Getting to the root of plant life

In 1882, Charles Darwin observed something that scientists have avoided talking about for fear of being labelled hare-brained. "The tip of the root (of plants) acts like the brain of one of the lower animals," Darwin said.

Roots that act like brains? Does this mean plants have memory? Collect data, store them, interpret them, and then act on them, in constantly changing, dynamic situations? This sounds so perilously close to words and phrases associated with humans, such as "thinking," "intelligence," and "decision making," that science shied away from anything that suggested plant life could be sentient.

In modern times, molecular biologists saw no need to ask such questions. They focused on DNA as the single template from which all life was fashioned and maintained.

However, with their mapping of the human genome, they discovered that humans carry only about 25,000 protein-coding genes. This was startling, because the simple nematode worm has about 19,000 such genes – and the human body is immeasurably more complex than a worm's. So, why didn't humans have a lot more protein-coding genes – genes that instruct proteins what to do?

To find answers, molecular biologists had to revise their notions of the genetic code. They knew that a huge number of genes in the human genome, making up more than 98 per cent of the genome, don't code protein. These they had previously dismissed as evolutionary leftovers, or junk DNA.

In an enormous turnaround, they began looking at these non-coding genes more closely and discovered they were not junk after all.

They had an extremely important function. A key to the mystery lay in the nature of complexity. There was no doubt protein-coding DNA was capable of creating complexity.

It could issue instructions for creating the legions of proteins that, in the case of humans, make up half their dry weight. But regulating the process was another matter. Without regulation, the results would be mostly chaotic.

In addition, as the complexity of organisms increased, the amount of regulation that was needed increased exponentially.

Regulation, it turns out, is the job of RNA (ribonucleic acid), located in the nucleus of cells along with DNA. It's from the so-called junk DNA that RNA gets regulatory instructions.

This revelation opened the intellectual floodgates, and put to rest the notion that life was ruled by a robotic DNA ritually coding proteins, much like a machine stamping out widgets.
Once regulation became a new focus, it raised the question: How does internal regulation adapt to constantly changing external conditions? Or, in the case of plants, how do they respond to changes in their surroundings?

There are 15 to 20 things that plants monitor – including weather conditions, light, calcium and aluminum availability, locations of other plants, electrical fields, chemical signals, smells, and waves of all kinds. In addition, they have remarkable capacities for communication. For instance, when infected by pathogens, they can release airborne volatiles, warning neighbouring plants to beef up their immune systems.

As Professor Anthony Trewavas of the University of Edinburgh puts it, there are so many variables to which plants react, that a plant genome – all the protein-coding DNA and all of what used to be called junk DNA – can't supply all the answers. There has to be something else at work, and that's where memory, interpretation, and choice come into the picture.

**Excitable Plants**

In researching last month's Origins essay on the origin of the nervous system, I was struck by the range of behavior and electrical excitability exhibited by organisms that lack nerve or muscle cells. Some sponges, for example, have a sneeze-like reflex that flushes out sediment (see video), whereas others generate electrical “action potentials” much like the impulses that convey information in nerves and brains. Electrical signals have been recorded even in the single-celled Paramecium, where they appear to play a role in escape and avoidance behaviors.

And it doesn't stop there. As far back as the 1870s, researchers had measured action potentials in two plants: the Venus flytrap (Dionaea muscipula) (left) and the touch-sensitive Mimosa pudica (right). To find out more, I recently visited Elizabeth Van Volkenburgh at the University of Washington (UW) in Seattle. She co-authored a provocative 2006 review paper on “plant neurobiology” in which she and colleagues argued that electrical excitability is just one of several signaling mechanisms used by both animals with nervous systems and plants to gather information about their environment and change their behavior accordingly. Yes, behavior. In plants.

In a tour of the UW greenhouse, Van Volkenburgh demonstrated two famous examples, the quick snap of a Venus flytrap and the folding leaves of a Mimosa plant (see video at bottom of page). Root growth is another well-studied example of plant behavior, Van Volkenburgh says. The tip of a growing root can seek out moisture and steer a course around rocks and other obstacles. "If you look at video clips of root growth, you see a lot of behavior that looks like worm behavior," she says. Charles Darwin made a similar observation in The Power of Movement in Plants, published in 1880: "It is hardly an exaggeration to say that the tip of the [root] … acts like the brain of one of the lower animals; the brain being seated within the anterior end of the body, receiving impressions from the sense-organs, and directing the several movements."

More than a century later, scientists are still investigating the sensory abilities of plants. In 2006, researchers reported in Science that seedlings of the parasitic dodder plant can sniff out their preferred host, growing toward a tomato plant—or even a vial of tomato extract—and shunning wheat. Sensing light is crucial for plants, and Van Volkenburgh says there are likely dozens of plant photoreceptor proteins for detecting different wavelengths of light. "They're detecting the quality of light, the intensity of light, the direction light is coming from, … and they're doing it all over, in every single cell."
As in animals, photoreceptors stimulated by light can trigger electrical activity in plants, her lab has found. "When light is shined on a young leaf, one of the first things that happens is what looks like an action potential," she says. That electrical impulse kicks off a series of events that enable the leaf to grow bigger. Other researchers also have found evidence that plants use electrical signaling. A 1996 study, for example, found that damaging the leaf of a tomato plant evokes an action potential, followed by a boost in gene expression for a proteinase inhibitor that makes the plants indigestible to insects. Electrical stimulation alone, in the absence of leaf damage, had a similar effect. Earlier this year, researchers used arrays of fine microelectrodes like the ones used in some neurobiology experiments to demonstrate synchronized electrical activity in the root tips of maize plants.

Plants also make a number of compounds that function as neurotransmitters in animals, including glutamate, GABA, dopamine and serotonin (though little is known about their roles in plant physiology), and some researchers see a parallel between neurotransmitter release at synapses and the release of the plant hormone auxin. Like neurotransmitters, auxin is packaged in vesicles that fuse with the cell membrane to unload their cargo into the cleft between cells. František Baluška, a botanist at Rheinische Friedrich-Wilhelms-University Bonn in Germany has gone so far as to call this arrangement a plant synapse.

But Van Volkenburgh thinks that's reaching a bit. At synapses, an electrical signal triggers release of a neurotransmitter, which in turn triggers an electrical response in the neighboring cell. But that chain of events has not yet been demonstrated for auxin, she said. "I would love to see those questions answered."

The mix of plants, behavior, and neurobiology is a strange cocktail. Even Darwin sounds slightly less than sober when he conjures up the image of tiny brains in the tips of growing roots. All the same, as Darwin realized, and as Van Volkenburgh and others have argued more recently, plants are far more responsive and dynamic than most animal-centric researchers give them credit for. That they do what they do without a nervous system makes them all the more fascinating.

Plants and sensitivity to pain.

Apparently there has been evidence (not particularly new by any stretch of the imagination but I've only recently stumbled upon it) to show that plants respond to stimuli- with some sources going so far as to claim that they feel pain.

So before I delve into this research, I should point out that I don't understand how this logically is a possibility. To feel pain, you need to be conscious. Maybe you don't need to be sentient or sapient but consciousness is a prerequisite. Since plants have no brains, hence no cerebral cortices, they can't be conscious. This begs the question: if they aren't conscious, how do they feel pain?

Even is they do feel respond to stimuli (which they probably do), I don't see how we could empirically conclude that they feel "pain" in a way that is equivocal to the way we do. Humans and plants have completely different neurobiology and anatomy. Humans feel empathy because of mirror neurons* (which are neurons that fires both when an animal acts and when the animal observes the same action performed by another). If we understand the pain of others, and assume that they feel pain in the same way as us because of mirror neurons, we can't do the same with plants as we have different hormones and nervous systems etc. Thus it would be illogical to conclude that plants feel pain in the same way as us.
Plant neurobiology:

*Auxin* is a hormone unique to plants which in charge of growth and plant behaviour. It stimulates the formation of vascular strands and roots. It also regulates vesicle trafficking and gene expression in roots.

Root apices are the "brain-like structure" of a plant. They're very sensitive to auxin and they are involved in lateral root formation (lateral roots are roots that extend from the primary root and anchor the plant to the ground—see picture on the left).

*Plant synapses*—Two adjacent cells which auxin and other chemicals are transported across. These synapses also play a part in immunology because they are the basis of cell-to-cell adhesions with other organisms (namely bacteria, viruses and so on). The cell-to-cell adhesions are also the active sites of the transport of molecules and metabolites.

And plant nerves:

Vascular strands: acts as a plant endoskeleton (something that holds the plant together) as well as the plant nerves. The leaves have single strands which combine to form the bundle of the stem and the vascular cylinder.

As for xylems and phloems, xylems are involved in the transmission of action-potential-driven electric signals (which cause short lasting events) and phloems are involved in the transmission of hydraulic signals (i.e. water-driven signals).

And root apices are, to quote:

Plant Brains: Each root apex harbours a unit of nervous system of plants. The number of root apices in the plant body is high and all brain-units are interconnected via vascular strands (plant
nerves) with their polarly-transported auxin (plant neurotransmitter), to form a serial (parallel) nervous system of plants. The computational and informational capacity of this nervous system based on interconnected parallel units is predicted to be higher than that of the diffuse nervous system of lower animals, or the central nervous system of higher animals/humans.

So all of this concludes that plants do indeed have a nervous system, albeit not as complicated as that of animals. Then again, none of this has specified that plants feel pain, just that they can transfer hormones and electrical impulses. Until I find more conclusive evidence, I won't subscribe to the idea that plants do feel pain, but I do accept that they respond to stimuli.

NB: Obviously, none of this is mine. I've stolen everything from this website and reworded so that it's easier to understand. If you're interested in reading more about human pain and the mechanisms behind it, this website seems pretty interesting.

I think I'm going to follow up this post with another one about the ethical and philosophical implications for me if as a result of this research because I'm not sure about whether or not, in light of this, plants should have more of a moral status.

* Note that the existence and significance of mirror neurons is by no means definitive in humans, although it is generally accepted in monkeys so I'll just give the theory the benefit of the doubt.

John Baldessari is not demonstrating developmentally appropriate interaction strategies

From Electronic Arts Intermix's description of John Baldessari's 1972 video art structuralist critique, Teaching a Plant the Alphabet:

Teaching a Plant the Alphabet is an exercise in futility, an absurdist lesson in cognition and recognition. The scenario is elementary: A small potted plant sits atop a stool. In the role of teacher, Baldessari holds up a series of children's alphabet cards in sequence, repeating each letter to the plant until he has completed the alphabet. The plant, of course, does not respond.

communication, that's not teaching. And this whole, "Of course, the plant does not respond" thing just sounds like negativity and low expectations. And don't even get me started on flash cards.