State of Brain Emulation 2025 AT A GLANCE

The essential summary of all materials published as part of the State of Brain Emulation Report 2025

Brain emulation models are computer programs that digitally replicate brains in physical detail: their wiring, activity, how connections change over time, and how behavior emerges from all of it. Such brain models would be a one-of-a-kind scientific tool; a digital way to study how neurological diseases arise, or how cognition forms, or even to reverse-engineer evolution's solutions to hard computational problems.

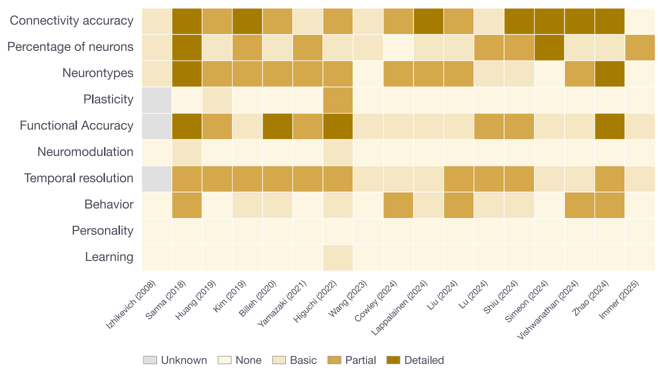
No other tool offers this combination of biological realism and experimental control, including AI. Despite similar terminology, modern AI architectures are fundamentally different from brains. Just as glass crystals imitate the sparkle of a diamond, AI imitates brain-like behavior convincingly and is enormously useful; but only lab-grown diamonds actually resemble the real thing.

To most, brain emulation sounds like science fiction. Yet it is a field shaped by rigorous and thoughtful scientists. We spent over a year interviewing experts, reviewing references, and collating datasets to capture the current state, and to identify existing bottlenecks. From this work it is clear that neuroscience has made major advances toward digital brains in the past decades. The sophistication of proof-of-concept brain models has grown substantially (see figure).

A key insight of the report: the main barrier to better brain emulation models is not hardware or algorithms, but rather more and higher-quality experimental data. Although data acquisition capabilities have grown roughly fivefold per decade since the 1980s (see figures), we haven't yet recorded the full brain for any organism at single-cell resolution. Even for the small organisms like the worm *C. elegans* or the fruit fly, available data is scarce and incomplete. Neuroscientists would like to record a library of hour-long color movies, so to speak, but currently only have access to a few minutes or blurry, stuttering, monochrome footage that barely covers one percent of the desired scene.

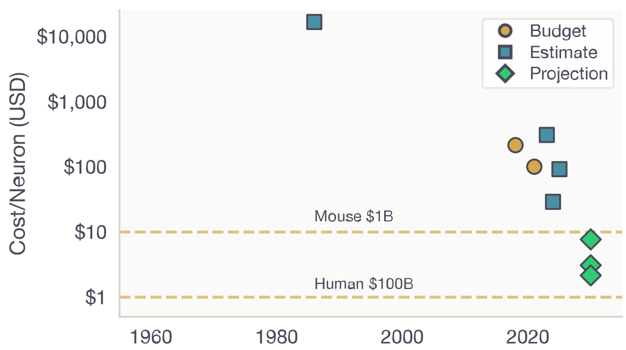
1 Simulation Capabilities

A heatmap comparing simulation fidelity across 10 biological dimensions for 12 landmark neural simulations, revealing strong connectivity modeling but limited behavioral validation



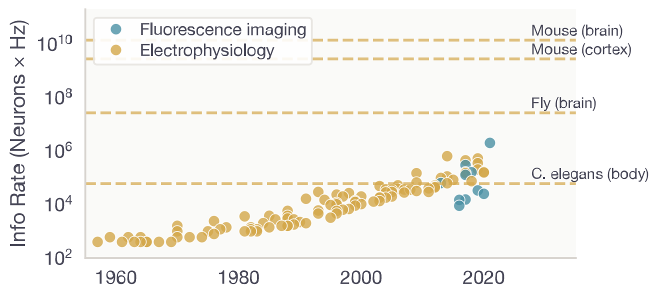
2 Connectomics Cost per Neuron

Connectomics costs declining from ~$16,000/neuron in 1986 toward ~$1/neuron by 2030, with budget thresholds for mouse ($1B) and human ($100B) whole-brain connectomes



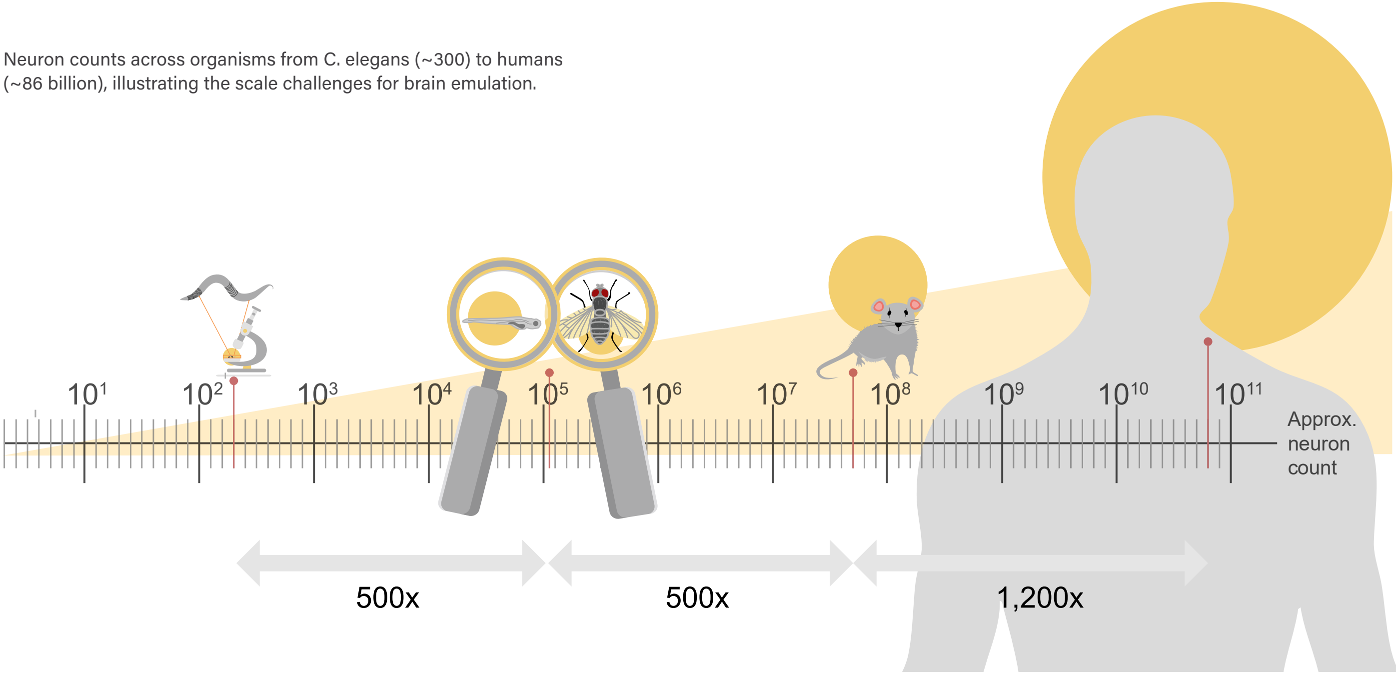
3 Neural Recording Information Rate

Neural recording information rates from 1960-2020, approaching whole-brain coverage only at the scale of C.elegans and fruitfly



> The main barrier to better brain emulation models is not hardware or algorithms. It is more and higher quality experimental data.

Neuron counts across organisms from C. elegans (~300) to humans (~86 billion), illustrating the scale challenges for brain emulation.



Scale compounds the problem: an accurate map of the mouse brain at the resolution needed to trace neurons is gigantic; similar in scale to a high-resolution reconstruction of Earth. A human brain is about 1,000 times larger still. Capturing the brain's many physical dimensions at once is extraordinarily hard. Think of a 10-sided Rubik's cube: progress on one face reshuffles the others. The faster you record, the smaller the image; the more you capture, the lower the resolution.

But at the scale of organisms under 1 million neurons — like fruit flies, small fish, bees, or mosquitoes — capturing all aspects of the brain faithfully is increasingly plausible. This means brain emulation models for these organisms could arrive within the decade. A sub-million neuron brain emulation project would likely cost in the low $100Ms. Such a project would help address critical unknowns: How much data, at what quality, improves computational models by how much? What structures are essential, what are nice-to-have? These questions must be answered before scaling to mammalian brains.

A mouse brain with 500 times more neurons has 10,000x the brain volume of a fruit fly; a human brain has about a million times more neurons and 30 million times larger. Both cases raise challenges beyond sheer scale. Physical limits on whole-brain recording will likely require extrapolation from partial data. And ethical constraints around animal and human welfare grow in complexity and relevance.

Today, everyone worldwide focused specifically on brain emulation could fit in a single workshop room. Total global funding for basic neuroscience over the past 20 years was roughly $0.5 billion per year — about 1% of the NIH's annual budget, and fragmented across many small academic grants. **Any individual or funder entering this field can have outsized impact.**

Explore further at

brainemulation.mxschons.com

Full report /report

The complete 200+ page technical analysis, with executive summary.

Articles /articles

Accessible explanations of brain emulation and its significance.

Data and **Figures** /resources

All datasets, figures, and code under CC BY 4.0.

Budget guesstimator /guesstimator

Estimate costs and timelines for brain emulation projects.

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Brain Emulation Projects Across Orders of Magnitude

What could be done with more resources? A non-exhaustive list of project ideas, organized by funding level and domain.

FUNDING ESTIMATES	FIELDBUILDING	DATA COLLECTION	TECHNOLOGY (R&D)	INFRASTRUCTURE	FINANCE & CONTESTS
~$100K+	• **Roadmapping:** technologies, unknowns, organisms • **Workshop series** / symposium • **Online lecture series**	• **Neurocrawl:** organism-specific catalog of all public datasets in computational neuroscience • **Data gap analysis:** identify most relevant missing data per organism	• **AI-driven literature mining** for brain emulation insights • **Small-scale tech pilots** in existing labs • **Metrics and benchmarks** for brain emulation models	• **Compute credits** to organizations/labs • **Reporting checklist** for neuroscience publications + journal implementation • **OpenWorm IT** contributions	• **Challenges and prizes,** e.g., "AI-based annotation" or "most versatile simulation" • **Conference track sponsorship** (NeurIPS, SFN, ICLR, etc.) • **Economic impact report:** unit economics, potential market sizes
~$1M+	• **Fieldbuilding org** coordinating roadmaps, conferences • **Epoch.ai / OWID equivalent** for brain emulation trends • **Government lobbying** for science investments • **Technical roadmap** (in-depth)	• **Multi-modal data collection** across recording and scanning modalities • **Electrophysiology gap-filling** for C. elegans / fruit fly / zebrafish • **Molecular annotation** in neural tissue (e.g., 100 molecules)	• **Scientific prototypes:** miniaturized 2P scopes, viral barcoding, voltage imaging • **AI-based proofreading** and segmentation enhancements • **AI vs. insect brain** comparative studies	• **Port OpenWorm** to other organisms to standardize computational neuroscience	• **"Kaggle for Brain Emulation":** continuous public competition on neuro dataset challenges • **Larger prizes** for above-mentioned domains • **Seed funding** for brain emulation orgs (for-profit / FRO) • **Academic grants** for various PhDs
~$10M+	• **Launch FROs,** e.g., "structure to function," "new model organisms" • **University institute** for brain emulation (seed funding)	• **10 mm^3 mouse brain** imaging and reconstruction • **Integrated datasets:** structure + function + behavior • **Interindividual comparison:** 5–20 insect individuals recorded + scanned • **C. elegans end-to-end** proposal	• **Industrial-scale prototypes:** 3-photon, next-gen ExM, barcoding kits • **X-ray tomography / voltage imaging** for small mammals • **Exploratory tech:** plasticity, identity, glia • **Scaling laws** from massive new datasets	• **Synchrotron beamline** (initial build) • **Mini-AWS:** compute + large-scale datasets in one place	• **X-Prize style challenge**
~$100M+	• **Insect-scale brain emulation** model effort • **Brain emulation institute**	• **First mouse connectome** • **Structure-to-function** feasibility studies	• **Dedicated chip development** for microscopy / simulation • **Full synchrotron** or x-ray tomography center	• **Brain emulation fab** prototype (centralized)	• **Venture fund** for brain emulation • **DARPA-style program** on brain emulation • **Philanthropic endowment** in the field
~$1B+	• **Mouse brain emulation** model effort	• **Comprehensive mouse datasets** (multi-modal) • **Partial human connectomes**		• **"BrainFab"** with robotics, advanced scanning	• **"BRAIN Initiative v2"** or large philanthropic consortia
~$10B+	In about a decade or more: **Human Genome / CERN-scale coalition** unifying governments, philanthropy, and industry for human brain emulation models.				