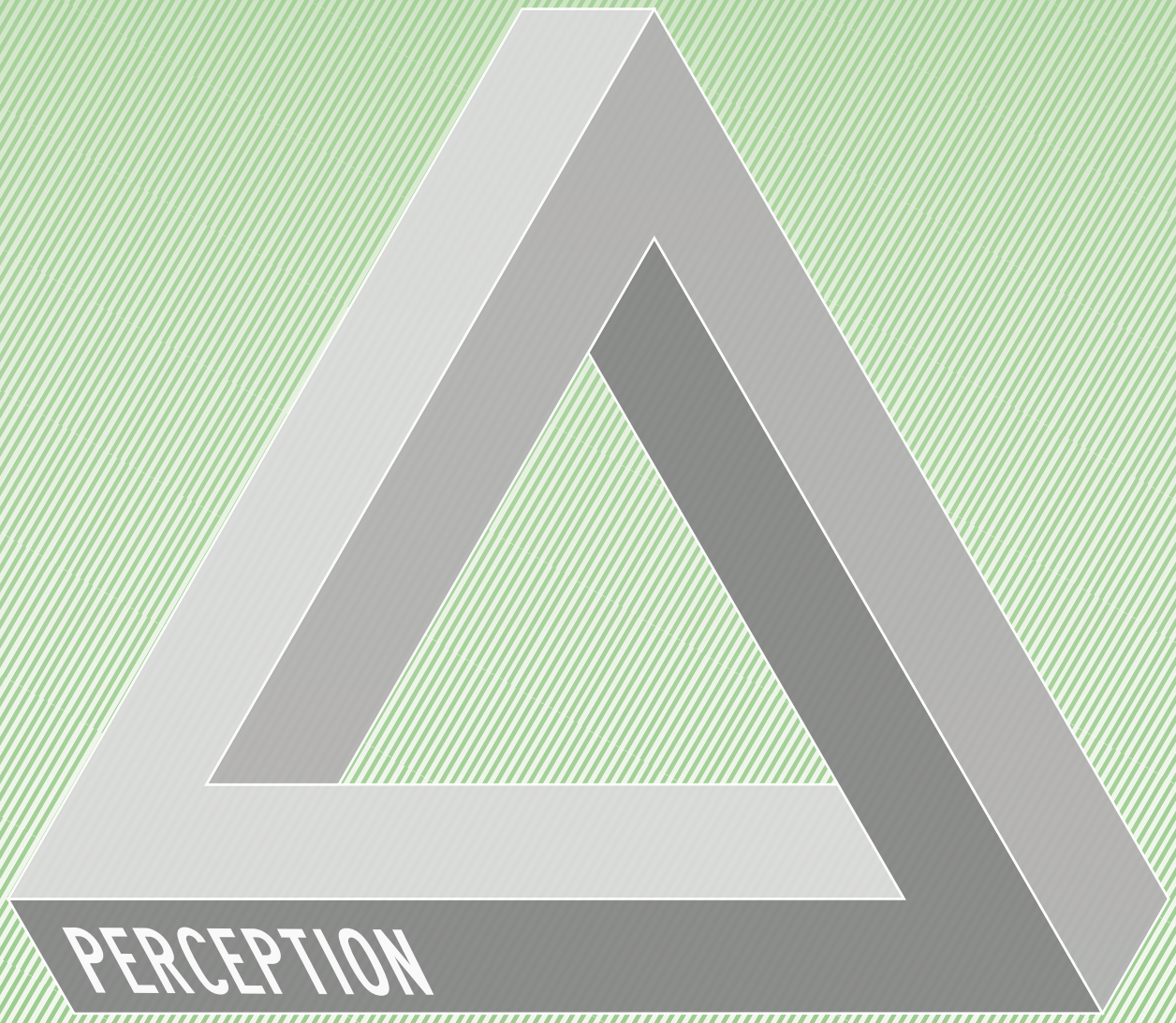
I, SCIENCE

THE SCIENCE MAGAZINE OF IMPERIAL COLLEGE



I, SCIENCE

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I, SCIENCE

Thanks for picking up this summer 2012 issue of *I, Science*! Beauty is in the eye of the beholder, they say. But so is science. Modern science as we know it – the scientific tradition that we trace back to Galileo and his new view of the world – is grounded in what can be perceived. Hypotheses are tested and theories are debunked through observation. We witness strange phenomena and spin stories to explain what we see.

We take it for granted that scientists are able to explore the world, but the fact that our human senses, evolved over millions of years for utterly different purposes, can probe the mysteries of the universe is astonishing. Of course, science has typically only been able to move forward through observations made using tools, from Galileo's telescope to particle colliders such as that at CERN.

As W. B. Yeats put it, "the world is full of magic things, patiently waiting for our senses to grow sharper". Our senses now grow sharper with the progression of technology. What knowledge we can be said to have of the world is mediated by our use of instruments and apparatus, and the possibility of scientific discovery is limited by the technology available to us. Despite their wonderful sophistication, our tools cannot replace our basic senses.

With that in mind we have dedicated this issue to perception – our perception of time and space, the world around us, and each other. But in so doing, we question whether our perception of things is as unshakeable as we like to assume. After all, humans are easily deceived and illusions abound.

Take our perception of time, for example. How do we 'store' time? Childhood memories all have some sense of time embedded within them, whether it be a sense of an event's duration, or a sense of distance. We partially measure distance by using our knowledge of time. If it takes us about 15 minutes to walk to the nearest Starbucks, we can then mentally map out the distance of various other destinations in relation to this – all based on a sense of time.

But researchers have found that it is possible to train neurons in the brain to react at certain times. For example, one study carried out back in 2008 at the Humboldt University of Berlin in Germany measured the 'firing' of individual neurons in rats' brains. Rats ran down a track and were rewarded with food at the end. The researchers identified individual neurons that fired at specific places on the track along the way. As the rats neared their goal – in this case, food – the neurons all fired in reverse order. In other words, the rat was effectively reversing time and mentally storing it that way as a memory.

Are we so different from these rats? Read on as we explore the role perception plays in how humans make sense of time, space, intelligence, animals, art, science, gender, and even objectivity itself. Enjoy! ■

NICOLA & DOUGLAS

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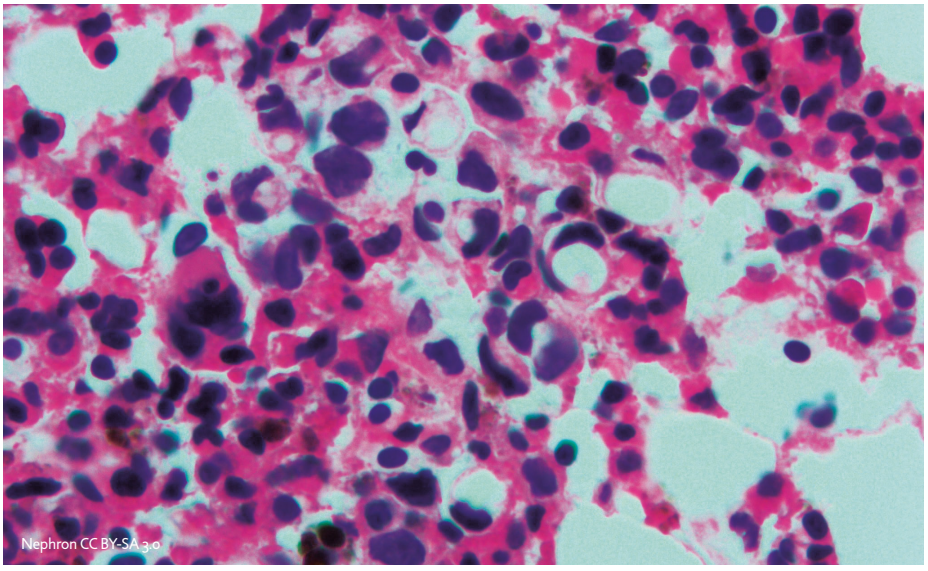


Nephron CC BY-SA 3.0

PREDICTING BREAST CANCER IS A BLOOD TEST AWAY

Recurrent visits to the radiologist could be a thing of the past; new research suggests that it may be possible to anticipate an occurrence of breast cancer many years in advance.

Imperial College London researchers have identified an epigenetic marker that could predict breast cancer years before it occurs. Epigenetic changes have already been found in breast cancer, but the study, led by Dr Flanagan and published in Cancer Research, shows that such modifications pre-date tumour formation, and can be identified through a simple blood test. Women with high levels of DNA methylation in their ATM gene were found to be almost 1.9 times more likely to develop breast cancer than those with low levels.

Methylation is a chemical process that can influence gene activity without altering the genetic code. Dr Flanagan's team analysed blood samples from prospective studies of 1381 healthy women, 640 of whom went on to develop breast cancer. On average, the cancer occurred 3 years after the initial blood test, but for some women this was as much as eleven years. These women showed higher levels of ATM DNA methylation and this effect was the strongest in women under 60.

Dr Flanagan says "the next step is a genome-wide approach to try and find all the associated genes". Indeed, if more epigenetic risk markers can be found, early prediction of breast cancer may be possible from blood samples. Baroness Delyth Morgan from Breast Cancer Campaign, an organisation that part-funded the work, said the research suggests that "the risk of developing breast cancer could be decided many decades in advance. By piecing together how this happens we can look at ways of preventing the disease and detecting it earlier to give people the best possible chance of survival". ■

MOLLY DOCHERTY

NEW LEADERSHIP FOR IMPERIAL

Imperial College London is splitting the leadership role of Rector into two. Last April, Imperial announced plans to establish the two positions of 'President & Rector' and 'Provost'. Current Rector Sir Keith O'Nions will now be known by the title of President & Rector. The search for candidates for the role of Provost will commence at the end of May.

The division will allow the President & Rector to oversee all functions of Imperial as well as foster greater collaboration with external groups such as alumni, governments and industry in the UK and globally. The Provost will bear the responsibility for Imperial's core academic mission, reporting directly to the President & Rector. The new model of leadership structure is more associated with American universities. With Sir Keith due to retire at the end of 2013, inauguration of the new model will only fully take place at that point, with a President & Rector and Provost taking up their respective positions.

The change reflects the latest challenges to higher education and has been driven by the need to separate key functions of the leadership. Chair of Imperial's Council, Baroness Manningham-Buller, said: "In changing the leadership structure we can place more emphasis on strengthening our relationships with those who share our vision of the importance of higher education… Doing so will allow Imperial to maintain its position as one of the world's top universities." ■

DHARSHANI WEERASEKEERA

EUROPE'S LARGEST BIOMEDICAL RESEARCH CENTRE TO OPEN IN LONDON

A new world-class medical research centre is to open in London, next to St. Pancras International Station.

Named after the British co-discoverer of the structure of DNA, The Francis Crick Institute will be the largest centre in Europe for research and development in biomedical sciences. It will carry out ground-breaking interdisciplinary research on the causes of heart disease, strokes, cancer, infections such as HIV, and neurodegenerative diseases.

The Institute is a consortium of six of the UK's major scientific organisations; Imperial College London, the Medical Research Council, Cancer Research UK, the Wellcome Trust, UCL and King's College London. Its management will be led by Sir Paul Nurse, President of the Royal Society.

1,250 scientists from various disciplines will be employed at the centre, including physicists, biologists, engineers, chemists, mathematicians and computer scientists. The Institute says its work will focus on the combination of specialist knowledge in a flexible and dynamic workforce to encourage new ideas, and ensure that laboratory discoveries are turned into treatments as quickly as possible.

Construction of the research centre has already started, and it is due to open in 2015. The total cost of the project is £650m and it is estimated to cost £100m per year to operate.

JOEL WINSTON

IMPERIAL LEADS THE FIELD IN DEVELOPMENT OF NEW ORGANIC TRANSISTORS

More responsive organic transistors could be used in the development of flexible displays

HARALAMBOS DAYANTIS

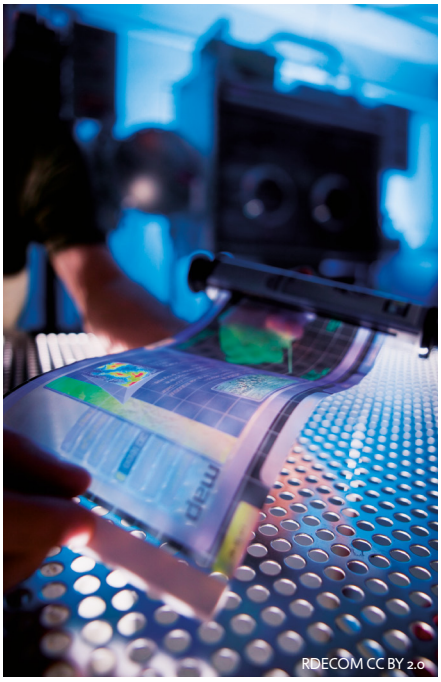
An Imperial-led team of scientists have developed the world's most responsive organic thin-film transistors (OTFTs). The work was carried out by Imperial's Centre for Plastic Electronics in collaboration with material scientists from the King Abdullah University of Science and Technology in Saudi Arabia. OTFTs can be used in electronic components such as computer and smartphone displays, but are generally slower to respond than their inorganic counterparts. However, the new OTFTs have the highest carrier mobility ever recorded in organic compounds, a property which determines how fast electrical charges can move. This could allow them to compete with more traditional silicon-based components.

Organic semiconductors are cheaper to manufacture than inorganic ones, since they can be produced on larger scales. They can also be deposited on a variety of surfaces, which has led to the development of flexible displays. The problem with such displays is that they are slow to respond, so cannot display moving images clearly. The new research could lead to flexible displays which are as responsive as those we see in commercial use today.

The high carrier mobility in the new OTFTs was achieved using a blend of "small molecule" and "polymer" semiconductors. Small molecule semiconductors have crystalline structures, which promote high carrier mobility. Yet these are notoriously difficult to produce in uniform films, limiting their potential usefulness.

Polymer semiconductors are relatively easy to create in large, uniform films. The problem is that their carrier mobilities are much lower than those of small molecule semiconductors. By creating a solution which blends both semiconductors, the researchers have managed to produce consistent films with mobilities five times higher than previously achieved.

Dr Thomas Anthopoulos, who led the research at Imperial, says the work may "lead to the development of organic transistors with performing characteristics well beyond the current state-of-the-art".



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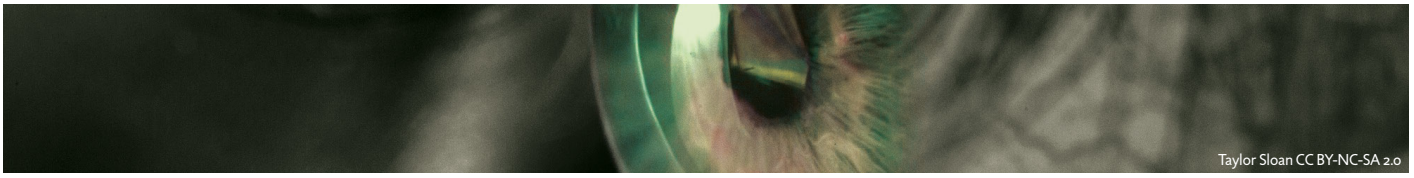
WORLD NEWS

PICK OF THE BEST



RETINAL IMPLANT RESTORES VISION IN PATIENTS WITH DEGENERATIVE EYE DISEASE

Two British men have regained partial vision thanks to a pioneering clinical trial investigating the implantation of electronic retinas.

The two eight-hour operations took place in April at the Oxford Eye Hospital and King's College Hospital, London. During the procedure, light-sensitive implants designed to mimic the eye's natural light-processing abilities were inserted into the back of the retina. From there, a fine cable connected the implants to a control unit beneath the skin behind the ear. When the implants were switched on post-surgery, both patients were able to detect light and even some shapes, despite having previously had no vision.

The 3mm^2 implants are made up of 1,500 light-sensitive pixels that take over the function of photoreceptor cells damaged as a result of the incurable genetic disorder retinitis pigmentosa. When light enters the eye and reaches the chip it stimulates the pixels, which send electronic signals to the optic nerve and subsequently to the brain, where an image is formed.

Speaking to The Telegraph, trial co-leader, Dr Tim Jackson, explained how the implant "replicates the action of the cells that have died" in his patients' eyes. "You can think of the retina as the film in the back of a camera that has died away, but the remaining connections are still intact and we can use these to transmit a signal to the brain". Patient Robin Millar described how, since undergoing the procedure, he had dreamt "in very vivid colour" for the first time in 25 years, "so a part of my brain which had gone to sleep has woken up".

Retinal disorders are the second largest cause of blindness in the developing world, with retinitis pigmentosa affecting an estimated one in 4,000 people in the UK. The success of this trial offers hope of future treatment for both retinal conditions and other causes of vision loss. ■

LUCY VAN DORP

A SEARCH FOR EXTRA-TERRESTRIAL LIFE

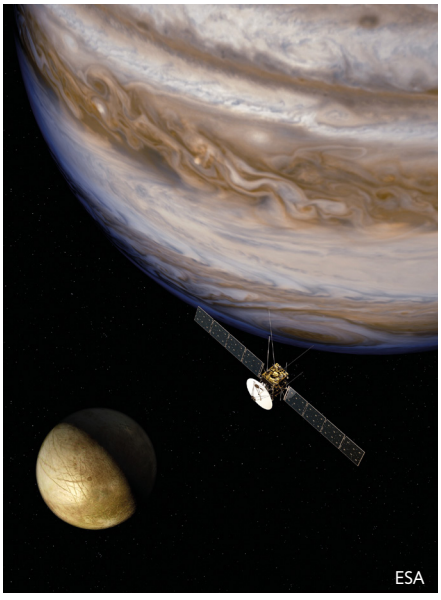
Imperial-led project is set to explore Jupiter's icy moons

The European Space Agency (ESA) has approved a new billion-euro mission to explore Jupiter's icy moons, to be launched in 2022. The project, nicknamed JUICE (JUpiter ICy moon Explorer), is led by Professor Michele Dougherty of Imperial College London. The main purpose of the mission will be to study Ganymede, Jupiter's largest moon, thought to contain a liquid ocean beneath its icy surface. JUICE will also be making flybys of Callisto and Europa, Jupiter's other icy moons, which may also harbour oceans.

These moons are especially exciting to researchers because the oceans beneath their surfaces could contain the potential for microbial life. When JUICE reaches Ganymede's orbit in 2032, it will measure many aspects of the moon's surface and internal structure. This will allow researchers to determine whether or not the moon could support life. Since no life outside Earth has yet been discovered in the solar system, JUICE may lead to the first discovery of extra-terrestrial life.

The ESA's approval of the proposal demonstrates Imperial's reputation as a world leader in science research. Professor Dougherty was elected to the Fellowship of the Royal Society in April, along with five other Imperial scientists. ■

HARALAMBOS DAYANTIS



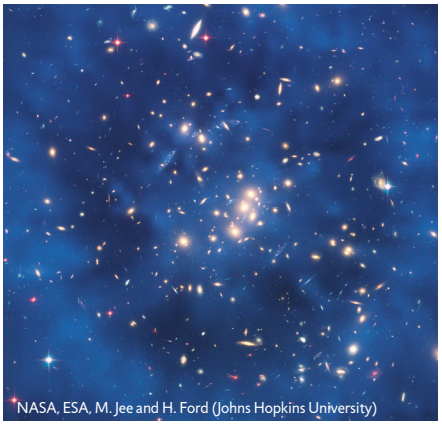
NEW THOUGHTS ON DARK MATTER

SOTIRIOS KARAMITSOS

Two astronomical studies have called the currently accepted dark matter theories into question. Researchers at the European Southern Observatory (ESO) in Chile have concluded that dark matter is actually scarce in the vicinity of Earth, and astronomers at the University of Bonn have discovered that the configuration of celestial bodies orbiting the Milky Way contradicts standard dark matter models.

While dark matter cannot be observed directly, it explains certain gravitational phenomena which visible matter alone cannot account for. A likely candidate for dark matter must be massive and difficult to detect, such as the colourfully-named WIMPs (Weakly Interacting Massive Particles) and MACHOs (MAssive Compact Halo Objects). Current models estimate that dark matter comprises almost a quarter of the universe's mass-energy. However, the analysis performed at the ESO indicates that the motion of about 400 stars within a relatively close distance from Earth can be solely attributed to visible matter. As such, the study concludes that the dark matter density of our galactic neighbourhood is negligible. The authors note that the only way to reconcile this low local density with current models is to assume an unlikely distribution of dark matter over our galaxy.

The ring of dark matter



NASA, ESA, M. Jee and H. Ford (Johns Hopkins University)

Even if one is prepared to make this assumption, the University of Bonn study poses a greater threat to current theories. Globular clusters and satellite galaxies have long been known to orbit the Milky Way – however, this study demonstrates that they do so at a right angle to the galaxy itself. Lead author Marcel Pawlowski's explanation is that these astronomical objects shed stars that align themselves with the globular clusters' plane of rotation, indicating that their trajectories along this perpendicular plane are stable. This is something that cannot be explained by existing dark matter theories, and Pavel Kroupa, professor of astronomy and team member, notes that "…it is next to impossible for [satellite galaxies] to end up distributed in such a thin plane structure." Jan Pflamm-Altenburg, a postdoctoral researcher, attributes this arrangement to a collision between our galaxy and another that occurred approximately 11 billion years ago.

These two studies may cast reasonable doubt on the validity of accepted cosmological dark matter models. While the ESO researchers are cautious in interpreting their results, stressing that further investigation is necessary, Kroupa at the University of Bonn has said that their model of the clusters' formation marks "the beginning of a paradigm shift, one that will ultimately lead us to a new understanding of the universe we inhabit."

At the time of going to print, a new study emerged that suggested these findings were incorrect. The paper, from scientists based at the Institute for Advanced Study in the US, is currently awaiting peer review. Watch out for updates on the matter on *I, Science*'s Space for Thought blog. ■

THE CHEATING POWERS OF GREEN TEA

KARIN VALENCIA

cyclonebill CC BY-SA 2.0

Research carried out by Professor Declan Naughton and his team at Kingston University in London has revealed that certain kinds of tea could help athletes mask illegal testosterone doping.

The team found that certain chemicals present in green and white tea, though not in black tea, have the potential to reduce the amount of the performance-enhancing hormone found in urine.

These findings could make the World Anti-Doping Agency's job very difficult in the upcoming 2012 Olympics, as drinking enough green tea could give athletes a way to mask illegal doping.

Steroids like testosterone can be used by athletes to enhance performance by increasing protein synthesis within cells, resulting in the build-up of muscular cell tissue. Special enzymes in our body are involved in labelling testosterone molecules so that the kidneys recognise them and excrete them in urine. This labelling can serve as a flag to help spot steroid abuse in the world of sport.

This recent study has found that testosterone labelling is inhibited by chemicals called catechins, which are present in green and white tea. Catechins stop the labelling of molecules for excretion, meaning that they could remain inside the body and thereby hide the evidence of doping.

But could athletes really legally increase their levels of testosterone by simply drinking green and white tea? To answer that, we'll have to wait for tests to be carried out on human subjects. After all, the body might find other ways to get rid of the excess testosterone. ■

BEHIND THE HEADLINES

***Nicola Guttridge** and **Jo Poole** unpick some of the most interesting science headlines from the past few months*

1 IN 6 CANCERS CAUSED BY TREATABLE INFECTIONS

Whilst this may be true worldwide, statistics often involve bias. We suddenly visualise being able to eradicate 1 in 6 cancer deaths. But this is unlikely. In developing countries, 23% of cancers are infection-related. These are liver and cervical cancers, caused by Hepatitis B and Human papilloma virus. However, cancers are not a significant health priority in the developing world where infection is likely to kill you first. HIV, TB, malaria and parasites are a more substantial concern. In the developed world, 1 in 6 cancers are not infection-related – just 7% are. The leading cancers in the UK are lung, breast and bowel, caused predominantly by smoking, genes and a poor diet respectively. Those which are infection-related are already being treated. So whilst the cancer charities say vaccination programmes should be implemented in the developing world, vaccination for childhood diseases and access to sanitary conditions are still the priority.

Guardian, May 2012.

STRUCTURAL BRAIN CHANGES IN PSYCHOPATHY

We all know people we consider crazy or cold-hearted, but psychopathy represents a true and serious deviation from normal social and moral responses. People with this disorder genuinely lack self-conscious emotions like guilt or embarrassment, have similar neuroimaging responses to the word 'rape' as they do to 'table', and are much more likely to conduct violent crime. Neuroimaging allows us to investigate the structure and activity of the brain and how it correlates with behaviour. This study found that violent psychopathy was significantly associated with reduced volume in the medial frontal cortex and upper temporal lobes. These areas are activated when contemplating moral behaviour and damage is associated with a loss of empathy and remorse. It's hoped imaging can highlight which offenders may respond to cognitive behaviour therapy. Unfortunately there's a large variation in what is 'normal' – where do you draw the line? After all, Einstein had a disappointingly 'normal' brain and yet a vast intelligence. There are many people with the psychopath trait who are not serial killers. Structural imaging also raises important ethical questions. Psychopathy can be considered a neurodevelopmental disorder, thus are they responsible for their actions?

Guardian, February 2012.

DO HEARTS BENEFIT FROM LOWER LEVELS OF POLLUTION?

This study was carried out during the 2008 Beijing Olympic Games. Beijing is notorious for its high levels of pollution; during the games, organisers halved the amount of time cars were allowed on the roads and closed inner city factories in a bid to raise air quality. Researchers took blood samples before, during and after the games from a sample of young, healthy adults to measure the effect that this pollution has on ongoing cardiac health and the potential development of cardiovascular diseases. The researchers found that levels of biomarkers for conditions such as thrombosis and inflammation decreased substantially during the Olympic period along with the concentration of particulate and gaseous pollutants in the patients' bloodstreams. However, some of the markers examined did not change significantly from during- to post-Olympic periods, and the scientists admit their results to be of "uncertain clinical significance". The consequences of such short-term changes on long-term heart health also remain unknown – this study is "quasi-experimental" and requires further research. In this sense, the BBC article is slightly misleading.

BBC, May 2012.

RUN FOR YOUR LIFE

This study is part of the Copenhagen City Heart Study, a programme that has monitored the health of 20,000 Danish men and women since 1976. A sub-set of 1,116 male and 762 female joggers were tracked over 35 years to see if jogging had a substantial effect on the human lifespan. The results showed that one to two-and-a-half hours of moderately-paced jogging per week was optimal, and added an average of 5.6 years and 6.2 years to female and male lives respectively when compared to the non-joggers in the overall sample. According to the lead scientist, Dr Schnohr, jogging leads to "raised oxygen uptake, increased insulin sensitivity, higher levels of 'good' HDL cholesterol, lowered blood pressure, reduced blood clotting...improved heart and immune function...and protection against obesity". There have been conflicting ideas about the health benefits associated with jogging, and Schnohr caveats his research with a sensible plea for people to visit their GP if they have such concerns. The Independent covers this study accurately.

Independent, May 2012.

CHEMICALS CAN LOWER MALE FERTILITY

Many scientific studies begin on animals and infer their results on to humans. This BBC news article confuses the two and treats the causal link between chemicals and low fertility as a foregone conclusion (for humans as well as sheep). Although such an article must contextualise, when a study has not yet been tested in a human environment these inferences are misleading. This study investigated the impact that everyday chemicals – via the application of sewage sludge to pasture – have on the sperm counts of male sheep from when they are conceived through to puberty. The results showed that "evaluated as a single group, exposure to sludge [environmental chemicals] was without significant effect". However, a closer study revealed 5 of 12 adult rams to display "major spermatogenic abnormalities". The conclusion from this appears to be that there is a potential link between exposure to such chemicals and reproductive abnormalities, but this is highly dependent on individual susceptibility to such adverse consequences – and, so far, a link only shown in sheep.

BBC, May 2012.

IVF INCREASES THE RISK OF BIRTH DEFECTS

This study looked at the risk of birth defects from natural conception vs. traditional IVF and a form called ICSI. The risks were 5%, 6% and 10% respectively. It is probably unsurprising that fertility treated embryos are at higher risk of damage due to anomalies in the reproductive cells themselves, unnatural cellular exposures and laboratory manipulation. However the fact it almost doubles the risk is quite alarming. It's believed that in the case of ICSI, a direct approach where sperm are injected into the egg, the patients have more germline problems in any case, and the technique is not responsible. Thus banning it denies a proportion of the population the chance to reproduce. However IVF is a controversial form of 'healthcare' and has been responsible for a lot of premature births and birth 'defects'. Furthermore, expectant mothers are told to avoid alcohol and smoking – moderate consumption of which is associated with less risk than ICSI. Is this sort of fertility treatment fair on the child? It's up to these sorts of studies to clarify the dangers.

The Telegraph, May 2012.

EXERCISE REDUCES THE RISK OF ALZHEIMER'S

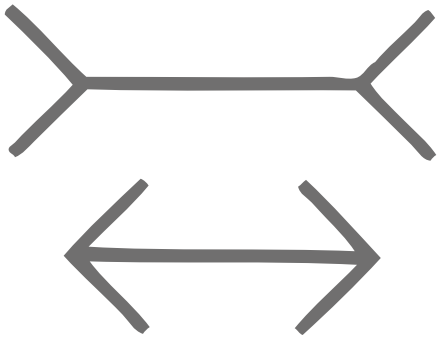
Ultimately, Alzheimer's has a heavy genetic predisposition. You cannot (yet) rewrite your genome in order to avoid it, and running 5 miles a day does not get you off scott-free. Exercise is, however, good for you. There is evidence that regular exercise makes you live longer and happier. You might not want to pop to the gym tonight, but if you make yourself, you may be able to go 5 years longer without a zimmer frame. This study found that when they followed 700 seniors and compared activity levels amongst them, those in the lowest 10% of activity were twice as likely to develop Alzheimer's. While this may be due to active individuals having an improved cardiovascular system, fewer microstrokes, better blood supply, improved mood, improved brain metabolism, it may also be a reverse correlation in the sense that those who experience cognitive decline become less active. Essentially, clean, healthy living is the best way to lower the risk of Alzheimer's, so exercise certainly isn't a bad idea.

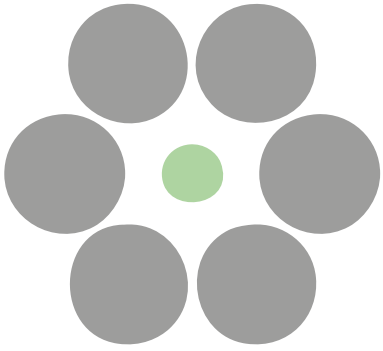
Neurology, April 2012.

It is entirely possible that behind the perception of our senses, worlds are hidden of which we are unaware

– Einstein

PERCEPTION





It's hard to believe but the two lines above are actually the same length and the two green dots are exactly the same size.

The Latin name *Homo sapiens* translates as 'knowing man'. It's an apt title; our curiosity and desire to know the world around us is arguably our defining characteristic. Over our 200,000 year history, this ability to explore, understand, invent, and share what we learn has taken us from simple hunter-gatherers to members of today's diverse and developed societies.

However, it is the last three hundred years – since the beginning of the Enlightenment, or 'Age of Reason' – that have seen our most startling phase of understanding take place. We have begun to appreciate that, despite all of our past achievements, we were and potentially still are surrounded by mysterious and hidden worlds.

Our discoveries are made possible by our senses. But, as Albert Einstein once said, "it is entirely possible that behind the perception of our senses, worlds are hidden of which we are unaware". Our senses are limited in what they can detect, and we only perceive a fraction of nature's phenomena. Take sight, for example: we are blind to wavelengths in the infrared or ultraviolet because our eyes only sense a narrow band of the full electromagnetic spectrum. It is only with the help of specialised scientific tools that we can overcome these limitations and push open the 'doors of perception'.

Equipped with today's perception-altering tools we are beginning to discover nature's secrets, from the enigmatic edges of space to the miniscule world of atoms. We are starting to comprehend our world from a truly vast perspective, viewing it as just one layer amongst the many that make up our universe.

But could this view of the universe also be just one of many? What does it mean to conceive of a world wholly separate from our human-centred point of view? The more we learn about ourselves, the more we learn that things we took for second nature – such as our sense of time or the way we speak – might influence our perception. We are also easily deceived; our tendency to believe what we see is almost as strong as our innate urge to seek out truth. As we start to build artificial intelligences we must in turn decide how these should perceive *their* world.

Our senses have revealed more of the universe than our ancestors would ever have thought possible – and they will continue to do so. But it is important that we not take them for granted; perceiving is not always believing. ■

VANNA BARBER

ABOUT

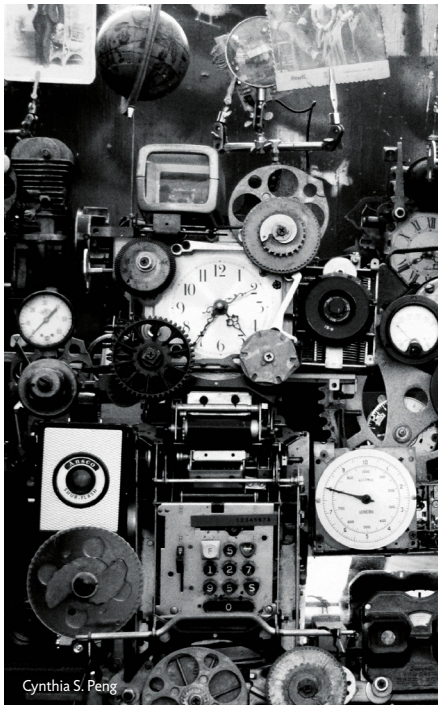
We have come a long way since we tracked our minutes using sundials, but we still do not fully understand why some seconds seem to stretch on forever. ***Nicola Guttridge*** *investigates how we construct, manipulate and experience time.*

When discussing time, it is difficult to avoid clichéd statements or thought experiments. The adage, 'time flies when you're having fun', for example, may be irritatingly overused, but there is evidence to suggest that our internal monitoring and experience of time really is linked to levels of enjoyment. We all take the passage of time for granted, but what exactly is time, and how do we perceive it?

"TIME PRECEDES EXISTENCE"?

In physics, time actually helps us to define space – in 4D spacetime, the co-ordinates are x, y, z, and time (t). Our current understanding is that time is relative to motion. We live on a 'world line' rather than a linear timeline, where a particular object's movements through 4D space define the passage of time for that object. In popular culture this is often described via examples such as the 'twin paradox' – when one twin journeys into space and comes back younger than the twin that stayed at home. This attempts to explain time dilation, a phenomenon caused by a change either in gravity or in relative motion. In order for it to occur, there must be more than one frame of reference.

However, using time as a co-ordinate in physical models raises issues. The smallest observable time step is called the Planck time, which is equal to 5.391×10–44 seconds, or the time taken for a particle travelling at the speed of light to cross a distance known as a Planck length. If we trace our universe back to its inception, some physicists state that there must have been a moment between the Big Bang and the formation of this small time unit when there was effectively no time. This implies that we may never exactly know when an event occurs, as we will always become stuck when time steps become less than this Planck time. If a particle is fast-moving enough to cross the Planck length quicker than this time, physical dimensions struggle to accurately record what is going on.


Cynthia S. Peng

Research has suggested that the answer might lie in spontaneous broken symmetries, a process through which symmetrical systems randomly become asymmetrical. The standard explanation of broken symmetry is to imagine a Mexican hat with a ball balanced in the middle, at the highest point. This system is symmetrical, but if the ball were to spontaneously roll into one of the wells of the hat, it would not be – though the ball and the hat would both have retained their individual symmetries. The standard physical view assumes that time follows existence. Some scientists, most notably physical chemist and Nobel laureate Ilya Prigogine, advocate that this is not so and suggest that "time precedes existence"; that it is an entity that is separate to the creation of our known universe.

This Planck time is the same for the entire universe – assuming that the constants we work with are uniform throughout. The 'Planck' units are sometimes referred to as 'God's units', as they are obtained from nature using a mix of the most important physical constants we know of (gravitational constant G, Planck constant h, and the speed of light c). However, the idea of time 'breaking down' is a simplification, and assumes that time is quantised – this might not be the case.

TIME!

TICKING AND FIRING NEURONS

Regardless of when 'time' arose, our brains have in-built ways with which to measure it. This is still at the forefront of neuroscientific research, and there are many different ideas about how the human brain handles the passage of time. Some scientists turn to music to explain this measurement. Warren Meck of Duke University describes a method involving musical pulses that the brain monitors and 'listens' to, counting various clumps of firing neurons in a similar way to chords on a piano. Other scientists turn to nature. Dean Buonomano, a neuroscientist at UCLA, instead uses the analogy of ripples on a pond, suggesting that the brain detects a set of auditory neurons firing when it hears a sound. It then compares this signal to the one detected a few seconds later when it hears yet another sound, and compares these two differing instances to construct a time value.

A study† led by van Wassenhove of the California Institute of Technology a few years ago aimed to explore this subjective time perception across the senses. "The ability to estimate the passage of time is of fundamental importance for perceptual and cognitive processes," wrote the scientists. "One experience of time is the perception of duration, which is not isomorphic to physical duration and can be distorted." This distortion has been measured: scientists at UCLA studied the effects of stimulants such as crystal meth and cocaine on our ability to track time. In the study, two groups of healthy and stimulant-addicted people were asked to guess the duration of a 53-second period of silence. On average, healthy people guessed 67 seconds had passed. The unhealthy group instead guessed that 91 seconds had elapsed. Removing our means of reference can skew our internal clock.

Even our sense of 'current' time is tricky to define – it actually extends slightly into the future. This may be based on our past experiences. We know that if we reach out to press a doorbell we will feel metal against our fingertip followed very quickly by the sound of the bell. In this way, reaching out to press the bell partially extends our mental perception of 'current' to hearing the bell itself. Similarly, we seem to need all of our senses to fully appreciate the passing of time – standing in a darkened room or wearing earplugs affects our internal ability to judge it.

We have developed technological ways of tracking time as we cannot rely solely on our brains. Advances in neuroscience may allow us to fully understand biological time-telling, but so far it has shown us that our brain's internal clock can be easily fooled. ■

†*Distortions of Subjective Time Perception Within and Across Senses. doi:10.1371/journal.pone.0001437*

WAIT A SECOND...

In a recent lecture (reviewed on page 31), Dr. Patricia Fara explained how we have become increasingly detached from the natural roots of time-telling (for example, the path traced out in the sky by the Sun, and the rotation of our planet) with our progression from sundials to motorised clocks. How do we actually define time?

Our base unit of time, the second, can be defined in two ways. The first is to define it using atomic physics, as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom. This corresponds to a certain electron in such an atom spontaneously 'flipping over' and emitting the perfect frequency to define a second.

Or, we can define a second astronomically. The definition of a year is the length of time it takes the Earth to complete one orbit of the Sun. Astronomers took this definition and arbitrarily chopped it up, defining a second to be 1/31,556,925.9747 of a year as measured in January 1900. However, the length of each year changes based on the Earth's rotation, so this brings in the need for a leap second every so often (the next one will be added on June 30th this year).

RELATIVELY SPEAKING

***Douglas Heaven** asks whether the words we use determine the world we perceive.*

If I say *to-mah-toe* and you say *to-may-toe*, to call the whole thing off would be rash. But if I say tomato and you say *la tomate*, we might be living in subtly different worlds. Do your tomatoes have something in common with cars (*la voiture*) and houses (*la maison*) and the Moon (*la Lune*) that mine do not, simply in virtue of the gender of your words?

Lera Boroditsky, Assistant Professor in the Department of Psychology at Stanford University, thinks so. In a series of studies exploring linguistic relativism, she claims to have shown that "even small flukes of grammar, like the seemingly arbitrary assignment of gender to a noun, can have an effect on people's ideas of concrete objects in the world". †

In one experiment, for example, Boroditsky and colleagues asked German and Spanish speakers to describe a key – an object named by a masculine noun in German and a feminine noun in Spanish. Boroditsky found that German speakers were more likely to say "hard", "heavy", "metal", and "useful", while Spanish speakers favoured terms like "golden", "intricate", "little", and "lovely", which would appear to suggest that German speakers see keys as having more masculine qualities than Spanish speakers do. It is a fascinating claim, but a controversial one. "Unfortunately," says Professor Gabriella Vigliocco, of University College London's Division of Psychology and Language Sciences, "lack of replication is a major issue in this area."

> "WE ARE BEYOND ASKING WHETHER THERE IS SOME FORM OF RELATIVISM OR NOT"

"Language is a fundamental feature of how we think about the world," says Vigliocco. "Language tells us a lot about what concepts there are, and how we should conceive of the world in general." But her own findings in experiments with English and Italian speakers do not support the idea that linguistic gender has a conceptual effect – despite admitting that it would be "far more interesting" if they did. "The fact that in Italian 'the fork' is feminine doesn't make the fork more female-like, so to speak, than in a language that doesn't have a gender," she explains.

According to Vigliocco, linguistic gender comes into play in such experiments only once speakers are prompted to come up with characteristics for an object. "People use whatever resources they have [available] in order to solve such tasks, and if the language has gender, why not?" she says. "If your language were to divide objects into male or female, then that's an obvious way to go about classifying them."

The issue is complicated. "Of course language is playing a fundamental role in shaping our cognition," she says. "On the other hand, it's also not as black-and-white or as simple as saying 'oh, this language has two genders, male and female, so for these speakers all the things that have a masculine

gender are going to be more male-like than the things that have the female gender.'"

Of particular interest are the more abstract concepts "related to society, politics, religion, and so forth" that we can only access through language– things we cannot experience with our senses. "We learn to categorise the internal world via language," she says. Our grasp of more abstract concepts may be more susceptible to linguistic influence than concrete ones. Boroditsky, for example, has also looked at whether our perception of time is affected by the way we talk about it. Though there are again difficulties with replication, Vigliocco is more open to that possibility. "In my work, I always claimed that effects of language on cognition should be assessed one by one," she says. "But this does not exclude the possibility of an effect for time."

Brain-imaging techniques are now being used to complement behavioural experiments, which might open up new lines of research. "It's a two-way street," she says. "Especially if you are looking at how other systems – like perceptual systems – work and are affected by a specific language." By monitoring what goes on in the brain while people speak, we can learn how words are processed mentally. New techniques might also help with the replication issues of behavioural work. "They are different experimental techniques that really go hand in hand," she says.

But what of our initial question? Does the way we speak really affect our perception of the world? "I think there is good enough evidence now that language can affect cognition under some conditions," she says. "So, really, we are beyond asking whether there is some form of relativism or not. Yes, there is. However, this does not also imply that language is the only force sharing our cognitive make-up. Our culture, our physical environment, and our bodies also play a critical role in how our cognition is shaped." ■

† *"How Does Our Language Shape the Way We Think?", in Max Brockman (ed.) What's Next? Dispatches On the Future of Science.*

PHANTOMS IN THE BRAIN

***Jo Poole** investigates the mechanism thought to be behind the concept of 'phantom limbs' in amputees*

The human body is a complex biochemical system. Sometimes, it can seem like such an elegant solution to the mechanics of life that people think it must be designed. On other occasions, it can go awry and its complexity becomes problematic.

Roughly 5000 limb amputations a year are carried out in the UK. The immediate disfigurement and loss of function are obvious. However, a lesser-known consequence is phantom limb pain, which is pain that feels as though it originates in the missing body part. It carries the classic hallmark of nerve injury, 'burning' in nature, and can be excruciating. Tragically, it affects 60-80% of patients.

Anna Bauer CC BY 3.0

In earlier years, phantom pain was thought to be the derivative of inflammation in the nerve endings as a result of being cut. Surgeons would re-amputate above the stump in an attempt to remove the damaged tissue. Unfortunately this only led to additional phantom pain. Painkillers such as opiates, tricyclic antidepressants and ketamine have also been used, but to poor effect. Phantom pain is notoriously intractable and is linked to chronic sleep deprivation and even suicidal thoughts.

Current theories on phantom pain centre on the brain's plasticity. We all possess a 'body map' in our brains. Each body part is assigned a group of neurons, which are organised systematically to recreate an internal mini-me (almost like a voodoo doll). Stimulation of the hand area of this map will recreate the sensation of being touched on the hand. Adjacent fingers correspond to adjacent neurons, and so forth.

When the brain is damaged, remnant cells reach out tentatively with new connections in order to regain what function they can. When a finger is amputated, the corresponding neurons in the brain go silent for a few days. However after this, they start responding to signals from adjacent fingers, which correspond to neighbouring neurons in the map.

In the case of hand amputations, the hand area forms connections with its closest neighbour – the face, especially the lip region. This represents a 'shift' of only 4mm, but with 20,000 neurons per cubic millimetre the response alters enormously. A patient touched with cotton wool on this area of the face will sense it in their absent hand.

Equally, neuroimaging studies show that when subjects are asked to imagine moving the affected hand, the 'lip area' of the map is active. After daily practice, particularly with the use of a mirror so patients can 'see' the phantom limb using a reflection of the other, hand movements start to activate the true hand area. This corresponds with a reduction in phantom limb pain. Those fortunate amputees, who never experienced pain to begin with, never showed the map shift.

It is thought that imagining a limb, which feels real to the patient, activates its neuronal counterparts in the brain. Honing in on one body part induces large networks of inhibitory processes that tend to go awry in pain syndromes. Motor feedback is known to be a good pain antagonist – we often rub an injury or wave it in the air. It might be a lack of feedback, or stop signal, that leads to phantom pain. To the brain of an amputee, the last signal it received was excruciating pain – and then no further correspondence. In the absence of counter-instructions, the brain assumes massive injury, and pain is the result.

Just as plasticity is responsible for the map shift, it is also responsible for the permanent cementing of a pain circuit that's built following months and years of persistent pain – in the same way that if we practiced juggling 24/7 we would soon be able to do it in our sleep.

> "A PATIENT TOUCHED WITH COTTON WOOL ON THIS AREA OF THE FACE WILL SENSE IT IN THEIR ABSENT HAND"

Recognising the burden of phantom pain has led to a deluge of medical practices designed to avoid it. This includes local anaesthetic and pain relief even before amputation, early amputation balanced against the chance of a limb recovering, and drugs that interfere with the axonal regrowth of neurons. However, they are not overwhelmingly successful.

Other methods include stitching undamaged nerves into muscles surrounding the stump and using these muscles to control a prosthetic device. Not only does this reduce phantom pain, it is of obvious functional benefit. In the last couple of years, direct stimulation of the part of the map that corresponds to the missing limb has proven itself effective in extinguishing phantom pain.

Phantom limbs are one of the starkest illustrations that our perceptions are based on our brain's interpretation of external signals. With 45 miles of nerves in the human body, and chronic pain costing Europe over 2 billion euros a year, it is imperative that we gain more insight into the mechanisms behind it.

Pain is likely to be an elaborate transformation of a simple reaction. But just as it is not obvious to the uninitiated what 3.1415… has to do with the volume of a sphere, it is not clear what transformations are applied to injury x to produce pain y. Proven influences include genes, mood and countless chemical transmitters in the central nervous system itself. Until we learn to control these influences, pain is never going to be ours to command. ■

SCIENCE BEHIND THE PHOTO

PHOTOGRAPH BY MIGUEL MENDEZ
WORDS BY PETER LARKIN

You'd be forgiven for thinking that this photo was an intricate model of a train set – but you would be mistaken. It is, in fact, a photograph of a life-sized DART train in Dublin, combined with some post-production magic to fool us into thinking it is tiny.

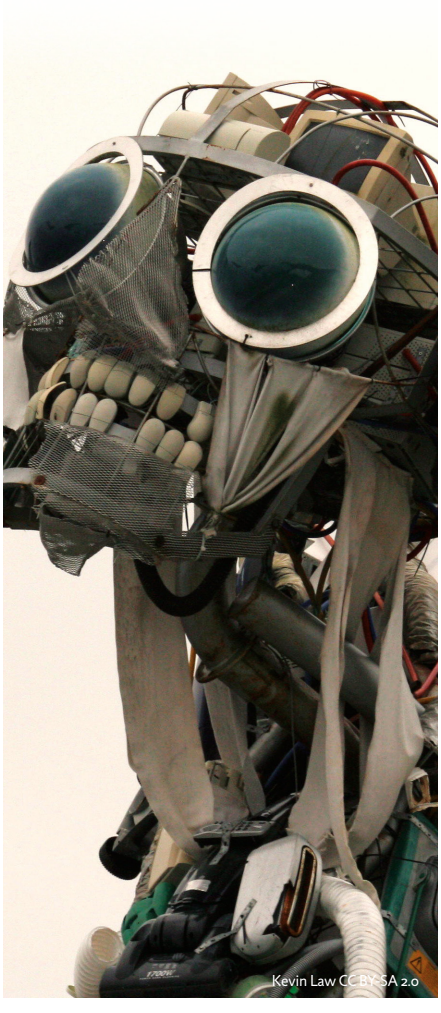
This effect, known as 'miniature faking' or a 'diorama illusion', takes advantage of the shallow depth of field we normally encounter with macrophotography. Unavoidably, depth of field always decreases as magnification increases, so by blurring parts of the photo and simulating a shallow depth of field our brains are fooled into thinking we are actually seeing a miniature model. This can be achieved optically by using a tilt-shift lens, or by applying the effect digitally in post-production.

With a tilt-shift lens, it's possible to physically tilt the front portion of the lens. This sets the plane of focus at an angle to the image plane – something not normally possible with a regular lens, which has all the lens elements in parallel. This creates a short band of the image that appears in focus and leaves the rest of the image as a blur thus simulating a very shallow depth of field. With image-processing software, a similar effect can be achieved with a combination of gradients and blur filters.

For the best results, these images are normally taken from a high vantage point as if the viewer were looking over a diorama in a museum. It even helps to boost the colour saturation to mimic the brightly coloured paint used in miniature scale models. All of these techniques combined show how accustomed we have become to depth of field in photographic representations of the world – and how easily our visual perception can be fooled. ■

ROBOT SEE

***Pavitar Singh Devgon** and **Douglas Heaven** take a look at the world from a computer's point of view.*



Kevin Law CC BY-SA 2.0

Everywhere we look computers and machines have integrated themselves into our lives. We are seeing an increase in 'smart technology', where a mobile phone, for example, is capable of planning a trip – telling you where you are and the fastest route to your destination, even going so far as to integrate itself with the transport networks in the local area. CCTV cameras will then follow your progress and the footage automatically monitored and analysed by computers. But do machines have a sense of place? And can they recognise what they see?

"I think there's no reason at all why computer vision systems should have the same limitations as the human vision system", says Andrew Davison, who leads Imperial College London's Robot Vision research group. But getting a computer to see is no simple task. "An image from a camera is obviously just colour information," he says. "That is very different from actually understanding the 3D shape of things."

Much of Davison's work has focussed on what he calls "the chicken-and-egg problem" of how to get a moving robot to construct a map of its surroundings and simultaneously using that map for localisation. These systems are also based on probabilistic algorithms. "As soon as you look at real sensors and the data coming from them you realise that the information that they give isn't perfect," he says. "Every single measurement that you make in an image is corrupted by an imperfection of that sensor so the algorithms that we use are all about taking lots and lots of those measurements and putting them all together." A computer builds up a 3D view of its world by matching patterns across successive 2D images and then triangulating between them.

"We're doing pretty well now using real sensors in the real world to get detailed geometric information about what's out there," he says. "But that's still not close to what you need for a robot to really be able to go and interact in that world." There is an enormous difference between seeing an object – "just a shape" – and recognising it as, say, a coffee cup. "You might want to understand what things are so you can predict how to pick them up," he says. "A lot of interest in perception is moving towards that higher level of cognitive understanding – semantic understanding."

Meanwhile, researchers at the Massachusetts Institute of Technology's Media Lab are working on developing computers that can distinguish different emotions by reading human facial expressions. Given that many cameras can now locate faces when taking photographs, recognising what that face shows might seem the next logical step. But while it is second nature for us to read basic expressions such as

ROBOT DO

> IF A HUMAN CAN TELL THE DIFFERENCE BETWEEN THINGS, THEN A COMPUTER WILL BE ABLE TO ONE DAY

happiness, fear, or anxiety in a face, software must of course be trained to monitor the positions of facial muscles and use those cues to identify the emotion expressed.

But what about reading the subtleties of human behaviour, such as recognising the difference in CCTV footage between a drunken brawl and a boisterous play fight? "If a human can tell the difference between things, then a computer will be able to one day," Davison says. "If you just feed it enough examples, eventually it's going to find some way to discriminate between them."

"But there's all kinds of cues that a human uses to make inferences that come from this whole wealth of experience and learning that humans have that we don't yet really know how to build onto computer vision systems," he says. "But seeing the rate that things are going at the moment I would not be surprised if those things are possible soon." ■

***Murray Shanahan**, Professor of Cognitive Robotics at Imperial College London, explains the basics.*

> WHAT DOES IT MEAN FOR A MACHINE TO PERCEIVE ITS WORLD?

If a machine's behaviour shows a systematic sensitivity to a set of features in its environment, then we might say that it perceives those features. For example, if a robot is capable of approaching a particular object, such as a person, using vision from different starting positions, in various lighting conditions, when the person is sitting or standing, is moving or still, and so on, then there's a sense in which it perceives that person.

> WHAT ARE THE BIGGEST CHALLENGES IN THIS FIELD?

Well, I don't think you can talk about perception separately from behaviour. A big challenge is to make a robot capable of seeing (or feeling or hearing) what its environment affords. When a carpenter sees a hammer, they see what they can do with it. So integrating perception with intelligent action is a great challenge.

ON 'TELLING THE TRUTH' IN SCIENCE

***Flora Malein** asks whether or not the practice of science is, ultimately, a subjective endeavour. Can we find 'truth' from science?*

Duck or rabbit?

One of the first cautionary tales I remember learning in my scientific career came from my high school science teacher, Mrs Ellis. My lab partner and I were involved in a series of disastrous experiments involving a potato and various sucrose solutions. As we contemplated our results and discussed 'modifying' them so that they gave us the 'correct answer', we were overheard by our teacher. Instead of telling us off, she simply pointed out the number of times scientists had missed out on making brilliant discoveries just because they had twisted their results to get the answers they expected.

It turns out that, although wrong, we were in good company. Albert Einstein can be considered guilty of this scientific misdemeanour, too. By adding a 'cosmological constant' to his theory of relativity he made it possible for the size of the universe to remain constant. In doing so, he missed out on correctly identifying that the universe is actually expanding, a fact that came to light several years later.

While not on such astronomical proportions, our misjudgement of character became a lesson that I carried through the rest of my scientific career. Telling the truth is not just something that your mother thinks is a good idea: science says that we should do it too. But is this enough? Does 'telling the truth' mean that science can (more or less) accurately describe the way the world really is?

Writing in the New Organon in 1620, Francis Bacon identifies what he calls the 'idol of the tribe'. This 'idol', or illusion, springs from the fact that as scientists, all our observations are ultimately founded in human nature. He writes, " All perceptions, both of sense and mind, are relative to man, not to the universe." In reminding us of the limitations of our human bodies and minds, I believe that Bacon touches on an almost heretical idea about science: in spite of what we observe, or record using our scientific instruments, we can never experience anything about our world directly. This suggests that science is ultimately a matter of human subjectivity.

For a modern example of how scientific instruments can malfunction, consider the recent furore surrounding the apparent discovery of faster than light neutrinos by the OPERA collaboration at the Gran Sasso laboratory in Italy. This discovery was eventually shown to be untrue – the results were due to an experimental error. Even with increasing technical advances it would seem that scientific instruments remain only as good as the scientists who build and use them.

In our discussion of whether science can ever reach the truth we perhaps tread very dangerously, into the territory of postmodernism. Applied to science, postmodernism suggests that not only are there no absolute truths, but there is no objective standpoint from which to judge whether something is an absolute truth. This may be too nightmarish a possibility to contemplate: it leaves us in a world without answers, without truth or even falsity.

It is for this reason that the application of postmodernism to science has been largely disregarded. In spite of the messiness that our humanity brings to its study, I believe truth-seeking remains an essential element in the practice of science. Even if our senses cannot give us a definitive answer, truth is still a value worth consideration. ■

WRITTEN BY JULIA ROBINSON

THE SIX GREAT SENSES

1 SIGHT

Until recently, retinal blindness was thought to be irreversible. However, a new clinical trial has shown that this may not be the case. Two patients who had been totally blind for many years have had part of their vision reactivated after receiving retinal implants. The implant, which is placed behind the retina, has light-sensitive pixels that perform functions normally carried out by the rod and cone cells. When light enters the eye and hits the implant, it stimulates these pixels to send signals to the optic nerve and brain. Both patients have reported significant improvements in their perception of light.

2 TASTE

Taste and the perception of flavour are often used synonymously but should be distinguished. Flavour is intrinsically driven by our sense of smell. Without food's aroma, our ability to distinguish different 'flavours' becomes limited to sweet, sour, salty or sour tastes. This explains why we have difficulty savouring our food when we catch a cold. According to a study performed by the Nestle Research Centre earlier this year, how we taste also depends on what we see. Study participants reported a neutral tasting stimulus more pleasant after viewing pictures of high-calorie foods, such as pizza, compared to pictures of low-calorie foods such as watermelon.

3 SMELL

Smell evokes memory in a way that no other sense can – to identify a smell, we must remember it. As a result, damage to the temporal cortical region of the brain, where memory is controlled, also results in damage to our sense of smell. Studies have highlighted that loss of smell – or 'anosmia' – can be an early indicator of Alzheimer's disease and memory loss. This association between smell and memory means that odours could be used as therapeutic tools in medicine. Scientists have developed techniques using positive smell recognition to treat conditions such as epilepsy, migraines and even diabetes.

4 TOUCH

Touch is the first sense to develop in the embryo and continues when our other senses fail. It is regulated by the somatosensory system, an area of the brain proximate to that responsible for motion. A film called 'Touch: The Forgotten Sense 'follows a woman left wheelchair-bound after a virus deprives her of all bodily sensation. Neuroscientists have also explored the role of hair in our sense of touch, and discovered that different types of hair have specific nerve endings. Each hair follicle sends out a wire-like projection that joins others in the spinal cord, making every hair an important sensory organ.

5 HEARING

Hearing is a crucial sense for humans and their development, and has an important and interesting link to our emotions. Researchers have found that youngsters with severe hearing impairment sometimes have difficulty both judging the expected emotional responses of others, and interpreting facial expressions of those closest to them. More recently, scientists have discovered that there is a common genetic thread between hearing and touch. A study carried out on twins has revealed that touch sensitivity is highly heritable and connected with hearing ability. It was found that the better the twins could sense touch, the better they could hear, and vice versa.

6 A SIXTH SENSE?

There has always been deliberation about whether or not humans have a sixth sense - but proprioception comes close. Proprioception is a function of our nervous system and comprises our ability to sense the position, location, orientation and movement of our body and its parts without having to look at them. Individuals with serious proprioceptive disorders may collapse in the dark because they can no longer see their bodies, thus losing a sense of their location. Research has shown that proprioceptive training of children suffering from cerebral palsy has helped to significantly improve their sense of balance and, consequently, increase their muscle strength.

TAKING A LOOK AT VISUAL AGNOSIA

Sophie Buijsen *discusses living with a condition that leaves her unable to recognise faces.*

Ed Moore

Have you ever introduced yourself to someone only to find out you'd met them before? How about when someone approaches you and starts talking to you as if you've known each other for ages, but you can't for the love of science figure out who they are? If this happens to you on a daily basis, then perhaps, like me, you suffer from a condition called prosopagnosia. It is caused by a defect in the visual cortex, which makes it impossible for me to recognise faces.

The visual cortex is a part of your brain responsible for the analysis of the stimuli it receives from your eyes. It recognises the shape, colour, texture, movement and placement of an object and labels it accordingly. When something goes wrong in this categorisation process, it is called visual agnosia. Visual agnosias are caused by damage in the visual cortex. How this condition expresses itself is dependent on which part of the cortex is damaged. In the case of prosopagnosia, the damage is in the fusiform face area, a section of the visual cortex that deals strictly with the recognition of faces.

Prosopagnosia is also called 'face blindness', but this is a misleading term. Someone with prosopagnosia can see faces just fine. A better way of explaining it is that although most of us agree that all of the features on the front of a head together constitute a thing we categorise as a 'face', those with prosopagnosia don't have this category available to them and just see the features as separate entities.

There are other visual agnosias including akinetopsia, which disables the perception of motion. Patients with akinetopsia visualise movement as a series of static pictures. Then there is environmental agnosia, which makes it impossible for the patient to navigate his or her way to a location, even if they are very familiar with it. There is also a condition called 'total agnosia', which is most common with patients who recover from blindness. Because these patients have never processed visual information, their visual cortex is unable to provide them with any of the categories the sighted rely on. It is possible to recover from total agnosia by training the visual cortex, much like a baby needs to learn to categorise the visual world.

"...DOESN'T EVEN RECOGNISE HIS OWN FACE IN THE MIRROR"

Prosopagnosia is very much a spectrum affliction. Famous neurologist Oliver Sacks, for example, has very severe prosopagnosia and therefore doesn't even recognise his own face in the mirror. Others are able to recognise some faces, usually close relatives or loved ones.

Some people, like myself, are born with the condition and it is thought to have a genetic cause. However prosopagnosia is mostly reported in people who have suffered brain damage after a stroke or accident. This may be because the loss of an ability is more noticeable than the original absence of it. One benefit of the condition is that I always have a way out of the awkward situation when I fail to recognise someone. And now, so do you. ■

For more information on prosopagnosia visit *www.faceblind.org* or read Oliver Sacks' book, *The Mind's Eye*.


Smithsonian Institution Archives

A MIND-FORGED GENDER GAP?

The supposed difference in ability between men and women has always been contentious. ***Luke Sheldon*** *explains how gender bias in science may be a figment of our perception*

In 2005, in a move that lead that lead to his resignation, the President of Harvard University remarked that the under-representation of women in science was due to a "different availability of aptitude at the high end". This statement, although controversial, appeared to voice a commonly held view. Looking around Imperial College London with its 2:1 gender ratio some people may see this as further proof of an innate difference between the sexes' scientific ability. However, experimental psychology has shown that this apparent gender gap crumbles and disappears with the slightest scrutiny.

One of the most startling examples of the wizardry with which gender bias is magicked away is seen with the mental rotation performance test. This test follows a format where a participant is shown an unknown 3D shape from which they must decipher which standard shapes have been rotated and amalgamated to form it. This test has a strong gender divide with males making up an average of 75% of above average participants. The test has been used to explain the greater proportion of men in science and technology.

When the test was presented to the participants in different ways, the results completely shifted. In one study, a group was told that the test was an indication of ability in "aviation...and nuclear propulsion engineering" while the other group were told it related to "sewing and knitting, crocheting and flower arrangement" skills. All fair interpretations of the test. Although the men outperformed the women in the first group, this advantage was not seen when they were told it could be related to activities judged as feminine – the sex difference vanished. Other experiments using mental rotation tests have shown that merely making people identify themselves through their gender can alter their performance. Even as crude an action as announcing unsubstantiated statements such as "women do really well in this" can demolish the gender gap. These findings are not just restricted to rotation tests and have also been observed in maths tests.

This example of the way that our behaviour is affected by how we are perceived has been termed "stereotype threat". Psychologists are now getting to the bottom of why such conditioning of participants before tests can alter the results. How the stereotype threat plays out was shown in an experiment using a mathematics test where students had to write about their emotions in between each question. One half, told that there was a strong gender difference in performance, wrote down far more negative thoughts than the group told there was no difference. As the test went on, the performance of the groups drastically diverged. The theory is that the mental resources involved in thinking and attempting to suppress negative thoughts take up effort that could instead be concentrated on the task at hand. This demonstrates clearly that the gender gap in science is a stereotypical figment of our gender perception. ■

THE BLACK GHOST KNIFEFISH AND ITS ROBOTIC OFFSPRING

***Juan Casasbuenas** writes about how studying the electroreception systems of mysterious nocturnal Amazonian fish may help humans dive deeper and explore further.*

In the murky waters of the Amazon lives a fish that emerges only in the blackness of night, yet manages to prey on tiny insect larvae with remarkable agility and precision. Studies investigating how this extraordinary fish achieves this feat are casting new light on human perception, and may offer a model for our own attempts at underwater exploration.

In order to sense its surroundings and hunt, the black ghost knifefish (*Apteronotus albifrons*) relies not on its eyes but on a highly developed electroreception system. This remarkable method of perception employs an electric organ, found in the fish's long, flattened trunk, to generate a continuous electric field around the knifefish's body. Across the fish's skin, electroreceptors detect any disturbances caused by prey entering the electric field, enabling the predator to immediately locate its victim. A long ribbon fin provides propulsion and agility, enabling the fish to hunt its target down.

This curious Amazonian creature has been the subject of thousands of scientific papers, many of which are now telling us about perception in humans. I spoke to Professor Malcolm MacIver, an expert in Biomedical and Mechanical Engineering at Chicago's Northwestern University, to understand why.

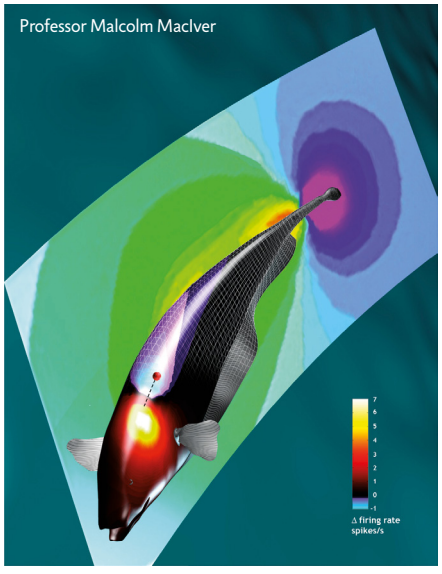
"By learning about the fish, we are learning a lot about how humans integrate movement and sensory information," explains Professor MacIver. While this may seem counterintuitive, the Professor assures me that "human brains are not all that different to those of animals like the knifefish. In terms of the parts of the brain responsible for integrating movement and stimuli, much of the structure is conserved. We can learn a lot from them as a biological model".

Another reason for Professor MacIver's interest in these fish is their potential contribution to bio-inspired technology; his team at Northwestern have been working on robotic fish that can move and sense in much the same way as their Amazonian counterparts. "We're kind of putting Humpty-Dumpty back together," says MacIver. "We've managed to make very good technological models for how the fish moves and how it senses, and we've integrated them into the same platform."

However, it is a huge challenge to replicate nature. Previous generations of robotic fish have been able to move rigidly in very controlled environments, but not with the freedom necessary underwater. "We don't want to release a robot and have it tumbling to the ocean floor", explains Professor MacIver, "so we are trying to work out how to keep it from tumbling, and that requires some additional work."

If the Professor's team is successful in developing an agile robotic fish capable of using 'electric sonar' to sense, their creation could have many potential applications in environments that are not only dark, but also hugely chaotic. "There is a need for underwater vehicles that move with greater ability in highly cluttered spaces, for example around coral reefs, ship wrecks or oil spills." ■

The black ghost knifefish can generate an electric field around its whole body



LOOK AWAY NOW


Victor Bezrukov

***Lorna Stewart** explains the link between attention bias and anxiety.*

Are you feeling anxious? If so, you're not alone: 1 in 10 of us will suffer a disabling anxiety disorder in our lifetime, yet psychologists still don't really know why it happens or how to help.

Professor Colin MacLeod of the University of Western Australia is one of a growing number of experimental psychologists around the world working on a new procedure known as Cognitive Bias Modification (CBM). Patients sit at a computer and push one of two buttons, reacting to symbols and images that flash onto the screen, some of them scary. After 20-30 minutes, their therapy session is done. But what the heck is going on?

Experimental psychologists have long known that anxious people look more quickly and for longer at threatening images and words. Its a paradoxical finding that those who try hardest to avoid threat and suppress threatening thoughts are the first to look and the last to look away. This attention bias creates a vicious cycle, where looking for threat makes you more anxious, and being anxious makes you look for more threat. But as well as maintaining anxiety, attention bias may actually be causative in the development of anxiety. MacLeod's method originally allowed psychologists to measure the extent of these biases, but it's now being turned into therapy.

As MacLeod explains: "It wasn't simply the case that we understood it theoretically and then we could apply it to the therapeutic context, it was that the application in the therapeutic context enabled us to extend our understanding of the causal role. The very studies that were telling us about its causality were also delivering effectively evidence for its therapeutic potential. It is a really nice example of the cycle of science, the cycle between theoretical and applied science." And it's all happening within one single experiment.

MacLeod's early work was picked up by academics across the globe, keen to better understand psychopathology and gain new insights for therapy. Dr Mike Browning of the University of Oxford looks at CBM for depression in comparison to other treatments, like medication. Browning's work shows that antidepressants and CBM affect different parts of the brain. Antidepressants seem to act on the amygdala, a part of our more basic emotional system, while CBM impacts upon frontal parts of the brain which are used for flexible thinking and planning.

All of which makes you wonder what CBM is really doing. "When people try not to think about X, they can't and they do think about X," says MacLeod. "Most of us that don't have anxiety problems successfully avoid thinking about a lot of things. We don't have the thought and go, 'Oh my god, I'd better get that thought out of my head', we just thwarted it at an earlier level. Maybe CBM prevents the development of the thought through avoidance and information processing at an early stage."

But before we all skip off into a threat-free mind-controlled future, MacLeod offered a dose of realism. "I could imagine that the successful screening out of threat may keep anxiety levels generally low, and for the majority of people may result in a better quality of life. But it may not be the best strategy for those people who experience trauma," he warns. " [We need to] teach people to deal with anxiety when it occurs, by having exposure-based programmes and coping programmes. And teach people strategies that reduce the likelihood of anxiety coming up." Those strategies are where CBM comes in. ■

"I love the idea of science

***Antonio Torrisi** met up with **Anna Starkey**, 'creator of impossible projects' at Lottolab, the world's first public perception research space. Lottolab is directed by its founder Dr Beau Lotto, a reader in neuroscience at University College London. Lottolab's studio was, until recently, based inside the Science Museum and unites science, art and education in a bid to engage the public in their research on perception and human senses*

WHEN DID YOU FIRST BECOME INTERESTED IN NEUROSCIENCE?

I was interested in neuroscience ages ago, because it seemed to me to deal with the massive issues about life and what we are doing here, what it all means, how we find a meaning in it. It was all a part of philosophy of physics, which interested me as well.

WHEN DID YOU START WITH LOTTOLAB?

I had this funny feeling about a year ago that I needed to meet Beau [Lotto, founder of Lottolab] because I wanted to do some original research. I was filming at Kinetica Art Fair and I met an artist there that had collaborated with Beau, and I wanted to film an interview between her and Beau. I filmed it and then we just got chatting and he found out I was a writer of children's books. He said he wanted to write a book about perceptions so we started working together and I started to work for Lottolab.

WHAT IS THE IDEA BEHIND THE LOTTOLAB?

The idea is that of a living lab, that is not confined to an institution behind closed doors where you only get a specific dataset of people to come in; it is about this idea of "street science" which is not only having the public coming and looking a lab in progress – and not even to come along and be part of the experiments – but to be active in creating the science itself. So it is kind of science and science communication together.

AND ENTERTAINING, I NOTICED.

Well, yes. Lottolab is all about studying human perceptions and the way we see the world around us, how we interact with other people, how we run a love life, how we deal with things at work. And perception is about art, music, architecture, design, so why not work with those people who have gathered experiences about it from what they do? All this is also functional to understanding people's perception. I love the idea of science as theatre. We have illusions that completely flip the lid off the top of your head and suddenly suspend your disbelief in a similar way to when you go to the theatre.

HOW DO YOU PLAN THE EXPERIMENTS?

We sit down and we ask, "OK, what have we got so far? What is interesting out there, what do we want to find more about and how do we get that information?"

I SAW A LOT OF THINGS BASED ON VISION AND SOUND, BUT WHAT ABOUT OTHER SENSES LIKE TOUCH OR TASTE?

Beau started with colours because the most basic things the brain does is seeing and perceiving colours. By looking at colour illusions, you understand more about how we perceive things and ultimately about consciousness. But actually there are ideas about touch. One is in the dark, having a lot of boxes where you can either touch people's skin or some fake skin, and we see how each is perceived. Lots of artists have done stuff around it and there is a lot of research on the benefits of touch. We collaborate with lots of artists, musicians and designers of exhibitions, people setting up galleries or installations.

IN INVESTIGATING PERCEPTION YOU CONSIDER NATURE, THE HUMAN, AND ALSO ARTIFICIAL INTELLIGENCE AND ROBOTICS. DID YOU FIND ANY SIMILARITIES?

Well, yes, there are similarities. A lot of what we see is about our visual history; the meaning we assign to something is not the reality of what is in front of us, but what has been useful so far in our visual history of human beings. In the [Blackawton Bees] experiment, for instance, the children found that the bees' matrix composed of colours and networks was actually manipulating the visual history of the bees, so that they started learning in a similar way what the colours are and where they lay down. I also spoke with the guys at Imperial Col-

as theatre" – Anna Starkey, Lottolab

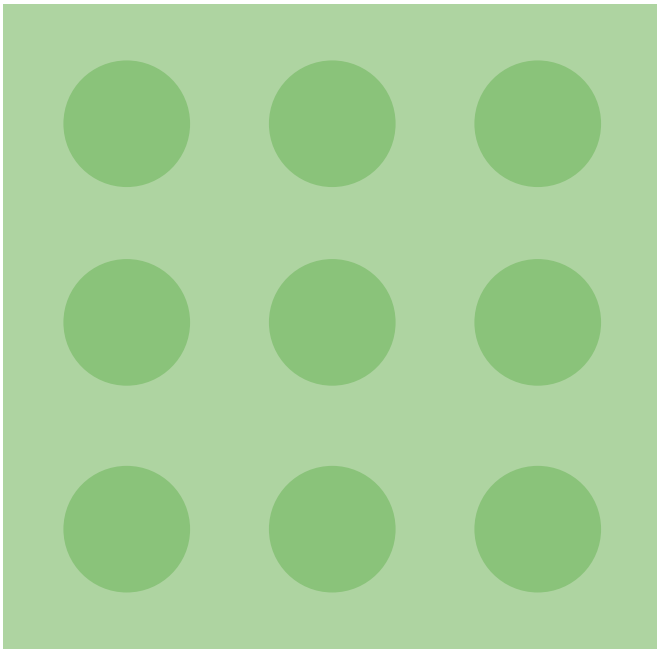


Image inspired by Lottolab's 'Beacon' installation in Shoreditch

lege London who are programming the robot AIBO to be like the human mind in terms of how we learn meanings. I would love to see if it would also get tripped up by that colour illusion. Is there ever a position where a robot becomes so advanced that will get confused in the same way as we do, saying "That's yellow" – "No AIBO, it's grey".

DO YOU THINK THAT LOTTOLAB IS EXTENDABLE TO A WORLDWIDE SCALE?

Yes! We have planned to extend it towards the entire universe! It should be done, because cultural differences in perception are fascinating. There are things around the world that are all the same things that will be quite different. What would be lovely is to run experiments which are the all the same everywhere so that we can make a contrast and comparison but also use local people and local artists. It could be in a theatre somewhere, or in a village, in the street, in a park, wherever people are.

DO YOU HAVE A FAVOURITE LOTTOLAB EXPERIMENT?

I think the one of colour illusions. What I like about that illusion is that you are looking at something that appears yellow or blue; you know that it is grey when folding down the mask, but you still cannot see it as grey unless you take away all this contextual information. And in that moment you are holding two realities in your mind. It is the idea of "seeing yourself seeing": you are seeing your own brain perceiving something.

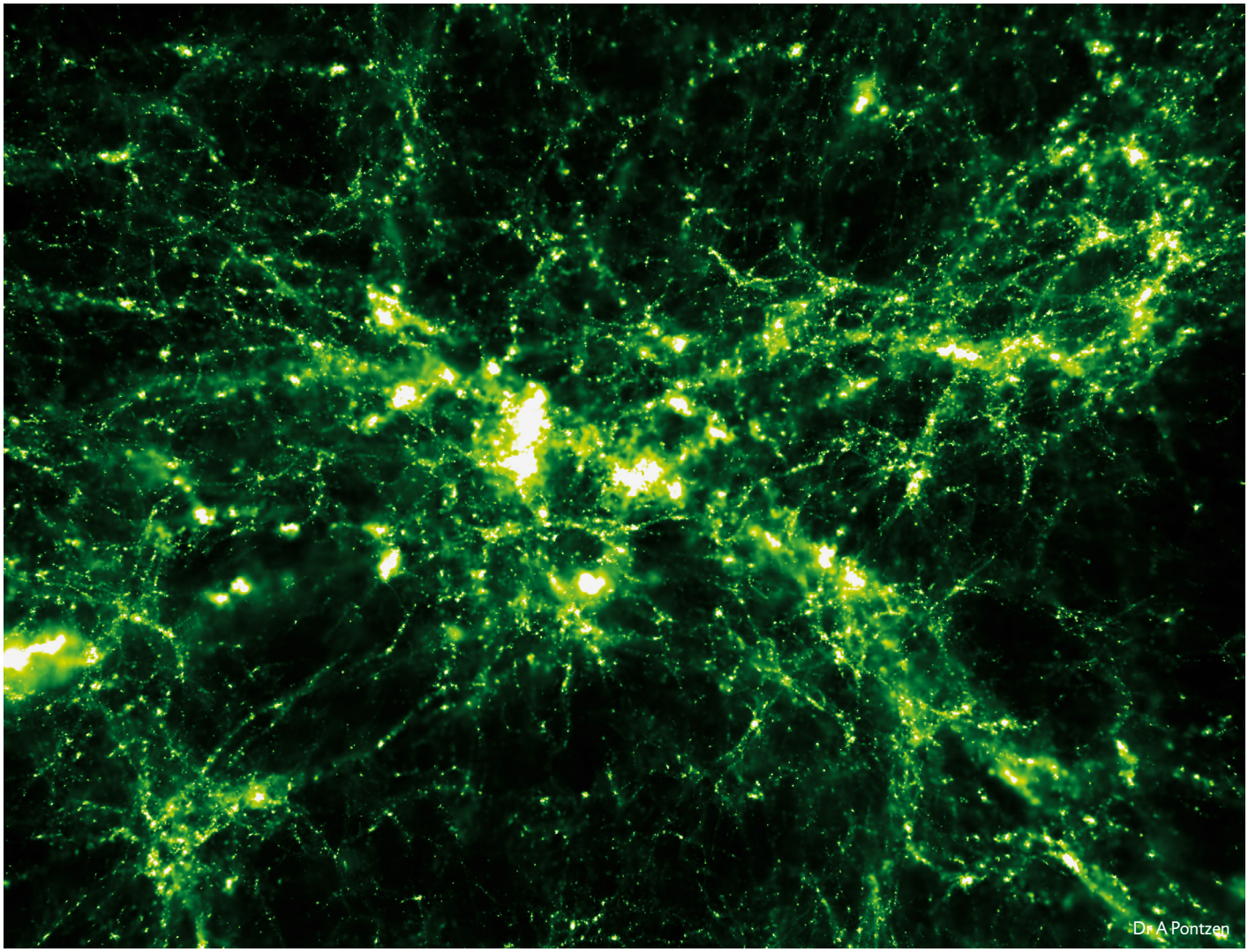
WHAT DOES THE FUTURE HOLD FOR LOTTOLAB?

We are at a transition phase at the moment and the future of Lottolab is to develop this idea of 'street science', so that Lottolab will pop up in different venues or maybe repeatedly in one venue. It will be a kind of bigger and better version of the Science Museum Lates. We will start with something in London. We could pop anywhere. It will be on the website, of course. Keep your eyes peeled! ■

BLACKAWTON BEES

In collaboration with Blackawton School in Devon, Lottolab developed the idea of getting the children involved in novel experiments. The children came up with the idea of seeing if bumblebees could learn to recognise different spatial configurations of colour and devised the questions, reasoned an answer, designed the experiments, and did all the data analysis. All 25 children contributed to the resulting paper, complete with figures that are hand drawn in crayon. The paper is deliberately written in 'kids speak', and even begins 'Once upon a time…'. *From Lottolab.org*

DARK CHATTER


Dr A Pontzen

*When it comes to a concept as abstract as dark matter, is it a case of 'seeing is believing'? **Jennifer Whyntie** talked to astronomer **Dr Andrew Pontzen** and particle physicist **Dr Tom Whyntie**, who have teamed up to share their knowledge with science festival crowds. Their sell-out show, Dark Matters, examines the current scientific consensus about this missing 25% of the universe. Here they discuss dark matter, the difficulties of visualising the invisible, and why so much effort is made to do so.*

"How long is a piece of invisible fluff?"

When asked how far away we are from a consensus on what dark matter is, this is my husband's response. Andrew has already made the comparison to the length of a piece of string, and, left unchecked, they start rapidly building a metaphor of cosmic proportions.

The reason that they can do this is because we don't really know what dark matter is yet. Only about 5% of our universe is what we think of as normal, visible matter. Scientists hypothesise that roughly 70% is dark energy, which we know even less about. The remaining 25% is dark matter, so-called because it is invisible. Essentially it is, as Tom puts it, "missing stuff" that from the astrophysical point of view is necessary to hold the universe together and describe how it has evolved.

I try a different tack and ask about how dark matter can be represented visually. For the recent BBC Stargazing Live series, Andrew produced a series of animated digital galaxy formations, including one displaying dark matter. It was made by programming a supercomputer to simulate some of the physical laws thought to be important in galaxy formation, along with information about the observed state of the early universe. The computer then evolved this virtual universe and, after considerable animation wizardry and "blood, sweat and tears", the inferred dark matter was illuminated with a green colour. This was selected – it is not usually present in astronomical images – to remind us that we wouldn't be able to take a picture like this. One of the representations generated is shown here. It depicts dark matter distributed across the digital universe at the large scale (~50 million light years across) as it would have been some 10 billion years ago.

For me, this takes a little while to process. It highlights something I hadn't considered – the convention of using arbitrarily assigned colours for particular astronomical objects that we cannot see. But why is it so important to have a visual representation of a substance that is, by definition, not visual at all?

This question generates some discussion. After considerable back-and-forth, Andrew summarises an answer:

"I think Tom and I are both saying – Tom can correct me if I'm wrong – that we're basically very visual creatures. And so by turning something into a visualisation – even if it's quite an abstract mapping from what's really going on to the way that you choose to make it visual – you learn something about your data that you couldn't have got at just by doing abstract mathematical analysis on it."

> "WHY IS IT SO IMPORTANT TO HAVE A VISUAL REPRESENTATION OF DARK MATTER, WHICH IS, BY DEFINITION, NOT VISUAL AT ALL?"

Digitally visualised or invisible, audiences for Dark Matters indicate that the missing "stuff" causes intrigue. Andrew tells me why he feels that their show is important. "Dark matter is a subject that simultaneously a lot of people are interested in, and also a lot of people mistrust immediately, because it's such a strange idea – that to understand the universe; to understand what we see in the universe, we have to suppose that there exists all this invisible stuff. Five times more invisible stuff than there is visible stuff. So it immediately raises people's suspicions and gets people asking questions."

Tom explains why this questioning is so valuable. "We know we've done it right when the questions we get are, 'Why do you believe in that?' or 'Why should we keep pumping money into research to try and find out?' because that's the kind of thing that we want to get at." He muses further, "I wonder if this element of how much you believe in something is a function of how you can see it, with the old adage, 'seeing is believing'. And with dark matter, whether that intrinsic scepticism people have is because we can't see it."

Andrew points out that perhaps this is a truism – people would obviously believe in dark matter if they could see it. Tom quickly replies:

"But, for example, you never actually "see" an electron with your own eyes. Why should dark matter be any different? The show is about the role of belief in science and paradigms; dark matter is the dominant model with good reason. So what makes it so difficult for some people to accept? I personally hadn't explicitly thought before: Is it just that we can't see it?" ■

Find out more about Andrew & Tom on the I, Science website, where you can also find links to Andrew's galaxy formation animations. Catch the Dark Matters show at the Cheltenham and British Science Festivals.

REVIEWS

WHAT YOU SEE DEPENDS ON HOW YOU LOOK: TIME & SPACE IN SCIENTIFIC IMAGERY

Royal Institution, London
10 May 2012 with Dr Patricia Fara

"A painter has but one sentence to utter, but one moment to exhibit" – Sir Joshua Reynolds

Historian Dr Patricia Fara focuses on the role of art and representation in science, as shown through her recent talk at the Royal Institution (RI). Here, Fara discussed the dichotomy of images and the subjectivity of interpretation.

Traditionally there has been a stringent separation between art and science, but Fara questions whether this is valid. One of her examples was a painting of a vase of flowers, which most of us would immediately classify as a piece of art. However, the artist had paid great attention to creating a true representation of each flower, each of which bloomed at a different time of year. Therefore, it can also be described as a visual catalogue of those flowers. Fara argues that there can be both artistic and scientific interpretations; we need not limit it to one or the other.

Fara also debated the search for objectivity. Scientists, like Robert Hooke for example, felt that using scientific instruments would produce true representations of nature and remove all objectivity. But, as Fara points out, modern technology in science relies on people being able to interpret the information their instruments provide (as shown when considering bubble chamber data). Thus, we have reached a point where subjectivity has been reintroduced into the scientific process – if it was ever truly removed.

This brief review does not do credit to the complex questions Fara tackles, as I have only discussed a little of an extremely interesting Royal Institution lecture. The talk was to promote her most recent book, *Science: A Four Thousand Year History*, which I will most certainly be reading! ■

PENELOPE HILL

ANIMAL INSIDE OUT

Anatomist Gunther von Hagens made his name with his plastination technique – a method used for preserving organic tissue by replacing its fluids with plastic. While his groundbreaking *Body Worlds* exhibitions proved controversial due to their human subject matter, his latest show, *Animal Inside Out* at the Natural History Museum, is treading safer ground by focusing exclusively on animals.

In many ways this was probably a good decision, giving the exhibition a much greater breadth than his previous work. The visitor is presented with a stunning variety of animals including squid, giraffes, ducks, bulls and sharks. Even for specimens of the same species, different preservation methods give the visitor a completely different point of view – some exhibits focus on the skeleton, others on the organs and others the vascular system. One of the highlights is a shark whose skin has been removed to reveal a network of blood vessels so dense you can't even see internal organs.

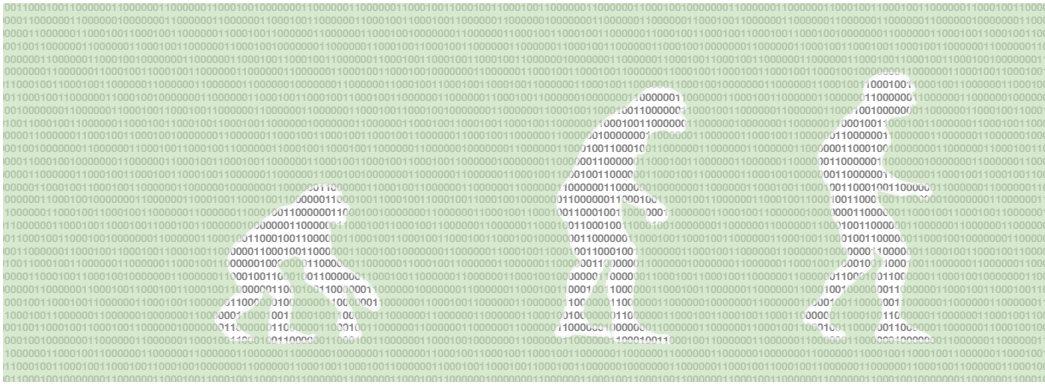
While one of the most impressive parts of the exhibition is the last room – with the largest specimens, including a full grown Asian elephant – even the smallest animals keep your interest. The real strength of *Animal Inside Out* is that, while von Hagens' artistic sensibilities are clearly on show, the main focus is the science, with all the exhibits coming together to form part of the fascinating bigger picture that is animal anatomy.

The exhibition is open until the 16th of September and, at just £6 for a student ticket, is definitely worth checking out. ■

MACIEJ MATUSZEWSKI

INTELLIGENT DESIGN

What does it mean to be intelligent? ***Michael Cook*** *describes how current work in computational creativity is questioning the concept of 'true' intelligence*



In 1950, pioneering computer scientist Alan Turing began to reflect on the nature of intelligence and whether we may one day produce a machine that we could confidently call 'intelligent'. The Turing test that he proposed is now infamous in the field: if you cannot differentiate between a conversation with a computer and one with another human being, then that computer has achieved true intelligence.

A simple description of this test has inspired countless researchers to strive towards achieving artificial intelligence (AI). But as we make strides towards machines that can outwit us at chess or compete against us in television quizzes, many researchers are questioning the worth of a test that holds imitation of humankind as its ultimate aim. For them, the perception of the software itself is more important than the emulation of a human mind. However, if the Turing test is no longer needed, what can we use as a measuring stick for the next generation of AI?

This is the question facing researchers in computational creativity – a rapidly growing area within AI that aims to build systems that exhibit creative behaviours either independently or in co-operation with humans. Research in this area includes software that can write poetry, design games, compose music, create paintings, and reason mathematically. In many of these endeavours, producing work which appears human-like is a poor end goal, resulting in work which is a pastiche of existing human designs. But imitating human work is not enough.

The freedom to explore which behaviours software can demonstrate opens up computational creativity research to the possibility of transcending expectations of humanity, and to ask questions about what creativity looks like in the absence of humans. Machines process and translate data concerning every aspect of our lives, from the music we listen to, to the financial statistics that affect our global economy. By considering the unique perspective that computers have, we can explore the potential for computers to exhibit a new kind of creativity, one removed from the constraints of our creative perceptions and from what it is to be human.

But this transformation is unlikely to take place overnight. The modern perception of computers is that they are unlike humans in every way; they follow orders; they never tire; they cannot make judgements autonomously. The binary data describing a sonata is no different to a computer as that describing the data collected in a particle accelerator. We compartmentalise machines and Turing's test shows how blind that can be – the notion that we could only accept machines as intelligent if they can pretend to be more like us. As new ways of assessing the intelligence of machines are developed, we can begin to accept computers and software as a parallel track in intelligence and creativity, rather than a branch of our own. ■

Michael Cook is a PhD researcher in the Computational Creativity Group at Imperial College London.

THE ZEN OF CATCHING NEUTRINOS

Visiting researcher in Imperial College London's Science Communication Group and science journalist ***Shigeyuki Koide*** *explores the concept of Zen in science.*

"Catch neutrinos in your hands!"

With that aim, 30 high school students in Tokyo took part in an experiment to catch this elusive quantum particle with two hand-held devices: a photon-counting detector and a scintillation counter. This experimental programme at the Science Museum in Tokyo was guided by Nobel laureates, including mentor Dr. Masatoshi Koshiba, whose pioneering work on neutrinos won him the 2002 Nobel Prize in Physics.

Students taped up the surfaces of two cylindrical devices with black vinyl tape to keep out light interference, connected electric cables to an oscilloscope and observed the results. There were yellow and blue horizontal lines running on the oscilloscope's display; the yellow line indicating the data from the photon-counting device, the blue line from the scintillation counter. When neutrinos come to Earth from space, they change their character to a particular 'flavour' at the atmospheric surface of Earth, forming muon neutrinos. Students would be able to capture these particles with their devices.

After a minute, the flat yellow line suddenly curved and formed the shape of a wave. This was proof of one muon crossing the photon-counting detector. Seconds later, another muon crossed the scintillation counter! The blue line became a wave. There were a lot of muons falling.

"OK, hold both devices vertically," Dr. Koshiba advised them. Yellow and blue pulses simultaneously appeared on the display. "You got it. One particle just crossed the two devices vertically." The surprised students shouted, "Ooh!", "Amazing!", "Yahoo!" as they felt the existence of invisible quantum particles in their hands.

In the lecture he gave after the experiment, Koshiba told them:

"We set out to research the smallest entities in the universe. By looking at the very small, we understood the very large. Neutrinos had a very important role in the history of the cosmos."

He described the history of the Big Bang, explosions of supernovae, the birth of the sun and the earth, and the meaning of the periodic table as the "Iliad and Odyssey" of the cosmos.

It seemed to me that he expressed not only the scientific facts, but also the important truth about our thinking of life and philosophy. For example, reminiscent of the famous Zen mantra, who are we? Where did we come from? Where will we end up?

Another time, I interviewed the biophysicist Dr. Tokindo Okada in Kyoto. He explained the narrative of life using RNA and DNA: "I can express that from the birth of RNA, life has not been interrupted but has kept flowing to your life and mine. There has been no break."

As science has developed, the language of science has been used to describe the truth of philosophy. One example of this is Professor James Lovelock's Gaia hypothesis. Of course, there may always be the opinion that we should not transfer the scientific word into another area so readily. However, I think that science is gaining words. It has the language not only to describe philosophy, but also explain the insight of Zen thinking. ■

We are grateful to Shigeyuki Koide for writing for I, Science. His career has spanned 35 years at The Yomiuri newspaper, in Tokyo, Japan. Most recently working for a senior science editor at the Yomiuri.

Zen is a Buddhist concept that emphasizes the attainment of enlightenment and the personal expression of wisdom and understanding. Scientific progress has changed the way we envision such spiritual thought. For example, neuroscience has changed our view of the brain and its stimuli, and emotions and empathy are better understood. However, 'Eureka!' moments – experienced by scientists such as the Japanese students catching neutrinos, Kekulé determining the structure of benzene and Tesla's discovery of alternating current – are sympathetic with a Zen thought process.