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04 Nov 2017

Systems Inspired by the Brain

A Brain Built From Atomic Switches Can Learn[1]

Current problems that have arisen in today's system designs include a variety of efficiency issues, one of which is circuit inefficiency. Moore's Law predicted that " the number of transistors in a dense integrated circuit doubles approximately every two years"[2]. However, despite this observation, system designers are seeing the limits to miniaturization and efficiency that is due to the decay of Moore's Law[3]. Instead, designers are turning to innovative ways to design systems to increase efficiency. Some of these designers are looking towards the brain for inspiration.

The brain is a tremendously energy efficient system. The power consumption of the brain is on average, equal to that of a 20-watt light bulb. Compare that to the K supercomputer, located in Kobe, Japan. The average power consumption of the supercomputer is equivalent to that of 10,000 light bulbs — 10,000 times that of the human brain. Moreover, the supercomputer took an entire 40 minutes just to simulate a single second of one percent of human brain activity. Indeed, looking towards the brain for power efficiency inspiration would improve these results.

Today, systems that mimic the brain's structure already exist in the form of neural networks. However, this is one of the first physical systems to mimic the structure of the brain

[1] Bubnoff, Andreas von. "A Brain Built From Atomic Switches Can Learn." *Quanta Magazine*, Quanta Magazine, 20 Sept. 2017, www.quantamagazine.org/a-brain-built-from-atomic-switches-can-learn-20170920/.
[2] "Moore's law." *Wikipedia*, Wikimedia Foundation, 1 Nov. 2017, en.wikipedia.org/wiki/Moore%27s_law.
[3] Simonite, Tom. "The foundation of the computing industry's innovation is faltering. What can replace it?" *MIT Technology Review*, MIT Technology Review, 6 Feb. 2017, www.technologyreview.com/s/601441/moores-law-is-dead-now-what/.

itself. At the California NanoSystems Institute at the University of California, Los Angeles, researchers Adam Steig, the CNSI director, and chemistry professor Jim Gimzewski, “inspired by the brain to generate the properties that enable to brain to do what it does”, are pioneering a system inspired by the brain’s structure.

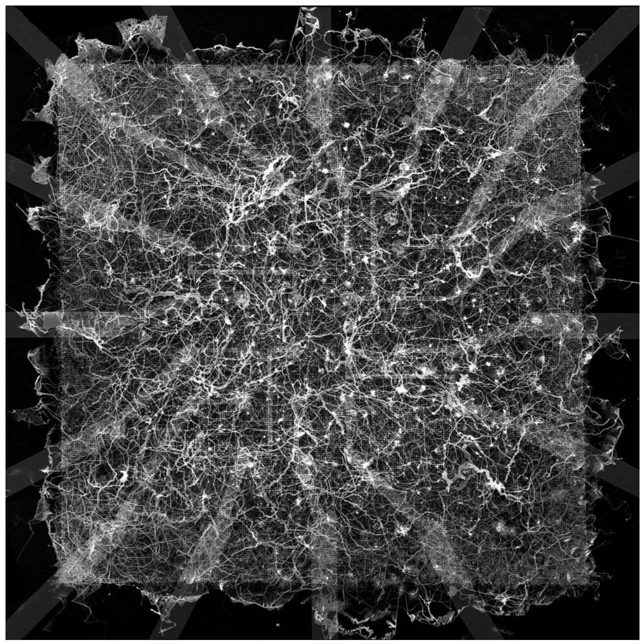

Image of the silver nanowire network created by researches Adam Steig and Jim Gimzewski.

The system is a two millimeter by 2 millimeter mesh of nanowires that is connected with artificial synapses. These artificial synapses are created with atomic switches. Atomic switches are a nanoscale circuit element[4] controlled by ions. Several types of these switches exist but they are currently being studied because their behavior has been observed to be synapse-like and could prove useful in creating systems similar to the brain.

[4] “Atomic Switch Networks for Cognitive Technology.” *International Center for Materials Nanoarchitectonics(WPI-MANA)*, International Center for Materials Nanoarchitectonics(WPI-MANA), 1 Aug. 2014, www.nims.go.jp/mana/research/highlights/vol17.html.

Because of the use of these atomic switches, there exist several similarities to the brain that have been observed by the researches. The system is itself disorganized like the brain. It also has demonstrated an ability to learn — the system is said to be able to solve a T-maze test. Most importantly, the system has demonstrated power-law behavior which has also been observed in the brain. This enables a state of "criticality" to be possible, meaning that a state between order and chaos indicating that the system has been operating maximum efficiency has been achieved. Moreover, the system is also able to enter a "sleeping" state when given the correct pattern of inputs. These similarities lead to a variety of benefits.

The system, as previously mentioned, is able to perform simple learning tasks and logic operations. However, it is also able to clean out unwanted noise from a variety of signals, opening doors for a variety of applications. In addition, the switches used are able to remember their history — if used more often, the switch would turn on more easily and if unused for some time, it would turn off automatically. The switches are also able to interact with each other — one switch being turned on would sometimes "inhibit or turn off others nearby". This behavior is what mimics synapses. In addition, there is no software needed, the system is used by distorting input signals. The system is also very fast — this is due to the fact that it does not separate processing and memory like traditional computers. Because there is no extra time needed to shuttle data back and forth, the system is able to make computations much more quickly. All of these benefits lead to a variety of applications.

For one, the system can be used for image or voice recognition. Due to its ability to clean out unwanted noise from signals, the system would be particularly useful in image and voice recognition. The unique structure of the system allows researchers to also align the structural complexity of the system itself with that which is being modeled. This would allow for more accurate and comprehensive models. Moreover, the nature of the system's inputs and outputs make it useful for reservoir computing.

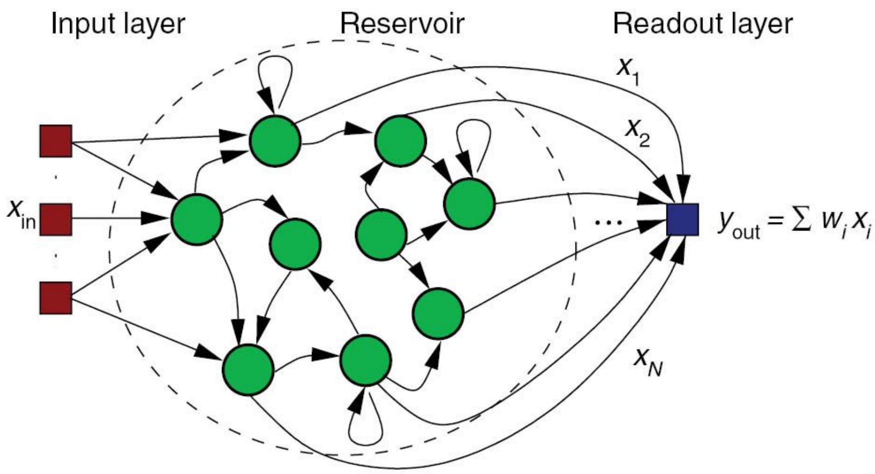

Diagram illustrating the basic principle of reservoir computing

Reservoir computing, used in machine learning and artificial intelligence, is an extension of neural networks[5]. Inputs are fed into a "reservoir". A "readout" mechanism looks at the reservoir and gives corresponding inputs that are generalized based on the current data present in the reservoir. In the case of the system designed by Steig and Gimzewski, the inputs that are possible can create many different data points used for the "reservoir." The data points here can be combined in different ways to create the desired computation.

Currently, there exist some challenges to using this new technology. Issues with finding the right inputs and outputs for the system have appeared. Moreover, the question of how to encode and decode these inputs and outputs has yet to be addressed. Because the system needs to

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[5] "Reservoir computing." *Wikipedia*, Wikimedia Foundation, 28 Aug. 2017, en.wikipedia.org/wiki/Reservoir_computing.

be trained, there are also issues that arise with that. However, once these issues have been solved, the potential for systems like this is huge. This relatively new technology comes with challenges of its own but once these are overcome, the future of computing may be altered.