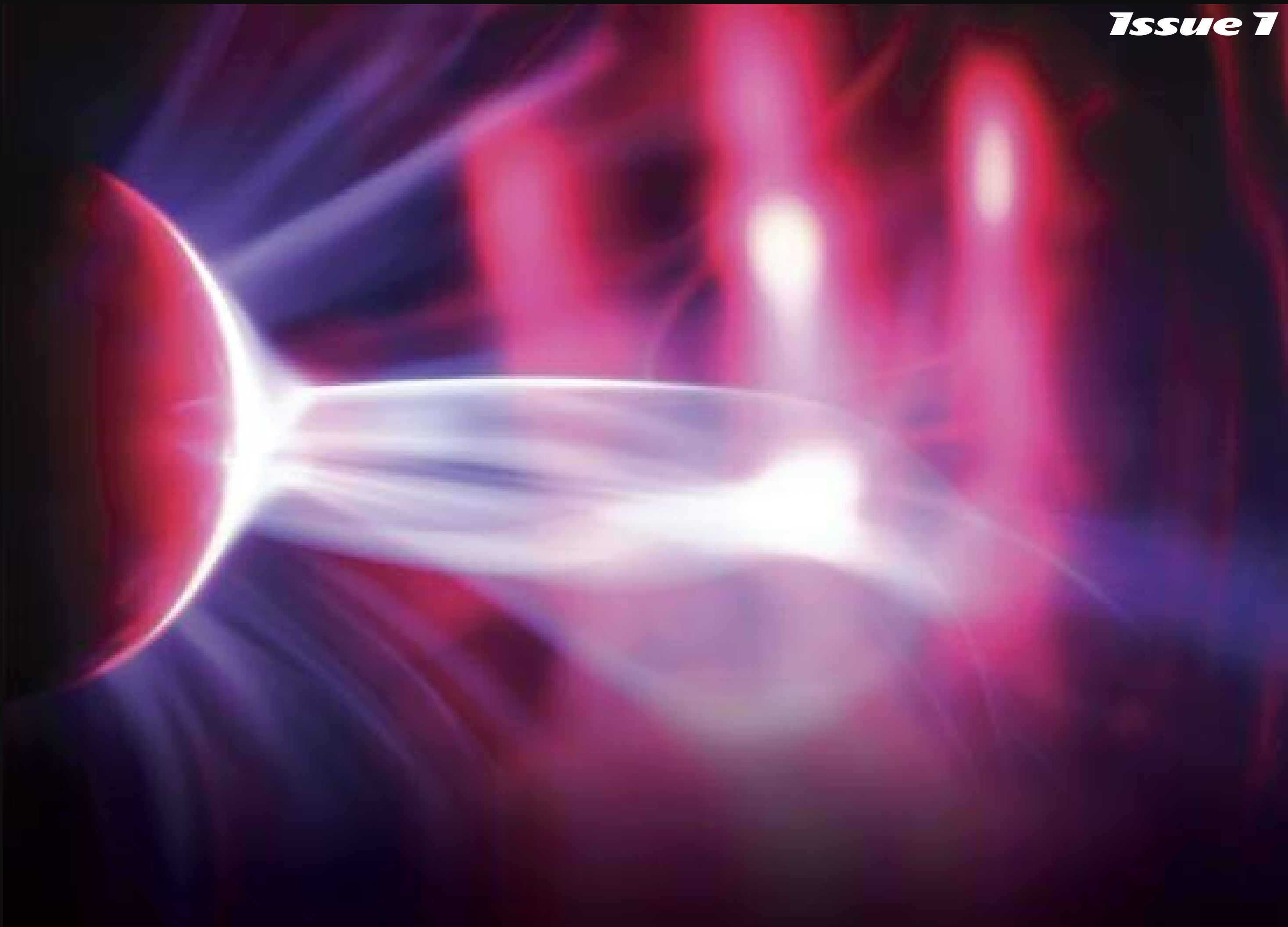
Issue 1



EE4FN

Electronic Engineering for Fun

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Queen Mary
University of London

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Editorial: Building things with intelligence

The modern world is completely dependent on electronic engineering and physical computing. Gadgets fill our kitchens and our living rooms. We carry them in our pockets and they run our cars and trains. Increasingly they are gaining senses so they know about the world around them, and are becoming intelligent. Someone of course has to come up with the ideas, solve all the practical problems and actually make it work. That takes creativity and an ability to solve problems as well as technical engineering skills. Electronic engineering isn't just about gadgets though, but also about the invisible infrastructure that those gadgets depend on – the mobile phone networks and the Internet, satellites and antennas, for example.

ee4fn is all about electronic engineering and physical computing. It's the place to be if you want to build things to solve problems or just for the fun of it. It's also the place to be if you want to make the world work better or change the way we all live our lives. It's about building things with intelligence!

Do you like 'photo-resist' art? Let me guess … you're trying to figure out what it is, aren't you? Here are some hints. They are drawings made with special brushes whose bristles are made of pure beams of light. As with watercolour or ink paintings, they can be created using different drawing techniques, each needing a specific brush and canvas. Their most astonishing feature is that they can hold within them the live streaming of any kind of information, whether text, images or sounds.

Maybe something that fits that description springs to mind? Maybe you would like to learn how to create such an amazing artwork? Here is another hint: a photo-resist artwork is probably right in front of you, but you didn't notice it. Photo-resist artists tend to hide their art inside things like music players and laptops!

Think about the core of a technological gadget. It's made of electronic components connected by communication lines. Think now about the contours of those components, and the communication lines between them. Suppose we think of them as pictures drawn on foils of conductive material, like copper, instead of paper. Maybe the drawing can be turned into a miniaturised world of cities and highways? Let science fiction movies, such as The Matrix and Tron, push your imagination. Let electrons move on the highways. Let them carry your music, your movies, your text. Each technological gadget is a different world, with its own cities and highways. Each city has a specific role. Connect the cities in different ways, and you will end up with different overall behaviour – designing photo-resist works of art is about creativity. Connect the cities in the wrong way, and the world will break down – it is also about knowledge.

You are starting to get a glimpse of the incredible vision that Paul Eisler, a researcher in the field of electronics, had about sixty years ago. He was right in the heart of London when he created the first photo-resist work of art. Photo-resist artists are in fact electronic engineers, and their photo-resist works of art are known as printed circuit boards. The patterns that make up the circuits are both beautiful and complex. They are 'drawn' using lasers, but unlike the drawings of a regular artist the precise pattern drawn matters if they are to come to life and do something useful. An entire functioning world in the palm of your hand. Just amazing.

Photo-resist art can hold within it the live streaming of any kind of information, whether text, images or sounds.

The Touching Booth

Have you ever felt that spark of true love when you kissed someone for the first time? Wouldn't it be great if you could have recorded it for posterity? Well in the future that spark of electricity might just take the photo itself!

Photo booths can be boring don't-smile-you-are-getting-your-passport-photo-done places. Or they can be playful places where as many friends as possible jam into the tiny space. GeekPhysical, a Danish group who like to play with physical computing, electronics and sensors to create new and often whacky ways for people to interact, decided to reinvent it to be as playful as possible.

The result was 'The Touching Booth'. It consists of two chairs set up facing each other. Rather than press a button to take the photo, the two people just touch. They could be shaking hands, giving a high five, kissing or making any other kind of contact come to that. That touch closes an electronic circuit that runs from the camera to the first chair, through the person sitting on it to the other person, on through their chair and back to the camera. When there is no contact the circuit is broken, so nothing happens, but as soon as they touch the electricity really flows, firing the camera. The result is a photo taken of the moment of the touch. Surprised that a person can be part of a circuit? We are pretty good conductors as it happens!

The two people are a giant electronic switch

To add an extra twist of mischievous fun, though, GeekPhysical decided to have the touch only take a photo of one half of the scene. The other half is taken on the second touch. That means people can play with the possibilities, touching in different ways or even swapping people between the two touches.

So if you happen to be somewhere with a Touching Booth in the future, give it a go. Who knows, a spark of electricity with a complete stranger might break the ice and lead to something special. If it does, you will even have the photo of the moment it happened to look back on!

See the Touching Booth in action at **geekphysical.blogspot.com/2011/07/touching-booth.html**

It must be fiction

In Star Wars, Luke controls objects with his mind – he feels the force. Surely that is total fiction! Well, using brain-computer interfaces (electrodes connected to a computer that moves magnets around) you can now play a game where you move a metal ball just by thinking. It's called Mindball!
See **www.cs4fn.org/braininterfaces/competitivezen.php**

The optical Pony Express

Suppose you want to send messages as fast as possible. What's the best way to do it? That is what Polina Bayvel, a professor at UCL, has dedicated her research career to: exploring the limits of how fast information can be sent over networks. It's not just messages that it's about nowadays of course, but videos, pictures, money, music, books – anything you can do over the Internet.

Send a text message and it arrives almost instantly. Sending messages hasn't always been that quick, though. The Greeks used runners. In fact, the marathon originally commemorated a messenger who supposedly ran from a battlefield at Marathon to Athens to deliver the message "We won" before promptly dying. The fastest female marathon runner in the world right now, Paula Radcliffe, at her quickest could deliver a message a marathon distance away in 2 hours 15 minutes and 25 seconds (without dying!)

Horses improved things (and in fact, the Greeks normally used horseback messengers, but hey it was a good story). Unfortunately, even a horse can't keep up the pace for hundreds of miles. The Pony Express pushed horse technology to its limits. They didn't create new breeds of genetically modified fast horses, or anything like that. All it took was to create an organised network of normal ones. They set up pony stations every 10 miles or so right across North America from Missouri to Sacramento. Why every 10 miles? That's the point that a galloping horse starts to give up the ghost. The mail came thundering in to each station and thundered out with barely a break as it was swapped to a new fresh pony.

The Pony Express was swiftly overtaken by the telegraph. Like the switch to horses, this involved a new carrier technology – this time copper wire. Now the messages had to be translated into electrical signals in Morse code. The telegraph was followed by the telephone. With a phone it seems like you just talk and the other person just hears but of course the translation of the message into a different form is still happening. The invention of the telephone was really just the invention of a way to turn sound into an electrical code that could be sent along copper cables and then translated back again.

Why are optical fibres such a good way to send messages? Well the obvious answer is that you can't get much faster than light!

The Internet took things digital – in some ways that's a step back towards Morse Code. Now, everything, even sound and images, are turned into a code of ones and zeros instead of dots and dashes. In theory images could have been sent using a telegraph tapper in the same way … if you were willing to wait months for the code of the image to be tapped in and then decoded again. Better to just wait for computers to be invented that can do it quickly.

In the early days of the Internet, the message carrier was still good old copper wire. Trouble is, when you want to send lots of data, like a whole movie, copper wire and electricity are starting to look like the runners must have looked to horse riders: slow, out-of-date technology. The optical fibre is the modern equivalent of the horse. They are just long thin tubes of glass. Instead of sending pulses of electricity to carry the coded messages, they now go on the back of a pulse of light.

Up to this point it's been mainly men taking the credit, but this is where Polina's work comes in. She is both exploring the limits of what can be done with optical fibres in theory and building ever faster optical networks in practice. How much information can actually be sent down fibres and what is the best way to do it? Can new optical materials make a difference? How can devices be designed to route information to the right place – such 'routers' are just like mail sorting depots for pulses of light. How can fibre optics best be connected into networks so that they work as efficiently as possible – allowing you and everyone else in your street to be watching different movies at the same time, for example, without the film going all jerky? These are all the kinds of questions that fascinate Polina and she has built up an internationally respected team to help her answer them.

Why are optical fibres such a good way to send messages? Well the obvious answer is that you can't get much faster than light! Well actually you can't get ANY faster than light. The speed of light is the fastest anything, including information, can travel according to Einstein's laws. That's not the end of the story though. Remember the worn out marathon runner? It turns out that signals being sent down cables do something similar. Well, not actually getting out of breath and dying but they do get weaker the further they travel. That means it gets harder to extract the information at the other end and eventually there is a point where the message is just garbled noise. What's the solution? Well actually it's exactly the one the Pony Express came up with. You add what are called 'repeaters' every so often. They extract the message from the optical fibre and then send it down the next fibre, but now back at full strength again. One of the benefits of fibre optics is that signals can go much further before they need a repeater. That means the message gets to its destination faster because those repeaters take time extracting and resending the message. That, in turn, leaves scope for improvement. The Pony Express made their 'repeaters' faster by giving the rider a horn to alert the stationmaster that they were arriving. He would then have time to get the next horse ready so it could leave the moment the mail was handed over. Researchers like Polina are looking for similar ways to speed up optical repeaters.

You can do more than play with repeaters to speed things up though. You can also bump up the amount of information you carry in one go. In particular you can send lots of messages at the same time over an optical fibre as long as they use different wavelengths. You can think of this as though one person is using a torch with a blue bulb to send a Morse code message using flashes of blue light (say), while someone else is doing the same thing with a red torch and red light. If two people at the other end are wearing tinted sunglasses then depending on the tint they will each see only the red pulses or only the blue ones and so only get the message meant for them. Each new frequency of light used gives a new message that can be sent at the same time.

The tricky bit is working out which people can use which torches at any given time so there aren't any clashes. At any instant, messages could be coming and going from anywhere in the network. If two people try to use the same torch on the same link at the same time it all goes to pot. This is complicated further by the fact that at any time particular links could be very busy, or broken. That means different messages may also travel by different routes between the same places, just as you might go a different way to normal when driving if there is a jam. To come up with the best possible optical network as Polina is aiming to do, she'll have to solve all these hairy problems and more.

Polina has been highly successful working in this area. She has been made a Fellow of the Royal Academy of Engineering for her work and is also a Royal Society Wolfson Research Merit Award holder. It is only given to respected scientists of outstanding achievement and potential. She has also won the prestigious Patterson Medal awarded for distinguished research in applied physics. It is important to remember that modern engineering is a team game, though. As she notes she has benefited hugely by having inspiring and supporting mentors, as well as superb students and colleagues. It is her ability to work well with other people that allowed her to build a critical mass in her research and so gain all the accolades.

RFID knickers

Electronic gadgets have become so cheap shops just give them away with every purchase. They are so cheap that you then just throw them away without even noticing you had them. Did you get a DVD for Christmas? There was probably a chip stuck to the package – used just to sound an alarm if Santa walked out the shop without paying for it. Buying a new skirt with your Christmas money? It will probably be tagged too.

These gadgets – essentially computers with aerials – are called 'RFID tags'. Their job is just to communicate their identity to other computers (RFID readers) in the shop: like the ones connected to the tills and those controlling the door alarms. Each RFID tag has a unique identity: a number different to that of every other tag in the world. That means every single item in a shop that is tagged is announcing exactly who it is to any computer close enough that wants to listen. It isn't just saying it is a skirt, but saying it is a particular skirt. The store's main computer holds lots of information about it that it can look up once it has that identity number. What information? Well, things like that it is a denim skirt, the make, the size, whether it is made of organic, fair-trade cotton, and whether it has been paid for and is allowed to walk out of the store.

The simplest RFID tags consist of just a chip and a radio antenna. For it to be of any use it needs more than just the tags – whole networks of readers, networks and databases lie behind them. When tags pass near a reader they send it the information they have stored – their identity – using a radio frequency. That is all RFID stands for 'Radio Frequency IDentification'. As they do a very simple thing – transmit their information when asked – the chip on a RFID tag is very simple. That is why they can be made cheaply enough to be throwaway items. They cost only a few pence each.

Simple they may be, but with a little ingenuity people have come up with all sorts of intriguing ways to use them. In shops they are used for stock control as well as anti-theft devices. The main computer can keep track of every individual item that passes through the tills and through the door. They are used in travelcards in cities round the world as a way to make sure only people who have paid can travel. Modern passports contain them. They have even been implanted in people's arms in Mediterranean nightclubs. By noting the person's credit card number with the tag ID when it is implanted, they can then be used to automatically charge people for drinks so they don't have to worry about their wallet being nicked.

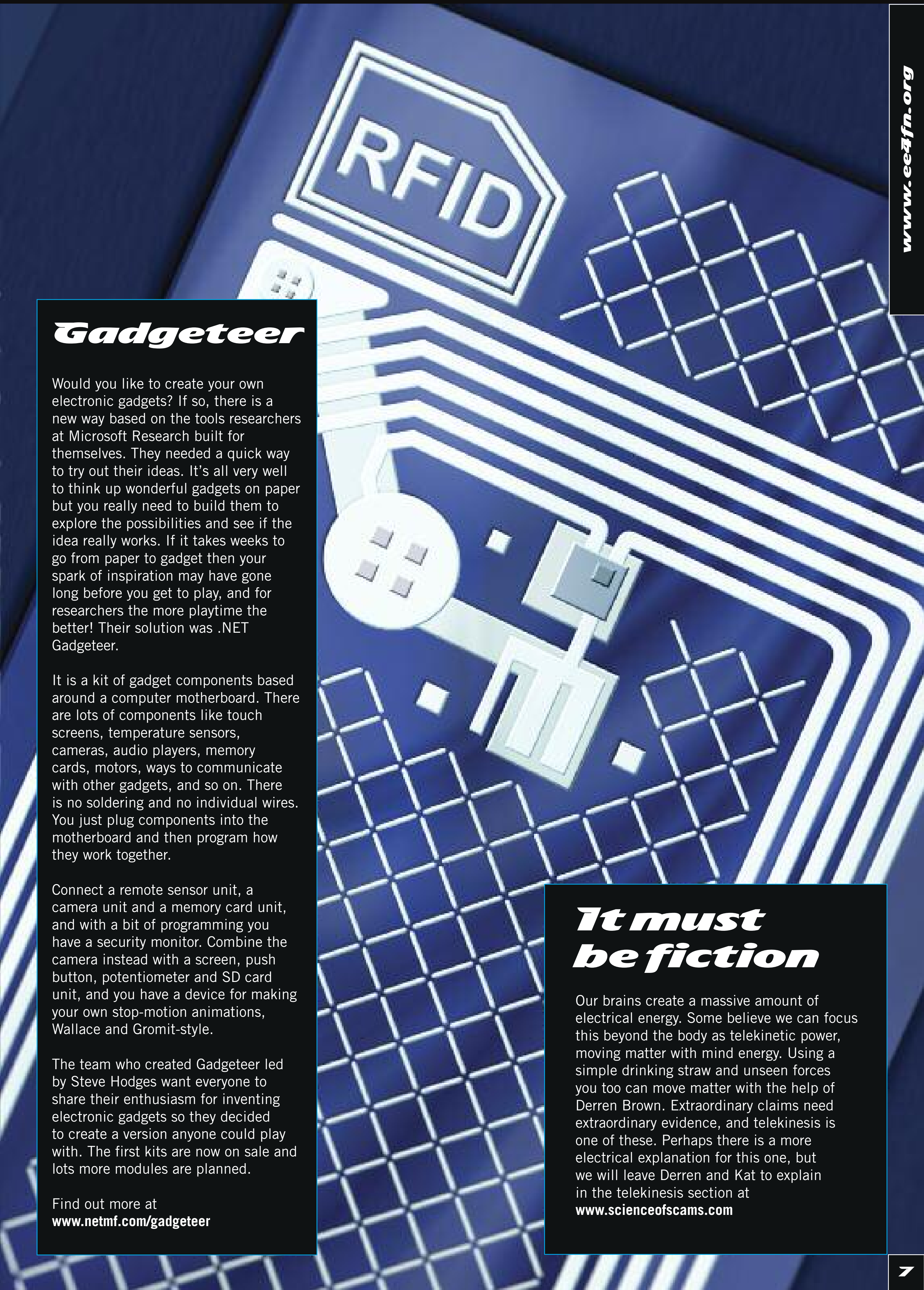
Shops are coming up with new ways to use them too. For example, once you have put something in your basket – that skirt maybe – readers around the store can track it. That means if you then wander past a mannequin wearing a jacket that would match that skirt perfectly, it could shout you over to have a look.

A mannequin could shout you over to have a look.

Of course, there is no reason the shop has to forget about the tag once it has left, and no reason for them to be thrown away with the rest of the packaging, either. If the problem of making them survive a washing machine is solved, the tags could be permanently sewed into the labels. Computers round the shop could then help you find something to match the clothes you were wearing based on the RFID information they transmit as you walk around.

There are other possibilities of course. It might also mean when you next returned to your favourite clothes shop, having previously bought some of their famous underwear, the shop would immediately notice you were wearing their boxer shorts or knickers. Perhaps more to the point, it would notice if you were wearing someone else's knickers ... a competitor's we mean, not actually someone else's ... you get the point. Anyway, the computers round the store could then work hard at persuading you to go look at their lingerie, offering you discounts to bring you back into the fold.

Of course the downside is that you are giving up some privacy with all this RFID use. The shop knows all about the underwear you wear when shopping. But then you've already given over a lot of privacy already. Shops already can keep track of all the things you buy, transport companies can record every journey you take and search engine companies record all the sites you browse. Perhaps you don't care if they start to log how often you change your underwear too!



Gadgeteer

Would you like to create your own electronic gadgets? If so, there is a new way based on the tools researchers at Microsoft Research built for themselves. They needed a quick way to try out their ideas. It's all very well to think up wonderful gadgets on paper but you really need to build them to explore the possibilities and see if the idea really works. If it takes weeks to go from paper to gadget then your spark of inspiration may have gone long before you get to play, and for researchers the more playtime the better! Their solution was .NET Gadgeteer.

It is a kit of gadget components based around a computer motherboard. There are lots of components like touch screens, temperature sensors, cameras, audio players, memory cards, motors, ways to communicate with other gadgets, and so on. There is no soldering and no individual wires. You just plug components into the motherboard and then program how they work together.

Connect a remote sensor unit, a camera unit and a memory card unit, and with a bit of programming you have a security monitor. Combine the camera instead with a screen, push button, potentiometer and SD card unit, and you have a device for making your own stop-motion animations, Wallace and Gromit-style.

The team who created Gadgeteer led by Steve Hodges want everyone to share their enthusiasm for inventing electronic gadgets so they decided to create a version anyone could play with. The first kits are now on sale and lots more modules are planned.

Find out more at
www.netmf.com/gadgeteer

It must be fiction

Our brains create a massive amount of electrical energy. Some believe we can focus this beyond the body as telekinetic power, moving matter with mind energy. Using a simple drinking straw and unseen forces you too can move matter with the help of Derren Brown. Extraordinary claims need extraordinary evidence, and telekinesis is one of these. Perhaps there is a more electrical explanation for this one, but we will leave Derren and Kat to explain in the telekinesis section at
www.scienceofscams.com

Nicola Tesla, the invisible genius

Nicola Tesla is an enigma wrapped in a mystery. Not bad going for an electronic engineer. Born, so the stories go, in the middle of a thunderstorm in Serbia, Tesla has left behind a fascinating legacy. Magnetism is measured in Tesla, a unit named after him, but it's perhaps a different victory we owe him most for. He fought a battle to show that alternating current (A/C) was superior to direct current (D/C) when it came to transmitting electricity over a distance. His opponent was none other than America's most respected celebrity inventor, Thomas Edison.

Absolutely shocking behaviour

In the so-called 'Battle of the Currents' Tesla and his entrepreneurial partner George Westinghouse eventually won (they had maths on their side). If he hadn't, the world would have been filled with electrical substations at the end of each road, because D/C doesn't do distance well (why? See the box on the right). But the fight was a really dirty one – there was ego and money at stake. Edison got his employees to badmouth A/C to try to convince the public it was dangerous. They used A/C to execute stray cats and dogs to try to prove to the press that it was more dangerous than Edison's system of D/C. They even filmed the A/C electrocution of Topsy, a circus elephant from Coney Island! Edison's spin doctors also tried to popularise the term "Westinghoused" to mean being electrocuted. The battle cost an astronomical amount, and toward the end Tesla pulled out, tearing up the contract that could have made him the world's first billionaire, and leaving Westinghouse to capitalise on the final victory. Tesla retreated, and invented the world's first remote controlled boat instead, but he had another card up his sleeve – he had invented the radio, and had the patent. Success was short lived, though. After a few years the US courts decided that Guglielmo Marconi was the real inventor of radio and Tesla lost out again. In fact in 1909 Marconi was awarded the Nobel Prize for Physics for the invention of radio, and the rumour was that Tesla and Edison's fight had lost them the chance of being included in the award.

He also claimed to have worked out a 'dynamic theory of gravity' – even Einstein failed to do this

Springing back into action

Never daunted, in 1899, Tesla moved to Colorado, where he had enough room for his high-voltage, high-frequency experiments. He told reporters that he was conducting wireless telegraphy experiments, transmitting signals from a mountain called Pikes Peak in Colorado to Paris. He transmitted extremely low frequencies through the ground as well as between the earth's surface and the ionosphere, and patented the ideas. He also calculated that the resonant frequency of the Earth was approximately 8 Hertz. Later in the 1950s, researchers confirmed that the resonant frequency of the Earth's ionosphere was in this range, but chose to name it the Schumann resonance. Tesla was invisible again!

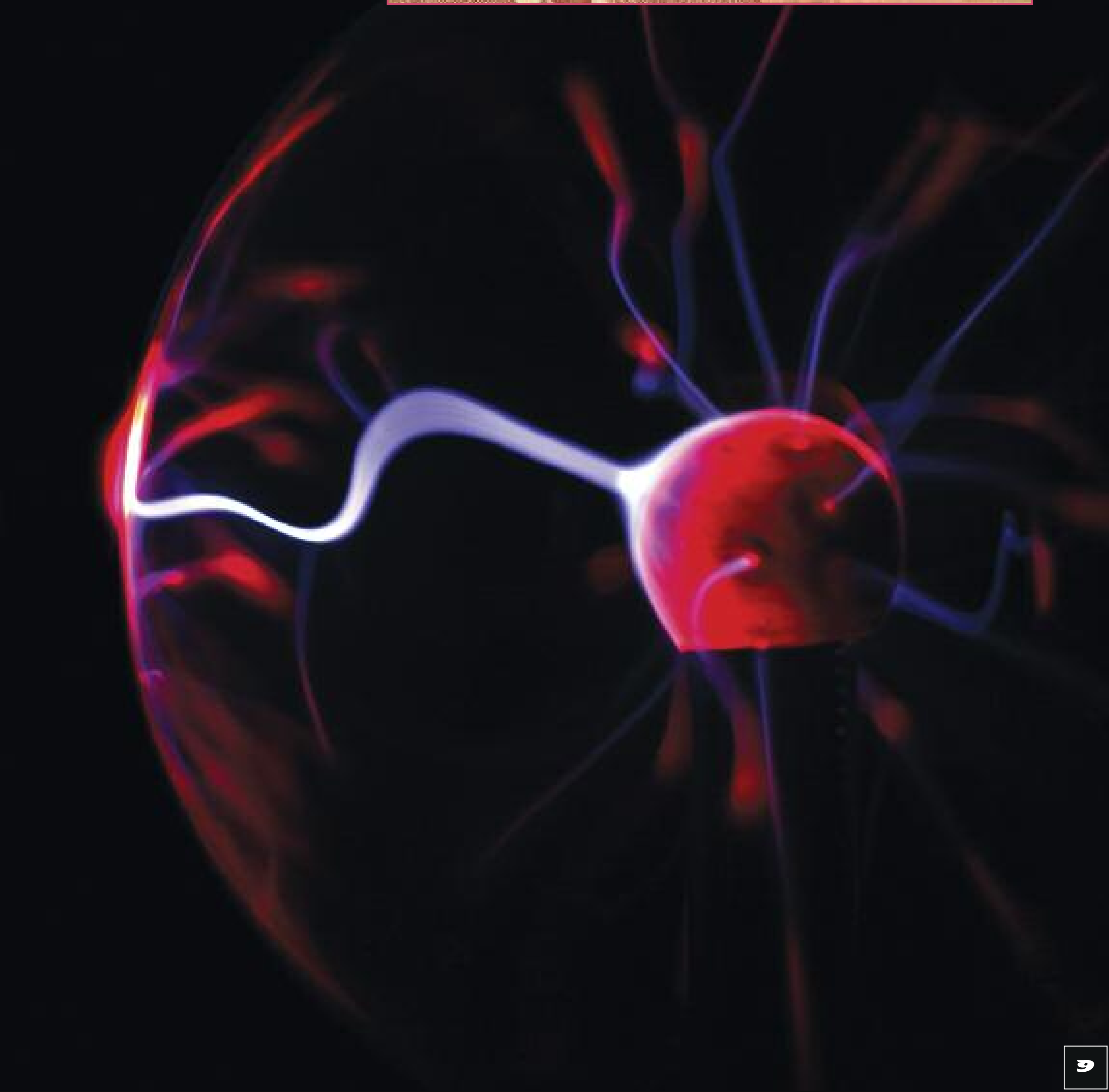
This is the end?

Tesla was no good with money. His genius and lifetime of invention led to him dying alone of heart failure, in a New York hotel room, impoverished at the age of 86. The story goes that the documents he had were seized by the American secret service under the direct orders of J Edgar Hoover. Tesla had been developing his radical ideas about transmitting power without wires through the earth over great

Why is A/C better?

AC is better for distributing power over a distance because it allows the easy changing of voltages with a transformer. Power is calculated as current times voltage ($P = IV$). For a given amount of power to be sent, a low voltage requires a higher current. But metal conducting wires have resistance; some of that precious power will be lost as heat in the wires. Theory (always important to know the theory) says that power loss is given by $P = I^2R$. So from this it's obvious that low-voltage, high-current transmissions will cause a much greater power loss than high-voltage, low-current ones. This fact holds whether DC or AC is used. But, and here is the clincher, transforming DC power from one voltage to another is difficult and expensive. In Tesla's day it needed a large spinning device called a rotary converter, and moving parts are always a problem. But with AC these voltage changes can be done with simple and cheap transformer coils with no moving parts and no maintenance. Tesla wins in theory and in practice.

distances. He called this a peace ray; it could manifest electrical power in mid-air wherever it was needed on the Earth. He also claimed to have worked out a 'dynamic theory of gravity' – even Einstein failed to do this – but it was never published. Tesla's life has of course been the subject of movies; he appears in the film 'The Prestige', played by rock star David Bowie. Tesla is also featured on the bank notes of Serbia. So when you next plug in your mobile phone charger or use wifi, remember Tesla, the invisible genius who made it all possible.



Engineering a cloak of invisibility

You pull a cloak around you and disappear! Reality or science fiction? Even in Harry Potter's world it takes powerful magic and complicated spells to make it work. In fact Harry's Cloak of Invisibility is one of the three 'Deathly Hallows' rumoured to have been created by Death himself. The other two are the Resurrection Stone – the secret of bringing people back to life – and the Elder Wand – the most powerful wand ever created. Strong stuff!

Could an invisibility cloak ever be a reality? It sounds impossible especially if you understand how light behaves. It bounces off the things around us, travelling in straight lines. You see them when that reflected light eventually reaches your eyes. I can see the red toy over there because red light bounced from it to me. For it to be invisible, no light from it must reach my eyes, while at the same time light from everything else around should. How could that be possible? Akram Alomainy of Queen Mary, University of London, tells us more.

It's all about controlling the behaviour of light.

Well maybe things aren't quite that simple…halls of mirrors, rainbows, polar bears and desert mirages all suggest some odd things can happen with light! They show that manipulating light is possible and that we may even be able to bend it in a way that alters the way things look – even humans.

Light fantastic

Have you ever wondered how the hall of mirrors in a fun fair distorts your reflection? Some make us look short and fat while others make us tall and slim! It's all about controlling the behaviour of light. The light rays still travel in straight lines, but the mirrors deceive the eye. The light seems to arrive from a different place to reality because the mirrors are curved, not flat, making the light bounce at odd angles.

A rainbow is an object we see that isn't really there. They occur because white light doesn't actually exist. It is just coloured light all mixed up. When it hits a surface it separates back into individual colours. The colour of an object you see depends on which colours pass through or get reflected, and which get absorbed. The light is white when it hits the raindrops, but then comes out as the whole spectrum of colours. They head off at slightly different angles, which is why they appear in the different rainbow positions.

What about polar bears? Did you know that they have black skins and semi-transparent hair? You see them as white because of the way the hollow hairs reflect sunlight.

So what does this have to do with invisibility? Well, it suggests that with light all is not as it seems. Perhaps we can manipulate it to do anything we want.

Water! Water!

Now for the clincher – mirages! They show that invisibility cloaks ought to be a possibility. Light from the sun travels in a straight line through the sky. That means we see everything as it is. Except not quite. In places like deserts where the temperature is very high at noon, apparently weird things happen to the light. The difference between the temperature, and thus the difference in density between the higher air layers and the levels closer to the ground can be quite large. That temperature difference makes light coming from the sky change direction as it passes through each layer. It bends rather than just travelling in a straight line to us. It is that image of the sky that looks like the pool of water – the mirage. Our brains assume the light travelled in a straight line, so they misinterpret its location. Now, to make something invisible we just need to make light bend round it. That invisibility cloak is a possibility if we can just engineer what mirages do – bend light!

Nano-machines

That is the basic idea and it is an area of science called 'transformation optics' that makes it possible. The science tells us about the properties that each point of an object must have to make light waves travel in any particular way we wish through it. To make it happen engineers must then create special materials with those properties. These materials are known as metamaterials. Their properties are controlled using electromagnetism,

which is where the electronic engineers come in! You can think of them as being made of vast numbers of tiny electrical machines built into big human-scale structures. Each tiny machine is able to control how light passes through it, even bending light in a way no natural material could. If the machines are small enough – 'nanotechnology' as small as the wavelength of light – and their properties can be controlled really precisely to match the science's prediction, then we can make light passing through them do anything we want. For invisibility, the aim is to control those properties so the light bends as it passes through a metamaterial cloak. If the light comes out the other side of the cloak unchanged and travelling in the same direction as it entered, while avoiding objects in the middle, then those objects will be invisible.

Now you see it...

Simple cloaking devices that work this way have already been created but they are still very limited. One of the major challenges is the range of light they can work with. At the moment it's possible to make a cloak that bends a single colour frequency, but not all light. As Yang Hao, a professor working in this area at Queen Mary, notes: "The obstacle engineers face is the complex manufacturing techniques needed to build devices that can bend light across the whole visible light spectrum. However, with the progress being made in nanotechnologies this could become a possibility in the near future".

Perhaps we should leave the last word to J.K. Rowling: "A suspicious object like that, it was clearly full of Dark Magic." So while we should appreciate the significance of such an invention we should perhaps be careful about the negative consequences!

Learning to be a baby robot

Can a robot learn like a baby does? In 2007, researchers at Osaka University in Japan unveiled CB2, a robot that they hoped would think like a baby. They hoped it would gradually learn how to get on in the world by memorising and mimicking how it sees people behave. Behind its constantly flitting eyes are cameras that record the facial expressions of people it interacts with. CB2's processors try and work out what the expressions mean by grouping them together in emotions such as happiness and sadness.

CB2's creators want it to have more than just a social life, though. They've built it to interact with the physical world. It moves like a human with the help of 51 mechanical 'muscles'. Since an earlier version of CB2 was first switched on in 1997, it's taught itself how to walk. It can now walk across a room, even if it needs a bit of human help to do it. The researchers have big plans for CB2's continuing education – they're hoping that it will learn to turn its baby-like gurgles into actual speech. They want it to have the intelligence of a two year-old and be able to speak in basic sentences.

The researchers believe that in the next few decades a new kind of robo-species will appear on the scene, with a learning ability somewhere between humans and chimps.

It moves like a human with the help of 51 mechanical 'muscles'.

It must be fiction

In the comic and film Tony Stark built himself a high-tech metal suit that turned him into the invincible Avenger, Iron Man. That must only be in the comics! Actually, existing 'powered exoskeletons', as researchers call them, can already help soldiers march further with heavy packs. Others can help wheelchair-bound hospital patients walk again. See **www.cs4fn.org/fashion/fullmetaljacket.php**

Uncannily human

Robots can make people feel repulsed despite looking very human-like. When this happens they're deep in what researchers call 'the uncanny valley'. A roboticist called Masahiro Mori came up with the term in 1970 when he noticed that "as robots appear more humanlike, our sense of their familiarity increases until we come to a valley". What he meant was that in general, a robot with arms, legs and a head will seem friendlier than, say, an industrial robot that might be just an arm with a welder attached. You can keep making the robot more and more humanlike, and humans will find it friendlier. But there comes a point where the robot seems almost exactly like a human, but not quite. There's just something wrong. Perhaps the robot moves a bit strangely, or its skin looks fake. It's at that point where the friendly feeling takes a huge dip into the uncanny valley, and people start to feel spooked. The robot's trapped at a point where it doesn't seem either like a robot or a human – it just seems creepy.

The idea of the uncanny valley has such power that not many roboticists try to make their robots look exactly lifelike, for fear that they'll fall short and tumble into that creepy chasm. Some do though. David Hanson of the University of California is actively trying to jump the valley. He's constructing a robot head that's a perfectly lifelike model of a real person's – his fiancée's, no less. To do it he studied how the human face moves, poring obsessively over books of anatomy and classifications of facial expressions. He made sure to position the motors in the robotic face in exactly the right spots to make its expressions appear realistic, and when the material he was using for skin didn't move properly he invented his own polymer.

If David does succeed in getting across the uncanny valley it will not only be a huge advancement for robotics, but could also help psychologists study how people's facial expressions get meaning across to others. Being able to control a believable face down to each little muscle would point out the role they all play in telling other people how we're feeling.

Tattoo tags

Ian M Banks's novel Surface Detail is set in a future where artificial intelligences run the show, and people routinely back up their consciousnesses in case of accidents. Heroine Lededje Y'breq is given a present: a tattoo. Before dying her previous body had been covered in an elegant fractal tattoo that showed she was a slave. Her new tattoo, a present from the intelligent if sadistic military ship, Falling Outside The Normal Moral Constraints, is different. As she watches it snake across her body she realises it's really a gadget that she can control, changing the pattern or colour at will. That is just the start. Tattoo as gadget: is that fact or fiction?

It's no longer totally fiction. Researchers at the University of Kent, John Batchelor and Mohamed Ali Ziai, have created RFID tags on transfer tattoos. (RFID tags are electronic circuits with antenna to communicate often used as security devices in shops, for example – see page 6.) The Kent researchers' tattoo tag consists of conductive ink on a special plastic that can be stuck onto the skin. If the ink conducts electricity then drawn lines actually become wires. You really can draw a circuit!

It's actually not a problem to put ink onto skin (people write on the back of their hands all the time!) the trouble is making it work as a circuit. Firstly, skin flexes so that the ink cracks and breaks the circuit, and secondly, skin itself conducts electricity (see page 3). That reduces the effectiveness of the tattoos, shrinking the range the tags can communicate. The original versions were made of a special, nickel-based ink painted on using a stencil. The team are now working with chemists at Manchester University to create inkjet inks allowing the tattoos to be created using a normal printer in the future.

What use is an electronic tattoo? RFID tags are most commonly used to track objects, so the tattoos could be used in a similar way. Give your toddler a tattoo and you won't have to worry about them wandering off in the department store. There are more exciting ideas though. They could control medical implants inside the body like pacemakers, for example, or be used as a body-based network, connecting large numbers of devices you wear like your phone and exercise monitor, say.

More futuristically still, they might even be used to alter the visibility of a person to radar as though they were a stealth bomber aircraft. Personal stealth technology for military personnel: perhaps that takes us back to the sort of thing Falling Outside The Normal Moral Constraints was thinking about. You will have to read the book to find out.

The Kent researchers' tattoo tag consists of conductive ink on a special plastic that can be stuck onto the skin.

From a handful of sand to a fistful of dollars

Sitting at the heart of your computer, mobile phone or DVD player is the microprocessor that makes it all work. These electronic 'chips' have millions of tiny electronic circuits on them, allowing the calculations needed to make your gizmos work. But it may be surprising to learn that these silicon chips, now a billion pound industry worldwide, are in fact mostly made of sand. That's right, the same stuff that you find on beaches. Sand is mostly made of silicon dioxide. Silicon, the second most abundant substance in the earth's crust, has useful chemical properties as well as being very cheap. You can easily add other chemicals to silicon and change its electrical properties, and it's by using these different forms of silicon that you can make mini switches, or transistors, in silicon chips.

House Hose

A transistor on a chip can be thought of like a garden hose. Water flows from the tap (the source) through the hose and out onto the garden (the drain), but if you were to stand on the hose with your foot and block the water flow the watering would stop. An electronic transistor on a chip in its most basic form works like this, but electrical charge rather than water runs through the transistor. In fact, the two parts of a transistor are actually called the 'source' and 'drain'. The 'gate' plays the part of your foot; this is the third part of the transistor. Applying a voltage to the gate is like putting your foot on and off the hose; it controls whether charge flows through the transistor.

> **A transistor is just like a garden hose with your foot on it**

Lots of letter Ts

If you look at a transistor on a chip it looks like a tiny letter T. The top crossbar on the T is the source/drain part (hose) and the upright part of the T is the gate (the foot part). Using these devices you can start to build up logic functions. For example, if you connect the source and drain of two transistors together one after another it can work out the logical 'AND function'. How? Well, think of this as a long hose with you and a friend's foot available. If you stand on the hose no water will flow. If your friend stands on the hose no water will flow. If you both stand on the hose no water will flow. It is only when you don't stand on the hose AND your friend also doesn't stand on the hose that the water flows. You've built a simple logical function.

Printing chips

From such simple logic functions you can build very complex computers, if you have enough of them, and that's again where silicon comes in. You can 'draw' with silicon down to very small sizes. In fact a silicon chip is printed with many different layers. For example one layer has the patterns for all the sources and drains. The next layer chemically printed on top are the gates, the next contains the metallic connections between the transistors, and so on. These chips take millions of pounds to design and test, but once the patterns are correct it's easy to stamp out millions of chips. It's just a big chemical printing press. The fact that you can produce silicon chips efficiently and cheaply with more and more transistors on them each year that drives the technological leaps we see today.

> **A billion pound industry made of sand**

Beautiful silicon

Finally you might wonder how the chip companies protect their chip designs. They protect them by registering the design of the masks they use in the layer printing process. Design registration is normally used to protect works of artistic merit, like company logos. Whether chip masks are quite as artistic doesn't seem to matter (though see page 2). What does matter is that the chemical printing of silicon and lots of electronic engineers have made all today's computer technology possible. Now there is a beautiful thought to ponder when you're next on the beach.

Do you remember the birth of the memristor?

Electronics! It's all been done long ago, hasn't it? Resistors, transistors, capacitors, and inductors: all invented. Done it, filled in the worksheet, nothing else to discover...but did you miss the birth of the memristor?

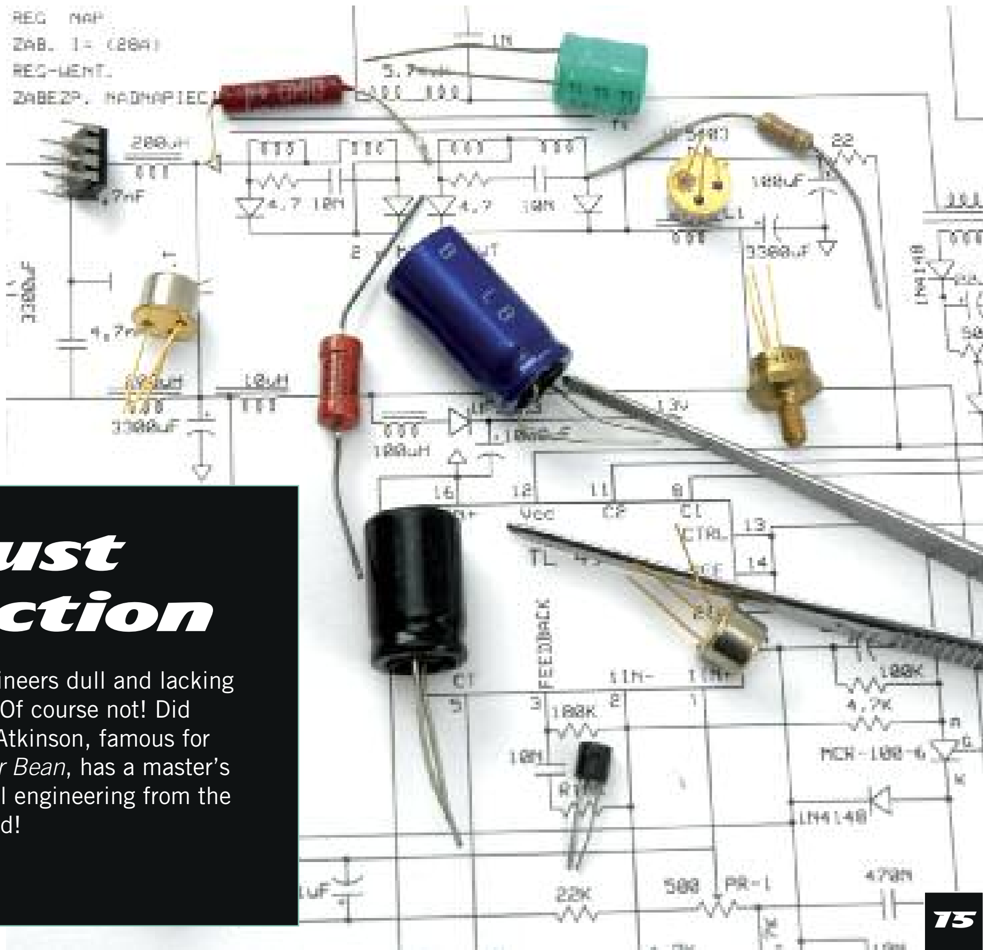
In 2008 a new member of the electronics family was born. It had been discussed in theory as the missing link. It was mathematically possible, but never actually built till electronic engineers at Hewlett Packard used nanotechnology to bring it into existence.

Memristors are resistors with memory. Clever name! It can work as a data store, being either off or on, but it can store this information without any power too. This ability to store binary data (1s and 0s) with no drain on a battery, combined with its tiny, nanotechnology size means that memristors can store more data than any normal hard drive, and can be accessed as quickly as RAM – the kind of memory computers currently use. That means that in the future computers may be able to store more, start faster and be more eco-friendly too.

Building brains?

That would be amazing enough, but it turns out that the memristor has another trick up its nano-sleeve. Rather than working in digital mode, saving on/off (1,0) data like normal computer components, it can also hold values in between! The values it holds change every time the memristor receives an electrical signal, which is exactly what happens in the neurons of our brain as we learn. In the future networks of memristors could mimic the way our brains work, storing the things they learned from their electronic experiences. That would open up the possibility of a compact, low power way to build artificial intelligences.

Not bad for a humble little addition to the family of electronic components. See what you can miss if you don't pay attention!



It must be fiction

Are electronic engineers dull and lacking in cunning plans? Of course not! Did you know, Rowan Atkinson, famous for *Blackadder* and *Mr Bean*, has a master's degree in electrical engineering from the University of Oxford!

Threads & Yarns

At first sight nothing could be more different than textiles and electronics. Put opposites together and you can maybe even bring historical yarns to life. That's what the G.Hack team at Queen Mary, University of London helped do. They are an all-woman group of electronic engineering and computer science research students (see ghack.eecs.qmul.ac.uk) and they helped build an interactive art installation combining textiles and personal stories about health.

In June 2011 the G.Hack team was asked by Jo Morrison and Rebecca Hoyes from Central Saint Martins College of Art and Design to help make an interactive artwork called Threads & Yarns. It was commissioned by the Wellcome Trust as a part of their 75th anniversary celebrations. They wanted to present personal accounts of the changes that have taken place in health and wellbeing over the 75 years since they were founded.

Flowers powered

Jo and Rebecca had been working on Threads & Yarns for six months. It was inspired by the floor tiling at the Victoria and Albert Museum in London and was made up of 125 individually created material flowers spread over a five-metre long white perspex table. They wanted some of the flowers to be interactive, lighting up and playing sounds linked to stories about health and wellbeing at the touch of a button.

Central Saint Martins College textile students worked with senior citizens from the Euston and Camden areas of London, recording the stories the seniors told as they made the flowers. G.Hack then ran a workshop with the students to show them how physical computing could be built into textiles to create interactive flowers. Short sound clips from the recorded stories were eventually included in nine of the flowers.

The interactive part was built using an open source hardware platform called Arduino. ('Open source' means free and available for anyone to use.) It makes physical computing accessible to anyone, giving them an easy way to create programs that control lights, buttons and other sensors.

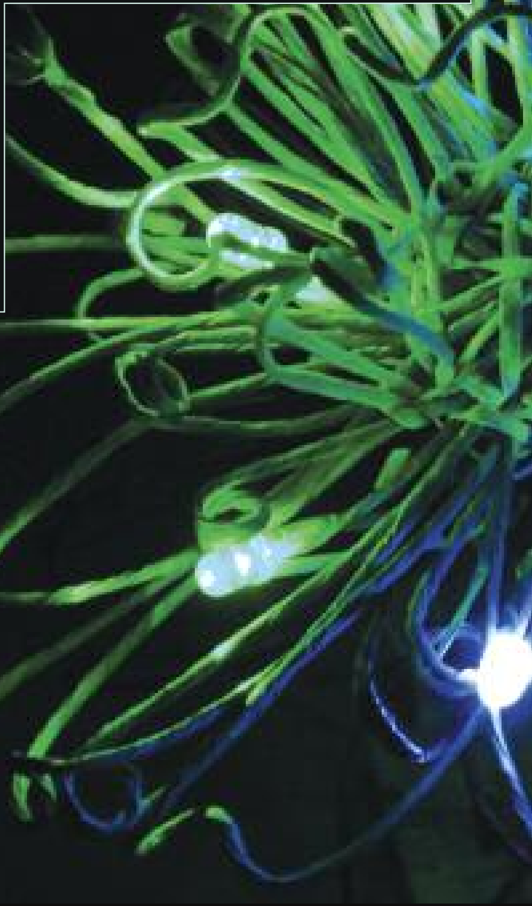
The audio stories of the senior citizens were edited down into 1-minute segments and stored on a memory card like those used in digital cameras. Each of the nine flowers were lit by eight Light Emitting Diodes (LEDs). They are low energy lights so they don't heat up, which is important if they are going to be built into fabrics. They are found in most household electronics, such as to show whether a gadget is turned on or off. When a button on Threads & Yarns is pressed, the appropriate sound clip plays and simultaneously the LEDs on the corresponding flower light up.

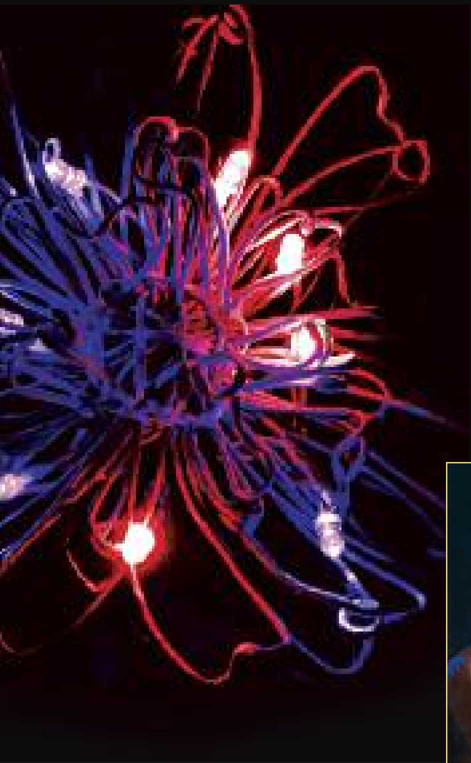
Smooth operators

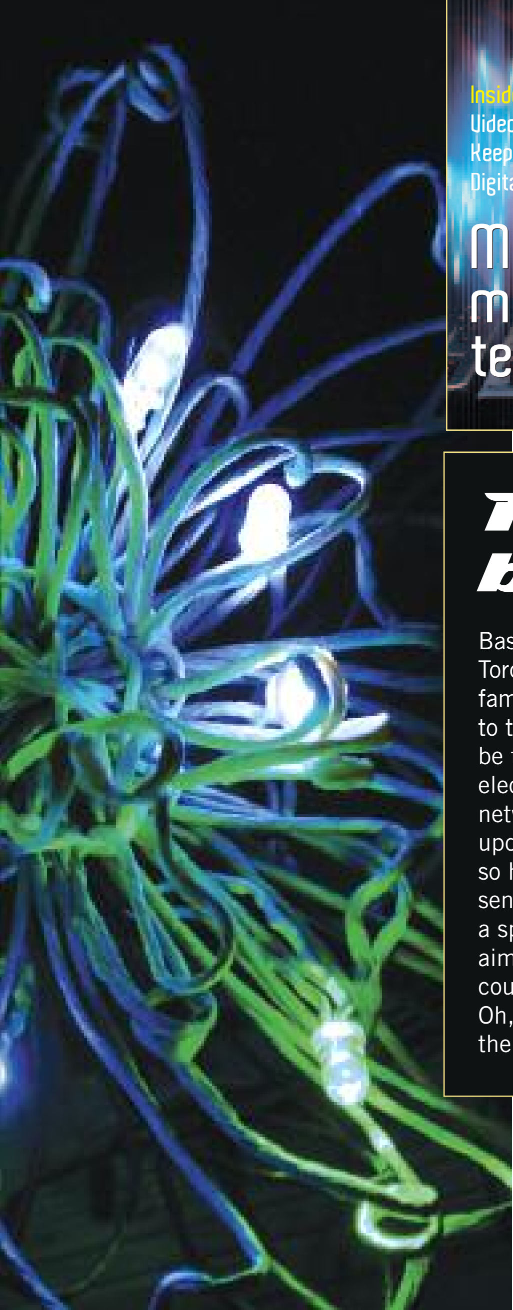
The artwork had to work without problems throughout an entire day, so the G.Hack team had to make sure everything would definitely go smoothly. The day before the opening of the exhibition they did final testing of the interactive flowers in their electronics workshop, then installed the electronics into the artwork. On the day of the exhibition, the team arrived early to test everything one more time before the opening. They also stayed throughout the day to be on call in case of any problems.

Leading up to the opening of the exhibition were a busy few weeks for G.Hack with lots of late nights spent in the workshop, testing, troubleshooting and soldering, but it was all worth it. The final artwork looked fantastic and received a lot of praise from people visiting the exhibition. Threads & Yarns is now off on a UK tour.

Art may have brought the textiles and history together as embodied in the flowers. It's the electronics that brought the yarn to life though.







Mad about music technology?

Ever fancied inventing a completely new musical instrument? How about creating a perfect-sounding virtual replica of a classic instrument like a Fender Stratocaster guitar? What's microphone bleed and why does it mess up your recordings? More interesting still, how might some electronic engineering fix it for good? What is set to replace mp3 players, allowing you to remix your music collection yourself? Want to create a virtual Albert Hall or make music with fire? It's all possible.

What do all these have in common? They are all projects of researchers working in a branch of electronic engineering called audio engineering. If you are mad about music technology, then check out ee4fn's sister magazine Audio! and find out about what the researchers who have turned their music hobby into a career are up to. Music has never been so hot!

Find out more at **www.audio4fn.org**

It must be fiction

Basil Fawlty, proprietor of the infamous Torquay hotel Fawlty Towers, once famously beat his car with a tree branch to teach it a lesson. Today's cars can be taught lessons in more sophisticated electronic ways including using cellular networks (the ones mobile phones use), updating the on-board computers. Not so happily, it was recently shown that sending a sneaky 'war text' message – a specially created text message that aims to hack a mobile phone network – could unlock a car and start the engine. Oh, no! I thought I said don't mention the war!

Billions of processors shipped

Which country do you think is responsible for designing the most computer processors used worldwide?

Processors are, of course, the brains of computerised gadgets, whether PCs or mobile phones, DVD players or SatNavs, game consoles or MP3 players. Without processors, there would have been no mobile revolution. None of the gadgets you take for granted would exist. So who has been making it possible?

Who do you think it is?

What are the choices? The US perhaps? They have lots of famous high-tech companies: Intel and IBM, Motorola and Microsoft, Apple and Google. Do they design processors though? Intel and Motorola still do but are they number one? What about Japan? That must be another possibility, with the likes of Sony and Nintendo. Japan is a leader in the field of high-tech games and gadgets, but they design the gadgets, not the processors that make those gadgets possible. Now that we are thinking of gadgets rather than PCs, Finland is maybe a contender. Nokia are one of the companies behind the mobile phone revolution. But are they responsible for the processors they use, or do they just buy them in?

From start-up to world domination

Actually the answer is the UK. A British company, ARM, has shipped well over 20 billion processors. That is vastly more processors than all the other companies put together! They grew from a small start-up company set up in 1985 called Acorn and were the people who created the famous BBC Micro. The processors they design are in just about every kind of gadget you can imagine, from phones to games consoles.

So how did ARM end up dominating the processor industry, and how come they sell more than older, more famous giants like Intel? Well, it boils down to basic economics and an electronics revolution known as systems-on-a-chip. The economics is simple. ARM chips can be as cheap as 10 cents each – far cheaper than the other chip manufacturers. Cheap enough to go into anything. Why? Because they rode the system-on-a-chip revolution rather than the PC revolution.

Out of a vacuum

The early computers of the 1940s were made of vacuum tubes. They were big glass bulbs with almost all the gases sucked out, in which clouds of electrons could be made to flow around so that controllable voltages and currents could form within them. By connecting them together it was possible to start making machines that could compute.

In the 1950s, vacuum tubes were replaced by transistors. They were basically the same but smaller. Now the electron clouds formed in special solids rather than a vacuum, no glass tubes needed. In the 1960s engineers found a way to squeeze lots of transistors – 10 or 20 – into one small case. Processors were made from collections of these 'integrated circuits' and as a result they got smaller. Soon it became possible to think of putting a whole processor on a chip. By the early 1970s, as transistors could be made smaller and smaller hundreds of thousands of transistors were crammed onto single chips.

One case fits all

This is the point where the idea of systems-on-a-chip comes into the story. In the 1990s the entire computer system, not just a processor, could be packaged on one chip: manufactured in one go and put in a single case. That meant they could be small and very, very cheap. A whole gadget with a chip at its core could now fit in your pocket, and be made cheap enough that everyone could afford one. It was that revolution that ARM pioneered. Rather than designing chips to form part of complex PC systems that would still be expensive, they designed cheap systems-on-a-chip that could control mobile phones. As the system-on-a-chip revolution then took off, all the other pocket-sized gadgets we now take for granted followed.

They think it's all over?

Is that the end of the story? Of course not! Don't underestimate the ingenuity of the electronic engineers and computer scientists responsible. Things have already moved on again. Now we can fit several entire computers on a single chip. This is called multi-core technology. Rather than trying to design ever-faster processors, the focus has changed to putting more and more simple computers into one case.

The challenge now is to work out how on earth we program these multi-core chips so that the separate processors work together, letting us exploit their phenomenal computer power. Right now no-one knows how to do that … but we will.

This article is based on part of the Kilburn Lecture given by Professor Steve Furber of the University of Manchester.

Computer Science for fun

Interested in the fun side of computing then check out cs4fn **www.cs4fn.org**. The magazine and website on computer science for fun.

Complete circuit

Kirchhoff's famous circuit laws describe the conservation of charge and energy in electrical circuits. They form the basis for circuit design as well, leading to many a homework assignment working out the current at different places in a circuit. Their creator, physicist Gustav Kirchhoff, was born in the town of Königsberg in what is now Russia.

Königsberg sits on several islands originally connected by seven bridges. It was this town plan that helped mathematician Leonhard Euler to pose and solve the famous Seven Bridges of Königsberg Problem. It helped develop the useful mathematical area called graph theory.

Graph theory is used by engineers when building mobile phone networks. Your mobile phone finds the nearest base station and locks onto it to send and receive information. Researchers recently revealed a midget drone plane called WASP, built on the cheap with parts bought on the Internet. It could fly unseen over a city mimicking a ‘local tower’ to intercept phone messages and wi-fi data.

Wi-fi is a set of agreed standards that allow radio links between all manner of electronic gadgets. These worldwide rules are based around the idea of ‘frames’. Frames contain the data that is to be sent or received in a particular format. Devices have to know these rules of conversation to talk to each other. They range from asking nicely in the ‘association request frame’ if the receiver is ready, willing and able to connect, to the ‘association response frame’ where the receiver answers “yes” or “no”.

Yes or no is an example of a binary encoding: only two options exist. Many electronic devices these days use binary encoding. The signal has only two possible values. That makes turning them mathematically into numbers and the subsequent calculations easier and more accurate. Analogue electronics, where voltage and currents can vary across a range of values, are more difficult to design but are still useful in some applications. They can have surprising advantages. For example, before digital radio took over it was possible to build a working ‘crystal radio set’ using analogue techniques with simple household items like wire and a rusty nail. This radio was powered by the radio waves and didn’t need batteries.

Batteries store energy and many see them as a big unsolved problem of electronics. They are heavy, need space and charging, and when they run out your gadget stops. They are also hard to recycle. Researchers are now looking at using common everyday stuff like plastics and concrete to store the energy we need. Another idea is to use energy from our walking on the go. Whatever way energy is created and stored in the future, it will still swirl round the circuit obeying Kirchhoff's laws.

GOTO START

If you love building things with a bit of intelligence, then visit www.ee4fn.org for more on the fun side of electronic engineering and physical computing.

EPSRC
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COMPUTING AT SCHOOL
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