Ghost in the Shell | by Sebastian M. Markert

A Lego robot is switched on. Timothy Busbice has been working on this robot a very long time. He's given it just some wheels and a touch sensor. And some very special piece of software. Now that he's switched it on, a miracle occurs: The robot is slowly moving forward! Soon, it hits an obstacle, the touch sensor activates, and it stops. But then it goes backward, slightly changes its angle, and tries forward again. And it hits the obstacle again. It doesn't give up, though. At one point, it finds a good angle to avoid the obstacle to continue its path. It's simple path-finding behavior. Not impressed? You think a robot like this is easy to program? You are completely right, of course. What the robot does is not remarkable at all. What is, though, truly remarkable, amazing, even, is the fact that this robot has *not* been programmed. Not to find a path, anyway. The robot, you could say, is acting out of his own "will" and motivation. What Timothy Busbice worked so hard on is not the robot per se, but it's "brain". He gave the robot the *mind of a worm*. The robot "thinks" it's a worm. It has the *soul* of a worm, if you will. Or maybe it's rather that a worm "woke up" in a machine. And now it's doing what it always does: it moves about, searching for food, pathfinding.

This is not science fiction. It happened. You can find a video of it on YouTube. However, few have realized how it works and what this means. The mind-blowing feat is eclipsed by the seemingly unimpressive behavior of the robot and the fact that the worm, a tiny *C. elegans* roundworm, is rather unremarkable as well. It's just one millimeter long, lives everywhere in the soil, and has only 302 neurons, not one more, not one less. As animals go, this seems to be one of the most primitive and boring. Yet it is exactly these features that make *C. elegans* my favorite lab animal.

I call myself a scientist. A neurobiologist, to be more precise. Science is often hard and ungrateful. Many abandon a career in science in favor of more worthwhile and healthier career paths. To stay in science, you need a *driving force*. Something that keeps you going through it all. Mine is this: I need to understand the human brain. Just think about it for a minute. You have in your head about two hands full of bloody jelly. And this mass of goop is the most complex network we know of. The most amazing thing in the whole universe! For this lump can be amazed about the fact that it is capable of amazement. It possesses consciousness, self-awareness. And it requires only as much energy to run as a dim lightbulb: about 20 watts. But how is all that even possible? It's just a bunch of cells, after all. Where in this cell-network are my thoughts? My knowledge? My insecurities? The concept of the number 7? Love? I want to know. I *have* to know! At least an inkling of insight of how unaware cells form a thought. But how? It's completely hopeless. As I said, the brain is the most complex thing in the known universe. How can we hope to understand it? Although we all have one in our skull, maybe it's impossible, on principle, to understand something that is as complex as the thing you try to understand it *with*. Probably, we need something way more complex than our brain to grasp how it works. But I don't give up that easily. If this is true then we just need to start small. Very small. As small as possible. Instead of billions and billions of neurons, let's start with 302! Let's start with *C. elegans*.

Of course, I'm by far not the first person with that idea. Scientists have been working on the nervous system of *C. elegans* for decades. Their approach is very straightforward: If we just get a complete map of all the neurons and all their connections, we will have the network of the nervous system in our hands and can understand it. Such a complete map of an animal's whole circuitry is called a *connectome*. The whole of all connections, just as a *genome* is the whole of all genes. I found this connectomics approach promising, and so I wanted to help. During my PhD, I worked collaboratively on methods to improve the mapping of connections in the worm. My own modest contribution. Thus, after great efforts, we have the *C. elegans* connectome. Yes, it's still incomplete and contains many errors, but for the most part it's there. For some years now, actually. And what is it that we learned from it? You'll be asking excitedly. Do we now understand how the worms thinks? The short answer is: Not at all. Even with the connectome in hand, we don't really have clue how it works, how a nervous system operates as a whole. It seems, even *C. elegans* is already too complex with its thousands of connections.

Now could be the time to despair. We don't even get the lowly worm, how can there be any hope to ever understand the brain? But one thing does give me hope. One thing gets me up in the morning: Timothy Busbice's Lego robot. He just took the connectome, imperfect and riddled with errors as it is, and put it in a machine. He connected the sensory neurons with the touch sensor and the motor neurons, which usually activate the muscles, with the wheels, and simulated all 302 neurons with their connections with each other weighed according to the connectome. And then he switched it on. And the biological programming of the worm started to work. The robot showed rudimentary worm-like behavior without any human ever telling it to. This experiment gives me hope that the "soul" really *is* inside the connectome. Somewhere. And that we can find it. Someday. And who knows? Maybe this will work with *Drosophila* flies next. And then with zebrafish. And then with mouse. And then, one day, you wake up in a machine. I hope that's a good thing.