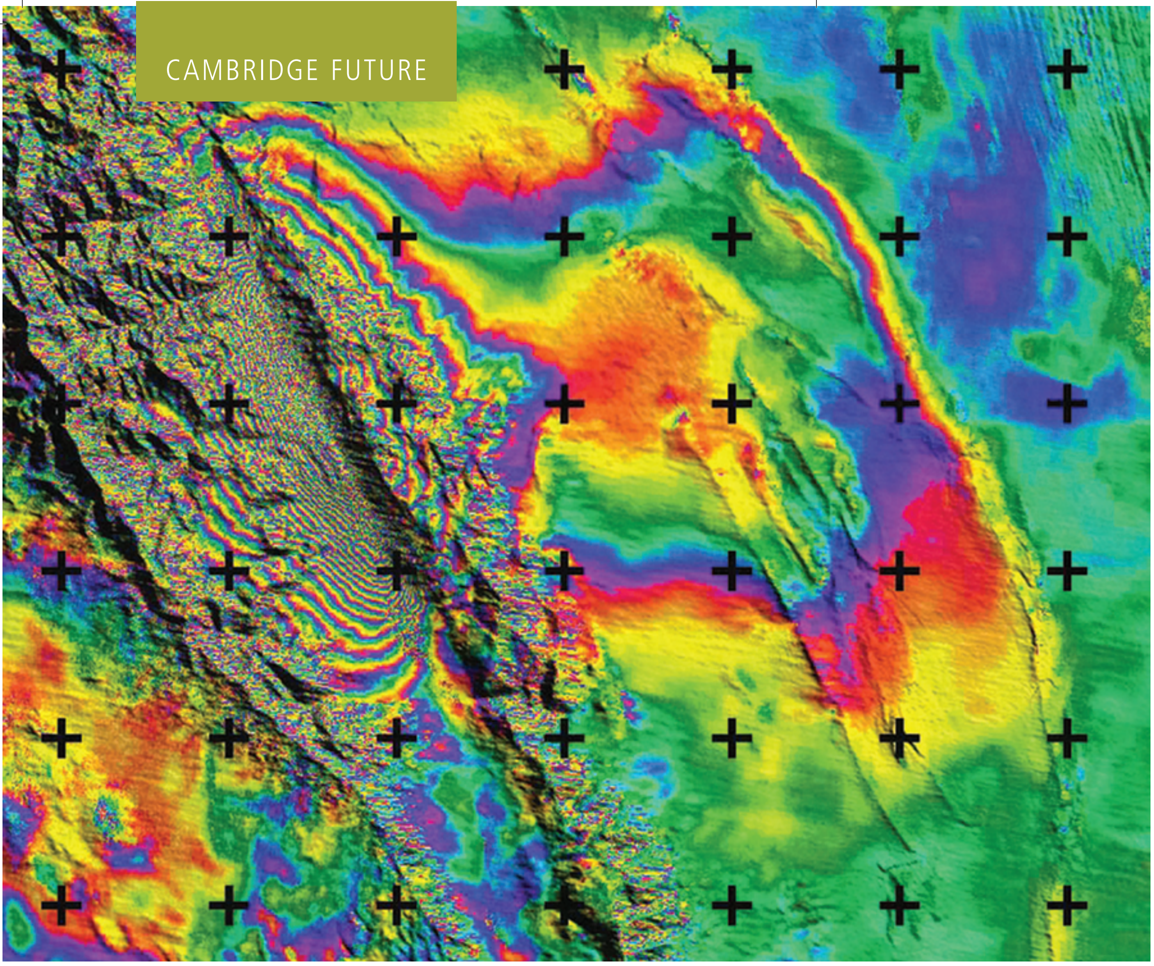


Imaging the universe

The digital revolution has put new analytical tools in the hands of researchers in every discipline. **Sarah Woodward** samples some of the dramatic results being won in Cambridge

Top. Map view of the central Iranian desert with grid crosses ~20 km apart. After an earthquake in 1998, a radar interferogram was draped over the topography so that each colour fringe distinguished a change of distance of 28mm between ground and satellite. The fault responsible for the quake can be seen clearly where the fringes concentrate, running diagonally top left to bottom centre. It moved by a metre. To the right, marked by a blue-red-yellow line, is a ridge. This grew by just 80mm – an observation that without radar could never have been obtained

James Jackson

is a geologist who studies how continents deform. Using satellite imaging he works at every scale, from single earthquakes to complex regional fault patterns that can deform huge areas. Born and raised in India, he is now Professor of Active Tectonics in the Department of Earth Sciences and a fellow of Queens' College

The Earth

The faults that move during earthquakes do not always come to the surface. They often die out below the surface, but form a ridge that may be much less obvious than a fault-line. Using space-based radar images we can measure the distance between a satellite and the ground, and by comparing images taken before and after earthquakes – an 'interferogram' – we can see how much these ridges grow at each seismic event. It may be just a few centimetres. The ridges that make up the landscape are made by repeated earthquakes over thousands or millions of years, so seeing how they grow allows us to recognize which ones are active and potentially hazardous. It is extraordinary that we can now observe fault movement of only a few centimetres from space.

Of course, the system is not yet perfect. The satellites are building up a database of pre-earthquake radar images and have most of the world covered, but at the moment the technique works best in desert areas. If you use it in Britain you're frankly just watching the grass grow. Tree cover gets in the way as well.

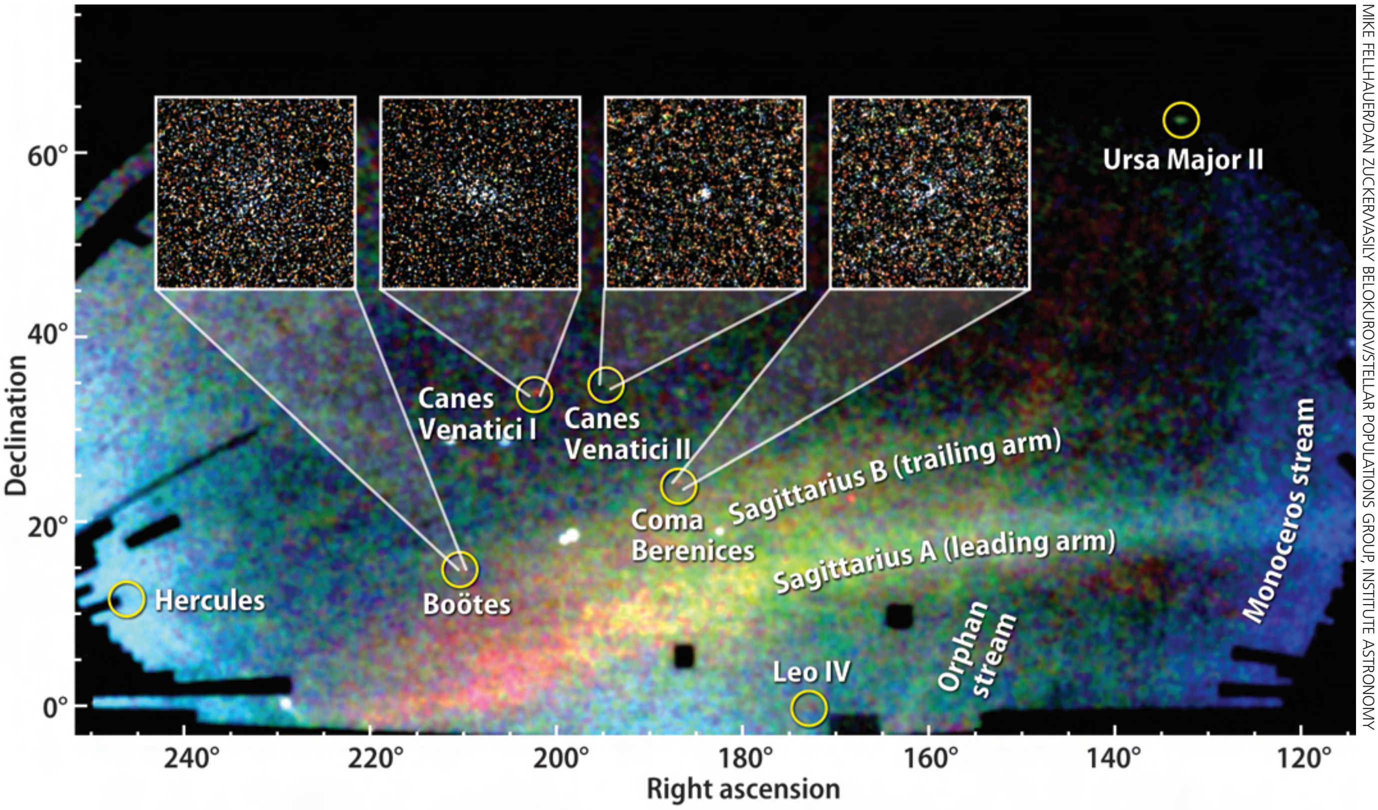
Take the fault that in 2003 destroyed Bam, a city in the desert of south-eastern Iran which was very similar in size and shape to Cambridge. We didn't even know where the fault was until after we received the post-earthquake radar images. In desert regions, people often live near active faults, because where there is a fault there is usually a water supply. And that means these places become part of major trade routes, like the Silk Roads across Asia from Xi'an to the eastern Mediterranean.

If you look at the historical evidence that exists for the last millennium, the number of earthquakes around the world is not increasing. What *is* increasing is the number of people killed by them. And the principal reasons for that are population growth and badly constructed apartment blocks. In Bam, with a population of 100,000, around 40,000 people were killed outright.

The shocking thing was that it really wasn't a very big earthquake. In 1994 a similar-sized earthquake in Los Angeles killed 40 people. But in the Pakistan earthquake of 2005 in Muzaffarabad, there were 73,000 dead outright from a total population of 170,000. The appalling scale of casualties is largely down to poor urban building.

What is even more frightening is that in many parts of the world poor-quality construction continues along or adjacent to major faults. In Tehran a brand new hospital has just been built right on an active fault. Should there be an earthquake in either Tehran or in the Ganges basin of northern India a death toll of a million is by no means inconceivable. Istanbul, with a population of eleven million, is very vulnerable for similar reasons.

Earthquakes repeat in the same places, though infrequently. Space-based radar and optical imaging has improved our ability to recognise active and hazardous geological structures, so we can tell the engineers and planners what is likely to happen, if not when. Whether they choose to listen is another matter.



MIKE FELLHAUER/DAN ZUCKER/VASILY BELOKUROV/STELLAR POPULATIONS GROUP, INSTITUTE ASTRONOMY

Above. The Milky Way belongs to a small cluster of galaxies that condensed out of the expansion of the universe. Here details of four constellations – Boötes, the Coma Berenices and the Canes Venatici – illustrate the sheer density of stars

Gerry Gilmore

is an astronomer whose research focuses on stellar populations and the nature of matter. His particular interest is our own galaxy, the Milky Way, which itself has an estimated 100 million stars. Originally from New Zealand, he is currently Professor of Experimental Philosophy, and Deputy Director at the Institute of Astronomy

Stars

Everything astronomers do is about imaging. Unlike virtually any other science, we can't do experiments, so we simply observe what nature provides. Observing small things like planets or distant galaxies is straightforward; observing the Milky Way, which fills the whole sky, is harder. When you are sitting out there staring at the stars on a clear night, you are effectively looking *through* the Milky Way. In order to see what is happening within it a special telescope is needed. A normal telescope is just like an ordinary, if very expensive, camera – it finds it hard to take wide angle images. But lately the technology has been revolutionised.

We are currently using a telescope based on Apache Point in New Mexico in order to map the northern sky as part of the Sloan Digital Sky Survey. The telescope stays still, and so lets the sky drift slowly across, allowing us to take many thousands of video scans that we can then stitch together to make an image. Before such digital technology became available we simply couldn't see the many complex aspects of the Milky Way that we now know are out there.

It is no understatement to say that the new technology is allowing us to understand the structure of the universe. We have already made spectacular steps forward. And we keep finding out things we simply did not expect, things that from all our predictions could not exist – but they do.

For example, for many decades astronomers thought that the dark matter that holds together the Milky Way was flat in shape, but analysis of the motions of newly discovered structures in the new images have shown that it is in fact round. We keep discovering new satellite galaxies of the Milky Way as well, which we call dwarfs. Until two years ago we only knew seven of them, but we have now found seventeen and suspect that there are several dozen more. We discovered another one just a couple of months ago.

Within the Milky Way we have also located a very large and previously unknown galaxy called Sagittarius, which is currently being cannabalised or shredded. We can see this from the tail it leaves behind. Another new discovery is an orphan stream of stars – a ghostly remnant the origin of which we don't understand. It's like the Cheshire cat's smile without the Cheshire cat.

Our next step is to look at the Milky Way in the southern hemisphere in the same way. We have predicted what we might see by building 3D computer models using calculations based on Newtonian principles of gravity. We expect that we will be at least partially right, but I also expect us to make completely unexpected discoveries, just as we did in the northern hemisphere. Astronomy is developing at an astonishing rate and nothing that we know today is what I was taught as an undergraduate. It is all very exciting.

Colin Humphreys

is particularly interested in the links between a material's atomic structure and its electrical and mechanical properties. He is Goldsmiths' Professor of Materials Science and a fellow of Selwyn College

Atoms

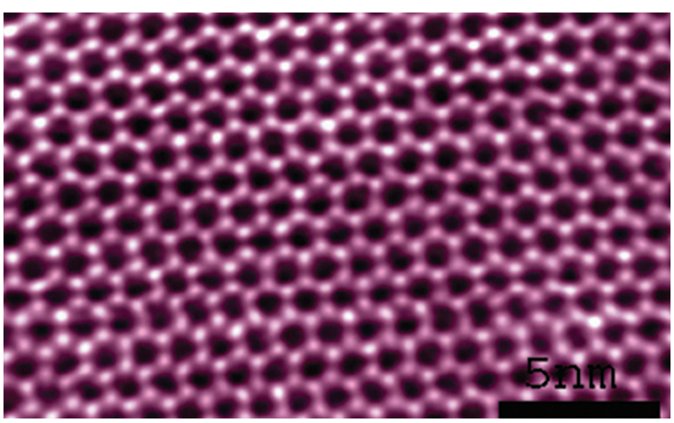
We can now distinguish single atoms in some materials, forming images at around 100 million times magnification using powerful electron microscopes. The first such microscope was developed back in the 1930s by the German physicist Ernst Ruska, who won a Nobel Prize for his work. From then on there were incremental improvements to the technology, until a step change a few years ago. This was the introduction of what is known as an aberration corrector. If you're using a camera lens you get a very high quality optical image because the lens has both concave and convex surfaces, which cancel out any aberrations. But until very recently there were no electron microscopes with aberration-free imaging.

Of course, they are not cheap, with the most advanced coming in at around £4million. But I am happy to say that next year the first of its type in the country will be installed in Cambridge. It will allow us to resolve atoms in *any* material. In addition, because it will contain an electron monochromater and energy analyser, it will enable us to identify each atom chemically (whether it is, say, aluminium or nitrogen) and also give information on how each atom bonds to its neighbours. It is so sensitive to its environment that we cannot house it within the department in central Cambridge because of the traffic vibrations. It is therefore going to be installed in west Cambridge, where it will be able to be shared across departments.

Crystals are like people: it is the defects in them which make them interesting. The reason why we need this microscope is that no crystal is perfect. In some a whole row of atoms is missing; in others a whole plane is dislocated. Our job is to look for defects, which then explain why a material is not working perfectly for a specific use. Just one atomic layer misplaced can change the properties of the material, causing your computer to fail, for example. So we need to be able to image single atoms in materials. This is more and more important as nanotechnology moves forward and devices shrink in size.

We believe that a score of the properties of any material are controlled at the level of individual atoms. At the moment, with the current excellent technology available, we still often see, say, a pair of atoms as one blob. The fact that we will now be able to have an electron beam focused down to the level of a single atom – and so image individual atoms – is quite remarkable. It will mean in effect that the test tube in which we used to analyse materials has now become one-atom sized. It will benefit our future health and wealth by allowing us to see things that we didn't expect – and to construct and image atom-by-atom new materials that we haven't yet dreamt about.

Below. A crystal of aluminium nitride imaged at high magnification using an aberration-corrected electron microscope. Each dot is a single atom, and the hexagonal arrangement of the atoms is clearly visible. The scale mark is 5nm. 1nm (nanometre) is one millionth of a millimetre



Roberto Cipolla

is a computer vision specialist whose knowledge of mathematics, art and photography has helped him develop a method for making highly detailed 3D models from digital photos. He is Professor of Information Engineering and a fellow of Jesus College

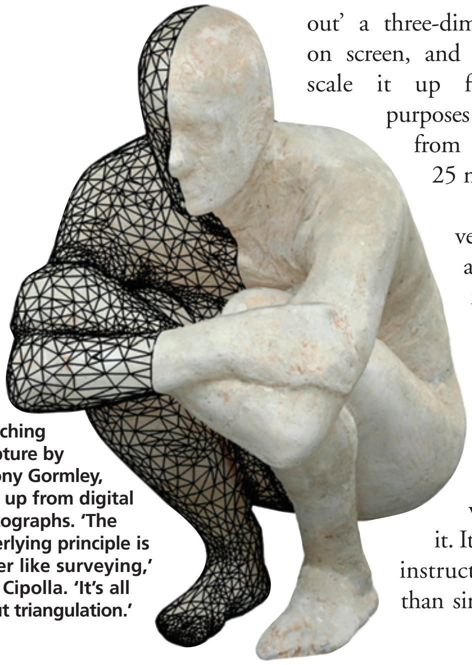
Shape

My research team's work focuses on how we recognise objects, and in particular how we can recover their three-dimensional shape. I have always been interested in sculpture, so it was natural for me to use sculptures as a way of demonstrating what we do. I'm just lucky my work allows me to incorporate a hobby.

Essentially we take pictures of an object from a number of different angles using a digital camera (though you could even use a mobile phone camera). We need a minimum of eight points of correspondence, and then it is all about geometry and optimisation. The mathematical dimensions allow the computer to calculate where to put the camera and the object in space, and can then build up a 3D image from a sequence of two-dimensional snapshots. The underlying principle is rather like surveying. It's all about triangulation.

Where there is no texture to an object – as in a smooth marble sculpture – you have some problems. The way round is to contrive a chiaroscuro, an interplay of light and shadow. We achieve this by literally waving a torch around the object as we photograph it, so we can calibrate where there is a light source in space and recover the surface orientations.

We have made 3D images of everything from the Parthenon Marbles to the sculptor Antony Gormley's naked body. He wrapped himself in clingfilm, and then crouched in the pose he wanted while we took high-resolution colour photographs in natural light. When processed, the silhouette and texture of each picture allowed a computer to 'carve



Crouching sculpture by Antony Gormley, built up from digital photographs. 'The underlying principle is rather like surveying,' says Cipolla. 'It's all about triangulation.'

out' a three-dimensional shape on screen, and if necessary to scale it up for fabricating purposes – in this case from life-size to over 25 metres high.

Museums are very enthusiastic about our results, because they allow viewers to view an object from every angle, just as if they were handling it. It is a much more instructive experience than simply looking at an object sitting in a glass case. The viewer can zoom in on particular aspects of the object, and even turn it upside down.

Computer vision is already very important commercially in everything from computer games to assisted parking in cars, but this is just the beginning. The next generation of search tools will be based on images rather than words. As we speak, cars with photographers are driving around Britain taking pictures for a databank of physical images that you will soon be able to interrogate to find out where you are: you will take a picture and the computer will identify it. Computers can also be set up to recognise particular objects such as a horse or a car, from what is effectively an online library.

Currently we are looking at applying computer vision to the human body. The day is not far off now when you will be able to photograph yourself from various angles, and simply email your coordinates to the shop of your choice in order to buy made-to-measure shoes or clothes.

For models created by computer vision that you can rotate on screen, go to: www.eng.cam.ac.uk/news/stories/2005/digital_pygmalion/

François Penz

studies the links between cinema and architecture – a relationship that dates from 1895, when the Lumière brothers captured the first images of a city on film. He is Reader in Architecture and a fellow of Darwin College

Space

Whenever architects have demonstrate visually to clients or town planners the way a building or even a cityscape will function they need people to illustrate scale and movement in whatever they present. Historically, representing the human body convincingly in a virtual environment has been very difficult. At the moment most architects use computer-aided design animation, but with CAD technology you get all sorts of problems, including fly-throughs crashing into walls and unpopulated spaces! Our solution has therefore been to draw on one of the oldest means of imaging we have – the cinema.

Architecture and the moving image have a long history together – Le Corbusier, for instance, was very interested in film. But the cinema also shapes the way we perceive cities, establishing preconceptions before we even visit. Even if you've never been to Paris or San Francisco or New York, you probably have a perceived idea of what they look like, drawn, say, from *Gigi*, *Vertigo* and *Taxi Driver*.

It is only recently that we've been able to people our buildings on a computer screen. For individuals to be properly inserted into digital images they need first be shot against a blue screen. Then you remove the blue from the image (blue being the colour that is least present in the human body). Enabling people to flow through a virtual building allows us to narrate the space, just as you would narrate a film.

We tell a story, which allows the viewer to imagine the space fully but at the same time keeps the architecture at the forefront. This is very important for understanding spatial issues, whether in the context of planning applications or wider public debate.

A good example is planning for the National Health Service. Quite often it is only after a hospital is built that doctors and nurses say that the use of space is not as they envisaged. Hospitals are highly complex buildings with tremendous navigational problems – they are almost like small cities. Perhaps in the future newly built hospitals will therefore have computer terminals on which patients and visitors can watch a film and work out where they're heading before they set off.

The future of imaging in architecture unquestionably lies in interactivity – moving through space in real time, just as in a computer game. Architects think a lot about space, but conveying their ideas to the general public has always been an issue until recently. In the future that expression of spatiality will change a lot. It is simply that right now the technology is changing faster that many architects' practices ability to use it in a meaningful way. ■

Above. Three images of dancers from a 3D reconstruction of one of Giorgio de Chirico's metaphysical paintings. Produced by the Architecture and the Moving Image MPhil workshop, 2005