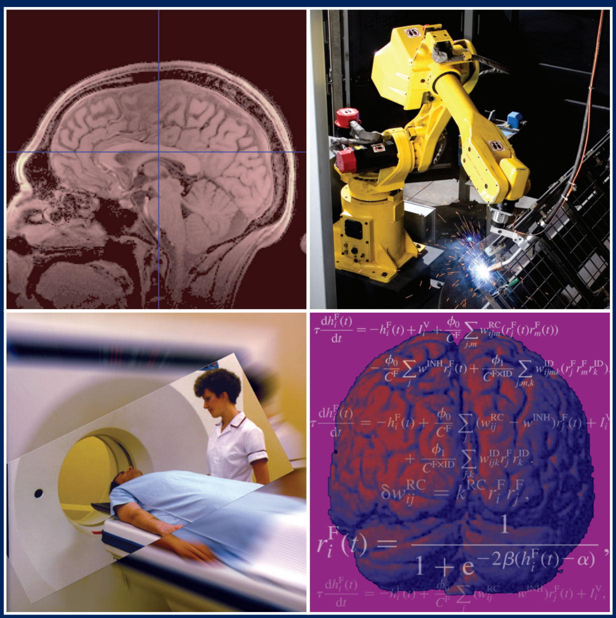
Oxford Foundation for Theoretical Neuroscience and Artificial Intelligence



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For over two millennia, philosophers and scientists have sought to understand the workings of the brain. Today, interest is greater than ever, with a huge volume of experimental work taking place in laboratories around the world. Due to the brain's immense complexity, however, powerful computer modelling techniques are now required to make sense of the experimental data and reveal the underlying processing principles of the brain.

The Oxford Foundation for Theoretical Neuroscience and Artificial Intelligence has been established to further the development of advanced mathematical and computer modelling techniques in brain science. These models are needed to help scientists interpret experimental data and develop a detailed understanding of the processing principles used by the brain. This research will bring many practical benefits for mankind.

Uncovering the principles of the brain will inform biomedical research aimed at developing new treatments for neurological disorders such as amblyopia, depression and Alzheimer's disease. At the same time, understanding how the brain works will lead to major advances in artificial intelligence, from automated manufacturing to software entertainment. As progress is made in modelling brain function, we will explore how this knowledge may be used in various application areas.

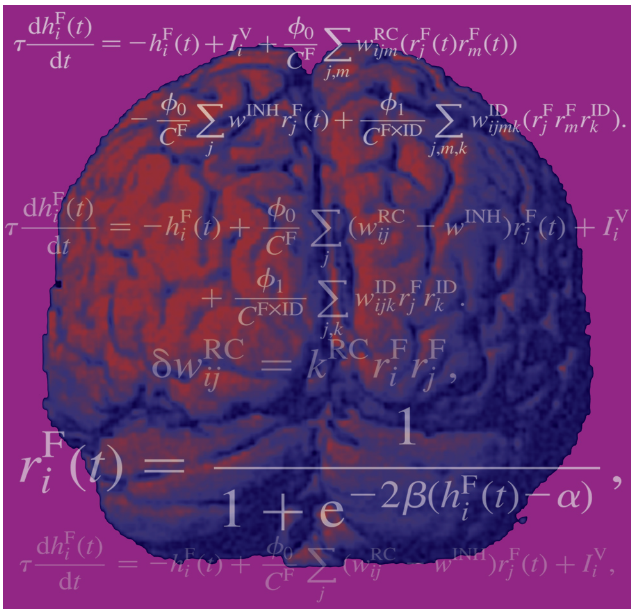
The Foundation currently supports computer modelling research at the University of Oxford within the Department of Experimental Psychology. The Foundation aims to provide a theoretical hub for the brain sciences at Oxford. We are working closely with experimental neuroscientists to develop detailed computer models of brain processes such as vision and navigation. Our theoretical work complements experimental brain research taking place in Oxford and at other institutions around the world.

The challenge of understanding the brain

Unlocking the secrets of the brain represents one of the greatest challenges of our time. Today, there is intense research activity in laboratories around the world. At Oxford, researchers are trying to understand fundamental areas of brain function including:

- How the visual system works. How are we able to recognise objects and faces so easily from different viewpoints?
- How the brain represents the spatial world, and is able to navigate flexibly and efficiently through complex real-world environments.
- How the brain learns to control motor behaviour given sensory feedback, including reward and punishment signals.
- How information from different senses is integrated to give a unified representation of the world.

Understanding these processes will support the development of new medical treatments for mental illnesses and neurological disorders, and will lead to advances in areas of engineering such as machine vision and robot control systems.



Experimental approaches

Oxford scientists are employing a variety of experimental techniques to investigate the brain. Functional magnetic resonance imaging (fMRI) is used to reveal which parts of the brain are involved in different perceptual and behavioural tasks. These experiments are complemented by other techniques which look at the activity of individual neurons. For example, some neurons have been found to respond to which face or object an animal is looking at, while other neurons respond to where an animal is in its environment. At a deeper level, researchers are investigating the biochemistry of individual neurons and synapses. This is important for understanding how synapses are strengthened during learning, which plays a critical role in how the brain develops.

The role of computer simulation

In spite of so much experimental work, key principles underlying how the brain works continue to remain poorly understood. The challenge is how to analyse the many sources of experimental data in order to discover precisely how signals are processed in the brain. However, this processing is extremely complex because it relies on trillions of interacting elements, such as neurons and synapses. Indeed, neurons and synapses, themselves, are complicated structures.

These elements interact with each other in complex ways that are difficult to predict. Because of this, the operation of the brain cannot be revealed without the use of computer models that incorporate detailed knowledge about how large numbers of such brain elements work together. Computer modelling is therefore set to play a vital role in interpreting experimental data, and discovering the functional principles used in the brain.

Brain modelling at Oxford

We are engaged in the development of computer models covering a number of areas of brain function, including memory, vision, spatial representation, movement and navigation. It is expected that theoretical advances in these areas will inform medical research aimed at developing new treatments for emotional, visual, spatial and motor disorders of the nervous system.

Similarly, understanding the dynamics of the brain will also lead to powerful new techniques in artificial intelligence, with applications in areas such as automated manufacturing and mobile robotics. As progress is made in modelling the brain, we will seek to use this knowledge in these various areas of application. Some of our research is briefly described below.

Memory processes and related disease states

We are developing models of various memory processes in the brain. Such models contain many thousands of connected neurons, which interact with each other in complex ways. For example, we are investigating the interaction between mood and memory systems in the brain. Associations between memories and mood states, and positive feedback between these systems, may play a major role in depression.

In other studies, neural network models have been used to understand how synchronous activity spreads through a population of neurons during epilepsy. These studies can help to shed light on the complex neural dynamics underpinning epileptic seizures, and may help to guide the discovery of effective drugs.

Another disease state, which we are investigating through computer simulation, is schizophrenia. This disabling disease affects approximately 1% of the population during their lifetime. We are exploring the possibility that classic schizophrenic symptoms such as paranoid delusions and poor attention may be due to unstable memory states.

Lastly, our research on memory storage in the brain has contributed to understanding the role of the hippocampus in retrograde amnesia in which episodic memories cannot be recalled, and anterograde amnesia in which new memories cannot be laid down. Revealing how the hippocampus works may help researchers to find new treatments for amnesia, including disorders such as Alzheimer's disease.

Vision

We are conducting research into various aspects of visual processing in the brain, including motion detection, face recognition in natural scenes, and the recognition of objects from novel views. Over successive stages, the primate visual system develops neurons that respond with view, size and position invariance to objects or faces. Our models explain how such neurons may develop their firing properties, and hence allow the visual system to recognise objects in natural environments.

This research has direct bearing on understanding disorders of visual perception such as amblyopia, in which one eye suffers reduced vision due to interference during early visual development. Amblyopia is the leading cause of vision loss in persons under 40 years of age. Other disabilities include prosopagnosia where subjects have difficulty recognising faces, or spatial neglect where patients ignore part of their field of vision.

Recently, our computer simulations have revealed a powerful new algorithm, Continuous Transformation Learning, that may account for how the brain learns to recognise objects and faces from different viewpoints. This discovery represents a major breakthrough in understanding the operation of the visual system, and should help to guide the treatment of visual disorders arising from developmental problems.

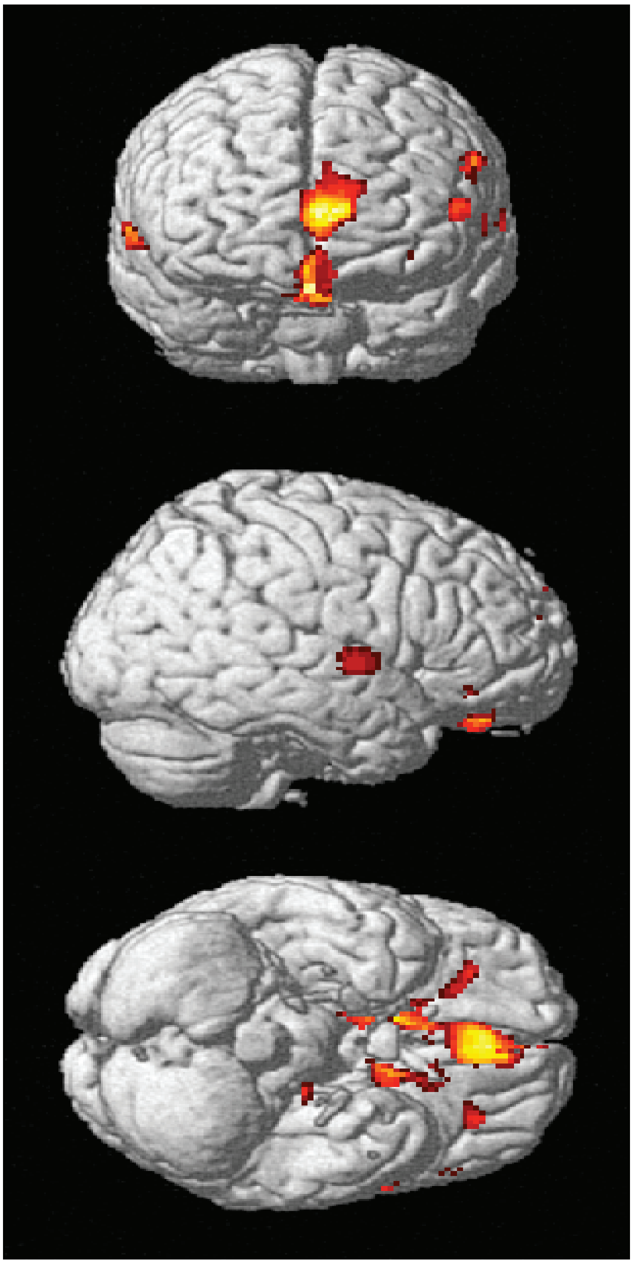
In addition to potential medical benefits, possible engineering applications of this research range from visual control and quality inspection in manufacturing to automated CCTV monitoring. The new Continuous Transformation Learning algorithm may help robots to operate more flexibly in real-world environments by enabling them to recognise objects from different viewpoints.

The representation of space

We are developing models of how the brain represents space. Certain types of neuron in the brain encode the orientation or position of an animal in its environment. Examples of such cells include head direction cells that respond when the animal's head is facing in a particular direction, and place cells that fire when the animal is in a particular location. Our computer simulations show how these cells may develop as an animal explores its environment

Our models are also able to explain how the brain's representation of space may be updated by vestibular signals during movement. Thus, these models will help to improve understanding of a range of neurological disabilities, including vestibular disorders of balance and disorders of spatial processing. We have also developed detailed computer models of spatial processing and memory storage in the hippocampus. Our models explain how damage to the hippocampus may lead to amnesia for episodic memories.

We have recently developed computer models based on Multi-Packet Continuous Attractor Neural Networks, which may explain how the brain is able to represent the full 3D spatial structure of an animal's environment. Control systems based on these models may help robots to move more easily within cluttered real-world environments. These models may permit more flexible movement of manufacturing manipulators, and provide more robust navigation for autonomous vehicles and mobile robots.



Looking to the future

Motor behaviour

We are investigating motor function in the brain. Experimental work indicates that during motor tasks such as reaching, the motor areas of the brain work in tandem with other brain areas that represent spatial information such as the position of the hand. Inspired by these findings, we are developing models which combine motor and spatial networks that work together to carry out motor tasks.

Our models are able to learn to perform arbitrary motor sequences, even in the absence of sensory feedback. Further work has shown how motor sequences can be learned with a delayed reward signal at the end of each training sequence. The models can also generate useful novel motor sequences, which were not performed during training. These are all important capabilities in animals.

We hope that our theoretical work in this area will help to inform medical research aimed at understanding and treating disorders affecting the motor functions of the nervous system. Such disorders may include motor neurone disease, multiple sclerosis, and Parkinson's disease.

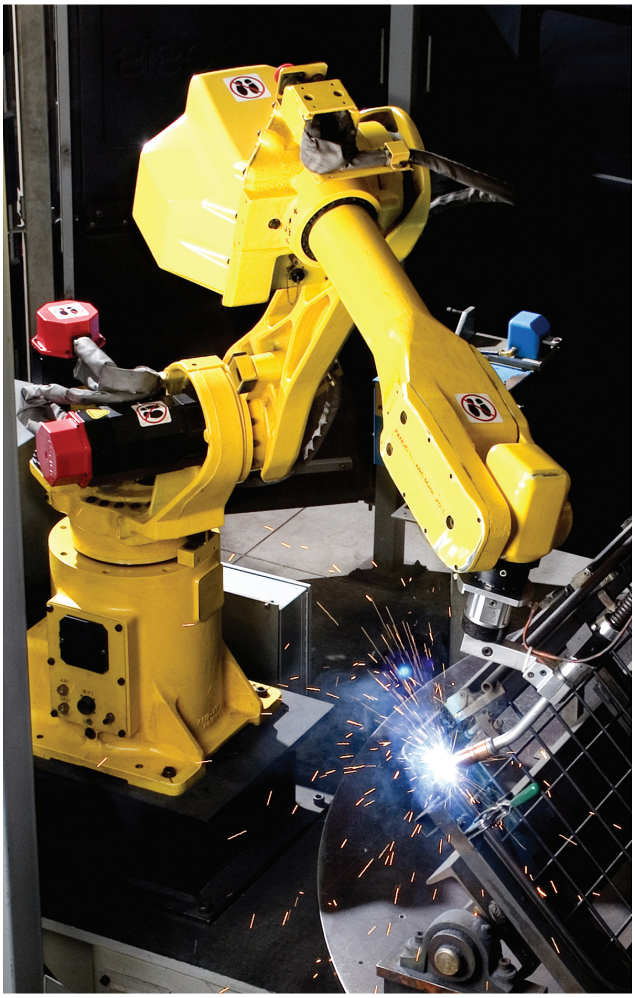
Regarding engineering applications, our brain-inspired models allow very flexible and adaptive behaviour, which can surpass current robot control systems that rely on either fixed action sequences or learned stimulus-response reactions. Another area of application may be automated character animation in computer generated films and games.

Embedding brain models within virtual reality environments

We are using 3D virtual reality software to embed brain models within simulated virtual environments. The use of 3D virtual reality allows careful control of the positions and velocities of visual stimuli, as well as the point of view of the brain model within the environment.

We have found that using this kind of realistic sensory input is critical to how, for example, models of the visual system develop their synaptic connections.

We are involved in modelling various areas of brain function, including vision, spatial representation, motor behaviour and navigation. However, these systems interact, and hence so should the models. The use of 3D virtual reality will allow us to explore how models of different brain areas can work together given realistic sensory input. This approach will permit the integration of various sources of experimental data into a unified theoretical framework, in which complete brain models are embedded in simulated 3D environments. We believe that this approach will eventually become invaluable for guiding further empirical research in brain science.



Education and training

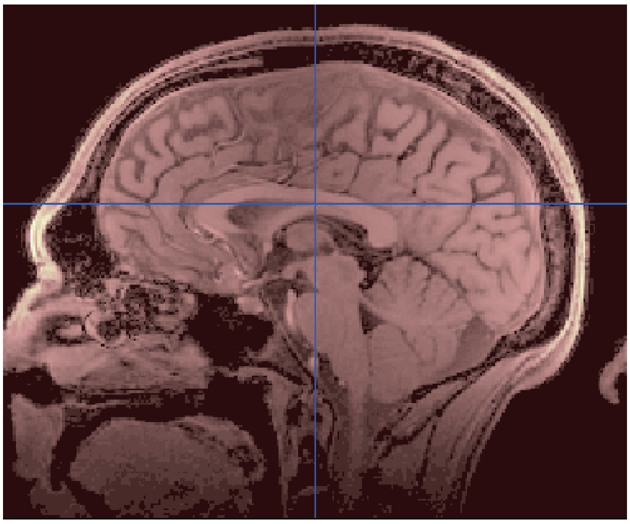
As well as supporting fundamental research in theoretical neuroscience, a major aim of the Foundation is to provide technical training for students and junior researchers. Indeed, we aim to support a number of training fellowships, which will enable more young scientists to learn how to apply computer modelling techniques in brain science. This is a key goal because computational neuroscience is a relatively new discipline, and there is a great need for more technical training to be made available to students in this area.

The Foundation aims to support undergraduate lecture courses and provide supervision for graduate research programmes. Many students have expressed enthusiasm to undertake research as funding becomes available. In addition, the Foundation will enable the transfer of skills through visiting research fellowships, lecture series and short residential courses. Expertise and research results will also be disseminated through publication.

The endowment fund

The Foundation has set up a permanent endowment fund to provide long-term stable support for researchers and students working in computer modelling of the brain. The fund will also support activities such as lectures, training courses, and visiting researchers. The Foundation is currently supporting modelling research within the Department of Experimental Psychology at the University of Oxford.

We are now seeking contributions to the endowment fund from individuals, charities and commercial organisations. Members of the Foundation are pleased to give presentations to those interested in supporting this exciting research through the endowment fund. If you would like to find out more about the Foundation, please contact us by e-mail or write to one of the addresses below.



About us

The Oxford Foundation for Theoretical Neuroscience and Artificial Intelligence is incorporated through UK Companies House as a charitable company limited by guarantee (Company No. 5722895), and is registered as a charity with the UK Charity Commission (Charity No. 1116075). The board of trustees includes academics and research scientists from the Department of Experimental Psychology at the University of Oxford, who have many years experience in developing computer models of the brain. Further information and selected publications can be obtained from our website www.oftnai.org.

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