Our Understanding of Life

In this exclusive interview, we talk to **Professor Stefano Mancuso**, founder of the study of plant neurobiology, and **co-founder** of the **LINV** (***the International Laboratory of Plant Neurobiology***). We discuss the very fundamental questions surrounding life itself and the profound discoveries he and his team have made about the nature of intelligence in our own ecosystem.

Vikas Shah, Thought Economics, January 2011

For thousands of years, humanity conceived the Earth to be a flat surface. This view, held by most pre-modern cultures was also combined with a Ptolemaic view, which held that the Earth itself was the centre of our Universe. These views shaped the very notions of our place in the universe, our relative importance within it, and even our understanding of science and religion. The Catholic Church, for example, found that accepting the idea of heliocentricism (*the Earth and planets revolving around a fixed Sun)* was in conflict with many of their teachings. If, they argued, Earth was God's creation, should it not hold that man is at the centre of the universe?. As explorers, academics and philosophers set about answering questions on the edges of the world, the nature of the universe, and the origins of Earth, they found that the answers destroyed the questions they were asking. Classic views changed irrevocably and fundamentally; and with those changes came a profound adjustment in the view of our place (*and relative importance*) in the universe.

Regardless of individual and social beliefs, science has dramatically changed human culture. We are now beginning to understand and appreciate the true diversity and variety of life within our own biosphere, and even within our own species. Advances in psychology, genetics, computing and other fields have also given us understanding into the shared experience of life. We now know there is up to ninety eight percent similarity between related genes in humans and apes, almost ninety percent between humans and mice, and almost sixty percent between humans and bananas. The more we understand, the more humbled we become in own image, and the more we are forced to change our relationship with the Earth. From climate change to forestry, agriculture and ocean-health, every new discovery leads us to act more as part of a system, rather than an observer to it.

One of the last frontiers of human arrogance remains our view on intelligence and life, that we only assume it to have value and legitimacy should it follow a very "human" form. Researchers around the world are now beginning to break down this wall too which, more than many recent discoveries, could alter our relationship with the Earth and the universe.

In this exclusive interview, we talk to Professor Stefano Mancuso, co-founder of the Laboratorio Internazionale di Neurobiologia Vegetale (*LINV, the International Laboratory of Plant Neurobiology*). We discuss the very fundamental questions of life itself and profound discoveries he and his team have made about the nature of intelligence in the ecosystem.

A prolific speaker and commentator, his TED profile reads, "*From his laboratory near Florence, Mancuso and his team explore how plants communicate, or "signal," with each other, using a complex internal analysis system to find nutrients, spread their species and even defend themselves against predators. Their research continues to transform our view of plants from simple organisms to complex ecological structures and communities that can gather, process and -- most incredibly -- share important information*."

Q: What is life?

[**Professor Mancuso]** We start with an easy question then?

I don't have any salient definition for life. It is a phenomenon which is too complex and important to be reduced to explanation in a few words. I can, however, tell you what life is not. DNA is not life. A single chemical molecule has nothing to do with life. DNA is merely a storage system. Nobody would ever say that the "Divine Comedy" is the actual paper and ink on which one of its copies is printed, however many influential scientists have supported this nonsensical viewpoint.

The duplication of synthetic DNA, and various initiatives like that, have nothing to do with life.

Life is a masterpiece of complexity. A sentence of Ilya Prigogine can help us, "*we will never understand, in a near future, the extraordinary complexity of the simplest forms of life.*"

Contemporary scientific culture, based on the principles of reducing complex phenomena to their simplest components, seems doomed to a fate of producing results with no more use than enriching databases. Today the vast majority of biologists are molecular biologists, interested in the study of the simpler components of phenomena which are, on the contrary, extremely complex. We are thus faced with a paradox. On the one hand, this approach has allowed for extraordinary discoveries and insights to be made; but on the other, it has also led to a similar extraordinary impoverishment of the general theory.

Q: What is intelligence?

[**Professor Mancuso]** This question is a little easier. I have quite a clear opinion on this. Intelligence is the ability to solve problems. Now, I know there as many definitions of intelligence, as there are authors who have studied it, but I really cannot think of a better definition than this. Of course, if you try to use this definition in any congress, there will always be someone who jumps in with some brilliant or funny definition that is limited to the intelligence of men or, mercifully, to most smart primates. It is as if they who speak are frightened of the possibility of losing their special place in the universe. In a sense, in biology we are still in a kind of Ptolemaic era with man considering himself the centre of the universe.

For me *intelligence is a property of life*. Even the most humble unicellular living organism must be intelligent to solve the problems of everyday life. Incidentally, these problems are not so different among species.

Human intelligence is, for want of a better phrase, a degree of magnitude greater than the intelligence of a Paramecium or, better, of a Chlamydomonas; but the difference is just quantitative and not qualitative. Where, otherwise, is the point of evolution when intelligence appears? We accept that primates are intelligent. But what about dogs? birds? reptiles? insects? Are they intelligent or not?

Many people are strong supporters of the theory behind the intelligence of higher animals; but if you admit the existence of intelligence in a single animal, you must admit some degree of intelligence in all animals down to the unicellular Amoeba (which, incidentally, is able to anticipate repetitive events and to solve a maze efficiently).

On the contrary, therefore, where is the threshold beyond which intelligence appears? and what is the nature of this threshold. Is it fixed and quantifiable? or, rather, is it continuously moving- being more of a cultural nature.

At the end of the nineteenth century, intelligence was the prerogative of man. Today, excluding a few fanatics, nobody would say that a chimp is not intelligent. Many would say that a good number of animals, not just chimps, are intelligent- and there are now many supporters of bacterial intelligence and, even an increasing number of people are convinced that plant intelligence is a real and valid phenomenon.

Q: What is plant intelligence?

[**Professor Mancuso]** There is, essentially, no big difference among "intelligences". They are not all the same thing but, as Vincent Vegas said in Pulp Fiction, "They are in the same ballpark." Whether we consider plant or animal intelligence- the fundamental property is to solve problems. At first glance, while one would think the kinds of problems that plants and animals must solve are different, looking more deeply reveals that they are substantially similar.

Everywhere we look, in the ways that plants react to problems, we can see actions that are not just automatic responses. Every plant has to endlessly sense and monitor a number of environmental parameters; and is constantly called upon to make decisions. This is not the place to list numerous cases of intelligence behaviour in plants, a huge volume of such examples can be found in scientific literature and, anyone who has spent only a few hours observing how plants react to environmental changes will have a clear idea about their acute senses and prompt responses.

Some may vaguely believe that there are actions and behaviours in the plant kingdom that look unquestionably intelligent, but there are many who also believe that plants act in a certain way simply because they have no choice; they are all passive objects in the hands of genes, instincts, environment and other similar puppeteers. I think that this way of reasoning leads nowhere as you could attribute the same mechanistic analysis to every single human thought (*are your decisions really free and independent or rather they are only possible as a result of a long train of interaction among genes, personal story and environment?*).

Q: What are the aims of the study of plant neurobiology?

[**Professor Mancuso]** When considering the lines of reasoning adopted by people who deny any cognitive possibility to the plant world, a common thread is that intelligence is associated with special groups of cells called "nerve tissue". This rationale relies on the circumstantial hypothesis that as plants have no trace of nerve tissue, this *de facto* prevents them from being intelligent; and this hypothesis seems to be held my many in the scientific community despite much convincing evidence to the contrary. It was, in part, to respond to this weak but widespread line of reasoning- combined with my convictions about plants- that some years ago, with my friend Frantisek Baluska, we founded the plant neurobiology institute.

If we look at the basic principle of "what" a nervous system is- we see that in, fact, a nervous system is just a group of cells specialised in transmitting impulses from one to another. Ordinary plant cells can do this, albeit in a less efficient way. Plant cells are joined together by special structures called plasmodesmata; thanks to them there is a continuity of protoplasm among cells through which electrical signals can easily travel. It is indisputable that there is no need of this "Holy Grail" of a nervous system to have the miracle of the transmission of electrical signals and communication.

Interestingly, the same phenomenon called “neuroid conduction” is well known to the invertebrate neurobiologists because very common in jellyfish and other lower animals.

Many plant scientists are fiercely opposed to the study of plant neurobiology but mainly because of a question of vocabulary: they assert that since plants have no neurons, plant neurobiology is nonsense.

Well, I do not think the language problem can be considered a serious impediment. The choice of the name was used to equate plants to all the other organisms- with the "neuron" being an umbrella term describing the existence of cognitive competences. In my opinion, the language should be related to function more than anatomy.

Gordon Shepherd, professor of neurobiology at Yale wrote in his “Foundation of the neuron doctrine” that “It appears that excitability should be regarded as a general property, found in a variety of cell types throughout the plant and animal kingdoms". One view would be that cells that clearly display this property be considered as having nervous, or neuroid properties. Rather than engendering confusion or vagueness, this conclusion instead may impart new unity to the study of nervous function. Just as the anatomical studies of the 1880s showed that nerve cells share the morphological unity of cell theory, so the physiological properties of the nerve cells can now be seen to be shared, to a greater or lesser degree, with basic biological functions common to many cells …one can suggest that a neuron is a cell that is part of an interconnected multi-cellular system concerned with the processing of specific information of behavioural significance.

Q: Can you explain the communication element of plant-intelligence?

[**Professor Mancuso]** Plants are astonishing communicators. It is something that we have known for at least the past quarter century. Plants normally communicate via volatile molecules, these are used both to transfer information inside a single plant and among different plants. The interlocutors can be other plants of the same clan (*it is now clear and evidenced that plants are able to distinguish kin from strangers and can adjust their behaviour accordingly*), other plants of the same species, other plant species, and finally, other non-plant species from bacteria to mammals.

Many important moments of the plant life-cycle are completely dependent on the efficiency of this complex communication system.

The cross-pollination phenomenon is a good example. The plant must be able to attract the "vector" for the transportation of the pollen (*it is not just insects, but also reptiles, birds and mammals that are used by plants as vectors of pollen*) giving it, for the service, a reward in the form of a sweet energizing substance known as "nectar". The entire pollination system can be described as a market with customers (*insects or other vectors*), buyers (*the plants*), banners (*the coloured flowers*), promotion (*fragrances*) and also, sometimes, misleading advertising (*as in the case of the orchid that deceives insects by imitating their female mating signals*).

The inspiring aspect is that this is just the beginning of the story, we are just now starting to understand how evolved the communication system of plants really is. Until now, research has been essentially directed to the investigation of the chemical substances used by plants to communicate each other; I, however, am convinced that plants are also able to use other communication systems.

In the coming years we will have some big surprises and changes to our points of view

Q: How does plant-neurobiology impact our understanding of evolution and ecology?

[**Professor Mancuso]** There is nothing against evolution in the notion and study of plant neurobiology; on the contrary I would say it is a further confirmation of Darwin's great idea.

From an evolutionary point of view the fact that intelligence has not appeared suddenly at a certain level of evolution, but slowly evolved from the most primitive form of life until the man, is further evidence that *nothing in biology make senses except in the light of evolution*.

Incidentally, the entire Darwin family from Erasmus (*Charles' grandfather*) to Francis (*Charles' son*) through to Charles himself who said "It has always pleased me to exalt plants in the scale of organised beings", have always been enthusiastically in support of a much more sophisticated vision of plants.

My hope is that this new vision of plants could have an impact on our relationship with the plant world. I mean, one thing is to treat the plant species' as if they were little more than inanimate entities; another is to be persuaded that plants are able to exhibit behaviours, sufficiently complex, that they can be described only by the term intelligence.

To understand that plants are extremely complex and evolved living beings will help us to respect them.

In a paper published through the Philosophical Transactions of the Royal Society (2004) Robert J. Sternberg and Elena L. Grigorenko argue, "*intelligence cannot fully or even meaningfully be understood outside its cultural context. Behaviour that is considered intelligent in one culture may be considered unintelligent in another culture, and vice versa. Moreover, people in different cultures have different implicit (folk) theories of intelligence, so may not even mean the same thing by the word. The relationships between different aspects of intelligence can vary across cultures, with correlations that are positive in one setting proving to be negative in another.*"

Anthony Trewavas expands on this thinking in his paper "Aspects of Plant Intelligence" (Published in the Annals of Botany 92: 1-20, 2003) stating, *"Intelligence is a term fraught with difficulties in definition. In part, the problems arise because of the human slant placed on the use and meaning of the world. However, although as a species we are clearly more intelligent than other animals, it is unlikely that intelligence as a biological property originated only with Homo sapiens. There should therefore be aspects of intelligent behaviour in lower organisms from which our superlative capabilities are but the latest evolutionary expression."He continues to cite that, "Stenhouse (1974) examined the evolution of intelligence in animals and described intelligences as 'Adaptively variable behaviour within the lifetime of the individual'.*

The more intelligent the organism, the greater the degree of individual adaptively variable behaviour. Because this definition was used to describe intelligence in organisms other than humans, it is a definition useful for investigating the question in plants. Do plants exhibit intelligent behaviour? The use of the term "vegetable" to describe unthinking or brain-dead human beings perhaps indicates the general attitude. ...one of the hallmarks of intelligent behaviour in the laboratory is the capacity of animals to run successfully through mazes and to receive an eventual reward. But the capacity of plants to grow through an environmental maze is not commonly assumed to represent intelligent behaviour and attracts little attention. Individual branches growing through gaps, towards sources of light are an obvious example. Numerous studies on rhizomes suggest that higher plants must be able to construct a three dimensional perspective of their local space and optimise their growth patterns to exploit resources, thus receiving rewards for successful behaviour. Higher plants do represent about 99% of the eukaryotic biomass of the planet. their sessile lifestyle is clearly successful and individuals then possess a fine ability to adjust and optimally exploit the local environment. How well they map the local environment and the extent of computation (with good estimates of computational skill) clearly still requires significant investigation in real and not artificial environments."

His views highlight one of the most important flaws in our scientific technique- that being our philosophy of reductionism- where science tries to understand the nature of complex things by reducing and averaging rather than understanding the phenomenon as a whole. Trewavas takes a wonderful paradigm explaining how, "*Chess provides a further and important illustration of how ignoring individual behaviour and simply averaging behaviour can confuse understanding. Each chess game represents a unique and highly individual trajectory, recording intelligent behaviour between two properly matched opponents. Suppose instead that we now averaged 1000 chess games, much as physiologists average responses, and then looked for meaningful variations. the averaging process would reveal that pawns had a very high probability (and a narrow standard error) of being moved right at the beginning and the king being irreversibly confined (mated) at the end, although with greater variability. Knights and bishops would have a high probability of being moved early on, although the probability mean would be lower than that for pawns and the standard deviation broader. Castles (rooks) and queens would be later still and with much more spread in the standard deviation, and so on. In fact, averaging any one large set of chess games would look very similar to any other large averaged set, and we would conclude that the chess game on this basis was rote, started with a clock, of little interest and certainly nothing to do with intelligence. And, in an attempt to understand what was going on, we might experimentally knock out pieces only to find that, yes they were necessary and you lose if they go, just as we currently knock out cells, chemicals, genes or signal transduction molecules in an attempt to understand what is going on. Another crucial point is surely that very simple rules govern chess but the order in which events take place (i.e. the trajectory) can be unique to each game*."

Both Trewavas and Sternberg also highlight the difficulties for us (as humans) to materially observe phenomenon which exist in a different timeframe to ours. We, as creatures develop from one to many trillion cells in a matter of months, before growing, changing and behaving in a very mobile and 'rapid' ways. For ecological phenomenon, these timescales would appear as mere blinks- with ancient forests and ecosystems which are many thousands of years old, and which can only be meaningfully observed as a whole (*rather than in a laboratory*). In the same way that we may observe for a few moments the life of a bubble, so the ecosystem may view our lives with a similar whimsical sense of our birth, existence and annihilation occurring in what seems, to it, to be moments. The key is to contextualise- and perhaps now is the time for us to redefine our understanding of diversity in terms of "cultures" rather than "species" -

thus plant, human, ocean, avian, bacterial, and many other cultures can simultaneously exist as a combined species of "life".

Even defining life itself suffers from scientific and philosophical debate. Ruiz-Mirazo et. al in a 2004 paper entitled "*A Universal Definition of Life*" state, "*Definitions of life are highly controversial. And it is not just a question of lack of consensus among the different proposals formulated so far. Some authors are very sceptical about the actual possibility of grasping 'in any scientifically relevant language' such a complex and multifarious phenomenon. Others think that we have to wait until biological theory(ies) become more rigorous, more encompassing and meaningful. And some others consider that it is not worth undertaking the challenge since, even if we could obtain a proper definition of life, it would still be a rather conventional one and would probably have little influence on the development of specific research programs in biology. The living phenomenology shows, indeed, many different sides (that appear at various levels of organization) and it is not easy to capture all of them in a single conceptual scheme. This is made even more difficult by life's ability to diversify and explore its own limits (always producing border-line cases, exceptions to the rule, ...). Last century's impressive advances in molecular biology have revealed a great underlying biochemical unity of all living forms, but it is not clear to what extent this is the result of contingency or of real necessity: i.e., whether that unity can serve to extract general biological principles or just derives from having a universal common ancestor of all terrestrial life. In addition, since the problem of the origin of life is also far from being solved, it is not at all obvious how those 'biological principles' would relate to the general laws of physics and chemistry, i.e., if they would be subject to an eventual reduction to the latter, or should have their own 'status' (with their own explanatory power, degree of abstraction, etc.) as scientific laws*."

In his posthumous piece "*Theory of Life*", Poet S.T. Coleridge discusses how, "*Nevertheless in science, as elsewhere, it is well worth the effort to ponder occasionally these seemingly false paths and fruitless divaginations if only to secure (us) from the narrow idolatry of the present time and fashions . . It is largely in that spirit that the present contribution is offered. The onrush of post-Darwinian biology has submerged, if not totally swept away, earlier searching into the nature of living things. Yet it may be that with the passage of another century our descendents will look back on our present understandings as yet another 'narrow idolatry' as 'another strange and alien world-view'*" Observers cite that Coleridge himself begun his piece by making fun of Bichat's well-known definition: "*life is the sum of all the functions by which death is resisted*." This he says is so obviously circular, "*life consists in being able to live*," his statement made as if to warrant no further discussion. Like so many discoveries of the past century, we are forced to realise that phenomenon which would previously have been relegated to the annals of science fiction are now empirically seated in our mainstream thinking. The potential for plants to be regarded as intelligent? the potential for an entire forest to exist as a single intelligent connected and ancient living entity? These questions now stand a greater chance of being truths rather than whimsical notions- and that is one of the most beautiful and profound discoveries we could have made. Understanding phenomenon such as plant-intelligence may also further aid our search for intelligent life elsewhere in the solar system and universe- meaning that rather than arrogantly assuming other variations of life to be humanoid 'beings' who communicate using electromagnetic signals, we could appreciate that intelligent life can take many forms- and our minds must be open to realise that.

For the culture of humanity, this level of understanding brings us home with other cultures within the species of the living. This brings with it a new-found respect and appreciation of our environment, along with the liberating and astonishing realisation that, finally, we are part of nature, not elevated above it.