COMS30017
Computational Neuroscience

Week 6 / Video 4 / V1 and the cortical microcircuit

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slides adapted from Dr. Cian O'Donnell

Intended Learning Outcomes

- V1 single cell responses: simple vs complex cells.

- The cortical microcircuit.

Primary visual cortex

- First place visual information arrives in the cortex.
- Variously known as V1, primary visual cortex, or striate cortex.
- Single V1 neurons tend to respond to basic features of the visual stimulus, like oriented edges.
- Often thought of as a canonical cortical region.

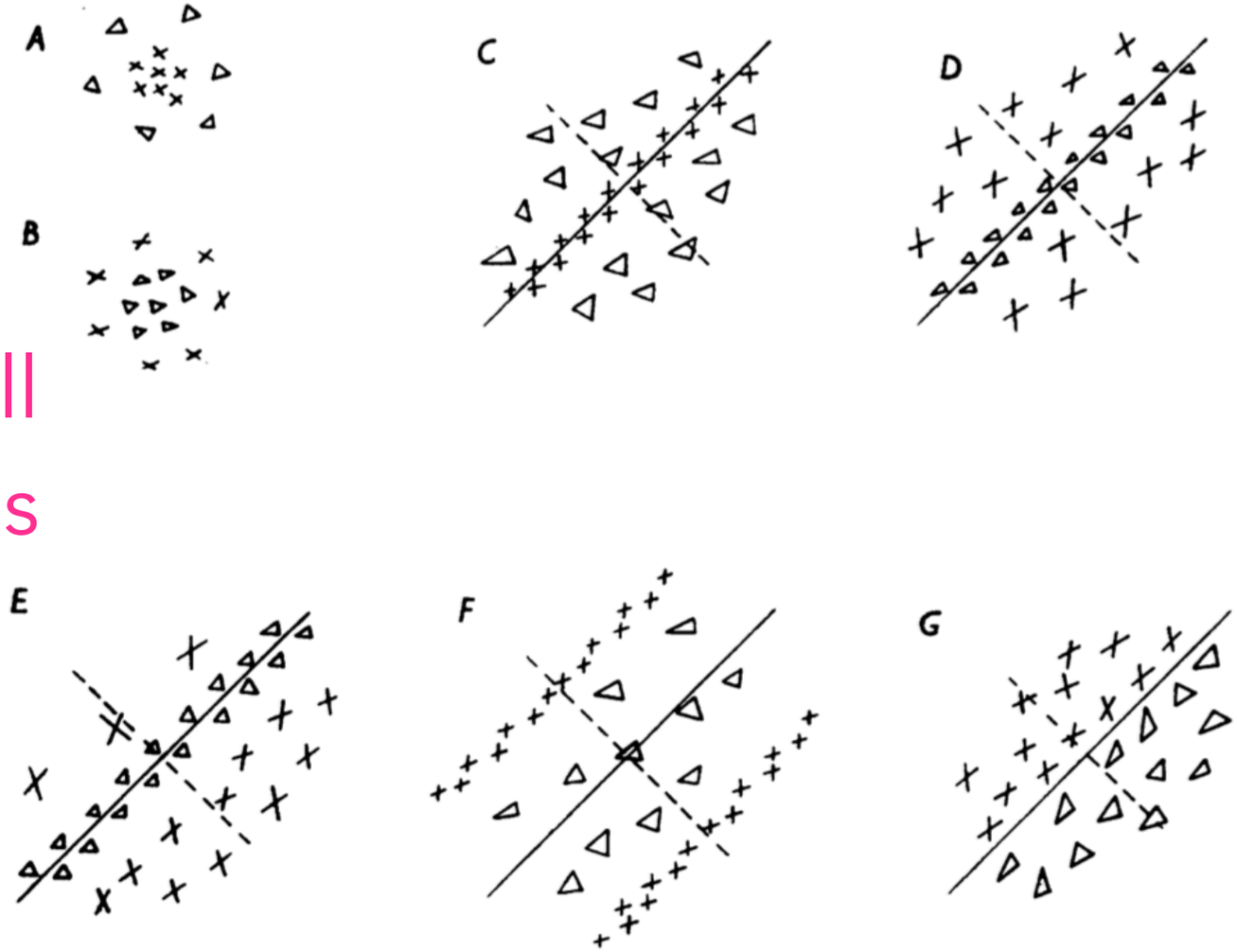
Simple vs complex cells

- Classical neurophysiologists distinguished two dominant types of single cell responses in V1.

- "Simple cells" respond to oriented edge/grating stimuli in a specific part of visual field only.

- "Complex cells" also respond to oriented stimuli, but exhibit some degree of spatial invariance. They will respond similarly no matter where the stimulus is located within the receptive field.

Simple vs complex cells



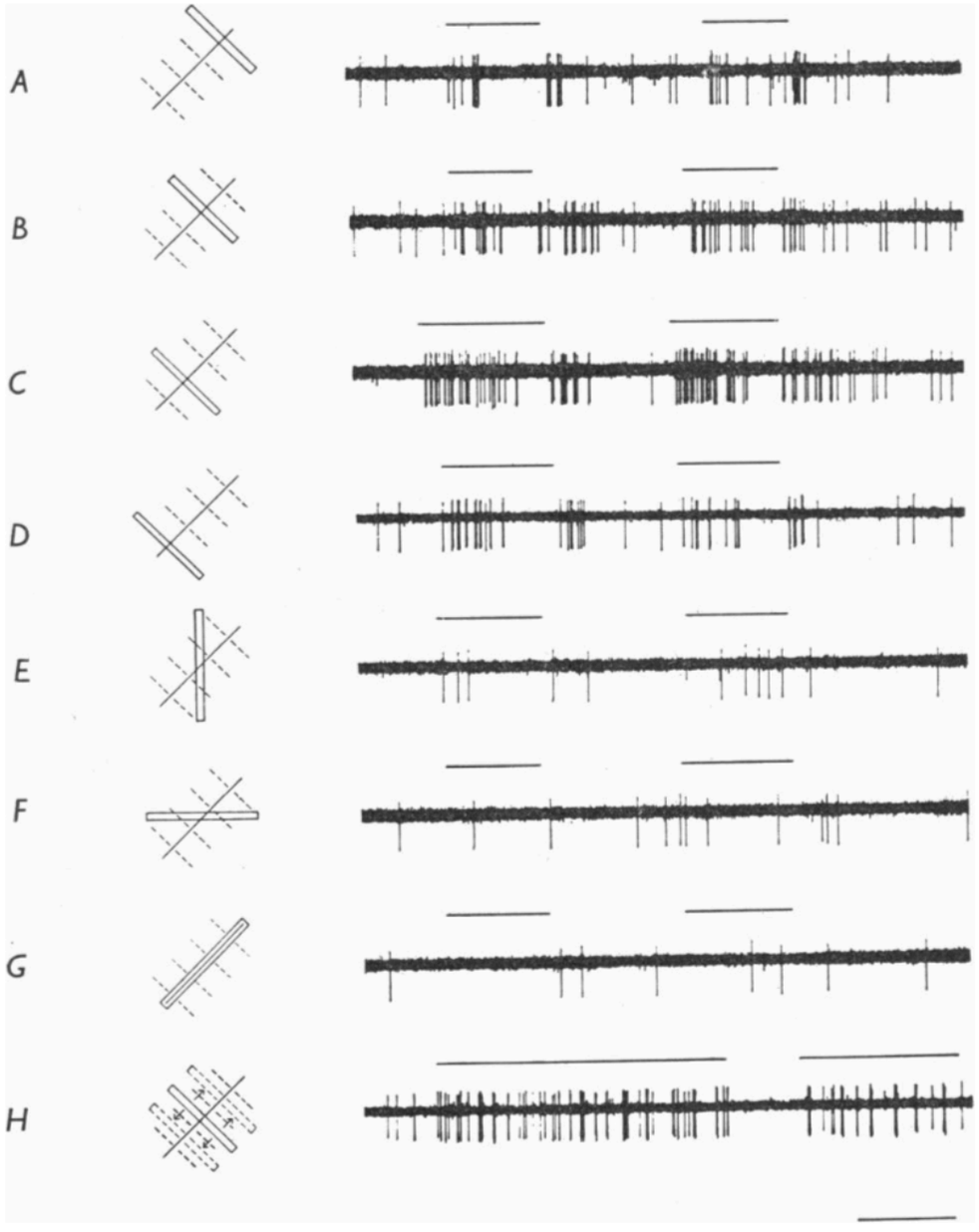
Simple cell receptive fields

Text-fig. 2. Common arrangements of lateral geniculate and cortical receptive fields. *A*. 'On'-centre geniculate receptive field. *B*. 'Off'-centre geniculate receptive field. *C–G*. Various arrangements of simple cortical receptive fields. ×, areas giving excitatory responses ('on' responses); △, areas giving inhibitory responses ('off' responses). Receptive-field axes are shown by continuous lines through field centres; in the figure these are all oblique, but each arrangement occurs in all orientations.

[Hubel and Wiesel, J Physiol, 1962]

Simple vs complex cells

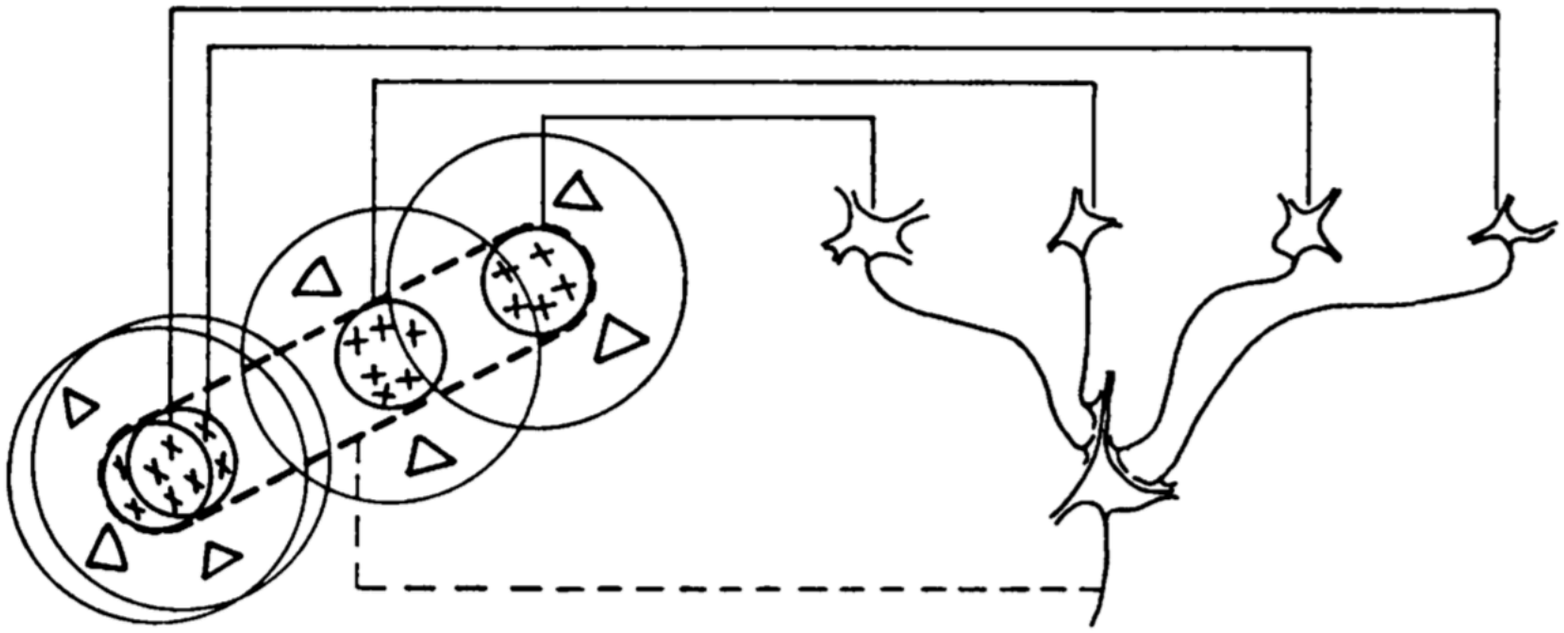
Complex cell responses



Text-fig. 4. Responses of a cell with a complex field to stimulation of the left (contralateral) eye with a slit $\frac{1}{8} \times 2\frac{1}{2}°$. Receptive field was in the area centralis and was about $2 \times 3°$ in size. *A–D*, $\frac{1}{8}°$ wide slit oriented parallel to receptive field axis. *E–G*, slit oriented at 45 and 90° to receptive-field axis. *H*, slit oriented as in *A–D*, is on throughout the record and is moved rapidly from side to side where indicated by upper beam. Responses from left eye slightly more marked than those from right (Group 3, see Part II). Time 1 sec.

[Hubel and Wiesel, J Physiol, 1962]

Hubel and Wiesel's model for orientation tuning



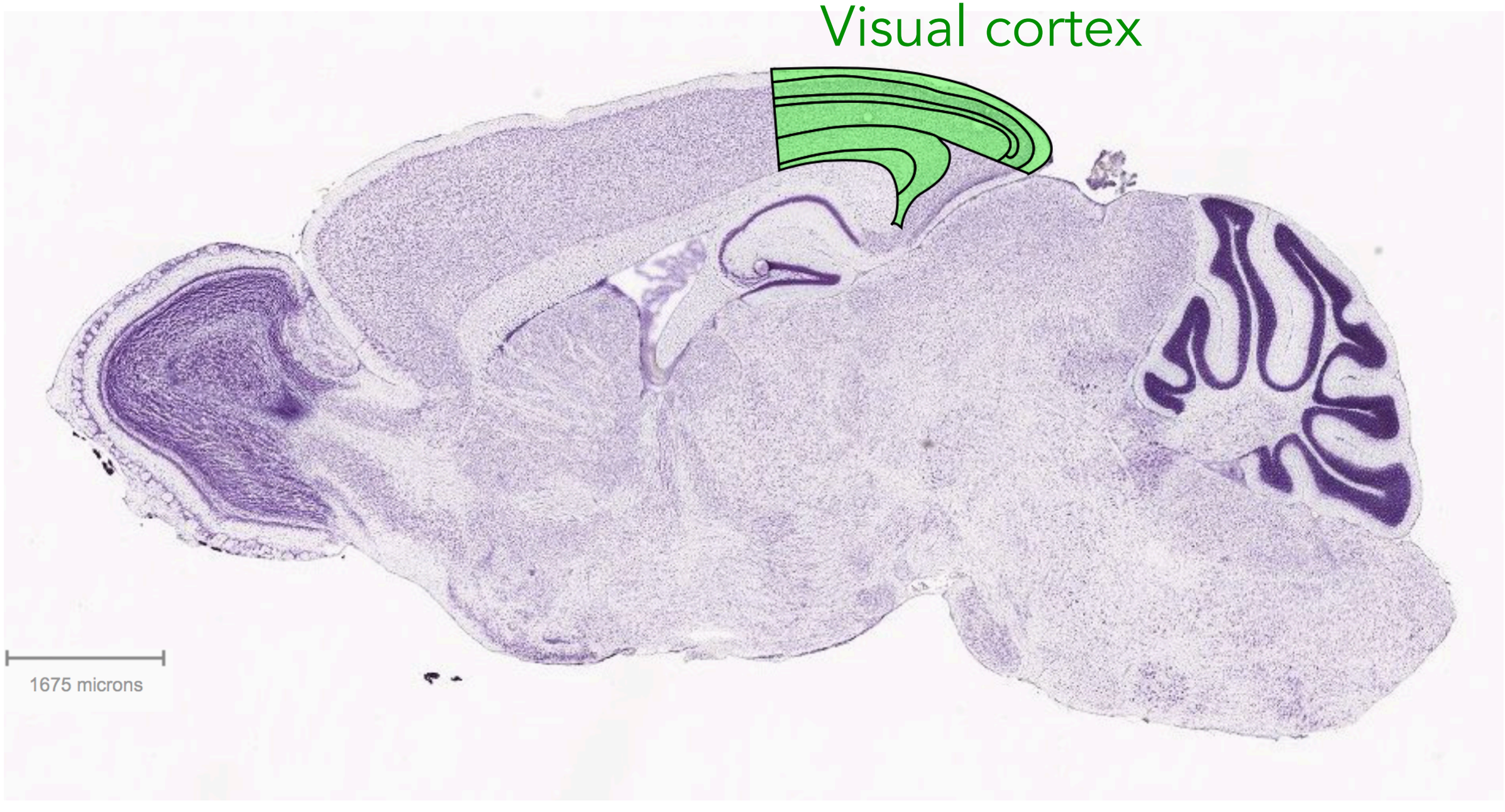
Text-fig. 19. Possible scheme for explaining the organization of simple receptive fields. A large number of lateral geniculate cells, of which four are illustrated in the upper right in the figure, have receptive fields with 'on' centres arranged along a straight line on the retina. All of these project upon a single cortical cell, and the synapses are supposed to be excitatory. The receptive field of the cortical cell will then have an elongated 'on' centre indicated by the interrupted lines in the receptive-field diagram to the left of the figure.

[Hubel and Wiesel, J Physiol, 1962]

What we will cover today

- V1 single cell responses: simple vs complex cells.
- The cortical microcircuit.
- Topographic maps.
- Sparse coding.

Cortical microcircuit



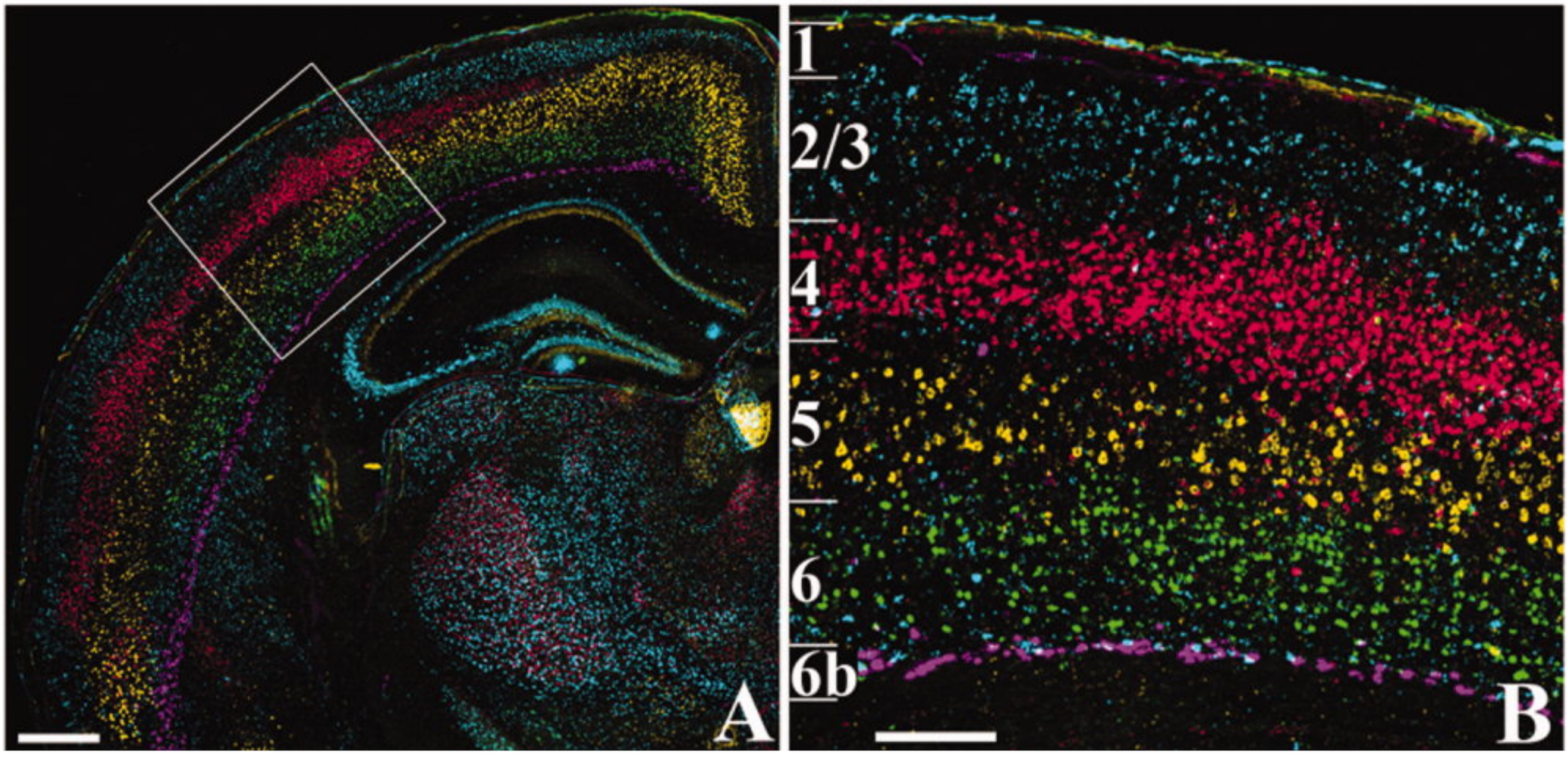
Allen Institute: http://atlas.brain-map.org

Cortical microcircuit

- The mammalian neocortex is fairly homogeneous: most parts of it look similar (with some key exceptions).
  - Therefore the hope is that if we could understand how V1 works, then we can generalise those principles to the rest of cortex.
- V1 has six layers, numbered from 1–6 starting at the brain surface (i.e. layer 1 is the most superficial, layer 6 is the deepest.
- Each layer has a mix of distinct excitatory and inhibitory cell types.
  - There are numerically more excitatory neurons than inhibitory neurons (around a 80/20% split), but there are many more subtypes of inhibitory neuron (around 10–20) than excitatory neuron (around 4–6).
- The classic route for information flow is:
  Thalamus → layer 4 → layer 2/3 → layer 5 → other parts of the brain.

Cortical microcircuit

Layers

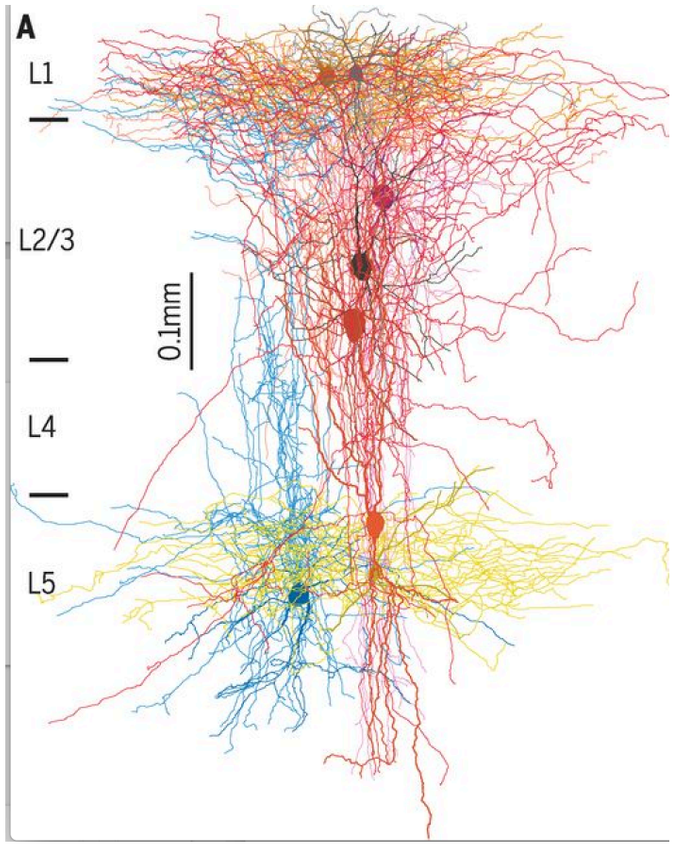


[Boyle et al., *J Neurosci*, 2011]

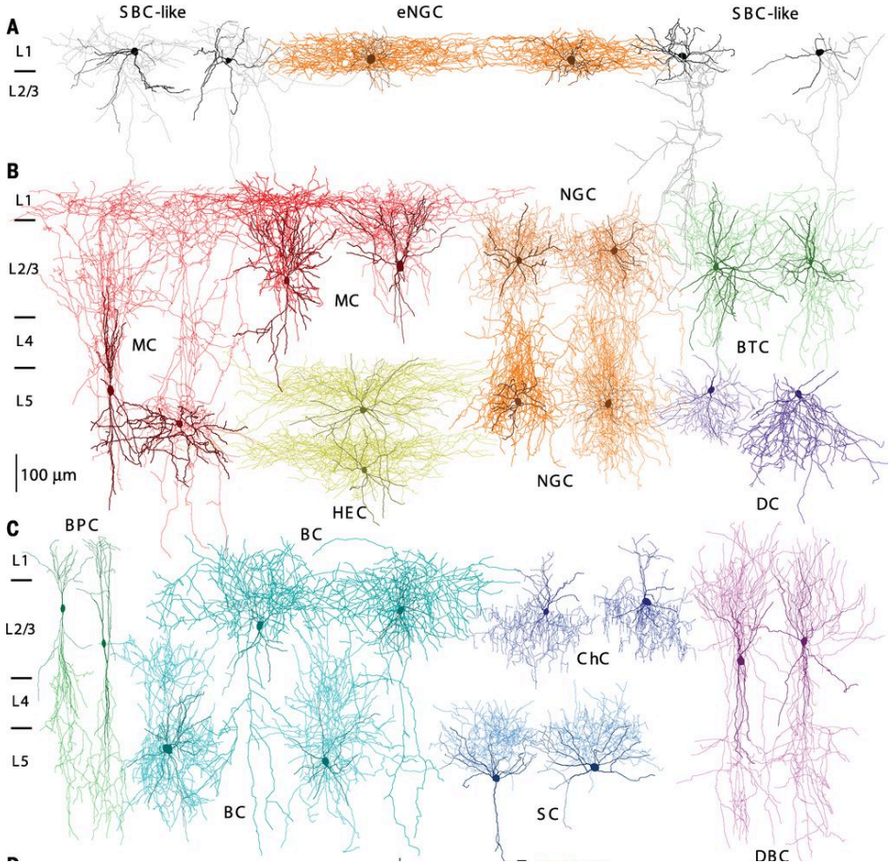
Cortical microcircuit

The circuit diagram

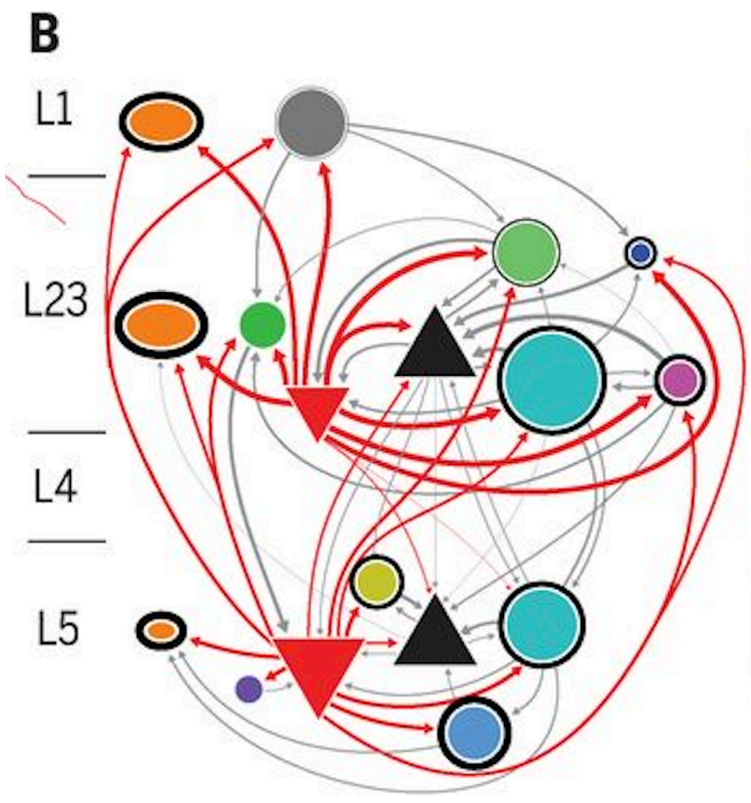
Excitatory (pyramidal) neurons



Inhibitory neurons

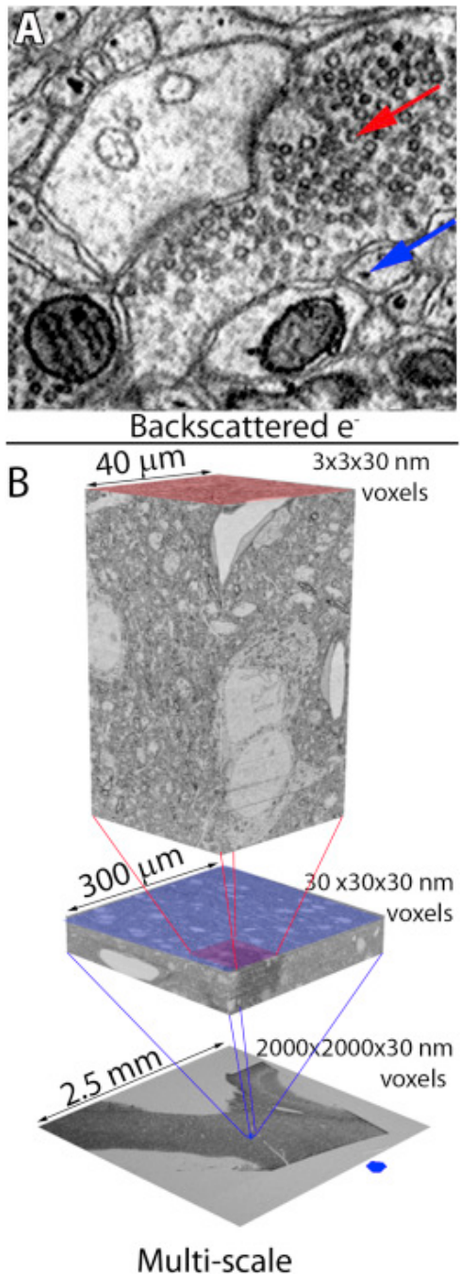


Circuit diagram

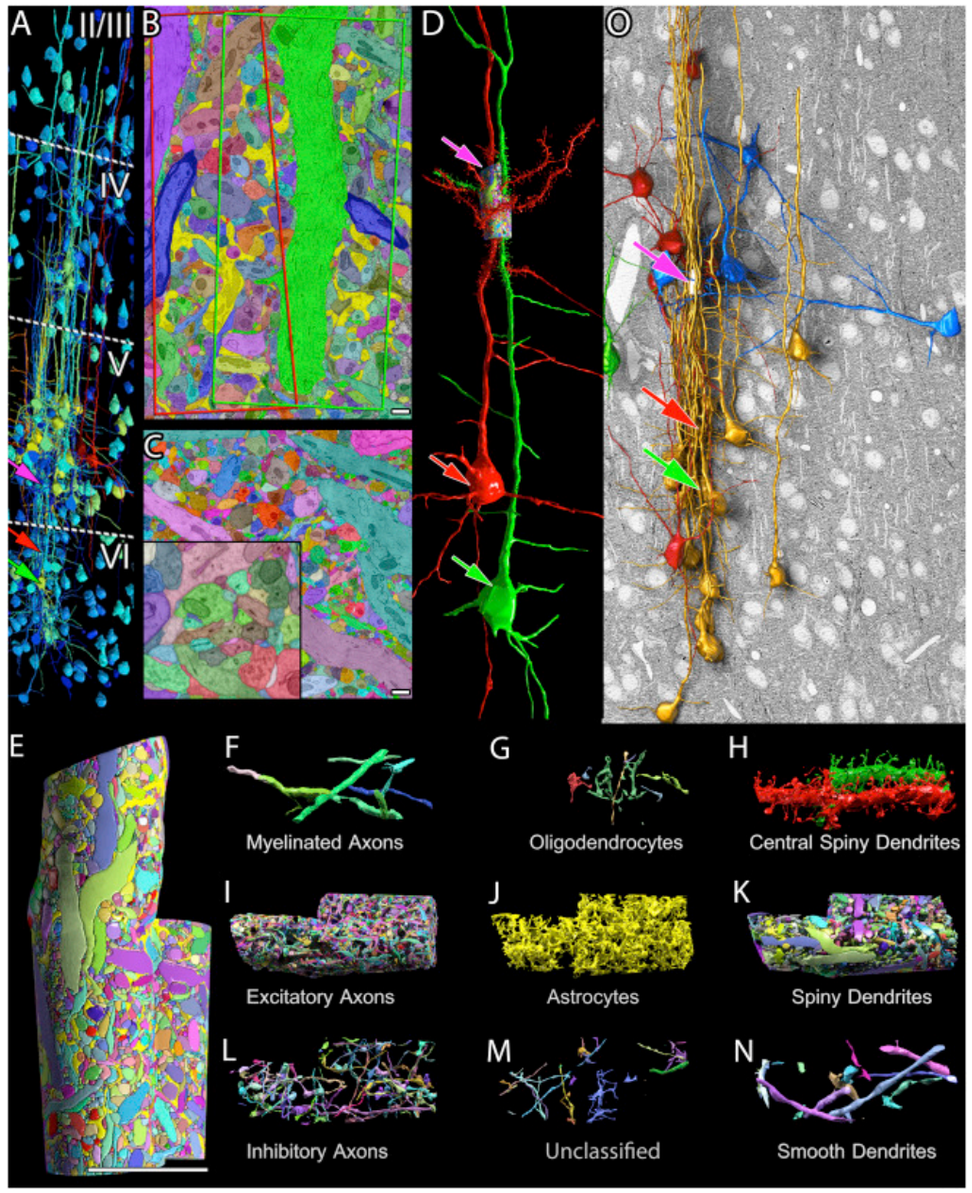


[Jiang et al., *Science*, 2015]

Cortical microcircuit



Multi-scale



Links for movies on labeling and flythrough.

Large-scale electron-microscopy to reconstruct cortical circuit at nm resolution.

[Kasthuri et al., *Cell*, 2015]

End