Who gets to be a stem cell?

If my arm were to be chopped off I would say "bummer" and I would have to start driving an automatic. However, if I cut off a branch of a tree it would say "easy come easy go" and it would grow a new one. This glaring difference between us and the plants comes from their ability to maintain clusters of very potent stem cells at the tips of each of their shoots.

Soon after our parents did the horizontal tango all of us humans started out our existence as an embryonic stem cell. This marvellous little thing would come to divide, over and over, and eventually give rise to everything which makes up our bodies—from liver cells to brain cells and eyeballs. This stem cell did however loose its ability to create new organs somewhere along our development to what we are today—fully assembled grown-ups with a distinct lack of available spare parts.

Plants start out their existence in similarly small scale, but during their development they manage to maintain strategically placed pools of stem cells, which in effect controls their continued growth as adults. The stem cells grow and divide, and in order to form a new organ—such as a flower or a leaf—they must give up their stem cell identity and specialize to become something else. If none of the stem cells specialized the plants would grow to spherical blobs of uselessness, but if all of the stem cells specialized the plant would loose the ability to branch out further. There must thus be something which very carefully decides which cell gets to be a stem cell and which cell must specialize instead.

But every cell is genetically identical, so how can a one of them sense that "ok, it's time for me to become a leaf", while another decides to remain a stem cell? The answer lies in a network of genes which can communicate with each other, both internally within each cell, and from cell to cell, across regions of tissue. This network enables the cells to make "decisions" based on the input from its surroundings. This would explain how the stem cells can grow and divide, and still be restricted to the very tip of the plant shoot—if a cell is pushed too far from this region it gets a different input from its neighbours and it can use this to decide its faith. Now, arguing that this is the case is all well and good, but imagine if we could fully understand the properties of this network. Not only could we use this information to see how they can keep on producing organs when we can not, we could also deduce how to best treat a plant in order for it to put maximum effort into growing the fruit, or corn, or wheat that we all rely on for our survival.

While the specifics of the different molecules which forms this network is studied in detail in laboratories, the behaviour of the network as a whole cannot be properly examined or understood without the help of mathematics and computers. By formulating a mathematical model and letting computers crunch through endless simulations we can ask the questions "what if this was true" or "what would then happen if we disturbed the system in such a way". By comparing all of the answers the computers gives us with all of the observations that the white-coated experimentalists has made, we can sniff out how the system must work.

Not only did such a mathematical examination indicate how parts of the plant stem cell network must work, it also showed how the requirements of the network neatly ensured that genetically identical cells could behave in vastly different ways. It turned out that the observed behaviour of the plant could only be reproduced if the model network was multi-stable. This means that the same system of communicating genes can end up stuck in many different configurations. Imagine that the genetic network is the French alps, where a skier will end up stuck in different valleys depending on where she starts her decent. The different valleys represent different stable states, in which the cells function differently. In one of them the cells are stem cells, and in the next valley the cell is a leaf. The genes, like the mountains, does not change, but signalling molecules from surrounding cells may act as ski-lifts which allows the skier to traverse the mountain tops and eventually end up in a different valley.

The mathematics told us that the system must have several of these valleys, and it gave hints about how the ski-lifts must operate. In doing so it also made claims regarding what must be true in order for our current understanding of the system to be true. These requirements are predictions which we can use to direct further experimental research. With new data from such research we can develop the model further and find more properties of interest for experiments.

We still have a very long way to go, but by iterating this loop of experimental and mathematical research we can hope to one day fully reveal the secrets of the plants. So, for now, we should probably try not to chop our arms off, but maybe one day we can take a leaf out of the plants' book and take such things a bit less seriously.

Niklas Korsbo
Lund University
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