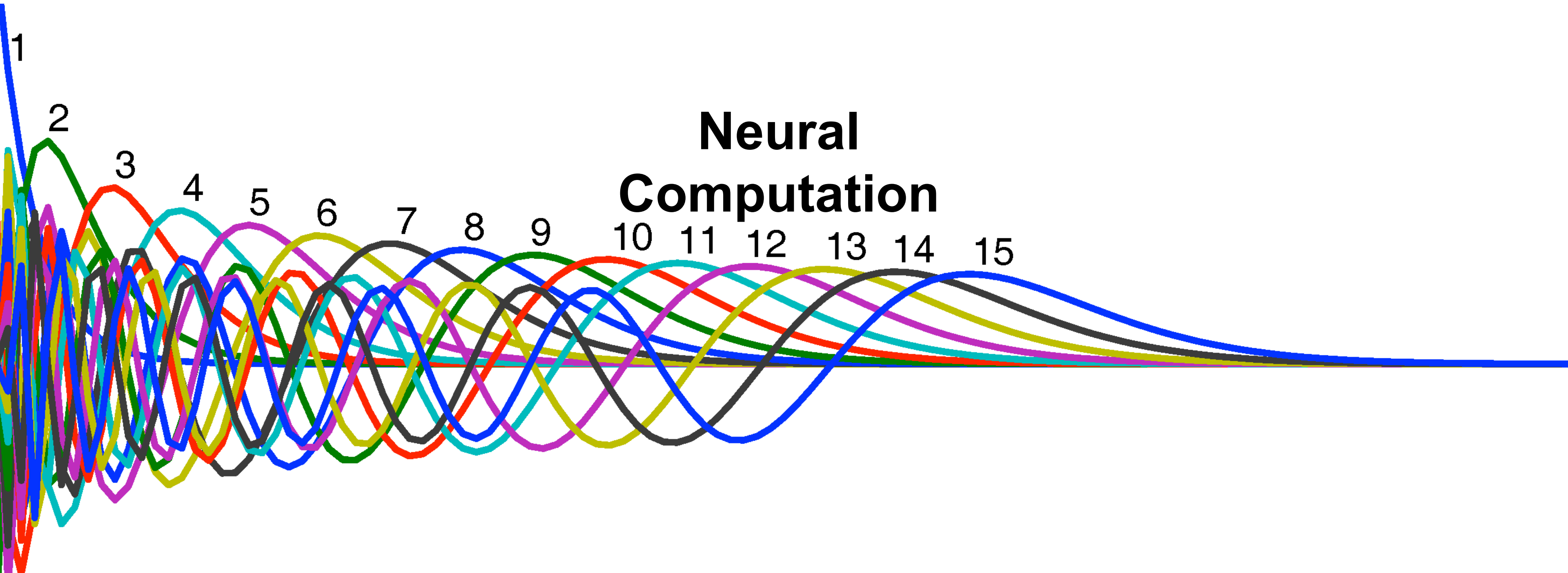
Applied Neuroscience

Columbia
Science
Honors
Program
Fall 2017



What is computational neuroscience?

1. Using a computer to study the brain
2. Studying the brain as a computer

The first is a *technique* but the second is an *idea.*

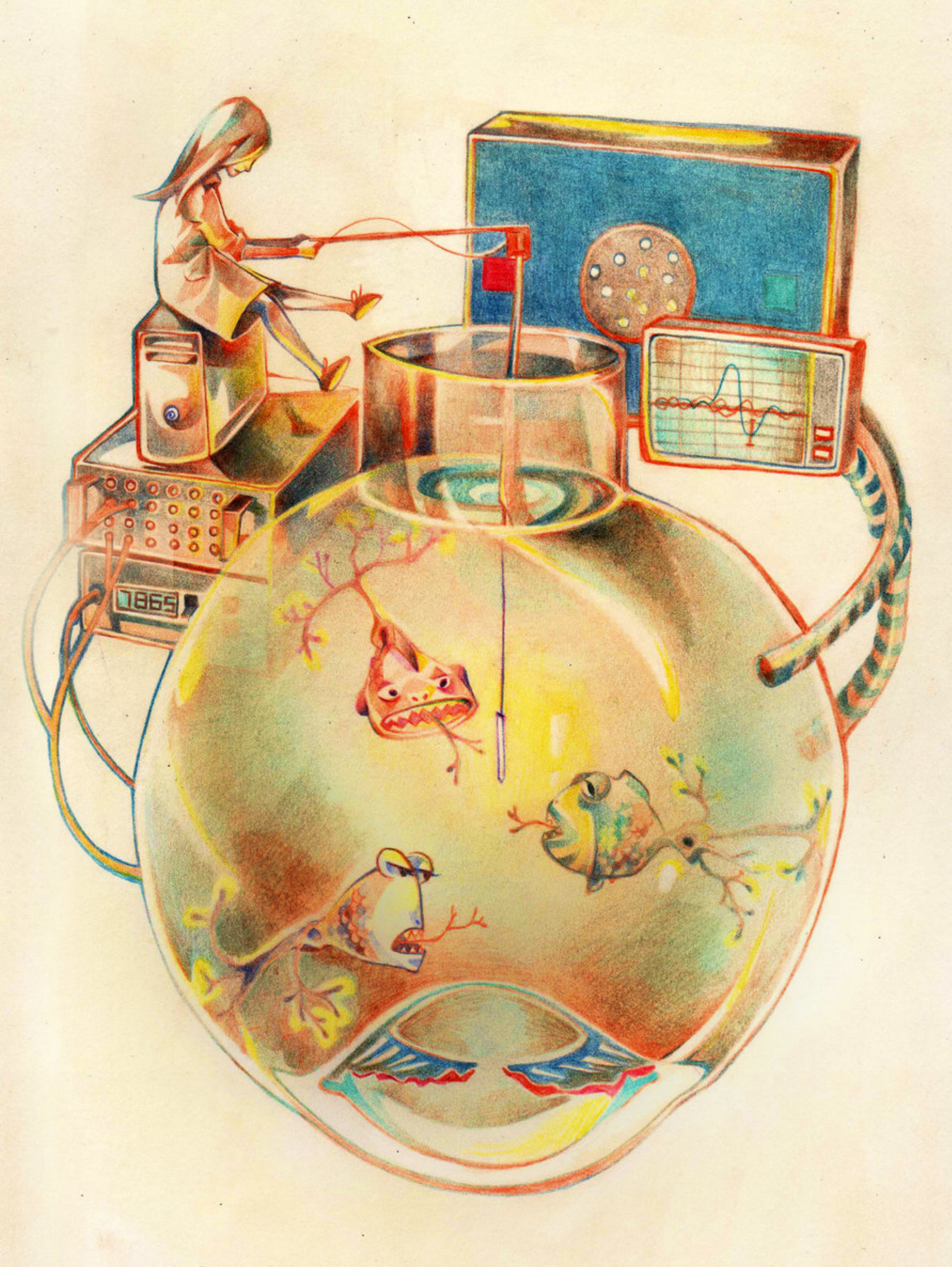
Machine learning has been used in neuroscience for both:

- For data analysis
  spike sorting and cell type classification
- For exploring theories of the brain with algorithms
  AlphaGo by Google DeepMind

Studying the brain as a computer…
is arguably more interesting

In this statement, a computer is a dynamic system that *represents* something else:

“Computer”	Representation
The states of transistors in computer memory…	Pictures and words on a screen
Location of beads on an abacus….	Money in a shopkeeper’s hands
Activation of neurons in our brains…	The things we *sense* and think about

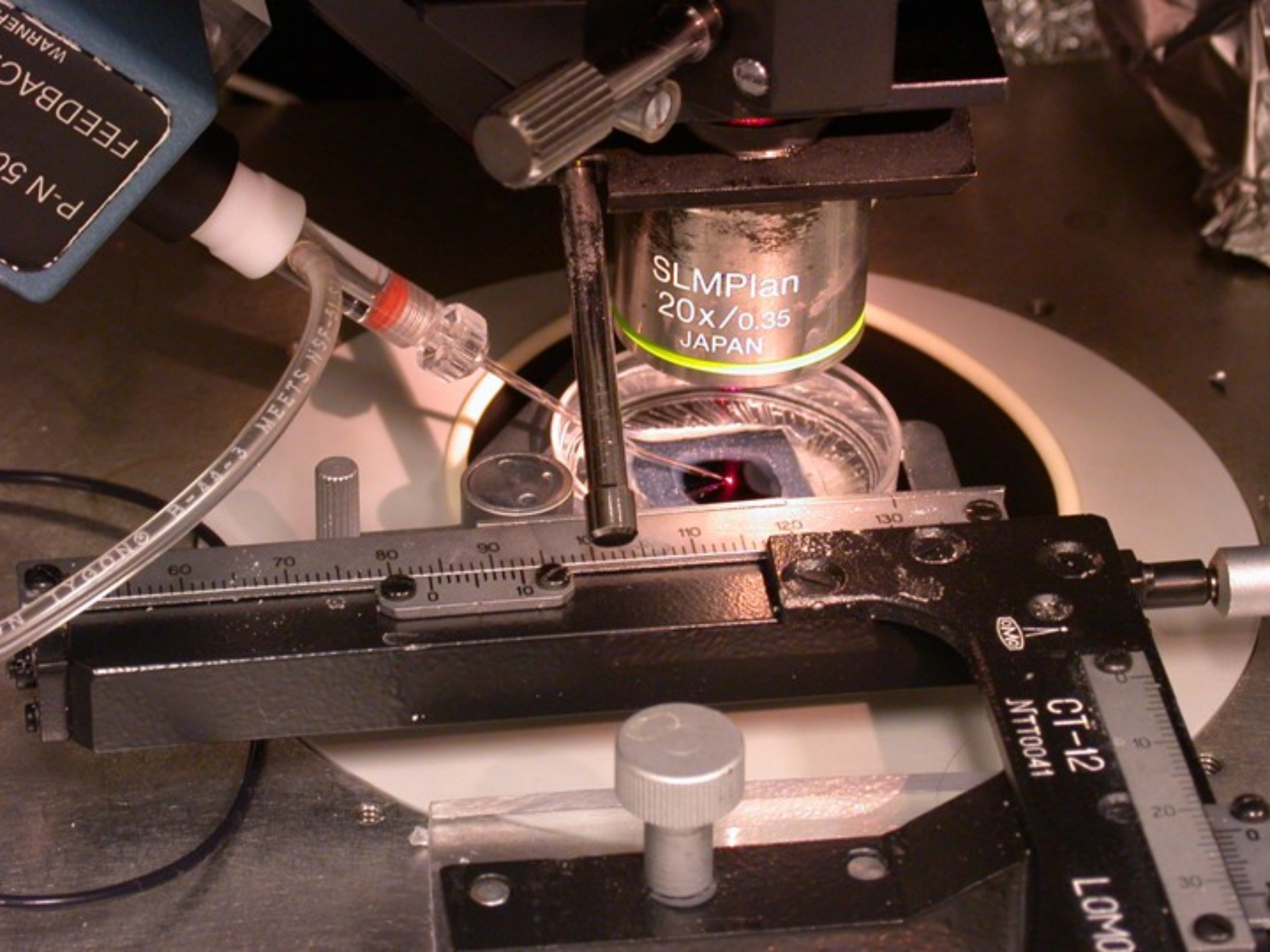


Neural Basis of Learning

<u>Synaptic Plasticity</u>

1. Global signals
(i.e. reward, motor error)
2. Local signals
(i.e. voltage, calcium)

The interaction between local and global signals is largely uncharacterized.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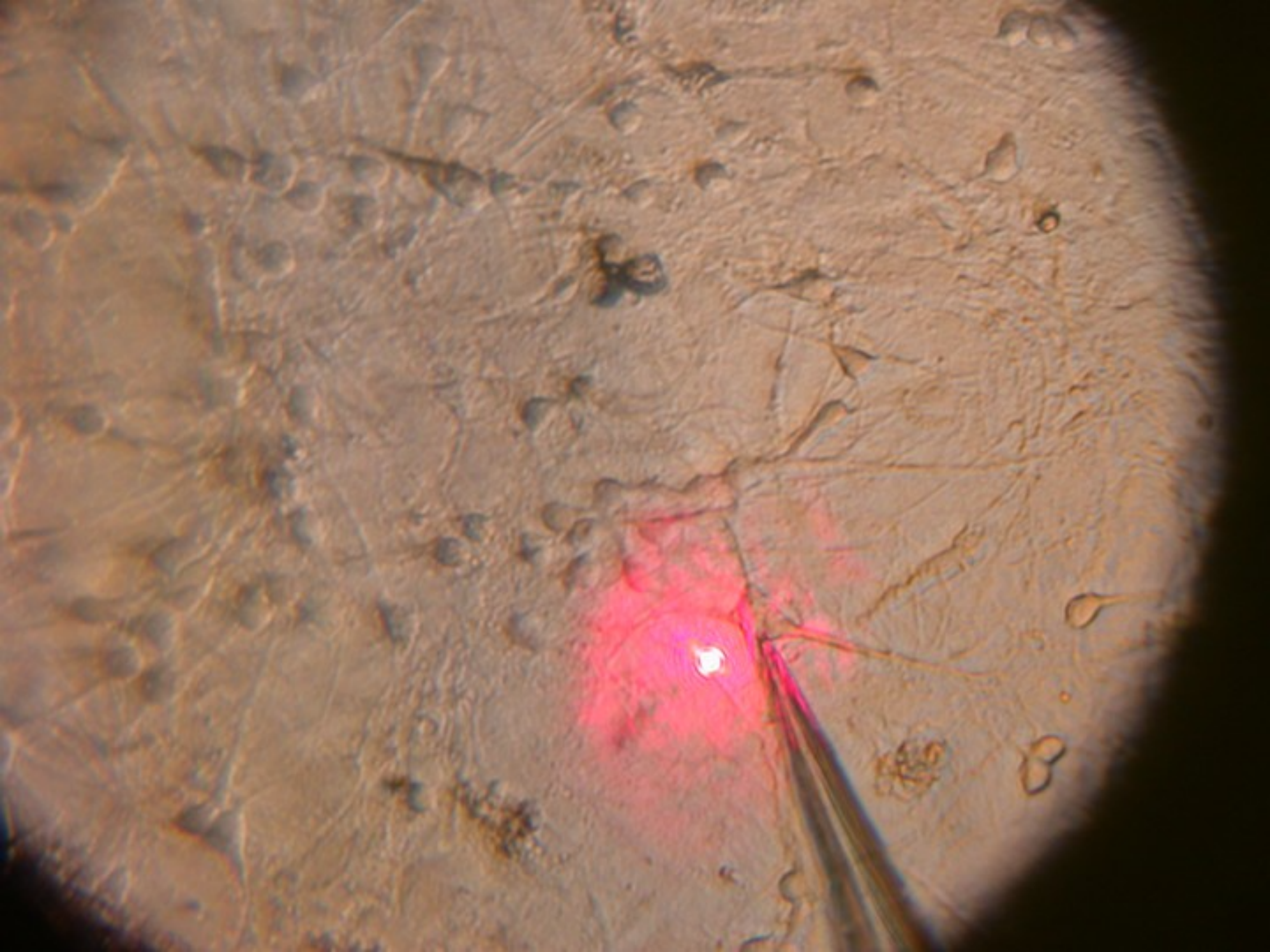
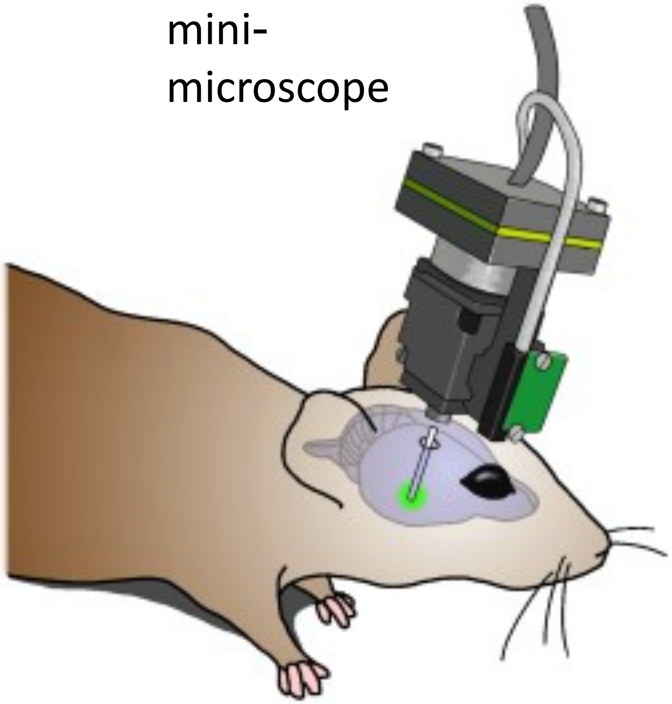
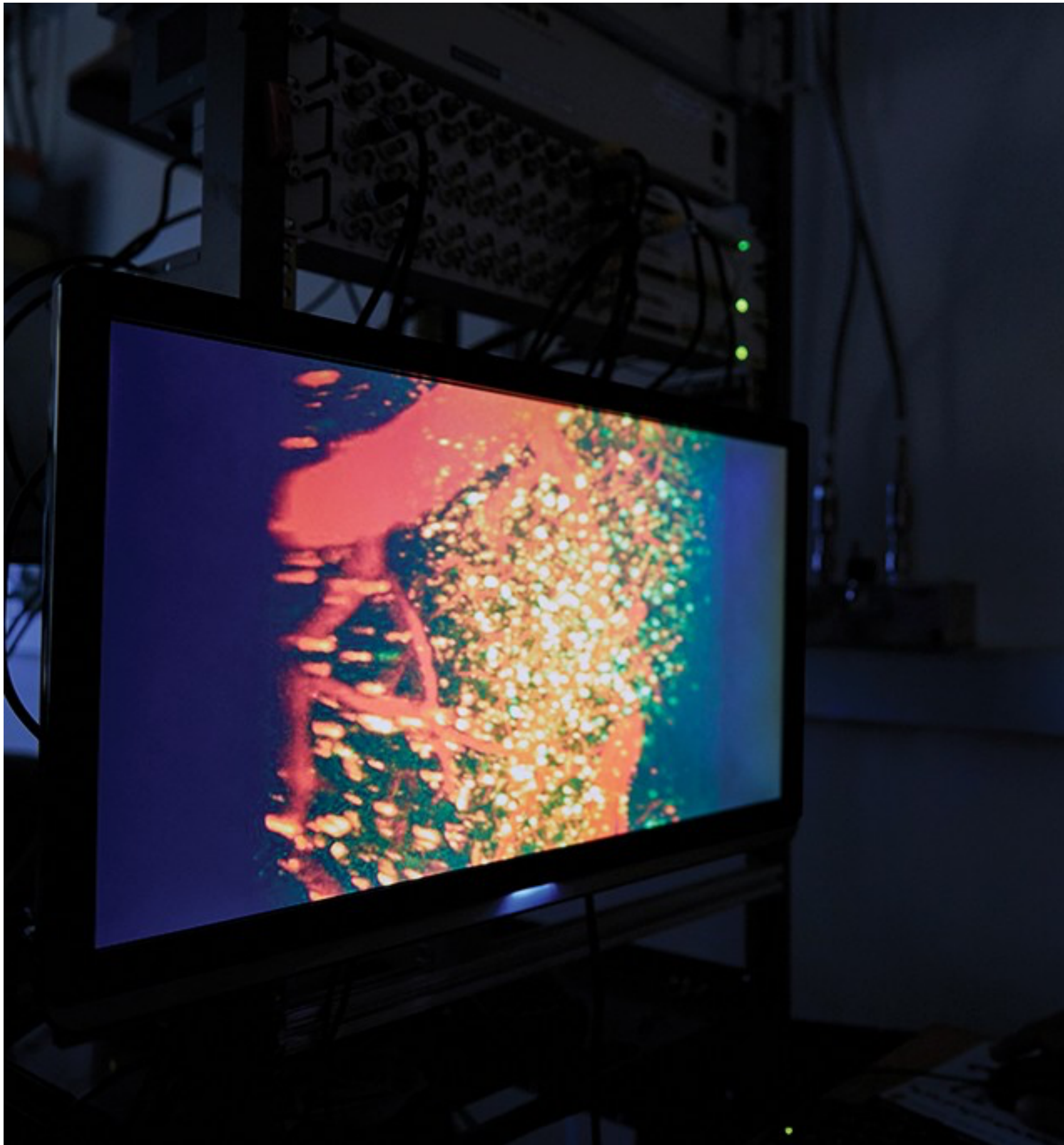


Step 1: Behavior Experiments with Live Rat





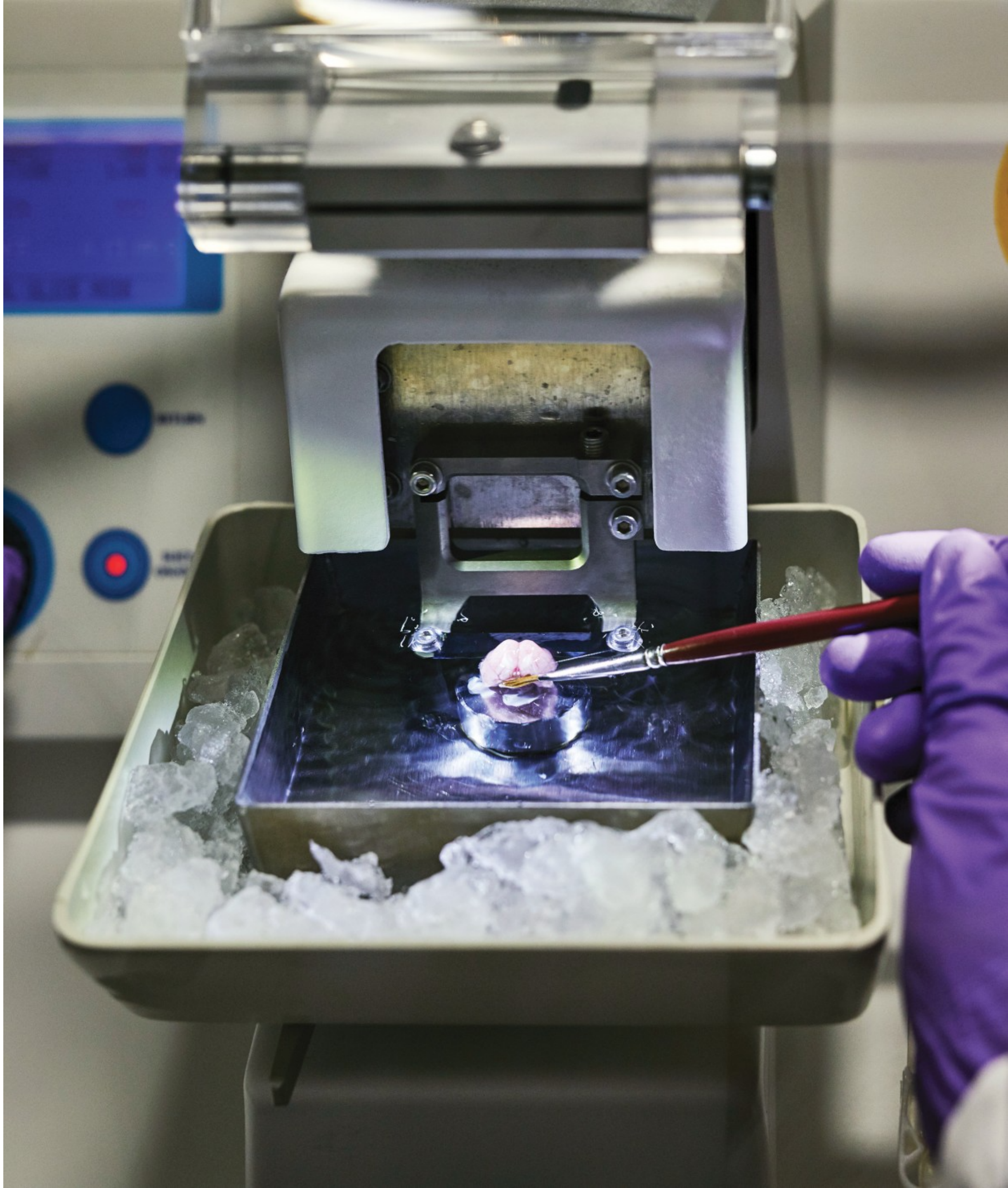
- Calcium imaging
- Tasks with conditioned and unconditioned stimulus

Step 2:
After the behavioral test, the rat’s brain is removed.

Step 3:
Rat brain in a dish

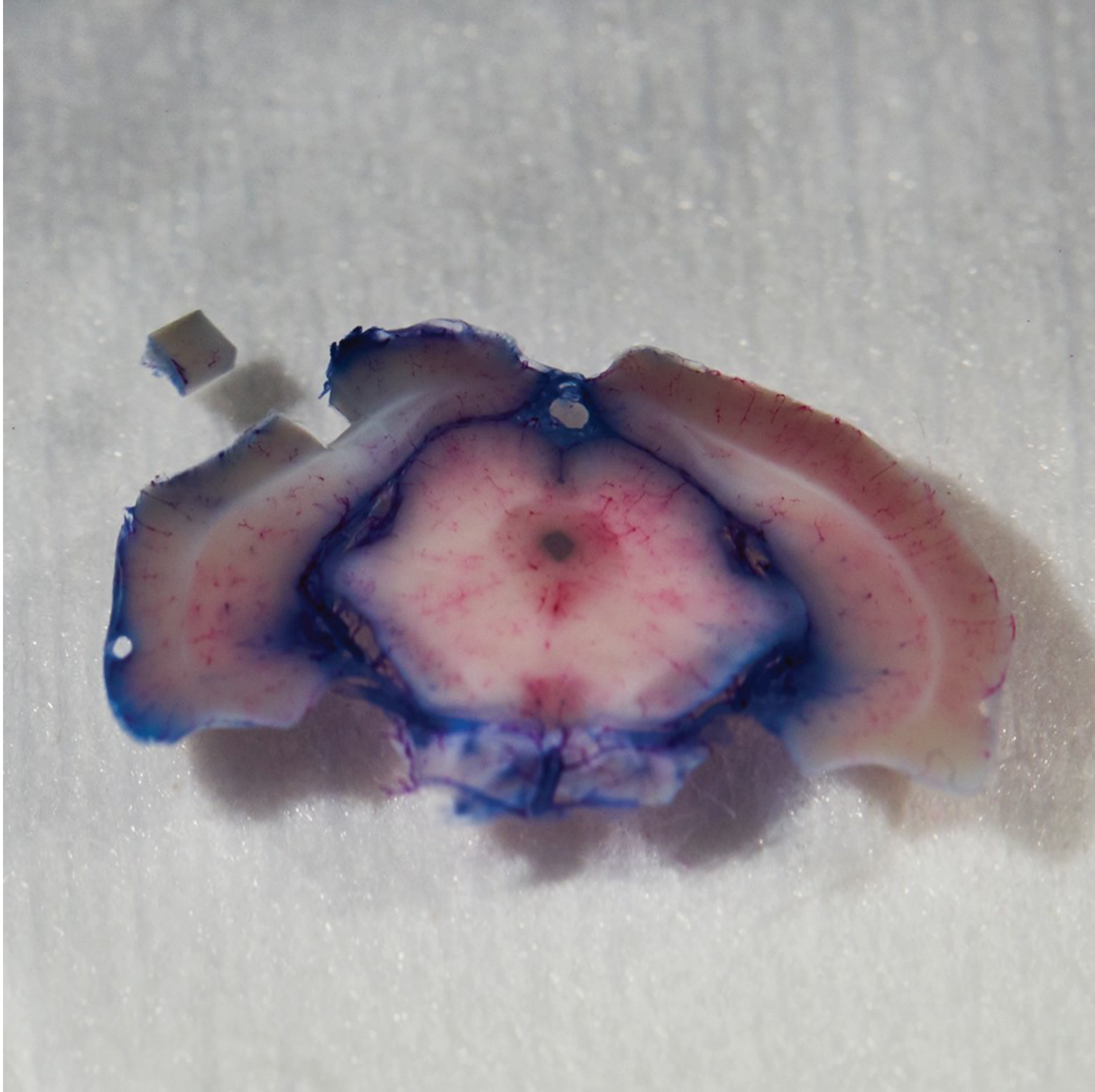
How is the rat brain different from the human brain?

Step 4:
The brain is glued to a plate before being scanned.

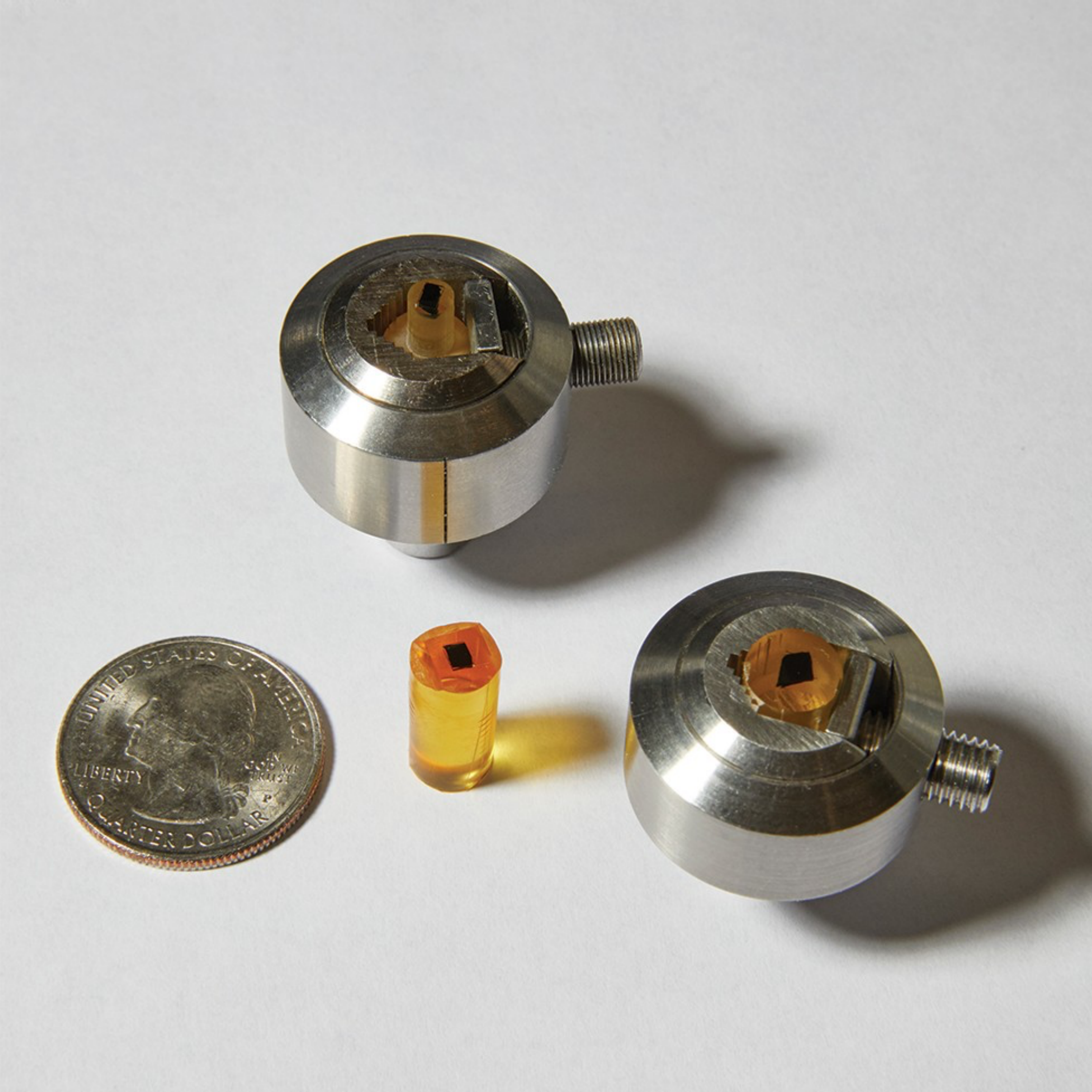


Step 5:

The small cube in the upper left is the portion of the brain that will be mapped.
That piece of the brain is encased in acrylic in preparation for being sliced extremely thin.

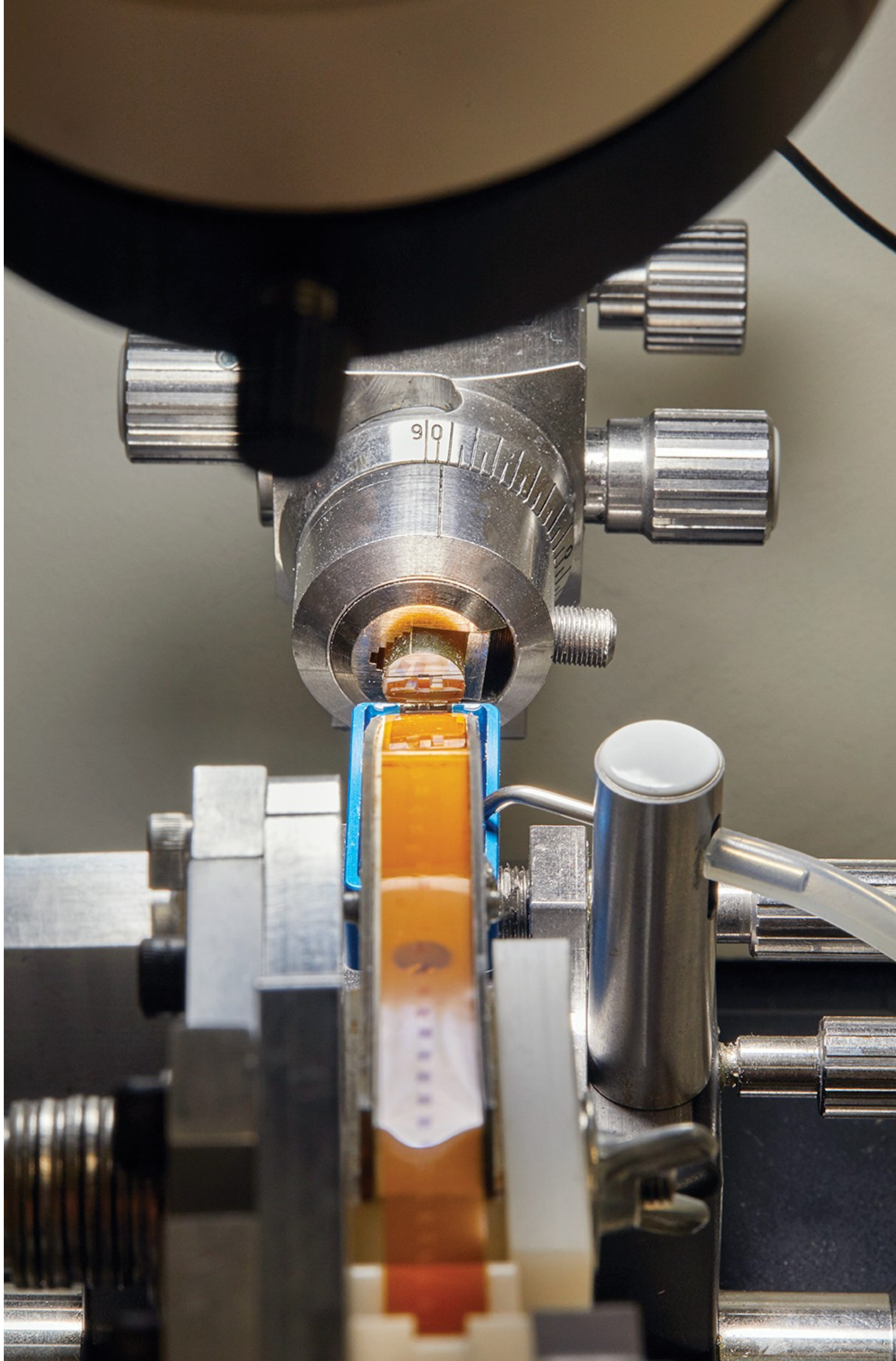


Size Comparison

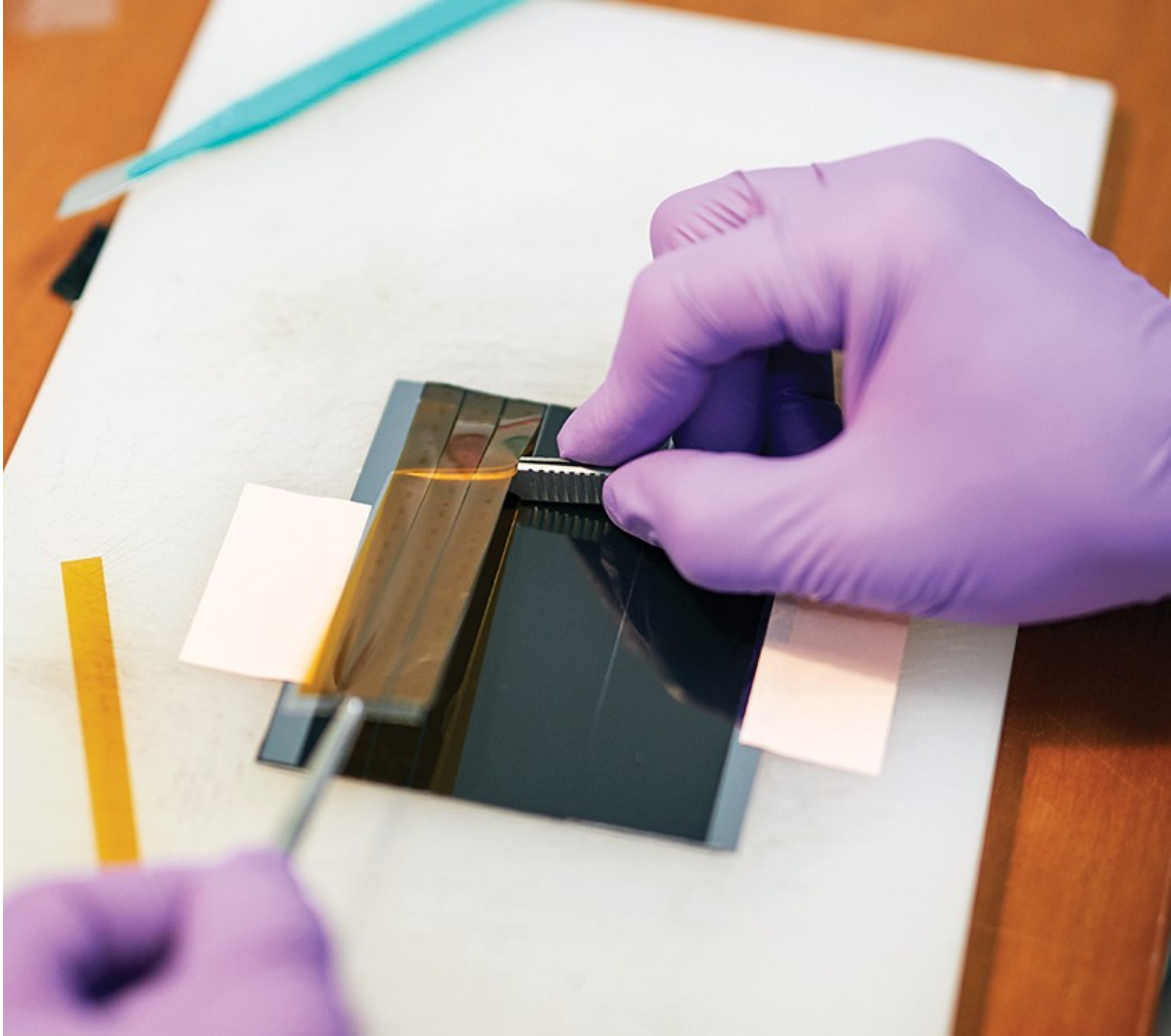


Step 6:
The cut slices of brain stick to a plastic tape.

Step 7:
The tape, with brain samples attached, is trimmed and put on a slide plate that will go on a huge scanning machine.



Step 7



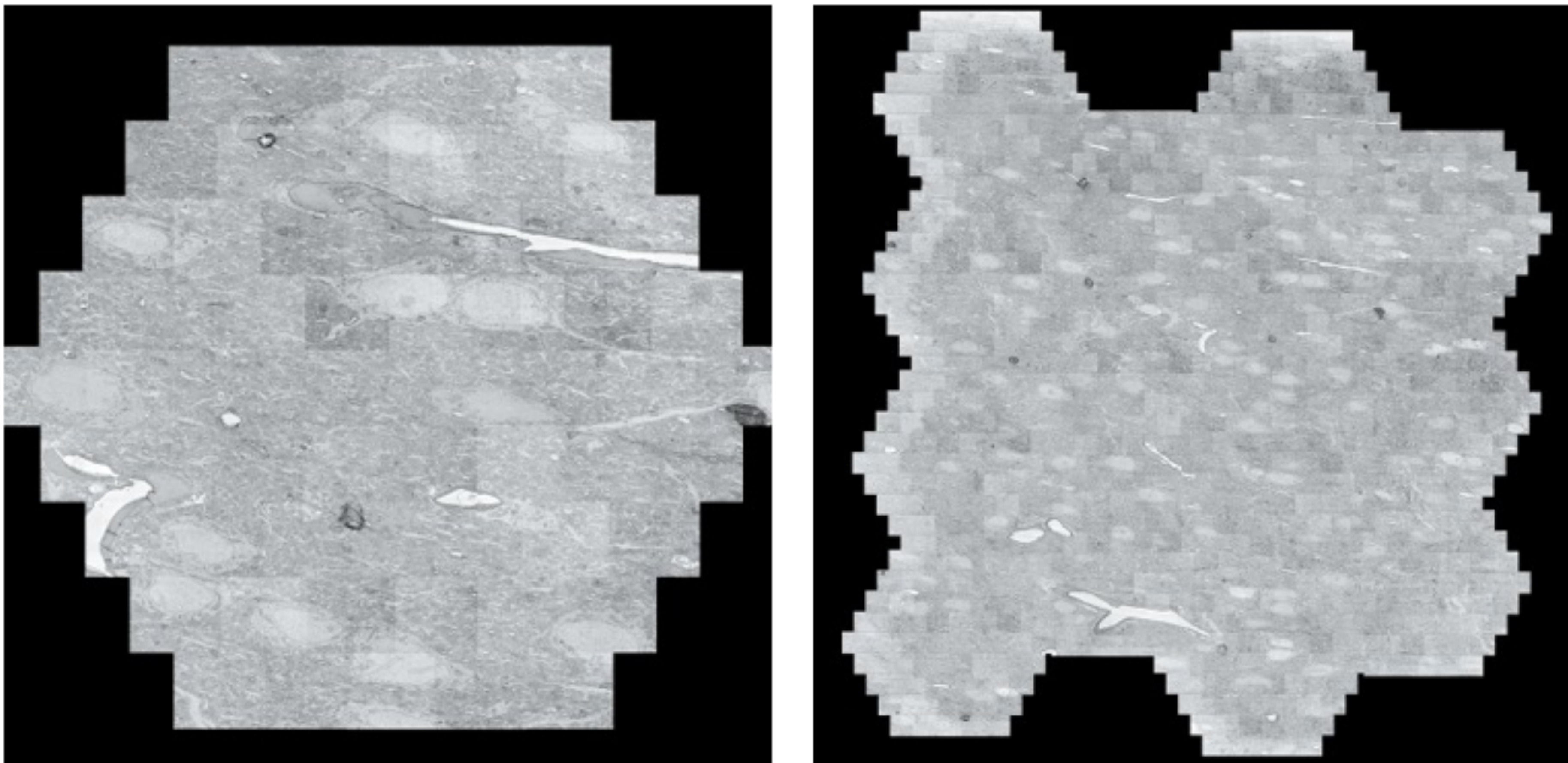
Step 8:
Scans of brain slices are stitched together by an algorithm.

Pre-Image Stitching

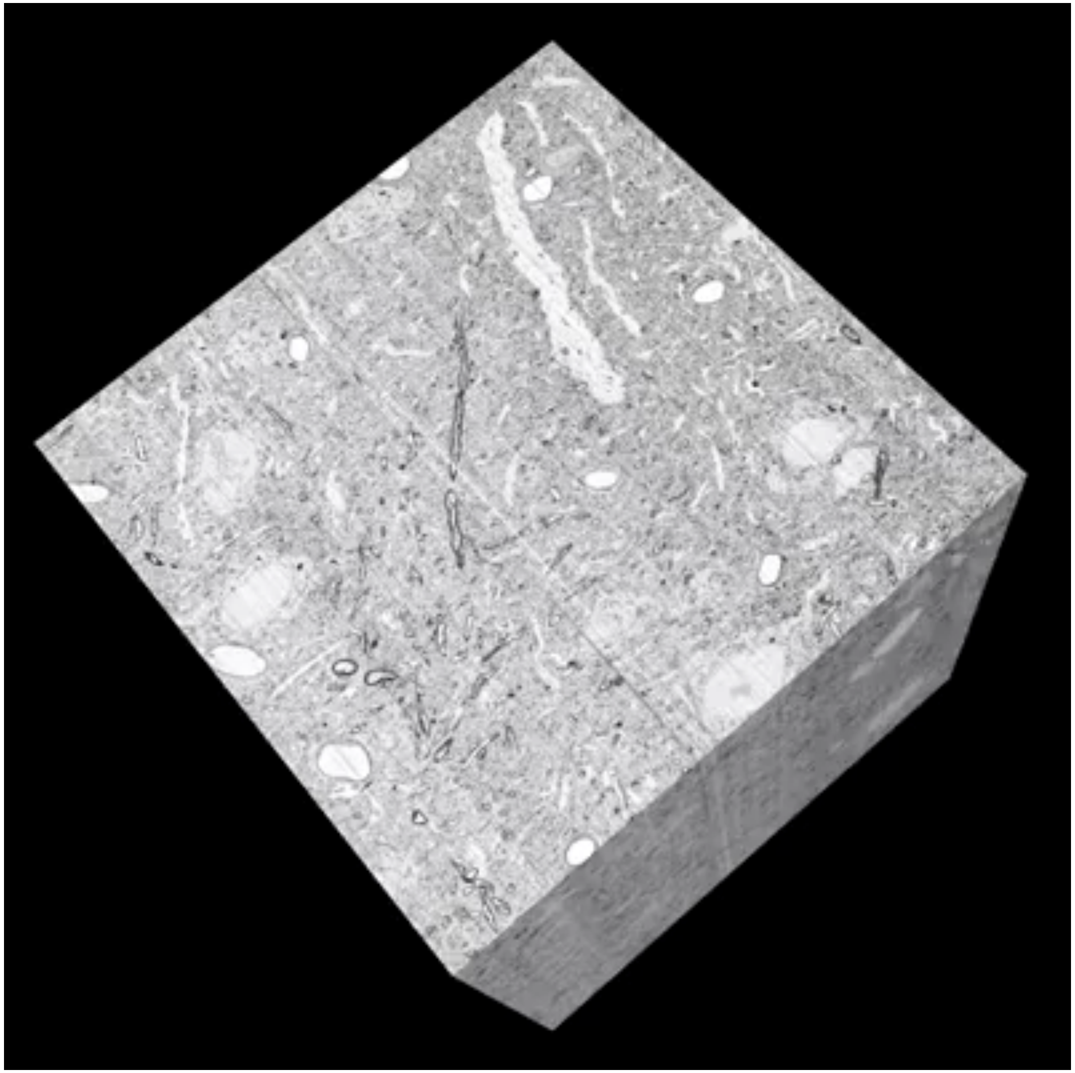
Post-Image Stitching

Step 9:

A “multi-beam field of view,” made of 61 images taken by the electron microscope, is seen at the left; 14 multi-beam fields of view are combined on the right.

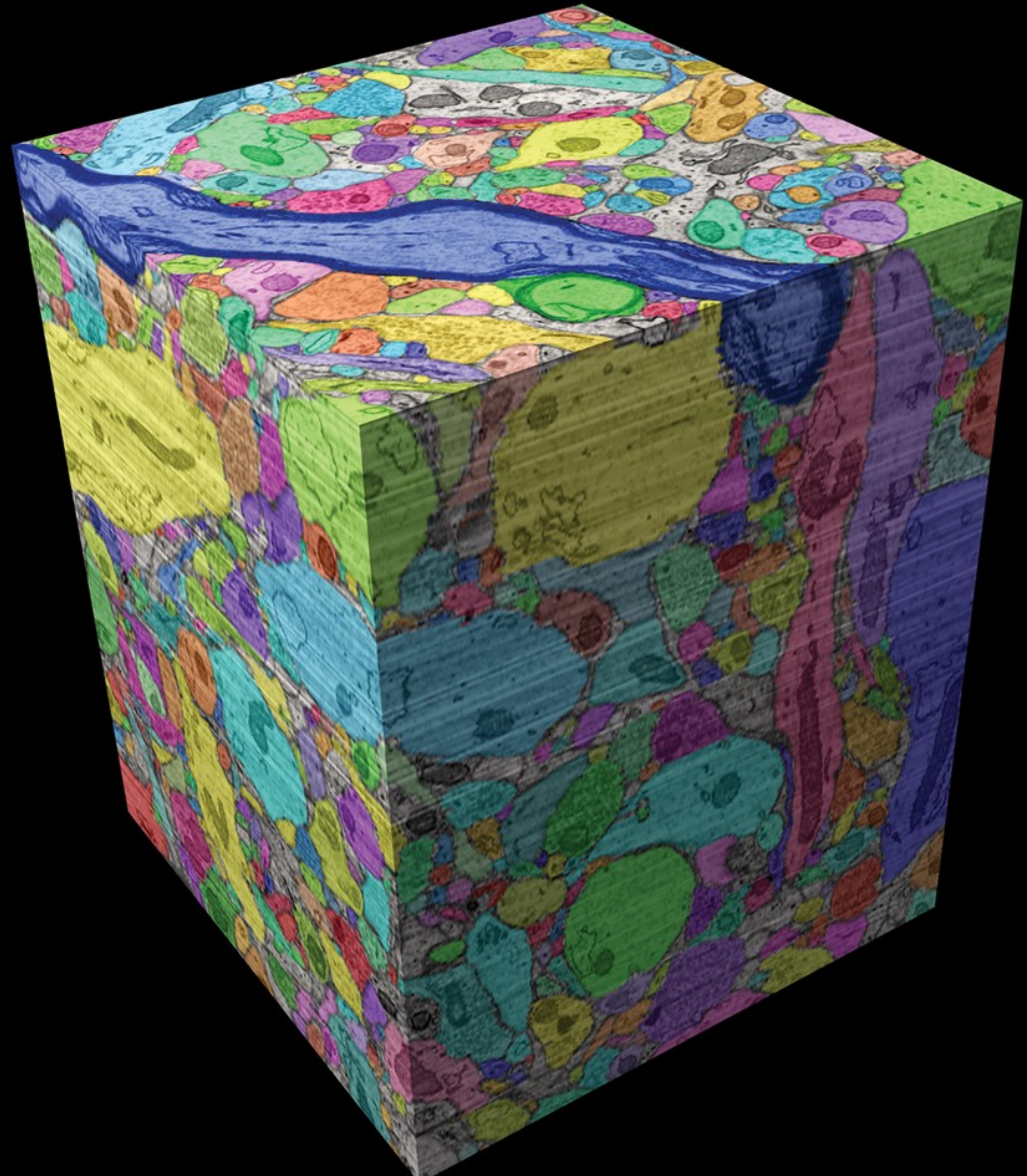


Step 9: 3-D image stitching

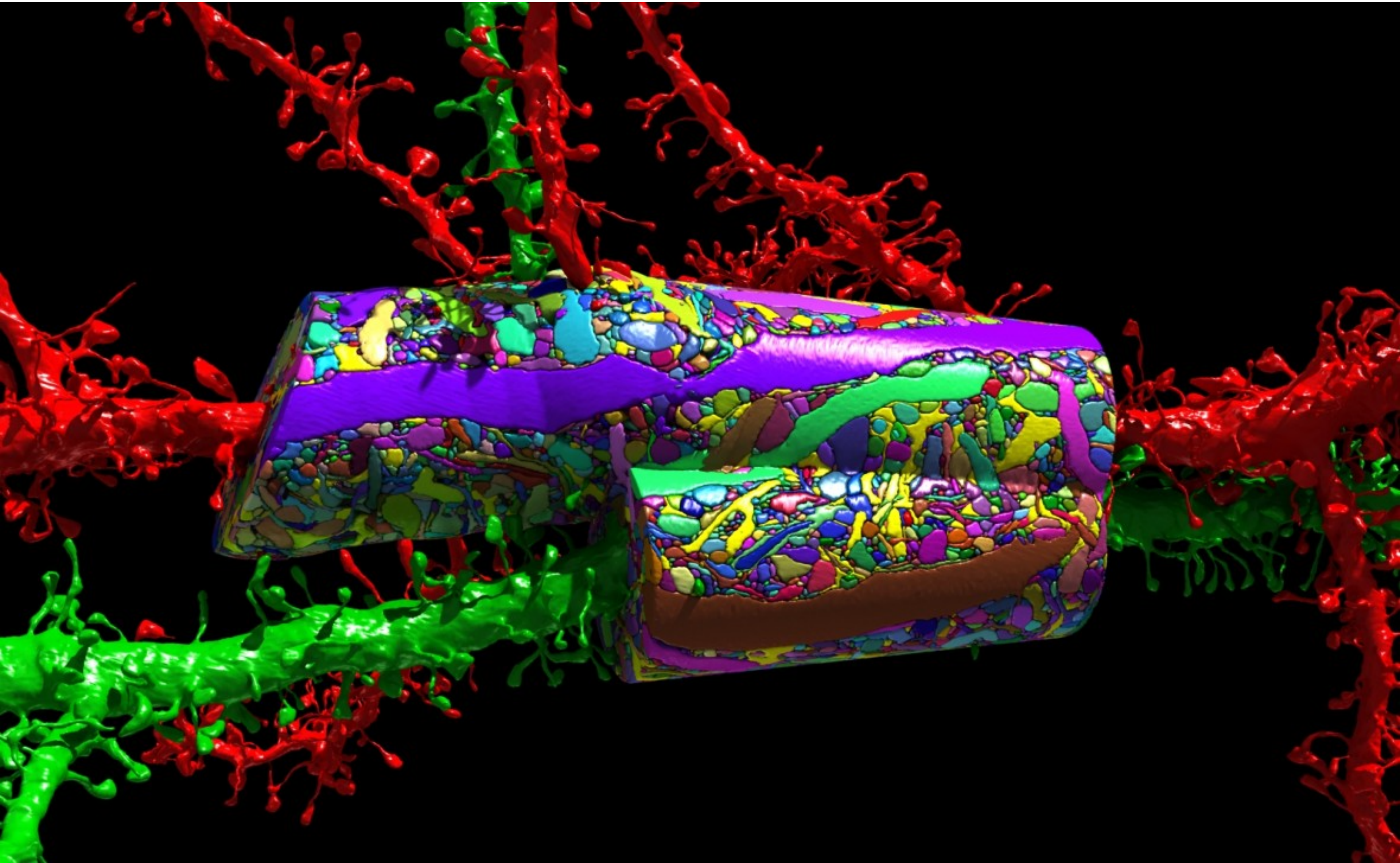


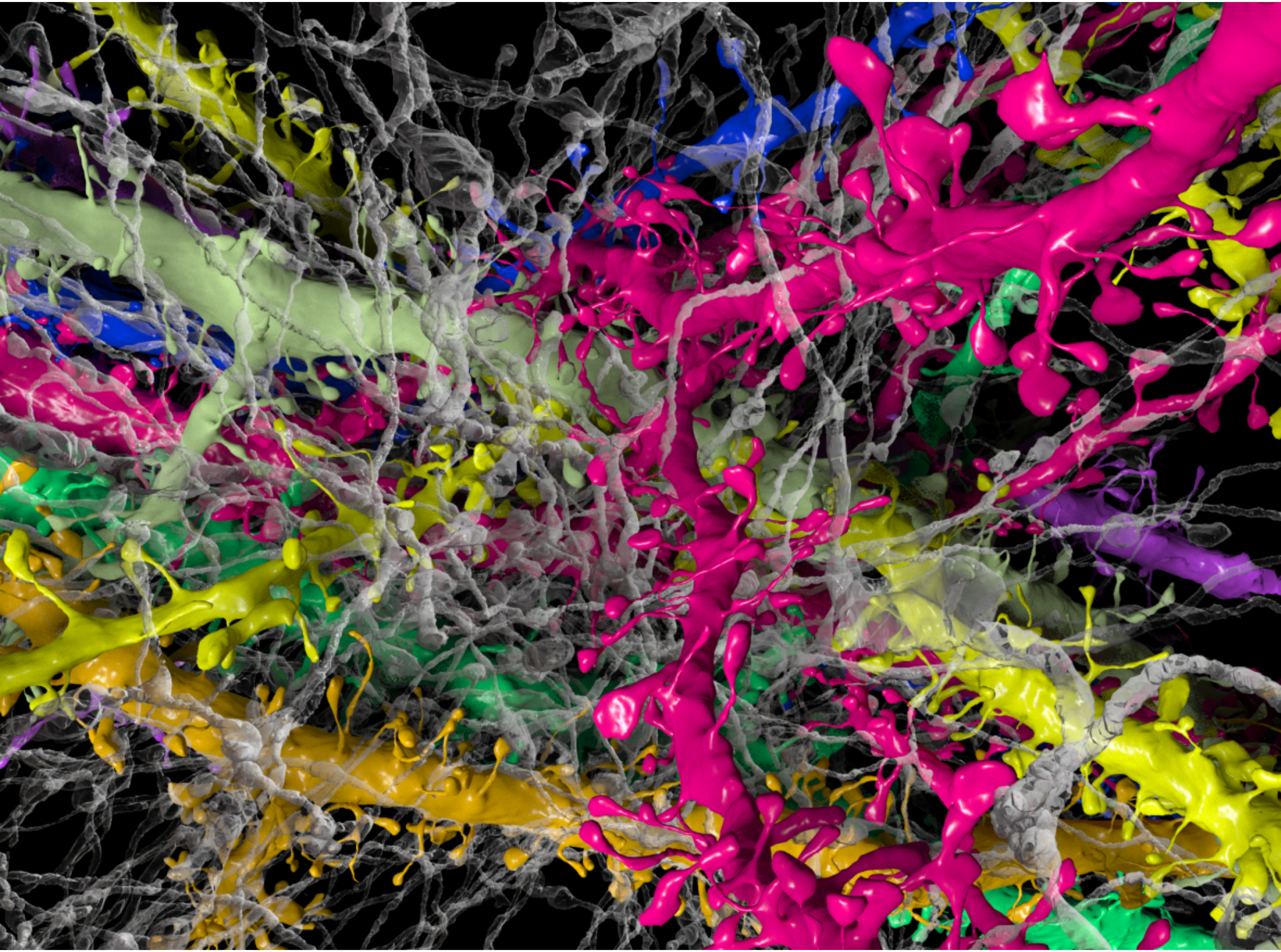
Step 10: Scans are assembled into a cube and colorized.

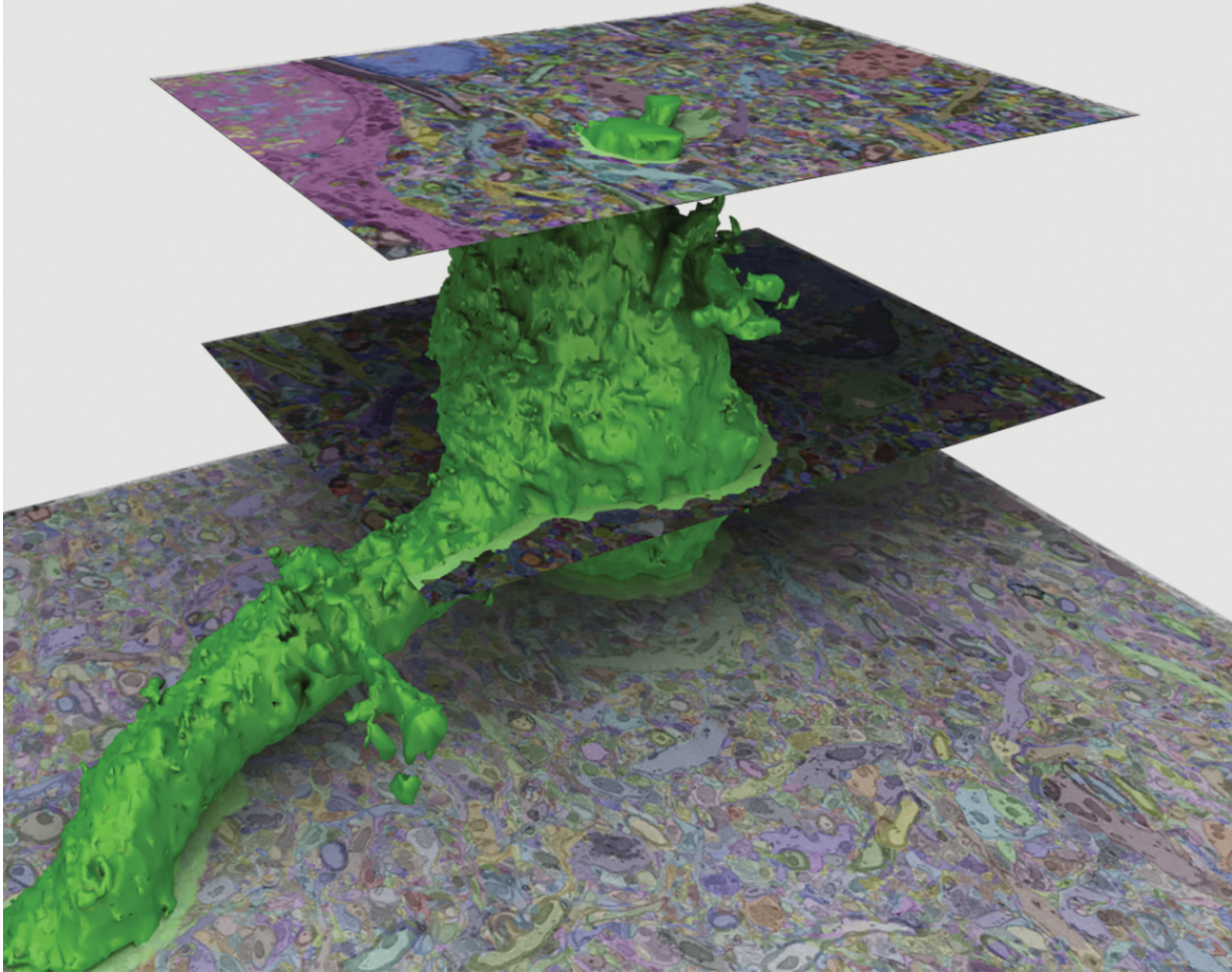
Image Segmentation

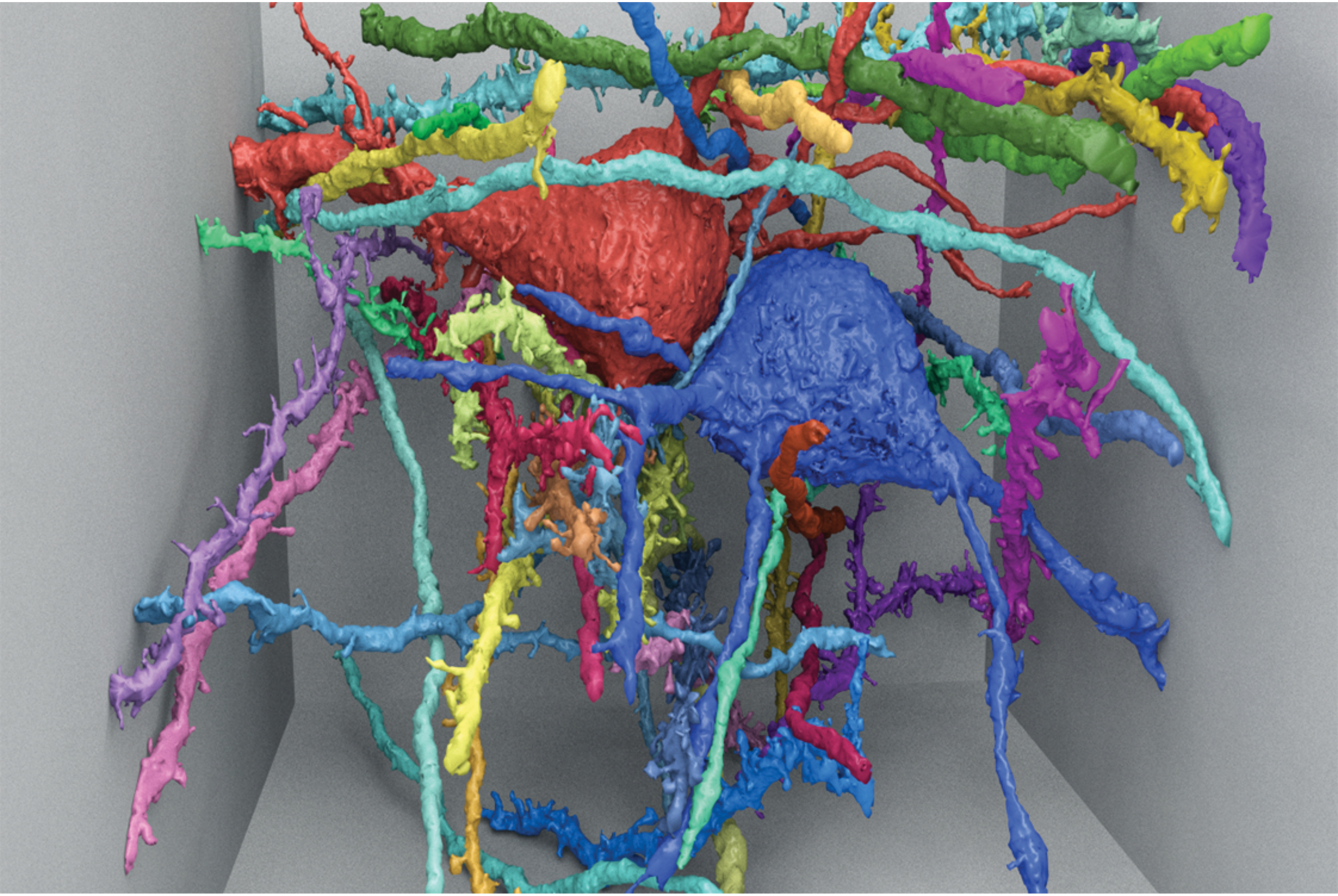


The colorized cubes are useful in 3-D illustrations of various neuronal structures and processes, giving scientists their most detailed map of what actually happens in the brain.









What is computation?

Computation = Coding + Dynamics

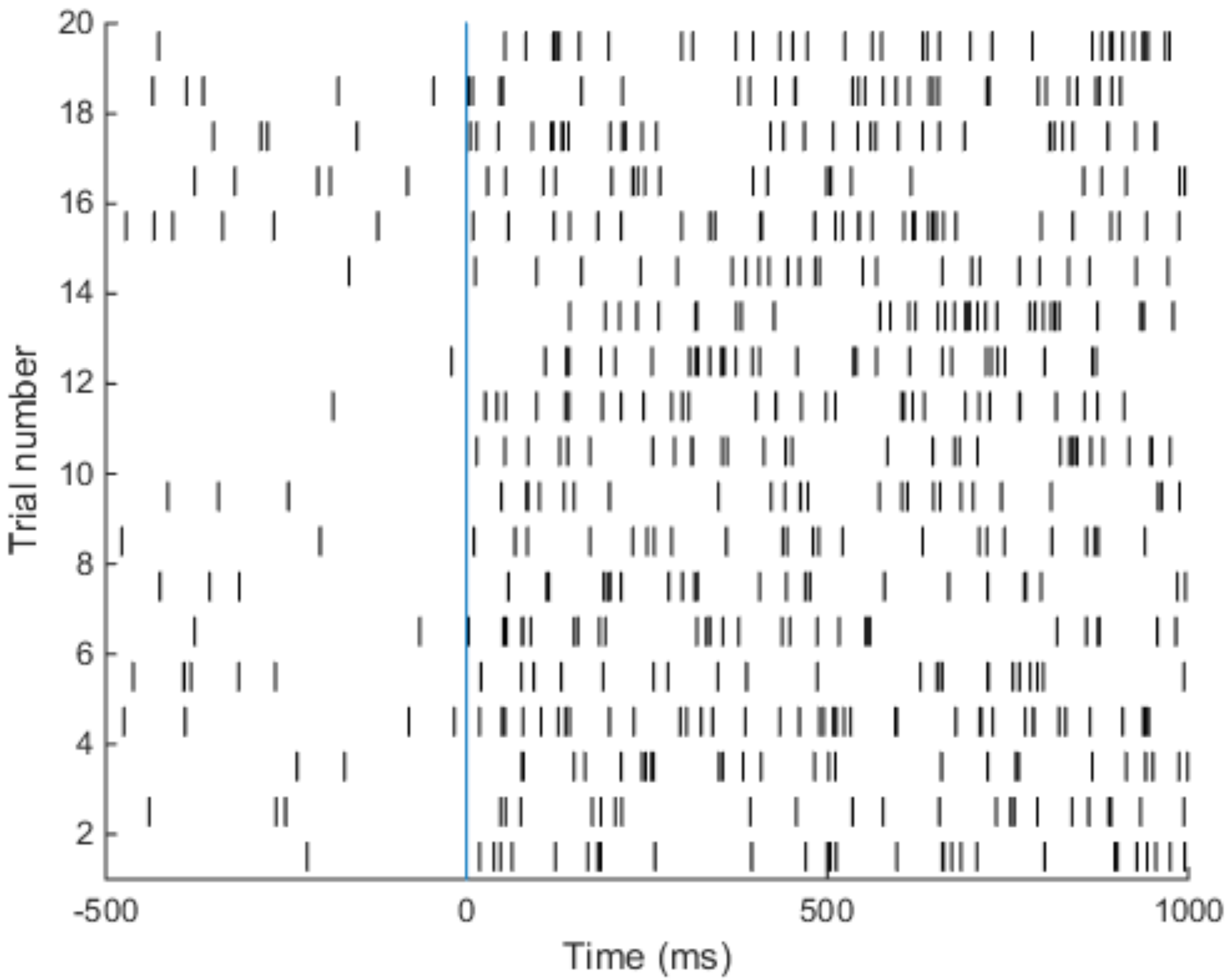
Coding: How are computational variables encoded in neural activation?

- Sensory processing (cat visual system)
- Motor variables (goldfish eye motion)
- Other (rat propioception)

Dynamics: How does the dynamic behavior of neural networks emerge from the properties of single neurons?

Raster Plot

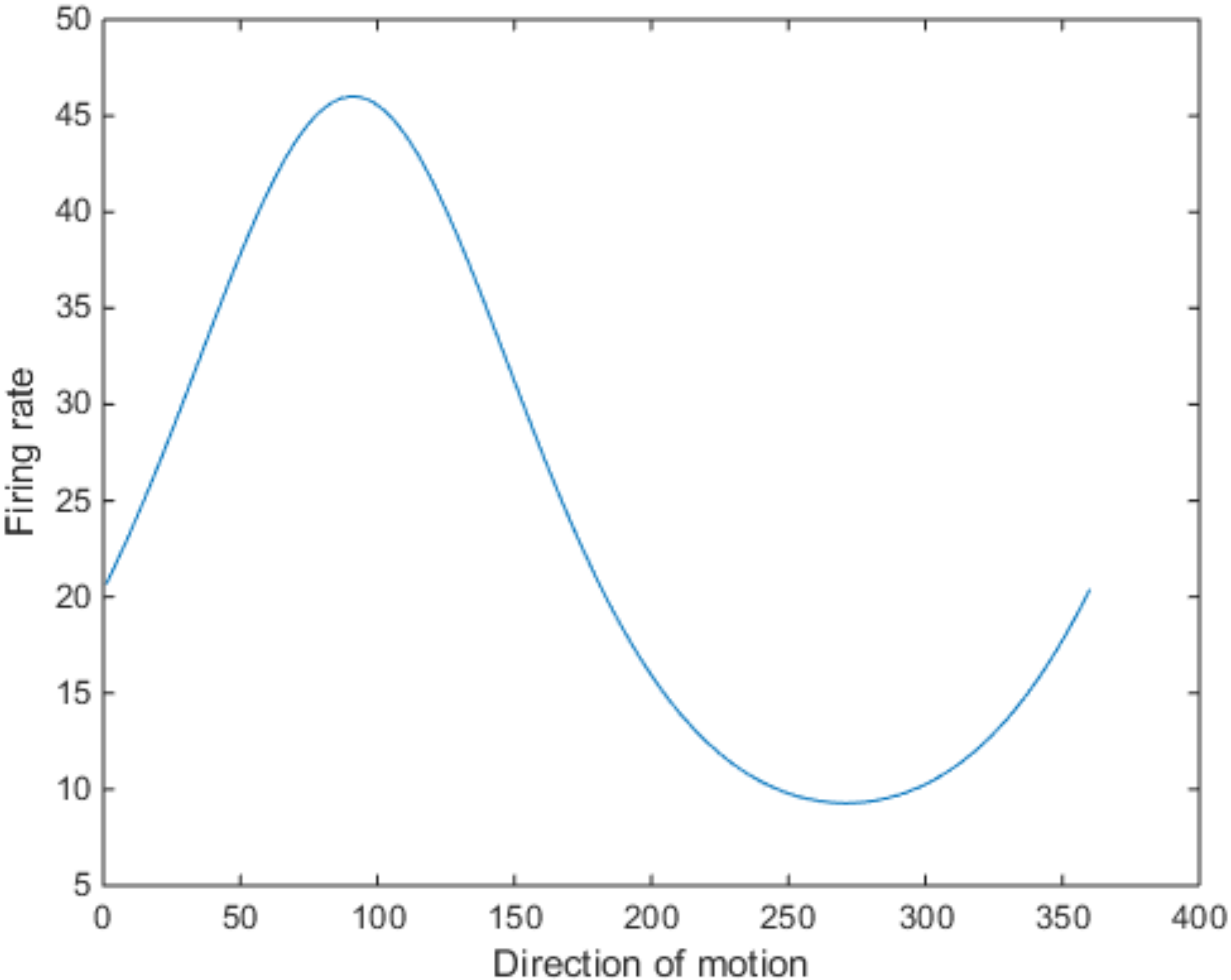
Each black bar represents one *spike* or *action potential*.
Each row of black bars is called a *spike train*.



Simulating spike trains, as seen in this raster plot, requires only one piece of information: ***the firing rate of the neuron.***

Tuning Curve

Neural encoding is transforming information from the *physical space (x-axis)* to the *neural space (y-axis).*



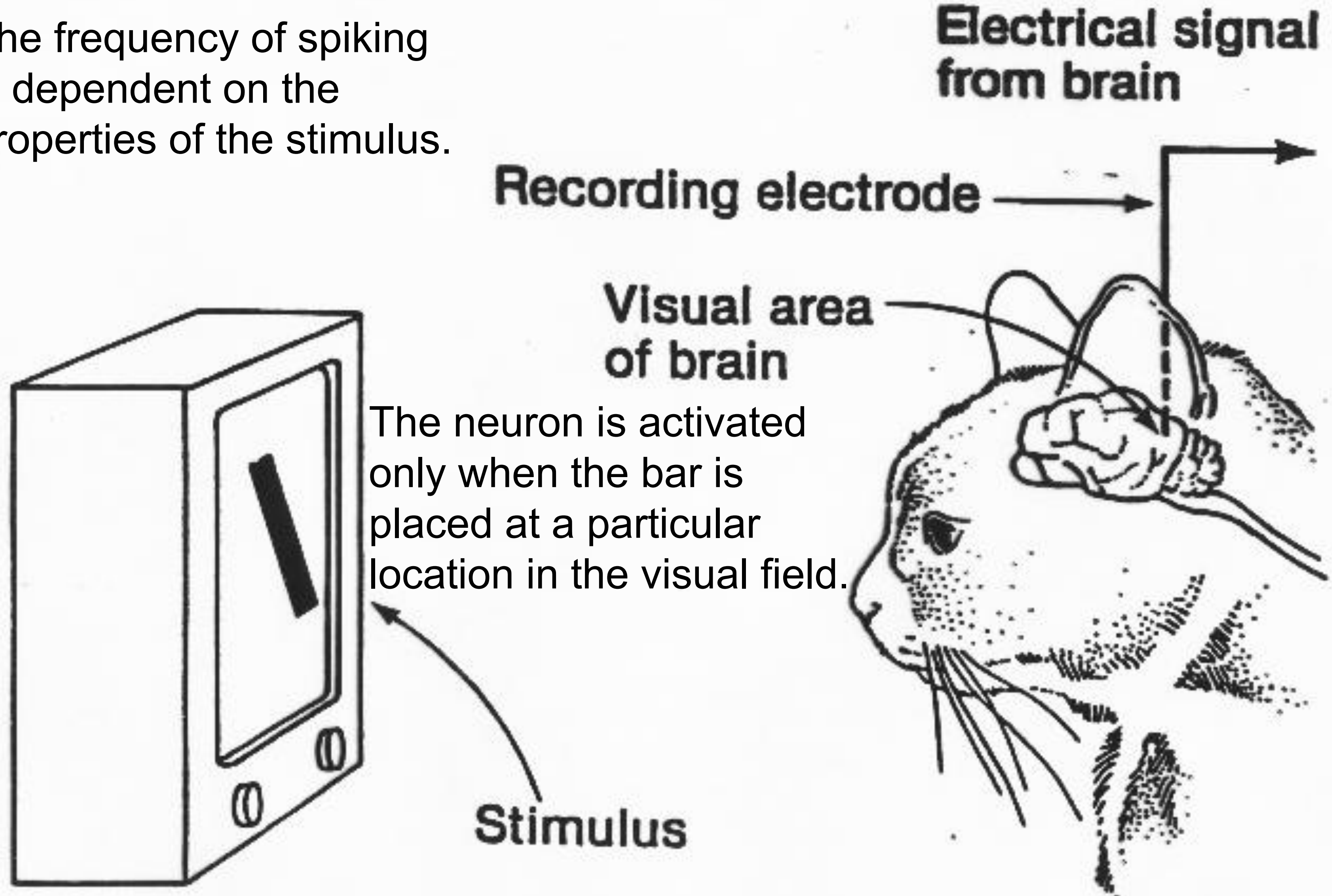
Physical Space:
Direction, shape, speed, color, loudness

Neural space:
Firing rate, morphology, receptor density, dendritic spine density, LFP amplitude

Neural Coding: Sensory Processing

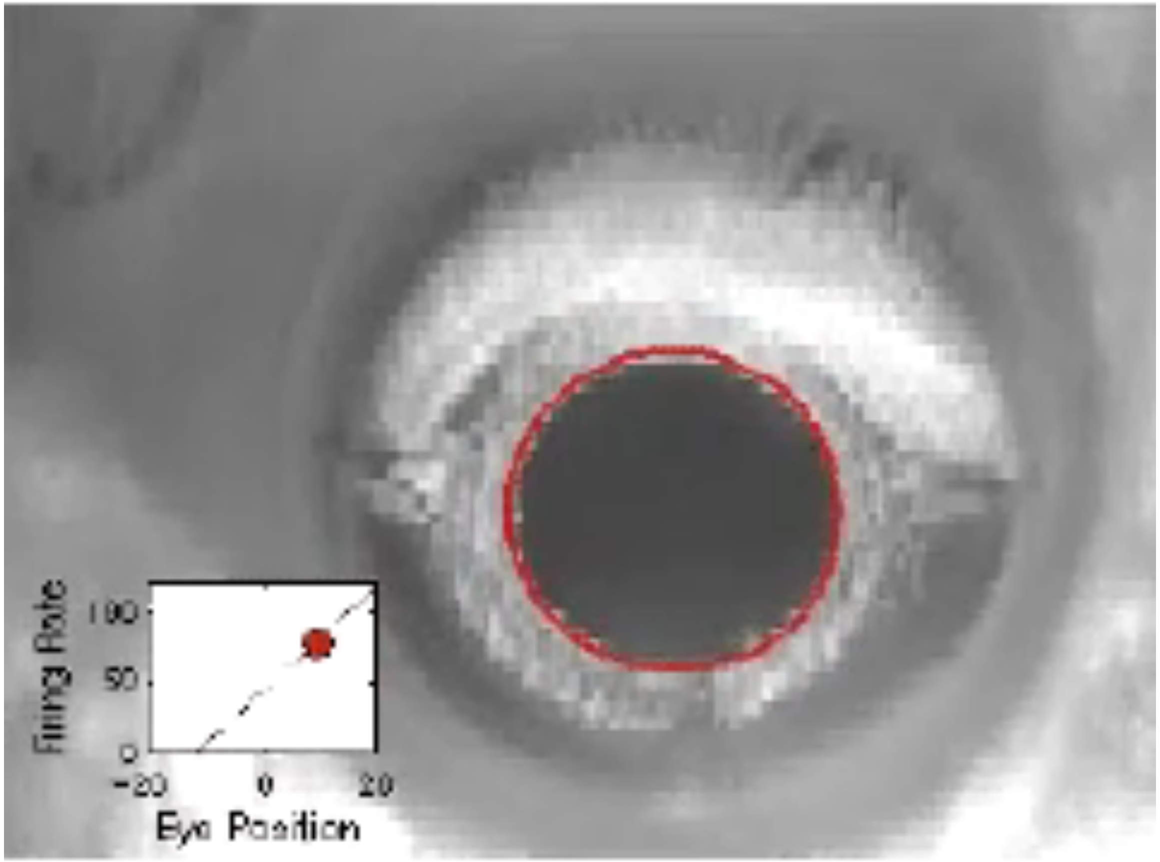
Hubel and Wiesel

The frequency of spiking is dependent on the properties of the stimulus.



The neuron is activated only when the bar is placed at a particular location in the visual field.

Neural Coding: Motor Variables

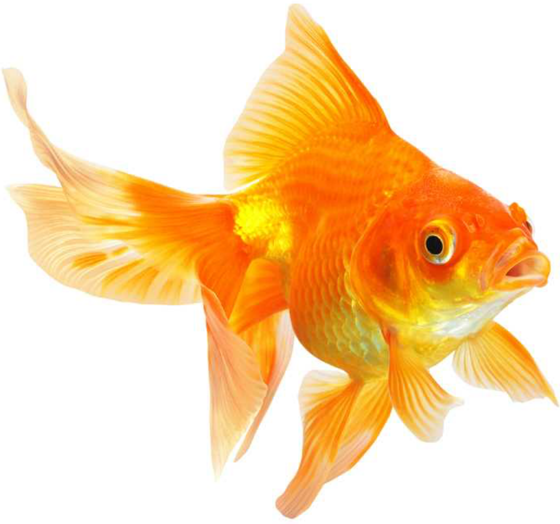


In this video, you…
- *see* the goldfish eye movements and
- *hear* the activity of the neuron controlling those movements

The rate of action potential firing during the fixation periods of eye movement is correlated with the horizontal position of the eye.

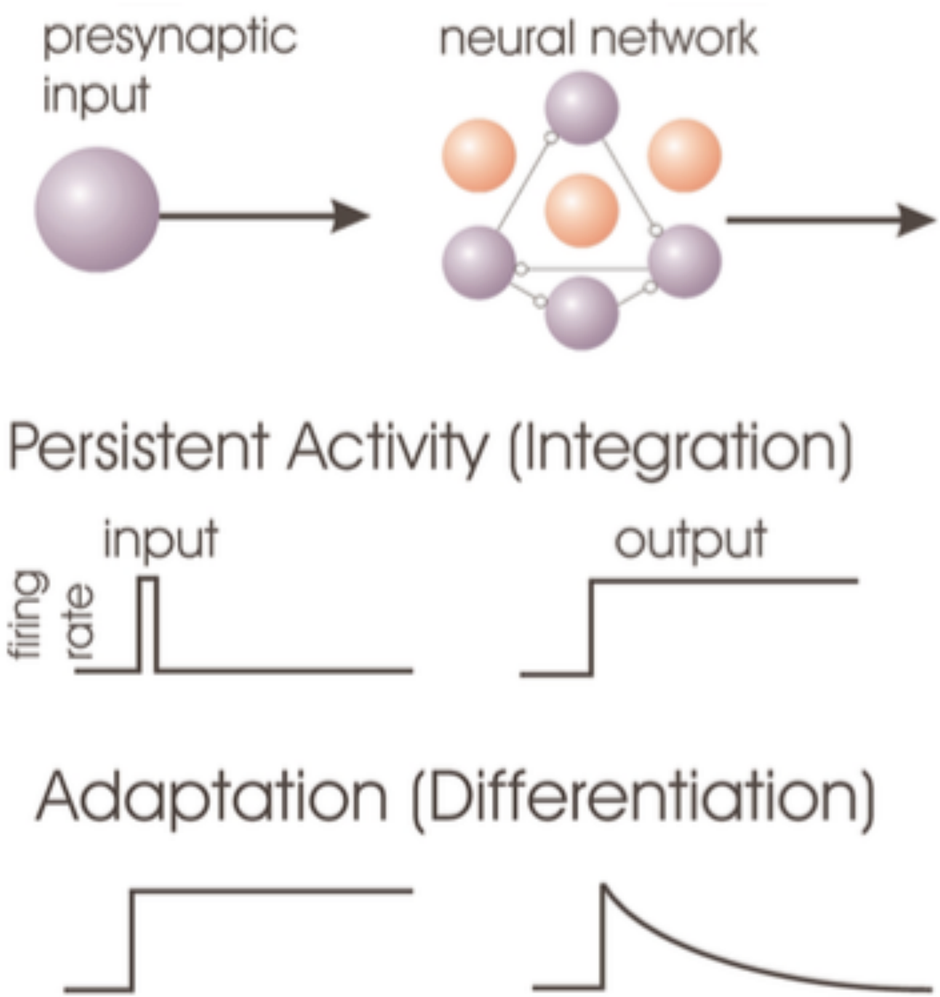
Brain Calculus: Neural Integration and Persistent Activity

How does the brain keep track of external and internal behaviors?
Hypothesis: Sustained synaptic excitation generated by reverbatory interactions among neuronal ensembles (Hebbian Learning)



Experiment by Laboratory of David Tank:
Why test the visual system?
Our eyes scan the world by rapid movements known as **saccades.** Each saccade is separated by a **fixation point.** A fixation point requires continuous contraction of eye muscles, ***which is an example of persistent activity that uses working memory.***
Why goldfish?
Goldfish continuously scan the visual world through a series of horizontal saccades.

Brain Calculus: Neural Integration and Persistent Activity



Each fixation point is maintained by persistent activity of neurons in the goldfish brainstem known as **Area I.**

How do we know so?

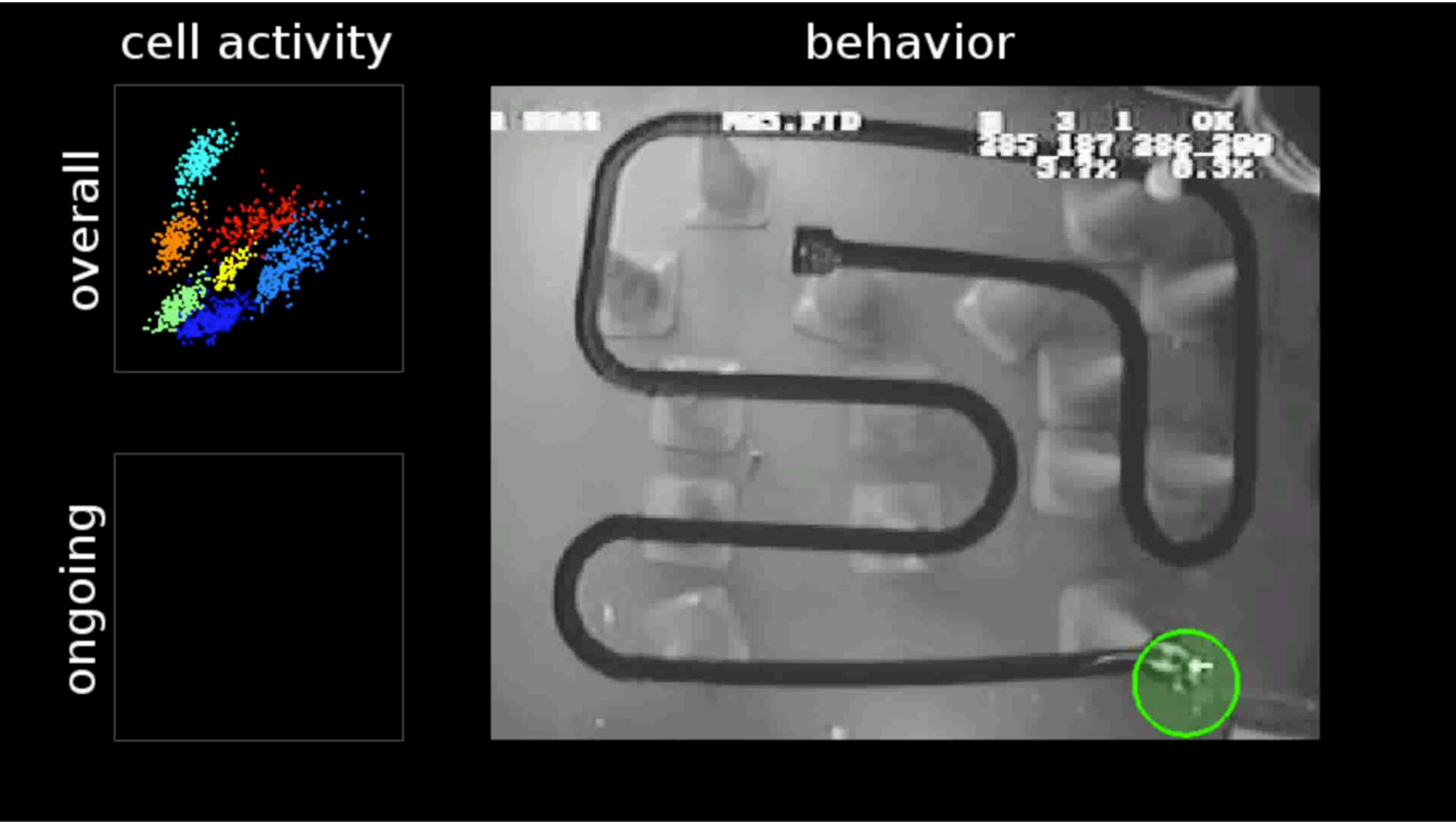
If Area I is inhibited, the goldfish loses the ability to fixate and instead gazes after each movement.

How is persistent activity generated?

Re-entrant excitation and transient activity through adaptation. Adaptation is the activation of hyperpolarizing currents or synaptic depression.

Neural Coding

Some computational variables are neither sensory nor motor.



Next Time:
Programming Demo

But more importantly, BTS is performing at the AMAs on November 19!