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INTELLIGENT EVOLUTION AND INTELLIGENCE

In which we observe that the evolutionary journey from ancient cell to humanity is marked by increasingly intelligent life forms. The human brain is the most highly interconnected, and therefore internally collaborative, entity on the planet.

In higher animals, consciousness has evolved and can be brought to bear on the problem of survival. With consciousness, true purpose emerges. Humans can set out to make things, having clearly visualised the end products. It seems likely that this ability to foresee the outcomes of certain activities is shared by some primate, bird and octopus species. There may be others, but more than 99 per cent of living creatures are plants and do not have this form of consciousness – yet they are able to solve the problems of staying alive.

Darwin was the undoubted biological colossus, the nonpareil, of the nineteenth century. The twentieth century, however, held many giants, two of whom concern us here. One was Lynn Margulis (1970, 1991), whose work on the symbiotic origin of modern cells from ancient cells forms one of the starting points of this book. She wrote, with co-author Dorion Sagan (1997), that:

The view of evolution as a chronic bloody competition among individuals and species, a popular distortion of Darwin's notion of 'survival of the fittest,' dissolves before a new view of continual cooperation, strong interaction, and mutual dependence among

life forms. Life did not take over the globe by combat, but by networking. Life forms multiplied and complexified by co-opting others, not just by killing them.

The other is James Lovelock (2013) with whom Margulis was an early collaborator. Lovelock is remarkable both for his longevity (he is still working at 100, as of the moment of writing) and the fact that he forged a career as an independent scientist. Even more remarkable is his world view.

Both Charles Darwin and James Lovelock created powerful metaphors to express and establish their ideas. Darwin took a concept that was almost unthinkable – that all life forms are shaped by evolutionary change – and clothed it with a plethora of scientific observation. His formulation of the metaphor of natural selection changed the world.

James Lovelock took Darwin's metaphor, and realised that the Earth was indeed a living world: a complex, self-regulating and self-organising entity.

Lovelock's personal epiphany occurred when he saw the first photographs of Earth from space. He saw a planet that was blue because of the oxygen in the atmosphere. It should not be there – on thermodynamic grounds alone, it should be tied up in nitrates and carbon dioxide. The awe-inspiring conclusion is that life itself regulates the composition of the atmosphere. Oxygen is there *only* because of the oxygen-producing activity of all the green plant cells on the planet, the photosynthesisers. Lovelock explains that if the laws of chemistry are all that matter, all the oxygen and most of the nitrogen in the atmosphere ought to have ended up in the sea, combined as nitrate ion.

The air we breathe cannot be a very fortunate one-off emanation from the rocks; it can only be an artefact maintained in a steady state far from chemical equilibrium by the biological process.

It was not always so. The first world of the ancient cells was anaerobic, oxygen-free. Then one type of ancient cell learned very early to make use of the carbon dioxide that was already in the atmosphere. It became a source of nutrition, used to make simple sugars. Oxygen was produced as a by-product of this biochemical process of photosynthesis, and it was poured out into an otherwise oxygen-free atmosphere for many millions of years. As fast as the cells produced oxygen it was mopped up by geological strata containing iron, causing them to 'rust' and form the ancient 'red beds' that are now a source of iron ore. Only when all the available iron

had finished ‘rusting’ could the oxygen begin to appear in the atmosphere. As life continued to evolve, the amount of oxygen in the atmosphere increased and, with many fluctuations, finally reached today’s level. From the point of view of all the other cells that were not photosynthesisers, it was the first great act of planetary pollution, to which they were forced to adapt. One way to adapt was to cooperate with the photosynthesisers.

The richness of metaphor is displayed when creative writers link the conceptual to the physical world. Lovelock happened to be friendly with the writer, William Golding. One day, he explained his idea to Golding and wondered if he could suggest a name. Golding suggested ‘Gaia’ for Lovelock’s vision of the world. Gaia was an ancient Greek goddess, a personification of the Earth and one of the deities at the beginning of all things.

Lovelock had realised that the biosphere, the sum total of life on Earth, continually interacts with the atmosphere on the one hand and the geosphere on the other. Within the biosphere, numerous interactions occur that help to stabilise the whole system. This living system – we may now call it Gaia – is a vast, but not limitless, self-regulating entity that humanity is on the verge of overexploiting and polluting, putting its own continued existence in peril.

Not everyone recognised the importance of this discovery; indeed, Lovelock was accused by many of trying to resurrect a caring ‘Mother Nature’. This scepticism explains why he felt more at home with those scientists – physicists, chemists, biochemists and engineers – who understood the centrality of the concepts of cycles, of feed-forward and feedback, up- and down-regulation, that are the marks of energy flows. He later remarked that his references to Gaia as a living organism were intended as shorthand, a metaphor, not to be taken literally, to describe an entity of globally interactive feedback systems displaying the capacity for self-regulation or homeostasis. This is illustrated in Figure 2, in which humans are represented as part of the biosphere. It was when they became too deeply involved in the biosphere that trouble started; the Industrial Revolution threw a monkey wrench in the works and disturbed the steady state.

Lovelock stated, rather irritably:

Of course the Earth is not the phenotype of any species of organism, but the coupling between all the individuals of the planet and their material environment (that) results in a homeostasis similar to that of the nest.

Figure 2. Humans in the biosphere.

‘The nest’ is a reference to the termite mounds, ants’ nests and other structures of social insects that allow them to maintain a steady internal environment (homeostasis). Illustrated in Figure 3 are two nests of cathedral termites: the unpredictable emergent consequence of the self-regulation of termites going about their daily business.

Newton’s third law of motion states that ‘for every action there is an equal and opposite reaction’. Le Chatelier rephrased it for chemistry and biochemistry as a principle, in the following terms: ‘if a system that is in chemical equilibrium (long-term balance) is subjected to a disturbance it tends to change in a way that opposes this disturbance’.

The carbon dioxide concentration in the atmosphere is at present increasing, and so are average global temperatures. As a result, weather is becoming more extreme and unpredictable; the poles, continental snow caps and glaciers are melting; the seas are becoming more acidic; ocean currents are being disrupted. It is difficult not to conclude that we are observing the global steady state adapting to new circumstances, and that outcome will be to establish a new steady state for Gaia. Humanity is contributing to those circumstances, so Gaia’s response carries a threat to humanity, for the new steady state may not be one friendly to humanity’s continued existence.

Figure 3. Termite mounds: the unexpected consequence of termites' self-regulation.

Source: Photograph by Chris Bryant.

It is important to understand the difference between the terms 'steady state' and 'equilibrium' when used by scientists. The steady state is an 'open' system, such as the river illustrated in Figure 4a.

1. An open system
in **Steady State**

2. An enclosed system
in **Equilibrium**

Figure 4a. Equilibrium and steady state systems.

A river flows along its course continuously. If you stand in the same place on a river bank to view it on consecutive days, the scene will look very much the same. During that time, however, the part of the river that you see will have been replenished many times by the water passing through. As Heraclitus is credited with saying, about 500 years BC, ‘you cannot step twice in the same river’, because the bit of water you stepped in a few seconds ago is now several metres downstream. If, however, you enclosed some of the water in a large can, it would not move. An enclosed system is a special case of the steady state called equilibrium. Nothing happens at equilibrium.

These two conditions are again represented in diagrammatic form in Figure 4b. On the left, a and b are two rivers that join to make a single large river ab . The lesser rivers, a and b , are draining water from a range of hills into the larger river, ab , made from their confluence. River ab continues to the sea where it discharges its water. As long as it rains in the hills, the rivers will flow – a steady state. If there is a drought, eventually river ab will not make it all the way to sea and the system begins to stagnate. There is no movement of water.

Now let us change the metaphor using the same figure. We are now looking at a series of reactions within a living cell; a is a chemical produced by one set of reactions, b by another. It is an open system within the cell and they can be replenished. The two can react together to produce ab which, in turn, can react with a variety of other substances to produce a range of products. The open system is full of possibilities for maintaining a steady state and even growth.

Figure 4b. Open and closed systems.

Compare this with the closed system inside the can. The same chemicals, a and b , are there, but as the can is closed there is no hope of getting any more. They can react to form ab but there is nothing for ab to react with. Its only option is to collapse back into a plus b , which is a futile equilibrium. Nothing interesting can happen until the can is opened and ancient cells can set to work on its contents.

The mechanism that builds changes into the biosphere is Darwinian natural selection. Natural selection is a testament to the power of iteration, which allows changes to build on themselves. Some examples of patterns generated by iteration are shown in Figure 5. Classic fractal patterns are generated by repetition at different levels of magnification. When the broken outline of the edge of an island, say, is viewed under greater and greater magnification, at each level, bays, coves and inlets are progressively revealed as repetitions of the larger pattern.

Figure 5. Fractal images.

Simple, repeated iteration in such patterns, as in the human lung or a branching tree, creates structures of high complexity. A fractal pattern thus stands as a simple metaphor for the structural complexity and repetition of evolutionary change. Darwin's evolutionary theory, of continual change by natural selection among life forms, is an iterated process in time – one that has been going on for 4 billion years.

The effectiveness of natural selection derives from the fact that organisms do not exactly resemble their parents. Some of the variants prove to be less able than others to survive in the environment in which they find themselves. They do not necessarily drop dead – they simply do not have resources enough to out-breed the lucky ones, so their populations dwindle. Their ultimate extinction may take many generations, and efforts to bring back species that have reached the ends of their lines, with population sizes that are no longer viable, may be doomed to failure. Dwindling in this way was probably the fate of the Neanderthals, who, though intelligent humans, were unlucky enough to coexist with more modern humans and now live on only as part of our DNA.

'Intelligent' is a wispy, smoky concept, and yet we all think we know what it is. Go to a dictionary and you find all sorts of circular definitions. One is 'having a high degree of intelligence and mental capacity'. Legg and Hutter open their 2007 paper on defining intelligence with the words:

Despite a long history of research and debate there is still no standard definition of intelligence. This has led some to believe that intelligence may be approximately described, but cannot be fully defined.

They go on to examine no fewer than 71 attempts at a definition of intelligence.

In this book we adopt the view that an intelligent action is one that leads to a good outcome for the entity that undertook it, whether it has consciousness or not. Thus, both Charles Darwin and Charles Darwin's earthworms (1881) were capable of making intelligent decisions. The difference is that the earthworms lacked consciousness but displayed what Daniel Dennett has called 'competence without comprehension' (2018). It is also as if evolution itself shows competence without comprehension, as its positive selections are, by definition, the survivors that breed.

The first half of the twentieth century was the twilight of a science era when everything had to be counted, including human intelligence. Psychologists became obsessed with the reductionist dream of a finding a single number – a quotient – whose magnitude indicated the intelligent capacity of a single person. The intelligence quotient, IQ, was pursued with the same enthusiasm that a previous generation had sought the missing link and was even more evasive. Attempts to quantify intelligence led to the development of an intelligence test of routine questions. The person of average intelligence scored 100.

Intelligence was also supposed to be heritable. This view was mainly due to Sir Cyril Burt, who seems to have manipulated his results in order to support his personal prejudices. Burt, as a young man, was impressed by Francis Galton and his influential eugenics movement. An early paper by Burt (1909) described the results obtained when the same intelligence test was applied to upper-class children in private preparatory schools and to lower-class children in elementary schools. The former did better and, no doubt much to the delight of the Edwardian Establishment, he concluded that the differences were innate. This implied, falsely, that the upper class was therefore fitter, in a Darwinian sense, while the lower classes deserved their various fates.

After Burt died, his work was re-examined by others. His studies of the intelligence of identical twins that had been separated and brought up in different homes suggested that, irrespective of nurture, their genetic similarity ensured they did equally well in the tests. Separated twins are difficult to come by, and Burt used an unreasonable number of pairs in his work. Efforts to trace many of them have failed. Two of his co-workers are similarly untraceable. The jury is out: did he falsify his studies or, like others before him, was he ‘helped’ by well-meaning assistants? Did he *have* any assistants? It is still a contentious issue. The IQ tests of 70 years ago still find occasional use but it is agreed that whatever it is that they measure is only a tiny part of human intelligence.

In discussing evolution by natural selection, the most appropriate definitions of intelligence come not from studies of human intelligence but from the field of artificial intelligence. Eighteen such are quoted in the Legg and Hutter paper mentioned above. All are relevant to different extents but two resonate. They are:

Any system ... that generates adaptive behaviour to meet goals in a range of environments can be said to be intelligent.

Intelligence means getting better over time.

According to these definitions, evolution proceeds as if it had both ‘intelligence’ and ‘purpose’. It also has ‘memory’, in highly conserved portions of DNA shared by every living thing, while every individual organism it creates displays both ‘intelligence’ and ‘purpose’ (competence without comprehension; staying alive). Higher animals and humanity display a form of competence *with* comprehension, which we call consciousness.

Natural selection seems to lead to increased complexity. The ‘Galaxy Song’ that is sung by Eric Idle as he steps out of the refrigerator in the Monty Python film *The Meaning of Life* contains the phrase ‘how amazingly unlikely is your birth’. That particular likelihood depends entirely on where you want to start. If we claim poetic licence and consider *birth* to refer to your ultimate origin, perhaps the very first cell ever, many people would now say that was a very likely event, given the circumstances in which it is imagined to have arisen. It is an event that has had consequences 3 or 4 billion years down the track, one of which is you. It now transpires, from a variety of sources of evidence, that given the conditions that existed on the primitive Earth, the origin of life was almost inevitable, barring cosmic accidents. The odds favoured the origin of life. It was a racing certainty.

Climbing aboard this idea, one can travel in one’s mind back down the genealogy of life to our very first hypothetical ancestors. This ancient type of cell, of which many representatives are with us today as bacteria, blue-green algae and many other highly specialised forms, was tiny, with its hereditary material dispersed in its cell substance. It is now accepted today that the first of the ‘modern’ cells – the ones of which *we* are made – was put together from ancient cells; three of them, in the case of animals, or four, in the case of plants. It should be clearly understood that so-called modern cells are pretty ancient, too, perhaps more than 3 billion years old, just less so than their 4-billion-year-old predecessors! This idea was the great contribution made by Lynn Margulis (1970). As a consequence, the modern cells are very different from the ‘ancient’ bacteria-like ones, although trillions of the latter are still with us in the world today.

Here is the cast of players, all ancient cells (Figure 6a):

Figure 6a. The ancient cells.

First is the ancient host cell. Little more than a sluggishly moving blob, it is anaerobic, using something other than oxygen for inefficient energy production. It probably lived on any ancient cell it managed to trap and engulf. Next come the oxygen respirers, shown as little cigar-shaped cells, the survivors of the great oxygen pollution event brought about by the blue-green algal bloom that introduced oxygen into the atmosphere. The blue-greens are represented in Figure 6a as a green oval. Finally, and most enigmatic, are the spirochaete-like cells – twisted threads that had developed intracellular ‘muscles’, called microtubules, that enable them to move about, and to move things *inside* themselves.

Figure 6b. Ancient cells transforming into modern animal cells, step by step.

The sequence of events cannot be known for certain, but it is plausible to think that an early step was the ancient host coming to terms with the oxygen respirer, creating an enhanced ancient cell capable of respiring oxygen (Figure 6b, upper right). The next step (centre) is likely to have been the acquisition of the spirochaete-like cell to equip the new partnership with microtubules and to create an internal mechanism that physically pulls the clump of DNA in two parts for accurate – but not too accurate – cell division. That step also contributed the cilia and flagella that allow the whole cell to move in its environment. Each cilium and flagellum in a modern cell has its own basal granule of DNA and there is DNA associated with the cell division mechanism, the centriole. Finally, the further acquisition one or more blue-green algae (Figure 6a, extreme right), and their capacity for photosynthesis, gave birth to the plant kingdom.

Figure 7. Modern cells: single-celled animals and plants.

After, no doubt, millions of years of evolution, the result (Figure 7) was something like the single-celled animal (left) or plant (right) that we know today, with its DNA wrapped up in a nucleus (the white circle).

How can we possibly know that this is true, you ask? Well, of course, we can't, it's a just-so story to help us understand what happened. *Something* like it must have happened and there are organisms with other inclusions, such as hydrogenosomes in parasitic protozoa and the apicoplasts in the malaria parasite and its relatives, that seem to have been derived by symbiosis with different ancient cells in a similar way. The world of ancient cells must have been a maelstrom of symbiotic experiment.

This DNA is the modern cell's genetic program in coded form, which carries the information necessary to make another cell. Modern cells also carry, outside the nucleus, but within the cytoplasm, DNA derived from those early symbioses; from chloroplasts and mitochondria and, in centrioles and the basal granules of cilia and flagella, from the spirochaete-like ancient cells. These small bodies inside the cell are what is left of the ancient cells that went to make up modern cells.

Every living thing on Earth, other than the ancient cells, is made up of modern cells and, therefore, from the ancient cells onward, every living thing is related to every other living thing. The whole of the biosphere (all life on the planet) was implicit in that very first cell. Inside those ancient cells, the DNA code used for making a new cell is more or less the same as that in modern cells.

Once the first modern cell had come into existence, and assuming no pan-global catastrophe occurred to wipe it out, an evolving biosphere was assured. The form that the biosphere took was contingent on circumstances. Life might simply have remained a covering of bacteria-like cells on a stony ball but instead it took the next step and gave birth to the modern cell. Once that happened, and once the first modern cells got the trick of working together, it was inevitable that life would increase in complexity and size with time.

And the triumphant result after 1 million or so years of experiment is the 'modern' cell (pink) that is the ancestor of all animal and fungal cells and the 'modern' cell (green) that is the ancestor of all plant cells (Figure 7). The white blob represents the nucleus, as coordinating the DNA from three or four cooperating symbionts requires a central organiser.

Complexity in a living organism implies structure. Structure requires the information necessary to build it. As complexity increased, the amount of structural information associated with the biosphere also increased. As intelligence is founded on the application of information to solving the problems of survival, the quality and amount of intelligence also increased. In fact, evolution acts as if it were intelligent even if it is not in a form immediately apparent to human beings.

Humans too are subject to natural selection. Selection occurs for genes for human hair type, skin colour or body shape, or for forming social groups under changing geographic conditions, such as the ending of an ice age. During the last ice age, natural selection allowed the appearance in the north of human variants who had lighter-coloured skins. It was probably because light skin permitted more UV light to pass through for vitamin D synthesis in these less sunny northern latitudes. At the equator, a darker skin was more advantageous, as it acted as a sunscreen, limiting UV damage while still permitting the passage of enough UV light for vitamin D formation.

Since the environment does not remain constant, organisms must also change to keep up. The current rate of global warming is set to provide humanity with an object lesson in the truth of this statement. The more an environment changes, the greater is the selection pressure exerted on its inhabitants.

Unstable environments, therefore, or the margins of stable environments, are hotbeds of evolution. The wildflowers of Western Australia are an illustration of this phenomenon. In Kalbarri National Park are dozens of flower species unique to its impoverished sandy soils and hot summers. The rate of speciation there smacks almost of desperation!

Human societies are part of, not separate from, this process. Over generations, wars have brought partnerships between the victors and the defeated in various combinations, giving the gene pool a vigorous stir. The Vikings, once at war with Britain, became part of Britain and contributed a Viking strand in the northern British gene pool. The mass

population movements of the twenty-first century are a continuation of the migrations of peoples that began at least 80,000 years ago out of Africa, all contributing to human evolutionary change. The future of human variation rests on the major flows of populations across the globe.

It is obvious that all forms of life must achieve a close relationship with their physical and social environments. They behave in an intelligent manner to establish it and are competent to ensure that this relationship continues. However, as any animal lover will tell you, the more complex plants and animals display something that is more than competence alone.

Consider the well-known single-celled 'slipper animalcule', the pond-dwelling *Paramecium*. This tiny freshwater organism has some well-developed avoidance mechanisms for getting itself out of a fix when it bumps into one. At the same time, it has to regulate its internal environment by getting rid of metabolic wastes and pumping out excess water through its vacuoles. In fact, it is ensuring a continual internal steady state, and because of this, stays alive. This surely is 'existential intelligence', arising from direct response to the environment, even if not accompanied by consciousness.

Charles Darwin (1881) certainly felt that his earthworms could be described as intelligent. Darwin's colleagues considered his earthworm study as a trifle for his old age. Yet his work showed that the entire surface of England rises significantly due to the continual deposit of earthworm casts. He wrote of earthworms choosing the right-sized leaves to haul into their burrows, without trial and error. He wrote:

If worms have the power of acquiring some notion, however rude, of the shape of an object and over their burrows, as seems the case, they deserve to be called intelligent, for they act in nearly the same manner as would man under similar circumstances.

Even a sedentary organism, one that stays put, such as, say, ivy, must be credited with existential intelligence. Its roots are continually exploring the earth in search of nutrients and water; its tendrils are continually probing, seeking places for attachment; its leaves are continually adjusting themselves to maximise their access to light.

Philosophers, such as Midgely (1980, 2004) and Ruse (2013) now allow us to assume that many of the higher animals experience a form of consciousness. It therefore would be churlish to deny them forms

of intelligence. The spatial intelligence of birds allows them to live in a world where their capacity for flight gives them access to an extended third dimension that humans only dreamed about until the beginning of the last century. Spatial intelligence has to be extremely well developed in an animal that moves freely in three dimensions (fish, birds, whales etc.). Perhaps it is even qualitatively different from that encountered in ourselves and our primate cousins. Humans are effectively confined to two dimensions of the Earth's surface, if you discount walking up and down hills and climbing trees.

If you doubt that spatial intelligence is highly developed in birds, join the remarkable flight of Darshan the eagle on YouTube (at: www.youtube.com/watch?v=um8M9azpmb4), as he is launched by a handler from the highest building in Dubai to search, successfully, for his trainer on the ground. Marvel at the aerial stability of his body as a platform for an ever-seeking head – and, in this case, a camera to record the experience. Spatial intelligence must also be well developed in cetaceans. Think of the global migrations of blue whales or the vertical expeditions of sperm whales into the deeps for their prey. On top of that, try to imagine the effect that sheer size has on bodily-kinaesthetic intelligence. These animals are so removed from us in evolutionary space that we can only begin to speculate on the workings of their brains.

A dog is a supremely olfactory animal, living in a world where scents, important reference points, swirl about it in a way that we would find bewildering. We can only begin to understand, with our own rather poor olfaction, a dog's way of knowing. For example, it is a spring morning outside, and a warm breeze brings a whiff of floral perfume. We can sense the direction from which the breeze comes and also identify the flower as lilac. But what else is on that breeze? Jip, the sentient dog genius of Hugh Lofting's (1926) famous creation, Dr Dolittle, might tell you! If he were specially gifted, he might have a nose as much as 100,000 times more sensitive than yours; the average pooch can certainly manage 10,000 times. Tales of the dog's acuity of smell are many. For example, some gifted dogs can sense killer whale faeces a mile away, although we hesitate to ask where lies the advantage. There are companion dogs that sniff out ketones and warn a diabetic person that an attack is imminent. Diagnosticians are greatly interested in cancer-sniffing dogs. How does a dog's brain process this information? These ways of knowing the world are all equally valid in the quest for survival. We are all here, sharing the same world, but we relate in different ways to different aspects of it.

Humans are able to use their minds in various ways to learn about the world and to respond to it. We are of course limited by our physical senses, compared with some animals, and by the information processors with which evolution has equipped us. We are, however, the great generalists. Our sense organs pick up information from a great many sources. We are blessed with the processing equipment that gives us a greater chance than most of integrating the different sorts of information supplied by our senses into a view of the world that we can live in. But this is only one view among many.

If we have difficulty understanding a dog's way of knowing, an animal with which we have about 82 per cent DNA similarity, how much harder must it be with a bird? The similarity between a mammal and a bird is about 60 per cent, further complicated by different gene organisation and a different brain architecture in the bird that crams many more cells into a small space. Mammals and birds have followed different genetic destinies for at least 200 million years. Although bird brains seem relatively small, some of them – such as the intensely studied, clever, tool-using crows from Caledonia – have at least the processing capacity of the great apes. Their assemblages of sense organs and ways of knowing are very different from those of mammals.

Homing pigeons and migratory birds navigate by sensory signals we are only just beginning to understand; among them is an inbuilt magnetic compass. Birds have bodily-kinaesthetic and spatial understandings for flight and homing. One has only to watch the gyrations of a restless flycatcher on the hunt for flying insects, or the total stillness of a white-faced heron fishing, or the untiring flight of the albatross on cleverly locked outspread wings as it skims the aerial up-currents caused by ocean waves, to know that. Swifts apparently sleep on the wing, half a brain at a time. What does that feel like?

According to studies of human ways of thinking, humans have at least nine ways of knowing their physical and social environments. Howard Gardiner has identified eight forms of human intelligence: inter and intrapersonal, logico-mathematical, bodily-kinaesthetic, musical-rhythmic, visual-spatial, verbal-linguistic and naturalistic. Brown (2008), and Brown and Harris (2014), have also identified the ways in which our social environment has shaped our thinking: as individuals, as community members, as specialists, as members of organisation organisations and as 'wholists' and more. Animals, collectively, must also have many different 'ways of knowing'.

We have already accorded plants an existential intelligence. Plants, however, have many other strategies, than the few we discussed, that all contribute to the great and intelligent aim of staying alive. Pitcher plants drown insects in leaves modified as containers, to obtain their nutrients. Sundews slowly enclose their prey with sticky tentacles. Trees, when damaged, release into the air molecules of substances that alert other trees in the vicinity to the presence of browsers, inducing them to produce substances that make them less palatable.

Gaia has acted with intelligence, with competence but without comprehension, to ensure her continued survival for more than 4 billion years. With the evolutionary advent of animals, and humans in particular, she can now add comprehension to her vast list of connected attributes. In *The Hitchhiker's Guide to the Galaxy*, Douglas Adams posits that the Earth is a giant computer, run by mice, a computer that has been crunching away at a problem for millennia. Can there be a sliver of truth for we humans in this fanciful image? Perhaps yes, if you consider how we take for granted the mechanisms by which Gaia has solved the question of continuous existence.

Gaia is essentially a self-regulating system that acts as if its objective were its own continued existence. Over 4 billion years, the golden thread of cooperative evolution has tended towards increased complexity. This is not to say that the simpler life forms that were created along the way have been discarded. If they have withstood the tests of natural selection, they are still with us. Thus, much of the world belongs to ancient cells, and the blue-green algae have been and still are important in shaping it by pouring out their waste product, oxygen. The first of the modern cells embarked with great success on the voyage towards multicellular complexity, but they also explored the capacity of such cells to achieve complexity within a single boundary membrane. This includes the great kingdom of the Protista, modern single-celled organisms, illustrating what can be achieved even at that scale.

Similarly, we see by looking around us the successful steps towards multicellular complexity. Sponges are aggregations of cooperating cells that still have a high level of individuality. They will re-aggregate if separated. The Volvocales (Figure 8) are spherical structures made up of cooperating unicellular algae. Obviously, it is a successful way of life as clusters stay together after a fixed number of divisions – up to *Volvox* itself, a construct of about 16 accumulating divisions. And successful because they are still here, as are liverworts, mosses, ferns and higher plants.

Figure 8. The amazing Volvocales.

There seems, however, to be another possibility offered by increased complexity, and that is the evolution of intelligence at high levels of functionality. This interesting phenomenon has arisen separately in a number of groups; in molluscs (octopuses), birds (in particular, in the crow and parrot families) and in mammals. In the course of evolution, brains have come to represent the highest level of complexity within Gaia. There are trillions of connections within a human brain.

An important characteristic of natural selection is that it has 'memory'. The reason we can say that all living things are related to some degree is that clusters of genes that have worked well in the past are conserved in the present. There are various degrees of conservation; highly conserved sequences are associated with vital functions like cellular respiration. The human foetus *in utero* passes through a stage where gill rudiments are formed; after all, they share 70 per cent of their genes with zebra fish. That first cry indicates the baby's switch to breathing air in their new environment. Even tomatoes share a great number of genes with humans, the ones that look after essential cellular processes. And as someone once said, 'being human is just another way of being a fish!' But so is being a bird.

One of the many great surprises afforded by modern genetics was the discovery that the human genome comprised less than a quarter of an expected 100,000-plus genes. It turns out that this is possible because no gene acts in isolation, but only in combination with other genes. It is as if individual genes are like individual neurons that work in combination with other neurons if we are to walk and talk. A particular characteristic – let us say, the possession of teeth – is represented by several genes, that make a sort of gene cluster. If, during evolution, teeth are no longer needed, their gene cluster does not get reinforced and, with time and the absence of selection pressure, may disappear altogether. But sometimes this cluster that is no longer useful persists among all the other apparently unused bits of DNA. Ancestral birds had teeth, but modern ones have beaks. If something goes awry in development, a few teeth may appear because the relevant gene cluster is still there and has been awakened by something going slightly wrong with the way the genome is translated (the professional term is ‘expressed’) into flesh and blood and bone. The saying ‘rare as hen’s teeth’ has power because our experience is that hen’s teeth are indeed uncommon but do crop up from time to time. And it is interesting that when they do, they appear to be quite crocodilian, a glimpse into their reptilian past (Harris et al. 2006).

The genetic sequence for hen’s teeth is an example of a gene cluster that is not being conserved in birds but is occasionally expressed accidentally. When, however, a cluster of genes codes for a really important function, such as the ability to manipulate and store energy, those genes are selected together, and are conserved – ‘remembered’ – for use in subsequent generations. There are many such highly conserved portions of the genome – that is why we have part of our DNA in common with tomato plants.

While very useful gene clusters are preserved in the genome upon successful Darwinian selection, all the other gene clusters that have proved useful fade without continual reinforcement. The discovery that the ‘eye cluster’ from chickens works in the fruit fly, *Drosophila*, was quite startling because chickens and fruit flies have not enjoyed a common ancestor for more than half a billion years (Tomarev et al. 1996). Even so, fruit fly-like eyes were produced rather than chicken eyes when the chicken genes were introduced into the early developmental stages of the fruit fly. It appears that the gene cluster is, effectively, a command that orders ‘make an eye’. The response is to make an eye of the type determined by other

surrounding genes: the context in which the eye cluster finds itself. It is all about context; genes act in teams and the local genetic environment of the activated gene is of the utmost importance.

The *Oxford English Dictionary* (1993) defines connectivity as the state, property or degree of being interconnected. The number of connections being made within Gaia at any moment is astronomical. Think of all of the animal offspring, of all the plant seeds, of all the spores of mosses and ferns and fungi, like dust, flying in the wind. Add in the reproductive adventures of the bacteria and Protista, and fish and whales, and everything that lives in water, and elephants and people and everything that lives on land, and you have an image of the biosphere, of Gaia, as a great engine of connectivity and natural selection. In fact, it resembles a great computer but, as far as we know, it is not run by mice and nor is the answer 42!

A very important property of connectivity, especially connectivity on a large scale, is that it leads to unexpected outcomes – emergent consequences. Here is a thought experiment that you can do, devised by Stanley Kauffman (1995).

Imagine a scatter of several hundred similar buttons on a flat surface, distributed so that no one button is touching another. Select two buttons randomly and join them with a thread and replace them on the table. Repeat the process and go on doing it. For the first few tries, it is unlikely that you will pick up a button that has already been joined to another one. As more and more buttons are joined, however it becomes increasingly likely that at the next try you will pick up, say, an unjoined button and a button that has already been joined to another. Make a threesome. If, next time, you pick up two strings of two buttons, make a foursome. Soon you will be creating fives and sixes and so on. Continue in this way and eventually each button you select will be attached to every other button. A net has been formed. And a net has properties – it can be made to hold things, for example – that a few handfuls of unconnected buttons and strings does not.

One can imagine evolution proceeding in this way. The ancient cell appears and proliferates. Three or four quite different ancient cells integrate their capabilities to form a modern cell. Cooperative evolution begins! The modern cell has a suite of advantages not possessed by its single-celled forebears. It proliferates into a wide range of environments (adaptive radiation). Some modern cells get together and form simple

multicellular plants or animals ... And so on, right up to the levels of simple ecosystems and beyond. At each stage, the emergent consequences set the scene for another round of adaptive radiation.

A recent paper explored the role of connectivity in understanding how evolution and ecology work together. The authors, Watson and Szathmari, suggested that, even though an ecological system was not a Darwinian unit for natural selection, such a system and all its components can behave like a learning system, promoting its adaptation to environmental conditions. It has even been suggested that landscapes – another name for an interconnected group of ecosystems – can adapt. A study of landscape recovery after clearing by humans or by fire showed that the succession of vegetation regrowth after clearance was not consistent, as one might have been led to expect in final-year botany. It depended very much on what had gone on before, the previous history of the system.

Another way that landscapes can evolve is by interacting with their animal occupants. The grassy South Downs of England owe their existence to browsing by rabbits, introduced 1,000 years ago, and grazing by sheep. The American prairies were maintained by tens of millions of bison. This is niche improvement on a large scale. Niche improvement occurs when animals and plants interact with their environment in such a way as to improve their chances of survival, thus increasing their Darwinian fitness. They change the niche as well as having to change themselves. Animals build nests, mounds and hives, and plants drop leaves that are converted to nutrient humus by fungal and bacterial activity. Trees can change the water table and water flow. By their activities, living organisms influence the way the environment changes.

The biosphere is thus continually changing in a coordinated manner as each of its components undergoes cooperative evolution. Many other things than genes are transmitted from parent to offspring: components of the egg, hormones, compounds that can switch genes on and off, antibodies and learned knowledge. Further, a given set of genes has the power to produce different types of adults. For example, the sex of some reptiles is determined by temperature: if the nest temperature is above 32°C, mainly males are produced. Seal point cats are fawn with brown extremities – tips of ears and tail, paws and nose. These are the coolest parts of the body, where the cold activates a gene that produces pigment that can absorb heat from the Sun.

Humans are particularly good at improving their environment to enhance their own survival and are able to live in communities from the polar ice to the equator. As a survival technique, however, it carries its own risks. The human release of fossil fuels is threatening to change the currently human-friendly atmosphere and there has been too little time for a genetic response to counter the threat, while a concerted social response is a victim of political inertia.

Human risk perception is poorly adapted to long-term dangers. It took more than half a century to convince people that smoking causes lung disease and cancer; even now it is a risk that many choose to take. And now, for human societies, studies of changes induced by the interaction of social systems with the human genome are only just beginning. All of these things have the effect of channelling evolution and providing, in human offspring, material for natural selection.

According to several schools of thought, an individual human intelligence is made up of contributions from a palette of different qualities of mind. They are listed here, in no special order of importance:

Table 1. Human qualities of mind.

1. Intelligences
Naturalist; Musical; Logical-mathematical; Existential; Interpersonal
Bodily-kinaesthetic; Linguistic; Intrapersonal; Spatial
2. Ways of living
Disciplined; Synthesising; Creative; Ethical; Respectful
3. Problem-solving
4. Collective thinking
Physical; Societal; Ethical; Aesthetic; Sympathetic
5. Knowledge cultures
Personal; Community; Specialised; Organisational; Holistic

Sources: Gardner (1983, 2007); De Bono (1999); Brown (2008); Brown and Harris (2014).

Multiple ways of thinking, intelligences, are mixed in varying proportions in every human being. In this way, they offer a very large number of possible combinations, which allow humans to think collectively in a spectrum all the way to genius. There are, however, questions that are usually, and quite rightly in our opinion, left unanswered: for example, how many, and how

much of each category is required to make a functional human being? It is sufficient to say that the mix of intelligence, emotional understanding and creative thinking has permitted humans to be resilient and adaptive.

Each of these ways of thinking contributes to the great objective of survival that humans share with every living being. All living organisms are dedicated to the universal enterprise of staying alive, and to do this they must act with intelligence, either unconsciously or consciously. The logical and empirical capacity in our thinking, that we call human intelligence, is obviously only one way of understanding the world. When talking about non-sentient creatures, it may help to think in terms of 'ways of knowing'.

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