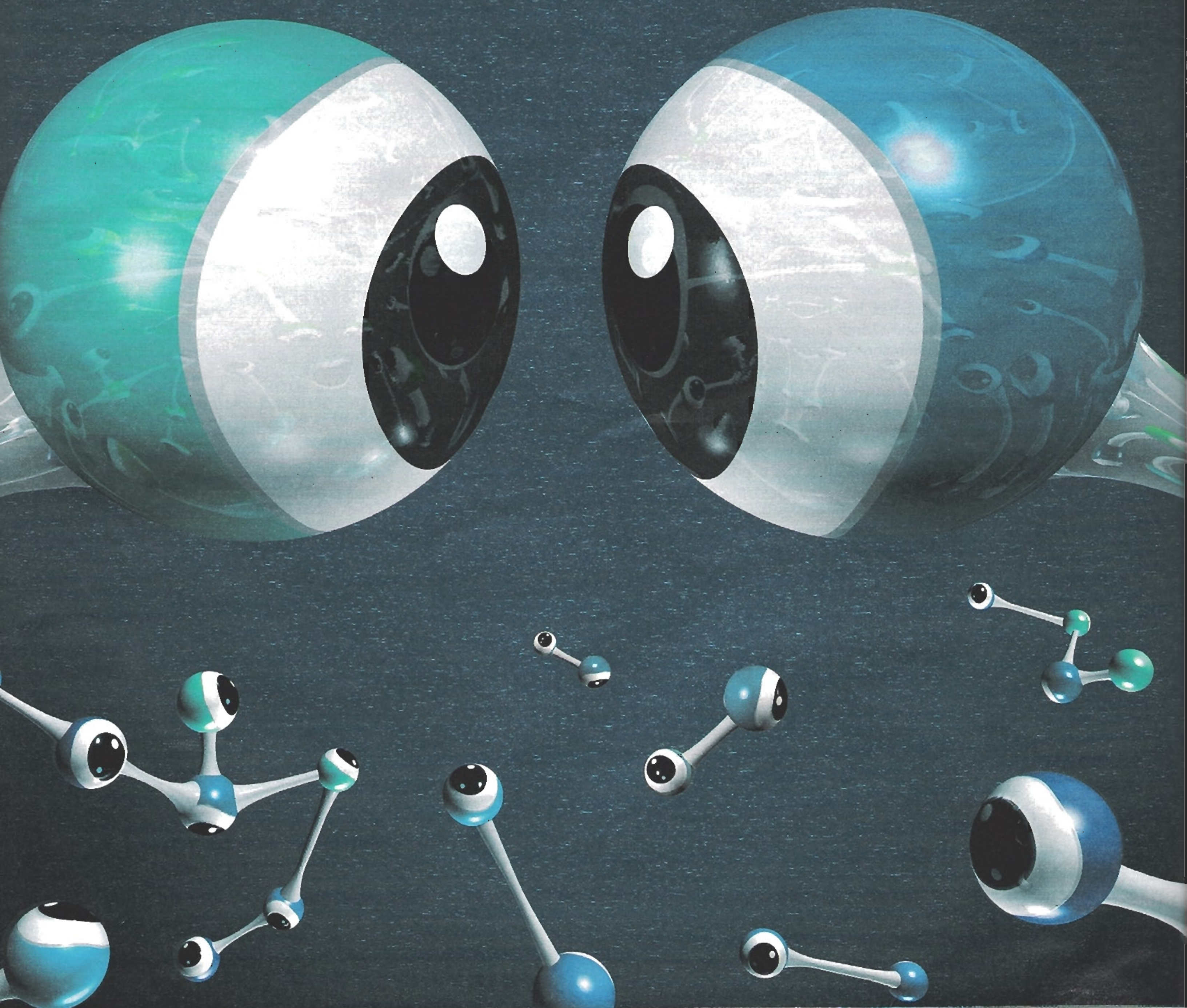
ART SHAY'S PRICELESS $3 BUGLE | RICK KOGAN ON THE CITY'S 50 FIEFDOMS

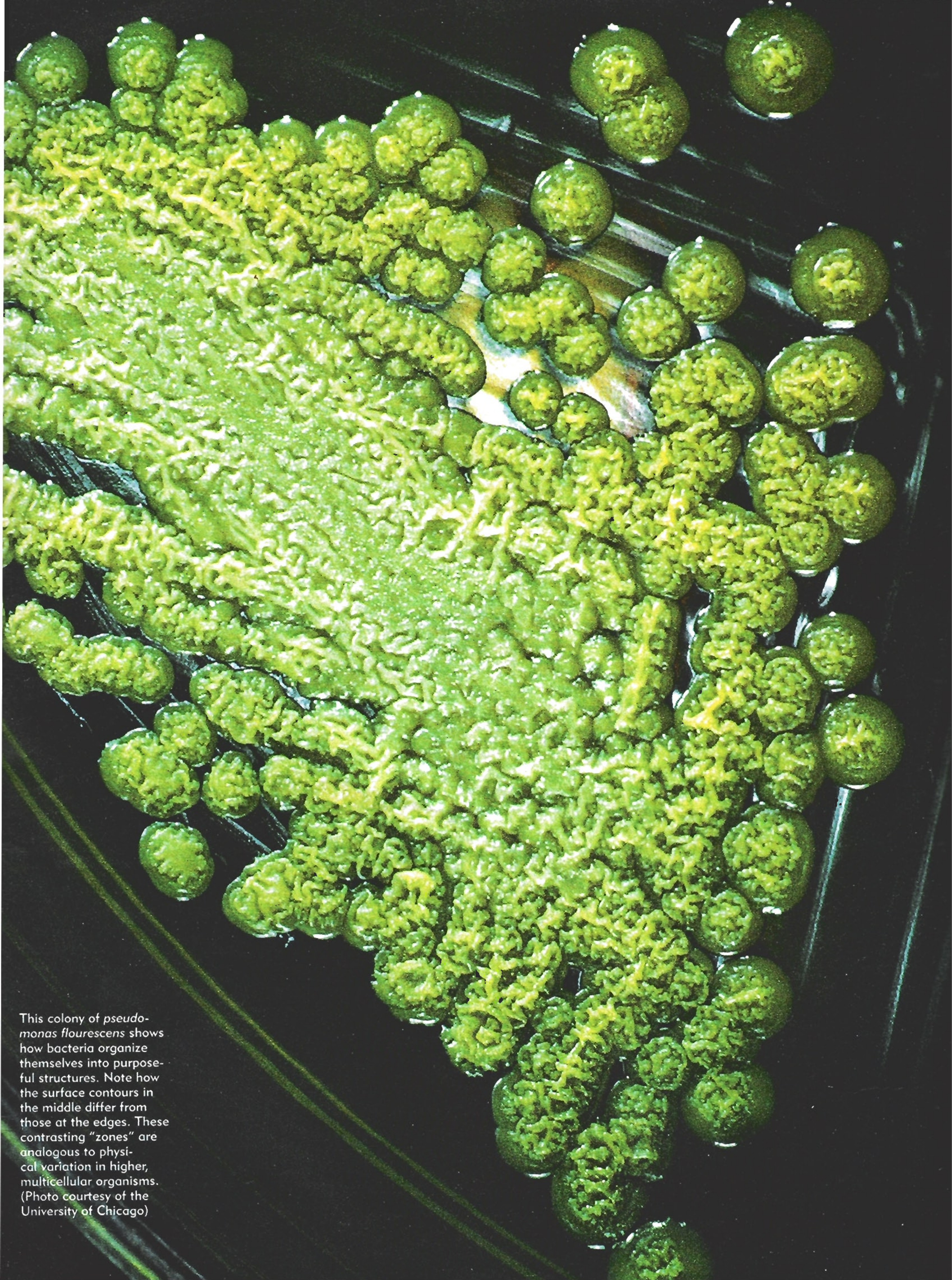
Chicago Tribune Magazine

JANUARY 8, 2006

THE INTELLIGENT UNIVERSE

SCIENCE TAKES A NEW LOOK AT EVOLUTION AND HOW NATURE'S BUILDING BLOCKS 'TALK' TO EACH OTHER

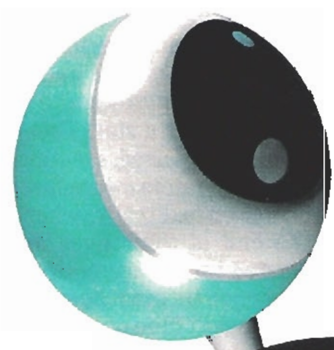




This colony of *pseudomonas flourescens* shows how bacteria organize themselves into purposeful structures. Note how the surface contours in the middle differ from those at the edges. These contrasting "zones" are analogous to physical variation in higher, multicellular organisms. (Photo courtesy of the University of Chicago)

the Cosmic conversation

how can
lifeless particles evolve
into living things?



they basica
talk themselves into it,
a group of
scientists say.

BY **RONALD KOTULAK**

TRIBUNE PHOTOS BY **E. JASON WAMBSGA**

THE ONLY REALLY BAD ARGUMENT

University of Chicago physics professor Henry Frisch can remember his parents having was purely academic. The question: If a lightning bolt struck a primitive soup of basic chemical building blocks enough times, is there a chance it could eventually make a baby? Frisch's father, an MIT physicist immersed in the knowledge that inanimate atoms combine to make living things said the probability was vanishingly small, but it was not zero. Given enough chances, such an event could conceivably arrange all the necessary atoms in the right order to produce an infant. His mother, a Harvard biologist steeped in the choreography of living cells, said that was utter nonsense. Life evolved slowly from the very simplest forms to more complex ones. There isn't an extremely small chance that lightning striking a concoction of chemicals, even an infinite number of times, could produce a baby. There was no chance. "They were sailing along and they ran onto a rock that they couldn't deal with," Frisch said.

Although Frisch didn't take either parent's side, he now finds himself drawn into an offshoot of the lightning-bolt question: How could something as complex as intelligence and consciousness evolve from the inorganic, elementary particles of the early universe? And is intelligence limited to humans and some animals, or do plants and even inanimate objects possess it?

The scientists raising these questions are part of a fascinating new field called emergent properties, which someday may reveal how complexity in nature ultimately crosses a threshold to produce intelligence and self-awareness.

Their research goes to the heart of a pivotal question in evolution, one that has become a hot-button political issue: Why is it that things that are very large and very complicated, and have many, many pieces to them, have structure and order?

For advocates of "intelligent design," life seems too complex to have just happened. Some supernatural force had to guide it.

But to emergent-properties scientists, it is clear that all things from the very beginning—atoms, molecules and so on, up to living organisms—do their own "thinking" without any outside help. They communicate, process information and form new unions, acquiring capacities that are unpredictable and greater than the sum of their parts.

Evolution, rather than being driven by competition among individual organisms, is propelled forward into more complicated organisms by symbiosis and cooperation among cells. Carbon atoms, for example, can be thought of as "talking" to each other, exchanging information on how to hold hands to create a diamond crystal.

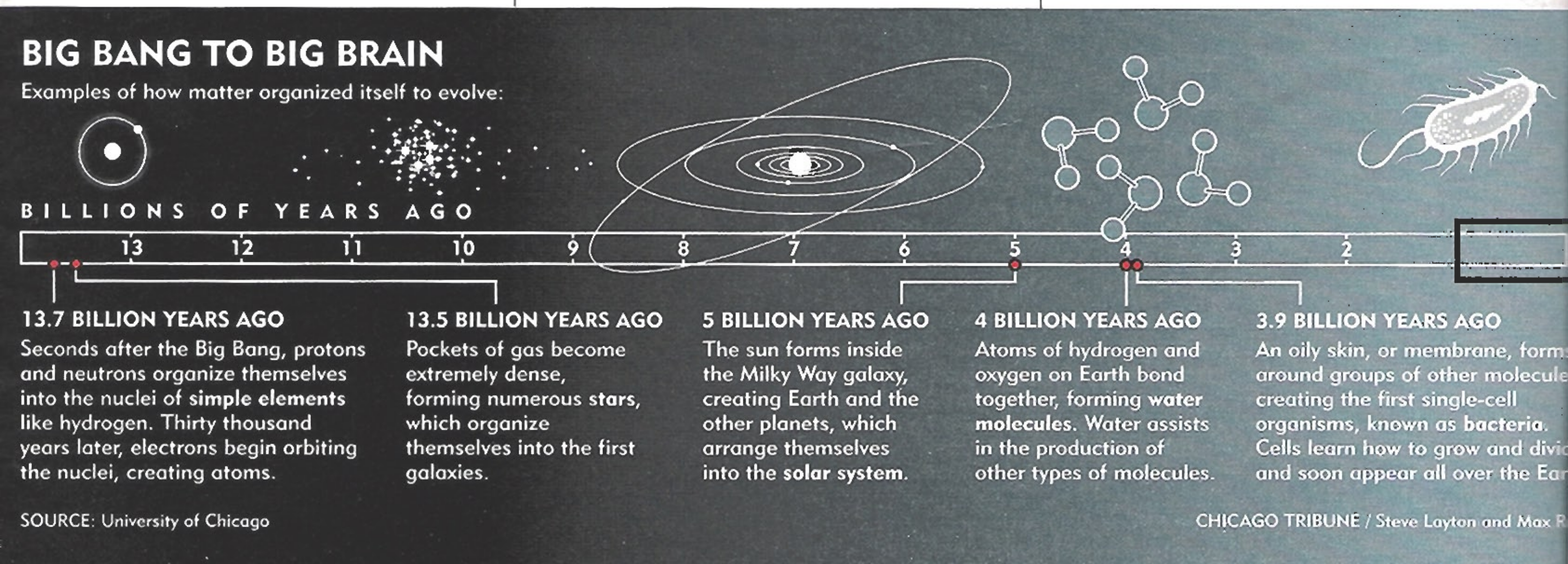
It's a concept that's shattering a long-standing assumption—that the behavior of atoms and of all life forms, except for human, is basically preprogrammed, preordained and reflexive.

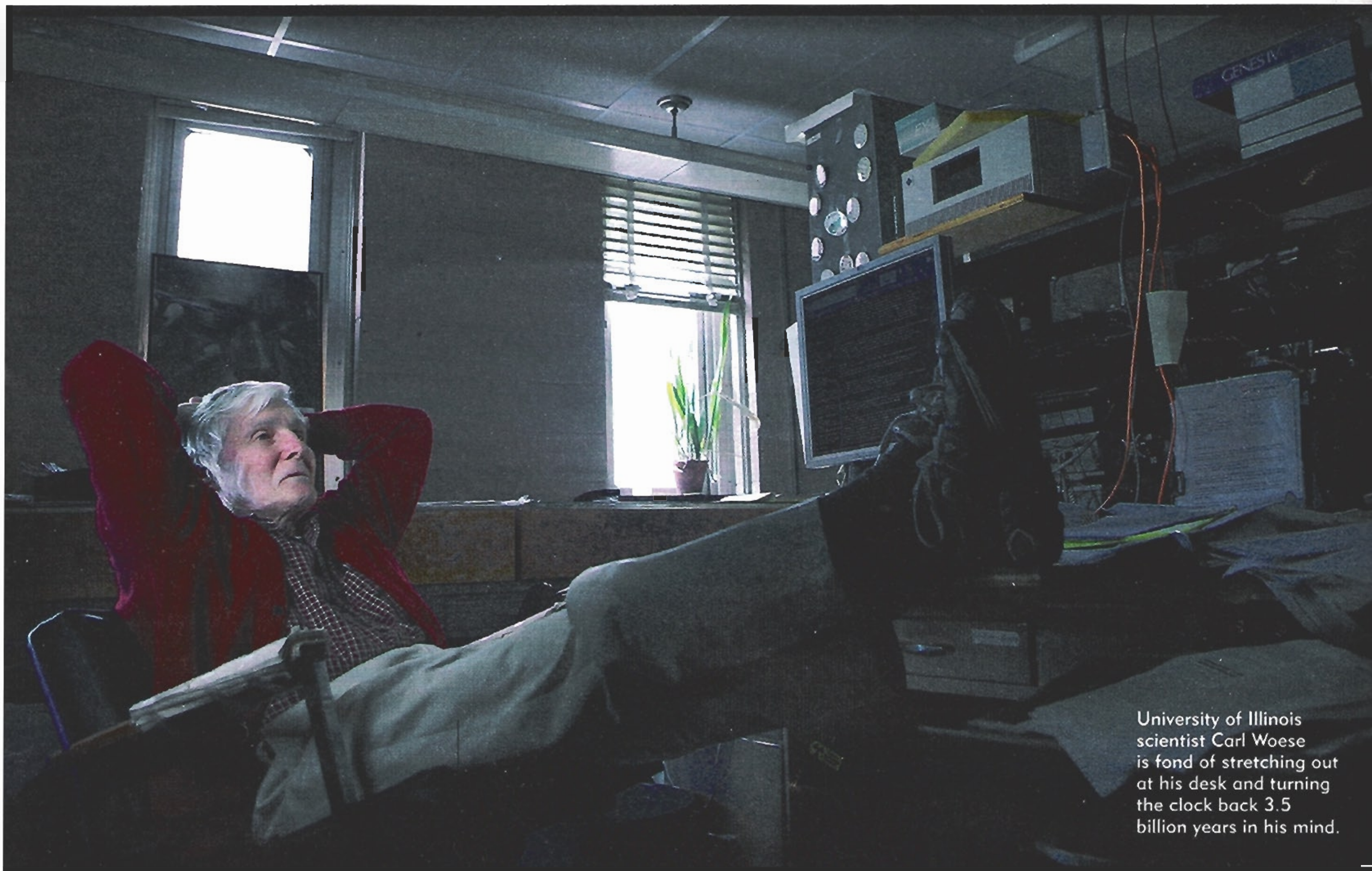
"All of life displays emergent properties," says Utah State University plant biologist Keith Mott. "Even a lot of things that are not life display emergent properties. It means that when you get a bunch of things together they do something that's completely different from what you would expect from all of the individual components."

As information is concentrated, it has the capacity to move around, be shared or seemingly amplify itself by providing a model for less-organized neighboring systems, explains Cornell University physicist Paul Ginsparg. "Once atoms form we can see how they communicate to form molecules and eventually how genes communicate to orchestrate life processes. It seems to me that information processing is possibly the thread that ties together complexity and the richness of the universe."

The concepts that underlie the field of emergent properties are rooted in the explosive development of the early universe. The Big Bang, researchers agree, left behind oceans of elementary particles with both positive and negative electrical charges. The oppositely charged particles attracted each other, forming hydrogen, the simplest atom.

Gravity drew the hydrogen atoms into denser and denser clumps until the pressure was sufficient to begin crushing them together, forming helium and releasing enough energy to ignite the fusion furnace that becomes a star. This process continued as new stars aged, creating heavier elements as smaller atoms were fused together to form bigger ones. Finally, when the stars reached the end of their lives and exploded, they blasted into space both the light and heavy elements, seeding the universe with the building blocks of life.





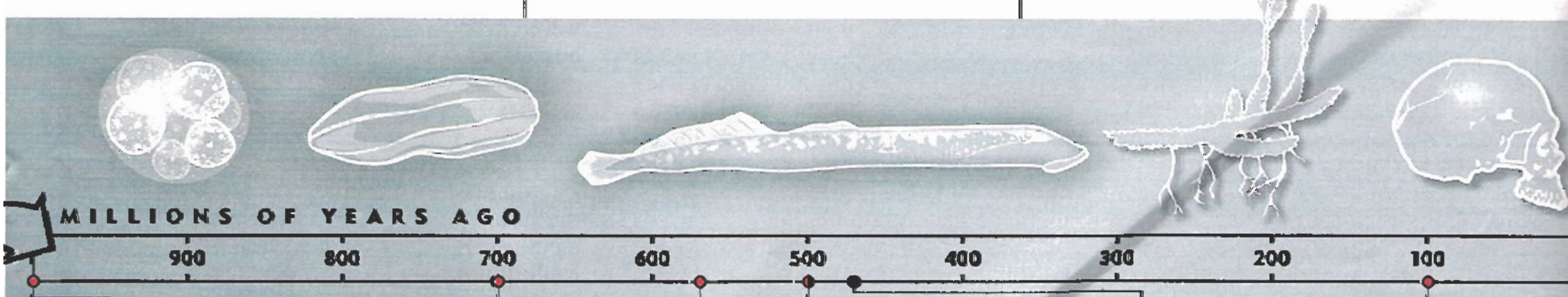
University of Illinois scientist Carl Woese is fond of stretching out at his desk and turning the clock back 3.5 billion years in his mind.

These particles interact, pushing and pulling each other, constantly throwing bits of information back and forth—their way of "talking." Electrons whiz around protons and the atoms they form are forever chatting with nearby atoms, joining into molecules, whose chemical reactions created the precursors of bacteria, plants and other organisms.

Finding out how all that happens, how life emerges from the interplay of inanimate matter, is the goal of a new $5 million grant from the National Science Foundation. Its ambitious aim is to duplicate the steps by which electrons, protons and all the other atoms and molecules form sets of chemical reactions that set the stage for life itself.

Among those whose work is funded by the grant are three University of Illinois scientists: physicist Nigel Goldenfeld, who studies snowflake formation in his pursuit of biological complexity; microbiologist Carl Woese, who has unveiled new phases

"IT'S NOT THAT BIOLOGY GIVES RISE TO JUST THIS INCIDENTAL TINKERING AROUND CALLED EVOLUTION. IT IS THAT EVOLUTION GIVES RISE TO BIOLOGY."—CARL WOESE



1 BILLION YEARS AGO
Cells called **algae** begin living together, becoming the first plants. This union allows each cell to perform a specific job. To make sure jobs aren't repeated, the cells develop hormones to communicate with one another.

700 MILLION YEARS AGO
More complex multicelled organisms evolve, including **jellyfish,** which develop muscles and nerves that allow cells to communicate more efficiently.

570 MILLION YEARS AGO
Jellyfish evolve into **flatworms,** which have organs, such as a stomach and brain, and a symmetrical structure that becomes the blueprint for all higher life forms.

500 MILLION YEARS AGO
The first vertebrates, some of which were ancestors of the modern-day **lamprey,** develop in water.

470 MILLION YEARS AGO
In the form of **ancient mosses,** the first life forms leave water to live on land.

100 MILLION YEARS AGO
First mammals appear. First apes appear 80 million years later.

100,000 YEARS AGO
Homo sapiens evolve with the largest brain in relation to body size.

of evolution; and chemist Zaida Luthey-Schulten, an expert in determining the molecular pathways needed for early metabolic activity.

They are, essentially, trying to create life in a test tube.

"All of these particles are inanimate," says Goldenfeld of the early universe, "but their dynamics are such that they form self-reproducing chemical reactions that feed on each other and the environment.

> "WE'RE UNDERSTANDING HOW REALLY SPECTACULAR CELLS ARE AT FIGURING THINGS OUT, PROCESSING INFORMATION, ANALYZING COMPLICATED SITUATIONS AND MAKING GOOD DECISIONS ABOUT THEM." —JAMES SHAPIRO

There's a gradual buildup of complexity as one stage creates elements that are then used to form the next stage.

"Although people have understood that process in a general way, we're trying to understand it in a very specific way."

For Woese, the opportunity to try his hand at creating life is a dream come true. A deep thinker who likes to cut through science's Gordian knots, he bears the academic scars from repeatedly upsetting biology's apple cart, and in the process bringing evolution into sharper focus.

In 1977, his brilliant analysis of the genetic composition of cells revealed a third form of life, after bacteria and plants and animals: the archea. They joined bacteria, whose genes are free floating in cells, and plants and animals, whose genes are packaged in a nucleus. Archea's genes are arranged in a way that lies somewhere between the system used by bacteria and animals.

Classical biologists were miffed at Woese's third life form, believing, as did Darwin, that the "tree of life" had only two main branches. Archea, they insisted, are not a separate branch but members of the bacteria family. How could an unknown upstart whose background was biophysics overturn a tenet of biology that had stood for nearly 150 years? One Nobel Laureate warned a colleague of Woese's to stop working with him if he wanted to salvage his own career.

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As technology improved and it became easier to trace the evolutionary history of life in genes, Woese's finding was finally accepted a decade later, and his three-branch tree of life is standard in biology texts.

Woese next went after a big stumbling block in classical evolution. Darwin's doctrine postulated that all living things eventually could be traced back to a single founding cell. But the odds against that happening are astronomically large. It would require all the building blocks of life to come together in one place at the same time to form the first founding parent.

Instead, Woese announced in 2002 that life did not start just once, as had long been taught, but possibly millions of times. It was relatively simple for raw chemicals, he said, to do what they do best—communicate and form bonds—and build the first primitive genes. These early organisms readily swapped genes among themselves, evolving more efficient survival skills in the exchange. Most of the early life forms consolidated or died off as three strains became dominant, he said, founding the three domains of life.

This time, recognition of his work was swift. In 2003 the Royal Swedish Academy of Sciences embraced the "Woesian revolution" by awarding him the $500,000 Crafoord Prize, which is given for scientific research not covered by the Nobel Prize.

His elevated stature hasn't changed Woese's work habits. He still sits in an old swivel chair, puts his feet up on a cluttered desk and with a computer keyboard on his lap lets his mind travel back in time more than 3.5 billion years to try to envision how life on Earth first started. The microbial world, he believes, holds the key to the genetic history of human evolution.

Biologists have long thought that the life of a cell depends on a two-step process: a source of energy and the molecules that take that energy and use it to perform their life-giving functions. But Woese thinks there is a crucial third step—organization. Things have a preferred way of getting together and that sets the course for evolution.

"Organization is not an arbitrary random ordering of things," he says. "Organization is something that evolves from within. It is the nature of the universe to organize with the passage of time."

And the laws of physics regulate that organization, he says. "Physics has changed. Physics is now talking far more about organization of our complex dynamic systems."

Woese made a discovery years ago that is now recognized as the possible missing link between physics and biology. He showed that long before amino acids became the building blocks of proteins, they had a special property, preferring either to associate with water molecules or be repelled by them, kind of like the 0's and 1's of computer code.

By communicating their preference, Woese and his colleagues believe, amino acids may have set about organizing how nucleic acids, the chemicals of genes, pair up with individual amino acids to knit them together into proteins. This dependence between amino acids and nucleic acids ultimately evolved into the universal genetic code of all living things.

"Evolution is the fundamental base of biology," he insists. "It's not that biology gives rise to just this incidental tinkering around called evolution. It is that evolution gives rise to biology."

Goldenfeld calls Woese's insight the turning point on the road to life. "This property that Carl measured is, in biology, like a relic of the Big Bang. It seems to be something that relates to very early properties of living matter, of the amino acids themselves before they became deeply involved in the molecules of life."

Evolution comes in two forms, Woese says. The first is the kind that he and his colleagues talk about, the natural inclination of the universe to organize into more complex structures, from atoms to living organisms. If the universe started over again, according to this line of thinking, it would have some interesting differences, but it would still end up very similar to the one we have now, complete with single-celled organisms, plants and animals.

THE SECOND IS the kind of evolution Darwin described from his observations of the variations in species caused by environmental pressures. So now we have Woesian evolution driven by the free exchange of genes among the first primitive cells, followed by the random mutation of genes that Darwinian evolution showed bestows better survival skills on organisms.

The University of Illinois' Nigel Goldenfeld is one of the beneficiaries of a $5 million grant from the National Science Foundation for the study of emergent properties as the model for cosmic change. "There's a gradual buildup of complexity as one stage creates elements used to form the next stage," he argues.

Norman Pace, professor of molecular, cellular and developmental biology at the University of Colorado, Boulder, says that the condemnation that Woese's ideas initially aroused evoked the ostracism Copernicus faced when he challenged existing dogma that the sun revolves around the Earth.

"It wasn't patently obvious to people in Copernicus' time that the Earth traveled around the sun, and in Woese's case they weren't prepared to think about the microbiological and deep evolutionary stuff he came up with," Pace says. "Woese has done more for biology than anyone since Darwin. What Darwin provided was mechanism, natural selection. What Woese gave us was evolution's map—here's what happened."

The U. of C.'s James Shapiro, a pioneer of emergent properties, faced similar skepticism when he first published his insights about cellular communication 17 years ago to an incredulous scientific community. In studying the behavior of bacteria he found that, although they consist of single cells, they do not behave like loners. They act together, just like an animal or any other multicellular organism.

His colleagues found this hard to swallow. "It wasn't well-received," he recalls. "I later learned that the people who study higher organisms didn't want bacteria to be able to do things higher organisms could do."

But now it's widely accepted that bacterial colonies of many parts can act as whole organisms. How they communicate and cooperate in large numbers has become the basis for studying how bacteria maintain the Earth as a livable planet. Because they make up the vast majority of living organisms, bacteria and archea drive biology's energy cycle, and they balance the atmosphere's oxygen and carbon dioxide content, among other things.

The communication among bacteria is similar to how our cells talk to each other. Human cells chat on a much more sophisticated level, doing such things as warding off cancer and repairing cellular damage. The chatter begins at conception when a fertilized egg starts dividing and daughter cells busily inform their neighbors whether they are headed off to become a brain, liver or toenail, so that they all don't try to do the same thing.

"What's going on in biology, and is really very major, is we're understanding how really spectacular cells are at figuring things out, processing information, analyzing complicated situations and making good decisions about them," Shapiro says. "The research agenda, at least for the beginning of the 21st Century, is focusing on cells and organisms as very sophisticated and powerful processors of information."

Others have shown how various organisms have evolved different ways to exchang this information. Ants, for example, communicate by chemical "words" called pheromones, as Harvard's E. O. Wilson discovered, leading him to develop the scientific discipline called sociobiology.

"The interesting point to be made is that different organisms and different cells use different modalities to communicate," Wilson says. "Humans are in a very small select group that use AV, audiovisual communication. Ants belong to the vast majority of organisms that use chemical pheromones, smells and tastes as their signal."

Organisms evolve these signals when it becomes advantageous to form groups that improve survival. "The group is better than the individual organism in competition for food, space and breeding," notes Wilson.

When Wilson expanded his theory to say that humans have social instincts that have a genetic basis, an irate scientist dumped a pitcher of ice water on his head at a meeting in 1978. The water-pourer objected on grounds that the brain was a blank slate and that whatever people do is learned. Since then science has come to terms with the joint roles that genes and learning play in behavior.

A key issue raised by the study of emergent properties is the nature of intelligence and consciousness, and whether bacteria or even diamonds can be said to think. Some scientists say this kind of communication is, indeed, a basic form of thinking. Others vehemently disagree. Intelligence, defined as the capacity to acquire and apply knowledge, is something only humans and maybe some animals possess, they argue.

"When two atoms start forming a crystal lattice, that is information transfer," says Hans Bohner, a University of Illinois professor of plant biology. "Some people would say a crystal has some intelligence, a salt crystal or a diamond, because the atoms are organized in a certain way. But I do not call that intelligence. It is intrinsic in the quality of the atoms."

While many scientists may be hesitant to give a diamond the benefit of thought, they are not so sure anymore about nonhuman organisms such as plants.

Plants process information and act on it, so they have a form of intelligence, says plant scientist Anthony Trewavas of the University of Edinburgh, Scotland, who has spent 40 years studying plant communication. They have self-recognition in the sense that they know the difference between another plant's roots and theirs. And they move and change shape, ever so slowly, to optimize exposure to the sun, water and nutrients.

"Part of the problem when I talk about plant intelligence is that people say, 'Oh, rubbish. They don't have a brain.' OK, they don't have a brain, but you don't need a brain for intelligence," he says. "What you actually need is an operating network of cells. If that network has a way of controlling the flow of information and manipulating it, in other words problem-solving, it is therefore regarded as intelligent."

Plants, for instance, can predict future shade from neighboring plants by sensing their infrared emissions, and undertaking maneuvers to move out of the way or to change their leaf structure so as to optimize the area for collecting sunlight.

Once considered fringe science, plant intelligence is being taken more seriously. Last May, an international group of scientists met in Florence, Italy, for the first Plant Neurobiology Meeting. A second one is scheduled for next spring in China.

Trewavas believes that brains evolved in animals, and not plants, because of the predator-prey relationship in animals.

Plants have no need for quick mobility

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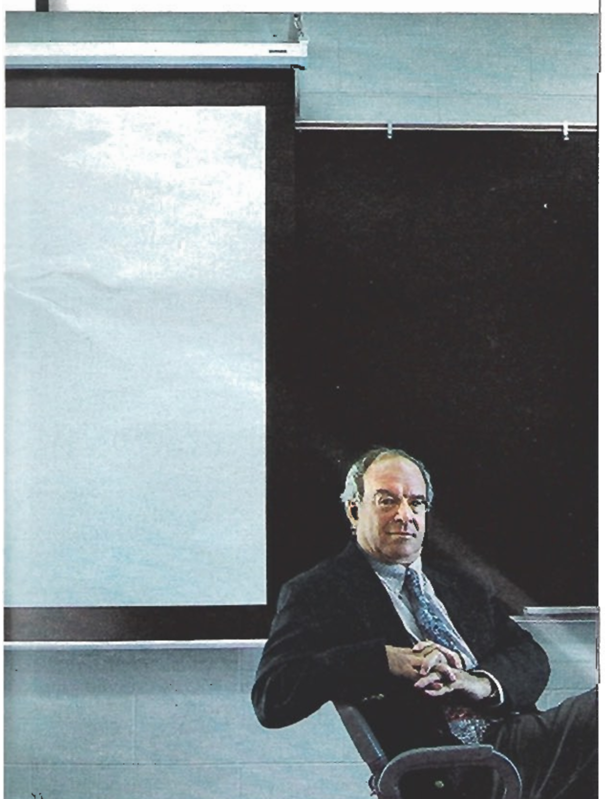


University of Chicago physicist Henry Frisch recalls his parents, both scientists, arguing over the origins of life.

Evolution

Continued from page 16

because they depend on the sun, soil and water for sustenance. But the first predatory organisms had to get smart to capture prey, and the prey needed to get smarter to escape. This resulted in a race to develop specialized cells to process information rapidly.

"You get this positive feedback system in which as predators become faster, prey has to become faster or it doesn't survive," Trewavas says. "You evolve even more nervous tissue to do it so you get up to organisms that now move extremely fast, at the speed we are familiar with . . . Eventually the brains continued to evolve until you end up with this complex structure with large numbers of emergent properties coming out that you cannot predict from the behavior of a few simple neurons—consciousness, for example, speech and things like that."

Giulio Tononi, a neuroscientist at the University of Wisconsin, says consciousness may, in fact, result when lots of information is shared at once. At the age of 16 in Italy, he decided that understanding consciousness was the greatest puzzle in science and he wanted to solve it. Now he believes the key may be understanding why consciousness fades when we fall asleep.

Consciousness, his theory holds, emerges when a system integrates information, such as when the different parts of the brain talk to each other. As sleep sets in, those parts stop talking among themselves, thereby dissolving the state of consciousness that emerged from that communication network.

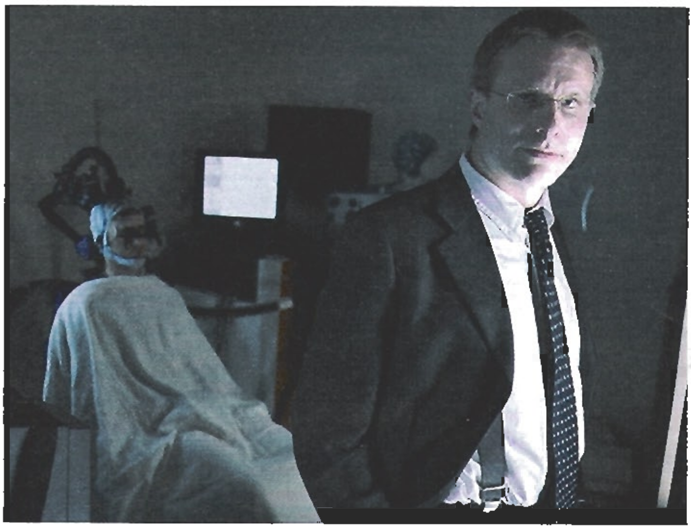
Scientists used to think that consciousness vanishes during non-dreaming sleep because the brain rests and stops working. Researchers showed that was wrong when they discovered that during slumber the brain is still electrically and chemically as active as during wakefulness.

Consciousness fades away not because the brain takes a nap, Tononi speculated, but because its different parts stop communicating. To test his prediction, he and his colleagues performed an ingenious experiment: When they electrically stimulated an area of the awake brain, that part quickly sent out conference calls to many other parts. But in the sleeping, non-dreaming brain, stimulation produced no conference calls. The area of the brain that was dialed up by the small jolt of electricity sat on the message.

"It fit exactly the key prediction of the information-integration theory," Tononi says. "The effect was very clear-cut."

Even though self-awareness, or consciousness, is the least understood property of matter, humans prize it for giving us the ability to quickly adapt to changing situations and thus a tremendous evolutionary advantage.

But all life forms solve problems, and Tononi says we may be small-minded in asserting that other organisms, or for that matter inanimate things, do not experience a degree of consciousness.



University of Wisconsin neuroscientist Giulio Tononi believes that consciousness consists of the different parts of the brain talking to each other, a state that vanishes during sleep.

"If you say that consciousness is a system's ability to integrate information, then anything that's made up of interacting parts will have a little amount of consciousness," he says. "Does a crystal have consciousness? At one level I have to say yes, but at another level I'd say it is so low that it's basically nothing. Animals will have it for sure, apes, monkeys, cats and dogs."

Even single-cell organisms might be said to have consciousness. The bacterium E coli, for example, can tell when its DNA has been damaged and turns on repair systems. It holds up cell division until all the DNA is mended so that daughter cells will be healthy. It can then "sense" when the repair is complete.

"Do you call that self-awareness? I don't know," Shapiro ponders. "You can get into a long debate about that. But until we understand emergent properties like that more thoroughly than we do, it's difficult for us to deal with some of these large philosophical issues.

"There's a lot of surprises coming up in biology and it's precisely this focus on information processing that is going to bring those surprises to us." □