Evolutionary Computation

Cover image interactively evolved by Emmanuel Cayla, *L'atelier des Fractales*, a start-up company of INRIA Projet FRACTALES ([illegible]).

Conference Review: Evolvable Hardware 2004

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The 2004 NASA/DoD Conference on Evolvable Hardware
Ricardo S. Zebulum, David Gwaltney, Gregory Hornby, Didier Keymeulen, Jason Lohn, Adrian Stoica, eds., Seattle, Washington, USA. IEEE Computer Society Press, 2004, ISBN 0-7695-2145-2, pp 352).

The 2004 annual NASA/DoD Conference on Evolvable Hardware (EH-2004) took place on June 24-26 2004, in Seattle, Washington, USA. The full list of sponsors, as well as most of the PowerPoint and PDF presentations of the conference can be found at http://ehw.jpl.nasa.gov/events/nasaeh04/presentations/index.html

The Conference

About 100 or so people were present at the conference, which was a bit up on earlier years (e.g., 70, 90, etc). There were 36 talks, a panel discussion, 12 posters, and at least 7 group posters. The first authors of papers, both invited and solicited, came from 13 different countries (US 13, UK 7, Germany 3, Mexico 3, Brazil 2, and 1 each from Czech Republic, Romania, Japan, Switzerland, Spain, Norway, France, Italy, or as is done increasingly lately, the EU. (European Union 14)).

From these sustained numbers, it is clear that the research field of evolvable hardware is now well established and is a stable component in other conferences such as Evolutionary Computation (EC), Artificial Intelligence (AI), Neural Networks (NNs), Evolutionary Systems (ES) etc. There is already a journal dealing with the field ("Genetic Programming and Evolvable Machines") and probably about 100 researchers in the specialty, spread worldwide over at least 16 countries (according to Adrian Thompson's list, to be found at http://www.cogs.susx.ac.uk/users/adrianth/EHWgroups.html, last updated, September 2003!). The UK is still the strongest nation in the world in EH with at least 16 groups, closely followed by the US with at least 14 groups, then Germany 5, Italy 3, 2 each for Canada, Japan, Norway, and 1 each for Denmark, Czech Republic, Israel, Holland, Switzerland, Romania, Mexico, Brazil, Australia.

The conference was spread over 3 days with 4 invited speakers who spoke an hour each, and 32 ordinary speakers of 25 minutes each. The first evening, a poster session (12 posters) included an additional group poster session (7 of them) that allowed the major EH research groups around the world to show off what they do.

The paper sessions were grouped into 7 categories: Evolution of Analog Systems (2 sessions), Evolution of Digital Systems (2 sessions), Revolutionary Technologies for Space (2 special sessions), Fault Tolerance and Survivability, Embryonics and

Bio-Inspired Architectures (2 sessions), Evolvability, From Biology to Robotics and Sensors, Multi Objective Optimization (special session), New Avenues for Evolvable Hardware.

New to this NASA/DoD EH conference were the two special sessions on "Revolutionary Technologies for Space", whose contents will be mentioned later in this report. What was also encouraging was the growth of embryonic (embryological electronics) thinking as reflected by the fact that there were two sessions on this topic at this conference. At earlier conferences, the topic merited only a single session. Obviously, a growing number of EH researchers are thinking that future electronics (especially at the molecular scale) will have to be "grown" the way a baby grows, embryogenically.

Highlights of the Conference

I now summarize briefly the contents of the four talks given by the invited speakers and then (based on a straw poll taken from a small handful of EH notables at the conference) summarize the talks given by a small selection of the "best" paper presentations, so as not to make this report any longer than it is.

Neville Marzwell (JPL, USA)
EH is vital to the needs of NASA

Neville Marzwell is manager of "Advanced Concepts and Technology Innovations" at JPL (Jet Propulsion Lab). He spoke about human and robotic technologies needed for NASA's vision of space exploration, especially since US President George W. Bush has committed the US to return people to the moon and to send people to Mars within the coming decades. He made the strong point that NASA will not be able to achieve its longer-term exploratory goals in space unless the research field of EH is able to solve some basic problems concerning electronic circuits such as self-repair, robustness, self assembly, etc. When spacecraft spend many years in space, they will inevitable fail for one reason or another (e.g., radiation damage). These failed circuits will need to self repair and re assemble themselves when faced with unexpected circumstances. Marzwell emphasized to his audience that in his opinion, what the EH research community is doing is of vital importance to NASA. One does wonder however whether he was telling his audience what it wanted to hear, or whether he truly believes it. Common sense says that the latter is probably true since NASA's spacecraft are very expensive and need to be robust if they are to undertake long voyages without failing.

Tetsuya Higuchi (NAIST, Japan)
EH is already succeeding well in Japanese industry

Professor Tetsuya Higuchi gave an invited talk at the NASA/DoD EH conferences every year, due to the extraordinary progress he makes each year in applying the principles of evolvable hardware to commercial applications in Japan. He is way ahead of anyone else in the world in terms of applying EH principles to commercial and profitable activities. He organized an EH workshop in 1996 and an EH conference in 2000 in Japan. At the 1996 conference he stated that "If EH is to survive, it will soon need to find its "killer ap(plication)". Thanks to Higuchi, killer aps have long since been found. He uses EH techniques to evolve the analog circuits of cellular phones, to increase their "yield" (i.e. the percentage of non faulty circuits). 100,000 such chips are made per month in Japan. He discussed several such applications, which I mention briefly here.

Higuchi's prosthetic hand that uses EH to adapt the circuit that maps human patients' electrical signals from their muscles to an artificial hand. Before this work, training a patient took months, now it takes 5 minutes to train the artificial hand to the muscle signals. He is currently trying to sell a cheap version of the artificial hand with a limited number of motions, costing less than $5000.

Data compression of 2D images, to aid on-demand publishing. He has managed to have his data compression technique become an international standard, which will be profitable for the Japanese printing industry.

EH based acceleration of clock speeds in digital circuits. By evolving the delays between components, he has managed to speed up clock speeds, lower power consumption, and decrease the surface area of his circuits.

The cellular phone example mentioned earlier.

EH based optical alignment of femto-second lasers.

Blind people point cameras on their head to items in a store. The image is sent to a volunteer who helps the blind choose products to buy. The EH system enables the camera to adjust its resolution and focus.

Deformable mirrors used to etch LSI circuits. The EH circuit corrects the phase of the laser beam doing the etching. A genetic algorithm is used to adjust 37 parts of the mirror.

Those of us who have been coming to EH conferences from the very first have become accustomed to seeing Higuchi report on his yearly EH commercial miracles. It is odd though, that EH is not better developed in Japan. There was only one other EH group from Japan at the conference.

John Koza (Stanford University, USA)
EH is now routinely humanly competitive and with high return

If anyone in the world is a rival to Higuchi in terms of relevance of EH to commerce, then it would have to be John Koza of Stanford University. Koza is the father of Genetic Programming (GP), a tree based representation approach to evolutionary computation, where crossover means swapping two sub trees. GP is now considered one of the four "dialects" of EAs (evolutionary algorithms), along with GAs (genetic algorithms), ES (evolution strategies), and EP (evolutionary programming). He is the author of 4 large books on his GP approach (see details at `http://www.genetic-programming.com/johnkoza.html`). Koza distributed a free CD at the conference explaining how his recent work is now routinely achieving human expert level design of analog circuits (e.g., filters, amplifiers, etc). His talk, entitled "Towards industrial strength automated design of analog circuits using genetic programming" showed amongst other things how Moore's Law (the doubling of electronic capacities of chips every 18 months or so) is now allowing GP techniques, as executed on his 1000 node PC cluster computer, to achieve humanly competitive analog circuit designs. To make his point, he took two examples of 21st century analog circuits designed by human experts, along with their specifications, and managed to evolve, GP style, comparable circuits in a reasonable time, and of comparable quality (fitness). He very persuasively stated that EH is rapidly coming of age. It will very soon be more than humanly competitive, and will have an impact on the world. That is what NASA is hoping for and is one of the reasons NASA/DoD sponsors these annual EH conferences.

Marc Schoenauer (INRIA (Institut National de Recherche en Informatique et en Automatique) Futurs, France)
Evolutionary algorithms that adapt

Marc Schoenauer is editor in chief of the most prestigious journal in the field of evolutionary computation, namely *Evolutionary Computation* (MIT Press). He gave a talk on techniques that EAs (evolutionary algorithms) can use to adjust automatically the values of the critical parameters used in an evolutionary run (e.g., the mutation rate, crossover rate etc). If EH researchers are to use EC techniques, they ought to use the best there are to accelerate their evolution times, even in hardware. Hence Schoenauer's talk was relevant. I was struck by the extraordinary comprehensiveness and competence of his talk, and others came up to him at the end of his talk with their memory sticks to get a copy of his slides. Since serious researchers of EAs usually need techniques to reduce their evolution times, a review of Schoenauer's talk should be useful to them.

Session Speaker Highlights

Special Sessions on Revolutionary Technologies for Space

Anthony Colozza, of OAI/Northland, spoke on *Solid State Aircraft Concept Overview*. He aimed to use new materials in his "rubber planes" that could flap their wings and glide in the atmospheres of other planets. He presented the slickest video I've ever seen at a conference, and I've been to a LOT of conferences. I suspect it was produced by the same team that made the famous Mars rovers video that featured on the NASA, Science, and Discovery channels on US television.

Marc Millis spoke of *Prospects for Breakthrough Propulsion from Physics*, the aim being to use "fringey" physics effects (such as the Casimir effect, vacuum energy, gravity shielding, electro-gravity effects, etc) to cause revolutionary breakthroughs in future space travel. He made the point that humanity will never reach the stars if we are confined to present day techniques of space propulsion (chemical, ion, solar sail, etc). Something new and radical will be needed, but what? He talked about the studies he had managed as project director, some being dismissed as unphysical, others possible, and others undecided.

Just what the relevance of these talks was to EH was highly questionable, but they were fascinating. I suppose, stretching a point, that one could claim that "hardware" can be broadly interpreted. It need not be confined to electronic circuits. But then how would one evolve a new type of hardware based on truly fringey physics? This would be a topic for future research.

Andy Tyrrell (University of York, UK)

Andy Tyrrell is one of the most productive and respected members of the EH research community, and arguably leads the planet's most active EH research group. Each NASA/DoD EH conference usually has several papers from members of his group. Julian Miller, one of the field's visionaries (more on him later) recently joined his group. Tyrrell spoke on "An Endocrinologic-Inspired Hardware Implementation of a Multi-cellular System" and I found it truly innovative. Since this is the 6th such

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NASA/DoD EH conference, the topics of the field are becoming increasingly settled. Most of the talks at this conference were situated within a relatively set framework e.g., evolution of analog and digital circuits, considerations of robustness, embryogenesis, fault tolerance, etc. So it was refreshing to hear a wholly new idea. Tyrrell devised a spherical concoction consisting of electronic cells that communicated locally with their neighbors, and "diffused" signals, in a way analogous to the endocrine system in biology. He used this system to show that if one cell "dies" the system still functions. He got it to perform a 2-bit multiplication, not a particularly edifying example compared to what Koza is evolving, but nevertheless, qualitatively new and therefore noteworthy.

Hugo de Garis (Utah State University, USA)

de Garis spoke of the impact "Avogadro Machines" will have on EH in 15 years time. This was one of two talks in the "New Avenues for Evolvable Hardware" session. An Avogadro Machine is one consisting of an Avogadro's number of components, i.e. a trillion trillion, which will be possible as Moore's Law takes electronic circuits down to molecular scale by 2020. Such circuits will have to be reversible, so as not to explode with the heat generated by today's irreversible circuits. Such irreversible circuits cannot be used when electronic densities increase to molecular scales. They will have to be robust, as the "yield" of such circuits will become effectively zero by 2020. Since molecular circuits will probably switch their state in femto seconds, the current paradigm of "fetch-execute" computing, with a centralized computer program memory, will die, being replaced by a "crystalline computing" approach, in which pieces of the program are distributed throughout the computational medium. Light travels a foot (30 cms) in a nanosecond, but only a distance of about 300 atoms in a femtosecond, so there is no time to fetch an instruction from a distant central memory. So each cell in the medium executes its own local instructions, and the overall solution "emerges" as all the cells interact locally. To achieve a desired functionality, EH will probably be critical. An Avogadro circuit will also have to self assemble embryologically. How? To program a 3D space that will be possible with reversible computing (no heat generated), signals will probably have to be sent in from 2 sides of the 3D "cube". When and where they collide will cause a bit to be set[1].

Simon Harding (University of York, UK)

Simon Harding is a grad student in Andy Tyrrell's team at York, being supervised by Julian Miller. He spoke of the results he had obtained in evolving a tone discriminator in a liquid crystal system. Miller is well known in the EH community for advocating the use of alternatives to electronic circuits as a hardware medium for evolution. Harding showed that he could evolve a "tone detector" similar to the famous experiment of Adrian Thompson of Sussex University, UK, who made himself famous by being the first person in the world to evolve an electronic circuit "intrinsically" (i.e. using an actual circuit to perform the evolution, not doing it "extrinsically", i.e. in software simulation, outside the circuit. "Intrinsic and extrinsic EH" are terms I coined in 1992 when I was postdocing in Japan, working in the same room with Higuchi.) Thompson and Harding evolved detectors that would give a high voltage output when the input signal was 10 KHz, and a low voltage output when the input signal was 1 KHz. Harding got his liquid crystal to evolve, and in far fewer generations than Thompson took, but Harding confessed he didn't know by what means his system evolved. Miller

[1] Several people came up to me after this talk, saying they enjoyed it very much, so I feel justified in including it here as a highlight, and that I'm not just abusing my power as the writer of this report.

says that this type of evolution is "exploratory", i.e. looking for new physical phenomena that the evolution can exploit. As an aside, Thompson has not been present at the last few EH conferences, which is odd, because he used to be lionized for his famous achievement. What happened to him?

General Remarks

Looking back over the conference, what sticks in my mind?

I think two things. One is that the field seems to be stabilizing in the sense that the topics it deals with seem to pop up year after year. This is to be expected with the growth of any new research field. Another is that the topic of embryonics (embryological electronics) has become a stable element of EH. There were two whole sessions on this topic at the 2004 conference. This I consider to be a most important development. As electronics reduces to molecular scale, it is likely that circuits will have to self assemble in their trillions of trillions, i.e. they will have to "grow" in an embryological way, like a baby.

I feel the rise of embryonics is inevitable, since the broad approach seems so applicable to the "Avogadro" systems (systems having a trillion trillion components) humanity will possess within 20 years, as Moore's Law continues its relentless doubling of electronic capacities. We need only look to biology to see how successful it has been in building its creatures, using a sequential gene switching (embryonic) approach. As electronic circuitry shrinks, both biological and electronic components end up at the same molecular size. I predict a very healthy and productive marriage between biology and electronics over the next few decades. The biologists will be able to test their theories in "electronic biology" based systems, and the electronics people will be inspired by biological ideas for their system building.

I am glad to be able to also report that Andy Tyrrell and Gary Greenwood have teamed up and are currently writing an Evolvable Hardware text that they say will be on the shelves in 2005. With a quality textbook to its name, the field of Evolvable Hardware should really take off, the way the field of Genetic Algorithms took off after the appearance of David Goldberg's classic text in 1989.

Finally, and this is the most important piece of information in this report, most talks of this conference will be available at the following URL: [illegible]