Pathways to perception in 3 (or fewer) synaptic steps

0  Input through sensory organ/tissue
1  Synapse onto neurons in spinal cord/brain stem
2  Synapse onto neurons in thalamus
3  Synapse onto cortical neurons in “primary ____ cortex”
4  Further cortical processing

Touch/“Tactile”

Skin
Spinal cord
Dorsal horn
Thalamus
Ventral posterolateral (VPL) nucleus
Cortex
Post-central sulcus (SI)

Communications in the spinal cord

- Sensory activity in back – *dorsal*
- Motor command in front – *ventral*

Touch: Inputs

Mechanoreceptors in skin
- Pacinian corpuscles – vibrations
- Meissner’s corpuscles – light touch
- Merkel’s discs – pressure and texture
- Ruffini endings – stretch

Thalamus – the “relay” station

Region names largely based on location
VPL for somatosensation

Region names
- VPL for somatosensation
- Nucleus ventralis posterolateralis
- Nucleus ventralis anterior
- Nucleus ventralis medialis
- Nucleus medialis dorsalis
- Nucleus medialis lateralis
- Nucleus reuniens
- Ventralis intermediolateralis
- Ventralis lateralis
- Ventralis oralis

Hearing/“Auditory”

- Cochlea
- Cochlear nerve
- Cochlear nucleus (→ Superior olive) → Inferior colliculus
- Thalamus
- Medial geniculate nucleus (MGN)
- Brain stem
- Primary auditory cortex (AI)
- Cortex

Regions of the brainstem

- Dorsal view (back-of-the-head)
- 2-3 synapses in auditory brainstem path

Seeing/“Visual”

- Retina
- Optic nerve
- Thalamus
- Lateral geniculate nucleus (LGN)
- Cortex
- Primary visual cortex (VI)

Lateralization

- Flipping of right and left in vision
  - Left hemisphere – right visual field
  - Right hemisphere – left visual field

Sensitivity to perceptual variations

- V1: Surround-suppression for shifted edges
- PFC: Same object detected at diverse locations and scales

Selectivity to perceptual variations

- More complex percepts invariant to greater spatial transformations
HMAX – model of hierarchical vision

- Higher cortical levels cover larger visual spans
- Object recognition invariant to changes in location and orientation

Higher HMAX layers cover more space

Example coverage for layer \( x \) neurons

Functions of HMAX layers

- Odd layers (layer 1, 3, 5, ...) look for specific combinations of lower-level features
- Even layers (layer 2, 4, 6, ...) provide invariance to some feature changes (e.g., shift in position)

Estimating the max

- Earlier models: \( r_{out} = g(\sum_i w_i r_i) \)
- What if \( g() \) were log()?
  - \( \log(100+4+5) = \log(100) \)
  - \( \log(20+5+2) = \log(20) \)
- Logarithms in nature:
  - Sound with 100x greater magnitude sounds \( \sim 3x \) louder
  - Sigmoid function \( g(x)=1/(1+\exp(-x)) \) ... \( \exp \) is \( \log^-1 \)
Each combination layer “tiles” visual space

- Compute weighted sum (combination) at every location
- Called “convolution”

Visual attention
- Emphasize details currently of interest

Model of Attention/Recognition
- Find blob -> Focus on blob
- Match blob w/memory
- Inhibit blob

Attention when percepts overlap

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Attention when percepts overlap
- Attention to A dims effects of other inputs; ignoring bars dims their effects
- \[ h = \sum w_{ij} r_i a_i \]
- \( w \) – weight on input
- \( r \) – current strength of input
- \( a \) – attention to input

Attention when percepts overlap
- Can attend to one of two voices (e.g., high-pitched voice or low-pitched voice)
Modulating inputs through multiplication

Algorithm: “Sigma-Pi Node”
- Multiply rates to modulate each input
- Sum to compute output rate

\[ h_i = \sum_t w_i r_i^{\text{att}} r_i^{\text{in}} \]

- \( r_i^{\text{att}} \) - attention input
- \( r_i^{\text{att}} = \sum_j r_{ij}^{\text{att}} \) - can sum over multiple attention inputs

Dynamic synaptic reweighting

Voltage-dependent NT-receptors (e.g., NMDA):
1. Other nearby receptor decreases voltage
2. Voltage dependent receptor detects NTs

Dendrite input

- Pre-synaptic neuron spikes
- Neurotransmitter (NT) released
- NT received by post-synaptic dendrite at time \( t' \)
- Post-synaptic voltage rises and then fades, \( \alpha(t) \)

\[ I(t) = \sum_j w_j \alpha_j(t) \]

Complexity of cortical networks

- Feedback: connections in both directions along cortical “pathways”

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