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4 CHALLENGES IN BRAIN SIMULATION

Simulating the human brain is one of the most ambitious scientific endeavours ever undertaken. First steps are being made, but daunting technical obstacles lie ahead.

BY SIMON MAKIN

	THE PROBLEM	WHERE WE ARE	LOOKING AHEAD
1	**Scale** With its one hundred billion neurons and one thousand trillion synapses working in parallel, simulating the human brain would push the limits of even the exascale computers — capable of executing one quadrillion operations per second — that are on the horizon.	The largest neural simulation so far used simplified point neurons to simulate 4 million neurons of the macaque visual system. Meanwhile, the most detailed reconstruction incorporated biophysical models of 31,000 rat cortical neurons, comprising 207 types, which were connected by 36 million synapses.	Although the electrical spiking that is simulated by point neurons is the main way in which information is encoded and transmitted in the brain, there is more to how the brain functions. Even the most complex models of the brain leave out much detail.
2	**Complexity** Producing a biologically faithful simulation of the brain would require an almost limitless set of parameters. Many details are therefore not incorporated into models, including the brain's extracellular interactions, and molecular-scale processes such as receptor binding.	Researchers at the European Human Brain Project and the Allen Institute for Brain Science in Seattle, Washington, are compiling comprehensive databases of cell types and their properties for specific species. But some data cannot be gathered non-invasively, so might never be obtained for the human brain.	We are unable to simulate the brain to the last molecular detail. But proponents of simulation hope that uncovering the principles by which the brain works will enable some details to be generated by algorithms. Some features could also be left out when simulating aspects of brain function, but it's not yet clear which ones.
3	**Speed** Processes such as brain development and learning occur across years or decades in humans. Unfortunately, no present technology can run large-scale simulations faster than in real time. (Typically, such models run more slowly.)	Advances in supercomputing are needed. Quantum computing might help, as could neuromorphic computing, which uses analog circuits that mimic neural architectures. These developments could overcome certain limitations of standard computing, including software complexity and energy consumption.	The ability to work faster than real time will not by itself enable long and complex processes such as learning to be simulated. For example, the rules by which synapses change the strength of their connections in response to experience might be more complex than any used in current simulations of synaptic plasticity.
4	**Integration** To model functions that involve brain-wide networks, smaller models of brain regions will need to be combined. Top-down models, such as those that cast the brain as a hypothesis-testing system, must also be integrated with bottom-up biophysical models that typify simulations so far.	The Human Brain Project is developing digital tools to enable researchers to use models as building blocks. Combining top-down and bottom-up models will be essential for grasping how the brain achieves speed, flexibility and efficiency, but is a challenge because we lack a strong theory of how the brain works.	Some aspects of mind, such as understanding, agency and consciousness, might never be captured by digital brain simulations. Simulations that lack a representation of consciousness might be of limited use in understanding phenomena as complex as psychiatric conditions.

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