From Social Synapses to Social Ganglions: Complex Adaptive Systems in the Jurassic Age

By Howard Bloom.

History of the Global Brain, Part V

Howard Bloom is reflecting in this chapter why birds congegregate in huge flocks. He describes the advantages of flocks as collective learning machines and explains the main principles of these collective adaptive systems.

> "How ya gonna keep 'em down on the farm, after they've seen Paree?"

For most of human history, the need to eke a living from the earth kept over 90% of the human population in the countryside. But once a small number could produce food for multitudes, a formerly repressed desire went hog-wild - our urge to cram together. Today, more than 75% of Europeans and North Americans have crowded into cities. In Belgium the figure tops 95%. This lust for company has hit the developing world even harder. In a measly two generations, Mexico's urban congregants have leaped from 25% to 70% of the population. Mexico City is now jammed with 27 million human beings, roughly three times the worldwide number of Hominids alive at even the lushest moment of the Paleolithic age.

1 Bird Flocks

Many species of birds are as attracted to their equivalent of the big city as we are, and given the chance, will congregate in the largest clusters they can possibly form. Some bird flocks outdo the largest human municipalities by a factor of two - reaching 50 million or more. This sociable overcrowding seems to court extraordinary risk. The larger the flock, the larger the territory it must cover to feed itself, and the greater the chances of encountering a famine. So why do avians become hypnotized by the urge to join a crowd?

The first guess ornithologists came up with was warmth. In winter, they reasoned, the birds could huddle, providing each other with protection from freezing cold. When researchers compared the energy costs of joining a roost to the energy saved by communal heat, the results were rather surprising. If the roost is thickly populated, the daily distance from home base to food is likely to involve an arduous commute. The calories burned in travel by far outweigh the pittance saved by toasty snuggles, swallowing 27% of a starling's entire intake for the day. Overnighting alone in a sheltered hollow - despite the need to generate extra body heat - would exact nowhere near that price.

Why then, do birds congregate in avian megalopolises? There is something far more critical than energy to be gained - information. Birds rely for their perception of the world on those around them. If you recall the experiment on imitative learning among octopi from our previous episode, this will sound like deja vu all over again. Experimenters put a young, inexperienced blackbird and an older, wiser flier in cages side by side. The savvy elder was shown an owl, and attacked the potential killer furiously. The youngster couldn't see the predator. Sly experimenters had placed a partition in his line of sight. But he definitely could witness the emergency response.

Not that there was nothing to surprise the junior bird as well. On his side of the opaque divider appeared a stuffed honey eater, a congenial creature which does not feast on blackbird meat. The setup was designed to convey the impression that the elder's pugnacity had been roused by the harmless sweet-snacker. Later the young bird was put next to an unseasoned fledgling like itself. Both were shown the honey eater. The newcomer was indifferent. But the bird who'd seen his elder go into a rage flew at the bee-juice connoisseur, assaulting it with might and main. Soon the novice picked up the message and joined in. Then it, too, was paired with a naive bird who couldn't have cared less. Like his teacher before him, the bird who'd learned his lesson demonstrated the importance of mobbing honey eaters to his pupil, passing the tradition on. Erroneous as it was, this response was reproduced in six blackbird generations before the researchers called it quits.

OK, birds have imitative learning. What's so astonishing about that? We've already shown the imitative passage of data in creatures as primitive as spiny lobsters 260 million years ago. And we've explained how emulative absorption acted like a synapse, allowing information to leap the gap from one creature to another. But a whole new kind of information processor arises when neurons or independent beings join more than mere bucket brigades. Huddled like roosting birds in the brain-precursor called a ganglion, neurons can swap and compare data by the batch, arriving at something far beyond mere linear transmission. Each adding to the mosaic, they can see the big picture. Or, to switch from church floor imagery to that of the kitchen counter, when kneaded, stretched and rolled by a social cluster, you never know what forms of output input will become.

In 1973, *Amot Zahavi*, the eminent Israeli naturalist, posited that the roost was an "information center." From 1988-1990, *John and Colleen Marzluff* of the Sustainable Ecosystems Institute in Meridian, Idaho, and Bernd Heinrich from the University of Vermont attempted to test the notion. They focussed their attention on ravens (Corvus corax) living in western Maine's pine forests. Their technique was to capture wild ravens and to keep these carrion consumers caged until all their existing knowledge about food locations was thoroughly out of date. Then the experimenters put a fresh carcass - the ultimate raven cold-cut buffet - in a previously unused site, let the birds in on its coordinates by showing them the lump of meat as the sun was setting, and set the newly enlightened ravens free. The next day, only one of the 26 birds let in on the secret showed up - leading 30 ravens from a roost over a mile away. During the next few days, two more of the experimentally isolated ravens also came back to feast on the cadaver. Each had a trail of roostmates in its wake. From this and a variety of other experiments and observations, the three researchers concluded that "Raven roosts are mobile information centres" in which the birds, by means unknown, swap data on where succulent cadavers are to be found, then follow the bird most in the know the next day when the flock takes off. In addition, the ravens share their information with others far away, engaging in a "social soaring display" which can attract hungry and clueless conspecifics from up to thirty miles.

So Zahavi had been right. Roosts, at least among ravens, are collective data processors. What's more, they are part of local networks, pooling data between strangers for the sake of all.

Somewhere between 145 million years ago, when the first feathered reptile, the archaeopteryx, arose, and 120 mya when modern birds appeared, imitative learning among vertebrates went from serial to parallel wiring, making a social group a learning machine. The mechanism for massed learning and collective adaptation was apparently at work in the herding and hunting beasts we know as dinosaurs. Paleontologist *Robert Bakker* hypothesizes that the herd allowed dinosaur herbivores to pool the input from their eyes, ears and nostrils, then mount a carefully phalanxed defense. Dino-carnivores were even subtler in their use of networking. Bakker suggests that like today's lions, they teamed up to stage elaborate stratagems. One Utahraptor might act as a decoy, distracting the attention of a brontosaurus pack. Meanwhile its huntmates would surround the prey and take it from behind. But how did communal learning machines arise among Jurassic kings and queens?

To understand the global brain's anatomy as it continues to unfold, we will have to take a side trip into theory. Specifically we've got to machete further down the path of complex adaptive systems. Later we will once again resort to theory, proposing a new model of cosmic basics. But one new concept at a time.

The exploration of adaptive systems I'm offering you does NOT come from complexity's Mecca, the Santa Fe institute. And unlike other theories on the subject, it is not based on computer simulations. It is the result of 29 years of fieldwork observing the real thing - social nets in action. The insights of Santa Fe systems modelers like *John Holland* have helped me greatly in this enterprise. But the principles I will enunciate emerge from a more elemental technique - that which Darwin used - venturing first-hand into the wilderness, accumulating reports from other empirical frontiersmen, and running vast quantities of data through numerous conceptual sieves in an effort to isolate nuggets of gold.

2 Essentials of a Collective Learning Machine

The result is a five-element dissection of a collective learning machine. The quintet of essentials: (1) conformity enforcers; (2) diversity generators; (3) utility sorters; (4) resource shifters; and (5) intergroup tournaments.

1. 2. *Diversity generators* spawn variety. Each individual represents a hypothesis in the communal mind. It is vital for the group's flexibility that it have numerous fallback positions in the form of participants sufficiently different to provide approaches which, while they may not be necessary today, could prove vital tomorrow. This can easily be seen in the operation of one of nature's most superb learning machines, the immune system. The immune system contains 10(7)-10(8) different antibody types, each a separate conjecture about the nature of a potential invader. However diversity generators take on their most intriguing dimensions among human beings.

2. 3. Next come the *utility sorters*. Utility sorters are systems which sift through individuals, favoring those whose contributions are most likely to be of value. These pitiless evaluators toss those who personify faulty guesswork into biological, psychological and perceptual limbo. Some utility sorters are external to the individual. But a surprising number are internal. That is, they are involuntary components of a being's physiology.

3. 4. Fourth are the *resource shifters*. Successful learning machines shunt vast amounts of assets to the individuals who show a sense of control over the current social and external environment. These same learning machines cast individuals whose endowments seem extraneous into a state of relative deprivation. Christ captured the essence of the algorithm when he observed "to him who hath it shall be given; from he who hath not, even what he hath shall be taken away."
4. 5. And bringing up the rear are *intergroup tournaments*, battles which force each collective entity, each group brain, to continually churn out fresh innovations for the sake of survival.

To understand how these five principles affect you and me, it may be helpful to reexamine the workings of a group brain in an organism normally thought to have no intelligence at all: our old friend the bacterium.

3 Bacterial Group Brain

In the late 1980s, two scientists we've frequently met before, University of Tel Aviv physicist *Eshel Ben-Jacob* and the University of Chicago's *James Shapiro*, were perplexed. Those supposed lone rangers known as bacteria actually lived in colonies which established elaborate designs as they expanded. Some rippled in ringlets. Others snaked in symmetrical tracery like that generated by graphic depictions of fractal equations.

Ben-Jacob detoured from normal physics and spent five years studying bacillus subtilis. Meanwhile Shapiro focused on such organisms as E. coli and salmonella. Unlike the traditional biologists who had preceded him, Ben Jacob applied an unconventional tool to his data: the insights he had absorbed from the mathematics of materials science. New developments in this field suggested that the elaborate patterns formed by bacterial colonies might be the result of the same processes which produce patterning in water, crystals, soil and rocks. The Israel physicist felt that this was wrong and set out to separate the products of "azoic" (non-living) processes from those which he suspected were the results of microbial hyperactivity.

Meanwhile among microbiologists another mystery was gumming up the works. Standard neo-Darwinism said that bacteria stumble from one innovation to another by random mutation. But a growing body of evidence was accumulating to indicate that bacterial mutations are not completely random. Seemingly every month fresh studies continued to suggest that these mutations might, in fact, be genetic alterations "custom-tailored" to overcome the emergencies of the moment.

Ben Jacob confirmed what he had suspected all along. Something far more than the principles which shape inanimate matter was at work within the petri dish. Separate investigations by Shapiro and Ben Jacob uncovered a surprise, one which answered the puzzle of bacteria's seemingly purposeful alterations and now threatens to topple long established evolutionary models. Rather than being a mere carrier of construction plans, the package of genes carried by each individual bacterium functioned as a computer. What's more, the genetic-bundle seemed to accomplish something even computers cannot achieve. Says Ben Jacob, "the genome makes calculations and changes itself according to the outcome." Unlike an assembly of silicon chips, the genome adapts to unaccustomed problems by reprogramming itself.

Reaching this conclusion left a puzzle. Godel's theorem implies that one computer cannot design another computer with more sophisticated computational powers than its own. So how does the individual bacterium's central processing unit confront large-scale catastrophe, natural disaster so overwhelming that it dwarfs the bacteria's solo computational abilities? The answer, Ben-Jacob hypothesized, lay in networking - in knitting the colony's multitude of genomic personal computers into something beyond even the massively parallel distributed processor known as a supercomputer. A supercomputer is only faster than its less sophisticated cousins, but does not transcend many of the smaller machine's most basic limitations. At heart both are merely diligent instruction repeaters. However the "creative net" of the bacilli, unlike a machine, can invent a new instruction set with which to beat an unfamiliar challenge.

Ben-Jacob has now analyzed thousands of colonies of bacilli to find out if his creative network hypothesis is true, and if so what makes the collective information-processor work. We've seem some elements of his conclusion in earlier chapters: bacilli are in constant contact, communicating through a wide variety of means, measuring their environment's limitations and opportunities, and feeding their data to each other, then finally summing the product through collaborative decision. In short, bacilli engage in many of the basic activities we associate with human beings.

Here's how Ben-Jacob's work appears when filtered through the lens of a social learning machine's five principles:

1. Bacillus subtilis colonies employ a variety of *diversity generators*. Says Ben-Jacob, bacterial clones (genetically identical offspring of the same mother) can assume intriguingly different variations. Which form each dons depends on the chemical signals it picks up from the herd around

it. These cues activate or deactivate individual genes, redrawing a bacteria's design and replacing its old operations manual. In the best of times, when food is plentiful, the colony clumps together for the feast. Divergent appetites and digestive abilities are vital to a gorging group's survival. The bacteria which concentrate on mining the new food source produce a poisonous by-product - bacterial excreta, the equivalent of feces and urine. Other bacteria adopt an entirely different metabolic mode. To them the excrement is caviar. By snacking heartily on toxic waste, they prevent the colony from killing itself. More diversity generators kick in when the colony's glut runs out. We've already seen some of them at work in 3.5 billion year old stromatolites. As famine approaches, individuals send out a chemical signal which makes them socially obnoxious, a "body odor" that says "spread out, flee, explore." This prods roughly 10,000 groups of cells to act as scouting parties, setting forth in a trek which unfolds before the human eye in the forms which had first caught Ben Jacob's attention, concentric circles, thick fingers flaring from a central core, or a spreading circle of fractal lace. Meanwhile other cellular cohorts apparently set up posts in the wake of the outward advance and channel the findings of the explorers toward the center.

2. At this stage the teams of pioneers (technically called "random walkers") utilize the third principle of a complex adaptive system: the colony's *utility sorters*. Those exploration parties which find slim pickings have an internal device, the bacterial equivalent of what British theorist Michael Waller, writing about human beings, has called a "comparator mechanism." This gauge determines that the outriders have chanced across parched and dangerous territory. Their mission, in short, has failed. The unfortunates send out the altruistic repellent which makes others in the group avoid them, leaving them to starve in isolation. Conversely, discoverers which encounter a cornucopia of edibles have their comparator mechanisms tweaked in the opposite direction. They disperse an attractant which makes them the star of the party.

3. Now the fourth principle of the complex adaptive system enters the petri dish: the *resource shifters*. Those stranded in the desert are deprived of nutrients - which their location cannot provide - of companionship, and most important from the point of view of the group brain, robbed of what might best be termed popularity. Meanwhile, those who find an overflowing buffet eat their fill and command the attention and protection of a gathering crowd. They are transformed into leaders, guiding the group mind. "To him who hath it shall be given; from he who hath not even what he hath shall be taken away." Should things prove truly grim, however, and even the most strenuous searchers confirm that food is nowhere within reach, another diversity generator, the most startling of them all, may rouse to meet the challenge. It is that mechanism which James Shapiro calls the "genetic engineer." Let us allow Ben-Jacob to repeat something we've already touched upon: "the cell carries a complete set of tools for genetic self-reconstruction: plasmids, phages, transposons and too many others to mention...the same tools, in fact, used in the lab today for genetic engineering." A microscopic research and development squadron goes to work recrafting its own genetic string. Which raises a question: does the genomic skunkworks merely trot out pre- fabricated parts which have worked in the past? Or is it capable of true innovation? This is when Ben-Jacob devised his tests of bacterial ingenuity, putting the poor creatures into nightmare environments whose like they'd never encountered before. If all the microbial team could do was recycle ancient programs, it would be finished. But that is not what happened. Through data pooling, experimentation, and tests of novel strategies, the bacteria managed to refashion themselves in radically new ways. This was not traditional random mutation at work. This was driven, inspired conception. Thanks to the synergy of the conformity enforcer, the diversity generator, the utility sorter, and the resource shifter, the colony was capable of something numerous humans never achieve - creativity.

4. In a natural environment, the fifth of a complex adaptive system's principles would presumably come into play: the *intergroup tournament*. Alas, until recently Ben Jacob has studied each colony isolated in its own petri dish, sealed off by plastic walls from competing groups. But as the resources which feed the bacillus subtilis run out, imagine what might happen if a spore of another bacterial species were to drop in, a species which found the inedible plateau on which the subtilis was stranded to be more nourishing than sauerbraten. The race would be on. While the bacillus subtilis reworked its genome in an effort to gain sustenance from the now (to it) barren waste, the newcomer would rush to reproduce, taking advantage of the fact that subtilis' inedible slabs are its entrée du jour. As the two groups struggled to take over the petri dish, would a new innovation emerge from

the contest, an innovation of the sort which enriches the fate of a species for eons? One which adds abundance to the environment, complexifying the planetary biomass, transforming ever more of this once barren planet into food for life?

4 Learning Machine in Raven Colonies

We have already seen these principles at work among crayfish, birds and bees. The raven who succeeds in spotting a banquet gains followers and magnetism. It is quite likely that he also wins the privileges of hierarchical rank - first dibs on mates, food, and the most comfortable overnight accommodations. The genes which make him a raven like his brethren are conformity enforcers. So are the tugs of imitative learning which pull him toward flying meekly with the flock. The maverick nature which causes him to buck that impulse is a form of diversity generator. It allows him to soar over territory his fellows have not explored, and thus to make new finds.

When his search is victorious, utility sorters shift the raven's hormonal gears, giving him internally-generated strength and confidence. Biology rewards him with an attitude which will draw a following. Cockiness is his equivalent of a bacteria's chemical attractor. This is equally true for innumerable species. The amount of chemotactic allure a bacteria can generate determines its leadership. The enthusiasm of a scout bee advertising a new find determines the number of followers she will attract. The regal strutting of a spiny lobster winner almost certainly helps captivate adherents who will follow him in his trek away from a glacial freeze. Each of these creatures has been turbocharged internally by success. And that endogenous upgrade makes all the difference in the world.

Meanwhile social machinery outside the new leader's physiological fabric sets the resource shifters into motion, honing to unbeatable sharpness his or her edge in nutrition, reproduction and influence. Very simply put, as the champion's hormones give him a boost, other inner chemicals downshift his former rivals and impel them to defer to him, funneling the group's bounty in his direction.

Finally, intergroup tournaments increase the odds that those groups which stumble in their use of the previous four mechanisms will also fail to survive. If faulty physiology draws you to the wrong leader, you are likely to leave no genetic or memetic legacy in your wake.

So ravens pool their findings and follow those who have demonstrated a record of meaty discoveries and of organizational savvy beneficial to the bunch. Raven flocks even share news of their richest treasures with aggregations from miles away, as if they knew that through this worldwide- webbish generosity, they would survive the famines which permanently down those who selfishly hog their data.

These are some of the secrets of the nascent global brain. Robert Bakker has inferred that this quintet of principles was at work among velociraptors and astrodons 120 million years ago. New finds of early birds (Confuciusornis) from the same era also hint that the beasts with the novel feathers may have used the five principles of a complex adaptive system in their group behavior. And we will soon see how the learning machine's pentagram extended its embrace to human beings.

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