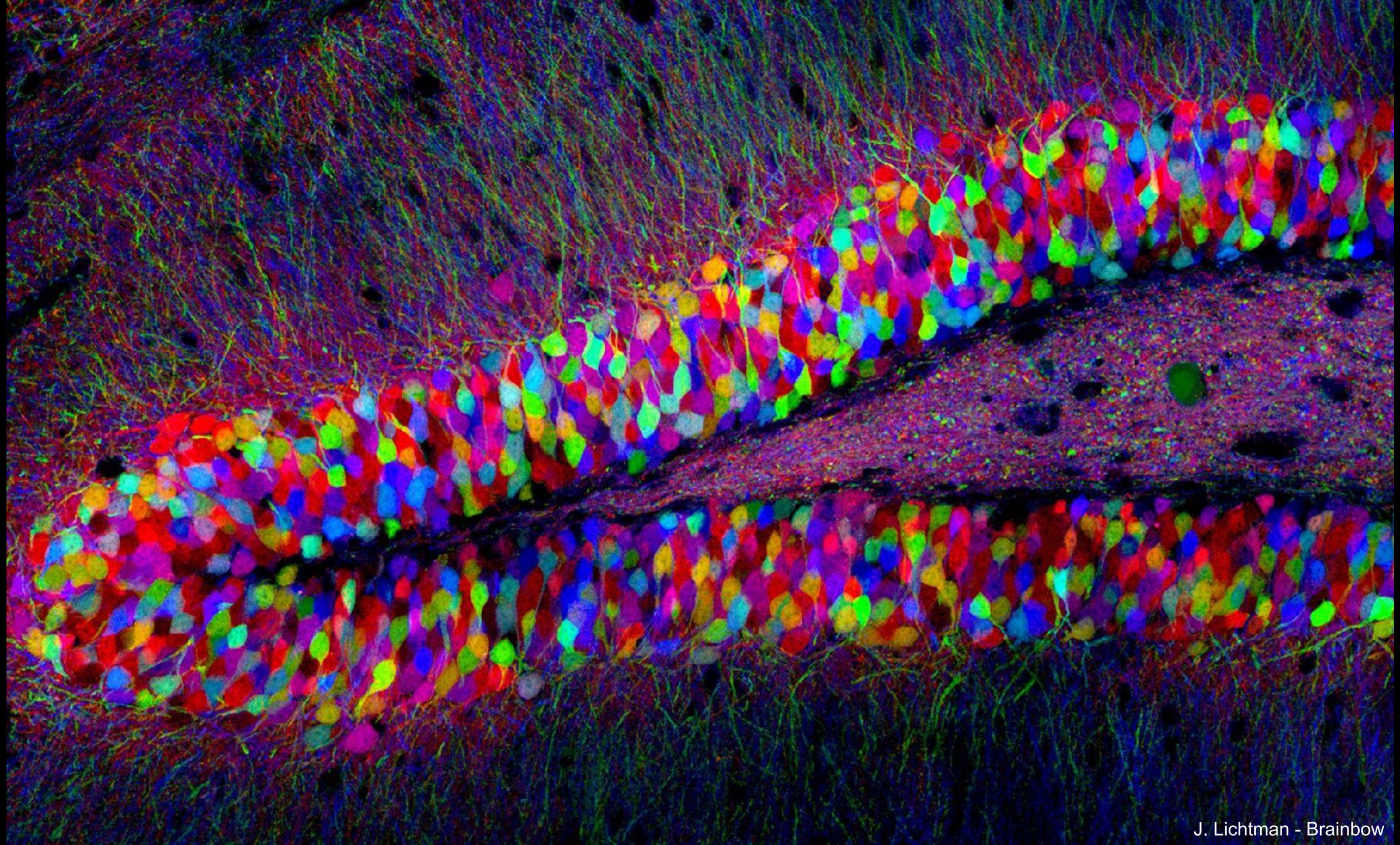
How a Discovery Fellowship will make me a future leader

Jacques Carolan
University College London

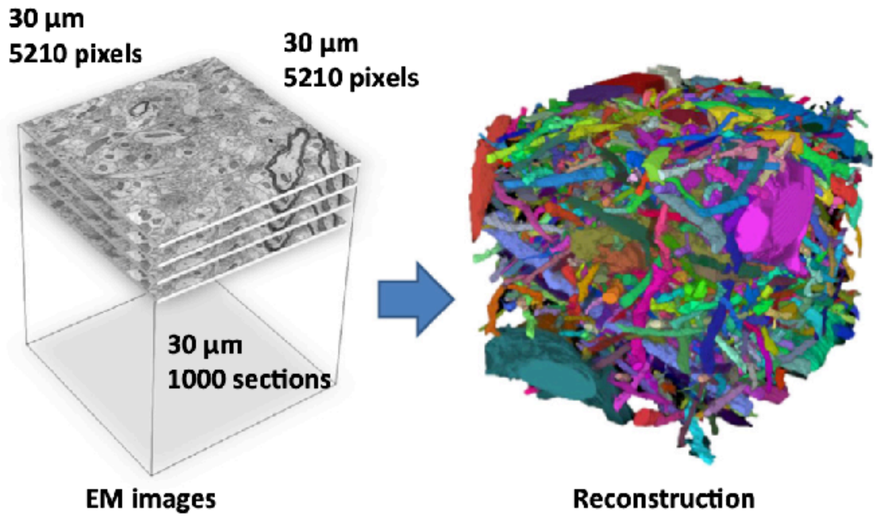


J. Lichtman - Brainbow

State-of-the-art connection mapping

Technology Gap: Map connectivity across neuronal microcircuits with neuron-scale resolution in the **awake, behaving brain**

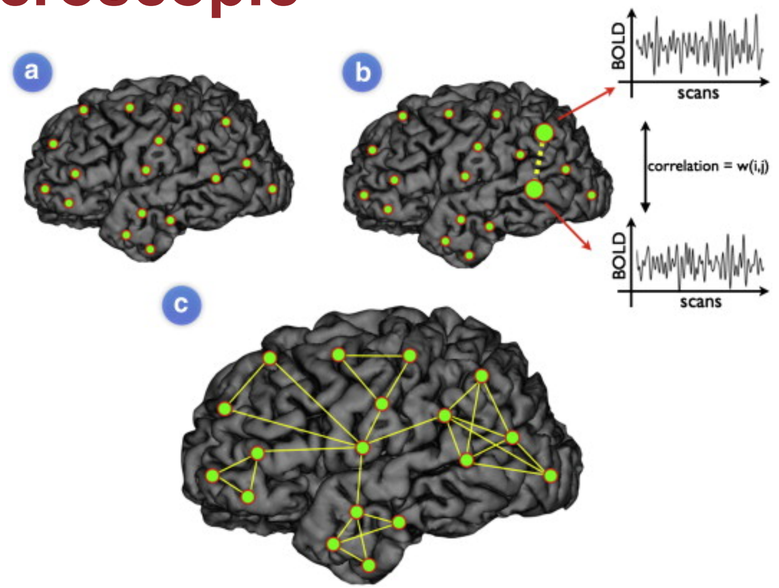
Microscopic



- **Resolution:** ~nm^3 << neuron
- **Volume:** mm^3
- **Speed:** Slow (1 year / reconstruction)
- **Temporal:** Static (post-mortem)

V. Kaynig et al., *Med. Imag. Analysis* (2015)

Macroscopic



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- **Speed:** Fast (~10 ms / image)
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MP Van Den Heuvel & HEH Pol, *European Neuro.* (2010)

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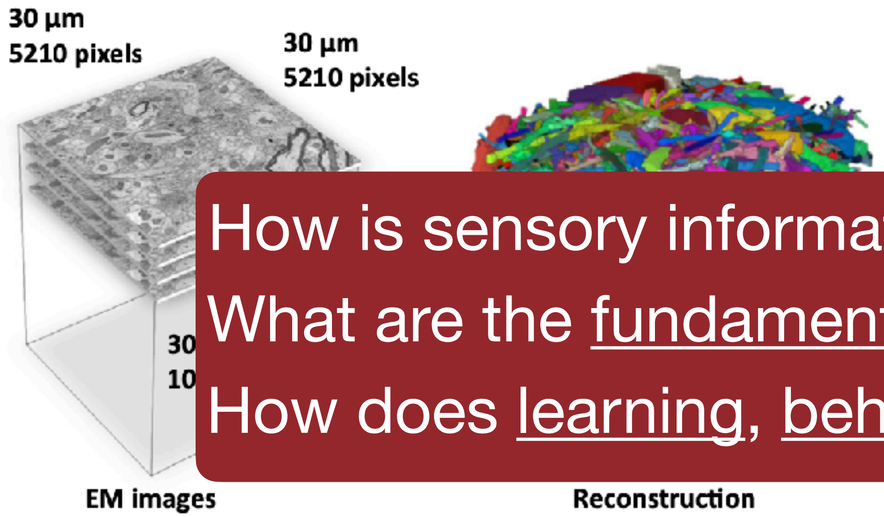

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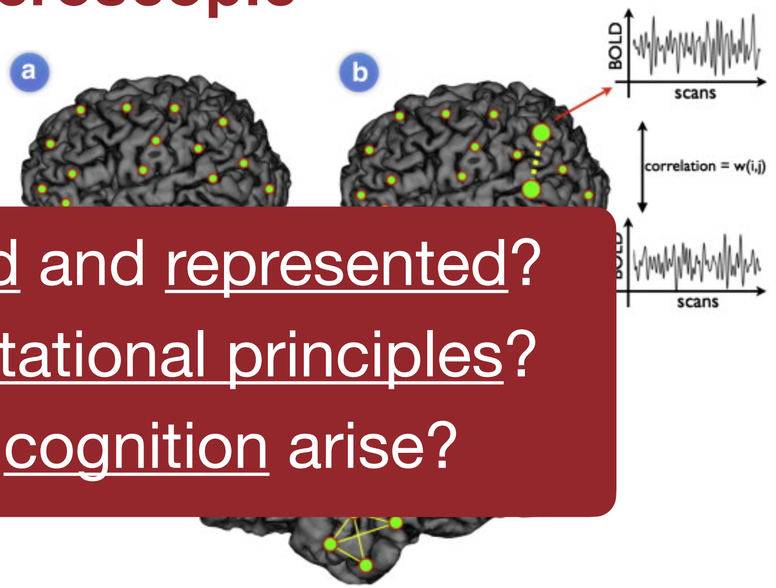

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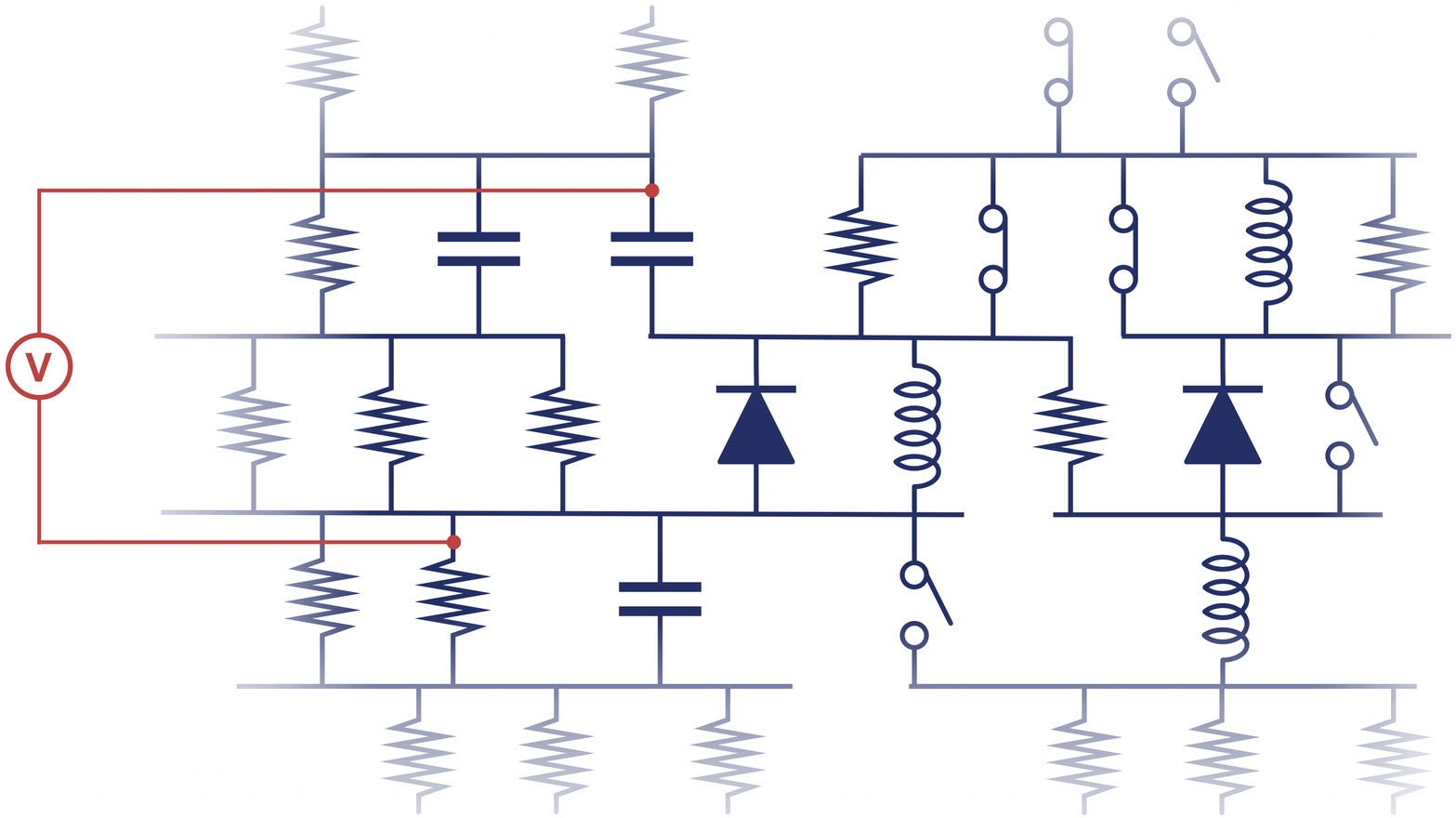
How is sensory information stored and represented?
What are the fundamental computational principles?
How does learning, behavior and cognition arise?

Mapping Connectivity



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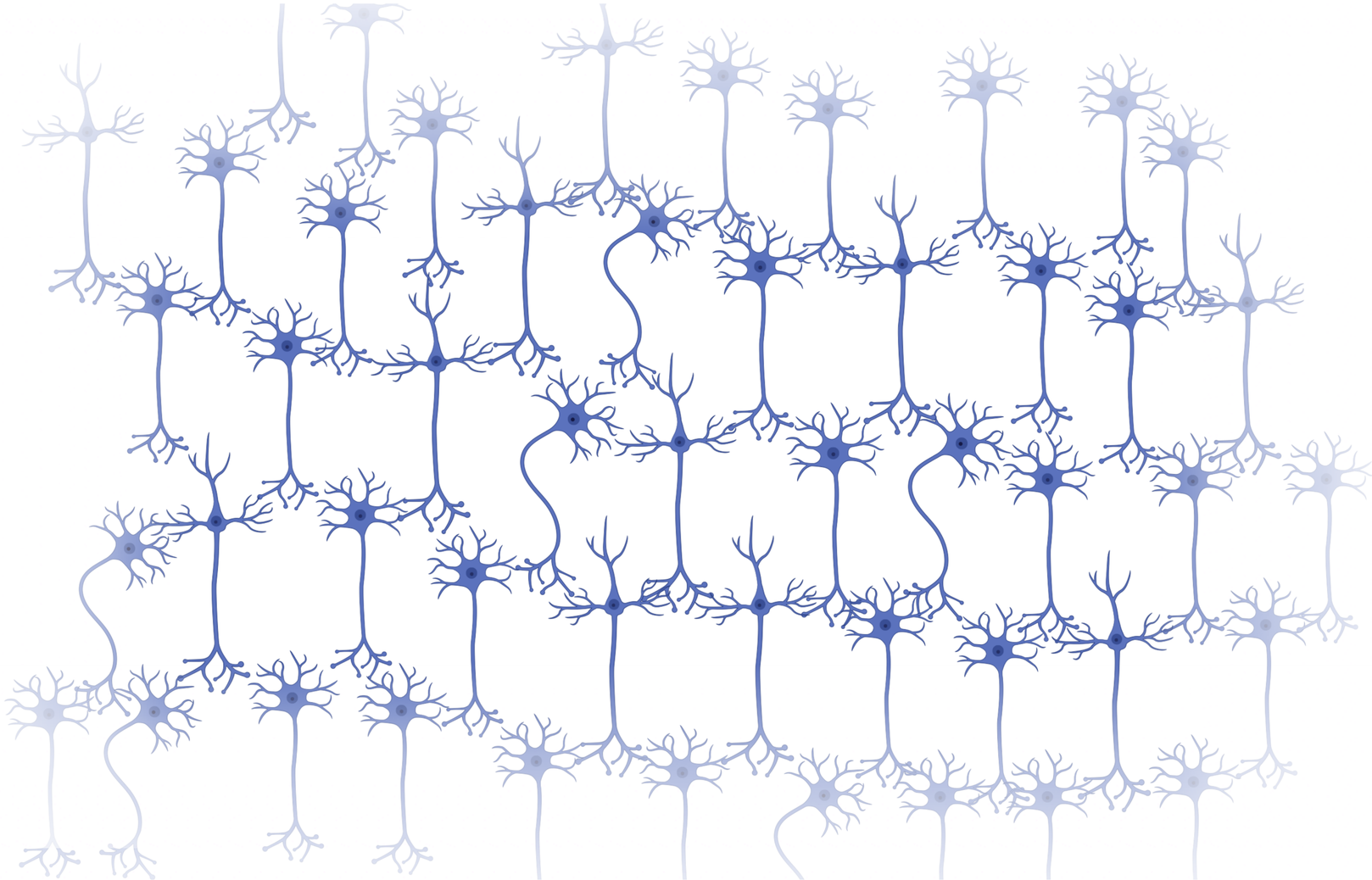

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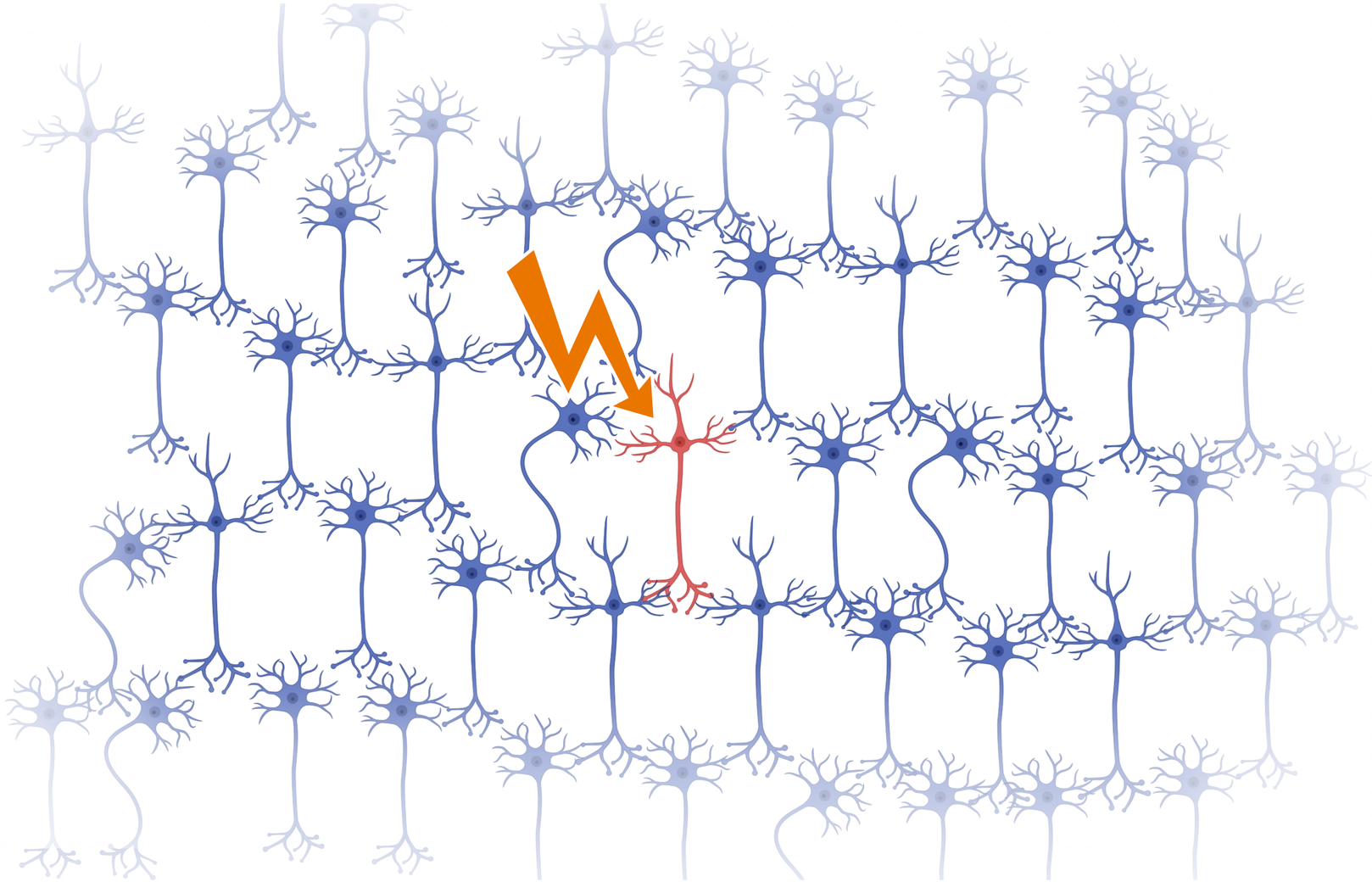

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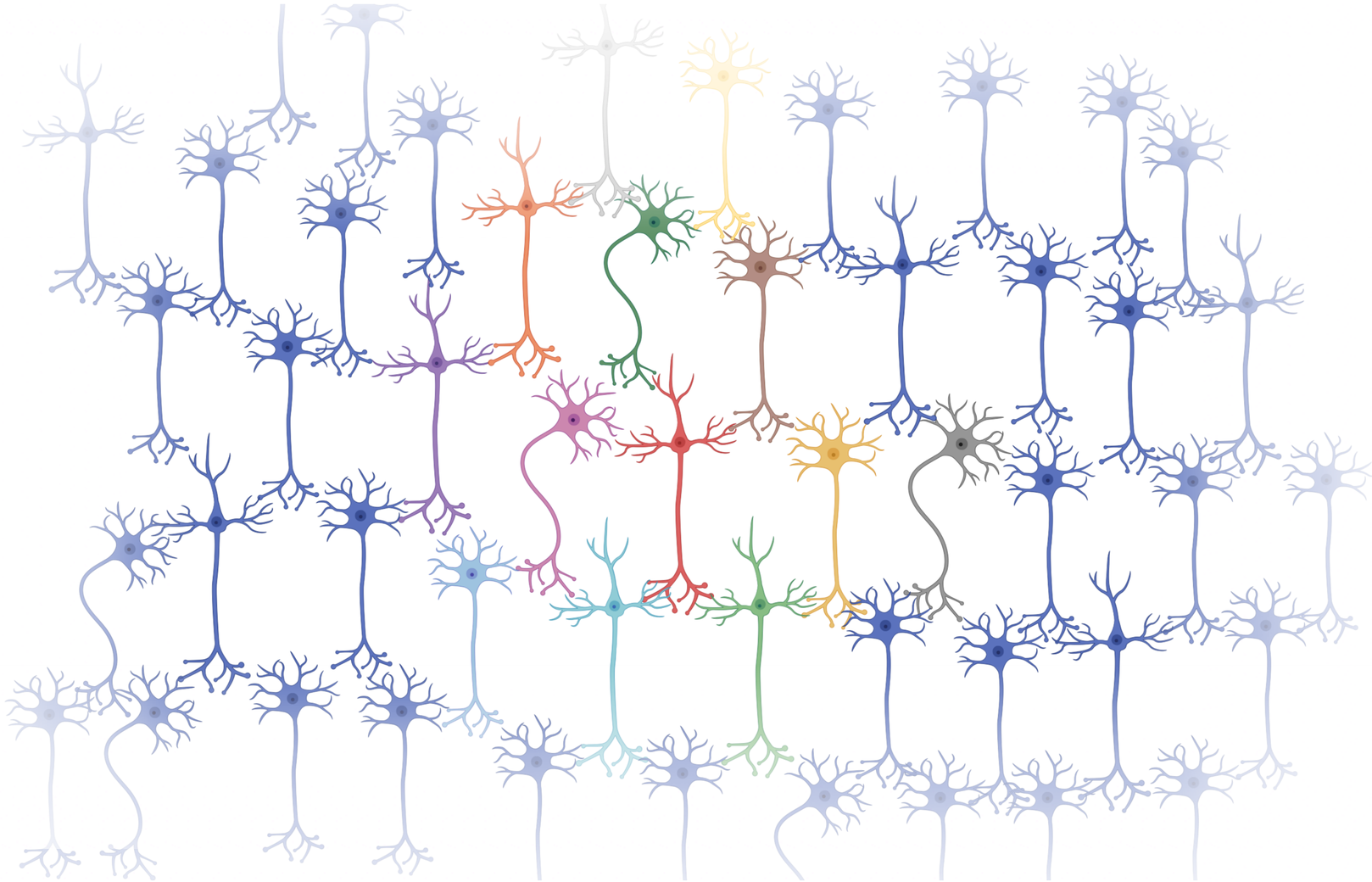

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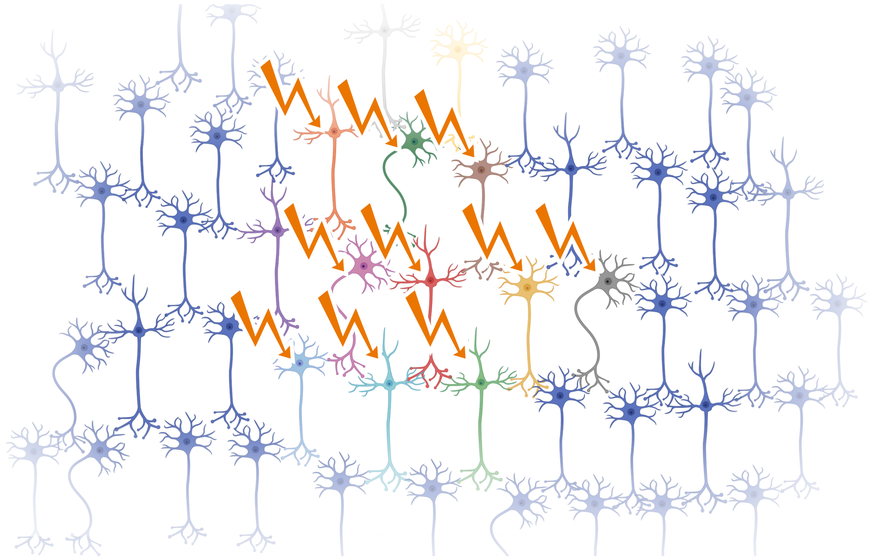
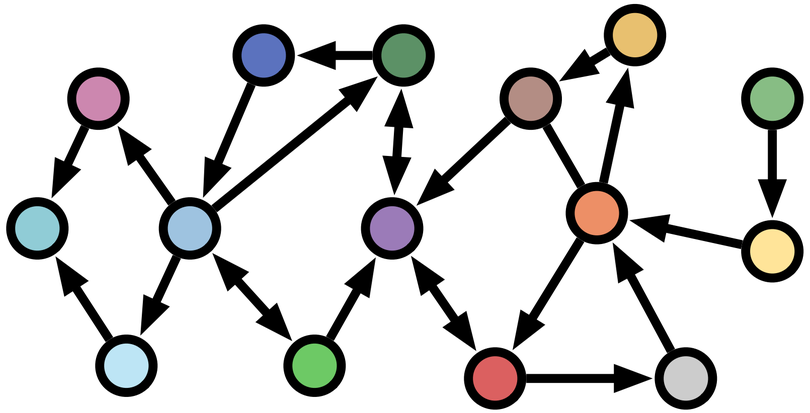




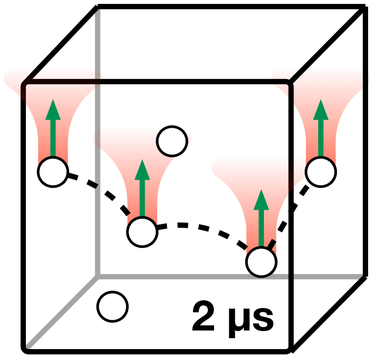
Wish list

- ☐ Control and readout of neural activity
- ☐ Neuron-scale spatial resolution (~10 μm)
- ☐ Action potential temporal resolution (~1 ms)
- ☐ Highly parallelizable (100s of neurons)

All-Optical Voltage Scope

O1. High-Speed Imaging

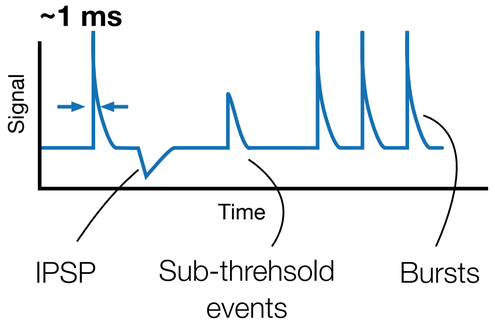
- Ultra-fast random access imaging at cellular resolution
- Multiplexing to maximize signal extraction



Technological Goal:
Image 500 neurons at 1 kHz across a 500 µm^3 FOV (state-of-the-art = 24 neurons)

O2. Voltage Indicators

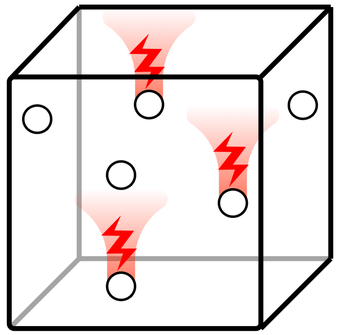
- *In vivo* imaging of GEVIs in the barrel cortex and cerebellum in awake, behaving mice



Biological Goal:
Track the onset of 'sparse representation' in response to a sensory stimulus

O3. Closed-Loop Optogenetic Stimulation

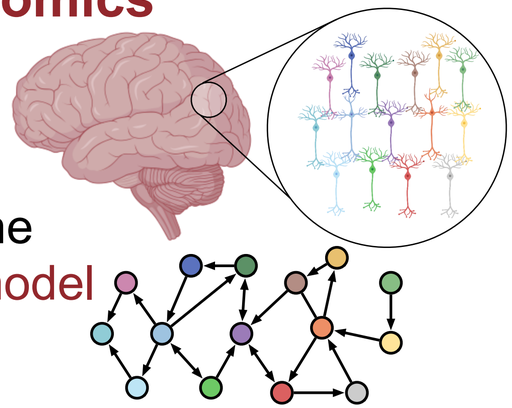
- Co-express opsins with GEVIs
- Cellular resolution patterned photo-excitation controlled by high-speed electronics (FPGA)



Technological Goal:
'Readout → computation → excitation' clock cycle of 200 µs < action potential

O4. All-Optical Connectomics

- Determine wiring diagram of a 500 neuron network
- Optimal control to determine a dynamical connectivity model

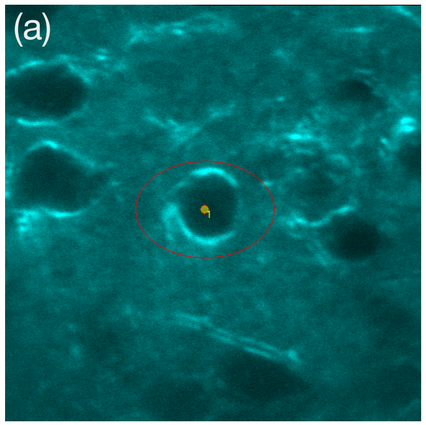


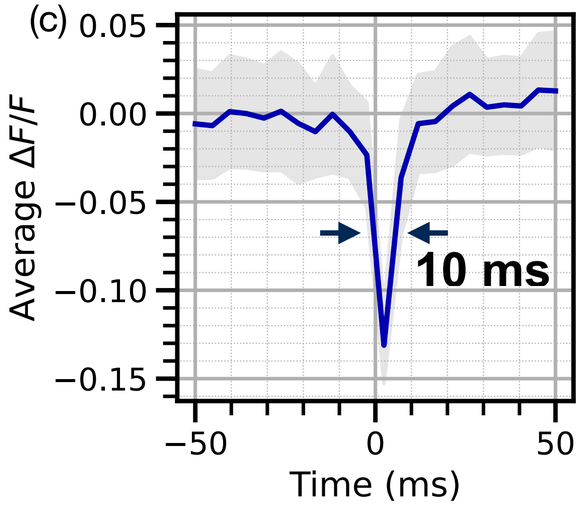
Biological Goal:
Investigate how connectivity enables sparsenning and how connectivity varies during learning

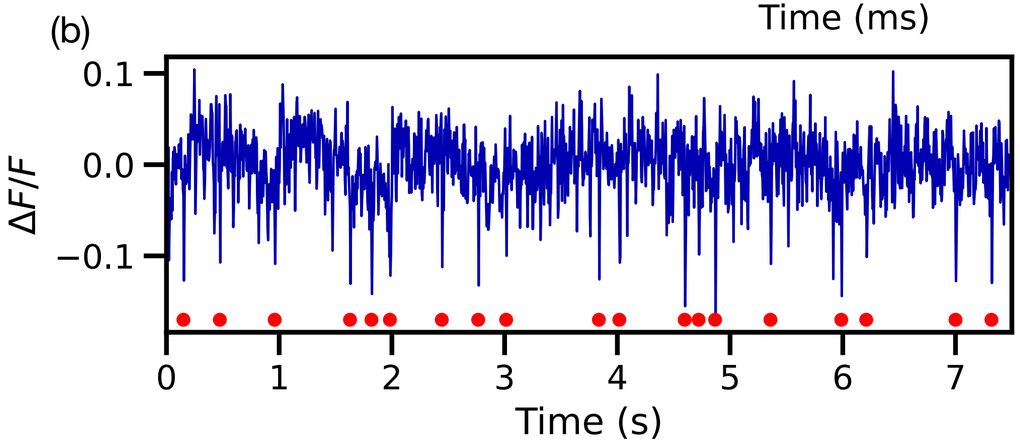
Voltage Imaging Pilot Data

Good expression of GEVIs + suitable for 2p imaging!

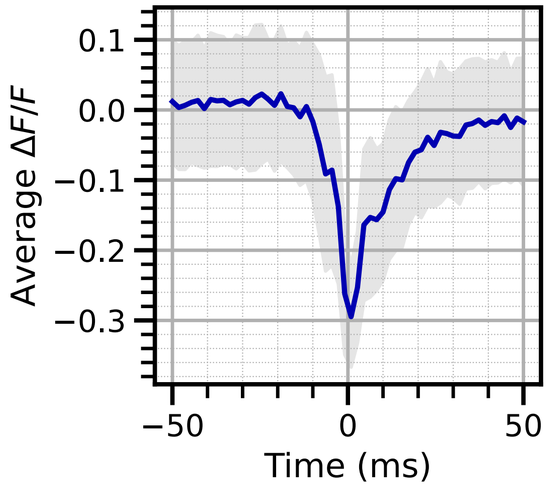
Barrel Cortex

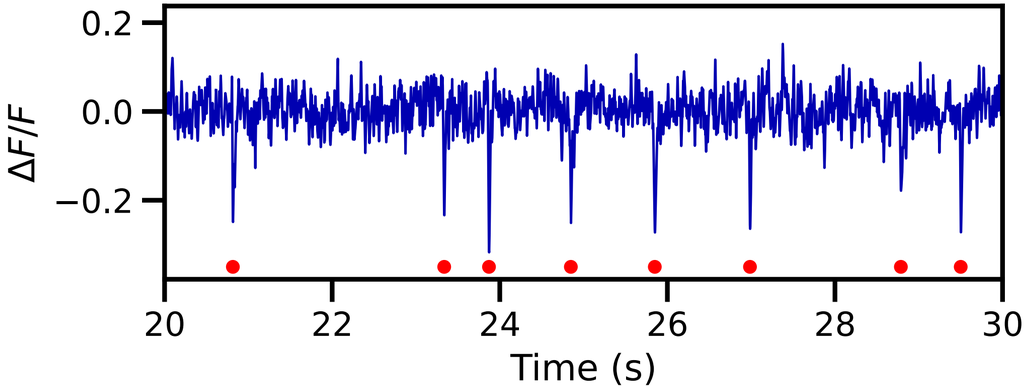






Cerebellum



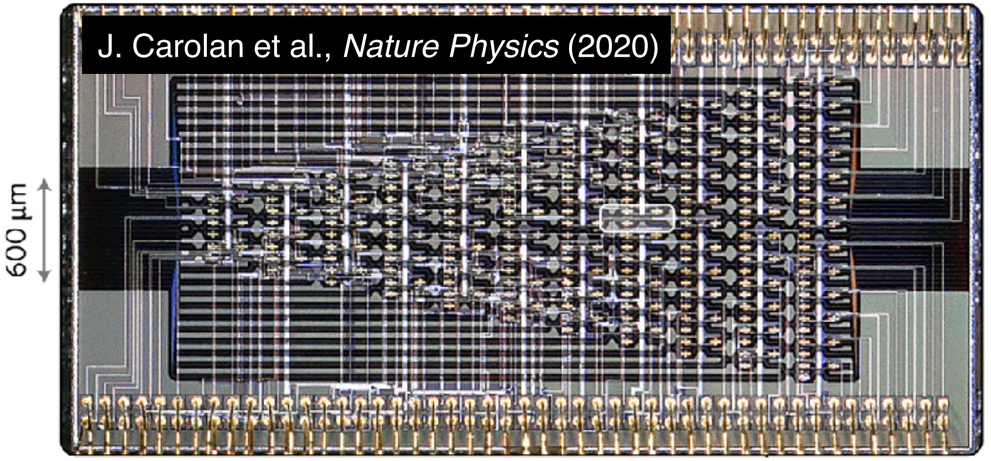


Why me?

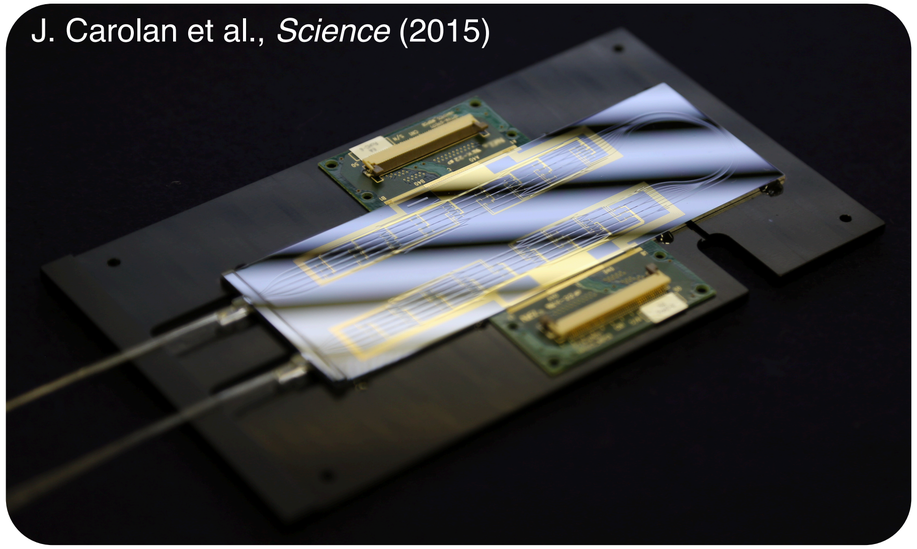
- **Requirements:**
  - Optical design
  - High-speed electronics
  - Systems engineering

⇨ **Circuit Neuroscience**

- **My research profile:**
  - Applied Physics
  - Developing photonic technologies to accelerate quantum and classical computing



J. Carolan et al., *Optica* (2019)
U. Chakraborty et al., *Optica*, 6, 335 (2020)



J. Carolan et al., *Nature Photonics* (2014)
C. Sparrow et al. *Nature* (2018)

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LINDAU NOBEL LAUREATE MEETINGS

THE ROYAL SOCIETY

Google AI ZAPATA MIT ELENION TECHNOLOGIES

nature physics ARTICLES
https://doi.org/10.1038/s41567-019-0747-6

Variational quantum unsampling on a quantum photonic processor

Jacques Carolan[1*], Masoud Mohseni[2], Jonathan P. Olson[3], Mihika Prabhu[1], Changchen Chen[1], Darius Bunandar[1], Murphy Yuezhen Niu[2], Nicholas C. Harris[4], Franco N. C. Wong[1], Michael Hochberg[5], Seth Lloyd[6] and Dirk Englund[1]

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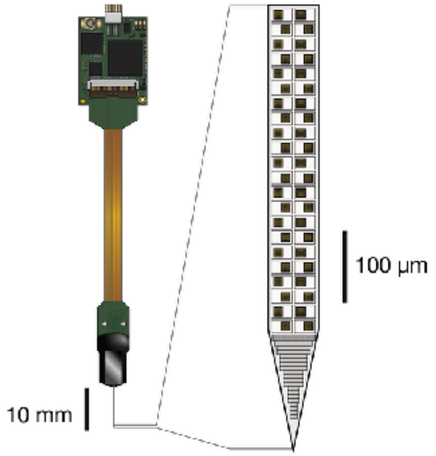
- **Service and Teaching:**
  - Committees: IEEE Emerging Tech. Taskforce
  - Science communication and outreach
  - Teaching and supervision

Location: University College London

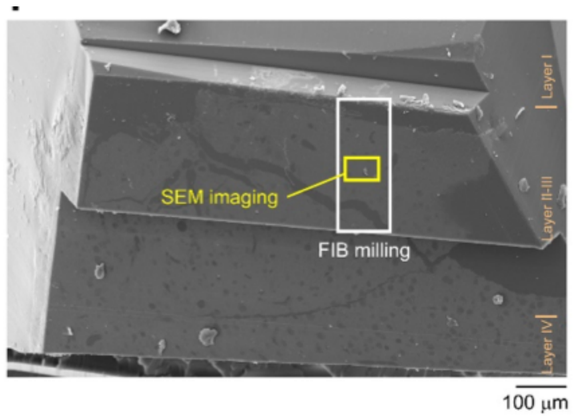
- **Neural Computation Lab at UCL**
  - Calcium based all-optical interrogation
  - Training:
    - Optogenetics, imaging, behavior
  - Resources:
    - Lasers, behavioral rigs, SLM, AODs
  - Mentorship:
    - Prof. Michael Häusser, Prof. Beverley Clark

- **Collaborations:**
  - Prof. Kenneth Harris
    - Cortical processing, neuroinformatics
  - Prof. Angus Silver
    - Microscopy, random access imaging
  - Prof. Mark Lythgoe
    - Centre for Advanced Biomedical Imaging

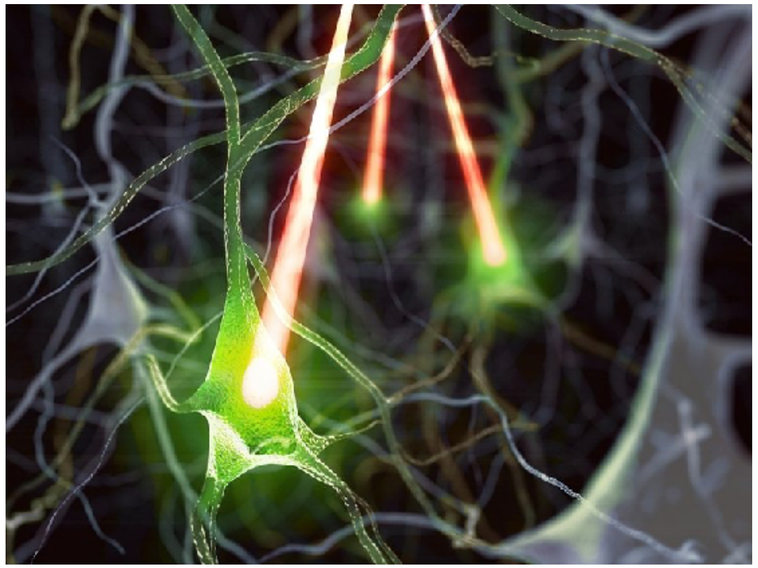
- **UCL Neuroscience:**
  - 2nd Globally and 1st in Europe
  - 13 different departments + 450 PIs



Jun et al., *Nature* (2017)



Simon, Roth, Sherdian et al., *bioRxiv* (2021)



Packer et al., *Nature Methods.* (2015)
Zhang et al., *Nature Methods.* (2018)
Robinson et al., *Cell* (2020)

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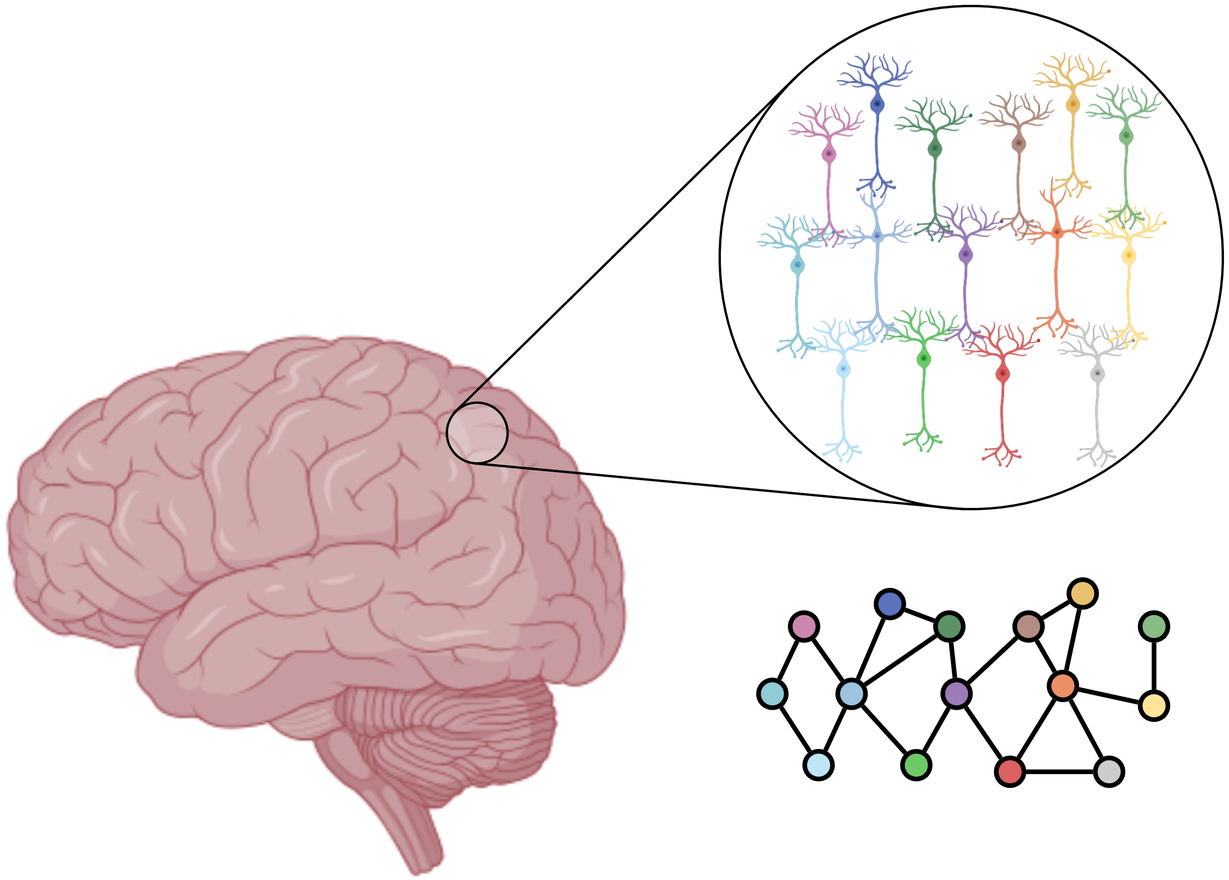
- **Baseline neuroscience knowledge:**
  - Classes (neuroanatomy)
  - Workshops (imaging, optogenetics)
- **Building scientific networks:**
  - Neuroscience Domain @ UCL
  - Conferences (SfN, COSYNE)
  - BBSRC Fellows
  - Outreach (YouTube, Brain Awareness Week)
- **Career Development**
  - UCL Neuroscience Careers Network
  - UCL Research Staff Development Program
- **Path to independence**
  - Project and financial management
  - Mentor PhD/Master student
  - 3-5+ year timeframe: apply for UKRI Future Leaders, Wellcome Career Development Award

How the DF will make me a future leader

Vision: To develop technologies across a range of modalities to both understand and repair the brain



Mentorship and training to transition into a new field

Build **new networks** across neuroscience and biology

Resources to develop next-generation technologies for systems neuroscience:

- Neural basis of brain disorders
- Brain machine interfaces
- Architectures for AI

Unique research profile spanning neuroscience, physics and engineering