

# THE BRAIN-COMPUTER METAPHOR (RICHARDS AND LILICRAP, 2022)

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## OUR ROADMAP

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## KEY DEBATE: IS THE BRAIN (LIKE) A COMPUTER?

- Computation has been a central feature of brain research for several decades
- Brain sciences often refer to concepts such as algorithms, information processing and coding
- The literature seems to be divided into two camps:
  - those comfortable applying computational terms and theories to brain sciences (e.g. van Rooij, Marcus); and
  - those which reject such comparisons, arguing computers are a misleading metaphor for the brain (e.g. Epstein, Cobb)

## KEY ISSUE: WHEN LIKENING A BRAIN TO A COMPUTER, WHICH COMPUTER?

- In computer science: a computer is any physical machinery that can, *in theory* (i.e. without resource constraints), implement *any* computable function
  - Computable function: its values can be determined by a Turing Machine / algorithm
- Outside of computer science: a computer is an electronic computer, i.e. any electronic device that can be used for calculations, communication, and entertainment
  - Particular focus on von Neumann architecture computers, i.e. those designed around CPUs, RAM and hard drives

## KEY POINT: WHETHER THE BRAIN IS (LIKE) A COMPUTER IS A MATTER OF SEMANTICS

- The authors' main argument: the two sides of the debate are only arguing due to semantic differences in the definition of 'computer'
- Under the computer science definition there is no metaphor: the brain is literally a computer (thus proponents of 'brains are computers' are right)
- Under the layperson's definition computers are a terrible metaphor for brains as they operate in radically different ways (thus critics of 'brains are computers' are also right)
- When one is clear on their definition there should be no debate

# COMPUTERS IN COMPUTER SCIENCE

- Computers were formalised with the Turing Machine, which defined computable functions (anything a TM can compute) and algorithms (how a TM computes)
  - Algorithm: finite instructions that, when followed, will produce an answer to a mathematical problem
- Concurrently Church devised lambda calculus, an equivalent formalisation. There have since been others, like general recursive functions
- Church-Turing Thesis: the conjecture that any attempt to formalise the definition of an algorithm will end up equivalent to a Turing Machine and that, consequently, any algorithm can be implemented via a Turing Machine

## IMPORTANT NOTE: A TURING MACHINE IS A MATHEMATICAL CONSTRUCT

- Turing Machines are a set of mathematical rules, not a physical device
- A brain or laptop is no more a Turing Machine than it is a lambda calculus
- Labelling something a computer, in the computer science sense, is not claiming it *is or works like* a Turing Machine, but that it can implement the same functions as Turing Machines

## WHY BRAINS ARE COMPUTERS IN THE COMPUTER SCIENCE SENSE

- When much of the computer science theory was developed electronic computers didn't exist: computers were humans trained to quickly perform lengthy calculations
  - Talk of a metaphor with electronic computers is nonsensical
- It's likely that real neural circuits are capable of implementing any function that an artificial neural network could – if not more (they don't cite any evidence)
- It has been shown that ANNs can implement any computable function, so the same should apply to brains

## WHY BRAINS ARE NOT LIKE VON NEUMANN STYLE ELECTRONIC COMPUTERS

- Brains use massively parallel processing rather than sequential processing
- Brains perform operations using high-dimensional, distributed representations rather than discrete symbols (hi James)
- Brains actively interact with and modulate the systems generating their input data (e.g. the perceptual system) rather than passively processing given inputs and producing outputs

## TAKEAWAY: THE COMPUTER-BRAIN METAPHOR DEBATE IS BORN OF SEMANTIC DIFFERENCES

- In computer science brains are literally computers, there is no metaphor
- In layperson's terms brains are not computers and computers are a bad metaphor for brains. At best, electronic computers can serve as a metaphor for *some types* of human cognition (e.g. following an algorithm to perform long division)
- Once this semantic difference is recognised there is no debate to have

## IF BRAINS ARE COMPUTERS, COGNITIVE SCIENTISTS SHOULD GET EXCITED

*“when one realizes that brains are literally computers (in the computer science sense of the word) then much of the theory about computation from computer science is applicable to brains.”*

ANY QUESTIONS?