Creative Nets in the Precambrian Age

By Howard Bloom.

A History of the Global Brain II

For roughly ten years authors and scientists have been churning out books on the subject of a coming global brain strung together by computer networks. The Internet, the

Worldwide Web and its successors already allow a neuroscientist in Strassburg to swap ideas instantly with a philosopher of history in Siberia and an algorithm juggler in Silicon Valley. But that, the visionaries of worldwide meta-intelligence say, is just the beginning of a looming human transformation. But a networked intelligence is very much older. In fact the origin reaches back in the beginning of life. Howard Bloom presents impressing insights into the world of networked bacteria - a fascinating new perspective which could change deeply our view of life.

Cells Alive

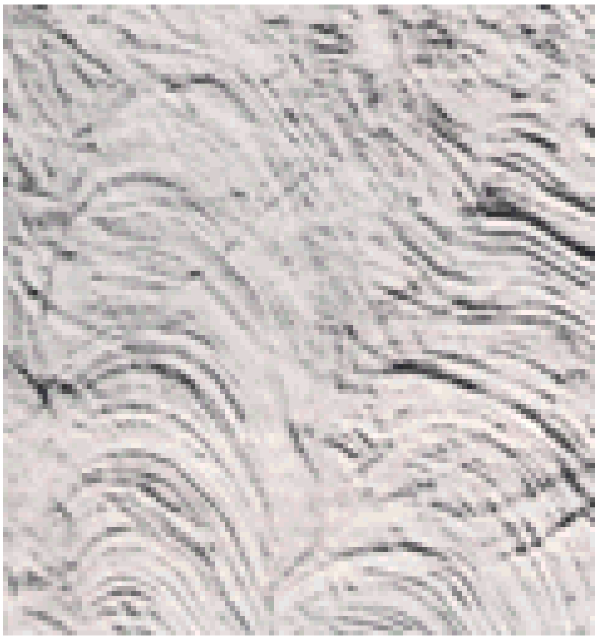
prokaryotic microorganism

My sixteen years of interdisciplinary work seem to demonstrate something very different. Yes, the computerized linking of individual minds is likely to bring considerable change. But a worldwide neocortex is not a gift of the silicon age. It is a phase in the ongoing evolution of a networked intelligence which has existed for a very long time. And it is neither uniquely human nor a product of technology. Nature has been far more clever at connectionism than we have. Her mechanisms for information swapping, distributed data processing, and collective creation are more intricate and agile than anything the finest computer theoreticians have yet devised.

The first shock to the theorists of electronically-networked intelligence might well be the biotic counterpart's age. Gravity pulled this earth together 4.7 billion years ago. A mere 500,000 years after the new sphere's crust had stabilized, the powers of chemical attraction yanked together the first detectable life. And a geological wink after that - in roughly 3.5 billion b.c.- the *first communal "brains"* were already making indelible marks upon the face of the waters. Those marks are called *stromatolites* - mineral deposits ranging from a mere centimeter across to the size of a man, and even to the vastness of a reef. Stromatolites were manufactured by cooperating protist colonies with more microorganisms per megalopolis than the human population of Mexico City. These prokaryotic communities throve in the shallows of tropical lakes and of the ocean's intertidal pools.

prokaryotic microorganism

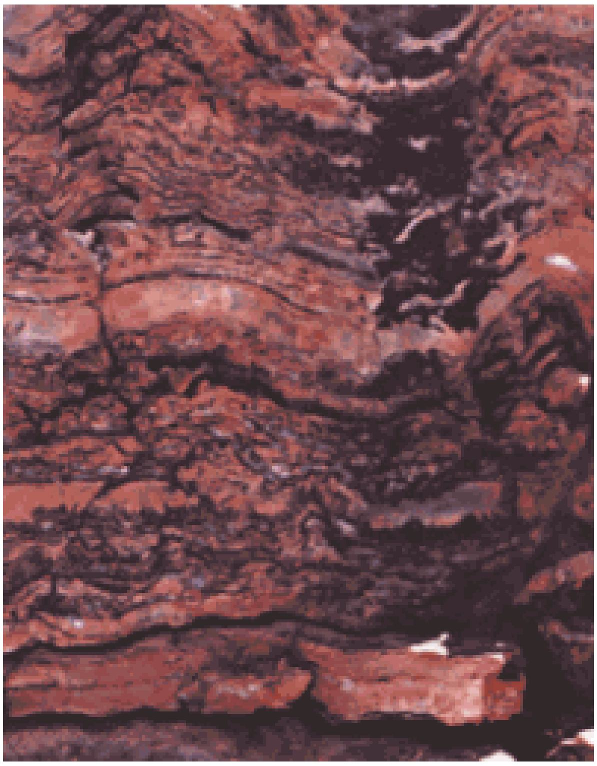
The rocky deposits ancient stromatolites have left behind were created by legions of *cyanobacteria*, organisms so internally crude that they had not yet gathered their DNA into a nucleus. But in their first eons of existence, these primitive cells had already mastered one of the primary tricks of society: the *division of labor*. Some colony members specialized in photosynthesis, storing the energy of sunlight in the ornately complex molecules of ATP. The sun-powered assemblers took in nutrients from their surroundings and deposited the unusable residue in potentially poisonous wastes. Their vastly different bacterial sisters, on the other hand, feasted on the toxic garbage which could have killed their photosynthetic siblings.



stromatolite

The mass of these interdependent beings were held together by an overarching shelter of their own construction. A mini-lasagna of interlayered cyanobacteria would begin a circular settlement. The waters within which the homestead was established would wash a layer of clay and soil over the nascent encampment. Some of the bacteria would send out filaments to bind these carbonate sediments in place. Tier by tier, the colony would create its infrastructure, an undulose or dome-like edifice which could easily become as large compared to the workers who had crafted it as Australia would be to a solitary child with pail and sand shovel.

Many stromatolites carry a peculiar clue whose meaning has gone overlooked. Their fossilized remains spread from a common center in ripples - a pattern extremely familiar to the handful of scientists studying a previously unsuspected bacterial property - *social intelligence.*



stromatolite

For generations bacteria have been thought of as lone cells, each making its own way in the world. Ben Jacob and Shapiro, on the other hand, have demonstrated that few, if any, bacteria are hermits. They are extremely **social beasts**. And undeveloped as their *cellular* structure might be, their *social* structure is a wonder. The ripple effect is one manifestation of a colony's coordinated tactics for mastering its environment. We could call it the probe and feast approach.

A bacterial spore lands on an area rich in food. Using the nutrients into which it has fallen, it reproduces at a dizzying rate. But eventually the initial food patch which gave it its start runs out. Stricken by famine, the individual bacteria, which by now may number in the millions, do not, like the citizens of Athens during the plague of 430 b.c., die off where they lie. Instead these prokaryotes embark on a joint effort aimed at keeping the colony alive.

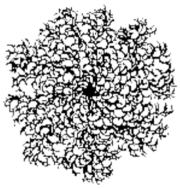
The initial progeny of the first spore were sedentary. Being rooted to one spot made sense when that microbit of territory was overflowing with edibles. Now the immobile form these first bacteria assumed is no longer a wise idea. Numerous cells switch gears. Rather than reproducing couch potatoes like themselves, they marshall their remaining resources to produce daughters of an entirely different kind - rambunctious rovers built for movement. Unlike their parents, members of the new generation sport an array of external whips with which they can snake their way across a hard surface or twirl through water. This cohort departs *en masse* to seek its fortune, expanding ring-like from the base

1 THE NETWORKED BACTERIAL "BRAIN"

Eshel Ben Jacob, at the University of Tel Aviv, and *James Shapiro* at the University of Chicago have been studying bacterial colonies from a radically original perspective - and have emerged with surprising results. Their findings explain why the ripple effect is a mark of **bacterial networking** - and of much, much more.

established by its ancestors. The travels of the fortunate lead to yet more food.

Bacterial Cybernetics Group



Eshel Ben-Jacob

Successful foragers undergo another mass shift. They give birth to daughters as determined to stick to one spot as their grandparents had once been. These stay-at-homes sup on the banquet provided by their new surroundings. Eventually their perch, too, is sucked dry. They then follow bacterial tradition, generating a new swarm of outbound pioneers. Each succession of emigrants leaves behind a circle thinned by its spreading search. And each generation of settlers accumulates in a thick band as it sucks nourishment from its locale. The ripples of ancient stromatolites are proof positive that life three and a half billion years ago already took advantage of *social cooperation*.

The work of Ben Jacob and Shapiro has demonstrated that bacterial communities are elaborately interwoven by *communication links*. Their signalling devices are many: chemical outpourings with which one group transmits its findings to all in its vicinity; fragments of genetic material, each of which spreads a different story from one end of the population to another. And a variety of other devices for long-distance data transmission.

These turn a colony into a collective processor for sensing danger, for feeling out the environment, and for undergoing - if necessary - radical adaptations to survive and prosper, no matter how tough the challenge. The resulting modular learning machine is so ingenious that Eshel Ben Jacob has called it a **"creative net."**

Take, for example, a process which may have led to the fossilized stromatolites that snake like epileptically misshapen sausages over a distance of two meters or more. All bacterial colonies do not use the round ripple strategy to explore and exploit. Some, like aquatic *myxobacteria* - gang-hunters which pursue prey ranging from fellow microorganisms to fish - will stretch and twist until they catch the chemical scent of a victim. But to understand the internal workings of one of these writhing cooperatives, it is wise to peer over Eshel Ben Jacob's shoulder as he carries on his seven-year study of *bacillus* and discovers how individual bacteria are "pre-wired" to be components of a larger information processing machine.

When famine strikes, some bands of bacterial outriders blaze a long trail which leads to territory as barren as that from which they have fled. But they do not suffer their fate in silence. For they are the sensory tentacles with which the larger group feels out its landscape. As such, they must communicate their findings. To do so, they broadcast a chemical message: "avoid me." Other exploring groups heed the warning and shun their sisters stranded in the desert. By releasing chemotactic repulsers, the failed scouts have sealed their fate. They will die in the Sahara into which they've wandered - unaided and alone. But their suicide has served the collective information-gathering process - adding survey reports to an expanding knowledge-base about the surrounding terrain.

Other bacterial cells encounter turbulent conditions which destroy them before they can transmit their chemical evaluations. But they, too, manage to ship back information about their findings. For the fragments of their shredded genomes filter through the colony, carrying a message of danger. Then there are the voyagers whose trek takes them to a new promised land. These send out a chemical bulletin of an entirely different kind. Loosely translated, it means, "Eureka, we've found it. Join us as quickly as you can."

In all this, the bacterial colony is displaying the classical characteristics of a **complex adaptive system** - a collaborative learning device. As *John Holland*, an early pioneer of complex adaptive systems studies, puts it, the "behavior of a diverse array of agents" when merged results in "aggregate capabilities" far beyond those of any individual. These are the powers of a massively parallel distributed system - another example of which is the modern supercomputer.

But Ben Jacob's studies suggest that the bacterial colonies of 3.5 billion years ago had taken giant strides beyond any computer man has yet built. For the informationally-linked microorganisms under Ben Jacob's microscope demonstrate a skill exceeding the capacities of any device from Cray Research or Fujitsu. Working as a group, bacteria possess a transformative knack long thought impossible. Not a random process like mutation, but a *goal-driven, "teleonomic" talent*. They are capable of acting as their own genetic engineers. In fact, they utilize the same tools as modern science's genetic tinkerers: plasmids, vectors, phages, and transposons. Should the colony's strategy of group hunt and peck prove useless, the messages sent back to the center do not unleash new waves of migrants. They become the raw data for genetic research and development.

Ben Jacob was curious to determine just how inventive the genomic-resculpting process could be. Did bacteria with their backs to the wall merely plug in prefabricated twists of DNA and revert to ancestral strategies? Or could they create solutions which were entirely new? The Israeli physicist-turned-microbiologist explains how he administered microbial ingenuity tests.

> We tried exposing bacterial colonies

> to conditions so novel that the creatures could never have encountered them before. Tough conditions, conditions of life and death. We wanted to know how inventive they could be in reworking their genetic code. For example, we took bacteria that can't move on agar but are able to roam freely in liquid. We put them on the wilderness of their worst nightmares, agar, and deprived them of food. The need to branch out in search of grazing land was a true creative challenge.

Ben Jacob
By forming a modular network beyond the supercomputer and retooling the very genome at their heart, the massed experimentation teams were able to solve the problem. So the networked minds of computer visionaries' dreams replicate one of the most ancient life strategies on this earthly sphere.

2 COMMUNICATION LINKS

Beyond mere networking lies another futuristic vision - that of the **global brain**. Here, too, the microbe has by far outdistanced humankind. Bacteria and their frequent enemies, the viruses, have long since mastered the art of worldwide information exchange. Both swap snippets of genetic material like humans trading how-to books. This system of molecular gossip allows microorganisms to telegraph an improvement from continent to continent. And the nature and speed of communication can be awesome. Let's take some modern examples. Viruses are such effective collectors of genetic parings that they've been known to clip and paste molecular material from whales to sea gulls, from monkeys to cats, and in the lab can transfer firefly genes into the cellular control panel of tobacco leaves, inspiring shaggy greenery to glow in the dark. Bacteria also benefit from this worldwide system of genetic mix and match.

In modern times, members of the microbial sisterhood have demonstrated the power of their *information splicing*. During the 1980s, newborns in modern hospitals unexpectedly died of pneumonia. Adults recovering from surgery came down with mysterious infections. The problem was not limited to one small spot. Patients in Germany, France, the United States, and Japan were besieged by new forms of bacterial attack. Most baffling of all was the fact that the bacteria pulling off these surprise assaults seemed capable of developing resistance to half a dozen antibiotics nearly overnight. A clinic in Tokyo would report that bacteria had suddenly shown an ability to storm the defenses erected by the formerly impregnable drug streptomycin. At almost the same time, a hospital in San Francisco would announce that the bacteria in its corridors seemed to have mastered the same dismaying trick.

The genetic equivalent of *data-base sharing* had allowed viruses and bacteria to outrace scientists networked by telephones, computers, international conferences and journal articles. And the new techniques the global microbial brain concocted were devilishly clever. For example, beta-lactam disrupts the construction of the bacteria's outer wall. Once pharmaceutical companies had perfected beta-lactam-producing antibiotics, they regularly changed their discoveries' composition to overcome bacterial evolution. The race between researchers and their microbial adversaries began in 1942. Scientists were in the lead for decades. Then the bacteria finally outpaced the researchers.

The beta-lactam antibiotic functioned by destroying a bacterial enzyme called beta-lactamase. Infectious bacteria countered by borrowing the instructions for impervious forms of beta-lactamase from non-infectious strains or by developing impregnable new varieties of their own.

Tetracycline, another formerly sure-fire disease killer, had been a drug of choice in the '60s, '70s and '80s. But by the '90s tetracycline was almost entirely ineffective. This antibiotic did its trick by sabotaging bacteria's pivotal protein synthesizers. The bacteria countered by developing a pump that literally spat the antibiotic out.

Today's microorganisms can move so quickly because they piggyback on two advantages their primordial relatives did not have - the ability to snatch useful genetic twists from millions of different species; and the helpfulness of high speed aircraft in transporting innovations from one population center to another.

But do not underestimate the potential reach of the microbial net in pre-Cambrian times. The odds are good that the earliest microorganisms rode planet-sweeping currents of wind and water. And scientists have already discovered eleven different bacterial types whose age seems to go back well over three billion years. Given the newness of these findings, this eleven are likely to be revealed in the next decade as the merest sliver of proto-biotic life's diversity. In all probability, then, the microbial global brain - gifted with long-range transport, data trading, genetic variants from which to pluck fresh secrets, and the ability to reinvent the genome itself - came into existence some 3.5 billion years before the birth of the Internet.

Ironically, future *multi-cellular* forms would come to land and sea with a plethora of new capabilities. Their microbial neighbors would continue to use the global brain. But despite the fact that networked intelligence would remain a key to the more "advanced" species' survival, it would take roughly 1.5 billion years of trial and error before the *global* brain would rise among the "higher animals"... along with the early spread of tools of stone.

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