

The NIH BRAIN Initiative®: Al in Neuroscience

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AIM-AHEAD AI-CARES — August 28th, 2024

The NIH BRAIN Initiative

Goal: to develop and apply new tools for understanding how neural circuits underlie complex behaviors in health and disease



tional Institutes of Health

- Leverage *emerging technologies* to enable new discoveries about neural circuit function
- Use these discoveries as a foundation for *new therapeutic strategies* for human brain disorders
- Disseminate and democratize technologies for basic discovery and clinical applications



BRAIN Research Areas Overview

- Brain Cell & Circuit Technologies
- Neural Recording & Modulation
- Neuroimaging Technologies Across Scales
- Systems Neuroscience
- Human Neuroscience

- Data Science & Informatics
- > Training, Inclusion, and Equity
- Neuroethics
- Dissemination & Commercialization

Finding BRAIN Funding Opportunities



https://braininitiative.nih.gov/ funding/funding-opportunities



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| | Research Training & Fellowships | | | | | | | | | | | | |

What is Al?

- Modern AI computing technologies are based on artificial neural networks (ANNs), which are network models of simple nodes and connections whose weights are adjusted due to training with data
- Once technical barriers to scale were surpassed, impressive capabilities of perception, cognition, and learning emerged in large ANN models, with more and more data and compute required to pre-train the biggest foundation and frontier models







Common Neural Networks Used to Understand and Analyze Neuroscience Data



Yang, G. R. & Wang, X.-J. Artificial Neural Networks for Neuroscientists: A Primer. *Neuron* **107**, 1048–1070 (2020).

Three Components: Architecture, Learning Rule, and Objective Function



Richards, B. A. et al. A deep learning framework for neuroscience. Nat. Neurosci. 22, 1761–1770 (2019).

NIH National Institutes of Health

Three Components: Architecture, Learning Rule, and Objective Function

| 1 | | | | 1 | import random |
|-------|---|------|--|-------|---|
| 2 4 - | lace Value: | | | 2 | from micrograd.engine import Value |
| 3 | """ stores a single scalar value and its gradient """ | | | 3 4 ~ | class Module: |
| 4 | | | | 5 | def and condition (A). |
| 5 ~ | <pre>definit(self, data, _children=(), _op="'):</pre> | | | 7 | for a in calf parameters(): |
| 6 | self.data = data | | | 8 | p.grad = 0 |
| 7 | self.grad = 0 | | | 9 | prigrau - v |
| 8 | <pre># internal variables used for autograd graph construction</pre> | | | 10 | def parameters(self): |
| 9 | <pre>selfbackward = lambda: None</pre> | 54 V | <pre>def backward(self):</pre> | 11 | return [] |
| 10 | <pre>selfprev = set(_children)</pre> | 55 | | 12 | |
| 11 | <pre>selfop = _op # the op that produced this node, for graphviz / de</pre> | 56 | # topological order all of the children in the graph | 13 ~ | class Neuron(Module): |
| 12 | | 57 | topo = [] | 14 | |
| 13 V | <pre>defadd(self, other):</pre> | 58 | visited = set() | 15 | <pre>definit(self, nin, nonlin=True):</pre> |
| 14 | other = other if isinstance(other, Value) else Value(other) | 59 V | der bulld_copo(v): | 16 | <pre>self.w = [Value(random.uniform(-1,1)) for _ in range(nin)]</pre> |
| 15 | <pre>out = Value(self.data + other.data, (self, other), '+')</pre> | 61 | if v not in visites. | 1/ | sett.b = Value(0) |
| 16 | | 62 | for child in w prev: | 10 | sect.noncin = noncin |
| 17 | <pre>def _backward():</pre> | 63 | build topo(child) | 20 | def call (self, x): |
| 18 | self.grad += out.grad | 64 | topo, append(v) | 21 | <pre>act = sum((wi*xi for wi,xi in zip(self.w, x)), self.b)</pre> |
| 19 | other.grad += out.grad | 65 | build_topo(self) | 22 | <pre>return act.relu() if self.nonlin else act</pre> |
| 20 | outbackward = _backward | 66 | | 23 | |
| 21 | | 67 | # go one variable at a time and apply the chain rule to get its gradient | 24 | <pre>def parameters(self):</pre> |
| 22 | return out | 68 | self.grad = 1 | 25 | return self.w + [self.b] |
| 23 | | 69 | <pre>for v in reversed(topo):</pre> | 26 | |
| 24 ~ | <pre>defmul_(self, other):</pre> | 70 | vbackward() | 27 | <pre>defrepr(self):</pre> |
| 25 | other = other if isinstance(other, Value) else Value(other) | 71 | | 28 | <pre>return f"('ReLU' if self.nonlin else 'Linear')Neuron((len(self.w)))"</pre> |
| 26 | out = Value(self.data * other.data, (self, other), '*') | 72 | <pre>defneg_(self): # -self</pre> | 29 | class Laws(Medula) |
| 27 | | 73 | return self * -1 | 30 V | class Layer(Hodule): |
| 28 | def backward(): | 74 | | 32 | def init (self, nin, nout, **kwaros): |
| 29 | self.grad += other.data * out.grad | 75 | <pre>defradd(self, other): # other + self</pre> | 33 | <pre>self.neurons = [Neuron(nin, **kwargs) for _ in range(nout)]</pre> |
| 30 | other.grad += self.data * out.grad | 76 | return self + other | 34 | |
| 31 | out. backward = backward | 77 | | 35 | <pre>defcall(self, x):</pre> |
| 32 | | 78 | dersub(self, other): # self - other | 36 | out = [n(x) for n in self.neurons] |
| 33 | return out | 79 | return self + (-other) | 37 | <pre>return out[0] if len(out) == 1 else out</pre> |
| 34 | | 91 | def rout (self other); # other - self | 38 | |
| 35 ¥ | def pow (self. other): | 82 | derrsub(setr, other): # other - setr | 39 | def parameters(self): |
| 36 | assert isinstance(other, (int, float)), "only supporting int/float | 83 | return other + (-setry | 40 | return (p for n in self.neurons for p in n.parameters()) |
| 37 | out = Value(self.datamenther. (self.), f'm*(other}') | 84 | def rmul (self, other): # other * self | 41 | def rear (self): |
| 38 | | 85 | return self * other | 43 | return f"Laver of [{', ', ioin(str(n) for n in self.neurons)}]" |
| 30 | def backward(): | 86 | | 44 | |
| 40 | self.grad += (other * self.data**(other-1)) * out.orad | 87 | <pre>deftruediv(self, other): # self / other</pre> | 45 V | class MLP(Module): |
| 41 | out, backward = backward | 88 | return self * other**-1 | 46 | |
| 42 | | 89 | | 47 | <pre>definit(self, nin, nouts):</pre> |
| 43 | return out | 90 | <pre>defrtruediv_(self, other): # other / self</pre> | 48 | <pre>sz = [nin] + nouts</pre> |
| 44 | | 91 | return other * self**-1 | 49 | <pre>sett.tayers = [Layer(sz[i], sz[i+1], nonlin=i!=len(nouts)-1) for i in range(len(nouts))]</pre> |
| 45 ~ | def relu(self): | 92 | | 50 | dat call (alt v); |
| 16 | out = Value(A if self.data < A else self.data. (self.) 'Delu') | 93 | <pre>defrepr(self):</pre> | 52 | for laver in self lavers: |
| 47 | out - return (0 11 Sechadia < 0 else Sechadia, (Sett,), ReLU) | 94 | <pre>return f"Value(data={self.data}, grad={self.grad})"</pre> | 53 | x = laver(x) |
| 49 | def backword(): | | | 54 | return x |
| 10 | colf and in (out data > 0) a out and | | | 55 | |
| 49 | sett.yrdd == (out.data > 0) = out.grad | | | 56 | def parameters(self): |
| E1 | outoothwaru = _uathwaru | | | 57 | <pre>return [p for layer in self.layers for p in layer.parameters()]</pre> |
| 51 | rature aut | | | 58 | |
| 52 | return out | | | 59 | <pre>defrepr(self):</pre> |
| 33 | | | | 6.0 | return f"MIP of [/', ', inin[str[]aver) for laver in self lavers]]" |

https://github.com/karpathy/micrograd

AI Applications in Neuroscience

- Hypothesis generation and theory development
- In silico modeling and physical simulation
- Encoding models to advance theory and understanding
- Neural decoding models for prediction and control
- BCIs including DBS and neuroprostheses





Pre-Training Generative Foundation Models for Single-Cell Multi-Omics



Cui, H. *et al.* scGPT: toward building a foundation model for single-cell multi-omics using generative AI. *Nat. Methods* **21**, 1470–1480 (2024).

Learning Multi-Objective Ontologies of Human Cognition and Brain Systems



Limitations and Ethics of Generative AI and LLMs

Fundamental challenges

- Hallucinations
- Dependence on large pre-training datasets
- Intensive computational requirements
- Reasoning capabilities

Biases and other ethical considerations

- Models inherit biases of training data
- Generative models can produce harmful, offensive, skewed, or misleading output
- Different users have different assumptions about the breadth, depth, and truthfulness of the knowledge and capabilities of AI tools

Bzdok, D. *et al.* Data science opportunities of large language models for neuroscience and biomedicine. Neuron 112, 698–717 (2024).



Messeri, L. & Crockett, M. J. Artificial intelligence and illusions of understanding in scientific research. Nature 627, 49–58 (2024).

The BRAIN Initiative was founded on ethical data sharing

O BRAIN 2025 core principles

4. *Establish platforms for sharing data.* Public, integrated repositories for datasets and data analysis tools, with an emphasis on ready accessibility and effective central maintenance, will have immense value.

6. Consider ethical implications of neuroscience research. BRAIN Initiative research may raise important uses about neural enhancement, data privacy, and appropriate use of brain data [and] should hew to the highest ethical standards for research with human subjects and with non-human animals...





The BRAIN Initiative Data Ecosystem

Mission

To promote the data science advances and data sharing & informatics infrastructure needed to leverage BRAIN-supported research data to understand the brain and enhance brain health.

Strategy & Funding Opportunities

- BRAIN Data Science & Informatics
 - Data Science and Informatics | BRAIN Initiative
- BRAIN Data Archives
 - <u>RFA-MH-25-110: BRAIN Initiative: Data</u> <u>Archives for the BRAIN Initiative (R24)</u>
- Data Coordination and AI Centers for the BRAIN Transformative Projects
 - <u>RFA-MH-23-130: BRAIN BBQS Data</u> <u>Coordination and AI Center (U24)</u> (*Expired example*)



The BRAIN Data Archives

| <u>Data Archive</u> | <u>Data Domain</u> | Dataset Totals | | | |
|--|--|---|--|--|--|
| BIL (Brain Image Library) | light microscopy | 5,773 datasets 473 anatomical structures 13 modalities | | | |
| NeMO (The Neuroscience Multi-omic Data Archive) | multi-omics | 2,964,483 files 562,648 samples 5 modalities | | | |
| DANDI (Distributed Archives for Neurophysiology Data Integration) | neurophysiology behavior | 698 TB 534 dandisets 1,345 users | | | |
| OpenNeuro (Also integrated with NEMAR and OpenNeuroPET) | human neuroimaging | 986 datasets 39,796 participants | | | |
| DABI (Data Archive BRAIN Initiative) | human invasive neurophysiology | 49+ studies 895+ subjects | | | |
| BossDB (Brain Observatory Storage Service & Database) | electron microscopy X-ray microtomography | 47 projects 9 modalities 7 species | | | |

Scientific/Research Contact & Program Officer Ming Zhan (NIMH), ming.zhan@nih.gov



BRAINshare Project Data Sharing Case Studies

"Sharing human brain data can yield scientific benefits, but because of various disincentives, only a fraction of these data is currently shared. We profile three successful data-sharing experiences from the NIH **BRAIN** Initiative Research **Opportunities in Humans** (ROH) Consortium and demonstrate benefits to data producers and to users."

Neuron

NeuroView

Benefits of sharing neurophysiology data from the BRAIN Initiative Research Opportunities in Humans Consortium

Vasiliki Rahimzadeh,^{1,12} Kathryn Maxson Jones,^{1,2,12} Mary A. Majumder,¹ Michael J. Kahana,³ Ueli Rutishauser,⁴ Ziv M. Williams,⁵ Sydney S. Cash,⁶ Angelique C. Paulk,⁶ Jie Zheng,⁷ Michael S. Beauchamp,⁸ Jennifer L. Collinger,⁹ Nader Pouratian,¹⁰ Amy L. McGuire,¹ Sameer A. Sheth,^{11,*} and NIH Research Opportunities in Humans (ROH) Consortium ¹Center for Medical Ethics and Health Policy, Baylor College of Medicine, Houston, TX 77030, USA ²Department of History, Purdue University, West Lafavette, IN 47907, USA ³Department of Psychology, University of Pennsylvania, Philadelphia, PA 19104, USA ⁴Department of Neurosurgery, Cedars-Sinai Medical Center, Los Angeles, CA 90048, USA ⁵Department of Neurosurgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA 02114, USA ⁶Department of Neurology, Massachusetts General Hospital, Harvard Medical School, Boston, MA 02114, USA ⁷Department of Ophthalmology, Boston Children's Hospital, Boston, MA 02115, USA ⁸Department of Neurosurgery, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104, USA ⁹Rehab Neural Engineering Labs, Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA 15219, USA ¹⁰Department of Neurological Surgery, UT Southwestern Medical Center, Dallas, TX 75390, USA ¹¹Department of Neurosurgery, Baylor College of Medicine, Houston, TX 77030, USA ¹²These authors contributed equally *Correspondence: sameer.sheth@bcm.edu https://doi.org/10.1016/j.neuron.2023.09.029

Sharing human brain data can yield scientific benefits, but because of various disincentives, only a fraction of these data is currently shared. We profile three successful data-sharing experiences from the NIH BRAIN Initiative Research Opportunities in Humans (ROH) Consortium and demonstrate benefits to data producers and to users.

https://doi.org/10.1016/j.neuron.2023.09.029



CellPress

Ethical Data Sharing for Human Research

- Identifiability has implications for ethics, oversight, and regulations
- Re-identification risk depends on the context in which data are released
- Important context includes: data types, de-identification strategies, and additional accessible data sources that could be combined with the shared research data



(Lowrance & Collins, 2007)

• There is a spectrum of identifiability depending on instrumentation, recording modalities, processing steps, and data analysis strategies

Hendriks, S., Ramos, K. M. & Grady, C. Survey of Investigators About Sharing Human Research Data in the Neurosciences. Neurology 99, e1314–e1325 (2022). <u>https://doi.org/10.1212/WNL.000000000207297</u>

For NIH Data Management and Sharing principles and best practices for human participant data, see <u>NOT-OD-22-213</u>.



AI Ethical Imperatives for Neuroscience? Open Models, Explainability, and Robust Data Provenance

 The output of our AI tools should be interpretable, and not *over* interpretable, to be useful, while minimizing biases in the underlying models and in how users understand the models and their output.

National Institutes of Health

- Ethical applications in neuroscience and other scientific domains will be impeded by "black box" AI models based on closed weights and proprietary architectures.
- Robust tracking and updating of metadata is needed, including data provenance, consents, and conditions of use for Al training. Provenance keeps *people* in-the-loop with downstream AI and data uses.



Artificial intelligence and illusions of understanding in scientific research

https://doi.org/10.1038/s41586-024-07146-0 Lisa Messeri^{1,4} & M. J. Crockett^{2,3,4}

Received: 31 July 2023

https://doi.org/10.1038/s41586-024-07146-0



Related Events

Recent and Upcoming Meetings

NASEM Neuroscience and Al Workshop — March 25–26, 2024 Exploring the Bidirectional Relationship between AI and Neuroscience Session 5: Regulatory & Policy Advocacy and Engagement

- Michael Littman, NSF; Session Moderator
- John Ngai, BRAIN Initiative
- Nita Farahany, Duke University; NASEM Planning Cmte
- Eva Weicken, Fraunhofer HHI
- Wade Shen, White House OSTP; ARPA-H

UPCOMING

SfN Professional Development Workshop:

Working With and Working for AI

Saturday, October 5, Noon-2pm CDT MCP Room S403, Chicago

This workshop will touch on AI applications and job opportunities that are or will be arising in this field. Speakers will address not only their employment of AI techniques but also employment opportunities in AI.





NASEM Workshop Videos & Materials



SfN 2024 Workshop Information



Neuroscience and Al: Emerging scientific questions

| nature communications Perspective Catalyzing next-generati Intelligence through Neu | bttps://doi.org/10.1038/s41467-023-37180-x Don Artificial roAl | Editoria | ı ew NeuroAl | https://doi.org/10.1038/s42256-024-00826-6 |
|--|--|---|--|--|
| Received: 11 September 2 Accepted: 3 March 2023 Published online: 22 March 2 Check for updates If deep learning is the questio | PER ng is the answer, what n? | and computer scientists proposed neural networks as solutions to key problems in perception, memory and language ³¹ . Contemporary deep networks resemble | des of develop- ne inspiration that neuroscience been nt initiatives make ga fresh look at the een the two fields. | Check for updates which will hold its third conference 'From neu- roscience to artificially intelligent systems' in autumn 2024. Academic institutions are embracing NeuroAI, as evidenced by NeuroAI and Intelligent Systems at Princeton Univer- sity and UCL NeuroAI at University College London, which encourage collaboration between the neuroscience and Alcommunities. antific meetings such as COSYNE have a to real to conversing successfor the real to acoustic |
| Andrew Saxe, Stephanie N Abstract Neuroscience re advances in machine learning new ways of thinking about n the possibility that deep no cognition and action for bio radically reshape our appro- computations performed by endowed by the researcher. model and understand biolo- who seek to characterize com | ellio and Chris earch is unde and artificial ir ural computat ural networks ogical brains. ch to understa eep networks iso, how can n ical brains? Wi putations or net | grid cells are the n? W. Mathis, and Alexander Mathis e de Lausanne (EPFL), Brain Mind Institute y@epfl.ch (M.F.), mackenzie.mathis@epfl.c .2023.01.031 | answer, is path integratic & Neuro-X Institute, Geneva, Switzerland hh (M.W.M.), alexander.mathis@epfl.ch (A.M.) | <pre>bn to the incomming researcher's drawin as that transcend traditional academic daries. In a perspective article on the ori- of COSYNE¹, Zador highlights how such ngscreate and nurture communities, such </pre> |
| perception, attention, memo goal is to offer a road map fo learning. We discuss the conc behaviour, learning dynamics systems, and we highlight neuroscience as a direct cons | y and executive systems neuror sptual and metion ind neural reprinew research equence of recommendations where the system of the | eurons known as grid cells are the that units with grid-cell-like pro- ate, and developed a unifying th nstraints are necessary and how | bught to play an important role in spatial cognition perties can emerge within artificial neural netwo neory explaining the formation of these cells wh learned systems carry out path integration. | n. A orks hich References & Citations · NASA ADS · Coogle Scholar · Semantic Scholar · Bookmark ※ @ |

https://doi.org/10.48550/arXiv.2105.07284 🚯



Upcoming Event

The 2024 BRAIN NeuroAl Workshop

November 12th & 13th — NIH Campus, Bethesda or Virtual

This two-day hybrid workshop will bring together researchers at all career levels to discuss how BRAIN's data, tools, and technologies can accelerate scientific discovery and transformative advances at the intersection of neuroscience and AI.

The intersection of neuroscience and AI. BRAIN Learn more about the workshop and register to attend at https://n4solutionsllc.com/BRAINNeuroAI



NIH BRAIN NeuroAl Working Group Joseph Monaco/NINDS [C], Grace Hwang/NINDS, Bo-Shiun Chen/NINDS, Nina Hsu/NINDS, Pantea Moghimi/ NINDS, Sandra Molina/NINDS, Leslie Osborne/NINDS, Sudha Srinivasan/NINDS, Jay Churchill/NIMH, Michele Ferrante/NIMH, Mauricio Rangel Gomez/NIMH, Courtney Pinard/NIMH, Elizabeth Powell/NIAAA, Jessica Mollick/NIDA, Susan Wright/NIDA, Roger Miller/NIDCD, Merav Sabri/ NIDCD, Clayton Bingham/NLM, Mohd Anwar/NIBIB, Chris Kinsinger/OD, Dana Schloesser/OBSSR

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