Introduction to sensory pathways

Gatsby / SWC induction week
25 September 2017
Studying sensory systems: inputs and needs

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Modality</th>
<th>Robots' Sensors</th>
<th>Biological Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Vision</td>
<td>Photodiodes or</td>
<td>Photoreceptors in the retina</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CCD</td>
<td></td>
</tr>
<tr>
<td>Sound</td>
<td>Audition</td>
<td>Microphone</td>
<td>Hair cells in the cochlea</td>
</tr>
<tr>
<td>Pressure</td>
<td>Somatosensation</td>
<td>Pressure sensor</td>
<td>Cutaneous mechanoreceptor</td>
</tr>
<tr>
<td>Chemical</td>
<td>Smell and taste</td>
<td>Chemical sensor</td>
<td>Chemoreceptor</td>
</tr>
<tr>
<td>Gravity</td>
<td>Vestibular</td>
<td>Accelerometer</td>
<td>Hair cells in the vestibular labyrinth</td>
</tr>
</tbody>
</table>

- **Psychophysics**
- **Physical stimulus** → **Neuronal activity** → **Conscious perception**

- **Sensory physiology**

#### Brain (Arduino)

**Inputs** → **Outputs**
Overview: dealing with different types of input

Vision

Audition

Olfaction
Overview: dealing with different types of input
Introduction to the visual system

- Vision is one of the best studied systems in the brain
- The most important modality for us, and the most complex circuitry
- NOT a camera: the visual system solves the inverse problem
The retina: just a CCD?
Early visual processing: thalamic pathway
Primary visual cortex (V1) decomposes image into low-level features: bars with a specific orientation
Functional organisation of V1

Ocular dominance

Orientation columns

Color blobs

Effects of lesions in different locations

Defects in visual field of Left eye Right eye

1 2 3 4 5 6
Beyond V1: dorsal and ventral streams

- **Ventral “what” pathway**
  - Specialises in object recognition
  - Includes areas V1, V2, V4 and inferior temporal areas

- **Dorsal “where” pathway**
  - Specialises in object localisation
  - Includes V1, V2, V3, MT (V5), MST and inferior parietal cortex
  - Each functional area contains a full retinotopic map
Dorsal vs ventral: example

Motion perception in V5 (MT)

Perception of shapes in IT

Size invariance

Position invariance
Take-home messages from the visual system

- Retinotopic mapping: geometric placement of neurons follows organisation in the retina

- The processing hierarchy: lower order areas encode lower order features of the image. Higher order areas encode higher order features

- Receptive fields grow when you ascend the hierarchy

- The dorsal stream tells you “where”, the ventral stream tells you “what”
Overview: dealing with different types of data
Introduction to the auditory system

hammer, anvil and stirrup

16,000 hair cells
Hair cells: mechanoreceptors in the ear
Tonotopy in cochlear hair cells

**Onde propagée**
Amplitude des déplacements de la membrane basilaire en fonction de la fréquence.

**Tonotopic organisation**

**Tuning curves for cochlear hair cells**
The auditory pathways: structure and function

- Auditory information is much more transient than vision
- Picking up on small temporal differences is important
- Extensive subcortical structures implement much of this quickly before information has reached cortex
- Not one, but three pathways from cochlea to cortex
Sound localisation in the superior olive

Sound localisation based on intensity difference

Sound localisation based on time difference

IID: Interaural Intensity Difference
ITD: Interaural Time Difference
Auditory cortex

- Auditory cortex consists of multiple areas and maintains a tonotopic mapping.

- There are cells that respond to either ear (EE) and cells that respond to one ear, inhibited by the other (EI).

- Its function is more ambiguous than visual cortex. Does it predict future events?

Rummell et al. 2016, JNeurosci
Take home message for audition

• The auditory system retains tonotopic mapping

• A lot of auditory processing happens subcortically

• Sound localisation in the superior olive: structure serves computation
Overview: dealing with different types of input
Introduction to olfaction

- The olfactory system processes information about chemicals in the environment: a specific mix of chemicals constitutes an *odour*.

- Molecules bind to Olfactory Sensory Neurons in the nose.

- Given the complex mixture of chemicals, which odours are present?
Diversity in olfactory receptors

- Different olfactory sensory neurons have different kinds of receptors with different sensitivities to certain odours.
- Genes in humans and rodents code for 1000 different types of odourant receptors.
- Each neuron expresses only one kind of receptor.
The olfactory pathways
Take home messages olfaction

• There are 1000+ receptor types in the nose

• Glomeruli in the olfactory bulb get input from a specific type of olfactory sensory neuron

• The relative location of these different glomeruli is highly genetically preserved across species
Overview: dealing with different types of inputs

**Vision**
- Goal: reconstruct 3D world from 2D image
- Most complex system: mostly cortical processing
- Functional specialisation in *what* and *where*
- Retinotopic mapping

**Audition**
- Goals: identify and localise sounds, speech comprehension, etc.
- Timing is crucial: extensive subcortical processing
- Tonotopic mapping

**Olfaction**
- Goal: demix odours to identify source
- Direct connections from olfactory bulb to many areas
- Preserved spatial organisation of odours