# CISC 3250
# Systems Neuroscience

## Representations in the brain

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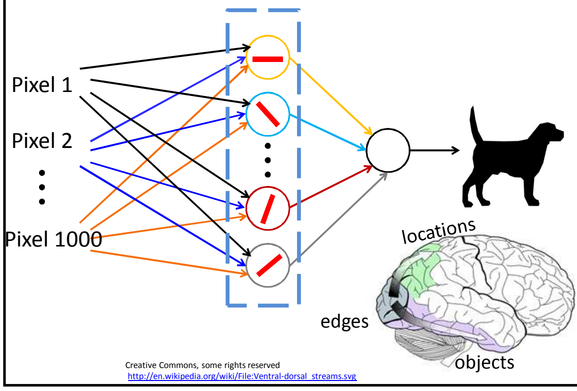
## Feed-forward network

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http://en.wikipedia.org/wiki/File:Ventral-dorsal_streams.svg

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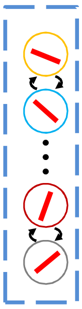
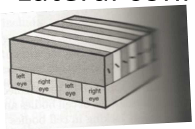
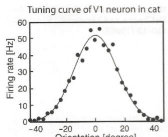
## Lateral connections






Nearby neurons respond to similar features

Neuron can respond slightly less to features slightly deviant from maximum preference




Henry et al., *J Neurophys* 1974.

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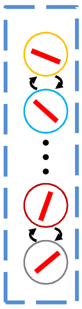
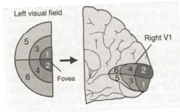
local inhibition – local competition

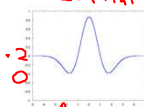
## Lateral connections: surround suppresion



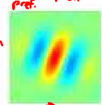



Nearby neurons respond to similar features

"wavelet" Mexican hat




Neuron can have suppressed response for features deviant from maximum preference




Gabor function

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## Classes of representation

Local representation

- Neural level: "grandmother" cell
- "Region" level: face region, place region

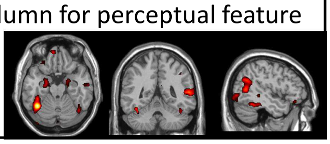
Fully distributed representation

- Every neuron/region plays a part

See Pres Obama recall voice, emotions/opinion, motor voting

Sparsely-distributed representation

- Neural level: hyper-column for perceptual feature
- "Region" level: face network



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## Principles of information coding

How many things can we represent with $n$ binary ($g^{step}$ activation function) neurons?

- Complete sparse coding: n things

● firing
○ not firing

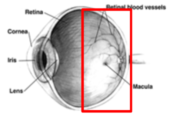
| | |
|---|---|
| ●○○ | banana |
| ○●○ | apple |
| ○○● | pear |

- Complete distributed coding: $2^n$ things

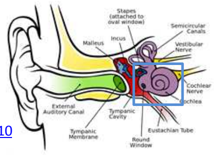
| | |
|---|---|
| ●○○ | banana |
| ●●○ | orange |
| ●○● | lime |
| ●●● | blueberry |
| ○●○ | apple |
| ○●● | lemon |
| ○○● | pear |
| ○○○ | grape |

## Biology of information coding

- Preserving energy – higher spiking rate requires higher energy
- Representational fan-out
  - ~1 million neurons in retina -> ~140 million neurons in V1 (primary visual cortex)



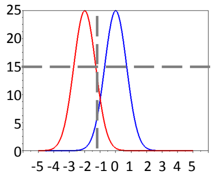

  - ~50,000 neurons in cochlea -> 1.6 million neurons in A1 (primary auditory cortex)




http://www.plosbiology.org/article/info:doi/10.1371/journal.pbio.0030137

## Decoding with tuning curves

Use spiking rates from multiple neurons to determine encoded feature




- 15 Hz firing rate for red neuron means feature -2.8 or -1.2
- 15 Hz for red and 6 Hz for blue requires feature -1.2

Actual decoding incorporates noise/natural variability in spiking

## Decoding by "population coding"

Each neuron votes for its most-preferred feature

- $\hat{s}_{dir} = \sum_i r_i s_i^{pref}$

r – spiking rate
s – encoded feature

"Normalized" firing rate

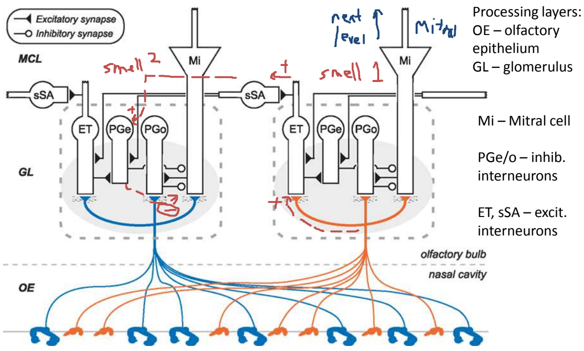
- $\hat{r}_i = \frac{r_i - r_i^{min}}{r_i^{max}}$
- $\hat{s}_{pop} = \sum_i \frac{\hat{r}_i}{\sum_j \hat{r}_j} s_i^{pref}$

Used in neural prosthetic technologies

## Suppression/competition with interneurons

- In common cortical circuits, there are feedforward excitatory inputs (e.g., through pyramidal or mitral neurons) and lateral inhibitory inputs (e.g., through types of interneurons)
- Relative weighting of feedforward and lateral inputs achieves balance between activation and suppression

## The neuroscience of smell: example inhibition with interneurons




Processing layers:
OE – olfactory epithelium
GL – glomerulus

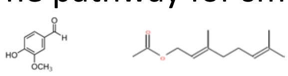
Mi – Mitral cell

PGe/o – inhib. interneurons

ET, sSA – excit. interneurons

Imam et al. Frontiers Neurosci 2012

## The pathway for smell processing

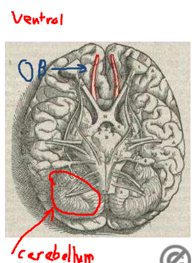



vanilla rose

Nose/olfactory epithelium → Olfactory bulb (in cortex) → Orbitofrontal cortex; Amygdala; Hippocampus

Chemical shape detection

limbic emotion

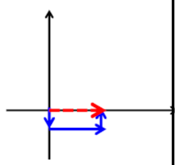


## Population coding to find direction of motion

Non-normalized population coding

- $\hat{s}_{dir} = \sum_i r_i s_i^{pref}$

| r | 1 | 4 | 1 | 0 |
|---|---|---|---|---|
| | ↓ | → | ↑ | ← |
| $s^{pref}$ $\begin{bmatrix} x \\ y \end{bmatrix}$ | $\begin{bmatrix} 0 \\ -1 \end{bmatrix}$ | $\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ | $\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ | $\begin{bmatrix} -1 \\ 0 \end{bmatrix}$ |



$$\begin{bmatrix} x \\ y \end{bmatrix} = 1\begin{bmatrix} 0 \\ -1 \end{bmatrix} + 4\begin{bmatrix} 1 \\ 0 \end{bmatrix} + 1\begin{bmatrix} 0 \\ 1 \end{bmatrix} + 0\begin{bmatrix} -1 \\ 0 \end{bmatrix} = \begin{bmatrix} 4 \\ 0 \end{bmatrix}$$

## Population coding to find direction of motion

"Normalized" firing rate

- $\hat{r}_i = \frac{r_i - r_i^{min}}{r_i^{max}}$

If $r^{min} = 1$, $r^{max} = 6$ for →
Then $\hat{r} = \frac{4-1}{6} = \frac{3}{6} = 0.5$

Normalized $\hat{r}$ will always be between 0 and 1

| r | 4 |
|---|---|
| | → |
| $s^{pref}$ $\begin{bmatrix} x \\ y \end{bmatrix}$ | $\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ |

## Population coding to find direction of motion

"Normalized" pop'n coding

For $\hat{s}_{pop}$, divide normalized rate by sum of all rates in neural population: $\sum_j \hat{r}_j$

- $\hat{s}_{pop} = \sum_i \frac{\hat{r}_i}{\sum_j \hat{r}_j} s_i^{pref}$

| $\hat{r}$ | 0.05 | 0.5 | 0.05 | 0 |
|---|---|---|---|---|
| | ↓ | → | ↑ | ← |
| $s^{pref}$ $\begin{bmatrix} x \\ y \end{bmatrix}$ | $\begin{bmatrix} 0 \\ -1 \end{bmatrix}$ | $\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ | $\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ | $\begin{bmatrix} -1 \\ 0 \end{bmatrix}$ |

$$\sum_j \hat{r}_j = 0.05 + 0.5 + 0.05 + 0 = 0.6$$

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{0.05}{0.6}\begin{bmatrix} 0 \\ -1 \end{bmatrix} + \frac{0.5}{0.6}\begin{bmatrix} 1 \\ 0 \end{bmatrix} + \frac{0.05}{0.6}\begin{bmatrix} 0 \\ 1 \end{bmatrix} + 0\begin{bmatrix} -1 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.83 \\ 0 \end{bmatrix}$$

Find most-favored motion direction, do no[t] amplify motion distanc[e]