Decision Making

Introduction to Modelling in Neuroscience (NSCI 401)
Dr. Gunnar Blohm

Outline

- What are decisions?
- Involved brain structures
  - Basal ganglia
  - Cortex
- Models of decision making
  - Race models
  - Diffusion models
  - Optimal decision criteria
  - Conflict resolution – winner-take-all

What are decisions?

- Decision making can be regarded as the mental processes (cognitive process) resulting in the selection of a course of action among several alternatives (www.wikipedia.com)
- Every decision making process produces a final choice
- The output can be an action or an opinion of choice

How do humans make decisions?

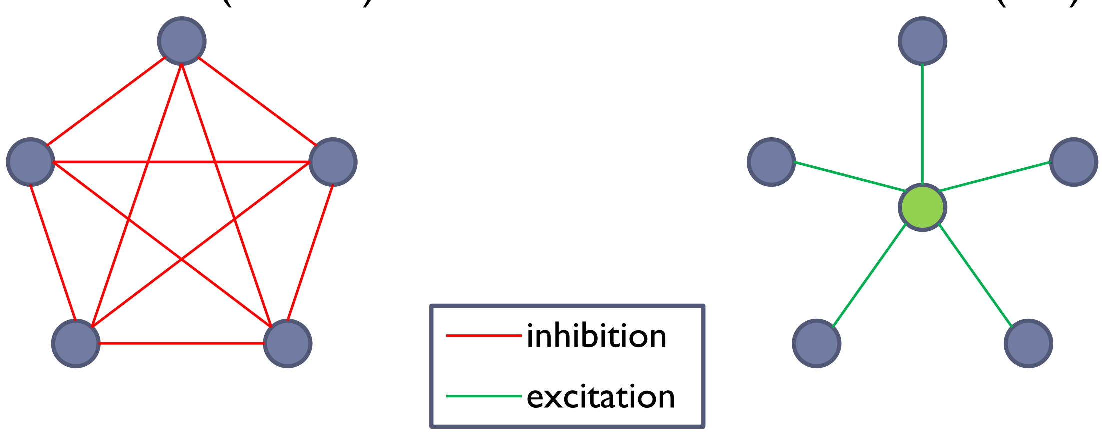
- Value = the payoff of a given event
  - E.g. Play the lottery and you can win $1,000,000 !
- Expected value = payoff * likelihood
  - The chance of winning p(win) = 1:10,000,000
  - Expected value (EV) = Value * p(win) = 10¢
- So which lottery would you chose?
  - A: 95% chance of winning $1,000,000
  - B: 50% chance of winning $3,000,000
  - Most people chose A (EV = $950,000) over B (EV = $1,500,000)
- Utility = the *subjective* payoff associated with a given event
- Expected Utility = utility * likelihood of the given event
- Expected utility theory: chose to maximize expected utility

Involved brain areas

Resolution of competition

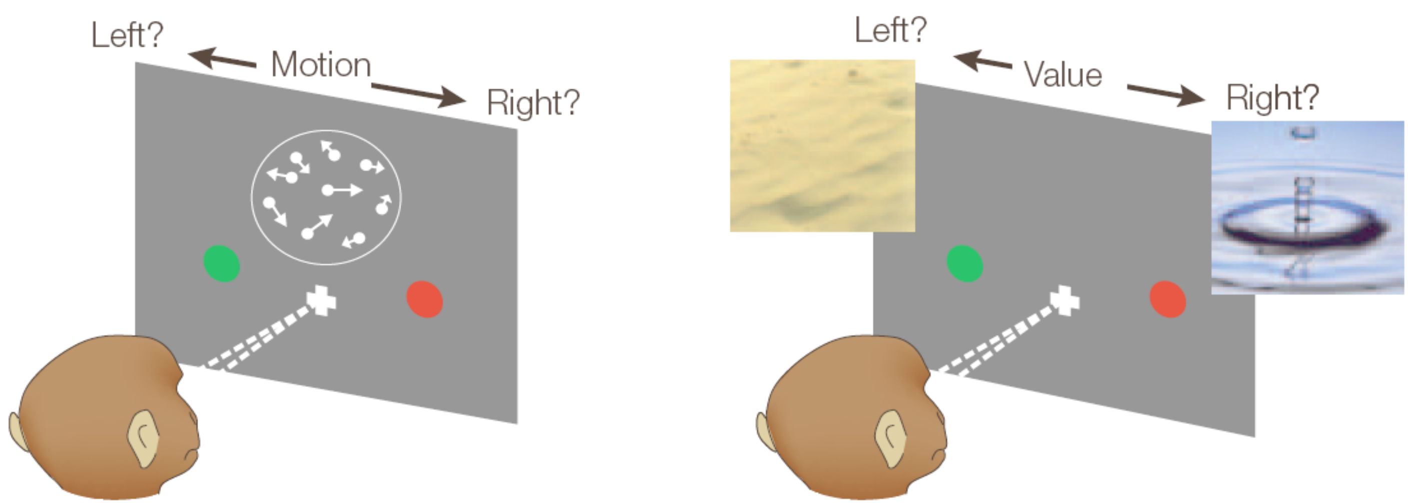
- Different potential goals compete in various cortical and sub-cortical brain areas
- This competition could be solved centrally or in a distributed way:
  - Centralized mechanism requires less "wires"
  - Both are present in the brain...

Distributed (cortex) Centralized (BG)



Basal ganglia

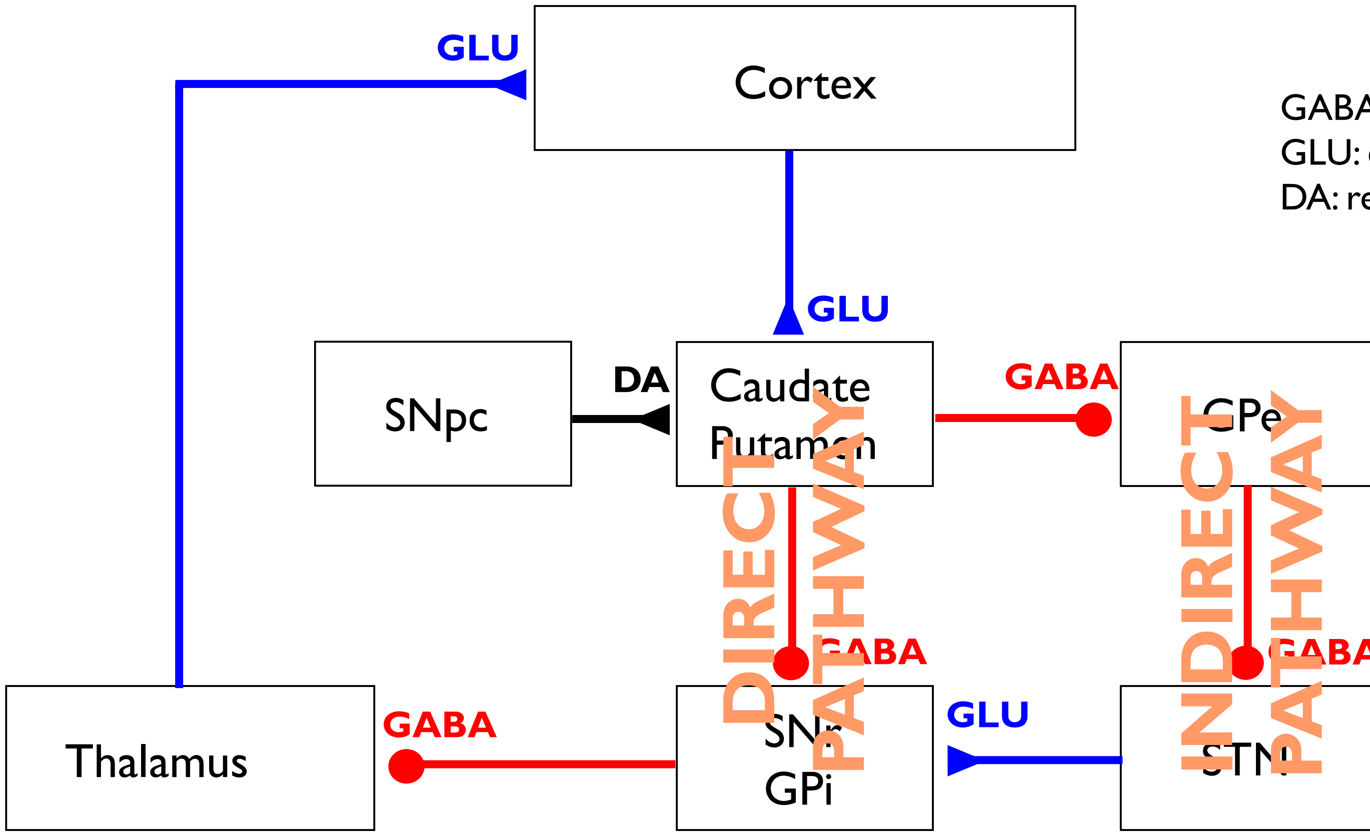
- BG = central switch in gating behavioural alternatives
  - Critical role in regulating cortical preparatory activity
  - Sub-thalamic nucleus (STN) prevents premature responses
  - BG implements optimal test for multiple alternatives



Sugrue, Corrado and Newsome, 2005

Basal ganglia

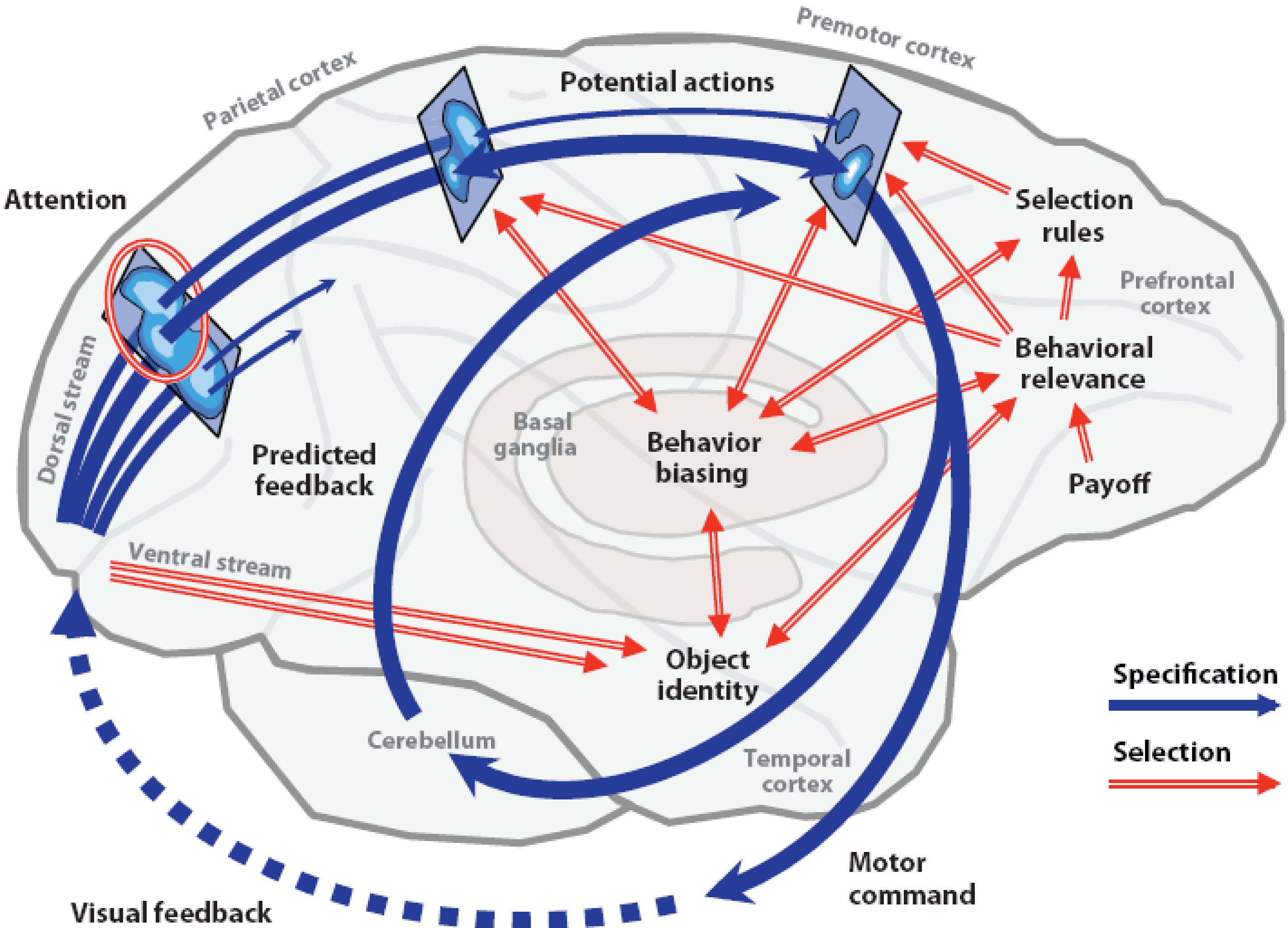
- Central switch



GABA: inhibitory
GLU: excitatory
DA: reward

Courtesy of Doug Munoz (Queen’s)

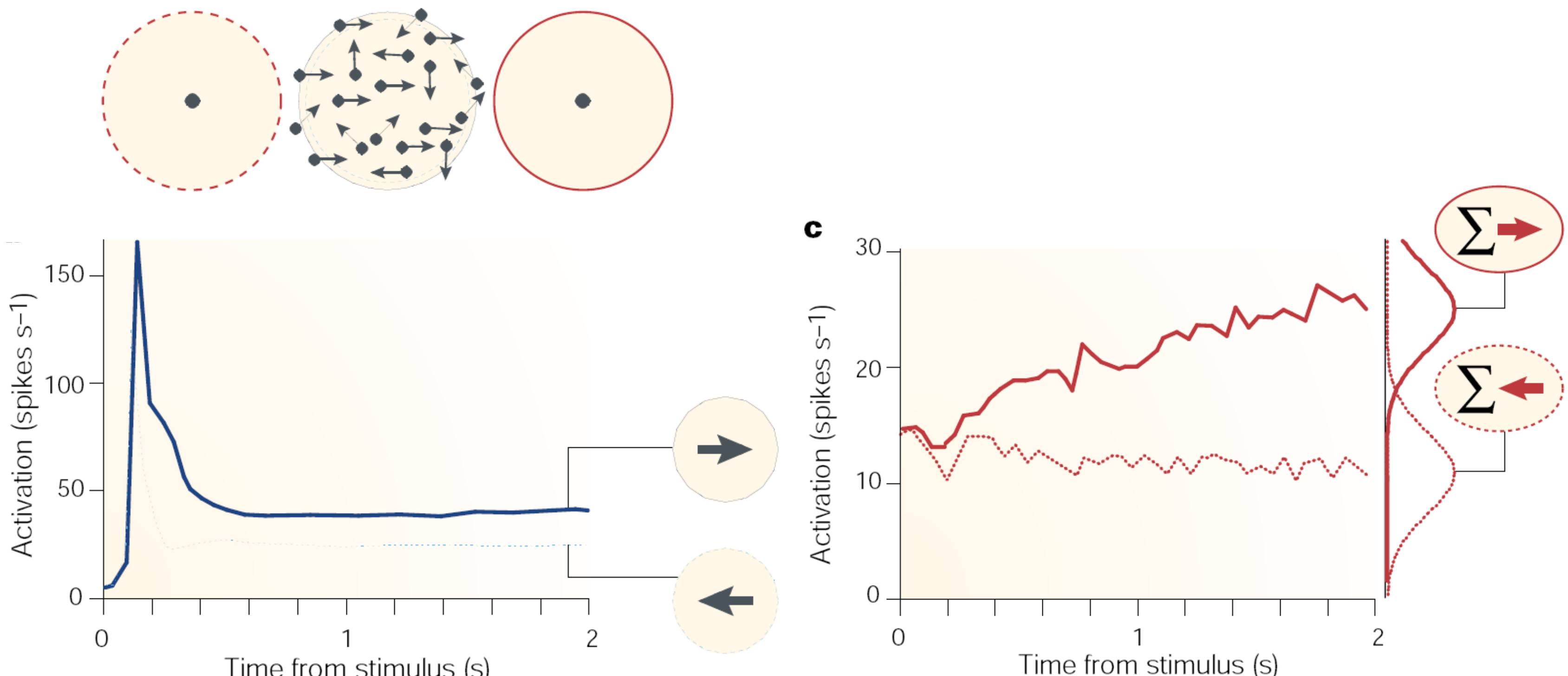
Cortex



Cisek & Kalaska, 2010

Cortex

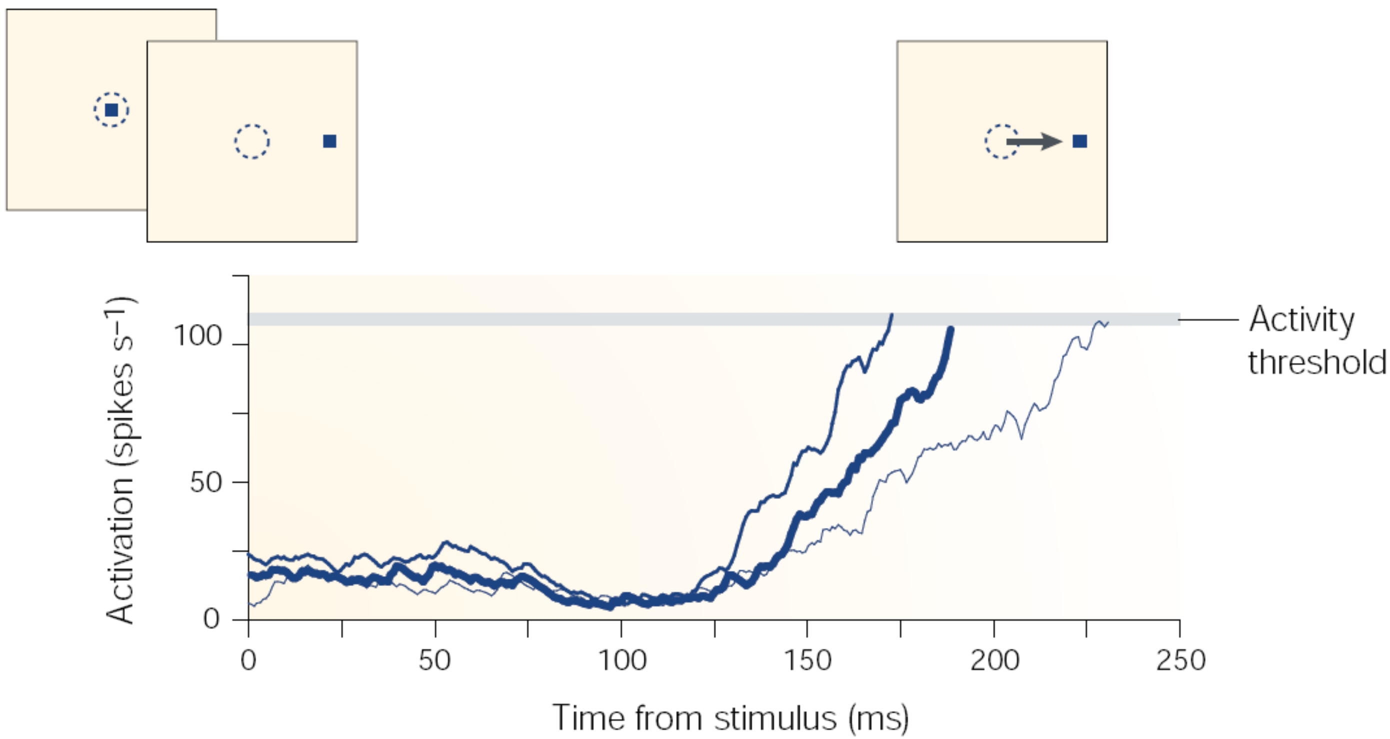
- Competition of alternatives
- Example 1: area MT
  - https://www.youtube.com/watch?v=oDxcyTn-0os



Schall, 2001

Cortex

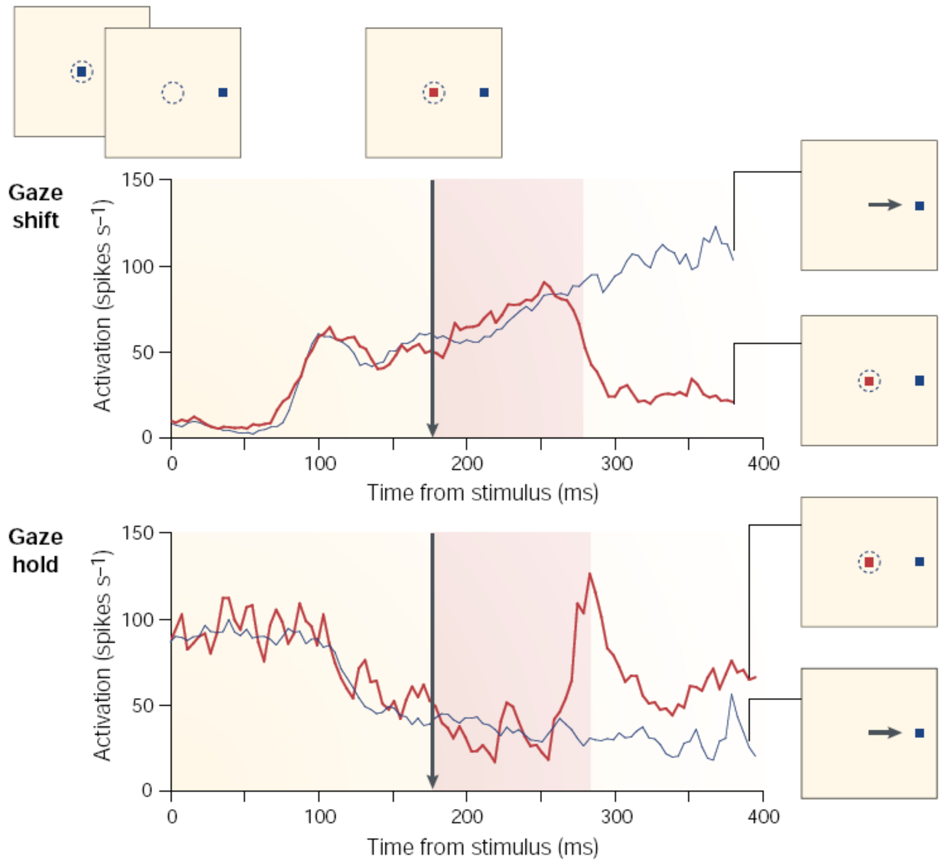
- Competition of alternatives
- Example 2: areas LIP / FEF



Schall, 2001

Cortex

- Competition of alternatives
- Example 2: areas LIP / FEF

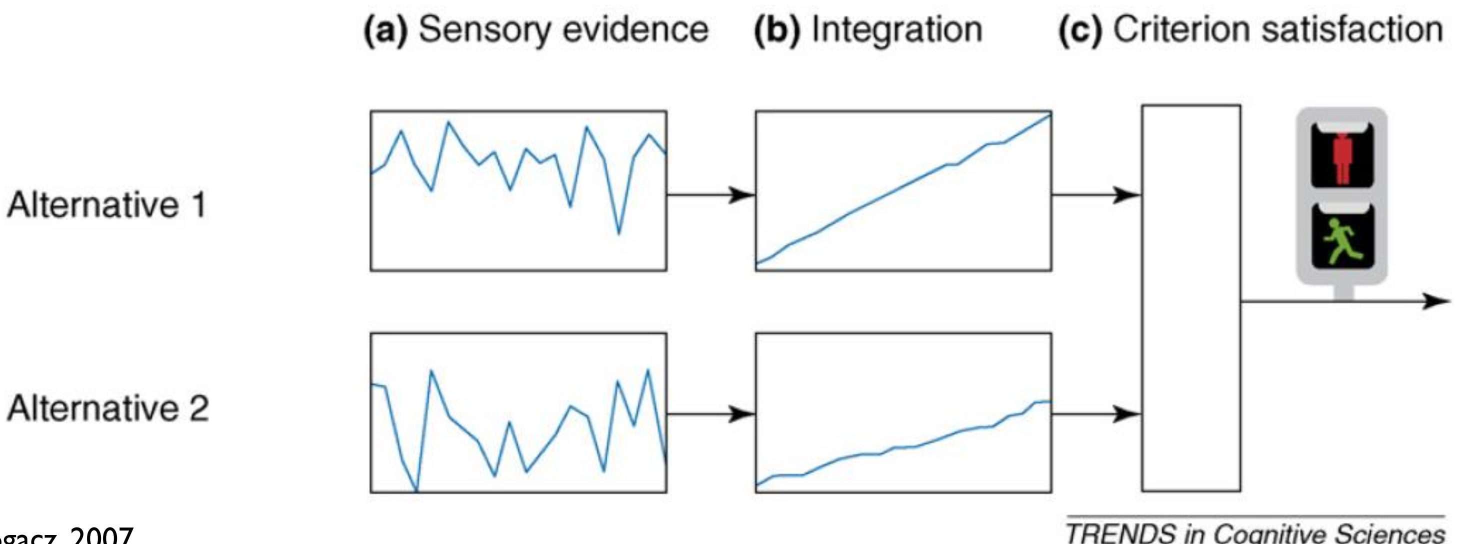


Schall, 2001

Models of decision making

Race models

- Sensory systems provide noisy evidence for alternatives
- Sensory evidence is integrated (e.g. LIP)
  - Integration gets rid of noise
- Choice is made when a criterion is reached
  - e.g. Threshold or confidence level



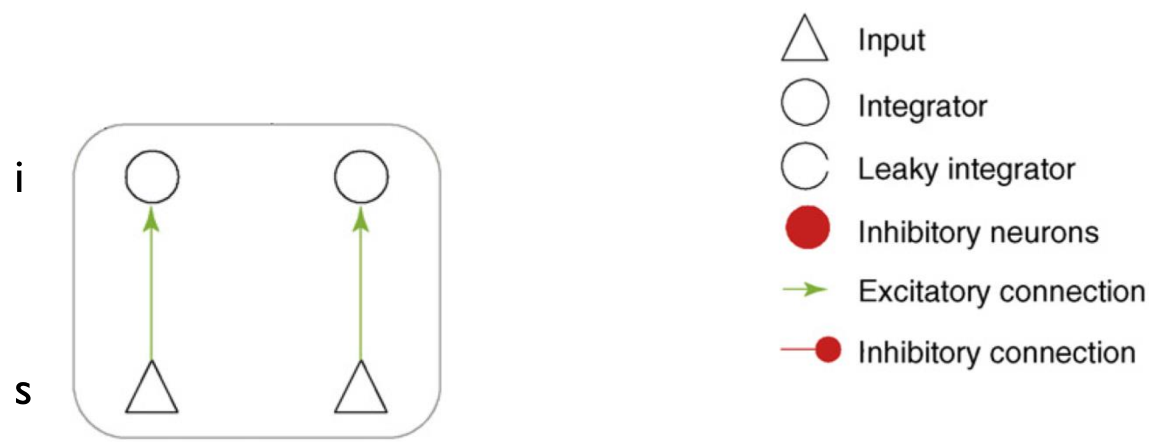
Bogacz, 2007

Race models

- 2 independent processes of integration
  - Sensory evidence (s) gets integrated by integration neurons (i)

$$i_{t+1} = i_t + s$$

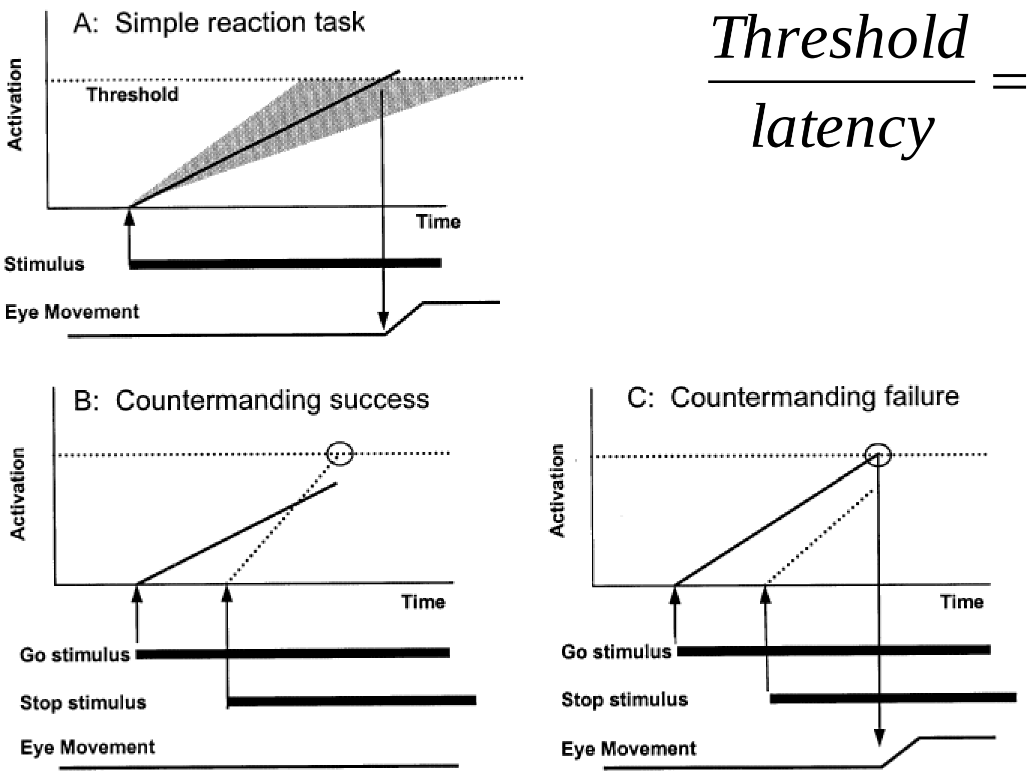
  - The process that first reaches a certain threshold value for i wins the competition



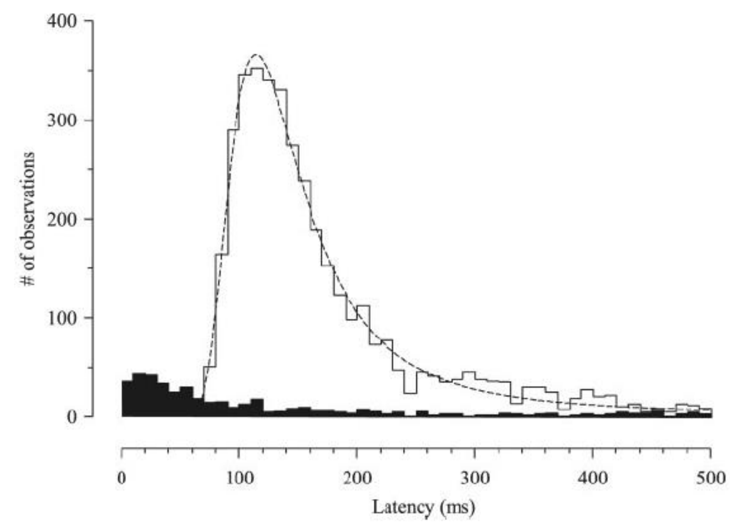
Bogacz, 2007

Race models

- Example: saccadic countermanding
  - Linear rise-to-threshold race model (LATER)



$$\frac{Threshold}{latency} = rate\ of\ rise = N(\mu, \sigma^2)$$



Blohm et al., 2003

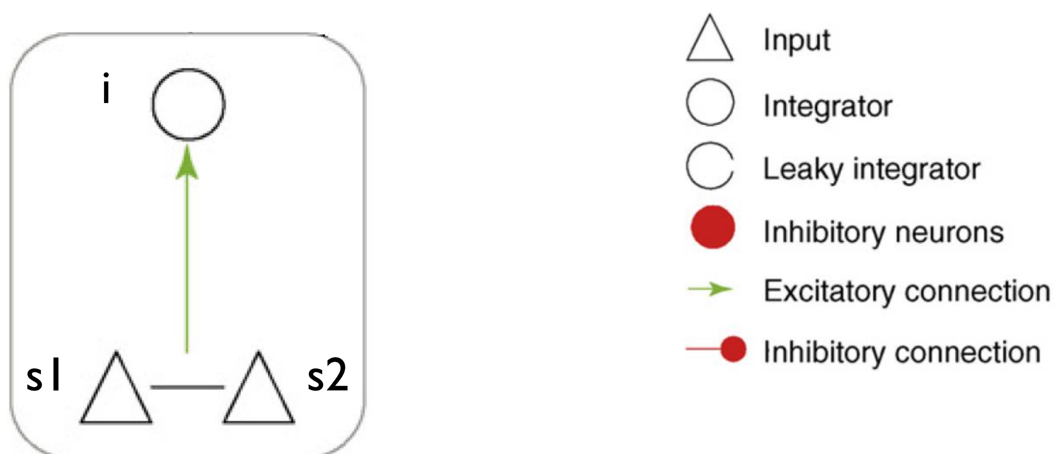
Asrress & Carpenter, 2001

Diffusion models

- A single process of integration
  - The difference of sensory evidence (s1-s2) gets integrated by integration neurons (i)

$$i_{t+1} = i_t + s_1 - s_2$$

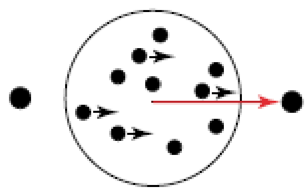
  - When the process reaches a certain (positive or negative) threshold value for i, a decision is made

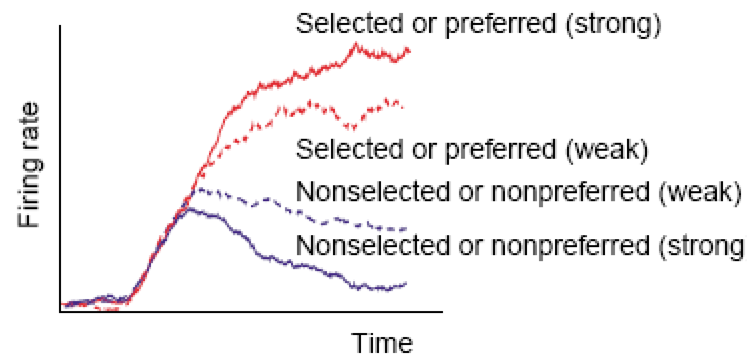


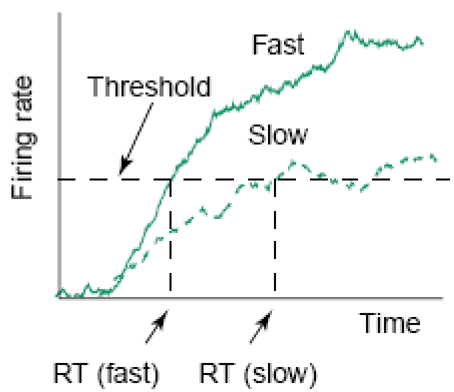
Bogacz, 2007

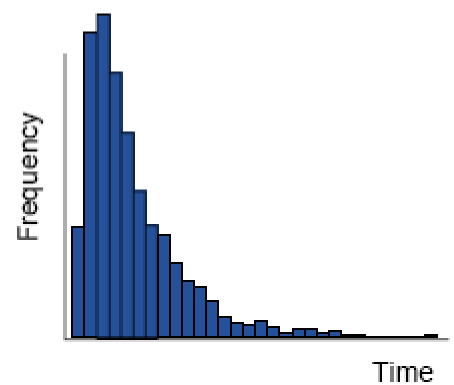
Diffusion models

- Example: left-right decisions
  - E.g. areas FEF, LIP, SC, MT…





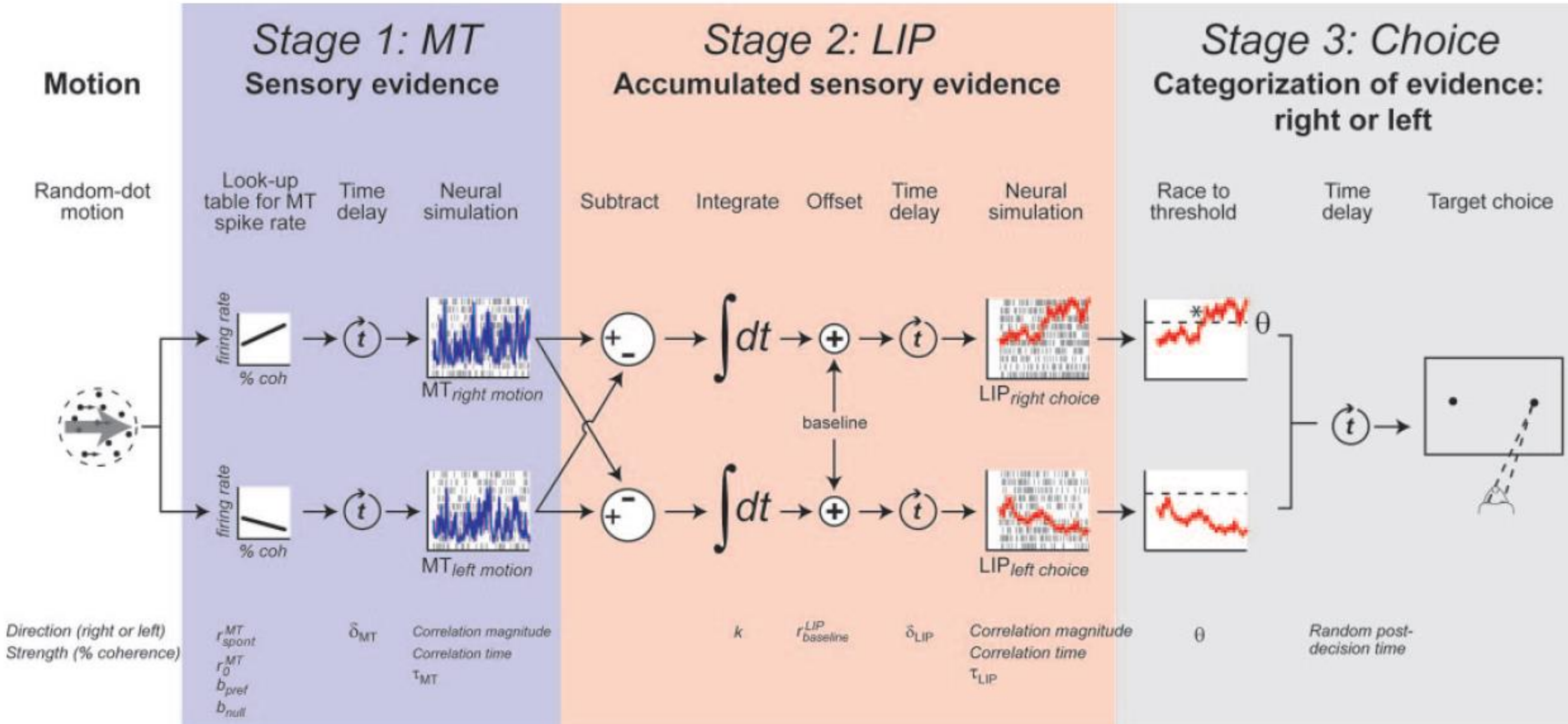




Smith & Ratcliff, 2004

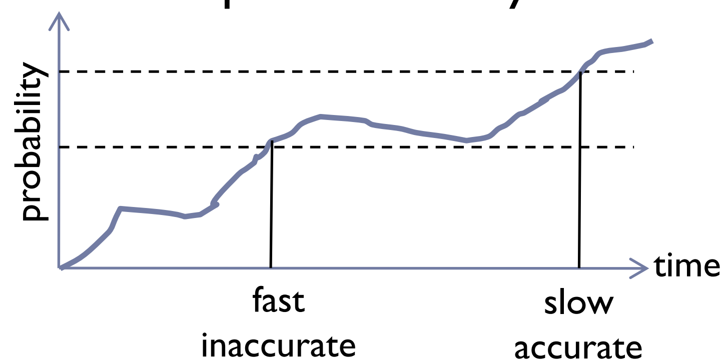
Diffusion models

- Example: left-right decisions
  - Integrated decision model (Mazurek, et al. 2003)



Optimal decision criteria

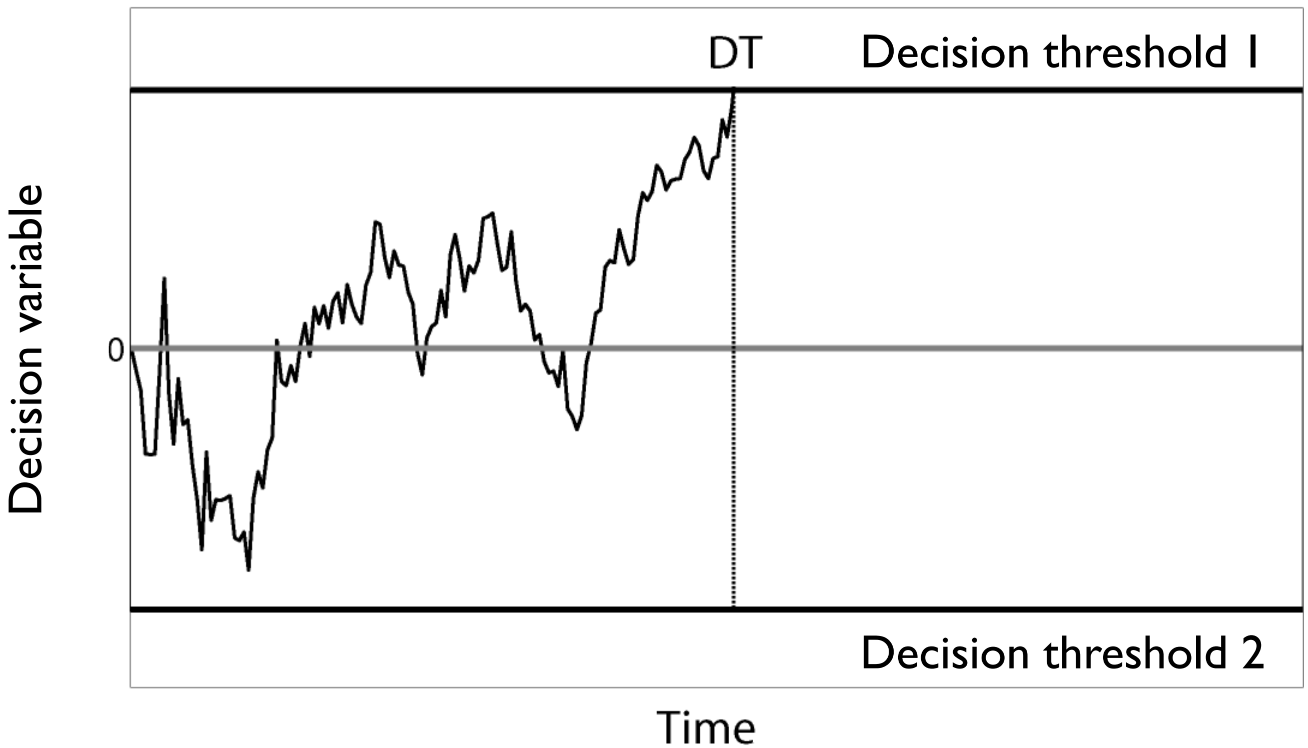
- Question: how to find a decision threshold?
  - Easiest way: fixed threshold
    - But does not account for speed-accuracy trade-off



    - No adaptive ability
  - Optimal decision: sequential probability ratio test (SPRT)
    - Optimizes the speed of decision for a given accuracy
    - Adaptive threshold
    - Given the same accuracy, diffusion model faster than race model (bc of adaptive threshold)

Optimal decision criteria

- Speed-accuracy trade-off



Optimal decision criteria

- Mathematically (deciding between 2 hypotheses):
  - Null Hypothesis H_0
  - Alternative hypothesis H_1
  - Decision variable: cumulative sum of log-likelihood ratio

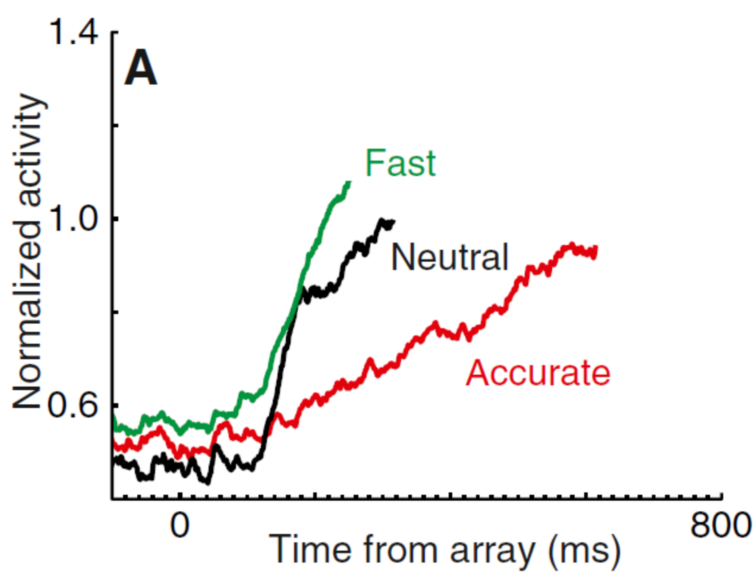
$$S_i = \sum_i \log \Lambda_i \qquad e.g. \quad \Lambda_i = \frac{p(R \mid e_i)}{p(L \mid e_i)}$$

  - Decision
    - If $S_i \leq a$: accept H_0
    - If $S_i \geq b$: accept H_1
    - Otherwise: continue sampling…
  - Estimation of thresholds:
    - Use desired Type I (false positive, α) and Type II (false negative, β) error rates

$$a \approx \log \frac{\beta}{1-\alpha}; \quad b \approx \log \frac{1-\beta}{\alpha}$$

Dynamics, not decision threshold

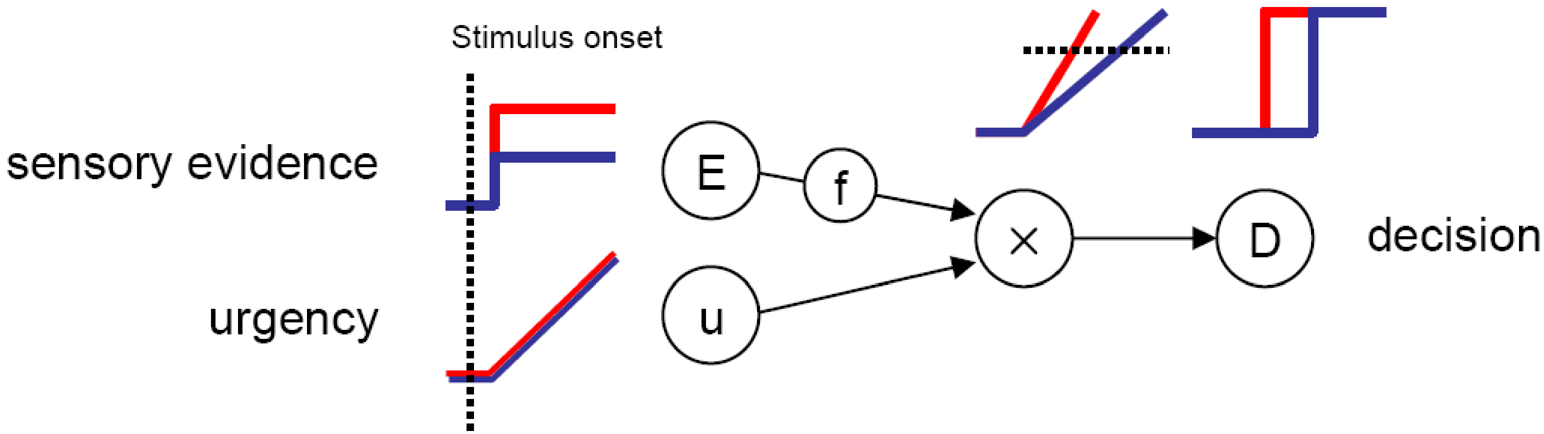
- No experimental evidence for a changing threshold
- Instead changes in network dynamics might implement speed-accuracy changes
  - Cognitive signals can lead to higher baseline activity
  - Higher baseline activity can boost neural dynamics → faster integration → faster decisions (Standage et al. 2014)



Heitz & Schall, 2012

Urgency gating model

- An urgency signal weights later evidence more
  - Multiplication of sensory evidence by a growing function of time
  - Threshold comparison



$$x_i(t) = g \cdot f(E_i(t)) \cdot u(t) \qquad -T < x_i(t) < T$$

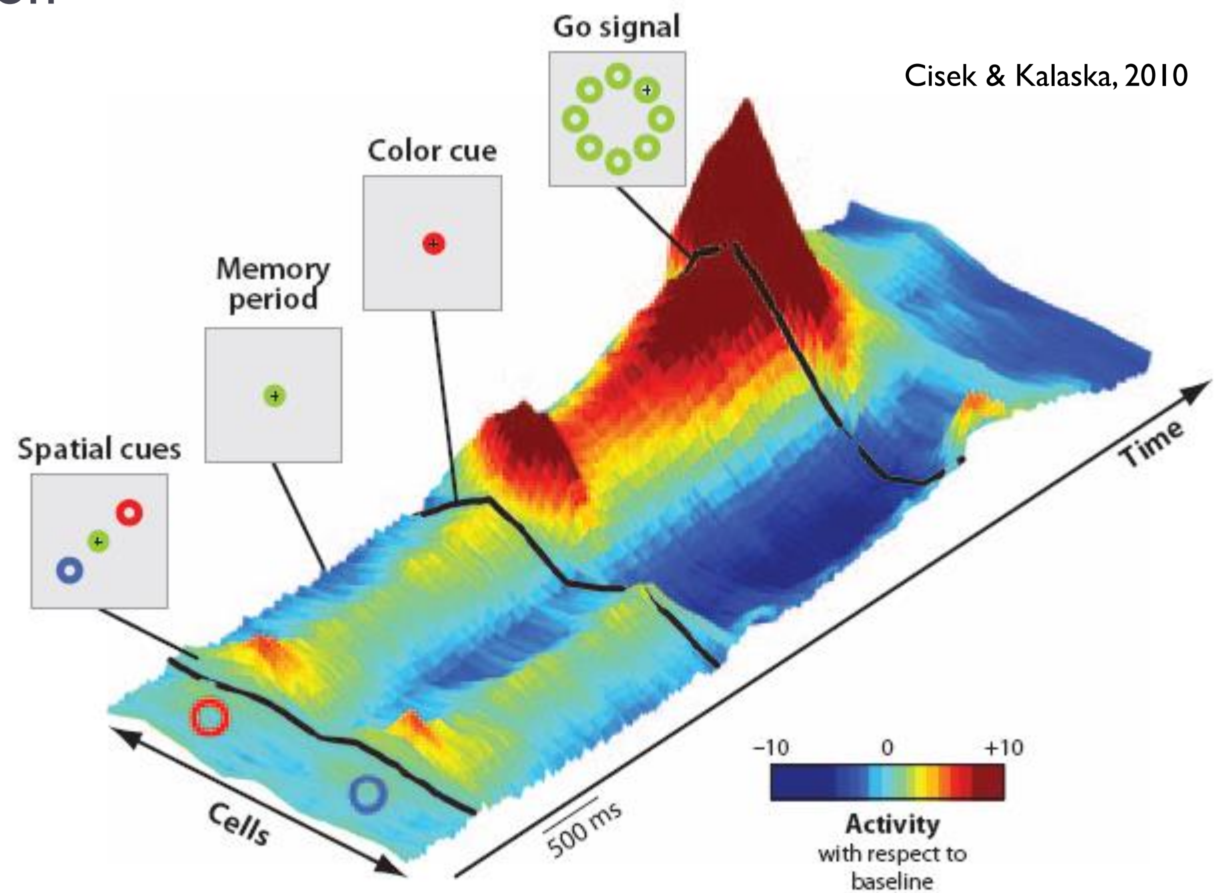
Cisek, et al., 2009

Conflict resolution

- In cortex, e.g. dorsal pre-motor area
  - Biased competition

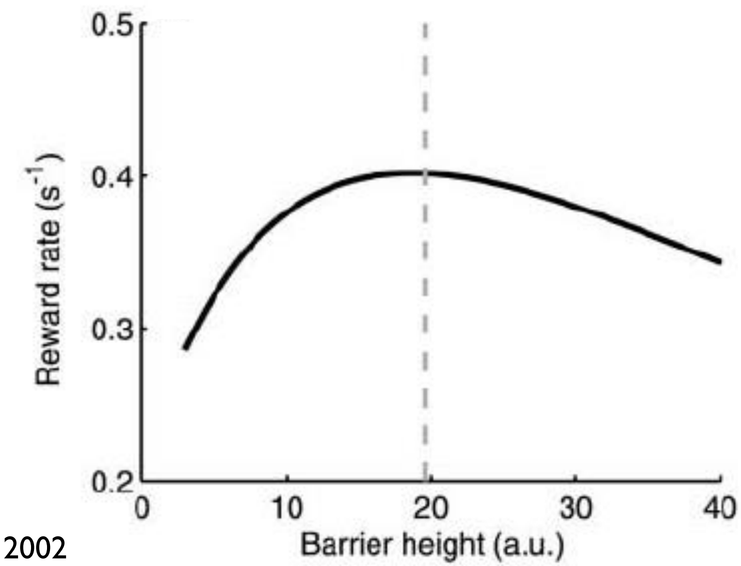
The interaction function between cells is such that differences between small competing peaks are ignored, but once activity crosses a "quenching threshold", behaviour becomes winner-take-all. (Grossberg 1973)

Cisek & Kalaska, 2010



Relationship with reward

- The higher the threshold, the more accurate the decision, the more reward...?
  - No, because the longer the time to get reward
  - Thus, at some point the reward rate drops again...
- Decision threshold choice might maximize the reward rate
- SPRT maximizes reward rate!
  - Bogacz et al., 2006



Gold & Shadlen, 2002

Summary

Summary & Conclusions

- Decisions are complex
  - Multiple systems
  - Multiple brain structures
  - Multiple mechanisms
- In theory, optimal decisions can be made
  - Decision signal rises to threshold
  - Flexible thresholds account for behavioural flexibility
  - Link to Bayesian integration
- Strength
  - Explanation of a variety of neurological deficits
- Limitation
  - Multiple systems: emotions, etc (not rational)
  - http://www.youtube.com/watch?v=N2iJF2I94pg

That’s all folks