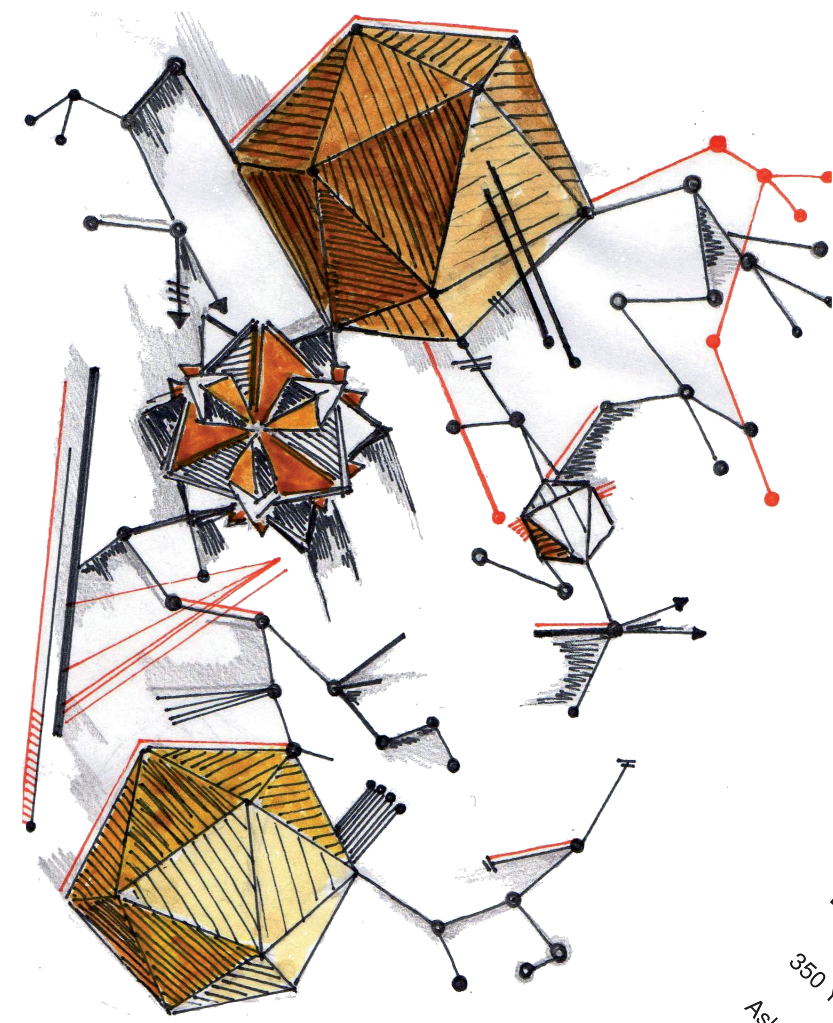
Bang!

Oxford Science Magazine
4th Edition
Hilary Term 2010

Contents



Bang! Science Magazine, Hilary Term 2010

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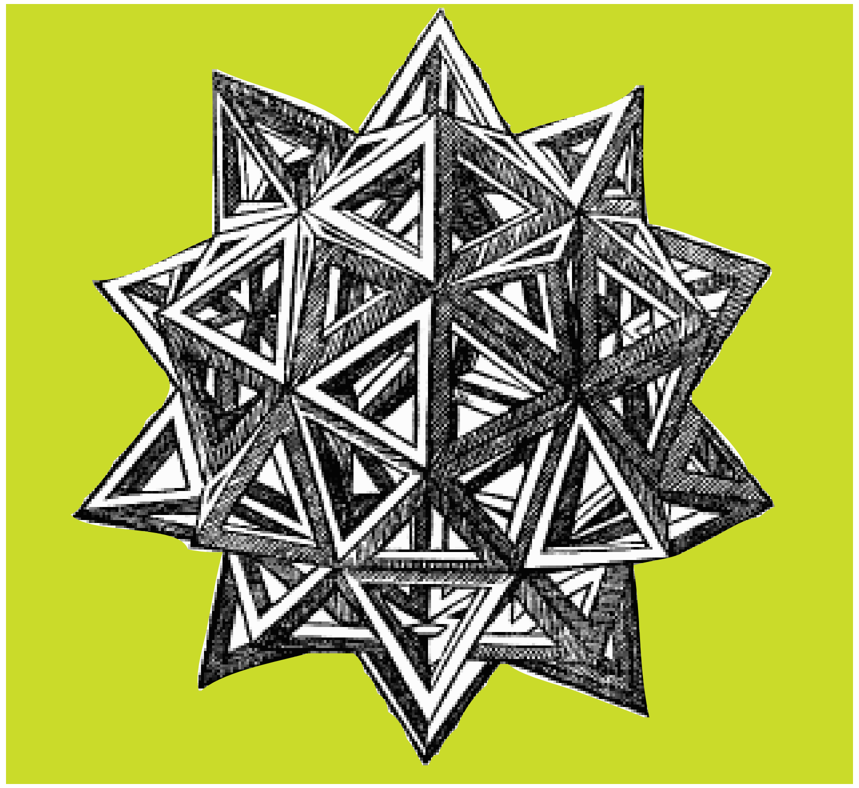

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Editorial

Art: Louisa Stoppard

Whether it's a first kiss or a synaptic bridge in the brain, connections are vital to life on all levels. We have always sought unifying principles behind such connections in an attempt to better understand the world around us: on the most fundamental level, physicists have for millennia been piecing together the forces of nature in the search for a 'Theory of Everything'.

Creating order out of chaos has revolutionised the way we view the world and our place in it, while also allowing us to manipulate our surroundings and even ourselves. Yet a breakdown often occurs across the most vital connection of all: that between scientists and the public.

Articulate, engaging communication of scientific research is needed to share the wealth of inspirational scientific discoveries with the public. But more than this, it is vital in avoiding misconceptions that can obstruct the progress of innovative scientific ideas. Advances in reproductive technologies have already caused alarm but, on the flip-side of the coin, with guided restrictions they have the potential to change many people's lives for the better.

Often influenced by these public perceptions, politicians must restore their trust and commitment to science as it comes to play an increasingly important role in the political challenges of today. Faced with short-term financial difficulties, politicians must respect the ability of science to produce huge, unexpected benefits in the long-term and direct funding accordingly— it is the unforeseen discoveries of open ended research that often have the greatest impact both socially and economically.

Likewise, across the whole scientific spectrum, it is the surprises which cause us to review existing paradigms and make the greatest advances in our understanding of Nature. The discovery of bat-eating birds sheds new light on the nature vs nurture debate; while it is literal sparks of lightning that have changed our understanding of the process of evolution.

You'll find all these ideas and many more in this issue of *Bang!*. It is the moment of illumination from a novel discovery or the realisation of a hidden connection that makes science so exciting and we hope to share this with you.

Thomas Lewton and Nicola Davis
Editors.

News

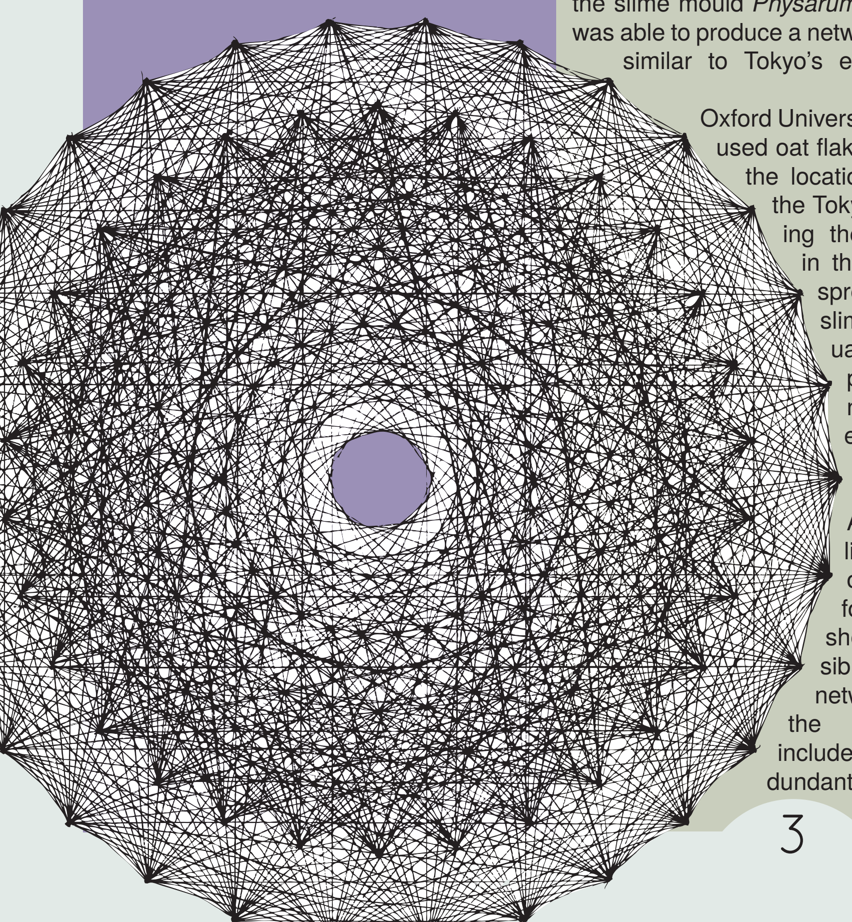
Golden ratio discovered in Quantum World

A complex form of mathematical symmetry linked to string theory has been glimpsed in the laboratory for the first time, as published recently in the journal *Science*.

The patterns, observed by Oxford University researchers, were the same as those in the 248–dimensional mathematical object E8. The extra dimensions refer to mathematical degrees of freedom rather than everyday spatial dimensions. E8 also appears in string theory, a contender for a 'Theory of Everything' which aims to unify the incompatible theories of general relativity and quantum mechanics.

"The patterns were the same as those in the 248–dimensional mathematical object E8."

They observed the exotic states by applying a strong magnetic field to crystals of cobalt niobate at near absolute zero temperatures. The cobalt atoms, which act like tiny bar magnets, can point either 'up' or 'down'— a property known as 'spin'. At such low temperatures the atoms all align in the same direction but, by applying a magnetic field, the direction of some atoms can be reversed by the process of quantum tunnelling.



"You might expect to see random fluctuations of the spins at this critical point, but what we uncovered was a remarkable structure in the resonances of the magnetic spins indicating a perfectly harmonious state," explained Radu Coldea leader of the team at Oxford.

The pattern of spin alignments matched that of the golden ratio, occurring throughout nature in, for example, the swirl of a snail shell. The golden ratio is also a characteristic signature of E8.

However, scientists have stressed that although E8 does show up in string theory calculations, observing the symmetry in magnetic crystal experiments does not provide any direct evidence for string theory itself.

Simple slime mould mimics Tokyo's railway

Years of planning goes into producing efficient, resilient rail networks, yet it seems a simple slime mould may be able to do the job a whole lot quicker. Despite having no central control over what it builds, the slime mould *Physarum polycephalum* was able to produce a network remarkably similar to Tokyo's existing railway.

Oxford University researchers used oat flakes to represent the locations of cities in the Tokyo region, placing the slime mould in the centre. As it spread out, the slime mould gradually refined its pattern of tunnels, strengthening those with greatest flow of material. After a day, the links between oat flakes formed the shortest possible connecting network. Further, the slime mould included extra redundant connections to strengthen the overall structure against breakage— a feature also found in Tokyo's railway.

"Remarkably, what we have found is that a simple organism such as a slime mould, which makes all decisions 'locally' without any reference to an overall blueprint, can build networks which match the performance of planned manmade networks.", said Dr Mark Fricker, an author of the paper.

Fricker hopes to harness the simple set of rules apparently employed by the mould in creating this self-organising behaviour. "There could be applications ranging from understanding how tumours plug into our blood supply, to building the high-performance, resilient mobile communications networks of tomorrow", he said.

Beauty and the Beast

Researchers at Oxford University's Radiocarbon Accelerator Unit have been using state-of-the-art techniques to reveal that Neanderthals were just as image conscious as we are today.

Investigations at two Neanderthal sites in Spain have unearthed marine shells bearing pigments, such as the yellow iron mineral natrojarosite, which were commonly used as cosmetics in ancient cultures. Further, the presence of perforations in some of the shells strongly suggests that they were worn as pendants.

Radiocarbon dating of the finds has placed them at around 50,000 years old— around 10 millennia before modern man appeared in Europe— contradicting the view that the use of jewellery and make up is limited to 'modern' society. Moreover, the reddish pigments found were a subtle blend of iron minerals suggesting that a particular 'look' was desired, calling into

question the assumption that Neanderthals were unintelligent.

Research leader, Prof João Zilhão, has been quick to point out the significance of this: "There's absolutely no scientific justification to consider Neanderthals as the brutish halfwits they have been portrayed as in popular culture— which has also, to a certain extent, influenced scientific thinking".

"There's absolutely no scientific justification to consider Neanderthals as brutish halfwits."

This is not the first time that such artefacts have been associated with Neanderthals: bone tools at Châtelperron in France have previously been excavated, but as they were dated between 40,000 and 45,000 years old, it was possible that they were made by modern humans. These latest finds in Spain add support to the view that these tools were in fact made by Neanderthals.

Stable vaccines cut the cold chain

The cold chain, ensuring vaccines are refrigerated all the way from manufacturer to patient, is one of the costliest factors in immunising the developing world. The temperature must be kept between two and eight degrees Celcius, or the fragile live virus loses its potency. But this could all change with a simple and cheap new method of producing vaccines that are stable even at tropical temperatures.

Oxford University researchers demonstrated that the Hypodermic Rehydration Injection System (HydRIS), patented by Nova Bio-Pharma Technologies, successfully enables storage of two different virus-based vaccines for six months at 45 °C with no degradation. What's more, the vaccines could be kept for over a year at 37 °C, removing the need for fridges or freezers.

HydRIS works by suspending the active virus of the vaccine in a thick sugary syrup, like a fly stuck in amber. No longer bombarded by surrounding molecules, the virus avoids degradation. Key to the method's success is the use of a membrane for effective drying of the sugar solution.

"The beauty of this approach is that a simple plastic cartridge, containing the membrane with vaccine dried on, can be placed on the end of a syringe," explains Dr Matt Cottingham, lead author of the paper published in *Science Translational Medicine*. "Pushing a liquid solution from the syringe over the membrane would then release the vaccine and inject it into the patient."

Usual methods of vaccine stabilisation involve freeze drying to avoid the formation of damaging ice crystals, but this aggressive technique can result in vaccine damage itself. In HydRIS, natural evaporation avoids this and, what's more, the sugar sticks to the virus surface taking on the shape preserving function of liquid water.

The team have high hopes for combining this stabilising method with novel vaccines currently in development. "We believe that it's very likely that we could stabilise other existing live viruses such as measles, mumps, rubella and yellow fever", said Dr Cottingham.

Immunisation against these killer diseases is key to survival in the developing world. Not only will the reduced cost of immunisation allow wider vaccine distribution, but there is also less chance of a child being given an ineffective vaccine because of temperature damage. What's more, areas previously too far from the beaten track for delivery of stable vaccines or lacking a local supply of electricity necessary for refridgeration will now benefit. "You could even picture someone with a backpack taking vaccine doses on a bike into remote villages," said Dr Cottingham.

Some things *are* set in stone

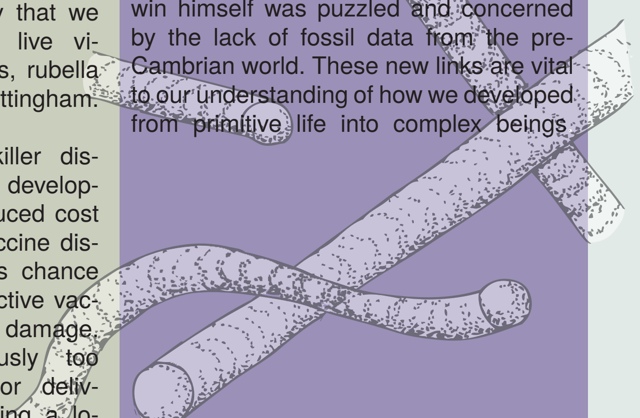
Palaeontologists at Oxford University have found evidence of pre-Cambrian animal locomotion in fossilised trails, providing crucial insights into evolutionary processes.

The fossil record is packed with information from the Cambrian period (542-488 million years ago), a time which saw an explosion of animal life, however fossils from the earlier Ediacaran period (630-542 million years ago) are rare.

All previously recorded Edicaran fossils have resembled fern-like or disc-shaped organisms which were likely to have been anchored to the sea floor. But the new findings from Newfoundland, Canada, suggest that pre-Cambrian life was much more diverse. The trails are the first to show that Ediacaran organisms could exert muscular control as they move, overturning previous theories that early organisms more closely resembled fungi than animals.

Little is known of the organism responsible for the fossils, but similarities to sea anemone trails suggest that they were soft-bodied creatures with muscles and collagen tissue potentially allowing locomotion across the sea floor by some form of muscular 'foot'.

Significantly these discoveries help to close a gap in the evolutionary chain; Darwin himself was puzzled and concerned by the lack of fossil data from the pre-Cambrian world. These new links are vital to our understanding of how we developed from primitive life into complex beings.



Words: Nicola Davis and Thomas Lewton
Art: Leila Battison

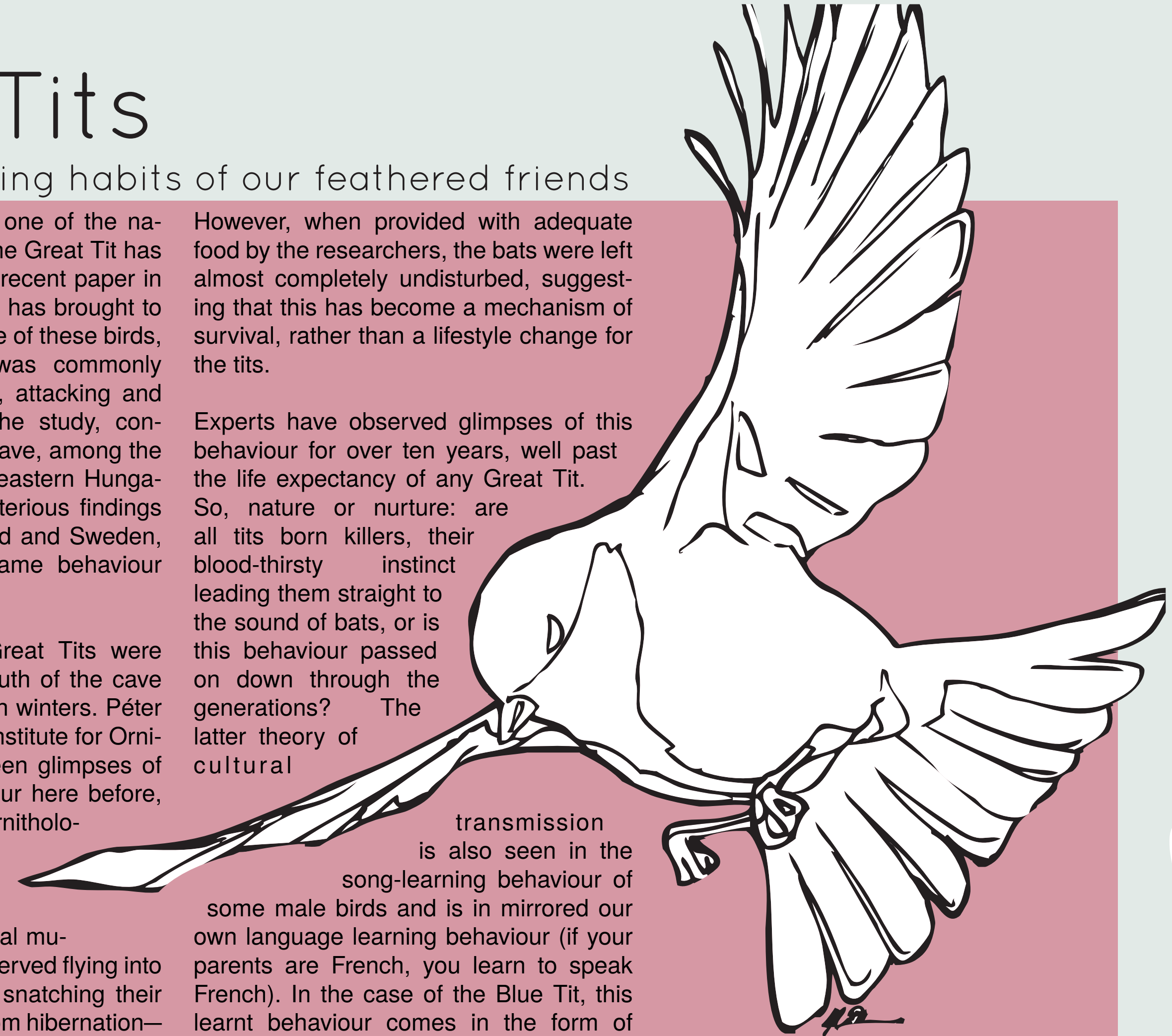
Killer Tits

The grisly feeding habits of our feathered friends

The fluffy reputation of one of the nation's favourite birds, the Great Tit has been shattered forever. A recent paper in the journal *Biology Letters* has brought to light startling new evidence of these birds, whose food of choice was commonly thought to be caterpillars, attacking and eating pipistrelle bats. The study, conducted in the Istállós-kői-cave, among the Bükk Mountains of north-eastern Hungary, was prompted by mysterious findings of bat carcasses in Poland and Sweden, and has revealed this same behaviour three years in succession.

Loose, large flocks of Great Tits were known to shadow the mouth of the cave in the punishing Hungarain winters. Péter Estók of the Max-Planck Institute for Ornithology, Germany, had seen glimpses of this extraordinary behaviour here before, and so along with fellow ornithologists Bjorn Siemers and Sándor Zsebők set out to find answers to this apparently bizarre behavioural mutation. The birds were observed flying into crevices in the cave and snatching their furry victims, still sleepy from hibernation— all the more cunning when you consider that most bats retreat to narrow crevices high up in the wall and cave ceiling and so aren't readily visible. Gruesome sightings indicate that the victims were eaten alive, eventually killed by savage pecks culminating in beheading— an injury which has become the bloody trademark of a Great-Tit-kill. But since this demonstrates that the feeding of the feathered terrors on the pint-sized pipistrelles was no chance event, how did the Great Tits know where to find them?

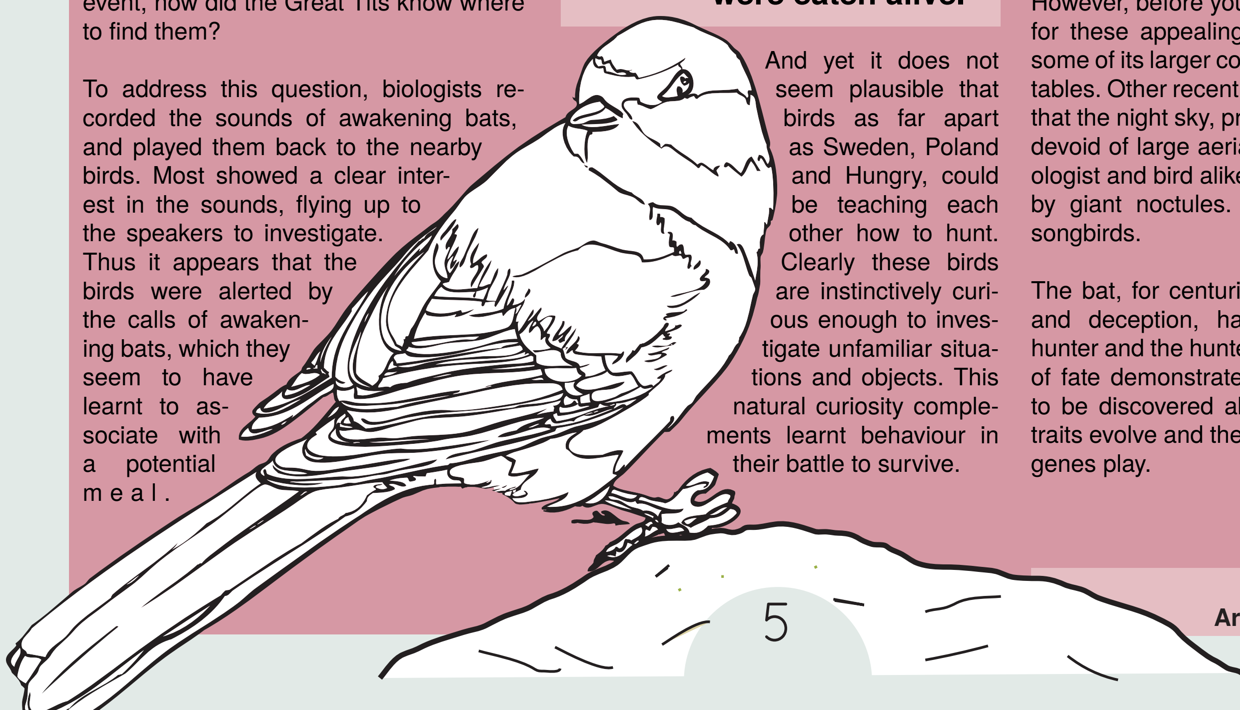
To address this question, biologists recorded the sounds of awakening bats, and played them back to the nearby birds. Most showed a clear interest in the sounds, flying up to the speakers to investigate. Thus it appears that the birds were alerted by the calls of awakening bats, which they seem to have learnt to associate with a potential meal.



However, when provided with adequate food by the researchers, the bats were left almost completely undisturbed, suggesting that this has become a mechanism of survival, rather than a lifestyle change for the tits.

Experts have observed glimpses of this behaviour for over ten years, well past the life expectancy of any Great Tit. So, nature or nurture: are all tits born killers, their blood-thirsty instinct leading them straight to the sound of bats, or is this behaviour passed on down through the generations? The latter theory of cultural transmission is also seen in the song-learning behaviour of some male birds and is in mirrored our own language learning behaviour (if your parents are French, you learn to speak French). In the case of the Blue Tit, this learnt behaviour comes in the form of milk-bottle opening, pecking through the top to slurp the cream. It only takes one innovative little bird of the closely related Great Tit family to realise there is a tasty source ofood to be had pecking off the heads of bats instead— raising whole generations of tits to be killers.

> **"Gruesome sightings indicate that the victims were eaten alive."**



And yet it does not seem plausible that birds as far apart as Sweden, Poland and Hungry, could be teaching each other how to hunt. Clearly these birds are instinctively curious enough to investigate unfamiliar situations and objects. This natural curiosity complements learnt behaviour in their battle to survive.

Similar behaviour has been observed even in animals as innocuous and innocent looking as sheep and deer— discovered to catch birds such as grouse and seabird chicks, sometimes eating them whole. Again, it is theorised that this only occurs in areas where their usual grassy fare cannot provide them with enough essential minerals.

However, before you start to feel too sorry for these appealing little bats, a look at some of its larger cousins quickly turns the tables. Other recent studies have revealed that the night sky, previously thought to be devoid of large aerial hunters (by both biologist and bird alike), is actually patrolled by giant noctules. Their diet: migratory songbirds.

The bat, for centuries a symbol of blood and deception, has become both the hunter and the hunted. This ironic reversal of fate demonstrates how much remains to be discovered about how behavioural traits evolve and the true extent to the role genes play.

Words: Anna Friedler
Art: Genevieve Edwards

Struck by Lightning

Accelerated evolution in bacteria

It is a muggy day in Southern California, where dark clouds hang heavy in the afternoon sky. Tinting the summery landscape in shades of grey, they descend, oppressively low, as if about to swallow the open fields. The scene is set for a crackling flash of lightning, suddenly bursting from its airy source like a furious reminder of Zeus himself. Hitting the ground, it zaps some harmless soil bacteria and transforms them into a massively virulent human pathogen. In no time it moves on to threaten the lives of thousands; no antibiotic treatment available, panic, chaos, apocalypse…

Sounds like some horror scenario crafted by a science fiction screenwriter? It is— check out season three of the Canadian program *Regenesis* to see how a team of scientists is confronted with just such a microbial attack. Yet a lot of the story is actually science. In 2001 a French research group developed a system to simulate lightning strikes in their lab at the Institut National des Sciences Appliquées in Lyon. They went on to demonstrate in Petri dish-sized soil microcosms how these naturally occurring events might indeed drive bacterial evolution.

It is known that some bacteria, responding to the need to frequently adapt to new environmental conditions, do not simply rely on accidental point mutations for genetic change. They can also perform 'horizontal gene transfer', which allows them to pick up DNA from other cells without being a descendent of the donor cell. A small fraction of all known bacterial strains are able to transform by actively gathering free DNA from the environment. Under laboratory conditions, however, scientists can artificially confer the ability to take in naked DNA to many more strains. A frequently used method is electroporation, where electrical pulses temporarily create pores in the bacterial membrane through which extracellular DNA from the surrounding medium enters the cell. This is where natural lightning hits the scene of evolutionary considerations.

A lightning discharge will deliver electric current to the ground in the area surrounding the impact point. The research team in Lyon argued that this may create appropriate conditions for electrotransformation of the soil bacteria with DNA from dead cells of the different bacterial strains present.

> **"In no time it moves on tothreaten the lives of thousands; no antibiotic treatment available, panic, chaos, apocalypse…"**

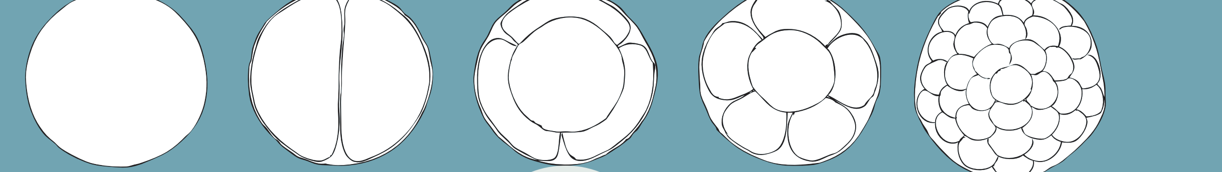
In order to investigate the validity of these suggestions, biologists' all time favourite bacteria, *E. coli*, was seeded onto sterilised soil samples and presented with DNA carrying a set of three appealing antibiotic resistance markers. The whole set-up was connected to a high-voltage generator to induce a current impulse very similar to natural lightning. The ability of a significant number of colonies to grow on antibiotic media showed that several cells had successfully taken up the plasmid DNA. Comparison to control samples treated the same way but lacking electrical encouragement proved that the driving force for transformation really had been the simulated lightning strike.

The question was now whether the laboratory findings would apply equally to naturally grown bacterial communities.

These were extracted from soil samples collected near the spa town of Montrond, France, and subjected to the electrotransformation procedures— with striking success. Two strains of the genus *Pseudomonas* were found which showed no natural competence for transformation, but when lightning struck, picked up DNA at an even higher frequency than the *E. coli* strain. *Pseudomonas* are found to be fast growing and capable of adapting to a wide range of environmental conditions. Therefore they might have been favoured under the given experimental conditions, thus masking the presence of an even broader range of electrotransformable bacterial strains in the soil samples. Nonetheless, even with only two easily identifiable strains in hand, the actual number of bacterial candidates for electrotransformation in a natural lightning strike was estimated to be more than 6 $x10^{16}$ per m^3 of soil.

For the *Pseudomonas* strains a single lightning strike can create appropriate electrical conditions for electrotransformation in up to 50 m^3 of soil, while France alone is hit by ca. 106 lightning storms per year. This is rather a lot of potential for bacterial evolution in all sorts of directions. Considering this, a retreat to some hermetically sealed panic room with a bottle of disinfectant could be wise. A better option might be a stroll to the next pub for a beer and some deep thoughts on how a full potential is not always exploited.

Words: Nele Dieckmann
Art: Leila Battison



Size is Everything

Exploring the new generation of big physics experiments

At 9:48pm on the 29th November 2009, a new world record was set. Deep beneath the Franco-Swiss border, a proton beam circulating inside the super-cooled confines of the Large Hadron Collider (LHC) reached an energy of 1.05 trillion electron-volts, beating the previous (2001) FermiLab record of 0.98 TeV. Just a few hours later, both of the LHC's proton beams were doing a full 27 km lap of the LHC in just 1/11,000th of a second—and this is just the warm-up. When things get going again in the spring, the beams will be brought up to 3.5 TeV each. And then they'll be smashed into each other.

This is big stuff, the culmination of decades of engineering, political debate, and financial juggling. But in all the clamour about the LHC, it's easy to miss the wider context: that the LHC, far from being a lone titan, is only one of a series of physics 'megaprojects' of staggering dimensions (and with budgets to match). How did these come about? What do these experimental colossi tell us about the state of physics at the start of the 21st century? And what hurdles and opportunities lie ahead for such projects?

> **"Experiments must either be powerful enough to create abnormal conditions, or sensitive enough to detect subtle evidence."**

A part of the reason for building such machines is simple: it's because we can. However, these are vast undertakings, and the tools needed for this scale of construction are still being pioneered. Certain technologies are necessary platforms for more ambitious projects; space-based megaprojects such as the Hubble telescope or the International Space Station could not be built or maintained without the pre-exisiting technological know-how to reliably send objects and people into space. Even more important have been advances in computing and communications technology. The LHC is expected to produce some 15 petabytes of data each year (enough to fill 1.7 million dual-layer CDs), which needs to be stored, processed, and farmed out to over 8,000 physicists worldwide. The network of distributed computing resources tasked with handling this —the Worldwide LHC Computing Grid— relies upon existing internet technologies to parcel out the work between more than 170 computing centres (encompassing around 100,000 computer processors). At the same time, it's pushing those technologies forward, building a 'parallel internet' from dedicated fibre-optic cables and new routing protocols.

However, there is also an increasing need for such experiments. Indeed, the required technology is often developed in response to the experimenters' needs: look at the Grid, or even CERN (The European Organization for Nuclear Research) who's last computer project is better known as the World Wide Web. Our current physical theories are an excellent description of reality under normal circumstances, but we know that there is still progress to be made. That means that experiments must do one of two things: either be powerful enough to create abnormal conditions, or be sensitive enough to detect the increasingly subtle evidence at the frontier of physics (see boxed text on the Japanese Super-Kamiokande Observatory). In practice, many need to do both: in addition to its power, the LHC is a phenomenally sensitive detection tool. Not all technology is purely research-focused either: the experimental nuclear fusion reactor ITER will, if successful, potentially open the way to clean, abundant power.

Vital statistics: the Large Hadron Collider (LHC)

Size: 27km in circumference
Place:Straddling the Franco-Swiss border
Cost: £5600 million

The newest and best-known of the physics megaprojects, the Large Hadron Collider is one of the biggest, most expensive, and most ambitious scientific project ever undertaken. It is the largest particle accelerator in the world, capable of recreating the conditions which prevailed in the Universe just moments after the Big Bang.

In its subterranean belly, magnetic fields some 275,000 times stronger than the Earth's (created by ultracold superconducting magnets) will accelerate protons to within a whisker of the speed of light. The debris from colliding these protons with each other will be picked up by one of six detectors, and passed to labs worldwide for analysis.

A big goal for the LHC is a sighting of the 'Higgs boson', the particle hypothesised as part of the mechanism for endowing matter with inertia (a propensity to resist changes of motion). Other aims include the discovery of extra dimensions and 'supersymmetric' particles.

Vital Statistics: Super-Kamiokande (Super-K)

Size: 41m tall, with 50,000 tonnes of water
Place:1km below Hida, Japan
Cost: £70 million

We can only detect physical objects through their interactions— either with us directly or via some machinery. The less inclined a particle is to make its presence known to the matter around it, the harder it will be to find it in the first place, or to make confident statements about its properties. The neutrino is just such a recluse: electrically neutral and nearly massless, it sleets through ordinary matter at almost the speed of light.

To have any chance of seeing these elusive characters we need a lot of very dense matter (to increase the chance of an interaction) and very sensitive detectors. Just such an experimental set up is buried deep beneath Japan's west coast.

Trillions of neutrinos pass through Super-Kamiokande's underground water tank every second; a few of these will interact with electrons in the water, each causing a tiny spark of blue light. The water must be constantly purified to give a clear view to the 11,146 photomultiplier tubes that watch for these glimmers in the dark.

Vital Statistics: ITER

Size: 30m tall and a weight of 21,000 kg
Place:Caradache, France
Cost: £10 000 million

Scientists have long coveted hydrogen fusion (the nuclear reaction which drives the Sun) as a power source. It produces no waste products, cannot spiral into dangerous chain reactions, and yields vast amounts of energy from relatively small quantities of hydrogen, found in plentiful supply in water.

To investigate such possibilities, scientists have designed ITER (the original name — the International Thermonuclear Experimental Reactor— was deemed too frightening, and so the acronym now officially stands for nothing at all). Once completed, it will seek to generate a 150 million °C super-hot plasma of hydrogen isotopes— so hot, in fact, that the nuclei can overcome their mutually repulsive electric charges and fuse into helium. In the process, they spit out high-energy neutrons which can be absorbed by ITER's walls, thereby generating heat.

If ITER can demonstrate the sustainability of fusion reactions, then more plants will be built to harness and transport the power currently locked in the oceans.

> **"What do these experimental colossi tell us about the state of physics at the start of the 21st century?"**

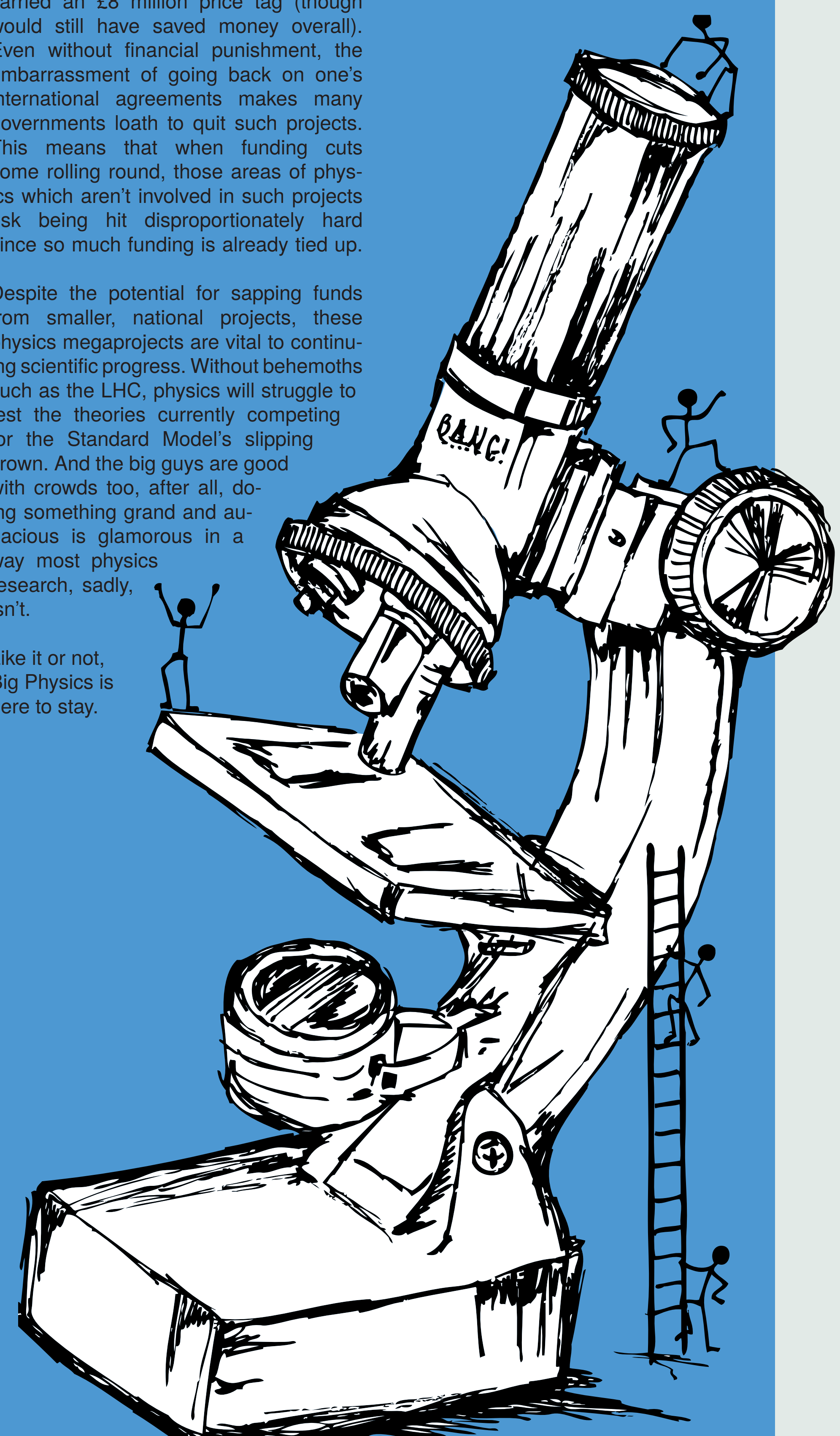
Nevertheless, Big Physics isn't without its problems. Such large-scale experiments often require large-scale investment, and (as with megaprojects in other fields), are frequently subject to delays and cost overruns. ITER was originally billed at €5 billion, but is now looking at double that; the LHC's start date has been slipping consistently for a couple of years; and the proposed Superconducting Super Collider's estimated cost quadrupled from $3 billion to $12 billion in just six years, causing its untimely cull by the American government (though not before $2 billion worth of hole had been dug in the Texan desert).

International collaboration is vital for these projects, but keeping everyone around the table happy can be a challenging task if squabbles break out over the distribution of costs, jobs and contracts. If anyone does pull out, major budgeting headaches can be created— as seen in November 2007, when the United Kingdom announced its withdrawal from the Gemini Observatory project based in Chile. After protests, it re-entered the project in February 2008, but announced in December 2009 that it would be ending its involvement when its contract expires at the end of 2012.

The Gemini rollercoaster also points out a converse problem. To stop participating nations from pulling out, the agreements usually come with withdrawal penalties: an early pullout from Gemini would have carried an £8 million price tag (though would still have saved money overall). Even without financial punishment, the embarrassment of going back on one's international agreements makes many governments loath to quit such projects. This means that when funding cuts come rolling round, those areas of physics which aren't involved in such projects risk being hit disproportionately hard since so much funding is already tied up.

Despite the potential for sapping funds from smaller, national projects, these physics megaprojects are vital to continuing scientific progress. Without behemoths such as the LHC, physics will struggle to test the theories currently competing for the Standard Model's slipping crown. And the big guys are good with crowds too, after all, doing something grand and audacious is glamorous in a way most physics research, sadly, isn't.

Like it or not, Big Physics is here to stay.



Words: Neil Dewar
Art: Lousia Stoppard

Choosing Children

Exploring ethical dilemmas posed by reproductive technologies

In early 2009, a 13 year-old girl sued the New York sperm bank Idant Laboratories under a product liability law more commonly associated with faulty car brakes and bad wiring. The damaged goods? The very sperm that was used to create her. Brittany Donovan was born with 'Fragile X syndrome', a genetic disorder causing mental impairment that was found to have been inherited from her biological father. The judge's decision to allow her to go ahead with her lawsuit could open up the floodgates to claims from other sperm recipients. It seems that society has lost perspective on the meaning of genetic material and the 'right' to exist. In 2010, a decade after the completion of the Human Genome Project, we must rethink the direction that genomic manipulation is heading in, particularly with regard to assisted reproductive technologies.

"Aspiring to this devalues the lives of current and future disabled or ill people."

While many scientific technologies are life-changing, some change lives before they even begin. Pre-implantation genetic diagnosis (PGD) is the process by which cells are taken from embryos created by in-vitro fertilization and their genetic information (or genome) analysed to test for characteristics, usually genetic diseases. Only those embryos deemed to have genomes 'safe' from particular disorders are transferred back into the woman's uterus to be carried to term.

Since the completion of the first draft of the human genome in June 2000, the improvement in our understanding of many genetic diseases has been phenomenal. With this information it is now possible to test for over one hundred genetic conditions using PGD. The technique is primarily used for couples at risk of passing on a serious condition (because they are both carriers of a recessive disorder, for example). However, the potential applications of PGD will expand as the human genome is mined further for the origins of various human characteristics. We need to think now about the ethical issues of selecting traits to essentially design babies.

Jude Law may truly be the epitome of male beauty. His genetically-modified character in the film *Gattaca* represents a manifestation of society's obsession with perfection. His alter-ego in the film, played by Ethan Hawke, represents the 'in-valid'— the 'normal' man of the 20th century. Interestingly, both characters are presented as victims to a society that got carried away with genetics; a society that put greater weight on physical perfection than human relationships. Without well thought-out legislation, this may represent our own society in the not too distant future. Parents are already choosing not to have children that have a statistical likelihood to suffer from Down's syndrome, severe autism, developmental disorders, muscular disorders and many more. It is likely that the criteria by which an embryo is judged to be genetically disadvantaged will continue to broaden.

At its essence, PGD allows parents to introduce healthy children into the world who would otherwise have experienced great suffering in their lives. No doubt this sounds like a blessing, but PGD should force us to think long and hard about what it means to suffer from a 'disorder' or be 'disabled' in the eyes of society. Standing tall and powerful on the flip-side of disability is the enhanced human being that society has not yet had to face. Aspiring to this being devalues the lives of current and future disabled or ill people, whether or not this is genetic. Yet if we dismiss PGD altogether we are knowingly, and some would argue irresponsibly, sanctioning suffering. So how do we reconcile these conflicts?

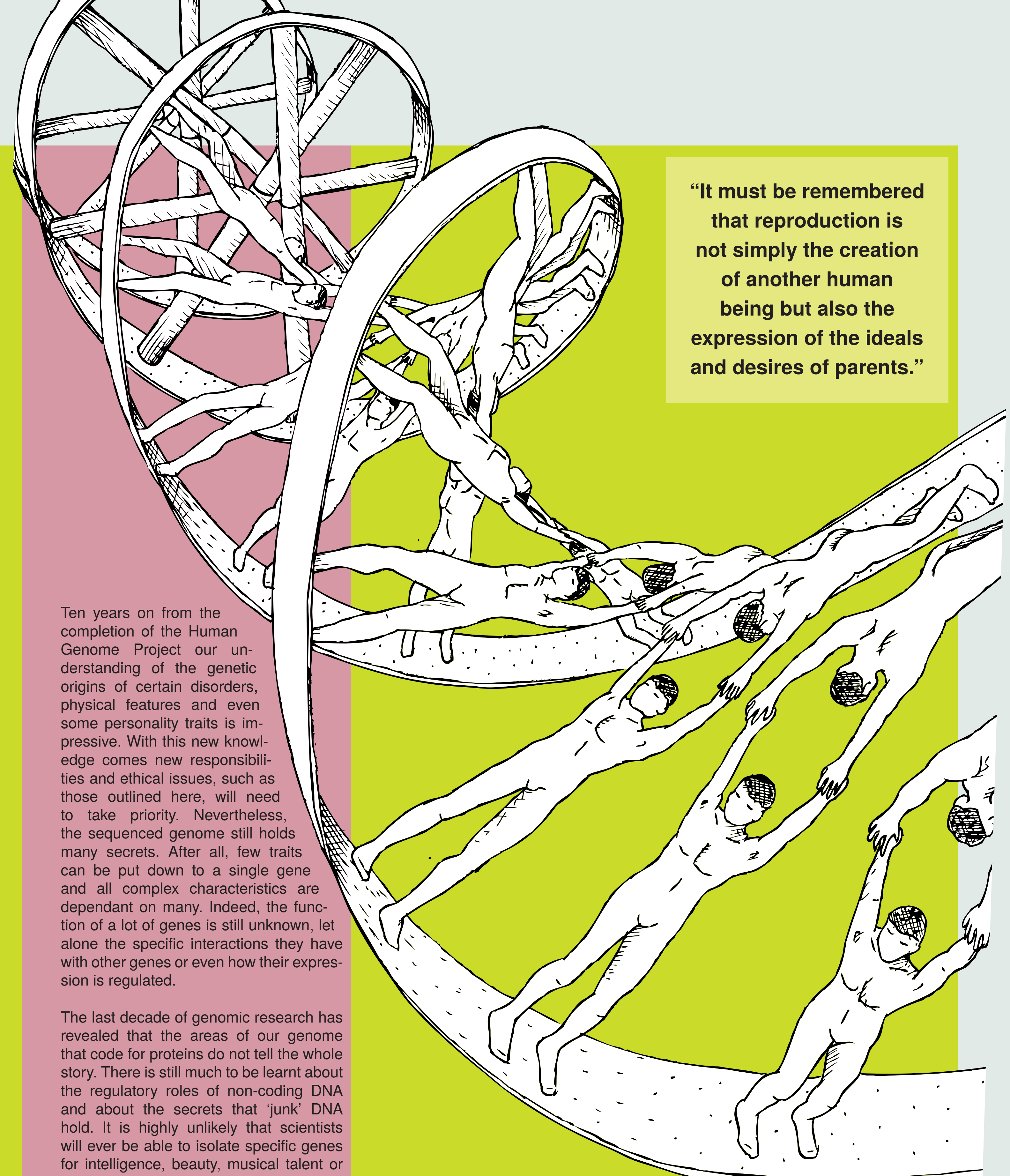
Much of the answer will rest on personal opinion. As a thought experiment, let us take the example of Sharon Duchesneau and Candy McCullough, a deaf lesbian couple who used sperm donated by a friend with hereditary deafness to have a deaf baby. Many argued that the parents acted irresponsibly, setting unfair limits on the child's development. However, the couple took the view that deafness is not a disability but a difference. The deaf community is large and supportive and the couple wanted their child to be a part of that. Indeed, the ability to hear might have been a significant barrier between the child and its parents.

The debate thus lies in pitting the reproductive freedom of parents against the welfare of the future child. Society is divided on this debate. Some religious groups, philosophers and clinicians argue that the welfare of the hypothetical child must be of the utmost concern, lest we forget the value of life. Others are concerned that, in elevating the status of the unborn child, we neglect the needs and personal freedoms of existing human beings. Ethicist Julian Savulescu suggests that parents should ultimately be allowed to choose what children they create, but that they should have the moral obligation to choose those children that have the best chance of happiness.

A potent danger in such a choice is the possibility of powerful manipulation of potential human beings, removing the latter's agency in their own future and breeching some unwritten rule of personal autonomy. Jodi Picoult's novel *My Sister's Keeper* explores just this theme. In the book, thirteen-year-old Anna sues her parents for medical emancipation when she is expected to donate a kidney to her dying sister. Anna had been created by PGD to be the perfect donor for her older sister. Unlike the genetically-engineered humans in *Gattaca*, 'saviour siblings' like Anna are not fictional. Most are still too young to be questioned on their feelings towards their mode of conception, but it is very important that we listen to them as they develop. Their testimonies will provide an invaluable contribution to policy-making on the use of genomic technologies in the future.

"Jude Law may truly be the epitome of male beauty."

In some senses the issues of PGD are not new. It seems unfair to argue that a parent should only be allowed to use PGD if they can guarantee the child a good life. Some parents are currently unable to provide their children with the best possible life if faced with economic, social or emotional problems. A poor person would never be stopped from having a child, nor an autistic person, nor, of course, a deaf person. However, PGD introduces a new dimension to the debate. It allows parents to actively choose to give their child a genetic advantage or disadvantage (according to your viewpoint). It must be remembered that reproduction is not simply the creation of another human being but also the expression of the ideals and desires of parents. PGD is now giving parents the unprecedented power to manifest these personal values in their child's biological make up.



"It must be remembered that reproduction is not simply the creation of another human being but also the expression of the ideals and desires of parents."

Ten years on from the completion of the Human Genome Project our understanding of the genetic origins of certain disorders, physical features and even some personality traits is impressive. With this new knowledge comes new responsibilities and ethical issues, such as those outlined here, will need to take priority. Nevertheless, the sequenced genome still holds many secrets. After all, few traits can be put down to a single gene and all complex characteristics are dependant on many. Indeed, the function of a lot of genes is still unknown, let alone the specific interactions they have with other genes or even how their expression is regulated.

The last decade of genomic research has revealed that the areas of our genome that code for proteins do not tell the whole story. There is still much to be learnt about the regulatory roles of non-coding DNA and about the secrets that 'junk' DNA hold. It is highly unlikely that scientists will ever be able to isolate specific genes for intelligence, beauty, musical talent or artistic genius, let alone wholly 'design' a human being through genetic engineering. But then these sound dangerously like famous last words...

Words: Alya Hazell
Art: Leila Battison

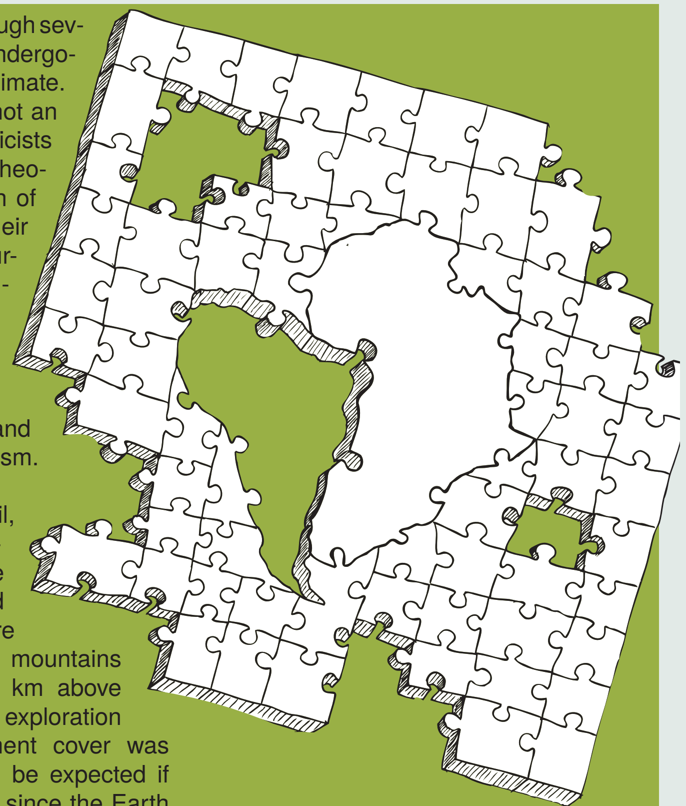
The Last Piece of the Puzzle

The rocky history behind the theory of Plate Tectonics

The similarities between the coastlines of South America and Africa, seemingly fitting together like jigsaw pieces, were first noted in 1596 by Abraham Ortelus, a cartographer. Writing that it is as though the Americas "were torn away from Europe and Africa… by earthquakes and floods", his views flew in the face of the prevalent notion of a fixed surface of the Earth, questioning the perfection of God's creation. Nearly 300 years later, scientists such as the geographer Antonio Snider-Pellegrini were still trying to reconcile Ortelus' observation with the concept of a fixed surface, invoking the biblical 'Great Flood' to explain continental fragmentation.

A lack of both a convincing mechanism and solid evidence held back support for this theory of Catastrophism, however during the 19th Century a radical concept called Uniformitarianism emerged offering an appealing alternative. Put forward by geologists James Hutton and Oxford's Sir Charles Lyell, this theory encompassed the view that the Earth's surface was not a static body at the mercy of the elements, but a dynamic system. Crucially, it argued that geological features formed in the past can be explained by processes still operating today.

Building upon Uniformitarianism in the early 20th century was the German meteorologist Alfred Wegener. By examining the fit of coastlines, rocks types, mountain belts and fossil ranges, Wegener suggested that a supercontinent 'Pangea' ('all the land') began to split 200 million years ago. Daring to contest the view that fossil matches could be explained by migration of animals across now submerged land bridges, Wegener proposed the theory of 'Continental Drift', with the continents gouging their way through a static ocean floor. The presence of coal in Britain and glacial rocks in southern Africa, South America, and Australia further supported his theory by suggesting that the continents had drifted through several degrees of latitude, undergoing drastic changes in climate. Wegener's concept was not an instant success. Geophysicists stuck to the land bridge theory, arguing that the notion of continents ploughing their way across the earth's surface was impossible without the ocean floor breaking up. Also criticized for his use of circumstantial data, Wegener's theory was ridiculed and showered with scepticism.



Later, in the quest for oil, increased ocean surveying led to a remarkable discovery. It appeared that ocean floors were not flat but variable, with mountains and huge ridges over 4 km above the sea floor. Further exploration revealed that the sediment cover was much thinner than would be expected if it had been accumulating since the Earth was formed. In addition no sediments older than 135 million years could be found. The concept that the earth's surface is fixed was once again under fire.

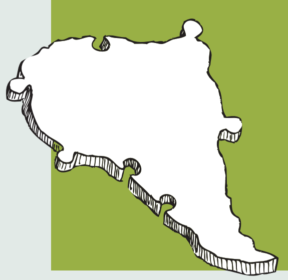
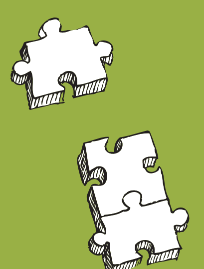
"Wegener's theory was ridiculed and showered with scepticism."

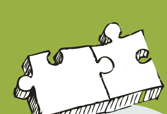
Further support for a dynamic ocean floor came from palaeomagnetism. Emerging in the 1950s, this science examined the magnetic field preserved in rocks by their minerals, allowing the movement of the continents over time to be mapped. Moreover, during the 1960's, alternate strips of rock with opposite magnetic polarity were found on either side of oceanic ridges. The mirrored pattern of these strips indicated that the two sides of the ridge are moving apart from each other; the alternations in magnetic polarity record the occasional reversals of the Earth's magnetic dipole. At the ridge itself, the rock's magnetic field is always aligned with that of the Earth.

Harry Hess, a geologist and US Navy officer, realised the significance of these discoveries. He proposed that ocean crust was created at ridge axes as magma was forced up from the mantle, while crust was destroyed at oceanic trenches bordering the ocean basins. This one elegant theory explained both the lack of old sea floor and the constant size of the Earth despite crustal growth. 'Sea Floor Spreading' finally provided a mechanism by which continental drift could occur.

The struggle for acceptance of continental drift finally reached its conclusion in 1968 when Jason Morgan and Dan McKenzie independently developed and published the theory of 'Plate Tectonics'. Building upon the concept of sea Ffoor spreading they defined continental plates as rigid bodies, moving over the Earth's surface by rotation about Euler poles. The concentration of seismic activity along the edges of the proposed plates was confirmation of the theory.

Nearly 400 years after Ortelus' enlightened notion of a continental jigsaw, the final pieces of the puzzle were in place. The theory of Plate Tectonics stands as a triumphant victor in the war of competing paradigms.

Words: Daniel Frost and Nicola Davis
Art: Leila Battison

Just Forget About It

Probing the power of memory erasing drugs

Ever done something embarrassing? So embarrassing you wished you could go back and erase it from time? Maybe you wished you could be like Clementine or Joel in *Eternal Sunshine of the Spotless Mind*, and delete forever the memory of a failed romance. This wish isn't so far fetched, as neuroscience's latest bag of tricks, the memory modifying technologies (MMTs), is beginning to demonstrate.

But what are memories? Donald Hebb's famous axiom "cells that fire together wire together" illustrates that information is stored as changes in synaptic connections, allowing us to form memories (to refresh your, well, memory of GCSE biology, a synapse is a structure that permits a neuron to pass an electrical or chemical signal to another neuron). The stronger the synaptic connection, the stronger the corresponding memory.

However, the molecules involved in maintaining this connection degrade over time and must be replaced; a process involving several vital proteins. Now imagine that one of these proteins is deactivated. The synapse wouldn't be refreshed and the memory would be lost.

Dr Todd Sacktor, a neurologist at the State University of New York, discovered one such molecular maintenance protein: Protein Kinase Mzeta (PKMzeta). Sacktor was then able to produce another molecule, Zeta Inhibitor Peptide (ZIP), which specifically inhibits PKMzeta without affecting other molecules.

Curious about the implications of the chemical, Dr Andre Fenton, a neurologist who studies spatial memory in rats, offered his experimental setting for testing. He placed the rats in a circular chamber and taught them to avoid certain areas by giving their feet tiny electrical shocks. The rats were able to remember these areas months after the training. However, after injecting ZIP into the hippocampus (the part of the brain that regulates memories) the rats forgot which areas of the chamber were 'dangerous'. Though the memory was still gone after a few weeks, the rats were able to establish new memories—suggesting that only relatively recent ones were affected by the drug.

Given these results, it is not difficult to imagine a scenario in which we can choose which memories to delete and even which memories to replace them with. In fact this is just the case in the film *Total Recall*. Douglas Quaid (Arnold Schwarzenegger) is haunted by a recurring dream about a journey to Mars. Hoping to find out more about this dream he buys a holiday at Rekall Inc, a provider of implanted memories. But the false memory transplantation goes terribly wrong and another personality surfaces. The reality of the situation is constantly questioned: Who is he and which version of reality is true? Though the film is set in the year 2084, current developments in MMTs suggest this could become reality far sooner.

Total Recall draws attention to the ethical dilemmas caused by such technologies. A memory that has gone cannot be brought back and, as for Douglas Quaid, might cause an existential crisis. Further, if we delete our memories, we cannot learn from our mistakes.

"Having control of someone's memories is a special kind of ownership, one with the potential for grave misuse."

But these concerns may be outweighed by the benefits provided by the use of MMTs in ameliorating post-traumatic stress disorder. Fenton and Sacktor have been researching the use of the beta-blocker propranolol for such an application. Propranolol blocks adrenaline, the hormone that surges when people are shocked or frightened and which is thought to affectsthe brain region that consolidates emotional memory. Although it has been misnamed "the amnesia drug", propranolol does not make people totally forget; it simply weakens the emotions attached to memories. In recent human experiments, the use of propranolol has shown some success in relieving the patient of certain fearful responses, helping them to reintegrate normally into society.

Whatever benefits to society MMTs provide, we must tread with care. As memories are interconnected there is no way to predict how deleting one memory would affect the others. As Dr Daniel Sokol, a medical ethicist at the University of London, points out: "Removing bad memories is not like removing a wart or a mole. It will change our personal identity since who we are is linked to our memories... it may be beneficial in some cases, but before eradicating memories, we must reflect on the knock-on effects that this will have on individuals, society and our sense of humanity."

Though the idea of travelling the Universe with virtual vacation memories may seem exciting, the sheer risk involved may just be too great. Having control of someone's memories is a special kind of ownership, one with the potential for grave misuse; you can only imagine the destruction that could be caused by a stressed out Finalist on exam day…

Words: Laura Mueller
Art: Max Gordon-Brown

Star Gazing from the Spires

It was on the cobbled back streets of Bath that astronomer William Herschel was discovered by the Royal Society. Looking at the moon through a home-made telescope far surpassing the technology of the day, Herschel went on to make many profound astronomical discoveries— most famously the existence of Uranus.

Yet such technology is no prerequisite for stargazing. Standing on our own cobbled North-East corner of Radcliffe Square, take a moment to look up. Though Uranus is rarely visible to the naked eye, a whole host of constellations await your gaze.

One of the most visible stars in the sky, Betelgeuse, could one day soon (or at least within the next 1000 years) become a whole lot brighter, violently exploding as a supernova so that it outshines even the moon. For the time being, however, it is Sirius that wears the crown of brightest star, appearing on the Southern horizon above St Mary's church.

Sirius was used by Queen's College alumnus Edmond Halley as a demonstration of the gradual movement of stars in the night sky relative to the Sun— known as a star's 'proper motion'. Halley revolutionised the notion of static stars fixed onto a 'crystalline sphere' in favour of a dynamic Universe.

Further evidence of celestial movement came from Herschel's discovery that many of these pinpoint objects actually consist of two or more stars. Orbiting about each other, these binary systems demonstrated for the first time that Newton's law of gravity applied outside the solar system. It was previously thought that binaries were mere optical illusions, but we now know that up to half of all stars have one or more partners. Notable binaries on our map include Rigel, Capella and Sirius.

With the Earth no longer residing in a special place in the Universe, the existence of extra-terrestrial life seemed perfectly plausible to Herschel. He even went as far as to suggest that every other planet was inhabited. Noting the changing polar caps of Mars in 1784, Herschel suggested they were made of ice or snow and that Mars had an Earth-like environment, fuelling ideas of intelligent life. Though a far cry from little green men, scientists today still hope to find evidence for bacteria-like organisms on Mars. Excitingly, rock formations indicate that liquid water, vital for life, was once present on the surface and recent missions have found very pure ice close to the surface across much of the planet.

Mars takes a prominent position high in our night sky trailing behind Pollux, a star with its own claims to extra-terrestrial life. Pollux was recently found to harbour an exoplanet (a planet outside of the solar system) named Polydeuces. Heavier than Jupiter and bathed in intense heat from its parent star, it is unlikely that Polydeuces harbours life; yet it is plausible a hypothetical moon of Polydeuces once provided the right conditions.

Position of stars as of 9pm, 8th week

Either way, huge advances in astronomical technology have caused a sudden boom in exoplanet discovery, with new ones being found weekly. Far more common than anyone had imagined, exoplanets provide support for the existence of life elsewhere in the Universe. one day soon it may even be possible to detect the telltale signs of life in exoplanet atmospheres. So as you stare in astonishment at the night sky take a moment to think about who might be looking back.

Words: Thomas Lewton
Art: Louisa Stoppard

A Broken Relationship?

The growing need for scientific and political collaboration

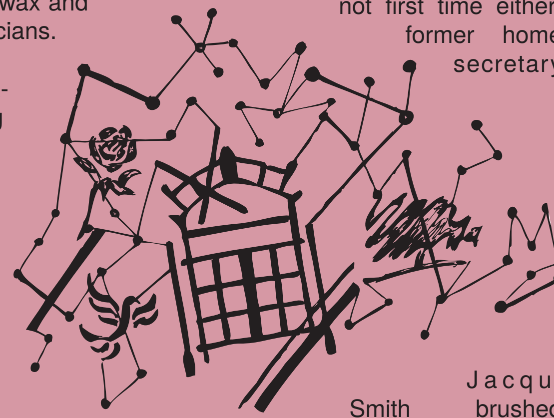
In late 2009, the scientific and political worlds collided at the UN's Climate Change Conference in what was hoped to be the next major step towards combating global warming.

Unfortunately, the climate talks ended with a hastily negotiated, non-binding agreement that was founded on a political, rather than scientific, agenda. The USA and China were the major forces behind a last minute 'Copenhagen Accord' which 'recognises' the scientific basis for keeping average global temperature rises to less than 2 ^{o}C. However, there were no commitments to cut emissions of greenhouse gases and when the Kyoto protocols expire in 2012 there will no longer be a legally binding multinational agreement.

> **"Scientific facts are not at the mercy of public opinion."**

Looking at the key players at the conference perhaps the outcome isn't such a surprise. The UK's representative, Secretary of State for Energy and Climate Change Ed Miliband, left Oxford with a degree in PPE. In fact, he's on a par with his political opponents: the Conservatives' shadow minister, Greg Clark studied economics, while the Liberal Democrat spokesman, Simon Hughes, studied law. In fact there is only actually one cabinet member with a science degree (John Denham, who has a BSc in chemistry). This lack of MPs' scientific grounding may well have contributed to the disastrous Copenhagen accord but the repercussions extend well beyond the issue of climate change. Putting vote-winning policy above the hard facts supplied by scientific bodies is a short sighted approach to tackling long term problems. Scientific facts are not at the mercy of public opinion; their significance should not wax and wane with the whims of politicians.

The consequences of this are exemplified in the recent sacking of David Nutt, the government's most senior advisor on the classification of drugs and chairman of the Advisory Council on the Misuse of Drugs (ACMD). Nutt's dismissal by Home Secretary Alan Johnson came following a paper in which he criticised the Government's drug policy for not following the science based advice provided by the ACMD. The media had a field day reporting Nutt's criticisms— a favourite being his comparison of the number of drug deaths caused by ecstasy to the number of deaths caused by horse riding. It appears this mass media coverage pushed Johnson's hand: he did not want Nutt undermining public confidence in drugs policy. Nutt's departure triggered a mass exodus from the ACMD, resulting in a council that was no longer quorate.



Yet this all begs the question of why Johnson did not accept the ACMD's recommendations in the first place. This is not first time either: former home secretary Jacqui Smith brushed aside their advice when reclassifying Cannabis to Class B in 2008. Recent classification decisions have been justified in terms of "public perception" and what Smith calls "the need to send out a message", rather than the evidence based policy at the heart of the ACMD. These changes seem to be focussed on winning votes rather than maintaining a clear cut classification system based on the relative harms of drugs.

However, often the science is not so clear cut. Though man-made global warming is generally accepted across virtually the whole scientific and political spectrum, there is still much debate about how much must be done and how soon to avert catastrophe. Making precise long-term predictions about a system as complicated as the Earth's biosphere is extraordinarily difficult. Politicians have a difficult task ahead of them, anticipating the likelihood of a multitude of future outcomes to avoid environmental disaster while minimising the damage to the economy.

Even when the science is well understood, it is sometimes appropriate for politicians to use their discretion. At the height of the swine flu pandemic, the UK government released vast stockpiles of the antiviral Tamiflu, yet a recent review had found that Tamiflu was only effective in severe and complicated cases that were caught very early. The government still authorised widespread provision of Tamiflu to avoid the public perception of a government withholding vital drugs. Maintaining public confidence in the government's handling of the pandemic was crucial, particularly in allaying fears should the crisis have escalated.

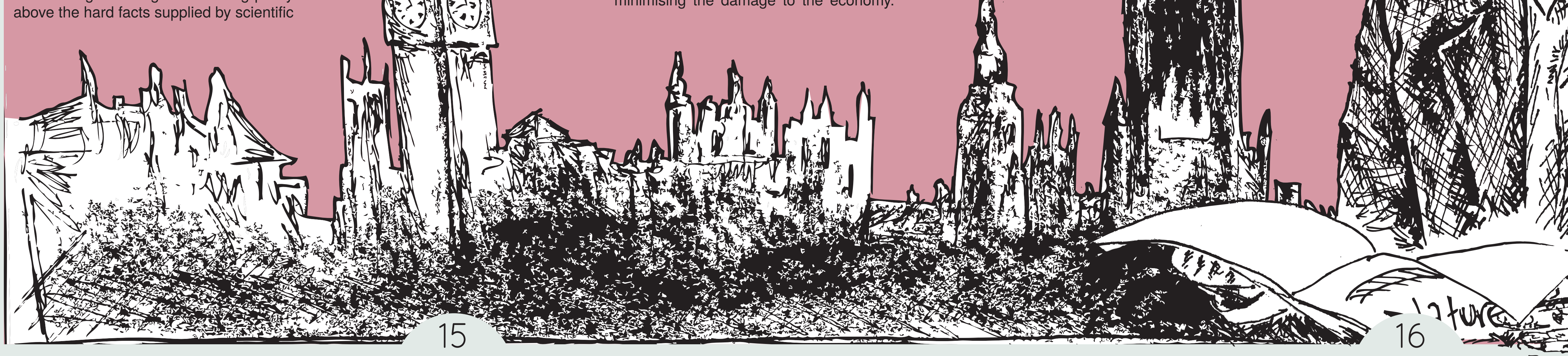
To make suitable judgements about global warming or health policy a broad perspective is needed which will often lack specialist scientific knowledge. It is therefore important that the scientific community is politically active, opening channels of communication and forming a cooperative community with trusted, respected opinions that are listened to.

On the other hand, politicians need to be more engaged in the science behind policies, and in particular must gain an understanding of the scientific method— it is only then that they can make informed decisions about the relative merits of debatable scientific ideas. Politicians must also be aware of the durable, circumspect nature of science; though the soundbite, quick fix world of politics gets things done, certain issues, such as climate change, require a longer-term outlook.

> **"Science and politics can, and have, worked side by side to tackle issues on the global scale."**

It certainly isn't impossible to bridge these culture differences— the eradication of Smallpox in the 1979 is proof. After the World Health Organisation launched a global eradication campaign in 1967 the scientific community worked alongside international politicians to eradicate a disease that killed between 300 and 500 million in the 20th century. Science and politics can, and have worked side by side to tackle issues on the global scale.

Today we are faced with equally large and difficult challenges and science will play an increasingly important role in tackling them. From climate change and the impending energy crisis to the potential misuse of genetic technologies, cooperation between scientists and politicians is more important than ever. A relationship needs to be rebuilt; a relationship that will prove crucial in mapping our way through these challenges.



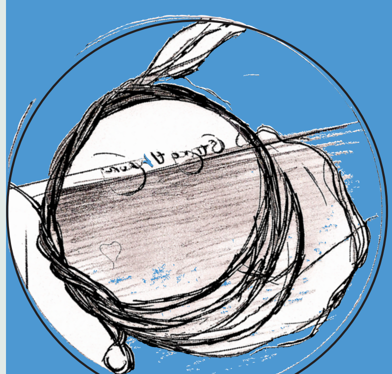
Words: Gareth Langley
Art: Anna Pouncey and Louisa Stoppard

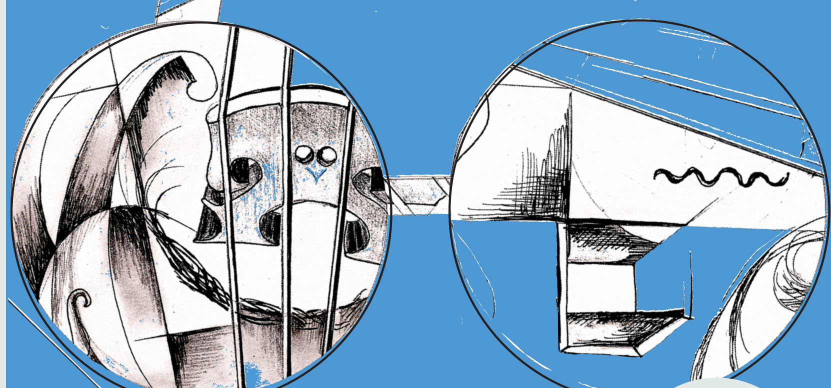
Müß es Sein?

Searching for a Theory of Everything

As Albert Einstein lay on his deathbed in 1955, he clung to a dream shared by some of the visionaries of his time. It was a dream which Einstein held for the last decades of his remarkable life: that there should exist a single set of equations, a single principle, which describes the fundamental laws of Nature. This 'Theory of Everything' (TOE) is not as outlandish as it might first seem. By 1698, Isaac Newton had realised that the same equations governed both the fall of an apple and the motion of the planets; thus the unified theory of gravitation was born. Further, by 1879, James Clerk Maxwell had established that the same equations dictated the properties of electricity and magnetism; giving rise to the unified theory of 'Electromagnetism'.

This spirit of 'unification' is the triumph of scientific reductionism and is the inspiration for theoretical physics. That observable Nature could be explained by an underlying structure, and that this structure is mathematically comprehensible, is what Einstein called the "most incomprehensible thing about the universe". In this ultimate quest for a TOE humanity has done well.





By 1916, treading along the glorious path led by Newton, Maxwell *et al.*, Einstein unified gravity with space and time, formulating the so-called special and general theories of Relativity. It explained, to great accuracy, the behaviour of the cosmos at a *macrocosmic* scale: the motion of stars and galaxies, the expansion of space and the passage of eons. By mid-twentieth century, the proponents of Quantum Mechanics, (Bohr, Heisenberg, and Schrödinger, amongst others), had unified the cosmos at a *microscopic* scale: the constituents of the atoms, the interactions of the elementary particles and the inevitable uncertainties of wave-particle duality. This Quantum description of a handful of indivisible elementary particles, such as the photon and the electron, unifies Maxwell's electromagnetism with the sub-atomic forces, comprising the so-called Standard Mode— which is verified to extraordinary accuracy. The experimental search for the last piece of this crowning achievement, the Higgs Boson, is a key purpose for the Large Hadron Collider at CERN, the European Organisation for Nuclear Research.

"A brain-child of the geometrisation of nature."

Humanity had reduced the fundamental laws of Nature into two sets of equations, from which all phenomena can, in principle, be derived: that of Einstein-Hilbert for gravity (characterising the macrocosmos), and that of the Standard-Model (describing the microcosmos). It is only natural that the marriage of these two, each of which can be written compactly in a few lines, would be the answer, the TOE. Sadly, naïve attempts to do so baffled even Einstein's last years: an infinite number of uncancellable infinities became the last great hurdle to a quantum description of gravity.

Enter String Theory. By the 1980s, theoretical and mathematical physicists stumbled on an apparent way out. It constituted a paradigm shift in the understanding of the world, just as Quantum Mechanics' interpretation of the wave-like nature of fundamental particles had before it. The theory proposed that the problem of infinities in quantum gravity was because we had inherently assumed (and had done so since Newton) that elementary particles were point-like. What is the essential size of the photon? Even the practitioners of Quantum Theory would have answered: zero. However, it is precisely this innocent assumption which caused the untameable infinities: by allowing interactions at a single point in space-time, energy was allowed to be concentrated at zero volume. As we recall from our childhood lessons, division by zero is problematic!

Smear the point out. Extending a point, an object of zero-dimension, gives a one-dimensional object, a line, which could be either closed into a loop or open like a segment. This line is the superstring, the fundamental constituent of everything, an indivisiable entity in its truest sense. With this single generalization, the infinities were cured and a consistent quantum theory of gravity emerged. Indeed all particles, all forces and interactions, and in fact, space-time itself became different vibrational modes of the string. All of reality is reduced to a cosmic string symphony, resonating harmoniously to give the rhythms of space, time, and matter.

So, are we done? Do we then have the ultimate TOE? Is the response to Einstein's dream or Newton's *Principia* this inevitable musical *leitmotif*? Not quite yet. The unification theory of superstrings only works in ten dimensions of space-time, rather than our familiar four dimensions (three of space and one of time). On the one hand, this is interesting: it is the first time a scientific theory has predicted the dimensionality of space-time. On the other hand, where did the six extra dimensions go?

One standard answer is that they are curled up, simply too small to see. It is like an ant crawling along a drinking-straw which looks as if it is moving only in the one dimension of the straw's length. However, upon closer inspection, we would see that the ant can also loop around the tiny circular cross-section, and would consequently detect two more dimensions. So, how small are these six curled-up dimensions?

"String theory has revolutionised pure mathematics."

Indeed, how big is the string? It surely must be much smaller than the atomic scale, or any scale we have so far probed, because we have not yet seen particles manifesting as strings. This question simultaneously invigorates and daunts us: it represents a conceptual break-through, and an experimental nightmare. The universe has a natural length scale, the so-called Planck Length, at which the strengths of gravity and quantum forces become comparable. This provides us with a natural length-scale for the string. The downside, however, is that this length is some 16 orders of magnitude smaller than anything we have yet observed, and far smaller than anything we are likely to ever directly measure.

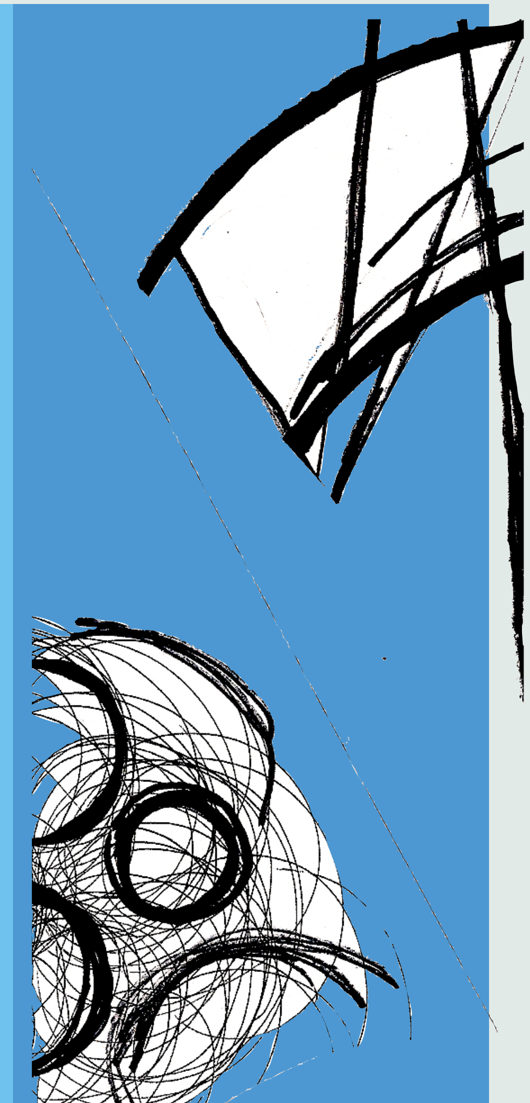
The theoretical picture is nevertheless clear: we have tiny superstrings of Planckian size vibrating in ten-dimensions, six of which are curled up to about the same magnitude. The geometry and topology of how these dimensions are curled up determine the physical observables of our large-scale four-dimensional Universe. There has been an increasingly successful theme of geometrisation of fundamental physics over the past century. This builds upon Einstein's realisation that gravity is the result of the geometrical properties of the space-time continuum, as well as C.N. Yang's insight that the quantum world of the Standard Model is described by a field of geometry known as bundles and manifolds. The geometrical nature of String Theory would stand as the pinnacle of this tradition. Indeed, as Plato said, "God is a geometer."

Short of experimental evidence (CERN is, however, looking for supersymmetry, a cornerstone to String Theory), why, you ask, is there so much effort invested? Though we should remain optimistically sceptical as physicists, as mathematicians, the answer is clear: the theory is beautiful. Aesthetics aside, history has taught us a peculiar and awe-inspiring characteristic of theoretical physics: theories with mathematical elegance tend to be correct. When Maxwell added a term to make his equations look symmetric, he did so purely out of the need for beauty. That term was measured within a decade. When Dirac predicted the existence of the positron, he did so for the sake of making his equation more elegant. The positron (the antiparticle of the electron) was detected shortly afterwards. Examples of this compulsion for mathematical structure in a theory predating the experimental verification abound; though we need not take Dirac's rather extreme viewpoint that "it is more important to have beauty in one's equations than to have them fit experiment".

And the theory does indeed possess mathematical beauty! A brain-child of the geometrisation of nature, in an almost unprecedented manner, String Theory has revolutionised pure mathematics. It has solved problems which bemused geometers, it has inspired new perspectives on algebra and number theory, and it has given physical insight to the most abstruse and pure branches of mathematics. This musical dialogue between physicists and mathematicians over the last few decades could only be compared to the Golden Ages when Newton conceived of calculus for classical mechanics, when Einstein breathed life into Riemann's geometry, or when abstract algebra and formulations of quantum theory danced their inseparable duet.

"The unification theory of superstrings only works in ten dimensions of space-time..."

Indeed, as Edward Witten, the torch-bearer of String Theory and only physicist to ever have the distinction of winning the Fields Medal, wisely said: "String Theory



is a piece of 21st century mathematics which accidentally fell into the 20th century." Now, in this new century, we hope that clever experimentalists will find some ingenious, indirect way of measuring stringy effects and that the theory will continue to blossom. As a field of mathematics, it has already justified itself, and we shall expect it to flourish as a field of physics.

Ludwig van Beethoven wrote the cryptic words, "Müß es Sein?" – "Must it be so?" - on top of his last string quartet. It is our wish that, to the divinely beautiful theme of our cosmic string quartet, where reality manifests as the sublime melody trembling on superstrings, our response would be a resounding "Es müß Sein" - "It must be so."

Words: Yang-Hui He
Art: Holly Rouse-Sweeney

Modern Day Newtons

How today's scientific high-fliers have made it to the top

Ask anyone to name a scientist and you'll probably get a few predictable answers: Einstein, Newton, Darwin. But how many would be able to name a living, researching scientist? In August 2009 a survey found that 65% of Americans couldn't, and a further 18% got it wrong.

Scientific research has exploded since Newton's day, making it tough to stand out from the crowd. Does the key to enduring fame lie in engaging in the world of business and exploiting the media frenzy? We take a look at some of the world's most renowned scientists to see how they have made it to the top.

Vilayanur S. Ramachandran

Listed by *Newsweek* as one of the most prominent scientists to watch in the 21st century, chances are that you have already come across Ramachandran's work. He studies the kind of disease that the entertainment industry loves: neurological syndromes. In these a small part of the brain does not work as it should, causing the patient to experience bizarre symptoms such as phantom limbs.

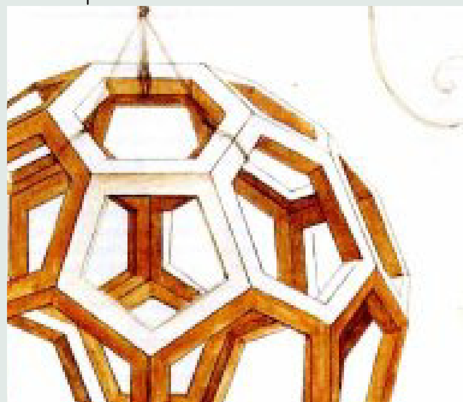
This phenomenon occurs when a person has had a limb amputated, yet still vividly feels its presence, commonly resulting in excruciating pain. Ramachandran realised that the key to understanding this pain was visual feedback. Patients with phantom limb pain often had the limb paralysed prior to amputation; every time the patient tried to move the limb they saw that they had failed. The brain 'learns' that the limb is paralysed and painful, and this carries over even after amputation.

So if visual cues cause the pain, could they cease it? Ramachandran created a 'mirror box' to test his theory: the patient places their real limb into one compartment, and the phantom limb into the other. A mirror between the compartments gives the impression that there is a real limb in place of the phantom limb so that when the patient moves their limb they see and feel the phantom move. Ramachandran gave the mirror box to his first patient, who had suffered ten years of agony. Two weeks later his phantom limb had 'disappeared'.

Paul Krugman

As Paul Krugman put it in a speech in 2007, economically speaking "we live in interesting times". It was in 1979 that Krugman invented the academic field of studying currency crises, and to quote the man himself "business has been good". Now a prominent blogger for the economist, Krugman is best known for his development of 'New Trade Theory', for which he won a Nobel prize in 2008.

Before Krugman, economists believed that countries traded because of their differences: tropical countries exported bananas, rich countries exported machinery. Krugman was unhappy with this theory— it didn't explain why, for example, Japan was so far ahead in the automobile industry, or why an industry might be concentrated in a specific location. Krugman suggested that tiny, almost accidental advantages became significant, and dictated the pattern of trade. His favourite example is that of a teenager in Georgia in 1895 making a tufted bedspread. One thing led to another, and now the carpet industry in the US is concentrated in Georgia. It doesn't seem that radical now, but it completely revolutionised the way we view our economy.



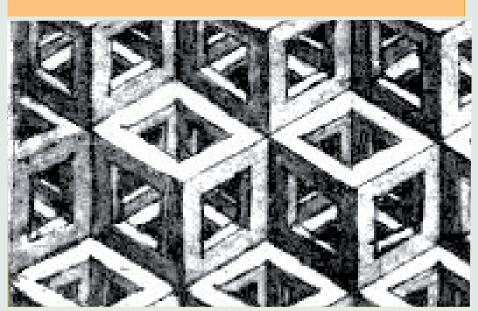
Craig Venter

Craig Venter is the founder of Celera Genomics, the company who led the private attempt to sequence the human genome, causing controversy along the way. Venter left Celera in 2002, and began conducting research in synthetic genomics.

The first success in this field was the creation of a synthetic chromosome which generates bacteria-killing viruses. Venter and his team designed small overlapping sections of DNA, stitched them together, and inserted them into *E. coli* bacteria. The synthetic chromosome then 'booted up' producing the virus and in doing so, killed the *E. coli*.

Venter believes that his work has many applications, most notably in the production of organisms that absorb carbon dioxide to slow climate change. However, he has been branded as an "opportunistic maniac" for never paying much heed to ethical issues and working on controversial and potentially dangerous enterprises. A maverick of science, Venter was the first person to have his DNA sequence analysed, something which others felt had severe moral implications.

Words: Bryony Frost
Art: Holly Rouse-Sweeney



Sci Phi

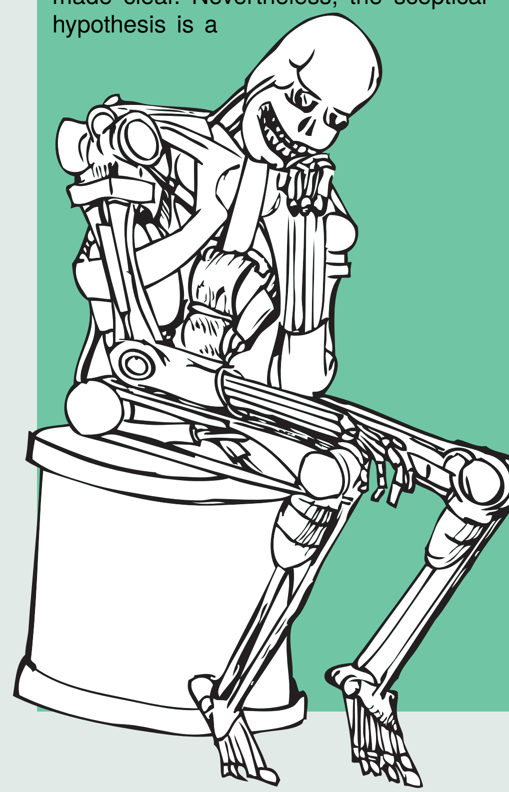
The philosophical conundrums posed by sci-fi films

Ah, sci-fi – favoured genre of nerds everywhere. But what you may not have realised, in the midst of all the blue-skinned aliens and questionably under-vowelled proper names, is that sci-fi is an unusually good genre for doing philosophy with. Freed from technological constraints, authors can ask questions that go to the heart of what we think about the world and realise characters who push the boundaries of what we understand being human to be. And then they can have a space war! What's not to love?

The Matrix (1999): the Sceptical Hypothesis

"Have you ever had a dream... that you were so sure was real? What if you were unable to wake from that dream? How would you tell the difference between the dream world and the real world?"

Wise words from Morpheus there, as he follows in an epistemological tradition going back some 300 years to the founder of modern Western philosophy: René Descartes. In his *Meditations on First Philosophy* (1641), Descartes considers the idea that "some evil demon of the utmost power and cunning has employed all his energies to deceive me", by feeding him false illusions of what the world is like. Whether the demon is doing this so as to harvest Descartes' bioenergy isn't made clear. Nevertheless, the sceptical hypothesis is a standard problem in determining what it is reasonable to believe, and Descartes' own response— "I think therefore I am"— has become one of the most instantly recognisable philosophical maxims.



The Terminator (1984): Time Travel

A question that has vexed critics for years: joyously overwrought cyborg-based thriller, or cunning thought experiment to explore the causal intricacies of time travel? Whether time travel is conceptually or physically possible has been a philosophical question for many years, and much intellectual energy has been expended on examining the various ways to avoid paradox. But the debate has heated up in recent years with the provision of a (sort of) plausible physical mechanism for time travel.

"Whether time travel is conceptually or physically possible has been a philosophical question for many years."

Certain solutions of the Einstein field equations (the equations that relate matter distributions to the shape of space-time) permit the existence of 'closed time-like curves'. These are paths in space-time which you could follow, ageing all the time, until you found yourself back at the same place and time that you started.

Whether such solutions actually describe the Universe is still up for debate and many argue that time travel is just inherently paradoxical. Consider The Terminator's own paradox: John sends Kyle back in time, who knocks up Sarah, who gives birth to John, who sends Kyle back in time, who knocks up Sarah, who...well, you get the point. Similarly, what would happen if you went back in time and prevented your own existence (or do like Terminator 2 and prevent the nuclear war)?

Despite his important contributions to the field, Arnold Schwarzenegger is sorely absent from the scientific literature.

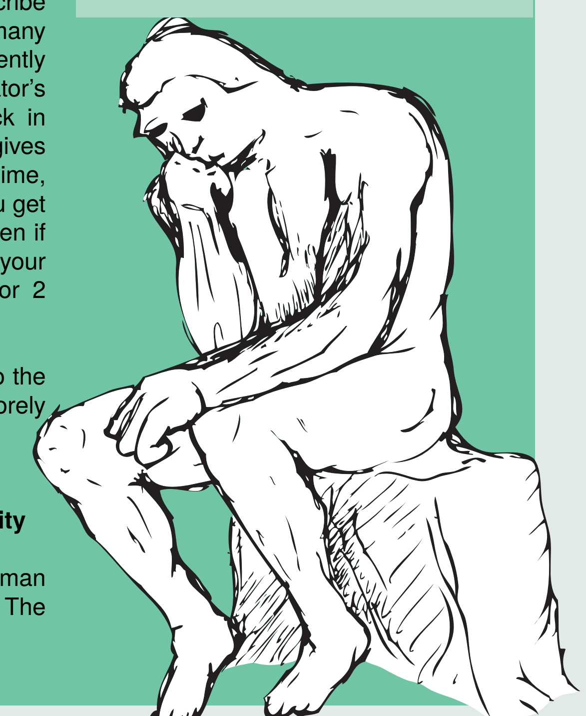
The 6th Day (2000): Personal Identity

Another Arnie classic here (the man obviously loves his metaphysics). The film follows Schwarzenegger as he plays a pilot who discovers he's been cloned against his will, and that the clone has taken up residence in his house. Many gunfights later, he discovers – gasp – that he is the clone. More gunfights follow, before he packs off so as not to get in the way of his original's family life.

Putting aside the film's other failings, it does a decent job of exploring what being a clone would be like— namely, that it would feel just like being the original. Is, then, the Arnie-clone the same person as the Arnie who was around until he got cloned? The film certainly thinks not: 'real' Arnie gets the wife, the kids and the house, while 'fake' Arnie goes to Argentina. But this conclusion seems problematic if we consider the scenario in which the original had been destroyed in the cloning process. Given someone who looks like Arnie, thinks like Arnie, has Arnie's memories and believes himself to be Arnie, the easiest thing is to say that he is Arnie.

Cases of cloning are difficult to deal with in common-sense terms. If you were told you were going to be cloned, and that one clone was going to be tortured and the other showered with gifts, what should you feel: apprehensive or overjoyed? Or both? Or neither?

Words: Neil Dewar
Art : Mark Ho



Beauty Lies in the Brain of the Beholder

Painting a new picture of the artistic world

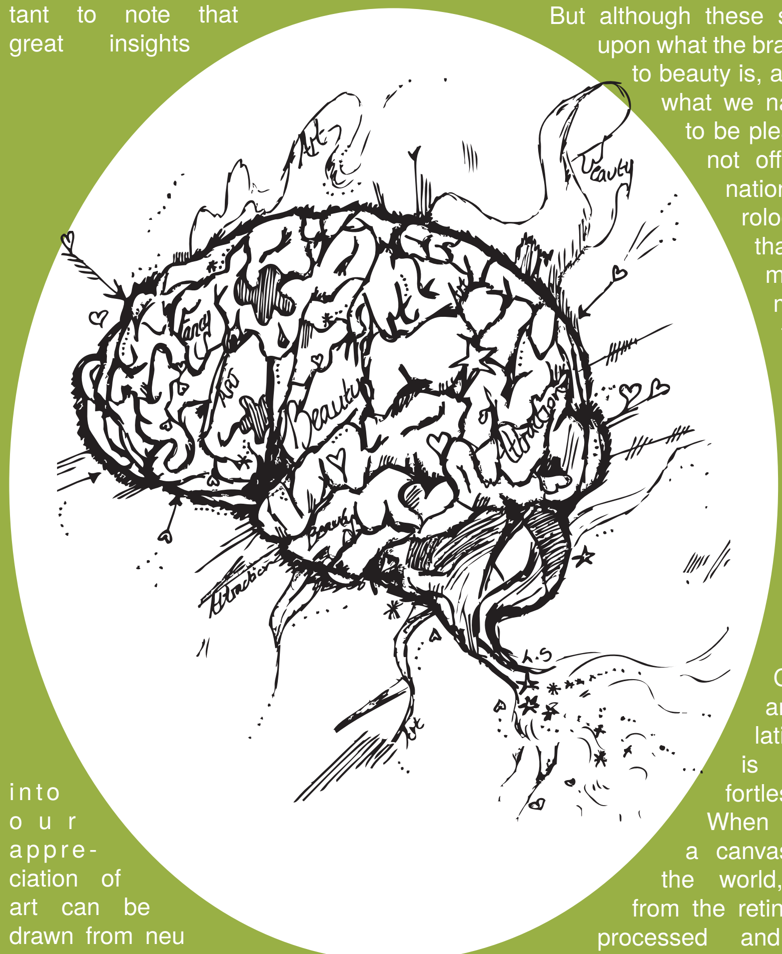
Why can a painting provoke emotion? What is the secret of the Mona Lisa's smile? What makes Mondrian's use of line so compelling? With advances in neurology, scientists claim that they hold the key to unlocking the secrets of art, beauty and even to define what makes artistic genius. Semir Zeki, Professor of Neurobiology at UCL, explains that this fusion of ethereal artistry and grounded science (which he terms "neuroaesthetics") is very logical: because human activity and experience, including art, is a product of the workings of the brain, they are also naturally subject to the restrictions and laws of neurology.

Using this principle, scientists are employing imaging techniques to discover which areas of the brain respond to beauty, what factors affect this and how the workings of our visual system impact the way that we interpret the world. By combining the responses of many individuals, neurologists believe they can expose a 'hidden grammar' inherent to all artistry. This may be used to explain the phenomenon of aesthetic appreciation and explain why, since the primitive etchings of cavemen, humans have been drawn to both create and appreciate art.

"...many discoveries found by neurologists have been employed by artists all along."

In order to understand what beauty is, we need to investigate how we respond to it. Initially, it was thought there might be a certain area of the brain activated in response to beauty that triggers the feeling of reward and appreciation. This was tested in recent experiments using functional MRI (fMRI). Neurologists exposed individuals to different images and asked them to judge whether or not they felt them to be beautiful. The machine was then able to highlight the areas of the brain that were especially active as the decision was being made. The results were surprising: there are not exclusively different areas in which activity provokes feelings of aesthetic appreciation or disgust. Instead, it is the relative activity of these areas that determine the response. For example, in the orbitofrontal cortex, pleasent images evoked a stronger response than ugly ones, while the reverse was true of the motor cortex. This finding is reasonable when you consider that appearances are judged on a continuous scale. However, since fMRI studies are not really delicate enough to show brain function on a neuron-to-neuron basis, neurologists suggest that important parts of the response remain hidden. Thus, there may still be specific neurons or areas that respond exclusively to beauty.

Despite the uncertainty surrounding the physiological response to beauty, it is important to note that great insights into our appreciation of art can be drawn from neurological studies.



One elegant investigation, using distorted images of Greek classical sculpture, was able to show preference for artwork displaying the 'golden ratio' (1:0.618), and also for symmetry. Since the volunteers were deemed to be critically naïve and results were fairly universal, they are indicative of standards that may be subconsciously used to appraise the world. Other research has revealed some mechanisms by which we relate to art; fMRI studies showed that when we regard sculptures, mirror neurons (used in learning) fire in the premotor cortex. This causes mimicking of the actions and sensations of the artistic subject, building an empathetic link between the art and the beholder that contributes to the aesthetic experience.

"By combining the responses of many individuals, neurologists believe they can expose a 'hidden grammar' inherent to all artistry..."

But although these studies touch upon what the brain's response to beauty is, and can tell us what we naturally judge to be pleasing, it does not offer an explanation why. Neurologists think that the answer may lie in the mechanisms that we use to view, learn from, and make sense of the world, as they play an important part in impression formation.

Contrary to ancient speculation, vision is not an effortless process. When we look at a canvas, or indeed the world, information from the retina is distilled, processed and compared, in order to decode what we see.

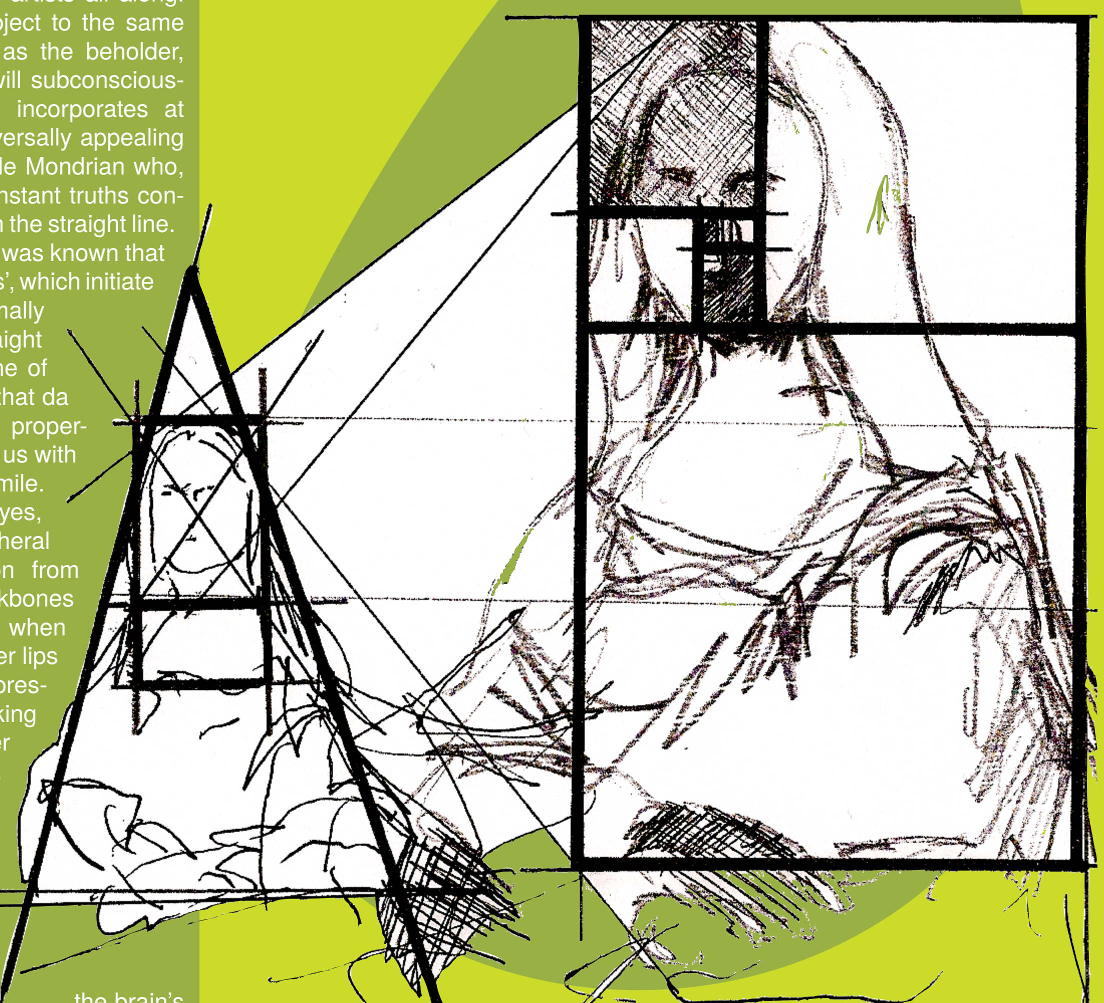
One important law of the visual system is that of constancy, which allows us to recognise our surroundings. Take for example a coffee cup: this will be seen in different lights, colours, positions and places, yet your brain will immediately recognise it. This is because the brain discards unnecessary 'noise' and takes the fundamental characteristics which will trigger specific cells to fire off in object recognition. In a sense, this distillation of an image down to the essentials is the role of an artist.

Thus a caricature, although not in proportion with reality, will elicit a faster, stronger response by 'deliberate hyperbole' to emphasise the features we use to determine somebody's identity. In his period of analytic Cubism, Pablo Picasso touched upon this aspect of brain function in his use of flat colour, multiple perspectives and exaggeration. These techniques gathered the essential and strongest characteristics of objects and subjects into his art, giving a cognitive impression more forceful than would be created by the real image itself. Conversely, the use of ambiguous or slightly unfinished artwork appeals to the brain by presenting a puzzle that the viewer can solve; it also allows the impression of the final image to be adjusted to satisfy the individual's preferences or ideals.

Perhaps unsurprisingly, it seems that many discoveries found by neurologists have been employed by artists all along. Since the creator is subject to the same neurological responses as the beholder, it follows that an artist will subconsciously produce work which incorporates at least some of these universally appealing themes. Take for example Mondrian who, in his search for "the constant truths concerning forms", settled on the straight line. He painted long before it was known that 'orientation selective cells', which initiate perception of form, optimally fire in response to a straight line. Margaret Livingstone of Harvard has postulated that da Vinci, too, exploited the properties of the retina to tease us with Mona Lisa's enigmatic smile. When we look at her eyes, our less accurate peripheral vision draws information from the shadows of her cheekbones and we see a smile. Yet, when our gaze is reverted to her lips we see an almost expressionless line, thus making the emotion of the sitter intriguingly ambiguous.

So, do neurological models provide real solutions? Or do they run the risk of trivialising masterpieces? Yes, Picasso's use of abstraction echoes the brain's perception of object permanence, but this theory disregards the strong revolutionary drive behind his painting. Yes, the Mona Lisa may smile because of the composition of your retina, but who was she, and why did Leonardo da Vinci feel the need to paint her? Does knowing that Monet had cataracts detract from the brilliance of his later work? Neuroaesthetics is still in its early stages, with broad sweeping statements hitting the press that, as of yet, have little evidence to back them up; there is a danger of distortion by oversimplification of complex principles. Just as scepticism should be employed if an artist were to diagnose your ailments, remember that current discoveries are as yet conjectures, and should be treated as such. Nevertheless, it cannot be denied that art and neurology are extensively linked, with art being an externalisation and expression of our inner selves, and neurology a study of the intrinsic mechanisms through which we function.

"The use of ambiguous or slightly unfinished artwork has also been shown to be appealing to the brain..."



Words: Anna Pouncey
Art: Louisa Stoppard & Max Gordon-Brown

The Poetry of Pi

"3.1 4159265358979..."

"How I need a drink, alcoholic of course, after the heavy lectures involving quantum mechanics."

The above is an example of a 'piem' or poem relating to π. The fundamental mathematical constant π is used in all manner of applications: from working out the volume of liquid in your can of coke to knowing how thinly to roll your dough to make the perfect pizza, π pops up all over the place, so it's often useful to know a few digits.

Piems are designed to help the reciter remember the consecutive digits of π: the number of letters within each word corresponds to the digits of π in order (a ten letter word is used whenever the digit zero occurs). A slightly longer attempt, the 'Cadaeic Cadenza' is a beautiful example of constrained writing whose words, in order, correspond to the first 3834 digits of π. As if writing to the digits of π were not restriction enough, the Cadenza's author, Mike Keith, also attemps to mimic portions of famous literary works such as Edgar Allan Poe's *The Raven* and *Jabberwocky* by Lewis Carroll. The first lines read:

"One. A Poem. A Raven.
Midnights so dreary, tired and weary,
Silently pondering volumes extolling
all by-now obsolete lore.
During my rather long nap– the weirdest tap!
An ominous vibrating sound disturbing my chamber's antedoor.
'This', I whispered quietly,
'I ignore'."

Memorising these lines makes the challenge of recalling the first 41 digits of π significantly easier:
3.14159265358979323846264338327950288419716 . . .

The word 'Cadaeic' itself corresponds to the first seven digits of π with 'A' corresponding to 1, 'B' to 2, 'C' to 3 and so on. Piems are a popular way, for those who have the time and patience, to memorise the digits of π. Chinese graduate student Lu Choa currently holds the Guinness world record, having recited 67,890 digits of π without mistake.

"Who needs an infinity of monkeys when you have π?"

Reciting the digits of π is almost as much a task of endurance as it is of memory: the 67, 890th digit Choa recalled coming over 24 hours after the first. However there is more to this intriguing constant than the challenge of recall; π has been found by mathematicians and scientists in the equations that govern the fundamental dynamics of the Universe. Heisenberg uses π in his uncertainty principle relating to Quantum Mechanics; Einstein in his field equations of General Relativity; Kepler in his third law of planetary motion. There are many other applications of π in diverse fields such as probability theory, the physics of electromagnetism and the study of complex numbers to name but a few. This in itself raises the question of how one goes about calculating the digits of π?

Early approximations to π have been found in ancient architecture. The Great Pyramid at Giza was built deliberately with a base perimeter of 1760 cubits and a height of 280 cubits giving an approximate ratio of perimeter to height of 2π. Even the Bible has a claim to an early approximation to π. The following passage can be found in the book of Kings relating to the construction of the 'sea of cast bronze' in the temple of Solomon

"And he made a molten sea of ten cubits from brim to brim ... and a line of thirty cubits did compass it round about."

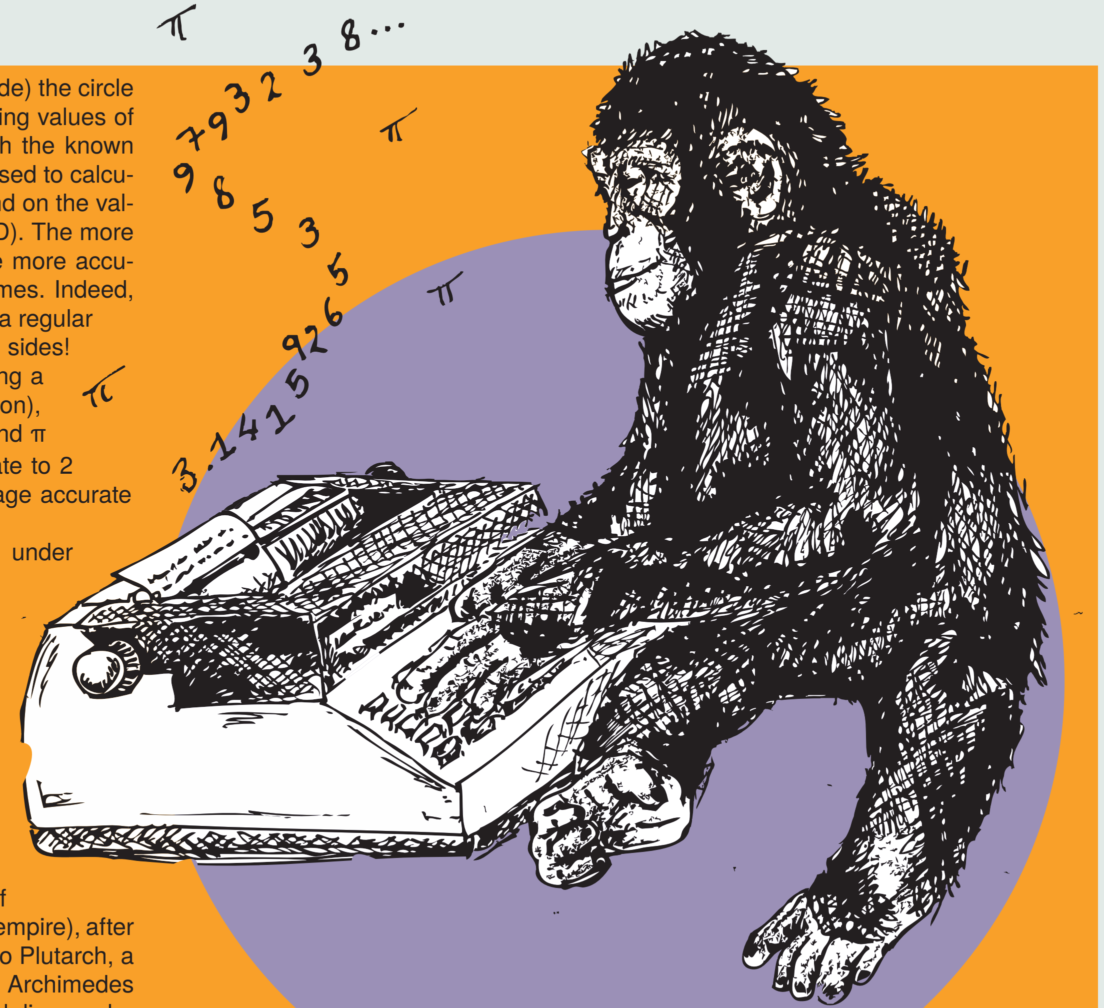
This estimate of π=3 is, however, notably worse than other available estimates at the time. Other primitive fractional approximations to π include the well known $^{22}/_{7}$ (accurate to 2 decimal places) and the less well known $^{333}/_{106}$ (accurate to 4 decimal places). In stark contrast to these earlier estimates, Fabrice Bellard, a French computer programmer, recently calculated π to almost 2.7 trillion (2,700,000,000,000) digits using only his desktop computer, as opposed to the supercomputers that had been employed to find previous record numbers of digits.

Empirically, π can be approximated by drawing a large circle, measuring its circumference, C, and diameter, D, and dividing the former by the latter (using the formula π = C/D). To get more and more accuracy we have to draw bigger and bigger circles and we quickly run into practical difficulties, not only with drawing the circles but with measuring them to the necessary degree of accuracy.

"Even the Bible has an early approximation to π."

Another more pragmatic attempt, attributed to Archimedes and known as the 'method of exhaustion', focuses on bounding the value of π between two approximations. He calculated the perimeter of a regular n–sided polygon circumscribing (outside) the circle and that of a similar n–sided polygon inscribing (inside) the circle (see Figure 1). These bounding values of the circumference, along with the known diameter of the circle, were used to calculate an upper and lower bound on the values of π (again using π = C/D). The more sides the polygons have, the more accurate the approximation becomes. Indeed, a circle can be thought of as a regular polygon with infinitely many sides!
By the time of his death, using a polygon with 96 sides (a 96-gon), Archimedes was able to bound π between $^{310}/_{71}$ and $^{31}/_{7}$, accurate to 2 decimal places with an average accurate to three decimal places.
In ca. 212 BC the Romans, under the command of General Marcus Claudius Marcellus, finally conquered Archimedes' home town of Syracuse, on the island of Sicily (then part of the Greek empire), after a two year siege. According to Plutarch, a Roman soldier came across Archimedes contemplating a mathematical diagram he had drawn in the sand. The soldier commanded Archimedes to accompany him to meet General Marcellus, but Archimedes was so enthralled with his work that he simply replied "Do not disturb my circles". The Roman soldier was so enraged with Archimedes that he is alleged to have killed him on the spot.

"Do not disturb my circles."



It is often said that a monkey hitting keys at random for an infinitely long time will surely type a given text, such as the complete works of Shakespeare (of course when the experiment was attempted with six Celebes Crested Macaques their entire literary contribution over a month-long experiment was five pages of text consisting largely of the letter 'S'). The infinite monkeys theorem, as it is known, is of course a metaphor for an infinitely long sequence of randomly generated letters. Equivalently we could extend the idea of piems to sequences of digits that represented the length of every word in the English language (two digits instead of one would allow us to represent all words of length up to 100 letters). If π could be shown to be truly random, we would surely be able to find a piem that corresponded to the complete works of Shakespeare, or any other text you can think of. Who needs an infinity of monkeys when you have π?

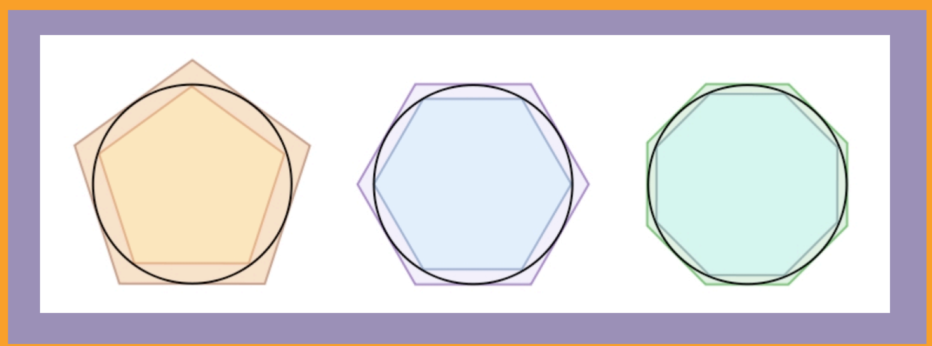


Figure 1: Archimedes' idea: pentagons, hexagons and octagons inscribing and circumscribing a circle. The more sides the polygons have the tighter the bounds on the perimeter of the circle and the better the approximation to π.

Words: Christian Yates
Art: Anna Pouncey

Embracing Empathy

The mysterious science of the mouth

It is often said that the first kiss is a make or break situation, a view which appears to extend beyond teenage neuroses. Scientific research suggests that there may be a good evolutionary reason for this pivotal peck. It turns out that kissing communicates a whole host of sensory information (smells, tastes, sound and tactile signals) that affect a couple's experience of each other and ultimately determines their level of mutual attraction.

In a survey of more than a thousand college students by Gordon Gallup, Professor of Psychology at the University of Albany, it was found that 59% of men and 66% of women reported that their attraction ended after the first kiss.

What's more, Gallup found that women tend to be attracted to partners with different immune system proteins than their own— a natural screening mechanism which leads to the creation of healthier children. It seems women are able to subconsciously detect these body proteins during a passionate kiss and this can instantly affect the attraction they feel.

"...that first kiss is truly as special as everyone believes."

The study further revealed that there are three distinct brain systems involved in mate choice and reproduction: sex drive, romantic love, and attachment. Sex drive initiates seeking partners, romantic love causes commitment, and attachment helps us last long enough to have a child. Kissing has evolved to stimulate all three of these systems. Since kissing can easily determine the early success or failure of a budding relationship, that first kiss is truly as special as everyone believes.

Who would have believed that yawning was actually contagious? Always thought of as an urban myth, one of those strange coincidences with no scientific basis, this little-studied fact may really be true. In most cases, you don't even need someone to yawn— you could just read about it or even hear someone yawn to set you off. Recent studies have shown that that this 'epidemic' is completely unconscious. The signals which cause yawning bypass the circuitry responsible for conscious behaviour, making this an 'automatically released' response.

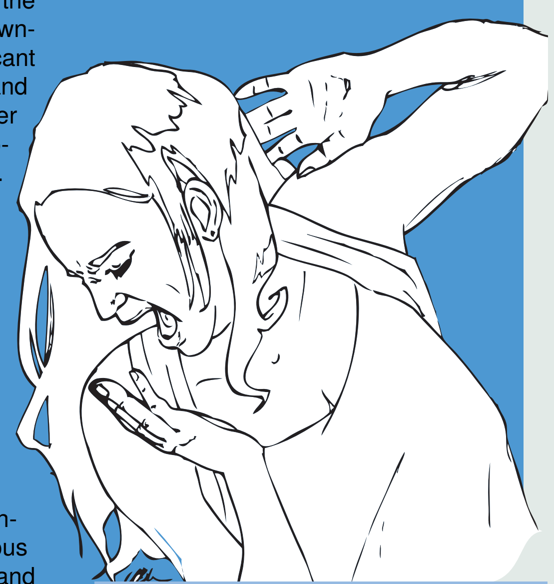
"Apparently, how contagious yawning can be depends on your 'empathy' quotient."

Scientists have connected this phenomenon with the personality of an individual. Apparently, how contagious yawning can be depends on your "empathy" quotient, the ability to understand and connect with the emotional state of others.

This theory has been tested experimentally by behavioural scientists at Leeds University where researchers selected 80 students of psychology and engineering. Each student was made to wait separately in a room, along with an undercover assistant who yawned ten times in as many minutes. The students were then given an "emotional quotient" test where they were shown images of eyes and asked what emotion each one displayed.

Interestingly, the results supported the idea of a link between contagious yawning and empathy. There was a significant difference between the psychology and engineering students, with the former scoring higher on the emotional quotient test and yawning more frequently. Less predictably, women, who are considered more emotionally sensitive than men, did not fare any better in the experiment. These results were strengthened further by brain imaging, showing that those parts of the brain associated with empathy were also associated with yawning, thereby establishing a direct correlation between the two.

The exact reason for this link is unclear but it is possible that contagious yawning may have helped animals and humans early in evolutionary history to convey emotions and information to each other. Indeed, yawning is a phenomenon observed across the animal kingdom— investigations are currently being undertaken on higher primates, such as chimpanzees. By helping to synchronize group behaviour, contagious yawning may have been an essential instinctive feature in the development of our species.



Words: Madhumitia Venkaaramanan
Art: Genevieve Edwards

350 Years of Blue Skies

The colourful history and continuing importance of the Royal Society

This year the Royal Society celebrates its 350th anniversary alongside the 400th anniversary of Wadham College. Independent though they may seem, the links between these two admirable institutions run deep: the roots of the Society were planted in Wadham's gardens by erstwhile warden Dr John Wilkins and his experimental science club.

Wilkins' group of 'amateur' gentleman scientists (including notables such as Robert Boyle and Christopher Wren) invented flying contraptions, transparent beehives and rainbow machines much to the amusement of College guests. Oxford became the setting for the new experimental philosophy, rejecting Aristotelian theoretical science in favour Francis Bacon's recent empirical methods. Meeting in coffee shops that still stand today, they would discuss their latest scientific research— from the nature of air to the practicalities of Wilkins' proposed flight to the moon in a wooden 'chariot' propelled by gunpowder, feather wings and springs.

Despite the frivolous and even absurd nature of some of these proposals and inventions, Wilkins' motives were largely practical: convinced the moon was inhabited, Wilkins was determined to set up trade links. More mundanely, transparent beehives revealed the mysterious processes of honey production. It was the suggestion of similarly practical, and potentially profitable, ventures that led to Charles II financially backing the Society. The founding members, including many of Wilkins' group, were confident that their research would bring about great innovations in technology and trade.

Research projects were unregulated, and as such, the Society was often criticised for wasting time on frivolous and futile experiments. Jonathan Swift, author of *Gulliver's Travels*, famously parodied the experimental philosophers, describing one member's fictional eight year struggle on a "project for extracting sunbeams out of cucumbers". But out of this jumble of curiosity driven investigation came groundbreaking work on geomagnetism, vital to navigation, and the creation of novel materials, employed in the rebuilding of London following the Great Fire of 1666.

In retrospect, the huge social and economic impact of such research is blindingly obvious, but it is often unapparent at the outset: Faraday's work in electromagnetic induction led to the commercial production of electricity— but only sixty years later. It is the unforeseen potential of unlikely ideas that most often leads to great scientific discoveries both in terms of financial payback and contribution to knowledge.

Today this message seems to be lost on government officials who last October announced that from 2012 a quarter of all research proposals would be judged on their potential "economic and social impact"— an impossibility if history is anything to go by.

"..flying contraptions, transparent beehives and rainbow machines.."

This misunderstanding of the scientific method was also inherent in a speech at the BA Science Festival by Sir David King, Director of Oxford's Smith School of Enterprise and Environment. He declared the money spent on the new Large Hadron Collider at CERN (The European Organization for Nuclear Research) would have been better directed at climate change and health science. Though the search for the Higgs boson may seem unjustifiable in the face of widespread epidemic diseases and environmental catastrophes, King's remark neglected the unforeseen social and economic impacts produced at CERN in its quest for an understanding of nature's fundamental particles.

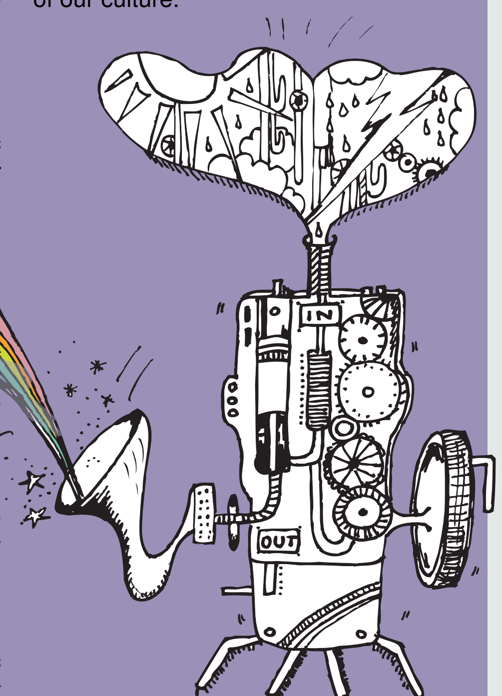
While at CERN, Oxford alumnus Sir Tim Berners-Lee created the internet because of the need for a communication network capable of supporting such a large scale scientific collaboration. Similarly, the unprecedented size of magnets needed to bend the particle beams at CERN required the development of sophisticated cooling technology. This is now being applied to the development of fusion reactors, likely to become an important source of clean energy.

Alongside the history of scientific discovery at the Society, the government could learn a thing or two from the Society's current funding policy. Realising the potential of unrestricted research they fund University Research Fellows for up to ten years at a time, providing the freedom to take investigative risks without the fear of funding reprisals. Last year's Fellows worked on projects ranging from the search for life on Mars to predicting the evolution of the influenza virus.

More than this, the Society understands the need for 'blue skies' research in breeding tomorrow's scientists. Young people with the imagination and talent to make great scientific discoveries will not put in the hard work required to grasp a technically difficult subject because it is useful, but because it inspires them.

In today's society there is an increasing dependence of social and political issues on science. As a result, it is vital that the public are able make informed decisions through an understanding of this science and the methodology from which it arose. The Society plays an important role in this education, engaging individuals through outreach events and debates.

In the year of its 350th anniversary the Royal Society continues to promote scientific education and facilitate creative, extraordinary research. In doing so, it leads the way in fostering science as part of our culture.



Words: Thomas Lewton
Art: Lousia Stoppard

Ask a Lecturer

We get Oxford dons to moot on your musings

What would happen if I fell into a black hole?

If you're determined to do this, it's going to be a one-way trip, so choose your black hole carefully. Avoid those in quasars—you will be fried by radiation or relativistic plasma long before you reach the black hole. Head instead for the centre of the Milky Way, where a black hole three million times the mass of the Sun lies dark and quiet. At a safe distance, you see from your spacecraft a black patch on the sky, about ten million kilometres in radius. At its edges the light from background stars is distorted into arcs and rings. Turn off the engines and you begin to accelerate inwards: initially you won't feel anything, being in free-fall. The hole in front remains dark, but the sky behind remains visible. As you cross into the dark region, the friends you leave behind see your image becoming redder, and fainter, and moving more and more slowly. However you experience nothing overtly dramatic: you can still see the outside world behind, but from now on, you can never get back out. And you only have about five seconds left to live.

When you get to within a few hundred thousand kilometres of the centre of the black hole, gravity is strengthening so quickly that your feet are being pulled towards the centre much more strongly than your head. Within microseconds, your body will be stretched out by this tidal force into a thin stream of matter. You have been spaghettified; this is the end.

Your mortal remains will crash into the centre of the black hole within the next second or so. All 10^{40} kilograms that comprise the black hole's mass are concentrated here, in a form that lies beyond our understanding. Einstein's equations of General Relativity no longer work here; we need a theory of quantum gravity, the creation of which is the job of future physicists. Provided they are sensible enough to avoid direct experimentation with black holes.

Dr Garret Cotter

How can bees fly with such big bodies, yet such little wings?

The myth that bumblebees can't fly because their wings are too small for their bodies was started in 1919 by Wilhelm Hoff, head of the German Aircraft Establishment during the First World War. Applying the fixed-wing aerodynamics of aeroplane flight, he used data from biologist Reinhardt Demoll to estimate that the bumblebee's wings would be too small to carry its weight.

Ignoring flapping was the problem. Almost one hundred years later, we now know how bumblebees flapping wings work: they independently force the air downwards on each side of the body. This is perhaps no surprise given the width of bumblebee bodies, but it is unusual in that it is an extremely inefficient means of lift-generation.

However, bumblebees don't care too much about efficiency in their role as collector and deliverer of nature's richest natural fuel: nectar. Rather, what matters most is the ability to manoeuvre rapidly between flowers and carry a large load of nectar back to the hive. Their independent-wing flight strategy allows them to generate more than enough force for flight while radically simplifying the control problem.

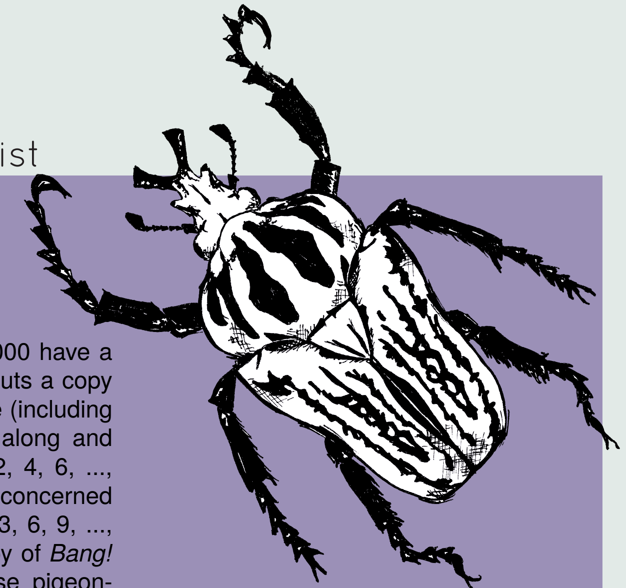
Current research in the Animal Flight Group of Oxford University's Zoology Department is focussed on the variation in aerodynamic mechanisms across a vast array of different insect flight-designs, and on aerodynamic control in hover-flies, hawkmoths, hawks, falcons and eagles.

Professor Adrian Thomas

Art: Anna Pouncey

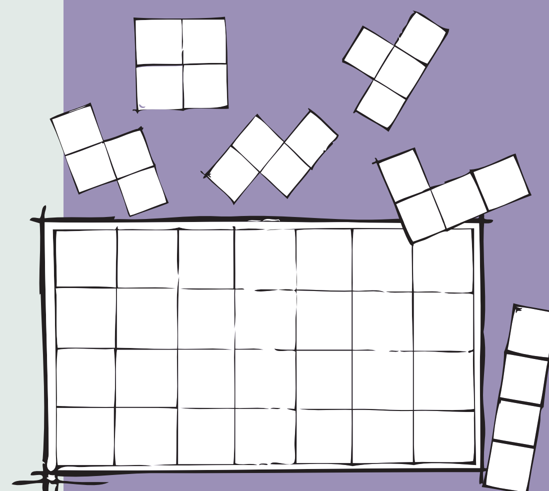
Riddler's Digest

Cerebral amusement for the modern scientist



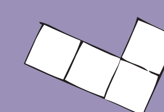
Tetris revisited

The game of Tetris involves the following seven tetrominoes, each made up of four square blocks: I, O, T, J, L, Z, S. Assuming each square block to have unit area and given a 4 × 7 rectangle that is made up of such blocks, is it possible to fit one tetromino of each kind into the rectangle?



Lucky numbers

Students 1, 2, ..., 999 and 1000 have a pigeonhole each. Student 1 puts a copy of *Bang!* into each pigeonhole (including her own). Student 2 comes along and empties the pigeonholes of 2, 4, 6, ..., 998 and 1000. Student 3 is concerned only with the pigeonholes of 3, 6, 9, ..., 996 and 999. She puts a copy of *Bang!* into each empty one of these pigeonholes but empties any pigeonhole that already contains a copy. Student 4 follows suit, checking out pigeon holes 4, 8, 12, and so on. One by one, students 5, 6, ..., 998 and 999 all drop by and deal with the appropriate pigeon holes until, finally, student 1000 shows up to find (as it turns out) a copy of *Bang!* in her pigeonhole, which she takes.

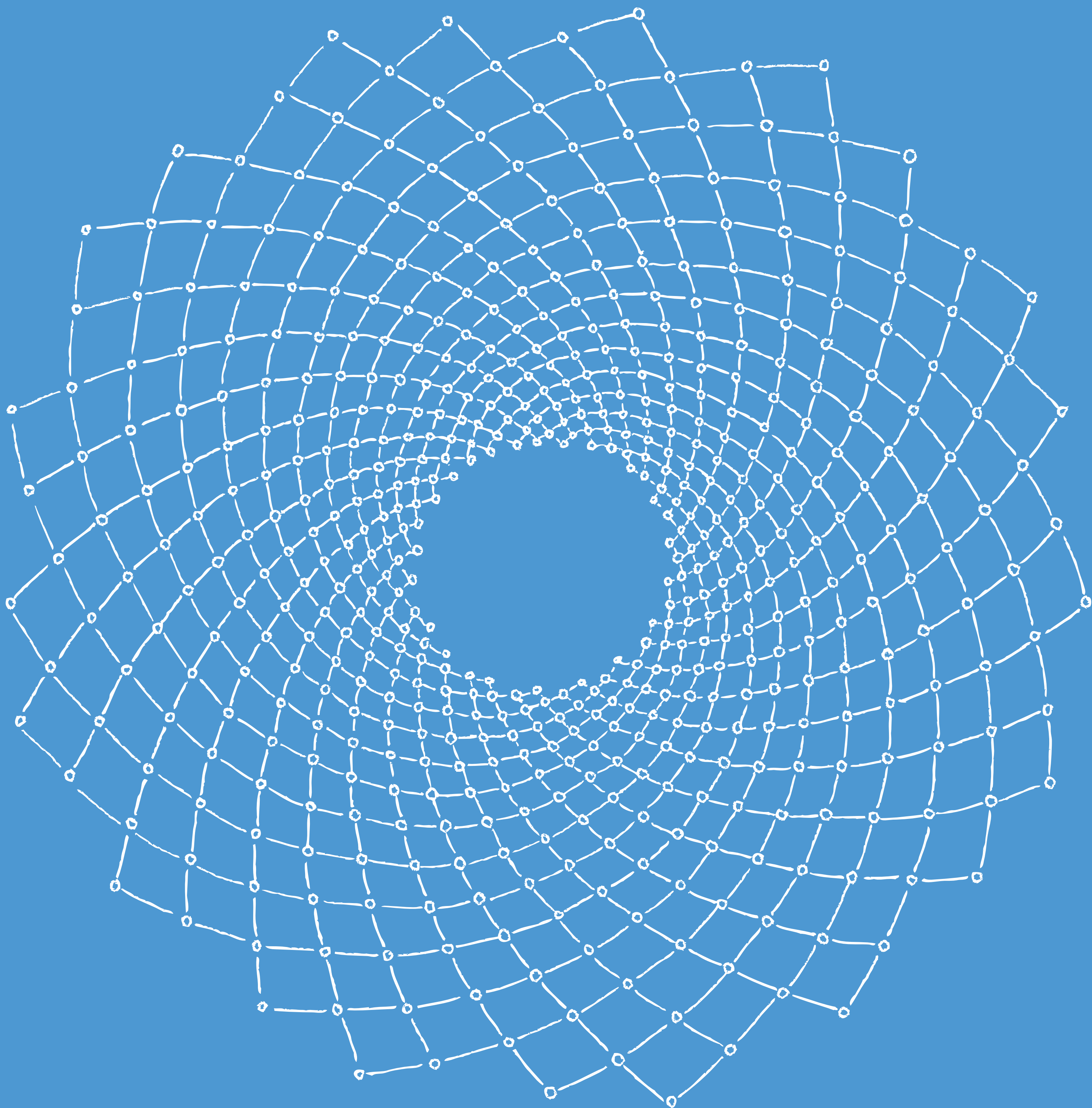


How many of the pigeonholes now contain a copy of *Bang!*?

The beetles

Four beetles, A,B,C and D, are placed on the corners of an a×a square. All beetles start moving at the same moment and each walks straight towards the beetle ahead of them (A walks straight at B, B walks straight at C, etc). If all beetles travel at the same speed, how far will each have travelled by the time they meet?

Words: David Seifert
Art: Anna Pouncey



www.bangscience.org