Networking in Paleontology's "Dark Ages"

By Howard Bloom.

History of the Global Brain III

Since software innovations - new forms of behavior and interaction - leave few fossil records, and since paleontologists have been virtually blind to proterozoic social activity, the record *seems* barren. But evidence indicates that intimate forms of organization were undergoing long and ever more intricate trial periods, resulting in multi-cellular life forms and brains as internets.

> Vitalism is not the only alternative to Darwinism. I propose a new option, that of cooperative evolution based on the formation of creative webs. The emergence of the new picture involves a shift from the pure reductionistic point of view to a rational holistic one, in which creativity is well within the realm of the Natural Sciences.

Eshel Ben-Jacob

In our , I laid out evidence indicating that the global brain foreseen by computer-futurists already existed 3.5 billion years ago. I attempted to demonstrate how the biology of the primitive *cyanobacterium* equipped it to act as a component in a parallel-distributed intelligence. The result: a social colony capable of networking data, solving problems, creatively retooling genomes, and of transmitting and receiving genetic upgrades via a worldwide web.

But 3.5 billion years b.c. was long ago. What, if anything, has happened to the global brain since then?

The story is a strange one. Evolution went on to produce life forms with radically new powers. Many of these retained the ability to operate as local networked intelligences. But in the course of their development, an ironic slippage took place. Bacteria and viruses, those stalwart veterans of the days shortly after the earth's crust first formed, held on to their global research and development system. But "higher" life forms, gifted with capacities whose full potential would ripen only with time, took what seems on the surface to be a large step backward. Yes, they preserved their ability to cluster in social groups and act as communal information processors. But high-speed global data pooling would remain a microbial specialty, one which the "advanced" species would take at least 2.1 billion years to reinvent. This is the next episode in the story of how and why.

1 Early Networking

The picture of early life is currently in flux, with new discoveries and fresh theories emerging month by month. But despite the shifting collage of guesswork and evidence, two facts stand out:

1) Each find pushes life's evolution further back in time. In November, 1996, the age of the first cells leaped from 3.5 billion years to 3.85. In the decade from 1986 to 1996, the age of the first nucleated cells bounced from 1.6 to 2.1 billion years.

2) More important, networking, often called synergy, has been a key to evolution since the universe's first second of existence. Roughly twelve to twenty billion years ago, a submicroscopic pinpoint of false vacuum arose in the nothingness and expanded at a rate beyond human comprehension, doubling every 10-34 seconds. As it whooshed from insignificance to enormity, it cooled, allowing quarks, neutrinos, photons, electrons, then the quark-triumvirates known as protons and neutrons to precipitate from its energy. A neutron is a particle filled with need. It is unable to sustain itself for longer than ten minutes. To survive, it must find at least one mate, then form a family. The initial three minutes of existence were spent in cosmological courting, as protons paired off with neutrons, then rapidly attracted another couple to wed within their embrace, forming the two-proton, two-neutron quartet of a helium nucleus. Those neutrons which managed this match gained relative immortality. Those which stayed single ceased to be. (Roughly twelve billion years later, the universe remains 25% helium.) Protons, on the other hand, seemed able to survive alone. But even they were endowed with inanimate longing. Flitting electrons were overwhelmed by an electrical charge they needed to share. Protons found these elemental sprites irresistible, and more marriages were made. From the mutual needs of electrons and protons came atoms. Atoms with unfinished outer shells bounced around in need of consorts, and found them in equally bereft counterparts whose electron protrusions fit their empty slots (and vice versa). Through these connective compulsions, to paraphrase Yeats, "a terrible beauty was born."

And so it continued. A physical analogue of unrequited desire was stirred by allures ranging from the strong nuclear force to gravity. These drew molecules into dust, dust into celestial shards, and knitted together asteroids, stars, solar systems, galaxies, and even the mega-matrixes of multi-galactic whorls. Theories like those of *Claude Shannon* imply that the intertwined elements were bundles of information - skeins of data whose proliferation of plugs and sockets disgorged newnesses at every turn.

One of the products of this inorganic copulation was life. The latest findings suggest that shortly after the molten earth began to harden its shell and massive rains of planetesimals ceased smacking this sphere like a boxer pummeling the face of his opponent, RNA paved the path for DNA. Massive minuets of deoxyribonucleic acid generated the first primitive cells - the prokaryotes - by 3.85 billion b.c. And 350,000 years later, unmistakable signs of complex social life - the multi-million-inhabitant bacterial megalopoli called stromatolites - appeared. Then paleontological dogma has it that virtually nothing of significance occurred until the Cambrian explosion roughly 535 million years ago. One popular science writer, summing up the opinion of the experts, calls this interim "three billion years of non-events" (*Karen Wright*, "When Life Was Odd," Discover Magazine, March 1997, p. 53). Oh, there was the occasional burp, say the yawning authorities. But such moments of evolutionary indigestion are hardly worth mentioning.

2 Confederations of smart molecules

The hints are many that there was little to yawn about. Since software innovations - new forms of behavior and interaction - leave few fossil records, and since paleontologists have been virtually blind to proterozoic social activity, the record *seems* barren. But evidence indicates that intimate forms of organization were undergoing long and ever more intricate trial periods.

The first cells - the prokaryotes - were highly coordinated confederations of what, for lack of a better term, we would have to call "smart molecules." Each of these molecular agents was dedicated to a vital function. Some pumped sugars and amino acids, responding to needs in the locations they served. Others reacted to power demand, disassembling molecular fuel to liberate its energy. Still others tuned the chemical balance, assembling proteins, amino acids, nucleotides, vitamins, and fatty acids even a human body cannot make by itself. (We use prokaryotes - bacterial colonies in our guts - to handle some of these manufacturing chores for us). Molecular groupings within the prokaryotic cell sensed food or danger and passed the message along to other molecular squadrons which created movement, allowing their host to pounce or to race away.

This coordinated operation of molecular agents resulted in such prokaryotic beings as bacteria, entities far more flexible than any mere computer net. Bacteria have populated the earth for at least 82% of its existence. Today, they are still going strong. However the fossil record shows new forms of interaction emerging as early as 2.1 billion years ago, when the first macroscopic organism, *grypania*, makes a hesitant appearance. This hoop-shaped relative of cyanobacteria, the size of a wire wrapped around a penny then let loose, is thought to have been the first eukaryote. If this hypothesis is true, *grypania* represents not only a major leap in size, but a form of life which thrived on radical breakthroughs in biological intranets.

3 The Invention of Intranets

Eukaryotic cells were bacteria capable of taking on fellow bacteria as boarders. They made permanent residents of such visitors as *mitochondria* (proteobacteria-like energy generators), *chloroplasts* (cyanobacteria-like solar converters which handle photosynthesis), and, most important, *spirochetes*. Spirochetes - wiry and multi-talented - were commandeered as struts for an intra-cellular skeleton, as contractile fibers for internal transport, as whirling oars for external movement, and as organizers for the reproductive splitting of the eukaryote's enormous genetic mass. All these former guests were now reproduced along with each replication of the host cell. It was largely this merged approach which, according to biologist *Lynn Margulis*, allowed life to survive the first toxic pollutant holocaust - the spread in the atmosphere of a gas lethal to previous life, oxygen. For mitochondria gulped oxygen and turned it into fuel. And other members of the new intracellular commune were able to clean up the poisons which oxygen left behind.

As so often happens in examining life, computer metaphors are too limited to describe the result. Even a bacterial colony is a flexible, self-organizing, self-repairing, and self-improving parallel processing device which not only reprograms and computes but acts out its calculations, then responds to the consequences. While a single bacterium is a biochemical net, the eukaryote is the web which emerges when masses of biochemical nets fuse.

At level after level, purposeful assemblies mesh to form a processor/responder which, in turn, becomes a module in the next step up the networking ladder. One of these modules is the gene. Another is the chromosome - a lengthy chain of genes which not only work together, but are welded into a single molecule. (Contrary to the implication of the phrase "the selfish gene," all genes function in teams. Even the genes of a bacterium are welded in a circular chromosome.)

A prokaryotic bacterium, with its free-floating single ring of DNA, could not accomplish the elaborate form of cell-division known as meiosis, a highly orchestrated process which would eventually make sexual reproduction - a key form of information mixing and matching - possible. This revolution in data-exchange would emerge from a eukaryotic invention - the marshalling of multiple chromosomes into files arrayed within a nucleus. Chromosomes regimented like well-drilled parade teams could mass in genomes literally a thousand times larger in size and infinitely greater in complexity than their predecessors.

Margulis contends that the eukaryote's tamed spirochetes could not perform the interior superintendence of replication and the exterior job of propulsion simultaneously. Leaving a cell immobilized through its "pregnancy" was a dangerous business. The dividing eukaryote could not aggressively seek food. Nor could it avoid the attacks of predatory fellow-eukaryotes whipping through the water in search of victims. The solution: to concentrate spirochetic propellers on the outside of one cell, then to generate an attached cell whose spirochetes could remain indoors handling reproduction. Thus, according to Margulis' spirochete hypothesis, the communal gathering within a cell led to another massive leap in the evolution of networks: multicellularity.

Colonies of single-celled organisms could be sieved apart, then if given freedom, were (and still are) able to reconstruct their shattered *polis*. The multicellular entities which emerged at the end of the paleoproterozoic era had lost that option. In exchange, they had gained the opportunity to perform far grander functions.

The first possible remains to be found so far of multicellular organisms, crudely called carbon films, were probably the leaves and strands of *early seaweeds* - 1.6 billion year old amalgamations of the prokaryotic algae to whose category *cyanobacteria* belong. These precocious eukaryotes were, according to some paleontologists, passive multi-cellular sheets which could only wave in the currents or settle on seabed rocks.

But the fossil record hints that a billion years ago, *single-celled eukaryotes* lifted themselves from the solar submissiveness of plants and showed the aggressive and restless characteristics we associate with animals. The one-celled rovers possessed internal skeletons of former spirochetes, external "shells" called pedicles, and the ability not only to whisk through water but to crawl along thanks to spirochetic microtubules which pulled one shell segment together with another then relaxed the pair again. Helping these protozoans achieve size and new functions were breakthroughs like a system of inner pipes and bladders which collected water and spat it out before an overload could bloat the cellular interior. This bilge-pump anticipated the later invention of the kidney. Another major advance was "development" - the ability to assume a succession of physical forms each dedicated to a different purpose. A protozoan might begin life as a fast *moving flagellate*, seek out new territory to mine, then settle down to the slow moving but powerful *blob of an amoeba* - a supreme environmental exploiter. This is the equivalent of being a scout plane early in life and a harvesting machine once a field of grain has been found.

4 The Advent of the Nervous System

There are tantalizing hints of innumerable as-yet-undiscovered steps in another key networking technology - the advent of a nervous system. 3.5 billion year old *cyanobacteria* were already capable of transmitting data from sensory molecules within the cell to molecular motion-makers, allowing a bacterium to scoot from trouble and zip toward opportunity. Cyanobacteria in colonies evolved the ability to broadcast data using chemical transmissions and genetic bits which travelled like messages in a bottle through the community and beyond.

But the eukaryote - an assembly of formerly independent beings which must live and die in unison - is a far larger and more intricate beast. Its equipment for internal communication includes the cytoskeleton - a tubular matrix alive to the nature of its surroundings. The *cytoskeleton* is such an agile coordinator that some audacious theorists have called it a cellular "brain." Interior data traffic is also aided by "second messengers" like cyclic AMP, which collects bulletins arriving at the ports of the outer membrane and rushes them to their targets, readjusting the operation of membrane channels, turning on energy-producing mechanisms, activating specific enzymes, and even changing the cell's speed and direction - literally altering its mission. Cyclic AMP's travels are notable not only for the accuracy of their routing but for the cluttered distances they cover. The average eukaryote is ten times the size of a prokaryote - and some eukaryotes are many thousands of times that of their cellular predecessors. Rapid detection by the membrane and the equally swift reactions made possible by second messengers proved extremely necessary.

Protozoans are endangered by fast-moving cousins, the carnivores of their world. Some *eukaryotic hunters* are equipped with poison launchers (toxicysts) on their exterior along with the flagella and cilia needed for brisk movement. A protozoan on the prowl needs to coordinate a host of spirochetic whips and propulsive whiskers (cilia) to produce precision movement. Its potential prey, provided with similar propulsion devices, has to be equally exact in marshalling its organs for evasion.

But more indicates that the prototype of a nervous system was in the making. The primary sensory ability of a prokaryote like a bacterium seems to have come from its ability to detect chemical gradients - flows whose growing weakness or strength allowed the bacterium to determine whether it was swimming toward or away from a chemical beacon's source. Single-celled eukaryotes moved a giant step further, developing specialized sentinels. One example is the eyespot of the *Euglena*. Some Euglena use this photoreceptor in tandem with another light-detecting speck on one of the flagella near their mouths, thus evolving an early forerunner of stereoscopic vision - dual-organ phototaxis.

Each bacterium had carried its own microprocessor - its single chromosome. A bacterial colony networked these isolated calculators into an awesome creative brain. But once again eukaryotic animals leaped ahead. They went from a single internal processing, programming and reengineering unit per cell to a tightly knit machine of many bound together in the nucleus. To generate additional information processing power, some cells had two or more of these multi-tiered thinking centers. A standard arrangement was to allocate the task of reproduction to a micronucleus and move the job of controlling daily cell life to a macronucleus up to forty times larger in size. Two proto-brains for the price of one.

What's more, single-celled eukaryotic protozoa, like their bacterial predecessors, were highly social beings. Extrapolating backwards from their behavior today, we can infer some of the resulting benefits. The 65,536 semi-independent cells in a *Volvox* took a major step toward a hitherto unknown pleasure - sexual reproduction. Gathered in a pinpoint-sized (1 mm.) hollow ball, the colony members divided into two different forms. One group concentrated on composing the cooperative's balloon-like body. The other, located prophetically in the posterior, focused on reproduction. Thus began the differentiation between somatic and germ cells which would be critical to the development of "higher" organisms. Volvox were apparently not content with one proto-sexual invention. They also were among the first forms to generate male and female colonies.

Prokaryotic *myxobacteria* form a "fruiting body" when they congregate - however it is so small that it must be magnified roughly 200 times before its details become clear. The height the tree-like structure can provide as a takeoff point for its spores is minuscule. However eukaryotic amoebas can join together in a giant cell roughly a foot (30 centimeters) across. That blob, called a *plasmodium*, holds within it literally billions of nuclei, and is able to undergo either sexual reproduction or to take another route and become a fruiting body immensely loftier than that of its bacterial counterpart. Should it "choose" sexuality, the plasmodium is able to complete a host of radically new processes which, in more advanced beings, would allow for the creation of an embryo. This has led some scientists to conclude that plasmodial slime molds - as these colonies of talented eukaryotic amoeba are called - may be a missing link between single-celled animals and such multi-celled beasts as you and me.

The jump in information exchange between eukaryotes showed yet another step toward the development of a nervous system. Several forms of cilia-powered protozoans (*Carchesium* and *Zoothamnium*) produced a second generation which, unlike their unicellular parents, did not totally wall themselves off at birth. Their direct connection to each other allowed one cell to sense an obstacle or an opening and to flash the data so fast that the multitude could react almost instantly and in total coordination. The "wiring" between cells prefigured neural components. Both were remodeled spirochetic microtubules , and both shared roughly 100 signal-transmission proteins The odds are good, then, that in the 2 billion years now blank to us, numerous further elements of primal nervous systems were developed through trial, error and occasional purposeful invention. (See my for evidence of purposeful invention among the earliest bacteria.)

These evolutionary achievements were incremental steps toward multi-cellularity. And as Wurzburg University biologist *Helmut Sauer* puts it, "Once multicellularity is established, all kinds of fungi, plants, and animals can evolve...."

5 Agglomeration of Machines within Machines

True to Dr. Sauer's words, 1.4 billion years after the new eukaryotic refinements had begun, the first truly exotic multicellular beings appeared. One recently discovered *fossil clam* dates to over 720 million years ago. The clam was a terra-flop ahead of anything seen before, dwarfing interlaced protozoans in size, complexity, and internal wiring. It possessed two hinged shells operated by a pair of powerful muscles capable of opening with exquisite control and clamping shut with massive power; a tongue-like foot of muscle able to dig a hiding hole in the sea bottom; a tube to penetrate above the marine floor and siphon oxygen-and-food-rich water below the surface when the being buried itself; and a filter-system of cilia through which the clam could pump the liquid it had sucked, and with which it could then sift out protozoans and other edibles, passing them via mucous carrier to the mouth. The early mollusk even possessed a heart with three chambers. All of this had to be wired to a host of sensors and a nervous system whose central direction was handled by three processing clusters (ganglia). Without exquisite synergy, these separate components would have been useless. When networked, they constituted something truly unprecedented: an immense and purposeful union of interacting parts - a nearly infinite agglomeration of machines within machines.

The era of this bivalve's birth was dominated by strange and as-yet-little understood creatures - the *Ediacarans*. These wildly varied higher life forms were apparently soft-bodied beasts living near the ocean's surface or crawling on its bottom. The complex multi-legged physiology of some indicates advanced data transmission between the billions of cells which made up each creature. Alas, the Ediacarans' full story and any hints it may carry regarding their mechanisms for information exchange is still shrouded in ignorance.

Yet we do have unmistakable indications that sociality continued. *Trilobites* dominated the period from 600 million to 500 million years ago. These armored sea scourers had not only heads, eyes, sensory antenna, and all the indications of a nervous system centralized in a brain, but their fossils tend to be found in groups. Some paleontologists, extrapolating backwards from the behavior of such trilobitic living relatives as horseshoe crabs, suspect that the armored ancients gathered for mating orgies in which they shed their shells for maximal body contact. Trilobite-specialist *Kevin Brett* cites evidence that males may have been larger than females (or vice versa), and that many trilobites were, in his words, "quite ornate." From that and the positioning of trilobites in fossil beds, he proposes the sexual festivities may not have been entirely promiscuous. Modern "toads," he points out, "will mate with just about anything - so they don't necessarily recognize members of even their own species." Brett suspects that trilobites were a bit more discerning.

Noted invertebrate zoologist *K.B. Clark* theorizes that the foot-and-a-half long (.5 meter), torpedo-shaped *Anomalocaris canadensi* swam in feeding herds. "The largest animals in most ecosystems are typically herding herbivores," he notes, "and I see nothing about Anomalocaris that precludes this." However Dr. Clark admits that science has neglected the study of the fossil indicators which could reveal further details of Cambrian social life.

One thing seems certain: a huge step forward was also an enormous step back. As *Lynn Margulis* and *Dorion Sagan* point out in their brilliant book **Microcosmos**, multi-celled organisms lost the rapid-fire external information exchange, extemporaneous inventiveness and the global data-sharing of bacteria, which continued living side by side with macrobeasts as both helpers and adversaries. Physicist-turned-microbiologist Eshel Ben Jacob argues that multi-celled eukaryotes did at least continue to exchange and reengineer genes, maintaining local versions of what he calls "creative webs." Communicating over small distances, however, the metazoans made awesome contributions to the elaboration of intranetting.

Ilya Prigogine, the Nobel Prize-winning pioneer of self-organizing systems, has observed that a breakdown of progress is frequently an illusion. Under the shattered fragments new structures and processes ferment. And from those innovations come fresh orders whose wonders seem without number. The new organisms had vastly increased their capacities as individual information processors. If these advanced modules could be linked worldwide, the nature of the game would change for good.

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