COMPUTING THE BRAIN: WHEN NEUROSCIENCE AND TECHNOLOGY COLLIDE

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Sherry Liu was selected as the winner of the 2021 *Broad Street Scientific* Essay Contest. Her award included the opportunity to interview Dr. Pamela Douglas, Ursula Geller Professor of Research in Cardiovascular Diseases in the Department of Medicine at Duke University and Director of the Multimodality Imaging Program at Duke Clinical Research Institute.

"The computer is incredibly fast, accurate, and stupid. Man is unbelievably slow, inaccurate, and brilliant. The marriage of the two is a challenge and opportunity beyond imagination." - Leo Cherne

At first glance, the human brain appears to be the most powerful computer in the world. It maintains an impressive 3.5 quadrillion bytes of memory and processes information at 2.2 billion megaflops per second, all while consuming less power than a typical light bulb (Fischetti). The two share the same basic function as well: to process data to make informed decisions. Yet take a closer look and you'll see that the human brain and the computer take vastly different approaches to achieve their goals. Integrating the advantages of each is key to advancing both neuroscience and computer science - and the future of humanity.

To begin exploring these differences, we turn to the distinct structures of the computer and the brain. At the heart of computers are transistors - minute devices that switch between two states to represent 0 and 1. Millions of transistors are packed into a microchip, and together they carry out sequential commands (Woodford). Computer data are concrete - they are physically stored and any changes must be explicitly, and often laboriously, programmed. In contrast, memories in the mind exist in many regions at once and are constantly edited, often unconsciously. To explain this, we examine the neuron - the basic unit of the brain. Neurons are branch-shaped cells that communicate with other nerve cells through connections called synapses. While transistors can only be turned on or off, the state of a neuron fluctuates as its threshold, or activation limit, changes. When stimuli from surrounding cells reach this threshold, the neuron propagates an electric signal that in turn may activate the thresholds of other neurons (Woodruff). Many neurons firing over time allows your brain to write and execute its own unique "program."

The beauty of the brain lies in its adaptability, or neuroplasticity. Through adjusting the thresholds and synapses of each neuron, we can identify patterns, learn from them, and generalize our findings to novel problems. This phenomenon is what allows you to recognize a familiar face from years ago and a child to understand social norms after observing relatively few examples. These are tasks that computers must be specifically programmed to perform with far less accuracy, if any. This flexibility also gives rise to uniquely human traits like creativity and open-mindedness at the crux of innovation.

Computers have advantages of their own. While the number of neurons is fixed at roughly 100 billion, transistors have yet to reach anything resembling a limit: Moore's law predicts the number of transistors in a microchip to double every eighteen months due to research efforts (Herculano-Houzel, Bell). Machines also execute programs with incredible speed and reliability, and their sheer constancy befits them for tasks like searching through catalogs and calculating trajectories that take orders of magnitude longer to perform manually.

Knowing the distinguishing strengths of man and machine, it's impossible not to envision a world where the two join forces. Pioneers of the neural network did just that. In 1943, neuroscientist Walter McCulloch and logician Walter Pitts united in an effort to model the complex decisions of the brain. While their goal was not novel, their key breakthrough lay in framing the brain as a probabilistic model that alters its state to fit stimuli. Suddenly, the intangible goal of "thinking like the brain" became a task perfectly fit for computers: "calculating changing probabilities." Armed with this powerful observation, the two researchers created the first neural network, an algorithm that adjusts the weights of "nodes" like the brain adjusts the thresholds of neurons in order to minimize the difference between observed and calculated outputs. Several layers of weights extract patterns in input data and correlate them with outcomes. This approach revolutionized computer science, merging the raw power of machines and the human ability to learn through past examples and launching an age of rapid growth for artificial intelligence that continues today. In 1996, IBM's Deep Blue supercomputer defeated the world champion in chess for the first time. Modern neural networks can be found interpreting radiology scans, guiding self driving cars, translating texts, and recommending movies, all while assisting the very species that inspired their creation.

Motivated by the success of neural network algorithms, which still use traditional sequential microchips, researchers are working to mimic the brain at the most fundamental level by redesigning computer hardware. Neuromorphic chips are microchips packed with artificial neurons that exchange electric signals in bursts at varying intensities, simulating the brain's structure as well as function (Zaleski). This developing technology has the capability to enhance neural networks in efficiency and scope, making artificial intelligence ubiquitous in tools ranging from smartphones to medical devices.

As some work to mimic the brain, others are inserting the brain itself into computers. Key to this is mapping the connectome, or every neural connection, and integrating it with technology. Currently, the human connectome is too complex to process, although advancements in image analysis, coincidentally through neural networks, may soon change this. Meanwhile, the open sourced project OpenWorm has scanned the connectome of the worm species *C. elegans* and inserted it into an extraordinary robot whose movement is solely controlled by the worm's brain, no code required (Sarma *et al.*).

Still others, including Elon Musk through his startup NeuraLink, are exploring ways to allow humans to control technology using Brain Machine Interface (BMI), a device that translates brain signals into commands understood by computers. A common example of this is the cochlear implant, which stimulates the auditory nerve using electric signals to restore hearing. Further, breakthroughs in mind controlled arm prosthetics are giving amputees sensations of touch (Moore). Fully integrated BMI would be revolutionary, allowing for seamless communication between brain and computer, monitoring of attention levels, and hands-free applications (Shih *et al.*).

As the line between computer and brain blurs, a common fear is that machines are intruding on our humanity. For a reality check, we turn to the Turing test, which states that a computer must converse with a human without being detected as a machine to demonstrate human intelligence (Rouse). This much is clear: artificial intelligence passing the Turing test does not exist presently and will not exist in the foreseeable future. The greatest concerns in technology lie not in computers themselves, but in how we use, or abuse, them to shape the minds of users. These complex challenges will require experts in both neuroscience and computer science to collaborate, as they so often do, to ensure technology molds the human brain for good.

From these insights it is clear that computers and brains each possess distinct strengths which, when combined, have astonishing applications and capabilities. Whether it's neurons in the brain, transistors on a microchip, or two separate disciplines, individual components are strongest when they form connections. As the future unfolds for both man and machine, let us take a valuable lesson from those at the intersection between neuroscience and computer science. Let us not be afraid to seek exposure to ideas beyond any single approach, for the greatest ingenuities arise when seemingly unrelated ideas come together.

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