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

Types of percepts in this lecture:
- Tactile (touch)
- Audition (sound)
- Vision (sight)

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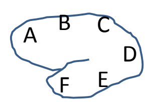
Touch/"Tactile"

Skin → Dorsal horn (Spinal cord) → Thalamus: Ventral postero-lateral (VPL) nucleus (spinal cord) → Cortex: Post-central gyrus (SI)



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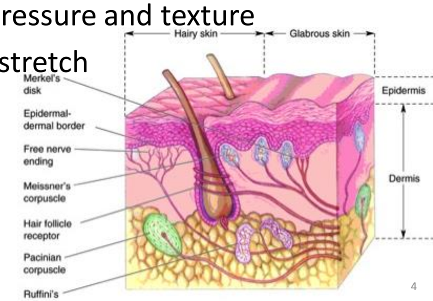
Touch: Inputs

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



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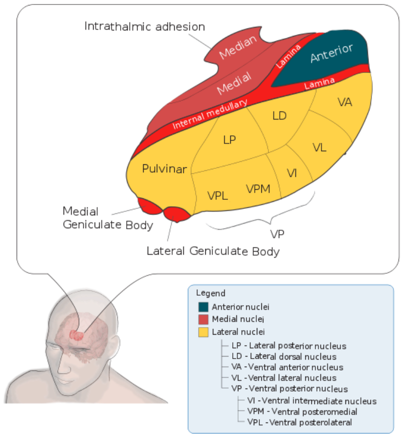
Thalamus – the "relay" station



Region names largely based on location

VPL for somatosensation

VPL =
Ventral (bottom)
Posterior (back)
Lateral (side) Nucleus

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

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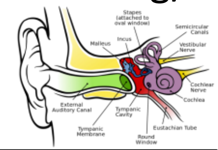
Hearing/"Auditory"



Cochlea

Cochlear nerve

Recall: in cochlea have tonotopy
Neurons selective for specific frequencies

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

Brain stem

Geniculate nuclei at most posterior ventral spots in thalamus

Thalamus

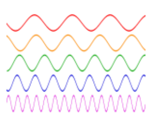
Medial geniculate nucleus (MGN)

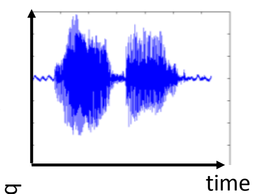
Cortex

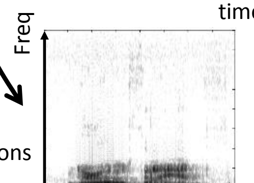
Primary auditory cortex (AI)

Hearing and frequency decomposition

Sound consists of times and frequencies

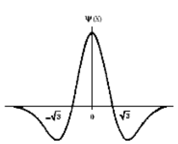






Spectrogram

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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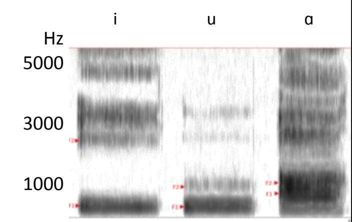
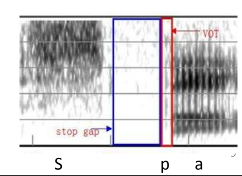
Common patterns in speech

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



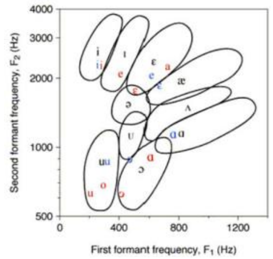
Top 2 freqs: i 300, 2500; u 300, 1000; ɑ 500, 1000

- Consonants may be broad-range frequencies, or sweeps

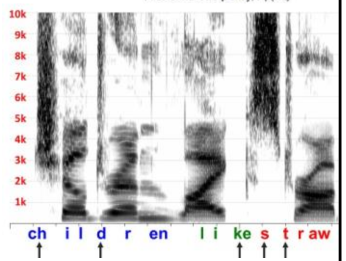


More speech pattern

- Speech **formant** ranges by frequency



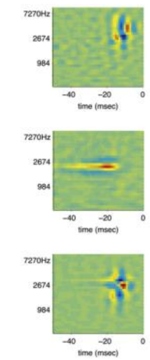
- ch, s – long high freq
- d, k, t – broad freq burst
- l, r, n, m – freq slide



Spectro-temporal receptive fields

Nagel 2008 Neuron
Zebra Finch (field L)

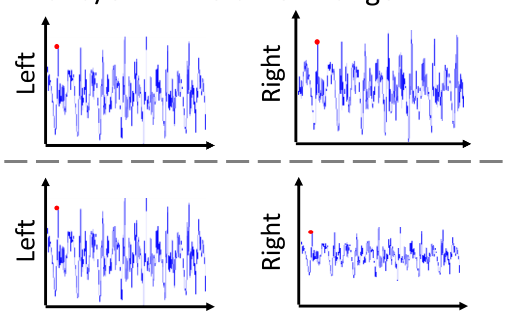
AI (primary auditory cortex) neurons selective for patterns in space and time



Binaural hearing

Comparing sounds from left and right

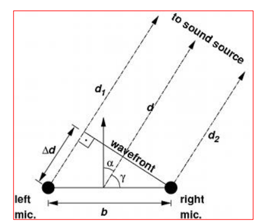
- Time shift and/or Volume Change



Applications:

- Localize sound source
- Distinguish sounds from multiple sources

Math of sound localization

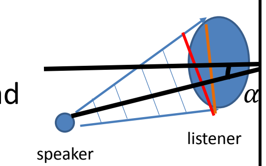


Speed of sound

c=343 m/s

Human head

b=0.2m

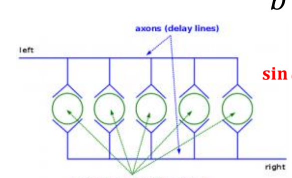


If Δt =5ms

$\boldsymbol{\Delta d}$=343x0.005 = 1.7m

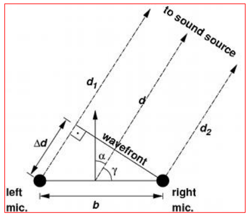
$$\alpha = \sin^{-1} \frac{c\Delta t}{b}$$

Jeffres '48
sound delay/
axon delay model



$$\sin\alpha = \frac{opposite}{hypotenuse} = \frac{\Delta d}{b}$$

Math of sound localization



Speed of sound

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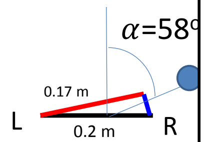


If Δt =**0.5ms**

$\boldsymbol{\Delta d}$=343x0.0005 = 0.17m

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

$$\mathbf{\sin\alpha = \frac{0.17}{0.2} = 0.85}$$

$$\boldsymbol{\alpha = \sin^{-1}0.85}$$

$$\boldsymbol{\alpha = 58^o}$$

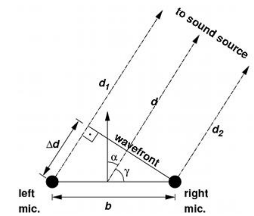
90º = 1.57 rad ($\frac{\pi}{2}$ rad)

x radians: $\frac{90x}{1.57} \approx \frac{360x}{2\pi}$ degrees

Sound gets R ear @ 1345.**2** ms

to L ear @ 1345.**7** ms

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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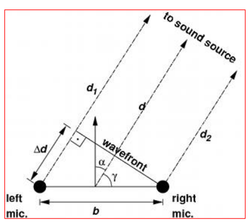
Math of sound localization



Speed of sound

c=343 m/s

Human head

b=0.2m

x radians: $\frac{90x}{1.57} \approx \frac{360x}{2\pi}$ degrees

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

Sound gets R ear @ ~~258.5 ms~~ **285.5ms**

Get to L ear @ 285.3 ms

Which ear is sound closest to?

The ear that sound arrives at first

Ear with smaller time of arrival

$$\boldsymbol{\Delta d = c\Delta t = 343 \times (0.2855 - 0.2853)}$$

$$\boldsymbol{\sin\alpha = \frac{\Delta d}{b} = \frac{343 \times 0.0002}{0.2} = \frac{.0686}{0.2} = 0.35}$$

What's my α?

Closer to L ear

$$\boldsymbol{\alpha = asin(0.35) = 20^o}$$

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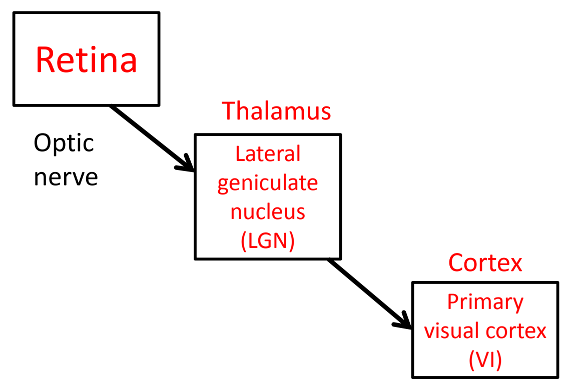
Seeing/"Visual"



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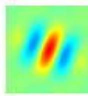
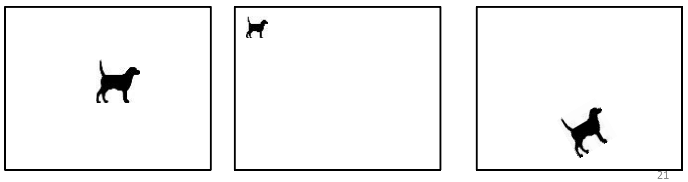
Sensitivity to perceptual variations

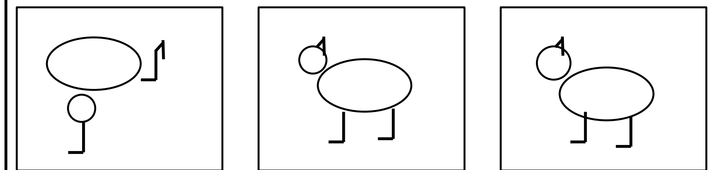
- V1: Surround-suppression for shifted edges



- PFC: Same object detected at diverse locations and scales

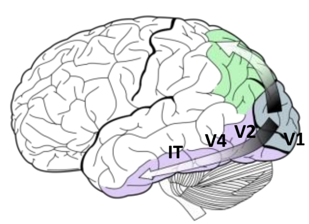


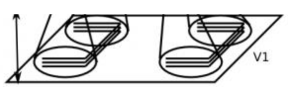
Selectivity to perceptual variations



- More complex percepts invariant to greater spatial transformations

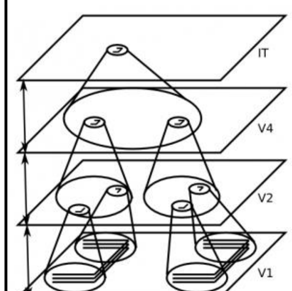
HMAX – model of hierarchical vision



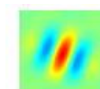


- Higher cortical levels cover larger visual spans
- Object recognition invariant to changes in location and orientation

HMAX – model of hierarchical vision

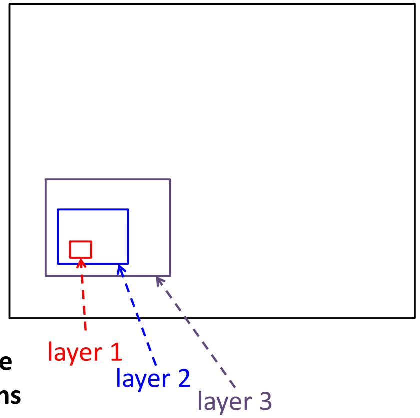


1. Gabor “filters” (edge detectors)



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

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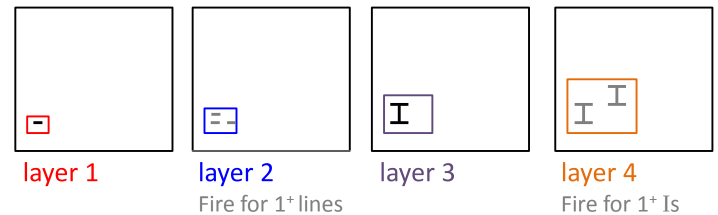
Functions of HMAX layers

- 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)



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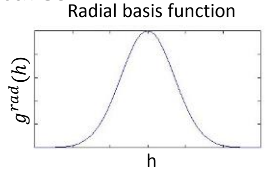
Functions of HMAX layers

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

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



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

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

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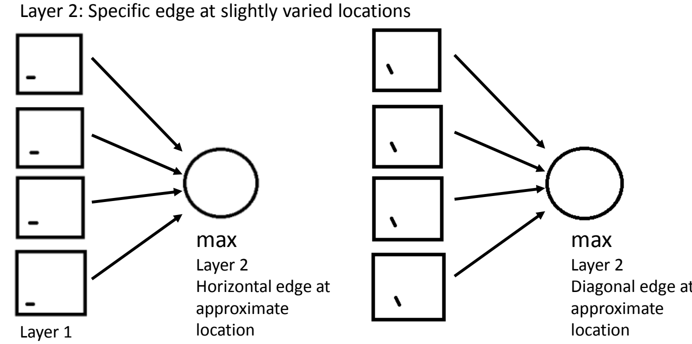
Detecting triangles: layer 2

Neuron outputs 1 if desired image viewed, otherwise 0

Layer 1: Specific edge at specific location

Layer 2: Specific edge at slightly varied locations



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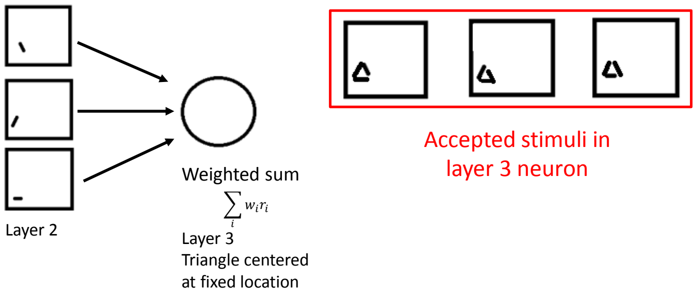
Detecting triangles: layer 3

Neuron outputs 1 if desired image viewed, otherwise 0

Layer 2: Specific edge at slightly varied locations

Layer 3: Combination of edges



Detecting triangles: layer 4

Neuron outputs 1 if desired image viewed, otherwise 0

Layer 3: Combination of edges

Layer 4: Triangle on the left