

Neuromechanics of Human Motion

Perception, Illusions, & Bayes' Theorem

Joshua Cashaback, PhD

Recap — Action Potentials

1. Basic nerve anatomy
2. Know what contributes to resting membrane potential
 - a. ions, electrochemical gradients, leak channels and Na-K pumps
3. Understand how action potentials occur
 - a. voltage gates, depolarization, repolarization, hyperpolarization (refractory period)
4. Hodgkin-Huxley Model

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Any questions on the assignment?

Lecture Objectives — Perception, Illusions, Bayes

1. Define Perception and Sensory Illusion.
2. Discuss (multi)sensory illusions
3. Discuss how the brain uses *prior* experience
4. Examples of how the brain integrates multiple senses
5. Learn about noise in the nervous system
6. Probabilities Primer (Bayes Theorem)

Why Study Perception?

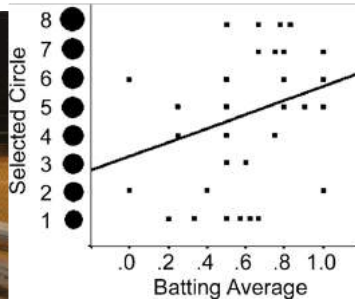
Perception

the organization, identification, and interpretation of sensory information to represent and understand the environment.

Why Study Perception?

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Motor Learning (elite, new skill)

Why Study Perception?

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autism, dyslexia

Why Study Perception?

Perception

the organization, identification, and interpretation of sensory information to represent and understand the environment.



Neuroscience: understand the brain before you can fix it.

Large portions of our brain are involved with sensory information, percept and integrating both together.

Why Study Perception?

Perception

the organization, identification, and interpretation of sensory information to represent and understand the environment.



human-brain interfaces (HBI), neurolink

how does the brain transform sensory information?

What is a Sensory Illusion?

Sensory Illusion

Where perception deviates from reality.



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A way to probe perception

What is a Sensory Illusion?

Sensory Illusion

Where perception deviates from reality.



A way to probe perception

Visual, Auditory, Haptic, Proprioception, Multisensory

Illusions

Illusions

Before we begin...

Illusions

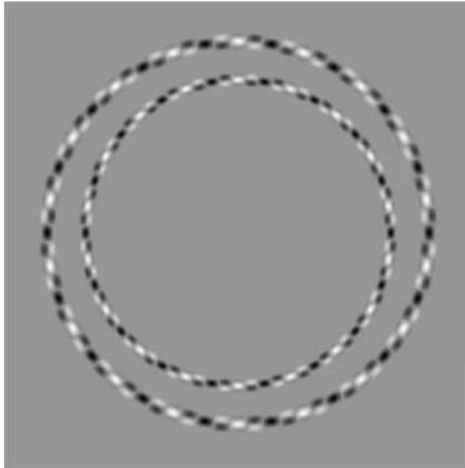


Warning!

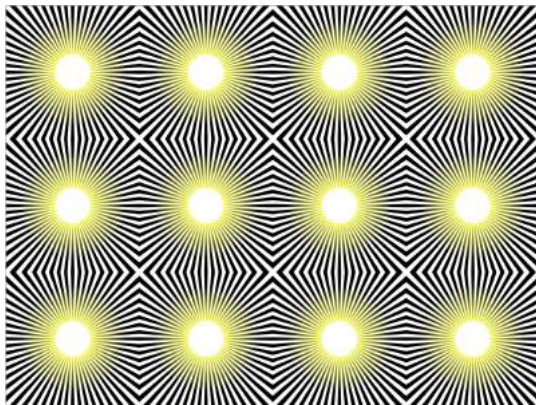
Some of the following images may cause nausea

Checkerboard patterns may cause seizures in certain forms of epilepsy

Visual Illusions — Circles

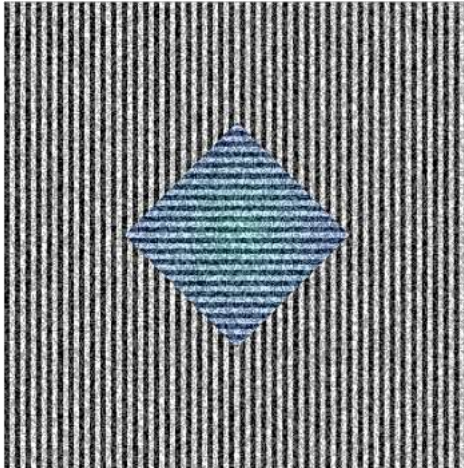


Visual Illusions — Luminance

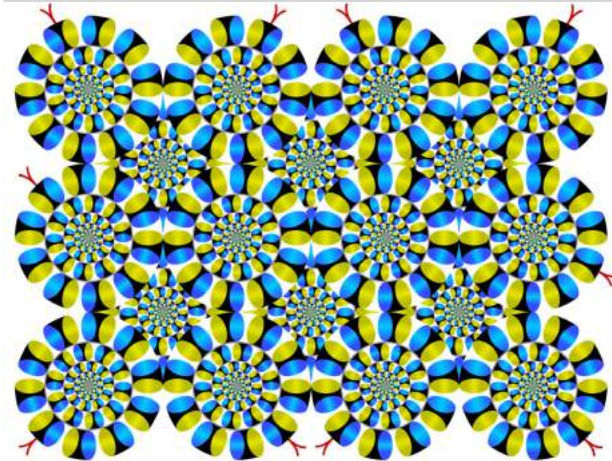


Pupil size is actually influenced by this illusion
(Laeng and Endestad, 2012)

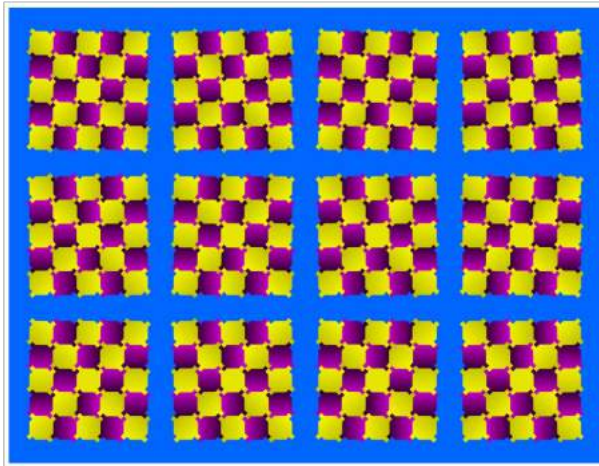
Visual Illusions — Diamonds in the Air



Visual Illusions — Moving Snakes

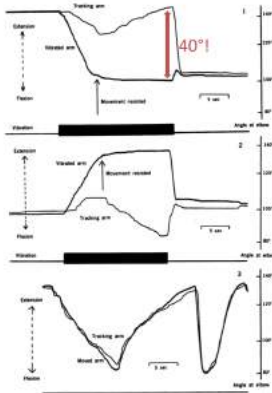


Visual Illusions — Tilt and Movement



Proprioception Illusion — Position Sense

Goodwin, McCloskey, Matthews (1972) Science

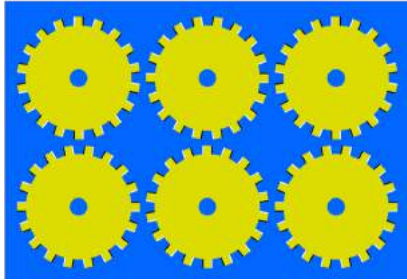


Biceps vibration causes arm flexion and a mismatch between actual and felt movement

Triceps vibration causes arm extension and a mismatch between actual and felt movement

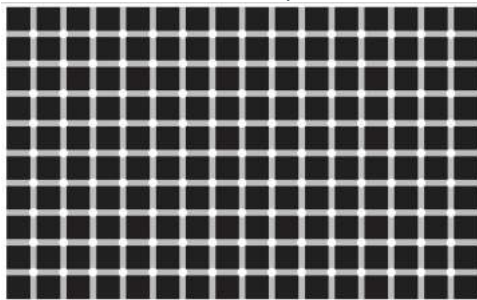
Tracking passive movement is very accurate

Why Study Illusions?



Why Study Illusions?

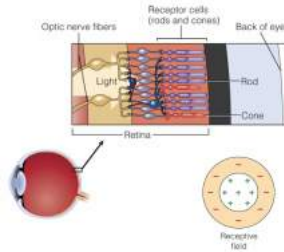
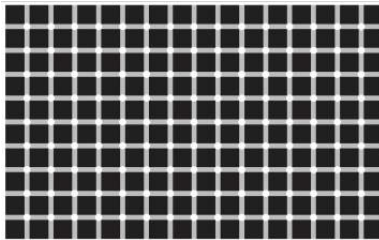
Probe Perception



Insight into Sensory Physiology

Why Study Illusions?

Probe Perception



1. Insight into Sensory Physiology

Why Study Illusions?

Probe Perception



2. Insight into how the BRAIN integrates sensory information

Hollow Face Illusion

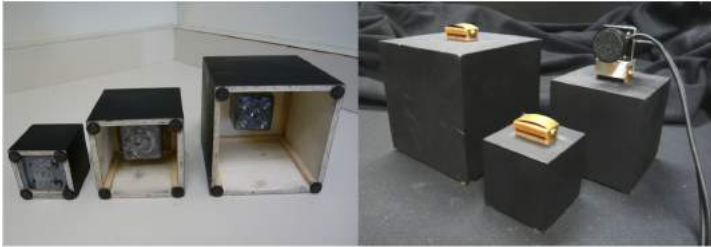
<http://www.youtube.com/watch?v=sKa0eaKsdA0>

Hollow Face Illusion

<http://www.youtube.com/watch?v=sKa0eaKsdA0>

Your Brain fills in blanks based on **prior** experience

Size Weight Illusion

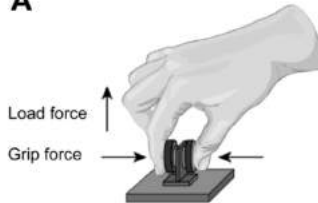


Different size boxes, same weight

Size Weight Illusion



A




Transducers to record force, measure motor output, and probe expectations

Size Weight Illusion

Size-weight illusion
Perceptions of heaviness

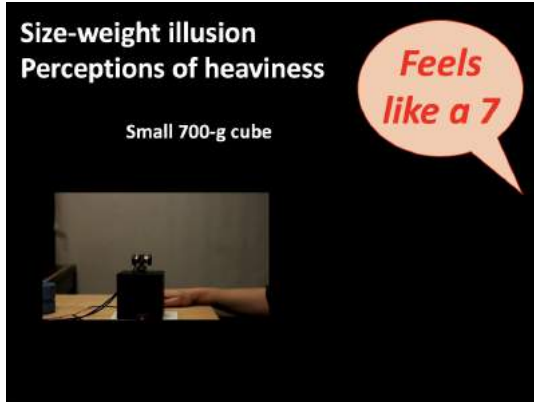
Large 700-g cube

Feels like a 3

A photograph showing a person's hand resting on a small, dark, cube-shaped object on a light-colored surface. The object is labeled as a 'Large 700-g cube'. The background is a plain, light-colored wall.

Big box feels light

Size Weight Illusion



small box feels heavier than big box!

Size Weight Illusion



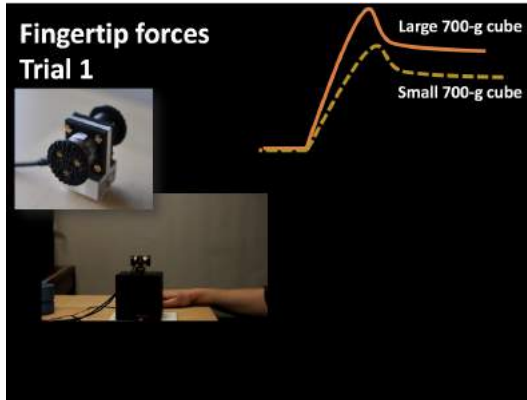
Our **prior** experience and expectation modifies our perception

Size Weight Illusion



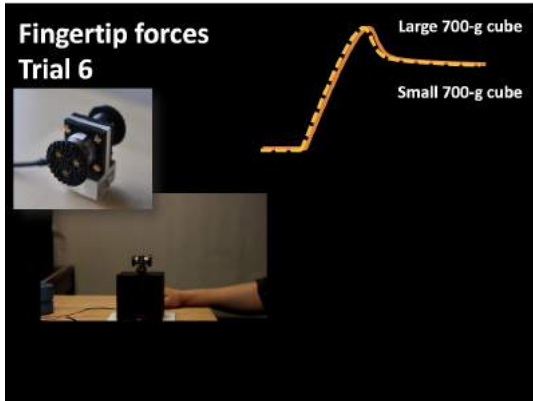
How does this influence our motor output?

Size Weight Illusion



Mismatch, despite same weight

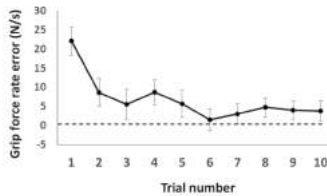
Size Weight Illusion



Adaptation

Size Weight Illusion

Grip/lift errors are rapidly corrected

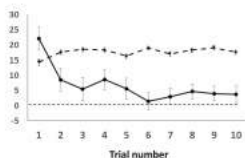


Learning Curve - Big Box

(dashed line = normalized to steady state behaviour)

Size Weight Illusion

Illusion remains unchanged



Despite motor output changes, illusion remains
(e.g., thick, dashed line = participants keep reporting '7')

Size Weight Illusion — What can it tell us?

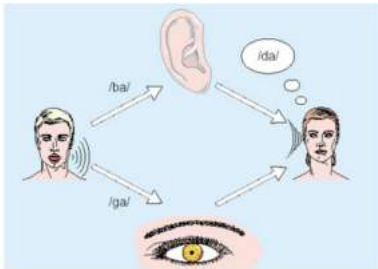


1. We don't always know the physical properties of our world
2. Our brain fills in gaps (based on prior experience)
3. Sensorimotor system can operate independent of conscious perception
 - a. perception influenced early behaviour but stayed constant while control changed.
 - b. (partially) separate systems for judging weight and lifting objects

Multisensory Integration



McGurk Effect — Visual and Auditory

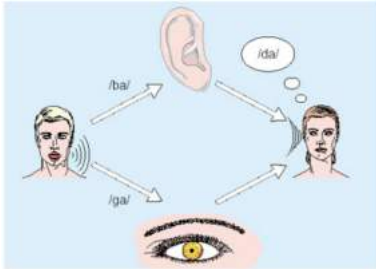


The McGurk effect is a perceptual phenomenon that demonstrates an interaction between hearing and vision in speech perception.

The illusion occurs when the auditory component of one sound (ba) is paired with the visual component of another sound (ga), leading to the perception of a third sound (da).

<https://www.youtube.com/watch?v=G-IN8vWm3m0>
(note, video using different combination of syllables)

McGurk Effect — Visual and Auditory

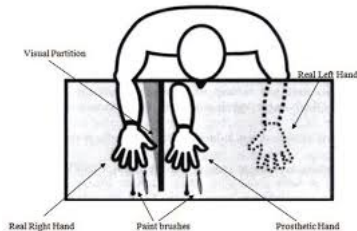


The McGurk effect is a perceptual phenomenon that demonstrates an interaction between hearing and vision in speech perception.

The illusion occurs when the auditory component of one sound (ba) is paired with the visual component of another sound (ga), leading to the perception of a third sound (da).

Our Brain combines our sensory inputs together (even when they are in conflict!)

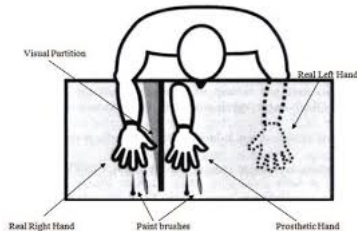
Rubber Hand Illusion — Visual and Somatosensory



Jared Madina (UD psych):

<https://www.youtube.com/watch?v=RhHzcVdyvWg>

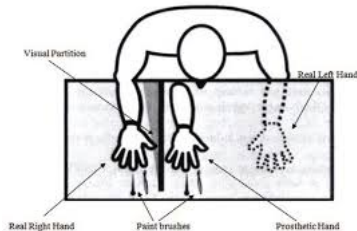
Rubber Hand Illusion — Visual and Somatosensory



Funny Extension:

<https://www.youtube.com/watch?v=MG22iFL-VgE>

Rubber Hand Illusion — Visual and Somatosensory



1. Combining vision and somatosensory
2. Adaptation
3. Phantom limb pain

Noise in the Nervous System

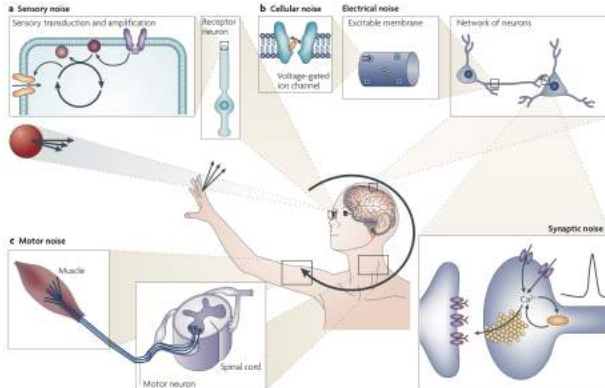
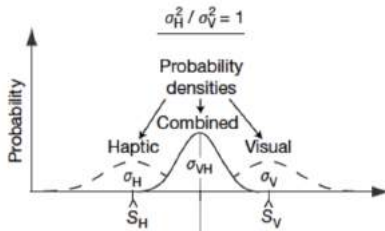


Figure 1 | Overview of the behavioural loop and the stages at which noise is present in the nervous system. **a** | Sources of sensory noise include the transduction of signals. This is exemplified here by a photoreceptor and its signal-amplification cascade. **b** | Sources of cellular noise include the ion channels of excitable membranes, synaptic transmission and network interactions (see BOX 2). **c** | Sources of motor noise include motor neurons and muscle. In the behavioural task shown (catching a ball), the nervous system has to act in the presence of noise in sensing, information processing and movement.

Optimally Combining Noisy Sensors



Ernst and Banks (2002) Nature

1. Nervous system is statistically optimal
2. Noise typically modelled with Gaussian or Normal probability distributions

Bayesian Integration

Bayes' Theorem can account for:

1. The role of prior experience
2. Adaptation
3. Sensory noise (statistically optimal)
 - a. Multisensory integration (explain illusions)
 - b. cost functions
 - c. state estimation (e.g., Kalman filters)

Probability Primer

1. Mutually Exclusive (Disjoint)
2. Joint Probabilitites
3. Complement Probability
4. Conditional Probability
5. Marginal Probability

Probability Primer

1. Mutually Exclusive (Disjoint)
2. Joint Probabilitites
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With these defined, we can derive Bayes' theorem!

Notation

S = sample space (all possible outcomes)

$p(A)$ = probability of event A

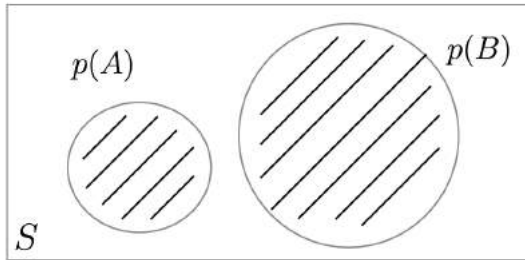
$A \cup B$ = union of events A and B

$A \cap B$ = intersection of events A and B

$p(B|A)$ = probability of B given A

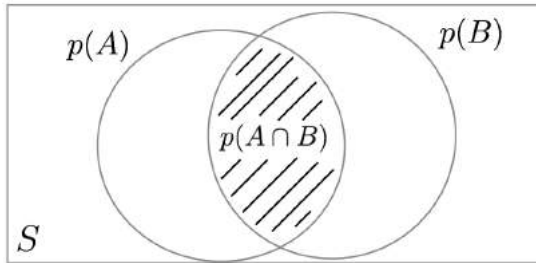
$p(A')$ or $p(A^C)$ or $p(\bar{A})$ = complement probability of $p(A)$

Mutually Exclusive (Disjoint Probability)



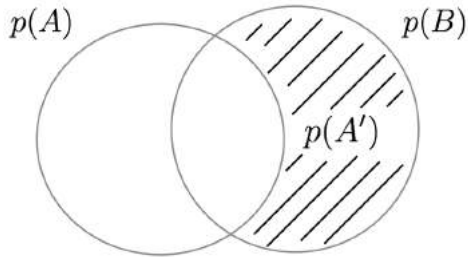
$$p(A \cup B) = p(A) + p(B)$$
$$0.7 = 0.4 + 0.3$$

Joint Probability



$$p(A \cup B) = p(A) + p(B) - p(A \cap B)$$
$$0.5 = 0.4 + 0.3 - 0.2$$

Complement Probability



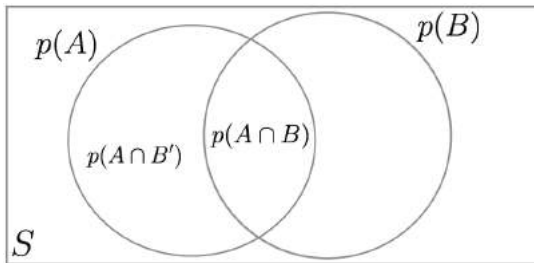
$$p(A') = 1 - p(A)$$

Marginal Probability

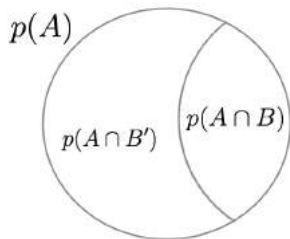
H \ L	Red	Yellow	Green	Marginal probability P(H)
Not Hit	0.198	0.09	0.14	0.428
Hit	0.002	0.01	0.56	0.572
Total	0.2	0.1	0.7	1

Probabilities of getting in an accident at an intersection given different lights

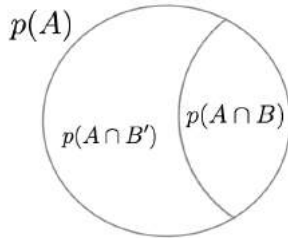
Marginal Probability



Marginal Probability

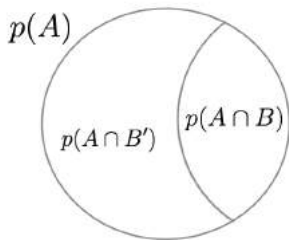


Marginal Probability



$$p(A \cap B') = p(A) - p(A \cap B)$$

Marginal Probability



$$p(A \cap B') = p(A) - p(A \cap B)$$

The marginal $p(A)$ or $p(B)$ is found by summing their disjoint parts.

$$p(A) = p(A \cap B) + p(A \cap B'), \text{ and similarly}$$

$$p(B) = p(A \cap B) + p(A' \cap B)$$

Conditional Probability Examples

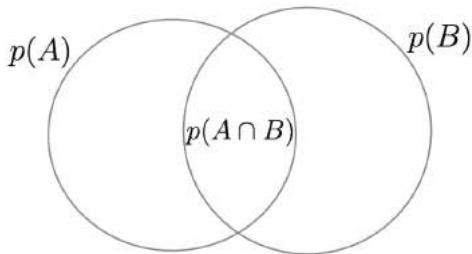
$$p(\textit{accepted}) = 0.3$$

$$p(\textit{funding}|\textit{accepted}) = 0.43$$

$$p(\textit{funding} \cap \textit{accepted}) = p(\textit{funding}|\textit{accepted}) \cdot p(\textit{accepted})$$

$$p(\textit{funding} \cap \textit{accepted}) = 0.43 \cdot 0.3 = 0.13$$

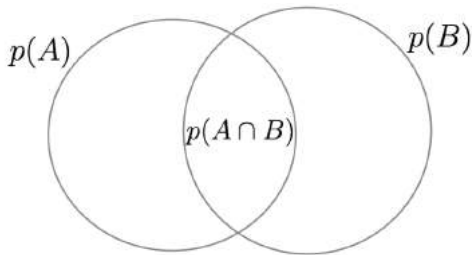
Conditional Probability



$$p(A \cap B) = p(B|A) \cdot p(A)$$

$$p(B|A) = \frac{p(A \cap B)}{p(A)}$$

Conditional Probability



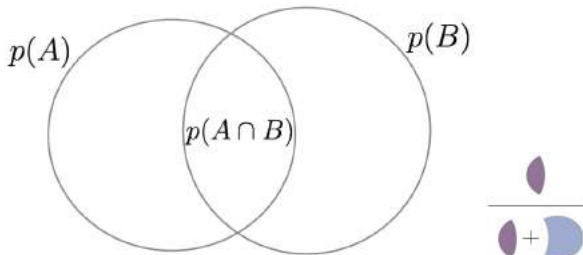
$$p(A \cap B) = p(B|A) \cdot p(A)$$

$$p(B|A) = \frac{p(A \cap B)}{p(A)}$$

$$p(A \cap B) = p(A|B) \cdot p(B) \text{ (in terms of B)}$$

$$p(A|B) = \frac{p(A \cap B)}{p(B)}$$

Conditional Probability



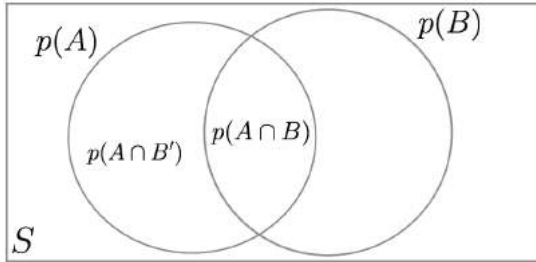
$$p(A \cap B) = p(B|A) \cdot p(A)$$

$$p(B|A) = \frac{p(A \cap B)}{p(A)}$$

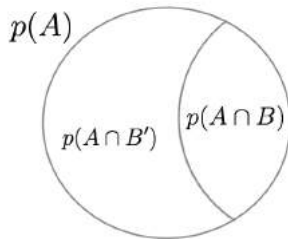
$$p(A \cap B) = p(A|B) \cdot p(B) \text{ (in terms of B)}$$

$$p(A|B) = \frac{p(A \cap B)}{p(B)}$$

Conditional Probability Complements

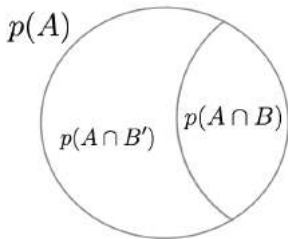


Conditional Probability Complements



$$p(A \cap B') = p(B'|A) \cdot p(A)$$

Conditional Probability Complements



$$p(A \cap B') = p(B'|A) \cdot p(A)$$

Other friendly complements:

$$p(A' \cap B) = p(B|A') \cdot p(A')$$

$$p(A' \cap B') = p(B'|A') \cdot p(A')$$

Bayes' Theorem



Reverend Thomas Bayes (1701-1761)

Good News! Bayes' Theorem is simply a conditional probability!

Deriving Bayes' Theorem

Remember:

$$p(A|B) = \frac{p(A \cap B)}{p(B)}, (eq.1)(slide 45)$$

$$p(A \cap B) = p(B|A) \cdot p(A), (eq.2)(slide 44)$$

Substitute (eq.2) into (eq.1):

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (eq.3)$$

Thats it!

Handy Dandy Steps for Point Estimates

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (eq.3)$$

Handy Dandy Steps for Point Estimates

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (eq.3)$$

Calculate $p(B)$ by using its marginal probability

$$p(B) = p(A \cap B) + p(A' \cap B), (eq.4)(slide 42)$$

Handy Dandy Steps for Point Estimates

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (eq.3)$$

Calculate $p(B)$ by using its marginal probability

$$p(B) = p(A \cap B) + p(A' \cap B), (eq.4)(slide 42)$$

Substitute (eq.4) into (eq.3)

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(A \cap B) + p(A' \cap B)}, (eq.5)$$

Handy Dandy Steps for Point Estimates

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (\text{eq.3})$$

Calculate $p(B)$ by using its marginal probability

$$p(B) = p(A \cap B) + p(A' \cap B), (\text{eq.4})(\text{slide 42})$$

Substitute (eq.4) into (eq.3)

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(A \cap B) + p(A' \cap B)}, (\text{eq.5})$$

Since,

$$p(A \cap B) = p(B|A) \cdot p(A), (\text{eq.6})(\text{slide 44})$$

$$p(A' \cap B) = p(B|A') \cdot p(A'), (\text{eq.7})(\text{slide 49})$$

Handy Dandy Steps for Point Estimates

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (\text{eq.3})$$

Calculate $p(B)$ by using its marginal probability

$$p(B) = p(A \cap B) + p(A' \cap B), (\text{eq.4})(\text{slide 42})$$

Substitute (eq.4) into (eq.3)

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(A \cap B) + p(A' \cap B)}, (\text{eq.5})$$

Since,

$$p(A \cap B) = p(B|A) \cdot p(A), (\text{eq.6})(\text{slide 44})$$

$$p(A' \cap B) = p(B|A') \cdot p(A'), (\text{eq.7})(\text{slide 49})$$

Substitute (eq.6) and (eq.7) into (eq.5)

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B|A) \cdot p(A) + p(B|A') \cdot p(A')}, (\text{eq.8})$$

Alternative Definition

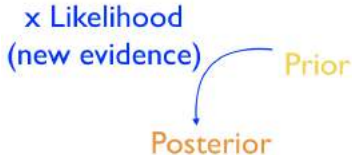
$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}, (eq.3)$$

$$p(B|A) = \frac{p(A|B) \cdot p(B)}{p(A)}$$

Why Bayesian?

Powerful way to continually account for new evidence given prior beliefs

$$p(A|B) = \frac{p(B|A) \cdot p(A)}{p(B)}$$



Next Class

1. point estimate examples
2. continuous probability
3. combining multiple senses
4. cost functions

Homework

1. Plot a Normal probability distribution

- $p(x|\mu, \sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$
- manipulate the mean (μ) and standard deviation (σ)
- discretize along x (make the number of data points used a variable)

2. Plot a Beta probability distribution

- $p(x|\alpha, \beta) = \frac{1}{B(\alpha, \beta)} x^{\alpha-1} (1-x)^{\beta-1}$
- manipulate α and β
- from scipy import special
- $B = \text{scipy.special.beta}(\alpha, \beta)$
- discretize along x (make the number of data points used a variable)

Acknowledgements

Gavin Buckingham

Michael Barnett-Cowan