Issue 2

EE4FN

Electronic Engineering for Fun

IN THIS ISSUE:

Inventing for the fun of it

Hacking tablecloths

Your phone inside you

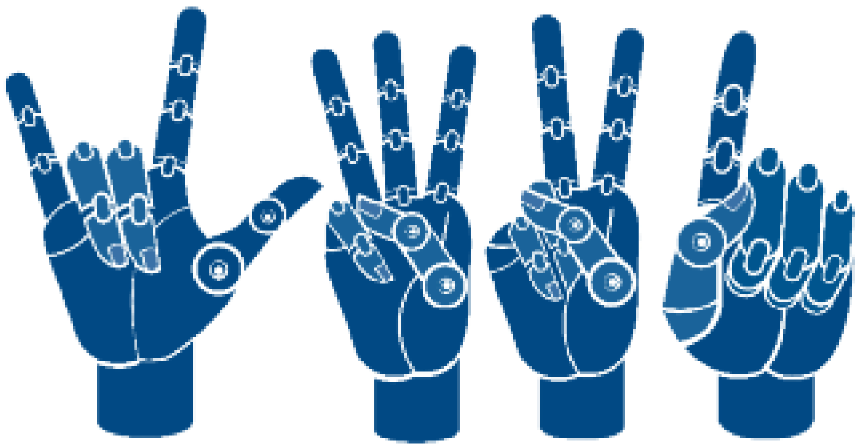
Queen Mary University of London

Building things for fun

ee4fn is all about the fun side of electronic engineering and physical computing. In this issue we explore surprises, cyborgs, speed and sudoku. We look at how ordinary objects can be hacked into surprising interactive things, and how your home may be being snooped on in a surprising way. We also look at how researchers are taking the first steps towards a cyborg future. We explore how the problems of building ever faster and cheaper computer chips have been overcome and how communication satellites can be sped up with a little help from Sudoku puzzles.

We also look at legendary engineer Claude Shannon who embodies what ee4fn is all about – inventing for the fun of it.

Robots teaching sign language



Robots were once science fiction. Now they are gradually edging their way into our lives. Industrial robots have worked on car production lines for a long time; you can buy robots that will vacuum your house from department stores, and there are plenty of toy robots about. Now they are even training to be teachers.

Most children learn their first language by being immersed in it: everyone around them is speaking it and they just absorb it. Deaf children who have deaf parents learn sign language as a native language just as verbal children learn their first language. That shouldn't be a surprise. After all, as languages go, sign languages are not really any different to verbal languages. They just use hand movements – gestures – rather than sounds to represent words. Ideally though there should be educational materials to help children learn sign language just as there are for English, French and Mandarin. Videos of people signing are often used but it would be better still if children could see the signs being made in 3D as gestures do make use of more than 2 dimensions.

Hatice Kose a researcher at the Istanbul Technical University in Turkey wondered if robots might be able to help. She therefore programmed some child-sized robots to sign. She also invented some games so that children could play with the robots while at the same time learning signs. One game is an imitation game. The robot makes a sign. The child then has to work out what it means and find the card with the picture that that sign represents. When they have, they show it to the robot. Hatice's robots are equipped with cameras and have been programmed to be able to recognize pictures. The robot can therefore check if the child really did understand the sign by checking it is being shown the right picture.

Robots aren't all out to take over the world, nor will they be happy to be treated as our slaves doing drudge jobs. In the future they will probably be our friends and companions, and quite probably our teachers too.

Hacking tablecloths

Textiles – that's all about cloth and fabrics isn't it? Not any more. Electronic textiles have arrived and G. Hack, an all-women hacking club at Queen Mary, University of London, have been at play again this time armed with fabric, sewing needles, thread that conducts electricity, 'thermochromic' inks that are affected by heat...oh, and a hacked teapot.

G.Hack's previous installation involved a map of London with each area of the map linked to sound recorded in a local London tea house. A teapot, tracked by a computer vision system triggered the appropriate recording to be played when a teapot was placed on it. Working with a team of design students from Central Saint Martins College of Art and Design, this time G.Hack started from the same idea but went all textile.

The G.Hack team wanted to make the installation more portable, so decided to translate the interaction from the hard surface of a tabletop to the soft surface of a tablecloth embedding sensors into the fabric of the map. In the new version it was these sensors rather than a computer vision system that detected where the teapot was placed. That information was sent on to an Arduino microchip and from there to a computer and interactive software that controlled the sound output. Simultaneously, the ink painted on the map changed colour or became transparent when a hacked teapot was placed on it. The teapot was fitted with a stand-alone circuit that emitted just enough heat to warm up its base. That was enough to trigger the thermochromatic paint to change colour. A heat sensor stopped the warming to avoid burning marks on to the tablecloth (although it was quite tempting to use burns as a design bonus).

G.Hack set up the resulting textile map of London with teapot, circuits, thermochromic inks, conductive threads, computer and speakers on a large table in the foyer of the new Central Saint Martins College of Art and Design building for an afternoon. Students and staff came by to share stories about tea and textile printing traditions, have fun painting the boroughs and play with the sounds.

Stir together some simple electronic know-how, fabric and lots of enthusiasm and what started off as a minimalistic drawing of London on a white cloth, turns into a colourful and noisy social event where a whole bunch of people get a taste for electronic textiles.

Let's hear it for the thermometer

Modern electronics gives us the ear thermometer. This device uses an accurate infrared detector to measure the heat that is produced by our 'tympanum', aka the eardrum. The measurement is quick to take and accurate to use, beating the old fashioned mercury thermometers hands down.

Interested in the sound side of electronic engineering? Why not look out for our Audio! magazine. See www.audio4fn.org

Snooping smart meters

Could your electricity meter be snooping on you? Silently recording what you are up to, minute by minute, making it available to anyone who wants to know about the intimate details of your life? If it isn't it could be soon!

To read an old-fashioned electricity meter, so you can be billed for the electricity you use, someone has to look at the display and write down the number shown. That's why there are an army of people who tramp the streets, knocking on doors, reading meters. Every single home in the country has to be checked several times a year. That's both expensive and inconvenient. Smart meters solve the problem by turning the meter into an internet-enabled computer giving them a two-way link back to the power company. That means your electricity use can be checked minute by minute. It's a lot cheaper but it also means that people can be charged more at peak times and less say in the middle of the night.

Uneven usage is really difficult for power companies to handle – it means they have to have enough electricity available to cover the biggest peak possible even though it's only occasionally needed. Anything that evens out the load is really good for them. Some believe that pricing like this could also lead to people reducing the amount of electricity they use overall which would be good both for bills and for the planet.

There is a downside to smart meters though. They will also allow the electricity companies to snoop on everyone's lives if they want to. They will be able to tell when you are watching TV and what you are watching, whether you are on holiday, that you are in the kitchen boiling the kettle, or even if you just put your baby to bed.

It's an opportunity for engineers

Once your usage is being recorded in minute-by-minute detail that data can be analysed for patterns. Researchers have shown that different gadgets use electricity in different ways and those patterns can be picked out. Boil a kettle and it will stand out as a spike in your usage. TVs have their own pattern of energy usage that will vary depending on what is being watched. Baby monitors have a distinctive pattern too: that's how a snooper could work out when your baby went to bed. Why would anyone bother?

Well the data gathered might be worth money. It could be used by companies to gather profiles about people to sell to advertisers. It might also be used by burglars, or just by people who want to pry, such as the tabloid press.

This all may be a problem, but another way of thinking about it is as an opportunity for engineers. The meters obviously have to have strong security that cannot be cracked. That just prevents anyone off the street listening in but what if you don't even want the power company to be able to snoop on you? Can engineers invent ways for people to block the leakage of information to the meter in the first place? That is the challenge that Georgios Kalogridis and a team from Toshiba Research in Bristol took up. They have shown that it is possible to manage electricity usage so that the underlying patterns are hidden. What they did was introduce a rechargeable battery between the rest of the system and the smart meter. Their system mixes up the power usage, using the battery as a reservoir of electricity, changing where the peaks and troughs are, so that no information actually leaks out of the house.

So privacy could be a problem with smart metering. An engineer's job is to solve problems, though. Just because it's the power company's meter, doesn't mean you can't keep them in the dark!

Cracking a smart meter

If burglars could get hold of data from a smart meter they could both work out what gadgets you have worth stealing and also tell whether you are in or not, all from the comfort of their own home.

How could anyone other than the power company get the data though? A German research team led by Dario Carluccio decided to see if it was possible. They have shown that the data from at least one kind of smart meter can be intercepted by anyone with the right software. Data needs to be encrypted – transmitted using an uncrackable code – to be safe from prying eyes. For the smart meter they examined that wasn't done securely. They could not only intercept the data, they could even tamper with what was sent back to the company, which meant they could have, for example, lowered their bills. All they needed was what is known as the 'MAC address' of the smart meter. A MAC address is just the unique network name that a computer uses to identify itself – all computers connecting to the Internet have one. Unless special security is used any computer can pretend it is some other computer just by using the target computer's MAC address when asked to identify itself. With the smart meter, to send bogus data, you essentially just need to get another computer to use the smart meter's MAC address before sending data. The researchers demonstrated this by changing the electricity usage data in a way that made the graph of peaks and troughs of usage read the message "U have been hacked"!

Designing a planet's road network

Can you imagine designing the world's road network from scratch? Plus all the pavements, footpaths, bridges and shortcuts? Can you imagine designing a computer with the complexity of a planet?

In Douglas Adams' classic 'The Hitchhiker's Guide to the Galaxy', there's a whole planet devoted to designing other planets, and the Earth was one of their creations. In the story, Earth isn't just a planet: it's also the most powerful and most complicated computer ever made, and its job was to help explain the answer to the meaning of life. Aliens had to design every last bit of it – one character, Slartibartfast, had the particularly complex job of designing the world's coastlines. His favourite thing to make was fjords, because he liked the decorative look they gave to a country. (He even won an award for designing Norway.)

That's just a story though, right? Could anyone ever design a computer of planetary complexity from scratch? As it happens that is exactly the task facing modern computer chip designers.

It is often said that modern chips are the most complex things humans have ever created, and if you imagine starting to design a whole planet's road network, you will start to get the idea of what that means. The task is rather similar. Essentially a computer chip is made up of millions of transistors: tiny elements that control how electrons flow round a circuit. A microscopic view of a chip looks very much like a road network with tracks connecting the transistors, which are a bit like junctions. Teams of chip designers have to design where the transistors go and how they are connected. The electrons flowing are a little like cars moving around the road network.

There's an extra complication on a chip though. Designers of a road network only have to make sure people can get from A to B. In a computer, the changing voltages caused by the electrons move data around the chip and also compute the data at the same time. Data also gets switched around and transformed as calculations are performed at different points in the circuit. That means chip designers have to think about more than just connecting known places together. They have to make sure that as the electrons flow around, the data they represent still makes sense and computes the right answers. That's how the whole thing is capable of doing something useful – like play music, give travel directions or control a computer game. It's like designing a planetary road network, except all the traffic has to mean something in the end! Just like the fictional version of the Earth, only in fact.

It's actually even harder for chip designers. Nowadays the connections they have to design are smaller than the wavelength of light. All that complexity has to fit, not on something as big as a planet, but crammed on a slab of silicon the size of your fingernail! Pretty impressive, but Earth's intricate fjords are still more beautiful (especially the ones in Norway).

This article is inspired by the Kilburn Lecture given by Professor Steve Furber of the University of Manchester in 2008.

Can you imagine designing a computer with the complexity of a planet?

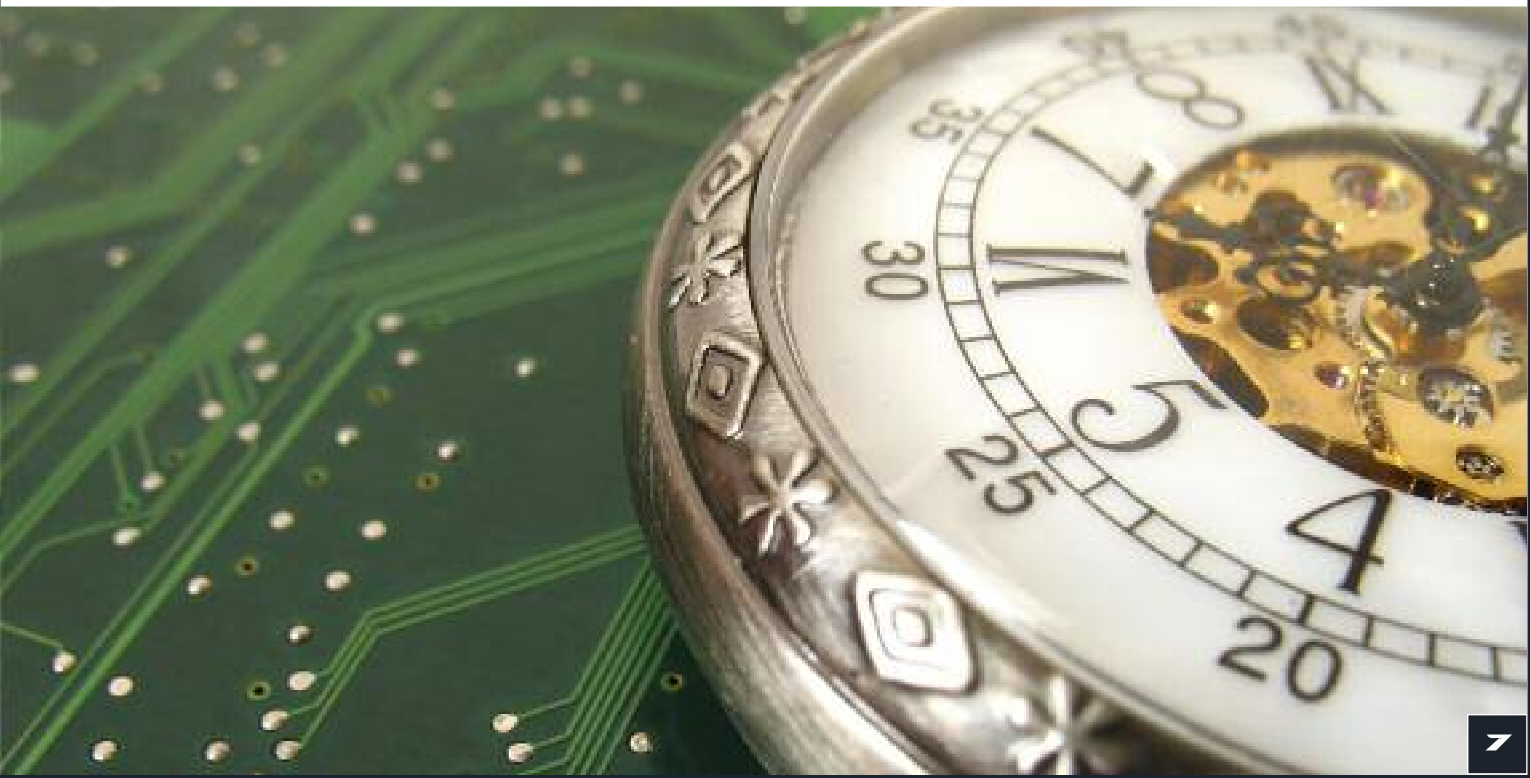
Fancy some green chips?

It's a documented fact that many species are disappearing as a result of pollution, environmental changes, and expansion into natural ecosystems. If we are to continue our progress and maintain an environmental balance, especially in light of climate change, we need new solutions to these problems. There are many ways future creative electronic engineers might help: devising algorithms that control how we harness natural energy efficiently, thinking of ways to reduce the energy usage of the technology itself, or coming up with new technologies that change the way we behave, such as developing the ways we use the virtual world to avoid the need to travel in the real world.

Energy efficiency has been important for a long time: back in 1992 the US Environmental Protection Agency introduced a voluntary labelling program, called Energy Star, designed to help encourage energy-efficiency in monitors and other technologies. This scheme led to the widespread use of sleep mode among consumer electronics. Of course now we need to go a step further and stop our lazy ways of leaving gadgets in sleep mode when we know we aren't going to use them for a while rather than switching them off! Today, energy efficiency is a vital part of any new technology. For example, engineers are working to try and make your chips cooler. The silicon chip in your laptop or mobile phone needs electricity to work. The chip (or processor) is made up of thousands of microscopic electronic switches that allow the computer program to do the calculations to make your application work. Normally all these switches click over at the same time. It's called a clock cycle. Your data goes in. Click. The data is processed. The data comes out. The problem is that these chips, particularly if they run quickly by having a high speed clock, get very, very hot. This heat is due to the current in the circuits that causes the materials to heat up. All this heat shortens you battery life and is very inefficient.

It's called a clock cycle. Your data goes in. Click. The data is processed. The data comes out

Intel came up with one cunning plan: build a chip that adapts its speed. It's called SpeedStep technology. When not much is going on, the clock runs slowly conserving your battery. Only when lots of data needs processing does the chip turn the clock speed up. This clever chip is just one way that electronic engineers are trying to build eco-friendly computers, and produce chips that won't fry your battery.



How do you make a $25 computer?

The Raspberry Pi, the brainchild of University of Cambridge researchers, is a new cheap computer intended to help school kids get programming. It's all the rage at the moment. In fact, when it was released, the demand was so great that the Raspberry Pi website crashed under the numbers of people trying to get their hands on one. It's really just a cheap but quite powerful computer. But how do you create a computer that can be sold for less than $25?

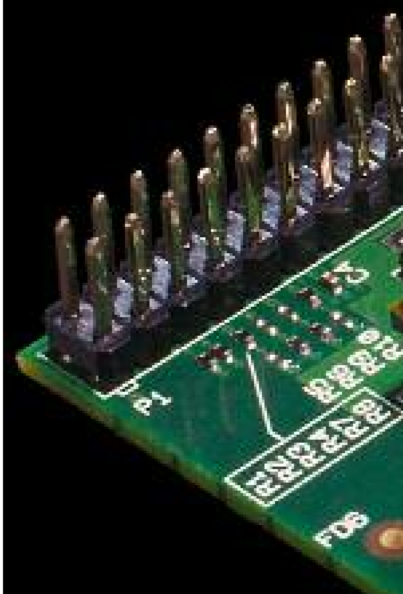
The Raspberry Pi is essentially made up of a computer processor with high performance video and graphics, a reasonable amount of memory, and sockets to connect camera memory cards, keyboard, mouse and the like. The most expensive component is the chip with the processor on. Chips are cheap to create but only once the fabrication plant is set up. It's very much like printing a book. If you wanted a publisher to only print a single copy of your new novel, that copy would cost thousands of pounds. Someone has to spend the time preparing it and setting up the press for printing it. That is expensive. Once the press is ready to print though it then doesn't cost much more than the ink and the paper to print more at the same time. If you think it will be a best seller and print tens of thousands, that initial cost is spread across all those copies so each one then costs pence. It's the same for computer chips. The big cost is in setting up the fabrication line. That costs tens of millions of dollars for a new chip. Once set up making each chip is a few dollars. It's therefore only economical if you are going to fabricate millions.

So a $25 computer is definitely possible if you know you will sell millions, but for Raspberry Pi the initial aims were more modest

So a $25 computer is definitely possible if you know you will sell millions, but for Raspberry Pi the initial aims were more modest. Fabricating millions of chips and then not selling them would just leave you bankrupt!

So how did the Raspberry Pi Foundation do it? Well it turned out similar chips already existed for HDTV set-top boxes – they are just computers in disguise. A semiconductor company called Broadcom had chips that were almost exactly what was needed and Broadcom were really keen to help given the Raspberry Pi foundation is a charity with the very laudable aim of getting more people programming. There was one problem though. The idea was that Raspberry Pis would use the Linux operating system. To do that you would need lots more computer memory than you could make available for $25. The existing chip wouldn't quite cut it.

Most computers get round this problem of lack of memory using 'virtual memory' hardware. What is virtual memory? It's just a clever way to give the appearance of having more memory than you really do. Suppose you are going shopping. You intend to buy clothes from your favorite boutique, food from the supermarket and some things for the house from a department store. Trouble is you know your memory isn't good enough to remember so many things. You are bound to forget something. No problem, you just write a list for each shop. When in the boutique you read off the things you wanted there. It's a small list so once looked at you can remember it all. When you go to the department store you can forget the boutique list completely and just read off the new department store set of items, then the same again in the supermarket. Now suppose you didn't get everything you wanted in the boutique.



After the supermarket you go to another clothes shop and check the boutique list again to see what hasn't been crossed off. Off you go again, mind only on clothes. No need to worry about the other lists.

Virtual memory works in the same way. It is used in situations where the computer will need to multitask. It can actually only do one thing at a time so each separate task takes turns just as you couldn't go in all the shops simultaneously so visited them one after the other. Rather than storing all the data needed for each task in memory at once, they are all stored out on an external disk (which acts like the piece of paper storing the lists). Each time a task is started or continued, its data is swapped back in to memory (just as you re-learnt the appropriate shopping list at each new shop). When it's another task's turn, all its current data is stored back out to disk, ready for the new task to take over.

Virtual memory hardware makes all this happen invisibly. It manages all the swapping so that the actual computer is completely unaware that it doesn't really just have one big memory where everything is. The hardware makes sure that task's data is just there in its memory when it needs it.

So back to the Raspberry Pi. What was needed was for Broadcom HDTV chips to include virtual memory hardware...and possibly because Broadcom were very supportive their next chip design did! That meant the Raspberry Pi Foundation didn't need a fabrication line to be set up just for them. They could buy what were now off-the shelf chips really cheaply.

So the Raspberry Pi is up and running. A lucky few have them already and it won't be long before there are plenty fabricated. Now what is needed is for the people who do get their hands on them to start programming.

For more on Raspberry Pi, see
www.raspberrypi.org

Your phone inside you

If you were to have a heart attack, you would probably be very happy to have a pacemaker implanted in your body. It's just an electronic device whose job is to keep you alive. That sounds worth having! Implants like that, placed in people's bodies by surgeons, are now routine, but why stick with medical devices? After all, it's a constant pain having to look for the TV remote or game console all the time. Mobile phones are too easily stolen too. You also have to leave them behind when you go swimming and teachers make you leave them at home. Why not get them surgically implanted in your body just like a medical device? Then they would always be there when you need them, and you'd no longer have to worry about missing calls because you took too long to get the phone out of your bag. Problems solved!

Implanting chips under the skin is no big deal in itself. Pets are routinely chipped by their owners, after all. With something like a mobile, the difficulty comes more in how to actually interact with it. Where are the buttons to press? How do you handle not having a screen? PhD student Christian Holz and a team of researchers in Canada and Germany have been exploring these sorts of questions. To test their ideas they even went as far as implanting devices into dead bodies.

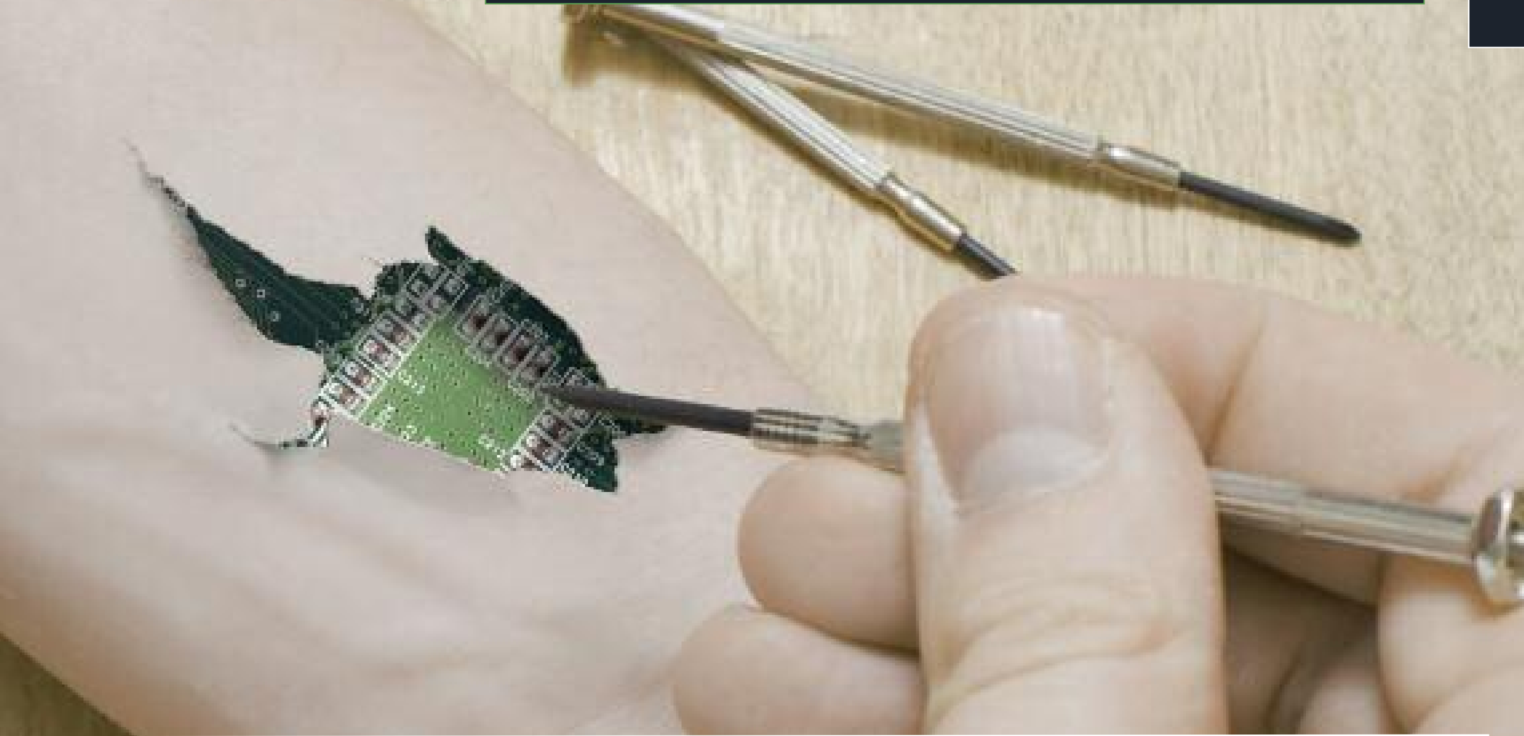
Tummy buttons

The first challenge to overcome if you implant a device inside someone is what do you do for buttons? How do you dial a number for example? One way would be to switch to a voice-activated interface. Sometimes, such as for privacy or when it's noisy, buttons are just more convenient, though. In fact, you can still, in theory, have buttons on an implanted device or even similar things like touch sensors. Light detecting sensors might also be able to tell when a finger is hovering over a particular position. Light does pass through the skin to some extent. Try it. Shine a strong torch into the palm of your hand. In the dark you can see the glow at the back of your hand. Of course that leaves the problem of remembering where those pesky buttons actually are. Perhaps a tattoo would help! An alternative would be to not bury devices completely in the first place but have them sticking out of the skin. A tiny camera could be implanted in this way and then be able to detect gestures in front of it.

Of course there are problems to be overcome – would you want your phone to accidentally dial your partner every time someone gave you a hug? A clear way to switch the device on and off is needed that couldn't be done accidentally just as phones use a variety of mechanisms to lock them in your pocket.

Making light work of safe circuits

Lots of medical devices involve connecting wires to patients, so that the body's electrical signals such as those from the heart or brain can be measured. But connecting a patient with wires directly to a device plugged into the mains carries a risk. What if something accidentally short-circuited? To get round this many medical devices use an 'optical isolator'. It converts the electronic signal into a light pulse, and that light pulse is then detected by a second adjacent circuit. That means that there is no direct conducting path between the patient and the mains. The light in between carries the information across the gap.



As a first attempt to find out how various implanted devices might work in reality the Canadian-German team tested a series of input and output devices. This included a normal button, a sensor that could detect pressure and another that could detect a person tapping it, and finally sensors that could detect something hovering above the skin. Output sensors included an LED to flash a light through the skin, a motor that vibrated to give tactile feedback and a speaker.

The devices were implanted by surgeons into the body of an 89-year-old man who had died and left his body to science. His body had been lightly embalmed to keep the skin flexible. They then set up a test rig that used a piston to trigger the input devices in controlled ways. They tested each a series of times as well as testing how well the output devices worked. The tests showed that all the input and output devices did still work through the skin.

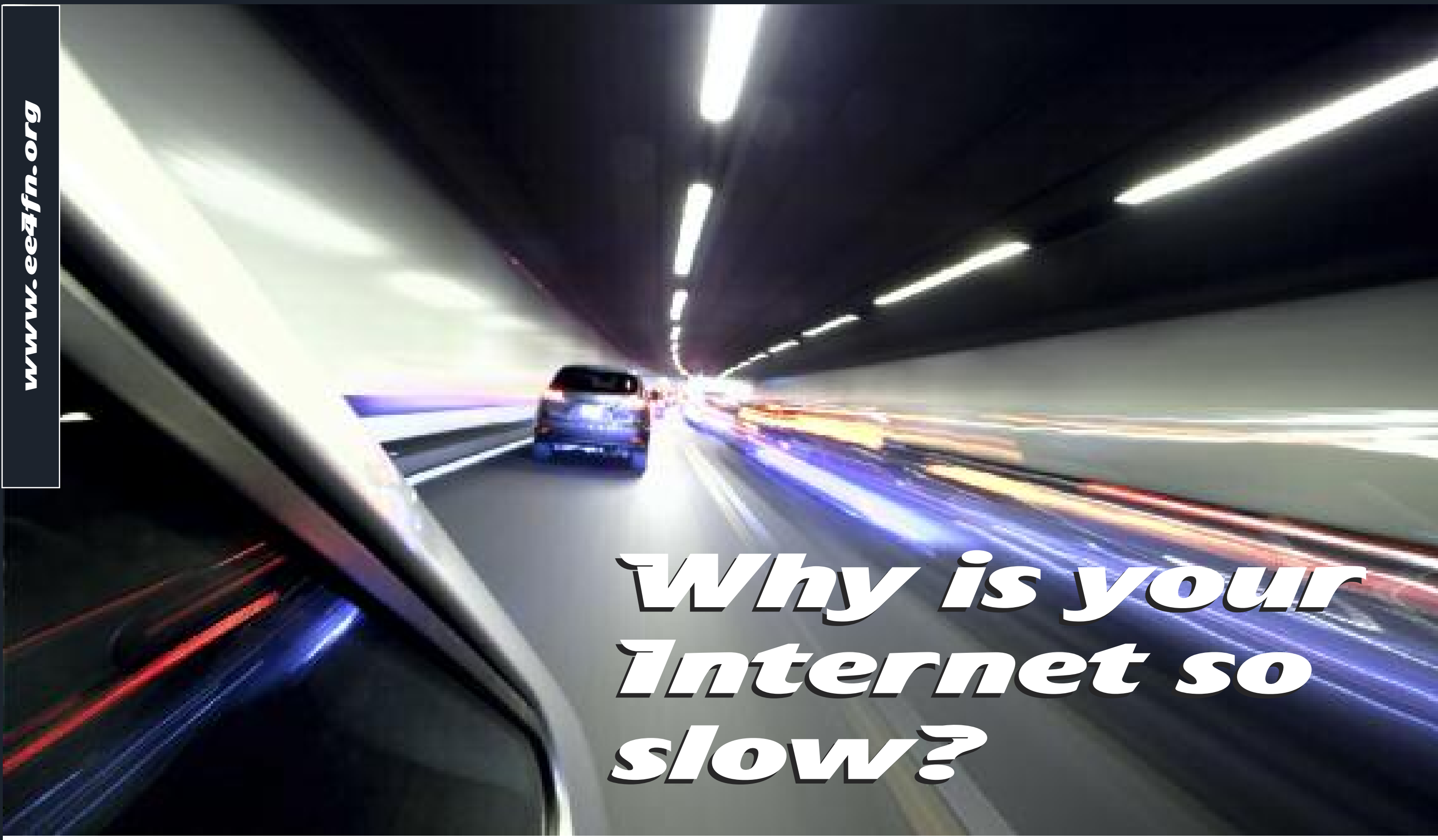
Skin deep

Having shown the devices still worked, the next step was to find out how real people would react to the idea of using devices under the skin. Rather than actually implant them though they used an artificial skin that felt like real skin – the sort of thing used by make-up artists in films. The device was laid on the person's arm and covered with the artificial skin. They got people to play a simple game that involved responding to outputs from the device by using different inputs: for example if the device emitted a sound they had to press the button, if it vibrated they had to tap the tap sensor. The faster they were at responding correctly, the higher their score. To make it more realistic the game was played while the person was doing a series of real tasks out on the streets of Toronto, like ordering coffee and getting a newspaper.

So how well did the devices work? All were relatively easy to use though no one liked using the pressure sensor and the LED was the hardest to notice. It could only be seen blinking when directly looked at.

Would you want your phone to accidentally dial your partner every time someone gave you a hug?

The participants got some odd looks, but that aside the team demonstrated that implanted devices are feasible. How long before you will be 'wearing' one just for the convenience?



Why is your Internet so slow?

The Internet is now so much a part of life that, unless you are over 50, it's hard to remember what the world was like without it. Sometimes we enjoy really fast Internet access, and yet at other times it's frustratingly slow! So the question is why, and what does this have to do with posting a letter, or cars on a motorway?

The communication technology that powers the Internet is built of electronics. The building blocks are called routers, and these convert the light-streams of information that pass down the fibre-optic cables into streams of electrons, so that electronics can be used to switch and re-route the information inside the routers.

Enormously high capacities are achievable, which is necessary because the performance of your Internet connection is really important, especially if you enjoy online gaming or do a lot of video streaming. Anyone who plays online games will be familiar with the problem: opponents apparently popping out of nowhere, or stuttery character movement.

So the question is – why is communicating over a modern network like the Internet so prone to odd lapses of performance when traditional land-line telephone services were (and still are) so reliable? The answer is that whereas traditional telephone networks send data as a constant stream of information, while over the Internet, data is transmitted as "packets". Each packet is a large group of data bits stuck inside a sort of package, with a header attached giving the address of where the data is going. This is why it is like posting a letter: a packet is like a parcel of data sent via an electronic 'postal service'.

But this still doesn't really answer the question of why Internet performance can be so prone to slow down, sometimes seeming almost to stop completely. To see this we can use another analogy: the flow of packet data is also like the flow of cars on a motorway. When there is no congestion the cars flow freely and all reach their destination with little delay. That means good, consistent performance is enjoyed by the car's users. But when there is overload and there are too many cars for the road's capacity, then congestion results. Cars keep slowing down then speeding up, and journey times become horribly delayed and unpredictable. This is like having too many packets for the capacity in the network: congestion builds up, and bad delays – poor performance – are the result.

Typically, Internet performance is assessed using broadband speed tests, where lots of test data is sent out and received by the computer being tested and the average speed of sending data and of receiving it is measured. Unfortunately, speed tests don't help anyone – not even an expert – understand what people will experience when using real applications like an online game. Electronic engineering researchers at Queen Mary, University of London have been studying these congestion effects in networks for a long time, mainly by using probability theory, which was originally developed in attempts to analyse games of chance and gambling. In the past ten years, they have been evaluating the impact of congestion on actual applications (like web browsing, gaming and Skype) and expressing this in terms of real human experience (rather than speed, or other technical metrics). This research has been so successful that one of the professors at Queen Mary, Jonathan Pitts, co-founded a spinout company called Actual Experience Ltd so the research could make a real difference to industry and so ultimately to everyday users.

For businesses that rely heavily on IT, the human experience of corporate applications directly affects how efficiently staff can work. In the consumer Internet, human experience directly affects brand perception and customer loyalty. Actual Experience's technology enables companies to manage their networks and servers from the perspective of human experience – it helps them fix the problems that their staff and customers notice, and invest their limited resources to get the greatest economic benefit.

Dial-a-molecule

Making new molecules is a complicated business. It takes years of effort to work out how to create even a relatively small molecule made up of only a handful of atoms. It matters though because our modern world depends on our ability to make new chemicals. Everything from drugs to plastics depends on it. Industrial chemists would love to be able to just dial in the molecule they were after and have it created by a computer on the spot without having to bother with lots of messy trial and error chemistry. The dream is a simpler version of that sometimes used in science fiction films where you tell the computer you would like an orange juice and it makes a glass of it on the spot without bothering using oranges! This 'dial-a-molecule' challenge has been taken up by teams of researchers across the UK. If they succeed, it will revolutionise the way everything from cosmetics to hi-tech Olympic swimsuits are made.

The way chemicals are made at the moment is both messy and wasteful. It often involves using a whole series of complicated reactions that need to happen in a specific order. It's a bit like a bunch of people trying to get across a crocodile-infested river where, rather than just wade across in a straight line, they have to jump from stone to stone, zigzagging their way across. Their route is determined by the stepping stones they know about. Ideally chemists would similarly like to just head straight to the desired chemical from the starting chemicals. Instead they work out a route and then jump from compound to compound based on the reactions that can happen. Each extra reaction produces unwanted waste products though. In a typical process a thousand times more waste might be created than of the actual chemical wanted. If chemists could use the most direct series of reactions possible, with little or no waste to get rid of, that would not only make the process much cleaner, it would use less energy and be cheaper.

Could electronic engineers help? A team from Queen Mary, University of London led by Rob Donnan are aiming to. They are exploring whether desired molecules can be created by applying specific pulses of electromagnetic energy to a mix of initial chemicals in a way that means that only a precise sequence of reactions happen. The idea is to use really high-powered 'terahertz' radiation – that is radiation with a wavelength less than a millimetre. Recent advances by electronic engineers in building apparatus called a 'vector network analyser' make this potentially possible. It allows precise kinds of radiation to be created in a way that is incredibly finely tuneable. The radiation can be used to activate a given chemical bond in a molecule but not, say, an immediate neighbouring bond. That means specific reactions can be activated avoiding others. The approach can also be used to immediately scan the aftermath of a reaction to work out what chemicals have been created by it for subsequent steps. Rob's team is exploring how easy it is to actually make desired reactions happen.

Whilst the science fiction vision of dialing up your dinner on a computer that is then chemically constructed on the spot is still science fiction, chemists may soon at least be able to dial up specific molecules they want and when it happens it will revolutionize the way chemicals are created industrially. With designer chemicals easy to make the science fiction future of industrially polluted wastelands may be a thing of the past.

Making money from technology

Communication technology changes the way people do business. As each new generation of technology comes along, there are new opportunities to make money. The history of the stock market is a good example.

The London Stock Exchange started life in the 17th century in coffee shops where people would meet and discuss commerce. People started to use the coffee shops to trade including buying and selling shares in companies. If you needed to raise money, that was the place to go. This was obviously good business for the coffee shop owners too. John Castaing began to publish a list of prices twice a week and that cemented his coffee shop as the place to trade. Eventually a group of traders built their own building with a dedicated dealing room and the Stock Exchange as we know it was born. At this point, chalk was the state of the art in display technology as prices started to be written up on chalkboards.

Information is always a good thing to have and that's even more true when you are doing deals – knowing that a ship with its cargo has arrived safely before everyone else gives you an edge. That means you need some kind of communication technology to get the information to you in the first place. The faster the technology you have the bigger your advantage. Early technology wasn't based around computer networks of course, it was horse-flesh based. Messengers on horseback would rush to London with any news that might give a trading edge.

Find a faster way of sending a message than a horse rider though and you have the edge. This was demonstrated by Nathan Rothschild at the Battle of Waterloo. No one knew who would win but obviously the result would make a big difference on the markets. In particular, if Napoleon won, British government bonds would become worthless. The story goes that Rothschild realised homing pigeons could get the result of the battle to him faster than anyone else so he shipped pigeons out to the battle field (and made sure everyone knew how clever he was to have done so!)

The battle ended and his pigeons arrived long before any horse-backed messenger, telling him that Napoleon had lost. Rather than buying bonds, though he did the opposite and immediately started selling them. People knew he must know the result of the battle because the pigeons had returned. The fact he was offloading bonds also told them (they thought) that Napoleon had won so everyone started to sell. The price crashed. Anyone wanting to buy bonds could now get them ridiculously cheaply. Little did they know that the people buying were a group of Rothschild's assistants! Of course when the horse riders arrived with the news that Napoleon had actually been defeated the price shot back up and Rothschild could sell at a healthy profit. By having better communication technology and using the information he had in a canny way, Rothschild made a killing (though probably not enough to make up for his losses as a result of an earlier bet on it being a long war).

Of course soon pigeons were a defunct technology too and chalkboard display technology didn't survive either, as the telegraph took over. A system was invented for the telegraph information to be printed on ticker tape. Eventually an enterprising company worked out a way to project the moving ticker tapes onto a big screen and chalk was history.

As the Internet appeared, in the 1980s the scene was set for another shift. Michael Bloomberg realised that financial companies would pay for fast, high quality financial information so he set up a company that produced computer terminals for traders ... and became rich as a result. Of course once information is being delivered in digital form computers can do things with it themselves. Who needs humans? In the last 10 years the traders have gone – the people replaced by software that can make decisions based on the incoming information (and without display technology at all) much more quickly.

Another reason computer traders turn out to be especially useful is to salami slice large orders. Suppose you want to buy 5 million shares in a company. If you buy them in one go then just the fact that you are buying so many will raise the price (just as Rothschild's selling caused the price to drop). If on the other hand you get an army of helpers each buying a few shares, it will take time before anyone realises what is going on (again just as no one realised it was really Rothschild doing all that buying). That means there will be no impact on the price. It's hard to find several million people to act as helpers but software helpers are easy to clone. Introducing a new technology led again to a commercial advantage.

The history of the stock market is a history of ever improving communication technology. Those getting and reacting to information the fastest have always had an advantage. Those that saw the potential of a new technology were also able to make a killing. The question is what technology comes next? Work that out and take advantage of it and you could be the next person to make a mint.

This article is based on part of a lecture given by Dave Cliff of Bristol University in June 2012.

Sudoko in satellite communication

How can satellites use Sudoku puzzles to communicate in a way that extracts twice as much information as was apparently sent? **Soren Riis** of Queen Mary, University of London explains.

Imagine two ground stations belonging to Jo and Kim that communicate via a satellite. Jo wants to send some information to Kim – just a bit (either a 0 or a 1) and Kim wants to send a bit (0 or 1) back to Jo. The obvious way to do this is for the satellite to get the two bits in turn and then beam them back to earth one at a time. That seems obvious but is it wasteful? Could the satellite do its job by only sending a single bit back in a way that both Jo and Kim get the information the other sent? That just sounds impossible! Surely there is no way they can both extract the possibly different pieces of information meant for them from a single bit! It would mean extracting more information from the message than was actually sent!

Impossible? Can you work out a way to do it?

Hint: There are 4 cases. Let's call Jo's bit of information j and Kim's k. We can list the possibilities:

Case 1: j is 0 and k is 0,
Case 2 : j is 0 and k is 1,
Case 3 : j is 1 and k is 0,
Case 4 : j is 1 and k is 1.

For each of the 4 cases the satellite will transmit either a 0 or 1: you need to work out a bit that can be sent that will allow Kim to work out what k is and Jo to work out what j is in each case. Try to find the ways to fill in the 4 empty cells in the table that solves the problem. Have a go before you read on.

	k is 0	k is 1
j is 0		
j is 1		

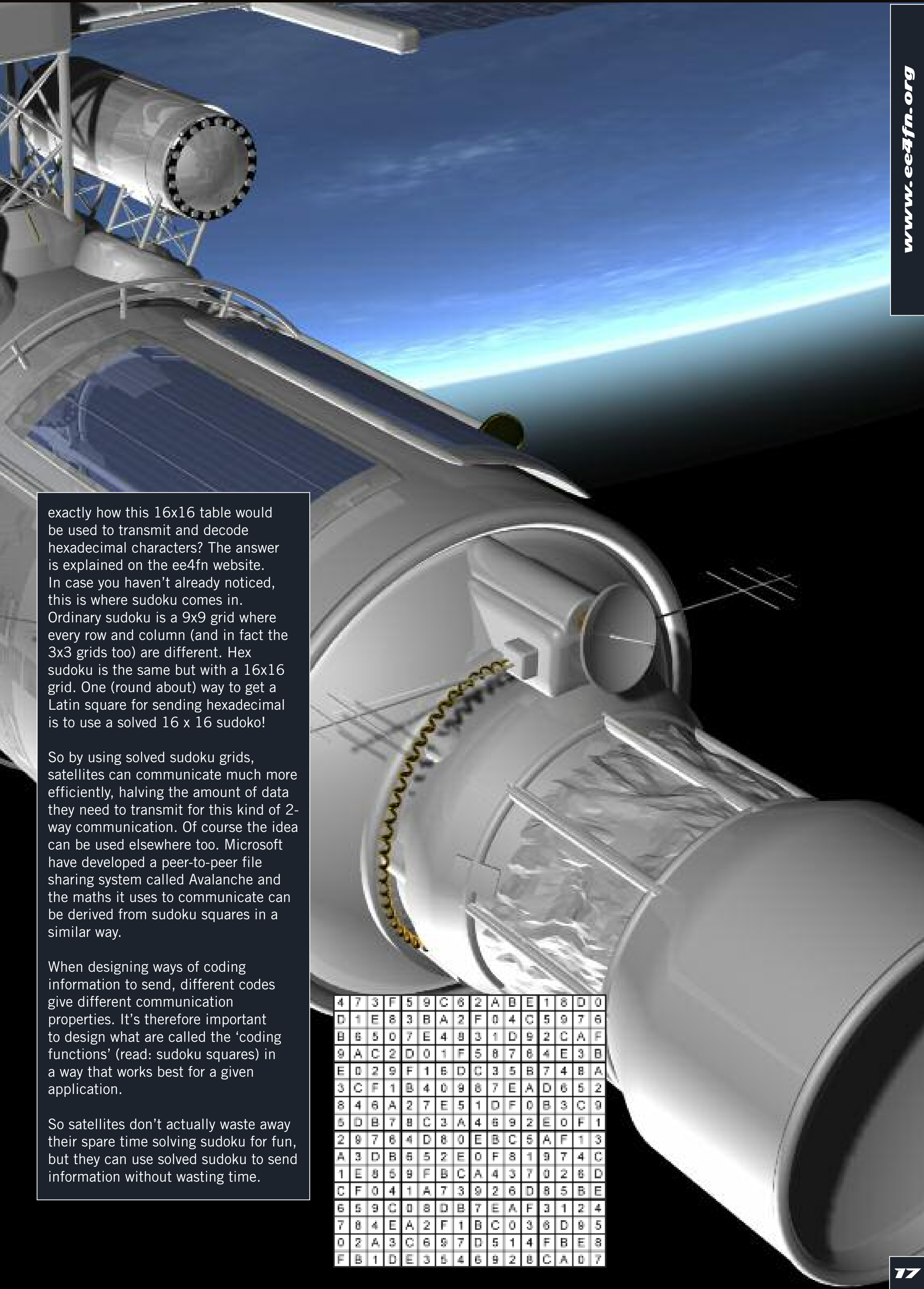
The problem is actually very simple. What you need to do is place the bits 0 and 1 in the four cells in a way so that each column and row in the table contains different bits. For example, one solution is

Case 1: j is 0 and k is 0. Send 0.
Case 2 : j is 0 and k is 1, Send 1.
Case 3 : j is 1 and k is 0, Send 0.
Case 4 : j is 1 and k is 1. Send 1.

But how does this help? How does it get round the problem of needing to extract more information than was sent? The trick is that both Jo and Kim have more information than just the bit they receive. They know what they sent too! They can use that together with whatever the satellite sends them to work out what the unknown bit that the other was sending is. Essentially the satellite is using a code where in this case 0 means "the bits I was given are different" and 1 means "the bits I was given are the same".

So far so good, but we don't want to just send bits of information. Suppose we are sending a text message. It's made of lots of letters not just a 1 or a 0. Computers store letters in what is know as hexadecimal. It's just another code where everything is translated into pairs of the 16 digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F. For example, the letter 'a' is 61, 'b' is 62 and so on up to 'z' which is 7A.

So suppose now that Jo and Kim are both beaming a sequence of hexadecimal numbers to the satellite. We can play the same trick on each digit to reduce the amount of data the satellite sends. As there are now 16 different digits Jo and Kim could be sending instead of 2, we just need to fill in a 16 x 16 table rather than a 2 by 2 one to work out what the satellite should transmit. We need to put a hexadecimal number in each square so that every column and every row contain different numbers. Mathematicians call this kind of table a Latin square. Find a way to do that and you have your code to send hexadecimal messages efficiently from the satellite. As with the binary version, you work out the message sent to you by looking up the message you sent and the message received in the table giving the code being used. Can you work out



exactly how this 16x16 table would be used to transmit and decode hexadecimal characters? The answer is explained on the ee4fn website. In case you haven't already noticed, this is where sudoku comes in. Ordinary sudoku is a 9x9 grid where every row and column (and in fact the 3x3 grids too) are different. Hex sudoku is the same but with a 16x16 grid. One (round about) way to get a Latin square for sending hexadecimal is to use a solved 16 x 16 sudoko!

So by using solved sudoku grids, satellites can communicate much more efficiently, halving the amount of data they need to transmit for this kind of 2-way communication. Of course the idea can be used elsewhere too. Microsoft have developed a peer-to-peer file sharing system called Avalanche and the maths it uses to communicate can be derived from sudoku squares in a similar way.

When designing ways of coding information to send, different codes give different communication properties. It's therefore important to design what are called the 'coding functions' (read: sudoku squares) in a way that works best for a given application.

So satellites don't actually waste away their spare time solving sudoku for fun, but they can use solved sudoku to send information without wasting time.

4	7	3	F	5	9	C	6	2	A	B	E	1	8	D	0
D	1	E	8	3	B	A	2	F	0	4	C	5	9	7	6
B	6	5	0	7	E	4	8	3	1	D	9	2	C	A	F
9	A	C	2	D	0	1	F	5	8	7	6	4	E	3	B
E	0	2	9	F	1	6	D	C	3	5	B	7	4	8	A
3	C	F	1	B	4	0	9	8	7	E	A	D	6	5	2
8	4	6	A	2	7	E	5	1	D	F	0	B	3	C	9
5	D	B	7	8	C	3	A	4	6	9	2	E	0	F	1
2	9	7	6	4	D	8	0	E	B	C	5	A	F	1	3
A	3	D	B	6	5	2	E	0	F	8	1	9	7	4	C
1	E	8	5	9	F	B	C	A	4	3	7	0	2	6	D
C	F	0	4	1	A	7	3	9	2	6	D	8	5	B	E
6	5	9	C	0	8	D	B	7	E	A	F	3	1	2	4
7	8	4	E	A	2	F	1	B	C	0	3	6	D	9	5
0	2	A	3	C	6	9	7	D	5	1	4	F	B	E	8
F	B	1	D	E	3	5	4	6	9	2	8	C	A	0	7

Printing your phone

We tend to think of printing as simply ink on paper these days, but that's all about to change. Printable electronics is a growing field of research and it holds the promise of being able to use traditional printing processes to produce electrical circuits and even electronic devices like mobile phones.

To print electronics first requires a substrate (think of this as the paper). It's often a form of flexible plastic that patterns can be printed on to. The patterns are produced by spraying carefully controlled jets of conductive 'ink'. These form the electrical connections between the devices on the substrate, like the wires of a traditional circuit. Electronics needs more than wires though, it needs active devices like transistors, capacitors and resistors too. How are these produced?

Semiconductor sandwiches

Rather than conductive ink, you can spray on or lay down thin layers of semiconductors. These useful materials lie halfway between being a conductor and a resistor, depending on the voltage that's applied to them. A sandwich of semiconductor between two conductors can therefore act as a switch. Depending on the voltage applied over the semiconductor it can either pass (as a conductor) or block (as a resistor) current. That means one electrical signal can control another. This is the basis of the transistor, the key component in modern electronics. They can be printed directly onto the substrate and joined up to form complex circuits.

Building gadgets

Electronic engineers are now exploring how to combine 3D printing with printed electronics. In 3D printing, shapes that are designed on a computer can be turned into real objects by printing them as multiple layers of plastic. It's like building a wall from tiny blocks of plastic. Into these objects can be built printed electronics too, piece by piece. A gadget like a mobile phone, made up of a plastic case and electronic innards, could be produced quickly and cheaply this way. In fact the sky's the limit. If you can design the package and the circuits in a computer the technology may soon exist to print it off in its full size usable glory. And in any colour you fancy too.

Making things bigger, making you better

Sometimes small things can make a big difference. In electronics this is called amplification. Often there will be a small signal we want to make bigger, whether its audio from your electric guitar that needs to be blasted out to the concert hall or the signal from tiny blinks of light that could indicate the presence of an exotic particle like the Higgs boson. Amplification is at the heart of many electronics applications, but how does it work? Historically it was done using rather exotically named devices like a 'long-tailed pair'. These days it's often done digitally.

These digital devices can do more that just make a small signal big, though. One useful example is the blood oxymeter. It's a clever device that clips on your finger and measures the amount of haemoglobin in your blood that is saturated with oxygen. The finger clip device contains two light sources with two different wavelengths (normally 650nm and 805nm). This light passes harmlessly through the skin and is partly absorbed by the haemoglobin. The amount absorbed depends on whether the haemoglobin is saturated or desaturated with oxygen. By calculating the tiny differences in absorption at the two wavelengths the device's computer can accurately work out the proportion of haemoglobin that's oxygenated. As the processing is digital the computer can also do other useful things with the signals, like measuring the pulse rate.

Claude Shannon: inventing for the fun of it

Claude Shannon, inventor of the rocket powered Frisbee, gasoline powered pogo stick, a calculator that worked using roman numerals, and discoverer of the fundamental equation of juggling! Oh yeah, and founder of the most important theory underpinning all digital communication: information theory. Claude Shannon is perhaps one of the most important engineers of the 20th century, but he did it for fun. Though his work changed the world, he was always playing with and designing things, simply because it amused him. Like his contemporary physicist Richard Feynman, he did it for 'the pleasure of finding things out.'

As a boy, Claude liked to build model planes and radio-controlled boats. He once built a telegraph system to a friend's house half a mile away, though he got in trouble for using the barbed wires around a nearby pasture. He earned pocket money delivering telegrams and repairing radios.

He went to the University of Michigan, and then worked on his master's degree at MIT. While there, he thought that the logic he learned in his maths classes could be applied to the electronic circuits he studied in engineering. This became his master's thesis, published in 1938.

It was described as *'one of the most important master's theses ever written... helped to change digital circuit design from an art to a science.'*

Claude Shannon is known for his serious research, but a lot of his work was whimsical. He invented a calculator called THROBAC (Thrifty Roman numerical BACkward looking computer). It performs all its operations in the Roman numeral system. His home was full of mechanical turtles that would wander around, turning at obstacles; a gasoline-powered pogostick and rocket-powered Frisbee; a machine that juggled three balls with two mechanical hands; a machine to solve the Rubik's cube; and the 'Ultimate Machine', which was just a box that when turned on, would make an angry, annoyed sound, reach out a hand and turn itself off. As Claude once explained with a smile, *'I've spent lots of time on totally useless things.'*

A box that when turned on, would make an angry, annoyed sound, reach out a hand and turn itself off

A lot of the early psychology experiments used to involve getting a mouse to run through a maze to reach some food at the end. By performing these experiments over and over in different ways, they could figure out how a mouse learns. So Claude built a mouse-shaped robot called Theseus. Theseus could search a maze until he solved it, and then use this knowledge to find its way through the maze from any starting point.

Oh, and there's one other paper of his that needs mentioning. No, not the one on the science of juggling, or even the one describing his 'mind reading' machine. In 1948 he published 'A mathematical theory of communication.' Quite simply, this changed the world, and changed how we think about information. It laid the groundwork for a lot of important theory used in developing modern cryptography, satellite navigation, mobile phone networks... and the Internet.

Complete circuit

In 1600 British scientist William Gilbert coined the term electricus, from the Greek word for amber, and from which we get the words electric and electricity. He was fascinated by the ancient Greeks discovery that if you rubbed a piece of amber (fossilised tree resin) with a bit of fur, the amber was able to attract small objects. How and why the Greeks first decided to do this type of rubbing remains a mystery but they had discovered the power of static electricity.

A build-up of electrical charge through rubbing forms the core mechanism of the famous Van de Graaff generator much beloved in school physics labs. Invented in 1929 by American physicists Robert Van de Graff the original device used a silk ribbon bought at a local store. The ribbon acts as a fast moving belt, running between two rollers. Friction between belt and rollers allows the buildup of electrical charge in the metal dome on top of the machine where a metal comb strips off the charge. Massive Van de Graaff generators are used to explore the structure of matter by creating high energy ion beams and massive voltages.

Voltage is named after Italian physicist Alessandro Giuseppe Antonio Anastasio Gerolamo Umberto Volta. He invented the first battery in the 1800s comprising zinc, copper and a jar of sulphuric acid. The battery wasn't particularly good, it ran down very quickly, and the sulphuric acid made it rather dangerous, but for his hard work he was made a count by Napoleon in 1801.

Biobatteries produce electricity using tricks from nature. A prototype biobattery using waste paper was demonstrated in 2011. In this battery shredded paper or old cardboard is dropped into a tank containing water and special enzymes. The enzyme, cellulase, decomposes the papers into glucose sugar which is then combined with oxygen and further enzymes to produce electrons and hydrogen ions.

Biobatteries can be made using fruit too. If you take a citrus fruit like a lemon, lime, orange or grapefruit, and puncture it with a copper nail and a zinc nail a small voltage can be generated. It follows the same chemical principals as Volta's original sulphuric acid filled battery. A fruit juice (citric acid) based battery has been used to power a walkman music player.

Electricity can be generated by people walking. In areas where lots of people walk test devices have been installed that convert the pressure of peoples foot fall into electricity, for example to power advertisement boards or lights. These devices replace standard paving stones or carpet tiles, and are being tested in the corridors of one school in England.

Substances that create an electrical change when they are put under pressure are called piezoelectric, these include bone, and the naturally occurring crystal quartz, which scientist William Gilbert mistakenly believed was an especially hard form of water, formed from ice.

GOTO START

visit www.ee4fn.org for more on the fun side of electronic engineering and physical computing.

EPSRC
Engineering and Physical Sciences Research Council

Much of the research described in this issue of ee4fn is funded by EPSRC.

COMPUTING AT SCHOOL
EDUCATE · ENGAGE · ENCOURAGE

ee4fn is part of the cs4fn family of magazines on the fun side of science, maths and engineering.

Queen Mary
University of London

Edited by Paul Curzon and Peter McOwan. Josh Reiss, Soren Riis, Nela Brown, Berit Greinke, John Schormans, Jonathan Pitts and Rob Donnan of Queen Mary, University of London, Dave Cliff of Bristol University and Steve Furber of the University of Manchester contributed to this issue.