Introduction to Neuroscience: Systems Neuroscience

Central visual processes

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Low pass firing rate = BOLD fMRI

Non Invasive
Whole brain coverage
3X3 mm in 3T scanner
Electrophysiology

Micro-electrodes
1-10 neurons
Firing rate

Contacts
$10^4$-$10^6$ neurons
Broad band Gamma Power

Firing rate = amplitude of fast (Gamma) fluctuations

Spikes
LFP
Spikes/Gamma

Nir et al.
The Visual Pathway
The Human Visual System
Definitions:

retinotopy, visual field, contra-ipsi, fixation point, vertical meridian, Horizontal meridian
Flow of information form the eye to the brain

Optic nerve, chiasm, tract and radiation

Figure 8-11
This horizontal slice through the brain shows the visual pathway from each eye to region V1 of each hemisphere. Information from the blue side of the visual field goes to the two left halves of the retinas and ends up in the left hemisphere. Information from the red side of the visual field hits the right halves of the retinas and travels to the right side of the brain.
LGN- Relay and gating station

Magno (~ motion) and Parvo (~shape) pathways
Atlas of human visual areas
The Concept of a Receptive Field

Firing Rate

1 2 3...

Visual Patterns
“Tuning curve”

Sharply or narrowly tuned, selective

Visual Parameter
(e.g. retinal position)
Invariance: lack of sensitivity to changes in a visual property

Firing Rate

Visual Parameter
(e.g. retinal position)
Unfolded atlas of human visual areas
Human primary visual cortex
Visual Area 1- V1
The properties of single neurons in area V1

The combinatorial explosion problem:
The number of possible visual patterns is ultra-vast
The properties of single neurons in area V1

David Hubel and Torsten Wiesel
The properties of single neurons in area V1
Receptive field of a visual neuron in area V1

Text-fig. 2. Responses of a complex cell in right striate cortex (layer IV A) to various orientations of a moving black bar. Receptive field in the left eye indicated by the interrupted rectangles; it was approximately $\frac{1}{2} \times \frac{3}{8}$ in size, and was situated $4^\circ$ below and to the left of the point of fixation. Ocular-dominance group 4. Duration of each record, 2 sec. Background intensity $1.3 \log \text{cd/m}^2$, dark bars $0.0 \log \text{cd/m}^2$. 
Stimulus selectivity of receptive fields

Receptive field of a “Simple” cell in area V1

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.
The simple cell model

Convergence, threshold, synchrony
An “and” function
The cortex is organized in layers.
Text-fig. 20. Possible scheme for explaining the organization of complex receptive fields. A number of cells with simple fields, of which three are shown schematically, are imagined to project to a single cortical cell of higher order. Each projecting neurone has a receptive field arranged as shown to the left: an excitatory region to the left and an inhibitory region to the right of a vertical straight-line boundary. The boundaries of the fields are staggered within an area outlined by the interrupted lines. Any vertical-edge stimulus falling across this rectangle, regardless of its position, will excite some simple-field cells, leading to excitation of the higher-order cell.

Complex cells: the first step towards position invariance
An “or” function
Columns: common vertical specialization
Ocular Dominance Columns
Monkey Ocular Dominance Columns- top view
Orientation columns - top view

Orientation vs. OD
Orientation and ocular columns - the “hyper–column”
Lateral Connectivity

Important: columns smoothly merge into each other!
Lateral Connectivity: massive, local, reciprocal interactions

[Image of neural network with arrows indicating connections. Scale bar indicates 0.2 mm.]
Lateral Connectivity connects similar-function columns
Large scale organizational principles of V1

Log Topographical representations in the human visual system

Magnification factor: how many mm cortex correspond to a mm on the retina
Polar Retinotopic organization of visual cortex

WORLD

CORTEX

0°

TETA

90°

fovea

periphery

HM

VM

R

Polar Retinotopic organization of visual cortex
Metabolic mapping of retinotopy in V1
Center-Periphery organization
The Hierarchy principle
Growing “abstraction” along the visual hierarchy

- Increased complexity
- Increased RF size
Hierarchical representation: illustration

Simple, complex… “grand-mother” cells
Deep Learning learns layers of features
Large scale specialization
Two streams in the visual system
Complex templates at the top of the VENTRAL stream

“Face” neurons
Fusiform “Face” Area
Parahippocampal “Place” Area
Large scale principles: Category organization
Electrical stimulation of the fusiform face area
Columnar organization of complex shapes in high order Ventral Stream

Neurons in the temporal lobe form columns that respond to categories of shapes.
Face “Patches” are built of “face-neurons”

D. Tsao
Content-Selectivity in human visual cortex

Dorsal-stream (Action)
- Motion (MT/V5)

Ventral-stream (Recognition)
- Gestalt templates (IT/FFA)

Local elements
- V1

Dorsal Stream
- Ventral Stream

Hierarchy
- Specilization
  - V1
  - V2
  - V3
  - V4
  - V7

Gestalt templates
- IT/FFA

Dorsal-stream (Action)
- Motion (MT/V5)
Direction selectivity in area MT- Dorsal stream
Motion coherence and MT neurons

Motion stimulus

Responses of MT neurons

Preferred direction
Columnar organization for direction and orientation in area MT

Columnar architecture in MT
Cortical microstimulation influences perceptual judgements of motion direction

C. Daniel Salzman, Kenneth H. Britten & William T. Newsome*
Electrical stimulation of MT direction column- shifts perceptual judgment
Motion blindness following dorsal stream lesion
Action specialization in dorsal stream cortex
Action specialization in dorsal stream cortex

Figure 4. Task-Dependent Modulation: Object-Oriented Task versus Action-Oriented Task

Shmuelof and Zohary
Perceptual stability during eye movements
Direction selective MST neurons reflect perceptual stability during eye movements
Direction selective MST neurons reflect “error signal” during eye movements
Direction selective MST neurons reflect “error signal” during eye movements
Massive “Top-Down” connections along the visual hierarchy
Attention mediated by top-down connections

Moran and Desimone
Top down attention in the human visual system
Spatial ("spot-light") attention in early visual system
Template – selective attention in high order, ventral stream
Spatial attention is mediated via the right dorsal stream

Copies of a clock and a daisy

Visual Neglect following right parietal lobe lesion