HOW ARE NERVE CELLS AND ARTIFICIAL INTELLIGENCE SIMILAR?

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In the field of artificial intelligence, which has a large influence on our lives today, the term "neural network" has been gaining popularity. It usually refers to a dense web of simple units, each of which may be in one of two states (on/off) and impacts of the state of other units connected to it. What exactly is the relationship between the way a nerve cell acts and the way artificial intelligence works? How is the action of an artificial neural network similar to a network of neurons in the human brain? This article tries to answer these questions. We will summarize how thinking happens, provide a short description of how a nerve cell works, describe the similarities between a nerve cell and a basic unit of a logical system, and finally show how connecting several such units is the basis for artificial intelligence.

THINKING INVOLVES LINKING CONCEPTS TOGETHER

From the dawn of culture, humans have been intrigued by their ability to think, perceive, classify, and make decisions. A common notion in the fields of psychology and philosophy is that our thoughts and

Figure 1

The thinking process can be described as roaming around inside a network of basic concepts that are connected in various combinations and strengths, determined by our experiences. **(A)** Black lines connect basic concepts that, together, represent the concept of "strawberry." Gray lines represent weak connections to basic concepts that do not belong to "strawberry." **(B)** Black lines connect basic concepts that represent the concept "watermelon." The gray lines represent weak connections to basic concepts that do not belong to "watermelon" (Figure credit: Renee Comet; public domain, *via* Wikimedia Commons).
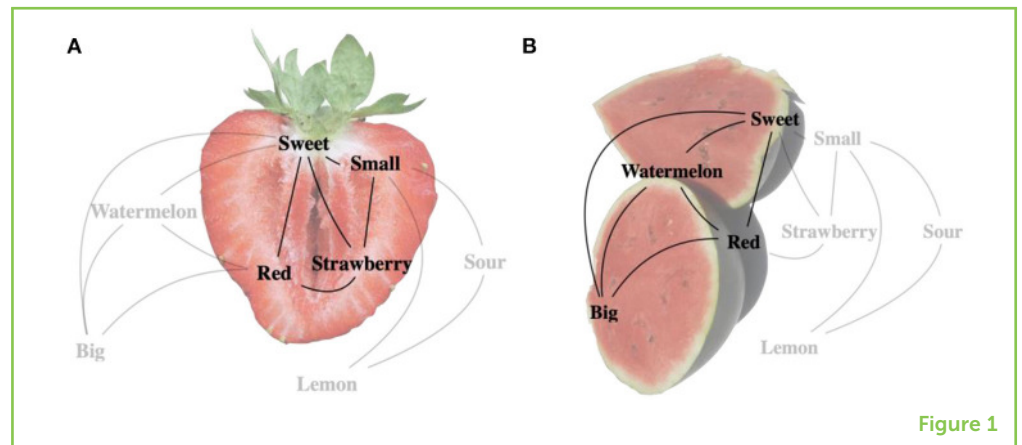
ASSOCIATIONISM

The idea that, as we experience the world, we connect abstract, basic concepts to each other in different combinations. For example, *sweet*, *red*, and *small* make up the object "strawberry."

NEURON

A brain cell capable of generating electrical impulses.

NEURON DOCTRINE

The idea that our ideas or concepts are represented in the brain by the activation of one or more nerve cells. Fibers connect nerve cells that represent similar basic concepts.

ideas are abstract, basic concepts that become linked to each other in different combinations as we experience the world around us. The name of this notion is **associationism**. According to associationism, thinking is a kind of roaming around inside an interconnected network of concepts that are joined to each other with various strengths. The trigger for roaming may be an external, sensory input such as sight, sound, smell, or touch.

For instance, let us imagine a group of concepts: *sour*, *sweet, small, big, red, lemon, strawberry*, and *watermelon* (Figure 1). Associationism implies that when the image of a *strawberry* comes to mind, there is a co-activation of associated, strawberry-related concepts, such as *red*, *small*, and *sweet* (but not *lemon*, *big*, or *watermelon*). The strength of the connections between associated concepts is built up by our interactions with the world around us. The more we experience a *sweet* taste occurring together with the sight of a *fruit* that happens to be *red*, the stronger the connection becomes between those three concepts.

HOW NERVE CELLS WORK

Associationism is interesting to scientists who are trying to understand how the human brain works. What happens inside the brain when we grasp a concept such as "strawberry"? The journey toward an answer to this question began back in 1835, following the development of methods that allowed high-quality microscopic observation of brain tissues. These early observations showed that the brain is made up of nerve cells, also known as **neurons**, that are connected to each other through fine fibers [1]. Over the years, these findings led to the development of a hypothesis called the **neuron doctrine**, which links associationism to the structure of the brain. Think about it this way: a concept (such as *red*, or *small*, or *sweet*) is represented in the brain by the activation of neurons. Fibers connect clusters of neurons, and this supports the association between concepts. Unique groups of neurons become active when we think of a complex concept or

Figure 2

IONS

Charged atoms or molecules. A positively charged ion is called *cation*; a negatively charged ion is called *anion*.

NEURAL IMPULSE

A small, quick change in the voltage between two sides of the cell membrane, which results from movement of ions between the inside and outside of the cell.
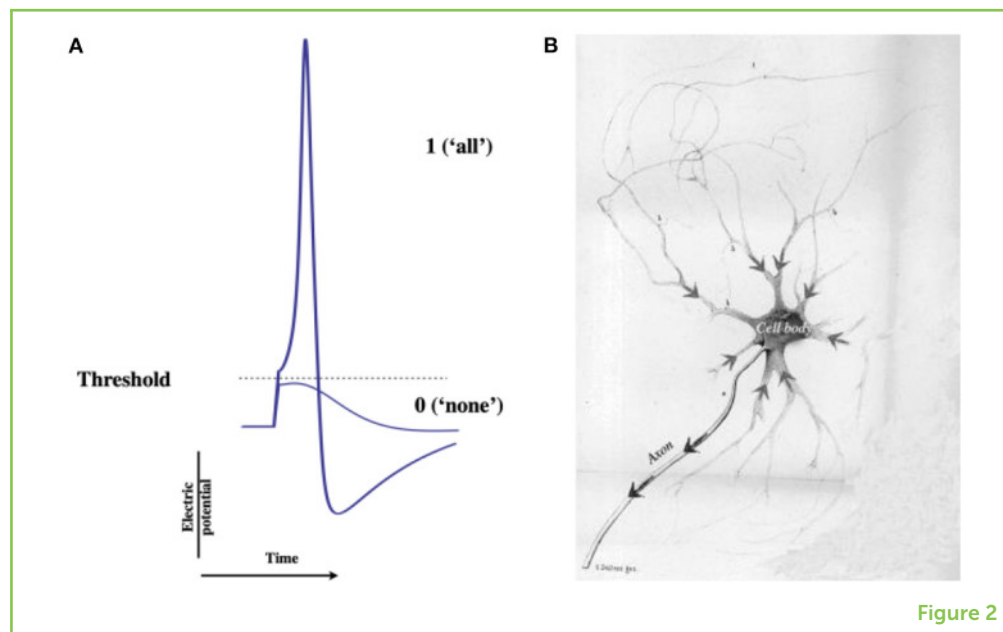
see an object in front of our eyes, like a strawberry or a watermelon (Figure 1).

But what actually happens in a nerve cell when the concept *red* comes to mind? The first clues came in 1926, with the development of advanced electronics that allowed identification and characterization of electric signals in nerves. These electrical signals happen when a nerve cell is active [2], and they involve a tiny change in the voltage measured between the two sides of the nerve cell's membrane. Specifically, the watery solution between all the body's cells (neurons included) is similar to sea water, with high concentrations of sodium **ions** (Na^+) and low concentrations of potassium ions (K^+). Na^+ and K^+ are common ions that carry positive electrical charges. Inside the nerve cell, K^+ is in high concentration and Na^+ is in low concentration. This difference between the internal and external ion concentrations leads to a voltage difference between the inside and outside of the cell, much like the difference between the two poles of a battery. Measuring the voltage showed that the electrical activity of a nerve cell is a very short (a fraction of a second) change in the electrical potential inside the nerve cell. This phenomenon was named a **neural impulse** or "spike" (Figure 2). Today we know that the spike results from the flow of Na^+ and K^+ ions through the cell's membrane. To create a neural impulse, the nerve cell must receive a stimulation that is stronger than a certain threshold; if the stimulation is not strong enough, nothing happens.

This "all-or-nothing" response of the nerve cell is similar to an on/off switch for a light. We can think about it in numerical terms as 1 (all) or 0 (nothing). This means that the strength of the stimulation causing the neural impulse does *not* affect the size of the neural impulse. These neural impulses allow us to feel, think, move, and more. Note that the

electrical activity in the brain results from electrical impulses in *many* nerve cells simultaneously.

At this point, there was still an important unanswered question: how exactly does a web of on/off switches explain how humans think and act intelligently? The search for an answer to this question has given rise to an exciting field of research that influences our daily lives—**artificial intelligence** (**AI**). Artificial intelligence technologies help people in many fields, including science and engineering. These technologies can be used to perform tasks ranging from identifying and sorting medical data and images, to the control of complex machines like autonomous cars. The origin of artificial intelligence may be traced back to 1943, where researchers suggested a possible connection between two very different scientific domains: mathematical logic and the operation of networks of neurons [3]. But what is the unique connection between these two domains?

LOGICAL SYSTEMS AND ARTIFICIAL INTELLIGENCE

A significant part of the thinking process may be described as a chain of statements that undergo true/false tests. To illustrate, let us use an example of the thinking process a doctor uses when a patient comes to her office and complains of having chest pains. The physician suspects that the cause of the chest pain is a heart attack. But to diagnose a heart attack, at least two of the following statements must be true: [a] Pains in the chest—yes or no? [b] Changes in the electrical activity of the heart—yes or no? [c] Changes in of the amount of a particular protein in the blood—yes or no? This means if the patient only complains about chest pain (meaning the answer to [a] is "yes"), this is not enough to diagnose a heart attack; the doctor will diagnose a heart attack only if the answer to statements [b] and/or [c] is "yes," in addition to the chest pain. The doctor makes the diagnosis based on a **logical expression**: "if [a] and [b] are true, *or* [a] and [c] are true, *or* [b] and [c] are true, *or* [a] and [b] and [c] are true, then there is a heart attack."
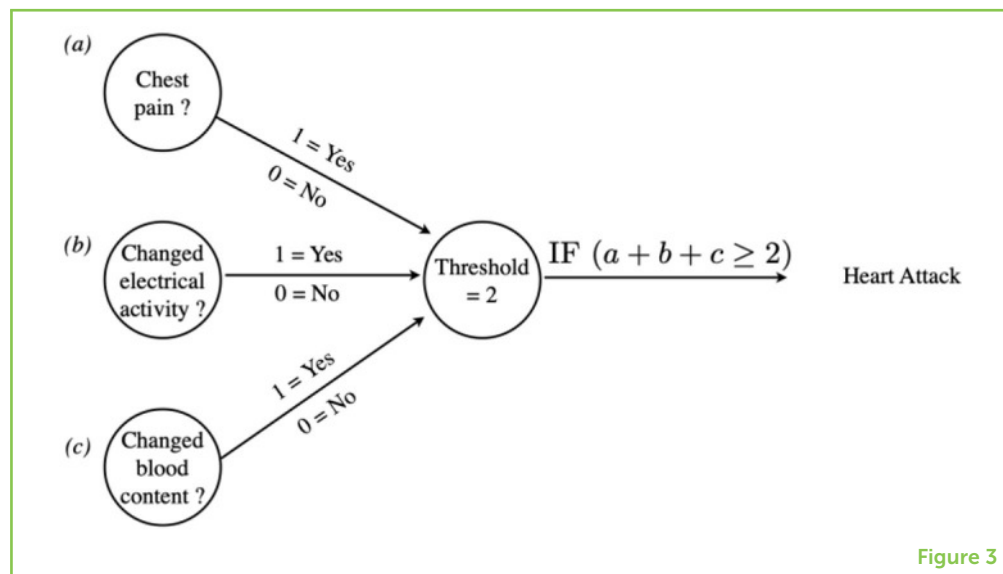
So, since a nerve cell responds in an all-or-nothing way and can only be in one of two states (0—not active, or 1—active), could a network of nerve cells represent the process of diagnosing a heart attack? Figure 3 shows such a network. This network has two layers. The first layer, called the input layer, consists of three cells whose activity represents the three signs of a heart attack: cell [a] represents chest pains, cell [b] represents changes in the electrical activity of the heart, and cell [c] represents changes in the protein concentration in the blood. The second layer (output layer) contains only one neuron, which receives the summed input of the three cells of the first layer. The activity of this one neuron in the second layer decides whether the conditions for diagnosing a heart attack have been fulfilled (Figure 3).

ARTIFICIAL INTELLIGENCE

Behavior of a computer or other machine that reflects an intelligence usually only attributed to a person. For example, a computer that plays chess, completes sentences, or summarizes an article.

LOGICAL EXPRESSION

A chain of operations such as "if-then," "and," "or," or "not," that is performed on data that is put into the system; the result is "true" (1) or "false" (0).

Figure 3

Researchers found that what a network can calculate is determined by the relationships between layers, by the strengths of the connections, and by the threshold value for activating the nerve cell. It seems that almost *every* logical expression can be described in terms of a neural network. This discovery was the basis for artificial intelligence, which is based on the activity of networks containing thousands of "cells" and many "layers," and is now part of almost all areas of our lives.

Further important progress was made as researchers figured out how to "teach" the network—through experience—to identify objects presented to the input layer, group them, and make the "right" decision in the output layer. Learning is performed by changing the connections strengths between cells or changing the threshold value. For instance, in Figure 3, the network could be "trained" to identify a heart attack if, and only if, all three conditions—[a] and [b] and [c]—were true; the "learning" could be achieved by changing the threshold value of the cell in the second layer to 2.5 instead of 2.

GAZING INTO THE FUTURE

Many challenges still face researchers who are interested in making analogies between the body's neural network and artificial intelligence. Several of these challenges result from the differences that exist between an abstract, mathematical representation of a nerve cell and a real nerve cell in the body. Yet, the biggest challenge of all keeps nagging our brains—is that all a person is? Are all our feelings, thoughts, and desires—our entire personalities—merely a network of electrical and chemical components seated in the brain? This answer will probably not be supplied by artificial intelligence; we will have to keep pondering it ourselves.

ACKNOWLEDGMENTS

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YOUNG REVIEWERS

AVIV, AGE: 15
My name is Aviv, I like to do many things: playing the piano – I have traveled to international competitions, and taking part in debates – speaking in front of an audience on various topics. I also like to play basketball, travel, and play ping pong.
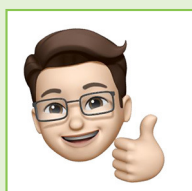
ISRAEL ARTS AND SCIENCE ACADEMY, AGES: 14–15
Israel Arts and Science Academy is a place for curious students who like to learn. In the 9th grade, as part of the elective classes we are the students who read scientific
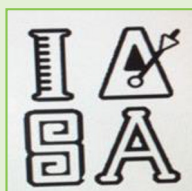
papers we chose. The course was led by Anat Maoz, the principal of our secondary school, which has a master's degree in marine biology.

AUTHOR

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I am a professor at the Technion, an institute at which I obtained my education as a researcher and medical doctor. My field of research involves the physical mechanisms of electrical phenomena in the living body in general, and in neural systems in particular. *marom@technion.ac.il