Motivation in ACT-R

ICCM ACT-R Workshop

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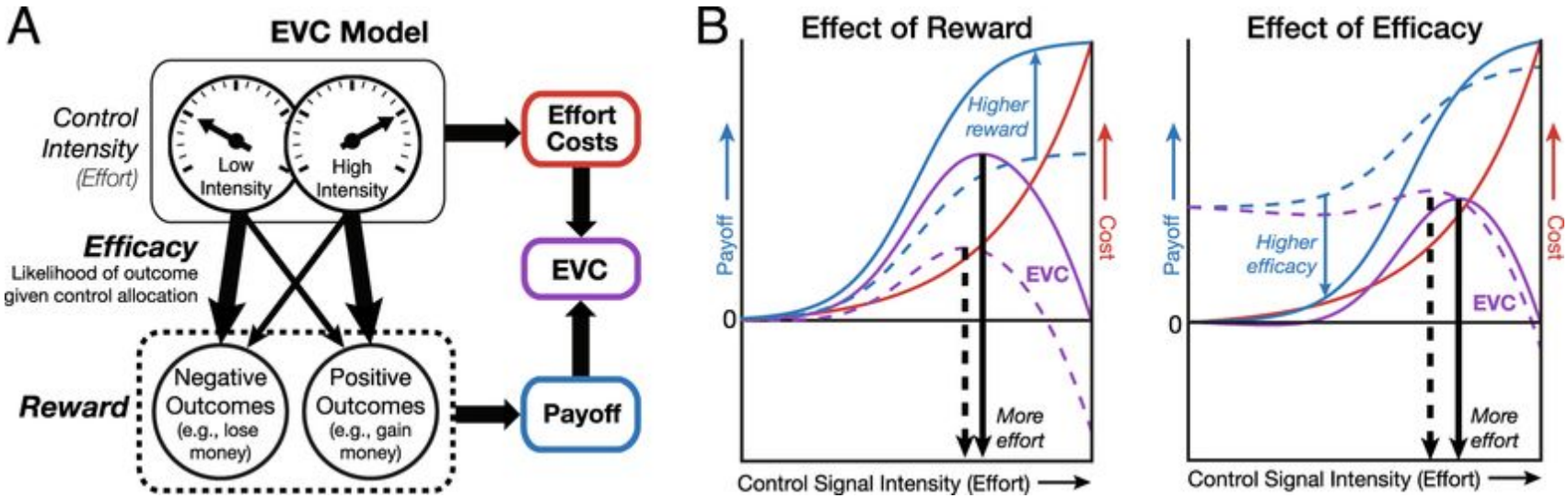
Modeling Motivation

- Motivation is described as an **unobservable driving force** behind behaviors, which is **interacting with many cognitive functions**
- It's crucial to study motivations:
  - the mechanisms of behavior drives
  - individual differences
  - predict learning process
- Computationally, motivation is nothing but **decision-making analysis**. People evaluate cost-benefit tradeoffs in order to maximize gains and minimize costs while performing tasks.

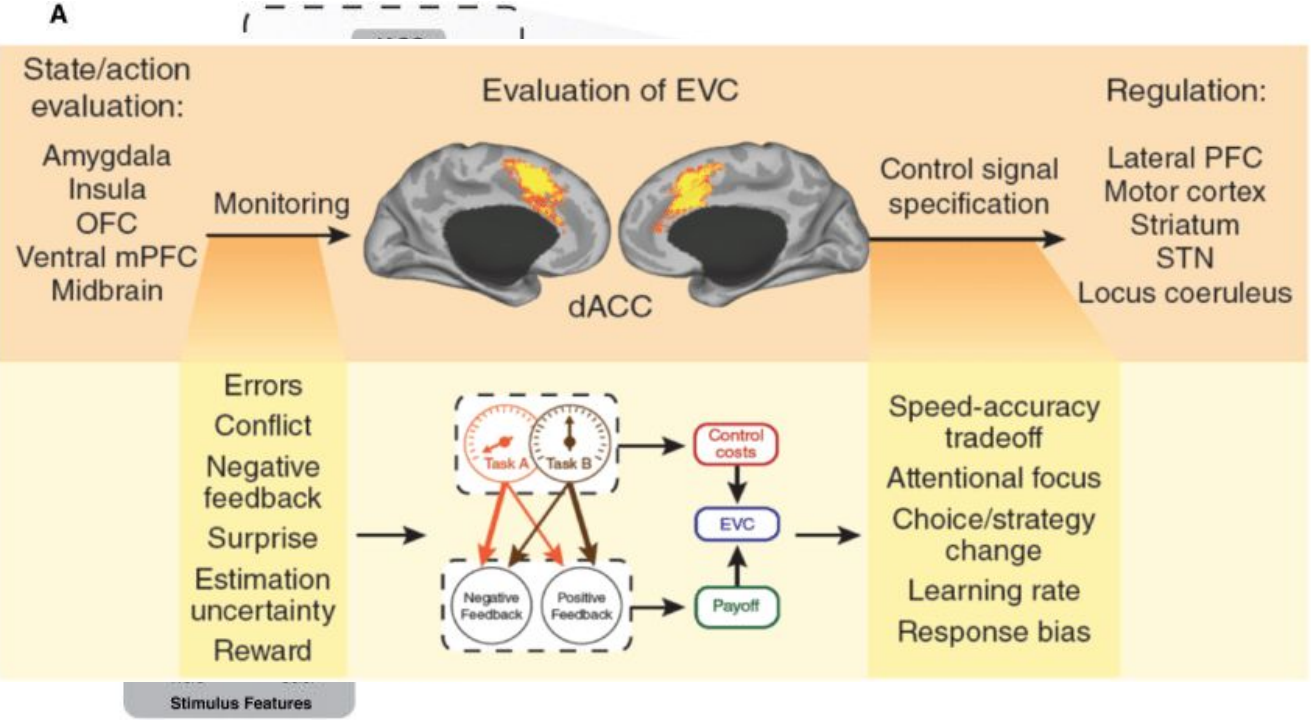
Expected Value of Control (EVC) Theory



$$EVC(signal, state) = \sum Pr(outcome_i | signal, state) * Value(outcome_i) - Cost(signal)$$

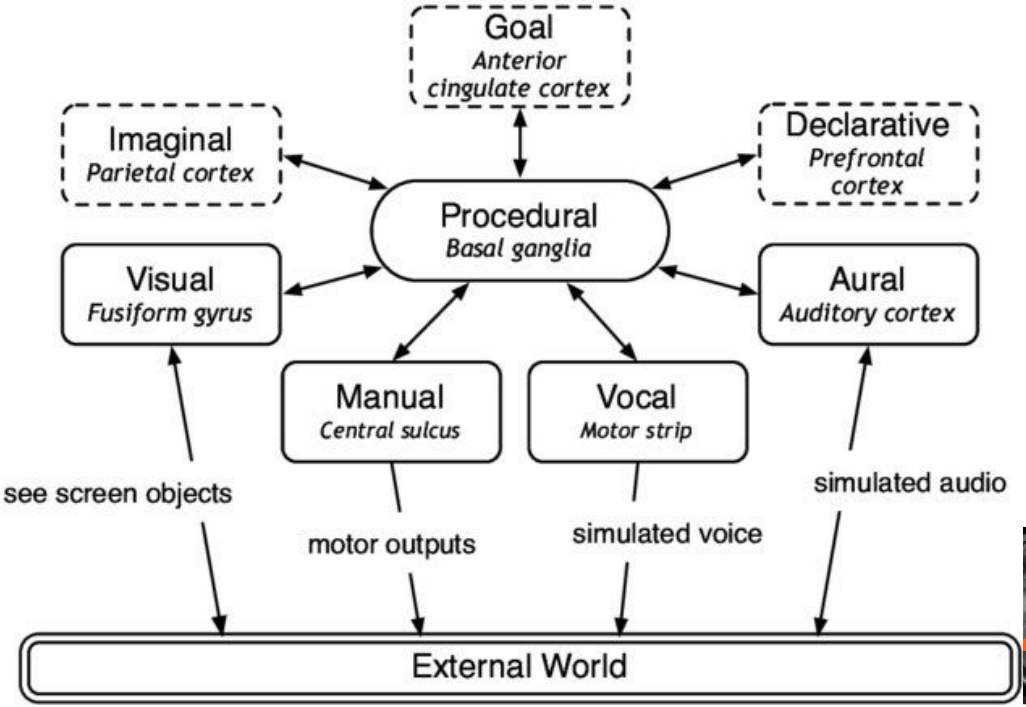
Motivation in the Brain

dorsal Anterior Cingulate Cortex (dACC)



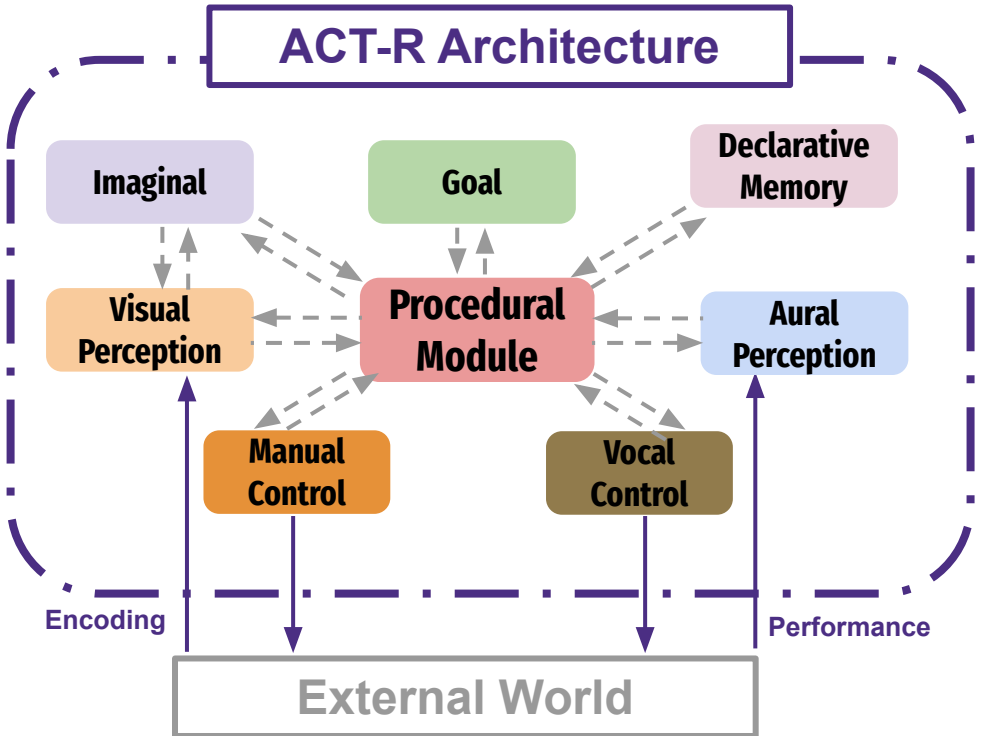
A Net Value of Control Allocation

ACC in ACT-R: Goal Buffer

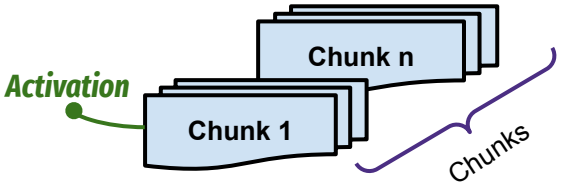


A Slot Value in Goal Buffer

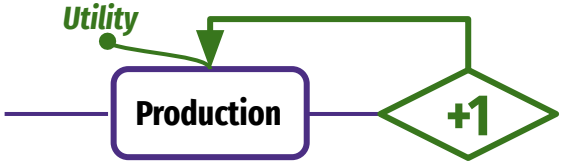
ACT-R Architecture Review



- Well-known Cognitive Architecture
- Declarative system



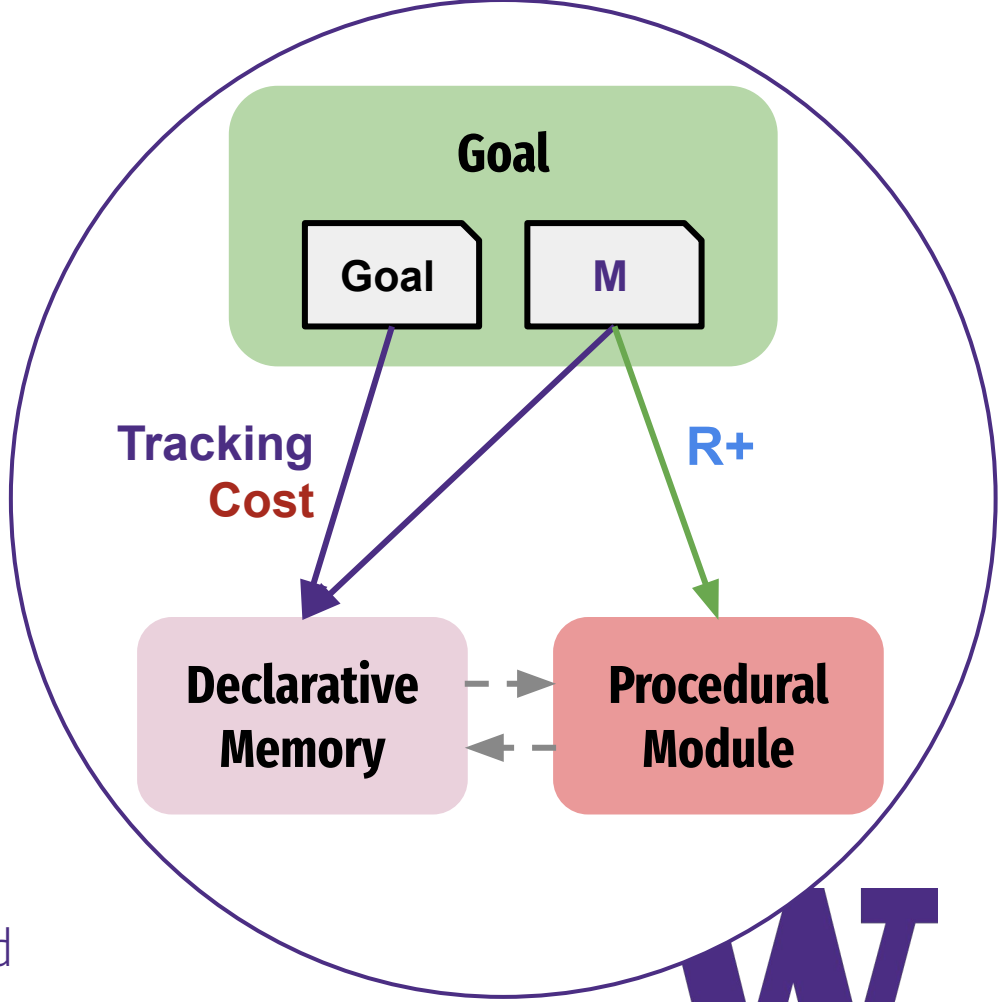
- Procedural system



Motivation in Goal Buffer

- **Old ACT-R:** Goal was associated with a value to rank production:

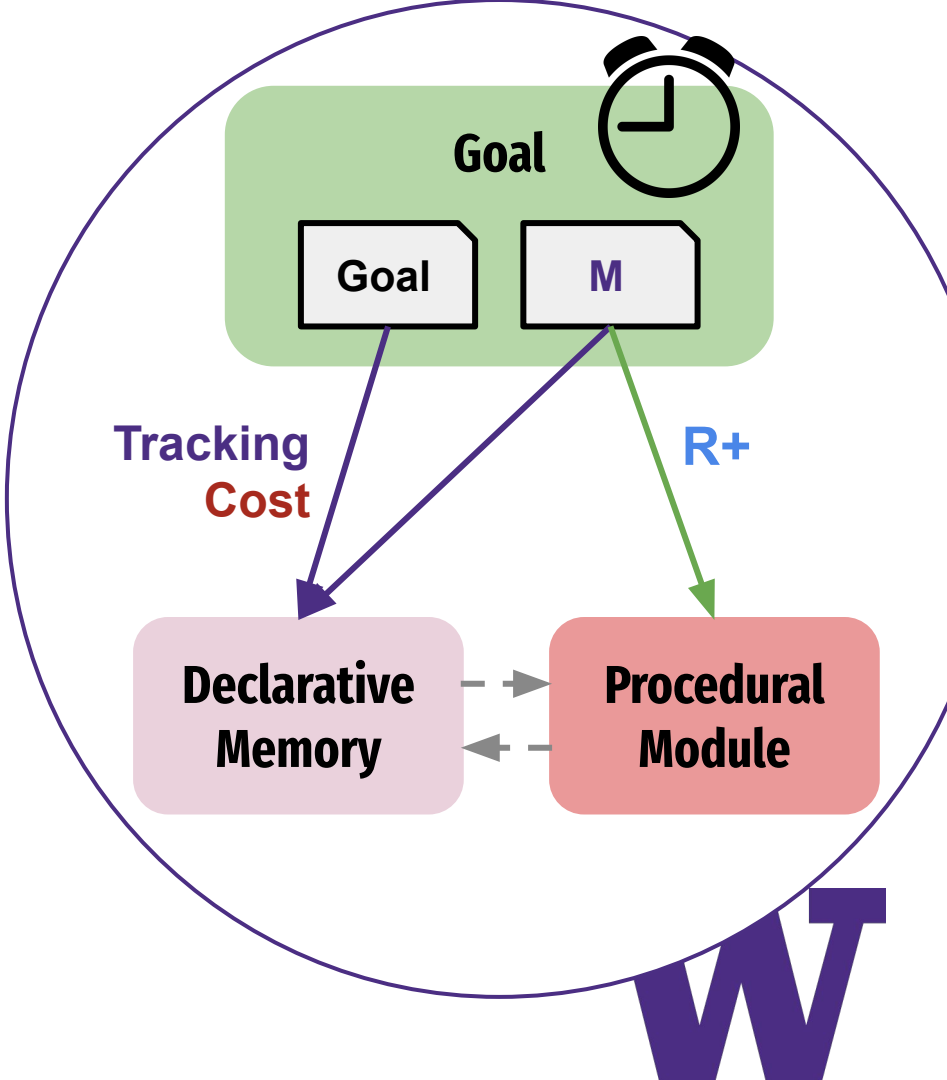
  (U = PG -Time)
- **Current ACT-R:** Goal is not related to reward
- **Next ACT-R:** Revisit Goal + Reward
  - Keep track of **cost**, **R+**
  - Estimate **EVC**
  - Deliver **R+** = **M** - **Cost**
- Goal buffer is the **ACTIVE** force behind adaptive behaviors



Cost, Reward, and M are all in time unit (ms)

Motivation in Goal Buffer

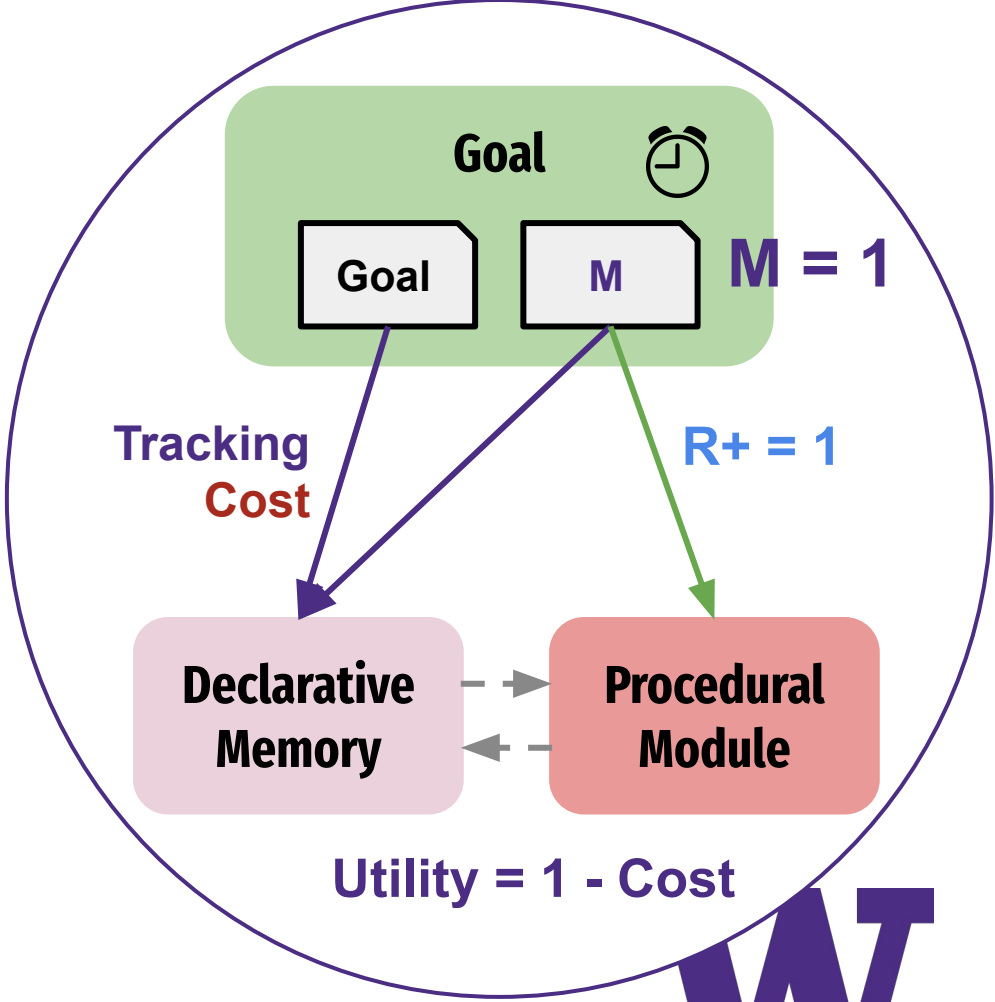
- **M** represents:
  - Subjective value of achieving goal
  - Time cost of the goal
- **M** accounts for
  - where intrinsic reward R_t come from, and
  - how **M** interacts with other cognitive functions by calculating expected R and Cost.



Low M

- M is 1
- The cognitive **Cost** is tracked by goal module
- A reward **R** (could be +/-) is delivered once the goal achieved
- When Cost > M and the goal has not been reached yet, the agent will gives up current goal and respond with whatever it has with no reward.

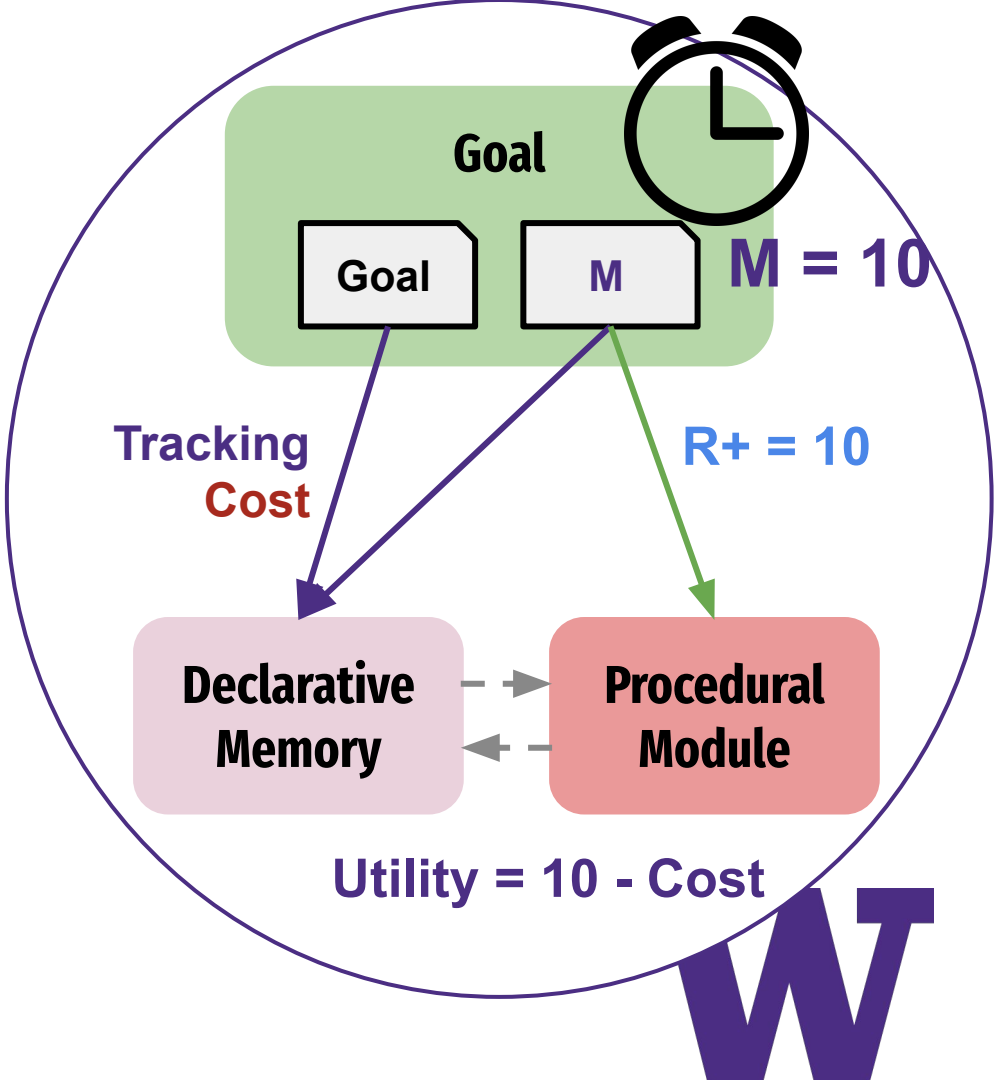
Low M - more quickly giving up the goal, even though it understands the potential rewards gained by achieving it.



High M

- M is 10
- The cognitive **Cost** is tracked by goal module
- A reward **R** (could be +/-) is delivered once the goal achieved
- When Cost > M and the goal has not been achieved, the model gives up current goal and respond with whatever it has with no reward.

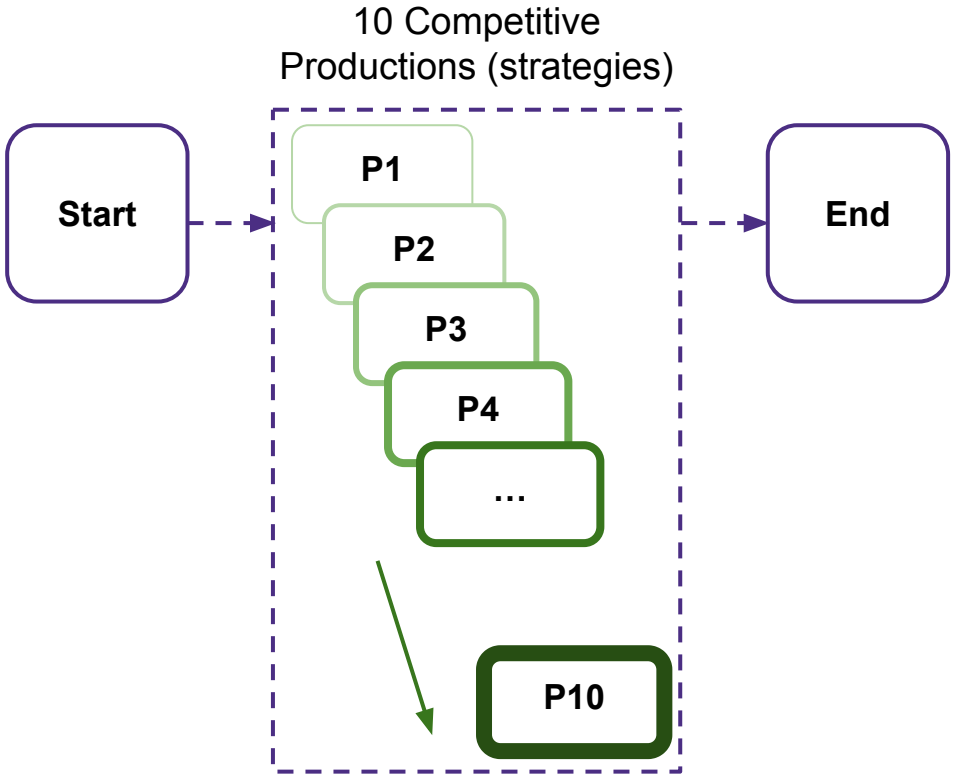
High M - the model is willing to spend more time in the task and obtaining the rewards, and the reward = M



Simple Model

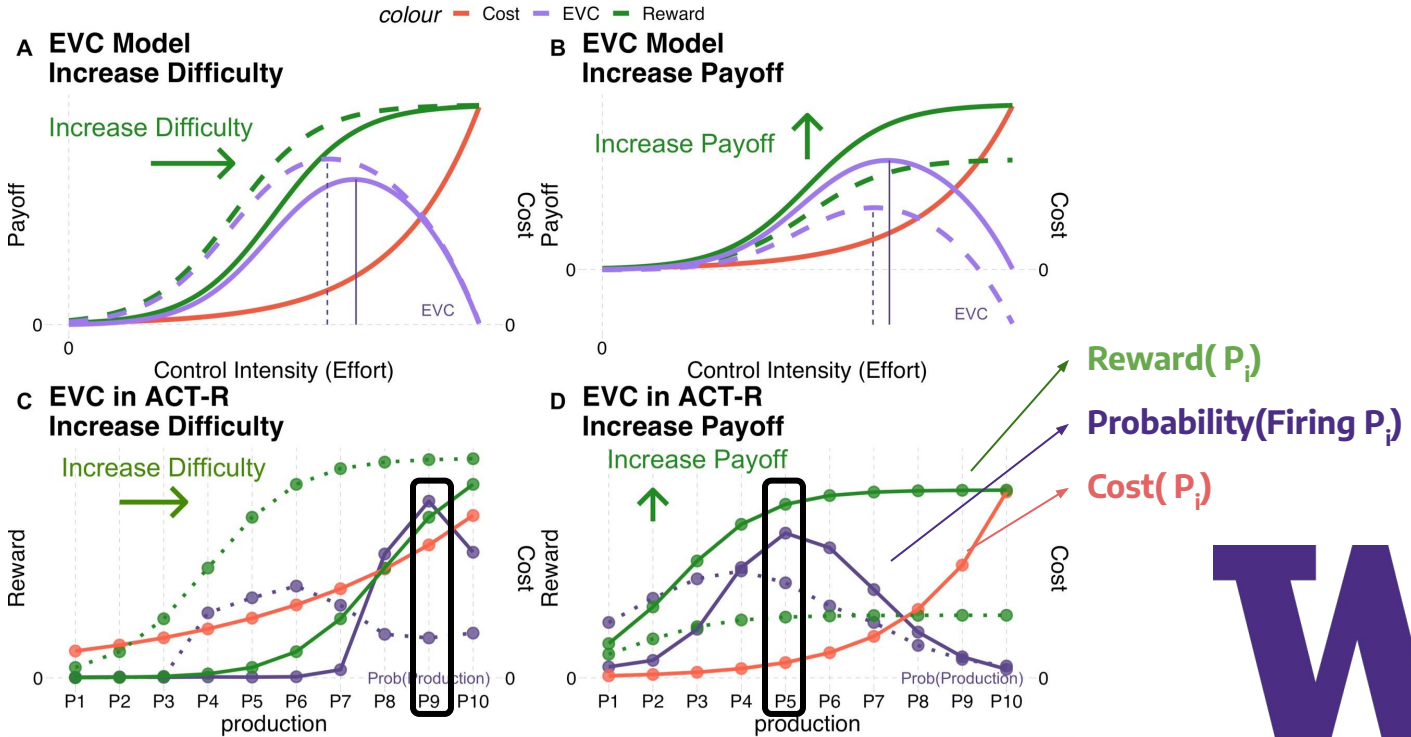
ACT-R Model
Abstract task

- 10 abstract strategies
  - Cost (:AT): P1 < P2 ... < P10
  - Reward (R): P1 < P2 ... < P10
- Which strategy is optimally selected by ACT-R?



Parameter	Value	Meaning
AT	0.01 - 0.1	Cost of control at T_0
R	0 - 10	Reward

Simulation Results



Reward(P_i)

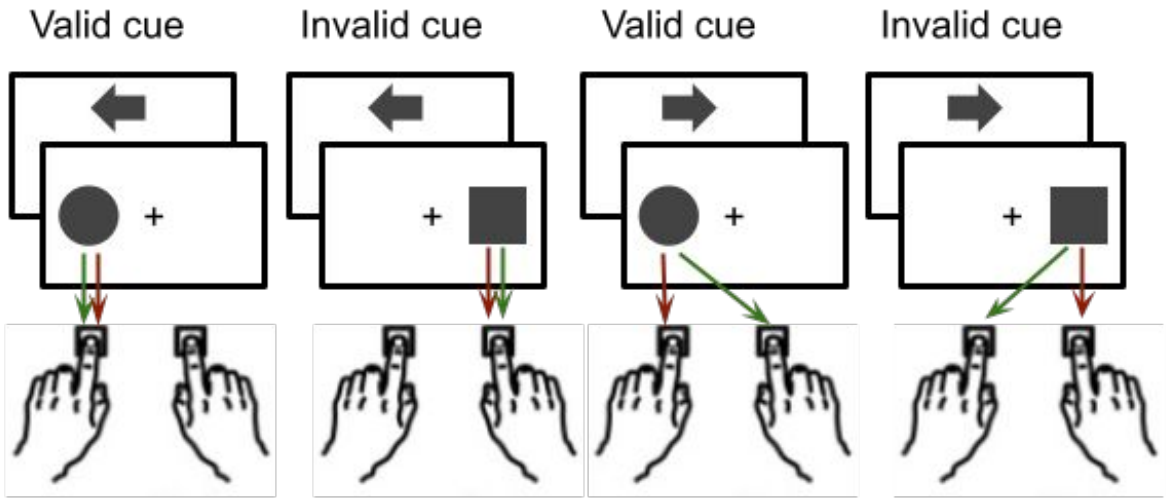
Probability(Firing P_i)

Cost(P_i)

ACT-R simulation:
Time = 100 s (ACT-R time)
Round = 100

Simon Model

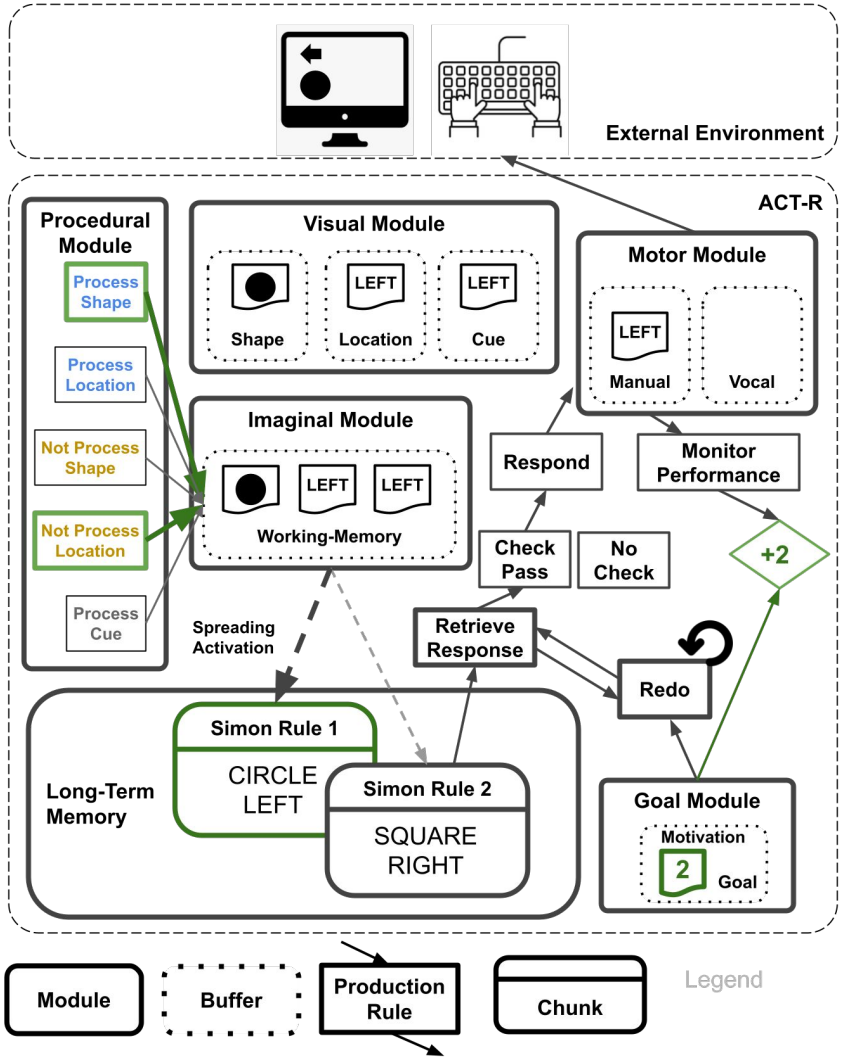
Simon Task


Valid cue
Invalid cue
Valid cue
Invalid cue
+
+
+
+
Congruent trial
Incongruent trial
According to shape
According to location

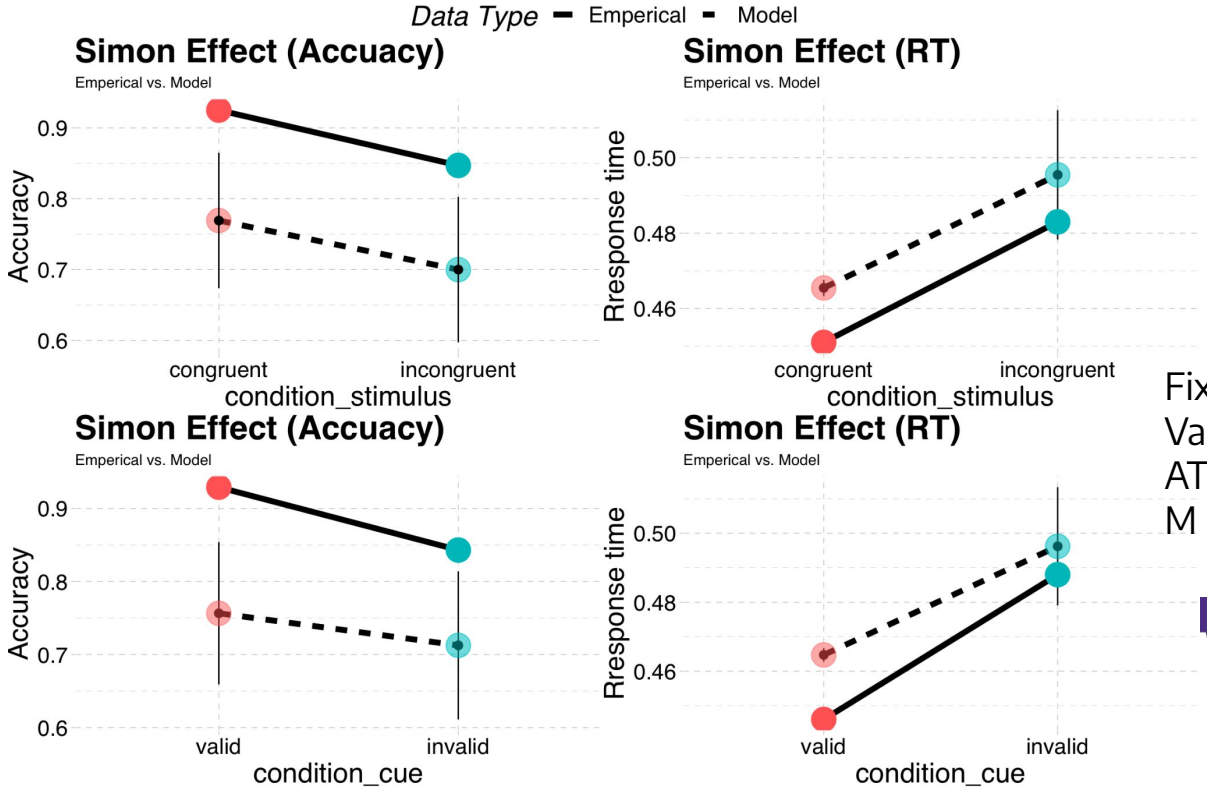
ACT-R Model:
Simon task

- Encoding Simon stimulus
- Retrieving Simon rule
- Responding
- Monitoring performance (M)
  - Check
  - Don't Check

Parameter	Value	Meaning
M	0.5 - 10	Motivation
VC	0 - 1	Task difficulty
AT	0.01 - 0.1	Cost of control at T_0



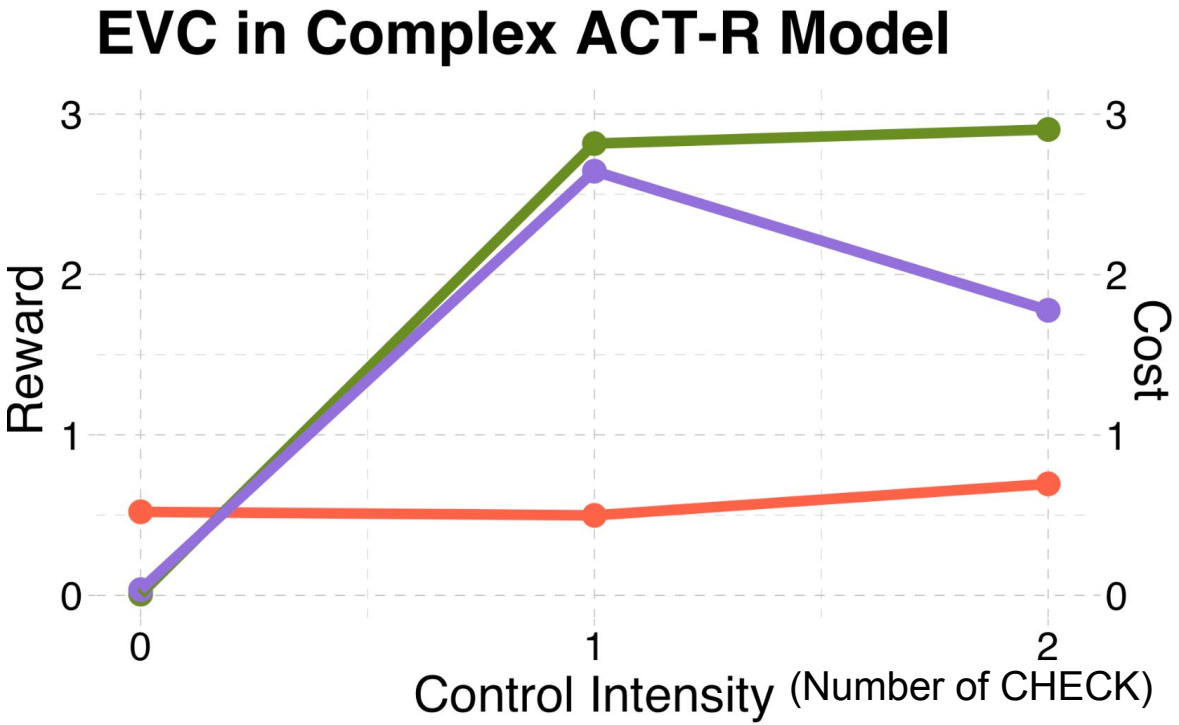
Results: Simon Effect



Fix Parameters:
ValidCue % = 0.5
AT = 0.05
M = 0.1 - 2

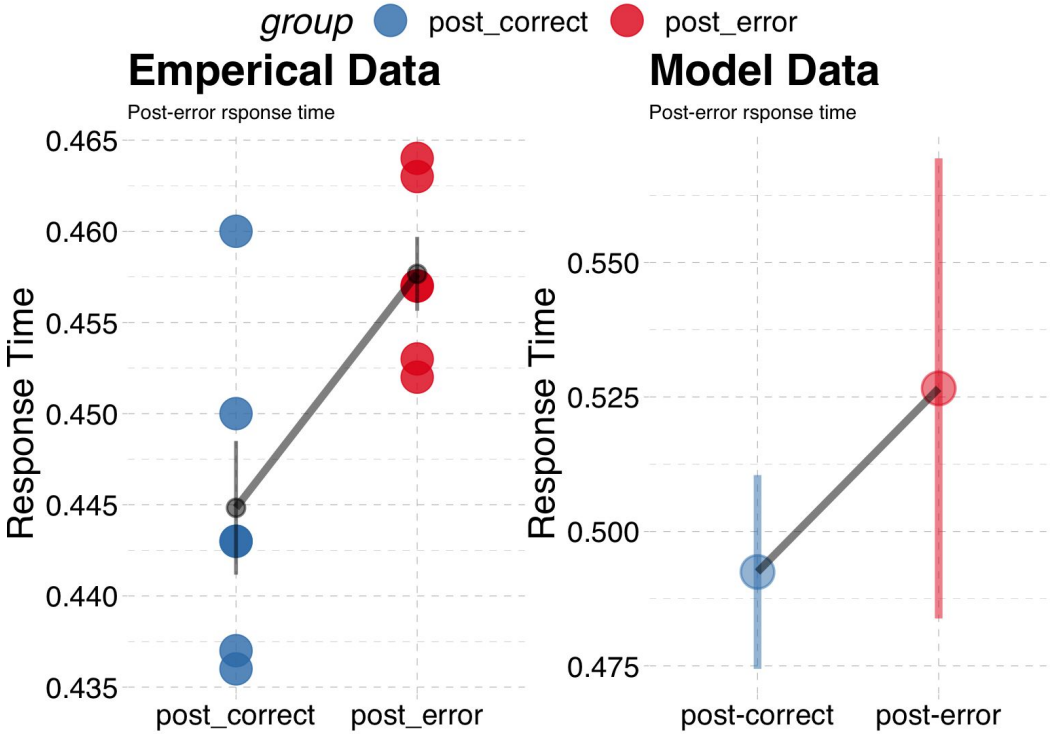
Boksem et al., 2006

Results: EVC



Fix Parameters:
ValidCue % = 0.5

Results: Post-Error Slowing



Main Take-away

- Proposed a mechanistic interpretation of motivation in ACT-R
- Computational model of motivation:
  - Goal module ≠ Imaginal Module
  - A scalar value: M in Goal Module
  - Translating M as the reward R_t that is triggered when the goal is accomplished.
  - ACT-R's utility learning mechanism then provides a way to adjust the specific combination of productions that are used to perform a task.

Take-away Continue...

- Abstract model demonstrates that our framework is consistent with the EVC theory
- Easy to implement in an existing model of common cognitive task - Simon Task
- Account for many well-studied experimental effects:
  - Congruency effect
  - Post-error slowing
  - Task Difficulty
  - Fatigue ...

Thank you!

Cognition & Cortical Dynamics Laboratory

Institute for Learning & Brain Sciences

Backup Slides

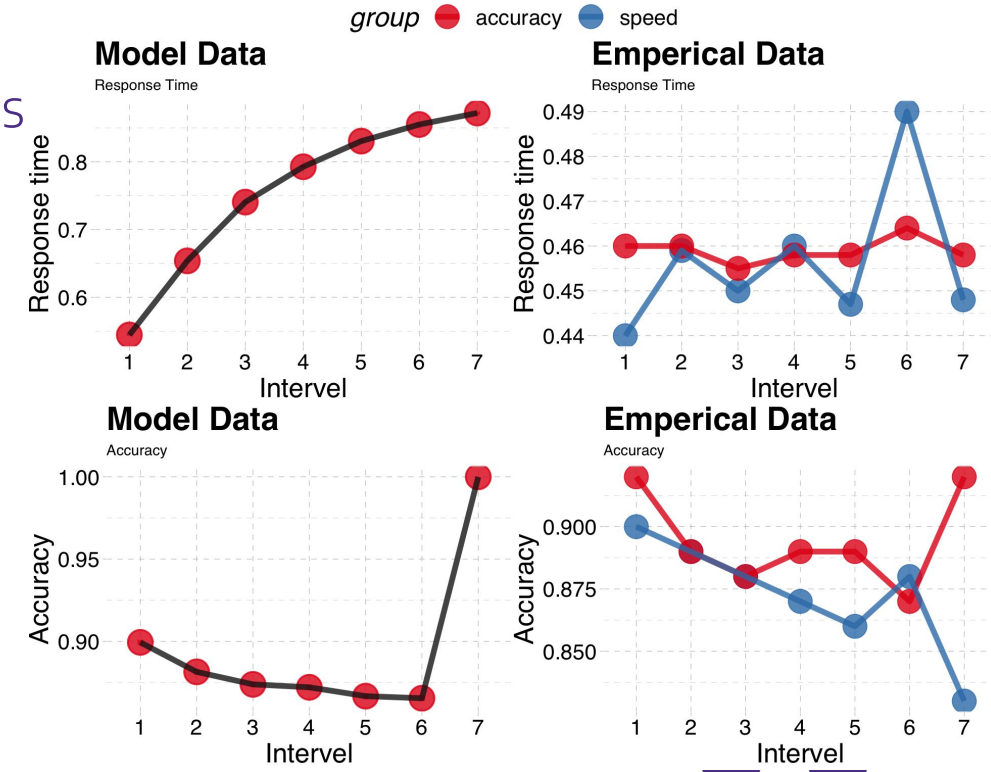
Results: Speed-Accuracy Tradeoff

Fatigue alleviated by extra incentives

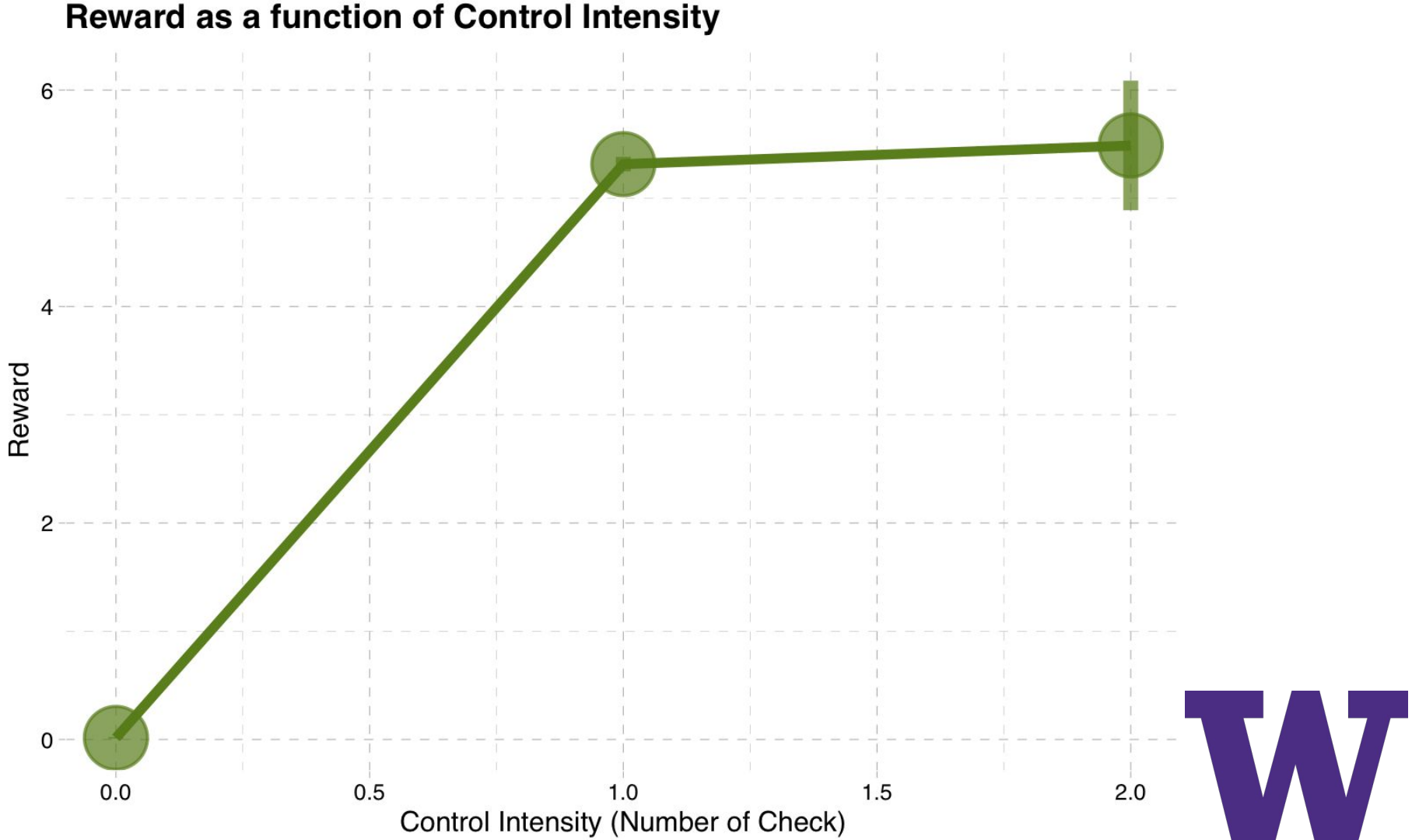
- Session 1-6 → Fatigue
- Session 7 → Reward

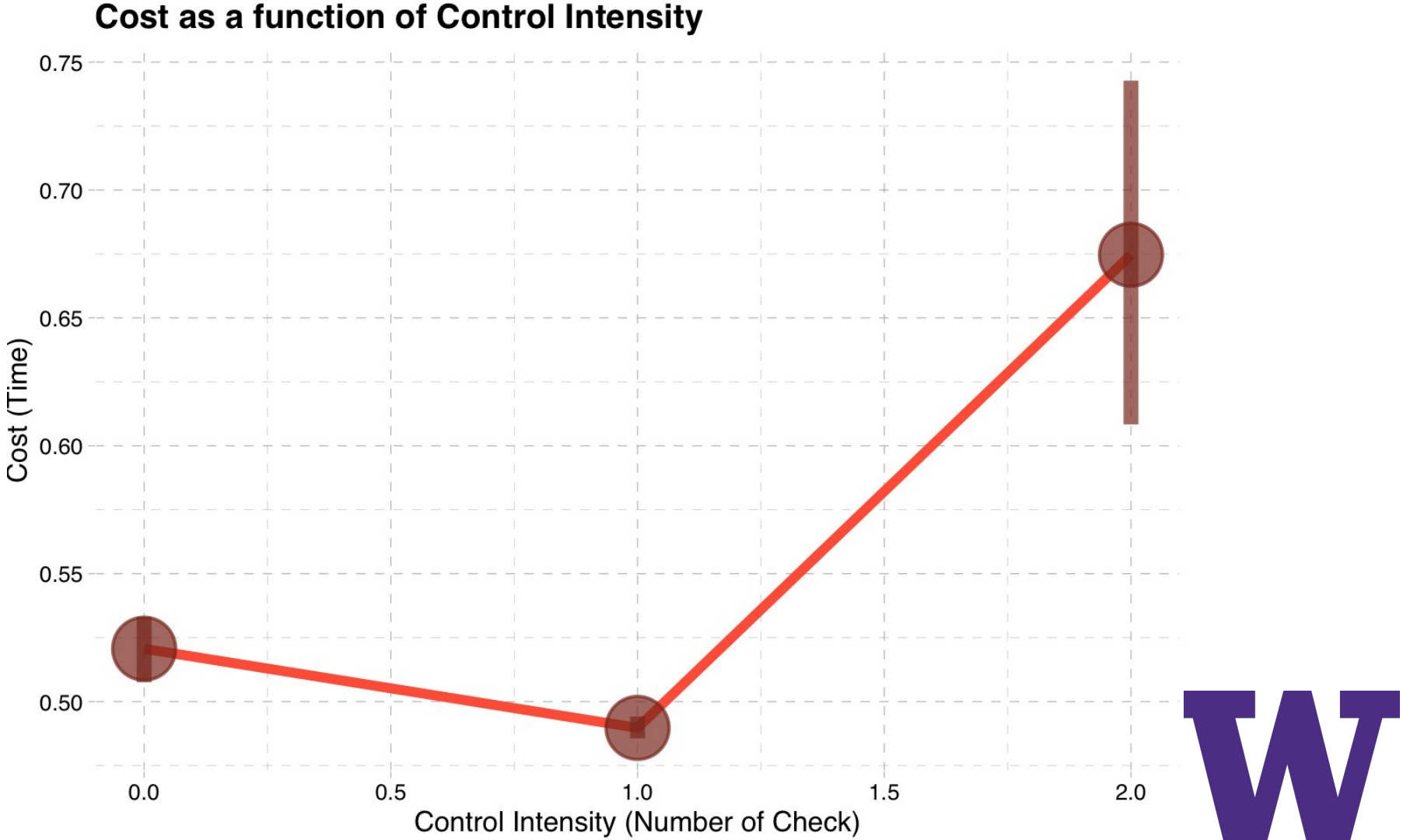
> **Speed group**

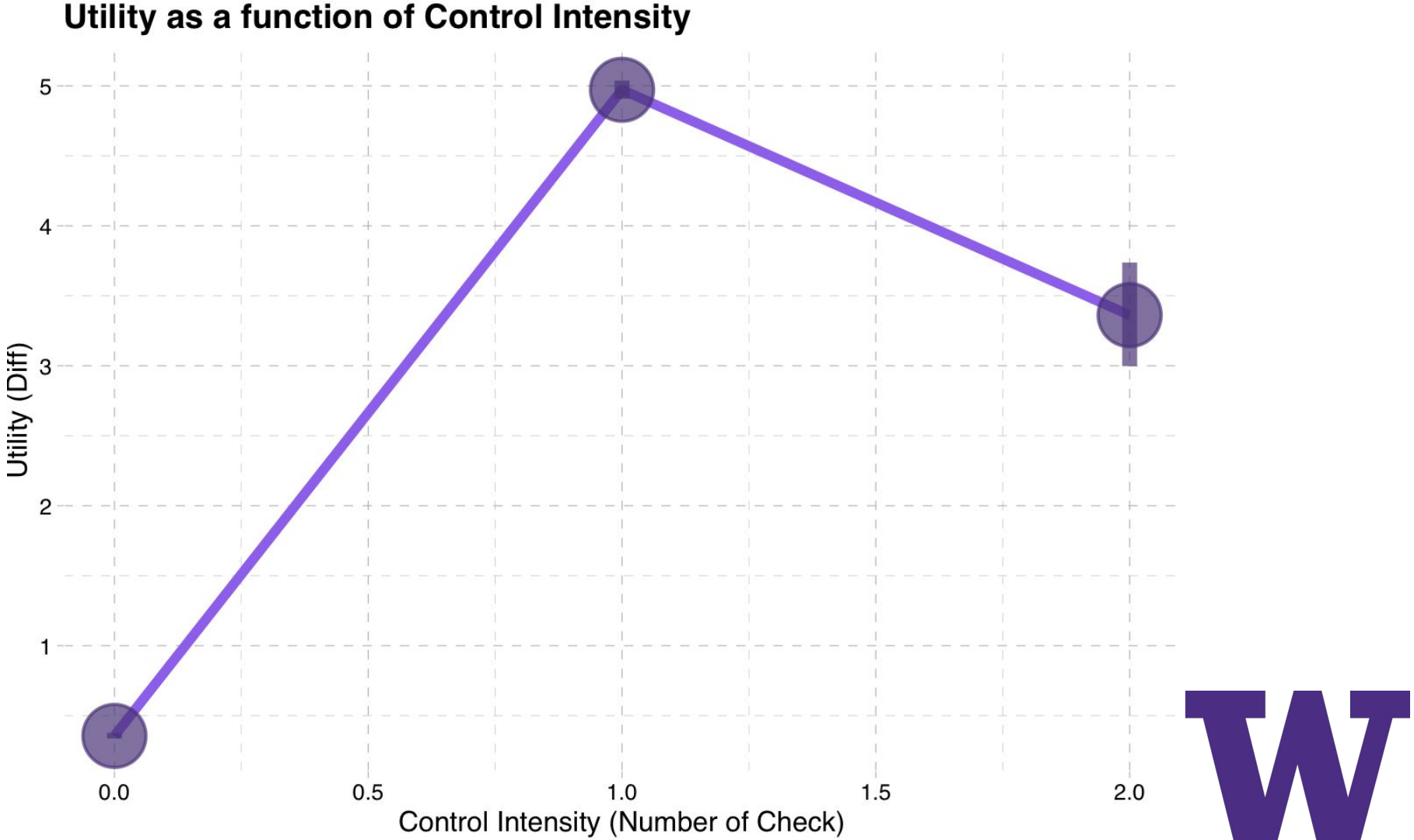
> **Accuracy group**



Bokesem et al., 2006


Reward as a function of Control Intensity
6
4
2
0
Reward
0.0
0.5
1.0
1.5
2.0
Control Intensity (Number of Check)


Cost as a function of Control Intensity
0.75
0.70
0.65
0.60
0.55
0.50
Cost (Time)
0.0
0.5
1.0
1.5
2.0
Control Intensity (Number of Check)


Utility as a function of Control Intensity
Utility (Diff)
5
4
3
2
1
0.0
0.5
1.0
1.5
2.0
Control Intensity (Number of Check)