Lesson 7.
How sensory codes become knowledge about real things
Hermann Munk (1878)
“Über die Funktionen der Grosshirnrinde”
“On the functions of the cerebral cortex”

blindness; stumbling into objects

vision conserved; loss of “visual memory” (agnosia)
Ian Whitfield (1979)
“The Object of Sensory Cortex”

• based on 100 yrs of neuroscience -- after ablation of sensory and association regions of cerebral cortex, animals can still perform many forms of sensory discrimination.

• cortical ablation ≠ deficit whenever behavioral task requires the elemental sensory signals to assume meaning according to previous experience.

• intracortical processing transforms mere physical data into the perception of things that are “out there” (Whitfield, p. 146) in the world.
predominant characteristic of things that are “out there” in the world is that we know them through multiple modalities
**ALL** sensory pathways from cerebral cortex converge in hippocampus, allowing this organ to combine information to create memories (even instantaneous “snapshots”): the “who, what, where, why, when” of episodic memory.
hippocampus Greek for “seahorse”
microelectrodes implanted in human epilepsy patient
knowledge of the world, as reflected in human hippocampus
Halle Berry
Quiroga et al. (2010)
the “who, what, **where**, why, when” of episodic memory.
Remember we are NOT claiming that the firing of one neuron by itself generates a conscious experience. The studied neuron is one of thousands of active neurons.

This neuron is a member of two populations – that correlated with Elvis Presley and with Ronald Reagan.
Rodrigo Quian Quiroga
Leicester, UK & Trieste
The Jennifer Aniston Cell

Can a single neuron embody a single concept? Dr. Rodrigo Quiroga describes his surprising new research into neuroscience.

Tuesday
Feb 28th
7.30pm
Free Entry
more evidence

Human single-neuron responses at the threshold of conscious recognition

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Fig. 1. Raster plots and peristimulus time histograms (PSTH) (100-ms bin size) of a single neuron in the right hippocampus that responded selectively to a picture of the patient’s brother. Pictures are covered for privacy. The different presentation durations are shown with the light red bars at the bottom of the PSTH plots. Trials where the pictures were (were not) recognized are displayed in blue (red). Note that responses changed dramatically depending on whether the picture was recognized or not and far outlasted the stimulus presentation duration.
Fig. 2. Raster plots and PSTH of a single neuron in the right entorhinal cortex that fired selectively to pictures of the World Trade Center. Note the striking difference in the responses to presentations when the picture was recognized (in blue) and when it was not (in red).
Identical visual input

Recognized
N = 116 trials

Not Recognized
N = 116 trials
where and how do modalities get combined?

Nader Nikbakht et al. Neuron, in press
Our point of departure regarding multimodal integration is based on two concepts:

- augmenting the reliability of unimodal signals
- generation of modality-independent knowledge
• we live in a noisy and ambiguous world...
• single modality not always reliable, by itself
• multisensory integration facilitates detection, discrimination, or recognition of stimuli
a real thing
90 degrees
LEFT is correct

Tactile condition

illumination is infrared only!!!
250 fps
90 degrees
LEFT is correct
Visual condition
Transparent screen
after training at 0-90 degrees, first test session at new angles

![Graph showing cumulative session performance across various angles.]
The ability to map sensory inputs to meaningful semantic labels, i.e., to recognize objects, is foundational to cognition, and the human brain excels at object recognition tasks along ventral processing pathways and across sensory domains. Examples include perceiving spoken speech, reading written words, even recognizing tactile Braille patterns.

Multisensory integration also has to occur along the dorsal pathway for purposes of, e.g., heading and navigation, in which case visual and vestibular signals have to be integrated.

In each sensory modality, object recognition and spatial navigation appear to be realized by “simple-to-complex” multi-stage processing hierarchies in which tuning complexity grows gradually from simple features in primary sensory areas to complex representations in higher-level areas that ultimately interface with task-related circuits.

The rats, unwittingly, mapped the stimuli never before encountered to semantic labels of “vertical” and “horizontal”
response times correlate with task difficulty

they do not “give up” on difficult trials, but try even harder
unimodal capacities vary among individual rats...
... but always better under VT than V or T.
peak psychometric curve slope as single measure for performance
peak psychometric curve slope
Information received through the senses is inherently probabilistic.

- Subject is presented with a cue: $s$.
- He estimates some feature of that cue: $\hat{s}$.
- $s$ is noisy and Gaussian-distributed: $s \sim N(\mu, \sigma^2)$.
- Reliability can be defined as the inverse of variance: $\frac{1}{\sigma^2}$. 

![Diagram of likelihood vs angle with distributions for Touch, Vision, and Touch + Vision]
calculation of the brainsons: comparison between \( s \) and a "fixed" reference: \( r \)

\[
P(s \geq r) \equiv CDF(\hat{s}) = \int_r^\infty P(s)ds
\]
\[
\hat{S}_{vt} = w_v \hat{S}_v + w_t \hat{S}_t
\]

\[
\mu_{vt} = \frac{\sigma_t^2}{\sigma_v^2 + \sigma_t^2} \mu_v + \frac{\sigma_v^2}{\sigma_v^2 + \sigma_t^2} \mu_t
\]

\[
\sigma_{vt}^{(opt)} = \frac{\sigma_v^2 \sigma_t^2}{\sqrt{\sigma_v^2 + \sigma_t^2}}
\]

\[
P(S|v, t) \propto P(t|S) P(v|S)
\]

Jacobs, 1999, Ernst and Banks, 2002
- measured=predicted

**supralinear**

**sublinear**

**linear**
measured threshold

8 9 10 11 12 13 14 15

predicted model threshold

8 9 10 11 12 13 14 15

measured=predicted

supralinear

linear

sublinear
a second approach to testing linearity
we treat V and T as two channels that provide the rat with streams of information

• assumes that the information present within the sensory channels is converted directly into a choice.

• compute Shannon’s Mutual Information between stimulus category (horizontal or vertical) and behavioral choice in each modality separately, V and T. Thus, 100% behavioral accuracy implies 1.0 bits of sensory information, 50% (chance) accuracy implies 0 bits.

• then we compute the quantities predicted by the linear combination of V and T signals.

\[ \text{visual information} + \text{tactile information} \]

\(^1\text{Adibi, Diamond, Arabzadeh (2012) PNAS}\)
within-rat consistency across models

Bayesian model

Information channel model

visual information

visual information + tactile information

visual information

visual information + tactile information

supralinear

measured=predicted

measured=predicted

$I(R;S_v) + I(R;S_t)$ bits

$I(R;S_v)$ bits

measured threshold

predicted model threshold
How can performance achieve supralinearity?
Behavior

Neurons
Bf: Barrel Field
PtA: Parietal Association Area
V: Visual Cortex

622 neurons from 5 animals
unimodal cortical representations

modality-shared representation of orientation and category in PPC
in 185 out of 622 neurons, trial-to-trial firing rate variations were best accounted for by stimulus orientation.
in 251 out of 622 neurons, trial-to-trial firing rate variations were best accounted for by upcoming behavioral choice.
neuronal responses are supramodal

average FR in 400 ms window preceding the response lick
neuronal responses are supramodal **across all angles**
**visual** trial

**tactile** trial

**visual tactile** trial

$k$ spikes

$k$ spikes, again

$k$ spikes, yet again!
are these neurons merely correlated with sensory inputs but not truly the basis for multimodal integration and decision making?
A category-free neural population supports evolving demands during decision-making

count uncorrelated trains of visual and auditory pulses
A category-free neural population supports evolving demands during decision-making

David Raposo, Matthew T Kaufman & Anne K Churchland

our study
Raposo et al.

- count independent visual and auditory pulse trains

Nikbakht and Diamond

- see and touch real thing

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<thead>
<tr>
<th></th>
<th>Raposo et al.</th>
<th>Nikbakht and Diamond</th>
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<tbody>
<tr>
<td>sensory tuning (code)?</td>
<td>not really</td>
<td>yes</td>
</tr>
<tr>
<td>category (choice)?</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>modality synergy (supralinearity)?</td>
<td>spotty</td>
<td>robust</td>
</tr>
<tr>
<td>modality specificity?</td>
<td>yes</td>
<td>no</td>
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Task dependent neurons {?}
Example trials: boundary between 60 and 75 (67.5 degrees)
Behavioral performance
• modality invariance – a step in the abstraction of stimuli from sensory domains (‘Robert Plant’)??

• not hardwired... emerges from interaction with real things

• besides supramodal knowledge, PPC circuitry also might shed light on the percept-to-action transformation.