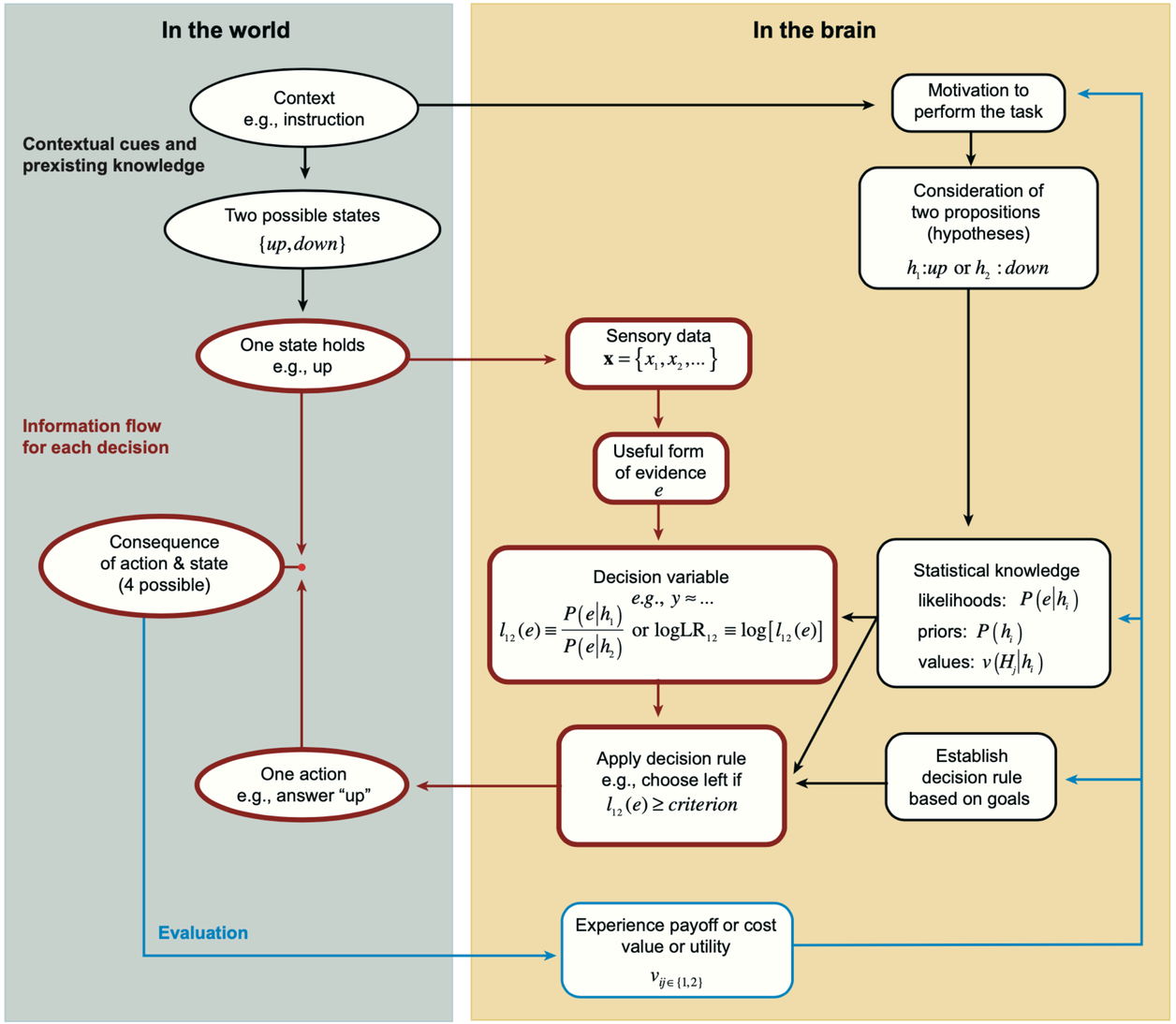
How do you use evidence to make a decision?

Readings for today

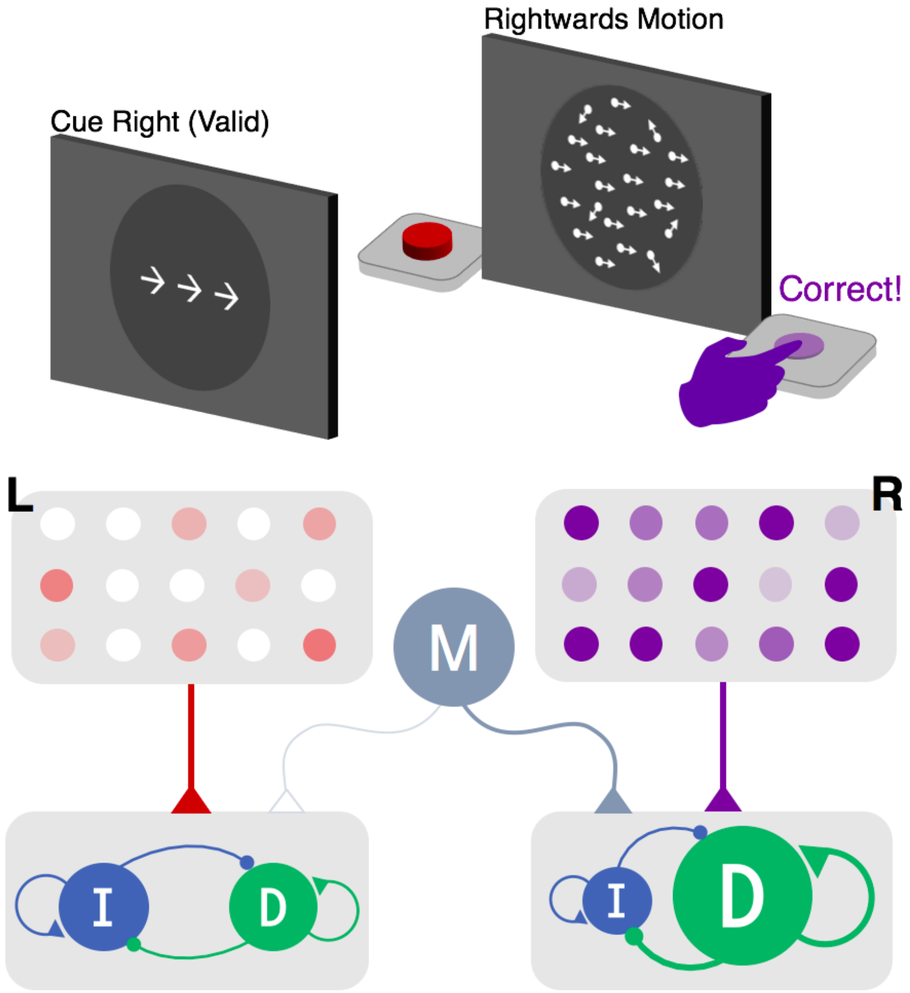
- Gold, J. I., & Shadlen, M. N. (2007). The neural basis of deci- sion making. Annu. Rev. Neurosci., 30, 535-574.

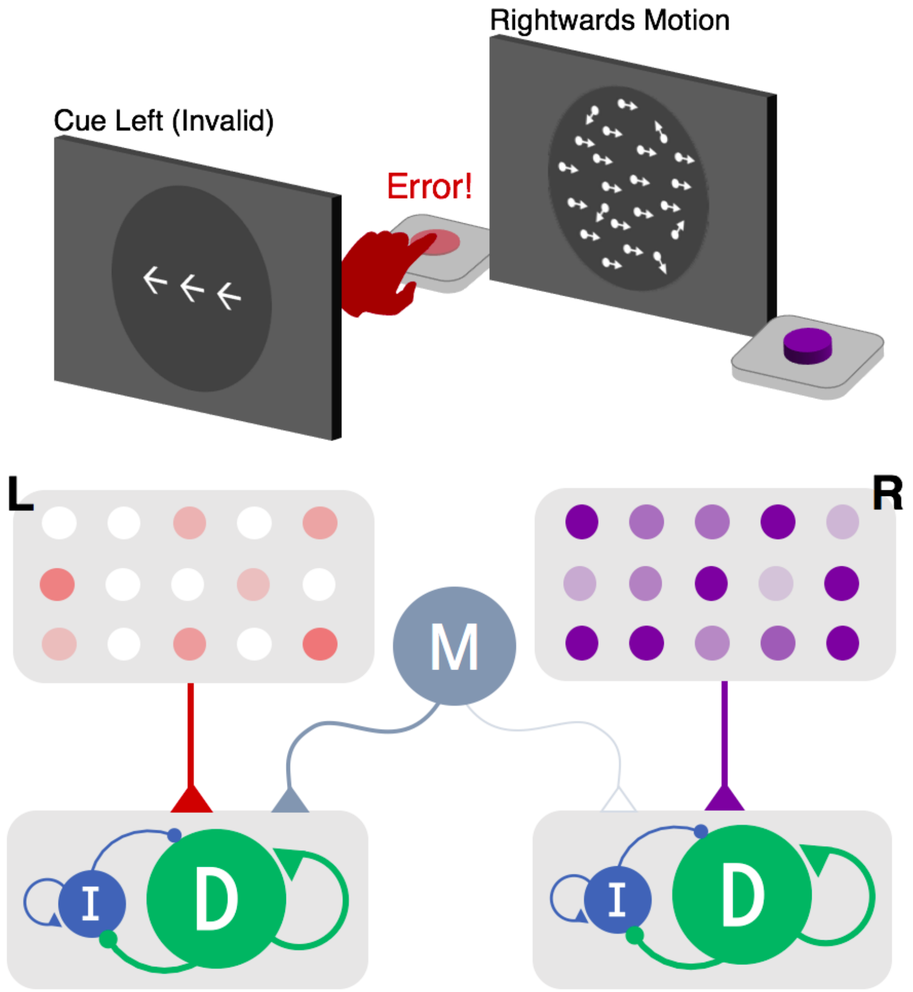
Elements of making a decision



(Gold & Shadlen, 2007)

Cued dot motion task





Serial evaluation of evidence

Sequential analysis framework

$$e_0 \rightarrow f_0(e_0) \Rightarrow \underset{or}{Stop}$$

$$\swarrow$$

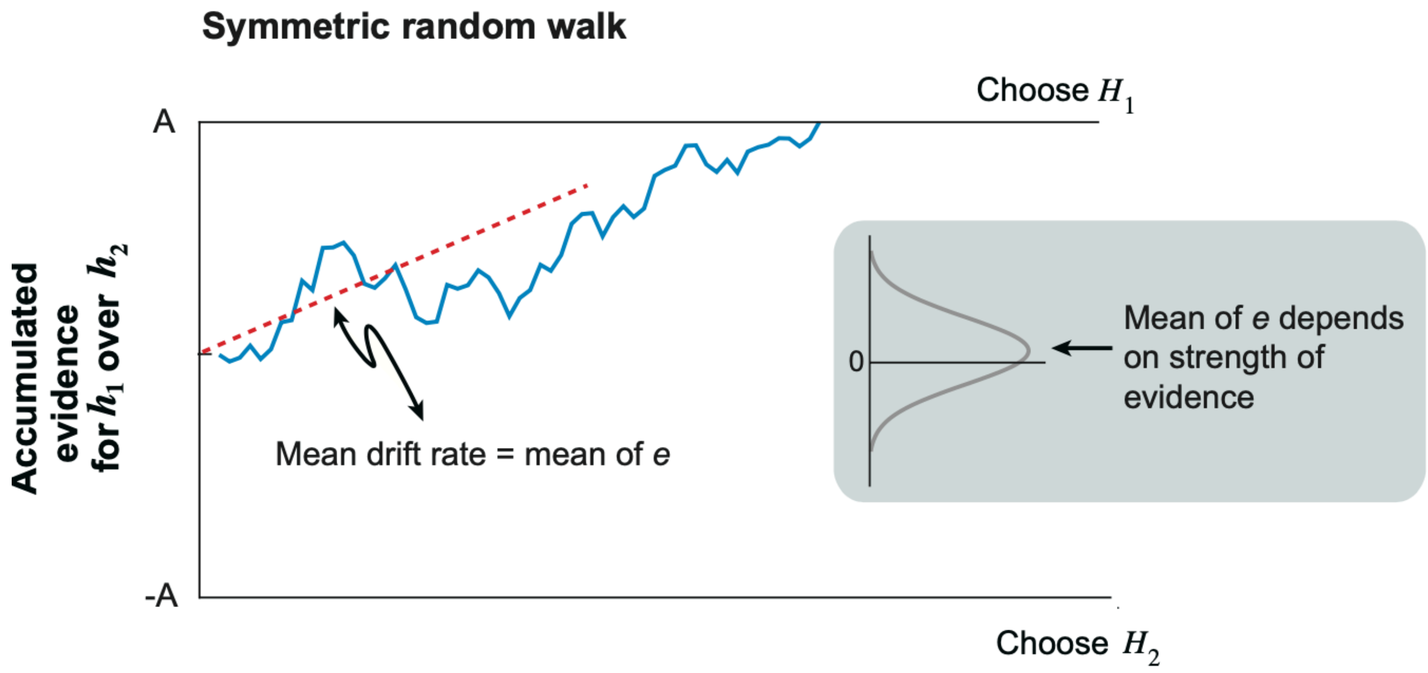
$$e_1 \rightarrow f_1(e_0, e_1) \Rightarrow \underset{or}{Stop}$$

$$\swarrow$$

$$e_2 \rightarrow f_1(e_0, e_1, e_2) \Rightarrow \underset{or}{Stop}$$

$$\vdots$$

$$e_n \rightarrow f_1(e_0, e_1, \ldots, e_n) \Rightarrow \ldots$$



(Gold & Shadlen, 2007)

Log-likelihood ratio (logLR) test

$$\log LR_{12} \equiv \log \frac{P(e_1, e_2, \ldots, e_n|h_1)}{P(e_1, e_2, \ldots, e_n|h_2)}$$
$$= \sum_{i=1}^{n} \log \frac{P(e_i|h_1)}{P(e_i|h_2)}.$$

Given *n* samples of evidence (*e*), what is the likelihood that the evidence was generated under one of two competing hypotheses (*h*)?

Problem: When have you accumulated enough evidence to make a decision?

(Gold & Shadlen, 2007)

The sequential probability ratio test (SPRT)

1. On each sample *i*, evaluate logLR

$$w_i = \log\left(\frac{P(e_i \mid h_1)}{P(e_i \mid h_2)}\right)$$

2. Sum all logLR tests up to current observation

$$y_n = \sum_{i=1}^{n} w_i$$

3. Determine stopping rule

$$y_n \geq \log\frac{1-\alpha}{\alpha}, \text{ then select } h_1$$

$$y_n \leq \log\frac{\beta}{1-\beta}, \text{ then select } h_2$$

$$\log\frac{\beta}{1-\beta} \leq y_n \leq \log\frac{1-\alpha}{\alpha}, \text{ continue sampling}$$

(Gold & Shadlen, 2007)

The Drift Diffusion Model (DDM)

θ : evidence (decision) variable.

$\theta(0) = z \rightarrow$ initialized with value z at $t = t_{er}$

<u>Continuous time for (Stochastic Diff Eq)</u>

$d\theta = vdt + \sigma dW$

dW : Wiener noise process

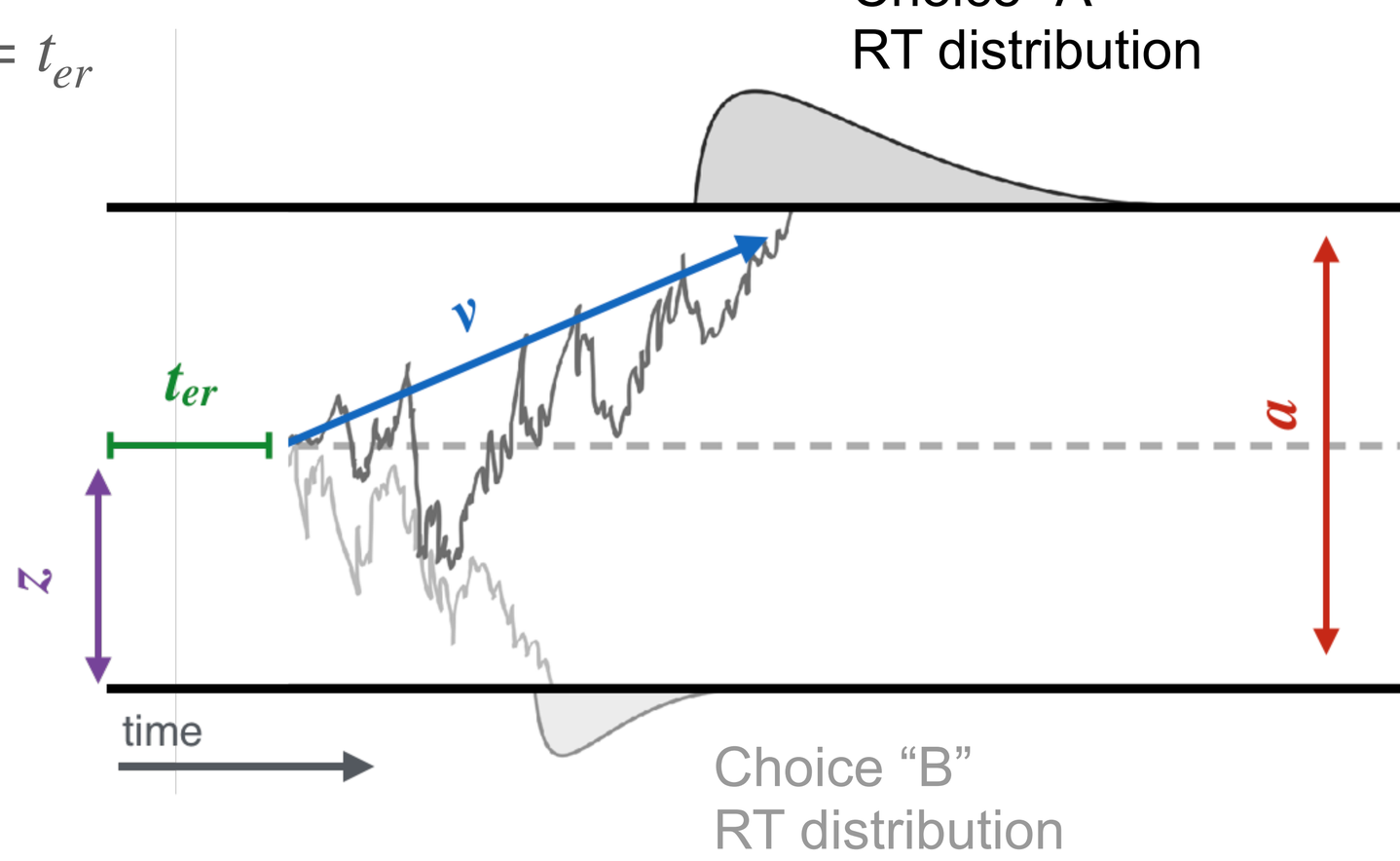
σ : diffusion constant (noise scalar)

<u>Discrete time form</u>

$\theta(t + \Delta t) = \theta(t) + v\Delta t + \sigma\sqrt{\Delta t}\epsilon(t)$

$\epsilon \sim N(0,1)$: Gaussian noise

Δt : timestep

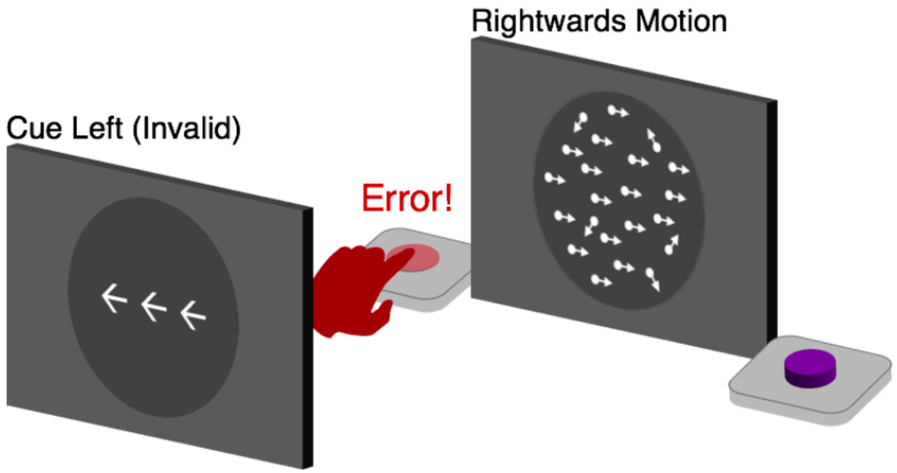


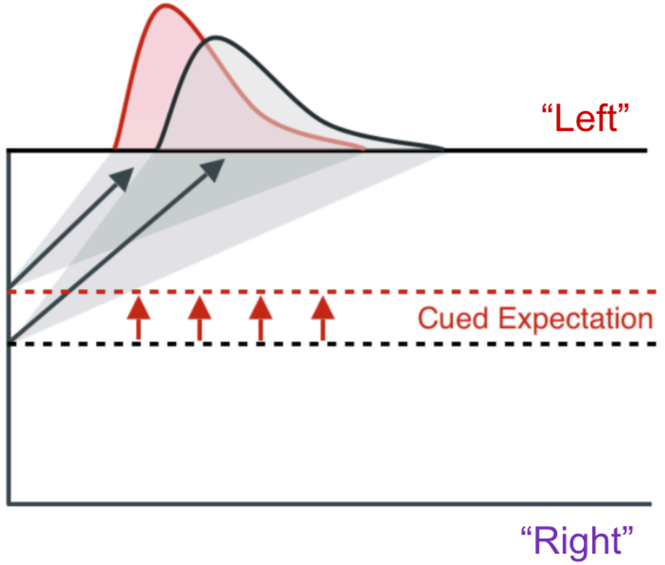
(Ratcliff 1978)

Two critical properties of the DDM

1. Parameters are ***identifiable*** (e.g., recoverable) from behavioral data (RT distributions and choice accuracy)

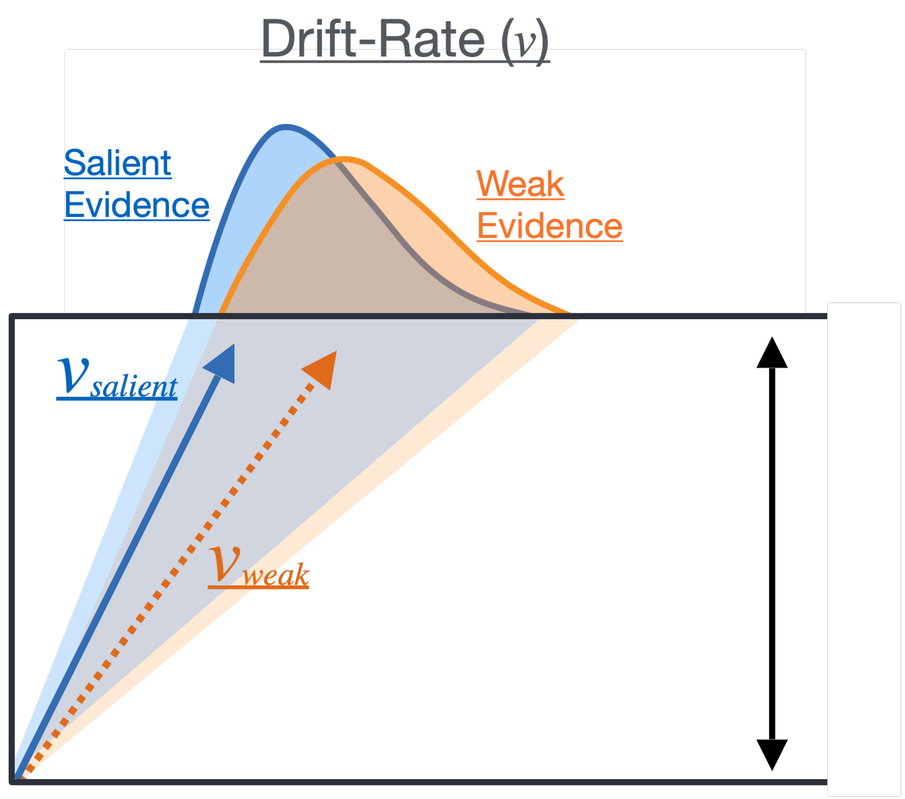
2. Parameters are reliably modulated by specific task variables, capturing sensible links between internal decision mechanisms and external task environmental demands

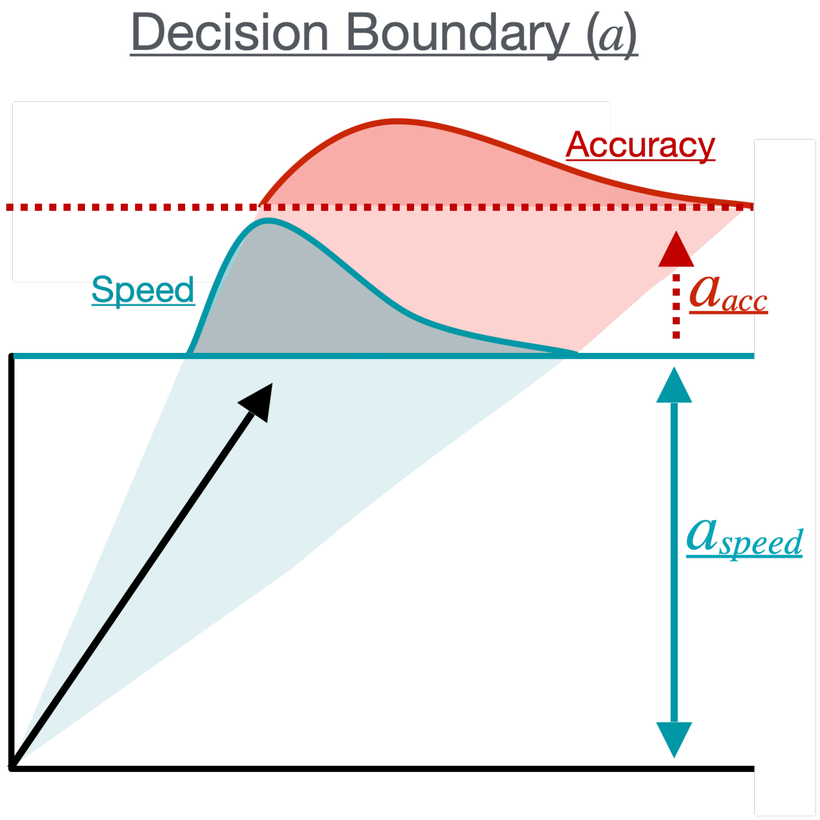




Parameter identifiability

Example: How do we distinguish between behavioral effects caused by a change in drift-rate (v) and change in boundary height (a)?





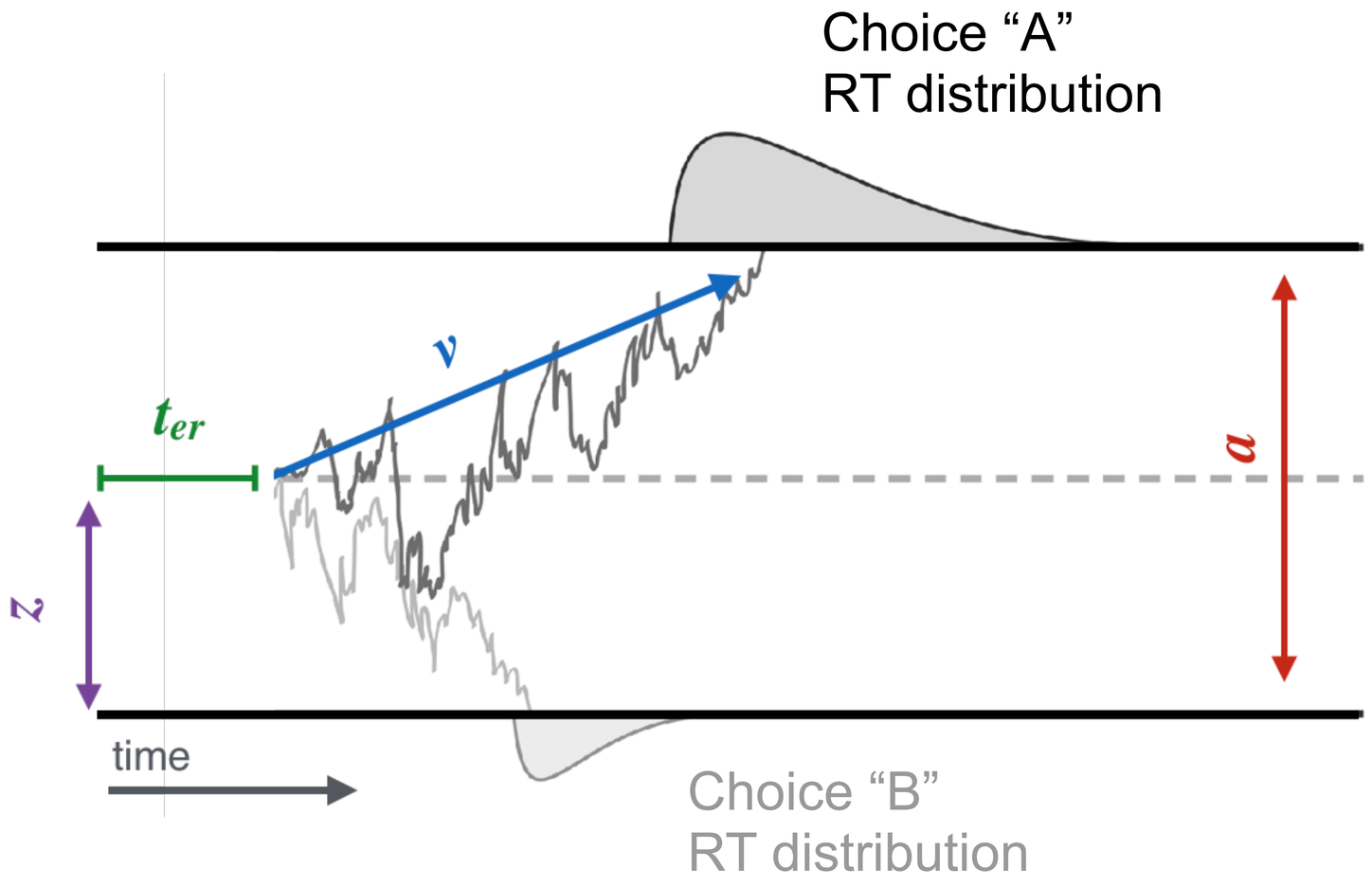
Links between variables & task parameters

- boundary height (***a***): evidence criterion
  - reflects internal strategy or priorities of agent
    - liberal strategy or prioritize speed (reduce ***a***)
    - cautious strategy or prioritize accuracy (raise ***a***)

- drift-rate (***v***): relative strength of evidence for two alt. choices
  - typically depends on environment (externally controlled)
    - higher motion coherence => increase in ***v***
    - greater difference in associated value of alt. actions => increase in ***v***

- starting-point (***z***): initial value of evidence, bias
  - reflects internal biases or expectations of agent
    - anticipate left motion, move ***z*** closer to “left” decision boundary
    - anticipate right motion, move ***z*** closer to “right” decision boundary

- non-decision time (***tr***) sensory and motor delays:
  - traditionally viewed as a “nuisance” parameter (i.e., capturing internal and/or external variables related to sensory or motor but *not* decision computation)



Food for thought

- What are the assumptions behind the SPRT? Are they reasonable for natural decisions?
- What are the limitations of the DDM, in terms of what it cannot capture relevant to decision making?
- What types of decisions does this model *not* cover?
- If “exploratory” decisions are simply the result of randomness, what does this imply about the nature of agency in taking a risk?