YOUR BRAIN DOESN'T CONTAIN MEMORIES. IT IS MEMORIES

AUTHOR: NICK STOCKTON SCIENCE

RECALL YOUR FAVORITE memory: the big game you won; the moment you first saw your child's face; the day you realized you had fallen in love. It's not a single memory, though, is it? Reconstructing it, you remember the smells, the colors, the funny thing some other person said, and the way it all made you feel.

Your brain's ability to collect, connect, and create mosaics from these milliseconds-long impressions is the basis of every memory. By extension, it is the basis of you. This isn't just metaphysical poetics. Every sensory experience triggers changes in the molecules of your neurons, reshaping the way they connect to one another. That means your brain is literally made of memories, and memories constantly remake your brain. This framework for memory dates back decades. And a sprawling new review published today in Neuron adds an even finer point: Memory exists because your brain’s molecules, cells, and synapses can tell time.

Defining memory is about as difficult as defining time. In general terms, memory is a change to a system that alters the way that system works in the future. "A typical memory is really just a reactivation of connections between different parts of your brain that were active at some previous time," says neuroscientist Nikolay Kukushkin, coauthor of this paper. And all animals—along with many single-celled organisms—possess some sort of ability to learn from the past. Like the sea slug. From an evolutionary perspective, you'd have a hard time drawing a straight line from a sea slug to a human. Yet they both have neurons, and sea slugs form something similar to memories. If you pinch a sea slug on its gills, it will retract them faster the next time your cruel little fingers come close. Researchers found synapse connections that strengthen when the sea slug learns to suck in its gills, and molecules that cause this change. Remarkably, human neurons have similar molecules.

So what's that got to do with your favorite memory? "What is unique about neurons is they can connect to thousands of other neurons, each very specifically," says Kukushkin. And what makes those connections a network is the fact that those specific connections, those synapses, can be adjusted with stronger or weaker signals. So every experience—every pinch to the gills—has the potential to reroute the relative strengths of all those neuronal connections.

But it would be a mistake to believe that those molecules, or even the synapses they control, are memories. "When you dig into molecules, and the states of ion channels, enzymes, transcription programs, cells, synapses, and whole networks of neurons, you come to realize that there is no one place in the brain where memories are stored," says Kukushkin. This is because of a property called plasticity, the feature of neurons that memorize. The memory is the system itself.

And there's evidence of memory-making throughout the tree of life, even in creatures with no nervous system—scientists have trained bacteria to anticipate a flash of a light. Kukushkin explains that primitive memories, like the sea slug's response, are advantageous on an evolutionary scale. "It allows an organism to integrate something from its past into its future and respond to new challenges," he says.

Human memories—even the most precious—begin at a very granular scale. Your mother's face began as a barrage of photons on your retina, which sent a signal to your visual cortex. You hear her voice, and your auditory cortex transforms the sound waves into electrical signals. Hormones layer the experience with with context—this person makes you feel good. These and a virtually infinite number of other inputs cascade across your brain. Kukushkin says your neurons, their attendant molecules, and resultant synapses encode all these related perturbations in terms of the relative time they occurred. More, they package the whole experience within a so-called time window.

Obviously, no memory exists all by itself. Brains break down experience into multiple timescales experienced simultaneously, like sound is broken down into different frequencies perceived simultaneously. This is a nested system, with individual memories existing within multiple time windows of varying lengths. And time windows include every part of the memory, including molecular exchanges of information that are invisible at the scale you actually perceive the event you are remembering.

Yes, this is very hard for neuroscientists to understand too. Which means it's going to be a long time before they understand the nuts and bolts of memory formation. "In an ideal world, we would be able to trace the behavior of each individual neuron in time," says Kukushkin. At the moment, however, projects like the Human Connectome represent the cutting edge, and they are still working on a complete picture of the brain at a standstill. Like memory itself, putting that project into motion is all a matter of time