

popularising the science and researchers of PASCAL

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Communication is one of the most fundamental skills required by contemporary scientists.

Without appropriate and effective dissemination, even the very best research can be overlooked.

Yet, the frenetic world of 24-hour media and fast-paced journalism often precludes science in favour of the meaningless sound-bite.

Such are the barriers of communication, that it is extremely difficult for scientists to communicate their work beyond their specialist conferences and journals.

For those that break the barriers, the rewards are clear: popularised science that catches the imagination of others can create new opportunities.

An enthusiastic portrayal of successes can lead to growth in that field, as new researchers are attracted to it and new funders become keen to exploit the advances.

There are several routes to broader dissemination.

One is simply to expand traditional scientific outputs, inviting delegates from broader scientific fields to workshops, or producing web pages with “friendlier” interfaces.

However, science writers and journalists rarely attend scientific events, and with only a few hours to write their articles, rarely have the time to read a broad range of scientific publications.

Today, the media look for easy-to-digest “news stories” – examples of successes that have been proven through peer review, and which also have a broad impact and interest.

This project exploits the services of an experienced science communicator in order to find and publicise such stories, to improve the visibility of PASCAL research and researchers.

New Electronics

11 OCTOBER 2003

Evolutionary activity

Can digital biology help to create electronic devices that truly deserve to be called intelligent?



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DIGITAL BIOLOGY

COVER STORY

process of development. Gordon's aim was to show that incorporating developmental elements would result in EC that is inherently more scalable than systems lacking it.

In a series of experiments, Gordon evolved fully functional 2Dk adders using fpgas. He also demonstrated that development can enhance the scalability of hardware evolution using two benchmark circuit design problems - that is his adder problem and the sum to his party problem. The development model used consisted of two layers a 'genetic' layer that models biological development and an architecture layer that maps the products of development to a circuit. The result is implemented in a Xilinx Virtex Fpga. A paper by Gordon and Bentley describing the work, from a conference on evolvable hardware that took place in Washington DC, was published recently by the IEEE Computer Society.

Bentley's current focus is on trying to create a mathematical overview, or formalism, of what is critical to the very nature of the development process itself. The potential result of this work may be that a radically different kind of computer architecture will be needed to perform evolutionary computing, one that supports

themselves, highly parallel and modular, so that development is extremely efficient because everything happens at once. Even if cells are growing relatively slowly, if several billion are operating at once, highly powerful computation can result.

One practical result from Bentley's Digital Biology Group has been a brain that operates inside a bug robot, enabling it to navigate through an environment like a mouse. Many of these have been produced, some using evolutionary techniques, but one unusual feature of Bentley's is that if the brain is damaged, it can still work a feature that results from the incorporation of developmental properties.

"Because you have created a set of instructions for what the solution should be, if the solution gets damaged to an extent, the knowledge of what it should be is retained. Typically, these things can partly repair themselves and regenerate. They show a level of fault tolerance that conventional systems cannot achieve."

Such 'partial degradation' is a long sought after feature of electronic and computing devices designed to work in environments where repair by humans is impossible (for example, in space or extremely hostile earth environments).

Several specific areas of digital biology involve:



New Electronics www.neon.co.uk November 2003

Along with others in computing and robotics it is simple to state, but proving difficult to do without getting involved in program themselves. The hope is that, if we could just get the program going, it could be a giant leap in creating electronic devices that deserve the term 'intelligent'.

A decade ago, research suggested that just might happen soon. Hardware and software were being created through techniques such as genetic programming and evolutionary computing (EC) by people like Adam Thompson of Sussex University (see *New Electronics* 10 December 1996) and John Koza of Stanford University. They produced - on 'spies' - working electronic devices like analog multi filter and amplifiers, and robot controllers, without anybody directing specifically what was happening.

Unfortunately, it's still a dream and for one key reason - scalability. The early forms of EC proved wanting when it came to doing anything complex without human intervention. This was pointed out by Peter Bentley, head of the Digital Biology Group at University College London, explains. "Traditional methods simply don't scale to greater levels of complexity. Or rather, in order to get them to do that, you have to add knowledge, but

"The problem with conventional EC approaches is that every parameter of the thing being designed must correspond directly to one binary value," Bentley explains. "Unfortunately, very complex solutions have to be defined by an awful lot of parameters, hence genes, and this rapidly makes the whole process unscalable."

The idea is that, by incorporating development, you avoid the one to one correspondence between a gene and a parameter. We are trying to get to the point where the genome is more like a recipe, a set of instructions for how a solution should grow, rather than a complete blueprint specifying every last detail in advance."

This is what nature does. Today, the principle that some kind of development based approach is needed if EC is ever to fulfil its promise is nearly accepted. The problem is, how can it be implemented?

"It is actually really hard," says Bentley. "In nature, very intelligent building blocks have evolved in the form of cells and the process of development relies critically on those. These blocks effectively make themselves and communicate with each other to know where they are, what their neighbours are doing and, hence, what function they are to perform."

Evolutionary activity

Can digital biology help to create truly intelligent electronic devices?
 By David Boothroyd

If you're looking for a system that can produce very complex results, but can only do so by having more and more information supplied by humans, then why bother? It deflates the promise that Bentley thinks they know why this was in. The old EC techniques lacked something that is critical in real evolution: development.

In a typical EC system, the computer contains a set of solutions to a problem. It assesses each solution according to a fitness test, then selects the better ones to produce the next generation from randomly mixed bits of the fit. These shuffles, passing from one generation to the next, are the digital equivalent of genes, so the new generation resembles its parents, but with variations. The aim is that, over many generations, consistently improving solutions to the problem evolve.

Creating such building blocks is proving a major challenge and is probably the key to cracking the whole EC problem. Bentley's team has adopted an approach in which a digital genome can be defined by just two numbers, one for its name, the other its concentration. So a digital gene 001011 001010 001100 would mean: 'If protein 001011 mixes with a concentration above 001010 THEN increase concentration of protein 001100'. Sets of these numbers, representing genes and gene sets such as a program routine name, which act as Bentley and his colleagues, see successful evolution.

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But Gordon, like his model-based approach, has also evolved the robot's adder using Xilinx Virtex fpgas and demonstrated that development can enhance the scalability of hardware evolution. The development model consisted of two layers a 'genetic' layer that models biological development and an architecture layer that maps the products of development to a circuit.

ing self-organizing development are proving valuable areas of study for computing, for example tools for developing the immune system.

"There are quite a lot of algorithms based on how the human immune system works and it is clearly related to development because it involves a group of cells that have to communicate with each other, only this time they are trying to counter very specific attacks to the host organism," Bentley says. "One reason this is difficult is that each person has, within their gut, bacteria that are not genetically the same as them, but which the immune system must not attack. Similarly, every time you see something, you take it foreign material and a pregnant woman must carry a genetically different being which must not be rejected."

This problem - the 'selfless self' problem - is of great interest to the field of computer security. With millions of computers operating on networks, how can the system as a whole know if they are attacked? How do you recognise software as a virus? How do you know that unique new activity of a person just added to a network is not harmful? This problem will get more important and complex and the hope is that artificial immune systems will play a part in the solution. These algorithms may also give the aim to create algorithms - modelled to an extent on biology - which can grow themselves into a virtual structure representing a computer network. The artificial immune system will sit on top of that and look at the virtual issue. If strange things start happening to the network, this is reflected in the immune system and the immune system will take action to deal with it, repairing the network.

This is not far from practical application. Bentley is currently collaborating

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with biologists and network intrusion experts as a project to develop network protection algorithms.

There is huge potential here. Today, virus protection software works by constantly analysing the latest virus and writing a new patch to update the virus checker. The immune system is far superior - it does so. If every time you caught a cold, the doctor had to analyse what you had and give you precisely the right infection, you would live very long. Artificial immune systems will learn for themselves, they are not told what is harmful, nor how to counter attacks. Instead, humans had to do just this by trial and error through many generations, artificial ones will do the same."

Despite the challenges, EC research programs are making in practical results. The Evolvable Systems Group at NASA Ames Research Center in California has used EC to design antennas for the Mars Observer and Space Technology 5 spacecraft. There are superior to human control designs in several ways smaller, less power hungry, and more uniform coverage.

More digital biology work by NASA takes place at the Jet Propulsion Laboratory, also in California. Here, the Biologically Inspired Technology and Systems Group (BIT) forms part of the Flight Systems Electronics section. Its aim is to apply EC to electronic space wiring systems, in particular to develop capabilities of intelligent recognition for non mission requirements and environments. Key objectives are the automated synthesis of signal processing functions used in space applications and increased survivability.

Another project is the modular transformer robot (MUTRAN) being developed by Japan's National Institute of Advanced Industrial Science and Technology. This consists of modules which are able to stick together in various ways, like real cells. This enables the robot to form legs dynamically and walk, then reconfigure itself and squirm along the ground like a worm. EC techniques have been used to control the robot.

Bentley is no doubt that evolutionary computing has made major progress. "There is every chance that the use of developmental processes with such hardware could produce a field of self-designing, self-repairing robots within two years," he concludes.

*Finally, GW Gordon and Peter J Bentley (2003), Developmental Design Scalability in Hardware Evolution. In Proceedings of the 2003 NASA/ESA/DLR Conference on Evolvable Hardware, Washington DC, USA, 11-14 July 2003, pp. 275-282, copyright Bentley Computer Collaborating.



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Fast cars could be tuned by evolution

16:03 18 June 2004
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Can evolutionary theory help rival Formula 1 teams break Michael Schumacher's seemingly unassailable hold on top-flight motor racing? Computer scientists at University College London think it might.

Peter Bentley and Krzysztof Wloch have used genetic algorithms software that mimics evolution's drive for fitness to breed the best tuning configurations for racing cars.

Using the technique, achieved by an experimental conference on evolutionary Genetic algorithms m

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Robot spy can survive battlefield damage

19:00 20 August 2003
 Exclusive from New Scientist Print Edition. [Subscribe](#) and get 4 free issues. Duncan Graham-Rowe

A military reconnaissance robot being developed at a British lab can keep moving even if it gets damaged on the battlefield. When any of the snake-like robot's "muscle" segments are damaged, clever software "evolves" a different way for it to wiggle across any terrain.

The serpentine spy is a research project funded by aerospace company BAE Systems to make a low-cost military robot that can be dropped out of helicopters to carry out reconnaissance missions. Because it is not wheeled, the low-profile, ground-hugging snakebot should make a versatile battlefield spy. The team behind it has also developed a shape-changing antenna that broadcasts high-quality video and audio.

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ANATOMY OF A SNAKEBOT

The battlefield spy that won't stop wiggling

- Foam protects the wires and forms the snakebot's body
- Copper wires deliver power to the lab
- Shape-memory wires allow snake to flex



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Anatomy of a snakebot

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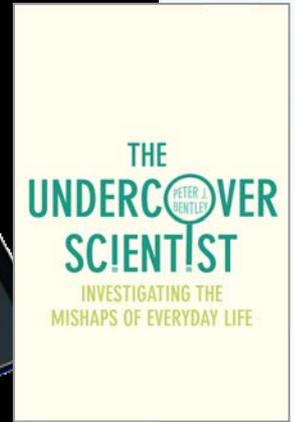
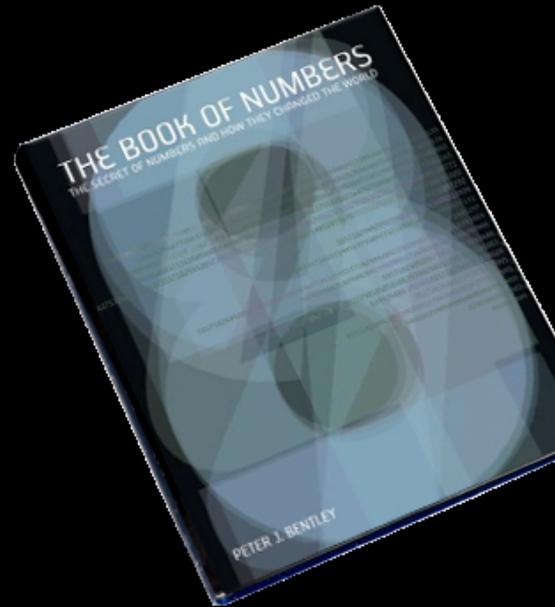
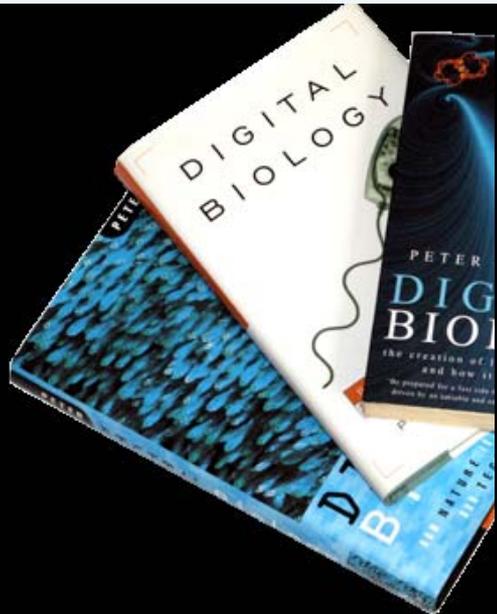
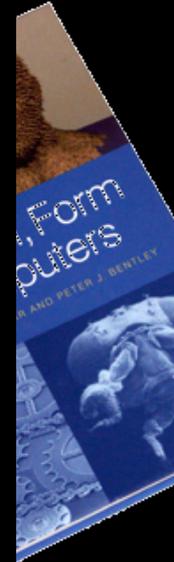
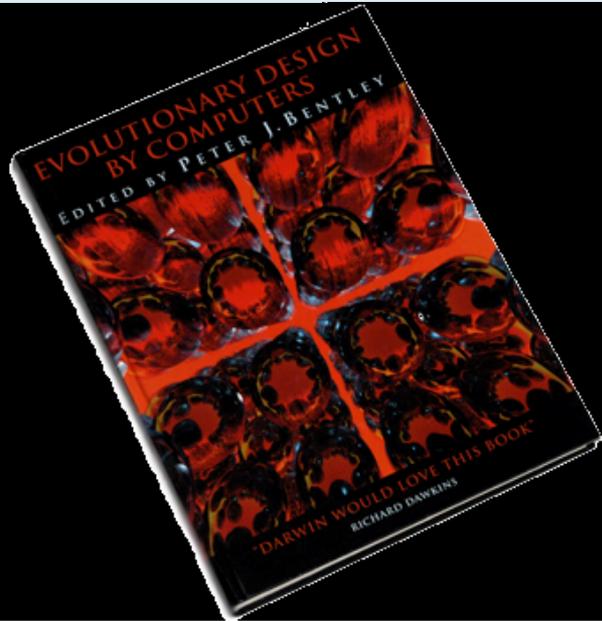
Insect swarming inspires jazz software

08:00 06 May 2002
 Exclusive from New Scientist Print Edition. [Subscribe](#) and get 4 free issues. Duncan Graham-Rowe

Jazz musicians who enjoy freeform improvisation may soon be using computer software to accompany themselves. A team at University College London has written a program that mimics insect swarming to "fly around" the sequence of notes the musician is playing and improvise a related tune of its own.

The Swarm Music program is the creation of computer scientists Tim Blackwell and Peter Bentley, who study how natural processes can be modelled in software. The pair believe that improvised music is self-organising in the way swarms of insects and flocks of birds are.

Their software works by treating music as a type of 3D space,





WHAT ARE YOU LOOKING AT?

You're waiting at the station for your train and you glance at the electronic poster next to you. It notices that you're looking at it, and from your gaze it works out what you would most like to see. The display changes to show you new brands of mobile phone, and then changes again to



show handheld computers as it notices your gaze flicker. You glance at the clock and so it brings up a list of forthcoming trains, then zooms in on yours and shows you exactly how long it will take to arrive. It's as though it's reading your mind – but really it's reading your eyes.

Intelligent displays such as this may only be a few years away thanks to the fascinating research of computer scientists who specialise in eye tracking and machine learning software. Like computerised mind-readers, eyetracking technology follows the strange patterns of our gazes, and machine learning software is used to learn what it all means. But reading our gazes is not easy. It's so hard to

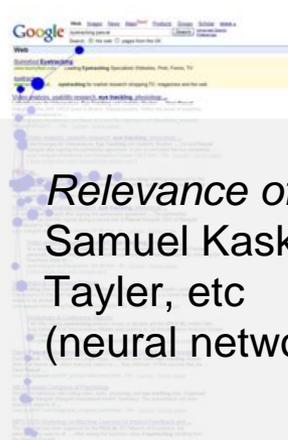
program would it need to run?

Our eyes really do give away many of our thoughts. Only a tiny part in the middle of our vision called the fovea is capable of seeing detailed images. Everything else is just a blur. To give us the illusion that we see everything around us in perfect clarity, our eyes dart about several times a second in saccades.

Gaze patterns contain both direct and subtle cues about users' attention and interests

do that in 2005, PASCAL (a European funded network of scientists who specialise on pattern analysis, statistical modelling and machine learning) sponsored a challenge: could a computer learn to tell whether we found something useful, just by watching our eyes? Could a computer look deep into our eyes and guess our thoughts? If it could, what kind of

sampling different parts of the scene around us, and our brains glue together the separate parts to make the complete view that we think we see. Even as you read this text right now, your eyes are not sliding smoothly along as a camera might. You are hopping from word to word, often focussing on the middle of a word, maybe focussing twice on a longer or unfamiliar word such as *saccade*,



Not a leaking pen, this is the pattern of eye fixations over a period of less than 5 seconds as a person searches up and down a Web page for the right link. Larger blobs mean the eye fixated on one spot for longer. Surprisingly few words are read. The red 'x' marks the link that was chosen. Image produced using a Tobii X50 eye tracker, operated by Sven Laque, Research Student, Human Centred Systems Group, UCL. Eyes belong to Peter Bentley.

Support Vector Machines

SVMs are cousins of neural networks, and in fact a certain kind of SVM is exactly the same as a multi layer perceptron. But SVMs originate from the world of mathematics rather than biology. They work by automatically dividing a set of values (vectors) into two classes – effectively figuring out the best straight line that can separate the values from each other. When several values are used in each vector, this line becomes a plane, or more commonly, a hyperplane (a plane in more than 3 dimensions). But this only provides a linear (straight-line) separation between the vectors, so the trick used by SVMs is to use a kernel function, which maps vectors onto a new *twisted* space where they can then be separated by a hyperplane. (Mapping the flat plane backwards to the old space would twist the plane until it was a lumpy and convoluted surface, able to separate the overlapping data points.) An SVM with a sigmoid kernel function is equivalent to a two layer perceptron neural network.

So SVMs work because they are able to use a simple hyperplane in combination with kernel functions to separate data. And if you can separate the data, you can also separate the relevant parts of the movements corresponding to the text.

When you can predict a binary eye movement that will correspond to you finding text relevant or not, based on finite state machines to learn to predict the probability distributions to the data label sequences in an approach known as conditional random fields. Fascinatingly, although each competition was won by a different group of scientists, the same kind of method came out top for both: machine learning software based on neural networks (see box).

Michael Pfeiffer and his colleagues at the Graz University of Technology, Austria, won the first challenge. They used the clever observation that, in a multiple choice exam, the answer that a person perceives as being correct is likely to be read more often than the other options. This gives their final answer. So their method ignored most of the tiny movements of the eye and concentrated on the larger and conscious movements. Although clever – attaining the best accuracy of 72.31%, this idea couldn't work for all applications, and indeed it did not win the second challenge where only the raw eye movement data was given. In this more difficult problem, Tuomas Lepola of the University of Helsinki was most successful, with an accuracy of 64.8% on unseen test data.

The future looks promising for this remarkable area of research. Since the competitions were run, PASCAL funded a "pump-priming" project to investigate the ideas further. In this recent feasibility study, researchers from the Helsinki University of Technology, the University of Southampton and UCL collaborated to try an even harder task: could a computer learn whether you found a whole

When we first started we thought there was no way it could work

section of text relevant to a single keyword or search term? Would the search words scanned with computers be any more relevant or not? The answer would be used in the tests, "they were too interested in subjects such as astronomy and so read the text more often than we were. It was more successful. The feasibility study has now been expanded into a full-scale project

EyeTools

The idea of eye tracking is now big business. EyeTools is a company specialising in the area, providing their own analysis of eye movements when presented with adverts and web pages of a huge range of commercial and corporate clients. Rather than helping users to find relevant content, EyeTools helps their corporate clients to design eye catching websites by analysing where people look. If nobody ever looks at an advert, headline or contents list, then this is indicative of a serious design flaw. In this way EyeTools is able to help companies produce the most effective visual designs possible. Companies such as EyeTools work offline, analysing data in order to improve a document. Researchers of PINVIEW want to use machine learning and analyse our gazes in real time.

this was a tremendously challenging task. "When we first started we thought there was no way it could work... but actually for some topics it performed amazingly well," says Hardoon. The main problems with accuracy were actually caused by the test subjects themselves. The system was learning to understand how we skim-read text in order to pick out just a few key words – this is how we determine if something is useful to us. But this

mean that if any test subject decided to read the whole passage of text, the computer would not be able to tell if the text was relevant or not. The researchers used in the tests, "they were too interested in subjects such as astronomy and so read the text more often than we were. It was more successful. The feasibility study has now been expanded into a full-scale project

re no different than data stored on hard rough the net.

you could always block the systems with a pair of dark glasses.

The scientists involved with this work are aware of these issues.

alarming. Mental images of the scene from the movie *Minority Report* moving to mind, with the computer predicting our feeding us irresistible advertisements tailored to our every glance and mood. This may be highly desirable for companies wishing to sell their products to us, but you would always be able to escape. If eye tracking ever did become as ubiquitous and intrusive as television or internet advertisements,

Kai Puolamaki, another of the organisers of the original competition acknowledges, "The privacy issues have to of course be taken seriously. In this sense the eye movements are no

I think it would make a lot of sense to integrate eye tracking technology to computer systems in the future

different than other personal data stored in hard drives and sent through the net? Luckily, your eye movement data without the machine learning software was interpreted them as unlikely to be as easily exploited as information such as your emails or typing on a keyboard, so the movement of your eyes will always be more secure than your fingers.

Consequently, the researchers prefer to take an optimistic view. In the

words of Samuel Kaski, "I think it would make a lot of sense to integrate eye tracking technology to computer systems in the future... gaze direction is special because it is tied very

closely to our attention and intentions."

The goal of researchers like Kaski, Puolamaki, Hardoon and Shawe-Taylor is to help the public find what they want with the minimum of difficulty. Ideally this technology will be the perfect way to enable us to navigate through the vast and ever-growing information that surrounds us today. Before long, the right information for you may be just a glance away.

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Resources:
PASCAL: <http://www.pascal-network.org/>
Eye Movements Challenge: <http://www.pascal-network.org/Challenge/README>
Workshop: <http://www.cis.hut.fi/ijcnn2005/>
Pump-priming project: <http://www.cis.hut.fi/projects/mi/pump06/>
EyeTools: <http://www.eyetools.com/>

THE MIND READING WIZARDS

Telepathy was once nothing more than a parlour trick played by illusionists to entertain us. Names would seemingly be pulled out of our heads, numbers would be correctly guessed, our hiding places revealed. It was all done through trickery – reading our body language, tone of voice, and movement of eyes. Magic doesn't really exist, and neither did mind reading. At least that used to be true, until the mind-reading wizards arrived. Now something resembling telepathy is becoming a reliable reality. Being poker-faced will not help you any more. Even if you control every movement of your muscles or flicker of your eyes, you will never hide your brain activity. The magic word is not abracadabra, but Hex-o-Spell!

The art of mind reading is much more useful than the party tricks might have you believe. Being able to read the mind of a serious person might be the only way to establish contact with a communist who uses a machine that records brain activity without giving the user a chance to express themselves and control their lives.

The computer wizards who specialise in Brain-Computer Interfaces had these aims in mind as they developed the *Hex-o-Spell* system. Their computer doesn't just read a name or word, it allows a user to communicate any message by thought alone. It's a brain-reading, machine-learning, text-input system that allows the user to type using their minds.

Simple brain-computer interfaces (BCIs) have been demonstrated for several decades. Using sensors placed on the head, often using gel to improve contact, the electrical impulses produced by large groups of neurons in different regions of the brain could be measured. The broad patterns or frequency of electroencephalogram (EEG) signals would then be used as the input to the computer. The problem is that our brains are hugely complex organs, each with its own individual design. It is possible for people to develop normally with just half a brain although their brains look very different to ours, and as Benjamin Blankertz explains, "also in normally developed humans, functions are differently located in the brain. And due to the foldings of the cortex, small

changes in location may cause strong differences in the EEG." Doing something as predictable as moving a finger or a foot, different people will have very different patterns of brain activity. Even worse, brains throw out new and different patterns of signals at the time of some tasks, and the signals are unreliable – the gel dries out between sensor and head, or sensors are placed incorrectly or slip – so at different times the sensors may misread the brain activity. To overcome these problems, two standard approaches are used: either the user is asked to perform a task to produce more predictable signals. For example, if the more a person falls into a state resembling meditation, the more regular and slow the frequency of the EEG waves becomes. This method can be successful in some cases, but it requires lengthy training periods for users and so can be very limited.

What was needed was a way to pick out the activity in the precise regions of the brain that were relevant, and somehow overcome all of the variability inherent in EEG signals.

The problem is rather like listening to the muffled sound of a huge orchestra through a thick wall, and trying to interpret the melody from a single violin – when the orchestra change their seats and play a slightly different tune every time you listen. The traditional approach was to train the whole orchestra to all play more or less the same note. The solution as used in *Hex-o-Spell* was to train the listener to pick out that elusive violin. To make this work, the field of brain-computer interaction had to combine forces with machine learning.

The Berlin BCI group is the first to achieve this new fusion of sciences. They have become the world leaders in the area, organising three machine learning competitions, supported by PASCAL (the European funded network of scientists who specialise on pattern analysis, statistical modelling and machine learning). But the latest success has come from a PASCAL "pump-priming" project, in collaboration with Dr John Williamson from Glasgow University, to create a system that can work without the users needing to be trained. *Hex-o-Spell* comprises three elements: EEG measurement of brain activity, machine learning to interpret that activity, and an intelligent hexagonal grid of the alphabet that uses a language model in order to simplify the picking of letters.

Users of *Hex-o-Spell* are asked, for example, to move a finger of their right hand or a finger of their left hand. The brain signals in the sensorimotor cortex corresponding to the motor command for each movement occur in slightly different places. (Imagined movements can also be used, but since the technology is intended for users who may be amputees or paralyzed, the use of actual motor commands in the brain is better. In these patients, a "phantom command" may be there but the movement is not.)

The 128 electrodes in the EEG are filtered down by a machine learning method known as common spatial patterns (CSP). This algorithm is trained on past data to produce filters that extract the most useful. Finally linear discriminant analysis (LDA) is used to separate the data into different classes by separating them with a line (or plane or hyperplane). To achieve this, the data is transformed (rotated) until the distance between data in the same class is minimised and between different classes is maximised. In this way, new EEG data can be classified as belonging to one or another class, and so the patterns corresponding to the intention to move the left or right finger can be identified.

Once a signal has been identified by the computer, it is then fed into the *Hex-o-Spell* interface. This comprises six hexagons in a circle, each containing five symbols (letters of the alphabet, backspace and simple punctuation). If, say, the intention to move the right finger is detected, then an arrow in the middle will rotate, pointing to each hexagon in turn. If the intention to move the left finger is detected, then that arrow will grow in length until the current hexagon and its symbols are selected. Those symbols are then used to replace the contents of the six hexagons, and the arrow can once again be used to pick the single letter or punctuation required. The clever part in the system is the way the symbols are arranged – their presentation is



The *Hex-o-Spell* system in action

automatically changed according to a predictive language model, which works out which letters are most likely to be chosen next, and places those closest to the arrow. This ensures that the user never has to rotate the arrow far to choose the next letter, and speeds up the whole process dramatically.

Hex-o-Spell was demonstrated at the CeBIT fair 2006 in Hannover with remarkable success. Two users who had little or no practise with any similar device successfully used the system for many hours. One person managed between 2.3 and 5 characters a minute and the other achieved between 4.6 and 7.6 characters a minute – world class performance for this type of BCI.

The Berlin BCI group is continuing its research. Collaborator Roderick Murray-Smith from Glasgow University explains the wider context of the work: "BCI vs general HCI can be compared to

BCI vs general HCI can be compared to Formula 1 cars vs mass-production cars

Formula 1 cars vs mass-production cars. BCI gives very extreme challenges to interaction designers, which at the basics of their field, because many standard techniques have implicit input mechanisms. That is, the value in BCI might find application in a different form on, for example, mobile phones with novel sensors such as GPS & accelerometers."

Work investigating how well patients can use the technology is underway now. If the wizards at the Berlin BCI group are successful, then one day anyone who can think, will be able to communicate, no matter what their physical disability might be.

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Resources:

- Berlin Brain Computer Interfacing Project: http://ida.first.fhg.de/projects/bc1/bc1_official/index_en.html
- PASCAL: <http://www.pascal-network.org/>
- Challenge: http://ida.first.fhg.de/projects/bc1/competition_iii/
- Workshop: http://ida.first.fhg.de/projects/pascal_workshop/pascal_workshop.html
- Pump-priming project: <http://www.dcs.gla.ac.uk/~jhw/dibci.html>

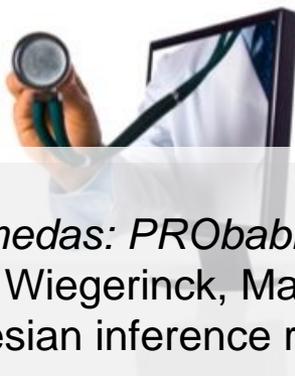
THE DESKTOP DOCTOR

Hundreds of years of medical experience. An infinite patience and the ability to take every symptom into account. Precise and logical, up-to-date, and never short on ideas. All just casually sitting on your doctor's desk. It may not have much of a bedside manner, but then its job is not to meet patients. Its role is to brainstorm with human doctors and help them look at all possibilities when diagnosing illnesses. It is Promedas, the desktop doctor.

Promedas is a PRObabilistic MEdical Diagnostic Advisory System – a computer program that figures out how likely certain medical diagnoses are from a given set of symptoms and test results. It addresses the hugely complex task faced by doctors every day: how to ensure that even unusual or obscure causes of symptoms are not overlooked. Whether the doctor is a specialist in one area or a general medical practitioner, keeping up-to-date and remembering the myriad relationships between illness and symptoms is often tremendously challenging. Promedas does not make a diagnosis, but it suggests alternatives to the doctor and based on the information it has been given, shows exactly how likely it is for the patient to be suffering from each condition.

Since the beginnings of Artificial Intelligence, there has been a dream of creating a computerised expert, filled with our knowledge, and able to infer new conclusions of its own. These computer programs became known as expert systems, often using elaborate trees constructed of rules: "If symptom A and not symptom B then ask about C, if symptom C then diagnosis is D". But unlocking the knowledge held within scientific journals and coded in the neurons of specialists was not so easy. In medicine, for example, medical conditions and symptoms are not either true or false. Not all people experience the same symptoms, and the appearance of some symptoms is hugely more significant than others. There can also be a large number of symptoms, leading to rules with excessive numbers of variables. So the old "decision tree" methods were often cumbersome and made bad decisions, sometimes ruling out possibilities for no other reason than data being presented in an unexpected order.

The failure of these rationalist "good old fashioned AI" (GOFAI) methods led to many scientists rethinking the ideas. Clearly an expert system needed to represent knowledge in some form, and clearly that



Promedas: PRObabilistic MEdical Diagnostic Advisory System

Wim Wiegerinck, Martijn Leisink, Bert Kappen, Jan Neijt

Bayesian inference rules

knowledge needed to be used with data to infer some form of decision. But how best to achieve these goals?

One common solution was to use fuzzy logic, where the binary true or false rules were turned into linguistic variables such as "partially true" or "mostly false". But even fuzzy logic still suffered from problems: it might enable the expert system to define degrees of truth, but in fields such as medicine, a partially true diagnosis is not ideal. Instead, it would be much more useful if the probability of a diagnosis being true was provided. For example, while a runny nose might result in a "partially true" diagnosis that you have a virus in a fuzzy logic system, it would be more helpful if the system could infer that you have a certain probability of suffering from several different illnesses, some much more probable than others. The solution, as exemplified by the medical decision support system Promedas, was to use Bayesian inference rules.

Thomas Bayes was a mathematician born in London in 1702. Amongst his works, he wrote about probability. Instead of being concerned with, say, the probability of drawing a black ball from a bag of a

certain number of black and white balls, Bayes was interested in the inverse probability of the event. In other words, if you had drawn more black balls compared to white balls from the bag, what was the probability that the bag contained more black balls and so you would draw another black one next? Given a hypothesis (for example that the next ball will be black) and some information about which balls have been picked previously, Bayes figured out the maths to infer the probability that the hypothesis was true or not. Several decades later, Frenchman Laplace developed these ideas further, creating a more general version of the Bayes theorem for use in astronomy and physics.

Amazingly, two centuries later, systems such as Promedas now use Bayesian inference to achieve decision support. It's ideal for an application such as medicine where we have plenty of evidence that certain symptoms tend to be observed for specific illnesses.

Promedas is the result of many years of development by researchers such as Wim Wiegerinck, led by Martijn Leisink and

Bert Kappen of Radboud University Nijmegen in the Netherlands. It now contains Bayesian inference rules that

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have a base set of the advanced rules of the Dutch doctor Martijn Leisink. The case of a patient with a cough and a fever, for example, could lead to each other. If one finding leads to two different diagnoses these are difficult to merge in a rule based system. At least one additional rule is necessary. In the probabilistic setting, making use of the basic probabilistic rules, it is immediately clear how to combine evidence and variables."

The success of Promedas relies on its careful structuring of the dependencies (which findings imply which diseases). It organises its information as a tree in a three-layered noisy "OR" model. The layers of the tree correspond to risk factors such as occupation or drug use, possible diseases and the tests and symptoms. Each node in the network (either a risk factor, disease or test result) is linked according to specific probabilities of cause and effects, with some risk factors likely to cause some diseases, and some diseases likely to cause some

symptoms and results of tests. By representing each node as a "noisy OR" Promedas simplifies and speeds up the inference process, making the assumption that each cause can behave independently but multiple causes combine to make outcomes more probable. With a given model and data about the risk factors and test results, the probabilities of different diseases can then be inferred.

As with all such systems, often the main bottleneck is simply the input of data. Many patient records are incomplete or are not in the right kind of format to enable easy input, and typing in the results of tens or hundreds of different observations and tests can be laborious. As more patient records become stored electronically, this will become less of an issue but in the near future the use of Promedas is likely to be restricted to those mysterious cases where the doctor needs some new ideas. It's an important role, for specialists who have chosen to focus on one specific area of medicine may become less knowledgeable about other areas. The vast amount of expert knowledge in Promedas means that all physicians of all

specialisations will have access to the same up-to-date specialist information.

There can be no doubt that a list of possible diagnoses of a patient makes an excellent decision support system, for it may suggest rarer alternatives that could be confirmed by additional tests.

The first large-scale trial will begin in early 2008 at the University of Utrecht, Netherlands. While results are still not perfect, initial experiences by doctors are very positive. In the words of Dr Jan Neijt of the University of Utrecht (the physician who has so far provided all of the medical knowledge for Promedas), "...used with reason it is always helpful... This is the future for medicine with all the sub specialists. They need a program that looks further away than their sub specialisation."

Perhaps one day systems such as Promedas will become as ubiquitous as the stethoscope, with their databases updated as new medical findings are published. We can never remove uncertainties from medicine, but with decision support systems we can ensure that all decisions made by our doctors are as well-informed as possible.

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Resources:
Promedas (including online demonstration): <http://www.promedas.nl>
Promedas publications: <http://www.srn.ru.nl/nijmegen/publicatie.php?project=Promedas>
PASCAL: <http://www.pascal-network.org/>



Wéiqi, Baduk or simply, Go. Over two thousand years old, this challenging game of strategy and tactics has taught warriors, monks and intellectuals to focus, concentrate and plan. Far more complex than chess, there are more possible games than there are atoms in the known universe. Computers can now equal the performance of the best players, but none are equal to the human player. This is a deceptively simple game. But one program is one-armed bandit has stolen first prize more often than any other. It's MoGo, or Monte Carlo Go.

The game of Go may have simple rules, but to play successfully requires enormous skill. Few computer programs are able to navigate through the unimaginable number of possible moves and find the best strategy. The solution, as shown by MoGo, is not even to attempt to look at all the possibilities. Instead, a randomised exploration of the options based on one-arm bandits makes this problem more manageable. The secret behind the success of MoGo is Upper Confidence Trees – an algorithm that has shown success in areas from game-playing to webpage optimization.

The idea of using machines to take the role of our opponent in a game arose even before computers had been created. Chess has long attracted the attention of designers of these machines. While the very earliest chess automaton were frauds, by the 1950s the subject

MoGo: Monte Carlo Go

Remi Munos, Yizao Wang, Pierre-Arnaud Coquelin, Olivier Teytaud, Sylvain Gelly, Rémi Coulom, Levente Kocsis, Csaba Szepesvári

Upper Confidence Trees

than the one for chess. So even supercomputers, a brute-force search simply doesn't work for the

search is one useful way to make more manageable. Instead of fully search the whole space, a Monte Carlo samples points in the space. Results of that sampling to action. It's like the game of random sampling is used to build an of where the ships are on the grid. Monte Carlo search to a game tree, this many branches of the tree see which player might eventually moves were followed, and then branch to follow. Traditional Monte Carlo search the game tree, but they sampled each branch with

An even better approach, as researchers Levente Kocsis and Csaba Szepesvári used to bias the random sampling of method called Upper Confidence Trees (UCT). This is an extension of a previous method called Bandits. The different bandits are treated like different arms of a slot machine. Each time a one-armed bandit is chosen from a random selection

lose branching out from the current state of the board. The game of Go is a board game where the board state from which new branches grow. Chess has a finite number of possible board states, but Go has an infinite number of possible board states. In the late 1990s and early 2000s, our best computers were fast enough to search significant parts of the tree. Computers such as Deep Blue and later Deep Fritz were able to beat human chess grand masters using these brute-force approaches.

But the game of Go was another matter entirely. Compared to chess, which may have around 10¹² legal 37 moves possible each turn on average, Go has rarely fewer than 50 moves possible, and typically over 200 each turn. This means that the game tree for Go is

They joined forces with another researcher, Pierre-Arnaud Coquelin, and Olivier Teytaud and his PhD student Sylvain Gelly at University of Paris-Sud. With the help of Coulom, this team applied the UCB algorithm to the game tree of Go and without realising it, independently invented the UCT algorithm at almost the same time as Kocsis and Szepesvári.

MoGo uses UCT to bias its Monte Carlo search – a strategy that enabled the program to win the CGOS tournament where games were played on a smaller 9x9 grid, in August 2006.



MoGo was first introduced in the On-line Trading of Exploration and Exploitation Workshop 2006 (sponsored by PASCAL, the Network of Excellence on Pattern Analysis, Statistical Modeling and Computational Learning).

The same team went on to use UCT and win the 2006 "PASCAL Exploration vs. Exploitation Challenge", set by TouchClarity (now Omniture TouchClarity).

Remarkably, the technology of TouchClarity provides another example of the successful application of UCT. The company focuses on optimizing the online experience for users – it decides what should and should not be shown within webpages, based on the interaction of past users. An extreme example of this might be to show specific news stories that are likely to interest the user on a news webpage. Real examples are much more subtle. The problem can be regarded as being similar to a game where the human players (users) make their moves by clicking on certain parts of web pages, and the computer responds with its move of changing the

ly that the user will choose others (and profitable for the CT technology can also evolved.

ises of the MoGo team, I'm sceptical about their vain Gelly, "at that time, the Go were considered rGo community only for the ed doomed by the fact that the "real" game. 9x9 Go ner game unrelated to 19x19

It did not lose hope and it year improving MoGo (to Action Value Estimation). a 19x19 computer go. Computer-G in September 2007 and now works at Coulom continues to improve CrazyStone which is now the main challenger to MoGo in computer-Go.

Remi Munos summed up the MoGo work with enthusiasm: "From my point of view, this project (or adventure...) has been really a wonderful collaborative work which has led to some advances not only in the field of Go, but also which has opened new perspectives in other fields as well, such as in optimal control, large scale optimization problems, and complex sequential decision problems, in particular (such as in games)."

Resources:
INRIA article and links for MoGo: http://www.inria.fr/renseignement_recherche/11-computer-culture/mogo-champion-program-for-go-games/
PASCAL: <http://www.pascal-network.org/>
PASCAL Exploration-Exploitation Challenge & Workshop: <http://www.pascal-network.org/Challenges/EEC/>
<http://www.homepages.ucl.ac.uk/~ucab2hu/OTEE.htm>



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Things you can do to help:

- always try to make yourself available and be friendly to journalists; they have tight deadlines and if they can't talk to you they'll give up or use someone you might prefer they didn't.
- provide general information on websites: biographies, summaries of research, pointers to important new papers and results.
- learn how to explain your work using everyday language (it often makes the concepts crystal clear in your own mind if you can talk without any terminology)
- think of a major new result or discovery which has a broad impact as a news event and write a press release with the help of your university.

Think about how to communicate with a more general audience - it'll benefit you.

It's nice to talk to peers, but there's a whole world out there.

Questions?