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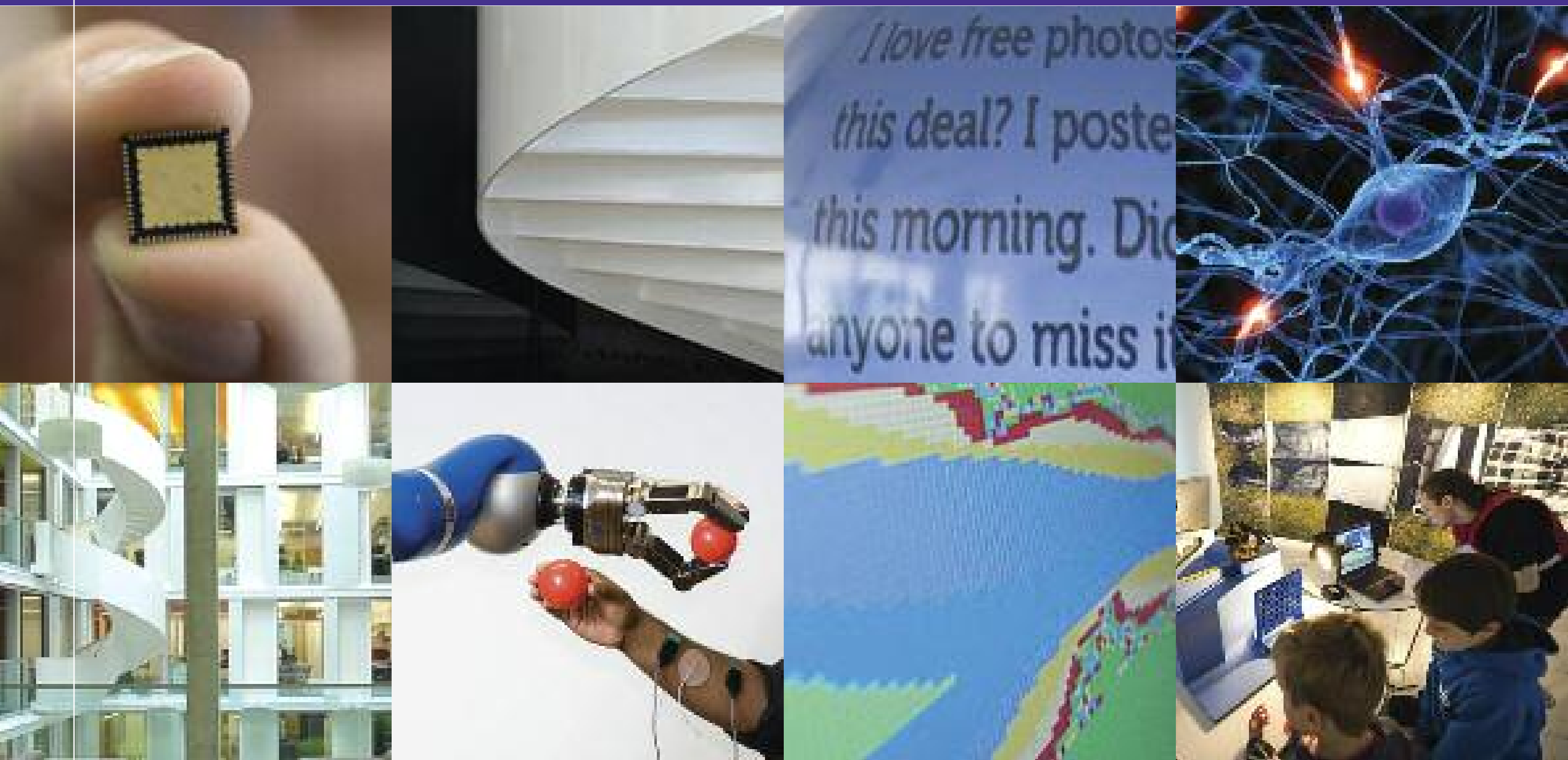

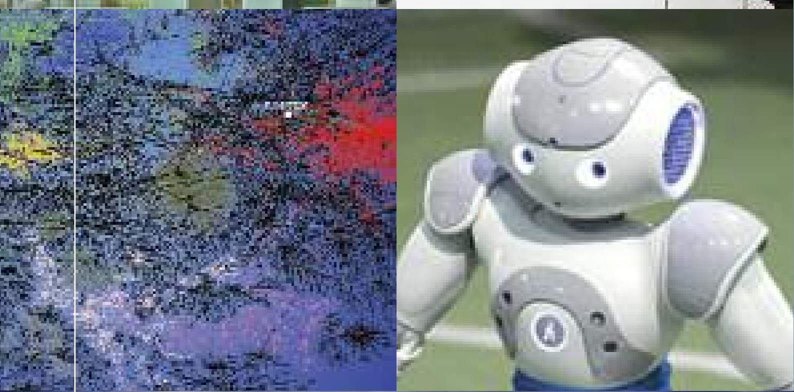

Informatics

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Foreword

PROFESSOR MUFFY CALDER

Informatics

This issue of *Science Scotland* focuses on some of the research challenges for Computing Science and Informatics, and advances made by researchers in these areas across Scotland. These are exciting times, as computing and information systems are becoming smaller and larger (from iPhone to air traffic control), more interconnected and mobile, and sometimes more autonomous. They involve new types of human interaction, from touch to smell and thought, and they are becoming integrated into our entire social infrastructure, from Facebook to government. We are increasingly reliant on these systems for advances in other areas of science – in mathematics, technology, medicine and the arts. From rocket science to internet shopping, the power of computing is changing lives. But the sheer ubiquity of computing sometimes obscures the fundamental intellectual challenges of the discipline; this issue aims to reveal some of these challenges.

The main focus of the issue is on SICSA – the Scottish Informatics and Computing Science Alliance, a collaboration of over 200 researchers in Scottish Universities. It was formed in recognition that Scotland has one of the five biggest top-quality research clusters in Computing Science and Informatics in the world, with a critical mass of research excellence rivalling Boston, Pittsburgh, Kyoto and Silicon Valley. SICSA is already catalysing new collaborations between universities, and allowing Scottish institutions to exploit critical mass in funding, recruitment and commercialisation.

The overarching research aim of SICSA is to secure, interface, model and engineer the systems of tomorrow. Some of the highlights covered here include low-carbon computing, system robustness, mathematical modelling and next-generation internet. For example, research in low-carbon computing aims to answer questions such as how to design energy-efficient hardware and software, without which computing system energy consumption is set to treble over the next decade. Research in modelling uses advanced mathematics and computer science theories to model and reason about system behaviour: when there are hundreds of variables and millions of system states that cannot be explored by raw compute power, clever representations of problems are needed. This research applies to both computing systems and other systems such as biological ones, thus demonstrating the effect computing is having on thinking in other disciplines. Robustness involves developing systems in which data are secure yet easily accessible, and the systems are platform- and location-independent; for example, we might require a system to run on a mobile phone or a laptop. Research into the next-generation internet is motivated by the fact that we are running out of internet addresses, and soon speed and security just won't be acceptable.

The last two articles cover advances in two other, related, organisations: the Edinburgh Parallel Computing Centre (EPCC) and the Scottish Bioinformatics Forum (SBF). The EPCC is a supercomputing research centre that has developed and applied supercomputing research to a wide range of problems requiring massive compute power, ranging from challenges set by physics research to those encountered by large businesses, such as Rolls Royce, as well as by small- and medium-sized enterprises. The SBF brings together researchers in industry with bioinformatics activities and researchers across several academic research pools in, for example, the life and medical sciences, engineering and computing."

Professor Muffy Calder, FRSE, FIET, FBCS

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The net worth of networks

The Scottish Informatics and Computer Science Alliance (SICSA) is helping Scotland punch above its weight in the highly competitive world of computing. It is the biggest cluster of computing researchers in Europe, bringing together more than 200 leading academics in 11 universities throughout the country, and its members attract a significant share of the UK's total ICS research funds. After two years, SICSA is beginning to establish itself as a significant force in international computer science, recruiting world-class researchers at the same time as building strong connections with business at home and abroad. So how will SICSA develop in future – and contribute to the national economy?

SICSA may appear to be a "virtual" community of academic researchers, but the organisation is focused on real-world objectives – not just in terms of technological or economic benefits but also the role of computing in everyday life. Ultimately, SICSA wants breakthrough ideas and products to generate profits for business in Scotland and beyond, but it also wants to make a difference by having an impact on society, culture and health – how people use intelligent devices to interact with each other and access different services.

According to founding director Jon Oberlander, who is now the director of knowledge exchange, SICSA is a "vibrant ecosystem" of people and organisations, set up to take advantage of new opportunities in ICS (informatics and computer science) by leveraging Scotland's strengths in various disciplines and combining this with world-class international recruits. And within two years, SICSA has not only managed to achieve its initial objectives but has also become a first point of contact for outside investors, including industry giants such as Google, Apple, Lockheed Martin, Amazon, Microsoft and Cisco, who are now beginning to regard SICSA as the "portal" to Scotland's leading research groups and ICS talent – or what new director Ian Sommerville calls a "one-stop shop" for potential investors and industry partners.

In Sommerville's opinion, the "easy part" (including recruitment) is over – and the real challenge still lies ahead. The two original objectives were to improve the quality of the research done in Scotland and change the research culture from competitive to co-operative. SICSA has made a significant difference already, he says. In the past, researchers tended to collaborate with overseas partners, but SICSA set out to create the circumstances where researchers would find partners closer to home, and Sommerville believes that there is "a greater realisation of the need for openness and understanding" as a result. "The next two years will be more challenging, however," he adds. "Creating critical mass is vital. Everyone now has to work together to put our ideas in action."

SICSA research projects

"The music industry used to be controlled by record labels and radio – now it is being controlled by you."
Research at **Robert Gordon University** is supporting this trend and creating new ways to enhance the online music world. **Ben Horsburgh's** PhD project focuses on music recommendation and making improvements by forging a link between human semantic descriptions and the audio itself. Many online websites, such as Last.fm, allow users to freely 'tag' artists and songs, creating rich vocabularies. At present, however, a computer cannot understand these words and link them to the actual sound of what has been tagged. When this link has been fully achieved, websites may be able to recommend music by knowing what you like as well as your best friend does.

PROFESSOR IAN SOMMERVILLE: HIGH-QUALITY RESEARCH IS KEY TO SUCCESS.

According to Alan Settery, SICSA's Business Development Executive, the next step is to make further progress with knowledge exchange and secure funding, by "seamlessly bringing together Scotland's diverse community" of researchers on collaborative projects. This involves creating "academic champions" to spend more time focused on knowledge exchange, within SICSA and beyond. The recent academic and research appointments from countries all around the world also help to create an "instant international network" of people and activities which enables SICSA to compete at an international level.

Sommerville, who has been involved with SICSA since the outset and was until recently Director of the Graduate Academy, also believes it's important to expose SICSA's PhD students to international experts, via conferences and master classes, and "get involved in collaborative activities," as part of the effort to encourage a culture change among academic researchers in general.

Collaboration is the key to the success of any organisation which hopes to make progress in the competitive world of computing. As Oberlander puts it, "if you collaborate more, you also get more funding," but collaboration also produces results which are more than the sum of their parts. In Scotland's case, this means bringing together a wide range of ICS talent, including world leaders in topics such as information retrieval, networking, linguistics, data modelling, security and machine learning.

Oberlander also says that SICSA has changed his own perceptions about people's "willingness to co-operate." Scotland has a long tradition in interdisciplinary research – for example, during the Enlightenment – and many researchers are used to the idea of working together and sharing ideas, and treating each other as equals. Collaboration is becoming "second nature" now, says Oberlander.

What is SICSA?

The Scottish Informatics and Computer Science Alliance (SICSA) was set up in 2008 to make the country's universities more "globally competitive" and rival existing research clusters in places such as Stanford University. It also aimed to "catalyse new collaborations" and "exploit critical mass in funding, recruitment and commercialisation." So far, this has involved an investment of about £30 million, jointly funded by the Scottish Funding Council and the universities themselves, recruiting more than 30 world-class ICS researchers and funding 20 PhD students per year (aiming for a total of 80 students over the first five years), not just from Scotland but from all around the world.

One of SICSA's key activities is knowledge exchange. In practical terms, this involves facilitating collaboration among different groups of researchers, not just in ICS but also in other academic disciplines. It also means providing educational support, including funding PhDs and organising conferences, distinguished visitor lectures and training courses for students, covering subjects such as entrepreneurship and venture creation, as well as building links with industry to turn academic research into real-world applications and products.

SICSA focuses on four strategic research themes:

1. **Next Generation Internet** (including security and trust, programmability, manageability and mobility)
2. **Multimodel Interaction** (focusing on multiple, rich communication channels between people and vast bodies of information)
3. **Modelling and Abstraction** (the development and use of predictive models)
4. **Complex Systems Engineering** (to meet the needs of industry and society)

The overall objective of these four research themes is to "secure, interface, model and engineer the systems of tomorrow." Specific research topics cover virtually all areas of ICS, both theoretical and practical, including hardware design, networking and middleware, wetware, artificial intelligence, human–computer interaction and social informatics. SICSA also encourages interdisciplinary projects involving maths, engineering, psychology, the humanities and the social sciences.

The participating universities are:

- Aberdeen (Computing Science)
- Abertay Dundee (Computing and Engineering Systems & Institute of Arts, Media and Computer Games)
- Dundee (Computing)
- Edinburgh (Informatics)
- Edinburgh Napier (Centre for Informatics Research)
- Glasgow (Computing Science)
- Heriot-Watt (Mathematical and Computer Sciences)
- Robert Gordon (Computing)
- St Andrews (Computer Science)
- Stirling (Computing Science and Mathematics)
- Strathclyde (Computer and Information Sciences)

Commercialisation: From Blue Sky to Real World

The primary purpose of SICSA is to strengthen Scotland's research capabilities and encourage the informatics community to collaborate more, but commercialisation is becoming increasingly important – to make best use of Scotland's intellectual assets to develop the economy.

According to SICSA's Business Development Executive, Alan Settery, there needs to be a culture change in the researchers' approach to commercialisation, as well as greater emphasis on teamwork. "Blue sky thinking" can lead to significant breakthroughs, says Settery, but the pressure is growing to deliver concrete economic benefits and marketable products.

One of Settery's jobs is to help informatics innovators in Scotland engage with home-grown SMEs (small- and medium-sized enterprises), as well as build bridges with large corporations. The multinationals are not just on the look-out for talent and products but also want to talk about the skills sets they believe the industry will need in years ahead, so universities can plan their future courses and equip graduates accordingly. Some of these companies have a long "shopping list" when they arrive for discussions with SICSA, or are looking for specific skills. For example, if they plan to build a new data centre in Scotland, they will be looking for graduates with the appropriate training – students "prepared for the real world," as Settery puts it.

Settery describes his primary aims as marketing, branding and public relations, to raise awareness of SICSA, as well as promotion of knowledge exchange – including commercialisation – "to the benefit of science and society." This involves focusing on what he calls "capability mapping," gathering data on what research is going on in Scotland and the skill sets available, trawling the country for talent then providing a national showcase. In Settery's opinion, research today is driven by "market demand problem solving," and even though SICSA is built around four major themes, there is lots of research going on in other areas. Settery's job is therefore to help to identify interesting projects across the whole spectrum of research, linking knowledge transfer right across Scotland.

When it comes to commercialisation of Scotland's informatics research, SICSA doesn't seek to duplicate what other existing knowledge transfer programmes are doing but complement them – and add momentum. According to Settery, it's also important to recognise that "one solution does not fit all" universities or individual researchers. The University of Edinburgh (UoE) has the largest informatics department in Europe, and Settery says that his aim is to "dovetail into existing knowledge transfer programmes" such as ProspeKT, a partnership between UoE and Scottish Enterprise, as well as into other programmes across Scottish universities such as Converge at Heriot-Watt and the University of Glasgow's Innovation Network.

SICSA seeks to embed itself in all informatics activities happening in Scotland and works very closely with other organisations "to inspire students to take a more entrepreneurial approach," to commercialise research and found new companies. This activity is strongly supported by Informatics Ventures, another UoE programme, which was set up in 2008 to nurture a profitable Scottish technology cluster and "increase the economic impact of Scotland's formidable base of research and innovation." About a quarter of all SICSA events revolve around knowledge exchange, and most of these focus on entrepreneurship, says Settery, welcoming PhD students from all institutions. These events expose the students to commercial activities, bringing in industry experts to encourage best practice and teach people how to pitch for funding, venture capital and angel investors. A support strategy called "engage, invest and exploit" encourages early start-up and spin-out businesses that need further funding and want to move on from the academic environment to become SMEs. SICSA also organises workshops, meet-ups and industry forums to encourage academics and business to network and learn from each other.

"We must be synergistic, enhance existing knowledge transfer programmes, promote the breadth of the research base and launch new initiatives," Settery says. Ultimately, all the research pools in Scotland will start to engage with each other much more: "Knowledge transfer across multiple disciplines is not yet pooled across Scotland, but convergence will happen as more research teams get established – for example, linking informatics, physics and life sciences."

SICSA research projects

Vijay John is doing a PhD project with the Computer Vision and Image Processing group of the School of Computing at the **University of Dundee**, focusing on **marker-less human motion capture and recognition**. Vijay's system tracks a "skeleton" model of the human body in motion, using synchronised sequences from several video cameras, with and without assuming what action is being performed – e.g. running or jumping. Marker-less human motion capture from video sequences is a major problem in computer vision, with applications in virtual character animation, medical posture analysis, surveillance and human-computer interaction, etc., and the project attempts to accurately estimate and recognise human actions without the need for an expensive commercial marker-based motion capture system.

Progress so far

SICSA's performance can be measured in a number of ways. Executive Officer Chris Jowett highlights the activities organised so far and identifies three key achievements:

- recruiting more than 30 world-class researchers, from overseas and other parts of the UK, plus over 50 new PhD students
- bringing researchers together via different events (e.g. 26 research theme and 11 knowledge exchange events, involvement in five international conferences, and 53 distinguished visitor seminars in 2009-2010)
- engagement with students, including a PhD conference, organised by the students themselves, five summer schools and six training courses in the last year alone, including workshops on practical topics like "how to write a thesis," plus an iPhone "boot camp"

Jowett also talks about what he calls "SICSA-flavoured" activities – for example, events which stress collaboration, or PhD students having access to a pool of nationwide supervisors, to supplement the supervision provided in their own institution. He also says that having an exchange with business and society at large is a characteristic which SICSA very actively promotes. "Availability of funding is highly important," says Jowett, "but we also work hard to establish connections and encourage knowledge exchange between industry and academia" – including classes in commercialisation and entrepreneurship for students.

ALAN SETTERY: LINKING KNOWLEDGE TRANSFER RIGHT ACROSS SCOTLAND

As well as publishing numerous ground-breaking papers, SICSA is proud of the quality of its appointments, as part of its ambition to "increase the net excellence" of the informatics community in Scotland and give its universities an international presence. The new appointments have undoubtedly boosted the "energy" of the research pool, Sommerville says, and the steady stream of distinguished visitors also increases the "internationalisation" of Scotland's research base, with many speakers touring the country rather than simply visiting one institution, as they did in the past.

Diverse Research

When it comes to concrete achievements in terms of research, Oberlander focuses on recent developments in machine learning – which has a major impact right across the spectrum of research and is one of the most important growth areas in informatics today. According to Oberlander, some of SICSA's members are doing important research in the subject, while some are using it to solve real-world problems (e.g. in natural language processing) and others straddle the boundaries between pure research and applications.

The emphasis on machine learning is also reflected in the fact that the 29th International Conference on Machine Learning (ICML) is scheduled to be held in Edinburgh in June 2012, while the Conference on Empirical Methods in Natural Language Processing (EMNLP) will also be held in the capital city in July 2011 – putting Scotland on the world stage in this key strategic area of science.

Sommerville, who is also Professor of Software Engineering at the University of St Andrews, highlights several other areas where Scotland and SICSA already have an international reputation, including digital tourism (or "smart" tourism), networking and distributed systems, Human–Computer Interaction (HCI), cloud computing and socio-technical systems – an area in which Scotland has more top researchers than the rest of the UK added together. The study of socio-technical systems – or "how the system fits with human, social and organisational activities" – is one of Sommerville's specialist subjects. "We should be looking at the broader environmental issues," he explains, "not just the technology itself but how to facilitate different systems working together." Sommerville also describes socio-technical analysis as a "sanity-check" for technology.

Cloud computing is another of Sommerville's passions, with St Andrews hosting a facility for the rest of the SICSA community – the Co-Laboratory for Cloud Computing. Sommerville says the main benefit of cloud computing is not necessarily financial. "There is a lot of hype about savings in costs," he explains, "but the savings are much less than some people try to suggest. Cloud computing does enable new business models and new ways of working, but if you have a predictable workload, there isn't so much benefit – unlike an SME trying to cope with elastic demand."

SICSA research projects

SICSA-funded PhD student **Andrew Macvean** of **Heriot-Watt University** is designing and developing an **affective location-aware game**. Targeting adolescent females, the system aims to improve attitudes towards exercise. Using a selection of psychological models for motivation (previously not investigated within the context of pervasive gaming), the game will require exercise to complete its goals. Sensor technology will then be used to monitor the motivation levels of players, allowing the game to intelligently alter its state, based on the emotions of the user. In this way, as a user becomes bored or demotivated, the game will adapt to the needs of the user to ensure prolonged interest and therefore more exercise.

Low-carbon Computing: The Challenge

One of the biggest worries in technology today is the amount of energy consumed by information and communications technology (ICT). The levels of ICT carbon emissions are second only to the aviation industry and are also set to treble from 2008–2020, according to a recent report by The Climate Group. To address this challenge, SICSA has formed a consortium to do extensive system-wide research into low-carbon computing (LCC), "taking an holistic approach, from the underlying systems up to the organisation."

The vision behind the SICSA work is to "change organisational and user behaviour in usage of ICT systems and services, to enable energy savings of 50% by 2020, above what is possible through energy-efficient hardware alone."

According to a survey by the National Computing Centre, server systems utilisation and power efficiency is typically "very low" in organisations, and only 13.4% of them monitor power consumption. In addition, there is little knowledge or experience about "being green," and current legislation offers very few incentives to be green. In SICSA's opinion, it is not enough to look at technology savings alone but important to focus on people's behaviour and awareness of energy issues, from individual user level upwards.

SICSA plans are to work in five areas to tackle the low carbon challenge:

Measurement & Control *– measure system-wide energy usage in systems and software for ICT systems, and devise appropriate metrics, key performance indicators (KPIs) and policy to control energy usage.*

Modelling & Simulation *– provide models to evaluate alternative energy reduction strategies in heterogeneous large-scale systems and balance energy consumption against non-functional requirements such as performance, dependability and availability of services.*

Software Ecologies *– develop a fine-grained model of the energy characteristics of the individual and interacting software components in desktop systems, and the effects of introducing new components with known energy needs.*

User Behaviour *– provide means for individuals to monitor their energy usage of ICT systems & software and enable support for changing individual user behaviour to reduce energy consumption.*

Organisational Behaviour *– discover the critical socio-technical issues in complex organisations that will influence the use and uptake of low-carbon computing.*

SICSA theme leaders will play a critical role, with Greg Michaelson (Heriot-Watt University) working at the platform level, dealing with "software ecologies," Steve Brewster (University of Glasgow) dealing with user behaviour, Saleem Bhatti (University of St Andrews) focusing on measurement and control and SICSA director Ian Sommerville (University of St Andrews) looking at organisational issues, complemented by Professor Michael Pidd of Lancaster University and Stephen Gilmore of the University of Edinburgh, both working on modelling and simulation. The SICSA team will work with partners in the ICT industry, business and government to produce the final report.

SICSA is adopting an holistic, system-wide approach to LCC, focusing on the "energy-awareness of users, and changing user and organisational behaviour," rather than on technology issues alone. Its proposal states: "Individual users are unaware of the energy usage from their direct or indirect use of ICT systems, especially where such systems may not be restricted to their desktop, but are part of a large, distributed system, e.g. use of cloud systems." And this approach requires the team to work across multiple disciplines and universities, drawing on a pool of talent all across the country to deal with an issue that is not just of national interest but of increasing global concern.

SICSA research projects

Yolanda Vazquez-Alvarez of the School of Computing Science at the **University of Glasgow**, is designing ***Spatial Audio Interfaces for Mobile Devices: Supporting Multitasking and Context Information.*** As the functionality of mobile devices increases, users perform more tasks when mobile and increasingly require eyes-free multitasking. Many tasks performed on mobile devices are also related to context information such as finding a restaurant on a mobile service search application. Thus, future audio interfaces will have to support multiple audio streams to enable multitasking and potentially some means of audio spatialisation to represent context, i.e. location-based information. The aim of Yolanda's project is to evaluate different techniques for simultaneously presenting multiple audio streams when mobile, including 3D audio techniques, "to better understand the affordances of these different delivery mechanisms."

Future targets

As well as facilitating world-class research, SICSA is adding momentum to many other international projects – for example, the recent bid for funding from the European Institute of Innovation and Technology's Knowledge and Innovation Community, with support from other national organisations including Scottish Enterprise. Oberlander sees this particular bid as a perfect example of SICSA's core mission – to exploit its critical mass to secure large-scale funding.

Sommerville highlights another recent initiative where SICSA will collaborate with other researchers to develop "low-carbon computing" technologies, including power usage in data centres, and infrastructure, as well as other major projects in "technology-enhanced tourism" and technology-assisted healthcare.

Ultimately, SICSA will be judged by the quality of its research, its commercial success and contribution to the national economy. "It's easy to attract people to Scotland and persuade them to stay," says Sommerville. "It's also important to showcase research and facilitate networking among our researchers and strengthen links with business, but the key thing is to develop our research so that Scotland retains and improves its position amongst the world leaders in ICS research."

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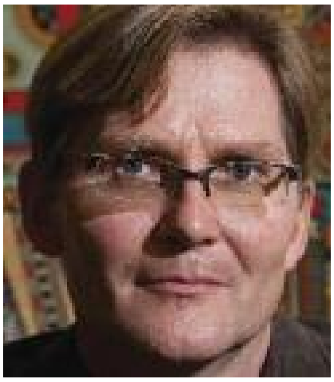


PROFESSOR JON OBERLANDER

In search of the invisible computer...

Professor Jon Oberlander talks about his experience as the founding director of SICSA and how it mirrors his own academic career – bringing diverse disciplines together so the end result is greater than the sum of its parts...

In informatics, everybody talks about solutions, but for Jon Oberlander, it isn't so much about answering questions as "asking new questions and finding new ways to ask questions." Oberlander's first degree was in philosophy, and listening to him today, more concerned with human dialogue and ethics than hardware and software, the former SICSA director seems to have travelled full circle. But his career so far is just as much a spiral as a circle, returning to subjects again and again, to see them from different perspectives, gained through his experience with different researchers and projects. And the last three years as founding director of SICSA have exposed him to a more diverse range of projects than ever before, some of which may seem at first more science fiction than science.

Oberlander's "spiralling" career path also reflects the way that informatics has evolved in recent years, drawing together researchers from the arts and social sciences as well as computing. Now SICSA's director of knowledge exchange and Professor of Epistemics in the University of Edinburgh's School of Informatics, as a young man he wanted to study artificial intelligence but was persuaded to explore more general studies and specialise later. After graduating in philosophy from Pembroke College, Cambridge, he received his PhD in cognitive science at the University of Edinburgh, in 1987. Later on, he started to focus on natural language processing and "the intersection of computational linguistics and cognitive science" – how human beings interact with each other as well as with machines, with the ultimate aim of creating more "human" machines.

Communication is the key to Oberlander's research – whether it is words, graphics, icons or gestures. For example, he recently analysed thousands of blogs by comparing the results of personality tests with the style of the writing (as opposed to the content), analysing the typical characteristics of extroverts and introverts and the different expressions they use – even the way people use very simple devices such as exclamation marks, full stops and parenthesis. By mapping such characteristics, it should be possible to "psychoanalyse" people simply by reading their emails – interpreting the "secret" signals all of us send to each other.

Oberlander also talks enthusiastically about the challenges faced in developing robots which have "social graces" and are able to empathise with human beings, recognising how we feel and making the appropriate response. For example, SICSA researchers are currently engaged in a joint research project with colleagues in Greece and Germany to develop an "intelligent barman" called James. The idea is not to programme social skills into the robot but to make it capable of learning them, Oberlander explains. And what interests him most about projects like this is that in the process of developing the robot, we are forced to ask ourselves what makes us human. For example, human beings "align" with each other when we talk to each other – echoing each other's words and mirroring our body language (crossing arms and legs, etc.). To build a "realistic" robot, therefore, it has to be able to learn for itself how to align with the people it meets. Similarly, if we want to build a robot which is capable of making decisions, then we have to understand not just how human beings make decisions by building a model of the decision-making process, but also how they learn to make decisions.

SICSA research projects

Life sciences have traditionally relied on manual analysis of experimental datasets to determine biological significance. However, this is no longer feasible due to the large amounts of data produced by advances in instrumentation and experimental protocols, and scientists now depend on computer-based analysis and visualisation. New software developed by **Yasmeen Ahmad** of the **University of Dundee** provides a suite of tools to meet the fast-increasing needs of proteomics research (***"Computational Tools for the Management and Mining of Cell Biology Data"***). The new software, called PepTracker, collates a large number of experiments and enables researchers to carry out novel computational analysis involving super-experiments, bringing datasets together to enhance one another and extend into new biological exploration.

JON OBERLANDER: "WE CAN'T GET THE TECHNOLOGY RIGHT WITHOUT UNDERSTANDING OURSELVES BETTER."

These intelligent machines are not simply clever devices but "models of real things." Some researchers, says Oberlander, are even beginning to create "digital animals" (e.g. ants), not for its own sake but in order to learn what hardware and software is needed to be a "successful" animal, and how the same techniques may be employed for more practical applications.

Oberlander's interest in human–machine interaction dates back to his work at the Human Communication Research Centre (HCRC), an interdisciplinary research centre at the Universities of Edinburgh and Glasgow, founded in 1989. As soon as HCRC researchers started building up large collections of human conversations and extending techniques for computational linguistics, they started to accumulate a huge amount of data – and that was how, for Oberlander, one discipline led to another.

Scotland, especially Glasgow, has traditional strengths in information retrieval, but as Oberlander's colleagues got to grips with the masses of information linked to human conversations, they developed a new strand of expertise in information extraction, at the same time finding common cause with researchers in more mainstream areas of computing.

Over the years, collaboration has become second nature to Oberlander and his fellow researchers. "To stretch yourself," he says, "you need to find new challenges, and tackling these new challenges demands collaboration.If disciplines look inward, they become less interesting. If they look outward, they become much more healthy."

The social dimension

For Oberlander, social challenges are also of central importance, including how to make complex systems more usable and improve our quality of life by developing more advanced systems and tools in tune with individual requirements – including non-technical users.

Easy access to technology is also important. "We are at a transformational point in society," says Oberlander, "and informatics is the glue which keeps us together. The social effects of new communication tools are really just beginning to make themselves felt. These tools could pull existing institutions apart, but they can also pull us together."

The Internet may be an increasingly social place, but Oberlander questions whether the Web as we know it today is as smart as it should be. For example, researchers have long been predicting the advent of the "Semantic Web" – a term coined by World Wide Web pioneer Tim Berners-Lee to describe methods and technologies which allow machines to understand the meaning of information. In this more advanced "linked data" Web, the intelligent agents are smart enough to put information in context, act on our behalf, search, shop or negotiate, not simply follow the obvious path to an answer – in other words, "think" for themselves, as if they are extensions of the people who use them.

Technology, however, is not yet as advanced or pervasive as we sometimes believe, he continues. Broadband coverage does not yet cover every part of Scotland, and bandwidth is limited. There are also many privacy issues to deal with. At the same time, increased coverage brings with it deeper questions about privacy, as people start to question their relationship with digital media such as social networks and use smart devices which not only know where we are all the time but also gather masses of personal data, as if they know much more about us than we do.

Intelligent systems which help to improve life (or "technologies for assisted living") are coming closer to reality, says Oberlander, and a major focus of SICSA research. For example, researchers who are working on social inclusion at the University of Dundee are developing a new AI (artificial intelligence) system which uses visual tools and synthesised speech to provide subtle prompts to people with cognitive or memory problems (e.g. Alzheimer's sufferers), combining perception and reason to know when it's appropriate to intervene and talk to the person in need, trying not to be obtrusive or annoying while the person is doing an everyday task such as boiling a kettle.

Who's watching?

It may be hard to draw the line between surveillance and monitoring or observation, but technologies are already being developed that blur the distinction. For example, Oberlander draws attention to the "meeting room" created in the Informatics Forum – an intelligent room which listens to discussions, using speech recognition to search the Internet for relevant data.

Although this may seem rather scary, like having someone read our minds, Oberlander takes an optimistic view of future technologies, stressing the benefits of personalisation – including the idea that we can be more in control of the data and systems we use, with computing tools which learn from our experience rather than simply processing masses of data which we may or may not find useful. Oberlander himself has helped to develop a "personalised interaction" solution for use in museums which allows the visitor to experience different exhibits and discover a web of connections between them, building up new data in the process, rather than simply moving from exhibit to exhibit in sequence, and hearing the same script as everyone else.

Oberlander also cites the example of FestBuzz, an application developed in Edinburgh by Jennie Lees, which puts together "crowd-sourced" reviews of events at the Edinburgh Festival, helping users check what other people like or dislike by scanning "the word on the tweet" instead of depending on "expert" reviews in conventional media outlets.

When it comes to privacy issues in general, Oberlander takes the view that Europe has the chance to get it right when it comes to information security by providing individual protection without stifling innovation. "Smart technologies promise a lot, but there's always a price," he says. "You have to give up information about yourself. We have to help people make sensible decisions about these bargains, and we're just not there yet."

Art of the possible

As well as being interested in public engagement with science, Oberlander (who comes from a family of architects) also has a passion for the visual arts and loves to show his visitors the School of Informatics' collection of works by the Edinburgh artist Eduardo Paolozzi, who tried to visualise the art of the machine – the complex and abstract connections between different concepts and data – in a series of screenprints inspired by Britain's "father of computing" Alan Turing. He is also director of Inspace, a project to "make research visible, by exploring the cultural significance of informatics and new media practice," run by the School of Informatics in partnership with New Media Scotland. One recent project – blipfoto.com's "life.turns" – gathers images from photographers based in countries all around the world, and Oberlander stresses that such mass participation highlights the fact that groups of individuals with the right tools can achieve things that organisations will never be able to do.

This visual theme is also reflected in Oberlander's interest in graphical communication and multi-modal interfaces, including a project in Glasgow to develop a "no-touch" computer which responds to hand gestures rather than keyboard or mouse. For example, you may wish to invite someone to share a resource like a web page. The question is what gestures are we comfortable with – and which gestures may be misinterpreted or even cause offence in different cultures?

Oberlander believes that the ideal information system should be about "conversation not navigation," so systems learn and adapt to our personal needs. It's not so much about technology as people. "And we can't get the technology right," he declares, "without understanding ourselves better."

Such questions will continue to challenge researchers and Oberlander believes that the ultimate breakthrough will come when the computer is invisible, so smart and unobtrusive that we don't even notice it's there – until it goes wrong. It is ironic, he continues, that the more technology changes, the more we like things to stay the same, at least on the surface. As innovations are developed, they are used to make the world look much the same as it has always looked. "

The future will look a lot more like the present than some of us like to think," he says. "But that's a matter of styling – there will be plenty of changes under the bonnet."

SICSA research projects

Miguel Lurgi of the **University of Edinburgh** is doing an MSc project which focuses on **artificial or "intelligent" agents**. He writes: "In complex systems of autonomous intelligent agents, it is important to advance the emergence of stable networks of relationships among them in order to provide the system with robustness and persistence. In ecological systems of interacting species, this problem has been perfected through the process of evolution by natural selection – real communities form entangled networks of interacting individuals that display features of complex systems (e.g. self-organisation, adaptation). We take inspiration from the mechanisms acting at the individual level of interactions among biological organisms in mutualistic associations in order to promote stability and collaboration in societies of artificial agents." One application would be to implement a digital business ecosystem in which the agents represent companies seeking appropriate partners for collaboration.

did you know?

13 hours of video per minute is uploaded to YouTube – which accounts for about 10 per cent of all Internet traffic...

PROFESSOR JANE HILLSTON

Model behaviour

Understanding vast amounts of data from experiments is always a challenge, and sometimes we can't see the wood for the trees – or see what we wish to see rather than what's really there. No matter how powerful computers become, it's the maths not just the hardware that reveals what is happening under the surface...

One of the biggest challenges in computer science today is how to make sense of the fast-growing mountains of data generated by research across a range of different disciplines, including social sciences, life sciences and business – looking at everything from how people move around cities and buildings, the behaviour of insects, biochemical pathways and nerve cells, to project management, logistics, financial analysis and traffic control.

According to Professor Jane Hillston, SICSA's theme leader for modelling and abstraction, the use of advanced mathematics – particularly appropriate abstractions – makes a critical difference in the analysis of data, sometimes speeding up the process from several hours to a matter of seconds, at the same time as improving understanding, validation of theories and the accuracy of predictions.

Trying to model a system may involve hundreds of interacting variables and millions of states or "possible configurations" of the system. When the number of states gets too large, there can even be what mathematicians describe as "state space explosion," and modelling becomes extremely difficult. If you tried to analyse every single combination of factors, the process would be highly complex and take lots of time, and the final results may not seem very clear. But if you eliminate the most unlikely outcomes and assume that very large populations will behave in more predictable or "average" ways, the problem becomes much simpler to model and easier to understand. In other words, behaviour can often be less random and more "systematic" than we may at first believe, and understanding this in one application – in nature or human behaviour – can help in many other different spheres by developing appropriate models to map that behaviour.

For example, studying problems in systems biology can inspire the development of a way of modelling which helps design buildings, to make them safer in emergencies such as fires. The two applications may seem very different, but modelling the behaviour of cells in an organism can be regarded as similar to the ways groups of people behave in a designed or engineered environment such as a building, or what Hillston describes, in this case, as "using a dialect of process algebra developed in the context of biology to analyse crowds."

Hillston initially trained as a mathematician. At that time, using a computer was a novelty – simply a tool which she used overnight to batch-process large calculations. After graduating with degrees in mathematics from the University of York and Lehigh University in the US, she worked for Logica Financial Systems in London, and became increasingly interested in how computers work, ultimately leading her to Edinburgh to do a PhD in computer science. Her specialist subject is the development of languages to sit between computer systems and mathematics, "making it easier to construct and learn from mathematical models about the dynamic behaviour of the system." In this area of performance modelling, she explains, the focus is on the timeliness of behaviour and efficient use of resources rather than on the correctness of systems with respect to specified behaviour.

Having established herself as a computer scientist, Hillston is now branching out in different directions, with an emphasis on systems biology. Scotland is developing a strong reputation in systems biology, and modelling and abstraction has a large contribution to make, she says, moving beyond its traditional role in computer science, where it is used to check the behaviour of systems, to help marshal the increasingly large datasets generated by advanced experimental techniques.

"Modelling is the bottleneck in systems biology," Hillston explains, and computer scientists who specialise in modelling and abstraction are in high demand in that sector because they are used to abstracting ideas and enshrining them in languages which help us to understand problems – working with a simple language to give a mechanistic account of what is happening. "We develop formal descriptions," says Hillston, "to make it easier to describe systems and translate them into formal models which can be used to test and formulate hypotheses to explain the data."

SICSA research projects

Lars Kotthoff of the **University of St Andrews** is developing **smarter software** that "adapts itself to the problem it solves." The kind of problems under consideration involve exploring very large search spaces to find solutions. If the software can rule out large parts of this search space, the problem can sometimes be solved in a matter of seconds, instead of days. The current state-of-the-art systems are highly tuned but also general, so that they are able to solve many different types of problems. Lars' research is about taking advantage of additional information about specific problems as they are solved and using this knowledge to improve performance.

JANE HILLSTON: COMPUTER SCIENTISTS HAVE A PIVOTAL ROLE TO PLAY IN MULTIDISCIPLINARY WORK.

The SICSA challenge

When SICSA decided that modelling and abstraction would be one of its four major themes, Hillston and her colleagues were completely open-minded about which direction to go. The idea was to try to identify the key challenges within the theme, and systems biology simply came top of the list, along with other topics such as ubiquitous systems modelling – for example, modelling how small embedded computers interact with each other.

Another field attracting increasing attention is epidemiological modelling. At the University of Stirling, for example, mathematical biologists are working with computer scientists to use formal modelling methods to understand disease and disease spread. Their research project has looked at the spread of bubonic plague amongst prairie dogs and at bovine tuberculosis, to investigate the effects of different interventions. The Stirling-based research team also recently organised a workshop on multi-scale modelling to disseminate their results and provide a forum for other researchers working on similar topics. At Heriot-Watt University, a different computer science-based approach to modelling has been used to study the progression of HIV infection.

"Computer science is coming of age," says Hillston, "and playing an important role in many other disciplines such as systems biology, where the interface is a rich one and practical benefits may be achieved."

One of the projects she is working on now is a study of the Circadian clock mechanism in plants – how cells respond to the light and dark cycle of days. Individual cells behave in individual ways in different seasons and weather conditions, and building a stochastic model (taking account of randomness) helps to analyse what is happening to identify how robust the individual cells are, with a view to developing new breeds of plants which will give better crop yields by taking better advantage of daylight. For this particular project, Hillston's team is led by one of her post-doctoral researchers, Maria Luisa Guerriero, working in collaboration with Professor Andrew Millar and his team at the Centre for Systems Biology at Edinburgh.

SICSA research projects

In a joint project between the school of computing and the school of nursing at the **University of Dundee**, PhD student **Zahra Zohoor** is developing a **self-management tool** to help survivors of head and neck cancer. The new tools will be web-based and focus on older adults who have completed their primary course of treatment and are trying to cope with the long-term social, physical and emotional side-effects of cancer. The system will provide both expert advice and peer support so that patients can self-manage these side effects. The design of the tool will be based on a structured review of the literature, a patient-centred assessment of needs and consultation with clinical specialists.

Modelling & Abstraction

The development and use of predictive models is a common strategy in the analysis of complex systems of interacting elements. In some cases, the primary task is to create a model from observed data which best encapsulates the current knowledge of the system, to aid our understanding of the natural sciences, the life sciences and, increasingly, the social sciences – e.g. communities of insects, gene expression networks and interacting nerve cells. Where the system under study is designed or engineered, the principal aim is to construct a model which abstracts from detail but which will nevertheless facilitate reasoning and analysis.

In the context of computer systems, the development and analysis of models complement traditional design review and testing. Artefacts built in software and hardware must often be scrutinised by appropriate models to ensure the appropriateness of their behaviour. This is increasingly seen as crucial if complex computer systems – on which so much of the modern high-tech economy depends – are to function reliably, safely and efficiently.

Computational modelling is now an established approach to understanding the nervous system, and work in Scotland ranges from foundational modelling to neuroscience and systems biology, focusing on scalable analysis, not just to deal with very complex systems but because the models themselves are so vast that they require new analysis techniques, system description languages, methods and tools.

Scottish researchers already collaborate on the application of process algebras to systems biology, and on model checking techniques. By bringing all this work together, and by stimulating neuroscience modelling and visualisation, SICSA aims for scientists in Scotland to take a leading international role in developing scalable analysis.

SICSA research projects

Three SICSA-funded PhD students at the School of Computer Science at the **University of St Andrews**, are working on a joint project involving StACC – the St Andrews Cloud Computing Co-laboratory. According to **Ali Khajeh-Hosseini, David Greenwood and James Smith**, "Cloud computing represents a shift away from computing as a product that is purchased, to computing as a service that is delivered to consumers over the internet from large-scale data centres – or 'clouds'. New cloud computing services provided by companies such as Amazon, Microsoft and Google have raised significant interest in enterprises and many organisations are questioning whether the cloud offers a better way of providing IT." The **Cloud Adoption Toolkit** being developed by the three students is designed to help decision makers address this question and make better use of cloud computing.

Pruning the tree

Research in one area often has surprising implications in other fields. SICSA-funded researchers at the University of Strathclyde, for example, are developing planning techniques to help with project management and scheduling, including new techniques to handle "probabilities of success." These techniques have a wide range of applications including air traffic control and logistics, and a key area of research is to limit the number of possibilities which must be considered, akin to "pruning a tree" to concentrate growth in the most promising direction. In planning processes such as scheduling planes for landing and take off, choices must be made between alternative orderings. Each choice and the subsequent events can be regarded as one "branch". Important criteria such as safety and efficiency must be taken into consideration at each branch point, but there may still be many valid branches. The techniques developed at Strathclyde aim to identify an optimal "plan" or sequence of decisions, even in situations when time and probability of success may alter according to the decisions made.

What interests Hillston is identifying the key features of diverse problems, whether it is scheduling the mixing of concrete, delivering parcels or managing airports, to develop modelling approaches which have wide applicability to what may seem at first like very different processes. In her own work, for example, she has used modelling approaches developed for cells and signal processing to analyse human behaviour. One recent study looks at what happens when people evacuate buildings, and Hillston is currently talking to fire engineers to find out how she can help them give advice to designers and owners of buildings to improve their safety. This particular project was inspired by the use of personalised electronic tags which can monitor people in real time as they move around an area such as an airport or hospital, much like electronic tagging for convicted criminals – and so offer personalised advice on navigation.

Psychology vs technology

Hillston thinks computer scientists have a pivotal role to play in multidisciplinary work – a big change from the days when they were treated as technicians by other researchers. "There was a fear we would be asked to write the software," she continues, "but computer science can offer not just a service but a true collaboration with other disciplines, solving intellectual problems and stimulating developments in other fields."

SICSA has encouraged collaboration between different disciplines right from the start. "We always try to think creatively about who talks to whom," she says. "And this creates a lot of possibilities for cross-fertilisation of ideas within and between different disciplines."

In Hillston's view, this translates into a "style" of intellectual enquiry rather than simply a collection of methods, and researchers who are exposed to this kind of collaborative environment often find themselves changing direction when they see their work from different perspectives.

Having started off in pure mathematics and gradually become more involved with computers, Hillston is well placed to describe how informatics has evolved through the years. Formal modelling has emerged from its use in computer system testing and design to become a useful tool in other disciplines, but no matter how spectacular, technological progress is not the whole story.

"There has been a change of ethos rather than technology, psychological rather than technological," she says. "Computer science has gained more confidence as a discipline and realised it has a huge contribution to make to other disciplines."

did you know?

Google refreshes about 20Tb of data every four hours...

The system of systems of systems

Most computer users never stop to think about what's in the box or "out there" in the corporate network, but there is more to it than hardware or the application software producing results on the screen. Faced with our increasing dependence on increasingly complex networks of computers, the scientists involved in complex systems engineering are trying to improve performance by developing intelligent systems of systems – as well as educating the people and organisations who use them...

PROFESSOR GREG MICHAELSON

What do *The Buddha and the Robot*, lambda calculus and complex systems engineering have in common? The answer is Professor Greg Michaelson – computer scientist and novelist, and one of the SICSA theme leaders. As an academic (Professor of Computer Science at Heriot-Watt University), he is interested in programming language design and implementation, "in particular functional languages for parallel, distributed and mobile deployment." And as a writer who has just completed his second novel (the follow-up to *The Wave Singer*), he is interested in trying to describe a dystopian future where people hoard "pieces of technology that can no longer be powered" – somewhat ironic in view of the fact that Michaelson is one of the SICSA team focusing on low-carbon computing (see sidebar), to solve our future energy problems and prevent his own fiction from becoming a reality.

Even though Michaelson may appear to live separate lives, there is a logical connection between them, embodied in his personal approach to computing and teaching – as well as his role as a SICSA theme leader, looking after complex systems engineering (CSE). "I am interested in how computers co-operate," Michaelson says, "but even more interested in how people co-operate."

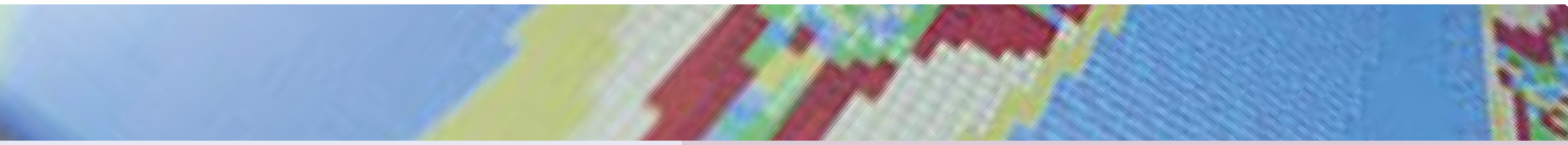
Michaelson focuses on programming languages, taking mathematical ideas and turning them into computer systems which translate data into something meaningful that people can use, at the same time as helping the systems work faster and more efficiently by optimising hardware and software resources. He is also co-designer of the Hume language, "a tool for exploring formal guarantees that software satisfies strong resource bounds," working with colleagues at the universities of Edinburgh, St Andrews and Queens Belfast on "the optimal implementation of Hume on heterogeneous platforms combining multi-core, SIMD and FPGA."

Such language may appear alien or esoteric to non-technological minds, but as a teacher and a writer, Michaelson is also aware of the need to communicate and help people understand what matters in computing. He may analyse the highly complex details of systems to make them work smarter, but he also recognises the need for a "cultural" change in both people and organisations, beyond the mathematics and the science, so they can take full advantage of every technological advance.

Themework...

Similarly, when it comes to Michaelson's role as a SICSA theme leader, his work focuses not only on "systems of systems" but also on the need to "energise" 135 people in 11 universities all over Scotland, organising events (including workshops, seminars and summer schools) and encouraging collaborative projects.

Among the first collaborative groups to emerge from discussions with other specialists in CSE are SEABIS (Self-organising, Emergent, Autonomous, Biologically Inspired Systems), which is headed up by Ben Paechter of Napier University, THREADSS (Theory of Resources for Autonomous, Dependable and Scalable Systems), with Professor Kevin Hammond of the University of St Andrews in charge, plus SEMANTICS (Software Engineering Modelling and Networks: Theories in Computer Science), run by Dr Hans-Wolfgang Loidl of Heriot-Watt University, and SSTS (the Scottish Socio-Technical Systems Network), run by Chris Johnson of the University of Glasgow.



CSE: The Scottish perspective

The fundamental economic, governmental and social infrastructure in society depends on large and complex systems. As hardware and networking capabilities increase, this leads to an increasing demand for greater software capability and integration. It is no longer appropriate to think of these large systems as single entities but as systems of systems whose components are independent entities. New systems of systems must be engineered to meet the needs of industry and society, operating robustly within an often hostile external environment. However, the development of such large-scale systems of systems is problematic, as evidenced by continuing reports of software cost over-runs in large scale projects and repeated failures of systems to satisfy the requirements of those who procure and use them. Furthermore, complex systems constantly change, as hardware and software subsystems are modified and updated, and as user requirements and practices shift. Thus, Complex Systems Engineering (CSE) is a socio-technical as well as a scientific challenge.

The problems of CSE require theoretical and practical research to elaborate new techniques and tools for designing, constructing, modelling, monitoring and reasoning about complex systems, to capture these dynamically changing characteristics. Hence, the research challenges in CSE span a wide range of disciplines from fundamental mathematics, through hierarchies of hardware and software, to educational and organisational change.

Scotland is already an international leader in Complex Systems Engineering. Areas of excellence include programming languages, heterogeneous systems, parallel, distributed and mobile computing, ubiquitous and pervasive systems, socio-technical systems engineering, and evolutionary- and biologically-inspired computing. There are numerous complementary strengths in these key areas across the SICSA partners, and SICSA's intention is to capitalise and grow such synergies. The SICSA CSE theme is also closely linked to the Next Generation Internet and Modelling and Abstraction themes, and enjoys strong cross-theme interactions.

A major collaborative project launched with help from SICSA CSE is the MultiCore Challenge. This will bring together researchers in parallel programming, from Scotland and around the world, to implement applications on networks of multi-core machines and in the process learn about the strengths and weaknesses of current systems. The results were discussed at a workshop in early December 2010.

Like the other theme leaders, Michaelson expects a lot of projects to overlap, drawing on researchers from multiple fields as well as from multiple universities. People may also participate in multiple themes, and Michaelson welcomes the fact that SICSA has provided the framework, as well as the time and the space, to facilitate collaborative projects on a scale which would not have been possible only a few years ago. Michaelson himself has worked with many other academic partners for years but also recognises that SICSA has brought many scientists out of their silos, encouraging them to co-operate more, rather than competing for funding in much smaller groups.

Software ecologies

Michaelson defines CSE as "technologies for managing systems of systems," describing the scope of the challenge as follows: "New systems of systems must be engineered to meet the needs of industry and society, operating robustly within an often hostile external environment." This means using systems to build and understand systems of systems – modelling, managing and understanding complexity, as well as making users more aware of the need to streamline and optimise the networks of computers which government and business are becoming more dependent on as time goes by.

For example, says Michaelson, users generally don't have a clue what the impact will be when they add on new software or open multiple programs – not just in terms of performance but also of potential carbon footprint. "When you buy software, you have no idea what difference it makes to the rest of your system, in terms of resource need as well as the impact on the other software," he says. And his job is to look at this "ecology" of systems to work out how to optimise computing resources, from the desktop level right up to the largest of corporate networks, using the latest mathematical methods to make all these systems work smarter – starting at the lowest level. "Every single instruction also has an energy cost," he explains.

In basic terms, Michaelson and other CSE researchers study what is happening inside the systems of systems, adding up the costs of the instructions and trying to understand the "tree" of decisions the system is being requested to make – as well as the impact that one process has on another. Once they have a picture of the system, they can then suggest improvements which will optimise performance, saving time and energy – and money.

GREG MICHAELSON: "EVERY SINGLE INSTRUCTION ALSO HAS AN ENERGY COST."

One concept used in CSE is the development of "self-aware" or autonomic programs for use in systems such as distributed processing networks. These autonomic systems are smart enough to know how to optimise network resources, automatically allocating different data-processing tasks to the best available components, so that idle or under-used parts of the network can relieve the processing burden on over-used parts. For network managers or users to perform this same task would be virtually impossible, and to develop these intelligent agents, you first have to analyse what is really happening inside the systems of systems.

Michaelson describes the biggest challenges facing CSE researchers today as follows:

TECHNOLOGY: Ensuring the predictability and robustness of enormous heterogeneous systems whose hardware and software components are constantly changing.

USERS: Providing seamless continuity of service which is platform-and location-independent, so users see the same environment wherever they are and whatever they are using: mobile phones, laptops and desktops, on public transport and in internet cafés, etc.

ORGANISATIONAL: Enabling interconnectivity of arbitrary systems across organisations to support shared access to large-scale composite computational/information resources while preserving security and confidentiality of local information.

In Michaelson's script for a short film called *The Buddha and the Robot*, a robot complains to the Buddha about elephants knocking him over. The Buddha makes the robot big enough to knock over the elephants, and they in turn complain and become even bigger, suggesting that the increase in size may go on *ad infinitum* – perhaps a metaphor for the increasingly difficult challenges of complex systems which scientists face...

Interaction in action

If we were designing computers from scratch, using all the different interfaces and other technologies available now, the mouse and the keyboard would probably still be very popular options, along with touch-screens and speech recognition, but our mobile phones, laptops and desktop computers might also be all-singing, all-dancing, all-smelling systems – plugged into our brains...

PROFESSOR STEPHEN BREWSTER

With multimodal human–computer interaction, "you start with the person, not the computer," says Professor Stephen Brewster. And people can now interact with computers in ways that would have been hard to imagine a few years ago – not just with all of their senses but also with their brains.

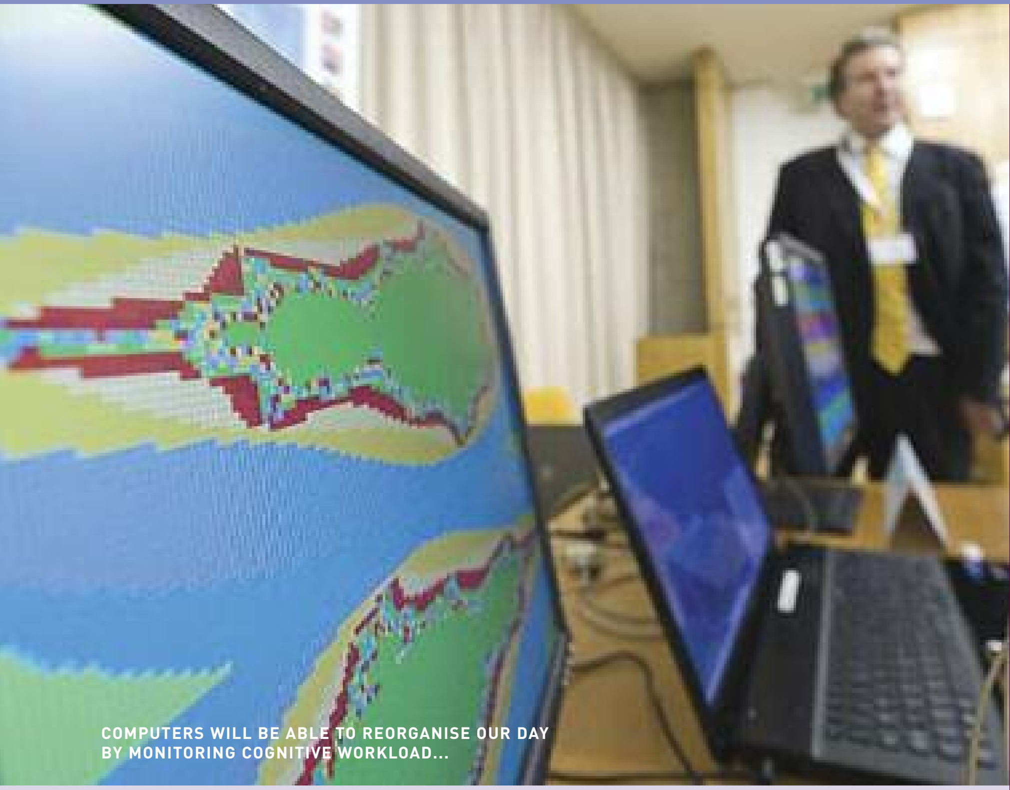
Brewster is SICSA's theme leader for multimodal interaction, Professor of Human–Computer Interaction in the Department of Computing Science at the University of Glasgow, and a key member of the Glasgow Interactive Systems Group – one of the the biggest research groups of its kind in the UK or Europe. Other universities in Scotland also do research in human–computer interaction (HCI), including Abertay (focusing on games), Dundee (accessibility for older and disabled people), Edinburgh Napier (artificial companions), Strathclyde (usability and user experience) and St Andrews (multi-touch and surface displays), while the University of Edinburgh is a leader in speech recognition and synthesis. But Glasgow leads the way in HCI, exploring what Brewster describes as "unusual ways of interaction, "including novel visual and 3D audio systems, tactile and haptic (touch-based) systems which directly interface with the brain by detecting changes in electrical activity, and even experiments with smell-based interfaces. In recent years, the emphasis has also been on mobile applications, taking advantage of the rich technologies now integrated into mobile devices and the fact that mobile computing is becoming ubiquitous – part of our everyday lives.

Many academics define multimodal interaction as simply "different types of interaction," but Brewster prefers to define it as how human beings interact with computers, sending and receiving information via eyes, ears and skin or using gestures – an area of HCI where Glasgow is doing some leading research. Brewster also explains that researchers in Scotland are interested in interfaces which work across the spectrum of human abilities, including people with cognitive, hearing and vision impairments. Theoretically, if researchers make further progress with brain–computer interfaces, even somebody with "locked-in syndrome" may be able to interact via electrodes attached to the scalp, moving a cursor around on a screen just by thinking, without moving one single muscle.

Cultural technology

One of the most intriguing projects going on in Glasgow is research into gestures, looking not just at how to use gestures to interact with mobile devices but also at the social and cultural acceptability of different gestures – e.g. rotating your wrist or tapping parts of your body. Brewster says the group are asking very basic questions, such as "would people use these gestures?" in a normal environment (in the street or an office), without feeling embarrassed or being misunderstood by observers. Would they look weird or feel weird? Are the gestures too complicated or even too simple? Are there any universal gestures which would work in any country without causing problems? Do these innocent-seeming gestures mean something rude in other cultures?

The researchers in Glasgow are still at the prototype stage, sending students into the real world to experiment with different gestures by recording the reactions of the people around them as well as of the users themselves. Another study is comparing the reactions of people in the UK and India to study the cultural issues involved. "This is where signal processing meets social computing," says Brewster.



COMPUTERS WILL BE ABLE TO REORGANISE OUR DAY BY MONITORING COGNITIVE WORKLOAD...

Brainwaves, smells and touchy-feely systems

By rotating your arm in a clockwise direction, you may be instructing the system to perform a particular task, like turning up the volume. But Rod Murray-Smith of the University of Glasgow is also interested in the enormous potential of brain–computer interfaces. He is working on interaction techniques which can detect a "motor-imagery" event in the brain, such as imagining a hand or foot movement, filtering the signal from the other electrical disturbances (such as those caused by blinking and facial movements), and using this to control a computer. "The big problem," says Brewster, "is that input is still very slow," but researchers are confident of future progress – not so much reading the mind as allowing users to control software by imagining certain actions.

If brain interfaces seem strange, then a smell interface may appear even stranger. Researchers in Glasgow have studied the possibilities of such a system, looking at some basic applications like using smells as "fire!" alerts or as reminders to perform tasks such as "eat" or "take medication." One idea was to use smells to aid memories by creating links to digital photos – e.g. the smell of seaweed may prompt a search for photos of a day at the beach. The major problem with "smell interfaces," however, is that they are hard to synthesise – "there is no RGB of smell," says Brewster.

What kicks off these ideas is the fact that human beings offer so many practical options for non-verbal interaction with computers, allowing researchers to "take advantage of the richness of our bodies and brains," using everything from skin and smell to muscular movements and "brainwaves."

Haptic computing, including the use of "force-feedback" devices which create the illusion of touching and manipulating real three-dimensional objects, is another key area in HCI, and the subject of extensive research in Glasgow and elsewhere. According to Brewster, haptics have a key role to play in creating interfaces that feel 'real' to users – e.g. to add a third dimension to displays in museums, particularly useful for people with visual impairments. Haptics have also been used to teach various physical skills, including everything from making jewellery to simulating veterinary procedures.

Multimodal Interaction

Personal ubiquitous interfaces require research enabling multiple, rich communication channels between people and vast bodies of information.

Every day, huge numbers of people interact with information, and each other, via a diverse set of systems that combine computing and communication. These systems include desktop computers, shared computer clusters, the internet, mobile phones, PDAs, cameras and cars. Yet, while the amount of information online increases inexorably, our systems remain less usable and useful than they should be, with problems at the interface between human and system. Today, the most common form of information access involves an individual person sitting at a computer screen, typing a query in English into a search engine such as Google. This model of interaction may be out of date but going beyond it demands a new approach to human–information interaction that combines an understanding of people and information, and the interactions between them, individual human intellectual and social abilities, means of structuring vast amounts of information, and ways of exploiting multiple rich communication channels.

Scotland has a range of expertise doing advanced research into the problems of human–information interaction, especially the new dimensions of interfaces which are opened up by multimodal information processing capacity. Researchers all over the world are considering both conventional, textual ways of accessing multimodal information (such as video), and also unconventional, multimodal ways (such as gesture). The research groups in Scotland have traditionally had different emphases and focused on specialist topics – for instance, information retrieval and human–computer interaction (Glasgow), speech recognition and synthesis (Edinburgh). But by working together on joint research projects such as MATCH (Mobilising Advanced Technologies for Care at Home), researchers from the different universities in Scotland have recognised that they can share solutions and work more closely together, enabling them to make an international-level contribution through SICSA.

The mobile dimension

Brewster has been interested in HCI since he was a student, writing his PhD thesis on *Providing a structured method for integrating non-speech audio into human–computer interfaces* at the University of York in the early 1990s, when he focused primarily on earcons (structured sound patterns used to represent specific items or events) and non-speech sound. At that time, mobile phones were crude devices which just about managed to handle a phone call and nothing much else, but dramatic advances in mobile technology in recent years have made them the focus of research in countries all over the world – as HCI embraces the development of novel multimodal interfaces for mobile devices.

According to Brewster, mobile devices are just beginning to get enough processing power to enter the next stage of HCI – ubiquitous computing – when embedded computing devices become second nature, available anywhere at any time, enabling people to use them discreetly while carrying out other tasks. Computer scientists may say "you ain't seen nothing yet" with these powerful mobile devices, but you could also say "you ain't seen/heard/touched/smelled/thought nothing yet" when it comes to their long-term potential.

Enabling disability

Mobile devices will be one of the major technologies used in the home to deliver "telehealthcare" in the future. According to a recent survey, people in their sixties are becoming increasingly comfortable with mobile devices, so "techno-phobia" is less of a barrier to widespread adoption.

The prime motivation to develop the new home-care systems is simply the fact that the population is ageing, making it more cost-effective to enable people to remain at home until they're much older. As we age, we also develop multiple "small impairments," while more and more people also have more serious disabilities. As well as health care, older people also need to keep in touch with friends and family, and access different types of information, so overcoming social isolation is another priority.

Brewster and colleagues at the University of Edinburgh are interested in the development of various options for multimodal interaction, ranging from very simple ambient devices – e.g. lights which change colour to signal or prompt an event – to more complex solutions delivered via mobile devices which users carry around with them all of the time. This diversity is needed to cope with different levels of cognitive and physical ability, starting at the most basic.

For example, some people may benefit from a device which reminds them to eat or take medication, via visual, auditory or tactile interaction, or even an appropriate smell. Others may benefit more from communications systems tailored to their personal needs, delivered via mobile devices. The possibilities are endless, but scientists are also aware of the need for discretion. "It's important to develop unobtrusive devices and deliver information and reminders in the most appropriate way," says Brewster. As well as developing high-tech solutions, researchers have also done studies to look at the disruptiveness of signals or alerts, so they can make them more timely as well as appropriate. "If no one uses the system," says Brewster, "it's not a good system," and that's why usability is also extremely important.

RESEARCHERS ARE INVESTIGATING HOW PEOPLE REACT TO DIFFERENT GESTURES USED IN PUBLIC SPACES TO INTERACT WITH MOBILE DEVICES...

Back to the future

Ten years ago, Brewster and other HCI specialists were beginning to turn more attention to mobile devices as the integrated technologies began to mature, taking advantage of open platforms and multiple functions (vibration and cameras, etc.) to try to "do things with them that they don't already do." Tablet computers now bridge the gap between mobile and desktop devices, and social media have led to an explosion in activity. Interfaces have also developed in every direction, and social, educational and business needs have also evolved. So what about ten years from now?

Brewster anticipates more focus on usage than on user devices, and different forms of interaction with embedded devices as we enter the era of ubiquitous networking. In terms of applications, home care will be high on the agenda, including remote monitoring of health care as well as psychological/emotional support. He also thinks that information systems will be able to "monitor cognitive workload," so that if you are stressed, doing too much at once, the computer will reorganise your workload.

Will systems also read our minds and know what we think before we do? Even Brewster can't answer this question – yet.

Tangible results

You don't need 3D holograms, surround-sound and a simulated fairground ride to stimulate a child's imagination – sometimes reading bedtime stories does the job better. SICSA appointee Dr Eva Hornecker of the University of Strathclyde is interested in all sorts of multimodal interaction, including spatially-embedded systems, tangibles, haptics and whole-body interaction – what she calls "beyond-the-desktop" computing – but she's more concerned with usability and user experience than in the hardware and software. "What is most powerful in learning terms is sometimes very simple," she explains. And old-fashioned books can be much more effective than even the smartest of novel technologies.

Engagement is one of the keys to the success of any interface, and for Hornecker this includes how it supports social interaction and learning. "What gets people talking?" she asks. "And what gets them using the system and learning?" Content is important, but Hornecker also believes that groups of users may create their own content through interaction and collaboration, and as a result have more fun at the same time as learning.

"I tend to focus on the user experience of multimodal interaction," she explains, "working with qualitative methods, including ethnographic observation and detailed analysis of videos, as well as more objective aspects – for example, the influence of speed of interaction or correctness."

The Mobiquitous Lab, run by Hornecker and Dr Mark Dunlop, studies user behaviour in relation to mobile devices and multimodal interaction – for example, working with teenagers in local secondary schools to develop new ideas for mobile study aids. Among the other projects they support is a "mixed-initiative planning" application for interactive multitouch tables, developed by one of their students in collaboration with the Artificial Intelligence group at Strathclyde, a tabletop "voting" system for children, in collaboration with Professor Ian Ruthven, and a PhD project which explores the utility of multitouch in maritime equipment.

Hornecker is also working on a project for the National Trust for Scotland, "test-driving" educational displays for its new Robert Burns Birthplace Museum in Ayrshire, focusing on the usability of prototype touch-screens and an interactive table (with physical buttons for interaction) by studying how young families "play" with the new installations.

Many "interactive" devices are not as interactive as they're claimed to be, says Hornecker. Instead of interacting with the people around you and sharing information through discussion and participation, some displays lead to a "tunnel effect" where the user only relates to a small part of the overall content, in isolation from everyone else. Hornecker says it is important not to make assumptions about new technologies but see them in use first, and she also advises her students to "expect the unexpected" when it comes to designing and assessing new systems. For example, when she and her colleagues studied new technologies for steering wheels, they discovered that tactile navigation information tended to be confusing for drivers, but then found that feedback from tactile plus visual devices produced a much more positive result. Similarly, when mobile phones came onto the market, no-one imagined that people would primarily use them for texting (and nowadays also for email and Facebook) rather than voice calls.

"It's a question of attitude," Hornecker explains. "We should prepare to be surprised – because if something doesn't work, we can learn from this, and this may teach us how to create something better. Sometimes we can turn our failures into successes, if we investigate why things didn't work, where our assumptions were wrong, and rephrase our research question or revise our approach."

Always On or Never-Never?

PROFESSOR SALEEM BHATTI'

Everybody wants to use the Internet whenever they want and wherever they are, but no one seems willing to pay to ensure that it always stays on, whether they're consumers, business users, governments, equipment manufacturers or service providers. As the Internet continues to expand, and our dependence on it also increases, meltdown becomes much more likely and also more scary, but researchers in Scotland are doing their best to ensure that the Next Generation Internet will be fit for purpose – not just to survive a cyber-crime attack but also X Day...

For almost 20 years, the Internet has hardly changed at all, in terms of fundamental architecture. There have been lots of tweaks or engineering "workarounds" and the physical layer has changed out of all recognition, but the core protocols (the message exchanges used to manage data traffic) are basically the same as they were at the time of the last major change in 1993 (and indeed not very different from the mid-1970s), when the Internet emerged from academia and entered the public domain – now approaching two billion users.

As mobile networks grow and demand from social media, e-commerce, online gaming and video streaming accelerates, the problems are accumulating rapidly, from spam to cyber-terrorism and denial-of-service attacks, as well as worsening traffic congestion and problems with deployment of new applications. Many services have ported to the Internet from traditional business (e.g. retailers and banks) while others are the children of the Internet (e.g. Facebook or Twitter). All these users, services and applications put tremendous pressure on the network, slowing traffic down or even threatening breakdown and, according to many observers, nothing will improve unless the companies who profit from the Internet think there is money to make, and users are willing to pay more for high-availability, high-speed, high-quality access.

Domestic customers may sometimes be willing to lose data now and again, accepting lower quality of service and occasional downtime in return for lower prices. But utility companies, large corporations and government agencies, including the military, can't afford to make the same trade-off – even though they use private networks, they also use the Internet for many mission-critical functions.

The problem is that nobody wants to pay now to solve a problem that may or may not happen in the future – just in case the Internet grinds to a halt. In fact, says Saleem Bhatti, SICSA theme leader for Next Generation Internet, "parts of the network often operate at the limits of their capability," and within the next two or three years, there will be no more IPv4 addresses available for distribution to new networks – what is called X Day.

Even though a lack of "statically assigned" address space may not affect domestic users directly, it could have a serious impact on organisations who offer always-on services. And that is why scaling is a critical issue, says Bhatti: "The use of the IP address today is 'wrong'. The fundamental architecture needs to change." What we need is not just technological but cultural change – new attitudes to payment and incentives, as well as new core protocols, so users get the services they want and business makes money.

Different rates for different qualities of service may be part of the answer – e.g. gold, silver and bronze data access – but this would be extremely difficult to implement Internet-wide, taking account of the complex connections that users make while travelling, piggybacking on various cross-border networks at once. What the industry is trying to promote as a next-step solution is IPv6, but Bhatti and many other scientists think that the Internet needs much more radical changes.

THE INTERNET HAS REVOLUTIONISED OUR LIVES – BUT IT "ONLY JUST WORKS..."

"We need a system-wide approach," says Bhatti, "but system-wide changes are hard, and industry and users want incremental changes." The old Internet was a "co-operative experiment," but the current version is "a landscape of competitive services," and incentives are key to success. "We can have excellent technology for the network of today," Bhatti continues, "but we also need to incentivise innovation for the network of tomorrow."

So what does the Next Generation Internet need? Bhatti, who is also Professor at the School of Computer Science at the University of St Andrews, wants to "reheat some cold research topics" where progress is harder, such as architecture, naming and routing. "We need experimentation," he says, "and more sharing of data and code. We need to be disruptive, and test new things out in the wild, but disruptive research and the cost of change can appear to be too high for end users."

One of the problems with the Internet, Bhatti continues, is that incremental engineering retrofits have made the current technology landscape very complex, and to introduce radical changes which impact a large number of components and functionality could have a correspondingly complex effect on the network and on users. In addition, it is widely agreed that if a large customer asks a service provider to deliver a particular service, the inclination is to say "yes," to make the customer happy and hold on to the business, but delivery of that request may result in increased complexity in the existing network engineering – which may in turn lead to major (very costly) problems in the future.

Bhatti also says that IPv6 (which greatly increases the available addresses, taking over from IPv4) is not taking off yet because it offers little benefit to users, other than a larger address space, so vendors and developers still stand to make money out of workaround solutions. In addition, not all applications can be easily ported to IPv6. So what is the answer?

Next Generation Internet

As the Internet evolves towards ubiquity, the key research targets include security and trust, programmability, manageability and mobility.

In its 25-year lifetime, the Internet has succeeded beyond the wildest dreams of its creators in changing the way people live, work and play – and increased in size by seven orders of magnitude. The simple, original Internet architecture (16 specification documents) has increased to several hundred additional protocols and extensions. Networks based upon this complex architecture are increasingly difficult to manage, so that the qualities of service meet the needs of well over one billion users.

Security is also a more complex issue today. The original Internet was designed in an era of mutual trust. Many of the protocol additions/ extensions have had to retrofit protection mechanisms to reflect the less trustworthy current environment, and the volume and types of attempts to subvert the Internet can only continue to increase.

There is now considerable expertise in networking research in Scotland, addressing the practical aspects of networking, together with leading theoretical work on performance analysis and security in networked systems. The research challenges in this area cover a very wide range. Work is already in progress at Glasgow and St Andrews on manageability, and there is already planned collaboration on basic network architecture.
This gives an excellent basis for research on security and trust, as well as on mobility. Securing the internet against myriad current and future exploits is the single most critical challenge to resolve for the successful exploitation of the Next Generation Internet, and it is one that requires a return to first principles and collaboration between networking practitioners and theorists – an area where SICSA plans significant investments.

The pain barrier

Bhatti explains that the Internet "only just works," in the sense that problems are usually solved "just in time", when users and industry are forced to change because they have no other option. But he also believes we can be more proactive in establishing standards and introducing new technologies. "There will be pain," he says, but incremental change will still be possible.

One of the most critical issues is who will be willing to pay for the changes required, and this is where academic researchers may take the initiative, rather than industry. The scientists will try to develop solutions which meet universal requirements, with backing from government and business partners who recognise the benefits for everyone, including the general public. For example, Bhatti and his colleague Ran Atkinson of Cheltenham Research have published a number of papers describing what they think could be one of the answers to the problems of IP addresses or "namespaces" used on the Internet. ILNP (the Identifier-Locator Network Protocol) is a new network protocol which can be built on IPv6 incrementally, breaking the address into two separate spaces – a Locator and an Identifier – to enable harmonised functionality such as mobility, multi-homing, local addressing and end-to-end security at the network layer "through an improved naming and addressing architecture." Bhatti explains that the Locator names a single subnetwork and is used only for packet forwarding and in routing protocols – it is never used above the network-layer. The Identifier always names a node, rather than naming an interface, as an IP Address does today.

According to Bhatti, the threat of X Day is not a technological but an architectural issue, and "the root problem is in the overloaded semantics of the IP address." The new protocol he is proposing would alter the way that addresses are handled, using one or more "semi-permanent identities" on every device, wherever it is used. This will not solve every problem of scaling, says Bhatti, but it could be part of the solution, meeting important requirements such as routing state scaling, traffic engineering and mobility functionality.

Other new core protocols have been proposed, including LISP (the Locator-Identifier Separation Protocol), developed by Cisco Systems, and HIP (the Host Identity Protocol) developed within the Internet Engineering Taskforce (IETF). All of these promise advances – for example, LISP would enable the design of a "scalable routing and addressing architecture for the Internet," dealing with end-to-end functions – but none have been deployed yet on a large scale.

Equipment manufacturers may make lots of money by selling new boxes, when the new core protocols start to be used, but most other interested parties seem unwilling to make the first move – even though it makes perfect logical sense and it's in everyone's interest. Bhatti compares this to environmental action – we all know we should try to save the planet but we can't agree what to do first, when to act or decide who should pay. Industry is starting to express considerable interest in ILNP, even though it is still not completely developed, and Bhatti thinks the best way to test it will be to build it and give it away for free to encourage deployment. There is no "grand plan" for the transition, says Bhatti, but something will have to be done.

SICSA research

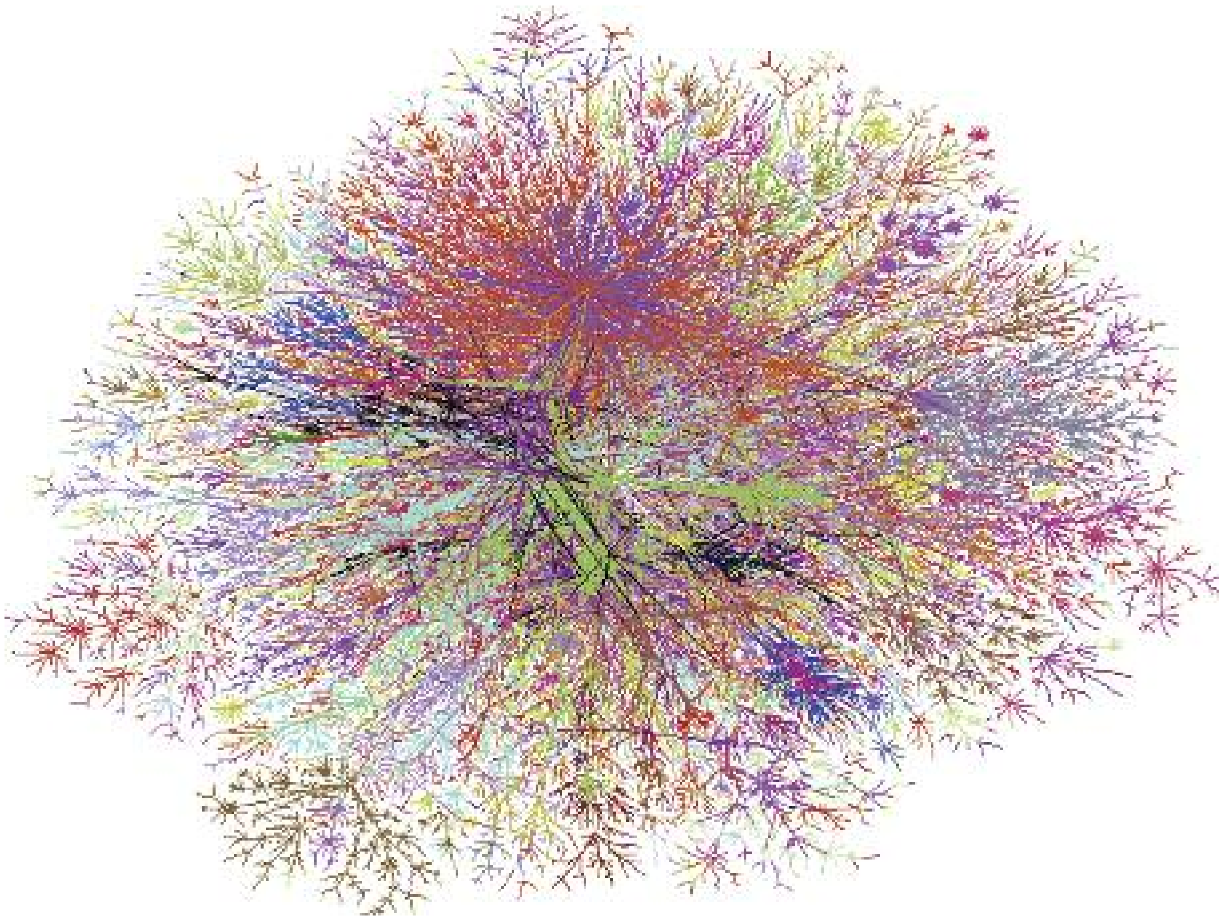
While Bhatti grapples with core protocols and other key issues like "green ICT," his colleagues in SICSA are also doing world-class research into Next Generation Internet. For example, researchers at several Scottish universities, led by Professor Bill Buchanan at Edinburgh Napier, are looking into issues of security and trust, including cybercrime, as part of the SICSA-supported Centre of Excellence for Security and Cybercrime, an initiative which brings together academics, representatives from industry, government agencies and the police, to improve people's lives "though excellence in research, knowledge transfer and teaching," including the creation of next-generation systems which protect the rights of individuals and reduce the risks they are exposed to.

In Glasgow, SICSA-funded PhD students supervised by Dr Colin Perkins are looking at routing in the Internet. The goal here is to reduce the amount of routing state (routing-related information) needed in the core Internet routers so that there are better scaling properties for the future Internet, by applying a mixture of mathematical techniques to our current understanding of the way the Internet topology grows.

At the University of St Andrews, other SICSA-funded PhD students, studying under the supervision of Dr Mirco Musolesi, a SICSA-funded lecturer, are looking at some fundamental aspects of network science. They are exploring the dynamics of the formation and growth of networks, including mobile networks and online social networks, and drawing inspiration from other sciences such as biology and psychology.

did you know?

The addressing scheme currently used for the Internet (IPv4) provides about 4.3 billion addresses – and recent projections suggest there will be no addresses for new networks in early 2012, unless we move on to IPv6...



MAP OF INTERNET: COLORED BY IP ADDRESSES BY WILLIAM R CHESWICK AT WWW.ND.EDU/~NETWORKS/IMAGE%20GALLERY/GALLERY.HTM

Green ICT

Bhatti's main research interests are "networked systems architecture and the control of network resources," but he also focuses on ICT energy usage – which accounts for about 2% of all carbon emissions. The ultimate aim is sustainable ICT systems, but Bhatti believes the solution will come from a combination of factors, including technological advances and changes in attitude. "Legislation is not an incentive," cautions Bhatti. "Businesses need environmental incentives that are better aligned with their business goals."

Increasing user expectations and the huge surge in the number of mobile devices are fuelling emissions, says Bhatti. When mobile users send a text, they rarely stop to think about the carbon-hungry infrastructure helping them perform this simple task – including the servers and routers, etc. Increasingly, consumers want always-on services and never switch off their computers, and business and government are becoming increasingly dependent on ICT systems, for services such as distance learning and telehealthcare. Even using a search engine adds to carbon emissions, with one estimate putting the cost of a single search as high as 7g of CO_2 – enough to boil half a kettle of water. The need for compliance with new legislation (e.g. requiring archiving and search for personal data), and the need to make systems robust and redundant also add to the problem.

Manufacturing, disposal and recycling of ICT equipment are also a headache, and Bhatti is concerned it can be cheaper to build new equipment than it is to recycle components.

Awareness of energy issues is key to success – to change the way we use computers at home and at work. According to a UK national survey in 2008, only 13% of IT managers monitor energy usage, and Bhatti says that there are not enough incentives to purchase low-energy options. The economics may be complex, but Bhatti is convinced we need a systems-wide approach to carbon emissions – in the same way that we need a total rethink for Next Generation Internet.

THE INFORMATICS FORUM – A HUB FOR SICSA RESEARCH AND HOME OF THE UNIVERSITY OF EDINBURGH'S SCHOOL OF INFORMATICS, THE LARGEST INFORMATICS RESEARCH CENTRE IN THE UK

FIFTY PROJECTS WERE SHOWCASED AT DEMOFEST, INCLUDING EVERYTHING FROM ROBOT FOOTBALLERS TO VIDEO FINGERPRINTING AND THE PUFFERSPHERE (TOP RIGHT) – AN INTERACTIVE SPHERICAL DISPLAY DEVELOPED BY DESIGN COMPANY PUFFERFISH IN COLLABORATION WITH DR MARK WRIGHT OF THE UNIVERSITY OF EDINBURGH.

SICSA research projects

Intelligent Minutes

Dr Mike Lincoln, a Research Fellow from the School of Informatics at the University of Edinburgh, is working on a revolutionary technology that could change the way we hold business meetings.

Multiparty Interaction Capture Analysis and Replay (MICAR) uses a 360-degree panoramic camera, microphone array and slide-capture device to create an audio-visual recording of everything that happens in a meeting. State-of-the-art speech recognition and language-processing technology is then used to transcribe and index the recordings, allowing them to be searched and replayed using a web-based 'meeting browser.'

According to Lincoln, using the technology "preserves and unlocks the information lost with traditional meeting minutes, and allows important review tasks such as decision audit, operational review and regulatory compliance checking to be performed quickly and accurately." Lincoln also describes it as "a potential must-have for all businesses, particularly organisations whose decisions are made with high accountability and scrutiny, such as the military and security services."

SICSA Showcase

Computer scientists and researchers from universities all over Scotland recently showcased their work at DEMOfest, an event organised by SICSA. The 50 projects covered everything from speech, language and homecare to security, simulation and modelling.

Researchers from the University of St Andrews are working on Video Fingerprinting for Digital Assets Management. Potential applications include multimedia copyright protection, file transfer software, network video piracy detection and TV and broadcast archive management.

SICSA-funded researchers at the Interaction Lab at Heriot-Watt University are developing novel techniques to enable people to communicate and access information in different ways. For example, by recording and analysing somebody's speech, information is fed into an internet search application and fed back to the person via graphics and speech – a solution which may be useful for hands-free assistance, patient monitoring and supermarket shopping.

From Big Bang to getting more bang for the buck

The EPCC, the supercomputing centre at the University of Edinburgh, recently celebrated its 20th anniversary. It was time to reflect on the quantum leaps achieved in technology since the centre was founded and turn the spotlight on some of the weird and wonderful projects it has handled through the years – focusing on everything from particle physics to mushrooms...

It has one of the most powerful computers in the world, but the EPCC uses its impressive number-crunching resources to investigate not only the origins of life in the cosmos but also the secrets of vegetable starters. One moment it is doing mind-boggling research into particle physics and the next it is helping detect faults in carpets.

As well as doing pure research, EPCC has carried out industrial technology transfer projects with over 400 companies, to develop new products and services, "transform their businesses" and improve productivity. Clients include high-tech giants such as Rolls-Royce, British Aerospace and AEA Technology, plus Scottish SMEs (small- and medium-sized enterprises) such as Kwik-Fit, Arran Aromatics, Red Lemon Studios and Golden Crumb – a Fife-based firm which makes a range of coated appetisers for the catering sector and asked EPCC to "assess the feasibility of using a machine vision system for grading mushrooms."

Speaking at the EPCC's 20th-anniversary celebrations, commercial director Mark Parsons made light of the more unusual projects the organisation has handled, but also drew attention to the "hidden demand" for high-performance computing (HPC) that exists in every business sector – whether they're aware of its potential or not. "Many companies don't know they should be spending money on HPC," he said. And to prove this, the EPCC recently launched what it calls the HPC Adopters Programme, designed for Scottish companies "with little or no experience of HPC," with support from Scottish Enterprise.

The pilot project has initially provided help to three firms. Its chief aims are to solve specific challenges and demonstrate the impact an HPC solution can have on a company's business, and in the process encourage similar companies to consider using HPC in their operations. This latest initiative is part of the EPCC Industry Hub, which offers high-level services to companies right across the spectrum of business, including access to the centre's computing facilities on a pay-per-use basis as well as a wide range of consulting services tailored to industry needs. Most of the work involves modelling and simulation, to help design, develop and test new products and services for sectors such as finance, retail, manufacturing and energy, including international names such as Shell, BT and Sun Microsystems, plus other leading organisations such as the UK Met Office.

"The reason we work with industry," Parsons continued, "is that our role goes beyond science, to transform businesses and stimulate economic growth."

This may seem a long way from the early 1980s, when a small group of physics researchers in Edinburgh first dreamed of having a supercomputer to help them solve the problems of cosmology, but right from the start, the EPCC pioneers recognised the need to work with industry as well as conduct pure research – and the centre continues to balance its practical and theoretical projects today, with a "win-win-win" strategy of working with academia, industrial end-users and computer manufacturers for mutual benefit.

PROFESSOR ARTHUR TREW

MARK PARSONS

How it all started

According to EPCC director Professor Arthur Trew, EPCC was conceived over a period of six or seven years in the early 1980s' by a small group of physics researchers who were interested in using "novel architectures" such as parallel computers to help in their projects – looking into esoteric subjects such as quarks and zero magnetism. At that time, said Trew, the USA was far ahead with supercomputers such as the Cray XI, and the UK researchers "had to do something imaginative to compete" with their American rivals.

Having got their hands on what was then the most advanced computer in the UK, ICL's Distributed Array Processor (DAP), the breakthrough arrived thanks to an "ingenious" bit of programming, and the researchers persuaded the University of Edinburgh's Department of Computing Science to provide further funding. With backing from the Science and Engineering Research Council (SERC) and the Department of Trade and Industry (DTI), the researchers were able to buy one of the very first transputer-based computers from Meiko, which "gradually grew to be one of the largest such parallel computers in the world."

In 1990, EPCC was founded "to accelerate the exploitation of parallel computing through industry, commerce and academia," developing simulation software to run on parallel computers, as well as providing consultancy services and training. It was staffed primarily by physicists who wanted to advance their theoretical research and also embraced the idea that they had to work with industry partners – for example, Barclays Bank and British Gas, two of their earliest clients. Over the years, the centre graduated from its early machines to a CM-200, then in 1994 it bought a 256-processor Cray T3D – then Europe's fastest supercomputer – soon followed by a Cray T3E, dedicated to particle physics.

In 2002, EPCC became lead partner in the HPCx consortium, supporting the national supercomputing service for UK academic research, and in 2008 it became the host for HECToR, a similar service, funded to the tune of £115 million over six years, from 2007 to 2013.

According to Professor Richard Kenway, EPCC's Chairman, the secret of EPCC's success was to "hire the brightest graduates and set them the hardest of problems – without telling them the problems were hard." The birth of the organisation was also "a long gestation period involving many parents," said Kenway, and today it has a staff of over 70 people.

HECTOR IS A MILLION TIMES FASTER THAN THE SUPERCOMPUTERS OF ONLY 20 YEARS AGO...

EPCC today and tomorrow

As well as expanding into Europe and writing the roadmap for the future of high-performance computing, the EPCC also continues to focus on industry projects, including everything from simulating climate change to how to tow a fishing net to maximise the catch. Over the last eight years, EPCC has spent almost £150 million on computing resources, but as Professor Trew said at the recent celebrations, "EPCC is not machines but its people."

Looking to the future, EPCC recognises that budgets may come under pressure, but "parallelism is now endemic," said Trew, and a golden age may lie ahead for high-performance computing.

Deputy director Alison Kennedy stressed the importance of Europe in EPCC's future plans, and said that it must "prove itself in Europe at the same time as delivering results at home." As a sign of its engagement with colleagues in Europe, EPCC has hosted more than 800 research visits in recent years under the HPC-EUROPA Programme which links across both universities and application areas – for example, automatic inspection technology, renewables, health and well-being. "We look at all these problems from an international perspective," Kennedy added, with collaboration focusing on expertise and services as well as on machine time. She also suggested that EPCC will have an increasingly key role to play in the future in the development of a European Data Infrastructure to cope with the data explosion, as computer simulation and data become more closely linked.

Twenty years ago, scientists dreamed of the kind of machines now available to the researchers at EPCC. For example, HECToR (High End Computing Terascale Resource) runs a million times faster than the "supercomputers" of only two decades ago. EPCC recently upgraded its facilities, and HECToR now has more than 44,000 Opteron processing cores and runs at more than 350 Tflop/s (Tflop/s = 1012 floating point calculations per second). In the 1980s, the quest to build a Gflop/s (109 floating point calculations per second) computer was considered wishful thinking, but now the target is the Pflop/s computer, capable of 1015 floating point calculations per second. EPCC has also had the equipment to make sure it has kept ahead of Moore's Law for the last 20 years, more than doubling its performance every two years, and consistently ranked in the world's top 20 HPC facilities.

In addition to its raw computing power, EPCC also strongly promotes its portfolio of services, including its helpdesk, training and consultancy services, as well as its involvement in collaborative research – for example, IBM and Cray.

EPCC has also not forgotten its role as a teaching resource, and introduced one of the world's first MSc degrees in HPC ten years ago. Next year, it plans a big increase in student numbers. "Universities should not be diverted from their core purpose," said Parsons. "It would be a big mistake to focus on short-term gain."

The challenge for the future, in the eyes of the EPCC, is not just to accelerate the power and intelligence of supercomputers but also to convince industry and government that it is worth it to invest in high-performance computing – like scientists in the USA, China, India and Japan, who are already investing billions of dollars in HPC. In Japan, for example, Fujitsu is involved in a $1.2 billion government project to develop a supercomputer capable of running at 10 Pflop/s, using a technology called "Tofu" – so maybe the link between supercomputers and mushrooms is not so strange, after all...

DR CHRIS JANSSEN

Unknown territory

When he first became director of the Scottish Bioinformatics Forum (SBF), Chris Janssen knew he was about to enter terra incognita. Four years later, he realises this will always be part of the job. The SBF will always be discovering new challenges, acting as a bridge between different research pools in Scotland to translate their specialist knowledge and skills into something of value to business as well as the general public – in an area of science where mind-boggling breakthroughs are made all the time...

Advances in biology and bioinformatics are happening so fast it's hard to keep up with the news – even for leading researchers. Ten years ago, the SBF director Chris Janssen was doing collaborative research at the Sanger Institute in Cambridge, struggling to sequence a fragment of the malarial genome – a job which, in totality, would have taken several years to complete using the technology available then. Today, it's possible to sequence the whole of the malarial genome five times in only three days. Janssen says that ten years from now it may be routine for individuals to have their genomes sequenced as part of their everyday healthcare. And it is against this ever-changing and increasingly dynamic background that the SBF works, helping with training as well as providing a forum and "matchmaking" leading researchers from universities all over Scotland and further afield.

Janssen says the key role of the SBF is to facilitate "interdisciplinary integration and inter-institutional collaboration," taking full advantage of the independence it enjoys as a project of the RSE Scotland Foundation, largely funded by the Scottish Funding Council. In practical terms, this means organising a programme of workshops, including in-depth training in the latest techniques and technology, as well as forums to discuss important future trends in bioinformatics – attracting over 2,000 people from academia and industry to recent events. It also organises scientific seminars and conferences, providing a stage for scientists based in Scotland and around the world, focusing on topical issues in computational biology and its impact on modern biomedical and life sciences. In 2010, for example, the SBF organised the International Conference on Computational Methods in Systems Biology, which attracted over 1,200 delegates from 51 countries.

According to Janssen, there has been a revolution in biology in recent years, using new computational methods and hardware to cope with the new kind of data produced – more complex and in much higher volumes than ever before. And this not only leads to breakthroughs in research but means that scientists who graduated several years ago need continuous training to learn the new skillsets required. The SBF is active in providing this technical training, but Janssen also sees its role as helping universities deliver the courses themselves.

The focus groups established by the SBF are also very high on the agenda, including the Scottish Biomodelling Network, which brings together engineers, physicists, informatics specialists and life scientists to discuss the latest developments, identify new challenges and make joint applications for funding. "Sometimes," says Janssen, "life scientists have major problems to solve but don't have all the tools they need, and sometimes informaticians have lots of powerful tools but don't know what to do with them – and that is why we try to bring the different groups together. In the current financial climate, the importance of this coordination takes on additional significance, since we now have to take every opportunity to share pooled resources."

Another major project where the SBF is providing support is strategic thinking for IT and informatics capabilities for a national, as well as regional, biorepositories, finding ways to tie together medical records, pathology records and molecular data from all across Scotland to help with the discovery of biomarkers (e.g. for cancer) through data mining – to make sense of the vast amount of data by developing new systems and approaches. This project has now received major impetus from the creation of the Scottish Academic Health Sciences Collaboration (SAHSC) by the Chief Scientist's Office, NHS Scotland and the universities of Aberdeen, Dundee, Edinburgh and Glasgow. The SAHSC mission is to establish "a world-leading clinical research platform for patient-oriented research," focusing on key areas such as scanning capabilities, tissue banking, clinical research support and information technology.

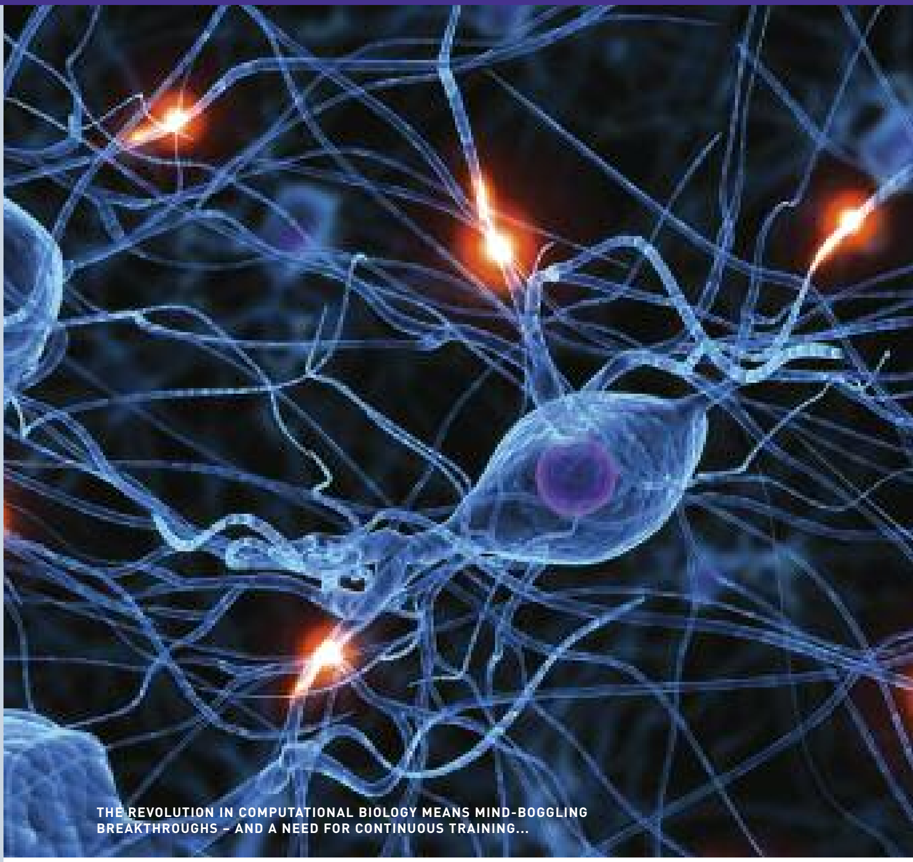
The first job, says Janssen, was to sort out the ethical and governance issues by providing "safe havens" for medical records, then move on to the technical issues. And Janssen believes Scotland has several advantages for such a project, including a rich set of data across a broad spectrum of diseases and "excellent international researchers to translate the data into meaningful research results."

What is the SBF?

The vision of the Scottish Bioinformatics Forum (SBF) is: "To establish Scotland as a globally-recognised and leading location for conducting cutting-edge bioinformatics research and sustainable commercial activity."

The SBF engages with developers and users of bioinformatics methods, and supports both the academic research base and commercial organisations by actively promoting training and facilitating access to bioinformatics skills. It also seeks to increase the international profile of Scottish bioinformatics, attract investment and encourage academic excellence in bioinformatics.

SBF activities are steered by a management group appointed by the RSE Scotland Foundation, with support from an advisory group which consists of representatives from academia, industry and development organisations across Scotland.



THE REVOLUTION IN COMPUTATIONAL BIOLOGY MEANS MIND-BOGGLING BREAKTHROUGHS – AND A NEED FOR CONTINUOUS TRAINING...

Together with the Edinburgh "GenePool" the SBF has also set up a focus group to discuss important issues in next-generation genome sequencing, looking at new technologies and computational methods dealing with high-throughput gene sequence data. Janssen is convinced that these technologies will be used in medical diagnostics and clinical research within a few years.

In Janssen's view, life scientists have to "think out of the box" and tap resources that they may not have tapped in the past. And while researchers based in Scotland work in this "rarified sphere" with their finite resources, the SBF tries to have a synergistic effect, not only "closing the loop" between different research pools such as SICSA (the Scottish Informatics and Computer Science Alliance) and SULSA (Scottish Universities Life Sciences Alliance) but also between different disciplines – what Janssen describes as "translating" ideas from one group of researchers to another. "We aim to join up different researchers in a co-ordinated manner that leads to directed interactions," says Janssen, "introducing novel methods and technologies from one field to another."

Above all, says Janssen, the SBF is independent and is well placed to provide an "holistic overview" of what is going on in bioinformatics in Scotland, performing a role that individual institutions could never perform on their own. "Only by sharing their expertise and experience will scientists be able to find manageable solutions," says Janssen, "and translate their bright ideas into concrete action, to compete with other international researchers." It is all about knowledge exchange, he adds, and the organisation's success can be measured in various ways, including competitive funding, intellectual property, commercialisation, interaction with industry and high-quality publications – as well as "breaking paradigms in research."

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