An Introduction to Learning

Lecture 1/13

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Agenda for Today

- Give a short overview of course for those still considering to enroll
- Go over syllabus
- Fill our pre-course survey
- What is learning? How is it a relevant area of study? How is it studied?
Who are you?

Todd M. Gureckis
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For the past 10 years, I’ve been studying human learning, memory, categorization, and decision making. I’m a electrical engineer/computer scientist by training that switched to psychology for my phd.

How to Email Me:

Examples:
Subject: [nyulearn] I have a question
Subject: [nyulearn] I am going to miss class
Subject: [nyulearn] I enjoyed the last lecture, here is a $$ tip
Course Webpage

http://smash.psych.nyu.edu/courses/fall10/learning/

- Or just google ‘todd gureckis’ or ‘smash nyu’ and find my lab webpage to follow the links

- All lectures, hand outs, announcements, etc... will be made here. Please check back often/bookmark
Grading

- 15% Attendance and participation
- 15% Homework and assignments based on readings
- 70% Two exams each covering a particular part of the course (each worth 35%)
- This is a core course in psychology, meaning you will be learning about basic concepts needed to be a member of the field. The material will generally be more basic (not an unstructured seminar) and you will be expected to demonstrate mastery.
Books, Readings, and Software

- Books: *Learning and Memory: From Brain to Behavior* by Gluck, Mercado, and Myers (should be available at the NYU Bookstore). TBD

- Additional readings and supplements will be provided on the course webpage

- Software (maybe some matlab/python code for some homework/exercises. will be simple. you don’t need to know either language.)
Why Should I Take This Course?

- You are interested in cognitive science, psychology, learning, memory, neuroscience, animal learning, marketing, education, computer science, sociology, and/or economics

- You have to
Why Should I Drop This Course?

- You have trouble waking up before noon
- You have other things you want to do at noon instead of attending class (it’s ok, NYC is a fun place, just don’t enroll and go do that other stuff)
- I don’t like reading assignments and prefer to try to “figure things out” by listening to lectures and hope I can fill in the gaps
What is this course about?

- **Short Version**: Learning

- **Less Short Version**: An Introduction to Learning

- **Medium Version**: An introduction to the basic principals of human learning.

- **Long version**: An introduction to the basic principals of human and animal learning. We will take a broad survey of the field of learning including elementary theories and findings about conditioning, perceptual learning, discrimination, stimulus generalization, learning and memory interactions, the neural systems of memory, computational and theoretical models of learning, innate versus learned behaviors, critical periods, implicit/explicit learning, etc...
What is learning?

- I think we all probably have some idea about what learning is. However, as soon as you try to define it, you can quickly find yourself stuck.

Learning is the acquisition of a new behavior or a change in behavior over time, which is dependent on experience, is not entirely transitory, and which is for the most part adaptive.
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Does it have to be new? Re-learning is learning! Learning to inhibit a behavior is learning (kicking the habit!).... ok we’ll include CHANGE in behavior.
What is learning?

We all know what learning is. However, as soon as you try to define it, you can quickly find yourself stuck.

Learning is the acquisition of a new behavior or a change in behavior over time, which is dependent on experience, is not entirely transitory, and which is for the most part adaptive.

We wouldn’t want to attribute behavioral change due to maturation or development alone as learning. Thus, must dependent on experience.

However, behavior can change due to experience for many reasons. Get tired? Get drunk/drugged? ... Sorry, but you’re NOT “learning”.
What is learning?

- We all know what learning is. However, as soon as you try to define it, you can quickly find yourself stuck.

Learning is the acquisition of a new behavior or a change in behavior over time, which is dependent on experience, is not entirely transitory, and which is for the most part adaptive.

How much experience? Can you learn something in 1 trial? Does it take repeated presentations/exposure?
What is learning?

- We all know what learning is. However, as soon as you try to define it, you can quickly find yourself stuck.

Learning is the acquisition of a new behavior or a change in behavior over time, which is dependent on experience, is not entirely transitory, and which is for the most part adaptive.

One way around the drunk/tired thing is to say learning is not transitory... but, of course, you can forget what you’ve learned.

Another way is that learning can’t be explained as some innate behavioral tendency in the organism (such as a drug reaction or evolutionarily wired requirements for sleep).
What is learning?

- We all know what learning is. However, as soon as you try to define it, you can quickly find yourself stuck.

Learning is the acquisition of a new behavior or a change in behavior over time, which is dependent on experience, is not entirely transitory, and which is for the most part adaptive.

Maybe you have to want to learn? Can learning be implicit --- in accessible to your conscious will or desire? Probably.
What is learning?

We all know what learning is. However, as soon as you try to define it, you can quickly find yourself stuck.

Learning is the acquisition of a new behavior or a change in behavior over time, which is dependent on experience, is not entirely transitory, and which is for the most part adaptive.

Is learning always adaptive? My argument would be yes. Learning is an ADAPTIVE change in behavior to contingencies in the world. That is the FUNCTION of learning. Surely there are mal-adaptive examples of learning (learning obsessive habits), but these are likely just manifestations of mistakes due to the flexibility of the system. The primary role of learning in a organism is to enable adaptation.
How does one know that learning has occurred?

- Besides measuring the synapses of individual neurons, we only know that learning has occurred by observing changes in performance.

- However many problems with this criterion:

  - Some things may result in learning but no immediate change in behavior (learning a new fact or something about the world may not immediately lead to a measurable change in performance)

  - Must be motivated to learn, but also motivated to express the change in performance.

  - Must be attending to the relevant information in the world in order to show change in performance.

- This is why studying learning in certain animals (e.g. children) is so difficult! We can’t be sure to have them properly motivated and attending so as to express behavior even if capacity for learning exists!
What is the difference between learning and memory?

- Is this a course about memory? NO!

- Is there a fundamental difference between learning and memory? Probably not! That is why most textbooks (including ours) have some variant of “Learning AND Memory” in their title.

- Both are experience-dependent changes to the structure of the brain. (e.g., the change or acquisition of an association between a tone and shock has to be a form of memory as well. Without memory what can be learned? without learning how can you form new memories?)

- That said, the particular research approaches for the study of learning and memory are quite distinct, despite being THEORETICALLY two sides of the same coin.
Why study learning (and memory)?

- Learning is everywhere! You are learning right now!
- Our experience shapes who we are (we are not our genes!)
- Imagine what it would be like to lose our memory... (ex: Clive Wearing)

- Accomplish musician who was got a herpes simplex infection
- **Anterograde amnesia** - can’t form new, lasting memories subsequent to event
- **Retrograde amnesia** - loss of memory from previous leading up to amnesic event
- Lives in a constant state of “reawakening” to the reality around him
The Learning Game!

Which of the following examples are or are not learning?
Learning?

Students in a classroom follow a lab report to perform and experiment and write a report of their results.
A rat is rewarded with food each time it presses a lever on one side of its cage while a red light is on. Over time the rat starts to immediately run over to the level and press it as soon as the light turns on.
Learning?

A child doesn’t like members of the opposite sex, but over time their opinion changes somewhat.
Learning?

A child goes from only eating macaroni and cheese and frozen peas to liking swiss cheese and caviar as an adult.
A drug user develops a tolerance to a particular substance in the course of abuse.
Learning?

Which of the following examples are or are not learning?

http://www.youtube.com/watch?v=hoRs6lKX1wM

A simple robot is designed so that two independent motors are differentially activated by sunlight on solar panels connected to it’s back. As a results the robot seeks out light in its environment and tries to stay in places to relative light.
The Dynamics of Associative Learning in Evolved Model Circuits

Phattanard Phattanasri¹, Hillel J. Chiel², Randall D. Beer³

¹Department of Electrical Engineering and Computer Science, Case Western Reserve University, Cleveland, OH 44106
²Departments of Biology, Neurosciences, and Biomedical Engineering Case Western Reserve University Cleveland, OH 44106
³Cognitive Science Program, Department of Computer Science, Department of Informatics, Indiana University, Bloomington, IN 47406
Figure 2  The structure of an individual trial. A trial is divided into five phases. First, a smell signal is applied. Second, the state of the mouth is evaluated relative to the correct action for the current environment (bold line). Third, there is a variable random delay. Fourth, a reinforcement signal proportional to the correctness (cross-hatched region) of the previous action is applied. Fifth, there is another variable random delay before the next trial begins.
Continuous Time Recurrent Neural Network (CTRNN) with NONPLASTIC Weights
Figure 3  A plot of the best fitness versus generation for the best evolved three-neuron nonplastic circuit. Transitions between stages of our incremental shaping protocol are marked with dashed lines and labeled by the length of the trial sequences used in that stage. Transitions occur when the best fitness reliably exceeds 0.95 (horizontal gray line). Note that the fitness drops sharply after the 2→3 and 3→6 transitions before the circuit can generalize to sequences of arbitrary length. Indeed, the 6→7 and the 7→8 transitions occur so close together that they appear as a single line.
Figure 4  Activity of the best three-neuron nonplastic circuit on a typical trial sequence. From top to bottom the traces correspond to the reinforcement signal (R), the smell sensor (S), the mouth state (M, given by the output of neuron 1) and the outputs of the remaining neurons (o). Small rectangles mark the time during which the mouth state is evaluated and the state that the mouth should be in during this time, with correct actions denoted by black rectangles and incorrect actions denoted by gray rectangles. Transitions between environments are marked by dashed lines. Note that the circuit takes an incorrect action and receives negative reinforcement after each environment transition before modifying its action map to be appropriate to the new environment.
Figure 6  The nonautonomous dynamics of the best three-neuron nonplastic circuit during the trial sequence $\uparrow O+\uparrow O-\uparrow \bullet+$, which switches from environment A to environment B after the first trial. As the input signals change throughout this sequence, the circuit’s autonomous dynamics is switched between the different phase portraits shown in Figure 5 and its state is attracted to the stable equilibrium point in whose basin it finds itself at each point. The change in action map from environment A to environment B is accomplished by shifting the circuit’s operating region from the neighborhood of the right stable equilibrium point of $\mathcal{P}_0$ to the neighborhood of the left stable equilibrium point of this phase portrait.
Conclusions: Adaptive learning without adaptive weights!

“Despite the fact that the basic CTRNN model lacks synaptic plasticity, an evolutionary algorithm was able to shape the network dynamics so that the agent could both generate bites in response to edible food while ignoring inedible food and learn which food was edible through the reinforcement it received from its interactions with its environment. In the best evolved circuits, this learning ability generalized to much longer trial sequences than they were evolved on.” (page 391)
Is learning synonymous with changes in weights?

“Although many view synaptic plasticity as definitional of learning, strictly speaking, learning is a *behavioral* phenomena, whose underlying mechanisms remain to be empirically investigated” (page 378)

- The term learning is, in fact, a very misleading one, and one that is perhaps best abandoned as a relic of an earlier age, and an earlier misunderstanding. (Noam Chomsky, *On the nature, use, and acquisition of language*, 1999, p43)
Historical Perspectives

“Those who cannot learn from history are doomed to repeat it” - George Santayana
A little history....

Progress (hopefully)
A little history....

Psychoanalytic Theory! \rightarrow SCIENCE! \rightarrow Behaviorism \rightarrow COMPUTERS! \rightarrow Cognitive “Revolution”

Reality?
A little history....

(cont.)

The BRAIN!

Cognitive Neuroscience!

Genes!

Epigenetics!

Quantum Theory!

String Theory!

????

Reality?
A little history....

Progress (yes, actually***)

** particularly in the area of learning where there is a very clear arc of incrementally more complex and detailed science
A little history....

Key Movements

Philosophical Views
Natural Science
Experimental Psychology
Behaviorism
Cognitivism

Key technical/conceptual developments
Philosophical Approaches

(note philosopher’s beard)

http://xkcd.com/675/
Philosophical Approaches

(note philosopher’s beard)

http://chaospet.com/2009/12/14/164-it-goes-both-ways/
Philosophical Approaches

Aristotle (384-322 BC)

Plato (427-347 BC)
Philosophical Approaches

Nature!

Aristotle

Plato

Most of knowledge is inborn and acquired during past lifetimes.
Philosophical Approaches

Nature!

Aristotle

Plato

Nurture!

Memory is associations which depend on continuity, frequency, and similarity.
Philosophical Approaches

Nature! Nurture!

Memory is associations which depend on continuity, frequency, and similarity.

Contribution:

This is still a topic of endless discussion!
Nice work guys on getting the early cite on that one.
A linkage between pairs of events, sensations, or ideas such that the activation or elicitation of one (EVENT A) results in the retrieval or anticipation of the other (EVENT B).

Three key principals

- **Contiguity**: Events experience at similar point in time or space are more easily associated.

- **Frequency**: The more often we experience something, the more strongly we associate them.

- **Similarity**: When two things that are similar, thinking of one can trigger the other (e.g., chair/table, dog/cat, iPad/awesomeness).
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**Artistotelian Concept of “Associations”**

Amazingly these are still among the key principals of associative learning that we study today!!

Aristotle: 2
Plato: 1
**Descartes and Cartesian Dualism**

- **Dualism**: A distinction between the material, physical *body* and the ephemeral *mind*.

- The body worked according to mechanical principals. The most famous explanation of this was Descartes description of *reflexes* as being innately specified mechanisms for behavior that operate according to mechanical principals.

- What about free will then? That’s all in the spirit-world of the “mind”
Dualism: A distinction between the material, physical body and the ephemeral mind. The body worked according to mechanical principals. The most famous explanation of this was Descartes description of reflexes as being innately specified mechanisms for behavior that operate according to mechanical principals. What about free will then? That's all in the spirit-world of the “mind”.

Contribution: In some ways some extreme advocates of computational cognitive science advocates a similar “dualistic” view of the mind (this time grounded in the theory of computation), although subtle (see also the Mind-Body problem, embodied cognition, connectionism)
John Locke and Tabula Rasa

- Drew inspiration from advances in chemistry and advocated the concepts and ideas are built out of similar experiences (red is built of ‘cherry’, ‘apple’, and ‘sunset’ experience). Early idea of COMPOSITIONALITY.

- Suggested an important role for experience in learning (children were Tabula Rasa or blank slates)

- Politically motivated by ideas of individualism, reformation
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Contribution:

Inspired a popular television show.
Home Town Hero: William James

- **Associationism** elaborate the Aristotelian view of associations to include networks of interrelated concepts (precursor to connectionist “Rumelhart” networks)

- Initiated study of habits and automatic associations

- Aimed to eventually detail the nature of his networks directly in the brain
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**Contribution:**

Claimed to be first psychologist. A rock star in his age and now. Most of modern psychology can be traced to his ideas.
Ever heard of **evolution of species**? Yeah, more or less first to strongly and coherently propose that idea.

How about **natural selection**? Ever heard of that? Yeah, discovered that too.

Most influential theory in contemporary science. The standard by which your dissertation will definitely be held. No formal training, took 20 years to write... you have a computer.

Relevance for learning: The key is that evolution is not Lamarckian. Your experience can’t be passed directly to your children through genes. Instead, your **capacity** for learning can be passed/selected for!!
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The Darwins

Fairly well known scientist who made modest contributions to human knowledge.
Francis Galton (a Darwin grandson)

- Nativist, father of eugenics an idea he never quite lived down.
- Amazing empiricist who set to measuring everything he could get his hands on
- Examined variability and inheritability of traits (including some of the first intelligence tests)
- Father of modern statistics (correlational studies, bell curve)
- Wisdom of the crowds effects
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Contribution:

Inheritability of traits including mental abilities (IQ). Modern statistical methods and correlational study designs.
Studying digestion and salivation in dogs

Noted that the dogs started salivating before the daily feeding (e.g., when they saw the bowl or heard the research assistants coming via footsteps)

Started an empirical lab focused on studying how animals learn such associations (CLASSICAL CONDITIONING or PAVLOVIAN CONDITIONING)

Also introduced the idea of EXTINCTION (unlearning or suppression of a previously learned response).

Looked at how animals GENERALIZE response from one cue to another (e.g., a metronome at 80bpm to 90bpm)

Ivan Pavlov (1849-1936)
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Ivan Pavlov (1849-1936)

Ivan Pavlov (1849-1936) was fundamental to the modern study of behavioral science, particularly learning. We’ll devote a couple classes to classical conditioning!
“Of several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to recur; those which are accompanied or closely followed by discomfort to the animal will, other things being equal, have their connections with that situation weakened, so that, when it recurs, they will be less likely to occur” (Thorndike, 1911)
Edward Thorndike and the Law of Effect

- Basically, repeat what works and is rewarding more, and stop doing things that lead to pain/punishment!

- Influenced by Darwinian ideas of natural selection (in this case certain behaviors within an organism are adaptively selected by the environment using a fitness function related to reward)

- The first reinforcement learning RL researcher (now a pretty large and growing area of neuroscience and computer science)

- His work really set the stage for behaviorism
Edward Thorndike and the Law of Effect

Along with Pavlov a key player in making learning and behavior a quantitative natural science. Rigors methods and control in behavioral experiments. Importance of reward in shaping behavior
Drawing from work of Pavlov and Thorndike was the leading proponent of BEHAVIORISM a movement in psychology during the middle part of the last century to do away with ideas from philosophy and psychoanalytic theory.

Focus on observable behavior and stimulus-response associations rather than on internal processes like thoughts, representation, feelings, emotions.

Advocate for the idea that psychology was a “purely objective experimental branch of natural science. It’s theoretical goal is the prediction and control of behavior.” (Watson, 1913)

Strong nativist, studied classical conditioning in humans (e.g., Little Albert experiment). Also did (controversial) work on rats showing habit formation/control of behavior absent sensory input.
Give me a dozen healthy infants, well-formed, and my own specified world to bring them up in and I'll guarantee to take any one at random and train him to become any type of specialist I might select – doctor, lawyer, artist, merchant-chief and, yes, even beggar-man and thief, regardless of his talents, penchants, tendencies, abilities, vocations, and race of his ancestors. I am going beyond my facts and I admit it, but so have the advocates of the contrary and they have been doing it for many thousands of years. [Behaviorism (1930), p. 82]
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Contribution:

Founder of behaviorism, stood on the shoulders of Pavlov and Thorndike to advance modern theories of learning. Quit academics and went into advertising (much scarier than his experiments).
**Skinner and Radical Behaviorism**

- Fewer of the general public knows about Watson compared to Skinner who was a bonafide celebrity scientist (appearing on the cover of Time magazine).

- Advocate of the so called “RADICAL BEHAVIORISM” perspective which argued that all things (including for instance language) could be understood in behaviorist (stimulus-response) terms

- A number of important empirical findings about learning (intermittent feedback), etc..

- Unfortunately strongly remembered as the foil for Chomsky’s influential book review of Skinner’s “Verbal Behavior” book which ushered the cognitive revolution
What’s wrong with behaviorism?

- The focus on establishing psychology as a hard, quantitative science. Behaviorism excluded much possible data and denied much of our mental lives.

- The enthusiasm that the early success in basic learning (Pavlov, Thorndike, etc...) lead to an over enthusiasm that other problems (such as language) would fall in a similar way.

- However, the focus has squarely shifted to cognitive and computational approaches which emphasize the structure of internal mental processes and how the brain represents the external environment.
Edward Tolman

- An early "cognitivist" in a way

- Argued that the behavior of rats was not simply stimulus-response pairings but of purposeful, goal-directed behavior

- Showed evidence of "problem solving" by rats who could find new routes to a goal in a single trial when blocked on a preferred route

- Could navigate to a goal starting from a novel start location in the maze

- A model of the environment - COGNITIVE MAP

- Latent learning (exploring a structured environment leads to creation of this map which can support later learning)
Hull, Estes and Mathematical Models of Learning Behavior

- Clark Hull (1884-1952) and William Estes wanted to bring quantitative precision to studies of behavior and learning.

- Sought formal equations that would relate probability of response to things like strength of stimulus and reinforcement schedule.

- Credited with first attempts to develop theories that compare to those in physics (E=mc^2) to explain behavior.

- Estes made a number of important theoretical contributions including STIMULUS SAMPLING theory, probabilistic modeling, memory models (exemplar approaches), etc., and also is credited with the CONDITIONED EMOTIONAL RESPONSE paradigm for studying fear learning.

- Estes was Skinner’s student who hated his work and thought he went crazy doing too much math!! (Note: Don’t know how true that is)
The death of behaviorism lead to increased interest in ideas of cognitive representation, unobservable mental processes, thinking & reasoning, etc...

Paralleled developments in computers at the time (symbolic AI systems)

Simon and Newell were the originators of the idea that the mind could work by manipulation SYMBOLIC REPRESENTATIONS (i.e., representations that stand for something in the external environment)

Emphasize planning, reasoning, decision trees, search processes in solution spaces, etc...

Paralleled work by Chomsky on symbolic representations in language (grammar learning, etc...)
While symbolic AI systems were useful metaphors there was a lack of biological plausibility to the kind of computations they perform.

The brain isn’t much like a traditional von Neumann computer architecture (i.e., the one in your laptop), but instead is instantiated in neural hardware.

CONNECTIONISM is a branch of cognitive science devoted to the study of how interconnected, neural-like assemblies might give rise to human thought.

Key idea of DISTRIBUTED REPRESENTATION whereby multiple unit contribute to the representation of a thought or idea.

Figure 1. Interactive Activation Network Model (after McClelland and Rumelhart, 1981).
Interim Summary

- Progress in the scientific study of learning has been slow and steady... NOT characterized by successive movements which blast each other into oblivion. Indeed, early philosophical ideas still hold considerable weight.

- Rediscovering ideas that people found 100-1000 years early is a sure path to fame and glory... Plato, Aristotle, Darwin, and Galton are the winners of our survey. Everyone else made a career referencing their ideas. :)

- Arguing about nature vs. nurture is sure to give some mileage.

- Learning is a detailed and quantitative science informed by multiple sources of evidence (neuroscience, philosophy, psychology).

- The history of learning science shows how at each stage research has been shaped by compelling technological developments of the time (mechanical systems, pipes, flowing water, symbolic computers, parallel machines).
Innate Behaviors and Adaptation (nature vs. nurture)

- How much of changes in PERFORMANCE can be attributed to biological changes within the organism versus experience?

- Very few things are only one thing or the other. You can make a career out of pushing one, but if you want to be right you will recognize they are two sides of the same coin.

- One productive way to think about this is in a term from machine learning: INDUCTIVE BIAS.

  - Any machine learning algorithm can learn some thing better than others. This difference is the BIAS in the system and is typically specified by the ARCHITECTURE of the system.

  - The inductive bias doesn’t constrain what is learned (experience shapes learning) but does influence how easy certain things may be to learn.

  - It is like the “preparedness” of the system.
Levels of Analysis: An Example from Owls

<table>
<thead>
<tr>
<th>level</th>
<th>issues</th>
<th>the barn owl example</th>
</tr>
</thead>
<tbody>
<tr>
<td>computational theory</td>
<td>What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?</td>
<td>Use timing [and intensity] differences measured at two locations to pinpoint the source.</td>
</tr>
<tr>
<td>representation and algorithm</td>
<td>How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?</td>
<td>Use coincidence detection and delay lines to transform time difference into a place code in the brain.</td>
</tr>
<tr>
<td>hardware implementation</td>
<td>How can the representation and algorithm be realized physically?</td>
<td>Arrange the neurons spatially and wire them up to reflect the algorithmic solution.</td>
</tr>
</tbody>
</table>

Table 4.2 — Marr’s levels of understanding, exemplified on sound localization in the barn owl.
Key Principals for the Semester

- Learning and memory are closely related and intertwined states of information processing
- Major insights about learning and memory have come from studies of the brain
- The concept of multiple memory systems unifies the study of learning and memory
- The underlying bases of learning and memory are the same in humans and animals
- Our theoretical approaches to studying learning are always closely tied to technological advances that are unfolding in general society (e.g., today - machine learning)
Readings

Textbook reading: Gluck, Ch. 1 - *The psychology of learning and memory*


Additional Reading:

Optional Reading (discussed in lecture):
References for Slides


Lecture notes from Yael Niv (http://www.princeton.edu/~yael/PSY338/index.html)

The interweb.