Chapter 13: Neural Maps: Their Function and Development

Lecture 13.1 Background

Reading Assignments

From the Textbook

Sections 13.1–13.3

Suggestions for Further Reading

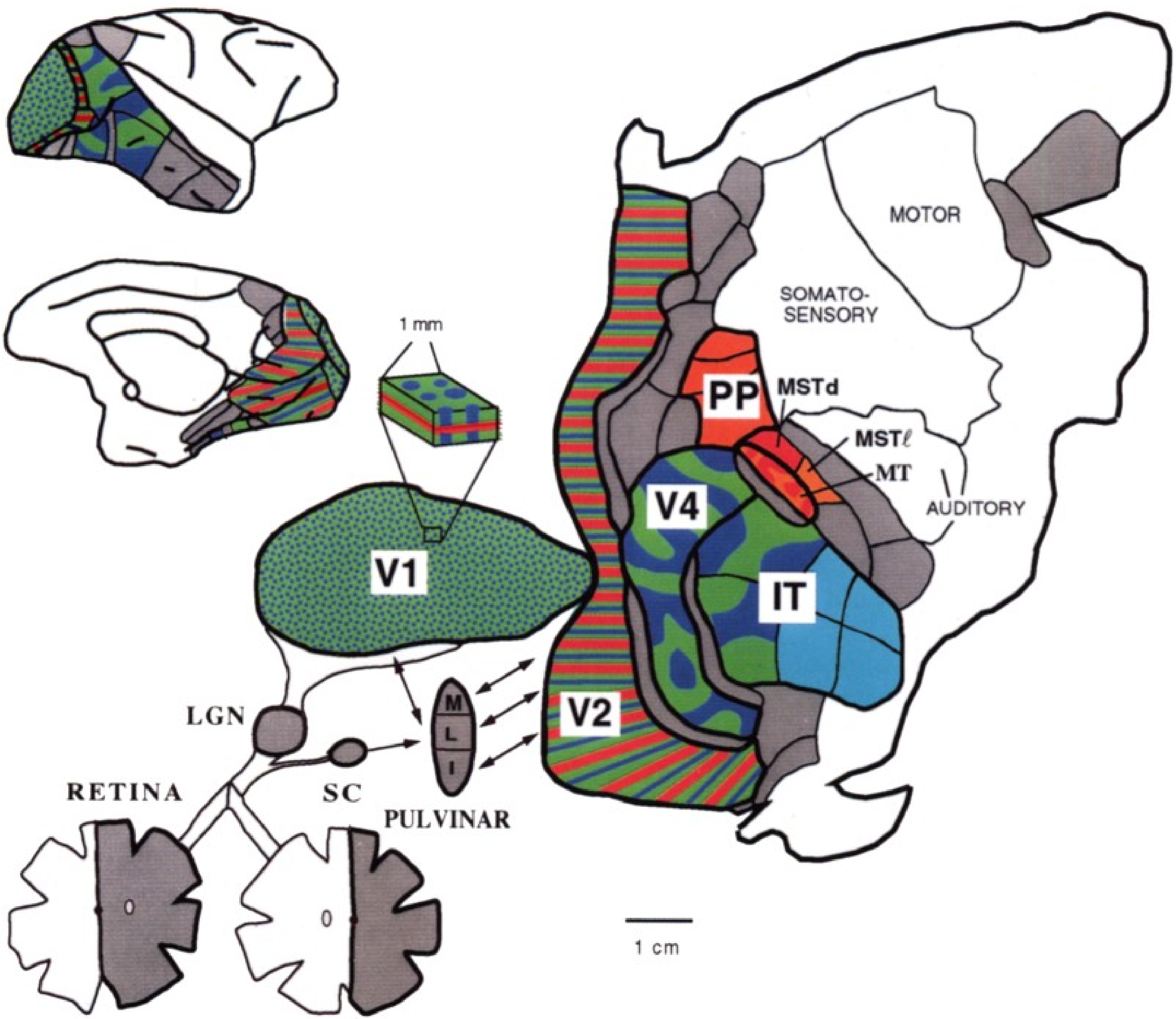
Experiments: Hubel & Wiesel (1962), Blasdel (1992), Okhi et al. (2005)

Neural maps: Definitions

- **Neural map**: A sheet of neurons systematically related to another population of neurons.
- **Topographic map**: A neural map that is organized spatially across the sheet, with the systematic mapping reflected in the spatial organization of the neurons.
- **Feature map**: A topographic map in which the organization reflects some abstract feature of the input, not just, e.g., a copy of the sensory receptor surface.

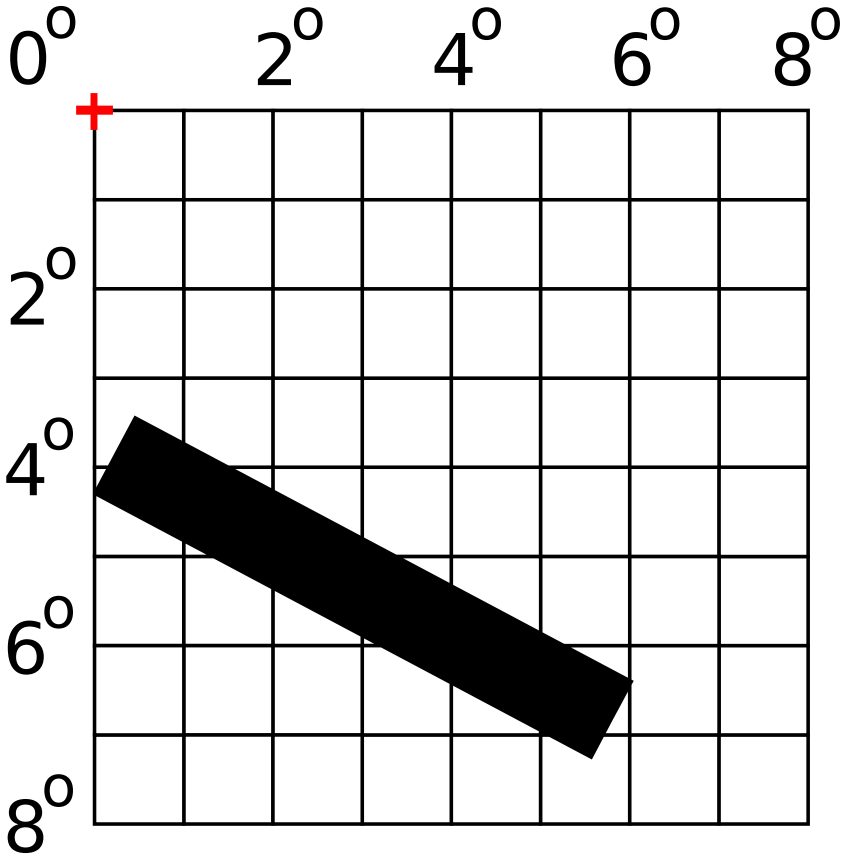
A large fraction of the brain is organized into such maps, and so it is important to understand how they function, how they develop, and what purpose they serve. Here we focus on maps in the visual system, but there are maps for the body surface, the cochlea of the ear, the olfactory neurons in the nose, the whisker pad in rodents, and so on.

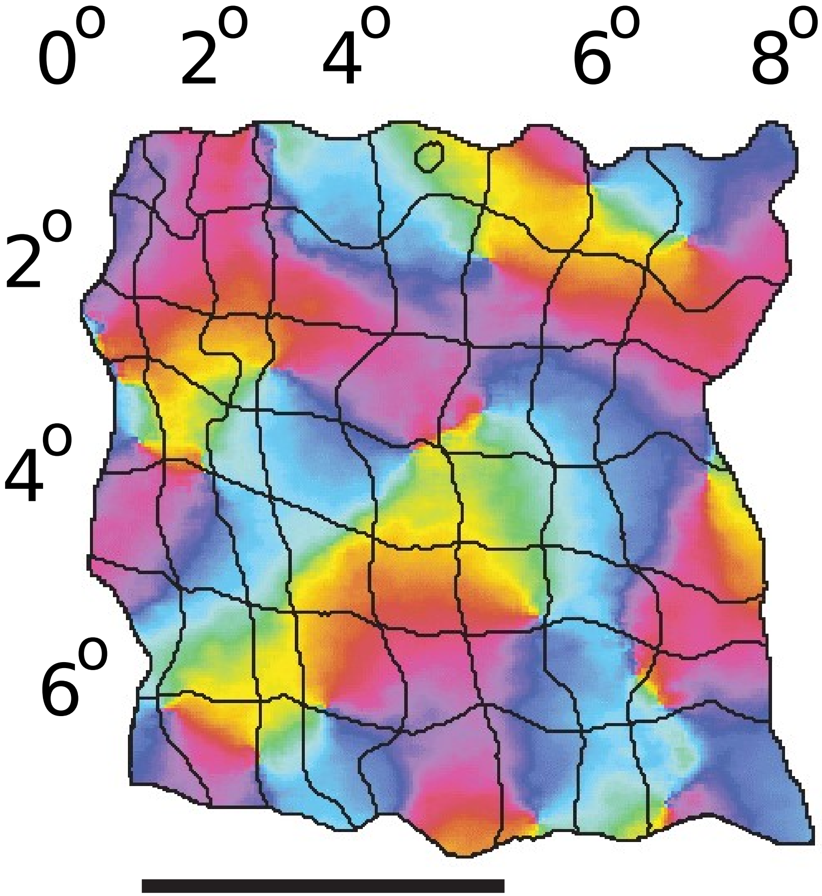
Visual maps in macaque monkey



- Much of the macaque brain is visually responsive.
- The surface of each named area here has a map of most or all of the visual field.
- Other areas are responsive to other modalities.
- Our examples focus on the path from retina to V1 via the LGN.

Visuotopic and orientation map in V1

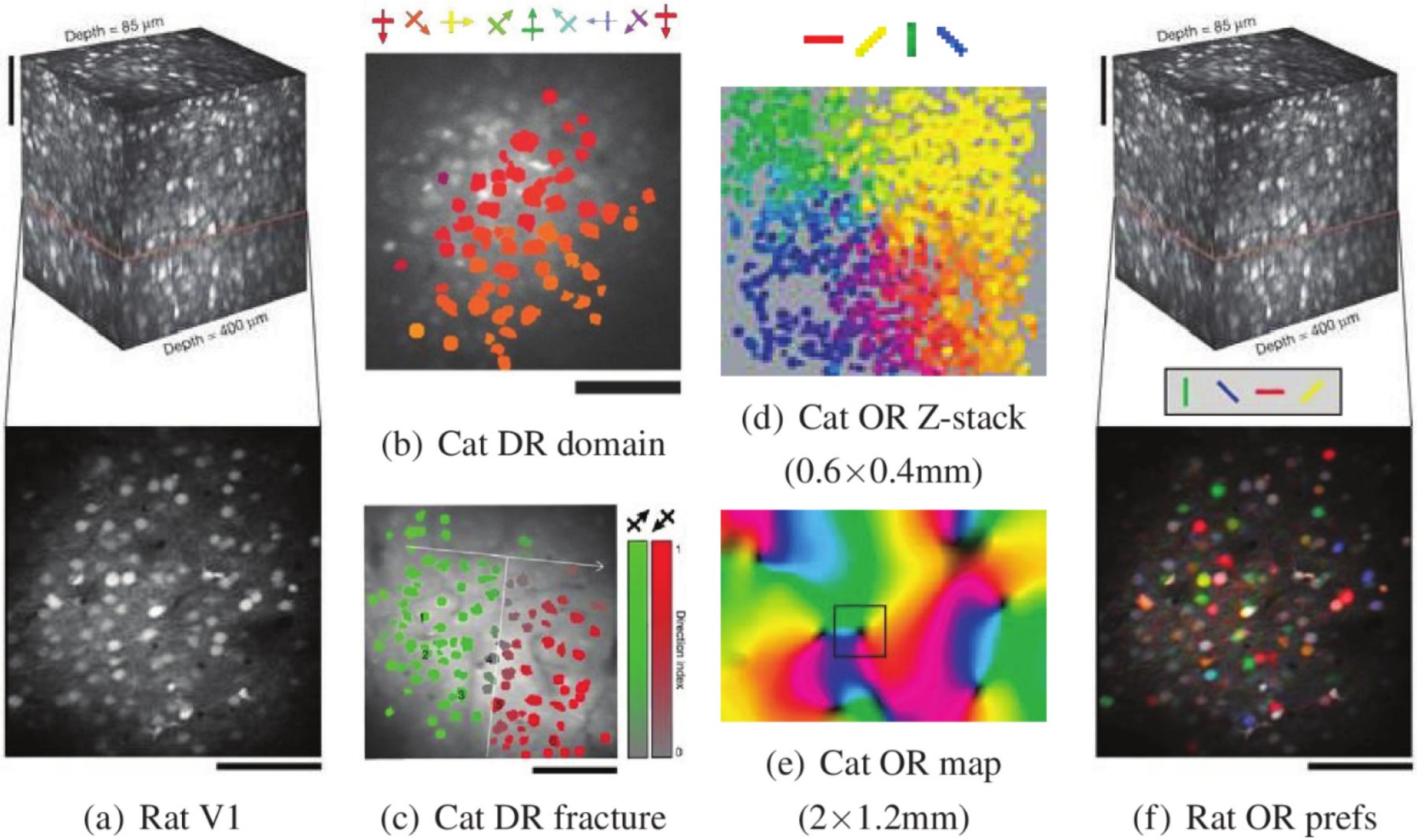




Visuotopic map: For a given fixation point (+), corresponding patches of cortical neurons respond to a visual stimulus.

Orientation map: Response depends on the local orientation of the pattern.

Single-cell organization of V1 feature maps



(a) Rat V1

(b) Cat DR domain

(c) Cat DR fracture

(d) Cat OR Z-stack (0.6×0.4mm)

(e) Cat OR map (2×1.2mm)

(f) Rat OR prefs

Maps are smooth down to single-cell level in cats (and primates).

Rodents have a retinotopic map, yet no smooth orientation map.

Questions to be addressed by modeling

In these lectures, we focus on the following four main questions:

Q1: How are topographic maps between neural regions established?

Q2: Why do feature maps have their observed patterns?

Q3: How do feature maps arise from neural mechanisms?

Q4: What is the information-processing goal of neurons in maps?

Each of these questions is typically addressed by very different types of models. Of those models, we focus on examples that are in current use yet are still relatively simple.

Types of map models (nonexclusive)

Phenomenological: Models designed to reproduce observed behavior, whether or not by the same mechanisms as the biological system

Geometrical: Phenomenological models of the topology or geometric structure of maps, not necessarily addressing individual neurons within

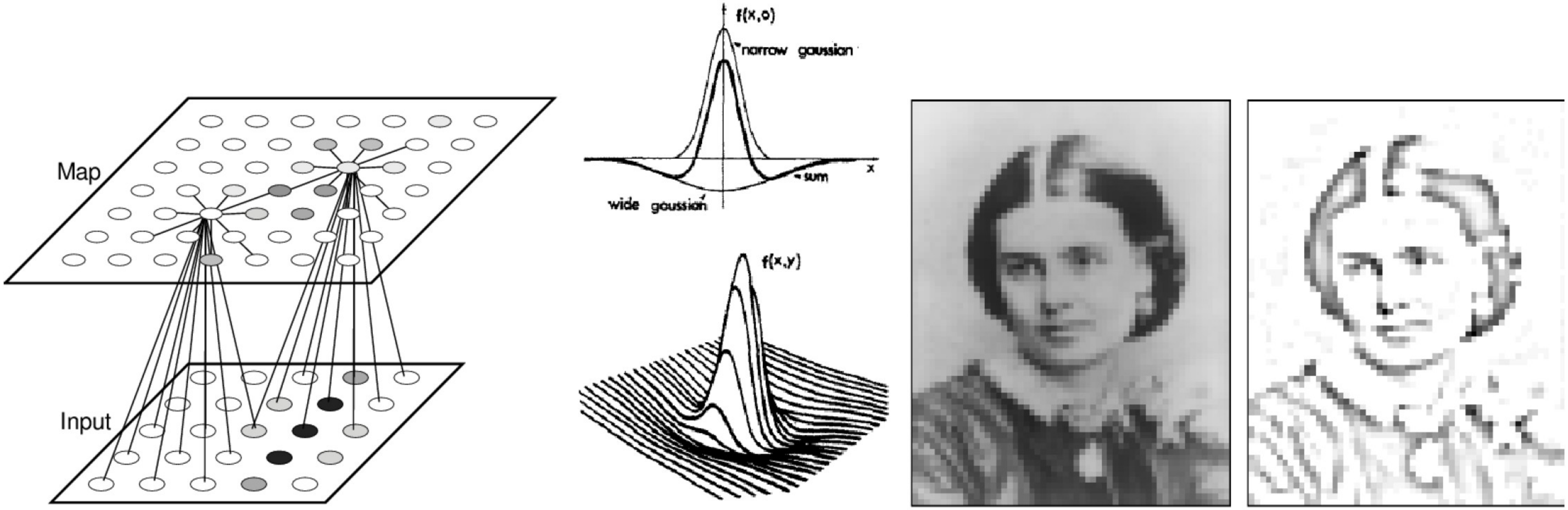
Mechanistic: Models with an explict isomorphism between model elements or mechanisms and the underlying neural hardware

Developmental: Models explaining emergence of adult-like circuitry from a simpler, younger starting point

Normative: Models derived not from observed neural elements or circuits, but from an explicit specification that the model should achieve a functional criterion

Generative: Normative models built with the specific objective of being able to faithfully regenerate the likely sensory input from the map's activity pattern.

Basic map model architecture



(a) Architecture (b) Receptive field (c) Sample input (d) Output

- Models map from (some portion of) an input sheet to each output neuron.
- Input units are weighted, e.g., by a difference of Gaussians if modelling retinal ganglion cells (RGCs) or the lateral geniculate nucleus (LGN).
- If all units have a DoG, the network does a parallel convolution, resulting in edge enhancement at a particular size scale.