CHAPTER 25

Intelligence and consciousness

Not just animals are conscious but every organic being, every autopoietic cell is conscious. In the simplest sense, consciousness is an awareness of the outside world.

(Margulis and Sagan 1995)

➲ Summary

Consciousness is a term rarely applied to other animals and never to plants, but Margulis indicates its likely ubiquity in all organisms. Assessment of signalling may be the clearest indication of conscious activity, but assessment in plants is not understood. In bacterial swimming, assessment and memory involves a limited number of proteins whose interactions and modifications by phosphorylation or methylation construct a simple assessment system. This simple system is obviously a model for more complex organisms with much greater numbers of proteins involved. 'Do cells think' is the title of a paper that examines some unusual behaviour of yeast in response to two distinct signals given at the same time. The authors indicate a higher order of control is operative in such cells, which is not presently understood. However, the recognition of awareness in other organisms is disguised by the imposition of human criteria on their behaviour. Can social insect colonies be considered conscious? Since nervous systems are strongly associated with consciousness in animals the plant nervous system characterized by Bose is briefly described. Action potentials are not uncommon transduction pathways in plants. They lead to changes in cytosolic calcium that can mediate the response, and provide for long-term learning and memory. Herbivore damage induces electrical signals, which initiate defence mechanisms. Are immune systems conscious? They learn and remember and are aware in the Margulis conscious sense. Are they the consciousness of the body?

Introduction

The title of this chapter is to be found in an informative book by Lynn Margulis and her son Dorian Sagan (1995). It is an attempt to start the intricate dissection of something often considered to be unique to human beings, consciousness. However, no statement concerning consciousness in any other organism than ourselves is currently open to investigation or refutation by any experimental treatment that is known. Whatever consciousness actually is cannot be established objectively, because it is personal to the individual. The only reason the term exists is because we have this feature of our mental activity, the internal self-referencing, thoughts, images, self-observation, thinking as though one part of the brain is observing another. We convey that process to others by means of language and it is on that basis that we consider humans are conscious, i.e. they are sentient. Religious attitudes describe it as the soul, but the inadequacy of communication with virtually most other species means we cannot assess whether they are conscious and probably never will. All that can be judged is whether their

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behaviour is consistent with their being conscious. Only on supposition can we deny it for other species. Trewavas and Baluska (2011) provide evidence that consciousness can be regarded as ubiquitous in all of biology.

Autopoiesis is a fundamental property of living systems

Autopoiesis is a left-over life property from Chapter 3. There I included Jacques Monod's emphasis on teleonomy. 'Teleonomy is that of being objects, endowed with a purpose which they show in their structure and execute through their performances. Rather than reject this idea (as certain biologists try to do), it must be regarded as essential to the very definition of all living being' (Monod 1971, p. 20). Purposive behaviour in plants was first indicated by Sachs (1887, p. 601), 'All those adaptations of the organism are purposeful which contribute to its maintenance and insure its existence'. Virtually all plant behaviour comes in that category of being purposeful. Autopoiesis originated because its creators, Maturana and Varela (1980), felt that teleonomy was a programme imposed on the individual by the species during evolution. So they included what they felt was equally crucial to life, the maintenance of organization. Autopoiesis derives from the Latin 'auto' as self and 'poiesin' as making. The individual acts as a unitary organism and 'Through their interactions and transformations, continuously regenerate and realize the network of processes that produced them' (Maturana and Varela 1980, p. 79).

98% of all the atoms of the human body are replaced within 1 year. From measurements of average turnover rates of protein and ribosomal RNA in plants this replacement rate will be similar (Trewavas 1970, 1972). Again, on average, each cell in the human body repairs about a million bases/day in DNA responding to oxidative damage or external radiation sources, and leaves one uncorrected mutation. The thoughts you have today as images in the brain and your consciousness, and based on molecules, will have been completely replaced next year by equivalent new molecules. How well ordered that process is will determine how much you remember.

Two kinds of consciousness

Consciousness does indicate intention, it does deal with things or events, it relies on memory and the associated process of learning, but is not a simple copy of experience. There are also the clinical aspects of consciousness, criteria concerned with alertness, motivational behaviour, orientation, and self-awareness.

Edelman (1992) has suggested two kinds of consciousness. Primary consciousness is the familiar properties of heart rate, respiration rate, digestive contractions, hormone release, etc. We are aware of them, but do not control them. Higher order consciousness starts with perception through the sense organs and then control of muscular activities that drives the response. Perception, assessment, response—these are fundamental behaviours for all organisms. Assessment is the issue and perhaps the equivalent of consciousness in all.

Even the simplest organisms perceive their environment through sensory mechanisms and respond accordingly. 'The biological self, incorporates . . . facts, experiences, and senses impressions, which may become memories. All living beings perceive their environment, not just animals but plants and microbes too. To survive, an organic being must perceive- it must seek or at least recognize food and avoid environmental danger'. 'Certainly some level of awareness and of responsiveness owing to that awareness, is implied in all autopoietic systems' (Margulis and Sagan 1995, pp. 32 and 122).

'The Conscious Cell' (Margulis 2001): what is assessment?

Lynn Margulis is famous for her symbiotic theory of life. Mitochondria and chloroplasts were originally free-living bacterial and blue-green algal symbionts that have in the passage of time become critical organelles in eukaryotic cells. Her hypothesis has been well corroborated by DNA analysis. Margulis considers that the evolutionary antecedent of the nervous system is microbial consciousness. Thus, the eukaryotic cell that contains these symbionts is, by definition, conscious too. Her hypothesis also includes a consideration of the origin of neurotubules also acquired through the symbiotic route.

Escherichia coli, originally isolated from the human gut, swims by means of motors that drive six flagellae by rotation. There are two kinds of swimming—smooth when the flagellae trail uniformally behind the cell and chaotic tumbling when the direction of rotation is reversed (Sourjik 2004). Each cell has 10 to 12 receptors in its outer membrane, which sample its surrounding medium for chemicals, usually either food or toxins. The tumbling process is used to comparatively assess the present concentration of a desirable commodity like sugars, amino acids, or toxins, with a previous assessment using the specific receptors. This checking period lasts a few seconds. After assessment, swimming then continues in the direction of food or away from toxins. These few seconds represent its memory that, when accessed, controls behaviour.

Strictly speaking, *E. coli* possesses neither a nervous system or a brain but it does have what could be described as a centralised intelligence system. At a simple level it does what bigger brains do. It integrates information from sensory mechanisms that detect salient features of the environment. It has central decision-making machinery that encodes and analyses information about its past and present, and enables it to chart its course into a well-chosen future. And it has the equipment-the behavioural effector systems-to execute the plan. (Lacerra and Bingham 2002, p. 15)

The basis of this intelligent process is derived from a fairly simple system of interconnected proteins and does involve protein modification through phosphorylation and methylation. The connections in this assessment network are transiently modified to adjust the procedures of tumbling and smooth swimming. Phosphorylation is used because rapidity of response is essential. The bacterial cell thus exhibits awareness of its surroundings. Consciousness at its simplest is thus a system, a network property. However, these proteins are embedded in a much larger network of other proteins that create the cell, and its sensing and motors in the first place.

Eukaryotic cells are an order of magnitude more complex than the common bacterial cell and the variety of their behaviour increases accordingly (Chapter 20). Again, the assessment process depends on a densely connected network of proteins, which are structurally and strategically located inside the cell. However, with many more potential interactions between proteins and numerous post-translational modifications, the complexity of behaviour is greatly increased. These data provide definite clues about the nature of assessment, the consciousness equivalent in plants, and complete the consideration of such behaviour in cells described in Chapters 22 and 23. Jennings (1923, p. 336) asks, 'Is the behaviour of lower organisms of the character which we should naturally expect and appreciate if they did have conscious states of undifferentiated character and acted under similar conscious states in a way parallel to man'. He concludes they do. When such cells, for example, draw away from unpleasant circumstances can we conclude they do not experience pain? Our behaviour would be similar. That question has, of course, no answer and never will. Jennings was merely trying to indicate the evolutionary origins of what is called consciousness.

'Do cells think?'

Ramanathan and Broach (2007) ask this question in a well-argued and provocative paper. They point to a large number of examples of single cells, where genetically identical individuals maintain a range of phenotypes in a uniform environment. Most notable among these are trypanosomes and others that generate antigenic variants in an infection population. *Candida albicans*, a fungus that infects humans can express a number of phenotypic variants. It can change virulence by altering antigenicity, or alter antifungal resistance or sensitivity to macrophage ingestion. Even *Escherichia coli* can switch into a quiescent state that increases resistance to antibiotics. The optimum switching rate between phenotypes should be proportional to the probability that the environment will change, too.

Slow behavioural changes in plants in response to environmental signals raise an issue here of some importance. When the new phenotype starts to emerge after signalling, it may be unsuitable for the present environment. If the environment changes frequently, then fitter individuals need to maintain a memory of the frequency of changes it has experienced in the past and adjust behavioural responses accordingly. Such a record can be deposited in protein phosphorylation states or epigenetic modifications, and should involve thresholds that are superseded when critical numbers of environmental changes have been recorded (Chapter 16). Even *Bacillus subtilis* can manage to remember previous starvation conditions some time after they have been experienced, and changes phenotypic switching accordingly (Suel et al. 2006).

Yeast cells (*Saccharomyces cereviseae*) respond to a number of environmental signals that are interpreted by several well-characterized transduction pathways. Cells can adjust osmolarity in concentrated sugar solutions or respond to mating pheromones for sexual reproduction. The transduction pathways involve well-established cascades of protein kinases and MAP kinase cascades and act like a switch. Some of these critical kinases are shared between the osmolarity and mating transduction pathways. When responding to the mating pheromone it switches off the osmolarity pathway and *vice versa*. In the presence of both signals, some cells switch on the pheromone pathway, while others switch on the osmolarity pathway. The proportion of each type is dependent on the relative strength of the two signals provided. Yeast cells are, in some way, weighing the odds of the signals that are received and adjusting the proportions of each phenotype to better fit the environment. This higher level of information processing 'begins to approach the complexity of a true thought process' (Ramanathan and Broach 2007), something normally identified as cognition. Bear in mind that the cellular system is hierarchical in its construction. This higher order process must work at the pinnacle of the system properties. Again, there is an indication of the mechanisms involved in the process of assessment used during plant behaviour. Systems behaviours become crucial to understanding.

However, the understanding of cognition or thinking may need reassessment. 'A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself. Living systems are cognitive systems and living is a process of cognition. This statement is valid for all organisms with and without a nervous system' (Maturana 1980). A statement made before the information above was published, but looks to have predicted it.

The evolutionary continuity of consciousness and perception

From the viewpoint of an evolutionary biologist it is reasonable to assume that the sensitive embodied actions of plants and bacteria are part of the same continuum of perception and action that culminates in our most revered mental attributes. 'Mind' may be the result of interacting cells. Mind and body perceiving and living are equally self-referring, self-reflexive processes already present in the earliest bacteria. (Margulis and Sagan 1995, p. 32)

A greater variety of terms are used to describe the behaviour of more complex organisms, such as motivation, appetite, drive, purposive behaviour (West Eberhard 2002). Again, these behaviours do describe what we observe in other organisms and about which assumptions are made. They are, of course, nuances of behaviour that we recognize in ourselves, but in essence are equally relevant to all organisms. *Hydra viridis* is a small multicellular coelenterate, and yet both Jennings (1923) and Bray (2009) refer to *Hydra* as sometimes being hungry and at other times full, because in the latter case it then ignores offered food.

Do plants intend to avoid the competition for light? They behave as though they do when they obviously grow away from competition. We do not use the word hungry for that circumstance, but is there a real difference in essence between a starving man and an etiolated plant? In both cases, the imperative is to find food or perish. The phenotypic mechanisms used by both to deal with this situation reflect what evolution has given them—movement in one case, growth (a form of movement) in the other—but oddly enough the molecular mechanisms look very similar since circulating sugar levels may be the crucial signals (Morkunas et al. 2012). A crucial kinase, snf 1 kinase, is activated by starvation and energy-depleting stress conditions in both plants and animals. Once activated, it enables energy homeostasis and thus survival, by up-regulating energy-conserving and energy-producing catabolic processes. It also limits energy-consuming anabolic metabolism. In addition, these enzymes manipulate and control normal growth and development as well as metabolic homeostasis at the organismal level. The plant uses a whole system assessment that is complex and used to change behaviour, mankind uses a more focused assessment to control hungry behaviour, the brain, but who can say one is not conscious and the other is.

West Eberhard (2002) describes the interesting example of salmon feeding, which under the watchful eye of a predator makes many more mistakes. Its behaviour swings between 'fear' and the necessity of feeding. It is an example of the use of the conflict between speed and efficiency. When the slime mould *Physarum* was hurried to make decisions, mistakes increase (Chapter 20).

Both organisms are finding their attention is modified by external circumstances. Attention reflects the ability to concentrate on one issue at a time, and if two are present one will supersede the other or they may simply alternate. Plant roots get round the issue of two signals by changing the sensing apparatus, which is in continual flux anyway (Chapter 15). There have to be choices, perceptions, decisions and can we add in desire, fear, and hunger? Jennings (1923) uses all these terms for simple organisms and the obvious answer is whether he was right to do so is that we simply do not know. These characteristics of behaviour are easy to see in our conscious selves and they are terms derived from our experience, but some features of all of these appear in some way or another in single cells and some of them in plants, too. It should be feasible to place a plant under stressful circumstances and see how many errors in behaviour emerge.

The natural world can be divided into human existence, other animals, plants and then single cells, but such classification hides the general truth that these divisions tend to merge at their boundaries. Animal life with its central direction of a society of cells, plant life with its organized republic of cells and cells with their organized republic of molecules (Whitehead 1938, p. 157). Like all true republics, plants will assess and vote by the majority view, controlled by a tissue quorum. The whole plant is equivalent to the animal brain.

In conclusion, in this section I agree with Kevin Warwick, artificial intelligence expert. 'I believe that dogs and cats are conscious in their own way and bees, ants and spiders are conscious, not as humans but as bees, ants and spiders. I cannot say that a robot with a computer for a brain is not conscious because its brain is not like mine and because it thinks in a different way to me' (Warwick 2000, p. 184). I will add to Warwick's statement that 'plants are conscious in their own way, not as humans but as plants', although there is no obvious way at present in which that can ever be accessed. Assessment, mentioned frequently in this chapter and arising from the connections between cells and molecules, hierarchically arranged in a complex system structure, may represent the plant equivalent of thinking. Those conclusions should hold for any network system sufficiently complex.

Is a social insect colony sufficiently complex to acquire a recognisable consciousness?

In Chapter 10, I indicated the distinct analogy in organizational structure between social insect colonies and large plants, such as dicot trees. In this discussion about consciousness, is it possible to conceive that colonies also possess a kind of consciousness? The component individuals through connections with each other form an obvious system whose emergent property is the colony, self-sustaining, and self-organizing; that is, swarm intelligence.

Although much of the original investigations on social insects concentrated on bees, ants also construct substantial colonies involving many thousands of workers. Colonies of ants not only gather information, they evaluate, deliberate, consensus build, face choices (and implement one of them), and they are sensitive to context. They hunt for new nest sites, assess their suitability from size and entry ways, and decide its use from quorum sensing. A threshold number must agree to the site after inspection (Franks 2008). Workers search for food and engage others to follow to this food site. Individual experienced ants teach other, less mature, individuals the directions to new nest sites (Franks and Richardson 2006). More experienced and knowledgeable individuals do the tuition (Stroeymeyt et al. 2011). They communicate all this information by pheromones.

The colony is certainly regarded as behaving intelligently. That is, it has the capacity to solve problems engendered by its environment (Franks 2008). Perhaps most crucially, the individuals are not credited with intelligence, but it is only the connections between the individuals that give rise to colony intelligence. Ant colonies acquire long-term memories of past experience because frequent movement to different nest sites progressively reduces the total move time (Langridge et al. 2004). The colony seems self-aware because the individual workers do not attack others in the nest, but will raid others nearby of the same or other species. The colony is certainly aware of its environment, as are those of bees and termites, and on that basis has a kind of consciousness, an awareness of the outside world, but it is a form of consciousness that we cannot at present access.

Individual bees in a hive obtain a map of their external circumstances and communicate it to others symbolically. This map is reinforced by repetition of flights. An effective image of the local area is thus slowly constructed, then resides in the colony. A memory of the acquired information presumably lasts as long as the individual workers continue collecting, but must then decline as workers die off. Does this provide a very simple model of how a brain functions?

Central to these concepts of consciousness is recognition of self and non-self. In colonies, members generally do not attack each other, but will do so against other colonies and hive intruders. It is thought that the recognition of non-self, which is what this represents, is the result of exchange of recognition signals between all individuals using again a chemical, a pheromone. When under attack, other pheromones are released that call other workers to deal with the invasion. Recent work suggests that, in some wasp colonies, facial recognition is also involved (Tibbetts and Lindsay 2008).

Conclusion on consciousness

In 1902, Charles Minot stated, in a speech to the American Association for the Advancement of Science, 'A frank unbiased study of consciousness must convince every biologist that it is one of the fundamental phenomena of at least all animal life if not, as is quite possible, of all life. Consciousness is a device to regulate the actions of organisms to accomplish purposes which are useful to organisms and are thus teleological'. This statement places a different perspective on how we assess plant life.

After a detailed description of insectivorous plant behaviour, Lauder-Lindsay (1876) stated 'that unless we re-define the term consciousness we must regard some form of it as occurring in both animals and plants that are destitute not only of brain but of a nervous system . . . to regard mind and all its essential or concomitant phenomena as common in various senses or degrees to plants, the lower animals and man'.

The nervous mechanism of plants

The title of this section is taken from a little-known book by J. C. Bose published in 1926. Altogether, Bose published about 12 volumes describing his research on plants, at a time (early twentieth century) and place (India) where very little science operated. His research gained recognition with a knighthood and being elected a Fellow of the Royal Society London. Bose has already been mentioned in Chapter 2 as one of those remarkable people that science is often blessed with. Because nervous systems tend to dominate discussion about consciousness and intelligence, I have included reference to his work here. Plants do not have a defined nervous system in terms of neurons and synapses that connect through a central brain. The lack of a defined nervous system does not exclude a complex system built on electrical conduction, something that has given rise to confusion in the past to some (Alpi et al. 2007).

Bose' extensive experimental information on plant nervous systems also required the construction of highly sensitive equipment, unique for the time, and that enabled so much to be uncovered. His prime experimental material was the touch-sensitive *mimosa*. He was able to demonstrate that the leaf droop after touch excitation was communicated by an action potential through the petiole to motor cells in the pulvinus. A massive efflux of potassium chloride from the vacuoles of these motor cells, results in a loss of turgor. Recovery takes about 45 min and, during this period, the potassium chloride is actively pumped back into these motor cells using cellular energy. However, Bose worked on other cells and species than Mimosa, so much of what he found can be generalized.

The benefits that animals gain by nerves and brains, is speed of connection between sensing system and muscular response. The brain provides for assessment and for awareness. It is part of the animal lifestyle of eat or be eaten that has accelerated the evolution of this apparatus. Predator and prey combined in an evolutionary dance of increasing speed.

Some of the information on the plant nervous system that Bose established

Bose clearly established the details of this nervous system in plants and he frequently compared the electrical system in plants with that in animals using the terms freely and rightly, in my mind, of both nerve and nervous system. The prime conductive tissue of action potentials he found to be the phloem and he identified this vascular tissue as the plant equivalent to a nerve by constructing a delicate voltage-detecting electric probe that penetrated the petiolar tissues to defined depths. He also isolated the nerves (phloem strands) from some plants and demonstrated their conductivity.

Transmission of the action potential is slower than those in defined nerves, but anyone who has observed the touch-induced leaf droop in Mimosa will know that the response is over in a very few seconds. A cold ring applied around the conductive tissue slowed the movement of the action potential. Further work established that, as in the animal synapse, conduction works only in one direction at the junction of the nervous tissue with the motor tissue.

By careful construction of further highly sensitive equipment, Bose observed the latent period after stimulation to be 0.08 sec and the velocity of transmission of the action potential in thin petioles to be about 400 mm/sec, intermediate between those of higher and lower animals. In the stem it can be as low as 5 mm/sec. In other plants, such as *averrhoa*, indirect stimulation electrically applied or when applied at a distance, led to an increase in turgor in remote tissues.

The pulvinus of Mimosa he found to consist of four different effector regions and stimulation of just one can give rise to torsional movements. There is a definite connection between the nerve end in each quadrant of the pulvinus at its centre and the corresponding subregion of the petiole. When the intensity for peripheral stimulation is adequate, the afferent impulse reaching the pulvinus becomes reflected along a new path and becomes an efferent impulse. A reflex arc is thus formed at the centre. This is considered different to mammals where the afferent and efferent impulses in a reflex arc are carried by separate nerves. However, Bose contends that there may be two kinds of phloem in Mimosa, which may conduct differently, one being afferent, the other efferent, thus mimicking the nervous organization of the reflex arc in animals.

Bose also reported that the heliotropic movements of leaves in which the leaf blade is positioned at right angles to the direction of light, was brought about by transmission of nervous impulses from the perceptive pulvinar region to the motor tissue of the same organ. Leaf movement was caused by contraction of the proximal and expansion of the distal side of this organ.

Bose (1926) draws several conclusions from his detailed studies.

Vascular plants possess a well-defined nervous system (p. 218).

Conduction can be modified experimentally in the same way as in animal nerves.

The conducted excitation may, therefore, be justly spoken of as a nervous impulse and the conducting tissue as nerve.

It is possible to distinguish afferent or sensory impulses from efferent or motor impulses just as in animals and to trace the transformation of one into the other to form a reflex arc.

'The observations involve the conception of some kind of nerve centre', but Bose admits no structure corresponding to the nerve ganglion of the animals has ever been detected in Mimosa.

Why did Bose' research largely disappear from scientific view?

Given the volume of work produced by Bose, it is always surprising that very little of it found its way into textbooks on plant physiology. There are undoubtedly some simple reasons. Mimosa and the Venus flytrap, whose trap was likewise controlled by an action potential, were considered as virtually unique and thus not relevant to most plants. The primary research emphasis in the 1930s was centred instead on crop plants and agriculture. The isolation of auxin in the early 1930s gave rise to a potential for chemical control of plant communication, growth, and thus yield. It is easier to modify plant development by adding a chemical than using complex electrical equipment. So the chemical approaches won out and the electrical ones all but disappeared, but even so Bose indicated, in his enormous compendia of data, that most of his results were applicable to these crop plants, as well. However, another reason was the behaviour of plants themselves. Any reason for electrical conduction was not obvious. Why it was asked did plants need rapid responses, they are slow to visibly respond. They don't get up and walk away.

Electrical fields took over this area of research

However, some took up the challenge in a different way. In the 1930s there was considerable interest in electrical fields. Could these provide explanation of embryonic fields, particularly in animal embryology or the meristem? Lund and Rosene (1947) provided summaries of several decades of study and measurement on bioelectric potentials in plants. These measurements showed that, for example, potential differences of 100 mV or thereabouts could be detected between the top and bottom of plant organs, such as the coleoptile. When the tissue was laid on its side, the new top and bottom rapidly assumed an equivalent potential difference, the so-called geoelectric effect. Potential differences they found existed everywhere—across plants, across organs—the plant was surrounded by electrical fields. Roots were found to have defined electrical fields around them and these could oscillate with periodicities in minutes (Scott 1957; Shabal et al. 1997).

Any mystery that might have surrounded these was quickly dispelled once it was indicated that these probably reflected no more than the differential accumulation of ions in plant cells across the plasma membrane (Scott 1967). The difference can be large up to –200 mV, compare that with a nerve cell at –70mV. Most research on electrical fields initially identified potassium ions in particular as being differentially regulated or accumulated across the plasma membrane.

Recent understanding has improved the perspective of the plant nervous system

Part of the reason for the oddity label applied to Mimosa was that the only thing affected seemed to be the turgor pressure. The sundew is another plant in which action potentials are used to help catch insect prey and in which relatively rapid movement occurs again using turgor pressure changes. If electrical conduction had greater relevance than just changing turgor pressure surely some other event should follow, a change in development for example?

Appreciation of the role of cytosolic Ca^{2+} in controlling many aspects of signal transduction: the missing link?

A slow accumulation of data starting in the 1980s indicated that cytosolic calcium was carefully regulated in plant cells at a very low concentration, about 100 nM (Trewavas 1985). Elevation by two to three orders of magnitude to a concentration of 10–100 µM could activate many numerous Ca^{2+}-dependent proteins and kinases in plant cells. Many of these proteins could modify transcription and translation, and change connections within cellular networks. What substantially propelled understanding forward was the development of an entirely simple method of measuring cytosolic calcium in plant cells using the Ca^{2+}-sensitive luminescent protein aequorin (Knight et al. 1991, 1993). When Ca^{2+} increased the plants luminesced. Very quickly it was found that numerous signals, such as touch, cold, light, oxidative signals or chemical elicitors of defence, and most signals to which plant respond could induce typical cytosolic Ca^{2+} transients in less than a second and lasting some 20–30 sec. Furthermore, imaging the luminescence and thus Ca^{2+} dynamics indicated self-propagating waves of Ca^{2+} elevation from the point of impact to thousands of responsive cells or as small cell clusters.

The speed with which a calcium signal could be induced, indicated that in contrast to the apparently slow response of plants, the initial impacts intriguingly, the transduction pathway involves MAP 3 kinase and probably MEK1 as it does in animal cells. There is a clear interaction between nitrate, the nitrate receptor, and the influence of glutamate.

It is extraordinary that the basic elements of signalling and memory events are shared between higher animals and higher plants, the latter in the absence of a defined nervous system.

Action potentials are involved in a variety of processes in plants (Fromm and Lautner 2007). How many of these involve glutamate and its receptors in plants, is not known.

Are immune systems intelligent, conscious or both?

The human immune system depends on both learning and memory. In simple outline, learning starts when the immune system detects a new antigen. Through trial and error processes, a kind of Thorndikean learning, the cell with the optimal antibody for this antigen is selected among a number of less optimal possibles and enormously replicated. The memory can last for a lifetime or disappear within a year or less. The immune system involves local contact, cooperation and direct recognition between several kinds of B- and T-cells, and uses information transfer, feedforward in replication and negative feedback to stabilize active cell populations. There may be epigenetic carry-over of resistance between generations. It is sometimes described as the molecular consciousness of the human body.

There are two kinds of immunity—innate and adaptive—and it is the adaptive form that has all the characteristics of swarm intelligence. It is self-organizing, lacks a central control, is initially imperfect in recognition, which is improved by trial and error, operates in stable overall fashion, adapts to changes in input giving a diversity of response and whose coordinate activity gives rise to evident intelligent behaviour (Timmis et al. 2010). The important feature to notice is that the immune system does not directly involve nerve cells. Instead of the collection of social insects in a colony, we now have a colony of interacting cells constructing a highly intelligent system.

Plants also have a complex immune system

Disease pests attacking plants seem to induce unique combinations of proteins that are equally responsible for resistance (Loon et al. 2006). The signalling is highly specific and seems tuned to the individual pest. Once attacked, the learning response is remembered and, again, it is primed for very considerable periods of time. As with herbivory, further attacks are then dealt with more quickly and more robustly (Conrath 2011). Priming results from:

1. Endogenous elicitors, signals arising from damage *per se*.
2. Molecular signatures arising from disease microbes.
3. Specific patterns of pathogen related damage.
4. Colonization by growth promoting bacteria.
5. Treatment with β-aminobutyric acid.

The initiation of priming is a learning process and priming can be remembered for years in perennials. The system is very obviously intelligent because it helps solve a problem of continued attack by pests and in showing such specific awareness agrees with Margulis definition of being conscious. The whole organism is involved.

More recent work has shown clearly that the primed state can be passed onto siblings and for several generations, suggesting epigenetic processes, DNA methylation, and siRNAs are likely involved with the learning process that controls specific methylases (Pieterse 2012).

Priming takes place against abiotic stimuli too

Perhaps the most extraordinary aspect of this process is the priming against abiotic stimuli. Treating plants with the amino acid, β-aminobutyric acid, not only primes against disease, but also primes against drought and salt stress—a process involving abscisic acid (Jakab et al. 2005). Large numbers of growth-promoting bacteria are associated with normal root systems and, surprisingly, induce systemic resistance to many fungi, bacteria and viruses even in the presence of pathogens (Loon et al. 1998; Kloepper et al., 2004). The growth-promoting bacteria produce a variety of compounds some of which are volatile, like butane diol. These on their own induce resistance mechanisms, but there is a range of small and large molecular weight chemicals that do so as well. Most significantly, these rhizosphere bacteria also help plants tolerate abiotic stresses like drought and excess salinity, and thus again alter behaviour (Yang et al. 2009).

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