OFTNAI NEWS

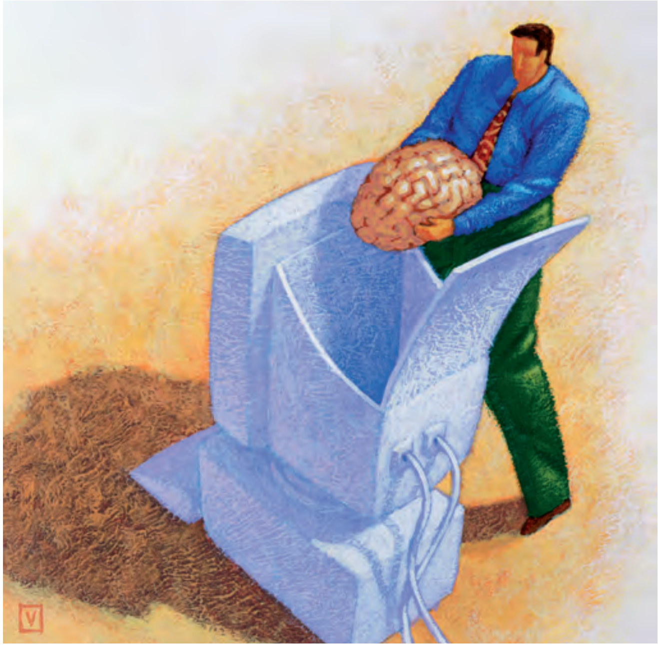
Newsletter - Summer 2010

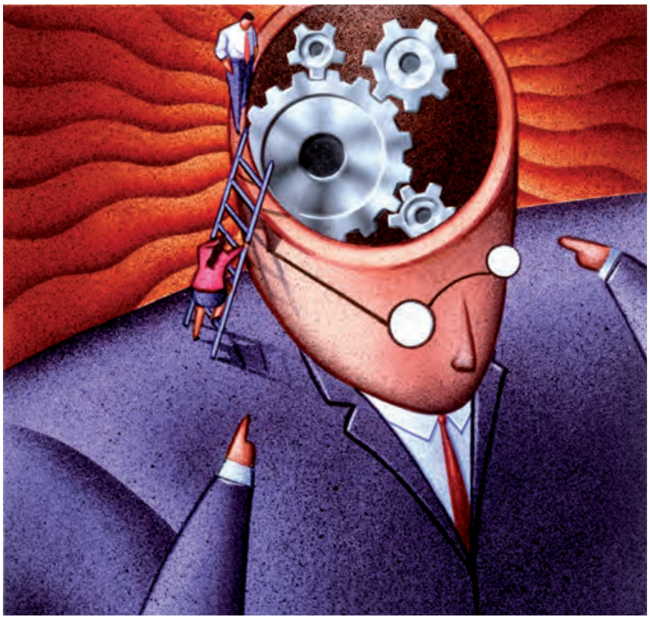
Oxford Foundation for Theoretical Neuroscience and Artificial Intelligence

Understanding how the brain works is one of the greatest intellectual challenges of our time. Progress in understanding brain function will guide the development of new medical treatments for mental illnesses and neurological disorders, as well as lead to major advances in artificial intelligence. Research may even shed light on the nature of consciousness, itself, surely the most extraordinary property of the brain.

The brain, however, is composed of vast numbers of interacting neurons and synaptic connections. Fundamental properties such as perception, intelligence and consciousness emerge from this sea of interacting elements. Because of this complexity, exploring how the brain works will require the tools of computer simulation. With the availability of today's powerful computers we now have a chance of achieving this goal.

Our foundation is currently supporting a new Centre for Theoretical Neuroscience and Artificial Intelligence within the Oxford University Department of Experimental Psychology. The Centre hosts multidisciplinary collaboration between mathematicians and experimental neuroscientists. It is hoped that the centre will become a major theoretical hub for the brain sciences at Oxford and perhaps within the UK.





Over the last two years, the Centre has continued to expand rapidly. Members of the Centre are using computer simulation to investigate various aspects of brain function, including for example:

- How does the visual system recognize objects from different views, represent their positions, and make sense of complex natural scenes? This research will guide the development of superior computer vision systems, for example, that can spot when an elderly person has fallen down.

- How do we learn to understand our 3-dimensional spatial world and move about within it? This ability of the brain is far beyond that of today's robots. Advances in understanding spatial processing in the brain will lead to robots that can move far more flexibly within real-world environments.

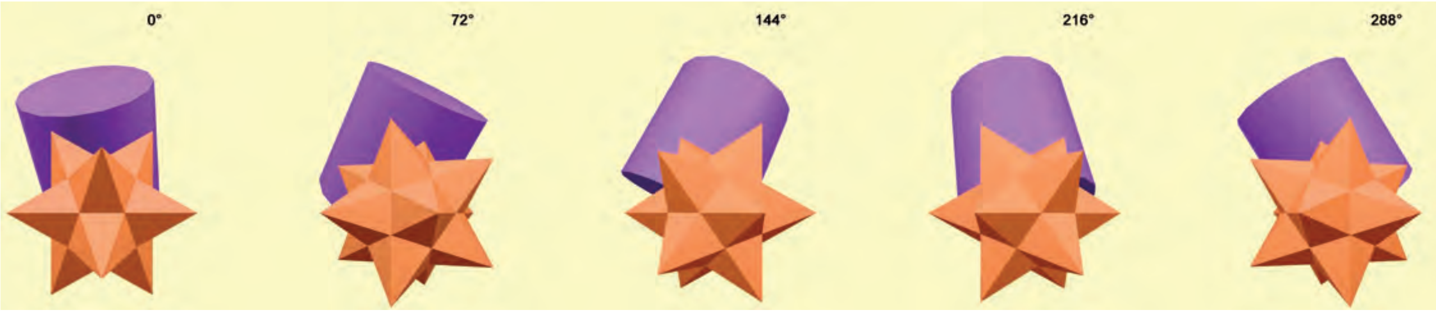
Our foundation is providing support towards teaching and research within the Centre. This includes funding for graduate students, the purchase of computers for simulation work, and the provision of textbooks for taught courses in theoretical neuroscience. Over the last year, the Centre has continued to make important advances in understanding brain function. Let us tell you about some of this work.

Learning to see separate objects within visual scenes

Our laboratory aims to understand how the visual system learns to make sense of complex visual scenes. As a step towards this goal, we are using computer simulation to explore how the visual system can recognize individual objects embedded within natural scenes with other objects present.

Recently, we have investigated how the brain might learn to recognize rotating objects if they are always seen partially occluding each other as shown below. In this case, the visual system must form separate representations of the objects, as well as link together the incomplete views of each object. This is an extremely demanding problem for today's computer vision systems.

To investigate how the brain may solve this problem, we employed a computer model, VisNet, of visual processing in the brain. The model is composed of a series of four layers of neurons, which correspond to successive stages of the ventral visual pathway. In simulations, we presented images of the rotating objects to VisNet during learning. VisNet was able to learn to recognize the rotating objects individually from any viewpoint, even when the objects partially occluded each other during training.



A star and a cylinder rotating together, with the star partially occluding the cylinder.
How might the visual system learn to recognize the objects separately from any viewing angle?

How do we recognize face identity and expression?

How can the visual system form separate representations of facial identity and expression? In experimental studies, some clusters of neurons have been found that represent particular face identities, while other clusters of neurons represent facial expressions. How can the visual system, which is always exposed to facial identity and expression simultaneously, develop separate clusters of neurons for these two dimensions?

To solve this problem, we incorporated additional excitatory connections between neurons within each layer of the VisNet model. These connections are believed to be present in the brain. Then we presented VisNet with lots of faces with different expressions. In these simulations, VisNet formed separate clusters of neurons representing either facial identity or expression.

This problem is important to solve as part of our overarching aim of understanding how natural scenes are represented in the visual areas of the brain.

Four faces representing different identities and expressions.
How might the visual system learn separate representations of facial identity and expression?

Where does our sense of direction come from?

How do we develop our sense of direction?

We are seeking to understand how the brain learns to make spatial sense of the 3-dimensional world and move about within it. There are various classes of neuron in the brain that appear to play a role in this, and which encode information about the position or orientation of an animal within its environment. One such kind of neuron is a *head direction cell*. Head direction cells respond maximally when the animal's head is facing towards a particular preferred compass direction.

A key challenge is to explain how these cells learn to respond to head direction given visual input from a natural environment with a mixture of nearby and distant visual cues. The problem is that, as the animal moves through different locations within its environment, only the bearings to the distant visual cues directly reflect the head direction of the animal. How do head direction cells learn to respond to the distant visual cues and ignore the nearby cues? We have shown using computer simulation how the known neural architecture of the relevant brain areas can solve this problem.

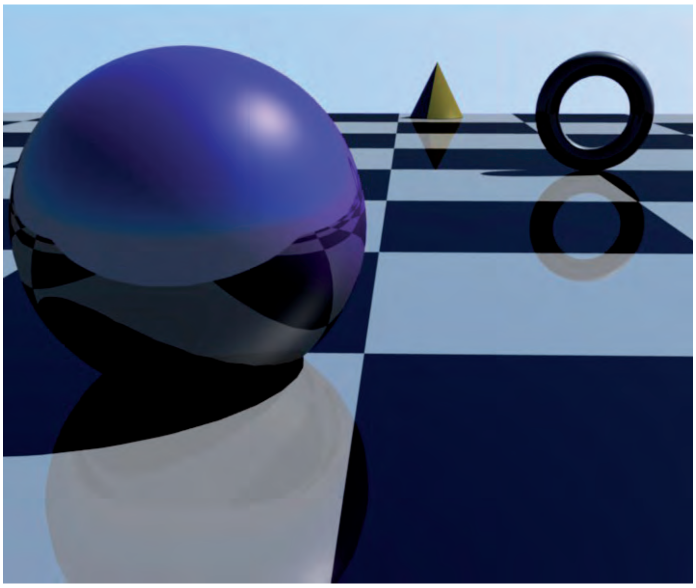
Finding your way home in the dark

A further property of head direction cells is that, in the absence of visual input, they can update their representation of the animal's head direction using internal vestibular rotation signals. This is known as *path integration*.

A major problem has been to explain how head direction cells can learn to perform path integration at the correct speed as the animal rotates within its environment. That is, how can the brain learn to use vestibular rotation signals to accurately track the true head direction of the animal as it rotates in the dark?

We have used computer modeling to solve this problem. Our model uses natural time intervals in the neural system, such as axonal transmission delays between neurons, to learn an association between vestibular rotation signals and corresponding changes in the head direction of the animal.

With these advances, we now propose to build the first complete model of the head direction system in the brain combining both visual and vestibular inputs. The full model will be tested in a realistic computer generated environment with nearby and distant visual objects.

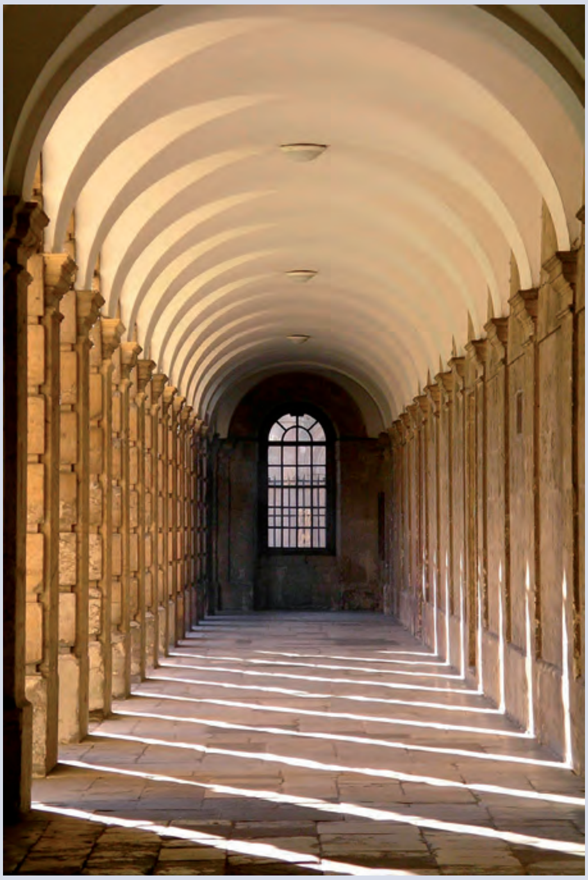


We will test the full model of the head direction system in a computer generated world of nearby and distant objects.

Foundation Dinners at The Queen's College

We regularly hold foundation dinners for charities, companies and individuals interested in Oxford research into computer simulation of the brain. These dinners are held in The Queen's College, Oxford.

Our last event on Thursday 18th March 2010 was devoted to our graduate students, who presented their own research into computer simulation of the brain. The students discussed recent advances that they have made in understanding visual and spatial processing in the brain.



Foundation dinners are held at
The Queen's College, Oxford.

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