GRAND CHALLENGES IN COMPUTING RESEARCH 2008

edited by John Kavanagh and
Wendy Hall

UK COMPUTING RESEARCH COMMITTEE

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Collective inspiration

Grand Challenges in Computing Research Conference 2008

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Contents

UKCRC

The UK Computing Research Committee (UKCRC) is an expert panel of the Institution of Engineering and Technology (IET), the British Computer Society (BCS) and the Council for Professors and Heads of Computing (CPHC) for computing research in the UK. Its members are leading computing researchers from academia and industry.

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BCS

The British Computer Society (BCS) is the leading professional body for the IT industry. With members in over 100 countries, the BCS is the professional and learned Society in the field of computers and information systems.

The IET

The Institution of Engineering and Technology is one of the world's leading professional societies for the engineering and technology community. The IET has more than 150,000 members in 127 countries and offices in Europe, North America and Asia-Pacific. The IET provides a global knowledge network to facilitate the exchange of ideas and promote the positive role of science, engineering and technology in the world.

Grand Challenges in Computing Research 2008

John Kavanagh and Wendy Hall

This report covers the third conference of the Grand Challenges in Computing Research initiative, held in London from 18-19 March 2008.

The initiative was launched by the UK Computing Research Committee, a joint expert panel of the British Computer Society (BCS) and the Institution of Engineering and Technology (IET).

Preliminary work led to a workshop in 2002. Seven proposals emerged and after discussion and refinement they were launched as grand challenges at the first conference, in 2004. The second conference, in 2006, reviewed those grand challenges and accepted proposals for two more (GC8: Learning for Life, and GC9: Bringing the Past to Life for the Citizen). Meanwhile two of the original challenges merged (GC2: Science for Global Ubiquitous Computing, and GC4: Scalable Ubiquitous Computing Systems).

The 2008 conference began on the evening of 18 March with short updates on all the grand challenges, at The Royal Academy of Engineering, and then discussion among the 65 participants over dinner at the Royal Society. This first event was opened by the BCS President, Rachel Burnett.

The full-day programme on 19 March at the BCS featured speakers from outside the Grand Challenges initiative for the first time, including people from funding bodies in the UK and the USA.

Speakers did not describe their grand challenges in detail but highlighted any changes in thinking, activities, progress and possible success criteria. This report therefore does not describe the grand challenges in detail but points to their home pages and to web reports from the 2004 and 2006 conferences for more information.

Grand Challenges in Computing Research home page: http://www.ukcrc.org.uk/grand_challenges/index.cfm

Commentary

Progress

At the opening of the Grand Challenges in Computing Research Conference 2008 Professor Wendy Hall, Chair of the Grand Challenges Steering Committee, said,

"We want action points: we want to keep on exciting and mobilising our community."

This reflects the report on the second Grand Challenges in Computing Research Conference, in 2006, which said, "There has been much activity since 2004, including workshops, document production and the development of communities... However, the final discussion session was on the requirement to step up research ambition and effort... That message is that, after two years' preliminary activity, each grand challenge should seek in the next two years to define a 'step up' action or series of actions that will clearly represent a serious attack on its challenge, on which it has begun work."

In the concluding session of the 2008 conference Professor Alan Bundy, a member of the Grand Challenges Steering Committee, said,

"Most of the computing grand challenges are in the community building phase. They've set up networks and through these networks they've organised workshops and other meetings, often bringing in other disciplines. Many grand challenges are happy to be at the stage; some want to be only a discussion forum. Some grand challenges would like to go beyond this and are working on the project phase. The Steering Committee invites grand challenges to move into the project phase... Is your grand challenge ready to upgrade to the project phase - and would it help if it did?"

Computer science leading the way

There was much praise from speakers from outside the grand challenges for the progress the computer science community has made. This was put down in particular to enthusiastic champions from different universities who have been prepared to work together and share ideas. Such community service would not be possible in the USA, where there is more institutional competitiveness.

The grand challenges are encouraging collaboration not only within computer science but also across disciplines. Some are actively working on engaging the general public. The challenges are promoting deep thinking about both computer science and wider scientific and philosophical issues.

Funding

Speakers from funding bodies in the UK and the USA highlighted new emphasis by governments worldwide on investing in research offering return on investment. In particular the UK government has identified areas it wants to focus science research on: the digital economy, security, eco-change, ageing, energy, and nanoscience.

Attracting students

There was discussion around shortages of students coming into computer science: one participant described this as a crisis. Participants talked about a need to excite young people and teachers about computer science. Experience showed that the grand challenges are generating excitement in universities and could be used to do so among school students.

Approaches to grand challenges

There was discussion on different occasions of the top-down and bottom-up approaches, with impetus coming either from a particular community, as with the computer science grand challenges, or from a broader perspective. An example given of the top-down approach was putting a man on the moon, where the impetus had come from the very top: the US president. It was suggested that there is no way such a grand challenge could be initiated and run by one scientific community.

GC1: In Vivo - In Silico: A 2020 Vision on Modelling Living Processes

Report from the Grand Challenges Conference 2008:
Professor Andrew Bangham
D'Arcy Thompson Centre for Computational Biology, School of Computing Sciences, University of East Anglia; and Chair of GC1 Steering Committee

World challenges

The world's most serious challenges, which face us all, include global warming and food supply. Solutions include conflict or war, and pandemics. These are not pleasant solutions. So there is a challenge to use science, hard work, business and politics to overcome the 'natural' solutions.

Food supply and energy and ultimately living standards are a function of plants.

What have plants got to do with computing? We're trying to build a bridge between the two. Let's set this aim in the context of other fields.

Spitfires embodied much the same aeronautics and physics as a Eurofighter, but in a dogfight a Eurofighter would win, because of today's informatics, computing and control systems.

The human genome project involved a lot of biology and biochemistry but in the sequencing lab it was much about robotics and algorithms.

In biology there are energetics, enzymes, genes, but fundamentally it's all about regulatory systems.

In these fields computing is key to design, modelling (and hence detailed quantitative understanding) and implementation.

Computer science challenges

But we need a new type of modelling, and a new language of biological super-models: existing languages are not sufficient. For example gene network modelling languages do not capture spatio-temporal aspects. Finite element modelling systems do not capture regulatory mechanisms: they don't grow. Material properties are not dynamic. So environments tend not to change: there are no competitors or parasites, for example, and existing models tend not to evolve.

What are the issues around a language of biological super-models?

Small is easy; the challenge is to go large: current models take years to program - minutes would be better.

Models need to cope with diverse, high-dimensional biology: we need a cyber-infrastructure for access, analysis and multidisciplinary collaboration, and both feedback processes and social network analyses for studying, evolving and refining the discovery environments.

Models need to be multiscale - more than nine orders of magnitude in space and time.

Coarse graining is needed: perhaps with the machine learning the I/O as models are executed, for example, or probabilistic models handling large numbers of unknowns.

GC1 website: http://fizz.cmp.uea.ac.uk/Research/ivis/index.jsp
Report from the Grand Challenges Conference 2004: http://www.ukcrc.org.uk/gcresearch.pdf
Report from the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4712

Models need to be dynamic, to grow and respond and offer a range of parameters to the external world.

Other issues include reusability, model evolution, self-reflection, model validation and checking.

Targets, activities and progress

Our initial target is a virtual plant, but the results will apply to all biology.

The biology has started: the Biotechnology and Biological Sciences Research Council has allocated £30m to systems biology. Some of the work is consistent with the grand challenge to model a higher organism. My university and the John Innes Centre (a centre of excellence in plant science and microbiology) have received around £3m of this: our work is directly relevant to the grand challenge.

Computational regulatory networks are essential but we need to expand these to capture spatio-temporal properties. We use a new finite elements environment with genes, reaction, diffusion and cells, showing growth by around two orders of magnitude.

Small-scale models are being produced for roots, shoots and leaves, with a snapdragon as an example, although these are not stitched together.

Success criteria

Our goal is a computational infrastructure enabling the virtual plant. The target date is 2020.

Success criteria will be the ability to 'grow' an entire flower from a seed, to provide the facility to click on different parts to get references and sources, and in 3D to zoom in to discover what is happening to a particular element and why.

As an example of the cost, in January the US National Science Foundation has funded the iPlant programme with $50m [http://www.nsf.gov/news/news_summ.jsp?cntn_id=111048]. But the challenge is larger than that - and the UK needs to remain world leading.

GC2/4: Ubiquitous Computing: Experience, Design and Science

This global challenge was formed from the merger of GC2: Science for Global Ubiquitous Computing, and GC4: Scalable Ubiquitous Computing Systems, after the Grand Challenges Conference 2004

Report from the Grand Challenges Conference 2008:
Professor Tom Rodden
Professor of Computing, School of Computer Science and IT, University of Nottingham; and member of GC2/4 Steering Committee

National and international challenges

Ubiquitous computing is very clearly intermingled with society. Computing is embedded, interconnected, constantly aware - on a planetary scale.

Our relationship with the computer has changed over time, from the mainframe era (one computer, many people) through the PC era (one per person) to the mobility era (several devices per person). The ubiquity era means on average thousands or even millions of computers per person across personal use and society, government and so on.

But human understanding of computing and the many issues around it has not developed at the same pace. This creates a fundamental challenge, a high-impact urgent problem.

The potential is enormous. There is economic potential in the form of business and wealth creation. There is societal potential in terms of improved quality of life through for example the revolutionising of health care through monitoring and data sharing, and improved disaster management through better predictions and responses. Scientific research and innovation can be expanded: just one example is planetary-scale monitoring and management.

But risks posed by ubiquity in those areas are equally enormous. The UK could get left out of markets and businesses. Quality of life could stagnate or decrease. Scientific research could be constrained, or bypassed by others.

Computer science challenges

The challenge for computer science is that the components of ubiquity are in place, and ready to be exploited, but the science of ubiquity - and its consequences - lag behind.

Ubiquitous computing demands a step change to reap the benefits and avoid the risks.

We need a step change at the core of computer science, interconnecting theory, systems and human interaction in a principled manner.

We need a step change at computing science's disciplinary interfaces, to understand the societal, legal and political consequences of technology everywhere and always on.

This demands a focused response. We need to articulate a research vision for a new approach. We need to drive scientific dialogue and debate - shaping an empirical foundation for commonly agreed problems and their solution. We need to engage the general public - not least to prevent public mistrust inhibiting innovation.

We need to establish a common, principled, interdisciplinary approach to the informatics of ubiquity, based on empirical evidence. We need to build an interdisciplinary scientific and

GC2/4 website: http://www-dse.doc.ic.ac.uk/Projects/UbiNet/GC/index.html
Report from the Grand Challenges Conference 2004: http://www.ukcrc.org.uk/gcresearch.pdf
Report from the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4716

public community: we have to design solutions that leverage interdisciplinary capacity, and engage with the public, government and industry to test their validity as solutions for the UK.

We aim to achieve this by interrelating multiple perspectives: the experience (user) perspective, the design (engineering) perspective, and the science (theory) perspective.

Regarding the user experience, we need to start thinking about the realisation of human experiences and about developing ubiquitous computing methods and techniques that are sensitive to the needs of both individuals and society, and the impact on them; and about new interaction paradigms that make ubiquitous computing usable by all. Part of the success of the grand challenge will lie here.

We need to define engineering design principles that pertain to all aspects of ubiquitous computing, are agreed among both academic and professional engineers, are taught regularly in Master degree courses, and are instantiated in the design and documentation of successful computational systems.

Regarding scientific theory, we need a coherent informatics science whose concepts, calculi, models, theories and tools allow descriptive, explanatory and predictive analysis of ubiquitous computing - and we need to employ these theories to derive ubiquitous computing systems, software and development languages.

Targets, activities and progress

The grand challenge has some overall goals:

- To catalyse a step change to the informatics of ubiquity - reshaping the core of computer science through agreed concepts and approaches informed from empirical evidence
- Beyond computer science, to forge links with key disciplines to understand the broad consequences of ubiquity.

Knowledge transfer will be at the core, with informed public debate on ubiquitous computing research, through public events and policy debates on key issues; and with innovation through the transfer of interdisciplinary approaches and new articulation techniques.

We are currently growing interdisciplinary dialogues and establishing a series of foothill projects.

Success criteria

Regarding criteria for success, let me leave you with a quote from computer science and ubiquitous computing specialist Mark Weiser in 1991: “There is more info available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating. Machines that fit the human environment instead of forcing humans to enter theirs will make using a computer as refreshing as taking a walk in the woods.”

GC3: Memories for Life

Report from the Grand Challenges Conference 2008:
Professor Nigel Shadbolt
Professor of Artificial Intelligence and Deputy Head of the School of Electronics and Computer Science, University of Southampton; and Chair of GC3 Steering Committee

Human challenges

This grand challenge is about one of the most compelling phenomena. We ARE quite literally our memories. Our memories are both personal and social. And they have huge importance as we grow, develop and age.

In one sense the challenge isn't about the ultimate memory technology. The hardware technology is already here. And in 10 years' time we will be able to put an entire year of our waking experience on a laptop drive at digital video quality; in 20 years we'll be able to put an entire waking life on a laptop disc of the time.

Computer science challenges

The challenge is how are we going to organise, manage and exploit a lifetime's worth of experience and content?

This raises many computer science challenges: in artificial intelligence - indexing, clustering, automatic annotation, associative linking, contextual retrieval, narrative generation; in human-computer interaction; in visualisation and virtual reality; in integration across senses, not only images and audio but also smell for example; in database systems - formats and metadata, including how to ensure these endure over different generations of systems; in operating systems; and in how we ensure security and privacy, as well as provenance and related factors.

But it's not just about computer science. There are excellent opportunities for interdisciplinary work. There's a convergence of at least three disciplines: device engineering, computer science, and psychology and neuroscience. The intersection of these disciplines provides potential to create a truly remarkable range of applications. That's what motivates us as a community.

Activities and progress

Here are the kind of activities we have been engaged in on the challenge as a community: a review of the science and technology of the challenge, for the Royal Society's Interface publication; a workshop and symposium in December 2006; funding from the Engineering and Physical Sciences Research Council to establish a network, including developing a website; development of a roadmap by the network; proposals submitted and granted funding for the first research projects; plus blogs and podcasts, and radio, press and TV activity.

This last activity is an important aspect of a grand challenge, and this is a very engaging topic for the public: we've had good interest from the press, radio and TV. We've been working quite hard to promote the challenge as a compelling and accessible application of computer science.

Success criteria

Our success criteria will be new kinds of memory augmentation exemplars. Areas we are working on include retrieving and managing a lifetime of images; developing a care companion

GC3 website: http://www.memoriesforlife.org/
Report from the Grand Challenges Conference 2004: http://www.ukcrc.org.uk/gcresearch.pdf
Report from the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.5203

for elderly people; and building a nomenclator: this is from Roman history, when important people had someone whispering in their ear information about people they were meeting.

Discussion among the conference participants:

Participant: Why would anyone want to have memories for life? People may well need to forget extreme situations that have happened to them. The issue of what you exclude or repress is extremely important. So there are questions here about memories on the one hand and forgetting on the other.

Participant: There are times when you want to remember things or put them to one side for a while: for example the death of a loved one. We have the technologies to do what we want but we're now getting into the ethical issues of what we want to do with those technologies.

Nigel Shadbolt: A huge amount of intelligence is about ignoring, laying to one side irrelevant information. Memories for Life is not about the deposition of everything. There's a question of whether it's worthwhile understanding what you can lay aside at the point at which you acquire it. In an age when so much is collected not only by oneself but by others - for example through surveillance - how do you forget, how do you maintain technologies to support your privacy?

Participant: If we can learn from an experience it's arguably better to remember it, even if it was bad and we'd rather forget it.

Nigel Shadbolt: One theme that has emerged is the idea of posthumous memory. We're all aware of questions we'd liked to have asked people who are no longer with us. There are issues around how one interacts and sympathetically records the memories and traditions of people who are dear to us.

Nigel Shadbolt: Some of the earliest contributions to our workshops were from artists, authors and poets, who were keen to remind us that many of the issues are essentially human. We are not at all about possessing this and making it our own. We're saying that technology now brings opportunities and offers us as computer scientists a way of engaging with people, with society. People are engaged and want to know what is possible and desirable. We as computer scientists are researching a set of capabilities and insights that are really going to have impact beyond what we imagine only because of unanticipated consequences.

Participant: Today monitoring goes on all the time and the Freedom of Information Act means anything is open to query, so can we be sure that our own private repository of memories won't be subject to invasion by the government and others?

Participant: If somebody happens to be recorded saying or doing something or being somewhere, they should have the right to have that information removed. The proposal for this grand challenge was that there should be a right to remove information, and the mechanisms should be designed so that this right can be exercised.

Participant: A problem arises here when memories involve more than one person. One person may want to forget and the other may want to remember. You can't force someone to erase a memory.

Nigel Shadbolt: On the whole issue of omission I'm not sure you can withdraw information; instead we need to develop the understanding that people cannot use certain information in certain ways. For example, you might not want a prospective employer judging you on your Facebook information. These conventions can be implemented. It's not about taking information back but about having responsible codes of behaviour and policies on acceptable use.

Participant: I'm very concerned that visual recordings don't present the full context. As the context changes so does the meaning of what you're seeing. To learn things from recorded memories you probably have to include something to correlate what happened with what was observed. This correlation is the important thing, not just the camera's view.

Nigel Shadbolt: You can get dominated by the visual medium, and that's not the intention of the grand challenge. In all the challenges there's the issue of the immediate computer science field needing to be offset by general questions, and some very compelling questions like this are coming out.

GC5: The Architecture of Brain and Mind

Report from the Grand Challenges Conference 2008:
Professor Steve Furber
ICL Professor of Computer Engineering, School of Computer Science, University of Manchester; and member of GC5 Steering Committee

Scientific challenges

This grand challenge is at one of the frontiers of science.

It is a computer science grand challenge but it draws on many disciplines, including philosophy, neuroscience, developmental psychology, animal behaviour.

We believe computer science has evolved in concepts and abstractions that are likely to be useful in this: areas including architectures, virtual machines, parallel processing. We want to bring those ways of thinking alongside the other disciplines.

We will know if we're making progress by testing our understanding by implementing computer and robot models.

Computer science challenges

The entire grand challenge is encapsulated in the objective of designing and building a humanoid robot capable of a range of sophistication of behaviour equivalent in some sense to that of an infant. There are different opinions in the steering committee over whether this means a child of three, four or five.

The challenge is to move from concrete neurological reality to abstract computer models: from 'white matter pathways' to a computer model of the neuronal workspace - from the biology to computing.

Starting with cognitive architectures, neuroscientists are getting increasingly detailed images of brain operation, an increasingly detailed understanding of the basic wiring of the brain, the broad network structures. This understanding will ultimately help computer science to define computer models.

Activities and progress

Various upper body and full body humanoid robot platforms are under development around the world. Several funded UK and European projects, including the EC Cognitive Systems initiative, are under way that are relevant to this grand challenge, and at Manchester we are working with Southampton on the funded SpiNNaker project, which aims to build a computer to mimic how nerve cells in the brain interact. This clearly contributes towards the objectives of the grand challenge.

Success criteria

How will we know when we've succeeded in the grand challenge? This challenge can score significantly in three dimensions.

It can advance work in robotics: our aim is a robot capable of a range of sophistication of behaviour equivalent to that of an infant.

It can advance understanding of information processing mechanisms in the brain, leading for

GC5 website: http://www.cs.bham.ac.uk/research/projects/cogaff/gc/
Report from the Grand Challenges Conference 2004: http://www.ukcrc.org.uk/gcresearch.pdf
Report from the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4717

example to new therapeutic treatments.

It can lead to a novel brain-inspired computer architecture - displaying biological levels of fault resilience and power efficiency: the brain is a million times as efficient as a computer.

Discussion among the conference participants:

Participant: How long will it be before we have a computer that behaves like an infant?

Steve Furber: I originally put timescales on this and then decided there were still too many unknowns. I shall be very disappointed if we have not got something fundamentally exciting in 20 years.

Participant: There's the famous Donald Rumsfeld quote about knowns and known unknowns and so on. Does this grand challenge have issues that are still unknown?

Steve Furber: There are unknown unknowns. I personally have a feeling that when we do understand how the brain works it's going to be much simpler than we currently think, although some other researchers have different views.

Participant: One issue for this grand challenge is to try to understand not only how the brain works but what it's for: in engineering terms what are the requirements that evolution had to meet in producing the design? We don't yet know. What is learning, what are emotions? So we will be learning a lot of deep and important things in less than 20 years - but that doesn't mean we'll be able to build the equivalent of a one-month or 10-month or three-year-old child in less than a few hundred years.

GC6: Dependable Systems Evolution

Report from the Grand Challenges Conference 2008:
Dr Juan Bicarregui
e-Science Information Services, e-Science Centre, Rutherford Appleton Laboratory; and member of GC6 Steering Committee

A long-standing computing challenge

We have 2,000 years of dependable systems evolution in civil engineering, for example in building bridges, but only 50 years in computer engineering.

Our grand challenge vision is of systems that are dependable and trustworthy throughout their lifespan.

The aim is to be able to prove that a program is correct before running it: this is an outstanding challenge in computer science that goes back 40 years.

The central principles are that theory should be embodied in tools, and tools should be tested against real systems.

Deliverables include a comprehensive theory of programming, covering the features needed to build practical and reliable programs; a coherent toolset automating the theory and scaling up; and a collection of examples.

Work is going on across the world, including in the UK, Europe, the USA, China and Brazil, on an international grand challenge in verified software. So part of the challenge is to ensure we can build on each others' work. Members of the steering committee have contributed to international development, workshops and conferences.

Targets, activities and progress

With much work going on in this area we are looking at a verified software repository, a managed repository of tools and challenges, to facilitate the use of tools and accelerate their development, and deepen knowledge of the challenges and progress development of design for analysis. Detail on the repository is at http://vsr.sourceforge.net/index.html and http://vsr.svn.sourceforge.net/viewvc/vsr/.

Each activity can accelerate the development of the other: tools development is encouraged and steered by challenges, and case studies are enhanced by results of analysis. From here we can provide feedback to tool developers and provide further analysis of the challenges. Meanwhile there can be constructive rivalry.

Since 2003 we have organised or contributed to more than 30 workshops, national and international conferences and other events.

We have run a project to verify a key property of the Mondex electronic purse on a smartcard, redoing work of 10 years ago. This was done by eight teams in different formalisms. The results from the teams were more or less the same - and all the results were much better than 10 years ago.

We also have a project in progress on specifying and verifying a flash memory filestore with fault tolerance. We have adopted a collaborative approach, with different teams doing different parts.

GC6 websites: http://vsr.sourceforge.net/introduction.htm http://www.fmnet.info/gc6/

Report from the Grand Challenges Conference 2004: http://www.ukcrc.org.uk/gcresearch.pdf

Report from the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4721

Success criteria

How will we know when we have succeeded? Systems will be dependable: for example no blue screens from failed applications, no 404s (web page not found). Systems will have verified components, and verification will be invisible. Evolution will be exemplified by plug-and-play software with instant reconfiguration, interoperation and portability. And the development process will benefit from reduced testing, reduced test failures, and predictable development times and costs.

GC7: Journeys in Non-Classical Computation

Report from the Grand Challenges Conference 2008:
Dr Colin Johnson
Computing Laboratory, University of Kent; and member of GC7 Steering Committee

A computer science challenge

What do we mean by non-classical computing? What if computers were built of different stuff or we organised traditional computing stuff in different ways: could we do new kinds of computations? One direction for example is to think about computing ideas beyond computing artefacts.

We chose the idea of journeys: it's about what we discover on the way rather than having a specific destination in mind.

There are some paradigms that define classical computing, and these are being systematically challenged to shape thinking on classics for the 21st century: for example the Turing paradigm, which assumes we know what resources are going to be available before we start a computation; the von Neumann paradigm, which restricts us to a sequential fetch-execute-store; assumptions about a process having a defined start and end, input and output - can we draw for example on bio-inspired algorithms in areas such as genetic programming, neural networks, social networks; the refinement of a specification to code, when there might be problems that are defined in terms of data, such as teaching a system to read handwriting; and the computer as an artefact: the very idea of a traditional computer, a device bounded by the laws of physics.

Activities and progress

Activities so far include a workshop in 2005, the Unconventional Computation Conference in 2006 and 2007, and development of plans for a national network.

Success criteria

We have two criteria for success: that non-classical computational tools (physical, mathematical, conceptual) are used as part of normal computing - with an expectation that computer science students understand natural science; and that computational concepts are used generally, beyond the specific context of talking about computing.

GC7 website: http://www.cs.york.ac.uk/nature/gc7/

Report from the Grand Challenges Conference 2004: http://www.ukcrc.org.uk/gcresearch.pdf

Report from the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4720

GC8: Learning for Life

Report from the Grand Challenges Conference 2008:
Professor Josie Taylor
Professor of Learning Technology, Institute of Educational Technology, The Open University; and Chair of GC8 Steering Committee

An interdisciplinary challenge

We are still in the technological Stone Age regarding learning technologies. So the idea of the grand challenge is to re-engage computer scientists to drive progress towards computing machinery and devices, networks, software that are actually up to the job so that every learner who wants to learn can learn what they want, in the way they want, whoever they are, wherever they are in the world, and whatever their age or literacy level; and every person who wants to teach can teach whoever wants to be taught in the way they want to teach, whoever they are and wherever they are in the world.

The challenge is to conceptualise learning environments and understand how people will engage with learning, and what learning for life will be like.

These new possibilities need to be understood in the context of our developing understanding of the co-evolutionary nature of learning and computing systems, mobile devices, ubiquitous computing, the semantic web, so we ensure that the full potential of learning for life is realised.

We need this understanding at personal, group and societal levels.

Clearly this is a highly interdisciplinary initiative, involving computer science, learning sciences and social sciences.

Success criteria

How will we know when we've succeeded? When all computers, whatever their form, can talk to all others through communication channels that let people pursue their interests and goals without obstacles. When all computers can talk with all other computers - without the use of cables - organising themselves into sensible networks. And when educational institutions exist solely for their social function.

GC8 websites: http://ukgrandchallenge8.open.ac.uk/ and http://kn.open.ac.uk/workspace/gccr_l4l/index.cfm
Proposal to the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4730

GC9: Bringing the Past to Life for the Citizen

Report from the Grand Challenges Conference 2008:
Professor David Arnold
Dean of the Faculty of Management and Information Systems and Professor of Computing Science, University of Brighton; and Chair of GC9 Steering Committee

National and international challenges

The vision is that citizens should be able to see events of the past replayed interactively, and beyond that to explore the circumstances and motivations of the participants, linking the reconstruction to the evidence and receiving explanations of the differing socio-political perspectives which are relevant to the events.

This challenge offers many economic and social benefits.

History is an important part of the huge tourism economy - but popular sites get overrun by tourists. There are opportunities for low-cost flights but concerns about energy and environmental impact.

In addition this challenge can help to deliver education and promote citizenship and cultural identity.

There are several challenges, some related to the sheer scale of 'heritage'.

For example there are 900 archaeological groups in the UK and more than 10,000 museums and visitor centres: how do you energise these communities? Around 60,000 portable antiquities were registered in 2006 alone. Legacy data is incompatible, hardly ever standardised, analogue. There are 20 years of digital data with little provenance information.

There are choices to be made. The UK Heritage Lottery Fund defines heritage as 'what is valued by the people'. Things change over time, so which past do you focus on: for example broken pottery gets reused as decoration, masonry gets reused. Interpretations have to be made, based on conflict, religion, culture. Just what is 'knowledge' about an artefact?

Computing challenges

There are digitisation issues around scale and accuracy. How do you handle the digitising of huge monuments, palaces and so on; and re-used inscribed stones: what do you record - the arrangement of stones, the inscriptions? How do you digitise content such as fur and jewellery?

How do you record the interaction of nature and artefacts: for example as nature gradually overruns abandoned monuments or buildings?

How do you communicate to the public: animation, re-enactment and so on? How do you distribute tools for common use?

How will heritage professionals react to curating in the age of Wikipedia?

Targets, activities and progress

There is a growing series of events in this area, such as the VAST series: the International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage. The new ACM Journal of Computing and Cultural Heritage is being launched in 2008. And there are related developments such as the funded programmes Preserving Our Past, and Science and

GC9 website: http://www.cmis.brighton.ac.uk/gc9/
Proposal to the Grand Challenges Conference 2006: http://www.bcs.org/server.php?show=ConWebDoc.4724

Heritage.

Our next steps include a workshop in May, seeking funding for a network, and the engagement of other communities, including narrative experts, museum curators, educationalists: this is clearly a multidisciplinary and interdisciplinary programme.

Success criteria

Termination will come when the approach is embedded, to the extent that there's a critical mass of integrated data; when you can't imagine undertaking history education without the tools; and when people plan holidays using the tools and historic interest rises up their list of priorities.

Intermediate goals may be specified in terms of targets for critical mass of data (for example all museums); and free navigation and scripted routes.

We can measure success by factors such as degrees of engagement and learning outcomes.

A View from South Africa: A Real-Life Grand Challenge: Bringing the Benefits of ICT to the Developing World

Dr Gary Marsden[1]
Associate Professor, Department of Computer Science, University of Cape Town, South Africa

Local circumstances

I am originally from Ireland and worked as a lecturer and senior lecturer in computing science in the UK before joining the University of Cape Town in 1999. The Department of Computer Science is mid-sized for a South African university, with 15 academics.

All our research - and our challenge - is around development and using information and communications technologies to improve quality of life for people in Africa.

Only 12% of people in South Africa have access to the internet: this includes being within walking distance of an internet café. For all Africa the figure is 5%. Access is slow: our university has one 10Mb line for 20,000 students and 2,000 staff.

Yet 77% of people have mobile phones. Ten out of 43 African countries have more than 90% GSM coverage; another eight have 70% coverage or more. Mains electricity power cuts are leading most people at my university to switch from PCs to laptops with mobile communications cards.

So to make impact with ICT on quality of life you have to look at mobile devices. For example we have worked on a system enabling people who visit HIV AIDS sufferers to record details on mobile devices and send the data back. UNESCO information on development farming, held on CDs, could not be accessed by people without PCs, so it has been adapted for use on mobile devices.

Listening to users

However, there is a danger of people from the developed world applying thinking and assumptions from their world. In particular, the understanding in the developed world is that if you have a problem you can keep throwing more and more technology at it.

For example the idea of downloading full open source operating and systems and applications software is not practical when internet access is limited and slow. So in our university we have a self-service system where we store software and people can insert a CD and select the software they want.

A mobile device was designed for lifelong experienced animal trackers, who are illiterate, to gather data on animals. But the interface was designed as a westerner would use it, with creatures categorised as reptiles, birds and so on. The trackers just laughed at it. So the designers then worked with them to let them devise their own interface.

Mobile phone companies promote a story from India, where fishermen phone from their boats to find the markets offering the best prices, to decide where to land. I told this to a fisherman in Malawi and he laughed: “The cost of the call is greater than any profit gain I would get - and why would I want to go to another market, when all my friends are in my home town?”

[1] http://people.cs.uct.ac.za/~gaz/

Lessons from all this are that we can't impose technology from one social structure on another, and wealth potential is not the only driver.

Local innovation

There is so much innovation in Africa, using the resources available. I met a guy who had reinforced his pedal bike and added extra springs so he could provide a taxi and delivery service: he stands on the pedals, a passenger sits on the seat, and the pannier at the back is piled high with goods. If you look around you see all sorts of engineering applications.

Yet most people in Africa believe that all digital media comes from the West, as a push. It doesn't seem to occur to them that their music, their culture, is just as valuable and could be pushed back.

Computer science challenges

As computer scientists we can give society tools to help people think and create. This is my research. We have personalisation of software at one end and open source at the other - but to make open source software work you need a lot of understanding. I'm exploiting the space in the middle, exploring tools to help people help themselves. I've come up with a terrible word: communitisation of software.

So our grand challenge is to create technology that will empower developing world citizens to create their own digital solutions.

There are wide implications. Should we be teaching students how to program for high performance computing - or how to program a cellphone? In Kenya there's a programme to show entrepreneurs how to develop basic SMS applications, so they can make business out of cellular networks. There's no redundancy in Africa - so how do you design or set up a solar cell powering a network node so that it doesn't get stolen? And if the power does go off, how does your network cope? We need appropriate curricula.

Our challenge in Africa could also be your challenge in the West: how do you do more with less technology? How do you fully leverage what you already have?

A US View of a Grand Challenge: Establishing Computational Thinking as a Skill for All

Jeannette Wing[2 3 4]
Assistant Director, Computer and Information Science and Engineering Directorate, National Science Foundation, USA; and Professor of Computer Science, Carnegie Mellon University, Pittsburgh, USA

The challenge proposal

My proposition is that computational thinking will be a fundamental skill used by everyone in the world by the middle of the 21st century.

The innovation that Gary Marsden talked about seeing in Africa and his suggestion that one role for computer scientists is to give society tools to help people think and create underlined the importance of mental tools, concepts, thinking tools and education - more so than the metal tools, the technology.

Just like reading, writing and arithmetic I can imagine every child knowing how to think like a computer scientist, having the fundamental skills that underline our field, as part of their daily living.

This has profound implications for how research will be conducted in every discipline. And it has profound implications for education, for teaching computational thinking at all levels.

The need

Computational thinking means that when computer scientists are presented with a problem we can consider whether it is solvable, in the sense of whether it is computable, and how best to solve it.

Characteristics of computational thinking that we take for granted in this process as computer scientists include the fact that it is about abstraction, thinking recursively, reformulating a seemingly difficult problem into one that we know how to solve, choosing an appropriate representation or modelling a solution, extraction and decomposition of a large complex task, designing for simplicity and elegance, the prevention, detection and recovery from worse case scenarios, modularising something in anticipation of different uses in the future.

When computational thinking becomes something we apply to everyday life, we will be using our computer science terms without thinking. That's how I imagine the future.

Computational thinking is already transforming other fields.

In biology we have machine learning and the ability to process masses of data, and computational thinking can be applied in a much deeper way, for example to represent biological problems in computational models.

Machine learning has revolutionised statistics. Statistics departments in insurance companies and other organisations are hiring computer science PhDs.

In economics there's a burgeoning new field called computational microeconomics, for example to optimise the placement of adverts in Google and other media.

[2] http://www.nsf.gov/
[3] http://www.cmu.edu/index.shtml
[4] http://www.cs.cmu.edu/~wing/

Research progress

In the USA a new five-year programme, Cyber-Enabled Discovery and Engineering, has $48m of funding this year. Next year we hope to expand this to $100m. In a nutshell, it's computational thinking for science and engineering. It's basically a recognition that the way science and engineering will be conducted in future will be with computational methods: that people will make discoveries and innovate and advance in their own fields because of the methods, principles, tools and concepts that computer science can bring to the table. There's been an incredible response to this exciting programme: 1,700 letters of intent and 1,300 preliminary proposals.

Where to start?

But at what age should we start teaching computational thinking? Everyone at undergraduate level will be exposed to it in some way, but that's already too late. We need to focus at lower ages. I think even high school is too late. So, with a lot of encouragement from the community, I'm focusing on issues around even younger children learning computational thinking.

This is a grand challenge for the computer science community: what are accepted ways of teaching computational thinking to children, and how do they learn it? At what point in a child's life is something like recursion something they can appreciate and then apply to everyday living?

There's a progression of learning of mathematical concepts that we know we can track with childhood development: understanding of numbers, algebra, calculus. We need to think about computational thinking in a similar way: think about the elemental concepts and then the reasonable progression of those concepts that track childhood development.

That's just the concepts. The other aspect of computer science is the computer, the tool. So we must ask at what point do we introduce the computer and how do we use the tool alongside the track of learning the concepts. We have to be careful. We don't want the tool to get in the way. We don't want pupils to think that just because they use the tool they understand the concepts.

An interdisciplinary challenge

We need other disciplines involved here, especially people who really understand education and people who understand how children learn. So in the National Science Foundation I'm working with the directorates for education, human resources and social, behavioural and economic sciences. They raise questions that computer scientists wouldn't think to ask. Learning sciences people discuss the nuances of ability and skills; others ask me what elemental concepts of computational thinking are we born with: for example we all have innate elemental concepts about maths, music and vision, things we don't have to be taught. Some of these are deeper questions than I was really looking at but this is the kind of thinking that can really push us as we get involved with other disciplines.

Now I'm at the National Science Foundation it really hits me that we computer scientists work in our universities with fellow computer scientists and although we may be starting to talk to people outside our field it's very easy to just narrowly think about computer science. Other people don't understand it and have no exposure to it apart from as users of cellphones, iPods, Google and other technology. There's a lot of computer science underlying Google but it doesn't get conveyed.

Computer science challenges

So we have a lot of technology drivers and we have science drivers: deep questions in computing. I've been trying to list some deep questions, and I'd like to challenge you to come up with your own lists of deep questions that are special to computer science and are not about how computing can be applied to physics and other fields.

The most fundamental question is what is computable? In thinking about that, you have to ask what is the machine that you are talking about in this context? For example quantum computing really challenges our notions of what a computer is. Think about the internet as a computer - and what is computable by that machine. Think about the computer as a human and a machine working together, as a computer. We humans compute, and we are still much better at vision than a machine. So why try to make a machine do what we can do so well? Why not work together, complementing each other's strengths - and then ask again what is computable?

What is intelligence? What is consciousness? What is information?

My last question is can we build complex systems cheaply, and if so, how? It's a long-standing challenge for all of us. We'd like to be able to build systems in a simple manner, yet we want the rich functionality that complex systems have. This is a real challenge.

The EPSRC and Grand Challenges

Lesley Thompson
Core Programmes Coordinator, Engineering and Physical Sciences Research Council

Return on investment in research

Governments worldwide are looking at how to invest in science with return on investment.

The UK government has identified problems in various areas and wants to focus science research on these: the digital economy, security, eco-change, ageing, energy, and nanoscience.

In the UK we have had for example the 2004 10-year White Paper on science and innovation; the 2006 report, Science and Innovation Investment Framework 2004-2014: Next Steps; and the formation in 2007 of the Department for Innovation, Universities and Skills, which for the first time saw researchers and the funding councils together under one umbrella. The Engineering and Physical Sciences Research Council (EPSRC) is seeing real-terms growth in its funding.

Grand challenges evolution

The first computing science grand challenges meeting, in 2002, was my first meeting with people from across the cohort. At that time it was very much a case of them and us: funding councils and researchers.

Since then you have a done a superb job with the grand challenges in providing vision - and it shows.

The way you've done it has useful pointers for other communities: in fact we are piloting your model in other fields, drawing on the experience in computing science.

How have you done it? You've undoubtedly had key enthusiastic champions who have been prepared to put their ideas together for community dialogue. You've really successfully allowed researchers to discuss and dream. You've formed communities of practice. You've influenced research funding applicants and referees: a large number of proposals for funding now mention being part of a grand challenge. You've raised the UK game.

EPSRC looks ahead

After the White Paper and the Next Steps report the EPSRC had a memorable meeting in October 2006 to discuss what was needed if we were to have an internationally revered science base which was really having an impact on the economy. We are now on a journey to 2014 that dates back to that meeting.

Some issues that emerged are relevant to grand challenges. The need to traverse boundaries, no longer worrying about whether this is physics or computing science: we should just do science. There should be two-way technology flow between industry and universities: some of the great creativity comes from this. There should be benefit to the UK economy and society.

For these and other targets the EPSRC has things to do. We should incentivise researchers, for example by having less bureaucracy. We need to foster the idea of research careers. We need to look at partner relationship management, changing our relationships with industry and universities. I also want better links with the learned societies. And let's look more internationally at projects and partnerships.

Approaches to grand challenges

The EPSRC has been looking at grand challenges. What is a grand challenge? It must be grand: a significant societal or economic problem that requires the application of research. It requires community effort, beyond the stakeholders. It should have the ability to enthuse society: this is hard in some areas of computing science, but a grand challenge offers more opportunity to do this.

We quite like the idea of your bottom-up approach. We would like to encourage other communities to self-assemble around grand challenges in this way. We are going to try this approach in chemistry, where we've picked some champions to start things rolling.

We also like the top-down approach, and we will try this with nanoscience and nanoengineering.

An interesting challenge for you now is how you in your universities and across other communities and globally can raise the dialogue about grand challenges as 'infection agents'.

A UK Grand Challenge: the Digital Economy

John Hand [5]
Programme Manager, ICT, Engineering and Physical Sciences Research Council
Digital Economy programme

Opportunities to meet

My first contact with this community was the event in 2006, just after I became ICT Programme manager at the Engineering and Physical Sciences Research Council (EPSRC).

The grand challenges initiative has offered great opportunities to meet a lot of people from across the community in the same place at the same time, at events like this, and to identify areas for proper engagement. So the grand challenges are a way of highlighting the excitement around this area and raising the profile of the subject.

It's also really useful to get to know about people who can work across disciplines, in grand challenges. We're often told, as funders of research, that there are real problems around peer review of interdisciplinary research, so by talking to people as a collective at conferences like this we get to know those who are good at looking at proposals for cross-disciplinary work.

Digital Economy programme

This is useful for the Digital Economy programme. The programme is not replacing the EPSRC core ICT programme, which looks at the disciplines that make up that programme.

The Digital Economy programme is something of a grand challenge. It's about the transformative abilities and effects of information and ITC - not incremental or augmental aspects but about really changing the way things are done: the way a business operates, the way society interacts, the way government interacts. Its about understanding how that happens, to enable the early adoption of these transformative effects.

So it's not just about ICT. It's everything that's necessary to capture, manipulate and use information. It's about engaging with social scientists, economists, management schools, to understand how these things are being used and what they're being used for. This is a cross-council programme that is inherently multidisciplinary. So we will really need a change in the way the communities interact, almost a change in culture. An obvious way to change a culture in a community is through grand challenges, which focus different disciplines on a common goal.

We're focusing on three key areas in the first three years of funding - health care, creative industries, and transport - but I anticipate that the programme will carry on beyond the three years, so will need to extend into new areas. If you have ideas or have done a project that exemplifies the programme, please tell us.

Top-down and bottom-up approaches

Drivers for the programme have come from the top down and the bottom up.

Top-down drivers have come from increased emphasis on the knowledge economy and the tools and skills needed to deliver that, to help maintain the UK's competitiveness in the face of growing strength of the Far East and India; but other drivers are around issues including the ageing population, global threats to security and energy, and how the digital economy and related skills and computing offer solutions to those problems.

[5] http://www.epsrc.ac.uk/researchfunding/programmes/de/default.htm

Influences have also partly come from the bottom up, from discussions we had with the community. A main source of input was the advisory team - each EPSRC programme has an advisory team made up of members of the community; Professor Nigel Shadbolt from the grand challenges community is on the ICT advisory team. Occasionally we get all the teams together, and we did this four years ago, and said that with a spending review on the horizon, what were the important areas we really needed to put some investment and time into developing. Several threads came out of that and these fed strongly into the Digital Economy programme.

It's difficult to do bottom-up grand challenges when you're drawing together different disciplines, so we want to think about how to do some top-down grand challenges in this area. We need to work with people who own those challenges and problems.

Industry involvement

These challenges will be different to the challenges discussed at this present conference in that some or a large part of those Digital Economy grand challenges will be industry-driven, but not exclusively so. The challenges being discussed at this event are more driven by a science problem or a social problem or a bigger philosophical problem.

Despite the industry involvement we don't want the Digital Economy research to be short-term. That's why we want to adopt a grand challenge approach. We need to get industry supporting this in 10-12 years' time rather than just in the short term. There are lots of challenges around that in itself.

In addition the EPSRC chief executive, David Delpy, has very much included social benefit as driving the EPSRC as well as economic benefit.

Size is an issue

Another difference is the scale and breadth. One thing that really struck me from the presentations on the current grand challenges was the number of meetings that some had had. Times that by eight challenges and that's an awful lot of community activity. How can we enable this to happen across an even broader range of people?

After the first three years of funding the real test in engaging with the government will be in measuring how we have met the challenges set down.

So there limitations to the grand challenges approach for the Digital Economy programme. In particular, can we do it on as big a scale with different types of projects? Your help as a group as we work to understand that and take the programme forward is very valuable.

A US View: Funding Grand Challenges

Dr Andrew Bernat [6]
Executive Director, Computing Research Association, USA

Persuading the funders

The Computing Research Association (CRA) is an association of more than 200 North American academic departments of computer science, computer engineering and related fields; laboratories and research centres in industry, government, and academia engaging in basic computing research; and affiliated professional societies. Pretty much everyone involved in computing research in academia, industry and government is a member.

The CRA's mission is to strengthen research and advance education in computing fields, expand opportunities for women and minorities, and improve public and policymaker understanding of the importance of computing and computing research in our society.

We have a long way to go in our mission. People have wireless communication, Windows, spreadsheets and so on, and they think it's all been done, that there are no more exciting areas. So a grand challenge we have is to show there's much more to be done in research communities. We've moved away from the term grand challenges and we talk more about visioning. A big part of our work is to capture visions that the government and the people will think are worth pursuing and will be willing to put their tax dollars into. The beauty and deep questions of computing are not of exceptional interest to our federal government, and particularly not to Congress: their interest is economic impact. So when we're trying to get funding we couch things in terms of economic impact. Where we do see beauty, science, deep questions, we don't pitch on these, because we wouldn't get funding.

Need to attract students

We need to bring back excitement to attract the best and brightest people. In the US we create more PhDs in physics and astronomy combined than we do in computing. Job prospects are clearly better in computing than in physics or astronomy, but students go into those fields because they feel intellectual excitement. For whatever reason we have not been able to capture what we believe is the intellectual excitement in a way that grabs those students.

Institutional competitiveness

The US context is clearly different to the UK context. The way you come together to discuss and vet grand challenges through the UK Computing Research Committee is more difficult in the US, because of institutional competitiveness.

Getting funds

Research funding in the US is highly concentrated: a year or two ago the National Science Foundation (NSF) provided 86% of computing research funding. The CRA, representing the vast majority of researchers, has no direct influence on funding sources: there's a process in the NSF and no group outside the NSF can say where money should go.

Lack of community service

Sadly, again unlike in the UK, community service is not a high priority among computing researchers, largely because it's such a fast moving field, with so many opportunities, that it's hard to get people to spend time at it. Half the programme directors at the NSF are rotators; I spent two years there. This is community service but it takes you away from your active

[6] http://www.cra.org/

research, so it's not a high priority for people.

Grand challenges activities

There has been activity and some outcomes on the grand challenges front.

The CRA organised three one-off grand challenges conferences. Arguably the most valuable product that came out is what's happening here in the UK, because our efforts have largely gone nowhere but you're going strong.

Two community-based activities have gone forward: the Cyber-Enabled Discovery and Engineering programme that Jeanette Wing of the NSF talked about in her presentation, and another from the networking community.

We also have three visioning efforts going on. One is on big data computing, and the NSF has announced a related programme to provide researchers with access to big computing. The other visioning activities are in theoretical computer science and a large-scale effort in robotics. These three are just starting and we are actively seeking others. We have worked extensively with the NSF on engaging community effort.

Other disciplines in the US do have grand challenges that go across communities: maths and physics, physics and astronomy have a national research council committee that works on a 10-year basis. The CRA put up a proposal to the NSF for a Computing Community Consortium. It works in partnership with the NSF on how we can move forward jointly. It doesn't weigh one grand challenge against another or make funding decisions, but it helps to guide the process.

Lessons for grand challenges

Some strategies and lessons have emerged from experience.

Number one, we learnt you have to involve the funding agencies from the start. You can't go off and do a grand challenge and expect someone to pick it up.

We want strong international cooperation and we have funding for this: in our NSF funding we have funds for international and US travel for example.

We try to generate clear visions. We want broad communities to coalesce around these visions, not lone researchers with a great idea.

We need to create the political will within the research communities, in the funding agencies and at Congressional level.

We're working hard to communicate with the public. In the past we in the computer science research community have not communicated with the public or indeed with students about the challenges and the excitement.

We have some anticipated outcomes.

Number one, we want to capture the excitement about computing research. We've done a very poor job on this. We've driven students away. We need to create visions that researchers are interested in pursuing and being part of. We want to attract the best and brightest - this is very important. We are the ageing, fading generation: we need the very best and brightest young people and need to get them excited about computing when thinking about their PhD.

It's important to get people involved in the effort, because one hoped-for outcome will be that this will encourage them to help service the community.

The Impact of Biosciences

Fionn Murtagh
Director, Information, Communications and Emergent Technologies Directorate, Science Foundation Ireland, and Professor of Computer Science, Royal Holloway, University of London

Biosciences influence

The Research Excellence Framework is to replace the Research Assessment Exercise, bringing a bibliometrics-driven approach to evaluating research. So much has changed in the last 10 years it's unbelievable. The way we carry out our research and scholarly work is that we have become very influenced by the biosciences. Take for example how journal citation rates are based on just two previous years: extreme recency has come to count greatly in citation practices, and a very small number of highly profiled journals tower over all others. Tradition is very much set to one side because of the way biosciences work.

Patents expire

Now, there is an elephant in the room. What is the greatest product of all time in terms of return on investment and development? It is the drug Lipitor, used for cholesterol treatment: it cost Pfizer $500,000 to develop and now brings in about $13 billion a year. However, the patent on Lipitor runs out in 2010. This is only one drug among many where intellectual property rights are going to change greatly in the next few years. Drugs are going generic as patents run out, costing an enormous amount less. As patents run out, and as competitive pressure prises open current intellectual property holdings, the whole pharma and bio sector will be affected by some serious issues, not least the fact that development costs of drugs are increasing very dramatically: this is tied in not least with the number of trials that must be carried out. Drugs companies will be desperate as they try to survive in a totally new era in a very short number of years from now.

A new health system?

The implications will be profound. There will be a very different health system, including insurance and medical domains. To have a feel for the direction of events, look at computer science and the ICT sector. Computer science and engineering is characterised by a wealth of models for research and for application.

As generic drugs gain ground, could they become like software? There are many formal similarities between them. Maybe, too, drug development will need a new Google-Pharma information search and fusion infrastructure at its core, making use of information and data which will be increasingly in the public domain. Beyond that perhaps our health system will be based on a Google-Health information infrastructure, with the door opened at last to a much tighter merger of health and computerisation in terms of personalised health care. That really requires a lot more interdisciplinary work.

Envisaging barriers between disciplines coming down is no bad thing. Computer science and engineering as a discipline is solid, sound, founded on a wealth of rigour and well based intellectual standards.

As technologies and society's information infrastructure evolve, fluidity and adaptability are needed. Computer science and engineering, I believe, will be very different in one or two decades from now - and I would welcome that - and I have no doubt that computer science will survive very very well.

The Origins of the Grand Challenges

Professor Sir Tony Hoare
Senior Researcher, Microsoft Research, Cambridge

Early influence

One of my first inspirations came in 1968 when I read Bob Floyd's paper on logical assertions and assigning meanings to programs just as I was moving from industrial secondment into academia. I made a resolution to devote my research to program verification and largely the scientific method for evaluating program methodologies and programming languages.

I thought there would be nothing of interest to industry at least until after I retired. An advantage in those days was that universities were allowed to do long-term research. I retired in 1999 and no one in industry had applied any of the methods I was researching.

Software research evolution

When I retired Microsoft Research offered me a job as a senior researcher in the Programming Principles and Tools Group. After a year or two I witnessed the installation of the PREfix and PREfast program analysis tools into Microsoft standard programming practice. This was the beginning of a series of tools which increasingly incorporated the results of earlier software verification research. But it also showed that the scale of software research would have to be much larger than in the past, when a single researcher would present a paper on a year's research. Effective research demanded larger teams and timescales, in line with other disciplines: in physics for example work is not done by lone researchers. Computer hardware progressed through work by teams in the 1950s and perhaps software is moving on now too.

Grand challenges criteria

Around 2000 I was invited to contribute an article to a specialist journal of the ACM on grand challenges in computing for the 21st century. I thought about trying to revive the ideas of Bob Floyd in 1968 on verification, and inviting other ideas. But I saw that criteria were needed to distinguish grand challenges from the challenges facing researchers every day. I made a list of criteria (these are at http://www.nesc.ac.uk/esi/events/grand_challenges/criteria.html).

One basic criterion was that it must be good science, preferably fundamental science, answering deep questions. I thought my hope for a verifying compiler was perfect. So we have to agree the basic deep scientific questions, and put aside, for the time being, all issues of commercial exploitation.

Professor Robin Milner
Computer Laboratory, University of Cambridge

First steps

Tony Hoare's grand challenges criteria are alive and well. We then wondered who would choose the grand challenges against the criteria. This was quite a frightening responsibility. Some impetus came from Tony Hoare's visit to the US Computing Research Association, which at the time had a similar initiative.

The first workshop was set up in Edinburgh in November 2002. We had a programme committee of nine people. We sent out an open call for ideas that would meet the criteria, and eventually got 109 submissions. The call for submissions said, "The aim is to inspire imaginative out-of-the-box thinking about the future progress of our subject, untrammelled by the constraints of historical legacy, commercial application or shortness of timescale."

That call for submissions is at http://www.nesc.ac.uk/esi/events/Grand_Challenges/call.html

Participation in the workshop was by invitation only, based on the submission. We had space restrictions and weren't able to invite as many as we hoped. I think 64 came. That sticks in my mind as the one thing we could have done better.

Categorising the topics

Before the workshop the programme committee categorised the submissions into categories not predetermined but dictated by the spectrum of topics in the submissions themselves. These ended up in four piles: strong software engineering, architecture of ubiquitous computing, humanly-oriented computing, and modelling or designing a brain or organism.

We were utterly non-judgemental on the submissions. It was decided to defer the treatment of them to the workshop itself. So at the workshop we appointed a panel for each of the four areas, asking them to consider every submission - whether or not the submitter was present - and on this basis to come up with one or two ideas for a grand challenge, reflecting as far as possible the consensus of the submissions. As a result, from the four panels we arrived at seven draft proposals, and during the subsequent weeks the panel chairs firmed up these drafts.

Since then the proposals have been continually refined and strengthened. The process, carried on in conjunction with building a community around each challenge, has worked quite well, but it remains under continual review.

Extra information from the report on the 2004 grand challenges workshop (http://www.ukcrc.org.uk/gcresearch.pdf):

At the 2002 workshop a set of possible topics for grand challenges was identified, and one or two champions for each were chosen to carry forward their development.

A drafting phase followed the workshop, leading to seven draft proposals. In January 2003 these were published on the web, each to be the subject of a public email discussion, moderated by the champions. The discussion was advertised to the research community.

A principle of the grand challenges exercise is that no submission from the community is or ever will be rejected by the committee: the UK Computing Research Committee has no desire to usurp the selective functions of the fund granting agencies. Indeed, the initial seven topics (later six as two of them merged) arose via panel discussions, from the original submissions to the workshop. Further submissions may be made at any time.

Discussion among participants at the 2008 event:

How did the initiative get so many submissions?

Professor Wendy Hall, Chair of the Grand Challenges Steering Committee: There was probably some curiosity, and some people perhaps thought they might get some money funding.

Perhaps it touched a nerve, in that a lot of people did feel 'trammelled' by the issues listed in the invitation. So the wording was perfect, as people did feel held back.

Wendy Hall: The fact that it was led by two of the UK's greatest computer scientists (Tony Hoare and Robin Milner) must have made a difference. The community owes so much to you two. In addition the leaders of the individual grand challenges are respected in their fields.

Wendy Hall: If we want to look at bringing in new grand challenges should we have another major event?

Robin Milner: We're progressing in the right way. We never assumed the current grand challenges would be the definitive list but I'd be nervous about having another meeting like that first one in Edinburgh to look at lots of new proposals.

Should we have an exit strategy in case we outlive the interest in a grand challenge?

Robin Milner: It would be more a case of resting a grand challenge. Certainly the idea of cancelling is utterly wrong: none of us has the right to do this. One reward is that you talk to people you wouldn't talk to before, or even want to talk to. You can apply for funding for networking (meetings and so on) and community building. Everyone can tap into that.

Tony Hoare: It's more a question of letting people out. People need to look at whether their work is contributing in the best possible way to the advancement of science. I've always said don't have a grand challenge unless it's the only way to get funds, because the overhead of planning, organising, attending meetings and so on.

How much of the entire UK computing science community do you think is involved in the grand challenges?

Robin Milner: Not much more than 30%.

Wendy Hall: Probably less than 30%.

What is the feeling of the others who aren't involved?

Wendy Hall: Scepticism and they don't really feel engaged. One challenge is to get others engaged. Many people have said that there's no grand challenge covering their research interests.

A Grand Challenge Experience: The WINES Programme

WINES is the Wired and Wireless Intelligent Networked Systems Programme of the Engineering and Physical Sciences Council.
There is no central repository on WINES. Many sites relating to WINES activity and individual projects can be found via Google or other search engines.

Report from the Grand Challenges Conference 2008:
Professor Morris Sloman
Director of Research and Deputy Head of the Department of Computing, Imperial College; original proposer of the WINES Programme; and Chair and of GC2/4 Steering Committee: Ubiquitous Computing: Experience, Design and Science

The early years

Before the grand challenges there were seven or eight universities collaborating on ubiquitous computing research, with funding from 2000. In 2001 the Department for Trade and Industry (now the Department for Business, Enterprise and Regulatory Reform) launched the Next Wave Technologies and Markets Programme, which was also about pervasive computing, with projects in areas including environmental monitoring, health care and commerce. It provided support for companies to collaborate with academic partners, so it was not so much university focused and was aimed more at shorter timescales.

Then came the grand challenges workshop in 2002. Two challenges emerged around ubiquitous computing.

Funding for networking

Around the same time I led a proposal for a grant for networking on ubiquitous computing. The aim was to parallel the Next Wave work with a more academic focus. There were some really strong groups on wireless communications, mobile computing and other fields, and we felt there needed to be more interworking between these communities. We got funding of £63,000 for 2003-2006 from the Engineering and Physical Sciences Council (EPSRC) for the UbiNet network. The ubiquitous computing grand challenges steering committees merged with the management committee and we funded workshops and summer schools, developed some websites and helped write the grand challenge manifesto.

Projects

We identified various areas for work and in May 2003 we asked the EPSRC for around £10m for a managed project over five years. In July the EPSRC announced the WINES programme. In the first two calls for projects, in 2005 and 2006, the EPSRC funded 13 projects with over £16m. A third call for proposals went out in March 2008, for £7m. So overall we have had £23m.

Projects have been funded in areas including health care, sports monitoring, market trading, intelligent airports, and urban design. They are all multidisciplinary. Most involve funding over three to four years, so they're reasonable-size projects.

The initiative has been a very successful means of bringing people together to collaborate in an interdisciplinary way: medics, architects, psychologists, sports specialists and others are involved in various projects.

The initiative is also multidisciplinary within computing, involving different streams of computing.

One slight disappointment is that most are engineering projects: there is some human-computer interaction but not much on theory. Only one project really addresses this.

Our network has extended as we try to get more international collaboration. We've been organising workshops, training camps, exchanges. We like the idea of exchanging tools and experience.

I'm not sure whether we will get engagement with the general public: this initiative is really to try to get better understanding. Privacy would be a good topic on which to engage with the public: it's a key area the public can relate to.

Lessons

A key lesson for other grand challenges is that a network is absolutely essential. It's got to come from the people. People have got to get together. You need a group of six to 10 people who are active, prepared to meet and work together, organise workshops, get the right people to attend. We typically get 60-100 people at events. The events generally are free to PhD students, with a small fee to others.

Quite a few collaborative projects have come out of workshops: people have met and started talking at the workshops and then put in proposals.

General Discussion

This section reports on open discussion after dinner on the first evening and after presentations at the conference the next day. Each paragraph is a contribution from a different participant.

The after-dinner discussion also raised significant points on GC3 (Memories for Life) and GC5 (The Architecture of Brain and Mind); those discussions have been included in the reports on those grand challenges.

Shortage of young computer scientists

What we're doing is important to us but how do we excite the people who will make a difference in computer science in the future? Some great people here have shaped computer science but we also need to encourage younger people to take on that mantle. And we need to do this from a younger age than lecturers, right back to young potential computer scientists.

The grand challenges are a good way to do that, to convey what computer science can do, what it can contribute to.

We have a crisis in that we are not getting enough people coming up through the system who can contribute to these grand challenges, and to other projects: I know of people who have had millions in funding for projects in recent years and they're finding it very hard to get good enough people to join them. Tinkering with undergraduate degrees or A-levels isn't going to fix this: we have to go right back to lower levels. In this country and I suspect worldwide there was a major opportunity 35 years ago to use computers to enhance education. It started here with the BBC Micro phenomenon and gifted teachers doing entirely new things, getting children to work together to think about complex structures and processes. Then the focus changed to teaching them the skills they would need in work, so all the past effort was thrown out and in came spreadsheets and word processing. So a lot of people coming up have no experience of design, analysis, debugging, documenting. We can't change that quickly. I wonder whether people can be inspired to do things for themselves, whether we could provide a national infrastructure to enable a small nucleus of gifted teachers who understand the issues to start trying, maybe in their spare time, maybe in some slots in the syllabus that allow this, to do this teaching. This could transform the digital economy as well as educate people.

My daughter's IT teacher at senior school recently told me that IT is part of public heath and social education: for example they learn how to do spreadsheets about why people shouldn't smoke. The teacher is enthusiastic about computer science but it's not part of the curriculum so he can't teach it.

If you don't have an effort coming from the teachers then it becomes just another imposed initiative that will fail.

How have grand challenges really impinged on PhD students? It would be very helpful to hear how to capture their imagination and how they want to drive forward what they do through a grand challenge.

A brutal fact is that they're also motivated by money. PhD students are on £15,000 and their first post-doctoral post will be £20,000-£25,000 - and their friends in medicine will be on £30,000, £40,000 and rising fast. The PhD is very enthusiastic about the small bit he's doing towards a grand challenge now but he's not articulating the big challenge, because he can't see how he'd get paid to do it.

No one here is worried about their salaries. We're driven by the excitement, the joy at pushing back the barriers. Clearly you have to pay the mortgage but it's about much more than that

http://www-dse.doc.ic.ac.uk/Projects/UbiNet/projects.htm
Report on 2007 workshop: http://www.epsrc.ac.uk/CMSWeb/Downloads/Other/WINESWrkshpRpt07.doc

if you're in academia. The future of computer science has to lie in using grand challenges to motivate PhD students. If we worry solely about money we're lost.

It is not just computer science that is suffering from a lack of people coming through. This is something that is very general. Electrical engineering and physics in particular have been suffering greatly recently.

Young scientists' role in making policy

Why are there not more young people at this event, the lecturers who are excited about grand challenges and have research projects? Lots of people here are articulating visions of the future but a lot of the people who might be working on them are not here.

It's no surprise that PhDs are not here: this event was never meant for them. They do come to workshops and they are happy with what they do. But this event is to set policies and strategies long-term. They don't think this is relevant to them, but when we organise events for them, they come.

I've been involved in five events concerned with GC5, bringing together people from biology, psychology and neuroscience, and PhD students have uniformly enthused enormously afterwards.

I'm not advocating that young people decide the research agenda; I just suggest we have a mix. Without it we can formulate policies as much as we like but they won't feed back to the people we expect to carry these agendas forward.

If we want PhDs at events like this we'd have to organise and advertise them in a different way and have lower registration costs.

Lack of hunger

If this was a meeting of chemists or physicists there would be a hunger that I'm not hearing.

In biology you look down a microscope and ask questions and do some tests and get answers, and it's very exciting. In computing a lot of things we've constructed are castles in the air which in the end turn out to be useful but there aren't quick results. Yet computing is most exciting, because it is the most creative, because you're constructing things out of nowhere. But it is slower and it doesn't look quite as exciting as peering down a microscope into a chemical reaction.

External regard for computer science

Are we too insular? A report in the US, Computing the Future, talked partly about how computing would be an integral part of solving bigger grand challenges that weren't pure computing. There was a firestorm in the computing research community opposing this view: people argued that computing is a science that gets no respect as a science and that this report was saying computing is only of value if it helps to solve a physics or chemistry problem. We can talk about grand challenges in computing but we have to get money for the computing research community, and the only way to do that is by making impact and working with other communities. There is a really strong tension over this in the US. It could be that computer science started more recently than the other disciplines like physics, who see these new people - who they just see as tool makers - trying to get a piece of the pie, which means that we take it away from them. I remember being told that by a professor I respected, "Don't waste yourself on computing: it's a machine." He was wrong, or at least I didn't follow his advice, but there's a tension there, at least in the US.

Insistence on timescales and success criteria

There is something worrying about insisting on timescales and precise success criteria for grand challenges. There's an impression here that a challenge has to be grand but not too grand, so that we can pin down when it will be successful and the criteria for success.

Top-down and bottom-up approaches

Regarding the top-down and bottom-up community approaches, the man on the moon is seen as a grand challenge - and it came from the very top, from the US president. It therefore pulled together all the resources needed to make it happen. With our grand challenges we are starting in our community and working out to other disciplines: there's no way we could put a man on the moon.

Conference Round-Up: Looking to the Future

Professor Alan Bundy
School of Informatics, University of Edinburgh; and member of the Grand Challenges Steering Committee

Computer science vs classic grand challenges

How do computer science grand challenges measure up against the common characteristics of classic grand challenges - the man on the moon, the human genome project and the urban challenge (driver-less cars)?

All the classic challenges have involved public engagement in some way, an understanding of the aims of the challenge, if not the science. Regarding public engagement with computer science there's a lack of public understanding of our subject.

The classic challenges have been task-led, with a clear end point. Some computing grand challenges are science-led, not task-led. Computing is open-ended and multifaceted, and we come at the challenges from many different angles.

The classic grand challenges have been interdisciplinary. Several of our computer science grand challenges have engaged very well with other disciplines. Computational thinking is now quite pervasive across a wide number of disciplines: it's hard to think of a grand challenge in any other discipline that would not have a strong computing element.

The classic grand challenges all had an element of competition. The man on the moon challenge had the Cold War and the space race; there were two human genome projects; and the urban challenge was a competition among car manufacturers. We do have competition for a couple of our computing grand challenges; how can we organise more competition?

Progress: community building

Most of the computing grand challenges are in the community building phase. They've set up networks and through these networks they've organised workshops and other meetings, often bringing in other disciplines. Many grand challenges are happy to be at the stage; some want to be only a discussion forum.

Time to move to the project phase

Some grand challenges would like to go beyond this and are working on the project phase. The Steering Committee invites grand challenges to move into the project phase.

In the project phase we might expect the following:

- A clear set of aims. From this we might expect a roadmap with milestones; some milestones might be grand challenges in themselves
- Regular progress reviews and reports
- Outreach activity, especially to the public.

Roadmap possibilities:

- Forming a collaborative project nexus
- Building exemplar systems
- Creating a shared toolset
- Creating a shared testbed
- Regular evaluation of different approaches, using the testbed.

[In the subsequent discussion there was some support for a landscape approach rather than a roadmap, with grand challenges being a landscape populated by projects, and less emphasis on being deterministic about a journey to a grand challenge target]

Possible outreach activities:

- Fostering public understanding of science, for example through the Senior Media Fellowship scheme and other initiatives of the Engineering and Physical Sciences Research Council (http://www.epsrc.ac.uk/publicengagement/default.htm)
- Collaboration with grand challenges elsewhere, including in other countries
- Assessing what other countries are doing in similar grand challenges. This could introduce the element of competition
- Collaboration with other disciplines, perhaps out side EPSRC funding.

In summary, how do computing grand challenges compare with the role model of classic grand challenges, and can we sharpen ours up to fit the classic model? And is your grand challenge ready to upgrade to the project phase - and would it help if it did?

Professor Wendy Hall
Professor of Computer Science, University of Southampton; and Chair of the Grand Challenges Steering Committee

Questions for us to consider:

- Are there some big gaps, some other computing communities who should be involved, such as the algorithm community?
- How do we encourage more effort from across our community: how can we get more people less sceptical?
- What is our process for ending grand challenges?
- Should we add other computing challenges, such as large-scale complex IT systems and the digital economy?
- Do we need another event with a call for proposals? The general reaction at this current event has been no.
- Do we need more meetings to discuss the science?
- What should be the format of future grand challenges meetings?

http://www.ukcrc.org.uk