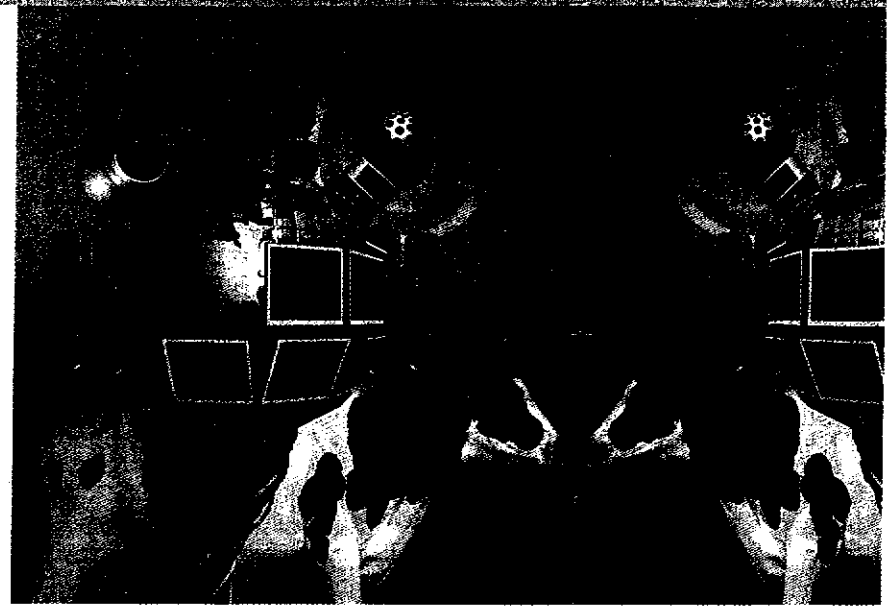
It's a smart world



Also in this section

Acknowledgments
Besides those cited in the text, the author would like to thank many others for their time, ideas and kindness during the preparation of this report. They include Bruno Berthon of Accenture, Eric Clementi of IBM, Tom Davenport of Babson College, Peter Elliott of PA Consulting Group, Scott Gnau of Teradata, Jeanne Harris of Accenture, Chris King of eMeter, Michael Liard of ABI Research, Michael LoCascio of Lux Research, Edzard Overbeek of Cisco, Joachim Schaper of SAP and Elisabeth Zornes of Cisco.

A list of sources is at

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An audio interview with the author is at

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The real and the digital worlds are converging, bringing much greater efficiency and lots of new opportunities, says Ludwig Siegele. But is it what people want?

WHAT if there were two worlds, the real one and its digital reflection? The real one is strewn with sensors, picking up everything from movement to smell. The digital one, an edifice built of software, takes in all that information and automatically acts on it. If a door opens in the real world, so does its virtual equivalent. If the temperature in the room with the open door falls below a certain level, the digital world automatically turns on the heat.

This was the vision that David Gelernter, a professor of computer science at Yale University, put forward in his book "Mirror Worlds" in the early 1990s. "You will look into a computer screen and see reality," he predicted. "Some part of your world—the town you live in, the company you work for, your school system, the city hospital—will hang there in a sharp colour image, abstract but recognisable, moving subtly in a thousand places."

Even two decades later that sounds like science fiction. But this special report will argue that Mr Gelernter was surprisingly prescient: mankind is indeed building more and more "mirror worlds", or "smart systems", as they are often called. The real and the digital worlds are converging, thanks to a proliferation of connected sensors and cameras, ubiquitous wireless networks, communications standards and the activities of humans themselves.

This convergence may not be instantly discernible, because it is happening in many places at once and is often not understood for what it is. It is most advanced in controlled environments. For example, software developed by Siemens, a technology conglomerate, maintains virtual replicas of factories to monitor and reconfigure them. But it is spreading everywhere and has developed a language all of its own. Glen Allmendinger of Harbor Research, a consultancy, calls it the "virtualisation of the real world". Researchers at MIT's Media Lab who connect real-life objects with copies in Second Life, a virtual world, refer to the result as "cross reality". Google's Earth and Street View services are the first, if static, replicas of the entire world; sensors placed in cows allow the tracking of their every move from birth to abattoir; smart power meters tell utilities in real time how much electricity is used.

The many uses of smartphones

Yet it is the smartphone and its "apps" (small downloadable applications that run on these devices) that is speeding up the convergence of the physical and the digital worlds. Smartphones are packed with sensors, measuring everything from the user's location to the ambient light. Much of that information is then pumped back into the network. Apps, for their part, are miniature versions of smart systems that allow users to do a great variety of things, from tracking their friends to controlling appliances in their homes. ▸▸

Smartphones are also where the virtual and the real meet most directly and merge into something with yet another fancy name: "augmented reality". Download an app called "Layar" onto your smartphone, turn on its video camera, point at a street, and the software will overlay the picture on the screen with all kinds of digital information, such as the names of the businesses on the street or if a house is for sale.

These and other services are bound to grow together into what Jan Rabaey, a computer scientist at the University of California at Berkeley, grandly calls "societal information-technology systems", or SIS. Technological progress is sure to supply the necessary components. Moore's law, which holds that the processing power of a single computer chip roughly doubles every 18 months, applies to sensors, too.

More processing power and better connectivity also allow the construction of computing systems capable of storing and crunching the huge amounts of data that will be produced by these sensors and other devices. All over the world companies are putting together networks of data centres packed with thousands of servers, known as "computing clouds". These not only store data but sift through them, for instance to allow a smart system to react instantly to changes in its environment.

The next big thing

Information-technology (IT) firms have identified smart systems as the next big thing. Predictably, the most ambitious designs have been produced by the industry's giants, particularly IBM, where Sam Palmisano, the firm's boss, made smart systems a priority. A couple of years ago the company launched a campaign called "Smarter Planet", touting digital technology that would make energy, transport, cities and many other areas more intelligent. Other firms have followed suit, each with a different take reflecting its particular strengths.

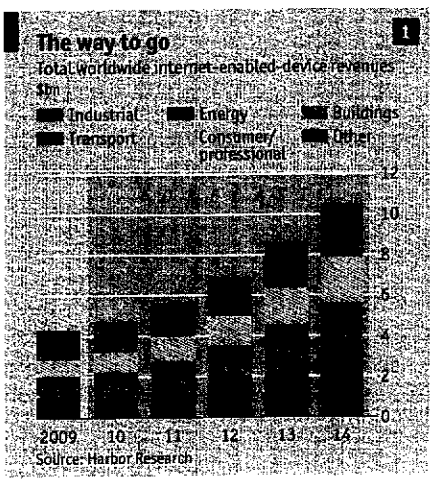
Cisco, the world's biggest maker of networking gear, is trumpeting "Smart+Connected Communities". Hewlett-Packard, number one in hardware, intends to spin a "Central Nervous System for the Earth". Siemens and its competitor General Electric, which are more at home in the physical world, plan to put together lots of smart systems in which they can deploy their deep knowledge of certain industries, such as health care and manufacturing. And there is a growing wave of "smart" start-ups, offering everything from services to pinpoint a devices's location to platforms for sensor data.

Governments, too, have jumped on the bandwagon. Many countries have been spending large chunks of their stimulus packages on smart-infrastructure projects, and some have made smart systems a priority of industrial policy. The "internet of things", another label for these systems, is central to the European Union's "Digital Agenda". The main contenders in this market are countries that are strong in manufacturing, above all Germany and China.

But the bandwagon is not just rolling for the benefit of technology companies and ambitious politicians. It has gained momentum because there is a real need for such systems. In many countries the physical infrastructure is ageing, health-care costs are exploding and money is tight. Using resources more intelligently can make taxpayers' money go further. Monitoring patients remotely can be much cheaper and safer than keeping them in hospital. A bridge equipped with the right sensors can tell engineers when it needs to be serviced.

China is a good example. It is becoming urbanised on a scale unprecedented in history. By 2025 an additional 350m Chinese—more than the current population of the United States—will have moved to cities, according to a study by McKinsey, a consultancy. Without an infrastructure enhanced by digital technology it will be very hard to provide the country's newly urbanised population with enough food, transport, electricity and water.

Most important, smart systems may well be humankind's best hope for dealing with its pressing environmental problems, notably global warming. Today power grids, transport systems and water-distribution systems are essentially networks of dumb pipes. If the power grid in America alone were just 5% more efficient, it would save greenhouse emissions equivalent to 53m cars, calculates IBM. In 2007 its congested roads cost the country 4.2 billion working hours and 10.6 billion litres of wasted petrol, according to the Texas Transportation Institute. And utilities around the world lose between 25% and 50% of treated water to leaks, according to Lux Research, a market-research firm.



With so much to gain, what is there to lose? Privacy and the risk of abuse by a malevolent government spring to mind first. Indeed, compared with some smart systems, the ubiquitous telescreen monitoring device in George Orwell's novel "1984" seems a plaything. The book's hero, Winston Smith, would soon have a much harder time finding a corner in his room to hide from Big Brother.

Second, critics fear that smart systems could gang up on their creators, in the way they did in "The Matrix", a 1999 film in which human beings are plugged into machines that simulate reality to control humans and harvest their bodies' heat and electrical activity. Fortunately, such a scenario is likely to remain science fiction. But smart systems might be vulnerable to malfunctioning or attacks by hackers.

Third, some people fret that those with access to smart systems will be vastly better informed than those without, giving them an unfair advantage. Mr Gelernter highlighted this risk in "Mirror Worlds".

There are plenty of other concerns, and unless they are dealt with they could provoke a neo-Luddite reaction. The world has already seen one extreme example: the Unabomber, a disaffected American who targeted, among others, computer scientists with mail bombs. Two years after the publication of "Mirror Worlds" he sent one to Mr Gelernter, who was seriously injured—though fortunately he survived. ■

A sea of sensors

Everything will become a sensor—and humans may be the best of all

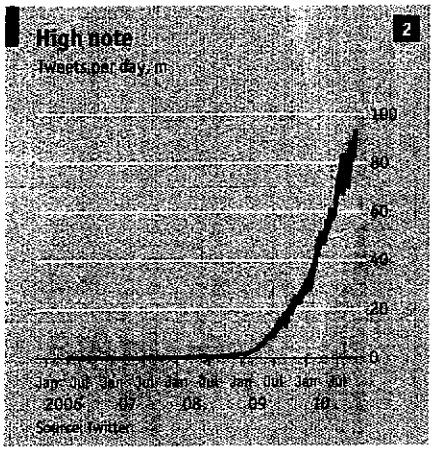
GERMANS are known to separate their rubbish diligently. Some even have dedicated containers for different kinds of metal. But they may soon need yet another bin: for electronic labels, also known as radio-frequency identification (RFID) tags. If not kept and treated separately, these could be very difficult to recycle, Germany's Federal Environment Agency said last year. The number being thrown away each year could rise from about 86m now to 23 billion by 2020, according to the agency.

RFID tags, which have been used to identify everything from cattle to tombstones, will not be the only type of sensor crowding the planet. Anything and anyone—machines, devices, everyday things and particularly humans—can become a sensor, gathering and transmitting information about the real world.

The concept of the "internet of things" dates back to the late 1980s, when researchers at Palo Alto Research Centre (PARC) in Silicon Valley imagined a future in which the virtual and the real world would be connected. In the following years much of the academic work concentrated on bringing this about with RFID tags, which are reliable, inexpensive and do not require a power supply. When exposed to a radio signal, they use its energy to send back the information they contain, mostly a long number identifying an object.

Now it is "active" tags (which have their own power source) and, even more, wireless sensors that are attracting most of the interest. As with all things electronic, these are becoming ever smaller and more versatile. "Tell me what you need, and we can build it for you," says Reinhold Achatz, head of corporate research at Siemens. Start-ups, too, are producing devices that sense everything from the rarest chemical to the most exotic bacteria. Optiqua, a Singaporean firm, has come up with a chip that measures how fast light passes through a water sample to detect contaminants. And a biosensor developed at the Lawrence Livermore National Laboratory in Berkeley, California, can identify about 2,000 viruses and 900 bacteria.

Researchers are also on the way to solving two big problems that have held back the deployment of sensors. One is power.



Having to run wires or regularly replace batteries would be too difficult. But sensors have started to power themselves by scavenging for energy in their environment, for instance in the form of light and motion. Similarly, some sensors already make more efficient use of another scarce resource: radio spectrum. Smart power meters form "mesh networks" to relay their readings.

Engineers working on sensors think this will eventually lead to "smart dust"—sensors as small as dust particles that can be dispersed on a battlefield, say, to spy on the enemy's movements. Such devices are still far off, but at Hewlett-Packard (HP) in Silicon Valley a taste—or more precisely, a feel—of things to come is on offer even now. To demonstrate the firm's new accelerometer, a device the size of a cigarette box that measures the acceleration of an object, Peter Hartwell, a researcher, puts it on his chest, and a graph of his heartbeat appears on a screen beside him. "This sensor", he proudly explains, "is one thousand times more sensitive than those in your smartphone."

One day, Mr Hartwell and his colleagues hope, a network of one trillion sensors will cover the world and deliver data to anybody who needs them, from carmakers to municipal governments. For now, the firm has teamed up with an oil company, Royal Dutch Shell. The computer-maker plans to dot a prospecting area with thousands of wireless sensors. They are designed to pick up the echo of the seismic vibrations created by contraptions called "thumper trucks" pounding the ground. The data thus gathered allow them accurately to pinpoint pockets of oil and gas.

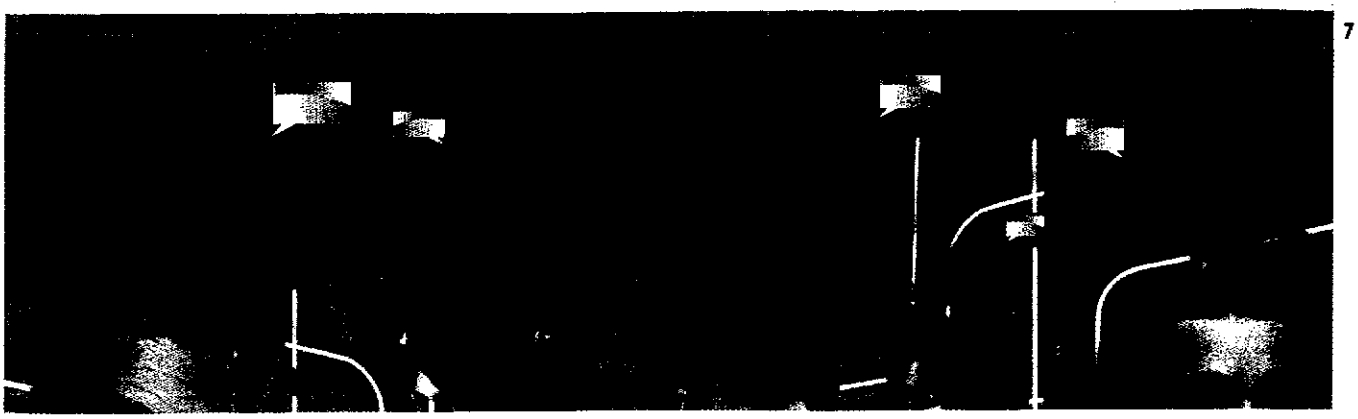
Yet RFID tags, wireless sensors and, for that matter, digital cameras (so far the most widely deployed sensor thanks to the popularity of mobile phones) are only half the story. Many objects no longer need an electronic tag or even a barcode to be automatically identified. For example, Goggles, a service offered by Google, can recognise things like book covers, landmarks and paintings. Users simply take a picture and send it to Google's computers, which will send back search results for the object.

Many of the innumerable machines and devices that populate the physical environment also already come with some data-generating digital technology. More and more are getting connected so that they can communicate the information they contain to the outside world. Examples range from coffee machines and refrigerators to aircraft engines and body scanners in hospitals. These can all now phone home, so to speak, and provide their makers with fountains of data.

People power

Most important, however, humans themselves have turned out to be excellent sensors. Many provide information without any extra effort, just by carrying around a mobile phone. TomTom, a maker of navigation devices, uses connection data from mobile networks to update directions if there are delays. Others are connecting additional sensors to smartphones. Such devices and smartphones are gradually turning people into the sensory organs of the internet, say John Battelle, boss of Federated Media, an online advertising agency, and Tim O'Reilly, who heads O'Reilly Media, a publishing house. "Our cameras, our microphones, are becoming the eyes and ears of the web," they write in a paper entitled "Web Squared".

More surprising than such "crowdsensing", as it has come to be known, is the willingness of many people actively to gather and upload information. The best example ▸▸



is Twitter, the micro-blogging service whose 160m users send out nearly 100m tweets a day (see chart 2, previous page). When they see, hear or read something, they type it into their computer or smartphone, 140 characters at a time. "Twitter is the canary in the news coalmine," wrote Jeff Jarvis, a new-media savant, after the service beat mainstream media to news about the earthquake that struck China's Sichuan province in May 2008.

But there are plenty of other examples. At OpenStreetMap, a wiki-style website, some 250,000 volunteers record their wanderings, using their smartphones' positioning functions. And SeeClickFix, a start-up, has come up with a smartphone app that allows users to report such things as broken streetlights or rubbish that needs to be picked up.

Too much of a good thing

It does not take much imagination to see that all these sensors will generate immense amounts of data. "They don't make enough disk space in the world to save all the data if every household had a smart meter," says Jim Goodnight, the boss of SAS, one of the pioneers of analytics software, programs that sift through data. "In fact the most difficult question is to decide what to discard."

The quantity of data likely to be produced is anybody's guess. Estimates by IDC, a market-research firm, need to be taken with a pinch of salt, because they are sponsored by EMC, a maker of storage systems. But for what they are worth, they suggest that the "digital universe"—the amount of digital information created and replicated in a year—will increase to 35 zettabytes, or 35 trillion gigabytes—enough to fill a stack of DVDs reaching halfway to Mars. Even that may prove a conservative estimate if sensors and other data-generating devices spread as predicted.

Fortunately, the tools to deal with this data deluge are getting better. Give a marker and a whiteboard to Bijan Davari, a researcher at IBM, and he will draw you a picture of the future of computing as he and his employer see it. On the left side there are small squares, representing all kinds of sensors. The data they produce are fed into something he calls the "throughput engine", a rectangle on the right. This is a collection of specialised chips, each tailor-made to analyse data from a certain type of sensor. "A system that can't deal with these streams separately would quickly become overloaded," says Mr Davari.

IBM has already introduced a product based on what it calls "stream computing" that can ingest thousands of "data streams" and analyse them almost instantaneously. The natal care unit at the University of Ontario is testing such a system to monitor babies born prematurely. It takes in streams of biomedical data, such as heart rate and respiration, and alerts doctors if the babies' condition worsens.

Analytics software is improving, too. It has long been used to crunch through data that are "structured", or organised in a database, and develop models to predict, for example, whether a credit-card transaction is fraudulent or what the demand for flights will be around a public holiday. Now such programs can also interpret "unstructured" data, mainly free-form text. Earlier this year SAS launched a product capable of analysing the "sentiment" of chatter on social media, including Facebook and Twitter.

The software is also able to find the people who post the most influential comments on specific companies on Twitter, who can then be sent special marketing messages. Indeed, Twitter itself is a kind of collective filter that continuously sorts the content published on the web. And Facebook users, by tagging friends in the pictures they upload, allow the service to recognise these people on other pictures. "Meaning is 'taught' to the computer," write Messrs Battelle and O'Reilly.

But the main goal of smart systems is "to close the loop", in the words of a report on the internet of things published in March by the McKinsey Global Institute. This means using the knowledge gleaned from data to optimise and automate all kinds of processes. The number of potential applications is vast, ranging from manufacturing to heading off car collisions. Yet the most promising field for now may be physical infrastructures. ■

Making every drop count

Utilities are getting wise to smart meters and grids

LONDON'S streets can be a bit of a maze, but below ground things are even more complex. Water pipes crisscross the city in all directions. Some areas used to have competing water companies, each of which built its own system. Not even Thames Water, the utility that operates the British capital's water-supply network today, knows exactly where all the pipes run.

Moreover, the network is ageing. Only a few years ago more than half of the 10,000 miles (16,000km) of water pipes below the streets of London were over a hundred years old and often burst. It did not help that over many years Thames Water, which was privatised in 1989, failed to invest enough. By the mid-2000s London had one of the leakiest water-supply systems in the rich world. Every day nearly 900m litres of treated water were lost and 240 leaks had to be fixed.

Over the past five years, though, Thames Water has replaced 1,300 miles of cast-iron Victorian mains, those most likely to break, with plastic ones, reducing leakage to 670m litres per day. And when the firm puts in new pipes, it also installs additional wireless sensors, giving it a better view of its network. "We can now tell where we have a broken main even before ▸▸

customers call us," says Bob Collington, its head of asset management.

Thames Water not only needs to know what is going on in its network, but to be able to act quickly on the information. The same is true of infrastructure operators around the world. Whether in water, power, transport or buildings, all are trying to turn their dumb infrastructures into something more like a central nervous system. That makes them pioneers of the convergence of the physical and the digital world.

Putting sensors and actuators (devices to control a mechanism) into physical infrastructures is not exactly new. Known as "supervisory control and data acquisition", such systems have been around for decades. But many still require human intervention: workers have to be sent out to download sensor readings or to fix problems. And even if sensors and actuators are connected, different types often feed into incompatible systems, so they cannot be easily combined to automate processes.

The operations centre of Thames Water in Reading, to the west of London, is a good place to see both the old and the new—and soon the future. A big video screen shows expected precipitation over the next few hours, and workers monitor the water level of reservoirs on their own screens. But if one of the pumps fails, they may still have to make a call: not all the valves can be remotely controlled.

Thames Water is investing £100m ($158m) so it can take action remotely and automate a lot of its processes. If the project works, the system will not only automatically deal with leaks but also schedule work crews and send text messages to affected customers. Employees in the operations centre, explains Jerry White, the utility's head of operational control, will then spend less time monitoring the network and more on making the utility's processes more efficient.

A big chunk of this work will be analysing the data collected by all the systems and correlating them with other information. Not every unexpected spike in the water flow is the result of a leak, says Mr White. For instance, water use leaps after dark during Ramadan and at half-time during World Cup football matches.

One day soon Thames Water may even be able to send out work crews before a main actually breaks. In early 2010 the firm began using a web-based service provided by TaKaDu, an Israeli company, that acts as the network's "eyes and ears", in the words of Amir Peleg, its founder and boss. The firm analyses historical and online data to provide a basis for comparison, enabling its algorithms to detect things that are about to go wrong.

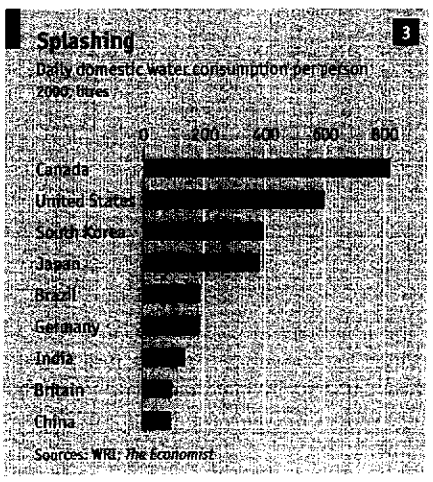
Similar progress is being made all over the world. The scope for preventing waste is enormous, in the water industry and elsewhere. Power utilities are well ahead, not least because they can use the grid itself to collect sensor data and control switches. Transport systems are behind, particularly roads, which often use nothing more than traffic cameras. Even buildings are getting more automated, with continuous checks on their energy use.

At the edge

For infrastructures to become truly smart, however, it is not enough to put more intelligence into the core of a network. The edge—the interface with users and devices—also has to become clever. This is the idea behind smart metering, which has made a good deal of progress in the power industry. According to Accenture, a consultancy, there are about 90 smart-grid projects around the world today. By the end of last year more than 76m smart meters had been installed worldwide. That number will almost treble by 2015, to 212m, estimates ABI Research.

Smart meters and other gear needed to make grids more intelligent will not come cheap. Morgan Stanley, an investment bank, predicts that the worldwide smart-grid market alone will grow from $20 billion last year to $100 billion in 2030. Yet the benefits also promise to be huge: power savings, reduced investment in electricity generation and lower carbon emissions.

The place to go to see the technology in action is Boulder, Colorado, home to what is considered the world's first fully fledged "smart grid". The local utility, Xcel Energy, did not skimp. It deployed equipment that automatically reports power cuts. It installed more than 20,000 smart meters, connected them via a fibre-optic network, launched a website to track power use and has started to offer pricing plans that encourage shifting consumption to off-peak hours. It has even equipped some households with gear that tells air-conditioning systems to turn themselves off when demand for electricity is high, a mechanism called "demand response".



The results so far are mixed. The system has certainly helped Xcel to run its grid more efficiently. The utility now knows what is happening in its network and power cuts have become rare. Problems can be pinpointed and fixed much more quickly. But customers are not using much less power than they did before.

Yet it is early days. Some firms are already beginning to show what can be achieved with demand response. EnerNOC, an American energy middleman, for instance, pays other firms for allowing it to shut down their non-essential gear at times of peak demand, thus freeing up capacity. By mid-year some 3,300 customers, from steel plants to grocery stores, had signed up. Their combined consumption, which can be made available to other users if needed, is 4,800MW, exceeding the output of America's largest nuclear plant.

The ultimate point of smart grids, however, is to allow dynamic pricing, with electricity charges fluctuating in response to demand. This could cut power demand by 10-15% during peak hours, estimates Ahmad Faruqui of the Brattle Group, a consultancy—more than twice the reduction likely to be achieved by just giving customers real-time information about their usage. That number could easily double again, he says, with a combination of dynamic pricing and demand response.

The main objective of smart power meters is to lower the peak load and thus enable utilities to keep down their peak generating capacity. In the water industry the economics are somewhat different, explains Stefan Helmcke, a water expert at McKinsey. Water can be easily stored and consumers have less discretion over when they use it (for instance, people cannot defer going to the toilet, which uses more water than any other activity at home), so the case for smart water meters is weaker.

Yet they are spreading all the same. Boston has long been the shining example. As early as 2004 the city's Water and Sewer Commission had equipped almost all its customers with wireless smart meters. But ▸▸

it will soon be outdone by New York, which plans to install more than 800,000 of the devices at a cost of about $250m. Even Thames Water, most of whose customers have no meters of any sort, is now planning to install some of the smart kind.

Getting on board

In transport the equivalent of a smart meter is a vehicle's on-board unit. That used to be a simple device, working like a radio-frequency identification tag when it passes under a gantry on a toll road, but it is also getting smarter. Germany's Toll Collect system, which ensures that lorry drivers pay for using the country's crowded motorways, relies on gadgets that are in some ways as clever as a smartphone. Among other things, they keep track of their position with the help of GPS, the satellite-based global positioning system.

Such toll systems are multiplying, particularly in big congested cities, including London and Stockholm. But it is Singapore that leads the pack. The city-state not only charges drivers for using much-travelled roads (driving on an expressway can be S$6, or $4.60); it also adjusts traffic lights to suit the flow of vehicles, uses data collected by taxis to measure average speed and is developing a parking-guidance system, noting that cars looking for somewhere to park are now a big cause of congestion.

Singapore may also become the first city to introduce real-time dynamic pricing on its roads. In 2006 the Land Transport Authority tested a traffic-prediction system built by IBM to set the tolls. And next year it plans to test a satellite-based system that does not require gantries and can charge according to how congested a road is at that particular time.

Another of the island's infrastructure-management systems has become a model for the world: that for water. At the information centre at the southern tip of the island, next to the Marina Barrage, visitors can literally get a taste of it by picking up a bottle of "NEWater", waste water that after extensive treatment has become potable again. But most of the treated water is fed back, via a separate distribution system, to Singapore's factories and power plants—and then treated again.

This closed loop is part of a water-supply system in which "every drop counts," in the words of Yap Kheng Guan, a director at the island's Public Utilities Board (PUB). The Marina Barrage is another case in point. It was inaugurated in 2008 and acts as a tidal barrier to keep seawater out, thus turning the island's most populated district into a water-catchment area and the harbour into a reservoir. When two other reservoirs are opened next year, more than two-thirds of Singapore's territory will be used to catch rainwater.

The city-state's desalination plants are also among the world's most efficient. All this means that the island—smaller than Luxembourg and home to nearly 5m people as well as an economy nearly as big as that of Hong Kong—is able to meet more than 60% of its water needs on its own. But it wants to go even further: 50 years from now it hopes to be self-sufficient.

Sensors play a relatively small part in Singapore's water management because the infrastructure is so new. On average there is only one leak a day. The PUB puts sensors only in a few key spots, for instance where water leaves the reservoirs. Should the system detect a dangerous contamination, that part of the network can be shut down immediately. And if heavy rainfall in central Singapore threatens to flood the city during high tide, seven huge pumps next to the Marina Barrage start to push water into the sea at 40 cubic metres per second each.

So far Singapore has no smart water meters, and at the moment there is no pressing need. Most Singaporeans live in multi-storey apartment buildings, which makes it easy to read meters. But if the PUB wants to reach its target of cutting daily domestic water use per person from 155 litres in 2008 to 147 litres by 2020 (about the same as in India, and a quarter of the figure in America, see chart 3 on previous page), Singapore will have to become smarter still—and set yet another example. ■

Living on a platform

For cities to become truly smart, everything must be connected

IN SINGAPORE conversations about water quickly turn political. The city-state no longer wants to depend on water from Malaysia when the current water-supply agreement between the two countries expires in 2061. More than once the neighbour to the north, of which Singapore was part before an acrimonious split in 1965, has threatened to increase prices or even cut off supplies.

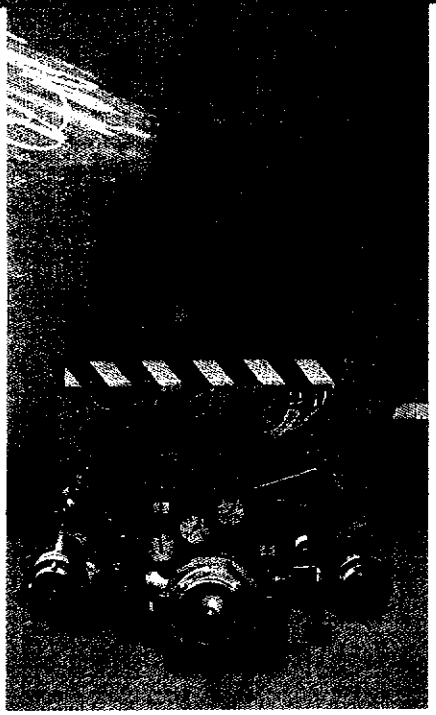
Yet politics is not the only reason for Singapore's advanced water system. The information centre at the Marina Barrage features pictures of floods and droughts. "We have either too much water or too little," explains Yap Kheng Guan, a director of Singapore's PUB. Even today, despite a sophisticated system of ditches and tunnels, floods can suddenly strike. In July parts of the main shopping district were under water after heavy rainfalls.

The problems of scarcity and excess are in evidence on the city-state's roads too. Singaporeans, who are among the world's richest people, love to drive, but space for roads is severely limited. When in the early 1970s the central area became too congested, the government introduced the world's first manual urban road-pricing system. In 1998 it became the first to be automated. "Singapore proves that necessity is the mother of invention," says Teo Lay Lim, who heads the local office of Accenture.

Now the city wants to become a "living laboratory" for smart urban technologies of all kinds—not just water and transport systems but green buildings, clean energy and city management too. Both local and foreign firms in these sectors will be able to develop and show off their products on the island before selling them elsewhere, explains Goh Chee Kiong, who is in charge of the clean-energy cluster at Singapore's Economic Development Board.

There is strong demand for making cities smarter, not just in China and other rapidly urbanising countries but throughout the Western world. Resources like water, space, energy and clean air are scarce in urban areas, which makes them the natural place to start saving, says Mark Spelman, Accenture's global head of strategy.

"Smart-city" projects have been multiplying around the world. Some of them are not as new as their labels suggest, and in any case what exactly constitutes a smart city is hard to define. But they all ▸▸



have one thing in common: they aim to integrate the recent efforts to introduce smart features in a variety of sectors and use this "system of systems", as IBM calls it, to manage the urban environment better.

The best-known smart city is Masdar, a brand-new development in Abu Dhabi that recently welcomed its first residents and will eventually become home to 40,000 people. It is being built entirely on a raised platform, which makes maintenance and the installation of new gear much easier. Below the platform sits the smart infrastructure, including water pipes with sensors and a fibre-optic network. Above it is to be a showcase for all kinds of green technology: energy-efficient buildings, small pods that will zoom around on paths (no cars will be allowed) and systems that catch dew as well as rainwater.

Yet experts see Masdar mostly as a property project: hardware in search of a purpose. What really matters to a city's smartness, they argue, is the software that runs on it and the network that connects its parts. "It is the common infrastructure for all the smart systems," says Wim Elfrink, who heads the "Smart+Connected Communities" initiative of Cisco, the networking-equipment maker.

Getting it together

Cisco is trying to demonstrate that point in Songdo City near Seoul, where the firm provides all the digital plumbing. Sitting on reclaimed land, Songdo is perhaps the most ambitious smart-city project so far. It is expected to cost $35 billion and will be home to 65,000 people. Like Masdar, it will boast all the latest green technologies. But its main claim to fame is that everything in the city is wired up.

Residents of "First World", the first completed apartment complex, already enjoy the benefits of this all-embracing connectivity. Smartphones unlock front doors. Air-conditioning, blinds and security systems are controlled by displays all over the apartment which can also be used to access all kinds of online services. With a few clicks or touches users are able set up a videoconference with a doctor, do business with the local government or find out how best get to work.

What Cisco sees as the most important application for running a smart city was shown at the World Expo in Shanghai this year. In its pavilion the firm built a command centre to keep tabs on an imaginary smart city. A huge video screen displayed everything from traffic maps and energy use to weather information and pictures from security cameras. Visitors were given a demonstration of how city managers would react to an accident on a city-centre bridge: cameras zoom in, an ambulance is dispatched, traffic is rerouted to other bridges—all automatically, within seconds.

The world's smartest city, however, may soon rise in an unexpected place: near Porto in Portugal. PLANIT Valley, designed for an eventual population of 150,000, is an ambitious attempt to "combine technology and urban development", in the words of Steve Lewis, co-founder of Living PLANIT, the start-up behind the project, who used to work at Microsoft.

His experience at the software giant proved an excellent preparation for the job. Microsoft is the very model of a platform company, providing technology to connect things (such as printers and PCs) and a foundation for the products made by others (such as browsers and media players). When he was at Microsoft in the early 2000s, Mr Lewis also oversaw the relaunch of a strategy called .Net—an early example of what geeks like to call "service-oriented architecture". The idea is to build programs as a combination of loosely-coupled electronic services that can be redeployed elsewhere.

After Mr Lewis left Microsoft in 2005, he tried to introduce the concept of re-usable components to the construction industry, which seemed ripe for it. Designs are often used only once, most buildings are not energy-efficient, the industry produces a lot of waste, and many materials are simply thrown away. All this amounts to around 30% of the cost of construction, according to a case study on Living PLANIT by the Harvard Business School.

But instead of selling products to construction companies, Mr Lewis ended up applying his ideas to an entire city. Even before the first concrete is cast, PLANIT Valley has already been built—in a simulation program that also allows detailed planning of the construction. Much of the city, which is to cost about $10 billion, will rely on prefabricated parts; its foundation, for instance, will be made of concrete blocks that come with all the gear for smart infrastructures pre-installed. Eventually the entire city and its buildings will be run by an "urban operating system" that integrates all parts and combines them into all kinds of services, such as traffic management and better use of energy.

Living PLANIT has a clear idea of who will live and work in its city: the employees of the companies that form its "ecosystem", another concept taken from the software industry. The start-up has enrolled a number of partners, among them Cisco, Accenture and McLaren Electronic Systems, a sister company of the eponymous Formula One brand, which will provide sensor technologies. The idea is that these firms will operate research facilities in PLANIT Valley, jointly improve the concept, develop applications and build similar projects elsewhere.

Such grand designs are possible only when building a city from scratch. But entrepreneurs like Mr Lewis and the planners of similar projects have other advantages. For a start they generally have government backing. Portugal granted the PLANIT Valley project "potential national importance" status, which among other things means cheap land and generous tax breaks. Songdo was launched by the South Korean government. And new cities are free from the constraints of having to deal with an established population, old infrastructure and bureaucracy.

Something old, something new

Making an existing city smart is a different problem altogether, as demonstrated by Amsterdam, the Netherlands' biggest city. Amsterdam Innovation Motor (AIM), a public-private joint venture created for this purpose, is not intended to come up with some master plan but to identify interesting "smart" projects, work with local firms and other stakeholders and find ways to make projects worthwhile for everybody.

So far AIM has launched a dozen projects, ranging from installing smart meters in some households to connecting ships to the electricity grid so that they no longer have to use diesel generators when berthed in the city's port. The most ambi- ▸▸

tious effort so far is something called "Climate Street", which aims to reduce the energy use of an entire shopping street.

Most existing cities, at least in the West, will go for such a step-by-step approach, predicts Carlo Ratti, an architect and engineer who heads the SENSEable City Lab at the Massachusetts Institute of Technology (MIT). He and his colleagues have come up with a number of smart urban projects of their own. In one, called "TrashTrack", they asked volunteers to attach small electronic tracking devices to hundreds of pieces of rubbish to see where they would end up in order to improve waste logistics. More recently they introduced the "Copenhagen Wheel", a bicycle wheel whose red hub can not only give the rider a boost but also measure environmental conditions, such as pollution and noise levels.

Yet many such projects will need a common platform that streamlines data gathering and supports all kinds of applications, says Mr Ratti. That would also enable him to realise his ultimate vision: turning the city into a "control system" that makes use of data from a variety of sources, from mobile phones to smart meters and sensors in buildings. The data could be mined to improve public transport and security.

So far Mr Ratti and his collaborators have mainly used data from mobile phones for their projects. In "WikiCity", implemented in Rome, such data allowed people to see visualisations of how they moved through the Italian capital. However, a new mayor elected in 2008 proved much less interested in Mr Ratti's projects than his environmentalist predecessor, so the team has gone off to Singapore.

But it will be not just governments, cities and utilities that will make the world smart. Private companies will also play their part, particularly start-ups. ■

Augmented business

Smart systems will disrupt lots of industries, and perhaps the entire economy

CALL it the democratisation of sensors. Pachube (pronounced "patch-bay"), a start-up based in London, offers a service that lets anybody make sensor data available to anyone else so they can use them to build smart services. One tinkerer has Pachube's computers control the fan in his office, guided by temperature readings uploaded from a thermometer on his desk.

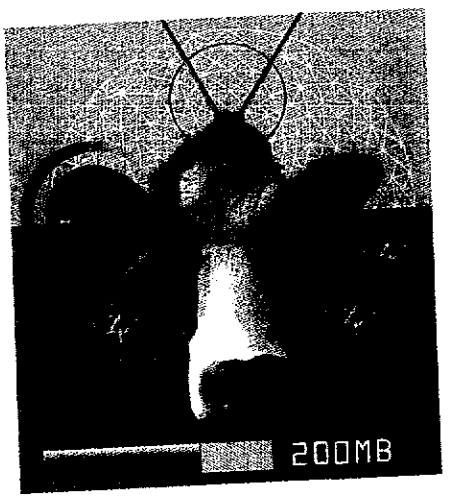
Such experiments are free, but those who develop more serious applications and do not want them to be available to anyone else have to pay. Usman Haque, Pachube's boss, hopes that more and more firms will do so as sensors multiply.

Pachube's business model is one of the more interesting attempts to make money from the convergence of the physical and the digital worlds, but there are plenty of other firms trying to cash in on smart systems. Many will fail, but those that succeed will disrupt more than one industry and perhaps the economy as a whole.

But what is most exciting about smart systems is the plethora of new services and business models that they will make possible. "The internet of things will allow for an explosion in the diversity of business models," says Roger Roberts, a principal at McKinsey and one of the authors of a recent study on the industry.

It is not just utilities that will benefit from smart systems but other sectors too. The chemical industry, for instance, has already installed legions of sensors and actuators to increase its efficiency. Others are just starting. In the paper industry, according to the McKinsey study, one company achieved a 5% increase in its production by automatically adjusting the shape and intensity of the flames that heat the kilns for the lime used to coat paper. FoodLogiQ, a start-up, allows food suppliers to tag and trace their wares all along the supply chain—and consumers to check where they come from. Sparked, another start-up, implants sensors in the ears of cattle, which lets farmers monitor their health, track their movements and find out a lot of other things about their animals that they never realised they wanted to know. On average, each cow generates about 200 megabytes of information a year.

Thanks to detailed digital maps, maintaining such things as roads and equipment will also become much more efficient. Asfinag, an Austrian firm, used aeroplanes equipped with special cameras to map the country's highways. Its employees can now fly over them digitally and even see what is underground. San Francisco's Public Utilities Commission knows the exact co-ordinates of every waste-water pump, its maintenance history and the likelihood of it failing. "Firms can now send out maintainance crews before things actually break," says Steve Mills, who heads IBM's software business. "Making the old stuff run better will be the most important benefit of such systems in the short run."



Moreover, smart systems make new forms of outsourcing possible, some of it to unexpected places. Pacific Control is not exactly a household name, but the company, based in Dubai, claims (with some justice) that it is the "world leader in automation solutions". Its global command centre remotely monitors buildings, airports and hotels, keeping an eye on such things as energy use, security and equipment. For the moment most of the firm's customers are in Dubai itself, but it should find more than a few abroad.

Significantly, once devices are connected and their use can be metered, there is no longer any need to buy them. Already some makers of expensive and complex equipment no longer sell their wares but charge for their use. Rolls-Royce, for instance, which makes pricey aircraft engines, rents them out to airlines, billing them for the time that they run. Makers of blood-testing equipment have taken to charging only if the device actually pro- ▸▸

The IT paydirt

CONTRARY to what might be expected, the industry that will see the least change is information technology. For most IT firms smart systems simply mean more business. This will drive a new wave of technology investment, predicts Andrew Bartels of Forrester Research. By 2017, he says, "smart computing technologies" will represent about half the spending on IT equipment and software in America (see chart 4).

Clearly some parts of the IT industry stand to benefit more than others. Harbor Research estimates that internet-enabled devices alone will net more than $10 billion worldwide in 2014, compared with $4.3 billion in 2009. And wireless sensors are growing exponentially. Last year a mere 10m radio chips for such sensors were sold, according to ABI Research. If it has its calculations right, that total will rise to 645m by 2015.

Since all the data gathered by sensors have to be kept somewhere, storage is hot, too. That explains the recent bidding war between Dell and HP over 3Par, a data storage company. HP won by offering $2.35 billion for a firm with only 650 employees and $194m in revenues. Forecasts from IDC, another market-research firm, throw light on why HP is willing to pay so much. IDC expects the capacity shipped to increase by 50% plus this year.

Vendors of programs that sift through data are also likely to do well. In recent years IBM has invested billions of dollars in buying firms that make business analytics software. In September, for instance, it gave $1.7 billion for Netezza, a vendor of data warehouses (specialised computer systems that quickly crunch through huge amounts of data). It is the biggest bet IBM has made in any area, says Ambuj Goyal, the firm's global head of development and manufacturing. If it comes good, IBM should be richly rewarded. The global market for analytics programs, for instance, will grow from $25.5 billion this year to $34 billion in 2014, according to IDC.

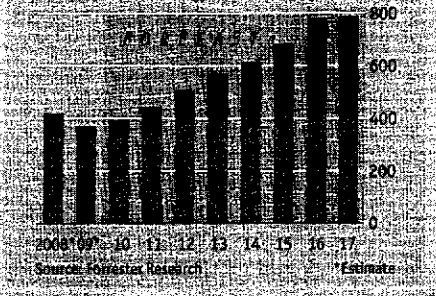
This technology wave will almost certainly produce new software champions too. SAP came of age when mainframes were dethroned by smaller computer systems that allowed companies to streamline many more of their business processes. Similarly, experts predict that new programs will be needed to manage a firm's interactions with the physical world. Already, there is a plethora of start-ups offering to help businesses cut greenhouse gases.

Platforms to integrate the data streams from all kinds of sensors are another new market. Examples include Pachube, a start-up, and Palantiri Systems, best described as a "Facebook for sensors". The service allows devices to have their own "page" on corporate social networks, so their readings are shown in the form of newsfeeds and people can ask questions about them. "Devices thus become part of the conversation," says John Canosa, Palantiri's boss.

As usual, most money will be made from IT services, in particular to set up smart systems in cities. China alone will need to add the equivalent of one New York every year to accommodate the number of people expected to migrate to urban areas by 2025, according to McKinsey. Big IT firms are chasing all over the country to get a piece of this huge pie. Cisco is already helping to build a Chinese replica of Songdo, the smart-city project in South Korea. IBM, for its part, hopes to help develop an entire network of smart cities and has started to collaborate with several of them.

4 Into the unknown

US government and business spending on IT equipment and software, $bn



Source: Forrester Research

▸ duces usable data. And Joy Mining Machinery, a maker of mining equipment, charges for support by the tonne.

Some firms are using metering in innovative ways. Zipcar and other car-sharing firms, for instance, put wireless devices with sensors into their vehicles so that customers can hire them by the hour. And insurance firms, among them Progressive in America and Coverbox in Britain, ask customers to install equipment in their cars that can measure for how long, how fast and even where a car is driven. Premiums can then be based on individual drivers' behaviour rather than on such proxies as age and sex.

Michael Chui, a co-author of McKinsey's report on the internet of things, says that such applications will allow companies to "have a much more dynamic interaction with customers". In Japan, for instance, vending machines can recognise a customer's age and sex and change the message they display accordingly.

The more data that firms collect in their core business, the more they are able to offer new types of services. By continuously assessing the performance of its jet engines around the world, Rolls-Royce is able to predict when engines become more likely to fail so that customers can schedule engine changes. Heidelberger Druckmaschinen, whose huge presses come with more than 1,000 sensors, has started offering services based on the data it collects, including a website that allows customers to compare their productivity with others. "Many companies will suddenly discover that their main business is data," says Paul Saffo, a Silicon Valley technology forecaster who wrote a widely noted essay on the impact of ubiquitous sensors back in 1997.

Hewlett-Packard is a prime candidate for such a Saffo moment—if its plans to scatter millions of sensors around the world come to fruition. It is doing this to increase demand for its hardware, but it also hopes to offer services based on networks ▸▸

of sensors. For instance, a few thousand of them would make it possible to assess the state of health of the Golden Gate bridge in San Francisco, says Stanley Williams, who leads the development of the sensors at HP. "Eventually", he predicts, "everything will become a service."

Apple, though it prides itself on its fancy hardware, is already well on its way towards transforming itself into a service and data business thanks to the success of its iPhone. When the computer-maker launched the device in June 2007, it did not expect "apps", the applications that run on smartphones, to become such a big deal. The "App Store", where users can download these pieces of software, was launched a year after the first iPhone was shipped. But the App Store now sells more than 250,000 apps that have been downloaded over 6.5 billion times. And with its new platform for mobile advertising, called iAd, Apple has started to make money from all the data it collects.

Some firms will make a living based entirely on mining "data exhaust", the bits and bytes produced by other activities. One example is Google's PowerMeter, which not only lets users check their use of electricity online but gives Google access to lots of data to analyse and, not least, sell advertisements against.

Conventional services, too, can be metered. Those supplied by governments may not be the first to spring to mind but, as a study by the Dutch economics ministry asks, why not use sensors for taxing things like pollution? That might be uncontroversial, but analytics software could also be put to more manipulative uses by fine-tuning charges for public goods to get citizens to behave in certain ways.

Much of the innovation in this field may come not from incumbents but from newcomers, and it may happen fastest on such platforms as Pachube. In a way it is a cross of YouTube and Windows. What made the video-sharing site so popular was the way it converted all videos to a common format. Pachube is doing the same for data feeds from sensors. And like Microsoft's operating system for applications, it provides basic features for smart services, such as alerts, data storage and visualisation tools.

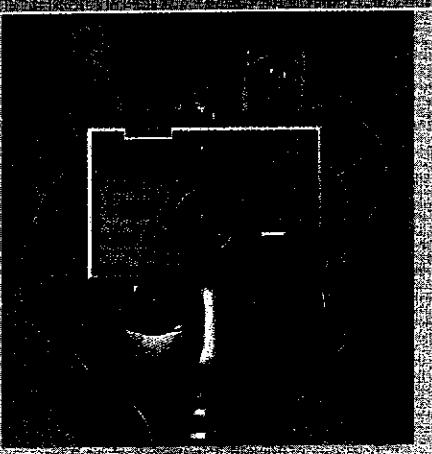
This spring at Where 2.0, a technology conference in Silicon Valley, the star of the show was Skyhook Wireless, a firm that offers geographical-location information as a service. It recently launched a new offer- ▸▸

Your own private matrix

"MIRROR WORLDS" is only one of David Gelernter's big ideas. Another is "lifestreams"—in essence, vast electronic diaries. "Every document you create and every document other people send you is stored in your lifestream," he wrote in the mid-1990s together with Eric Freeman, who produced a doctoral thesis on the topic. Putting electronic documents in chronological order, they said, would make it easier for people to manage all their digital output and experiences.

Lifestreams have not yet replaced the desktop on personal computers, as Mr Gelernter had hoped. Indeed, a software start-up to implement the idea folded in 2004. But today something quite similar can be found all over the web in many different forms. Blogs are essentially electronic diaries. Personal newsfeeds are at the heart of Facebook and other social networks. A torrent of short text messages appears on Twitter.

Certain individuals are going even further than Mr Gelernter expected. Some are digitising their entire office, including pictures, bills and correspondence. Others record their whole life. Gordon Bell, a researcher at Microsoft, puts everything he has accumulated, written, photographed and presented in his "local cyberspace". Yet others "log" every aspect of



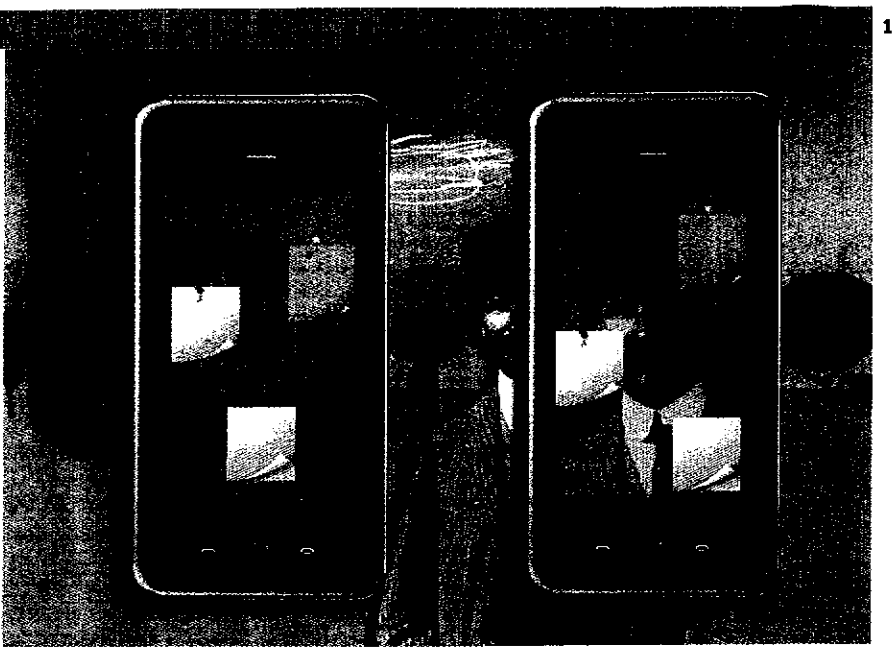
their lives with wearable cameras.

The latest trend is "life-tracking". Practitioners keep meticulous digital records of things they do: how much coffee they drink, how much work they do each day, what books they are reading, and so on. Much of this is done manually by putting the data into a PC or, increasingly, a smartphone. But people are also using sensors, mainly to keep track of their vital signs: for instance, to see how well they sleep or how fast they run.

The first self-trackers were mostly *über*-geeks fascinated by numbers. But the more recent converts simply want to learn more about themselves, says Gary Wolf, a technology writer and co-founder of a blog called "The Quantified Self". They want to use technology to help them identify factors that make them depressed, keep them from sleeping or affect their cognitive performance. One self-tracker learned, for instance, that eating a lot of butter allowed him to solve arithmetic problems faster.

A market for self-tracking devices is already emerging. Fitbit and Greengoose, two start-ups, are selling wireless accelerometers that can track a user's physical activity. Zeo, another start-up, has developed an alarm clock that comes with a headband to measure people's brainwave activity at night and chart their sleep on the web.

As people create more such self-tracking data, firms will start to mine them and offer services based on the result. Xobni, for example, analyses people's inboxes ("xobni" spelled backwards) to help them manage their e-mail and contacts. It lists them according to the intensity of the electronic relationship rather than in alphabetical order. Users are sometimes surprised by the results, says Jeff Bonforte, the firm's boss: "They think it's creepy when we list other people before their girlfriend or wife."



ing called SpotRank. Drawing on all the data it has collected in recent years from apps using its services, the firm can predict the density of people in specific urban areas—anywhere, any day and at any hour. "This will give us great insights into human behaviour," says Brady Forrest, the chairman of the conference.

Another hit at the conference was a service called Wikitude. Its "World Browser", a smartphone app, checks the device's location as well as the direction in which its camera is pointing and then overlays virtual sticky notes other users have left about things like local landmarks. So far Wikitude and similar services are mostly used as travel guides. But in principle users could collaboratively annotate the entire physical world—and even other people. TAT, another start-up, already experiments with something called "Augmented ID", which uses facial recognition to display information about a person shown on a smartphone's screen.

It is difficult to say what effect all this will have on business and the economy. But three trends stand out. First, since smart systems provide better information, they should lead to improved pricing and allocation of resources. Second, the integration of the virtual and the real will speed up the shift from physical goods to services that has been going on for some time. This also means that more and more things will be hired instead of bought. Third, economic value, having migrated from goods to services, will now increasingly move to data and the algorithms used to analyse them. In fact, data, and the knowledge extracted from them, may even be on their way to becoming a factor of production in their own right, just like land, labour and capital. That will make companies and governments increasingly protective of their data assets.

In short, we may be moving towards a "Weightless World", the title of a 1997 book by Diane Coyle about a future in which bytes are the only currency and the things that shape our lives have literally no weight. But for now, gravity has not quite been repealed yet. ■

Sensors and sensibilities

A smarter world faces many hurdles

THERE is not much to see in the city of Bakersfield, north of Los Angeles, but recent events have put it on the global electricity-industry map. As in many other Californian communities, Pacific Gas & Electric (PG&E), the local power utility, had installed smart meters in most households. Soon afterwards customers started complaining about rocketing power bills. For some people they almost trebled. Predictably, this caused a political storm. Local politicians and consumer groups jumped on the issue. Enterprising lawyers launched a class-action suit. PG&E admitted that some of its meters had technical problems, but the higher bills were clearly due to a combination of exceptionally hot weather, increased charges and changes in the rate structure.

An independent auditor found nothing wrong with the smart meters, and California's regulators did not stop PG&E from installing more of them. But utilities and regulators elsewhere, spooked by the incident, have become much more careful before embracing the technology. "Bakersfield is likely to slow down the installation of smart meters—not just in the United States but worldwide," says Ahmad Faruqui of the Brattle Group, a consultancy. Bakersfield also demonstrates that a smarter world will meet with resistance. The reasons are part technical, part institutional.

A list as long as your arm

Technology is a good place to start. Sensors are getting ever cheaper, but for many applications they are still much too expensive. HP, for instance, likes to point out that its super-sensitive accelerometers are made in the same factories as its printer cartridges. But the firm's sensors are still too pricey to use them for anything but high-value applications, such as oil exploration. RFID tags are a cautionary tale. They were supposed to revolutionise retailing but the readers, software and other gear needed to make them useful is still not cheap enough to be universally adopted.

Equally important, standards for such things as smart meters need to be sorted out. Setting them too early would hamper innovation, but in their absence utilities will hold back from investing, worried that they might bet on the wrong technology. Standards could also become a weapon of industrial policy, in particular in countries that see clean technology as an engine of growth. When China's State Grid Corporation, which operates most of the country's power network, announced its smart-grid plans in June, it also released the standards it intends to implement. Some say this was a move to protect Chinese firms.

The internet-address system is a worry as well. For a computer or any other device to be part of the internet, it needs a unique identifier—currently a long number called an internet-protocol (IP) address. Because of the network's rapid growth in recent years, these numbers could run out as early as the middle of next year. If the IT industry keeps dragging its feet on moving to IPv6, a new address system that uses many more numbers, the growth of the internet ▸▸

of things will be stymied.

Space is also bound to get tight in the ether. A few wireless sensors and devices do not make a difference, but as their numbers grow they will need an ever bigger chunk of the available radio spectrum. The number of wireless subscriptions has now reached 5 billion worldwide, earlier than expected, not least because so many SIM cards now sit in machines that communicate with other machines.

And then there are security concerns, particularly after the Stuxnet worm made the rounds in September. The malicious program quickly found its way into computers controlling industrial processes the world over, demonstrating how vulnerable control systems are to such attacks. But even before Stuxnet struck, security consultants had shown how large numbers of smart power meters could be hacked and shut down.

Turf, ego and power

Yet all these technical issues pale by comparison with the institutional barriers. For a city to offer smart services and save money, its departments have to work closely together, share their data and use a common IT infrastructure. London, for instance, has different payment systems for public transport, bicycle hire and toll roads. Such fragmentation is costly and makes it more difficult to come up with new offers (say, reducing the congestion charge for those who often hire a bicycle). But getting a city's islands of bureaucracy to work together tends to be difficult, says Mark Cleverley of IBM, who helps governments and cities develop plans for smart systems.

The problem is not just that departments often jealously protect their data, something experts call TEP, as in "turf, ego and power". Officials also lack a common language or generally agreed criteria for a smart city—which is a big issue, too, for the many companies that are usually involved in a project. "It's hard to build a business case if people don't understand each other," says Simon Giles, in charge of strategy for smart technologies at Accenture.

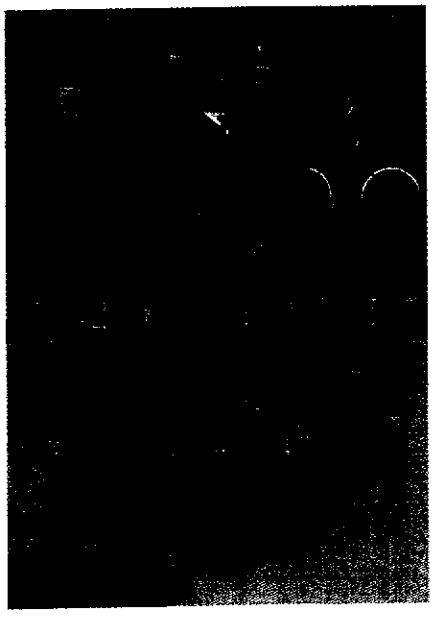
Things are easier in Singapore. Ministries and agencies compete for reputation and resources, but they also co-operate closely on implementing master plans such as "A Lively and Liveable Singapore: Strategies for Sustainable Growth", the city-state's roadmap to becoming smart. That helps to explain why Singapore will probably be the first city to combine its various smart systems into a single one.

More generally, Asian countries seem to have an advantage in building smart systems because governments are often less democratic and administrations more hierarchical. China's State Grid Corporation intends to have its smart grid fully built by 2020. The country's government has also made the implementation of IPV6 a central part of its five-year plan to build the "China Next Generation Internet". It showed off its efforts at the 2008 Olympic games in Beijing, where everything that was connected—cameras, taxis, security systems—used IPV6.

In the West it will often take a crisis to get there. When Thames Water in 2006 failed to meet targets set by the regulator to reduce leaks and was subsequently sold, the new leadership went on to organise things differently. Today, at the utility's operating centre in Reading, the workers who monitor the network, take calls from customers and schedule work crews all sit in one open-plan office, allowing them to communicate much more easily across departmental boundaries.

Similarly, when Bill Ritter became Colorado's governor in 2007, he made the consolidation of the state's chaotic IT systems a priority and named a state chief information officer who is also a member of his cabinet. Since then Colorado has made great progress in achieving one prerequisite for becoming a smart state: a common IT infrastructure capable of delivering new services.

Amsterdam, being the capital of a highly pluralistic country, had to take a different approach. Instead of relying on the municipal administration to become a smart city, it created Amsterdam Innovation Motor (AIM), a public-private joint venture in charge of coming up with projects and mediating between the parties involved. "Being a translator and making sure that a project is worthwhile for everybody are our main jobs," explains Ger Baron, AIM's project manager.



If these three examples are any guide, smart systems may well change the way that local governments, in particular, are organised. Instead of being a collection of departmental silos, they could come to resemble computing platforms. Most services, from payment systems to traffic information, would be provided in only one version and used by all departments—or by private firms that want to offer their own urban applications.

Some cities, such as London, San Francisco and Washington, DC, have already opened their data vaults. IBM, among many other companies, has already built a web-based application called City Forward that takes in data from 50 cities. Yet others are not that generous with their data, which is the third barrier. More openness should be good for innovation, not just in terms of the information itself but how it is handled. But firms with lots of data—be they power utilities or makers of medical equipment—will be loth to give them up, says Glen Allmendinger, president of Harbor Research.

At the same time, Mr Allmendinger predicts, some firms will be forced to give up control of their data. Hospitals, for instance, will hardly put up with dozens of dashboards that monitor the activities of different types of equipment: they will want a unified view. And some clever startups and IT firms will find ways around data monopolies. Nobody can stop consumers from giving data about their power usage to non-utilities, for instance. Some private meters, attached to a sensor clamped around the main power line, can now send the data they have gathered to web-based energy-monitoring services, such as Google's PowerMeter and Microsoft's Hohm.

Data are a problem for governments too. Li Yizhong, China's minister of industry and information technology, has expressed concerns about IBM's Smarter Planet initiative. "The US tries to use its information network technology for things as small as controlling one computer or one generator and as large as controlling a whole industry, to control every country's economy," he is reported to have said. "We

must be enlightened and vigorously develop strategic emerging industries, but also must raise our vigilance and cannot fall under the control of anyone."

China's concerns with IBM's Smarter Planet (called "wise Earth" in Mandarin) point to the fourth set of barriers: government regulation—or the lack thereof. Privacy legislation tops the list. New laws will multiply in response to an increasingly smart world. Germany's government plans to strengthen its rules to deal with Google's Street View, an online service that lets users pan through photos of streets. Among other things, the new bill is likely to enshrine in law what Google has already agreed to do under pressure from data-protection officials: giving people the option to have their house blurred on Street View. Nearly a quarter of a million have done so.

The regulation of smart grids is a murkier area. Some countries push utilities to reduce energy demand, but out-of-date rules encourage them to sell more, says Accenture's Mr Giles. Elsewhere, ill-conceived deregulation of the power market is holding things up. Since the grid now has more than one owner, it is often hard to know who will bear the risks and who will garner the rewards.

A host of new legal questions will also have to be answered. Who is liable if an autonomous system, such as an autopilot that governs the movement of cars on a motorway, causes an accident? What if a single company manages to dominate data from certain types of sensors or control the information about where sensors can be found and which of them are active? And can private surveillance still be restricted when cameras and other sensors make it ubiquitous? "The sensor revolution will challenge hidden assumptions in a bewildering array of doctrinal fields," writes Kevin Werbach, of the Wharton School of the University of Pennsylvania, in a paper entitled "Sensors and Sensibilities".

Lastly, consumers may not play ball. PG&E's woes in Bakersfield are not the only example. In Boulder, Colorado, the showcase for smart grids, customers of Xcel Energy, the local utility, are becoming increasingly cross because they will have to pay much of the project's costs. In the Netherlands the government backed down from making smart meters mandatory because of concerns that the data collected could be used to see whether properties are empty or expensive new gadgets have been purchased. Consumers also dislike feeling that they are being squeezed dry, particularly in America, which makes dynamic pricing hard to bring in. Even simple rate plans where the price of electricity depends on the time of day have had to be abandoned after customer protests.

Nor is such resistance limited to smart meters. The smooth introduction of Stockholm's toll system was the exception rather than the rule. In many countries politicians do not even try. Germany, for instance, charges lorries for using its motorways, but only a suicidal government would attempt to extend the system to cars in a country where even buckling up was long opposed by motoring clubs as interfering with drivers' freedom.

Make it attractive

It is odd, then, that everybody loves mobile devices, which are not that different from smart meters or on-board units. In particular, smartphones and the applications that run on them generally keep a close watch on what users do. Even so, nearly 270m of these devices will be sold this year, 55% more than in 2009, says IDC.

The difference is that Apple and other smartphone makers have made it their business to find out what consumers want—traditionally not the forte of utilities and government agencies. For example, it took that flurry of protests to prompt PG&E to open a dedicated call centre for questions about smart meters. Yet communicating with customers should be one of the first things for firms to do when introducing smart meters, says Mr Giles.

Another lesson is that utilities should not try to achieve too many things at once, says Mr Giles, who recently surveyed smart-grid projects worldwide for a study on how to speed up their introduction. Some utilities brought in smart meters and new pricing schemes at the same time, thus overwhelming consumers and obscuring the reasons for higher bills.

To avoid such problems, Amsterdam is trying "co-creation", in the words of AIM's Mr Baron. "We did not just put in smart meters and ask consumers to pay for them," he says. Instead 500 households in the district of Geuzenveld were invited to make suggestions on how to save energy and monitor consumption.

Yet utilities may have to resort to social engineering to get customers more engaged. Opower, a start-up, lets them see not only their own consumption figures but numbers for their neighbours too (anonymised to preserve privacy), and offers them tips on saving power. Peer pressure, the company claims, persuades people to reach for the switches much more often. Given enough time, all these barriers to building smart systems can probably be overcome. But how smart does the world really want to be? ■

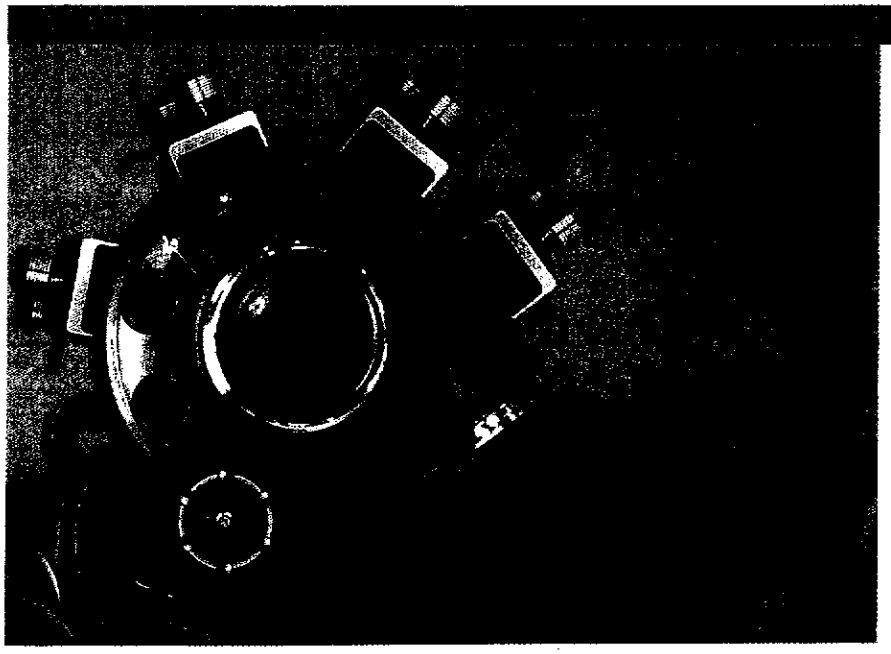
Horror worlds

Concerns about smart systems are justified and must be dealt with

"IT IS not possible to make a lasting compromise between technology and freedom, because technology is by far the more powerful social force and continually encroaches on freedom through repeated compromises." Thus wrote the Unabomber, also known as Ted Kaczynski, in his manifesto, published in 1995 by the *New York Times* and the *Washington Post* in the hope that he might end his terror campaign or somebody might recognise his style of writing and unmask him.

Mr Kaczynski's methods were abhorrent. His bombs killed three people and injured 23 over nearly 20 years. He was arrested in 1996 and is currently serving a life sentence. But his concern that technology will slowly but surely undermine human freedom is shared by quite a few mainstream thinkers. As this special report has argued, smart systems will improve efficiency and could help solve many environmental problems, in particular global warming. Yet if those systems seriously impinge on people's freedom, many people will balk. The protests against smart meters in Bakersfield and elsewhere may be only the start.

Smart systems are rekindling old fears. Top of the list are loss of privacy and gov- ▸▸



ernment surveillance. Internet users have only recently begun to realise that every single thing they do online leaves a digital trace. With smart systems the same thing will increasingly apply to the offline world; Google's Street View is only the beginning.

Even the champions of a smarter planet admit as much. "Some citizens have expressed discomfort at living in not a safer society but a 'surveillance society'," said Sam Palmisano, the boss of IBM, in a speech earlier this year. He cited a newspaper article recounting that there are now 32 closed-circuit cameras within 200 yards of the London flat in which George Orwell wrote his book "1984".

Hopes and fears

Mr Palmisano would be in the wrong job, however, had he not gone on to say that such concerns have to be rethought and to stress the economic and social benefits of smart systems. Others point out less obvious advantages. "All this technology actually strengthens the human side of cities," says Carlo Ratti, director of MIT's SENSEable City Lab. People who are always connected, he argues, can work wherever they like. And Mr Haque, the boss of Pachube, claims that "sensors empower people because measuring the environment allows them to make decisions in real time."

On the other hand smart systems are also undeniably useful as an instrument of control. Singapore has made an impressive job of smartening up its physical infrastructure, but its network of security cameras could also be used for enforcing rules more objectionable than a ban on chewing gum. Similarly, the operations centres and dashboards for local governments in China being built by Cisco, IBM and others beg the question whether their only purpose is to make these cities smarter.

Other deep fears brought on by smart systems is that machines could be hacked, spin out of control and even take over the world, as they did in the film "The Matrix". As the Stuxnet worm and the May "flash crash" on Wall Street have shown, the first two are already real possibilities, even if the third still seems somewhat remote—although well-known computer scientists, artificial-intelligence researchers and roboticists met in California a couple of years ago to discuss that risk.

And there is a more subtle danger too: that people will come to rely too much on smart systems. Because humans cannot cope with the huge amounts of data produced by machines, the machines themselves will increasingly make the decisions, cautions Frank Schirrmacher of the German daily *Frankfurter Allgemeine Zeitung* in his recent book "Payback". Similarly, Nicholas Carr, an American commentator on the digital revolution, in his book "The Shallows" claims that the internet, the mother of all smart systems, is on its way to smothering creativity and profound thinking.

A further worry is that smart technology will ultimately lead to greater inequality—and not just because it could create an "information priesthood", in the words of Mr Gelernter. Paul Saffo, a noted Silicon Valley technology forecaster, expects ubiquitous sensors to give a huge boost to productivity—at the expense of human monitors. "We are likely to see more jobless recoveries," he says.

Whether computers will indeed start to eliminate more jobs than they create remains to be seen. But smart systems certainly represent a conceptual change. So far IT has been used to automate and optimise processes within firms and other organisations as well as the dealings between them. Now it will increasingly be used to automate and optimise interactions with the physical environment.

Some of the concerns raised will be hard to deal with. For instance, there would be little point in passing laws that would give individuals the right to decide whether their data can be used by smart systems if cameras and other sensors are already ubiquitous. And building in circuit-breakers to keep automation from going too far could defeat the purpose of smart systems and stifle innovation.

Still, technological progress is not some force of nature that cannot be guided. "We can and we should exercise control—by democratic consensus," says Mr Gelernter. Yet for a consensus to be reached, there must be openness. The biggest risk is that smart systems become black boxes, closed even to citizens who have the skills to understand them. Smart systems will make the world more transparent only if they themselves are transparent. ■