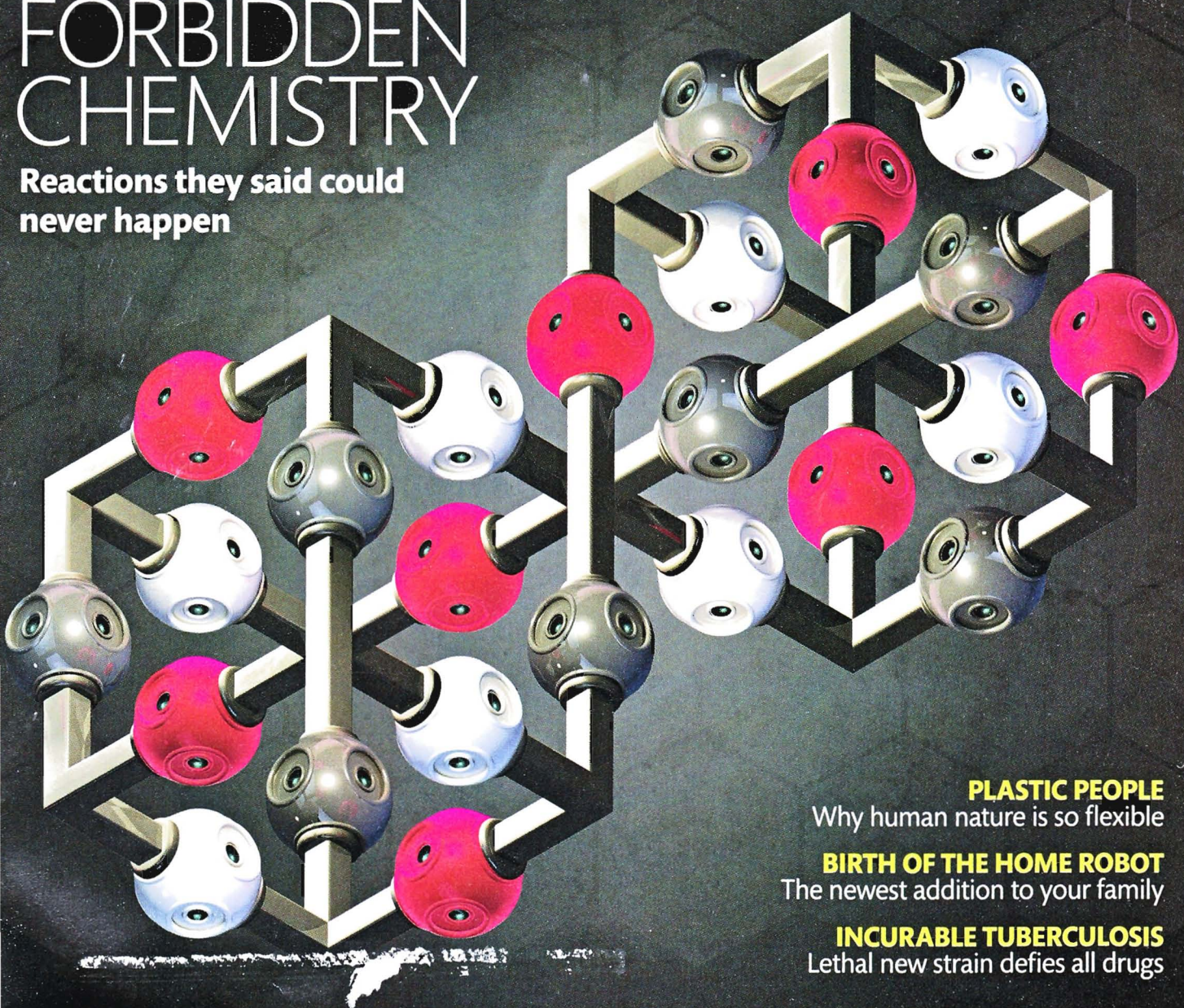
ULTIMATE TIME CAPSULE
The crystal that can outlast the universe

NewScientist

WEEKLY January 21-27, 2012

FORBIDDEN CHEMISTRY

Reactions they said could never happen



PLASTIC PEOPLE
Why human nature is so flexible

BIRTH OF THE HOME ROBOT
The newest addition to your family

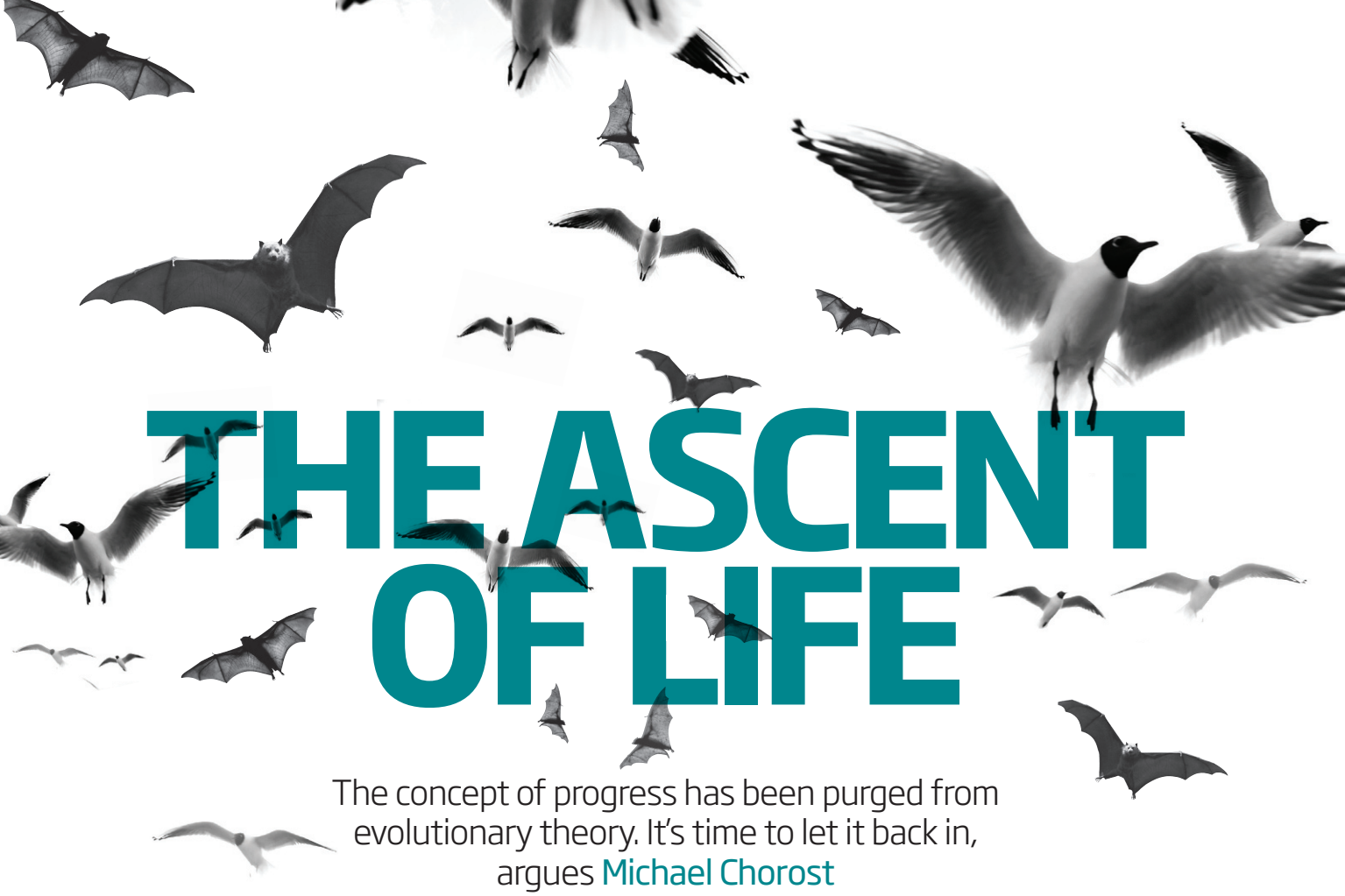
INCURABLE TUBERCULOSIS
Lethal new strain defies all drugs

No2848 US$5.95 CAN$5.95

The arrow of evolution

Does life have a direction?

Science and technology news **www.newscientist.com** US jobs in science



THE ASCENT OF LIFE

The concept of progress has been purged from evolutionary theory. It's time to let it back in, argues Michael Chorost

CELEBRATED palaeontologist Stephen Jay Gould once wondered what would happen if we could rewind the tape of life. If it were possible to turn the clock back half a billion years and then let evolution happen all over again, what would we see? Gould famously argued that the history of life would not repeat itself. The world would be unfamiliar, and would probably lack humans.

His point was to demonstrate that evolution is not a process of inexorable progress but of contingency. Mutations happen unpredictably. Sexual reproduction combines genes at random. Droughts, ice ages and meteorites strike without warning and kill off fully fit individuals and species.

We tell ourselves stories of evolutionary progress but these are just wishful thinking. Life produces abundant variations; most fail. The few that survive we call the most advanced, but that is a profound error which conflates "latest" with "best". As Gould wrote in his classic book *Wonderful Life:* "Life is a copiously branching bush, continually pruned by the grim reaper of extinction, not a ladder of predictable progress".

Gould also had little time for humanity's hubris. Far from being the pinnacle of evolution, we are just another product of contingency. "Perhaps," he wrote frostily, "we are only an afterthought, a kind of cosmic accident, just one bauble on the Christmas tree of evolution."

Gould's view is the orthodoxy of evolutionary theory. Yet it remains hard to reconcile with the intuitive sense that life has indeed progressed over time. All life was once single-celled, yet now a single organism can contain tens of trillions of cells. The number of cell types has increased, too, from one kind in single-celled organisms to 120 in mammals. Brains have grown larger. And humans have accelerated this trend in the past 50,000 years with our own uneven but powerful ascent.

> "We tell ourselves stories of evolutionary progress but these are just wishful thinking"

For many years, a small but energetic group of researchers has been trying to rehabilitate the concept of evolutionary progress and explain it in theoretical terms. They hope to show that Gould's view of evolution is too bleak and that certain kinds of biological progress are not merely accidental or illusory, but necessitated by physical law. If these researchers succeed, it could lead to a crucial modification of current theory.

Gould and those who followed in his footsteps accepted that life has increased in size, complexity and diversity. However, they argue that this is not because evolution is inherently progressive.

Instead, it is an illusion. By definition the first life was very simple. As variation increased, some organisms inevitably became more complex. Humans pay the most attention to the complex ones, leading to a belief in an upward march. As Sean B. Carroll, a professor of molecular biology at the University of Wisconsin-Madison, puts it: when there is nowhere to go but up, some species will go up (*Nature*, vol 409, p 1102).

Development-oriented theorists accept ›

"Progress is difficult to define because what counts as progress depends on who is doing the defining"

these passive increases in complexity. But they argue that there are also "driven" processes that bias evolution toward increasing complexity. John Smart, a member of the evolution, complexity, and cognition research group at the Free University of Brussels in Belgium and a leading thinker in this field, argues that evolution and development can be reconciled. That is, it will be possible to define progress in objective terms and explain why it must happen. The case laid out by Smart and other theorists is based on at least four arguments.

The first concerns a new way of thinking about progress – a concept that is notoriously difficult to define, largely because what counts as progress depends on who is doing the defining. More complexity seems valuable to us, for example, but many organisms – especially parasites – are successful thanks to a reduction in complexity.

Energy flows

Rooting a new definition in basic physics would be one way around this problem. Eric Chaisson, an astrophysicist at Harvard University, has put forward the idea of energy rate density, a measure of how much energy flows through each gram of a system per second. A star, for all its spectacular output, has a much lower energy rate density (2 ergs per gram per second) than a houseplant (3000 to 6000 ergs per gram per second). This sounds counter-intuitive until you remember that stars are just balls of gas.

Humans do better still, with a basic energy rate density of 20,000 ergs per gram per second. Societies, too, can be measured in this way. Chaisson estimates that hunter-gatherer societies have an average energy rate density of 40,000 ergs per gram per second, while technological societies use 2 million ergs per gram per second (*Complexity*, vol 16, p 27).

Chaisson argues that energy rate density is a universal measure of the complexity of all ordered systems, from planets and stars to animals and societies. Furthermore, when he plots the energy rate density of such ordered systems against the time they first appear in the history of the universe, the line goes unequivocally upwards, indicating a general increase in complexity over time (see diagram, below).

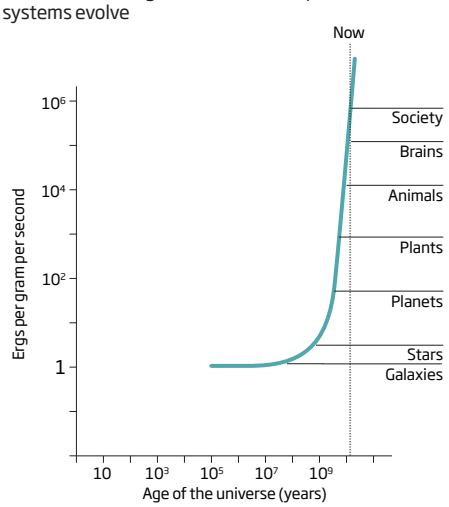
The second argument concerns thermodynamics. At first sight, the second law of thermodynamics is a gloomy affair. It seems to indicate that increases in disorder are inevitable and irreversible and that the universe is running out of the energy needed to create and sustain complex entities such as living things.

A literal reading of this law implies that the ascent of life is extremely unlikely. More nuanced readings, however, have been used to argue that local increases in complexity are not merely permitted by the law, but required by it, and order can and does emerge spontaneously from chaos.

Physicist J. Miguel Rubí of the University of Barcelona in Spain says that, strictly speaking, the second law of thermodynamics applies only to systems in equilibrium, a state in which nothing changes. This condition is

Growing energy density

As the universe ages, ever more complex systems evolve



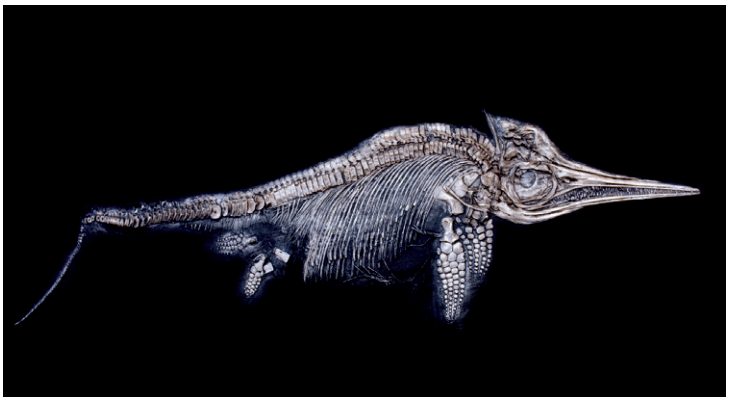
SOURCE: CHAISSON

SEAN DAVEY/PLAINPICTURE

rarely present in the universe. Earth, for example, is heated by the sun, creating energy gradients on its surface (*Scientific American*, vol 299, p 62). Where energy gradients exist, pockets of complexity can arise even as the system as a whole decays into disorder. These pockets provide a foothold for further increases in complexity. Energy gradients thus provide a loophole in the second law that permits life to arise and ascend.

Argument number three is convergent evolution. Taking a different view to Gould's argument, the tape of life has been rerun many times – at least partially. In many cases, very different species living in similar environments have independently evolved in similar ways.

In his book *What Technology Wants*, Kevin Kelly, the founding editor of *Wired* magazine, gives numerous examples of convergent evolution to support his argument that the outcomes of evolution – of which he considers technology one – are not accidental. Flapping wings evolved independently in birds, bats and pterodactyls. Dolphins, bats and several species of cave-dwelling bird separately hit on echolocation. Fish in the Arctic and the Antarctic independently evolved antifreeze compounds. Perhaps the best-known example is the camera eye, which has evolved independently at least six times. The



NATURAL VISIONS / ALAMY

Convergent evolution, as seen in ichthyosaurs and dolphins, may suggest inevitable patterns in life

implication, Kelly writes, is that many outcomes of evolution are not accidental but inevitable. These outcomes include not just organs but brains, minds, societies, and technologies.

Intelligence may be another convergent property. Nicola Clayton, a professor of comparative cognition at the University of Cambridge, and Nathan Emery, a cognitive biologist at Queen Mary, University of London, argue that while primates and crows are far apart on the evolutionary tree and have very different brain structures, they have independently evolved many similar kinds of cognition, including tool use, deception and complex social groupings. The implication, again, is that intelligence always emerges in favourable conditions.

Last of all, a theory of development must account for catastrophism. The occurrence of unpredictable, planet-altering events is a challenge for any developmental perspective on evolution. Had the dinosaurs not been killed by an impact, critics of the theory say, mammals would not have had the opportunity to expand into new niches and there would have been no evolutionary sequence leading from primates to tool-wielding, language-using apes. In short: no impact, no us.

Simon Conway Morris, a palaeontologist at the University of Cambridge, counters this by arguing that while catastrophes delay or accelerate the developmental process they do not significantly change it. The key is convergent evolution.

Hold the extinction

Suppose the deadly meteorite had sailed harmlessly by, Conway Morris suggests. The dinosaurs would have survived for the next 30 million years until Earth's next glaciation. The cold would have killed off those dinosaurs living north and south of the tropics, opening up niches for the warm-blooded mammals and birds that co-existed with them. Eventually tool-users not unlike us would have evolved and sooner or later any dinosaurs remaining in the tropics would have been hunted to extinction. "The mass extinction of the dinosaurs would then have been under way, perhaps 30 million years behind schedule in comparison with the real world," he writes.

So whatever catastrophe hits, the tape of life would probably run more or less the same way. It might delay the developmental process by reversing an advance, but the advance would eventually happen again. Or it might accelerate the process by opening up an environmental niche. In either case, the outcome would not change substantially; only the timing would.

If these four arguments hold up, it would mean a significant expansion of evolutionary theory is needed, showing that life not only evolves, it develops.

The implications would be profound. Development, unlike evolution, has a direction: an acorn becomes a tree, an embryo becomes a newborn. It never goes the other way. And while the outcome is not fully determined, it is powerfully constrained.

Direction and constraint, however, do not imply design and purpose. A developmental view of evolution needs no help from teleology. Such a theory of evolution offers no support for intelligent design. Indeed, it would strike another major blow to it by offering a cogent naturalistic explanation for the emergence of complexity.

Perhaps more profoundly, admitting progress into evolution would give a different perspective on our own existence. In offering a naturalistic explanation for the emergence of intelligence and its offspring, language and technology, it would cast them as predictable outcomes of the cosmos rather than as accidents of contingency. Far from being "just one bauble", we would have an explicable, even inevitable, place in the order of things. ■

"Whatever catastrophe hits, the tape of life would probably run more or less the same way"

Michael Chorost is a science writer based in Washington DC