Introduction to Computational Neuroscience
Lecture 10: Perception
<table>
<thead>
<tr>
<th>Lesson</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>2</td>
<td>Structure and Function of the NS</td>
</tr>
<tr>
<td>3</td>
<td>Windows to the Brain</td>
</tr>
<tr>
<td>4</td>
<td>Data analysis</td>
</tr>
<tr>
<td>5</td>
<td>Data analysis II</td>
</tr>
<tr>
<td>6</td>
<td>Single neuron models</td>
</tr>
<tr>
<td>7</td>
<td>Network models</td>
</tr>
<tr>
<td>8</td>
<td>Artificial neural networks</td>
</tr>
<tr>
<td>9</td>
<td>Learning and memory</td>
</tr>
<tr>
<td>10</td>
<td>Perception</td>
</tr>
<tr>
<td>11</td>
<td>Attention &amp; decision making</td>
</tr>
<tr>
<td>12</td>
<td>Brain-Computer interface</td>
</tr>
<tr>
<td>13</td>
<td>Neuroscience and society</td>
</tr>
<tr>
<td>14</td>
<td>Future and outlook: AI</td>
</tr>
<tr>
<td>15</td>
<td>Projects presentations</td>
</tr>
<tr>
<td>16</td>
<td>Projects presentations</td>
</tr>
</tbody>
</table>
Machines vs Brains

precise, symbolic data
memory / computation
centralized processing
sequential
programming
clock-driven
fast & hot

vs.

low resolution, ambiguous data
memory & computation
distributed processing
parallel
learn
event-driven
slow & cool
Brains make sense of input
Brains make sense of input
Brains make sense of input
Learning objectives

• Recognize the role of uncertainty in cognition
• Understand perception as a probabilistic inference phenomena
• What is Bayesian inference?
The problem

Distal stimulus (book)

Proximal stimulus (retinal image of book)

Percept (recognition of object as a book)
Definition

**Perception:** organization and interpretation of sensory information to represent and understand the environment

At every moment, we perceive patterns, objects, people, events (cognitively speaking it is amazing!)
Not easy!

Areas responsible for visual processing occupy half of cortex
Figure-ground separation

Type of perceptual grouping vital for visual recognition

Ex: printed words (figure) in a sheet of paper (ground)

Figure can be defined by differences in depth, color, texture, or motion with respect to the background
Gestalt principles
Remarks

Perception is more than the sum of static, individual sensory inputs.

We do more than simply recording the visual world around us, we are not cameras!

Perception involves combining small bits of information from the environment into larger pieces, and the expectations and theories about what the stimulus is.
Two streams of information

Bottom-up (sensory input)

Top-down (memory, attention, expectation)
Combining two streams of information allows the brain to better sense the world than if it only had the sensory information stream. One needs to apply a weight to each stream (Bayesian inference).
Advantage

Perceptual systems allow the individuals to “see” the world around them as stable, even though sensory information is typically rapidly changing and incomplete.

Lesion study: patient RW (stroke in parietal and occipital cortex)
Disadvantages

If our top-down predictions are wrong, the percept might be particularly inaccurate (illusions)

3 coins experiment

Small price to pay for a process that enhances our sensing in ambiguous and noisy environments
Prosopagnosia
Perception

A world of uncertainty

The Bayesian inference hypothesis
Uncertainty is an intrinsic part of neural computations.
Age inference

(a)

Key:
- Prior
- Likelihood
- Posterior

Probability

0 20 40 60 80 100
Quick math quiz:

\[ x + 3 = 8 \]

What is \( x \)?
Quick math quiz:

\[ x + y = 9 \]

What are \( x \) and \( y \)?

This is an example of an *ill-posed* problem

- problem that has no unique solution
Perception is also an ill-posed problem!

Example:

\[
\text{Spectrum of Illuminant} \times \text{Reflectance function of surface} = \text{Light Hitting Eye}
\]

Question we want to answer: what are the surface properties (i.e., color) of the surface?

Equivalently: \( X \times Y = \text{some cone responses R} \)

Given R, was Y?

(you’d have to know X to make it well-posed)
Same light hits the eye from both patches
Comparison patch

Same light hits the eye from both patches
Perception is also an ill-posed problem!

Example #2:

3D world $\Rightarrow$ 2D retinal image

Question: what’s out there in the 3D world?

Ill-posed because there are infinitely many 3D worlds that give rise to the same 2D retinal image

• need some additional info to make it a well-posed problem
Luckily, having some probabilistic information can help:

\[ x + y = 9 \]

Tables showing past values of y:

<table>
<thead>
<tr>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 7 7</td>
</tr>
<tr>
<td>7 7 7</td>
</tr>
<tr>
<td>5 7 7</td>
</tr>
<tr>
<td>7 6 7</td>
</tr>
<tr>
<td>7 7 7</td>
</tr>
<tr>
<td>7 7 7</td>
</tr>
<tr>
<td>8 7 8</td>
</tr>
<tr>
<td>7 7 7</td>
</tr>
<tr>
<td>7 7 7</td>
</tr>
</tbody>
</table>

Given this information about past values, what would you guess to be the values of x?

How confident are you in your answer?
Perception

A world of uncertainty

The Bayesian inference hypothesis
How the brain makes sense of the world?
Which dimples are popping out and which popping in?
Which dimples are popping out and which popping in?
Brain takes into account “prior knowledge” to figure out what is the world given ambiguous sensory data.

\[
P(\text{world} \mid \text{sense data}) \propto P(\text{sense data} \mid \text{world}) \cdot P(\text{world})
\]
\[ P(B \mid A) = \frac{P(A \mid B) \cdot P(B)}{P(A)} \]

Bayes’ rule
P(B | A) = \frac{P(A | B) P(B)}{P(A)}

Bayes’ rule

Formula for computing:

P(what’s in the world | sensory data)

this is what your brain wants to know!
Bayes’ rule

$P(B \mid A) = \frac{P(A \mid B) P(B)}{P(A)}$

from

$P(\text{what's in the world} \mid \text{sensory data})$

this is what your brain wants to know!

“Likelihood” given by laws of physics; ambiguous because many world states give rise to same sense data
Bayes’ rule

Formula for computing:

\[ \text{P(what’s in the world I sensory data)} \]

from

\[ \text{P(sensory data I what’s in the world)} \] & \[ \text{P(what’s in the world)} \]

\[ \text{P(A | B)} \frac{\text{P(B)}}{\text{P(A)}} \]

“Likelihood”
given by laws of physics;
ambiguous because many world
states give rise to same sense data

“prior”
given by past experience
$P(\text{IN} \mid \text{image}) \quad \text{VS} \quad P(\text{OUT} \mid \text{image})$
Applying Bayes rule:

\[ P(IN \mid image) \quad VS \quad P(OUT \mid image) \]

\[ P(world \mid sense \ data) \propto P(sense \ data \mid world) \cdot P(world) \]
Applying Bayes rule:

\[
P(IN \mid image) \quad VS \quad P(OUT \mid image)
\]

\[
P(\text{world} \mid \text{sense data}) \propto P(\text{sense data} \mid \text{world}) \times P(\text{world})
\]

\[
P(IN \mid image) = P(image \mid \text{IN & light below}) \times P(IN) \times P(\text{light below})
\]
Applying Bayes rule:

\[ P(IN \mid image) \text{ VS } P(OUT \mid image) \]

\[ P(\text{world} \mid \text{sense data}) \propto P(\text{sense data} \mid \text{world}) \times P(\text{world}) \]

\[ P(IN \mid image) = P(image \mid IN \& \text{light below}) \times P(IN) \times P(\text{light below}) \]

\[ \text{VS} \]

\[ P(OUT \mid image) = P(image \mid OUT \& \text{light above}) \times P(OUT) \times P(\text{light above}) \]
Applying Bayes rule:

\[
P(IN \mid image) \quad VS \quad P(OUT \mid image)
\]

```
\[
\frac{\text{posterior}}{P(world \mid sense \ data)} \propto \frac{\text{likelihood}}{P(sense \ data \mid world)} \times \frac{\text{prior}}{P(world)}
\]
```

\[
P(IN \mid image) = P(image \mid IN \; \& \; light \; below) \times P(IN) \times P(light \; below)
\]

\[
VS
\]

\[
P(OUT \mid image) = P(image \mid OUT \; \& \; light \; above) \times P(OUT) \times P(light \; above)
\]

“OUT” is much more probable because Sun is usually up and your brain uses that fact automatically!
Summary so far:

- Perception is an ill-posed problem
- equivalently: the world is still ambiguous even given all our sensory information
- Probabilistic information can be used to solve ill-posed problems (via Bayes’ theorem)
- Bayes’ theorem:

\[
\text{posterior} \propto \text{likelihood} \times \text{prior} \\
P(\text{world} \mid \text{sense data}) \propto P(\text{sense data} \mid \text{world}) \cdot P(\text{world})
\]

- The brain takes into account “prior knowledge” to figure out what’s in the world given our sensory information

(Note that the “posterior” can be considered the prior for the next time step in an ongoing learning process)
Two **take-home facts** about “what it means to be Bayesian” in psychology / neuroscience:

1. **Use priors**
   - We recognize that perception is ambiguous (“ill-posed”), and that the only / best way to deal with that is to use prior information (built up over last 2 minutes, last 2 days, last 2 decades, last 2M years, etc.)

   **refs:**

2. **Keep around a “full posterior distribution”**
   - Use probabilistic information (don’t just store the “most likely answer” — also store an estimate of our uncertainty)

   **refs:**

lunes, 2 de enero de 17
How the brain makes sense of the world?

The brain takes into account “prior knowledge” to figure out what’s in the world given our sensory information.
Summary

• **Perception** refers to the organization and interpretation of sensory stimuli

• **Perception is an ill-posed problem** that requires prior knowledge to resolve ambiguities

• **Perception** can be cast as a probabilistic inference process, which for simple tasks is close to optimal

• How probabilistic computations are implemented in the brain is one of the most pressing questions in Neuroscience
Eye and brain
Richard Gregory,
Princeton University Press
<table>
<thead>
<tr>
<th>Lesson</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>2</td>
<td>Structure and Function of the NS</td>
</tr>
<tr>
<td>3</td>
<td>Windows to the Brain</td>
</tr>
<tr>
<td>4</td>
<td>Data analysis</td>
</tr>
<tr>
<td>5</td>
<td>Data analysis II</td>
</tr>
<tr>
<td>6</td>
<td>Single neuron models</td>
</tr>
<tr>
<td>7</td>
<td>Network models</td>
</tr>
<tr>
<td>8</td>
<td>Artificial neural networks</td>
</tr>
<tr>
<td>9</td>
<td>Learning and memory</td>
</tr>
<tr>
<td>10</td>
<td>Perception</td>
</tr>
<tr>
<td>11</td>
<td>Attention &amp; decision making</td>
</tr>
<tr>
<td>12</td>
<td>Brain-Computer interface</td>
</tr>
<tr>
<td>13</td>
<td>Neuroscience and society</td>
</tr>
<tr>
<td>14</td>
<td>Future and outlook: AI</td>
</tr>
<tr>
<td>15</td>
<td>Projects presentations</td>
</tr>
<tr>
<td>16</td>
<td>Projects presentations</td>
</tr>
</tbody>
</table>