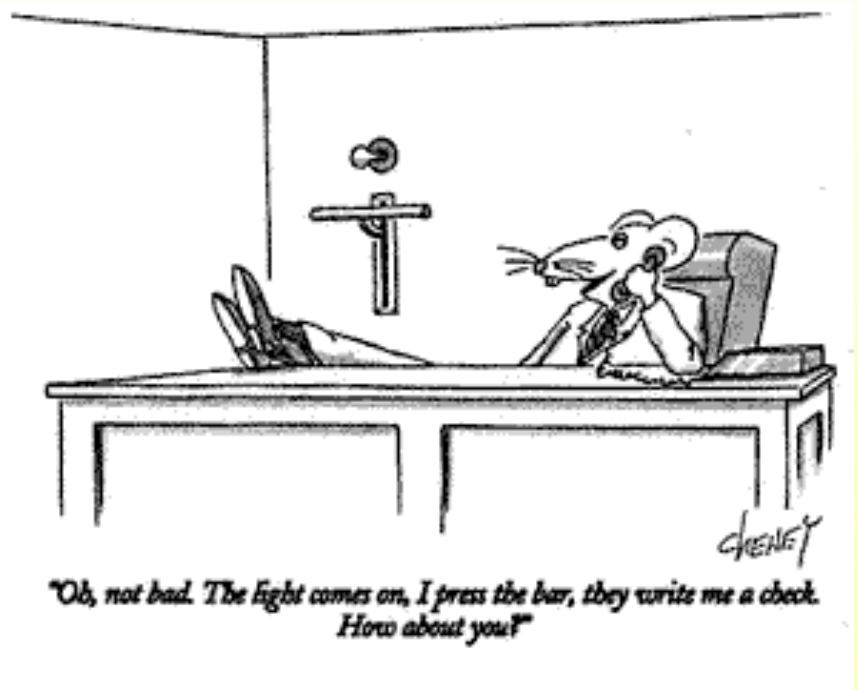
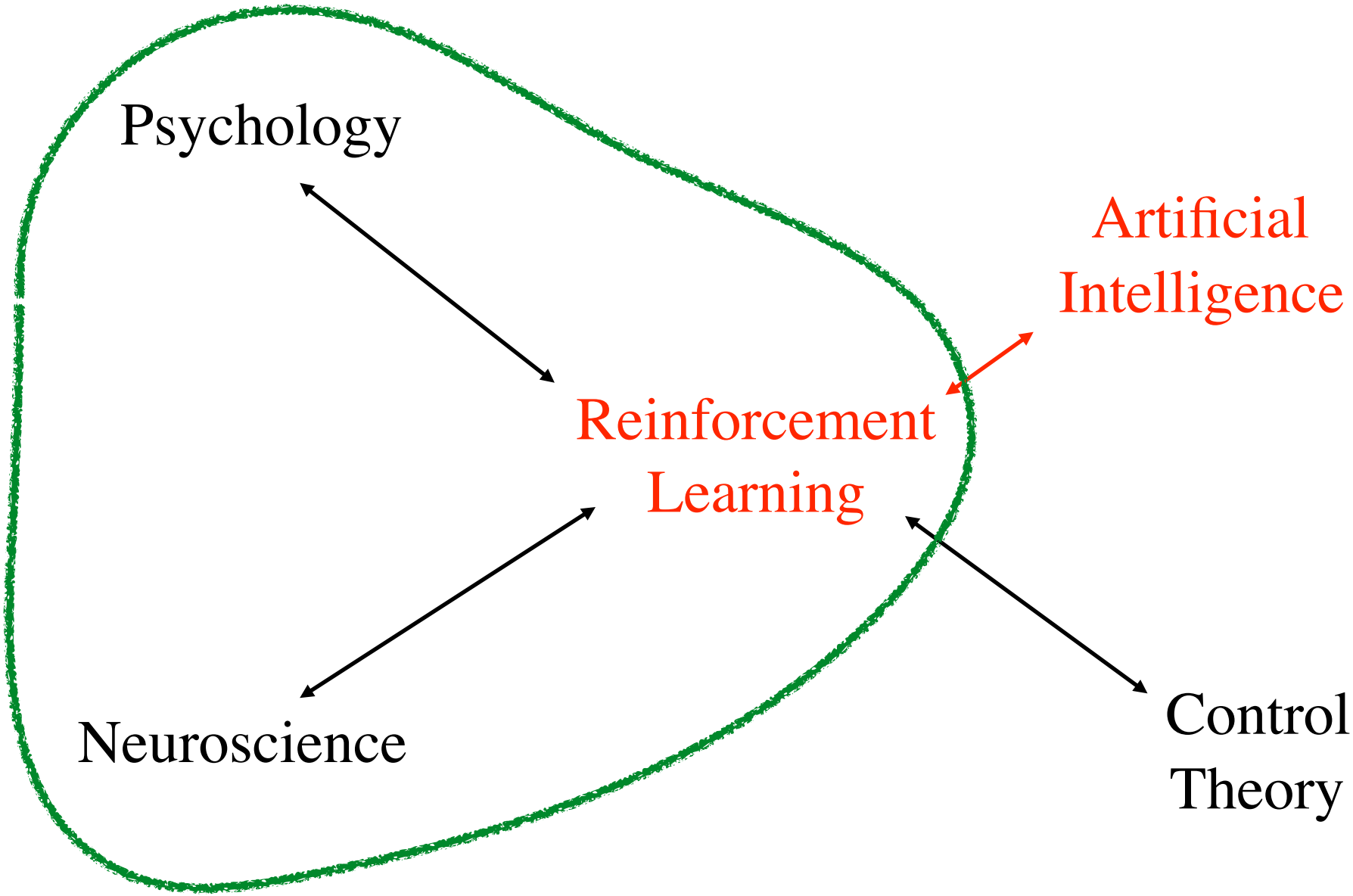
Reinforcement Learning in Psychology and Neuroscience



with thanks to
Elliot Ludvig
University of Warwick


Psychology
Artificial
Intelligence
Reinforcement
Learning
Neuroscience
Control
Theory

Any information processing system can be understood at multiple "levels"

- The Computational Theory Level
  - *What* is being computed?
  - *Why* are these the right things to compute?
- Representation and Algorithm Level
  - *How* are these things computed?
- Implementation Level
  - How is this implemented physically?

David Marr, 1972

Goals for today's lecture

- To learn:
  - That psychology recognizes two fundamental learning processes, analogous to our prediction and control.
  - That all the ideas in this course are also important in completely different fields: psychology and neuroscience
  - That the details of the TD(λ) algorithm match key features of biological learning

Psychology has identified two primitive kinds of learning

- *Classical* Conditioning
- *Operant* Conditioning (a.k.a. Instrumental learning)
- Computational theory:
  - *Classical* = Prediction
    - What is going to happen?
  - *Operant* = Control

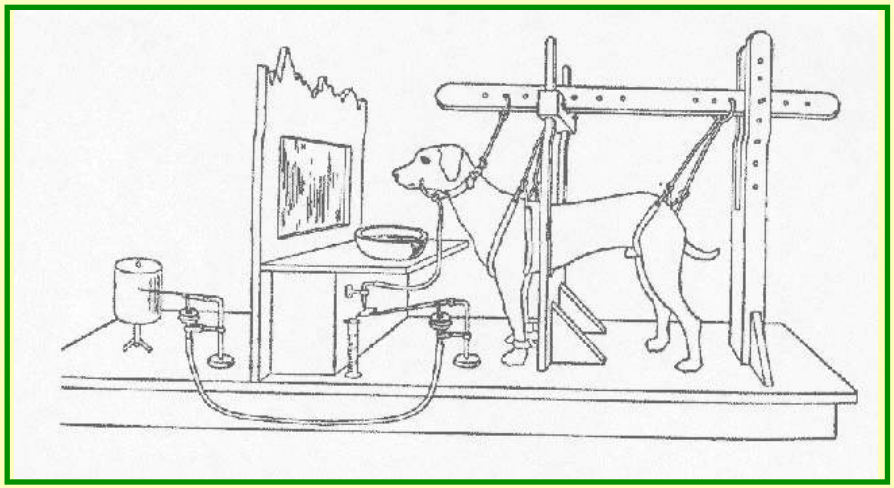
Classical Conditioning

Classical Conditioning as Prediction Learning

- Classical Conditioning is the process of learning to predict the world around you
  - Classical Conditioning concerns (typically) the subset of these predictions to which there is a hard-wired response

Pavlov (1901)

- Russian physiologist
- Interested in how learning happened in the brain
- Conditional and Unconditional Stimuli



Is it really predictions?

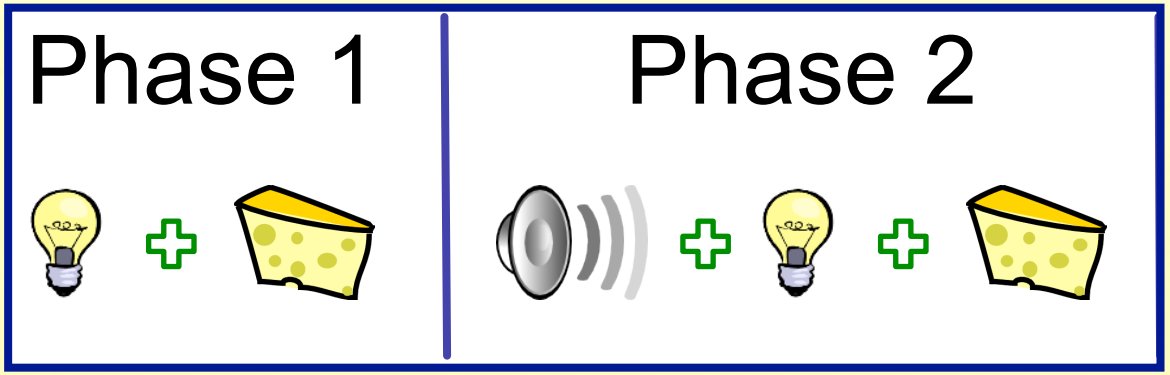
Maybe Contiguity?

- Foundational principle of classical associationism (back to Aristotle)
  - Contiguity = Co-occurrence
  - Sufficient for association?

Contiguity Problems

- Unnecessary:
  - Conditioned Taste Aversion
- Insufficient:
  - Blocking
  - Contingency Experiments

Blocking



Rescorla-Wagner Model (1972)

- Computational model of conditioning
  - Widely cited and used
- Learning as violation of expectations
  - As in linear supervised learning (p2)
  - TD learning is real-time extension

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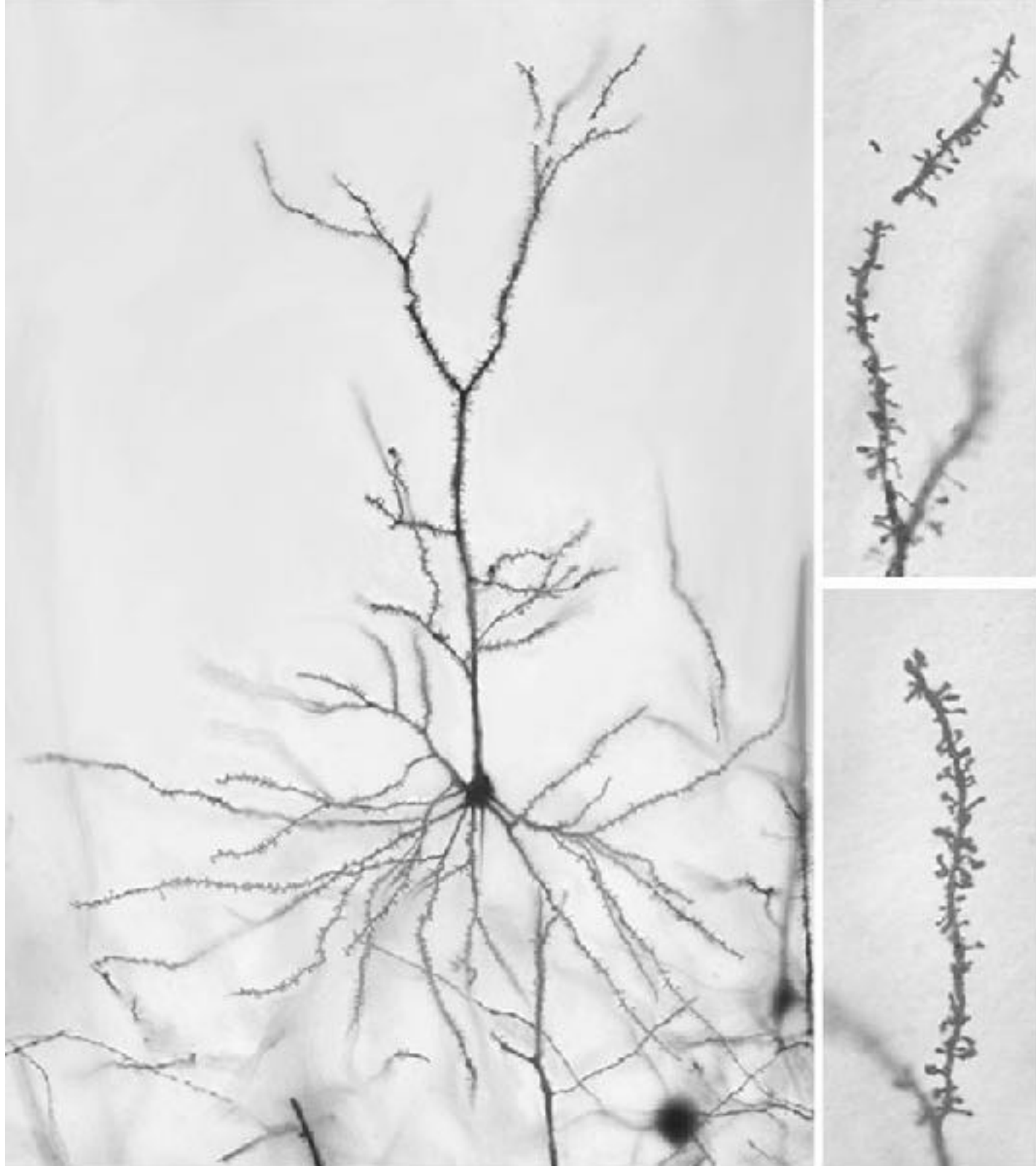
David Marr, 1972

The Basic TD Model

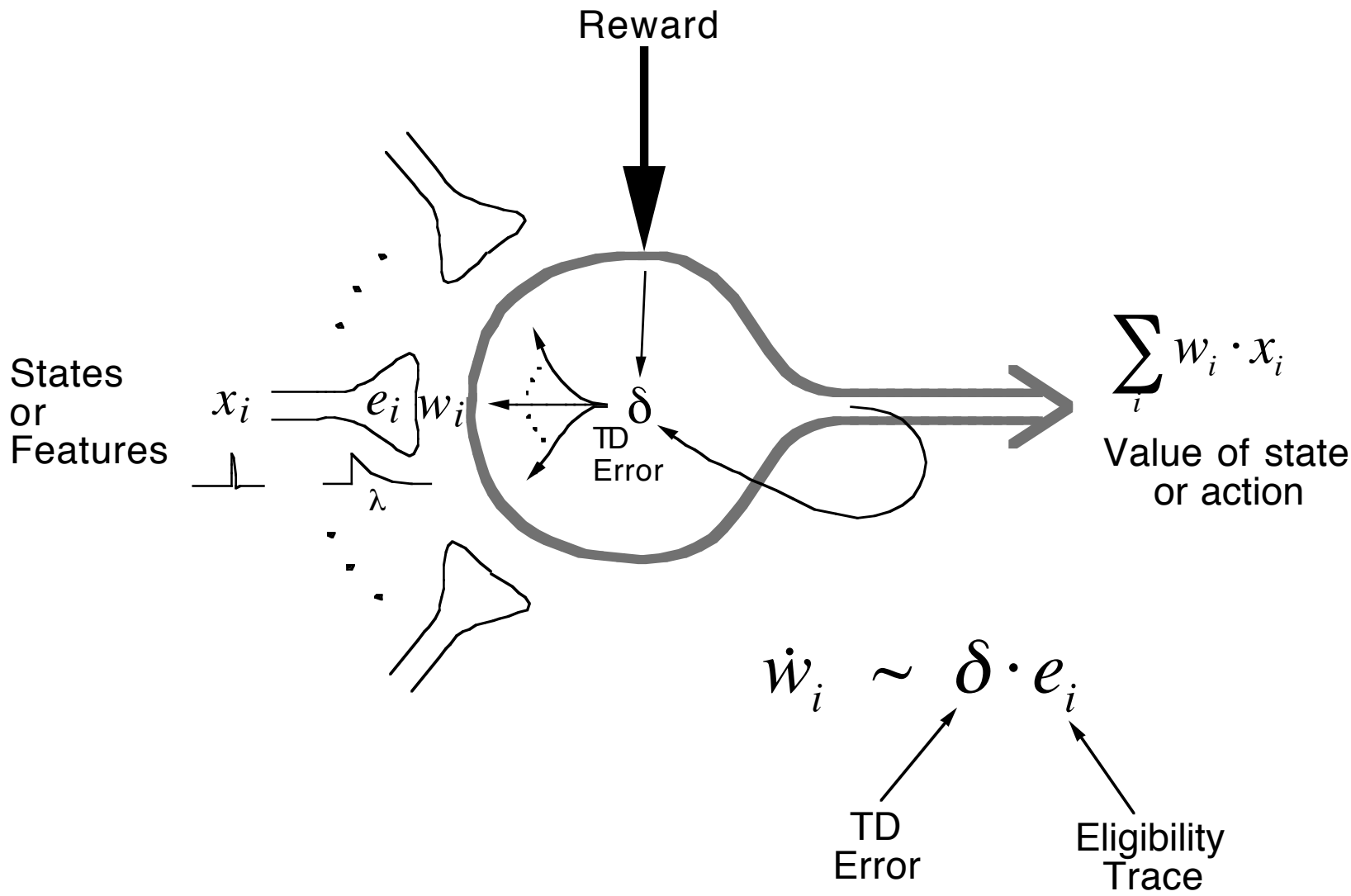
- Learn to predict discounted sum of upcoming reward through TD with linear function approximation

- The TD error is calculated as:

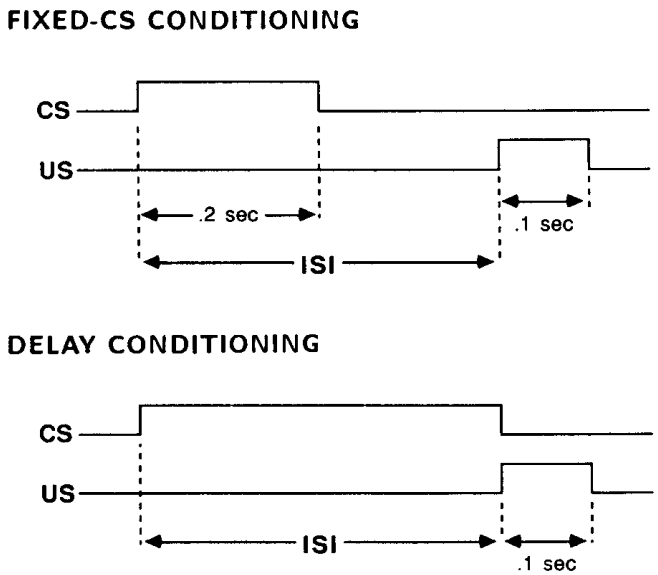
$$\delta_t = R_{t+1} + \gamma \hat{v}_{t+1} - \hat{v}_t$$



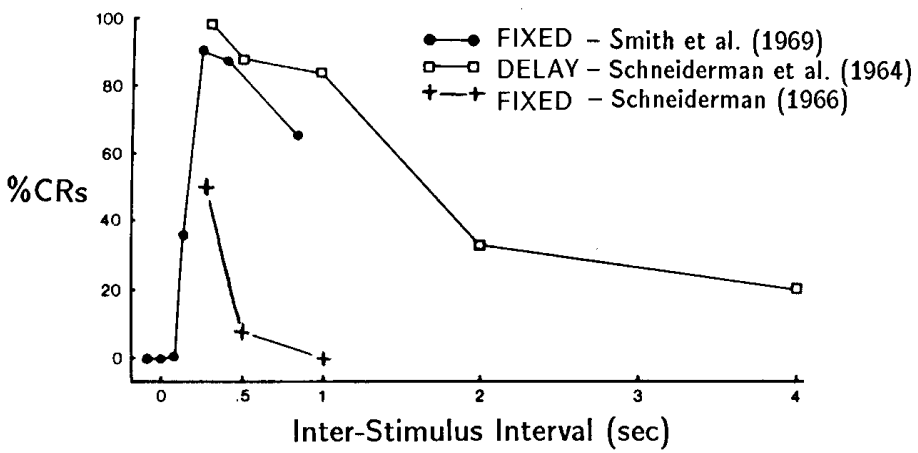
TD(λ) algorithm/model/neuron



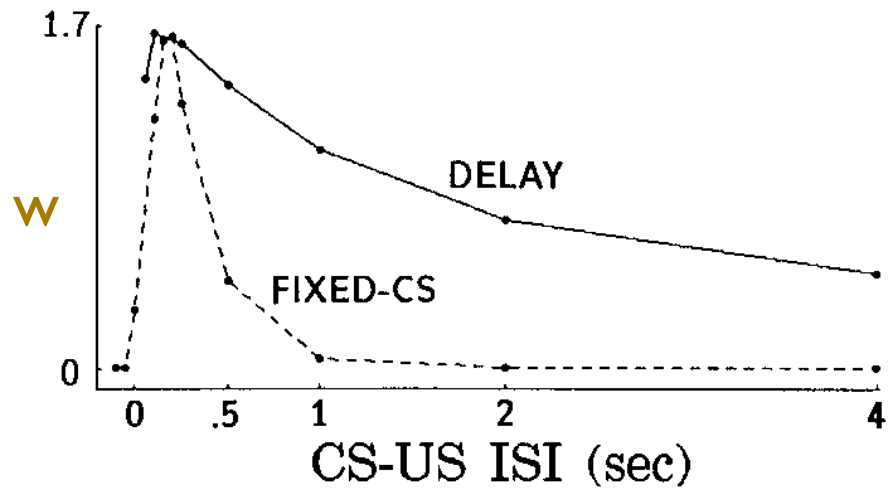
Effect of inter-stimulus interval



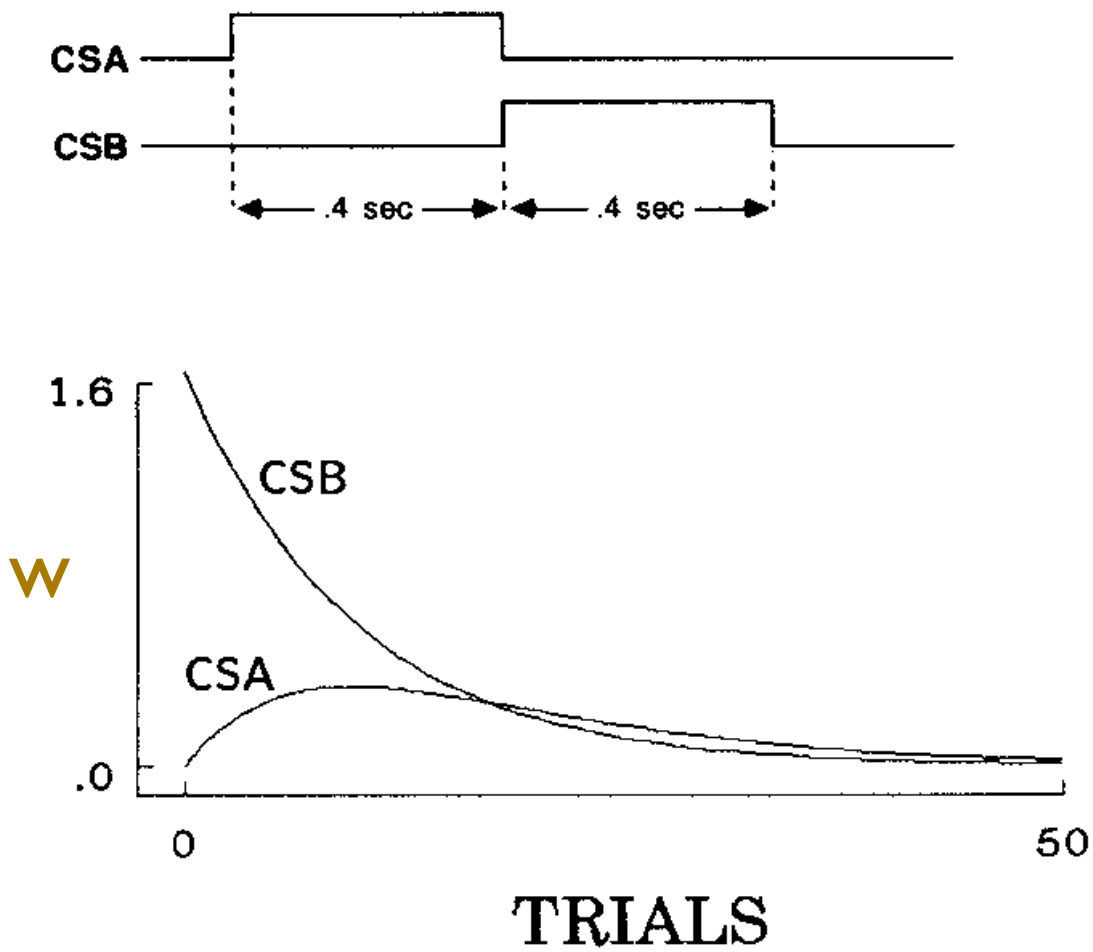
Animal data (eyeblink)



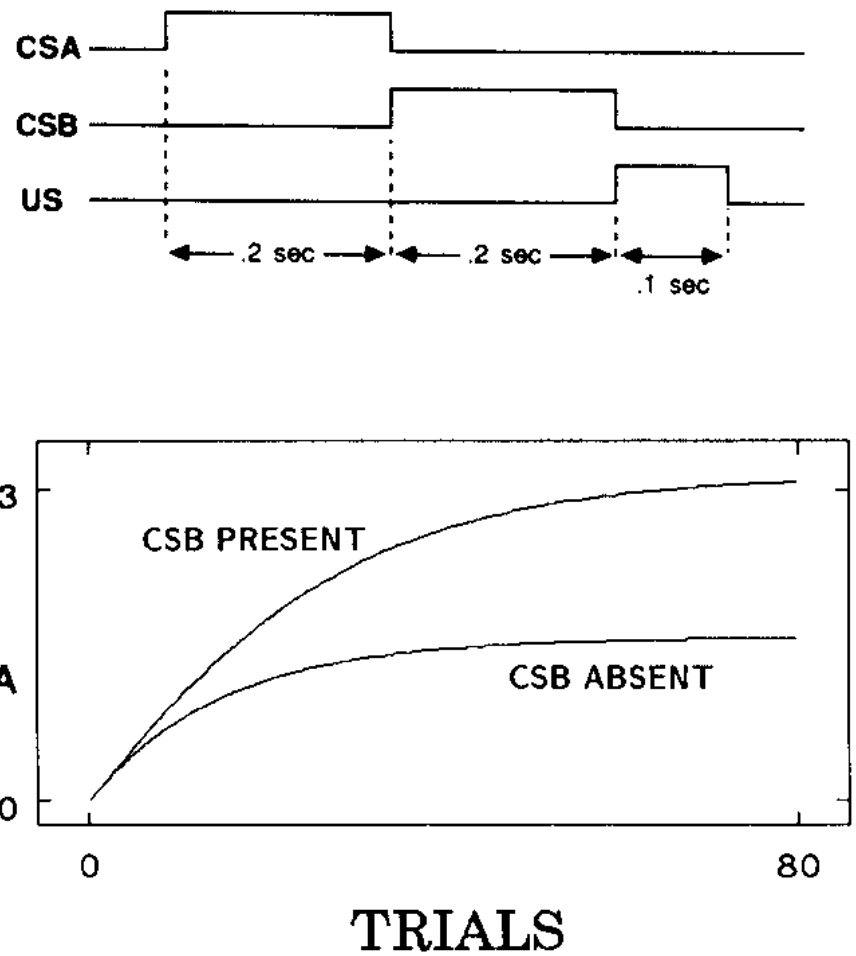
TD model



Second-order conditioning in the TD model

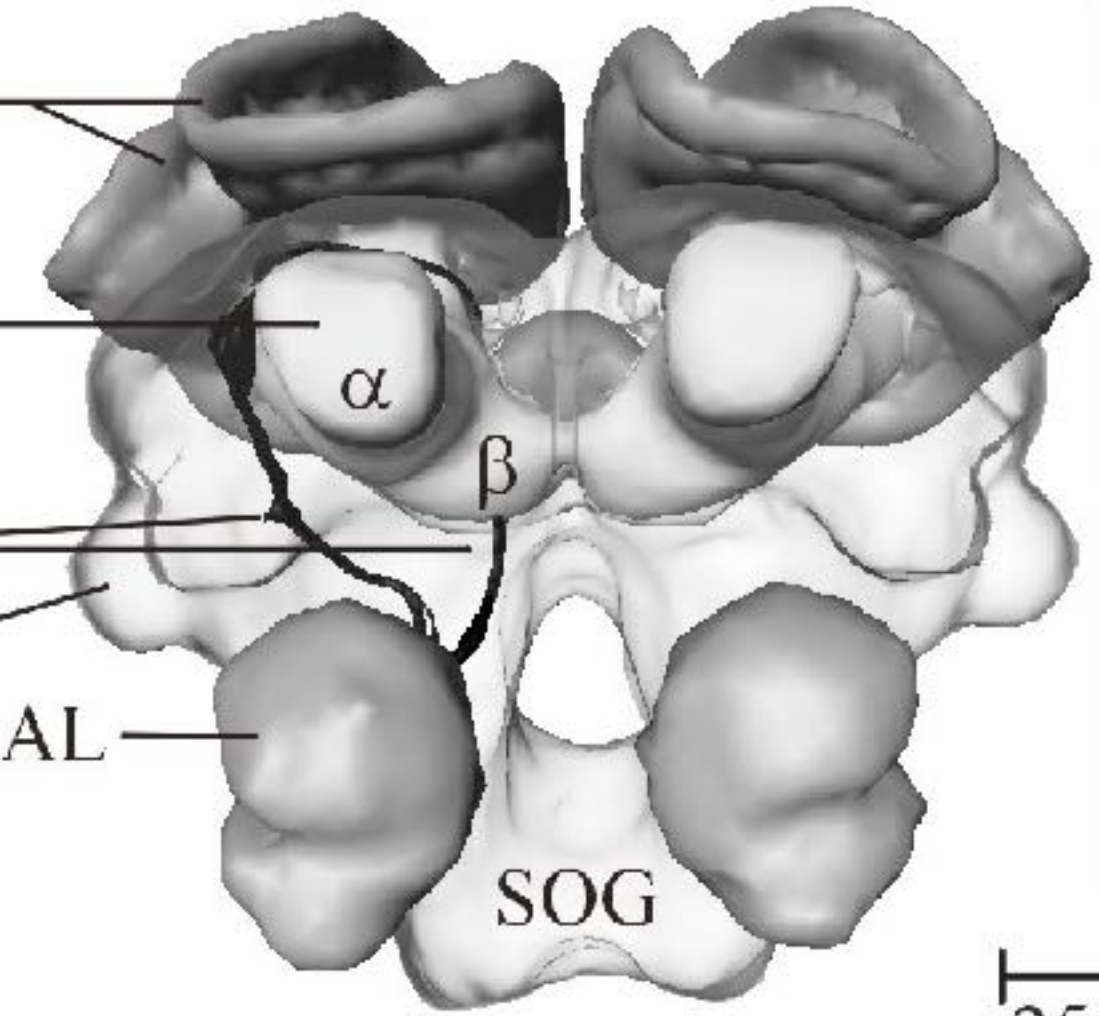


Primacy effect in the TD model

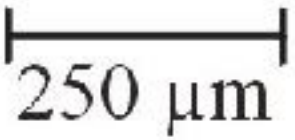


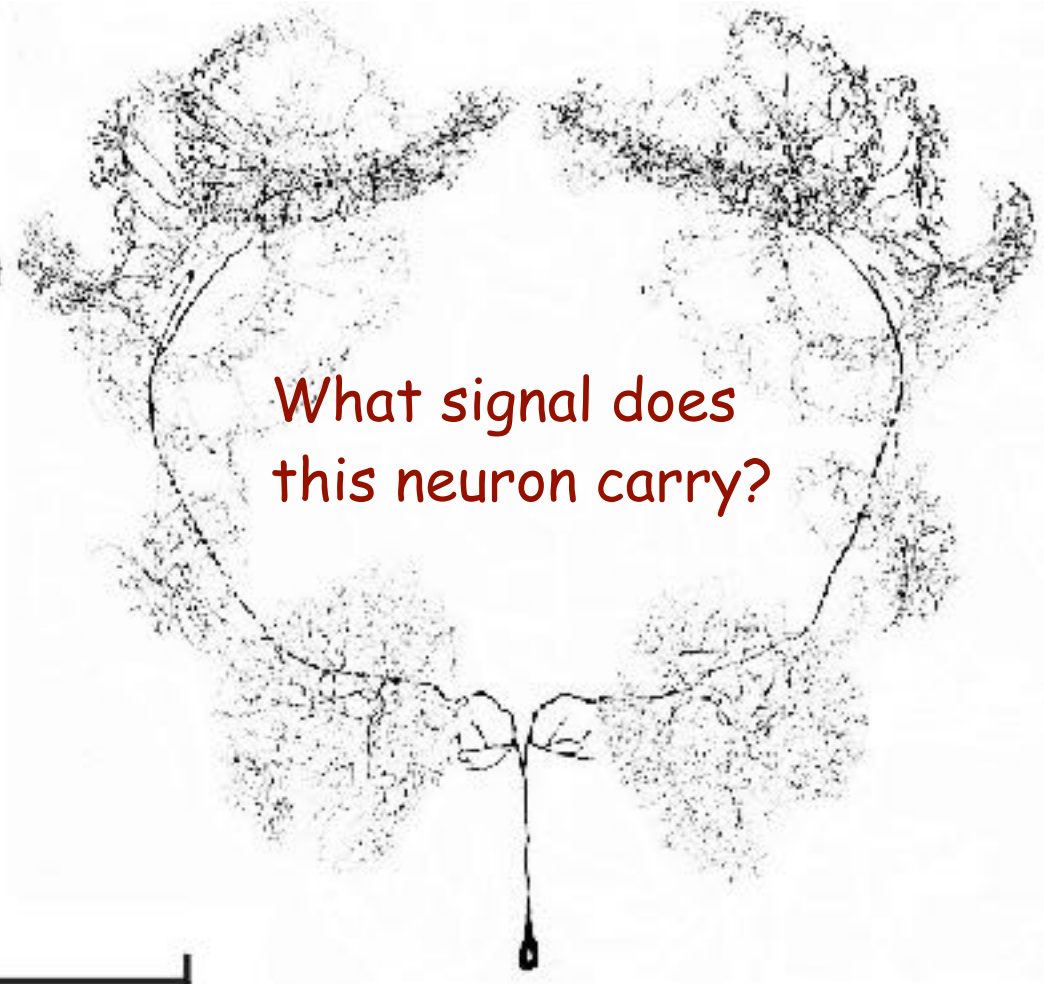
Facilitation of a remote association by an intervening stimulus

Brain reward systems



Honeybee Brain





VUM Neuron

Hammer, Menzel

Dopamine

- Small-molecule Neurotransmitter
  - Diffuse projections from mid-brain throughout the brain

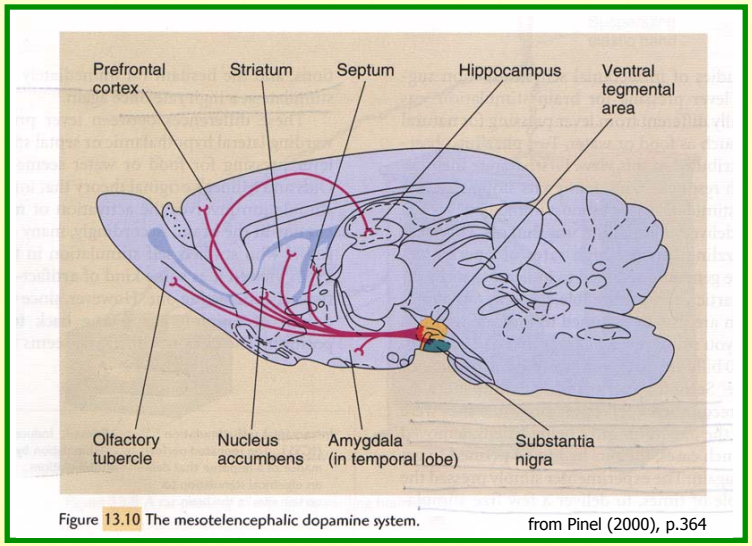


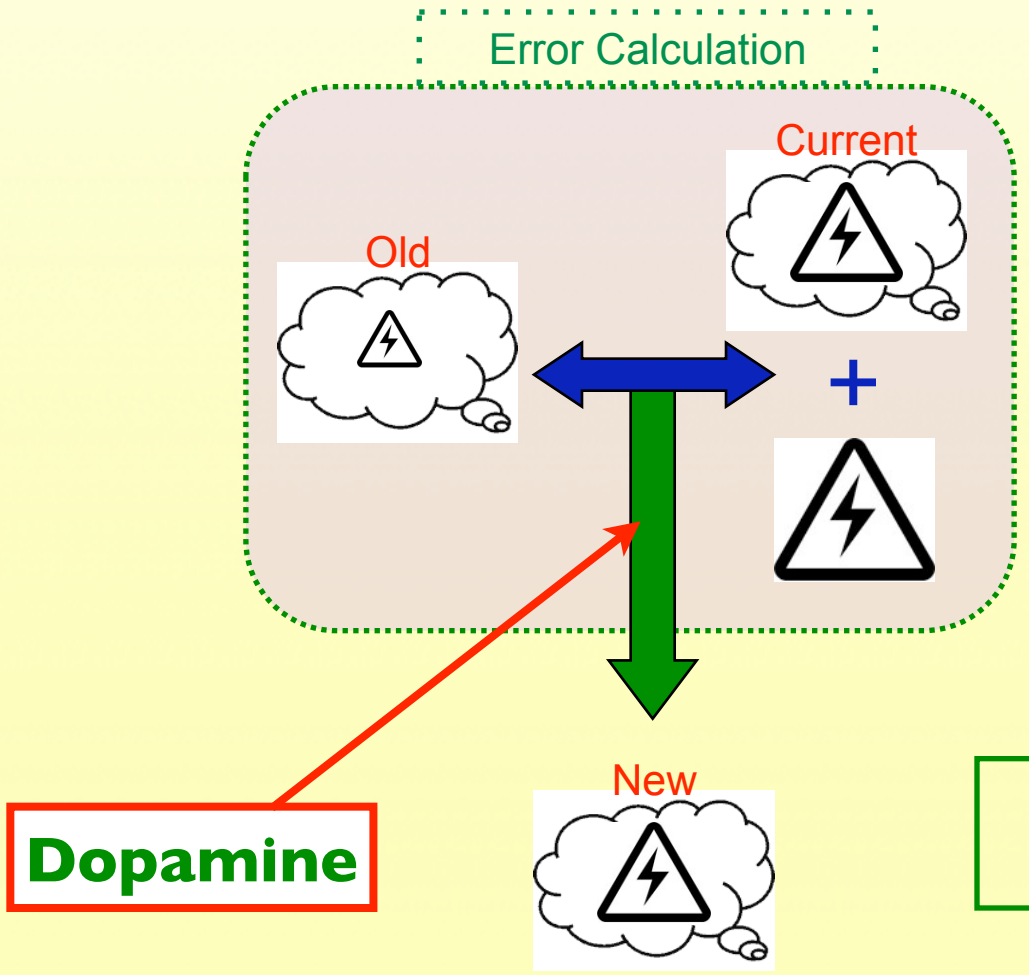
Figure 13.10 The mesotelencephalic dopamine system. from Pinel (2000), p.364

Key Idea: Phasic change in baseline dopamine responding = reward prediction error

What does Dopamine Do?

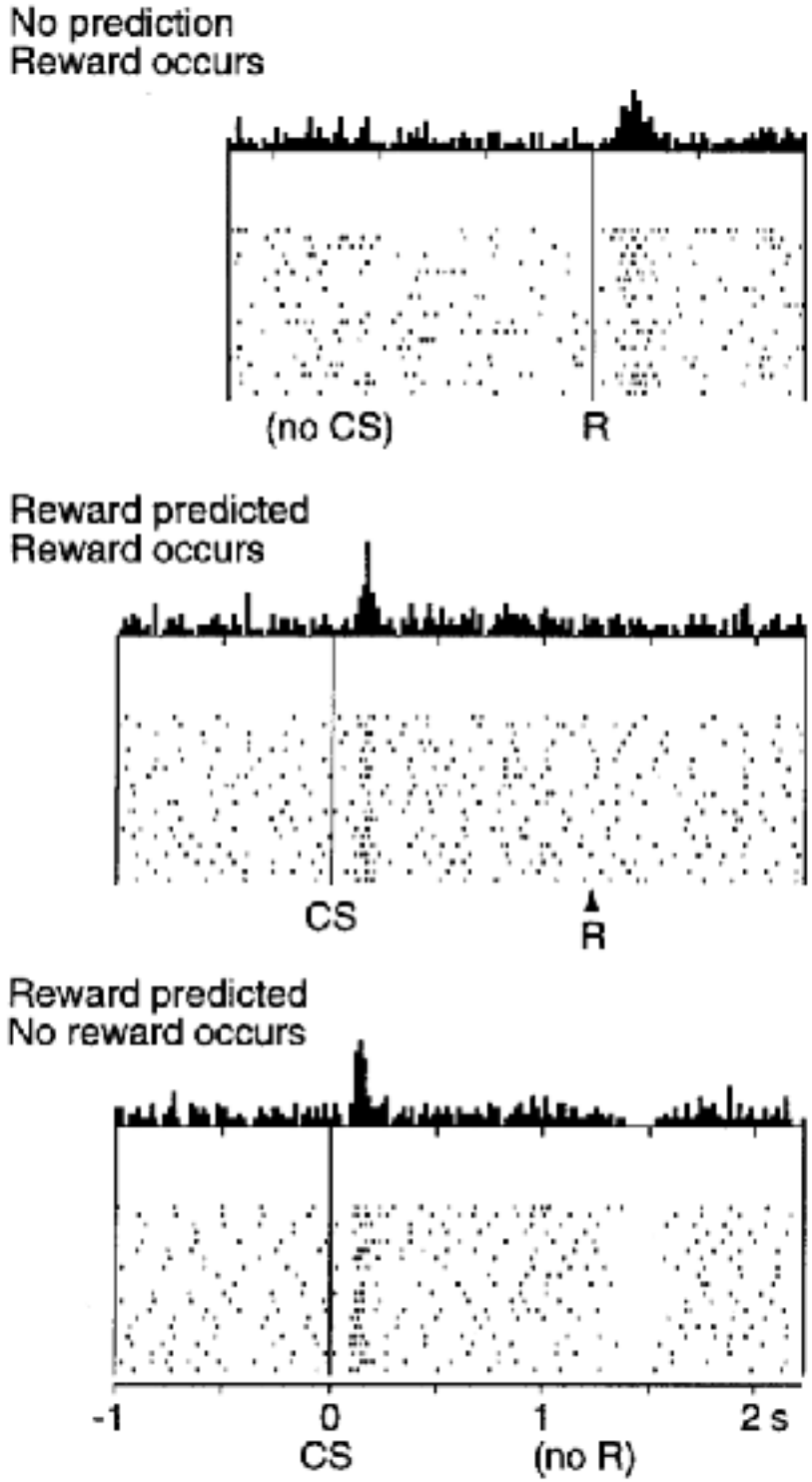
- Hedonic Impact
- Motivation
- Motor Activity
- Attention
- Novelty
- Learning

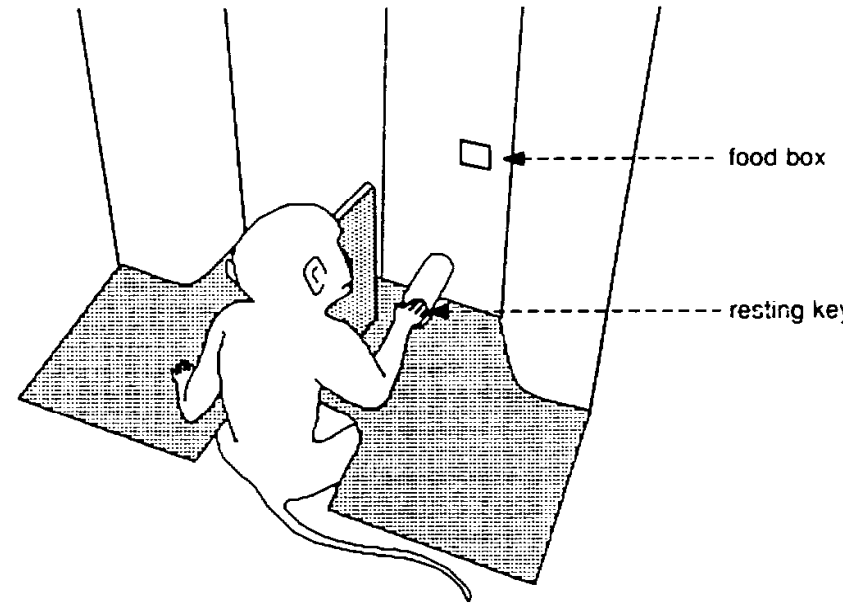
TD Error = Dopamine



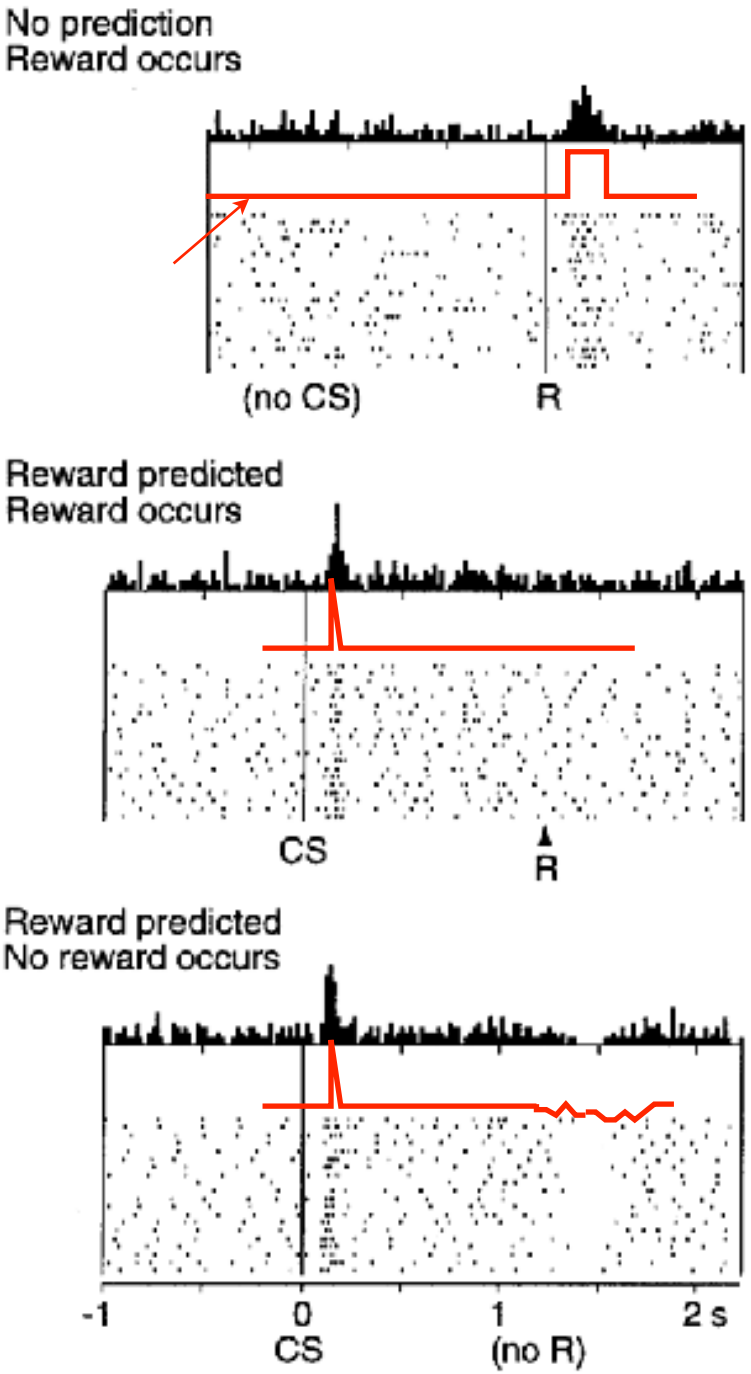
Schultz et al., (1997);
Montague et al. (1996)

Dopamine neurons signal the error/change in prediction of reward





Wolfram Schultz, et al.



Reward Unexpected

Reward

Value

TD error

Reward Expected

Cue

Value

TD error

Reward Absent

Value

TD error

$$\delta_t = R_{t+1} + \gamma \hat{v}_{t+1} - \hat{v}_t$$

The theory that *Dopamine = TD error*
is the *most important interaction ever*
between AI and neuroscience

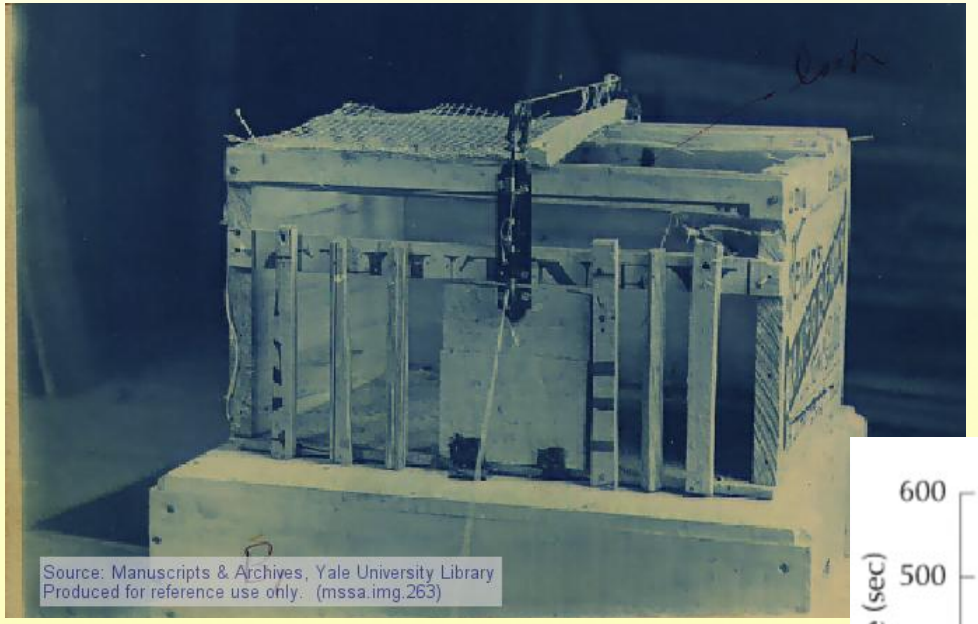
Operant Learning

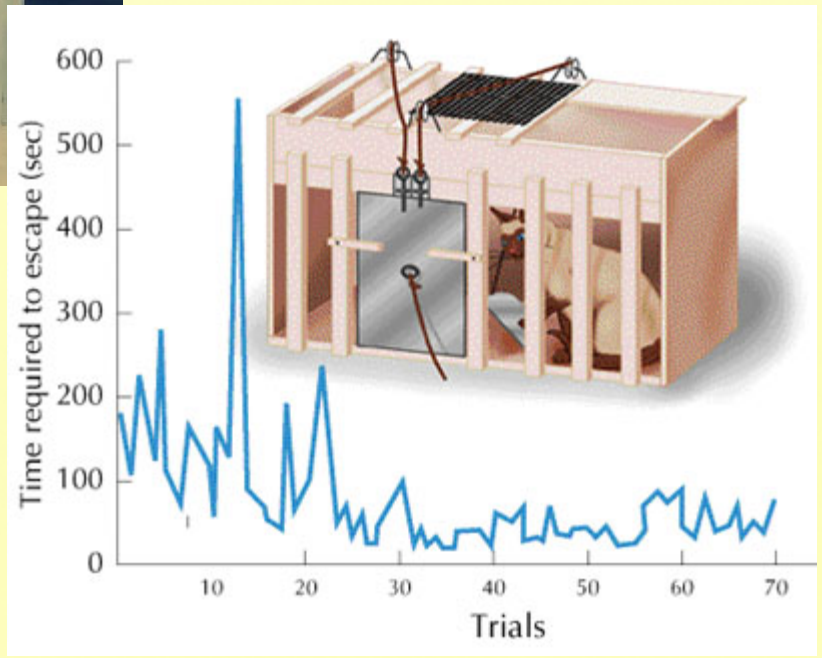
- The natural learning process directly analogous to reinforcement learning
- Control! What response to make when?

Rat Basketball at Wofford College

QUINTESSENTIAL... A WOFFORD EDUCATION

Thorndike's Puzzle Box (1910)

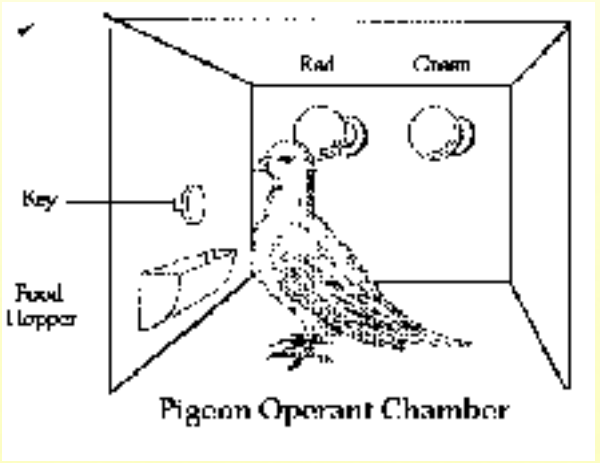




Law of Effect

- "Of several responses made to the same situation, those which are accompanied by 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..." - Thorndike (1911), p. 244

Operant Chambers

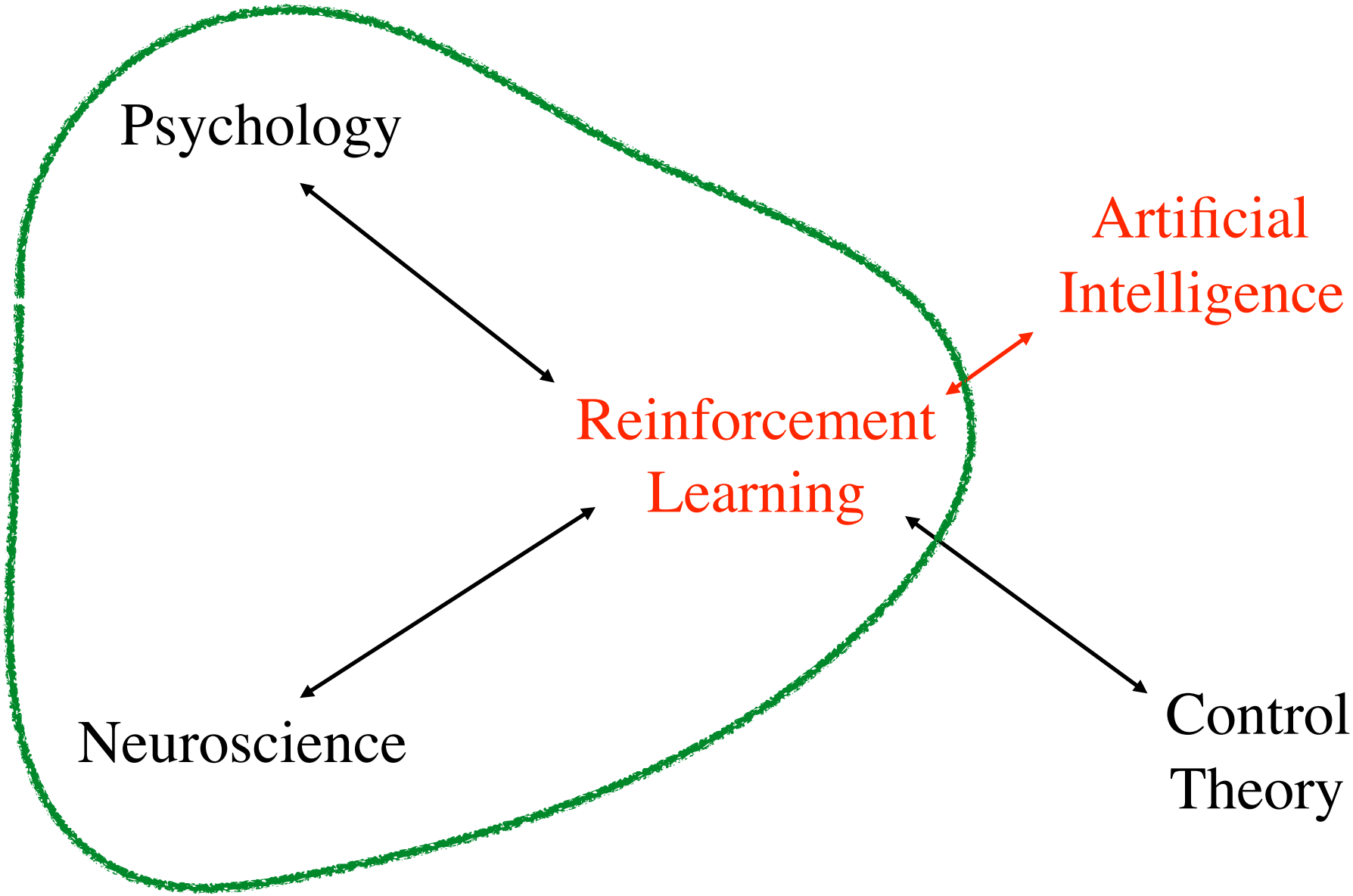


Pigeon Operant Chamber

Complex Cognition

What have you learned about in this course (without buzzwords)?

- "Decision-making over time to achieve a long-term goal"
  - includes learning and planning
  - makes plain why value functions are so important
  - makes plain why so many fields care about these algorithms
    - AI
    - Control theory
    - Psychology and Neuroscience
    - Operations Research
    - Economics
  - all involve decision, goals, and time...
    - the essence of...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