CISC 3250 Systems Neuroscience

Perception

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JMH 332

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

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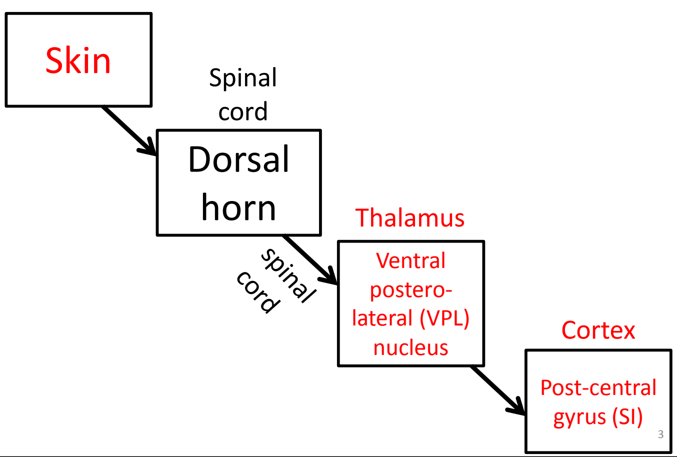
Touch/“Tactile”



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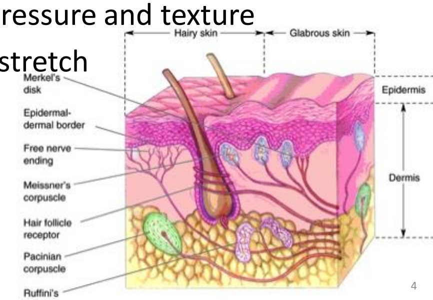
Touch: Inputs

Mechanoreceptors in skin

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



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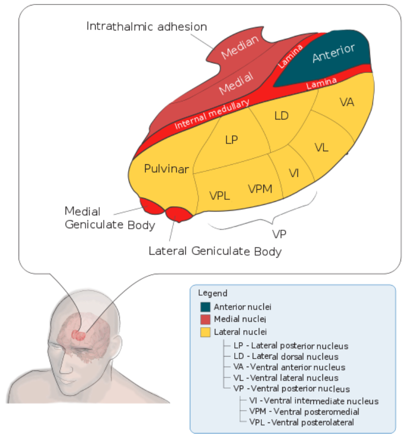
Thalamus – the "relay" station



Region names largely based on location

VPL for somatosensation

http://en.wikipedia.org/wiki/File:Thalamus-schematic.svg

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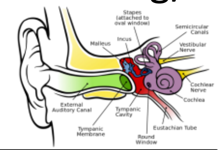
Hearing/"Auditory"



Cochlea

Cochlear nerve →

Cochlear nucleus (-> Superior olive) -> Inferior colliculus

Brain stem →

Thalamus

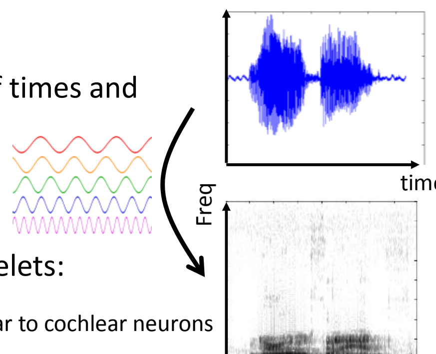
Medial geniculate nucleus (MGN) →

Cortex

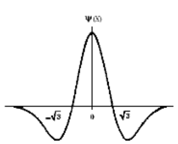
Primary auditory cortex (AI)

Hearing and frequency decomposition

Sound consists of times and frequencies



Time-bound wavelets:



"Mexican hat"

Similar to cochlear neurons

$$\frac{2}{\sqrt{3\sigma}\pi^{1/4}}\left(1-\left(\frac{t}{\sigma}\right)^2\right)e^{-\frac{t^2}{2\sigma^2}}$$

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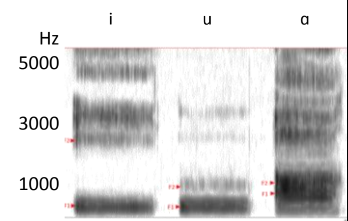
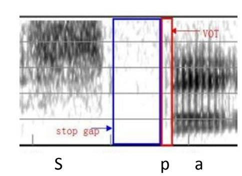
Common patterns in speech

- Vowels (a,e,i,o,u) correspond to steady frequency combinations



- Consonants may be broad-range frequencies, or sweeps



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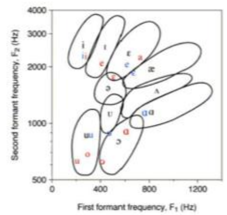
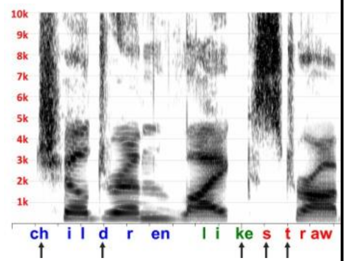
More speech pattern

- Speech formant ranges by frequency



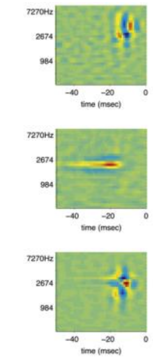
- ch, s – long high freq
- d, k, t – broad freq burst
- l, r, n, m – freq slide



Spectro-temporal receptive fields

AI (primary auditory cortex) neurons selective for patterns in space and time

Nagel 2008 Neuron
Zebra Finch (field L)



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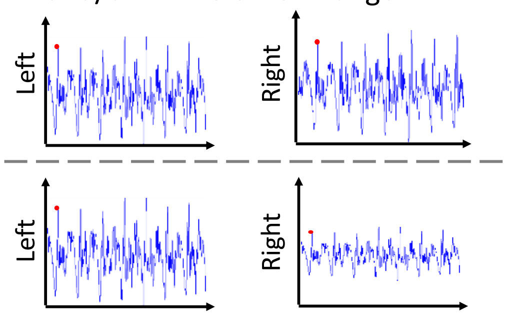
Binaural hearing

Comparing sounds from left and right

- Time shift and/or Volume Change



Applications:

- Localize sound source
- Distinguish sounds from multiple sources

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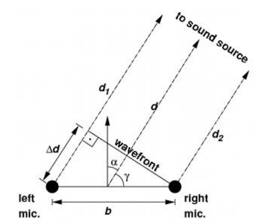
Math of sound localization



Speed of sound

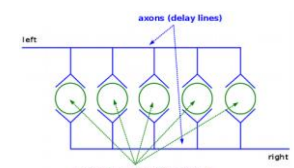
c=343 m/s

Human head

b=0.2m

$$\alpha = \sin^{-1}\frac{c\Delta t}{b}$$

Jeffres '48
sound delay/
axon delay model



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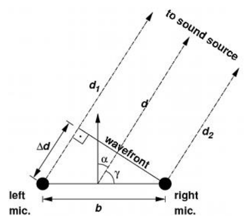
Math of sound localization



Speed of sound

c=343 m/s

Human head

b=0.2m

$$\alpha = \sin^{-1}\frac{c\Delta t}{b}$$

Pick direction for comparison

$$\Delta t = \begin{cases} > 0 & \text{rightSound earlier} \\ < 0 & \text{leftSound earlier} \end{cases}$$

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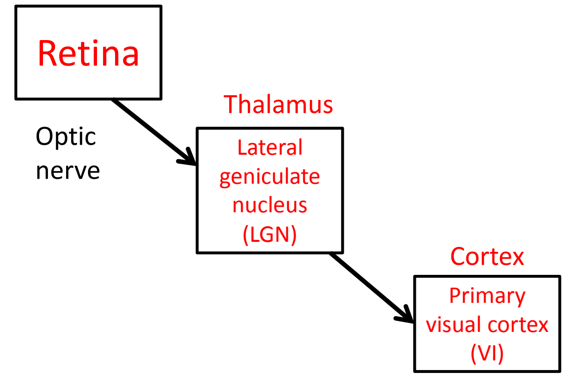
Seeing/“Visual”



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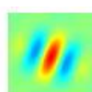
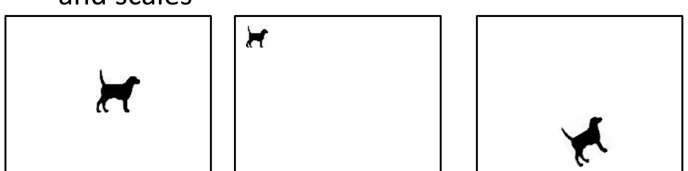
Sensitivity to perceptual variations

- V1: Surround-suppression for shifted edges



- PFC: Same object detected at diverse locations and scales



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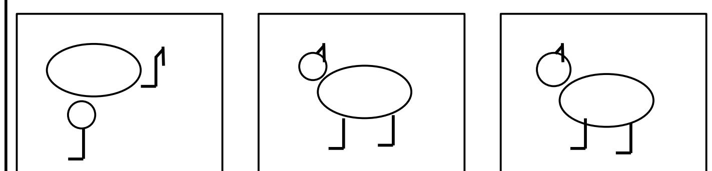
Selectivity to perceptual variations



- More complex percepts invariant to greater spatial transformations

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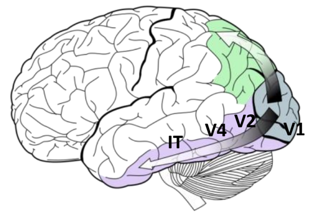
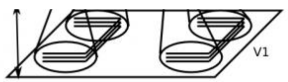
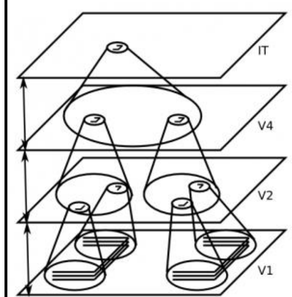
HMAX – model of hierarchical vision



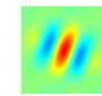


- Higher cortical levels cover larger visual spans
- Object recognition invariant to changes in location and orientation

HMAX – model of hierarchical vision

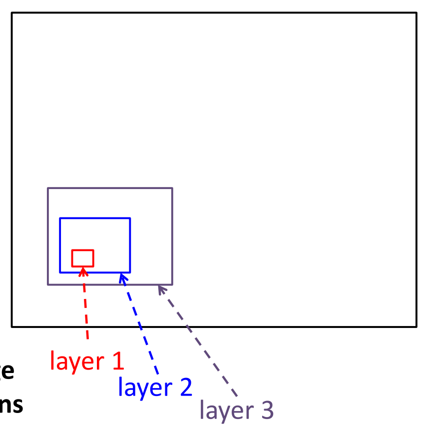


1. Gabor "filters" (edge detectors)



2. Perform "Max pooling" (semi-invariance over space)
3. Weighted combination of space-invariant edges
4. Further max pooling

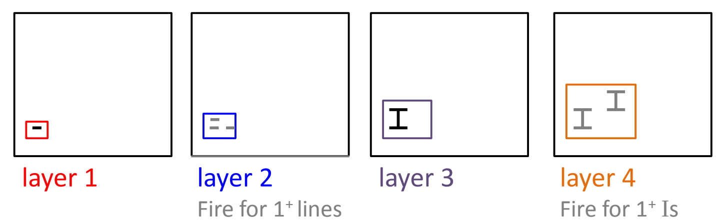
Higher HMAX layers cover more space



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)

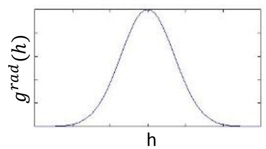


Functions of HMAX layers

- Odd layers (layer 1, 3, 5, …) look for specific combinations of lower-level features

$h=\sum_j w_j r_j^{in}$ $\quad r^{out} = g^{rad}(h)$

Radial basis function



- Even layers (layer 2, 4, 6, …) provide invariance to some feature changes (e.g., shift in position)

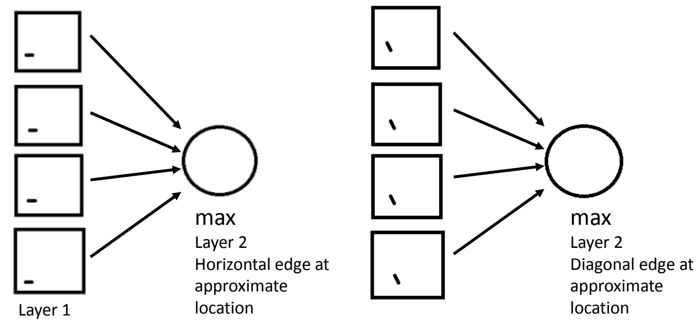
$$r^{out} = \max([r_1^{in} \quad r_2^{in} \quad \cdots \quad r_J^{in}])$$

Detecting triangles: layer 2

Neuron outputs 1 if desired image viewed, otherwise 0

Layer 1: Specific edge at specific location

Layer 2: Specific edge at slightly varied locations

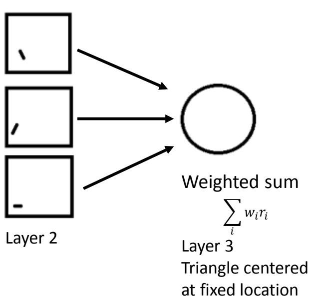


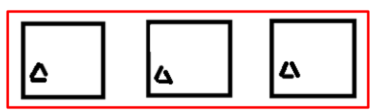
Detecting triangles: layer 3

Neuron outputs 1 if desired image viewed, otherwise 0

Layer 2: Specific edge at slightly varied locations

Layer 3: Combination of edges





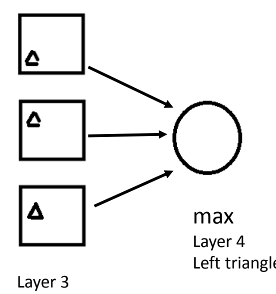
Accepted stimuli in layer 3 neuron

Detecting triangles: layer 4

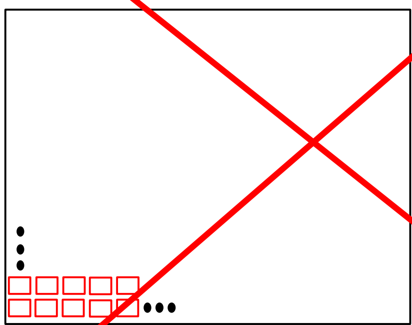
Neuron outputs 1 if desired image viewed, otherwise 0

Layer 3: Combination of edges

Layer 4: Triangle on the left



Each combination layer "tiles" visual space



Compute weighted sum (combination) at every location

Called "**convolution**"

Not covered in class

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Visual attention

- Emphasize details currently of interest

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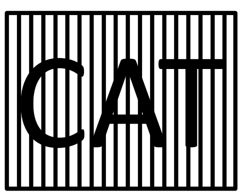
Attention when percepts overlap



$$h_i = \sum_i w_i r_i^{att} r_i^{in}$$

Cocktail party problem

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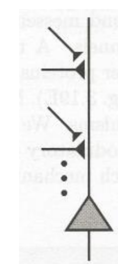
Modulating inputs through multiplication

Algorithm: "Sigma-Pi Node"

- Multiply rates to modulate each input
- Sum to compute output rate

$$h_i = \sum_i w_i a_i^{in} r_i^{in}$$



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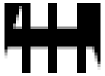


Attention when percepts overlap

Attention a

Ignore vertical edges: $a_{|}=0$

Pay attention to all other edges: $a_{-}=a_{/}=a_{\backslash}=1$

Rate r

If feature present: 1

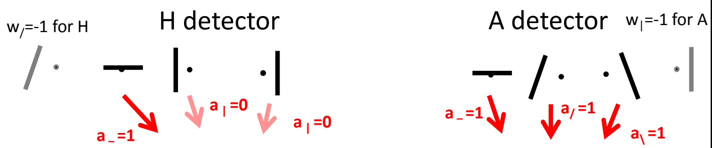
If feature not present: 0

In this example, |, –, /, \ present

Weights w

H-detector looks for | and – $w_{|}=w_{-}=1$ $w_{/}=w_{\backslash}=-1$

A-detectors looks for / , \ , – $w_{-}=w_{/}=w_{\backslash}=1$ $w_{|}=-1$



$\sum_i w_i a_i^{in} r_i^{in} = 0$ $\sum_i w_i a_i^{in} r_i^{in} = 3$

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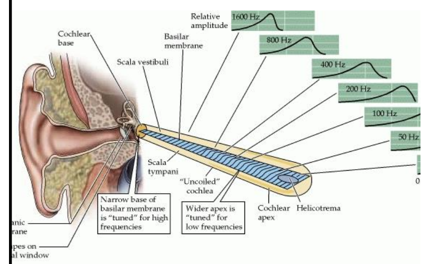
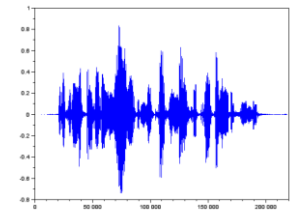
Attention when percepts overlap





Can attend to one of two voices (e.g, high-pitched voice or low-pitched voice)

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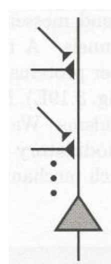
Modulating inputs through multiplication

Algorithm: "Sigma-Pi Node"

- Multiply rates to modulate each input
- Sum to compute output rate

$$h_i = \sum_i w_i a_i^{in} r_i^{in}$$



- a_i^{in} - attention input
  - $a_i^{in} = \sum_j r_{ij}^{att}$ - can sum over multiple attention inputs

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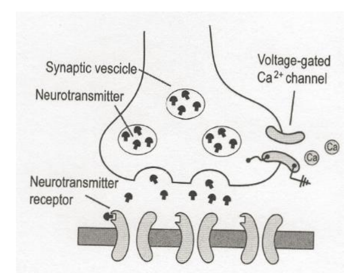
Dynamic synaptic reweighting

Voltage-dependent NT-receptors (e.g., NMDA):

1. Other nearby receptor decreases voltage
2. Voltage dependent receptor detects NTs



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Complexity of cortical networks

- *Feedback*: connections in both directions along cortical "pathways"