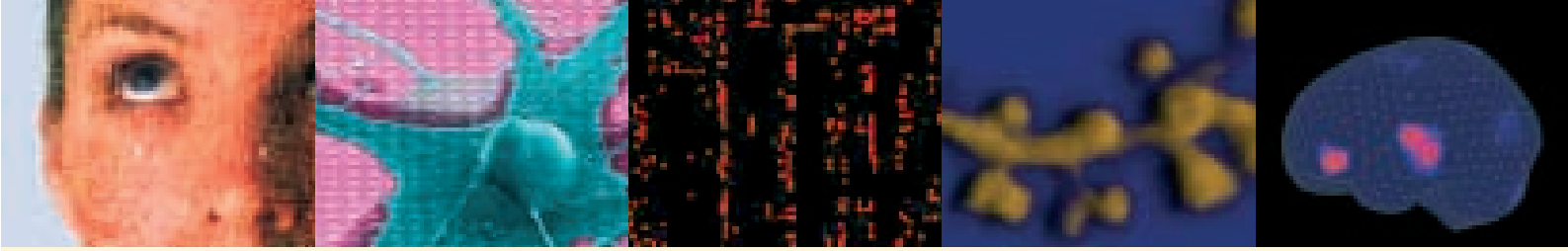


Foresight Cognitive Systems Project

Where brains meet technology

Robots can be fast and accurate, but they are generally dim-witted. Outside of science fiction movies, real robots have poor cognitive systems. They cannot match the manipulative dexterity – physical and emotional – of even a six-year old. And their ability to know where objects are in space barely comes up to the skill of a two-year old. Computers can, when properly trained, recognise speech but the family dog beats them when it comes to understanding the words they hear. And yet researchers have spent a half a century or more developing smarter robots and computers.

Advances in artificial cognitive systems will not come simply from throwing ever more and ever faster computer power at the problems. We need to apply some of the intelligence that we want to instil in robots. In particular, we should draw on our growing understanding of how people, and other cognitive systems, go about their tasks. Improved understanding of sensory systems, including speech processing, of the processes underlying learning and memory, and of the control of actions, could lead to new 'brain-style' computing in devices that we use every day.

Brain researchers will also learn from engineers and from information technology. For example, the massive increase in the amount of data generated in brain research will demand vastly more sophisticated analysis and modelling from the IT community. Brain scientists also constantly turn to physical scientists for new measurement tools – functional magnetic resonance imaging, which recently won its developers a Nobel Prize, is one example.

The Foresight team of the Office of Science and Technology acted as facilitator for the Foresight Cognitive Systems Project, but they placed the activity firmly in the hands of the scientific community. It was down to researchers from both physical and life sciences to decide if there really is anything in common between them. They decided that there is, and have spent the past 18 months talking to one another.

Indeed, a key achievement of the Foresight Cognitive Systems Project is an infectious enthusiasm for sharing ideas and knowledge, and for working together. There were other achievements, including the charting of a research agenda that combines the physical sciences and life sciences in new ways that could deliver rapid progress. By building on the work of the many scientists who have contributed generously to the project, we can put the UK in a position to benefit from these opportunities.

Dr John Taylor
Director General of the Research Councils
Director Foresight Cognitive Systems Project.

The project

The Foresight Cognitive Systems Project set out to provide visions for the future of research in natural and artificial cognitive systems.

The Office of Science and Technology chose research in cognitive systems as a trial investigation in a new round of activity for the Foresight Programme. For this project, the OST looked for an area of research where there had been recent progress and where the challenges were such that different disciplines might profitably work together more effectively than in the past. Cognitive systems filled the bill on several counts.

To begin with, understanding cognitive systems is important in its own right in two key areas – health and information technology. Medicine benefits from our growing knowledge of the ultimate cognitive system, the human nervous system, for example through better understanding of the effects on the brain of Parkinson's disease. Information technology (IT) relies on better understanding of how to devise and construct artificial cognitive systems.

What is a cognitive system?

Any discussion of a technical subject depends on an agreed understanding of what everyone means by the terminology. It became clear early on in the Cognitive Systems Project that there is no universally accepted definition of 'cognitive systems', certainly no definition that covers the use of the term in both the life sciences and physical sciences.

During the project's various workshops and meetings, the research community arrived at one possible definition:

"Cognitive systems are natural or artificial information processing systems, including those responsible for perception, learning, reasoning and decision making and for communication and action."

Progress in science

In the life sciences, brain research benefits greatly from advances in technologies that can begin to monitor brain activity in 'real time' and at ever greater resolution. IT also continues to progress as ever declining costs, improved performance and mobile devices make massive amounts of computing power available to more users. The challenge for the future is how to make best use of it.

Research challenges

In both the life sciences and physical sciences, progress may be rapid but there are challenges at a fundamental level.

In the case of IT, it seems clear that conventional 'engineering' approaches to problem solving are running into difficulties. For example, we will not be able to move from speech recognition to natural dialogue with machines simply by throwing computer power at the problem.

For its part, brain science could benefit from information processing techniques

that are widely deployed in IT. Researchers will also need better techniques for measurement and analysis.

Both areas also face a common challenge in explaining their work to wider audiences. Without an appreciation of what researchers hope to achieve, and how society can benefit from their work, it will be all too easy to lose public acceptance.

One way ahead could be to introduce expertise from one domain into another. But this depends on a common understanding of language and the issues involved. While the dialogue between domains has recently been relatively muted, there is good reason to believe that this could change with some encouragement and better mutual understanding.

Community support

One task during the Cognitive Systems Project was to elicit the views of the research communities involved. In particular, it was important to see if they agreed that there could be fruitful discussions between life scientists and researchers in computer science.

From the outset, the scientific community itself has been in the driving seat for the project. The Foresight Directorate has been the facilitator of a dialogue between, and within, the research communities.

The technical aspects of the project were in the hands of two scientific experts. Professor Lionel Tarassenko, from the Engineering Department in the University of Oxford, is the technical coordinator for the physical sciences. Professor Richard Morris, of the Centre and Division of Neuroscience at the University of Edinburgh, is technical coordinator for the life sciences. Both will continue in these roles after the project formally ends.

Research Reviews

As part of its review of the current state of research, the Cognitive Systems Project commissioned leading researchers in brain science and IT to write a series of Research Reviews. The topics chosen came out of a series of workshops that set out to define the project.

After agreeing that, thanks to recent progress, there was much new common ground, it soon became clear that both communities are interested in similar problems. Thus several research reviews consider subjects from the different perspectives of brain science and IT. For example, there are two papers on aspects of speech and language, one on human speech the other on automatic speech recognition.

This 'mapping' of issues was further confirmation not just of the timeliness of the Cognitive Systems Project but that there is much in common between life sciences and physical sciences.

PHYSICAL SCIENCES

- Sensory Processing
- Interaction, Planning and Motivation
- Memory, Reasoning and Learning
- Large-Scale, Small-Scale Systems

LIFE SCIENCES

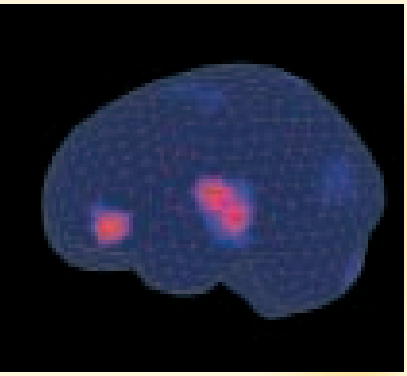
- Representation
- Speech and Language
- Action
- Learning and Memory
- Self-Organisation in the Nervous System
- Advanced Neuroscience Technologies
- Social Cognition

Outcomes

Cognitive systems – natural and artificial – sense, act, think, feel, communicate, learn and evolve.

We see these capabilities in many forms in living organisms. The natural world shows us how systems as different as a colony of ants or a human brain achieve sophisticated adaptive behaviours.

Our growing understanding of natural cognitive systems is now contributing to the development of artificial cognitive systems. We can think of prosthetic devices that are 'wired' to the brain to operate artificial limbs. PDAs and mobile telephones are just the beginning of a move towards a world of connected 'smart things', a personal digital environment.



Intelligent vehicles could learn how to drive much more safely than humans, communicating with one another to avoid accidents. (What will insurance companies say about that?)

These are just some of the artificial cognitive systems that could happen. (For a review of these and other opportunities, read the paper "Applications and Impact" prepared for the project by Bill Sharpe.)

The Foresight Cognitive Systems Project gave the research community an opportunity to spend time discussing recent progress in research on cognitive systems in the life sciences and in computer research.

A new community

Among the more significant outcomes of the project was the conclusion that research into natural and artificial cognitive systems is indeed at a exciting stage. The researchers who took part in the project also agree that there could be great benefits in bringing together the life sciences and physical sciences to consider how they can collectively accelerate progress in cognitive systems.

For a decade or more, the two disciplines had, with a few exceptions, worked separately. To a certain extent this was a result of earlier disappointments in artificial intelligence, based on incomplete and over-simplified views of how the brain works.

In brain research, the physical sciences have played a key role in developing new tools and techniques. For example, functional magnetic resonance imaging (fMRI), allows increasingly detailed measurements at better resolution in time and space. Researchers can also record the activity of ever larger arrays of individual neurons.

Over the past decade information technology (IT) has continued its usual relentless path. Declining costs have made massive amounts of computing power available to ever more users.

The challenge for the future is not how to continue to supply more computing power but how to make best use of it.

Complex networks

New challenges require new solutions. It is by no means clear that traditional 'engineering' approaches to IT will supply all the answers. For example, the Internet and other networks are ever larger and more complex. This makes it important to understand how different components and systems interact with one another. While we may understand how the individual components operate, it has become increasingly clear that we face challenges in anticipating and responding to emergent behaviour – where we simply cannot predict how the system will behave on the basis of the properties of individual components.

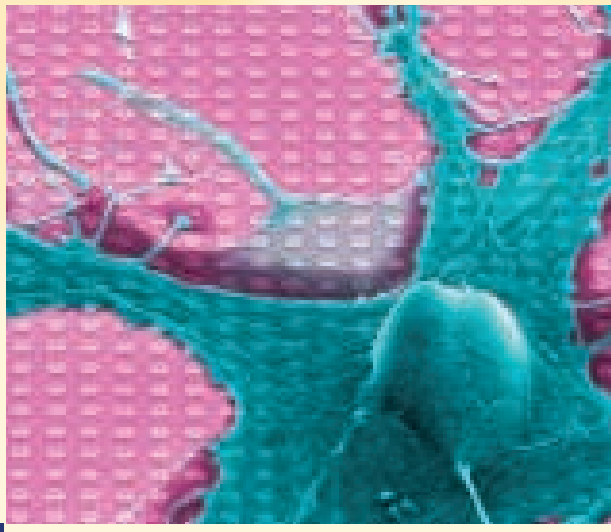
The project set out to define the issues involved at a series of preliminary 'brainstorming' sessions. These paved the way for a series of 11 Research Reviews on the state of the science. In turn, these provided the starting points for two major research workshops. At these the community highlighted a number of subjects that warranted the development of more detailed agendas for research.

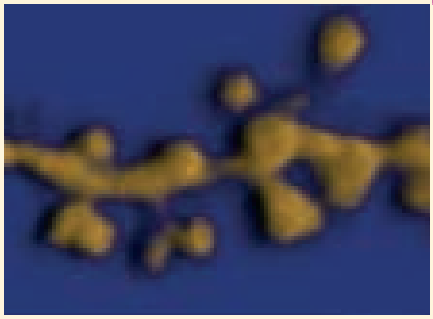
The Foresight Project then commissioned a number of papers, described as 'Grand Challenges', that were the basis for a major InterAction Conference that combined the physical sciences and life sciences in a way that had not been attempted before.

Rapid progress

In themselves, these events and papers are among the outcomes of the Foresight Project. Added to the newfound feeling that together the two scientific domains can progress more rapidly than they might on their own, this provides the foundations for future activity.

The project did not set out to solve all of the problems of brain science or IT research. Its value has been in encouraging discussions that simply could not happen without the involvement of experts from both domains and where research would benefit from an 'expertise transplant'. Thanks to the project, the research community is now much happier to accept that input.





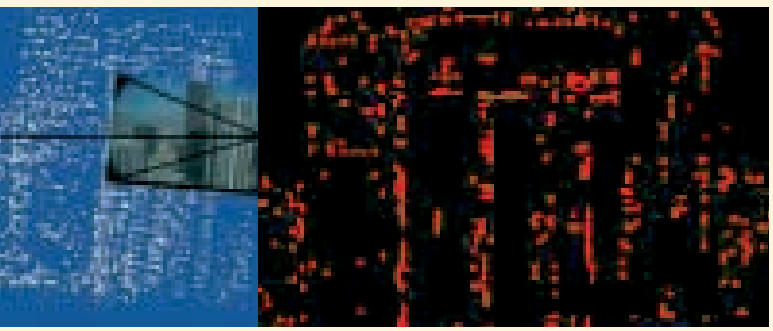
The way ahead

As the project ends, other organisations are taking up the challenge.

The project has shown that a dialogue between life scientists and physical scientists can provide valuable insights into the future direction of research into cognitive systems. It has also shown that researchers in these areas are enthusiastic about the possibilities of collaboration, and are keen to move ahead.

As well as refining the research manifestos that have come out of the project, the discussion needs to move on to fill the gaps, to develop similar manifestos in areas that were not covered in the grand challenges, in the area of "self organisation" for example, something that natural cognitive systems do extremely well and that could provide lessons for the development of artificial systems.

The Cognitive Systems Project did not set out to influence funding decisions, certainly not to prepare bids for further spending. However, by assembling evidence showing that research into cognitive systems is at an exciting stage, and it would be fruitful to encourage collaboration between disciplines, the project has laid down some important markers for funding agencies.



Key issues

The project identified a number of issues for further attention:

Facilities – Brain research depends increasingly on access to large and expensive equipment, for functional magnetic resonance imaging, for example. Any follow up to the Foresight Project should consider the case for such facilities.

Training – Future research in cognitive systems will need contributions from researchers who are comfortable to work across traditional disciplinary boundaries while still being experts in their own field.

This could be encouraged through "cross discipline" PhD students with supervisors from the life sciences and physical sciences.

For established researchers, fellowships could provide opportunities for life scientists to acquire knowledge of the physical sciences, and vice versa.

Funding – The Cognitive Systems Project has shown that there are exciting opportunities in research across disciplinary boundaries. While there is certainly a case for investigating the possibility of further funding mechanisms, the Research Councils and other organisations have already shown interest in discipline breaking research and are likely to reflect this in future funding decisions.

The project did highlight the need to enable cross-disciplinary proposals to be assessed on equal terms with proposals of more traditional structure.

The community is working to overcome some barriers, by creating a pool of referees, for example.

Public debate – Research in natural and artificial cognitive systems has enormous social implications. If society is to appreciate the possibilities, to accept novel applications and technologies and to influence their development, it is important to debate the issues in advance. The Foresight Project is working with several organisations to find ways to enable this discussion.

The Foresight Project is talking to a number of organisations that have shown interest in helping the researchers involved to continue their work.

The technical coordinators of the project will continue to support the initiative. The hope is that groups from physical sciences and life sciences will meet to develop the ideas of some grand challenges to the stage where they become genuine manifestos.

As the InterAction Conference showed, the project is something of a pioneer, with few comparable activities in other countries. Many countries have yet to discover the benefits of bringing together the many disciplines that contributed so much to the Cognitive Systems Project. Another hope for the future is that there will be an international meeting to bring an even broader range of expertise into the discussions.

Rising to the challenges

Research manifestos can guide the scientific agenda

The project commissioned researchers, brought together from the life sciences and physical sciences, to develop proposals for areas of science that could benefit from fertilisation of ideas across traditional disciplinary boundaries.

Known within the project as 'Grand Challenges', Foresight's challenges share the ambition of the UK Computing Research Committee that "The grand challenge should be directed towards a revolutionary advance, rather than the evolutionary improvement of legacy products that is appropriate for industrial funding and support."

The Foresight commissions also shared the belief that "The ambition of a grand challenge can be far greater than what can be achieved by a single research team in the span of a single research grant."

Building on the Research Reviews commissioned for the Foresight Project, the OST commissioned groups to work up Grand Challenges on:

- Memories for life
- Localisation in animals and artificial systems
- The role of rhythmic activity in the brain
- Neurocomputational approaches to speech and language

The Foresight Project commissioned these reviews as representative proposals for presentation at the InterAction Conference in September. Many more ideas came up at the Foresight workshops. In the follow on to the project, we hope that there will be opportunities to develop these, and to turn them, and some of the existing grand challenges, into manifestos for properly worked out research programmes.

Foresight – Round III

In the current round of Foresight, projects look in-depth at areas of science that might create exciting possibilities or help in tackling significant challenges. The Cognitive Systems Project has explored the potential to create new scientific opportunities within its field. A project called "Exploiting the Electromagnetic Spectrum" also starts by exploring the possibilities of adventurous new science. This plans to take a broad view of the spectrum and its potential exploitation, looking for topics where a focussed effort across disciplines could lead to new applications.

Two other projects will draw strongly on some of the work on cognitive systems to explore different themes. A project – provisionally called "Brain Science and Drugs" – will take an interdisciplinary look at the key factors affecting our understanding of addiction and related areas of brain science and behavioural change. The "CyberTrust and Crime Prevention" project is studying implications of next generation information technology for crime and crime prevention, and the factors that influence trust in the digital age.

A further project took as its starting point the challenge posed by climate change as it creates new risks from flooding and coastal erosion over the next century. It is using science to work with decision-makers to gain a better understanding of the long term pattern of risks and potential new responses to them.

Further details

The Research Reviews described in this document, along with a major review of the potential impacts of developments in cognitive system, appear on the Project's web site:
www.foresight.gov.uk/cognitive.html

The team

Dr John Taylor, Director General of the Research Councils, Project Director

Professor Richard Morris, Project Coordinator Life Sciences

Professor Lionel Tarassenko, Project Coordinator Physical Sciences

Michael Kenward, Project Science Writer

Prue Backway, Project Leader

Mary Lawrence, Project Manager

Gerard Rand, Project Coordinator

Future contacts

Professor Richard Morris
Department of Neuroscience, University of Edinburgh, R.G.M.Morris@ed.ac.uk

Professor Lionel Tarassenko
Department of Engineering Science, University of Oxford,
lionel@robots.ox.ac.uk

Foresight Directorate
1 Victoria Street
London SW1H 0ET
e-mail:
cognitivesystemteam@dti.gsi.gov.uk

dti
FORESIGHT
OFFICE OF SCIENCE AND TECHNOLGY

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