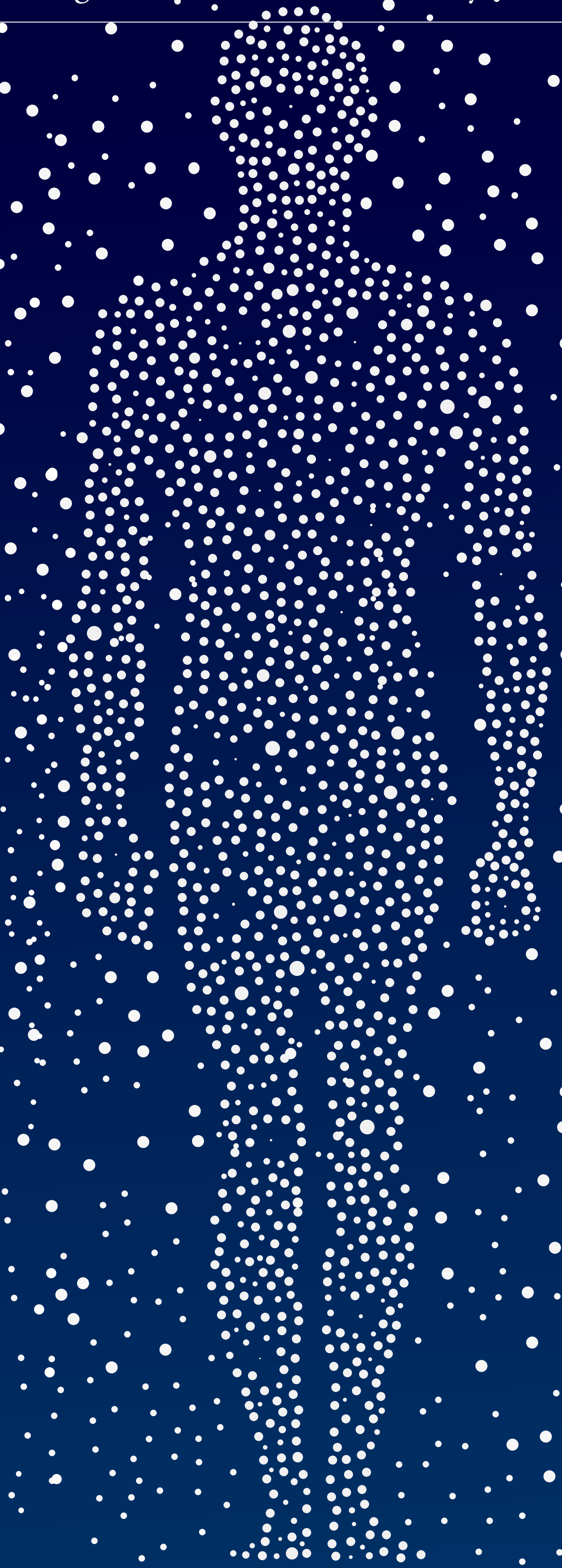
Research

Horizons

Pioneering research from the University of Cambridge



Issue 26

UNIVERSITY OF CAMBRIDGE
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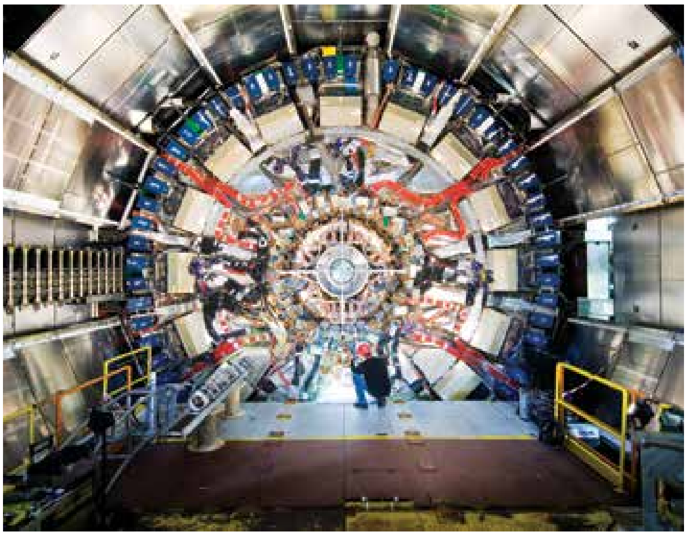

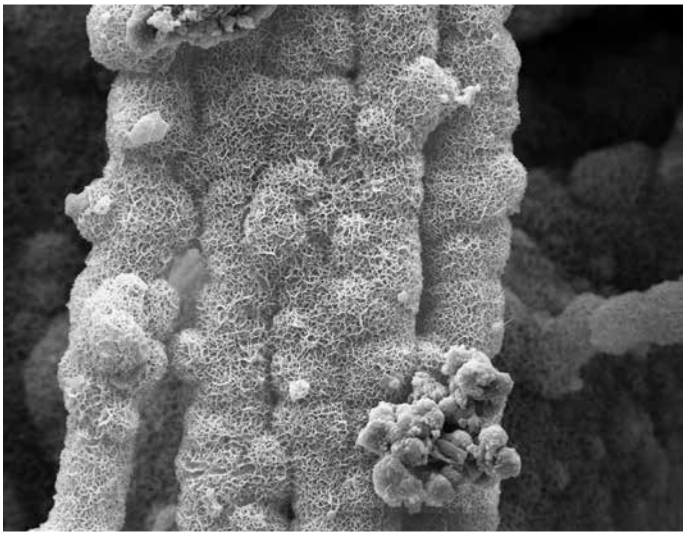

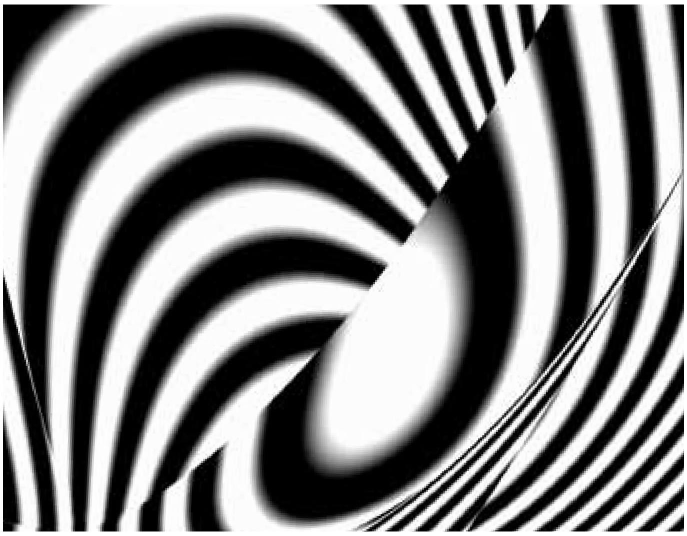

Welcome

If there's one thing that Cambridge has always excelled in, it's finding new ways of looking at the world. And now, this is quite literally true. Here we focus on research that's been enabled by the ability to explore far beyond what the eye can see. From visualising microscopic cells to massive galaxies, imaging is a core tool for many research fields today, and it's also the basis of a surge in recent technical developments – some of which are being pioneered in Cambridge.

Much of the excitement around imaging is linked to its remarkably cross-disciplinary nature. We are seeing biologists working with physicists and mathematicians, chemists with art conservators, astronomers with clinicians. Central to these activities is the development of imaging techniques and the interpretation of the images obtained. Cambridge has huge strengths in these areas.

As imaging becomes more complex, the information we gather becomes greater. A single experiment can generate terabytes of data, requiring complex mathematical algorithms to make sense of it all. 'Big data' issues are now so frequent in imaging, as well as in other fields, that last year we launched a University-wide Strategic Research Initiative in Big Data – a topic we'll be covering in the next issue of *Research Horizons*.

In this issue, we also cover the Large Hadron Collider (LHC), itself a prolific generator of data. Following the discovery of the Higgs boson, the LHC has been shut down for two years to upgrade and is now being prepared for its second run by scientists, Cambridge researchers among them.

Finally, do take a look at our website (www.cam.ac.uk/research). There you will find many other research stories, as well as the films and audio slideshows that accompany some of the articles in this issue: hear the unique sounds of a Ugandan street language, see some of the results of a microscopy 'revolution in resolution' and take a trip back in time to hear about a 1930s fungi expert whose research actually took to the air. We hope you enjoy this issue.

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News

Credit: Colin Shaw

Internal secrets

A new imaging facility offers researchers in Cambridge and beyond the chance to see what lies within objects, without breaking them open.

Image
High-resolution CT image

The Cambridge Biotomography Centre (CBC), which launched early in 2015, houses the latest high-resolution computed tomography (CT) scanner available on the market. One of only a handful in the country, the CT scanner uses X-rays to measure density differences within objects, generating a precise three-dimensional reconstruction of the internal and external architecture of almost any object or specimen.

Already being used to scan everything from ancient Egyptian leg bones and fossils hidden inside rocks, to the muscle and skeletons within dead rats, the facility has been launched with the intention of providing not just Cambridge researchers but also the wider international research community with the chance to unlock their material's closely held secrets.

"Although CT is frequently used in hospitals, this type of imaging has only recently become available to researchers," explained Dr Colin Shaw, one of the leaders of the facility.

His work in the Department of Archaeology and Anthropology is analysing the behaviour of our prehistoric ancestors through the analysis of their bones. "A continuum of different behaviours that stretches from couch potato to ultramarathon runner puts stresses and strains on bones which can be measured to reconstruct what our lives were like in the past," he explained.

However, the information is hidden deep within the honeycomb-like structure of the bone itself, and the ancient remains he studies are too precious to be broken open. "For objects like these, the ability to do this non-invasively without cutting or slicing is a real benefit," he added. "It means we can carry on studying the object long after the measurements have been made."

The CBC (www.cbc.zoo.cam.ac.uk) is one of several new developments in imaging happening across the University… see our Spotlight section later in this issue.

REF confirms Cambridge's global research strengths

Almost nine out of ten of Cambridge's submissions for the 2014 Research Excellence Framework (REF) were rated 'world leading' or 'internationally excellent'.

The results of the REF, which assesses the quality and impact of research at UK universities, showed that 47% of Cambridge's submissions were awarded the highest rating of 4* overall ('world leading'), an increase from 32% in 2008. A further 40% of submissions were rated 3* ('internationally excellent').

"These results demonstrate Cambridge's strength in depth across research, in particular confirming our global leadership in the pure and applied sciences, clinical medicine, and in subjects as diverse as the classics, and business and management studies," said Professor Sir Leszek Borysiewicz, Vice-Chancellor of the University.

For the purpose of the REF, each academic discipline is assigned to a 'unit of assessment'. Each unit is judged by three criteria – Outputs, Environment and, for the first time, Impact (defined as 'an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia'). The results are used by the four UK higher education funding bodies to allocate block-grant research funding to universities.

Among the case studies submitted by Cambridge for Impact was research that led to Lemtrada, a new drug to treat multiple sclerosis. The drug is based on a long-standing programme of research at the University, and in 2014 it received approval by the National Institute for Health and Care Excellence.

www.cam.ac.uk/research/impact

News in brief

More information at www.cam.ac.uk/research

28.01.15

Cambridge is one of five universities to lead the Alan Turing Institute on advanced mathematics, computer science, algorithms and 'Big Data'.

14.01.15

A daily short walk reduces the risk of early death, finds a study showing that lack of exercise causes twice as many deaths as obesity.

Michelangelo bronzes discovered

It was thought that no bronzes by Michelangelo had survived – now experts believe they have found not one, but two.

They are naked, beautiful, muscular and ride triumphantly on two ferocious panthers. And now the secret of who created these magnificent metre-high bronze male nudes could well be solved.

A team of international experts led by the University of Cambridge and Fitzwilliam Museum has gathered compelling evidence that argues that these masterpieces, which have spent over a century in relative obscurity, are early works by Michelangelo, made just after he completed the marble David and as he was about to embark on the Sistine Chapel ceiling.

If the attribution is correct, they are the only surviving Michelangelo bronzes in the world.

Their first recorded attribution was to Michelangelo when they appeared in the collection of Adolphe de Rothschild in the 19th century. But, since they are undocumented and unsigned, this attribution was dismissed and over the past 120 years, the bronzes have been attributed to various other talented sculptors.

Credit: The Fitzwilliam Museum

Image
Newly attributed Michelangelo bronzes

That changed last autumn when Paul Joannides, Emeritus Professor of Art History at the University of Cambridge, connected them to a drawing – now in the Musée Fabre, Montpellier, France. The sketch, by one of Michelangelo's apprentices, was of a muscular youth riding a panther, and suggested that Michelangelo was developing the idea for a work in three dimensions.

Dr Victoria Avery, Keeper of the Applied Arts Department of the Fitzwilliam Museum, said: "It has been fantastically exciting to have been able to participate in this ground-breaking project, which has involved input from many art historians in the UK, Europe and the States, and to draw on evidence from conservation scientists and anatomists. The bronzes are exceptionally powerful and compelling works of art that deserve close-up study – we hope the public will come and examine them for themselves, and engage with this ongoing debate."

www.fitzmuseum.cam.ac.uk

New cancer drug granted approval

A new drug for ovarian cancer developed by Cambridge researchers and AstraZeneca is approved.

Lynparza is the first of a new class of drugs known as PARP-inhibitors to be granted approval anywhere in the world. The drug, which inhibits the action of an enzyme that helps repair DNA, has been granted Marketing Authorisation from the European Commission.

The research that led to the development of the drug began in the mid-1990s in the lab of Professor Steve Jackson at Cambridge's Wellcome Trust/Cancer Research UK Gurdon Institute. It led to the launch of a University spinout company, KuDOS, which was acquired by pharmaceutical giant AstraZeneca in early 2006.

"This is a success story both for basic science and for UK scientific innovation," said Jackson. "The initial development of Lynparza would not have been possible without the freedom to pursue our own ideas, driven by our own curiosity, supported by charitable funding. Through our links to industry, this research has led to a considerable commercial opportunity for a UK-based company and a drug that will extend and enhance the lives of various cancer sufferers.

"Unlike traditional anti-cancer drugs, it makes the cancer cells – not the normal cells of the patient – sick. Today's development should pave the way for further therapies based on this approach."

Film available
bit.ly/1Dd7TnL

23.12.14

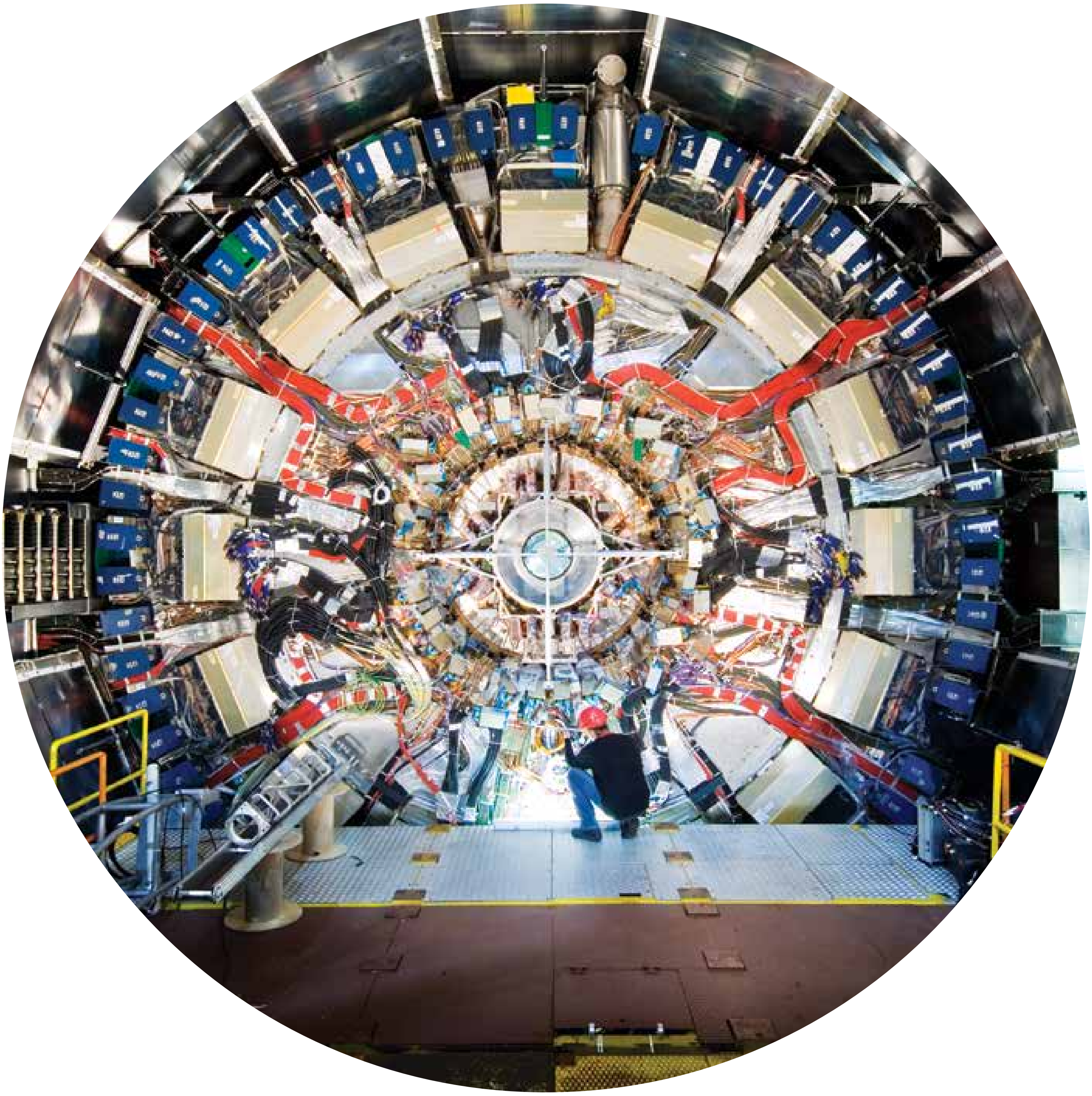
An aircraft capable of recharging its batteries in flight has been tested by Cambridge engineers in association with Boeing.

22.12.14

Researchers suggest reforms advocated by the IMF have contributed to a "lack of preparedness" in West Africa to cope with Ebola.

17.12.14

The earliest known example of polyphonic music – choral music written for more than one part – has been found.



Credit: ©CERN

Firing up the proton smasher

Image
Engineers perch in the crevices of the LHC, like tiny cleaner birds removing parasites

The Large Hadron Collider is being brought back to life, ready for Run II of the "world's greatest physics experiment". Cambridge physicists are among the army who keep it alive.

While it slept, we were allowed into the tunnels.

The Large Hadron Collider (LHC) had shut down for two years to upgrade following the discovery of the Higgs boson. In the main ring, 175 m underground, chunks had been cut out of the snaking tubes for essential maintenance. These tubes fire protons in opposite directions, whipping them ever faster until they almost reach the speed of light. Along the 27 km run are four ‘experiments’: vast machines envelop the points at which tubes intersect and particles collide to capture the results. The largest of these, ATLAS, is the size of a six-storey building.

Each collision, known as an ‘event’, produces a splurge of elementary particles such as quarks, gluons and – as we now know – Higgs bosons. On average, events occur 40 million times a second in the LHC.

The precision required for these events is exquisite. Our guide tells us to imagine two people standing six miles apart and each simultaneously firing a gun so that the bullets meet exactly head-on. Except instead of bullets, imagine needles. Inside the tunnels, engineers zip past on bicycles – the best way to get around underground unless you’re a proton. Next to every lift shaft is a bike rack.

In the next few months, the LHC will be switched back on. The 2012 triumph of demonstrating the Higgs boson affirmed the Standard Model: the elegant solution to the building blocks of the Universe. Now, with an anticipated almost doubling of energy for the LHC’s second run, physicists are aiming to “go beyond” the Standard Model.

One of the central goals is to prove or disprove the theory of supersymmetry: the “prime candidate” theory for unlocking the mystery of the dark matter in our Universe.

“Observable matter only makes up 5% of the Universe; the rest is what we call dark matter. We know it’s there because we can see galaxies rotating at velocities which require surrounding matter for such gravitational pull – but, unlike the part of the galaxies that we can see, we cannot detect it optically,” said Professor Val Gibson, Head of the Cambridge High Energy Physics (HEP) group.

Supersymmetry theory essentially predicts that every particle in the Standard Model has a matching particle waiting to be found. These partner particles (or ‘sparticles’) could be candidates for dark matter, but we haven’t yet seen them – perhaps because they are heavier and take more energy to generate, a problem LHC Run II could overcome.

“Supersymmetry theory predicts there is a sister particle of the electron called a ‘selectron’, which would have integer ‘spin’: its intrinsic angular momentum. For the quark, there would be a supersymmetric ‘squark’, and so on for every elementary particle we know,” said Gibson. If supersymmetry is correct, there would also be a further four Higgs bosons for us to discover.

“Proton collisions in the LHC might produce a heavy supersymmetric particle which decays into its lightest form, a light neutral particle, but different from those we know about in the Standard Model,” said Gibson.

“We have been looking for supersymmetry particles throughout the first run of the LHC, and the increase in power for Run II means we can look at higher energies, higher mass, and gradually blot out more areas of the map in which supersymmetrical particles could be hiding.”

Will supersymmetry be proved by the end of next year, or will the data show it’s a red herring? For HEP research associate Dr Jordi Garra Ticó, what is really fundamental is experimental evidence. “I just want to see what nature has prepared for us, whether that’s consistent with some current theory or whether it’s something else that no one has ever thought about yet, outside of current knowledge.”

The two experiments that Cambridge researchers work on are the mighty ATLAS and the more subtle LHCb – known as LHC ‘Beauty’ – which is Gibson and Garra Ticó’s focus. Beauty complements the power of ATLAS, allowing scientists to ‘creep up’ on new physics by capturing rare particle decays that happen every 100 million events.

> Imagine two people standing six miles apart and each simultaneously firing a gun so that the bullets meet exactly head-on. Except instead of bullets, imagine needles

Garra Ticó spent six months in Cambridge before taking up residence at CERN, where he works on LHCb. LHCb’s 10 million events a second create 35 kbyte of data each, a figure that is expected to go up to 60 kbyte during Run II – too much to ever imagine storing. “There is no guidebook,” he explained. “These machines are prototypes of themselves.”

ATLAS, the biggest experiment, feels like the lair of a colossal hibernating robot. Engineers perch in the crevices of the giant machine, tinkering away like tiny cleaner birds removing parasites. And sealed in the heart of this monster is layer upon layer of the most intricate electronics ever devised.

Dr Dave Robinson arrived in CERN as a PhD student in 1985, and joined the Cambridge HEP group in 1993. He went back to CERN in 2004 – expecting a stint of “one to two years” – and has remained. He is now Project Leader for the most critical detector system within ATLAS, the Inner Detector, which includes the ‘semi-conductor tracker’ (SCT), partially built in Cambridge.

Each collision event inside ATLAS leaves an impression on the layers of silicon that make up the SCT like an onion skin – enabling scientists to reconstruct the trajectory of particles in the events. “The sensitivity of the tracker is vital for making precise measurements of the thousands of particles generated by the head-on collisions between protons, including decay products from particles like b-quarks which only exist for picoseconds after the collision,” said Robinson.

He is currently working with Gibson and colleagues at the Cavendish Laboratory on the next generation of radiation-proof silicon technology in preparation for the LHC shutdown of 2020, the next time they will be able to get at the SCT, which is otherwise permanently locked in the core of ATLAS. The technology will have an impact on areas like satellite telecommunications, where cheaper, radiation-hardened electronics could have a huge effect.

This, for Gibson, is the way science works: solving technical problems to reveal nature’s hidden secrets, and then seeing the wider applications. She recalls being in CERN when she was a postdoc in the 1980s at the same time as Tim Berners-Lee, who was working on computer-sharing software to solve the anticipated data deluge from LHC-precursor UA1. He ended up calling it the World Wide Web.

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Music in the tree of life

Modern scientific methods for mapping the evolution of species are being applied to centuries-old hand-copied music, providing new inspiration for how it is performed.

When Joseph Haydn completed his *Symphony No. 95*, shortly before its first performance in 1791, he forgot to include the oboes.

Although Haydn corrected himself — his hastily scrawled 'flauto' and 'fagot' in the margin are crossed out and replaced by 'oboe' — this snapshot of musical history serves as an evocative reminder of human fallibility. It's impossible to get things right all of the time, and no less so than for activities like the writing or copying of complex musical scores.

In fact, 'mistakes' are quite common in hand-copied texts and music. Before the introduction of printing in the late 15th century, the only means of spreading written culture was for monks and other scribes to replicate manuscripts. For music, the challenges of printing musical notation meant that hand-copying continued well into the 17th and 18th centuries.

Unwittingly, the careless scribes — and those who deliberately made changes, perhaps to fit their own style or contemporary fashions, or to 'improve' on an earlier literary or musical composition — were helping future historians.

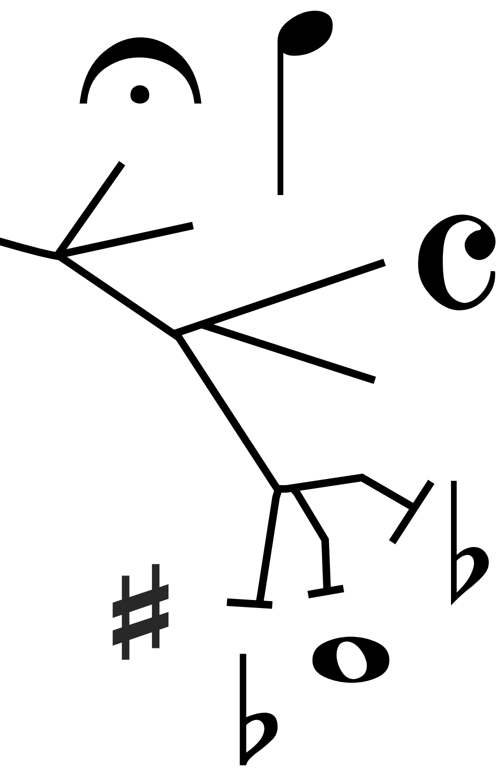
Each time a piece was copied, the change was propagated, and occasionally joined by a fresh change. Scholars use these variations to build family trees of "which was copied from which" that chart the relationship between pieces, helping them to ask questions about the authors, and the history and even the movement of specific texts across continents.

Two such scholars are Professor Christopher Howe and Dr Heather Windram. Yet, they are neither historians nor musicologists. They are biochemists.

Howe is known for his work on photosynthesis and the molecular evolution of photosynthetic microorganisms. It turns out that there are important similarities between the evolution of a species and the evolution of anything copied successively — texts, music, languages and even Turkmen carpets.

"What's exciting is how many different things follow this pattern of copying with incorporation and propagation of changes. It's just a fundamental principle about how the world is," said Howe.

"During the evolution of species, mutations that occur when DNA is copied are passed on and, as species diverge, "What's exciting is how many different things follow this pattern of copying with incorporation and propagation of changes. It's just a fundamental principle about how the world is"



you see their DNA sequences become increasingly different. Evolutionary biologists use what are called 'phylogenetic' computational methods to compare the variations and work out the family tree. We realised we could also do this for pieces of literature."

His first work in the 1990s was on Chaucer's Canterbury Tales. He and his collaborators found that the technique worked well and, with Windram, he proposed a new name for the process — 'phylomemetics' — "well, it's easier to say than phylogenetic analysis of non-biological sequence data," said Howe.

Very little work, however, has been carried out on music, until now. In what they believe is the first test case of this type of analysis, Howe, Windram and one of the UK's leading early keyboard players, Professor Terence Charlston from the Royal College of Music, have used their sophisticated algorithms to trace the relationships among a set of 16 copies of the *Prelude in G* by Orlando Gibbons from the 17th and 18th centuries.

"Although music is a form of written tradition, we needed to pick up on the relationships between pieces in a different way," explained Windram. "Music is a guide for performance so I was very conscious that some changes might be silent — like two tied quavers changing to a crotchet — but others might be sufficient to change the sound of the music."

In each of the 38 to 39 bars of music (depending on the source), Windram looked for changes in, for example, the note pattern, pitch and rhythm. She knew it should be possible — she had previously worked on a text that had 16,000 points of variation — and, with Charlston's expertise in 17th-century music, she was able painstakingly to unpick the 'mutant manuscripts' and turn the variations into a numerical code.

The researchers are quick to explain that no computer analysis can replace the expertise of the musicologist, who considers a mass of background information in addition to the patterns of variation. Where they see a significant advantage of their approach, however, is the ability to capture a large amount of complex information and then carry out multiple consecutive analyses.

"Once the coding is complete, you can focus on specific aspects of the music," explained Windram. "You can run the analysis again and again, perhaps considering only certain categories of changes, or only looking at a section of the music at a time. It's another tool in the musicologist's toolbox, and how you interpret what you are seeing is aided by their expertise."

Just as scholars of texts are using family relationships to ask broader questions about literature, the same can be carried out with music, as Charlston explained: "We can use these techniques to look at the corrections made by a single composer. Take Bach for instance. He was an inveterate reviser of his own music as he performed or taught it, and we can use these techniques to look at the creative process from notation to how it lives through performance."

What pleases the researchers is how the tool could also help performance choices in the future: "Current musicology tends to look for a single correct version but, for a piece like Gibbons's *Prelude in G*, there may be as many versions as there are people playing it at the time. My ideal would be to suggest to players today that within certain confines they should be seeking to make their own variants," said Charlston.

For Howe, the excitement of the approach also lies in what it might do for evolutionary biology. "We can use this technique to identify if a copyist is copying from more than one piece at the same time — called contamination. There is a parallel in biology called lateral gene transfer where unrelated organisms exchange DNA. We now want to see if a program that can handle contamination in text can tell us something about lateral gene transfer in living organisms."

The hope is that, like handwriting, musical notation will betray the hand of its composer or copyist. Analysis of variations in 'mutant' manuscripts — now carried out more quickly using the team's phylomemetic tools — will help both to reconstruct musical history and to provide a tantalising glimpse of a creative process evolving.

I
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Health-conscious concrete

Roads that self-repair, bridges filled with first-aid bubbles, buildings with arteries… not some futuristic fantasy but a very real possibility with 'smart' concrete.

Skin is renewable and self-repairing – our first line of defence against the wear and tear of everyday life. If damaged, a myriad of repair processes spring into action to protect and heal the body. Clotting factors seal the break, a scab forms to protect the wound from infection, and healing agents begin to generate new tissue.

Taking inspiration from this remarkable living healthcare package, researchers are asking whether damage sensing and repair can be engineered into a quite different material: concrete.

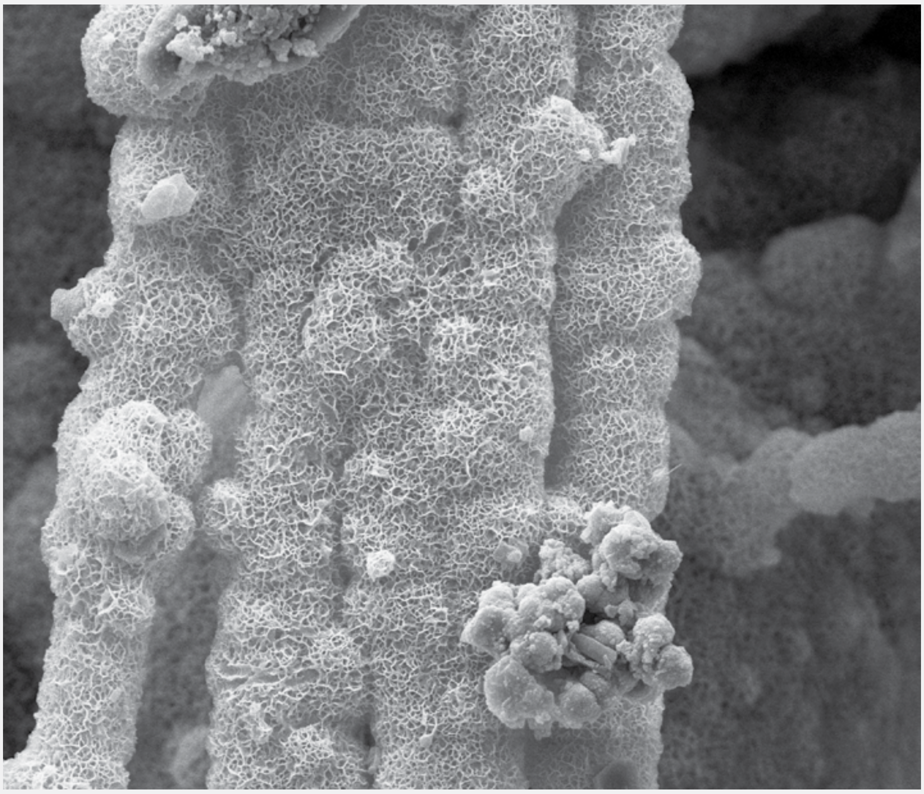
Their aim is to produce a 'material for life', one with an in-built first-aid system that responds to all manner of physical and chemical damage by self-repairing, over and over again.

Self-healing materials were voted one of the top-ten emerging technologies in 2013 by the World Economic Forum, and are being actively explored in the aerospace industry, where they provide benefits in safety and longevity. But perhaps one area where self-healing might have the most widespread effect is in the concrete-based construction industry.

Concrete is everywhere you look: in buildings, bridges, motorways, and reservoir dams. It's also in the places you can't see: foundations, tunnels, underground nuclear waste facilities, and oil and gas wells. After water, concrete is the second most consumed product on earth; tonne for tonne, it is used annually twice as much as steel, aluminium, plastic and wood combined.

But, like most things, concrete has a finite lifespan. "Traditionally, civil engineering has built-in redundancy of design to make sure the structure is safe despite a variety of adverse events. But,

Images
Bridging the cracks – concrete self-heals (above) when microcapsules (right) burst open to release healing material (left)



Credit: Right and top, Tanvir Qureshi

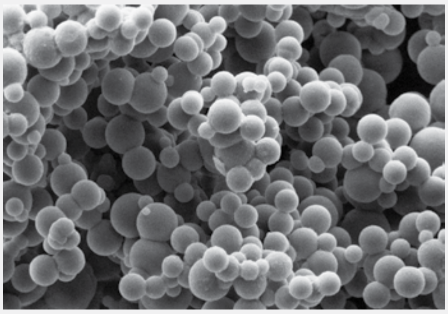
The UK spends around

£40 billion

per year on the repair and maintenance of existing, mainly concrete, structures

over the long term, repair and eventual replacement is inevitable," said Professor Abir Al-Tabbaa, from the Department of Engineering and the lead of the Cambridge component of the research project.

The UK spends around £40 billion per year on the repair and maintenance of existing, mainly concrete, structures. However, repairing and replacing concrete structures cause disruptions and contribute to the already high level of carbon dioxide emissions that result from cement manufacturing.



Credit: Chrysoula Litina

What if the life of all new and repaired concrete structures – and in fact any cement-based material, including grout and mortar – could be extended from an average of several decades to double this, or more, through self-healing?

In 2013, researchers in Cambridge joined forces with colleagues at the Universities of Cardiff (who lead the project) and Bath to create a new generation of 'smart' concrete and other cement-based construction materials.

"Previous attempts in this field have focused on individual technologies that provide only a partial solution to the multi-scale, spatial and temporal nature of damage," explained Al-Tabbaa. By contrast, this study, funded by the Engineering and Physical Sciences Research Council, provides an exciting opportunity to look at the benefits of combining several 'healthcare packages' in the same piece of concrete.

"Like the many processes that occur in skin, a combination of technologies has the potential to protect concrete from damage on multiple scales – and, moreover, to do this in a way that allows 'restocking' of the healing agents over time," she added.

Mechanical damage can cause cracks, allowing water to seep in; freezing and thawing can then force the cracks wider. Loss of calcium in the concrete into the water can leave decalcified areas brittle. And, if fractures are deep enough to allow water to reach the reinforcing steel bars, then corrosion and disintegration spell the end for the structure.

The team in Cambridge is addressing damage at the nano/microscale by developing innovative microcapsules containing a cargo of mineral-based healing agent. It's like having a first-aid kit in a bubble: the idea is that physical and chemical triggers will cause the capsules to break open, releasing their healing and sealing agents to repair the lesion.

"While various cargo and shell materials have been developed for other applications, from food flavouring and pharmaceuticals to cosmetics and cleaning products, they are not generally applicable to cement-based matrices and are far too expensive for use in concrete, which is why we have needed to develop our own," explained Al-Tabbaa.

Another challenge is to make sure the capsules will be strong enough to withstand being mixed in a cement mixer, yet fragile enough to be broken open by even the smallest of fractures. Innovative capsule production techniques are being investigated that can be scaled up to deliver the huge volumes of capsules required for use in construction.

In parallel, the team in Bath is investigating healing at the mid-range micro/mesoscale with spore-forming bacteria that act as tiny mineral-producing factories, feeding on nutrients added to the cement and facilitating calcite precipitation to plug the cracks in the concrete. Different techniques for housing and protecting the bacteria and nutrients within the cement matrix are being investigated, including the capsules that are being developed at Cambridge. The University of Cardiff researchers are engineering 'shape memory' plastic tendons into the cement matrix to close large cracks at the larger meso/macroscale through triggering of the shrinkage of the tendons by heat.

The project team are then collectively addressing repeated damage through the creation of vascular networks of hollow tubes, like the circulatory system of a living organism, so that self-healing components can continually be replenished.

As the Cambridge researchers move closer to the best formulations for the microcapsules, they have begun collaborating with companies who can scale up the production to the levels required to seed tonnes of cement. Meanwhile, the three research groups are also beginning to test combinations of each of their techniques, to find the best recipe for maximum self-healing capability.

By the summer of 2015, with the help of industrial partners, field trials will test and refine the most promising combined systems in a range of real

Concrete is everywhere you look: in buildings, bridges, motorways, and reservoir dams

environments and real damage scenarios. This will include testing them in non-structural elements in the Department of Engineering's new James Dyson Building.

"This is when it will become really exciting," said Al-Tabbaa. "To be truly self-healing, the concrete needs to be responsive to the inherently multi-dimensional nature of damage, over long time scales. We want concrete to be a material for life that can heal itself again and again when wounded."

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THE PROFESSOR IS WORLD CUP

Understanding 'secret' urban languages

Research into a 'playful' and increasingly popular urban language that grew out of the necessity for criminals to hide their true intent could help organisations in Uganda communicate better with the country's huge young population.

Uganda has one of the world's largest percentages of people under 30 – more than 78% of its 37 million citizens, according to a report by the United Nations Population Fund. Many do not use the commonly spoken languages of Uganda (Kiswahili, English and Luganda) in everyday speech but instead express themselves in an ever-evolving street language called Luyaaye.

Originally a 'secret language' spoken by criminals, Luyaaye has grown in popularity because it's seen as more playful and less traditional by many of its speakers, with its "joyful" use of English, Luganda and other languages.

Many of those who use Luyaaye are concentrated within Kampala, the capital city of a country that faces many challenges, including serious health problems. To combat these threats to health – and to get other social messages across – the government must communicate with its population effectively. This means using Luyaaye alongside the official languages, argue researchers from Africa and Cambridge who are working collaboratively as part of the Cambridge-Africa Partnership for Research Excellence (CAPREx).

Dr Saudah Namyalo from Makerere University and Dr Jenneke van der

Wal from Cambridge's Department of Theoretical and Applied Linguistics have joined forces to understand how this increasingly popular, yet currently undocumented, urban language is built. The need is increasing, said Namyalo, as more people come to use forms of Luyaaye to communicate. "It is currently classified as an Urban Youth Language but it is becoming more widespread and used by some older people."

Such languages are not unique to Uganda – elsewhere, forms of multicultural British English, the Dutch street language 'straattaal' and the 'Camfranglais' of the Cameroon are all examples of languages that have evolved out of, and usurped, the country's mother tongue in certain communities, explained Namyalo.

These languages are fast-moving in their appropriation of new words, often borrowing them from TV, films and music. "I love the speed at which Luyaaye changes," she said. "For instance,

> "The World Cup was seen as a very positive thing. So *world cup* quickly became a shorthand for 'a good thing' or 'excellent'"

the World Cup was seen as a very positive thing. So *world cup* quickly became a shorthand for 'a good thing' or 'excellent'.

"For a lot of people, Luyaaye is for fun – it is just for laughs! It often uses metonymy [calling something not by its own name but by a name linked to it] with surprising and comic results. So a *Professor* is someone with 'street smarts' who has learned to beat the authorities, to get away with anything."

However, the language also has its darker side. The growth of Luyaaye began in the 1970s during the Idi Amin reign. "Illegal trade grew and it is thought that the language provided a code to serve those people who were involved in trade between Nairobi and Kampala. It was mostly spoken by the illiterate, young business community," Namyalo explained.

Even today its past continues to influence its development as Luyaaye helps criminals conduct business and exclude the uninitiated from their ranks, said Namyalo. "Kampala is divided into five divisions and they are Luyaaye territories. If you are a criminal you are not supposed to cross into another territory – or you risk being burnt alive. The Luyaaye you use can show which division you are from or it can be used to uncover if you do not belong."

Namyalo points to these past links with criminality as a factor in the reticence of the establishment in accepting Luyaaye: "Higher society does not take the language, or those who use it, seriously. When you use Luyaaye you are thought of as uncultured, and yet it is the more meaningful language for the youth than Luganda or other formal languages used in Uganda."

She has begun the process of documenting this little-studied and evolving language, and would like to produce a dictionary. From her research, she now thinks of the language in terms of 'layers', each layer representing a slightly different set of vocabulary. The secret language used by criminals is what she calls 'core' Luyaaye, while the second layer is spoken by the youth, and the outer layer is the 'ordinary' Luyaaye, easiest to understand and popular with the general public.

Her work has so far concentrated on the lexical (word meaning) aspects of the language, but her collaboration with Van der Wal will allow them to examine the syntax (how sentences are constructed) of Luyaaye as compared with Luganda.

An expert in Bantu languages like Luganda, Van der Wal is also a member of a large-scale project to investigate the basic building blocks that underpin how languages of the world are structured – the Rethinking Comparative Syntax (ReCoS) project funded by the European Research Council and led by Professor Ian Roberts, also in the Department of Theoretical and Applied Linguistics.

"The ability to speak a language is something very special – it is unique and part of what makes us human beings," explained Van der Wal. "I want to find out what allows us to make grammatical sentences and how this varies between languages. For instance, unlike in some neighbouring languages, in Luganda you can say a word in two different ways: you can talk about eating rice (*omuceere*), but leave off the first vowel (*mucheere*) and it suggests you are *only* eating rice – it gives an exclusive focus on the rice."

Namyalo's visit to Cambridge and Van der Wal's recent visit to Uganda were funded by CAPREx and the Alborada Research Fund, both of which are initiatives within the umbrella Cambridge-Africa Programme at the University of Cambridge. The Programme aims to strengthen Africa's capacity for research by equipping African researchers with skills and resources, and to promote mutually beneficial, long-term collaborations with African researchers across a wide range of disciplines.

For Van der Wal, research in Africa with African academics has been vital for enabling her to carry out meaningful research: "I loved working with Saudah in Uganda and listening to the languages as spoken. It was great to do field work together and get my hands dirty – well, get my ears dirty – and learn about yet another Bantu language."

Namyalo sees the project as vital for helping her country combat some of its most challenging difficulties. "Programmes have been carried out to spread information about AIDS but even with increased dissemination there was a decrease in the take-up of that information. When asked what would help, people said 'speak our language'."

CAPREx is funded by the Carnegie Corporation of New York, the Alborada Trust and the Isaac Newton Trust.

www.cambridge-africa.cam.ac.uk/initiatives/caprex

Film available
bit.ly/1y829a3

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The independent witness

Images
Screenshots taken from cameras worn by Rialto Police Department officers

As President Obama pledges investment in body-worn cameras for police officers, Cambridge researchers show the technology can prevent unacceptable use of force.

"I can't breathe." These were the last words of Eric Garner, the unarmed black man placed in a fatal chokehold by a New York police officer last year. They became the rallying cry of protestors who took to the streets of Manhattan, echoing through the city in outrage over the grand jury decision not to indict the policeman responsible for Garner's death.

We know these were Garner's last words because a bystander filmed the tragic incident on a camera phone. The video has now been seen by millions online, on social media and on news programmes worldwide.

Video capture is common in the 21st century; most people carry a camera in their pocket as part of their smartphone, and CCTV – once condemned by privacy campaigners – has become commonplace.

Institutionalising video capture as policing practice seems like a logical next step. Small high-definition cameras known as 'body-worn video' can be strapped to a police officer's torso or hat to record every step of police–public interaction, with only case-relevant data being stored.

Some believe that videoing all interactions between the police and the community would allow unprecedented transparency – the closest approximation of actual events for evidence purposes: a digital 'independent witness'. Recently, President Obama requested $263 million of federal funds from Congress to pay for police body cameras and training.

But others have questioned the merit of camera technology given that the officer responsible for killing Garner was acquitted despite the video footage and the ruling by a medical examiner that the death was homicide.

As with all good police work, however, evidence is required, and the first full scientific report on the effectiveness of police body-worn cameras has just been published. It shows that the technology prevents unacceptable use of force.

The research by Dr Barak Ariel, Dr Alex Sutherland and Chief of Police Tony Farrar at Cambridge's Institute of Criminology concludes a landmark crime experiment conducted on policing with body-worn cameras in Rialto, California, in 2012 — the results of which have been cited by police departments around the world as justification for rolling out this technology.

During the 12-month Rialto experiment, use of force by officers who were wearing cameras fell by 59% and reports against officers dropped by 87% against the previous year's figures.

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The experiment showed that evidence capture is just one output of body-worn video, and that the technology is perhaps most effective at preventing escalation during police–public interactions whether it's abusive behaviour towards police or unnecessary use of force by police.

The researchers say the knowledge that events are being recorded creates "self-awareness" in all participants during police interactions. This is the critical component that turns body-worn video into a 'preventative treatment': causing individuals to modify their behaviour in response to an awareness of 'third-party' surveillance by cameras acting as a proxy for legal courts — as well as courts of public opinion — should unacceptable behaviour take place.

"The 'preventative treatment' of body-worn video is the combination of the camera plus the warning and knowledge that the encounter is being filmed. In the tragic case of Eric Garner, police weren't aware of the camera and didn't have to tell the suspect that he, and therefore they, were being filmed," said Ariel.

"With institutionalised body-worn camera use, an officer is obliged to issue a warning from the start that an encounter is being filmed, influencing the behaviours of all involved by conveying a straightforward, pragmatic message: we are all being watched, videotaped and expected to follow the rules," he said.

"Illegitimate use of force is likely to be affected by the cameras, because misconduct cannot go undetected — an external set of behavioural norms is being applied and enforced through the cameras. Police–public encounters

Credit: Rialto Police Department

become more transparent and the curtain of silence that protects misconduct can more easily be unveiled, which makes misconduct less likely."

In Rialto, the dramatic reduction in both use-of-force incidents and complaints against the police during the experiment resulted in the Rialto Police Department implementing an initial three-year plan for body-worn cameras. When the police force released the results, they were held up by police departments, media and governments in various nations as the rationale for camera technology to be integrated into policing.

Ariel and colleagues are currently replicating the Rialto experiment with over 30 forces across the world, from West Yorkshire, West Midlands, Cambridgeshire and Northern Ireland in the UK, to forces in the USA and Uruguay, and aim to announce their new findings at the Institute of Criminology's Conference for Evidence-Based Policing in July 2015. Early signs match the Rialto success, showing that body-worn cameras do appear to have a significant positive impact on interactions between officers and civilians.

However, the researchers caution that more research is required, and urge any police forces that are considering implementing body-worn cameras to contact them for guidance on setting up similar experiments. "Rialto is but one experiment; before this policy is considered more widely, police forces, governments and researchers should invest further time and effort in replicating these findings," said Sutherland.

Nevertheless, initial results suggest body-worn cameras appear to be highly cost-effective: analysis from Rialto showed every dollar spent on the cameras saved about four dollars on complaints litigations, and the technology is becoming ever cheaper. However, the level of data storage required as the cameras are increasingly adopted could become crippling.

"The velocity and volume of data accumulating in police departments — even if only a fraction of recorded events turn into 'downloadable' recordings for evidentiary purposes — will exponentially grow over time," said Ariel. "User licences, storage space, 'security costs', maintenance and system upgrades can potentially translate into billions of dollars worldwide."

Body-worn video has the potential to improve police legitimacy and enhance democracy, not least by calming situations on the front line of policing to prevent the pain and damage caused by unnecessary escalations of volatile situations. But there could be unintended consequences that potentially offset the benefits, which future research needs to explore. For example, if body-worn cameras become the norm, what might the cost be when video evidence isn't available?

"Historically, courtroom testimonies of response officers have carried tremendous weight," said Ariel. "But prevalence of video might lead to reluctance to prosecute when there is no evidence from body-worn cameras to corroborate the testimony of an officer, or even a victim."

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From one extreme to the next?

The threat to peace posed by the Islamic State group has been described as "unprecedented in the modern age", yet research on the rise and fall of an extremist group in 1980s Lebanon suggests that we may have seen this all before.

"While it's important to keep in mind that history does not necessarily repeat itself, the parallels are great between the history of the rise and fall of Tawheed's emirate in Tripoli and the current rule of the Islamic State"

Image
Lebanon is no stranger to conflict – here pictured after the 2006 War

Credit: Derek Henry Flood

A radical Islamist group has exploited the vacuum created by civil war to capture cities, towns and oil fields across Syria and Iraq – leaving horror and destruction in their wake. Although this might seem unique to a post-9/11 world, religious radicalism exploiting a power vacuum is not new, as research going back 30 years to a different civil war in the same region is showing.

Since April 2013, the Sunni jihadist group Islamic State in Iraq and the Levant, referred to as the 'Islamic State' (IS, or Isis), has taken control of vast swathes of Syrian and Iraqi territory, bringing with it an onslaught of appalling atrocities and acts of cruelty. "It will take some time before its full impact is determined… [the threat it poses] is unprecedented in the modern age," stated a recent report by the Soufan Group, a security intelligence firm in New York.

Meanwhile, Syrian refugees, fleeing IS and the bitter civil war, continue to spill across the borders of neighbouring states, straining their own societies and resources. Lebanon in particular has been greatly affected – almost a quarter of its current population are Syrian refugees.

Tawheed lost legitimacy when it began to be perceived as a militia using a religious discourse to mobilise people

Yet, while the sudden appearance of reports about the barbarity of IS makes this seem like an unprecedented shock, new research is starting to show that parallels may exist in the recent past.

In the 1980s, Lebanon itself witnessed the ascent of one such precursor Islamic movement, known as 'Tawheed', during the country's civil war. Raphaël Lefèvre, a Gates Cambridge Scholar and PhD candidate working with Professor George Joffe in the Department of Politics and International Studies, and until recently a visiting fellow at the Carnegie Middle East Center, is researching its rise and fall.

His work investigates the ways in which the group seized control of the northern port city of Tripoli and imposed its conservative agenda on locals, before being largely rejected and marginalised by civil society and leftist militants. "While it's important to keep in mind that history does not necessarily repeat itself, the parallels are great between the history of the rise and fall of Tawheed's emirate in Tripoli and the current rule of the Islamic State," he said.

IS may have few obvious antecedents in terms of the way in which its members practise their extremism, but because the pattern of its emergence presents a striking echo of those of earlier radical forces, says researcher Lefèvre, this pattern may provide pointers as to the direction and trajectory of IS.

He also hopes that his research on the events of the 1980s in Lebanon will focus attention on the roots of an increasingly unstable situation in the country. The timing of his research is poignant, given that street violence is rising, sectarianism is reaching boiling point and IS has now inaugurated a Lebanese chapter in Tripoli.

Today, references to the failed 'Tawheed phenomenon' are common among the citizens of Tripoli. During a year-long visit to Lebanon, where he has now returned, Lefèvre spoke to many who remember the events of the 1980s, and he finds commonalities between Tawheed and IS.

When Tawheed seized control, it imposed its ideological and religious norms on the people, but it also began to fill the socioeconomic gap left by the absence of a Lebanese state during the civil war. "They filled a void – provided security, ran hospitals and even gave education to the kids," he explained.

Likewise, IS has both imposed a harsh conservative social agenda on the population who live under its sway and used resources such as oil and gas fields to win over locals. "They distribute subsidies and provide state-like services to a population in severe need given the quasi-absence of the Syrian state in remote areas outside of Damascus."

Just like IS, Tripoli's Tawheed movement was led by a charismatic figure, the Sunni cleric Said Shaaban. He gathered under his wing three Islamist groups that merged together to form Tawheed. Their aim was to struggle against impurities in society – the warlords and drug dealers – in accordance with Sharia law.

"But, once Tawheed seized control of the city in 1983, all of these grand goals very quickly disappeared. People started realising that there wasn't much that was Islamic about the group; it was just another political faction trying to rule their city instead of Syria and Israel, and in increasingly corrupt and murky ways."

After three years, and in the face of pressure from the Syrian regime, internal disagreements over deciding the group's next steps led to its collapse from within.

IS, too, has been linked with corruption, including suggestions that the organisation has been selling looted antiquities and earning significant amounts from the oil fields it controls in eastern Syria by selling supplies to the Syrian government and across the borders into Turkish and Jordanian underworlds.

Tawheed lost legitimacy when it began to be perceived as a militia using a religious discourse to mobilise people. Lefèvre believes that movements collapse when they try to force society to adapt to their norms: "very often, civil society resists and in the end strikes back."

In Lebanon today, he sees an increasing feeling of socioeconomic and political marginalisation on the part of Lebanon's Sunni community – a "highly toxic cocktail", he calls it, of unemployment, low literacy rates and poverty, leading many to turn away from the state and look for alternative sources of support and protection, including joining Islamic groups. He fears that the current situation may lead back to a situation not dissimilar to that witnessed in the 1980s.

"The influence of the Syrian crisis on Lebanon is very real. Ultimately, whether the country is able to weather the storm, or fall prey to civil war and the rise of extremism, will depend on the ability of Lebanese policymakers to address issues that have long been ignored."

As for the future of IS, Lefèvre says: "It is unpopular in the cities it is controlling, but we are not yet seeing so much resistance – possibly because of the socioeconomic help they currently provide. While the same collapse may not necessarily happen to IS, the rise and fall of Tawheed shows that internal tensions within a group – whether about the group's leadership or its priorities – are an important factor that should be taken into account to understand how such movements operate. The 'IS phenomenon' is in fact far from being a new one."

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Credit: John S. Murray

Things

Glass fungi and the man who chased spores

Images
Dr W A R Dillon Weston and his glass models

Feature and film available
bit.ly/1H62CnV

A collection of glass fungi reveals a passion that led a Cambridge mycologist to ever-more inventive means of trapping fungal spores, even from the open window of an airship on its maiden flight.

Delicate tendrils stretch upwards, crisscrossing each other in a complex and fragile array of strands topped by tiny oval heads crammed with spores. For all its similarity to *Phytophthora infestans*, this is actually a glass model the height of a hand's span, and 400-times the size of the organism that caused the disease which triggered the Irish potato famine.

It was made during the first half of the 20th century by Cambridge mycologist Dr W A R Dillon Weston for the benefit of his students, and is housed along with about 90 of his other models in Cambridge's Whipple Museum of the History of Science.

Dillon Weston saw the majesty of mould – "People thought fungi repulsive, and I wanted to show how beautiful they can be" – but he was also acutely aware from his research of the impact of fungal species on food crops.

But as Dr Ruth Horry from the Department of History and Philosophy of Science has discovered, the glass fungi were just one example of Dillon Weston's ingenuity.

"In July 1930, British Airship R100 was flying across the Atlantic Ocean on its first intercontinental flight when its captain donned a pair of rubber gloves, opened the window of the control car and plunged a Petri dish into the skies." The experiment was at Dillon Weston's request, to explore whether air currents could explain the transport of spores over long distances.

Find out more about Dillon Weston's innovative airship experiment, and see the delicate beauty of the glass fungi, in a film now available on our YouTube channel.

www.hps.cam.ac.uk/whipple

Credit: Whipple Museum of the History of Science

Celestial bodies

Astronomy and oncology do not make obvious bedfellows, but the search for new stars and galaxies has surprising similarities with the search for cancerous cells. This has led to new ways of speeding up image analysis in cancer research.

Despite their red-brick finish, the corridors of the Institute of Astronomy can seem more like an art gallery than a research centre, so beautiful are the images of supernovae and nebulae hanging there. Dr Nic Walton passes these every day as he makes his way to his office to study the formation of the Milky Way and search for planets outside our solar system.

On the screen of Walton's computer is what appears to be a map of stars in our Milky Way. In fact, it is something that is around 25 orders of magnitude smaller (that's ten followed by 25 zeros).

It is an image of cells taken from a biopsy of a patient with breast cancer; the 'stars' are the cells' nuclei, stained to indicate the presence of key proteins. It is the similarities between these patterns and those of astronomical images that he, together with colleagues at the Cancer Research UK (CRUK) Cambridge Institute, is exploiting in PathGrid, an interdisciplinary initiative to help automate the analysis of biopsy tissue.

"Both astronomy and cell biology deal with huge numbers: our Milky Way contains several billion stars, our bodies tens of trillions of cells," explained Walton.

PathGrid began at a cross-disciplinary meeting in Cambridge to discuss data management. Walton has been involved for many years with major international collaborations that, somewhat appropriately, amass an astronomical amount of data. But accessing data held by research teams across the globe was proving to be a challenge, with a lack of standardised protocols. Something needed to be done and Walton was part of an initiative to sort out this mess.

The issue of data management in an era of 'big data' is not unique to astronomy. Departments across the University – from the Clinical School to the Library – face similar issues and this meeting was intended to share ideas and approaches. It was at this meeting that Walton met James Brenton from the CRUK Cambridge Institute. They soon realised that data management was just one area where they could learn from each other: image analysis was another.

Walton and his colleagues in Astronomy capture their images using optical or near-infrared telescopes, such as the prosaically named Very Large Telescope or the recently launched Gaia satellite, the biggest camera in space with a billion pixels. These images must then be manipulated to adjust for factors including the telescope's own 'signature', cosmic rays and background illumination. They are tagged with coordinates to identify their location, and their brightness is determined.

Analysing these maps is an immense, but essential, task. Poring over images of tens of thousands of stars is a laborious, time-consuming process, prone to user error, so this is where computer algorithms come in handy. Walton and colleagues run their images through object detection software, which looks for astronomical features and automatically classifies them.

"Once we start characterising the objects, looking at what's a star, what's a galaxy, then we start to see the really interesting bigger picture. Light is distorted by gravitational mass on its way to us, so the shapes of the galaxies, for example, can tell us about the distribution of dark matter towards them. When we start counting stars, we start to see structures, like tidal streams."

Professor Carlos Caldas, one of Brenton's colleagues at the CRUK Institute, and now a collaborator of Walton's, says the problems faced by medical pathologists are very similar, if at the opposite extreme of measurements. Could the same algorithms help pathologists analyse images taken by microscopes?

> "When we start counting stars, we start to see structures, like tidal streams"

When a patient presents with suspected breast cancer, a pathologist takes a core of the tumour tissue – a tiny sample, less than 1 mm in diameter. The tumour samples are arranged on a block, typically together with 200 other samples taken from different patients. Each sample needs to have its own 'coordinates' so that the researchers know that a particular tumour came from a particular patient.

"We then cut a slice of the 200 or so cores, mount it into a slide that is stained, and take a digital picture of this slide," explained Caldas, "but each of these high-resolution images is a few gigabytes of data, so we quickly accumulate hundreds of terabytes of data."

By adapting the astronomers' image analysis software, the PathGrid collaborators are able to analyse the tumour images, for example to recognise the three types of cells in the tissue samples: cancer cells, immune cells and stromal cells. Just as object identification in astronomy reveals hidden patterns and information, so the information from the slides begins to tell researchers how the different cell types relate to each other. Staining the samples to highlight elements such as potentially important proteins could also help the researchers identify new biomarkers to aid in the diagnosis or prognosis of cancers.

Equally important will be how the data is stored so that several years down the line, as researchers find new questions to ask, they can still access and analyse any of the 15,000 different tumours and their hundred stains. "We need to know that at some point in the future we can extract sample 53, for example, or find all tumours that were positive for a particular stain," said Caldas. "Imagine if you had a million sheets of paper and you just threw them all into a room and asked someone to find page 53. They'd have to sort through all the papers to find the right one, but if you could make it glow, you'd be able to find it more easily. This is similar to what we do, except we do this digitally."

As well as this technology allowing oncologists to ask new questions and at a much larger scale, Caldas believes that in the future it could be used as 'digital pathology', aiding diagnosis and prognosis even in regions with no specialist oncologists. "You could imagine a scenario where a clinician takes a biopsy and a pathologist processes and stains the slide, takes a picture and digitally relays it. This is then analysed by one of the algorithms to say if it is a tumour, identify the tumour type and say how aggressive it will be."

Walton makes an interesting and unexpected comparison between his and Caldas's work: "We deal with star deaths, they deal with patient deaths." If PathGrid is successful, this might change: while the astronomers continue to watch star deaths, their collaborators will hopefully become even better at preventing many more patient deaths from cancer.

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Image
Working with British Cycling and Google, a team of engineers is developing techniques that will advance how we experience sport

New methods of gathering quantitative data from video – whether shot on a mobile phone or an ultra-high definition camera – may change the way that sport is experienced, for athletes and fans alike.

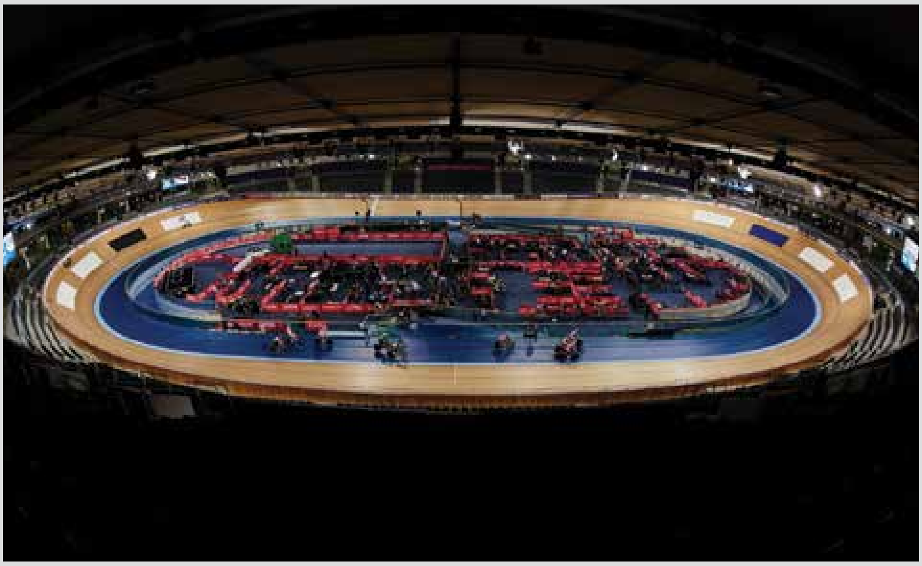
The bat makes contact with the ball; the ball flies back, back, back; and a thousand mobile phones capture it live as the ball soars over the fence and into the cheering crowd. Baseball is America's pastime and, as for many other spectator sports, mobile phones have had a huge effect on the experience of spending an afternoon at the ballpark.

But what to do with that video of a monster home run or a spectacular diving catch once the game is over? What did that same moment look like from the other end of the stadium? How many other people filmed exactly the same thing but from different vantage points? Could something useful be saved from what would otherwise be simply a sporting memory?

Dr Joan Lasenby of the University of Cambridge's Department of Engineering has been working on ways of gathering quantitative information from video, and thanks to an ongoing partnership with Google, a new method of digitally 'reconstructing' shared experiences such as sport or concerts is being explored at YouTube.

The goal is for users to upload their videos in collaboration with the event coordinator, and a 'cloud'-based system will identify where in the space the video was taken from, creating a 'map'

Sports calibrated



Credit: ©British Cycling

of different cameras from all over the stadium. The user can then choose which camera they want to watch, allowing them to experience the same event from dozens or even hundreds of different angles.

But although stitching together still images is reasonably straightforward, doing the same thing with video, especially when the distance between cameras can be on a scale as massive as a sports stadium, is much more difficult. “There’s a lot of information attached to the still images we take on our phones or cameras, such as the type of camera, the resolution, the focus, and so on,” said Lasenby. “But the videos we upload from our phones have none of that information attached, so patching them together is much more difficult.”

Using a series of videos taken on mobile phones during a baseball game, the researchers developed a method of using visual information contained in the videos, such as a specific advertisement or other distinctive static features of the stadium, as a sort of ‘anchor’ which enables the video’s location to be pinpointed.

“Another problem we had to look at was a way to separate the good frames from the bad,” said Dr Stuart Bennett, a postdoctoral researcher in Lasenby’s group who developed this new method of three-dimensional reconstruction while a PhD student. “With the videos you take on your phone, usually you’re not paying attention to the quality of each frame as you would with a still image. We had to develop a way of efficiently, and automatically, choosing the best frames and deleting the rest.”

To identify where each frame originated from in the space, the technology selects the best frames automatically via measures of sharpness and edge or corner content and then selects those which match. The system works with as few as two cameras, and the team has tested it with as many as ten. YouTube has been stress testing it further, expecting that the technology has the potential to improve fan engagement in the sports and music entertainment sectors.

Although the technology is primarily intended for use in an entertainment context, Lasenby points out it could potentially be applied for surveillance purposes as well. “It is a possible application down the road, and could one day be used by law enforcement to help provide information at the crime scene,” said Lasenby. “At the moment, a lot of surveillance is done with fixed cameras, and you know everything about the camera. But this sort of technology might be able to give you information about what’s going on in a particular video shot on a phone by making locations in that video identifiable.”

Another area where Lasenby’s group is extracting quantitative data from video is in their partnership with British Cycling. Over the past decade, the UK has become a dominant force in international cycling, thanks to the quality of its riders and equipment, its partnerships with industry and academia, and its use of technology to help improve speeds on the track and on the road.

“In sport, taking qualitative videos and photographs is commonplace, which is extremely useful, as athletes aren’t robots,” said Professor Tony Purnell, Head of Technical Development for the Great Britain Cycling Team and Royal Academy of Engineering Visiting Professor at Cambridge. “But what we wanted was to start using image processing not just to gather qualitative information, but to get some good quantitative data as well.”

Currently, elite cyclists are filmed on a turbo trainer, which is essentially a stationary bicycle in a lab or in a wind tunnel. The resulting videos are then assessed to improve aerodynamics or help prevent injuries. “But for cyclists, especially sprinters, sitting on a constrained machine just isn’t realistic,” said Lasenby. “When you look at a sprinter on a track, they’re throwing their bikes all over the place to get even the tiniest advantage. So we thought that if we could get quantitative data from video of them actually competing, it would be much more valuable than anything we got from a stationary turbo trainer.”

To obtain this sort of data, the researchers utilised the same techniques as are used in the gaming industry, where markers are used to obtain quantitative information about what’s happening – similar to the team’s work with Google.

One thing that simplifies the gathering of quantitative information from these videos is the ability to ‘subtract’ the background, so that only the athlete remains. But doing this is no easy task, especially as the boards of the velodrome and the legs of the cyclist are close to the same colour. Additionally, things that might appear minor to the human eye, such as shadows or changes in the light, make the maths of doing this type of subtraction extremely complicated. Working with undergraduate students, graduate students and postdoctoral researchers, however, Lasenby’s team has managed to develop real-time subtraction methods to extract the data that may give the British team the edge as they prepare for the Rio Olympics in 2016.

“Technology is massively important in sport,” said Lasenby. “The techniques we’re developing here are helping to advance how we experience sport, both as athletes and as fans.”

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If you go down to the woods today…

Recent advances in medical imaging are being applied to airborne remote sensing of vegetation, enabling conservation scientists to see the wood *and* the trees.

Soaring over the tree canopy of one of the most biodiverse forests on earth, a tiny unmanned plane buzzes quietly through the air. Its pilot stands 250 m below, controlling its flight remotely. This unmanned aerial vehicle (UAV) is gathering data essential to understanding and diagnosing the health of the rainforest below.

The plane is one of a small fleet currently undergoing test flights in Indonesia. Each has been equipped with remote sensors. Their task is to image both the Harapan Rainforest – a 100,000 hectare area of formerly logged forest that is now managed for conservation by a group of NGOs including the RSPB – and a highly threatened forested area on the coast of Kenya.

Globally, around one billion hectares of degraded tropical forest like Harapan might be restorable, enabling them to continue to contribute to the planet's biodiversity and its carbon and water cycles. But a major problem faced by conservation managers is how to survey extensive areas in which conditions can vary in just a few hundred square metres and are continually changing through natural regeneration.

A group of conservation scientists at the Department of Plant Sciences, RSPB and A Rocha International (which works in Kenya) has embarked on what it hopes is a cost-effective and high-quality solution, funded by the Cambridge Conservation Initiative Collaborative Fund. Lead researcher Dr David Coomes, explained: "Forest conservation activities often rely on airborne monitoring and satellite imagery to provide information but these are either expensive or don't offer a fine-enough resolution. We've decided to use inexpensive sensors on UAVs to spot areas of the trashed forest that are showing early signs of recovery."

The researchers need to measure the health of the forest on a tree-by-tree basis – locating, identifying and counting key species indicative of recovery. Multiply this up by hundreds of thousands of hectares, repeated at time intervals in the future, and it becomes a huge imaging, computational and 'big data' challenge.

As the datasets grow, being able to manage and analyse the images automatically and with very high accuracy becomes crucial, and so a key part of the project is to develop the mathematical tools that will do this. This is the job of Dr Carola Schönlieb and her team of digital image analysts at the Department of Applied Mathematics and Theoretical Physics.

The mathematical tools have similarities to technology they are also developing for tumours. For the past year, Schönlieb's group has been working on the VoxTox Research Programme – a five-year study funded by Cancer Research UK and led by Professor Neil Burnet at Cambridge's Department of Oncology – which aims to reduce the 'collateral damage' toxicity that can arise during cancer radiotherapy.

About half of all people with cancer receive a course of radiotherapy, a form of treatment in which X-rays are used to shrink or destroy the tumour. With the benefit of advanced systems, it's now possible to aim radiation beams at tumours more effectively than ever before, allowing increasing doses of radiotherapy with increased cancer cure rates, and also reducing side effects.

However, although clinicians use planning software to define the target area for treatment and deliver the optimal dose, any dose that falls outside the target area – for instance due to the positioning of the patient and their internal organs during treatment – can cause permanent and severe damage to normal tissues. VoxTox, which brings together cancer specialists, mathematicians, radiologists, physicists and engineers, is developing a set of tools that can be used to provide patients with the optimal dosage for their condition.

"The similarity between what we are doing in VoxTox and forest mapping is the development of mathematical algorithms that combine datasets – a process called registration – and then segment them into objects of interest," explained Schönlieb. For VoxTox, imaging data gathered during the course of a patient's radiotherapy is analysed mathematically pixel by pixel (or, in fact, 'voxel by voxel' because it's in three dimensions) within the patient outline, and the dose is then re-computed at that point, each day, during treatment.

Airborne remote sensors for conservation, by contrast, gather data on which trees are in the forest, where they are and how healthy. "It's like an airborne well tree clinic," said Coomes. The data might include digital photography to record what can be seen; a three-dimensional laser scanner (or LiDAR) to measure the height of the canopy; and hyperspectral scanners to monitor the wavelengths of radiation each plant absorbs – these 'chemical signatures' can be used to identify species.

"Being able to bring these datasets together gives us a much fuller idea of the health of the forest than each of the datasets individually," he added. "With the addition of GPS too, it means we can map the forest tree by tree, over time, in three dimensions."

The researchers need to measure the health of the forest on a tree-by-tree basis – locating, identifying and counting key species indicative of recovery

Credit: Gaia Vaglio Laurin, published in *PLOS One* DOI: 10.1371/journal.pone.0097910

Image
Airborne mapping of the tree canopy in a tropical West African forest

To develop the algorithms, researchers led by Schönlieb and Coomes are using test data previously acquired by Coomes' group using manned flights over five European sites, as well as data recently gathered from 200 km^2 of Malaysian forest as part of a project funded by the Natural Environment Research Council.

This is complex mathematical image processing, as Schönlieb explained: "As for VoxTox, the aim is to faultlessly match different types of sensing data as a hybrid dataset and then segment it based on the different levels of information present in each voxel. This sort of analysis hasn't been done before with this kind of accuracy. It pushes over the boundaries of state-of-the-art methods.

"The next stage is to see how far we can push the segmentation method, which is the part that identifies individual trees," she said. "If we can maintain high levels of accuracy using cheaper and fewer sensors – like those being used on the UAVs – then you can take imagery that's as good as it's going to get and maximise the information gain from what you have."

Meanwhile, by mid-2015, the UAVs will begin streaming data back to the researchers who, with their algorithms ready, will start mapping the voxel forest and feeding the results into its management. "The appeal of this technology is you are dealing with individual plants and trees," said Coomes, "it's finally approaching what conservation scientists need to have: seeing the wood *and* the trees."

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Illuminating art's history

Scientific imaging techniques are uncovering secrets locked in medieval illuminated manuscripts – including those of a thrifty duke.

Faced with the prospect of his rapidly approaching nuptials on 29 October 1442, and with no wedding gift purchased for his bride-to-be, Francis I of Brittany (1414–1450) did what many of us have done at some point: he 're-gifted'. He took something that was already in his possession and gave it to someone else.

But this was no ordinary gift: it was an illuminated manuscript, made for Francis' first wife, Yolande of Anjou, who had died in 1440. Francis had it altered and presented it to his new bride, Isabella Stuart, daughter of James I. The portrait of his first wife was covered with that of Isabella and an image of St Catherine was added, using cheaper pigments. Then, when Francis was made a duke, the portrait was painted over yet again to give Isabella a coronet.

Art historians have written volumes on the *Hours of Isabella Stuart* over the last century, but a cross-disciplinary Cambridge project is using a variety of imaging techniques to uncover this story of re-gifting. The team's work is challenging previous assumptions about this and many other manuscripts, helping them to see and understand medieval painting and illumination in new and unexpected ways.

Combining research in the arts, humanities, sciences and technology, MINIARE (Manuscript Illumination: Non-Invasive Analysis, Research and Expertise) currently focuses on uncovering the secrets of medieval art, but it is anticipated that many of the imaging techniques they are adapting may be used to study other types of art, from a range of different periods.

The project is led by Dr Stella Panayotova, Keeper of Manuscripts and Printed Books at the Fitzwilliam Museum, and Professor Stephen Elliott of the Department of Chemistry, who are working with colleagues from across the University and around the world.

"Working in a truly cross-disciplinary way can benefit art history, scientific research and visual culture in general, while pushing technology forward at the same time," said Panayotova. "Thanks to the imaging techniques we've been using, we can see things in these manuscripts that we couldn't see before."

Much of what we know about illuminated manuscripts comes from art-historical analysis and circumstantial evidence. Since they are so delicate and the layers of pigment are so thin, manuscripts are seriously compromised by taking samples, which is common practice for the analysis of panel or fresco paintings. To gather hard evidence about how these manuscripts were made, while preserving them, non-invasive techniques are required.

"For our team, it was about finding new applications for existing techniques, and pushing them far beyond current boundaries in order to analyse the very thin layers of a manuscript," said Elliott. "Part of our research is in the area of medical diagnostics and environmental sensing, where we analyse materials in very thin layers, which is not so different from analysing a painting. So we could certainly see what the problems were."

Using a combination of imaging techniques, including photomicroscopy, visible and infrared imaging at multiple wavelengths, reflectance imaging spectroscopy and optical coherence tomography, the MINIARE team is able to peer through the layers of a painting to uncover its history, as in the case of the *Hours of Isabella Stuart*.

"We do have to adapt conventional analytical techniques to make them safe to use on something as fragile as an illuminated manuscript," said conservation scientist Dr Paola Ricciardi. "For instance, Raman spectroscopy is a brilliant technique, but it's a challenge to use it on a manuscript as we tend to use one-hundredth of the laser power that we would on a less fragile object."

The technological challenge for the MINIARE team is making sure the imaging technology is non-invasive enough to keep the manuscript safe, but still sensitive enough to get an accurate result. Many of the imaging tools that the team use are in fact not cameras, but scanners that acquire a spectrum at each point as they scan an entire object. The resulting 'spectral image cubes' can then provide information about the types of materials that were used, as well as the ability to see different layers present in the manuscript.

Combining these non-invasive imaging techniques not only helps the researchers to distinguish between artists by analysing which materials they used and how they employed them, but also helps them to learn more about the technical know-how that these artists possessed.

"Many of the artists we're looking at didn't just work on manuscripts," said Panayotova. "Some of them were panel painters or fresco painters, while others also worked in glass, textiles or metal. Identifying the ways in which they used the same materials in different media, or transferred materials and techniques across media, offers a whole new way of looking at art."

For example, Ricciardi has found evidence for the use of smalt, a finely ground blue glass, as a pigment in an early 15th-century Venetian manuscript made in Murano. The use of a glass-based pigment is not unexpected given the proximity of the Murano glass factories, but this illuminator was working half a century before any other Venetian easel painter whose works are known to contain smalt.

Another unexpected material that the MINIARE team has encountered is egg yolk, which was a common paint binder for panel paintings, but not recommended for manuscript illumination – instead, egg white or gum were normally used. By making a hyperspectral reflectance map of the manuscript, the researchers were able to gather information about the pigments and binders, and determine that some manuscript painters were most likely working across a variety of media.

The techniques that the team are developing and refining for manuscripts will also see application in other types of art. "All of the imaging techniques we're using on the small scale of medieval manuscripts need to be scalable, in order that we can apply them to easel paintings and many other types of art," said Dr Spike Bucklow of the Hamilton Kerr Institute. "It's an opportunity to see how disciplines relate to each other."

MINIARE (www.miniare.org) involves the Fitzwilliam Museum, Hamilton Kerr Institute, Departments of Chemistry, Physics, History of Art, History and Philosophy of Science, and Applied Mathematics and Theoretical Physics, as well as the Victoria & Albert Museum, Durham University, Nottingham Trent University, Antwerp University, Getty Conservation Institute, J Paul Getty Museum, National Gallery of Art in Washington DC and SmartDrive Ltd.

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The Fitzwilliam Museum

Credit: The Fitzwilliam Museum

Image
Imaging techniques have uncovered the story of a thrifty duke: when Francis I of Brittany 're-gifted' the *Book of Hours* to his second wife Isabella – seen here kneeling before the Virgin Mary – he had his first wife painted over in cheaper paints; then, when he was made a duke, Isabella's headdress was painted over with a coronet

Life, lit by the glow of ten thousand tiny lights

Cambridge scientists are part of a resolution revolution. Building powerful instruments that shatter the physical limits of optical microscopy, they are beginning to watch molecular processes as they happen, and in three dimensions.

There has been a revolution in optical microscopy and it's been 350 years in the making. Ever since Robert Hooke published his *Physiological Descriptions of Minute Bodies* in 1665, the microscope has opened up the world in miniature. But it has also been limited by the wavelength of light.

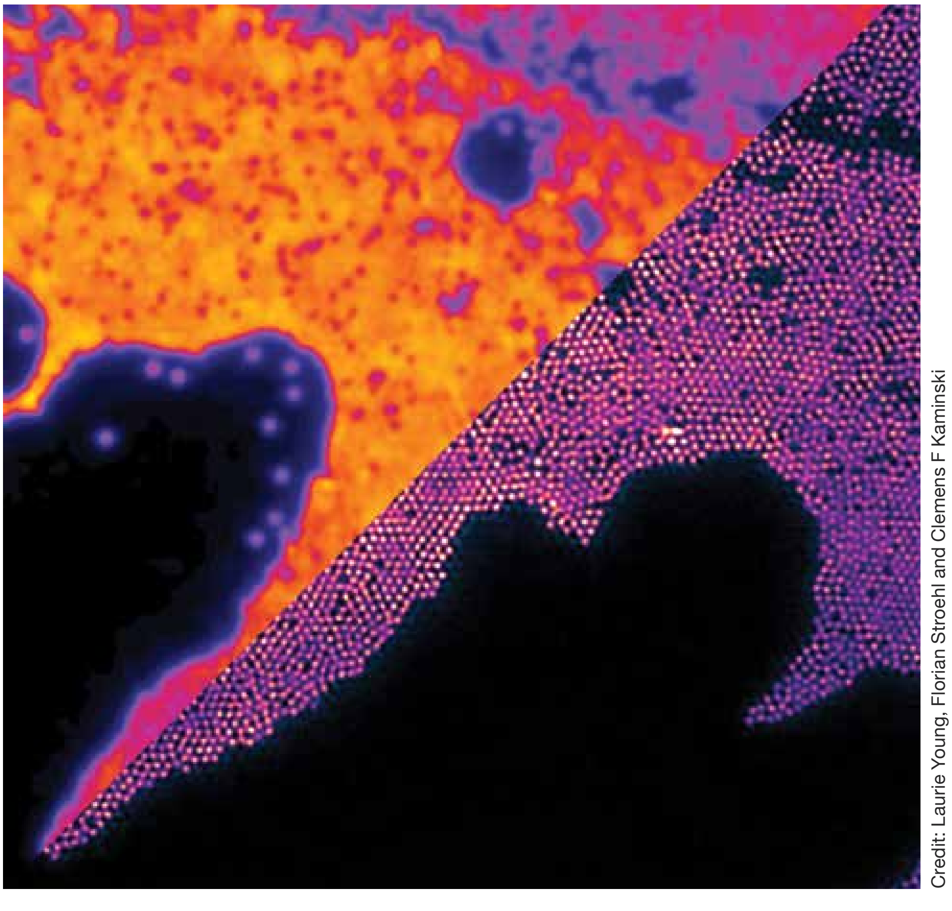
Anything smaller than the size of a bacterial cell (around 250 nanometres) appears as a blurred blob through an optical microscope, simply because light waves spread when they are focused on a tiny spot. As a result, resolving two tiny spots that lie close together has been tantalisingly out of reach using an optical microscope. Unfortunately, many biological interactions occur at a spatial scale much smaller than this.

But, thanks to recent breakthroughs, a new era of super-resolution microscopy has begun. The developments, which earned their inventors (Eric Betzig and W E Moerner from the USA, and Stefan Hell from Germany) the 2014 Nobel Prize for Chemistry, are based on clever physical tricks that work around the problem of light diffraction.

Professor Clemens Kaminski, whose team in the Department of Chemical Engineering and Biotechnology designs and builds super-resolution microscopes to study Alzheimer's disease, explained: "The technology is based on a conceptual change, a different way of thinking about how we resolve tiny structures. By imaging blobs of light at separate points in time, we are able to discriminate them spatially, and thus prevent image blur."

Imagine taking a photo of a tree lit by the glow of ten thousand tiny lights scattered over its branches. The emission

"By imaging blobs of light at separate points in time, we are able to discriminate them spatially, and thus prevent image blur"



Credit: Laurie Young, Florian Stroehl and Clemens F Kaminski

Image
What was once a fuzzy glow (left of image) can now be super-resolved (right) even if, as here, the structures are smaller than the wavelength of light

from each light would overlap. At best you would see a fuzzy, glowing shape lacking in detail. But if you were to switch on only a few lights at a time, locate the centre of each glow and take a picture, and then repeat this process thousands of times for different lights, the composite image would resolve into a myriad of distinguishable dots, denoting the exact position of each individual light on the tree.

This is analogous to the techniques developed by the Nobel Prize winners: in one technique, a sample is tagged with light-activated markers called fluorophores that can be switched on and off with pulses of light, like a switchable light bulb; in another, the light at the outer edges of each blob of light is selectively blocked.

Either way, by imaging a sparse subset of lights, they can be localised with nanometre precision. When combined, a picture starts to emerge that features a resolution that is 10 to 100 times better than previously possible.

"It's been hailed as revolutionary because it means that biologists can validate some of their hypotheses for the first time," said Dr Kevin O'Holleran who co-leads the Cambridge Advanced Imaging Centre (CAIC), which is currently building two super-resolution microscopes. "Although electron microscopy has very high resolution, it can't be performed on live cells. With super-resolution optical microscopy, scientists can track molecular processes as they happen and in three dimensions."

Meanwhile, Dr Steven Lee and Professor David Klenerman in the Department of Chemistry have built what they believe is the first 3D super-resolution microscope of its kind in Europe. They are using the machine to watch the organisation of cell-surface proteins at the point when an immune cell is triggered into action. Before super-resolution, they needed to artificially reduce the number of proteins on the cell surface to make visualisation easier; now, they can work with normal levels of up to 10,000 proteins at a time on the cell surface.

"These exciting discoveries have emerged through years of painstaking research by physical scientists trying to better understand how light interacts with matter at a fundamental level," explained Lee. "This work has enabled us to gain insight into biological processes by simply 'looking' at dynamic events at spatial scales that much better approximate the physical dimension that biomolecules interact on."

Kaminski's team has been visualising the ultrastructure of the clumps of misfolded proteins that cause Alzheimer's disease. "We'd like to study what causes proteins to become toxic when they aggregate, and visualise them as they move from cell to cell to see whether there are opportunities early in the process to halt their progression."

Like any fast-moving and transformative technology, super-resolution microscopy has required researchers to drive forward the capabilities of the lenses and light sources, as well as the chemistry of the fluorophores and the mathematical algorithms for image analysis. As a result, designing and building their own microscopes, rather than waiting for commercial devices to become available, has been the best option.

"The field is dynamic and no instrument is exactly right for the questions you want to answer. We have to build the instrument around the science," explained Dr George Sirinakis, who works with Professor Daniel St Johnston in the Gurdon Institute. His machines will be used to understand cell polarity and visualise the movement of thousands of tiny sacs called vesicles as they transport their cargo within cells. This process has never been seen before because the vesicles are so small and move fast.

No longer are these benchtop machines. Super-resolution microscopes resemble an army of lenses and mirrors marching across a table top, each minutely turning, concentrating and shaping the light beam that falls onto the sample stained with fluorescence markers. Tens of thousands of images are collected from any one sample – creating a deluge of 'big data' that requires complex mathematical algorithms to make sense of the information.

Quite simply, super-resolution microscopy is a feat of engineering, physics, chemistry, mathematics, computer science and biology, and it's therefore out of reach to researchers who lack the necessary expertise or funds to take a step into this field.

CAIC has recently been created to meet super-resolution and other microscopy needs in the biological sciences. "We are a research and development facility. We have state-of-the-art commercial microscopes and we build our own, tailoring them to the needs of the biologists who come to us as a service facility or as a collaborative venture," explained O'Holleran, who estimates that around 100 researchers will become part of the CAIC community.

"We're also a hub. We connect researchers who've built their own devices and we train PhD students in the cross-disciplinary skills needed for cutting-edge imaging."

CAIC, Klenerman, Kaminski and others have now been awarded funding as part of the Next Generation Microscopy Initiative Programme led by the Medical Research Council to help establish Cambridge as a national centre of excellence in microscopy. Part of this funding is being used for the two new super-resolution microscopes currently being built in CAIC.

The researchers hope that super-resolution microscopes will one day become the workhorse of biology, allowing ever-deeper probing of living structures. Breaking the diffraction barrier of light had seemed an insurmountable barrier until recent years. With continuing advances, biologists are beginning to look beyond imaging single cells to the possibility of moving through tissues, tracking the movement of molecules in three dimensions and visualising the process of life unfolding.

"The technology is based on a conceptual change, a different way of thinking about how we resolve tiny structures"

Film available

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Credit: Kevin Brindle; published in *Nature Medicine* (2014) 20, 93–97

Watching the death throes of tumours

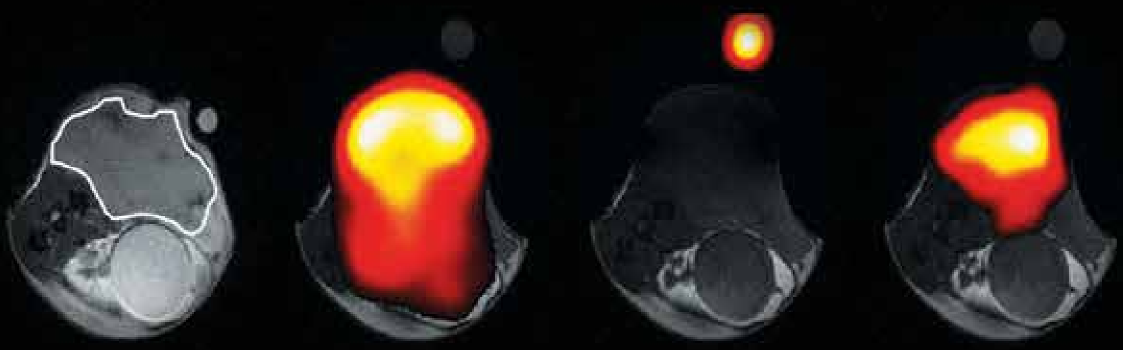

Image
An abdominal tumour (outlined in white) 'feeding on' carbon-13-labelled glucose (orange) provides a means of testing when cancer drugs are effective enough to affect the health of the tumour

A clinical trial due to begin later this year will see scientists observing close up, in real time – and in patients – how tumours respond to new drugs.

There was a time when diagnosing and treating cancer seemed straightforward. Cancer of the breast was breast cancer, for example, and doctors could only choose treatments from a limited arsenal.

Now, the picture is much more complicated. A study published in 2012, led by Carlos Caldas (see p. 20), showed that breast cancer was actually at least ten different diseases. In fact, genome sequencing shows that even one 'type' of breast cancer differs between individuals.

While these developments illustrate the complexity of cancer biology, they also offer the promise of drugs tailored to an individual. Chemotherapy is a powerful, but blunt, instrument – it attacks the tumour, but in doing so also attacks several of the body's other functions, which is why it makes patients so ill. The new generation of cancer drugs aim to make the tumour – and not the patient – sick.

But telling if a patient is sick is easy; telling if the tumour is sick is more challenging. "Conventionally, one assesses whether a tumour is responding to treatment by looking for evidence of shrinkage," explained Professor Kevin Brindle from the Cancer Research UK (CRUK) Cambridge Institute, "but that can take weeks or months. And monitoring tumour size doesn't necessarily indicate whether it is responding well to treatment."

Take brain tumours, for example. They can continue to grow even when a treatment is working. "The thing is that a tumour is not just tumour cells. There are lots of other cells in there, too."

For some time now, oncologists have been interested in imaging aspects of tumour biology that can give a much earlier indication of the effect of treatment. Positron emission tomography (PET) can be used for this purpose. The patient is injected with a form (or analogue) of glucose labelled with a radioactive isotope. Tumours feed on the analogue and the isotope allows doctors to see where the tumour is.

An alternative technique that doesn't expose the patient to ionising radiation is magnetic resonance imaging (MRI), which relies on the interaction of strong magnetic fields with a property of atomic nuclei known as 'spin'. The proton spins in water molecules align in magnetic fields, like tiny bar magnets. By looking at how these spins differ in the presence of magnetic field gradients applied across the body, scientists are able to build up three-

Telling if a patient is sick is easy; telling if the tumour is sick is more challenging

dimensional images of tissues.

In the 1970s, scientists realised that it was possible to use MR spectroscopy to see signals from metabolites such as glucose inside cells. "Tumours eat and breathe. If you make them sick, they don't eat as much and the concentration of some cell metabolites can go down," said Brindle.

Around the same time, scientists hit upon the idea of enriching metabolites with a naturally occurring isotope of carbon known as carbon-13 to help them measure how these metabolites are used by tissues. But carbon-13 nuclei are even less sensitive to detection by MRI than protons, so the signals are boosted using a machine developed by GE Healthcare, called a hyperpolariser, which lines up a large proportion of the carbon-13 spins before injection into the patient.

In 2006, Cambridge was one of the first places to show that this approach could be used to monitor whether a cancer therapy was effective or not. Combined with the latest genome sequencing techniques, this could become a powerful way of implementing personalised medicine. What's more, because no radioactive isotopes are involved, an individual could be scanned safely multiple times.

"Because of the underlying genetics of the tumour, not all patients respond in the same way, but if you sequence the DNA in the tumour, you can select drugs that might work for that individual. Using hyperpolarisation and MRI, we can potentially tell whether the drug is working within a few hours of starting treatment. If it's working you continue, if not you change the treatment."

The challenge has been how to deliver the carbon-13 to the patient. The metabolite has to be cooled down to almost absolute zero (–273°C), polarised, warmed up rapidly, passed into the MRI room and injected into the patient. And as the polarisation of the carbon-13 nuclei has a half-life of only 30–40 seconds, this has to be done very quickly.

This problem has largely been solved and, with funding from the Wellcome Trust and CRUK, Brindle and colleagues will this year begin trialling the technique with cancer patients at Addenbrooke's Hospital. If successful, it could revolutionise both the evaluation of new drugs and ultimately – and most importantly – the treatment of patients.

"Some people have been sceptical about whether we could ever get a strong enough signal. I'm sure we will. But will we be able to do something that is clinically meaningful, that is going to change clinical practice? That's the big question we hope to answer in the coming years."

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Lighting up the body

In many ways, light microscopy is a much better imaging technique than MRI and PET to study the nature of biological materials: it provides higher resolution and higher specificity as fluorescent markers can be used to highlight specific cancer cells and molecules in cells and tissues.

However, as Dr Stefanie Reichelt, Head of Light Microscopy at the Cancer Research UK Cambridge Institute, points out, there's an obvious drawback: "Light doesn't penetrate tissue, so we can't see deep beneath the skin."

Reichelt and colleagues are working on ways to correlate light microscopy with Kevin Brindle's medical imaging techniques. One technique that shows promise for bridging the gap is light sheet microscopy, a fluorescence microscopy technique with an intermediate optical resolution.

A thin slice of the sample is illuminated perpendicularly to the direction of observation; this reduces photo damage, thus allowing high-speed, high-resolution, three-dimensional imaging of live animals and tissues.

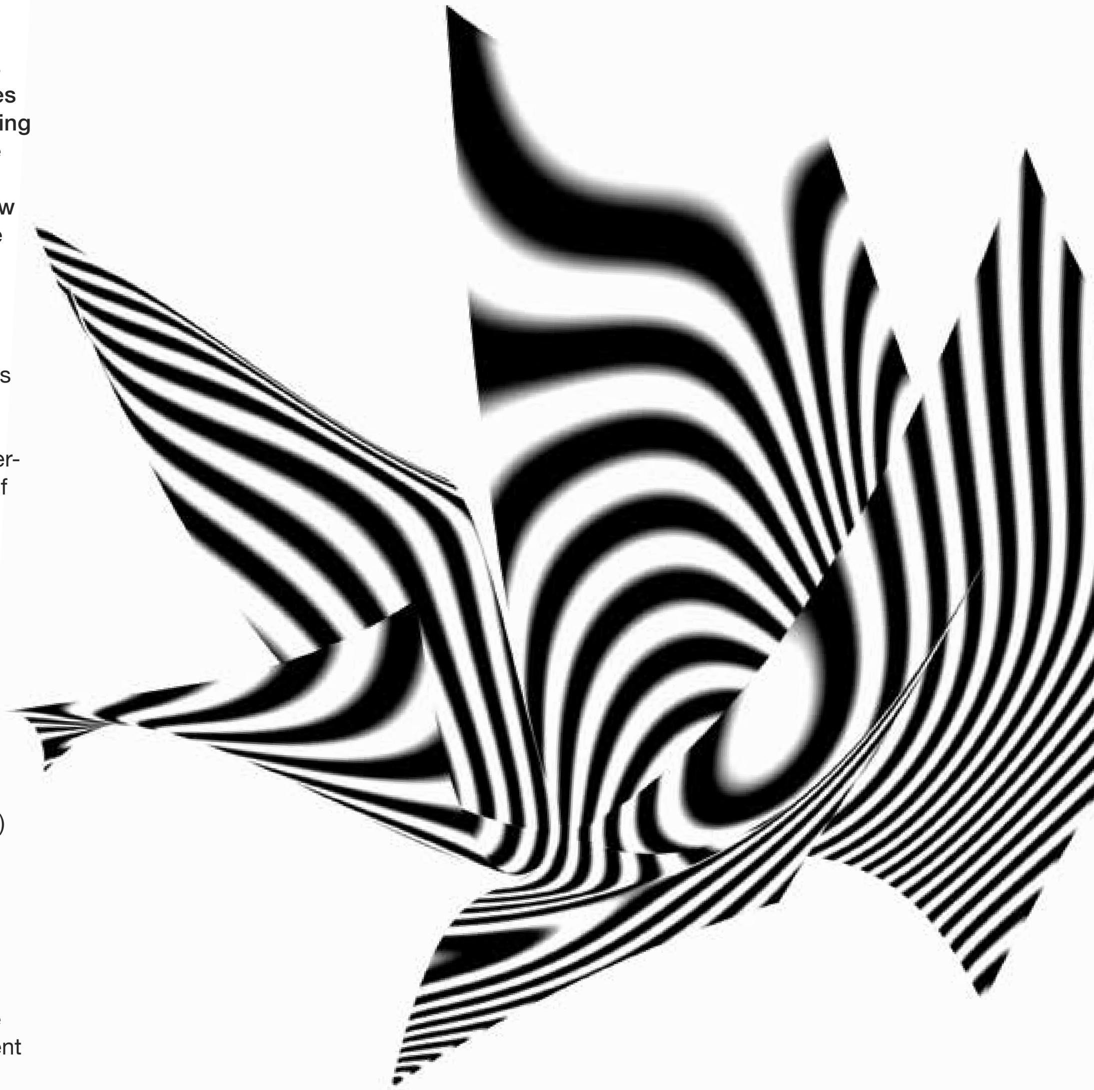
"The key for us is to be able to image whole biopsy samples or tumours rapidly and at a high level of detail."

Reichelt is also exploring new techniques such as Coherent Anti-Raman Stokes, which uses the nuclear vibrations of chemical bonds in molecules. This can provide a highly specific but label-free imaging contrast. This capability will allow the investigation of unlabelled live tissues from tumour biopsies with high specificity.

"These techniques will be particularly informative in understanding interactions between cancer cells and their microenvironment"

"You've got a friend in me"
Bringing designers and animators together

Aircraft designers and animators use different digital technologies to achieve the same goal: creating a three-dimensional image that can be manipulated. But a new method that links the two could vastly speed up how product designers create and simulate the performance of their products.



The adventures of Woody and Buzz Lightyear have been charming children – and adults – worldwide for 20 years this year. As well as a razor-sharp, hilarious script, Toy Story was the first full-length feature film made entirely using computer-generated imagery, marking the arrival of a new way of creating visual effects in three dimensions.

But the underlying mathematics that brought the toys to life, and continues to be used by a thriving visual effects industry, has actually been around since the 1960s. It's embedded in how the automotive, aeronautical and other manufacturing industries design their products.

The two branches of design – called subdivision surfaces (used by animators) and Non-Uniform Rational B-Splines (NURBS, used by the manufacturing industry) – have the same mathematical roots, but they have evolved in different directions.

Recently, however, researchers at Cambridge's Computer Laboratory have found a way to reconcile the two divergent paths, enabling product designers to access the easier and less-constraining tools used by the animation industry.

This all sounds like good news for the product designers. But, as lead researcher Neil Dodgson, Professor of Graphics and Imaging, explained, "there is understandable caution. Although the method used by designers gives greater freedom and increased usability, manufacturers have a back catalogue of existing models and around 45 years of experience. A move away from the method used by the manufacturing industry has to be sufficiently advantageous to warrant making." Dodgson believes that current research is providing that advantage.

The NURBS method was developed at a time when computers were very limited in their capabilities; by the time the subdivision surface method was commercialised, in the late 1990s, computers had vastly increased memories and processing power.

Essentially, the two methods address different priorities. When animators model three-dimensional surfaces, they want ease of design and their 'product' lives only on the screen. An engineer, by contrast, needs a design tool that is mathematically able to handle a wide range of requirements, including specifying cutting paths, mould shapes and objects that can actually be manufactured.

Dodgson's team's first breakthrough was to demonstrate, in 2009, a mathematical framework that made NURBS compatible with subdivision methods. Like a 'bolt-on' application, NURBS-based design could be imported to subdivision methods at the press of a button.

"It had been thought that the two methods had diverged so much as to be incompatible. Suddenly, we had a method that theoretically offered the manufacturing industry the flexibility the artists enjoy in subdivision. But the 'theoretically' is important… in practice there were two stumbling blocks."

With funding from the Engineering and Physical Sciences Research Council, his team has spent the past few years ironing out the problems. Ironically, one of the problems was to make creasing possible.

Take the Mercedes car. Part of its distinctive shape is the presence of two furrowed creases running the length of the hood. In fact, almost all cars have a crease somewhere. The NURBS method can accomplish this, and so can the animators' subdivision method, but the researchers' NURBS-compatible subdivision method had cases that just did not work. Now, however, the problem of creasing has been solved by Dr Jiří Kosinka.

“Suddenly, we had a method that theoretically offered the manufacturing industry the flexibility the artists enjoy”

The second challenge was to enable ‘trimming’. In NURBS design, holes and complicated joins are often made by mathematically trimming away part of the NURBS surface, which adds a further layer of mathematical complexity on top of the basic NURBS method. Subdivision does not need trimming, because it has the flexibility to allow holes and complex joins within its basic mathematical structure.

PhD student Jingjing Shen has tackled this problem by developing a method that will convert a trimmed NURBS surface to an ordinary, untrimmed, subdivision surface. Her current challenge is to extend this work from ordinary subdivision to NURBS-compatible subdivision.

“So will the industry take up our method? Well, a new piece of research might help persuade them,” said Dodgson. While the researchers in Cambridge were perfecting their conversion method, researchers in Europe and the USA have spent a decade developing a computational approach called isogeometric analysis (IGA) that would allow manufacturers to carry out design and simulation using the same tools.

New designs of products such as cars, planes and ships have to be rigorously tested using simulation software to be sure they will work – and work safely – once manufactured. At the moment, it is necessary to convert data from NURBS into a different geometrical representation for the analysis and testing phase. The engineers carrying out the analysis have to take the NURBS designs and then spend weeks or months creating new models that can be fed into the simulation system.

“Although IGA would enormously speed this process up, it cannot be used by product designers because it hasn’t been able to handle trimming,” said Dodgson. “We think we offer a way to avoid this problem.” Dodgson’s Austrian collaborators have recently developed IGA for subdivision surfaces and Dodgson suggests that the trimming problem can be completely avoided with Shen’s method for converting trimmed NURBS to untrimmed subdivision for analysis.

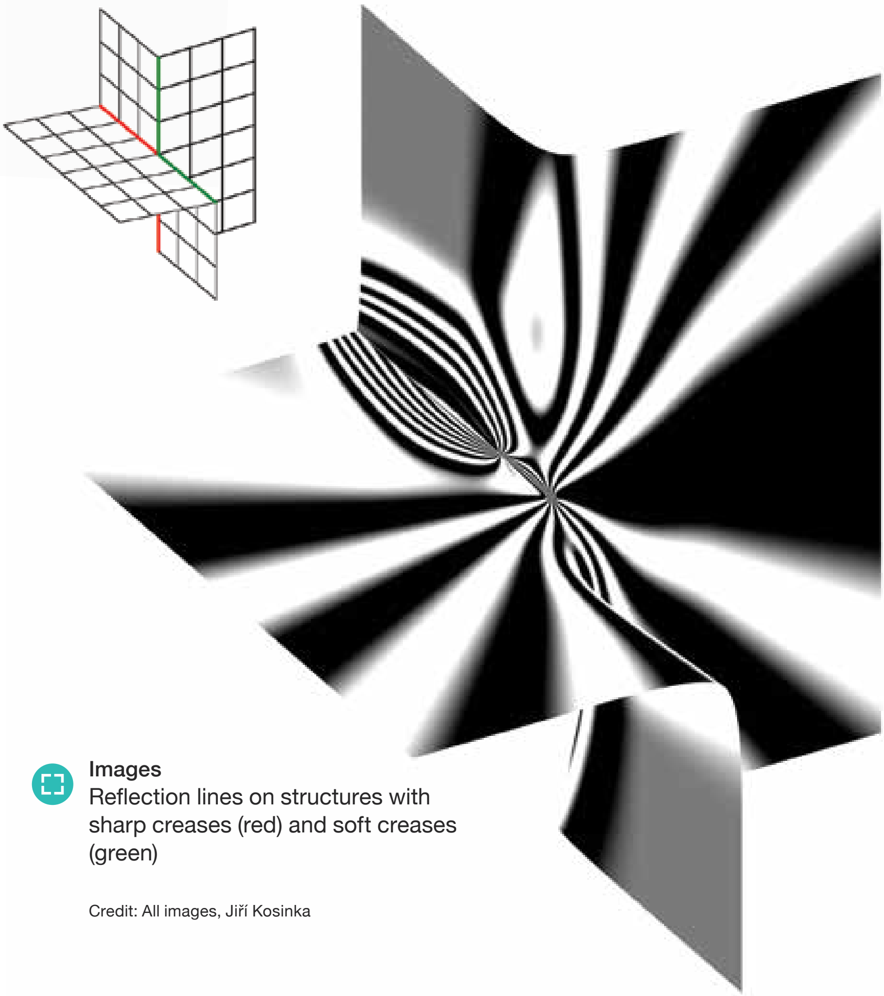
Dodgson points towards the example of a leaky teapot as an indication of how important the link between design and analysis is. When a teapot is designed using NURBS, the cutting and trimming needed to fit a spout to the body of the teapot leaves a tiny gap at one edge of the join. The same would be true for fitting the nose of an aeroplane to the body.

“At the production stage, these gaps don’t matter because the gaps are truly tiny. At sub-micrometer in size, they are smaller than the machining tools can cope with, so they simply vanish in the actual product,” he explained.

“But before you get to the production stage, when the design is going through simulation testing, they do matter. Any gap in a teapot would cause it to leak, in theory, and so the software throws up errors.”

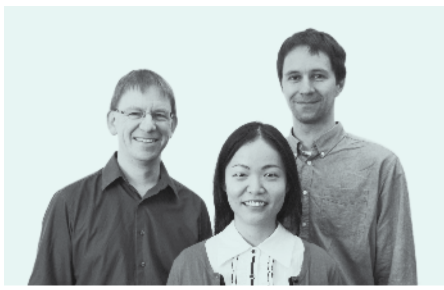
Dodgson believes that his conversion method can solve these difficulties: “When you convert from trimmed NURBS to subdivision, the gaps vanish: there is a true mathematical join between previously disjointed surfaces.”

He added: “This, combined with IGA, and subdivision’s increased flexibility and usability, all look very promising for being able to design and analyse automatically, and quickly feed the results back into re-design.” The researchers believe that the new process they are developing could make a vast difference to manufacturing design. Or, in the words of Buzz Lightyear, to infinity and beyond.



Images
Reflection lines on structures with sharp creases (red) and soft creases (green)

Credit: All images, Jiří Kosinka



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Credit: All images, Stephanie Hirmer

Extreme sleepover:
Keeping the lights on in rural Uganda

I have travelled here by a 'boda boda' motorbike and then night bus, sharing my seat on the 12-hour journey on unpaved roads to the West Nile Region of Uganda with two too many people, a goat lying beneath me, and enough chickens not to be able to ignore the smell. Only once I am on the bus do I realise that my local research assistant has accidentally booked us on the budget bus (only US$2 cheaper than the luxury coach).

To provide better infrastructure services to rural communities, it is fundamentally important to relate to the beneficiaries' needs and aspirations, and I need to travel to the areas to learn this at first hand. Infrastructure failure after the projects are handed over to the communities is common across the basic utility provisions such as water and electrification, and I am keen to discover if there is a way of improving project longevity by 'selling' a service that is valued.

Understanding the locals' real needs and desires can be a key element in overcoming the lack of technology uptake

Stephanie Hirmer travelled to Moyo in northern Uganda to ask which possessions the villagers most value and why. The results will be used to help reduce the failure rate of projects that bring electricity to rural communities.

"If I have a flush toilet in my house I think I can be a king of all kings because I can't go out on those squatting latrines… also it can protect my wife from going outside alone as recently my wife was almost raped by a thug when she escorted my son to the latrine at around 10:30pm in the night."

This is Paul. His declaration of the possession he would most value is met with laughter from his fellow villagers, but it highlights a very real concern – the safety of his family.

It's also a valuable research finding for me. Too often, projects that bring electricity to villages like Paul's fail because of lack of uptake and maintenance by the rural communities. But if, for instance, the benefits of electrification could be understood in terms of the safety value of night-time lighting, this could improve the sense of community responsibility towards sustaining the technology after its implementers have gone home.

Another villager, Michael, explains that he places most value in owning a corrugated iron sheet instead of grass-thatched roofing because this would reduce the risk of indoor fires. Here too, the value of electricity can be highlighted – it would avoid the need to cook on an open fire.

Understanding the locals' real needs and desires can be a key element in overcoming the lack of technology uptake. Finding out what these are is the aim of my PhD research, working with Dr Heather Cruickshank at the Centre for Sustainable Development. While the technology itself has been extensively studied, social attributes in project design have received little attention.

Seven villages and three days of focus group discussions per village seem like an achievable task in the two months scheduled. Today is the first day of fieldwork and we have arrived at the village of Moyo for the day's focus group discussions. The village is still very familiar to me; not much has changed since my last visit three years ago when I was working with the German Development Agency, GIZ, on the installation of the community-operated pico-hydropower scheme. These schemes are perfect for small communities with about 50 homes that require only enough electricity to power a few light bulbs and a small number of electrical items. In Moyo, however, the scheme no longer works, and the villagers are once more plunged into darkness while a more effective solution is being explored.

We meet one of the women to mobilise the six chosen villagers. We decide to start with the men, as by late morning some of the men in the village will be drunk.

Identifying what is important to rural villagers when implementing basic infrastructure projects is far more complex than simply asking "what is important to you?" I have made a 'value game' and explain to the locals that they must choose, initially individually, 20 items from a list of approximately 50 items that include cow, hoe, fridge, water pot, bed and utensils. Following prioritisation, they will be asked to give reasons as to why these items are important to them.

Another example arises during the discussion. The villagers use kerosene lamps to light their homes. Simply offering a solution that replaces light from one source with another is not enough. Modern technologies can offer benefits that are indirectly linked to aspects perceived as 'very important' in rural communities – in this case, avoiding the use of fume-producing kerosene would resonate with the mothers' hopes of keeping their children healthy.

The findings from my research will be fed back to project implementers. My hope is that only small adjustments in the project design will be required in order to communicate these 'additional' benefits to the target users, and that the lights will be turned on and kept on in rural villages like Moyo.

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