The Visual system
part I

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Outline

- Eye
- Retina
- LGN
- Visual cortex
  - Structure
  - Response properties
  - Cortical processing
- Topographic maps large and small
  - Retinotopy
  - Ocular dominance
  - Orientation
  - Sharp map borders

A large part of the brain is dedicated for vision

The visual pathway

Eye ➔ Thalamus (LGN) ➔ Visual Cortex (V1) ➔ Higher cortical areas

Van Essen 1992
Flatlined primate brain
The visual pathway is very complicated…

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The eye

Fig. 1. View of the human eye

The eye
The eye

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The retina

2 kinds of photoreceptors: Rods and cones
Rods can detect very dim stimuli (>=1 photon!)

Cones come in 3 flavors
Some people and animals (cats&dogs) have only 2

High resolution vision by cones in the fovea

Retinal circuits

Photoreceptors release glutamate in dark
They STOP releasing glutamate in light

Light stimulates glutamate release in ON bipolar cells
Light reduces glutamate release in OFF bipolar cells

Ganglion cell
Responses of retinal ganglion cells

Kuffler 1950s

More variety for color!

Fig. 19. Color-opponent units as recorded in monkey retina by Gouras (1968).

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Lateral geniculate nucleus (LGN)

Primate LGN

6 layers

psi eye: 2 3 5
Contra eye: 1 4 6

Magnocellular (BW): 1 2
Parvocellular (color): 3 6
LGN responses (Hubel & Wiesel ~1960s)

LGN receptive fields mapped with white noise stimuli

Kanold et al

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The visual cortex

Line of Gennari: myelinated axons from LGN
The visual cortex

V1 has a large neuronal diversity

Stereotyped connections
I.e: Layer 4c cells project to layer 2/3

Stereotyped information flow through cortex

Douglas & Martin 2004
V1 responses I (Hubel & Wiesel ~1965)

V1 responses II (Hubel & Wiesel ~1965)

Orientation tuning: Simple and complex cells

Response types are distributed differently

Orientation tuning: Simple and complex cells

Response types are distributed differently
**Binocular interactions (ocular dominance)**

Hubel & Wiesel

**How to make simple and complex cells? Feed-forward model**

Hubel & Wiesel

**How do these responses arise?**

Problem: Only small fraction of synaptic inputs to layer 4 come from LGN

Binzegger et al 2004

**Simultaneous recordings in LGN and layer 4 reveal strong functional connections**

Reid & Alonso 1995
Divergence and convergence

Kara & Reid 2003

~3% of V1 spikes driven by single RGC!

Silencing intracortical processing does not affect orientation tuning in layer 4

Ferster 1996  Chung & Ferster 1998

Simultaneous recordings in layer 4 and layer 2 reveal functional connections

Alonso & Martinez 1998

Feed-forward model seems mostly correct!

Hubel & Wiesel

Simple cell

Complex cell
Direction selective cells
(~30% of V1 cells)

Hubel & Wiesel 1968 (of course… )

Direction selectivity mediated by cortical inhibition

Non preferred direction
Preferred direction

BM = GABA blocker

Murthy & Humphrey 1999

Hypercomplex cells: End stopping

Are these contour detectors?

Hubel & Wiesel

Parallel pathways

Ventral (Color)
- LGN parvo layer
- V1 layer 4Cb
- V1 blobs
- V2 thin stripes

Ventral (Form)
- LGN parvo layer
- V1 layer 4Cb
- V1 interblob
- V2 inter-strips
- V4, MT

Dorsal (motion & disparity)
- LGN magno layer
- V1 layer 4Ca
- V1 layer 4B
- V2 thick stripes
- MT
At higher levels (i.e. V4) cells respond to shapes.

Passupa hy & Conners 2001

V4 cell responding to concave curvature at the right.

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Topographic organization

Eye specific segregation
Topographic mapping

Retinotopic maps & magnification
Inputs from 2 eyes are organized into ocular dominance columns in V1

From Hubel & Wiesel

And now both eyes labeled...

Tagawa*, Kanold*, Majdan, Shatz, 2005

Optical imaging of orientation maps in vivo

Kanold et al 2003

Low resolution (50-100um) technique!

Ocular dominance and orientation columns
Hypercolumn

Imaging functional responses of many neurons with single cell resolution

Tuning in pinwheel centers is sharp
Direction tuning maps are sharp

Ohki et al. 2005

Summary

- Visual information is processed in multiple stages
- Visual receptive fields get more complex with subsequent processing stages
- Center/Surround at initial stages (retina, LGN), oriented bars etc in V1. Shapes in higher cortical areas.
- Within V1 receptive fields are more “complex” outside layer 4.
- Cells with similar receptive fields are organized in columns.
- Columnar tuning varies in an organized manner in many species (I.e. orientation maps in cat but NOT rat).

- How does this all get wired up?

LGN layers form by refinement of retinal projections

Penn et al. Science 1998

Ocular dominance columns form by refinement of thalamocortical projections

LeVay, Stryker, Shatz 1978

Cat visual cortex

Age

2 Weeks

6 Weeks

13 Weeks
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- How does this all get wired up? See part II on Thursday!