantation (**33**).

Final reflections

One of the reasons Francisco Varela's departure has been so hard for many friends and students is that he left us precisely when these important ideas, incubated and developed for at least twenty years, were starting to bear fruit. It is not by chance that one month before his death Francisco Varela and his collaborators witnessed the publication of a paper in *Nature Neuroscience* containing the general ideas of their approach to electroencephalographic studies thus opening a small window in the understanding of mind processes (**34**). His last years in Paris must serve as an example; because although he was very serious ill (he even had to undergo a liver transplantation) he kept an intense and active academic activity. We must all reflect on this example. It was always obvious also that Varela loved to work in science, he enjoyed it. Once, for example, he considered that Rupert Sheldrake's metaphysical ideas on Morphogenetics fields were pure nonsense, and he devised an experiment to prove this (**35**). Another important aspect was his contribution in the vocational training of young scientists. During his stay in Chile in 1980-1984, he was fundamental in the education of a complete generation of students in the Facultad de Ciencias of the Universidad de Chile (John Ewer, Vivian Budnik, Michel Gho, Juan Carlos Letelier, Gonzalo Marín, Jorge Gollowasch, Francisco Aboitiz, Alfredo Kirkwood, Jorge Mpodozis, Frank Samson). In France this training activity only increased, forming a small army of scientists beginning with his long and fruitful collaboration with Adrián Palacios and Serge Neuenschwander. In this concise review of Francisco Varela's life I have left an enormous void: his relationship with Buddhism and his friendship with Tenzin Gyatso, 14th Dalai Lama. I leave this to others, more capable of presenting this important aspect of his life.

References.

[1] VARELA F, PORTER KR (1969) The fine structure of the visual system of the honeybee. I. The retina, Journal of Ultrastructure.Research 29:236-258.
[1a] VARELA F (1970) The fine structure of the visual system of the honeybee.II. The lamina, Journal of Ultrastructure.Research 31:178-194.
[2] VARELA F (1982) La corteza bien temperada: Análisis armónico de campos receptivos visuales, Archivos de Biología y Medicina Experimentales. 15:297-303.
[2a] ROSSLER J, VARELA F (1987) Exact results for the average dynamics and correlation of non-linear neural networks, Biological Cybernetics 57:249-256.
[3] LACHAUX JP, PEZARD L, PELT Ch, GARNEIRO L, VARELA F, MARTINERIE J (1997) Spatial extension of brain activity fools the single-channel reconstruction of EEG dynamics, Human Brain Mapping 5:26-47.
[4] LE VAN QUYEN M, MARTINERIE J, ADAM C, LACHAUX JP, BAULAC B, VARELA F (1997) Temporal patterns in human epileptic activity are modulated by perceptual discriminations, Neuroreport 8: 1703-1710.
[4a] PEZARD L, LACHAUD JP, NANDRINO JL, ADAM C, GARNERO L, RENAULT B, VARELA F, MARTINERIE J (1997) Local and global entropy quantification in neuronal systems, Journal of Technical Physics 38:319-322
[5] VARELA F (1980) Describing the logic of the living, in: M.Zeleny (Ed.), Autopoeisis: A theory of the living organization, North-Holland. New York, pp.36-48.
[5a] VARELA, F., Principles of Biological Autonomy, Elsevier/North-Holland, New York, 1979, 306 pp.
[6] SOTO-ANDRADE J, VARELA F (1984) Self-reference and fixed points, Acta Applicandae Mathematicae. 2:1-19.
[7] H.Maturana and F.VARELA,:De Máquinas y Seres Vivos: Una teoría sobre la organización biológica, Editorial Universitaria, Santiago, 1973, 121 pp.
[7a] H.Maturana and F.VARELA, (1980) Autopoiesis and Cognition. Reidel, Dordrecht. This book is the english translation of the original book De Maquinas y Seres Vivos. This book should be considered as the introduction of Autopoiesis to the englsih speaking literature.
[8] It is possible to grasp the use of the notion of Autopoiesis, in may fields, by performing a simple web search, like in www.google.com, with the keyword "autopoiesis".
[9] VARELA,F. (1984), Two principles for self-organization, In: H.Ulrich and G.Probst (Eds.), Self-organization and Management of Social Systems, Springer Verlag, Berlin, pp.25-33.
[10] VARELA,F. (1977), The nervous system as a closed network, Brain Theory Newsletter 2:66-67.
[10a] VARELA,F. (1984), Living ways of sense-making: A middle path for neuroscience, in: P.Livingstone (Ed.), Order and Disorder: Proceedings of the Stanford International Symposium, Anma Libri, Stanford, pp.208-224.
[11] VARELA,F., H.Maturana and R.Uribe (1974), Autopoiesis: The organization of living systems, its characterization and a model, Biosystems 5:187-196
[12] McMullin, B. and F.J.VARELA (1997) Rediscovering computational autopoeisis in: P.Husbands and I.Harvey (Eds.), Fourth European Confrence on Artificial Life, MIT Press/ Bradford Books, Cambridge, MA., pp.38-48.
[13] Deffuant, T.Fuchs, E.Monneret, , P.Bourgine, and F.VARELA (1996) Semi-algebraic organisms: the morphodynamical network perspective Artificial Life 2:157-179
[14] VARELA, F. (1997) Qu'est-ce que la vie artificielle? Pour la Science, No.240, Octobre, pp.10-12.
[15] Luisi,L. and F.VARELA (1989), Selfreplicating micelles as a chemical version of a minimal autopoietic system, Origins of Life 19:633-643.

[15a] Luisi,L. Lazcano,A. and VARELA,F. (1996) Autopoiesis: the very idea in: Defining Life: The central problem in theoretical biology, M.Rizzotti (Ed.), Universitá de Padova, Padova, pp.146-167.
[16] F.VARELA E.Thompson and E.Rosch The Embodied Mind: Cognitive science and human experience MIT Press, Cambridge, 1991
[17] VARELA, F. (1995) The re-enchantment of the concrete, in: L.Steels and R.Brooks (Eds.), The Artificial Life route to Artificial Intelligence: Building Embodied, Situated Agents, Lawrence Erlbaum Assoc., New Haven, pp.11-20.
[17a] VARELA, F. (1998) Construction du réel et affect: expérience du sujet, performances et narrations, In: E.Goldbeter-Merinfeld (Ed.), Constructivisme et constructionisme social, De Boeack Université, Brussels, pp.277-282.
[17b] VARELA,F. (1986), Experimental epistemology: Past, present, and future, Rev.Internat.Systemique 1:209-225
[18] VARELA,F. and H.Maturana (1970), Time courses of excitation and inhibition in the vertebrate retina, Exp.Neurol. 26:53-59.
[19] Maturana, H. and F.VARELA (1982), Color-opponent responses in the avian geniculate: A study in the quail (Coturnix corturnix japonica), Brain Res. 247:227- 241.
[19a] VARELA,F., G.Marín, J.Letelier, and H.Maturana (1983), The neurophysiology of avian color vision, Arch.Biol.Med.Exp. 16:291-303.
[19b] Budnik,V., J.Mpodozis, F.VARELA, and H.Maturana (1984), Regional specialization of the quail retina: Ganglion cell density and oil droplet distribution, Neuroscien. Lett. 51:145-150.
[20] VARELA,F., A.Toro. E.R.John, and E.Schwartz (1981), Perceptual framing and cortical alpha rhythms, Neuropsychologia 19:675-686.
[20a] Gho,M. and F.VARELA (1989), Quantitative assesment of the dependency of the visual perceptual frame on the cortical alpha rhythm, J.Physiologie (Paris) 83:95-101
[21] VARELA,F. and W.Singer (1987), Neuronal dynamics in the visual corticothalamic pathway as revealed through binocular rivalry, Exp.Brain Res. 66:10- 20.
[22] Vaz, N. and F.VARELA (1978), Self and non-sense: An organism- centered approach to immunology, Medical Hypothesis 4:231-267.
[23] VARELA,F. (1986), Networks: Immune and otherwise. A letter to the editor, Ann.Inst.Pasteur / Immunol. 137 D:127- 129.
[24] VARELA,F., A.Coutinho, B.Dupire, and N.Vaz (1988), Cognitive networks: Immune, neural, and otherwise, in: A.Perelson (Ed.), Theoretical Immunology, Part II , (SFI Series on the Science of Complexity), Addison-Wesley, New Jersey, pp.359-375.
[24a] VARELA,F. V.Sánchez-Leighton, and A.Coutinho, (1988), Adaptive startegies gleaned from immune networks: Viability theory and Classifier systems, in: B.Goodwin and P.Saunders (Eds.), Theoretical Biology: Epigenetic and Evolutionary Order (A Waddington Memorial Conference), Edinburgh University Press, pp.112-123.
[24b] Huetz,F., F.Jacquemart, C.Peña-Rossi, F.VARELA, and A.Coutinho (1988) Auto-immunity: The moving boundaries between physiology and pathology, J.Autoimmunity 1:507-518.
[24c] Stewart,J., F.VARELA, and A.Coutinho (1989) The relationship between connectivity and tolerance as revealed by computer simulation of the immune network: some lessons for an understanding of autoimmunity J.Autoimm. 2 (Supplement):15-23
[24d] Stewart,J. and F.VARELA, (1989) Exploring the connectivity of the immune network Immunol.Reviews N°110, pp.37- 61.
[24e] VARELA,F. and A.Cohen (1989) Le corps evocateur: une relecture de l'immunité Nouvelle Revue de Psychanalyse N°40, Automne 1989, pp.193-213.
[24f] VARELA,F. and A.Coutinho, (1989) Immune Networks: Getting on to the real thing Res.Immunol. 140:837-845
[24g] VARELA,F.and J.Stewart, (1990) Dynamics of a class of immune networks. I. Global stability of idiotype interactions, J.Theoret Biol. 144:93-101

[24h] Stewart,J. and VARELA,F (1990) Dynamics of a class of immune networks. II. Oscillations of the humoral and cellular compartments, J.Theoret. Biol. 144:103- 115
[24i] Coutinho,A., A.Andersson, A.Sunsblad, I.Lundkvist, D.Holmberg, M.Arala-Chaves, J.Stewart, and F.VARELA (1990) Immune network dynamics, in: A.Osterhaus and F.Uytdehaag (Eds.) Idiotype Networks in Biology and Medicine, Elsevier Science Amsterdam- New York, pp.59-63.
[24j] Stewart, J. and F.VARELA (1991) Morphogenesis in shape space: Elementary meta-dynamics of immune networks, J.Theoret.Biol. 153:477-498
[25] Palacios,A., V.Bonnardel, and F.VARELA (1990) L'"autoshaping": méthode psychophysique pour la discrimination chromaitque chez les oiseaux, Compt.Rend.Acad.Sci.(Paris) 311:213-218
[25a] Palacios,A., H.Gionni, and F.VARELA (1990) Chromatic discrimination in pigeons after thalamic lesions of nuclei Rotundis (Rt) and geniculatus lateralis ventralis (GLv): A psychophysical study, Compte Rendus Acad.Sci (Paris). Ser.III 312:113-116.
[25b] Gionnai,H. Palacios,A., and F.VARELA (1991) Role of the nucleus geniculatus lateralis ventralis (GLv) in the optokinetic reflex: a lesion study in the pigeon Exp.Brain Res. 86:601-607
[25c] Thompson,E., A.Palacios and F.VARELA (1992) Ways of coloring: Comparative color vision as a case study in cognitive science, Beh.Brain Scien. 15:1-45
[26] Neuenschwander, S. and F.VARELA (1993) Visually triggered neuronal oscillations in birds: an autocorrelation study of tectal activity, Europ.J.Neuroscien. 5:870-881 .
[27] Müller,J., Neuenschwander, S., Pezard,L. Renault,B., Martinerie, J., and VARELA, F. (1996) Detecting non-linearities in neuro-electrical signals of synchronous local field potentials, Physica D 94: 65- 91.
[27a] Müller,J., Neuenschwander, S., Pezard,L. Renault, B., Martinerie, J., and VARELA, F. (1996) Detecting non-linearities in neuro-electrical signals of synchronous local field potentials, Physica D 94: 65- 91.
[27b] Pezard,L. Martinerie, J., Müller,J. VARELA, F. and B.Renault Multichannel measures of average and localized entropy, Physica D 96:344-354 (1996).
[28] M.Le van Quyen J.Martinerie and F.VARELA (1999) Spatio-temporal dynamics of epileptopgenic networks, In: Peter Grassberger and Klaus Lehnertz (Eds.), Chaos in the Brain, pp. 86-96, World Scientific, 1999.
[28a] M. Baulac, M.Le van Quyen J.Martinerie, S.Cleme,ceau, C.Adam and F.VARELA (1999) Pre-ictal changes of the EGG dynamics in epileptic patients: clinical and neurobiological implications, In: Peter Grassberger and Klaus Lehnertz (Eds.), Chaos in the Brain, pp.77-86, World Scientific, 1999.
[28b] Martinerie, J., Adam, C., Le Van Quyen, Baulac, M., Clemenceau, S., renault, B., and F.VARELA (1998) Epileptic seizures can be anticiaped by non-linear analysis. Nature Medicine 4(10), 1173-1176
[29] VARELA, F. (1995) Resonant Cell Assemblies: A new approach to cognitive functions and neuronal synchrony Biol.Research 28:81-95.
[30] VARELA,F. (1971), Self-consciousness: Adaptation or epiphenomenon?, Studium Generale 24:426-439.
[31] VARELA, F. (1990) On the conceptual skeleton of cognitive science in: Beobachter, Wilhem Fink Verlag, München, p.13-25
[31a] VARELA,F. (1991) Brain Time, Cognitive time in: J.Montangero and A.Tryphon (Eds.), Psychologie Génétique et Sciences Congnitive, 12th Piaget Symposium, Presses Univ. Geneve, pp.195-209
[32] VARELA, F. (1996) Neurophenomenology: A Methodological remedy to the hard problem, J. Consc. Studies 3:330-350.
[32a] VARELA, F. (1999) The specious present: The neurophenomenology of time consciousness, in: J.Petitot, F.J. VARELA, B.Pachoud and J.M.Roy (Eds.), Naturalizing Phenomenology, Stanford University Press, pp. 266-314.

[33] VARELA, F. (1999) Intimate distances: fragments for a phenomenology of organ transplantation, J. Consc. Studies 8:5-7.
[34] VARELA, F., Lachaux, J-P., Rodriguez, E. & Martinerie, J. (2201) The brainweb: phase synchronization and large-scale inetgration. Nature Reviews Neuroscience 2, 229-239
[35] VARELA,F., and J.Letelier (1988), Morphic resonance in silicon chips: An experimental test of the hypothesis of formative causation, Skeptical Inquirer 12:298-300.

An analysis of Francisco Varela works can be found in:
http://www.enolagaia.com/Varela.html
also you can visit his own web site:
http://web.ccr.jussieu.fr/varela

Diagnosis and Control for Multi-agent Systems Using Immune Networks

Yasuhiko Dote

Muroran Institute of Technology, Department of Computer Science and Systems Engineering, 27-1, Mizumoto-cho, Muroran 050-8585, Japan

Abstract. Soft computing (SC) is an evolving collection of methodologies, i.e., fuzzy, neuro, and evolutionary computing. Chaotic computing and immune systems are added later to enhance the soft computing capabilities. The fusion of SC components creates new functions i.e. flexible knowledge representation (symbol and pattern), acquisition and inference (tractability, machine intelligent quotient), and robust and low cost product. Among them immune systems are very suitable for control and diagnosis of multi-agent systems (large-scale and complex systems) that interact among human beings, environment and artificial objects corresponding to the usage of complex interactions among antibodies and antigens in the immune systems. This paper describes novel sensor fault diagnosis for an uninterruptible power supply control system and new decision making of a robot in a changeable environment using immune networks. Simulation studies show that the proposed methods are feasible and promising for control and diagnosis of large-scale and complex dynamical systems.

Keywords. Nonlinear systems, multi-agent robot, UPS control system, diagnosis, soft computing, immune network, cognitive and reactive distributed artificial intelligence, large-scale and complex systems.

1 Introduction

Firstly, this paper proposes a new method of sensor failure detection for a large-scale and complex control systems such as multi-UPS systems operated in parallel using immune networks.

Recently, systems have been increasing in scale and complexity. In such systems, once a certain sensor becomes faulty (abnormal) it often causes a fatal situation since the influence of the failed sensor propagates through the whole system. To prevent the above situation, fault diagnosis techniques have become more and more urgent. Such diagnosis of plant systems, however, are bringing the problems that faulty states are often detected at the propagated points rather than at the failure origins. Therefore, it is necessary to identify the faulty sensor exactly by integrating the data obtained from the equipped sensors.

To overcome these difficulties, cognitive distributed artificial intelligence (CDAI) approaches and reactive distributed artificial intelligence (RDAI) approaches are now available. Cause consequence tree (CCT) [1][2], signed digraph (SD) [3][4][5] and fuzzy decision tree (FDT) [6][7][8] approaches were reported for CDAI. On the other hand, immune network approaches [9][10][11] were proposed for RDAI. Immunity-based systems were well reviewed by Dasgupta *et al.*

[12]. Since the immune network is one of the soft computing methodologies [13], it is well understood to compare it with a neural network [14].

Reactivity is a behavior-based model of activity, as opposed to the symbol manipulation model used in planning. This leads to the notion of cognitive cost, *i.e.*, the complexity of the over architecture needed to achieve a task. Cognitive agents support a complex architecture, which means that their cognitive cost is high. Cognitive agents have internal representation of the world, which must be in enough with the world itself. The process of relating the internal representation and the world is considered as a complex task. On the other hand, reactive agents are simple, easy to understand and do not support internal representation of the world. Thus, their cognitive cost is low and tends to what is called cognitive economy, *i.e.,* the property of being able to perform even complex actions with simple architectures. Because of their complexity, cognitive agents are often considered as self-sufficient: they can work alone or with a few other agents. On the contrary, reactive agents need companionship cannot work isolated, they usually achieve their tasks in groups. Reactive agents are companionship. Reactive agents are situated: they do not take past events into account and cannot foresee the future. Their action is based on what happens now. They try to distinguish situations in the world and world indexes and react accordingly. Thus, reactive agents cannot be foreseen ahead. But, what can be considered as a weakness is one of their strengths because they do not have to revise their world model when perturbations change the world in an unexpected way. Robustness and fault tolerance are two of the main properties of reactive agent systems. A group of reactive agents can complete tasks even when one of them breaks down. The loss of one agent does not prohibit the completion of the whole task, because allocation of roles is achieved locally by perception of the environmental needs. Thus, reactive agent systems are considered as very flexible and adaptive [15].

Ishida [9] studied the mutual recognition feature of the immune network model [16] for fault diagnosis. In his implementation, fault tolerance was attained by mutual recognition of interconnected units in the studied plant, *i.e.,* system level recognition was achieved by unit level recognition. However, this approach is steady state analysis and is not applicable to dynamical systems.

Kayama *et al.* devised a sensor fault detection scheme for a complex and large-scale feedback system using immune networks using Kohonen feature maps and fuzzy inference. In their work the sensors were considered as antibodies connected with each other. Each sensor watched another sensor's output and informed its abnormality by fuzzy decision making from learning vector quantizations from other sensors. The scheme presented by Kayama *et al.* cannot be applied to dynamical systems [10].

Ishiguro *et al.* [11] applied the immune network model [16] to online fault-diagnosis of plant systems. To apply the immune network to plant fault diagnosis, following assumption were made.

1) The number of failure origins is one;
2) Failure states propagate through branches without exceptions; and
3) No feedback loop exists in the future propagation.

Therefore their method is not directly applicable to feedback control systems.

In this paper feedback systems are decomposed into decision tree structure that has only the forward passes with branches using fuzzy decision tree concept [6] based on knowledge obtained by simulations. The presented system uses a fast fuzzy neural network with general parameter (GP) learning [17]. Then, the sensors are assumed as antibodies in our immune network. Each antibody receives the stimulation and suppression from the adjacent antibodies and also from itself by calculating failure rate with the fast fuzzy neural network [17], and the dispassion. The density (concentration) of each antibody, called as failure origin ratio, is calculated by nonlinear differential equation driven by the received signals presented by Farmer *et al.* The sensor that shows the highest failure origin ratio is considered as failed sensor. Secondly, the same decision making process described above by calculating concentration rate of each antibody in the immune system, a surviving robot in the environment where predators, obstacles, and foods exist, is proposed [19].

This paper is organized as follows. Section II describes sensor fault diagnosis using immune networks. Decision making of a robot interacting changeable environment is given in Section III and Section IV concludes this paper.

2 Sensor fault diagnosis using immune networks

2.1 Sensor Fault Diagnosis for UPS Control System

Ishiguro *et al.* applied immune network in fault diagnosis in a plant [11], and used following assumptions.

- The number of failure origins is one,
- Failure states propagate through branches without exceptions, and
- Nofeedback loop exists in the future propagation.

The variables that reflect the state of the sensors, called as *failure origin ratios*, are normalized between 1 and 0. If the failure origin ratio of a certain sensor increases, the possibility of failure origin of the sensor increases or otherwise decreases. The failure origin ratio corresponds to the concentration of antibodies in the immune network and varies by its stimulation and suppression and that of adjacent sensors on both sides. The magnitude of the suppression and stimulation vary based on the failure origin ratio of the adjacent sensors. When the fast fuzzy neural network [18] detect the faulty state of the sensor i, it stimulates (increases) the failure origin ratio x_i. The failure origin ratio x_{i-1} of the adjacent sensor $i-1$ on source side is increased by stimulation of the sensor i. In this case the failure origin ratio x_{i+1} of the sensor $i+1$ is decreased by the suppression of the sensor i. On the other hand, the fast fuzzy neural network detects the fault-free state of sensor i and suppresses (decreases) the failure origin ratio x_i. From the above consideration, the failure origin ratio x_i is calculated as follows.

$$\frac{dx_i}{dt} = \{b(x_{i+1}) - d(x_{i-1}) + s_i - k\}x_i \qquad (1)$$

$$x_i = \frac{1}{1+\exp\{a(x_i - \alpha)\}} \qquad (2)$$

where k and α are positive constants, a is a negative constant, b and d are the stimulation and suppression from the adjacent sensors, s_i represent the stimulation and suppression calculated by the fast fuzzy neural network [17], and k denotes the dispassion factor to ensure the global stability of the immune network. The described system is illustrated in Figure 1.

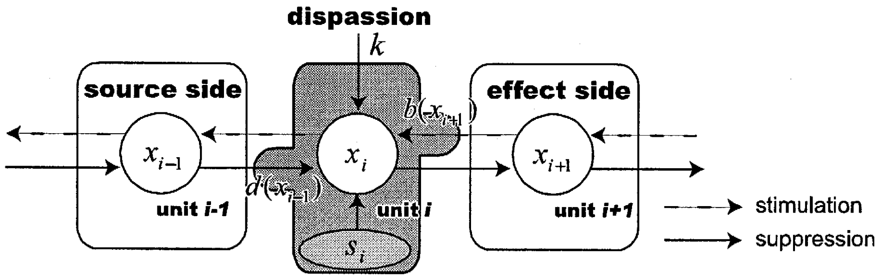

Figure 1. Concentration of antibody

In this paper, feedback systems are decomposed into decision tree structure which has only the forward passes with branches using fuzzy decision tree concept [6] based on knowledge obtained by simulations, as shown in Figure 2, which is automatically achieved by our developed fast fuzzy neural network with general parameter (GP) learning [17].

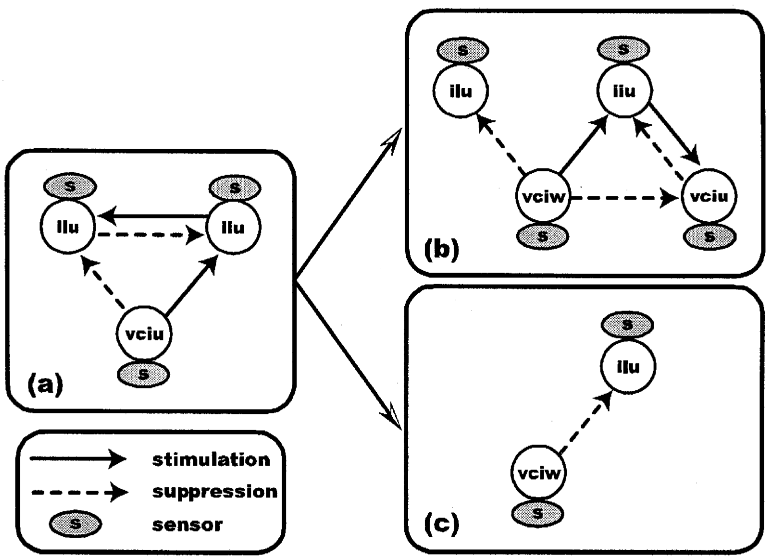

Figure 2. Decomposition of systems into tree structure

2.2 Simulation Results

The UPS system used in our research is shown in Figure 3. For simplicity, we consider four sensors, that is, an inverter line current (*iiu*), a load line current (*ilu*), a load *u*-phase voltage (*vciu*), and a load *w*-phase voltage (*vciw*).

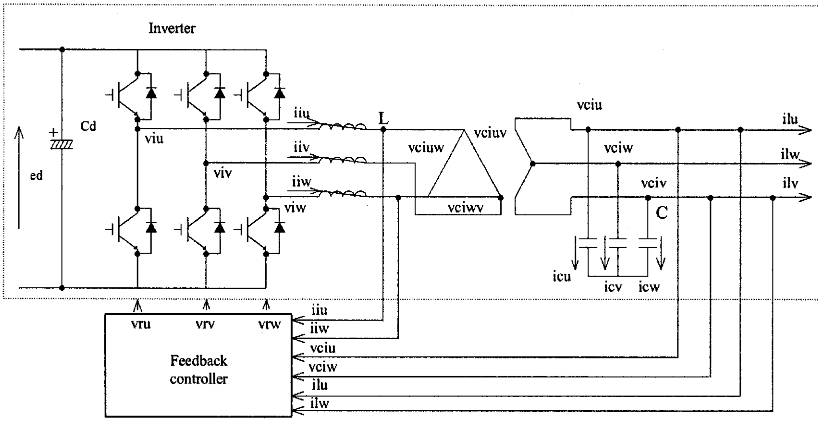

Figure 3. UPS control system

The configuration of the fast fuzzy neural network with GP learning is shown in Figure 4. The number of delay elements is set to 10. The number of Gaussian functions is 3 for *ilu* and *iiu* and is 2 for *vciw* and *vciu* . In Equation 1, s_i is 0 for normal state and is 0.4 for abnormal state. The centers of Gaussian functions were uniformly distributed over the whole range. The applied overlapping factor is 0.2.

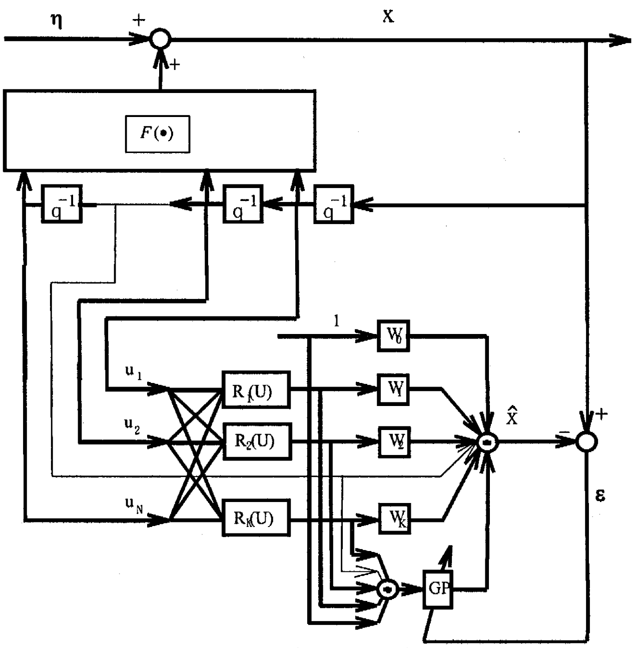

Figure 4. Fast fuzzy neural network

The stimulation and suppression (see Equation 1) are shown in Figure 5, where k is 0.1, a is 3.3, and α is 0.5. These parameters are empirically tuned. They will be self-tuned using evolutionary computation [18]. The result of sensor fault detection is shown in Figure 6.

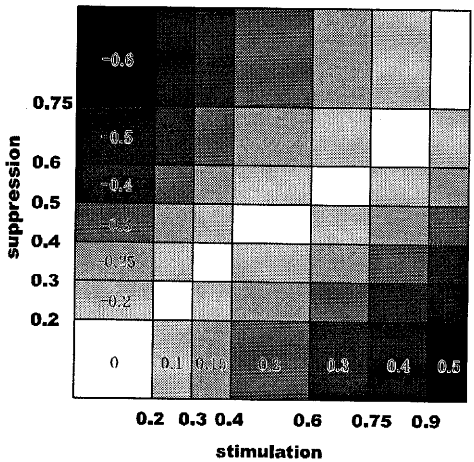

Figure 5. Ratio of stimulation and suppression

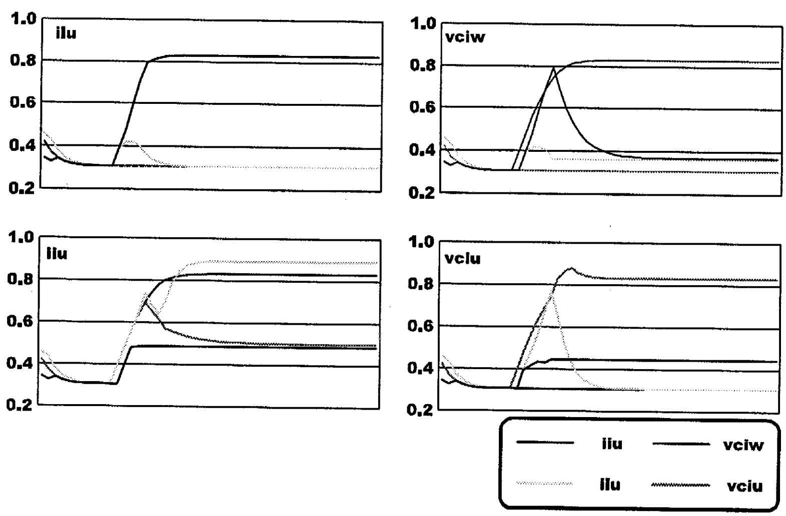

Figure 6. Result of sensor failure detection

3 Surviving robot in a changeable environment [19]

3.1 A surviving robot in a changeable environment using decision making by immune networks

An artificial decision making robot 'immunoid' by interactions among antibodies in artificial immune networks is considered. In this simulated environment, there are following three kinds of objects: (1) predator, (2) obstacles, and (3) food. It is assumed that pre-specified quantity of initial energy is given to the immunoid at the beginning of each simulation. For quantitative evaluation, the following assumptions are made.

1. If the immunoid moves, it consumes energy E_m
2. If the immunoid is captured by a predator, it consumes energy E_p
3. If the immunoid collides with an obstacle, it losses energy E_o
4. If the immunoid picks up food once, it obtains energy E_i

The predators attack the immunoid if they detect the immunoid within the prespecified detectable range. Therefore, in order to survive as long as possible, the immunoid must select a competence module (antidody) suitable for the current situation (antigen). The immunoid equipped with external and internal detectors. External detectors can sense eight directions as shown in Fig. 7. Each can detect the distance to the objects by three degrees, near, mid, and far. The internal detector senses the current energy level. The immunoid moves in the eight directions.
The detected current situation and prepared competence modules work as antigens and antibodies, respectively. To make a immunoid (antibody) select a suitable antibody against the current antigen, it is highly important how the antibodies are described. Moreover, it is noticed that the immunogical arbitration mechanism selects an antibody in bottom up manner by communicating among the antibodies. To realize the above requirements the description of antibodies are defined as follows. The identity of a specific antibody is generally determined by the structure of its paratope and idiotope.

A pair of precondition action to paratope, the number of disallowed antibodies and the degree of disallowance to idiotope are respectively assigned. In addition, the structure of paratope is divided into four portions: objects, direction, distance, and action.

For adequate selection of antibodies, one state variable called concentration is assigned to each antibody. The selection of antibodies is simply carried out in a winner-take all fashion. Namely, only one antibody is allowed to activate and act its corresponding its action to the world if its concentration surpasses the prespecified threshold. The concentration of the antibody is influenced by the stimulation and suppression from other antibodies, the stimulation from antigen, and the dissipation factor (i.e. natural death). The concentration of i-th antibody, which is denoted by a_i, is calculated by (3) and (4) gives the rate of interaction among antigens and antibodies.

$$dA_i(t)/dt = \left\{ \left(\alpha \sum_{j=1}^{N} m_{ji} a_j(t) / \sum_{j=1}^{N} m_{ji} \right) - \left(\alpha \sum_{k=1}^{N} m_{ik} a_k(t) / \sum_{k=1}^{N} m_{ik} \right) + \beta m_i - k_i \right\} a_i(t) \quad (3)$$

$$a_i(t+1) = 1/(1+\exp(0.5 - A_i(t)) \quad (4)$$

where N is the number of antibodies, and m_i denotes matching ratio between antibody i and antigen, m_{ij} denotes degree of disallowance of antibody j for antibody i. The first and second terms of right hand side denote the stimulation and suppression from other antibodies, respectively. The third term represents the stimulation from antigen, and the forth term the natural death.

3.2 Simulation results (All simulations are carried out in our laboratory).

100 simulations are carried out with
No. of predators= 5; No. of obstacles= 5; No. of foods= 10; and No. of antibodies= 91.

Average lifetime:
1. Immunoid's random walk: 313.14
2. Without interactions among antibodies: 564.86
3. With interactions among antibodies: 621.46

Table 1. No. of collides against predators and obstacles and obtaining foods

S. No.	Predators	Predators	Foods
1	19.91	1.84	0.54
2	9.04	5.92	4.27
3	7.84	5.23	5.02

The proposed method is clearly the best.

This approach is promising for decision-making in autonomous mobile robots (one of multi-agent robots). However, two disadvantages exist. One is how to cope with environmental changes. The other is how to design agents. It is required in the future to devise some real-time reinforcement learning. In these simulation studies, designs of agents are much improved.

4 Conclusion

Among soft computing methodologies immune networks are suitable to construct reactive distributed artificial intelligence. This paper proposed one of the promising methods for diagnosis and control of large-scale and complex systems (multi-agent systems) using immune networks and other soft computing methodologies.

Acknowledgement

The author is grateful to Professor A. Ishiguro, Nagoya University, Japan, for useful discussions and comments on immune networks and for providing pertinent materials to write this paper.

References

1. B. Frogner, *et al.* (1978) "Methodology, conceptual design, and capabilities of a disturbance analysis system," *SCI Report.*
2. L. Felkel (1979), "Analytical methods and performance evaluation of the STAR application in the Grafenehe in field nuclear power plant," *IAEE specialist meeting on NPPCI.*
3. T. Umeda, K. Kuriyama, E. O'shima, and H. Matsuyama (1990), "A graphical approach to cause and effect analysis of chemical processing systems," *Chemical Engineering Science,* vol. 35, pp. 2379-2388.
4. M. Iri, K. Aoki, E. O'shima, and H. Matsuyama (1980), "A graphical approach to the problem of locating the origin of the system failure," *Journal of the Operations Research Society of Japan,* vol. 23, no. 4, pp. 295-312.
5. M. Iri, K. Aoki, E. O'shima, and H. Matsuyama (1979), "An algorithm for diagnosis of system failures in the chemical process," *Computer & Chemical Engineering,* vol. 3, pp. 489-493.
6. D. Fuessel and R. Isermann (2000), "Hierarchical motor diagnosis utilizing structural knowledge and a self-learning neuro-fuzzy scheme," *IEEE Trans. on Industrial Electronics,* vol. 47, no. 5, pp. 1070-1077.
7. M. Kubat (1998), "Decision trees can initialize redial-basis function networks," *IEEE Trans. on Neural Networks,* vol. 9, no. 5, pp. 813-821.
8. E. C. C. Tsang, X. Z. Wang, and D. S. Yeung (2000), "Improving learning accuracy of fuzzy decision trees by hybrid neural networks," *IEEE Trans. on Fuzzy Systems,* vol. 8, no. 5, pp. 601-614.
9. Y. Ishida (1993), "An immune network model and its applications to process diagnosis," *Systems and Computers in Japan,* vol. 24, no. 6, pp. 38-45.
10. M. Kayama, Y. Sugita, Y. Morooka, and S. Fukuoka (1995), "Distributed diagnosis system combining the immune network and learning vector quantization," in *Proc. of the IEEE Int.l Conf. on Industrial Electronics*, Orland, FL, pp. 1531-1536.
11. A. Ishiguro, Y. Watanabe, and Y. Uchikawa (1994), "Fault diagnosis of plant systems using immune networks," in *Proc. of the IEEE Int. Conf. on Multisensor Fusion and Integration for Intelligent Systems, Las Vegas,* pp. 34-42.
12. D. Dasgupta and N. Attoh-Okine (1997), "Immunity-based systems: A Survey," *in Proc. of the IEEE SMC,* Orland, FL, pp. 369-374.
13. Y. Dote, S. J. Ovaska, T. Furuhashi, and Y. Suzuki. (Eds.) (2001), *The Special Issue on Industrial Innovation Using Soft Computing, Proceedings of the IEEE,* September.
14. D. Dasgupta (1999), "Artificial neural networks and artificial immune systems: Similarities and differences," in *Proc. of the IEEE SMC,* Orland, FL, pp. 873-878.
15. G. M. P. O' Hare and N. R. Jennings (Eds.) (1996), *Foundations of Distributed Artificial Intelligence,* New York, NY: John Wiley & Suns Inc.
16. N. K. Jerne (1974), *Towards a network theory of the immune system, annual immunology,* 125C, pp. 373-389.
17. D. F. Akhmetov, Y. Dote, and S. J. Ovaska (2001), "Fuzzy neural network with general parameter adaptation of nonlinear time series," *IEEE Trans. on Neural Networks,* vol. 16, no.1, pp. 148-152.

18. D. B. Fogel (2000), *Evolutionary Computation - Towards a New Philosophy of Machine Intelligence,* Piscataway, NJ, IEEE Press.
19. A. Ishiguro, Y. Shirai, T. Kondo, and Y. Uchikawa (1996), "Immunoid: An Architecture for behavior arbitration based on the immune networks," in *Proc. of the Int. Conf. on Intelligent Robotics and Systems,* Osaka, Japan, pp. 1730-1738.

http://www.springer.com/978-1-85233-539-7

Soft Computing and Industry
Recent Applications
Roy, R.; Koeppen, M.; Ovaska, S.; Furuhashi, T.;
Hoffmann, F. (Eds.)
2002, XXXV, 852 p. In 2 volumes, not available
separately., Hardcover
ISBN: 978-1-85233-539-7