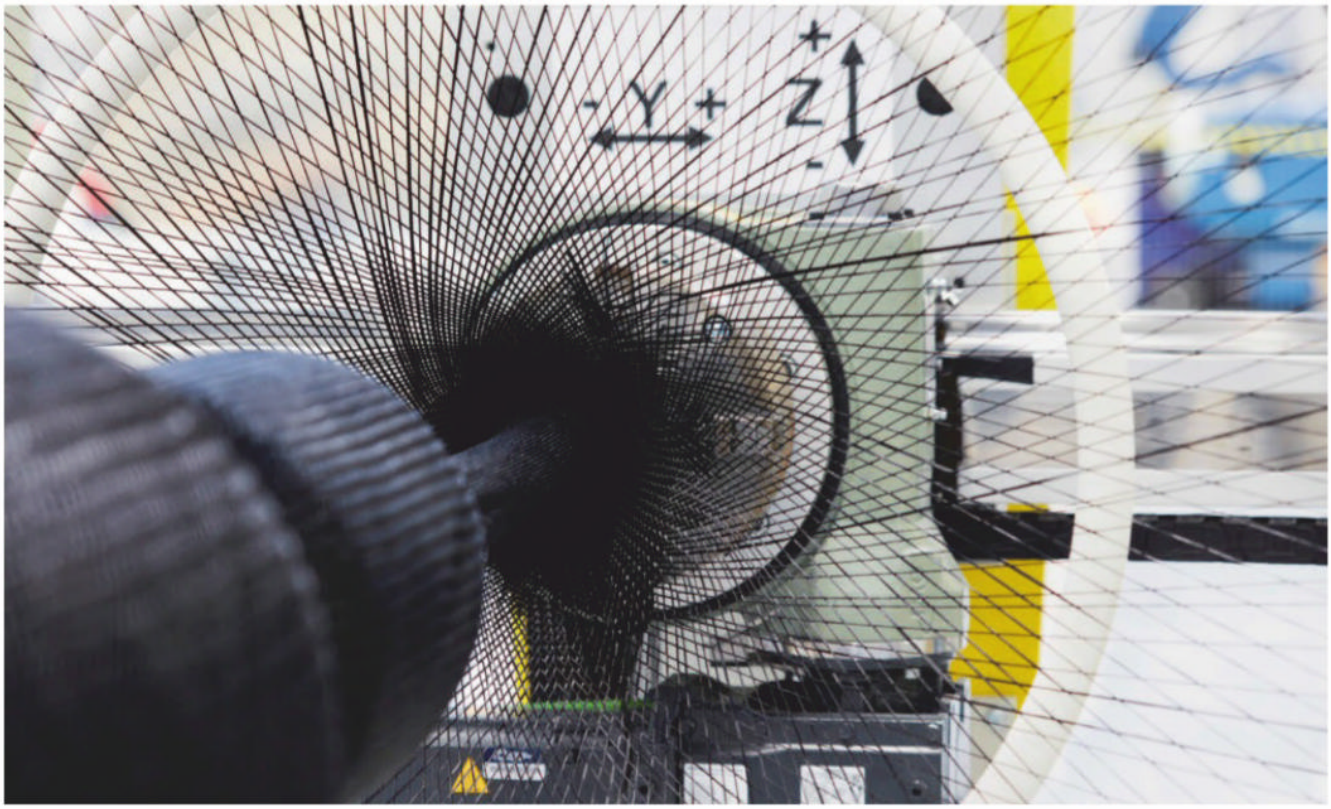


The new black arts of manufacturing

How to knit a sports car

BRISTOL

Faster ways to knit together carbon fibre will transform many products

BERTHA RESIDES on a quiet industrial estate in Bristol, in the west of Britain. The affectionate name has been given to what at first appears to be a giant loom from the Industrial Revolution. And in some ways it is. Bertha (pictured above) is an automated braiding machine. Like a horizontal maypole, ribbons of carbon fibre are drawn from 288 bobbins contained on a pair of huge rings, and passed over and under one another as they are wound tightly around a revolving mould. The final product could be a propeller for an aeroplane, a ship's hydrofoil or a set of wheels for a sports car. In fact, Bertha can knit just about any hollow component up to 800mm by ten metres, and do so quickly and accurately by depositing some 300kg of carbon fibre an hour.

Just as textile production began to be mechanised at the end of the 18th century, creating the modern factory, manufacturing is going through another revolution. This time it is driven by digital processes and new materials, such as carbon-fibre composites. Automated braiders are one of several new systems turning carbon-fibre production from a slow, labour-intensive craft into a mass-manufacturing process that will change many industries.

Carbon fibre is attractive because it is lightweight and exceptionally strong. The toughest fibres are up to ten times stronger than steel and eight times more so than aluminium, reckons Zoltek, an American carbon-fibre producer. Carbon fibre is also five times lighter than steel and half the weight, or less, of aluminium. Nor does it corrode. In transport industries, where "lightweighting" is most valuable, carbon fibre allows aircraft and cars to be made lighter and so travel farther on the same amount of fuel or a single charge of their batteries. This will help them meet tougher emissions targets.

And there are other advantages, too. One is that carbon fibre allows manufacturers to make much larger, more complex parts in one go, says Richard Oldfield, chief executive of the National Composites Centre (NCC), a research laboratory set up by the University of Bristol, and home to Bertha. Instead of making an aircraft's wing or car body by welding, riveting and bolting together hundreds of individual components, these bits can be consolidated into a single carbon-fibre structure. This saves time and materials and allows designers to come up with novel products.

Hot stuff

Engineers got interested in carbon fibre in the 1960s. The fibres consist of carbonised polymers, made up of long strings of molecules bound together by the powerful bonds between carbon atoms. The fibres are made by heating a precursor material to around 3,000°C in a protective atmosphere of inert gases. The most commonly used precursor is polyacrylonitrile (PAN), which is produced by the petrochemicals industry. Pitch, obtained from coal tar, is sometimes used instead. Once carbonised, the fibres are wound onto bobbins, spun into yarns or formed into tapes. Depending on the final application, they can also be woven into fabric sheets.

On their own, carbon fibres are brittle ▸▸

and can break easily. But their strength comes in tension (they resist being pulled apart). So, the fibres need to be aligned in such a way to impart their strength by distributing loads throughout a structure. This is done by placing the fibres, tapes or mats onto a mould in the required orientation, creating what is known as a preform. It is a slow process often done by hand. This is now being automated, aided by the fact that the optimal alignment of the fibres is often calculated using sophisticated computer-aided design systems, and the same data can program robots to lay-up the fibres or wind them on braiding machines such as Bertha.

The preforms then need to be made solid. This is done by impregnating the fibres with a chemically activated resin, which hardens when it is cured. The curing process is usually carried out inside a large oven called an autoclave, which applies heat and pressure to consolidate the structure and force out any air bubbles. It can take hours, sometimes with autoclaves left to run overnight. For a relatively low throughput this might not be a problem. But for higher volumes, especially in carmaking, faster cycle times are needed.

Various out-of-autoclave curing techniques are starting to be used. One is resin transfer moulding (RTM). This involves placing preforms inside a mould which is then closed. Resin is injected into the mould and heat and pressure applied. Depending on what is being produced, RTM can cut processing times by half or more.

Fast cars

McLaren has been making sports cars out of carbon fibre since the British company used the material for the world's first Formula 1 racing car in 1981. All F1 cars are now made from carbon fibre, and the protection it affords drivers has allowed many to walk away from spectacular crashes. To build its sports cars the company starts with a carbon-fibre "MonoCell", a giant tub which forms the main structure of the vehicle.

The company uses a specialist contractor to make MonoCells, although those for future car models will be produced at a new £50m ($65m) McLaren Composites Technology Centre in Sheffield, Britain. The first of the new cells has just been delivered. Impressively, the large and complicated structures are produced with RTM in one go—although McLaren is keeping the details secret. "I often look at the MonoCell and wonder myself how it is possible to make it," says Claudio Santoni, the centre's technical director.

McLaren says carbon fibre will be essential in keeping weight down in future hybrid and electric models. By 2025 it expects the centre to be making MonoCells for some 6,000 cars a year. As a high-end brand, it is not seeking large volumes. But other carmakers are. One is BMW, which uses a variant of RTM in Leipzig, Germany, to make bodies for more than 130 of its i3 electric cars every day. BMW plans to increase that number substantially.

Another speedy production process is "overmoulding". This combines sheets of carbon fibre with injection-moulded plastic. Injection moulding has long been used to produce plastic parts by extruding a molten polymer into a mould. It is quick and accurate. By combining the two processes, overmoulding allows plastic parts to be selectively reinforced with carbon fibre. Thus strengthened, such parts could be used as car doors, aircraft interiors and in many other products. The NCC reckons an overmoulding system it is working with in Bristol can churn out finished components in just 60 seconds.

Progress is also being made in reducing the cost of carbon fibre itself. Prices vary according to quality, but industrial-grade carbon fibre is roughly $20 a kilogram, although aerospace versions are more expensive. By comparison, steel used in carmaking is about $1 a kilogram. As carbon fibre is so much lighter and stronger than steel, less material is needed. And the additional cost is also compensated for by product-lifetime savings on fuel and emissions. Nevertheless, cheaper carbon fibre

Avian biology

Doubling their luck

How some birds adapt to climate change

One of the great concerns that ornithologists have is that climate change will throw the nesting activities of birds out of sync with the availability of food for the raising of chicks. For one species, the pied flycatcher, a new study shows that some of its clan are proving to be remarkably adaptable.

Upon returning to Europe from their African wintering grounds, the flycatchers time their egg-laying to the short period when juicy caterpillars are most abundant. During the past three decades this caterpillar peak has advanced by three weeks. Pied flycatchers initially had difficulty adjusting, but over time have started laying their eggs earlier to grab the caterpillars. Some, though, are doing a lot more to improve their reproductive chances of success, according to a study in the *Journal of Avian Biology* led by Christiaan Both of the University of Groningen, in the Netherlands.

Like most bird species, pied flycatchers have long been thought to lay a single clutch of eggs during the breeding season. This was widely considered to be a trait that does not change. Then, in 2007, a Swiss team led by Pierre-Alain Ravussin began to suspect that clutch numbers were flexible. They discovered a female pied flycatcher that immediately produced a second brood with a new male after raising an early set of chicks. Aware of Dr Ravussin's findings, Dr Both wondered whether this was just a single, odd instance or if second broods might be happening on a larger scale driven by the arrival of earlier springs. So, they collaborated to delve into the data to find out.

The team studied pied-flycatcher populations in the Netherlands and Switzerland that were known to be among the earliest nesting members of the species. In total, they tracked the egg-laying times and hatchling-rearing success of 8,848 breeding pairs in the Netherlands and 1,372 in Switzerland between 1980 and 2018. They found that since 2006, 11 cases of second broods were observed, all of them among the earliest breeders in both populations.

Do this all over again?

Further studies ruled out that the birds were making up for a failed first attempt at raising chicks or that the second group of nestlings suffered.

With no obvious downside to laying a double clutch, Drs Both and Ravussin conclude that the birds are attempting to double their annual reproductive output. While this behaviour is still rare, they argue that if the tendency is driven by heritable genes (which it may well be) then a succession of early springs could make the strategy much more common.

would find greater use in manufacturing.

Oak Ridge National Laboratory in Tennessee thinks it could cut the cost of industrial-grade carbon fibre by about half with more efficient production processes. According to some estimates, roughly 90% of the energy needed to make things with carbon composites is consumed in producing the fibre itself. Oak Ridge is looking at the use of cheaper alternatives to PAN and low-temperature carbonisation processes.

The lab also uses chopped-up carbon fibre in large-scale 3D printers to produce structures. It recently employed the system to print moulds for the precast concrete façade of the Domino tower, a new 42-storey building in Brooklyn, New York.

Chopped carbon fibres can be made from manufacturing offcuts or recycled material. Recycling will become even more important once a greater number of carbon-fibre cars, aircraft, ships, wind turbines and other products reach the end of their working lives. There will be mountains of the black stuff to deal with. Companies are coming up with ways to recover the fibres, usually with heat or chemicals. Sometimes the fibres can be re-spun, but if they are too short they can still be suitable for parts subject to less stress. A combination of lower-cost mass-production techniques and effective carbon-fibre recycling, will lead to a lot more Berthas knitting away furiously. ■

Human origins

The Hobbit's cousin

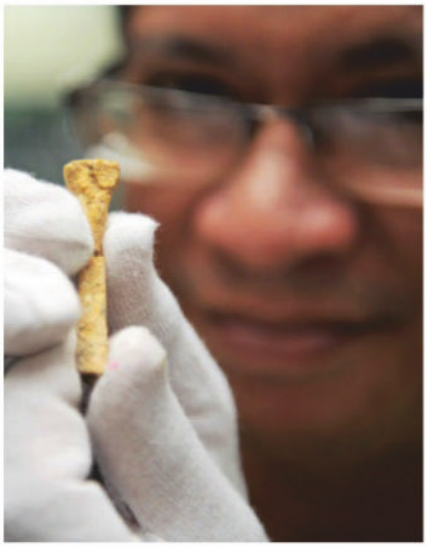
More new human species are discovered

THE HUMAN species is a lonely one. Today there are two species of gorilla, two of chimpanzees and a whopping three species of orang-utan, but just one sort of human. It wasn't always so. People are familiar with the idea that *Homo sapiens* once shared Eurasia with another human, *H. neanderthalensis*. In 2004 researchers announced to great fanfare that they had found the bones of a third contemporaneous relative, a rather short human species who lived on the Indonesian island of Flores. This became *H. floresiensis*, and was quickly dubbed the "Hobbit". Then, in 2010, geneticists declared that a single finger bone found in a cave in the Altai Mountains of western Siberia carried a distinct genome which suggested it belonged to a fourth group, the Denisovans.

Two new studies reveal that the landscape the ancestors of *H. sapiens* roamed across was even more crowded, until quite recently. One report draws on the power of genetic sequencing to show that the Denisovans comprised at least three different populations, which evolved separately for hundreds of thousands of years. The other study announces an entirely new species of hominin, *H. luzonensis*. Both findings centre on the islands that lay at the fringes of the ancient world; in South-East Asia, a region that has until quite recently been largely ignored by palaeoanthropologists.

Glimpses of the new species came in 2010, when a collaboration of Philippine, French and Australian researchers announced that they had found a human-like foot bone (pictured opposite) on Luzon, the largest island in the Philippines. The bone was 67,000 years old, meaning its owner was alive shortly before *H. sapiens* ventured out of Africa. It was discovered alongside butchered animal bones on an island separated from mainland Asia by a sea. All this pointed to a fairly sophisticated human, capable of creating sharp cutting tools, and quite possibly also able to build and steer a boat or raft (though some argue it may have floated, or swam across to the islands).

The same team, led by Florent Détroit of the Musée de l'Homme in Paris, report in *Nature* this week that alongside the foot bone they have also found two finger bones, two toe bones and a number of teeth. From these, they have identified at least three individuals with features that indicate that they belonged to a new species of human.



A little bit of luzonensis

The fossil remains of *H. luzonensis* are bizarre. The toe bones, for instance, suggest it was adapted to climbing trees as well as walking on two legs—something more typical of distant australopithecine relatives who lived millions of years ago in Africa. The Luzon premolar teeth also look primitive, but the molars are modern and *H. sapiens*-like. As with the Hobbit, it is likely that these features evolved in *H. luzonensis* as a result of its island living. Previous studies have shown that when species become isolated, as on an island, unusual features emerge.

The islands of South-East Asia were also once home to the mysterious Denisovans. What little is known about them has more to do with laboratory work than digging in the ground for remains. That is because very few Denisovan fossils have been found. A finger bone, a skull fragment (announced in March) and a handful of teeth are the only physical testimonies to their existence. They are not enough to say what the Denisovans looked like, or to assign them a species name.

However, by comparing DNA extracted from the finger bone to the genomes of people alive today, researchers have shown that Denisovans and Neanderthals shared a common ancestor sometime between 500,000 and 700,000 years ago, and that they interbred with each other and with the direct ancestors of *H. sapiens* on more than one occasion. These matings conveyed new traits to their descendants. Even today Tibetans carry a Denisovan gene that helps them reproduce at high altitudes. And the Denisovans seem to be widely travelled, with genetic evidence that at one time they could be found all the way from Western Siberia to Indonesia.

Murray Cox, a computational biologist at Massey University in New Zealand, and his colleagues pushed the analysis further by probing a new genetic database, containing modern genomes from the islands of South-East Asia, a region that is both densely populated and largely unrepresented in genetic surveys. The database includes genomes from New Guinea, where previous studies have indicated modern genomes contain more Denisovan DNA than is found in other regions.

Three's a crowd

As they report in *Cell*, Dr Cox and his colleagues found evidence of not one but three distinct groups of Denisovans that interbred with the ancestors of modern Papuans. One group, dubbed D2, evolved separately from the individual whose finger bone was found in the Siberian cave for 12,500 generations, or roughly 360,000

years. That makes it "about as different from the individual found in the Denisova cave [in Siberia] as it is from Neanderthals," says Dr Cox. Indeed, D2 evolved separately for longer than the 300,000 years that *H. sapiens* has been around.

There could be profound consequences, says Dr Cox's collaborator Guy Jacobs of Nanyang Technological University in Singapore. For starters, D2 could have looked very different from the Siberian individual. "If we're going to call Neanderthals and Denisovans by special names," says Dr Cox, "this new group probably needs a new name, too."

The genetic analysis estimates that the D2 Denisovans interbred with *H. sapiens* in Papua roughly 30,000 years ago, which suggests they outlasted the Neanderthals by some 10,000 years. Another Denisovan population may have interbred with *H. sapiens* as recently as 15,000 years ago, say the researchers. That would mean the Denisovans, not Neanderthals, were the last cousin of humanity to vanish, leaving *H. sapiens* as the only hominin game in town.

That they mated on the islands provides some of the first behavioural and social information about this group of early hominins. Like *H. luzonensis* or its ancestors, the Denisovans may have been capable of navigating, in order to cross the strong currents of the Wallace Line (see map). Present-day attempts to reproduce such journeys show this to be no small feat. Successful crossings require craft, and careful planning.

Through their promiscuity with *H. sapiens*, Neanderthals and Denisovans passed on fragments of genetic code that survive in humans today. Some of the fragments identified by Dr Cox and his collaborators appear to have played a role in helping *H. sapiens* adapt its diet and immune system as it spread into new regions, and are still present to varying degrees in modern populations. As Michael Petraglia, a palaeoanthropologist at the Max Planck Institute for the Science of Human History in Germany, puts it: "This is a story not only about history but about us ourselves today." ■

Black holes

Staring into the abyss

Astronomers take the first snap of a black hole

What black holes do to the things around them is hard to miss. Matter hurtling into them at almost the speed of light gives off all sorts of radiation, sometimes so much of it that it can be seen half a cosmos away. The black holes themselves, though, are another matter. They are, by cosmic standards, extremely small. And they are defined by having gravitational fields so strong that nothing, not even light, can escape them. That is why it is remarkable that an international team of more than 200 radio astronomers have, through years of painstaking work, actually contrived a glimpse of one.

The black hole in question (pictured below) is located at the centre of a galaxy 55m light-years from Earth called Messier 87, one of the largest and most luminous galaxies in the nearby universe. Astronomers have for some time suspected that it houses a phenomenally massive black hole—one 6.5bn times more massive than the Sun, and more than a thousand times more massive than the black hole at the centre of the Milky Way galaxy in which the Earth and Sun sit.

But massive does not mean large. The edge of a black hole is called an event horizon, because nothing that happens beyond it can ever be seen under any circumstances. The black hole in Messier 87 has an event about half a light-day across (about the size of the bit of the Solar System that has planets in it). This means that, seen from the Earth, it looks no larger than a coin on the surface of the Moon.

The smaller the thing you are observing appears in the sky, the larger the aperture of the telescope you need to look for it. The Event Horizon Telescope (EHT) team put together one with an aperture the size of Earth by bringing together data from radio telescopes all around the world. Adding together the signals received by these various telescopes allowed them to synthesise an image as good as the one they would have got from single telescopes as large as the distance between any two of the dishes, though a great deal dimmer. This sort of "extremely long baseline interferometry" has been used for decades—but never before with this amount of data.

In total, eight observatories on four continents were used to hunt for the black hole in Messier 87, including two, in Antarctica and Chile, that enjoy particularly dry skies. Because the observations needed to be precisely synchronised, each instrument was tethered to its own atomic clock.

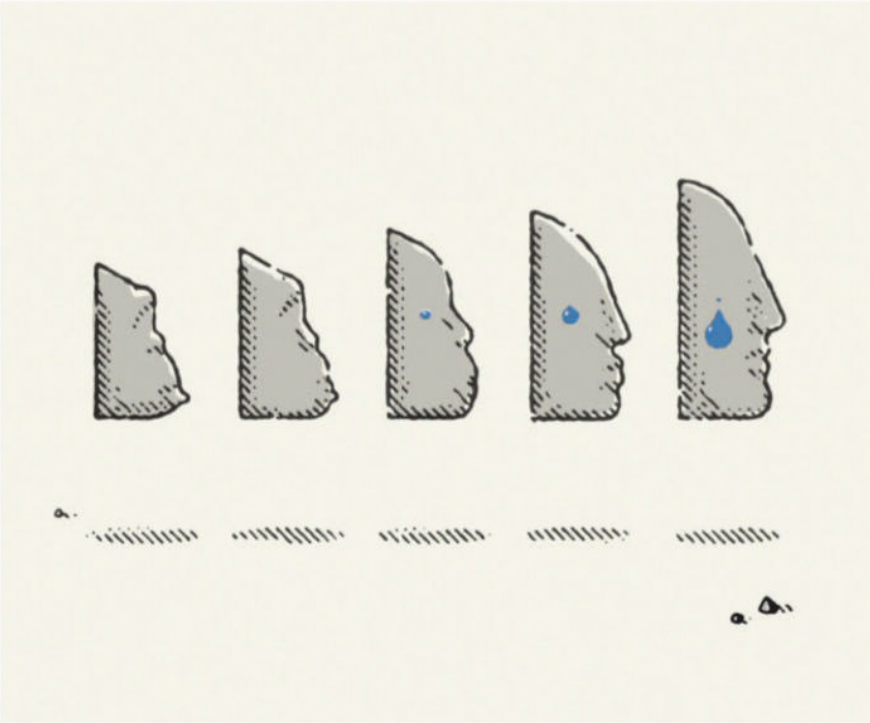
Once all the dishes were properly configured, the astronomers calculated they required ten days of clear weather in all the locations to collect the data that were needed. When they began their search in April 2017 the weather behaved, and they got five petabytes of data in seven days. These data were transported to the Haystack Observatory at the Massachusetts Institute of Technology in America and the Max Planck Institute for Radio Astronomy in Bonn, Germany, on half a tonne of hard drives.

These many numbers underwent much crunching. On April 10th the result was revealed. The first real picture of a black hole, which looks satisfyingly black and blobby, consists of radiation emitted by hot gases on the far side of the black hole and then bent by its gravity into a tube of light with darkness in its central cavity. The brighter yellow at the base of the circle indicates gases moving particularly quickly, hinting at a something of a slingshot effect taking place as the vortex of gases travel in a clockwise direction, much like water pouring down a plug hole.

In time, the same approach should be able to track changes in the environment around this black hole and others, helping to show, among other things, how the vast jets of energy it emits get their oomph and structure. In the meantime, there are two important take away messages. One is that black holes are round, as Einstein's theory of relativity predicted they would be. The world is used to Einstein being proved right; but each test that might contradict him and doesn't is an event.

The other is that if they see a possibility fascinating and spectacular enough, astronomers will be remarkably dogged in its pursuit, even using the whole moving Earth to plumb the heavens. ■

Seeing the unseeable



Evolution and psychiatry

The wisdom of sorrow

After centuries of discredited quackery, evolution may suggest a way to understand mental illness

Good Reasons for Bad Feelings. By Randolphe Nesse. *Dutton; 384 pages; $28. Allen Lane; £20*

Mind Fixers: Psychiatry's Troubled Search for the Biology of Mental Illness. By Anne Harrington. *Norton; 384 pages; $27.95*

"YOUR WHOLE field is confused. You know that, right?" The patient who delivered this parting shot had a perpetual knot in the pit of her stomach. She had lost interest in everything, was anxious, irritable and nauseous, and struggled to sleep. Her family doctor had told her it was "nerves". A psychotherapist asked about sexual feelings in childhood for her father. A psychiatrist offered drugs to fix what he said was a chemical imbalance in her brain.

Confused and desperate, she had found her way to yet another doctor, an assistant professor of psychiatry. Anxiety can be useful, he told her, but most people experience more than they need—because whereas too much merely makes you miserable, too little can make you dead. She was stuck in a cycle of worry, heightened vigilance and more worry. Cognitive behavioural therapy, which teaches people to break corrosive thinking patterns, would help. She brightened up—and offered a few home truths about the psychiatrist's profession.

Randolphe Nesse, now of Arizona State University, cites that encounter in his fascinating book to illustrate why he has spent his career studying the evolutionary roots of mental illness. Though doctors who treat physical ailments do not routinely refer to evolution, their theories about bodies are based on the fact that humans, and the pathogens that afflict them, are the product of aeons of natural selection. Disorders are defined by comparison with normal functioning. Symptoms such as rashes, fevers and pain are understood to be consequences of, or defences against, illness, not the illness itself. Treating an ailment like diabetes, in which a complex system malfunctions, means knowing how that system is supposed to work—and what it evolved to do.

Mental-health specialists lack such solid foundations. In general, they neither study the feelings of the well, nor consider what feelings are for. Of the 4,500 pages in America's most popular psychiatry textbook, normal emotions get half a page. Moreover, when it comes to diagnosis, they fail to consider underlying causes. The current version of the American "Diagnostic and Statistical Manual for Mental Disorders" (DSM-5) defines hundreds of disorders solely by their symptoms. Depression, for example, means at least two weeks experiencing five or more of eight symptoms, such as loss of pleasure in life, loss of appetite and feelings of worthlessness. The diagnosis is the same if you have just been bereaved or divorced or lost your job.

In Dr Nesse's definition, "specialised states that…increase the ability to meet adaptive challenges" constitute normal emotions. They are experienced as positive or negative because only situations containing opportunities or threats affect evolutionary fitness. A negative emotion may be just as evolutionarily useful as physical pain. A depressed patient's low mood, for example, may result from his realisation that a major life project is sure to fail. It feels terrible, but makes sense in evolutionary terms. People who do not suffer when pursuing unachievable goals may waste their energies on pointless effort, thereby harming their chances of reproduction. That insight taught Dr Nesse to ask the depressed: is there something very important that you are trying and failing to do, but can't bring yourself to give up?

Evolution has equipped people for a world very different from the one they now inhabit. They are obese because their appetites are adapted to scarcity, not superabundance. Similarly, some mental ill- ▸▸

nesses may be the result of having to negotiate situations they are not fit for. Others may be side-effects of selection for desirable traits. Dr Nesse draws an analogy with racehorses, bred for speed with the unfortunate result that their cannon bones are brittle. For every 1,000 that start a race, he says, one breaks a leg and has to be put down. It may have slightly weaker bones than the rest. Or it may simply be unlucky and stumble. Humans may have "minds like the legs of racehorses, fast but vulnerable to catastrophic failures".

When it comes to doctoring the body, you have to go back to the 19th century to find a time when the theories were baseless (infections were caused by miasmas, for instance) and the treatments often harmful (bloodletting, purging and the like). For doctoring the mind, as Anne Harrington's fine history of psychiatry shows, that point is much more recent. In 1949 a Nobel prize went to the Portuguese inventor of the lobotomy, an operation intended to sever the "worry nerves" of the brain. In 1952 the technique was sufficiently honed for an American acolyte to launch "Operation Icepick"—a 12-day road trip during which 228 patients were strapped down and anaesthetised, before he or an assistant slipped an ice-pick-shaped knife under each eyelid and into their brains, and gave a twist.

What ended that practice was not an outbreak of compassion, but the arrival of thorazine, a drug that caused such mental deadening that it was nicknamed the "chemical lobotomy". It was the start of the age of blockbuster drugs for mental illness. By the end of the 1950s one in three prescriptions in America was for meprobamate, which dampened anxiety. By 1990, 1m Americans received Prozac prescriptions each month. Pharmaceutical companies popularised the notion that anxiety, depression and so on were caused by chemical imbalances. Right them and you could become not just well, but better than well.

Under the influence of Freud, psychiatrists had sifted their patients' life histories for repressed emotions and memories. But in the 1980s psychiatrists declared a post-Freudian world, with mental illnesses ascribed to brain biochemistry and neuroanatomy. They expected to discover the genes that caused mental illnesses, and bespoke drugs that could heal them.

That revolution never happened. Instead pharmaceutical firms are pulling back, as stricter testing rules reveal how little good many of their products do. The evidence linking mental illnesses to defects of brain architecture or chemistry, or to specific genes, is scanty. With its checklist approach to diagnosis, DSM-5 is under attack. Ms Harrington's history ends with today's crisis in the psychiatric profession. If Dr Nesse is right, evolutionary thinking could provide a fruitful new direction. ■

Architecture

Haus style

Gropius: The Man Who Built the Bauhaus. By Fiona MacCarthy. *Belknap Press; 560 pages; $35. Published in Britain as "Walter Gropius: Visionary Founder of the Bauhaus"; Faber & Faber; £30*

"IF I HAVE a talent it is for seeing the relationship of things," reflected Walter Gropius in 1967, not long before he died. The world remembers him as an innovative architect of pared-down modernist buildings and the founder of the Bauhaus, a revolutionary school of art and design. His aim was to bring architects, designers and artists together in a working community to create what he called the *Gesamtkunstwerk*, or total work of art.

Charismatic, gifted, idealistic and well-connected, he wanted to do something new and life-affirming after fighting in the first world war. His invitation to join the Bauhaus was taken up by the most vibrant artists and designers of his day, including Vasily Kandinsky, Paul Klee and Laszlo Moholy-Nagy. The teachers and students led quasi-communal lives; their parties were legendary. In its various incarnations—starting in Weimar in 1919, then moving to Dessau and finally to Berlin—the fabled school lasted a mere 14 years, after which the *Bauhäusler* dispersed across the globe, many, including Gropius, to America.

Gropius in excelsis

Gropius was born in 1883 in Berlin into a cultured upper-middle-class family. His first job was in the office of Peter Behrens, a successful architect and designer who had already taken on a young Mies van der Rohe and a little later recruited Le Corbusier. In 1910 Gropius left to set up his own practice and was soon working on the Faguswerk in Alfeld, a futuristic factory built from glass, steel and yellow brick that became his first important building.

As Fiona MacCarthy's new book recounts, his private life was chaotic. In 1910 he had an affair with Alma Mahler, an accomplished society beauty who at the time was married to the composer Gustav Mahler. After Gustav died she took various lovers, including the painter Oskar Kokoschka, but she and Gropius were married in 1915. Their daughter, Manon, was born the following year. Then Alma started an affair with the writer Franz Werfel; after she and Gropius divorced, she made it hard for him to see his child. In 1923 Gropius found his life's companion in Ilse Frank, an independent-minded woman who was 14 years his junior. (He persuaded her to change her name to Ise, perhaps because it sounded less bourgeois.)

By then the Bauhaus was in full swing, but in 1928 Gropius left the school to devote more time to his neglected architectural practice. He and Ise settled in Berlin, where their home became a hub for the avant-garde. After the Nazis came to power, his commissions dried up (Ise, meanwhile, began a relationship with a former *Bauhäusler*, the graphic designer Herbert Bayer). The school suffered, too. Gropius had tried hard to keep politics out of art, but the Nazis were increasingly hostile to the Bauhaus, branding its output degenerate. Starved of funds, it closed in 1933.

Germany's loss proved the world's gain. In 1934 Gropius moved to London, but he found the artistic climate uncongenial. Soon he was offered the chairmanship of a new graduate architecture programme at Harvard, where he made a deep impression on a generation of students. After the second world war, with a group of colleagues half his age, he started an architectural practice which was to become America's largest and gave him the chance to design many striking buildings. He spent the last few years of his life burnishing the story of the Bauhaus and managing its legacy.

Ms MacCarthy, who has previously published books on William Morris and Edward Burne-Jones, among others, met Gropius (and Ise) decades ago and determined that one day she would write his biography. She eventually got round to it in time for the Bauhaus's 100th birthday this year. The result is a riveting book about a man who nurtured a vastly ambitious project through extraordinary times. ■

New American fiction

Dangerous games

Trust Exercise. By Susan Choi. *Henry Holt; 272 pages; $27. Serpent's Tail; £14.99*

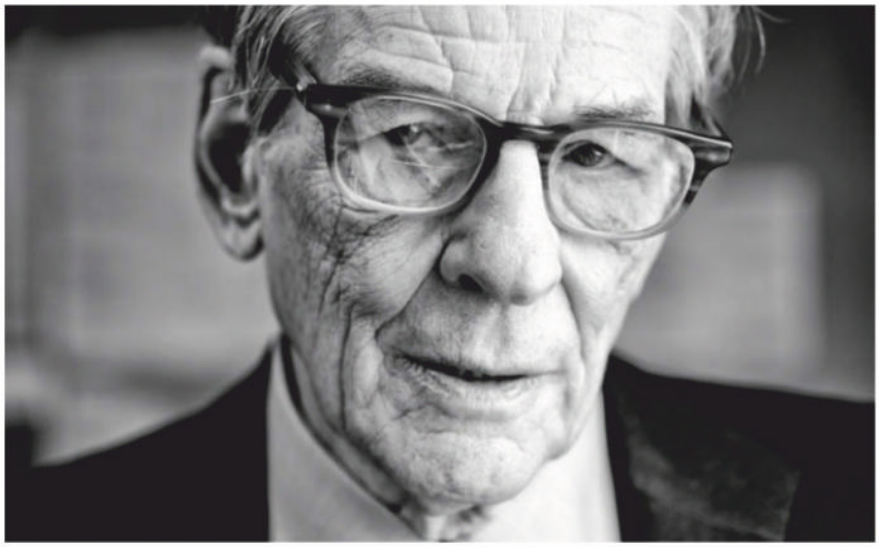
SARAH AND David are theatre students at a performing-arts high school, preparing for "exceptional lives". From the first page of Susan Choi's twisting novel, they are connected by a hot wire of desire. The stage seems set for a classic tale of young love. But nothing is as it seems in this artistic hothouse. Immediately, the story shifts: their teacher, Mr Kingsley, emerges as a Pied Piper, seductive and dangerous.

"Of the Trust Exercises there were seemingly infinite variations," Ms Choi writes. Mr Kingsley sets students groping in the dark, or falling into waiting arms, to learn an attitude of openness. Again and again, the youngsters are raked raw, their emotions deconstructed in the name of Art. In the course of this obsessive, repetitive examination, their lives begin to unravel.

Ms Choi's novels have won praise for their blend of exceptional prose and propulsive storytelling. Her previous book, "My Education", was a story of sexual obsession; the limit of self-knowledge is a recurring theme in her fiction. "Trust Exercise", her fifth novel, focuses on trust and its abuse—particularly between predatory men and teenage girls. But her vision is much broader than the politics and recriminations of #MeToo.

As the narrative unfolds, it becomes clear that it, too, is a "trust exercise". Readers place themselves in this gifted author's hands, only to be yanked, sometimes violently, in unexpected directions. Each of the three sections initially jars, as perspectives shift and splinter. Yet for all the dramatic reversals, this is not a straightforward thriller. The real pleasure of the novel lies in recognising the echoes that reverberate towards its unsettling conclusion, and the questions it raises about the truth of the stories people tell.

The author uses language brilliantly. Sarah and her friend do everything possible to their hair, from bleach to perms, "as girls do when vandalising themselves seems the best way of proving their bodies are theirs." Descriptions of sex are powerfully real. "Then Sarah is naked", Ms Choi writes, "and the hot, slippery fit is accomplished." She is an astute, forensic cartographer of human nature; her characters are both sympathetic and appalling. In the end, hers is a tale of missed connection and manipulation—and of willing surrender to the lure and peril of the unknown. ■



Lives of the biographers

A master builder

NEW YORK

Robert Caro, America's biographer-in-chief, reflects on his life and craft

ON NEW YORK'S Upper West Side, a stone's throw from Central Park, Robert Caro is in his office, writing. America's biographer-in-chief, now 83, is working on the fifth and final volume of "The Years of Lyndon Johnson", his seminal portrait of the 36th president. Cork boards displaying the outline of this last instalment hang on an otherwise bare wall. In the next room, filing cabinets house hundreds of folders of notes and interviews. The shelves include several copies of "The Power Broker", Mr Caro's Pulitzer-winning biography of Robert Moses, the "master builder" of mid-20th-century New York.

His books trace the lives of towering figures in American history. Both Moses and Johnson bent people and institutions to their will through cunning, determination and ruthlessness; both nurtured ambitions that inspired awe. They were supreme manipulators with complicated motives. Moses built New York's parks, bridges and expressways; but his schemes betrayed contempt for minorities and the poor, destroying their neighbourhoods and obstructing public transport. Johnson passed landmark legislation on civil rights, education and health care. He also pushed America deeper into war in Vietnam.

Yet Mr Caro's method triumphantly transcends such headlines. Few authors lavish attention on places and people as he does. His books are also about New York, Tammany Hall, the Senate, the Texas Hill Country, American individualism and, above all, political power, how it is wielded and what it can achieve.

Working. By Robert Caro. *Knopf; 240 pages; $25. Bodley Head; £20*

His latest book, "Working", is a collection of personal reminiscences. The journalist-cum-historian is conscious of time, and of all the books he has yet to publish. How to make sure that the knowledge he has acquired outlives him? "If it's not preserved between the covers of a book," Mr Caro reckons, "it's gone." In the course of explaining his reporting and writing process—which involves many longhand drafts and a typewriter—he also charts his own extraordinary life.

Mr Caro was a reporter for *Newsday* on Long Island when he began paying attention to Moses. "The Power Broker", a 700,000-word epic, tells the story of a man who shaped America's biggest city over four decades without ever being elected to office. Even now, 45 years after it was first published, Mr Caro is counting the words that were cut out. He mourns the would-have-been chapters on the city planning commission; his own copy is marked up with changes he still wishes he could make. "Cutting that book was really sort of the hardest thing I ever did," he says, thinking of the 350,000 words that never made it into print. He speaks quietly when recalling these lost sections. Evidently their absence pains him still.

After the success of "The Power Broker", Mr Caro decided to think bigger. Whereas his book on Moses was a study in urban politics, Johnson's ascent to the White ▸▸

House was a way to document power on the national stage. The most delicious parts of "Working" are behind-the-scenes snippets from interviews he conducted with associates of the president.

For example, when Mr Caro was searching for LBJ's college classmates to decipher how he acquired the nickname "Bull" (short for "Bullshit") Johnson, he called up a Texan named Ella So Relle. Peeved at the intrusion, Ms So Relle asked why she was being asked so many questions when the answers were all printed in the college's yearbook for 1930. Mr Caro looked for the pages she mentioned and found them to be torn out neatly from the binding.

A frantic drive to a second-hand bookstore turned up more copies—with the same pages missing. When he finally found an intact copy it was, as Ms So Relle had said, "all there in black and white": snide cartoons and drawings of Johnson depicting how he had stolen campus elections. It was that moment "of true revelation", Mr Caro says, that led him to rethink the golden image of LBJ that others had conveyed. He is animated as he recalls the discovery, gesturing as if to slap his desk as if he has just found the missing pages all over again. Fellow journalists will delight in such intrepid shoe-leather escapades.

In assessing Mr Caro's long career, one thing becomes obvious: he didn't do it alone. Each of his books is dedicated to his wife Ina, and for good reason. When Mr Caro spent all day, every day at the LBJ Presidential Library in Austin, Texas, Ina—an acclaimed author in her own right—sifted through documents two or three desks away. The Caros sat at those tables, together but walled apart by towers of boxes and papers, intent on turning every page. ■

Johnson Many and one

How to think about African-American English

America has always been full of languages, a fact that has been both a source of pride and a cause for consternation. But there has long been a fundamental misconception about one of its distinctive tongues: the speech of some of the country's black population, especially in highly segregated areas. Not only is the nature of this dialect widely misapprehended; often its speakers are literally misunderstood by some of their fellow citizens.

African-American English (AAE), is not a broken version of standard English, the mistake-filled attempts of someone trying and failing to talk correctly. Instead, it is like a cousin. It developed from the same roots, but in a different direction, born of unique circumstances. Enslaved people from various African backgrounds took what they learned of English and made it their own.

Centuries later, AAE is a rule-bound, internally consistent dialect. In some ways it is simpler than standard English. For example, it omits the *-s* on third-person singular verbs: *I speak, you speak, she speak*. But in some ways it is more complicated. *She comin' by my house* means something different from *She be comin' by my house*: the first is a one-off event, the second is habitual. *I been done that* means that I did something a long time ago. Standard English can achieve these effects with adverbs, but AAE integrates them into the verb system itself.

Misplaced snobbery about the nature of AAE is not the only problem. The dialect's differences from the standard also lead to dangerous confusion. Taylor Jones, a graduate student in linguistics at the University of Pennsylvania, carried out a worrying study that found a group of professional court reporters were able to transcribe only 60% of AAE sentences accurately, and 83% of the words. Asked to paraphrase what they had heard, they did even worse: about 33% of utterances were conveyed accurately. They are supposed to achieve a 95% accuracy.

Experienced court reporters did no better than newer ones, and black reporters little better than the white ones. Black participants explained their trouble with AAE by saying that they (like many other African-Americans) didn't "speak like that". Worse, both black and white court reporters tended to assume the recordings were from criminal court (they weren't). That people associate AAE with ignorance and criminality is bad enough. Misunderstanding aggravates the risk. No one can get justice from a court that doesn't know what they are saying.

The miscommunication runs both ways. Adult black Americans who use AAE can easily understand standard English, from exposure in school, work and the media. But youngsters from homes and neighbourhoods where AAE predominates are a different matter. In another study, Mike Terry of the University of North Carolina tested AAE speakers in second grade (roughly 7 years old) on their maths. He found that questions including the third-person-singular ending *–s* (*he talks*, which in AAE is *he talk*) made the students 10% less likely to answer correctly. Language is not just language; it is the interface with other kinds of knowledge. Such pupils are being judged as less capable than they really are.

A close linguistic analogy to AAE is Scots, which differs from standard English to a similar extent. In its full form, it is at least as hard for outsiders to understand. But in policymaking terms, it is not a useful comparator. Scots have a homeland and a nationalist movement; they are not generally the subject of disparaging prejudice.

It may be better to think of AAE as posing the same challenges as a foreign language, albeit in diluted form. Seeing the problems some of its speakers face as essentially ones of translation might let policymakers appreciate and solve them. This does not mean providing courtroom interpreters for black speakers, or classes taught in AAE. It means training court staff or teachers in the issues involved.

America is a diverse place, and standard English is part of the glue that holds it together. All the more reason to take a linguistically informed approach to teaching it. For example, classroom exercises similar to "translation" from AAE to standard English can help children master the standard, in a way that shaming them for "mistakes" (in fact, correct AAE) does not. The standard is not the only kind of English there is. Paradoxical as it may seem, recognising this linguistic diversity will help a divided country approach the ideal of its motto: *e pluribus unum*.