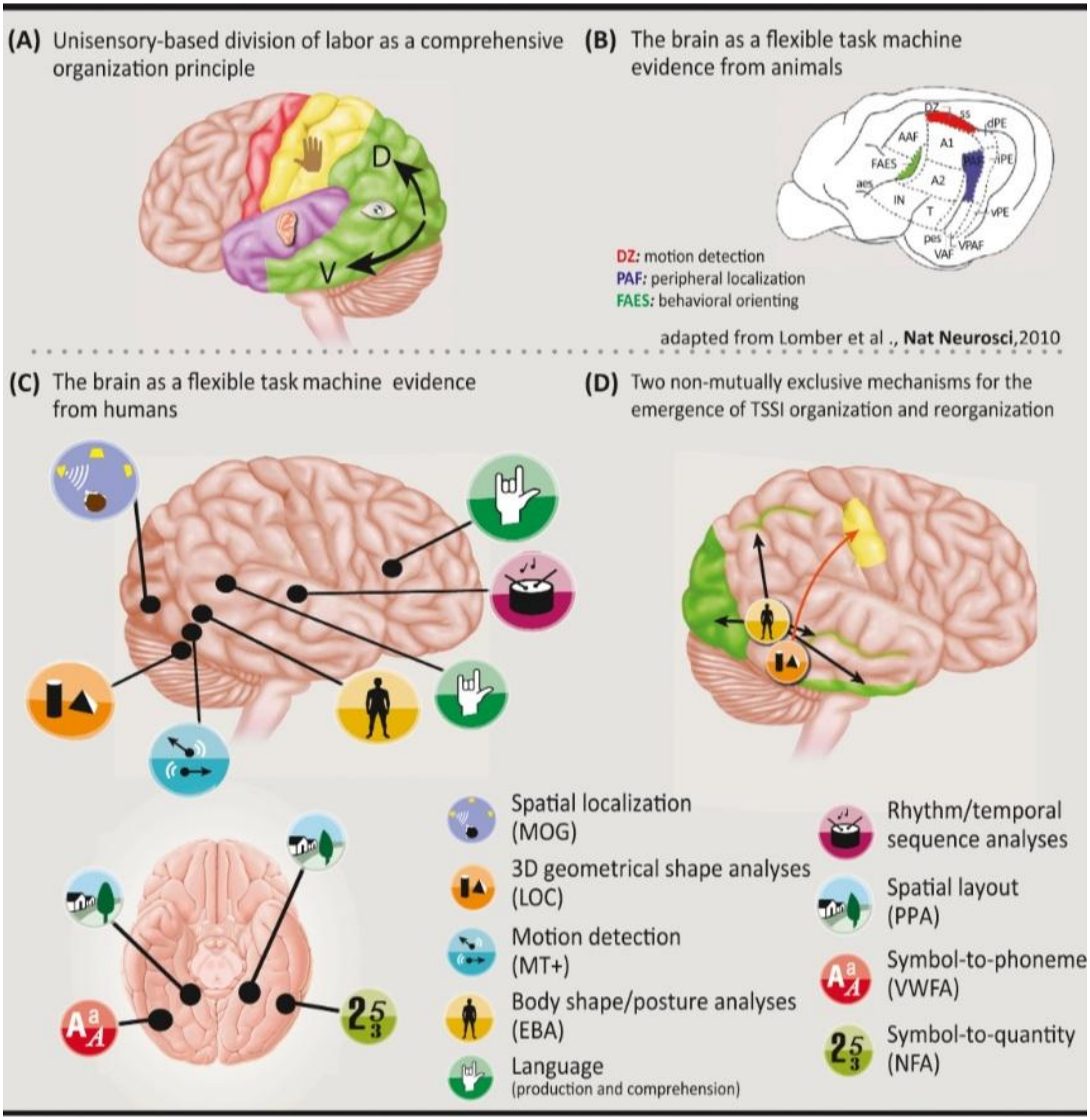
Your Brain is a Transducer


(A) Unisensory-based division of labor as a comprehensive organization principle

(B) The brain as a flexible task machine evidence from animals

adapted from Lomber et al ., **Nat Neurosci**,2010

(C) The brain as a flexible task machine evidence from humans

(D) Two non-mutually exclusive mechanisms for the emergence of TSSI organization and reorganization

Introduction

The computational model, comparing the brain to the computer, has been the most prominent metaphor in neuroscience and AI for decades. It implies that computers are very closely aligned to the functionality of the human brain. Any information-processing system consists of five main components — input, output, storage, processing and program. We can draw parallels between the brain and computers for each of these elements. Where it is appropriate, however, can be debated, particularly its usefulness for the advancement of science and technology. A growing number of indicators stipulate that the computer analogy is limiting our ability to look ahead, suggesting that a so-called 'Transducer-Model' might present a better foundation for explaining brain functionality.

Why the Brain is not a Computer

Thousands of researchers are devoting massive amounts of time and energy observing and exploring brain-activity. Every day, we learn of new discoveries that shed light on how brains of animals and humans function. As a result, new AI-technologies will improve the analysis of our behaviour as well as our decision making. And yet, there is a growing conviction among many neuroscientists that the present approach of collecting more data for detecting patterns has reached a dead-end. In an article recently published Why your brain is not a computer | Neuroscience | The Guardian, the author Matthew Cobb, Professor at the University of Manchester, provides an overview as to why the computational metaphor of brain functionality is wrong. In 2017, the French neuroscientist Yves Frégnac argued that the tsunami of data we are producing is leading to major bottlenecks because, as he put it, "big data is not knowledge". His colleague Romain Brette takes this argument a step further by challenging the most fundamental metaphor of brain functionality: coding. Since its inception in the 1920s, the idea of a neural code has come to dominate neuroscientific thinking. Brette's fundamental criticism is that, in considering "code", researchers inadvertently drift from a technical view – with a link between a stimulus and the activity of the neuron – to a representational view, where neuronal codes represent that stimulus. By viewing the brain as a computer that passively responds to inputs and processes data, we forget that the brain is an active organ, part of a body that is interacting with the world, and which has an evolutionary past that has shaped its structure and function. The brain is not simply passively absorbing stimuli and representing them through a neural code, but rather is actively searching through alternative possibilities to test various options. The brain does not represent information – it constructs it. But to imagine how that might work in practice, we would need an understanding of neuronal functions that go far beyond anything we can currently envision. Moreover, vast computational power and a simulation that precisely mimics the structure of the brain are required. For this to be possible we first need to fully model the activity of a nervous system capable of holding a single state, never mind a thought. We are decades away from taking this first step and some researchers like Rodney Brooks from MIT are questioning if this might ever happen if we follow the computational metaphor.

The Mind-Body Connection

The idea that our brains are like giant supercomputers, orchestrating and determining everything we do, is widespread. Science fiction scenarios like downloading the Internet directly to our brains or creating a new kind of a human with enhanced cognitive powers, are believed to become real in the not-too-distant future. In his new book, *The Biological Mind*, Alan Jasanoff, professor of biological engineering at MIT, explains why this “cerebral mystique” creates a false understanding of the relationship between the brain and the body. It ignores bodily influences on our psychology or the impact of chemicals in the blood and bacteria in the gut. As a result, we overestimate our capacity for free will or equate brains to inorganic machines like computers. But a brain is neither a soul nor an electrical network: it is a bodily organ, and it cannot be separated from its surroundings.

In an interview with Simon Worrall from the National Geographic Magazine, Jasanoff explains that a dualistic view of the brain and its relationship to the physical body and the physical world makes us see ourselves as unnaturally self-contained. In other words, we view ourselves as things that operate from *within*, so we are less sensitive to things that influence us *externally*. New research suggests that our emotions as much as our brains, are key in mediating how we perceive and interact with the world. Probably the most famous person who has advocated the view that emotions are key to learning or behavior is Daniel Kahneman. His studies showed that there is this apparently rapid, irrational, shoot-from-the-hip way to make decisions, which is important in the behavioral side of economics. In neuroscience, Antonio Damasio, Professor for Neurology and Psychology argues that there is a loop between the body and the brain and that the body is cognitively involved in our actions. This does not match the view that the brain is a self-contained machine. “The brain is a biotic organ, embedded in a continuum of natural causes and connections that together contribute to our biological minds. If we want to solve our problems, we should not reduce them to problems of the brain. We need to keep a broad view, which recognizes how the brain is connected both to the body *and* to the environment”, says Damasio.

Introducing the Neural Transduction Theory

A new theory of how the brain works — the neural transduction theory — might upend everything we know about consciousness and the universe itself. According to this theory our bodies are completely encased by transducers. Our sense organs – eyes, ears, nose, tongue, and skin – transduce distinctive properties of electromagnetic radiation, air pressure waves, airborne chemicals and temperature into distinctive patterns of electrical and chemical activity in the brain. In Your Brain Is Not a Computer. It Is a Transducer | Discover Magazine, Senior Research Psychologist Robert Epstein makes the point that evolution did not just create millions of new species of organisms, it also created millions of new types of transducers. Hard evidence that supports a neural transduction theory is lacking so far, but we are surrounded by odd phenomena that are at least consistent with such a theory. “The main reason we should give serious thought to such a theory is based on the sorry state of brain science and its reliance on the computer metaphor. Piano virtuoso and conductor Daniel Barenboim memorized all thirty-two Beethoven sonatas by the time he was 17, and he has since memorized hundreds of other major piano works as well as dozens of entire symphony scores. Do you think all this content is somehow stored in Barenboim’s brain? Studying his brain, you will never find a single note, a single musical score, a single instruction for how to move his fingers – not even a “representation” of any of those things. The brain is simply not a storage device”. If modern brain scientists begin to look for evidence that the brain is a bidirectional transducer, they might find it through a new understanding of neural pathways, structures, electro-chemical activity or brain waves. “It might take decades for us to see significant advances in transduction research, but with vast resources already devoted to the brain sciences, we could conceivably move much faster. If the transduction theory proves to be correct, our understanding of the universe and of our place in it will change profoundly. We might not only be able to make sense of dozens of odd aspects of human experience, but we might also begin to unravel some of the greatest mysteries in the universe: where our universe came from, what else and who else is out there – even whether there is, in some sense, a God”, writes Epstein.

Future Directions

Researchers from the Department of Computer Science at Cornell University and the School of Neuroscience at Tel-Aviv University have just published a new paper extending Epstein’s transduction theory to a probabilistic transducer theory. [2112.13388] The brain as a probabilistic transducer: an evolutionarily plausible network architecture for knowledge representation, computation, and behavior (arxiv.org). According to their model the brain represents a probabilistic network of nodes and edges. Although it has some similarities to standard neural network models, there are some significant differences. Nodes and edges of the neural network act as transducers that use a set of relatively simple rules to determine how activation levels and weights affect each other. These simple rules allows the network to acquire increasingly complex knowledge and simultaneously act as a transducer that facilitates planning, decision-making and the control of behavior. Their research demonstrates how evolution could endow the network with initial adaptive rules and goals which are enriched through learning. Hence, the developing structure of the probabilistic transducer network determines what the brain can do, breaking the barriers of the computational metaphor.

Conclusion

The arguments to advance AI-research from a computer to a transducer metaphor are intriguing. However, this endeavour competes with several other theories to overcome the limits of present AI-systems, especially in respect to causality or consciousness. Only time will tell which approach delivers the best results. Nevertheless, the human capacity to adapt to change will remain the limiting factor unless the quest for survival opens a new chapter in human evolution.

The Brain's Role in Consciousness: Generator, Antenna, or Receptacle?

Phenomenological philosophy advises that "to know what something is, know what it does". Colloquially, brains "do" consciousness. But the enduring hard question is "how?". To approach this, let's reverse the construct; ie – to get some understanding about what the brain "does", let's consider what the brain might be. For example, our group's work with Prof. Niko Kohls has asked: does the brain function as a generator, an antenna, or a receptacle?

If we view the brain as a generator, consciousness arises from the interactions of neurons, glia, and their network dynamics. This perspective aligns with traditional neuroscientific and materialist views, suggesting that consciousness is a function of physical brain processes. It implies that consciousness is biologically bound: it depends on the integrity and function of the brain, and thus raises questions about how we interpret consciousness in various stages of development; patients with specific neurological impairments; other species, or AI systems.

The brain might serve as an antenna, receiving consciousness from a universal source, akin to a cellphone receiving WiFi signals. This perspective resonates with philosophical and metaphysical traditions that propose consciousness to be fundamental to all living organisms (ie- pan-biopsychism), if not reality at-large. If the brain is an antenna, identities and subjective experiences are no longer solely products of biology but are influenced by an external, possibly interconnected, consciousness. This view would compel reconsideration of notions of agency and responsibility, potentially expanding ethical considerations to how we treat other living beings, and perhaps specific forms of AI.

If the brain is a receptacle, it'd be a vessel for consciousness, shaped by biological structural and functional properties, but not arising from, or defined by them. In this way, the brain could hold and shape consciousness. This view prompts inquiry to how consciousness might manifest in non-traditional structures or altered states of brain function (eg- psychedelic; meditative; near-death experiences); and if consciousness has some elemental core that could exist independently of the brain.

Or, a brain might be a combination of these, during different conscious processes, at various times throughout the lifespan, and under differing conditions. In sum, these brain-constructs each afford both views and attendant ethical considerations. The generator model emphasizes biological dependency, reinforcing materialist ethical frameworks. The antenna model implies collective consciousness, promoting interconnected ethics. The receptacle model suggests a broader, more inclusive ethics. With advances in neurocognitive sciences, examining these models can be useful to ethical discourse and responsibility as both organic and synthetic brain~minds continue evolving.

Your brain Works Like a Radio

Your brain cells learn best at an optimal frequency.

Ask a scientist what memory is, and you'll probably get long-term potentiation (LTP) as an answer.

To understand what LTP is, you need a little basic nerve cell (neuron) anatomy. Neurons have a nucleus and internal structures like other cells, but they also have fibrous projections called axons and dendrites. Axons carry messages (impulses—something like electrical charges) away from the cell body. Dendrites receive information from the axons of other neurons. But neurons do not touch, so nerve impulses must "jump the gap" from axon to dendrite. They do this chemically, by way of neurotransmitters that act as chemical messengers.

The axon of one neuron, a dendrite of another, and the gap between them are collectively called a synapse. LTP is the idea that synapses that are used often grow strong. That is learning. The action goes something like this: When a nerve impulse reaches the end of an axon, it triggers the release of a neurotransmitter into the gap of the synapse. When the neurotransmitter attaches to the dendrite of the next neuron, it starts an impulse in the second cell. If this happens many times, the signal is strengthened, maybe permanently. In this way, neurons become conditioned to respond strongly to signals they have received many times before.

LTP is a good explanation for the neural basis of learning, but researchers are constantly refining the idea. This week, UCLA neurophysicists report that there is an optimal brain "rhythm," or frequency, for changing synaptic strength. And further, like stations on a radio dial, each synapse is tuned to a different optimal frequency for learning.

Mayank R. Mehta and Arvind Kumar, researchers at UCLA, have found that stimulating neurons at high frequencies is not the best way to increase synaptic strength. For example, in these experiments, synapses stimulated with 10 impulses at a frequency of 30 per second achieved greater LTP than did synapses stimulated with the same number of impulses at a higher frequency (say, 100 per second). Thus, a synapse has a natural, preferred frequency for optimal learning.

That conclusion led the researchers to compare optimal frequencies based on the location of the synapse on a neuron. Mehta and Kumar found that the optimal frequency for inducing synaptic learning changed depending on where the synapse was located. The farther the synapse lay from the neuron's cell body, the higher its optimal frequency.

"Incredibly, when it comes to learning, the neuron behaves like a giant antenna, with different branches of dendrites tuned to different frequencies for maximal learning," Mehta said.
The researchers found that not only does each synapse have a preferred frequency for achieving optimal learning, but for the best effect, the frequency needs to be perfectly rhythmic—timed at exact intervals. Even at the optimal frequency, if the rhythm was thrown off, synaptic learning was substantially diminished.

Their research also showed that once a synapse learns, its optimal frequency changes. In other words, if the optimal frequency for a naïve synapse—one that has not learned anything yet—was 30 impulses per second, after learning, that very same synapse would learn optimally at a lower frequency, perhaps 24 per second. Thus, learning itself changes the optimal frequency for a synapse.

"Our work suggests that some problems with learning and memory are caused by synapses not being tuned to the right frequency," said Mehta. If that's true, the findings may lead to new therapies for treating learning disabilities. Perhaps drugs can be developed to "retune" the brain rhythms of people with learning or memory disorders. "We already know there are drugs and electrical stimuli that can alter brain rhythms," Mehta said. "Our findings suggest that we can use these tools to deliver the optimal brain rhythm to targeted connections to enhance learning."