Tuning tuning curves

So far:
Receptive fields
Representation of stimuli
Population vectors

Today: Contrast enhancement, cortical processing
$s_{\text{max}}(N_1) = 40^\circ$

$s_{\text{max}}(N_2) = 110^\circ$

$s_{\text{max}}(N_3) = 135^\circ$

$s_{\text{max}}(N_4) = 180^\circ$

$s_{\text{max}}(N_5) = 230^\circ$
s_{\text{max}}(N_1) = 40^\circ
s_{\text{max}}(N_2) = 110^\circ
s_{\text{max}}(N_3) = 135^\circ
s_{\text{max}}(N_4) = 180^\circ
s_{\text{max}}(N_5) = 230^\circ
In many sensory systems, the tuning curves of neurons are not identical to the receptive fields projected to these neurons by sensory neurons. They may be more narrow, include inhibitory parts of the curve, they may be wider or more separated from each other. There are a number of processes that “tune” tuning curves, these include interactions between neurons such as inhibition, excitation and feedback interactions. As we noted before, sensory receptive fields are often broad and relatively non-specific, for example frequency tuning curves in the auditory nerve can span a large range of frequencies.
Fig. 10. Center-surround receptive fields can be ON center or OFF center with the opposite sign annular surround.

Lateral inhibition

Strong response when center is bright, surround is dark.

Stimulus
FIG. 3.15 Diagrammatic representation of the direct (solid lines) and indirect (dashed lines) inputs to a bipolar cell from receptors and horizontal cells. Note that the direct and indirect paths have opposite effects on the bipolar cell.
N1 = 20-50 = -30 (=0)
N2 = 50 – 20 – 10 = 20
N3 = 10-50 = -40 (=0)
Exercise: Assuming linear interactions and all synaptic weights being zero, construct the approximate resulting receptive fields for these neurons and this network:

Excitatory neurons N1, N2, N3

Inhibitory neurons I1, I2, I3

for all neurons: $x = in$

for all synapses: $w = -1$
Exercise: Look at the recordings below. Think about what you could learn from these and what additional information you would need to get useful information from this experiment.
Because of broad receptive fields and tuning curves, neural circuits are thought to enhance “contrast” or increase the difference between sensory stimuli in order to make them more easily recognizable, their features more salient, more distinguishable from each other.

**Exercise:** (a) You have a number of chairs and a number of tables. List features these have in common. Now list features that differentiate them. Write a list of yes no questions that would allow you to decide (i) if an object does belong to either category and (ii) if it is a chair or a table. Now find some examples that would not easily be classified. Create a neural network with a layer of feature detectors (respond to a specific feature), a layer of inhibitory neurons and one or two more layers of neurons including a layer of output neurons. At the output, you want to know if the object you detect is a chair or a table. Think about which features you want to suppress (inhibit) and which you want to have compete against each other.
Exercise: (a) You have a number of chairs and a number of tables.

List features these have in common.

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<table>
<thead>
<tr>
<th># of carbons</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>U3</td>
<td>U4</td>
</tr>
<tr>
<td>U4</td>
<td>U3</td>
</tr>
</tbody>
</table>

Dot product $\vec{A} \cdot \vec{B} = |A| \cdot |B| \cdot \cos(\alpha)$

Distance: $D = \sqrt{(U3 - U4)^2}$

(5)< (4)< (5)< (6)
How to compare vectors
$$D = \sqrt{(U3 - U4)^2}$$

$$(5)-(4) < (4)(5) < (5)(6)$$

$$\text{Dot product } \mathbf{A} \cdot \mathbf{B} = |\mathbf{A}| \cdot |\mathbf{B}| \cdot \cos(\alpha)$$
Exercise: What happens to the distance measure and dot product measure if the vectors are “normalized” first (this means they all have length 1.0 and span the unit circle).
Photoreceptors in eye
Auditory receptors in cochlea
Olfactory receptors in nose
Other retinal neurons
Brain stem neurons
Auditory receptors in cochlea
Olfactory bulb
Olfactory receptors in nose
Acetylcholine
Noradrenaline
Serotonin
Dopamine
Peptides ....
I. Molecular Layer
II. External Granular Layer
III. External Pyramidal Layer
   \textit{Line of Kaes-Bechterew}
IV. Internal Granular Layer
   \textit{Outer band of Baillarger}
   \textit{- Line of Gennari in area 17}
V. Internal Pyramidal Layer
   Giant pyramidal cell of Betz
   \textit{Inner Band of Baillarger}
VI. Polymorphic Layer
Pyramidal cell

Cell body
Piriform cortex circuitry

Afferent Input from OB mitral cells (LOT)

Ia

Ib

II

III

Association Fibers

afferent input from olfactory bulb
association fibers from other pyramidal cells

output

cell body layer

Haberly, L.B. Chem. Senses, 10: 219 -38
(1985)
Piriform cortex circuitry

Afferent Input from OB mitral cells (LOT)

Ia

Ib

II

III

Association Fibers

afferent input from olfactory bulb

association fibers from other pyramidal cells

cell body layer

depth interneurons

output

Piriform cortex circuitry

Afferent Input from OB mitral cells (LOT)

Ia

Ib

II

III

Association Fibers

output

afferent input from olfactory bulb

association fibers from other pyramidal cells

cell body layer

deep interneurons

Feedforward interneurons

Feedback interneurons

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Piriform cortex circuitry

Afferent Input from OB mitral cells (LOT)

Ia

Ib

II

III

Association Fibers

output

afferent input from olfactory bulb
association fibers from other pyramidal cells
cell body layer
deep interneurons

Feedforward interneurons
Feedback interneurons

Neuromodulatory inputs
Other association fiber inputs

Layer II (cell bodies)
Layer Ib
Layer Ia
Stimulus: citronellal

Activity pattern across mitral cells

Activity pattern across pyramidal cells
Stimulus: citronellal

- Activity pattern across mitral cells
- Feedforward inhibition
- Activity pattern across pyramidal cells
Stimulus: citronellal

activity pattern across mitral cells

feedforward inhibition

association fibers between pyramidal cells

activity pattern across pyramidal cells
\[ x_{sj} = \cos(\alpha - \text{offset}_j) \text{ when } \cos(\alpha - \text{offset}_j) \geq \theta \]

and

\[ X_{sj} = 0.0 \text{ when } \cos(\alpha - \text{offset}_j) < \theta \]

where \( \text{offset}_j = 0, -30, -60, -90 \) and -120.
\[ I_{pj} = x_{sj}; \quad I_{ij} = x_{sj} \]
\[ x_{pj} = I_{pj} \quad \text{and} \quad x_{ij} = I_{ij} \quad \text{if} \quad I > \theta \quad \text{and} \quad x_{pj} = 0 \quad \text{and} \quad x_{ij} = 0 \quad \text{if} \quad I < \theta. \]
Exercise. Lets work through an example[1] to get used to writing and reading equations.
1) We will start by constructing a network of neurons in motor cortex receiving inputs from presynaptic neurons s with the following tuning curves as a function of the angle $\alpha$ of arm movement and $\alpha$ threshold $\theta$: $x_{sj} = F(\cos(\alpha - \text{offset}_j), \theta)$ where $\text{offset}_j = 0, -30, -60, -90$ and -120.

Now, we will create 10 postsynaptic neurons (5 excitatory pyramidal cells and 5 inhibitory local interneurons), each receiving presynaptic neurons, assuming all synaptic weights $w = 1$:
$I_{pj} = x_{sj}; I_{inj} = x_{sj}$ with $I_{pj}$ being the input to pyramidal cell $j$ and $I_{ij}$ the input to interneuron $j$. These are linear threshold neurons with continuous output for now, so $x_{pj} = I_{pj}$ and $x_{ij} = I_{inj}$ if $I > \theta$ and $x = 0$ and $x_{ij} = 0$ if $I < \theta$. In vector notation:

[1] Notations: I: input to a neuron; x: output from a neuron; j: neuron index; $\theta$: threshold; $\alpha$: movement angle; s: sensory neuron; p: pyramidal neuron; in: interneuron.
\[ I_{pj} = x_{sj} - x_{i(j-1)} - x_{i(j+1)} \]
$l_{pj} = x_{sj} - x_{i(j-1)} - x_{i(j+1)} + 0.5*x_{pj}$
\[ l_{pj} = x_{sj} - x_{i(j-1)} - x_{i(j+1)} + 0.5*F(l_{pj}, \Theta^2) \]
\[ l_{pj} = x_{sj} - x_{i(j-1)} - x_{i(j+1)} + 0.5F(l_{pj}, \Theta^2) + \text{SUM}_{k \neq j}(w_{jk} * x_{pk}) \]
\[ \text{prob} \ (x_{jp} = 1.0) = F \ (I_{jp}, \ \theta) \]
prob \( x_{jp} = 1.0 \) = \( F(I_{jp}, \theta) \)

\[ X = F(I, \theta) \text{ linear threshold function} \]

\[ X = 0 \text{ if } I \leq \theta \]
\[ X = I \text{ if } I > \theta \]

\[
\begin{align*}
\text{Prob} (x=1) &= 0 \text{ if } I \leq \theta \\
\text{Prob} (x=1) &= I \text{ if } I > \theta
\end{align*}
\]
\[ \text{prob} (x_{jp} = 1.0) = F (I_{jp}, \theta) \]

\[ \text{Prob} (x=1) = 0 \text{ if } I \leq \theta \]
\[ \text{Prob} (x=1) = I \text{ if } I > \theta \]

\[ \Theta = 0.0; \ I = 0.1 \rightarrow p = 0.1 \]
\[ \Theta = 0.0; \ I = 0.9 \rightarrow p = 0.9 \]

*On average, one spike every 10 time steps*  
*On average, nine spikes every 10 time steps*
Sensory neurons
Local interneurons
Pyramidal cells

\[ \alpha = -100 \]
\[ \alpha = 50 \]