

EvoNews

Newsletter of EvoNet – The Network of Excellence in Evolutionary Computing

<http://www.dcs.napier.ac.uk/evonet/>

Issue 11, Summer 1999

Evolvable objects

A single global EC-programming toolkit that allows rapid prototyping and repeatable experiments, and runs on any platform? It sounds like the evolutionary holy grail, but it's the goal of three research groups at the Universities of Granada and Leiden, and the École Polytechnique.

The three teams aim to develop an extensive library containing ready-to-use implementations of the four main types of evolutionary algorithm, a collection of cross-over, mutation and selection mechanisms, and an extensive set of monitoring and statistical tools that will allow the user to analyse algorithm progress during or after a run.

The toolkit will build on the already substantial achievement of EO, a templates-based, ANSI-C++ compliant evolutionary computation library developed by the Geneura team at Granada University.

'EO is flexible, allowing any kind of current evolutionary algorithm, and then some,' says J. J. Merelo, who heads the Geneura team. 'It's easy to program and extend, and it runs on both Windows and Linux/Unix platforms, so it's portable.'

He believes the toolkit will benefit the whole evolutionary computing community. 'It will be available for anyone to use – from researchers who want to create their own evolving objects (that's what EO stands for), their own operators or reproduction strategies, to people in industry who want to write their own user interface and fit-

ness function, while using tried and tested algorithms.'

So that researchers can run experiments on 'standard' benchmarks, the toolkit will also include a collection of commonly used problem instances, as well as general problem instance generators.

Benchmark problems

'To properly evaluate a method, you need to show it works,' explains Gusz Eiben who heads the Leiden University team. 'So you apply it to problem instances – preferably interesting (hard) problem instances, and a lot of them. There are collections of benchmark problems, but you can also use a generator that produces examples of the problem class you're interested in, more or less randomly and, very important, tunably. So, for example, if you're interested in the travelling salesman problem, the instances can be parameterised by, for example, number or distribution of cities. Then you can try an algorithm on different categories of the problem and come to some general conclusions about its performance, like it works only on problems of less than a certain size, or if the graph is not densely connected.'

It will be available for anyone – from researchers who want to create their own operators or reproduction strategies, to people in industry who want to write their own user interface and fitness function, while using tried and tested algorithms.

Not only will the toolkit be free, it will be supplied with a licence that allows users to modify and distribute it. As a result, programs written using it should also be freely available so that anybody can download and run them.

Repeatable

For Eiben, one of the key benefits is that experimental studies carried out using the library will be fully reproducible.

'Reproducibility of results is a major requirement in science, but in practice it is hard to achieve,' he says. 'While everybody uses his or her own EA, reimplementing and rerunning will almost never produce the same result. So a standard experimental tool, where only the novel ideas need to be added and tested, represents an enormous improvement on current practice.'

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MOLE at City University

Based at the Department of Computing, City University, London, the Machine Optimisation and Learning group (MOLE) conducts strategic and applied research in neural networks, data mining and modern optimisation methods – particularly evolutionary computation. The group aims ultimately to shape these technologies to fit the demands of problems in industry, engineering and commerce.

A distinctive aspect of the group's research is its work on the principled design of evolutionary and neighbourhood search optimisers.

'Given the success of GAs in many real-world problems it is surprising that their design is something of an ad hoc process, especially in the light of the No-Free-Lunch theorems which show that domain knowledge is required for a successful optimiser,' explains researcher Andrew Tuson. 'What has not been addressed so far in the EC or wider optimisation community is how this should be done.'

Design methodology

In order to secure the long-term future of EC, Tuson believes it is important to devise a principled, rigorous, design methodology so that EC practitioners have clear

guidance in producing GA systems whose behaviour can be justified. With this in mind, he has proposed and is developing a framework that EC practitioners can use to structure their design of GA-solutions to real world problems in a rigorous manner. His approach is drawn from modern Knowledge Based Systems, in that a GA is viewed as a system which embodies the designer's knowledge of the problem in a direct and formal manner, where accuracy of this knowledge determines the GA's performance.

'The types of knowledge that a GA can exploit have been formalised in such a way that operators can be derived using Nick Radcliffe's Forma Analysis,' says Tuson. This research forms the main part of his PhD and has since received support from the EPSRC and DERA.

Introns

Another area of strategic research for the MOLE group focuses on how to deal with the appearance of introns or non-functional code in genetic programming.

'The presence of introns leads to an increase in program size, known as code bloat,' says researcher Kim Harries. 'This makes the resulting programs hard to understand, and can often stop GP working at all!'

Harries and MOLE group convenor Peter Smith have investigated alternative selection schemes and operators for GP. These, coupled with a taxonomy of different types and causes of introns, have led to the formulation of a number of strategies that can counteract much of the code growth and thus allow GP to be applied to problems where code growth prevented a good solution being obtained.

Details of their research can be found in their recent paper in *Evolutionary Computation* (volume 6, issue 4).

Applications

The aim of the group's basic research is to support the design of effective EC applications – of which MOLE can boast a number of notable examples.

Two of the group's members, Helen Gray and Peter Smith, are currently working on the application of GP to the analysis of magnetic resonance imaging (MRI) data. Rather than adopting an image processing approach, their work exploits the fact that hydrogen atoms emit a signal at a different frequency in different environments – a phenomenon known as 'chemical shift'. GP was trained with MRI chemical shift data for brain tumours and was able to find an effective solution that successfully located the problem cases.

Nuclear Magnetic Resonance (NMR) can be used in two ways: either an image of the area examined can be produced with different tissues showing as different intensities on a greyscale, or a spectrum showing the concentration of different metabolites in the region of interest can be produced. This spectrum can be digitised.

A dataset of spectra from human brain tumour extracts ($n = 75$) was used. Principal component analysis was applied to the

Evolvable objects

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'A researcher will need only to implement the novel parts and plug it into the toolkit. To reproduce their published results, one need only download that small novel part, plug it into a copy of the toolkit and run it.'

'We plan to set up a repository of objects created for EO and link it to the EvoNet repository of papers,' adds Merelo, 'So that people can jump directly from the paper repository to the programs that were created for that paper. This makes results not only reproducible, but also reusable.'

For many, though, the chief incentive to use the toolkit will be that it facili-

tates rapid prototyping. Because it will be downloadable, ready to run, users need only add their own fitness function and redefine some values.

'This,' says Eiben, 'will make it an ideal resource not only for researchers, but also for practitioners who want fast feedback on the applicability of evolutionary computing to their problems.'

For more information about the toolkit, or if you would like to be involved in the development project, contact:

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digitised spectra to reduce the number of variables from 400 to 20, and GP was used to classify the tumours into meningiomas and non-meningiomas. Results were equivalent to those obtained using a neural network with up to 97% classified correctly.

According to Helen Gray, one of the most striking features of the analysis was that good classification (80-85% correct) could be obtained using very simple individuals (functions).

'Because of the transparency of GP results it was possible to refer them directly to metabolites to give a biochemical interpretation of results,' she comments. 'This may help in the choice of NMR spectroscopy methods for non-invasive studies in patients.'

The results of this research were published last year in 'Genetic programming for classification and feature selection: analysis of 1H

nuclear magnetic resonance spectra from human brain tumour biopsies', *NMR in Biomedicine*, 11.

Gray is currently investigating why GP can classify well into two classes but seems unable to classify into multiple classes with the same ease. The dataset at present being used consists of liver and kidney tissue and two types of hepatomas.

'The task involves trying to find a way of doing multiple class classification or to find a reason why it is not possible,' says Gray.

'I am looking at the GP operators – mutation, crossover and reproduction – and the fitness function, as well as the data representation. There will be some investigation of the landscape of such a type of problem.'

Resource redistribution

As part of his PhD research, Andrew Tuson has addressed the problem of resource redistribution in the Third World.

'The problem in many aid programmes is that resources are not in the right place,' he comments. 'Some areas have shortages

and others large surpluses. A system was needed that could suggest a high-quality redistribution plan that reduces these shortages as far as possible, subject to constraints on plan feasibility.'

Although this could be viewed as a non-linear multiple resource transportation problem, Tuson's sample problem involved over 200 sites and 12 resources, and was far larger than conventional operational research methods (or even Michaelwicz's GA formulation) could handle. Consequently, Tuson opted for an 'indirect' encoding, utilising a combination of evolutionary/neighbourhood search and a 'plan

builder' that produced a feasible shipment plan was used with good results.

The system was evaluated on data representative of that expected in the real world. Scenarios were devised, courtesy of Richard Wheeler (now at StarLab in Brussels), based on the

World Health Organisation's TB programme in mainland China.

Together with Nick Altmann and Joel Malard, Tuson has also investigated the optimisation of code for High Performance Computing (HPC) applications.

A GA was used to optimise the allocation of arrays in memory so as to minimise cache misses. On program codes for real-world HPC applications, such as ecological modelling, the GA was able to effect speed improvements of the order of 2-3 times that of standard unoptimised code, with cache hit rates of over 90%.

For further information about the MOLE group's research and publications, please contact:

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About EvoNet

Evolutionary computing can be used to 'breed' progressively better solutions to the complex logistical problems faced by industry and commerce. The European Commission has recognised it as one of the important new technologies of our time, and has funded a Network of Excellence in Evolutionary Computing, EvoNet, to assist in the transfer of knowledge and expertise to the manufacturing and service sectors.

As well as academic institutions and research groups, members of EvoNet include some of the key players in European industry – British Aerospace, Daimler-Benz, Dassault Aviation, Hewlett Packard Laboratories, Institut Francais du Petrole, Rolls Royce and Siemens.

Membership of EvoNet is free and provides easy access to information about:

- training, conferences, workshops
- commercial applications of evolutionary computing techniques
- consultancy
- where to get advice and assistance
- collaborative research opportunities.

Companies, academic institutions, or interested individuals wishing to join, should contact:

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SiGis: an integrated approach

Working under the supervision of Prof. Dr Horst Clausen and Prof. Dr Jochen Pfalzgraf, the Salzburg Interest Group on Integrated Systems (siGis) at the University of Salzburg aims to combine theoretical ideas from different areas and blend them in practical applications. The group was established in the spring of 1994, and after a phase of orientation in the field of artificial neural networks (ANNs), evolutionary computation and robotics, three faculty members designed and implemented the netGEN system.

As often happens, the initial motivation for constructing this system was based on a series of accidents. One faculty member, Reinhold Huber, ran into so much difficulty designing a reliable ANN for satellite image classification that he complained to his colleagues – fortuitously, he spoke to Roland Schwaiger, who happened to be researching the topology design of ANNs, and Helmut Mayer, who was working on biologically motivated extensions to GAs. From this chance juxtaposition of ideas an evolutionary system to design problem-adapted artificial neural network architectures was born.

The system, known as **netGEN**, uses genetic algorithms to evolve generalised multi-layer perceptrons.

‘The ANN chromosome structure is based on a direct encoding method, including neuron markers, and represents the network’s architecture,’ explains Helmut Mayer. Besides well-known ANN test problems and benchmarks, the group has used **netGEN** to investigate the problem of classifying land-use/cover from remotely sensed imagery (mainly using multi-spectral Landsat Thematic Mapper data). Moreover, the applicability of evolved ANNs to the industrial problem of predicting product quality from manufacturing data has been studied in co-operation with two Austrian companies.

Unfortunately, only one of these studies is in the public domain – this was a co-operative project with VOEST-AL-

pine-Industrieanlagenbau, Linz, in which **netGEN** was used to predict steel quality from production data. Although, the results obtained were comparable with more conventional approaches, managers at the plant were hesitant to trust a system based on evolutionary processes. Moreover, they were looking for a system that would not only generate good prediction results, but would also extract problem knowledge about the relevant production features. Given the potential to evolve input neurons (= features), this is something the system has the capacity to provide. However, a larger-scale study would be required to investigate this further.

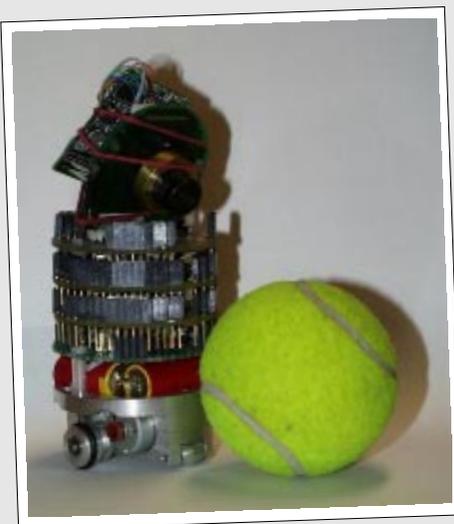
Another potential **netGEN** application arose out of a co-operation with Professor Skrabal at the Department of Internal Medicine at the University of Graz. As a result of modern automated procedures for glucose measurement, there is now a huge amount of data about diabetic patients. **netGEN** was used to predict glucose levels in diabetics based on their previous and current states (for example, nutritional levels, insulin doses, activities).

‘First results have been promising,’ Mayer reports, ‘And we will have talks this summer about an official interdisciplinary project.’

Training data sets

ANN research has tended to concentrate on investigating network types, network topologies, various types of neurons and training algorithms. ‘There has been comparatively little research into training data sets,’ says Mayer. ‘Given the ever-increasing amount of training data available for many domains, this is a pressing problem, particularly when it comes to selecting data sets from which an ANN can draw most information. In fact, for most real world applications even human experts familiar with the problem cannot provide accurate guidelines for the construction of the training data set.’

In view of this, **netGEN** has been extended to evolve (sub)optimal training data sets (TDS), using a genetic algorithm for the selection of appropriate input patterns. This feature allows the fully automatic generation of TDS, and it has been demonstrated that the evolution of appropriate subsets can simultaneously improve ANN performance and reduce training time. An obvious extension



Constructed in-house, EMMA (EMbedded Mobile Agent) is based on the Khepera robot, but with improved CPU and vision.

A future SiGis research topic will be the evolution of neurocontrollers for simple autonomous robots built in the group’s RoboLab. This is a small, experimental laboratory, where students can acquire hands-on knowledge in specialist fields such as multi-agent systems, mobile autonomous robots and evolutionary robotics. Substantial support has been provided by Siemens Bauelemente, Vienna, in the form of hardware devices (Siemens Microcontroller SAB C167CR) and software development tools.

Currently, the most advanced RoboLab activity is the in-house construction and development of autonomous robot soccer players.

of this research was the co-evolution of ANNs and training data sets, which the group has investigated in their latest papers.

The **netGEN** system uses PVM (Parallel Virtual Machine) software to create a parallel computer from an assortment of machines and networks. In order to more fully exploit its parallel capability and distribute computations over the internet, the system is currently being ported from a Unix environment to Java (Java's intrinsic Remote Method Invocation supports parallel computing across a variety of platforms). Potential hosts and collaborators should visit <http://www.cosy.sbg.ac.at/project/sigis.html>.

Crystal physics

In a Master's thesis completed last year, group member Thomas Schell designed a GA to analyse Moessbauer-Spectra employed in crystallography. Evolution was used to fit the measured data (Moessbauer-Spectrum) to an existing quantum-mechanical model of crystal physics. This is potentially an extremely useful tool in material science research and the system is now available to researchers at <http://www.cosy.sbg.ac.at/project/moessbauer/index.html>.

Orchestra staff

In another Master's thesis, now close to completion, Adrian Poje used evolutionary processes to automate the allocation of orchestra staff to various productions such as rehearsals and concerts. As usual with resource allocation problems, a number of constraints had to be satisfied. These included distributing working hours to musicians fairly, and according to their contracts; linking productions using the same musicians; and taking geographical considerations into account. The project was carried out in co-operation with the Mozarteum Orchester Salzburg and a prototype is already in use by the orchestra manager, who reports that the system not only saves several days each month in allocating musicians, but also comes up with very 'fair' and cost-saving schedules.

Frankfurt airport

Currently the group's largest project involves a co-operation with Lufthansa Frankfurt, Germany. Under the supervision of Professor Pfalzgraf two diploma students, Karl Frank and Juergen Weichen-

berger, developed an evolutionary system to optimise the positioning of aircraft at the various gates at Frankfurt Airport – an enormously complex problem, as up to 1,100 aircraft and 120,000 passengers pass through the airport every day.

In order to handle this degree of complexity Weichenberger used the concept of Logical Fiberings to develop a generic airport model that could be separated into subproblems (each gate, for example, obtains an own logical state space or 'fiber').

'The Logical Fiberings concept offers a natural mathematical "reusable" model,' explains Pfalzgraf. 'And one can model logical communication among the different fibers.'

In a second step, Karl Frank used extended and modified GAs to optimise the aircraft positioning under a large number of constraints (including passenger movement, aircraft destination, luggage movement, aircraft route on the ground, aircraft type and security level).

'We received very positive feedback from our main partner, Lufthansa Frankfurt, and although the two diploma theses have

been completed, they would like to continue the co-operation with us,' Pfalzgraf reports. 'Frankfurt Airport Agency also wishes to participate, and LH Munich Airport recently invited us to a meeting to explain the methods we used and to speak about our system.'

A prototype of this system is already in use in Frankfurt and the complete schedule for a single day takes one hour of computation time on a typical modern PC, whereas the human operators take up to a week. The system is currently used to assist the human operators, as short-term changes in flight schedules due to weather or delays have to be handled on the fly.

For more information about the SiGis group at Salzburg University, contact:

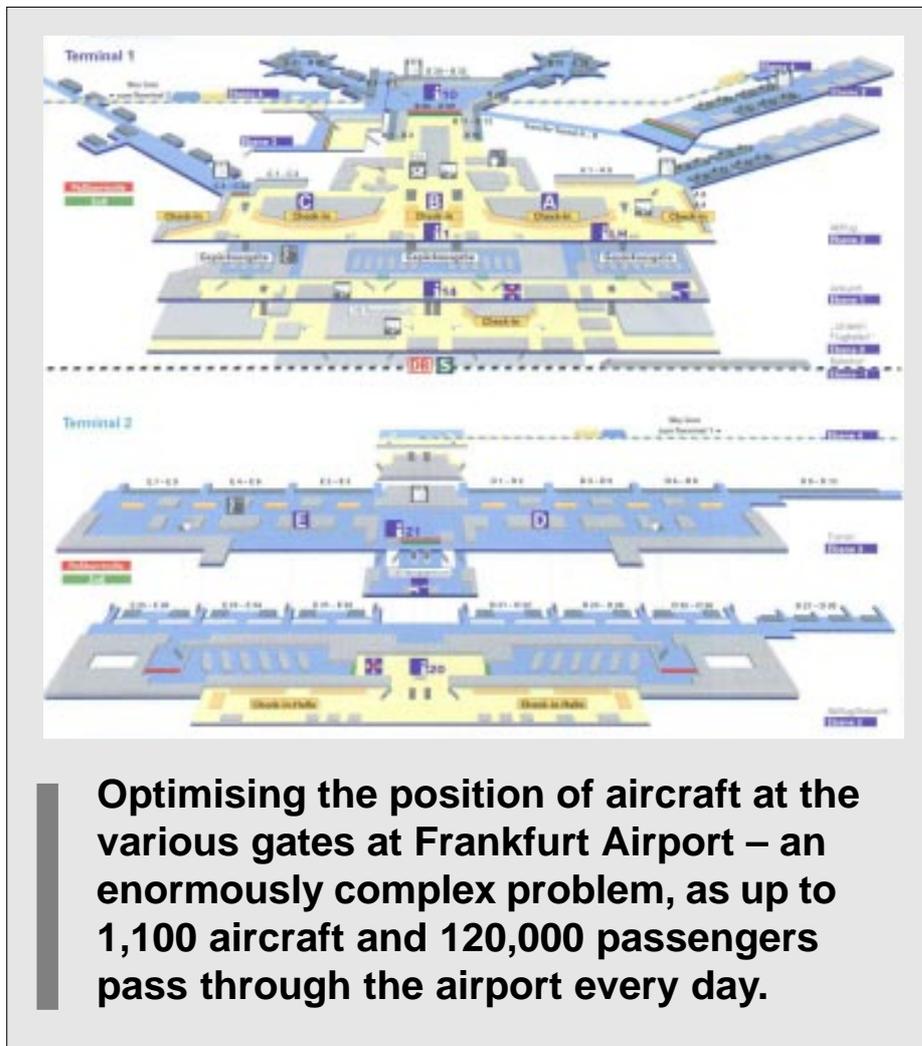
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Multiple-Valued Logic – An International Journal

Special Issue on Evolutionary Computation in Multiple Valued Logic

Guest Editors: Alioune Ngom and Zoran Obradovic

Call for papers

MVLJ creates a forum for scientists, engineers and practitioners throughout the world to present the latest research, results and ideas in the field of multiple-valued logic. This special issue provides a medium through which theoreticians and practitioners can exchange ideas and address the important issues in evolutionary computing in multiple-valued logic. It will consist of contributed papers focusing on the theory, implementation and application of evolutionary computing techniques to multiple-valued logic.

Topics must be limited to evolutionary computation and may include:

- fuzzy evolutionary systems in MVL
- neural genetic systems in MVL
- neural-fuzzy-genetic systems in MVL
- other evolutionary computing methods such as genetic programming, evolutionary programming,

evolution strategies, computer immune systems.

The topic areas may include:

- logic optimisation
- logic or functional decomposition
- datafusion or mining
- knowledge discovery
- fault diagnosis
- control
- signal processing or understanding
- image processing or understanding
- system identification
- pattern recognition, clustering or classification
- qualitative or approximate reasoning.

Submissions

Papers will be selected on the basis of their originality, significance, correctness and clarity of presentation. They should present original work, which has not been submitted or published in other journals.

Five copies of the paper (maximum 30 pages, double-spaced including figures) should be received by 15 January 2000. For each author, provide name, affiliation, full address, telephone and fax numbers, and email address. Please include keywords to indicate the topic and area of the paper.

Please send all submissions to:

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For more information, see <http://www.site.uottawa.ca/~ivan/mvl.html>

Journal of Systems Architecture

Special Issue on Evolutionary Computing

Guest Editor: Uday Kumar Chakraborty

The Journal of Systems Architecture invites original contributions for a forthcoming special issue on evolutionary computing. The special issue is scheduled to appear in mid-2001.

For the special issue, papers describing EA approaches to systems design, and novel architectures for EA-based systems are particularly encouraged.

Topics of interest include (but are not limited to):

- theory of EAs (mathematical description of EA-behaviour)
- design of new, improved EAs
- hybrid systems (such as neuro-fuzzy-EA or EA-simulated annealing-tabu search)
- evolutionary robotics
- evolving hardware architectures
- architectures for parallel EAs.

Submission deadline: 14 April 2000

Manuscripts (in English) should not normally exceed 10,000 words in length. Please provide a title page containing the title of the paper, names and affiliations of the authors, and mailing address, e-mail address, telephone and fax numbers of the corresponding author. The manuscript must contain a brief summary (maximum 150 words). Four hard copies (not faxes) of the manuscript should be submitted to the guest editor:

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For more informations, see <http://www.elsevier.nl/locate/sysarc>.

EvoNet Electronic Repository

OPEN NOW

The EvoNet Electronic Repository for published papers in the field of evolutionary computation in Europe is open now.

The Repository aims to provide easy access to research results, and is available to users in industry and commerce as well as academic researchers and students.

For more information, and to deposit your papers, please visit:

<http://krypton.ugr.es/~pedro/cgi-bin/repository/upfile.cgi>

Evol-artists

— *a new breed entirely*



'I CAN'T STOP. There is something compelling about this process. It feels as though the images are trying to break out of their hyperspace into the physical world. Sometimes I'll be two or three days into a run – dozens of generations with one or two hundred individuals in the population – when Wham! there's something familiar staring back at me from out of the computer screen, demanding to be made real.'

For the past six years Steven Rooke has been developing software to evolve images, and using it to generate a startling portfolio of work. He's one of a growing band of artists who breed images in the same way that our forebears extrapolated pit bulls and poodles from a single lupine stock. These people challenge just about every cherished cultural notion we hold about art. They're as well versed in the natural language of mathematics as in the artistic grammar of line, colour and form. They talk in terms of exploration and serendipity rather than inspiration and creativity. And as far as their work is concerned, they're symbiotic with computers. Neither artist nor machine could



produce alone what they produce together.

Evolutionary art, genetic art, evol- or evo-art, as it is variously known, was pioneered by biologist Richard Dawkins whose experiments with breeding simple 2D forms or 'Biomorphs' on his Apple Macintosh gave the first inklings of what a combination of evolution and the human eye could achieve.

The process is simple: an evolutionary art program generates a number of random genotypes – strings, trees or networks of mathematical expressions, of which the user remains as blissfully unaware as the first dog breeders were of DNA. All the user sees are the phenotypes – the images that are the physical embodiment or expres-

Made or born? Steven Rooke's evolved African Mask. Its genome is:
 $\text{cos}(\text{pmult}(\text{pdiv}(\text{pdiv}(M_PI, \text{pdist}(\text{pmult}(0.703097, \text{pdist}(\text{pdiv}(0.777147, \text{sin}(\text{pdiv}(y, \text{pminus}(-2.19658, \text{cos}(x))))), \text{cos}(\text{cos}(\text{sin}(y))))), \text{sin}(y))), \text{cos}(\text{pplus}(\text{cos}(\text{pplus}(\text{atan}(\text{sin}(\text{cos}(x))), \text{pmult}(x, x))), \text{pdist}(\text{spiral}(y, 0.418353))))), 0.494688))$

sion of the underlying code. Assign them a score according to your preferences and the computer does the rest – randomly altering, and in some cases merging, the genomes of favoured images to create a new gallery of phenotypes more tuned to your taste. In this way, over successive generations your personal aesthetic acts as a selection mechanism, breeding images that are increasingly pleasing to you.

But who's the real artist here? Jeffrey Ventrella, author of the interactive Evol' Art program at the now defunct Absolut Vodka website, believes that it's the creator of the software – whom he describes as 'the meta-artist'.

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‘Both the creator and the user of evolutionary art software can be seen as artists in a very real sense,’ he says. ‘But they are both playing very different roles. The creator of the tool has designed the very genetic space within which exploration and creativity happens. The user then exercises creativity and aesthetic judgement within that space.’

‘This is why I believe that the most important artist is the programmer of the ev-art system. When Picasso and Braque invented Analytical Cubism, were they using an application produced by someone else? No. They invented the very method of representing vision from scratch and then became users of that method.’

Like many evolutionary artists, Steven Rooke is both meta-artist and artist. ‘My library of genes coding for form in images expands with each new run, and provides the seed for successive runs,’ he comments. ‘After years of continuous work on this project, my genebanks are more valuable to my future artwork than the software system I wrote to create them.’

‘Superficially the images are two-dimensional height fields interacting with expanded colourmaps to provide simulated depth cues, shadows, perspectives. But mathematically, the identical program is applied to every pixel, and that genetically evolved program involves super-high dimensional spaces. The program has hundreds or thousands of branches, constantly swapping spatial variables with temporal or phase-space quantities. In a non-trivial sense, each image is a colored two-dimensional projection of a complex space having hundreds or thousands of dimensions.’

Although he sells several large prints each year, it’s the programming and the process of discovery that fascinate him most. He works on a Silicon Graphics Indigo workstation, programming in C++ – although this is something he thinks will inevitably change.

‘Late last year it became apparent that the only way to survive the sweeping changes in the computer industry is to have portable code,’ he says. ‘Java is only now becoming fast enough to support image evolution (an image that takes one minute to run on my 3-year old SGI in native C++, takes only eight minutes on a 300MHz laptop running in Java under Win95). A factor of eight is promising, given the much

lower costs and higher processor speeds in the PC world.’

He’s also moving away from the tree-structured genomes he has used for many years, to directed graph genomes, which allow much more complex connections between nodes.

‘I recently implemented a directed graph genome architecture in Java,’ he reports. ‘You can’t have loops or cycles with trees, but you can do just about anything with digraphs. However, they are much slower than trees, at least with the graph structures I’ve used so far – a factor of 600 times slower than in native C++ on the SGI – so I went back to trees.’

For Rooke, as for all evolutionary meta-artists, space and time are continually in conflict. The goal is human-computer collaboration – a genuine real-time interactivity. However, the more one extends the set of basis functions available within a system the harder it becomes to evolve a coherent image: the larger the search space the more time consuming the search.

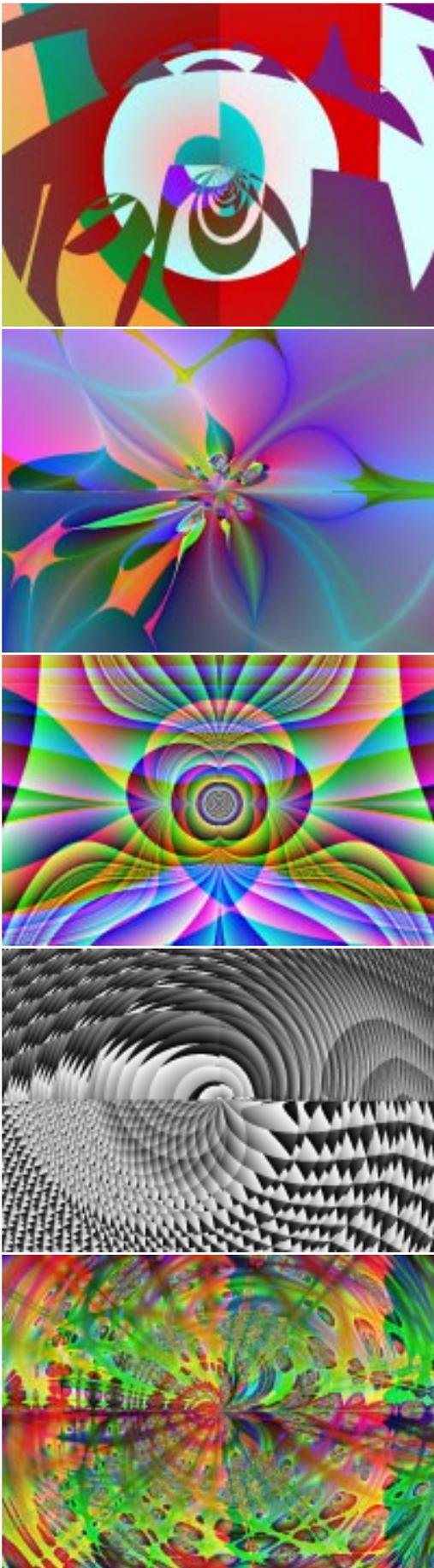
This is something that preoccupies Ken Musgrave, another evolutionary artist who, like Rooke, was strongly influenced by Karl Sims’ early work with Genetic Images.

‘I had been fascinated by the idea of genetic textures ever since visiting Karl Sims and playing with his original software on a 16,000 processor Connection Machine,’ he says. ‘I had my own ideas for how to create images with a naturalistic character, and I wanted to see if this could be done on today’s laptop machines.’

When Musgrave joined MetaCreations two years ago, he was given carte blanche to pursue the research area of his choice. The result is Dr Mutatis, an evolutionary art tool that Musgrave describes somewhat coyly as ‘research code developed here in the MetaCreations Skunk Works’.

Whether or not Dr Mutatis is destined to feature in a MetaCreations product, Musgrave is clear that it’s the most complex and intricate program he has ever written. Like Sims’ original program it works by functional composition, but there the similarity ends. Dr Mutatis runs on a Macintosh platform; it’s written in C++, not Lisp, and is engineered for a single processor, not a massively parallel SIMD machine.

‘When you have thousands of pointers, the Mac O/S isn’t the best for code development,’ admits Musgrave. ‘You



The images above were evolved by visitors to Mattias Fagerlund’s Web GP site (<http://www.acacia.se/Mattias/WebGP>). The evolved eyes on pages 7-9 can be found at <http://www.acacia.se/Mattias/EvolArt>.

spend a lot of time waiting for it to reboot when you make a mistake.’ This and engineering the necessary speed are the chief problems he faces.

‘In terms of generations, image evolution is swift,’ he says. ‘However, in terms of processor time on a two year old laptop, it still takes too long to compute an interesting image.’

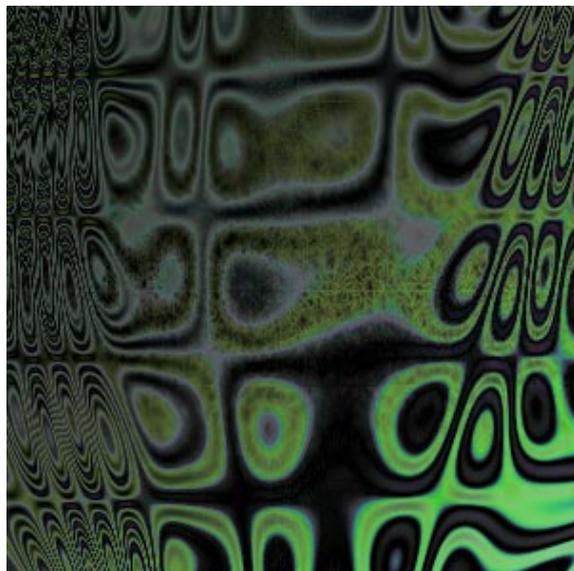
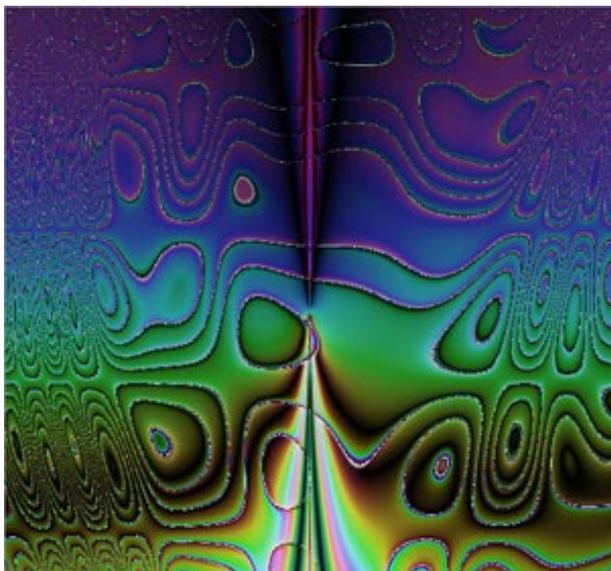
‘This kind of software needs to be highly interactive; we still need improvements in speed to get really rich and interesting genetic images on common home machines. But we’ll be there soon.’

Despite the development problems, his enthusiasm remains unblunted. ‘Evolutionary art programs can be incredibly exciting to work with,’ he says.

‘They really tap the potential of this powerful idiot savant assistant that is the computer. What evolutionary programs open up is the astonishingly fecund space of serendipity that today’s computing power makes it possible to evoke, thus turning the computer’s simple-mindedness into a system that displays interesting emergent behaviour.’

For Musgrave, as for Ventrella, the role of the meta-artist is to stake out sections within the gallery of all possible images, funnelling the user down avenues of potentially fruitful exploration. Evolutionary art programs can often be extremely specialised. At Leiden University in the Netherlands, Jano van Hemert and Gusz Eiben employed a handful of rules (only use white, red, blue and yellow for colouring planes; only use straight black lines that always end at a perpendicular line or the frame) to stake off the small ideosyncratic area of the gallery devoted to images in the style of Pieter Mondriaan.

Van Hemert calls himself ‘at most a very



Genetic Textures evolved by Ken Musgrave using Dr Mutatis

bad counterfeiter’, but his Mondriaan Evolver provides a perfect example of how evo-art systems can be used to model a particular artistic approach, providing users with a degree of freedom by altering parameters in the model.

‘The character of genetic images is partly determined by the basis functions that provide the expressive vocabulary available to the system,’ explains Musgrave. ‘My particular quiver of procedural random fractal functions, which have mostly been derived in my pursuit of visual models of natural phenomena, will I hope provide a particularly “natural” expressive vocabulary for my genetic image generation system.’

Basis functions prescribe the boundaries of the evolutionary system, the limits to what is possible. Widen the boundaries of the system, and ‘there will be diminishing returns very soon,’ Musgrave points out, ‘as there are only so many computationally feasible and visually distinct basis functions to be had.’

‘Just as our human DNA cannot produce any conceivable animal or plant, an evolutionary art program cannot produce an infinite range of products,’ says Ventrella. ‘There are limits and constraints



We simply need to engineer faster algorithms and hardware to make larger spaces available and their search feasible. Both are inevitable.

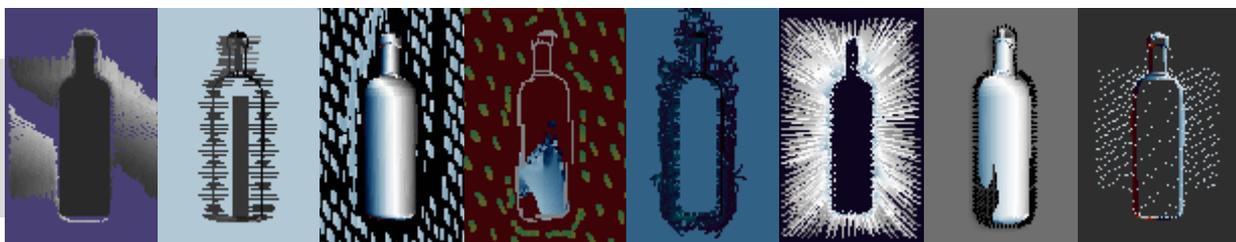
to what forms can arise. Infinity is not possible and it is not even the issue. The issue is great variety within a limited space of possibilities, and pathways within that space to facilitate exploration and discovery.’

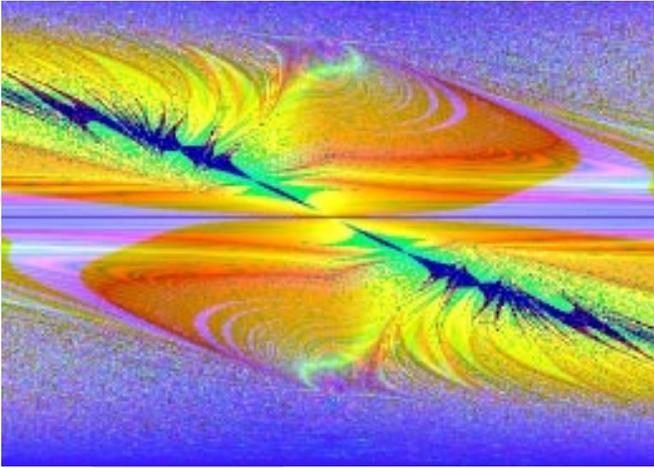
Nevertheless, at the University of Coimbra, researcher Penousal Machado is investigating the feasibility of opening a window onto the gallery of all possible images. His evolutionary art tool, NEvAr, can he claims in theory generate any image. This is because Machado has avoided using complex functions such as fractals and Lindenmeyer systems, which he says serve as ‘attractors’ generating local optima and thus resulting in a loss of freedom.

‘Currently we prefer to use only simple functions such as sin, cos, add,’ he says. ‘None of these functions is able to gener-

Continued on page 10.

Absolut Vodka bottle forms, meta-designed by Jeffrey Ventrella and bred by visitors to the (now defunct) Evo!-Art site.





The image above was evolved using NEvAr, the image generation system developed at the University of Coimbra.

Continued from page 9.

ate, by itself, a complex image. By using only simple functions there is no bias towards a specific type of image.'

Because complex functions reduce the number of generations required to breed good images, abandoning them results inevitably in longer runs.

To minimise this problem, NEvAr stores all the populations that it generates so that any complexity gained need not be lost. As a result, visually interesting images can be recovered and used to seed new generations.

'NEvAr treats each document as an experiment (the set of all populations, from the initial to the current one),' explains Machado. 'Its multi-document architecture allows us to work with several experiments at the same time so we can copy an image from one experiment to another.'

But the ability to hold and manipulate vast genebanks is not what chiefly distinguishes NEvAr from other evolutionary art systems, many of which also allow some form of migration. NEvAr's novelty is hidden in its name, which stands for Neural Evolutionary Art. This is because Machado and his colleagues initially planned to use neural networks to achieve fully automatic image generation.

Steven Rooke has proposed a similar scheme to develop what he describes as 'a co-evolving system of image generator and image commentator organisms'.

'An evolutionary artist would bootstrap the process by guiding the evolution of aesthetically pleasing images for some number of generations, say 20,' explains Rooke. 'Then you fire up the population of evolving neural networks, and have them cycle for however many generations it takes to come sufficiently close to your aesthetic fitness selection as they "look" at all the images in the populations of the twenty bootstrap generations. Once that happens, you turn over the aesthetic fitness selection for the twenty-first image generation to the "newly confident" neural network organisms. Now you can let the populations of image generators and commentators co-evolve automatically.'

Rooke maintains that no one knows what this process might reveal, or how far it might go. 'In principle, by analogy to the

supremely powerful metaphor of the co-evolution of flowering plants and pollinating insects, it could lead to the evolution of quite powerful, perhaps universal shapes or forms,' he says.

However, after some experimentation, Machado has scaled down the projected role of neural networks within NEvAr.

'The use of neural networks in this type of domain results, unavoidably, in a change of the fitness landscape and the generation of false optima,' he comments. 'The evolutionary algorithm will eventually find a "shortcut" and follow it. After a few populations the images will have high fitness values according to the neural network, but won't be fit according to the user.'

As a result, he plans only to partially automate NEvAr, using neural networks to filter some of the images that collide with the aesthetic principles of the user. However, bearing in mind the role complex functions play in reducing the total number of generations required to evolve an acceptable image, he is more optimistic about Rooke's scheme.

'Our experiments indicate that in the early populations things tend to go well, it is only after that the EA gets diverted,' he comments.

As interest grows amongst both researchers and commercial artists, the role of evolutionary art programs seems set to increase.

'For now I think they will mainly be used as a tool in the bigger picture, like an advanced brush or hammer,' comments van Hemert. 'Slowly they will be embedded in larger applications such as rendering software or desktop publishing, to create pieces of a larger work – think of evolving a quick texture that you can apply to the three dimensional chair you just modelled.'

'The larger the search space, the greater the potential for hitting aesthetic gold,' says Musgrave. 'We simply need to engineer faster algorithms and faster hardware to make larger spaces available and their search feasible. Both are inevitable.'

He believes that evolutionary art programs will eventually become ubiquitous and highly refined. 'I'm looking forward to the day when I can have a cheap, high quality, large format printer in my home. Then I may change the artwork on my walls on a daily basis. It's easy to come up with ten to twenty beautiful images a day with a program like Dr Mutatis.'

'Hang 'em up today, replace them tomorrow: disposable art.'

Evo-art online

To find out more about the artists and meta-artists whose work is featured in this article, visit:

- **Panousal Machado** <http://www.dei.uc.pt/~machado>
- **Ken Musgrave** <http://www.wizardnet.com/musgrave/mutatis.html> or <http://www.metacreations.com/people/musgrave>
- **Steven Rooke** <http://www.concentric.net/~Srooke/>
- **Jano van Hemert** <http://www.wi.leidenuniv.nl/~jvhemert/mondriaan/>
- **Jeffrey Ventrella** <http://www.ventrella.com/>

To evolve images yourself, visit Mattias Fagerlund's site at www.acacia.se/Mattias/WebGP (you can also view some of his evolutionary art at www.acacia.se/Mattias/EvolArt).

Alternatively, visit the gallery of random art at Carnegie Mellon University and take part in collective image evolution: <http://gs2.sp.cs.cmu.edu/art/random/>.

Linda Moss provides a good introduction to evolutionary computer graphics at <http://www.marlboro.edu/~lmoss/planhome/index.html>.

Andrew Rowbottom has an informative site on organic, genetic and evolutionary art at <http://www.netlink.co.uk/~snaffle/form/evolutio.html>.

Highlights from **EVOWORKSHOPS** 99

More than 70 people attended EvoWorkshops'99 in Göteborg this May for four days of presentations on the state of the art in evolutionary computing. The event, which brought together the expertise of four EvoNet working groups, promised to be wide ranging and inspirational. Here, some of the participants report back.

EuroGP A biologist's perspective

The Second European Workshop on Genetic Programming consisted of oral presentations and poster sessions covering GP theory and optimisation, current GP applications and future prospects. The participants came from a wide range of academic and industrial backgrounds, and the involvement of such a diversity of people led to a series of talks that ranged widely in both subject area and perspective. The result was a most interesting conference.

As a biologist, whose prior knowledge of GP was confined to applications, attending the Workshop enhanced my knowledge of the theory and complexity of GP. As with biological systems, every question answered and every hypothesis tested raised a new set of questions. The Workshop enabled the dissemination of information and the discussion of GP in terms of both the programmes and their application as tools. It became apparent that close communication between theoretical scientists and practitioners is essential for the development and optimisation of this technology.

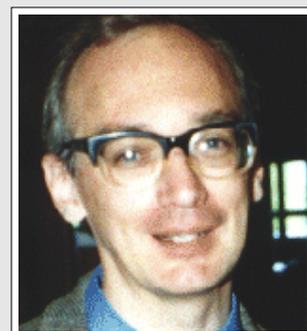
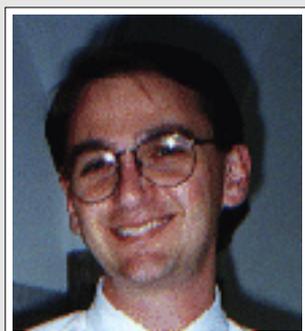
The first presentation by John Koza was hugely beneficial, providing a concise overview of GP theory, a very good introduction especially for novice GP users such as myself. Throughout the course of the two days the huge potential of GP became apparent. The applications described ranged from circuit board design to robot training, from analysis of the hidden layers within neural networks to ship detection by satellite SAR imagery. The Workshop concluded with a lively and thought provoking group discussion focusing on computer creativity and intelligence in comparison with that of humans.

For me, the conference was a success: I left knowing significantly more about GP, and with an increased curiosity about the future potential of computing and how the technology may be applied to biological systems.

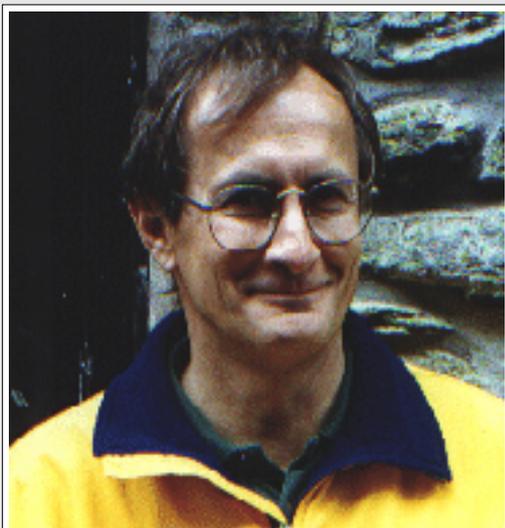
Helen Johnson is based at the Institute of Biological Sciences, University of Wales, where she uses genetic programming in her research into the effects of salinity on tomato crop yield and fruit quality.



Winners of EvoWorkshop'99 Special Jury Awards for outstanding work presented by a student or young researcher (clockwise from top right): Lucia Ballerini, Giovanni Squillero, Marc Ebner and Penousal Machado.



Faces at EuroGP'99 (clockwise from top left): David Fogel, Bill Langdon, Wolfgang Banzhaf and Connor Ryan.



Dana Ballard, invited speaker at EvoIASP'99 and EvoRobot'99.



Faces at EuroECTel'99: Brian Turton (above left) and Martin Oates (above).



Left: EvoIASP Chair Stefano Cagnoni.

Below, participants visit the Old Carlstens fortress.



EvoIASP Invited speaker

Dana Ballard is well-known for his work on active vision – an approach which is based on the idea that vision control is task-related. His presentation, 'Virtual Reality and Cognitive Bandwidth', started with a video fragment of an experiment where subjects had to copy a model

of an aeroplane by moving parts into place one at a time. The experiment clearly demonstrated that subjects frequently look back at the model they have to copy before moving a part into position. These results support Ballard's active vision paradigm, and indicate that instead of constructing a detailed model in memory, people may rely on vision to extract information from the environment at the moment it is needed.

After presenting neurobiological results which reveal that animals can learn to anticipate rewards by developing sensitivity to triggering events, Ballard discussed a computational approach to this principle. The problem is to discover what constitutes a useful trigger. This selection of task specific memory is addressed by Andrew McCallum's work on sequence learning. His central experimental result is a reinforcement learning program that learns to control a car on a busy highway. A video of this high quality graphics simulation showed that the algorithm had developed a strategy that was rather different from a human approach: when driving in the fast lane, it looked backwards for extended periods of time, apparently checking whether anyone was catching up!

The third subject Ballard addressed was 'looming' – the phenomenon whereby approaching objects appear to increase in size. A demonstration showed that an algorithm based on log-polar co-ordinates could determine whether an object in a sequence of images is approaching or receding. This fed into the final issue that Ballard raised – what types of problem solved by the human brain may require genetic algorithms? He argued that there is no point using GAs for tasks that do not require any internal state, since these can be adequately solved by other methods. Instead, a possible use of GAs might be to develop libraries of visual filters for tasks such as looming.

Edwin D. de Jong

EvoWorkshops A signal processing perspective

I attended EvoWorkshops'99 hoping to find some broad inspiration, and that's exactly what I got. EuroGP presented a surprising number of variations on GP's classic tree representation. Of particular interest was Michael O'Neill and Conor Ryan's implementation of a grammatical evolution system using

Backus Naur Form grammars – an approach I had never previously considered, but which could readily be adapted to circuit design by replacing their use of C with a subset of VHDL.

EuroEcTel offered an invited talk by BT's Martin Oates on his work in using evolutionary computing for distributed database management. The main topic is too far from my own work to be immediately practical, but their peripheral findings on a bimodal feature in the results of varying mutation levels will definitely be worth keeping in mind. Its immediate industrial application is also encouraging to those of us starting out in the field. Another surprise came from Brian Turton's paper on evolving networks with

desirable topologies. Although the chosen application was computer networking, analogous problems exist in the acceptability to experienced engineers of evolved circuits, for which his solution might be adapted.

EvoIASP's surprises fall into the category of broader interest rather than their applicability to my current work. Tony Belpaene's poster on evolving visual feature detectors presented an interesting application of biologically inspired approaches, while Louchet's poster on 'The Fly Algorithm' suggests a very unusual implementation of a fast GA for stereovision, based on the fitness value of an entire population rather than individual solutions. Julian Miller's paper on evolving digital filters deserves a second look with respect to my own work.

Some of the work presented at EvoIASP'99 could be of interest to my colleagues at Edinburgh. Bellerini's paper on genetic snakes for medical image segmentation, for instance, presented a practical method for identifying interesting regions in retinal scans. F. Corno et al presented a poster on evolving for low power constraints. These will be among the papers I report on to my group.

Finally, EvoWorkshops'99 offered a welcome break from routine. In particular, the final day of presentations on board a ship provided an experience the organisers of EvoWorkshops2000 will no doubt struggle to match next year in Edinburgh. I look forward to it.

Morgan Tamplin is researching a potential application for PALMO, a novel reconfigurable mixed signal device developed at the University of Edinburgh.



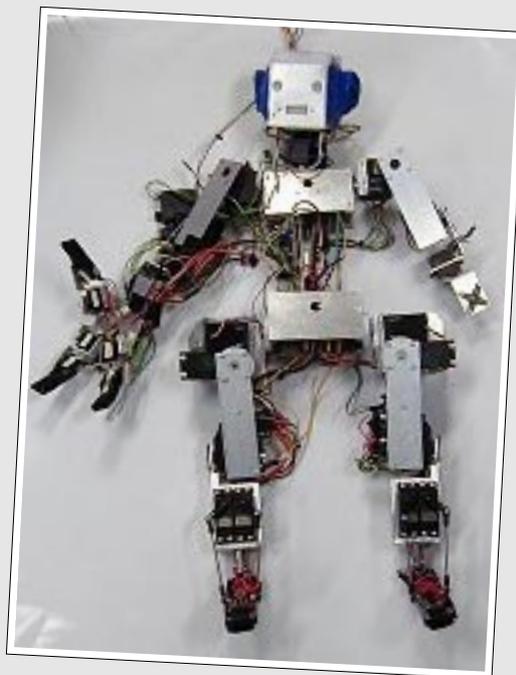
The Workshop was opened by ELVIS, a prototype robot built at Chalmers University as part of a project to produce a full-size, bipedal humanoid robot, controlled by a hierarchy of evolutionary systems.

Following an invited talk by Dana Ballard, the cycle of presentations began.

Peter Nordin described the hardware used to build ELVIS and the plans he and his students have to use Genetic Programming to program ELVIS. Christian Balkenius focused on what robot builders can learn from the human brain and its evolution, and proposed a high level cognitive architecture by analysing some homogeneous mechanisms of the human model. Roger Andersson and Ulf Petterson demonstrated the first commercial autonomous 'service robot' – a lawn mower produced by the Swedish company Husqvarna – and described the challenges involved in turning a good idea into a profitable consumer product. Jens Ziegler presented a GP controller for the motion control of a robot with a random architecture and Frank Francone described a realistic learning system based on a model of the real world that is dynamically updated.

On Day Two, the workshop was water-borne – while participants cruised through the Göteborg Archipelago en route for Marstrand island. Marc Ebner presented 'Evolving a Behaviour-based Control Structures: From simulations to the real world' and Robert Feldt introduced 'Software Diversity and N-versions systems'. After a tour of the picturesque Old Carlstens fortress, participants returned to the boat for lunch, where they had the opportunity to talk with some of the other delegates and enjoy the beautiful Swedish coast line.

Alain Racine and Jeroen Eggermont



**Presented at EvoRobot'99:
ELVIS the humanoid robot (prototype 1).**



**Faces from
EvoRobot'99:
Peter Nordin (top),
Frank Francone
and the
Husqvarna,
autonomous
lawnmower.**



All the events listed on these pages include coverage of, or welcome papers on, evolutionary computing techniques.

13–16 September 1999

EUFIT'99: 7th European Conference on Intelligent Techniques and Soft Computing, Aachen, Germany

Contact

✉ events@mitgmbh.de
<http://www.mitgmbh.de/eufit>

13 September 1999

Virtual Agents'99: Workshop on Intelligent Virtual Agents, University of Salford, UK

Contact

✉ d.ballin@iti.salford.ac.uk
<http://www.salford.ac.uk/cve/va99/>

27–28 October 1999

IES'99: Industrial Electronic Seminar, Surabaya, Indonesia

Contact

✉ sonk@eepis-its.ac-id.net
<http://www.eepis-its.ac-id.net>

29–30 October 1999

EWRL-4: Fourth European Workshop on Reinforcement Learning, Lugano, Switzerland

Contact

✉ ewrl@iridia.ulb.ac.be
<http://iridia.ulb.ac.be/~ewrl/EWRL4/EWRL4.html>

3–5 November 1999

EA'99: Artificial Evolution 99, Dunkerque, France

Contact

✉ EA99@lil.univ-littoral.fr
<http://www-lil.univ-littoral.fr/EA99>

15–16 December 1999

18th Workshop of the UK Planning and Scheduling Special Interest Group, Manchester, UK

Deadline for papers: 17 September 1999

Contact

✉ sig99@angmar.iti.salford.ac.uk
<http://www.salford.ac.uk/planning/PLANSIG99/>

20–22 December 1999

CIT99: Conference on Information Technology, Bhubaneswar, India

Contact

✉ rabi@cs.tamu.edu
<http://www.oits.org/icit99>

4–7 January 2000

ECCAP 2000: International Conference On Evolutionary Computing for Computer, Communication, Control And Power, Chennai, India

Contact

✉ <http://www.preciousmicrotech.com/eccap/>

15–16 April 2000

EuroGP 2000: European Workshop On Genetic Programming, Edinburgh, Scotland

Deadline for papers: 15 November 1999

Contact

✉ <http://www.cs.bham.ac.uk/~rmp/eebic/eurogp2000>

EVONET event

17 April 2000

EvoTel 2000: European Workshop on Evolutionary Computing and Telecommunications, Edinburgh, Scotland

Deadline for papers: 19 November 1999

Contact

✉ <http://www.sys.uea.ac.uk/evotel>

EVONET event

17 April 2000

EvoIASP 2000: European Workshop on Evolutionary Computation in Image Analysis And Signal Processing, Edinburgh, Scotland

Deadline for papers: 15 November 1999

Contact

✉ <http://www.ce.unipr.it/people/cagnoni/evoiasp2000.html>

EVONET event

24–26 May 2000

Viennese Workshop on Optimal Control, Dynamic Games and Nonlinear Dynamics: Theory and Applications in Economics and OR/MS, Vienna

Contact

✉ <http://www.bwl.univie.ac.at/bwl/prod/EVENTS/ws2000>

11–16 June 2000

Invited Session on Evolutionary Robotics at WAC2000, Hawaii, USA

Contact

✉ gaparker@cs.indiana.edu
http://wacong.com/wac_info.html

29 June–2 July 2000

EIS'2000 Engineering of Intelligent Systems, University of Paisley, Scotland
Deadline for papers: 30 November 1999

Contact

✉ fyfe0ci@paisley.ac.uk
<http://www.icsc.ab.ca/eis2000.htm>

18 September 1999

EWLR-8: European Workshop on Learning Robots, Lausanne, Switzerland

Contact

✉ jlw@cs.bham.ac.uk
<http://www.cs.bham.ac.uk/~jlw/ewlr/>

21–30 September 1999

WSC4: On-line World Conference on Soft Computing in Industrial Applications, Organised by Cranfield University, UK

Contact

✉ r.roy@cranfield.ac.uk

12–15 October 1999

SMC99: Systems, Man and Cybernetics Conference, Tokyo, Japan

Contact

✉ http://www.intergroup.co.jp/smc99/html/main_ef.html

7–10 November 1999

ANNIE'99: Smart Engineering System Design: Neural Networks, Fuzzy Artificial Neural Networks in Engineering, Missouri, USA

Contact

✉ dagli@umr.edu
<http://www.umr.edu/~annie>

8–9 November 1999

CIRA'99: IEEE International Symposium on Computational Intelligence in Robotics and Automation, Monterey, USA

Contact

✉ schultz@aic.nrl.navy.mil
<http://voronoi.sbp.ri.cmu.edu/~cira99/>

7 December 1999

AWAPAP'99: Australian Workshop on the Application of Artificial Intelligence to Plant and Animal Production, Sydney, Australia

Deadline for papers: 30 September 1999

Contact

<http://www.fit.qut.edu.au/~abbass/awapap99.html>

2–4 February 2000

ISTA2000: International Conference on Advances in Intelligent Systems: Theory and Applications, Canberra, Australia

Contact

✉ ista@ise.canberra.edu.au
<http://beth.canberra.edu.au/conferences/aista2000/index.htm>

27 Feb–3 March 2000

FEA'2000: The Third International Workshop on Frontiers in Evolutionary Algorithms, Atlantic City, USA

Contact

✉ ccpgrrom@si.ehu.es
<http://www.ee.duke.edu/JCIS/>

19–21 March 2000

SAC 2000: Evolutionary Computation Track / Symposium on Applied Computing, Como, Italy

Contact

✉ raidl@apm.tuwien.ac.at
<http://euler.mcs.utulsa.edu/~rogerw/callwww.html>

17–18 April 2000

ICES2000: International Conference on Evolvable Systems: From Biology to Hardware, Edinburgh, UK

Deadline for papers: 15 November 1999

Contact

✉ j.miller@cs.bham.ac.uk
<http://www.dcs.napier.ac.uk/evol/ices2000.htm>

26–28 April 2000

ACDM 2000: Adaptive Computing in Design and Manufacture 2000, Plymouth, UK

Deadline for papers: 15 September 1999

Contact

✉ ptrund@soc.plym.ac.uk
<http://www.tech.plym.ac.uk/soc/research/edc>

3–5 May 2000

APGA'2000: Asia-Pacific Conference on Genetic Algorithms and Applications, Hong Kong

Deadline for papers: 1 November 1999

Contact

✉ mskkilai@cityu.edu.hk
<http://orsc.edu.cn/apga2000/>

3–7 July 2000

IPMU 2000: Information Processing and Management of Uncertainty in Knowledge-Based Systems, Madrid

Deadline for papers: 15 November 1999

Contact

✉ <http://www.mat.upm.es/ipmu>

8–12 July 2000

GP-2000: Genetic Programming Conference, Los Angeles, USA

Contact

✉ www.genetic-programming.org

16–18 August 2000

PATAT2000: International Conference on the Practice and Theory of Automated Timetabling, Constance, Germany

Deadline for abstracts: 21 January 2000

Contact

✉ <http://www.asap.cs.nott.ac.uk/ASAP/ttg/patat-index.html>

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