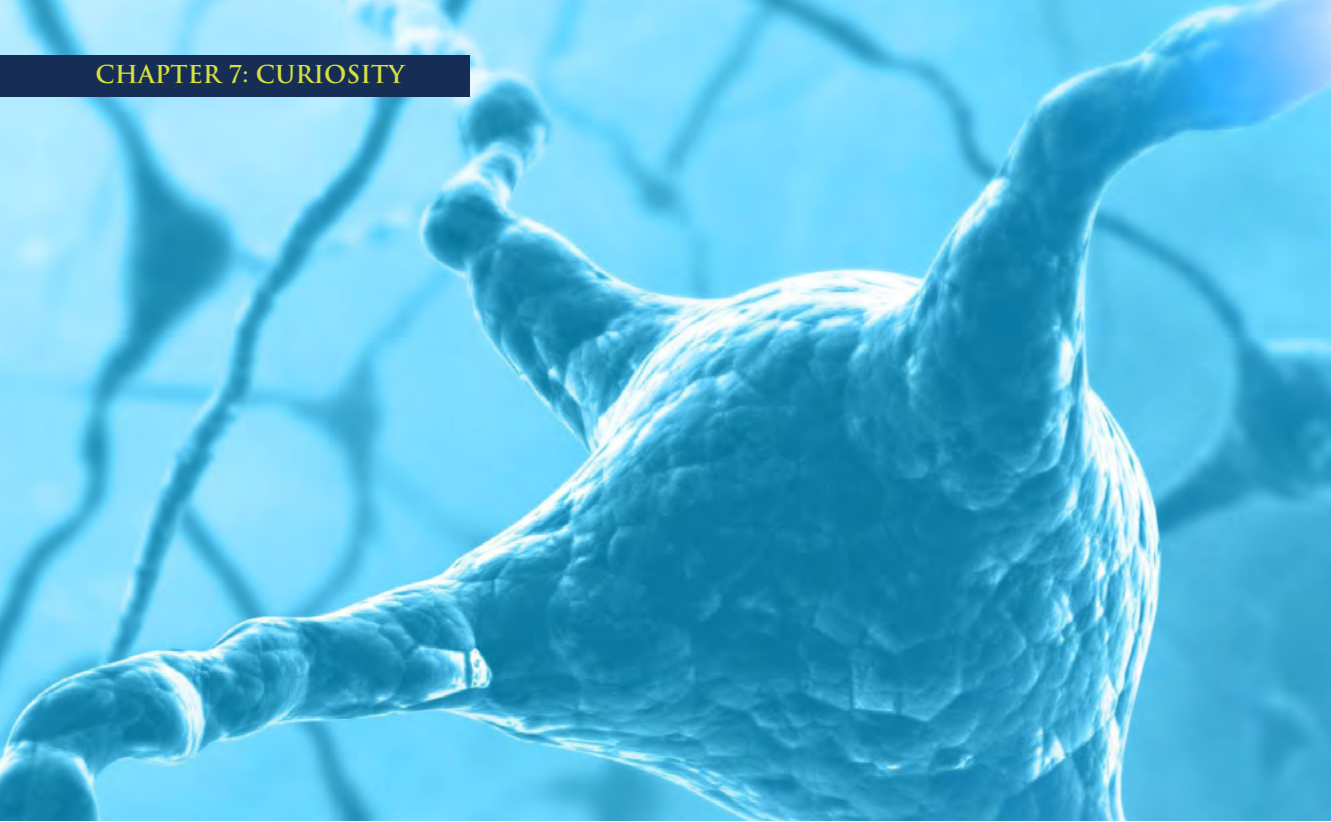




MIND AND MATTER

The human brain is nature's most complex operating system, but scientists are teasing out its secrets, writes **Charles Watson**

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WHAT DO HUMAN brains and insect brains have in common? Quite a lot! A busy cockroach can find food, escape from danger, and produce offspring with a brain the size of a pinhead.

Insect brains have structures surprisingly similar to the basic motor control systems of the mammalian forebrain and the nerve cord of insects develops under the control of the same genes that make our brain stem and spinal cord. It looks as if the basic components of a brain were developed in very early living animals, and that the major elements have been retained ever since then. Researchers at the Queensland Brain Institute have learned a great deal from the brains of bees and fruit flies.

This isn't really surprising. Insect and mammal brains like ours have the same fundamental purpose, survival: of the individual and the species. Brains code information from the outside world and from internal sensors into millions of signals that can be processed and interpreted by networks of cells called neurons.

The aim is to choose the best possible responses by the body's muscles and glands when challenged. The brain ensures that the individual survives by getting it to eat and drink when it senses hunger or thirst, and to defend itself from attack by other animals when it perceives an approaching threat. In vertebrates, the brain ensures that the species survives by encouraging sexual reproduction and care of the offspring. In humans, these survival functions are coordinated by the hypothalamus, a very small region only about 1 cubic centimetre in volume.

On the input side, the hypothalamus is informed by messages from all of the senses and memories of important past events. This part of the brain can initiate movements and control hormone systems. The movement control systems are organised very economically. Important movement sequences such as running, grasping, licking, and chewing are encoded in parts of the brain in much the same way as computers use subroutines, enabling each movement to be ordered with a single command.

Depending on the need, different combinations of movement modules are enlisted. For example, hunger in a rat will trigger looking for food,

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running to find it, grasping, licking, chewing and swallowing it. Using its control of endocrine glands and internal organs, the hypothalamus is able to maintain a stable internal environment (such as a constant temperature) in the face of external challenges. This function is called homeostasis. The Herzog group at the Garvan Institute are unravelling the homeostatic control of appetite and obesity.

The human brain has the same survival systems as other mammals and a great deal of what we do every day uses these simple systems. The difference between simple brains and the human brain is that we have a huge cerebral cortex sitting on top of the hypothalamus, giving us a much wider range of choices about the way we live our daily lives.

Researchers have learned much about the human brain by looking at our recent evolutionary history. Humans evolved from the same distant ancestor as monkeys and apes and with them we form a group known as primates. Among the special features of the primate brain are elaborate systems for accurate vision and precise control of hand movement. We inherited these features and have developed a very



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powerful capacity to take advantage of them – the power of complex communication.

All animals communicate at a basic level, mostly through vocalisation and body language. But over the past three million years the human brain has developed a system of communication with almost infinite potential that uses not only vocalisation and body language, but also written and electronic forms of communication. This has led to an explosion in knowledge transfer.

Three million years ago early humans walked upright, lived and hunted in groups, and used

MACHINE BRAINS

The film *2001: A Space Odyssey*, with the very human-like fictional computer named HAL, kick-started a fascination with the prospect of Artificial Intelligence, with computers so complex they could operate like a human brain. While computer simulation of human brains is in question, there's no doubt that computers are enormously powerful in their own way, and can outperform humans in very complex tasks. IBM's 'Watson' computer proved that it could beat humans in quiz contests, and is now being used to assist cancer diagnosis and treatment.

The IBM-sponsored Blue Brain project in Switzerland has attempted to build a computer model of a basic element of rat cerebral cortex, a small cylinder of cortex consisting of 10 000 neurons. The project's successor, the one-billion euro Human Brain Project, aims to create thousands of computer replicas of this cortical cylinder and link them together. The project was announced in January 2013 and will be directed by the Swiss Federal Institutes of Technology in Zurich. It seeks to reveal how the human brain works by building a silicon version in a supercomputer.

The BRAIN Initiative, launched in April 2013 by President Barack Obama, will not focus primarily on computer modelling of the brain, but will attempt to develop technologies for mapping the activity of tens of thousands of neurons simultaneously. This is still very ambitious.

Despite advances in simulating human thought processes, the operating system of the human brain is fundamentally different from the way computers work. Until we understand that operating system of the human brain, computer simulation may be shooting in the dark.

primitive stone tools. The development of communication through speech was highly advantageous because it assisted the group in hunting and defence and ensured that any invention was shared between all members.

Complex communication led to the formation of groups with strong social bonds and an ability to share duties of food gathering, defence, and child rearing. In evolutionary terms, the advantages of sophisticated communication skills were so great that every step in brain expansion was exploited to the benefit of each human society. The result was continuous expansion in the number of neurons in the cerebral cortex, from 30 billion in our earliest ancestors to around 86 billion in modern humans.

Counting neurons isn't easy. The number of neurons in the human brain has been the subject of debate for decades. Fortunately, Brazilian neuroscientist Associate Professor Suzana Herculano-Houzel, with the Federal University in Rio de Janeiro, developed a simple way of accurately counting neurons in 2005. She puts a brain in a blender with detergent to

release the nuclei from all the brain's cells. The intact nuclei of neuronal cells and non-neuronal glial cells (glial cells are the supporting cells of the nervous system – they help to keep neurons alive) can be distinguished with special staining, and the counting can be done quickly and accurately with a standard red blood cell counting system.

There's an interesting culinary twist in the story of human brain expansion. While early humans were skilled food gatherers, using stone tools to strip carcasses and break bones to get marrow, their brains would probably have stayed at about the 40 billion neuron mark if it weren't for the invention of fire. Fire was crucially important because cooked food is about four to five times more nutritious than raw food.

Gorillas and chimpanzees, with a brain the same size as our early ancestors, need to spend six to eight hours a day gathering food. The brain is a very greedy organ. Although it is only 2 per cent of body weight, it uses more than 20 per cent of the energy from food. Without fire and cooking, brain evolution

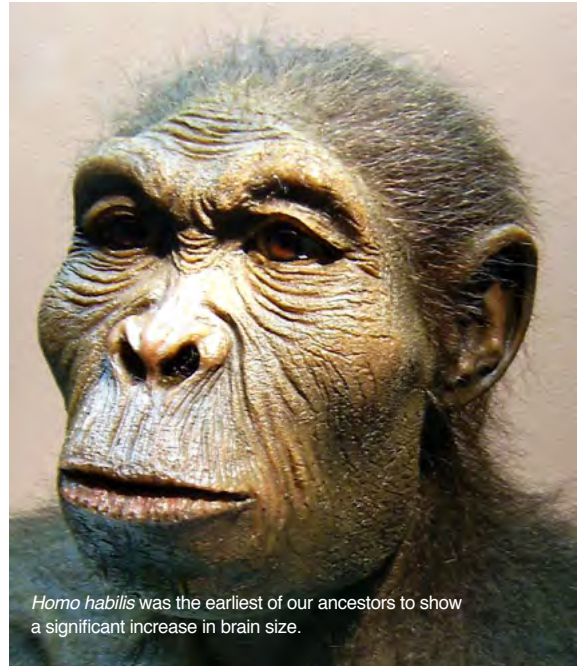
would have stalled because there weren't enough hours in the day to collect more food to feed a bigger brain.

Apart from its sheer size, the human cerebral cortex has many more specialised areas than most other mammals. Rats, for instance, have about 20 centres that receive sensory information, give commands for movement and store memories, but which don't do much else. In contrast, the human cerebral cortex evolved roughly 200 distinct areas, most of which are engaged in analysis, understanding and communication, rather than simple sensory reception and control of movement.

Go back to that cockroach brain. There's no doubt our elaborate brain beats the insect brain hands, or neurons, down. Scientists have used their own big brains to learn much about brain structure and function. Still, there's a long way to go. The main limitation is a poor understanding of the operating principles of the *Homo sapiens* cerebral cortex.

Meanwhile, Australian neuroscientists at the Florey Institute, University of Melbourne, and the Brain Mind Institute at the University of Sydney are focusing on identifying the underlying mechanisms of degenerative brain conditions such as Parkinson's and Alzheimer's diseases. The goal is early treatment of these debilitating disorders.

This isn't the same as understanding how the whole brain works, but progress here promises enormous impact worldwide. At a basic science level, the researchers at Neuroscience Research Australia at the University of New South Wales



Homo habilis was the earliest of our ancestors to show a significant increase in brain size.

are the world leaders in brain mapping, which is essential for clinical studies.

Where to next? Intense research in Australia on early treatments for Alzheimer's, Parkinson's, and multiple sclerosis will deliver results over the next five to 10 years. The prospect of gene therapy for brain conditions is now just starting to open up.



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FURTHER READING

Herculano-Houzel, S., Lent, R. 2005, 'Isotropic fractionator: A simple, rapid method for the quantification of total cell and neuron numbers in the brain', *Journal of Neuroscience* 25(10): 2518-2521.

Herculano-Houzel, S. 2012, 'The remarkable, yet not extraordinary, human brain as a scaled-up primate brain and its associated cost', *Proceedings of the National Academy of Sciences of the United States of America* 109(Supp 1); 10661-10668.

Strausfeld, N.J., Hirth, F. 2013, 'Deep homology of arthropod central complex and vertebrate basal ganglia', *Science* 340(6129): 157-161.

Watson, C., Kirkcaldie, M., Paxinos, G. 2010, *The Brain: An introduction to functional neuroanatomy*, Elsevier Academic Press, San Diego.

Wrangham, R. 2010, *Catching Fire: How cooking made us human*, Basic Books, New York.