Cellular Intelligence

D. Andrew White M.Sc. 31/10/2007

Living things are special manifestations of matter. The self-building and self-replication seem to be properties unique to biota. For the last several decades there has been much talk of the ‘cybernetic’ features of life. That is, there has been a superseding of the old ‘clockwork’ metaphor with one based on the computer metaphor. Even more a propos is the idea that biota are like the software virtual entities known as cellular automata. Biota have evolved to become evermore self-adjusting – or adaptable. This adaptability has been ratcheted-up by natural selection to ever higher levels of complexity. Eventually bio-systems attained a level of sophistication that they became quasi-intelligent. Which brings up the question, is the Creator still at work? Are cells themselves intelligent? Or is biotic intelligence just another metaphor?

Several words have been coined for this ability of biota to build themselves. ‘Entelechy’ was once a popular term for this trait. The preferred term is nowadays ‘autopoiesis’. The idea of autopoiesis as we know it is based on the work of the biologists Humberto Maturana and Francisco J. Varela. The basic idea is that living things dynamically maintain their structure. Furthermore, they reproduce. They are therefore somehow capable of self-maintenance and self-building. The word ‘autopoiesis’ is a transliteration of the Greek for: self (autos) writing-building (poiesis). F.J. Varela defined autopoietic systems as those structures that:

(1) Continuously regenerate and actualise the network of interactions that produce them, and
(2) They constitute a system that acts as a unified entity.

Many of the strategies of biota seem to be very clever. Consider the Myxobacteria or bacterial moulds. Like many ‘colonial’ bacteria, each bacterium can communicate chemically with other bacteria. The co-operating bacterial cells specialise into different roles. They even have self-defence against ‘cheating’ bacteria that fail to co-operate. When sporulation is signalled the cells over a broad area are called together. They form a slug-like mass which crawls up to an exposed location. The cells collectively form a small toadstool-like sporangium. Some cells become the stalk of the spore-bearing body, others form the actual spores. The stem cells sacrifice their own continuance for their comrades’ chance at dissemination (Ben-Jacob et al 2004). In other words, the myxobacteria co-operate strategically and seemingly ‘altruistically’.

Some of the mind-like attributes of life might be of purely mechanical origin. The Belgian cyber-philosopher Francis Heylighen proposed that life is dependent upon natural selection working at a variety of levels. Selection is involved in sorting out self-enhancing systems from self-destroying systems. The emergent properties that are life arise out of the struggle between self-replication (copying) and selection (sorting). While not downplaying other factors, theorists such as Heylighen argue that natural selection is a key ingredient in the generation of autopoiesis (Heylighen & Gershenson 2003).
One biologist, G. Albrecht-Buehler has detailed the workings of protozoan cells and showed how they process sensory information, assess its import, and respond in a nuanced fashion. Many protozoan cells can detect infrared light, exchange chemical signals with other cells and navigate around obstacles. He revived the idea of ‘cellular intelligence’ and attempted to explain it in material terms. More controversial has been Albrecht-Buehler hypothesis that the centromes of cells are control centres and that microtubules pass signals around inside the cell. The extent to which these tubes act as logic gates is still an open question (Albrecht-Buehler 1985).

Experiments indicate that some protozoa, such as the ciliate *Stentor coerulens*, can learn. If prodded with mechanical stimuli the protozoon defensively retracts. Repeatedly prodding elicits ever diminishing responses, provided the irritant is not actually harmful. Experiments indicate that combinations of mechanoreceptor ‘senses’ gives the little protozoon the ability to learn simple tasks. The creature can learn the best escape route from a very simple maze – a thin tube. Basically, it can learn whether the best escape is downwards or upwards (Wood 1988). The effect is considered to be a form of operant conditioning. Doubtless similar conditioning occurs in the wild. Though, it may be difficult to see these behaviours from the outside.

Another ciliate, *Paramecium caudatum*, can also be habituated and also learn to escape from a tube-maze. There are indications that the protozoon can associate two kinds of stimuli. They can be ‘taught’ to associate vibration and electrical stimulation. Other kinds of discriminatory learning can also occur (Armus et al 2006). The effect is a conditioned readjustment of the protozoon’s otherwise innate responses, i.e. operant conditioning.

The *Phycomyces blakesleeanus* fungus has been found to be able to learn after-a-fashion. The fungus naturally seeks out light. This is basically their way of finding open areas to release their spores. The sporangiophores of Phycomyces can become habituated to light. That is, it can ‘learn’ to ignore or tone-down responses to light stimuli that are repeated too often. (Ortega & Gamow 1970). Habituation is widely considered to be one of the ‘lowest’ forms of learning.

Plants are also capable of habituation. The sensitive plant (*Mimosa pudica*) is a legume that responds to touch. If touched, its compound leaves fold-up. This can protect the plant from grazing animals. If they are repeatedly prodded by the same kind of stimulus they habituate to it. Eventually they virtually ‘ignore’ that kind of stimulus. Interestingly, they can moderate their sensitivity to tactile stimuli that differ in rather subtle ways. For example, they can be conditioned to distinguish wet droplets that touch them from dry poking objects. While habituated to one kind of touch, they still can retain their sensitivity to the other kind (Applewhite 1972).

By the turn of the millennium the idea of ‘biotic intelligence’ was widely taken for granted. James Lovelock, Lynn Margulis, Dorian Sagan and many others began to write as if it were self-evident that evolution has perfected organisms such that they have become purposive. Margulis, for example, has often described the various biochemical means by which a protozoon can maintain its internal homeostasis. This balancing act figuratively speaking is like proto-intelligence. Very few researchers have directly attributed ‘intelligence’ to bio-systems. Mostly they merely suggested a tight analogous relationship between bio-systems and actual bona fide intelligence. It was widely agreed, even by the sceptics, that life has developed some attributes that are at least reminiscent of ‘mental function’.
The immunologist E.J. Steele and T. Steele began describing immunocyte interactions as ‘quasi-Lamarckian’. The idea being that evolution is not always directed by external selection. In some cases selection operating inside an organism can sort and cull cell lines. H. Hoenigsberg hypothesized that such ‘internal selection’ was the original impetus in the evolution of cell differentiation. Inter-cellular struggle eventually gave rise to cells working in co-operation in the embryogenesis of multi-cellular creatures. If true, this scenario implies that evolution can have a high degree of internal directivity. Lamarck’s vision of evolution having internal foresight may not have been totally off target (Steele et al 1981, Steele et al 1989, Hoenigsberg 2003).

The physicist Eshel Ben-Jacob, in Israel, has argued that bacterial colonies evolve by endogenous adaptive mutagenesis. It is as if a bacterium is programmed to allow hyper-mutation in a select set of genes apropos to changing environmental conditions. Furthermore, these hyper-mutations can be shared via plastid exchange and spread rapidly through the colony. One can appreciate therefore that there is a semblance of a memory-learning algorithm in bacterial colonies. An individual bacterium does not learn much in itself. The algorithmic ‘learning’ of the collective works at the multi-generational level. It is not like animal learning that occurs inside of a single organism and during its lifetime (Ben-Jacob et al 2004).

Claus Emmeche has critiqued the computational metaphor for life, but he has found some merit in it. Likewise the team of Steen Rasmussen, Carsten Knudsen and Rasmus Feldberg studied the relationship between computer programs and life. This work suggested that biota is somehow similar to programmable devices. The fact that cellular networks are like programmes to some degree was not in doubt. The novelty was the suggestion that cell interactions can be close enough to computational networks for the computer metaphor to be usefully applied to life (Emmeche 1994).

One recent proponent of the intelligent biota idea was Frank T. Vertosick Jr. Vertosick, an American neurosurgeon, argued that intelligence varies by degree, and is not confined to brains, nor is it restricted to individual animals. His most forceful claim was that Darwinian evolution as a whole is like intelligence in that it is similar to an algorithm that learns. He included examples such as the mammalian immune systems, the rapidly adaptive natural selection of bacteria, and even the regulatory logic of social insects’ interactions (Vertosick 2005).

In Scotland the molecular biologist Anthony Trewavas suggested that plants have some features similar to intelligent behaviour. In particular, it is well known that plants can be preconditioned or acclimated. For example seeds can be hardened by exposure to cold, and become more tolerant of cold-spells than are seeds not so pre-conditioned. Basically when a plant responds to a stimulus, the response can become quicker during repeat stimulations. Plants adaptively respond in many ways, including osmotic adjustments to calcium levels and by protein syntheses. Either cold or drought stress will increase the expression of these proteins. The physical adjustments wrought by the stress can linger around after an initial stimulus. This lingering effect preconditions the plant for further stresses (Trewavas 1999 & 2003). This kind of response is certainly at least a little bit like memory.

The Italian horticultural botanist Stefano Mancuso has become famous for his references to ‘plant smarts’. Plants in their pre-conditioned responses do seem to have a sort of memory. Furthermore, the growing apices of roots or shoots act like ‘command centres’ for co-
ordinating signals within a plant, signalling whether to stimulate or to inhibit other tissues. In addition to chemical signals, electrical impulses are also used for cell–to-cell messaging. Plants can seemingly ‘compute’ solutions to conflicting physiological demands (Baluška et al 2004, Brenner et al 2006).

‘Memory’ in plants can be even stranger. Some plants determine which bud shall become the dominant apex by external signals. In the case of Bidens pilosa seedlings, irritating one cotyledon can simulate a lateral bud on the opposite side. Usually this is most evident when the leading bud is removed, and the laterals are thus ‘released’, the bud opposite the irritation becoming the new leader. The release of the lateral can be delayed by delaying the removal of the apex. This stimulation of the cotyledon can be ‘recalled’ even after very long delay (Tafforeau et al 2006). Plant reactions are certainly quite comparable in their complexity to the behaviours of ‘lower’ animals like jellyfish and sea-sponges. If the very same behaviours occurred in animals they would be considered examples of primitive cognition.

Biotic processes can be somewhat analogous to intelligence. Consider for example the true slime mould Physarum polycephalum. In the early 2000s Toshiyuki Nakagaki, in Japan, found that slime moulds could ‘calculate’ the shortest route to food. They could ‘solve’ mazes. Nakagaki’s team placed a slime mould in a maze. There was a food source at two portals of the maze. At first the slime mould’s plasmodium spread out its slimy tendrils throughout the maze. Though, once the food was found the whole plasmodium condensed into a few strands. Eventually these strands condensed into a single strand spanning the shortest route between the two sources of food (Nakagaki 2003).

Since the 1930s it has been suggested that sexual reproduction is a strategy for evolving. Research suggests that ‘evolvability’ can be a set of traits that are themselves favoured by natural selection. Under certain conditions sexual reproduction has a strategic advantage over asexual reproduction. Sexual recombination has the advantage of mixing alleles from different lineages. This gene mixing makes evolution at once more rapid and more controlled. Some other examples of evolvability traits include the hyper-mutation in bacteria, and the chromosome crossing-over of eukaryotes (Stewart 1993).

In computing theory information must be processed for a system’s ordered states to increase. Biota apparently obeys both the laws of thermodynamics and the ‘laws’ of computation. Life increases local order (negentropy) at the expense of external disorder (entropy). Metabolism utilises externally derived energy (via. catabolism) to forcibly press molecules into an ordered state (via anabolism). Overall the external disordering caused by life is greater than the order life creates.

It has sometimes been maintained that ‘natural selection’ is logistically incapable of creating ‘specified complexity’. However, computerised models of selection belie this presumption. Clearly natural selection is at least logically possible. But just because something is not self-contradictory, that does not mean that it really does happen in practice. So, is natural selection physically feasible? Empirical studies seem to indicate that it really does occur (Heylighen & Gershenson 2003). The claim of autopoietic theory is that this selection is has become biased in favour of teleonomic traits.
Does life evolve ‘on purpose’? Does it ‘plan’? It almost seems so. Here it is important to remember that bio-theorists are not positing that physical processes have an innate intelligence. Rather, the more mind-like biota evolved gradually from less mind-like predecessors. Natural selection has ratcheted-up the level of biotic complexity over time. Eventually this selection gave rise to organisms that can adjust to their environment. This autopoiesis could then itself be fine tuned by natural selection. These autopoietic systems have at least a metaphoric resemblance to ‘intelligence’.

References


