The 2002 annual NASA/DoD Conference on Evolvable Hardware (EH-2002) took place on July 15-18 2002, in Alexandria, Virginia, USA, sponsored by the National Aeronautics and Space Administration (NASA) and the Defense Advanced Research Projects Agency (DARPA), and supported by the Center for Integrated Space Microsystems, JPL, Life Detection Science and Technology JPL, NASA Ames Information Sciences and Technology Directorate, NASA Goddard Space Flight Center.

The Conference

About 80 or so people registered for the conference from 13 countries (US 54, UK 12, Germany 4, Norway 2, Brazil 2, Japan 2, and 1 each from Nigeria, France, Russia, Switzerland, Belgium, Ukraine, Canada). This number was a bit down relative to the similar Evolvable Hardware workshops of 2001 (about 90), 2000 (about 90) and 1999 (about 130). Despite the lower numbers, it is clear that the research field of evolvable hardware is now better established and is a stable component in other conferences such as Evolutionary Computation (EC), Artificial Intelligence (AI), Neural Networks (NNs), 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 15 countries (according to Adrian Thompson’s list, to be found at <http://www.cogs.sus.ac.uk/users/adrianth/EHW_groups.html>, last updated, April 2002). 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, Holland, Switzerland, Romania, Mexico, Brazil, Australia.

The conference was spread over 4 days (up from the 3 day workshops of previous years), with 7 plenary speakers (Brian Snow, Rich Katz, Tetsuya Higuchi, Subhasish Mitra, Adrian Stoica, Peter Athanas and Xin Yao), and 21 single session speaker slots. The first day kicked off with 4 plenary speakers, and the afternoon was devoted to an innovative "group poster" session allowing the major EH research groups in the world to show off what they do. 12 such groups took the opportunity.

The ordinary speaker sessions were grouped into the following 7 categories:

1) Evolution of Digital Systems
2) Evolution of Analog Systems
3) Evolution of Controllers
4) Real World Applications
5) New Avenues for Evolvable Hardware
6) Cellular Automata

7) Embryonics and Bio-Inspired Architectures

The last 3 categories were new relative to previous workshops and reflect the ongoing development and thinking of the field. It was particularly encouraging to see embryonic (embryological electronics) thinking being taken up by a large enough group of researchers that it merited its own session topic (4 speakers).

Highlights of the Conference

I will cover some of the invited speakers and then (based on a straw poll taken from a small handful of EH notables at the conference) a small selection of the best session speakers, so as not to make this report any longer than it is.

1) Brian Snow (NSA, USA) - "Please help us!"

When I first arrived at the conference and looked at the attendants list, I was amazed to find that one of the plenary speakers was from the NSA (America's "National Security Agency"). The fact that the organizers of the conference were able to attract someone from (some say) the most powerful and influential agency in the US, was impressive. Snow is the technical director of the Information Assurance Directorate of the NSA. He asked for help from the EH research community on quality assurance of software and hardware systems, remarking that current commercial products were simply inadequate. For example, today, more than $100M in law suits in the US are filed against software vendors, because their products have failed to do what the vendors claimed they should do, or failed in some other important respects. He would like to see the EH community contribute towards the creation of 3rd party testing of commercial products for the US government. I guess the fact that not only NASA and Darpa are interested in EH, but now the NSA as well, augurs well for the future of the field (although the attendance numbers show the field is not in rapid growth, as mentioned above).

2) Tetsuya Higuchi (NAIST, Japan) - "We have our killer ap(plication)"

Higuchi regularly gives a plenary talk at EH conferences, due to the extraordinary progress he has made in applying the principles of evolvable hardware to commercial applications. He organized EH conferences in 1996 and 2000. In 1996 he stated that "If EH is to survive, it will soon need to find its "killer ap(plication)". Thanks to Higuchi, that killer ap has 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 7 such applications, which I mention briefly here. 1) His 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 took months, now it takes 5 minutes to train the artificial hand to the muscle signals. 2) Data compression of 2D images, to aid on-demand publishing. 3) EH based acceleration of clock speeds in digital circuits. 4) The cellular phone example mentioned earlier. 5) EH based optical alignment of femto-second lasers. 6) 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. 7) 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.

Session Speaker Highlights

1) Julian Miller - "Looking Beyond the Silicon Box"

When I was conducting my straw poll on whom to select as highlighted session speakers, quite a few people said they enjoyed Julian Miller’s (Birmingham Univ, UK) talk the most. Miller’s principle point (according to my notes) was that "silicon cannot do what we want it to do", that EH "should consider a wider range of technologies, not just silicon". Miller likes Adrian Thompson’s work. Thompson was the first to perform what I call "intrinsic" (in-chip) evolution. Thompson’s point was that the evolution should take advantage of the properties inherent in the very physics of the medium being evolved. Miller is a strong advocate of this viewpoint. At present he feels the EH field is stuck in a rut by imposing evolution on existing hardware, i.e. conventional digital circuitry. He would like to see universities do more blue-skies research into other media that have rich physics that can be evolved. He said (almost as a slogan), "Don’t understand intrinsic EH, just use it!" He stated, "The genome doesn’t specify how to make a cell, let alone the organism. Once the components are made, they obey their own physics". As suggestions for new evolvable media for EH, he listed - "mesoscopic systems, such as liquid crystals, conducting and electroactive polymers, voltage controlled colloids, irradiated silicon, Langmuir-Blodgett films, molecular monolayers, etc".

He raised some conceptual issues that will arise when nanotechnology arrives. For example, he said "Nanotech will not solve our problems! How to get millions of molecules to arrange themselves into exact arrangements? How to test the billion molecule electronic circuit? Nanoscale computing is amorphous! What is the price to be paid for programmability?" He suggested the creation of FPMAs (Field Programmable Matter Arrays) where the matter would be chemical substrates that relax back to their former state when the voltage is removed. These FPMAs could have erasable wires that grow and be placed under evolutionary control. The down side would be that each array would be unique, i.e. individualized, which would not be good for mass production techniques.

2) Nick Macias - "A Self-Assembling and Autonomous Fault Handling Circuit"

Nick Macias (Cell Matrix Corp, VA, USA) stated that as nanotech approaches, there will be so many components in systems (i.e. "Avogadro Machines", with a trillion trillion components) that it will be impossible to build circuits that are perfect, i.e. faultless. So the circuit will need to reconfigure itself. Such a circuit will have to place-and-route and perform fault testing in the circuit itself. This was his starting set of principles.

To achieve this goal, Macias sliced up a 2D grid of his basic ("Macias") cells into "supercells", consisting of 270 by 270 Macias cells (=72900) which his software simulated, with a maximum number of 16*16=256 supercells. The detailed structure of these supercells was not clear from his paper. He states that these supercells are capable of fault detection, fault isolation, configuration of new supercells, determination of inter-cell wiring paths, and implementation of the
final target circuit. Using a fixed "configuration string", the system can self-
configure, regardless of the location of the faults of the system. The algorithm
he employs is as follows: a) create an abstract description of the target
circuit, without reference to particular elements within the reconfigurable
device, b) analyze the reconfigurable device’s hardware, noting the locations of
faulty areas, and c) configure the device to implement the target circuit, based
on the abstract circuit description, while avoiding the faulty device regions
identified in step b).

Macias gave a animated Power Point presentation of his supercells as they
tested for faults in neighboring cells. If they were found to be fault free, then
identical offspring supercells were grown, thus tiling the whole space, going
around the faults. The supercells themselves were then used to configure
themselves into the target circuit, using the configuring string that was passed
from supercell to supercell. The details as to how this was done were not
particularly clear in the half hour Macias had to describe years of work and
thinking.

3) Martin Lukac (Portland State Univ) - "Quantum Circuit Evolution"

Martin Lukac gave a talk on the evolution of quantum circuits for quantum
computing, a hot new topic in computer science and applied physics. There have
been a growing number of researchers giving quantum computing type talks in
evolutionary computation conferences over the past few years. Lukac used a
conventional (classical, not quantum) genetic algorithm (GA) to apply quantum
operators (sequential matrix operators on quantum-bit (qubit) vectors) to
produce desired quantum states. To those in the audience who understood quantum
mechanics (a prerequisite for understanding quantum computing) the talk was a
highlight of the conference, but for those who hadn’t a clue what a Hilbert
Space or a commutator bracket was, the talk was gobbledygook.

Since quantum computing has the potential to vastly outstrip classical
computing, any self respecting computer scientist ought to be studying quantum
mechanics and quantum computing to stay on top of things.

I asked Lukac if he has considered the idea of using a quantum approach to do
everything, i.e. measuring the fitness values quantum mechanically as well,
instead of only applying quantum operators using a classical GA. He hadn’t, but
was excited by the idea. Quantum computing will surely have an impact on EH (and
everything else) in the coming years.

Panel Discussions

Two panel discussions took place during the conference. The first was in the
afternoon of the 2nd day, and the second at the very end of the 4th day, after
all the session talks were done. I can’t say I was particularly inspired by the
discussions. In my notes (that I was busily scribbling away at, all through the
conference with the intention of writing up this report, the 3rd time I have
done this) the following ideas and remarks caught my attention.

a) There is a need for EH benchmarks, so that different EH research groups can
compare their results. Perhaps a working group should be set up to establish
these.
b) EH researchers should be attempting to evolve more complex circuits than those undertaken so far.

c) The nanotechnology/EH link was mentioned. Some panel members thought that EH would play a vital role in coping with the enormous complexities of nanotechnology, and that nanotech structures could be evolved.

d) The idea of a "fitness definition compiler" was floated, namely using programmable hardware to compile fitness definitions to be applied to evolving circuits to guide their evolution. I liked that idea.

**General Remarks**

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

I think two major things. One was the increased interest in embryonics. Two whole sessions were devoted to that topic. I feel its rise 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 other highlight, IMHO, was Miller’s inspirational talk on the longer-term future of Evolvable Hardware. At the present time we seem stuck in the silicon electronics based paradigm, but there could be many other substrates that could prove to be evolvable in the future.