A Model of Two Interacting Accumulators for Reach & Saccade Reaction Times

Daniel Martí

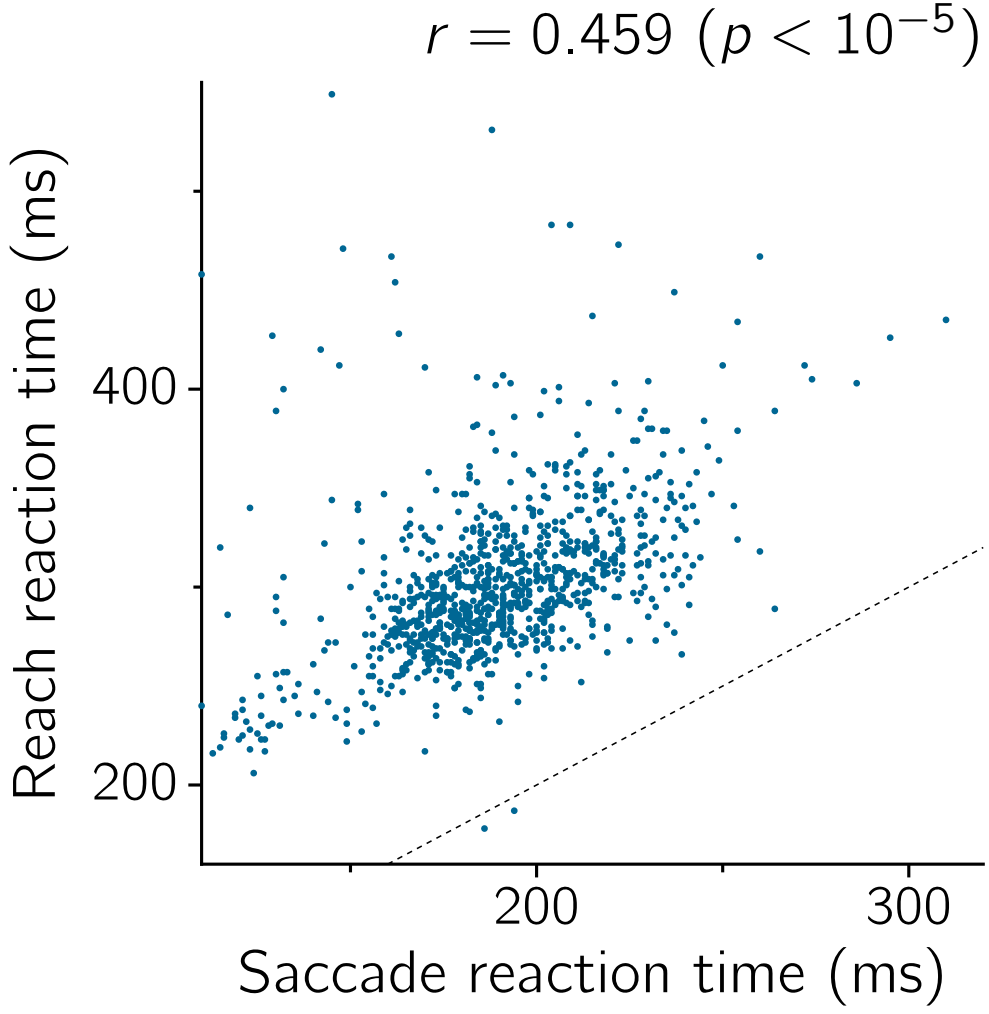
Center for Neural Science

New York University

Motivation: Arm-Eye Coordination

- Arm movements (reaching, pointing) are usually accompanied by saccadic eye movements.
- Typically, eyes begin moving $50 - 100$ ms before the initiation of hand movement.

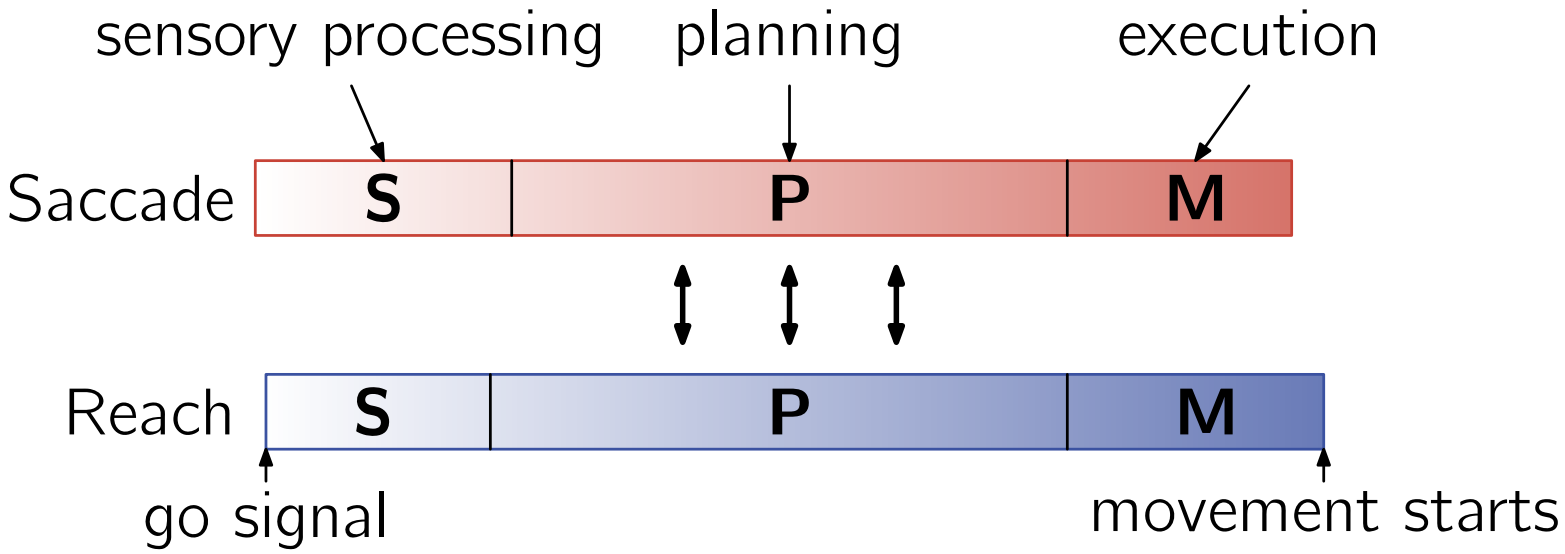
Saccade and Reach Reaction Times are Correlated



Where do these correlations come from?

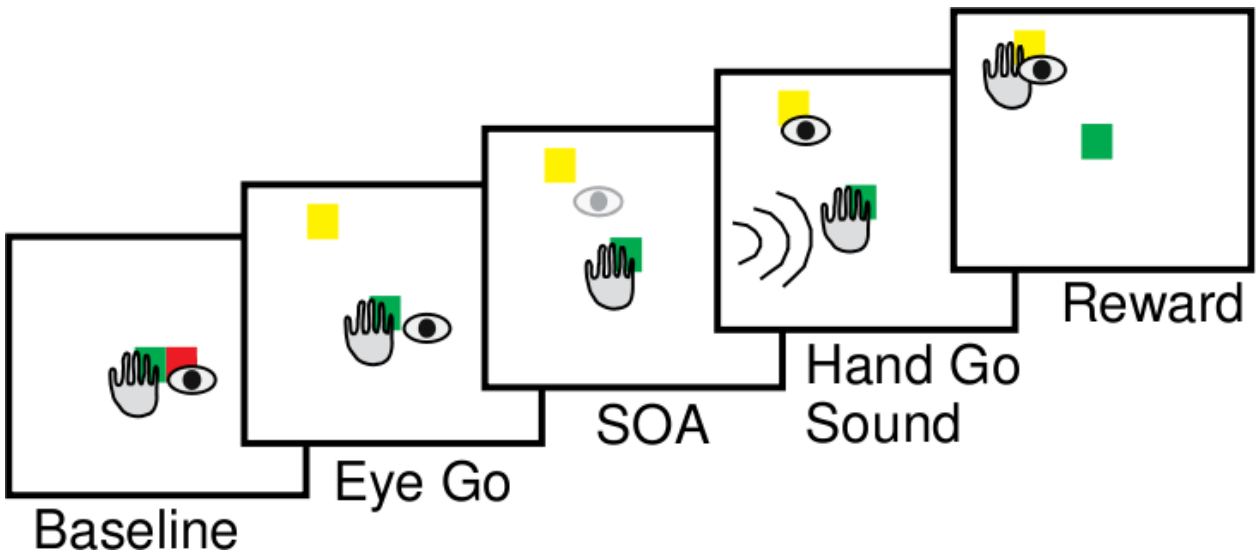
Hypothesis

Correlations may arise from the interaction between planning stages of saccades and reaches



Stimulus Onset Asynchrony (SOA) task

- Dual reaction time task.
- The go cue for the reach is delayed with respect to the saccade.

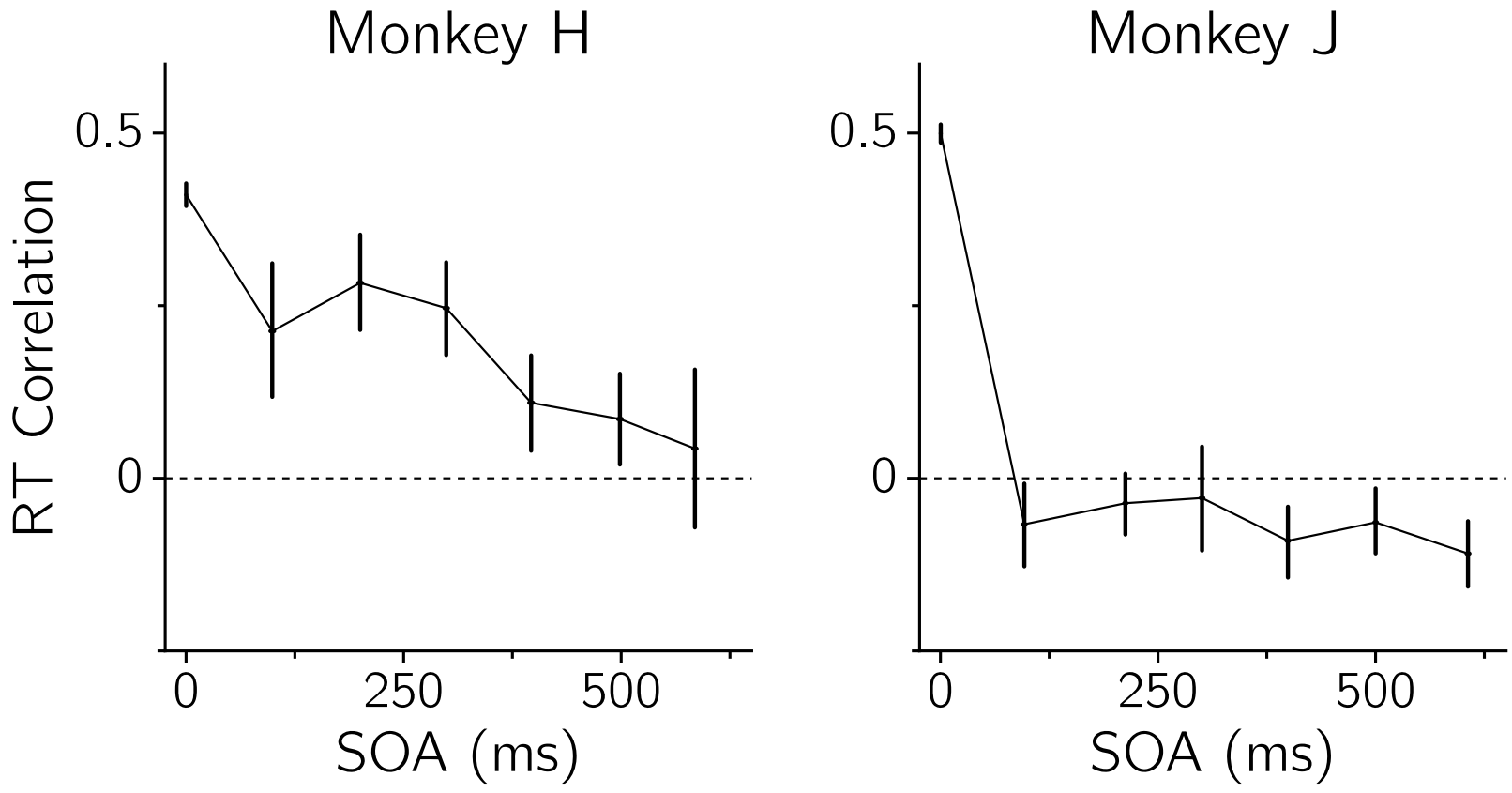


- SOA is varied randomly from trial to trial.
- Increasing SOA decreases overlap between planning stages of both movements

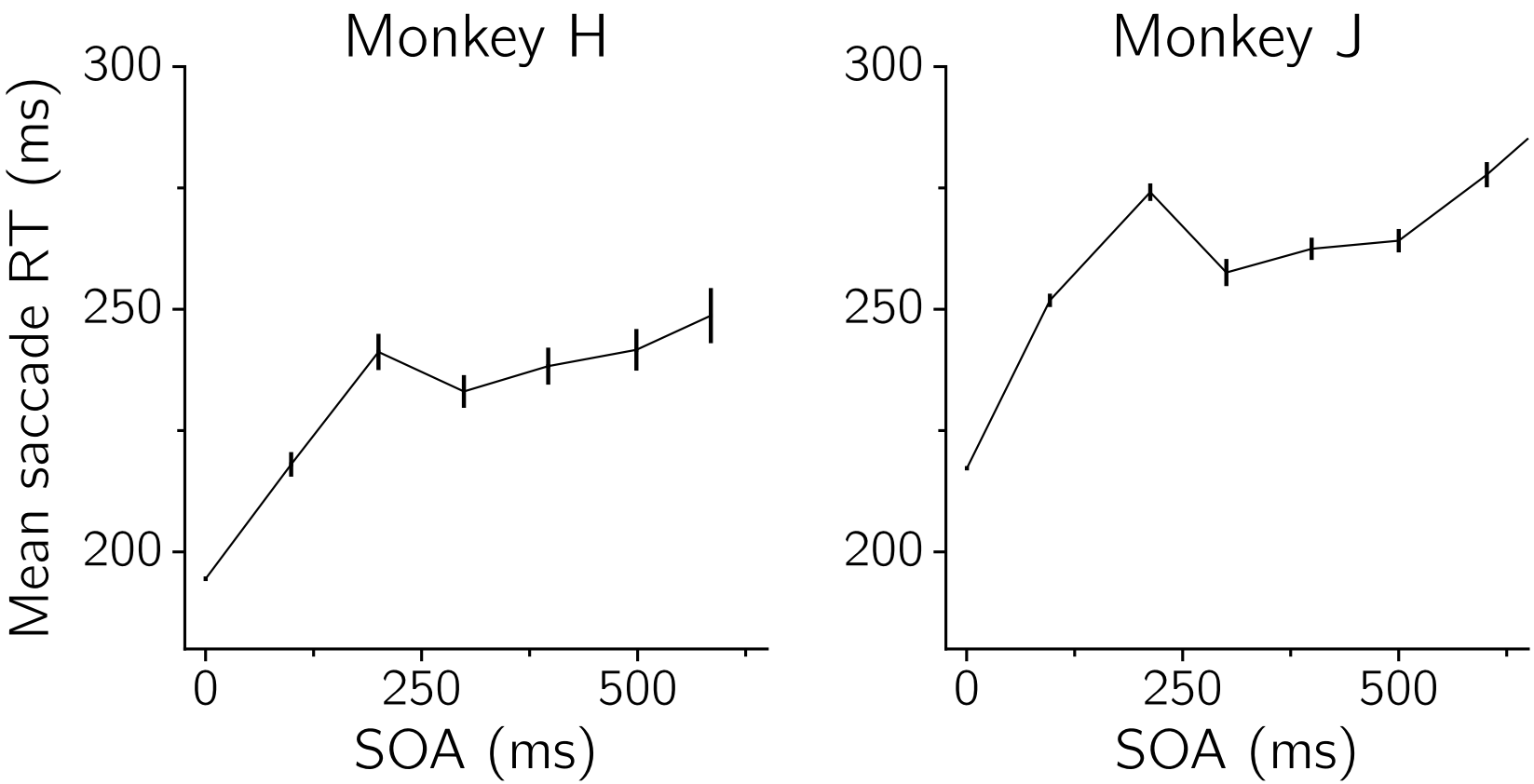
Correlations Decrease with Increasing SOAs

Correlations as measured by the correlation coefficient

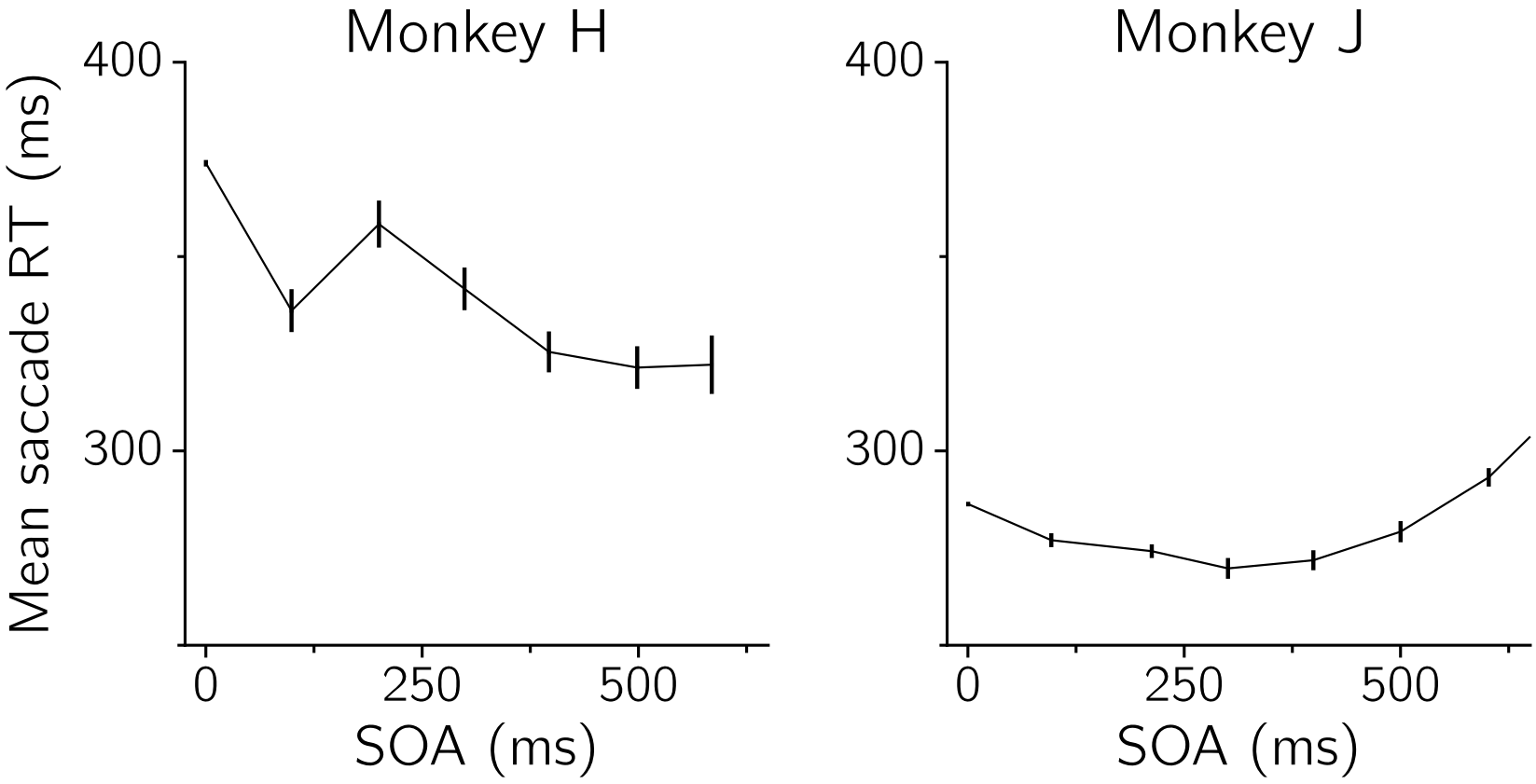
$$\rho_{\mathrm{SRT,RRT}} \equiv \mathrm{cov}(\mathrm{SRT}, \mathrm{RRT})/(\sigma_{\mathrm{SRT}}\sigma_{\mathrm{RRT}})$$



Shorter Mean Saccade RTs for Short SOAs

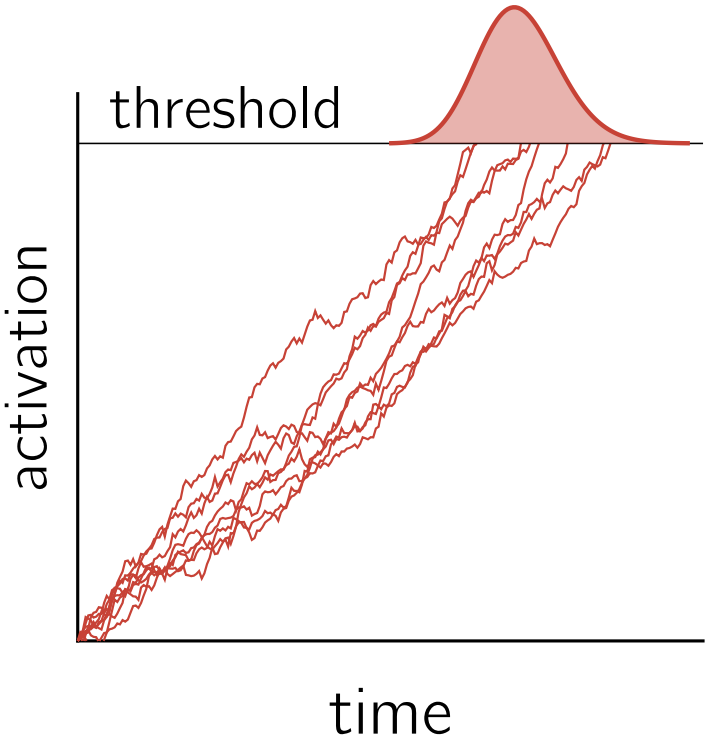


Longer Mean Reach RTs for Short SOAs



Uncertainty about time of occurrence is known to slow down reaction times (Klemmer 1957)

Integrate-to-threshold models

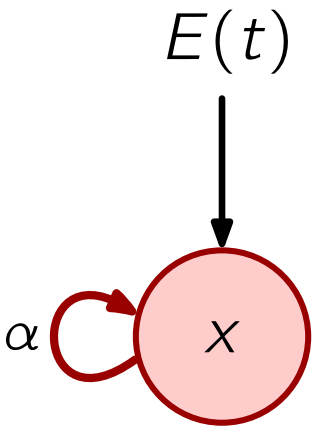


- Integration of noisy sensory inputs toward a threshold
- Reaction time (RT) is the first passage time through threshold
- Describe behavioral data of:
  1. 2-choice tasks (Ratcliff 1978,...)
  2. simple RT tasks (Emerson 1970, Smith 1995)

- Can be related with neurobiological models (Wang 2002, Roxin & Ledberg 2008).

Model: Neural Integrators

The planning stage of a particular movement is encoded in the rate of a population of neurons:

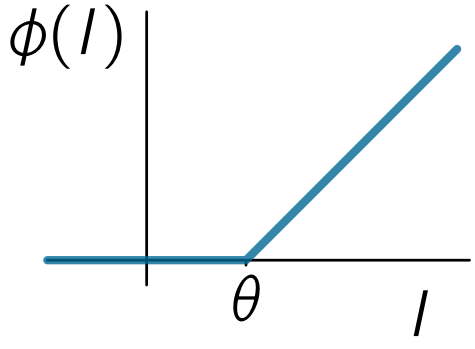


Leaky accumulator

$$\begin{aligned}\tau\dot{x} &= -x + \phi(I) \\ &= -x + \phi\big(\alpha x + E(t)\big),\end{aligned}$$

where

- $\phi(I) = g[I-\theta]_+, g > 0$, is a threshold linear input-output function.
- $\alpha > 0$ is a self-coupling parameter.
- $E(t)$ is the external input.



Model: External Input

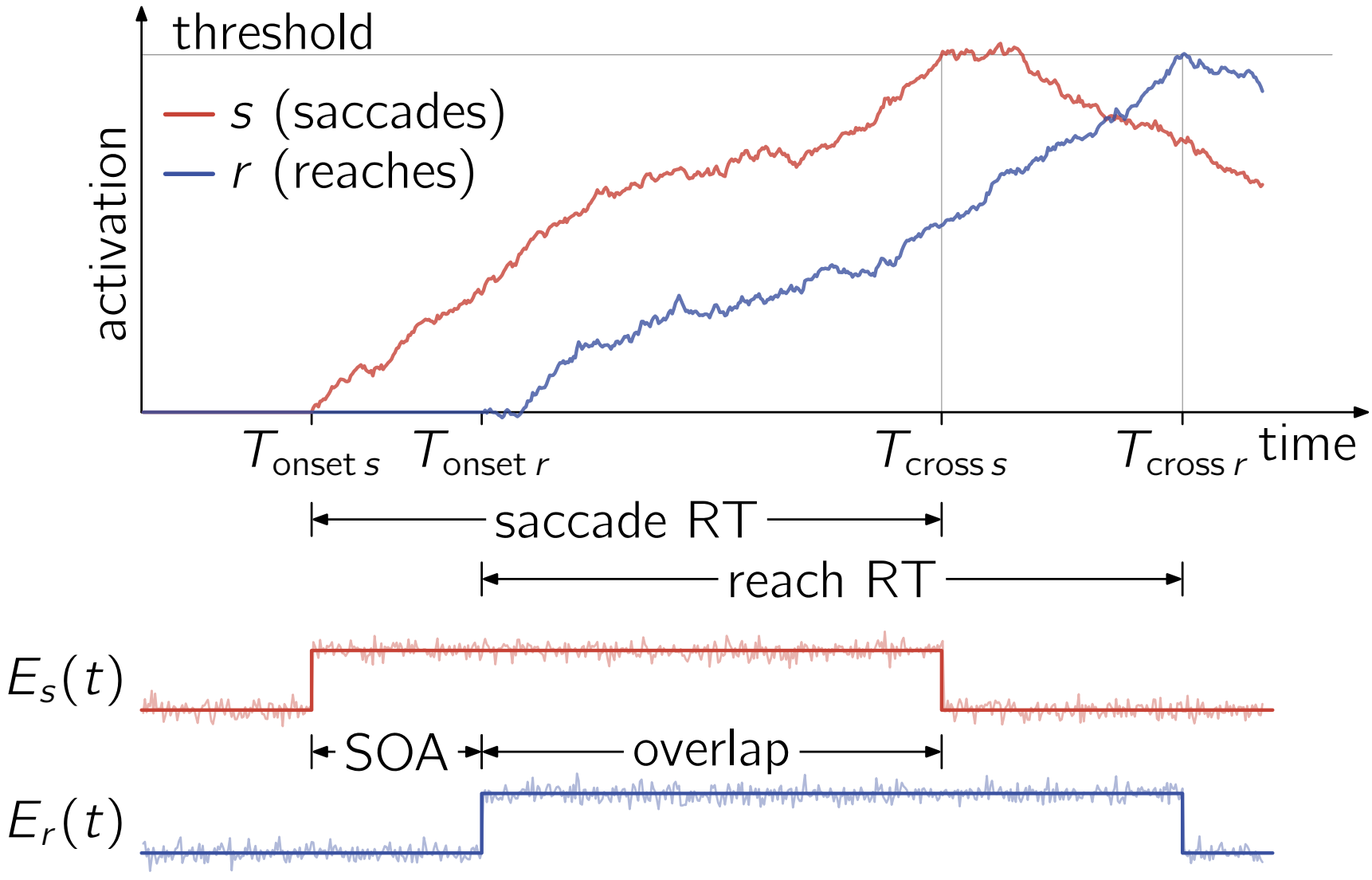
- The sensory external input $E(t)$ is noisy

$$E(t) = \underbrace{\langle E(t) \rangle}_{\text{DC comp.}} + \underbrace{\sigma \eta(t)}_{\text{noise}}$$

- The DC component mimics (modulo residual times) the go cue signals of the task.

- Noise is white and gaussian.

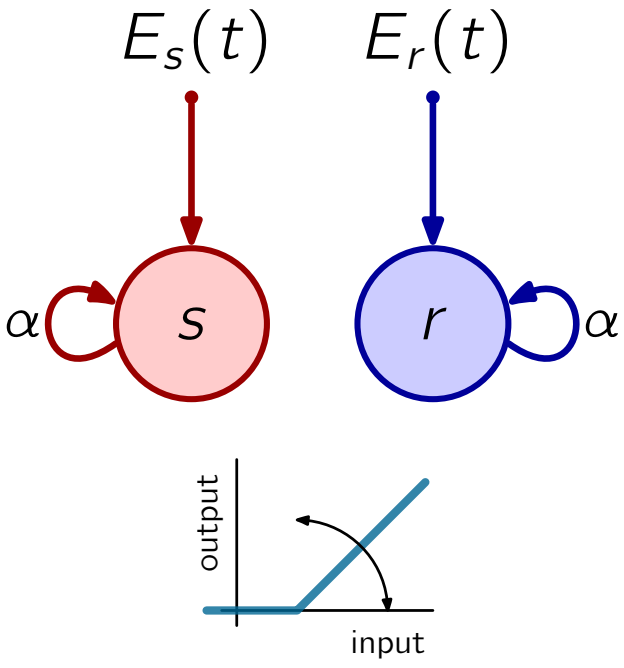
Sample Paths of the Dual Accumulation Process



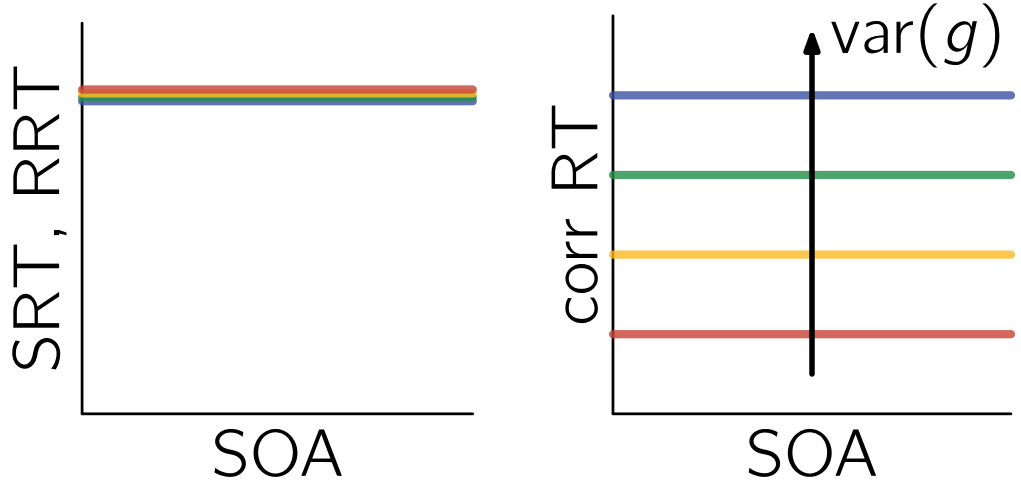
Possible Mechanisms for Facilitation & RT Correlations

1. Common neuromodulation (due to, e.g., arousal).
2. Shared inputs.
3. Mutual excitation.

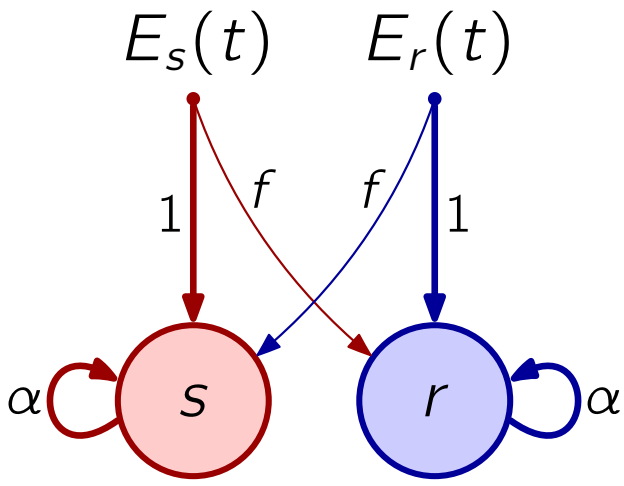
Model I: Common Neuromodulation



- common change in the gain g
- $\tau_g \gg \tau$: modulation much slower than the accumulation process.
- assumed to vary randomly from trial to trial



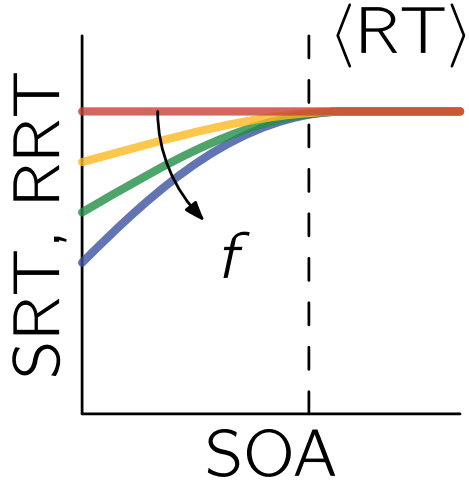
Model II: Shared Signals

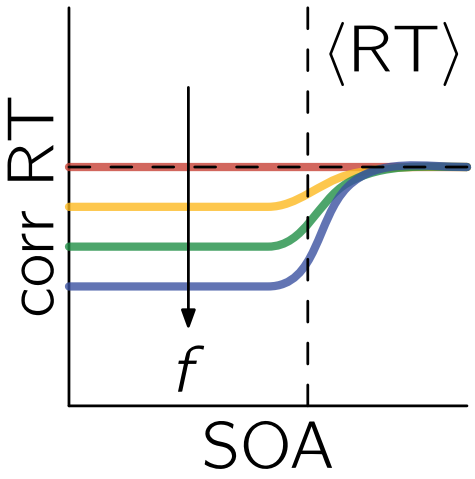


$0 < f < 1$

$$I_s = \alpha s + E_s(t) + f E_r(t)$$
$$I_r = \alpha r + E_r(t) + f E_s(t)$$

- "Correlated signals" (Gawne & Richmond 1993), or forward excitation.
- Facilitation for both effectors for short SOAs
- Negative correlations for short SOAs.

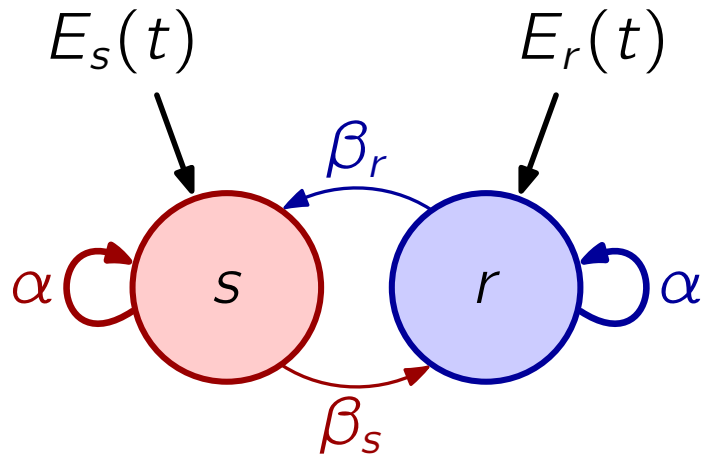




Model III: Mutually Coupled Accumulators

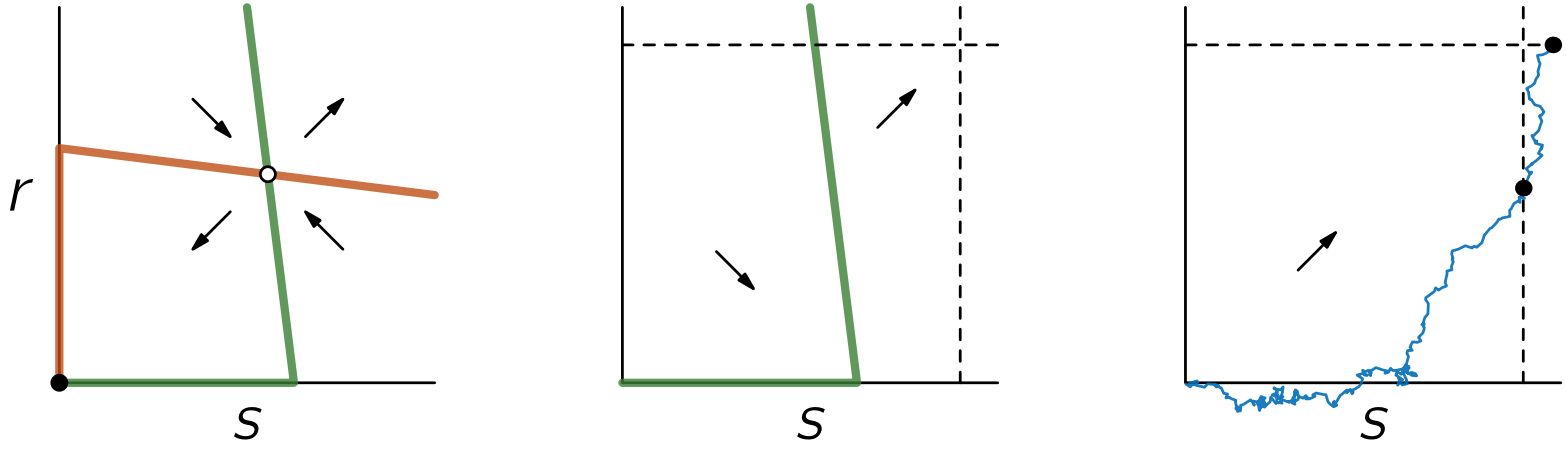
- Mutual *excitation*:

$$I_s = \alpha s + \beta_r r + E_s(t),$$
$$I_r = \alpha r + \beta_s s + E_r(t),$$

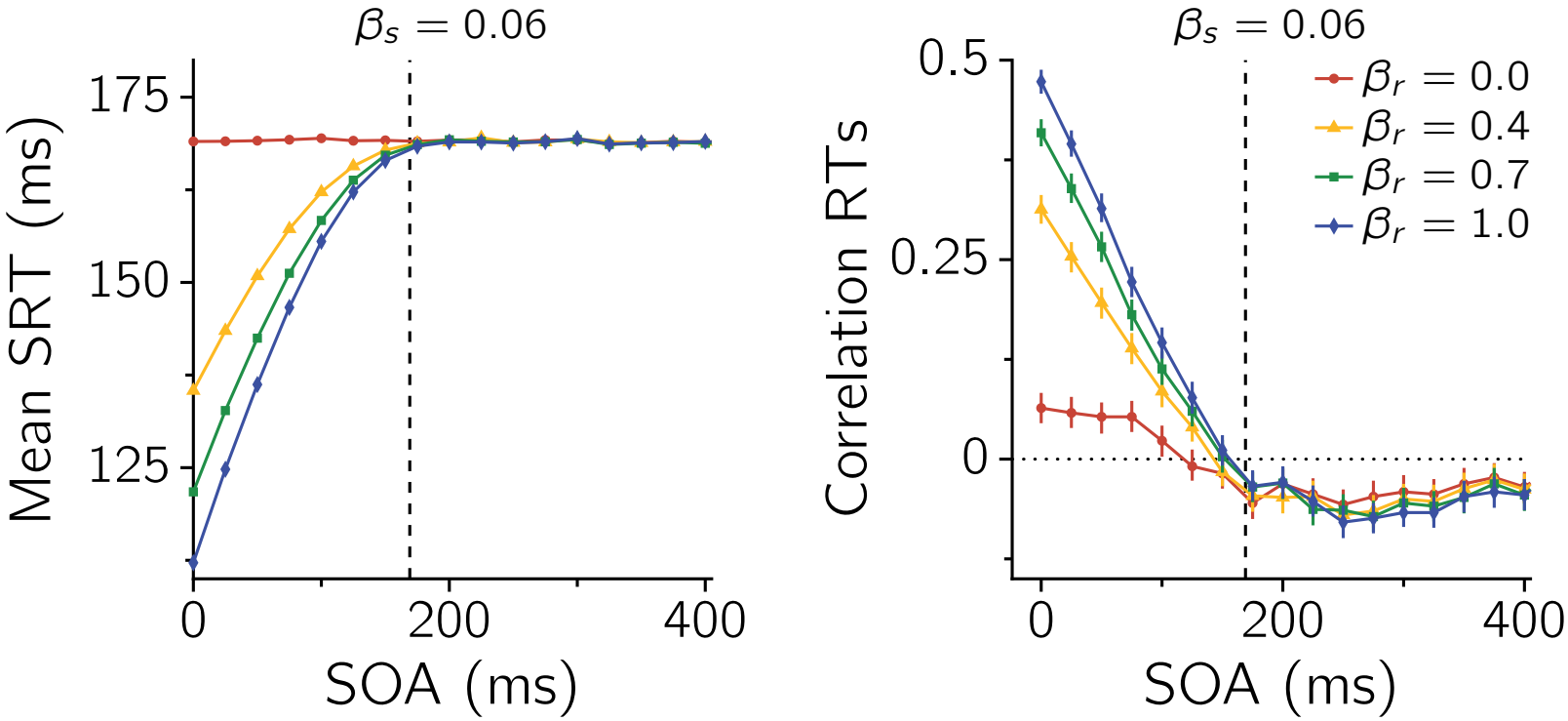


where $\beta_s, \beta_r > 0$, not necessarily equal.

- When both inputs are on, the system describes a 2-D Ornstein-Uhlenbeck process



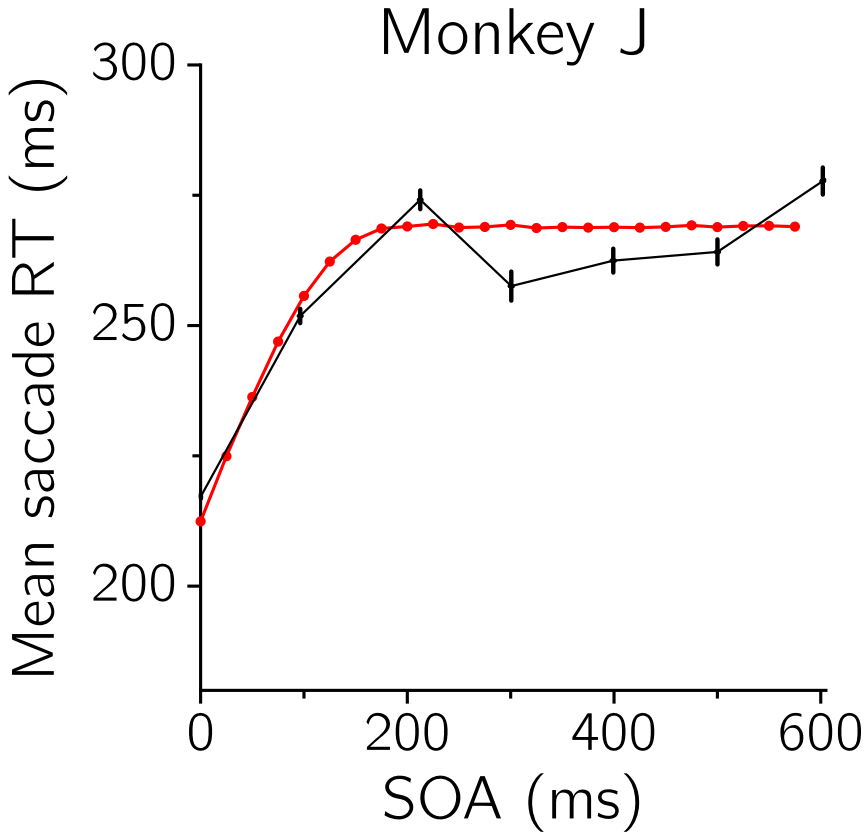
Mutually coupled accumulators describes facilitation and decaying correlations

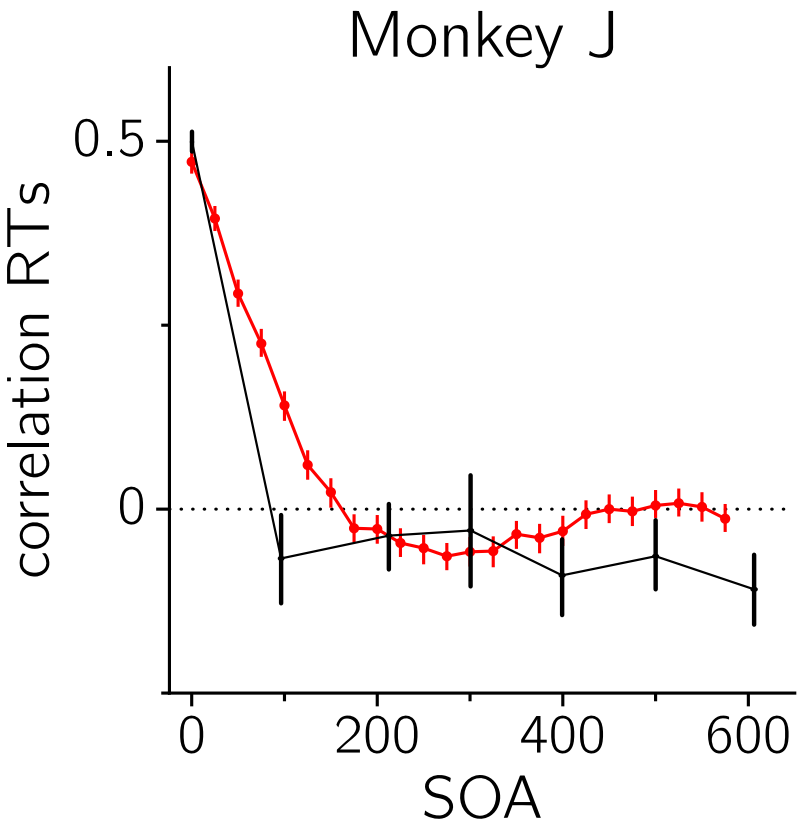


Qualitative agreement if $\beta_r \gg \beta_s$.

Fits

Reasonably good fits varying the parameters of the model ($\alpha, \beta_s, \beta_r, \tau, \sigma$, and residual times).





Summary

- For movements of two effectors, correlations of reaction times quantify how coordinated movements are.
- When hand and eye movements are made separately, correlations of reaction times disappear.
- A model of two accumulators coupled through excitatory connections describes both correlations in reaction times and the facilitation of coordinated movements.

Acknowledgements

John Rinzel

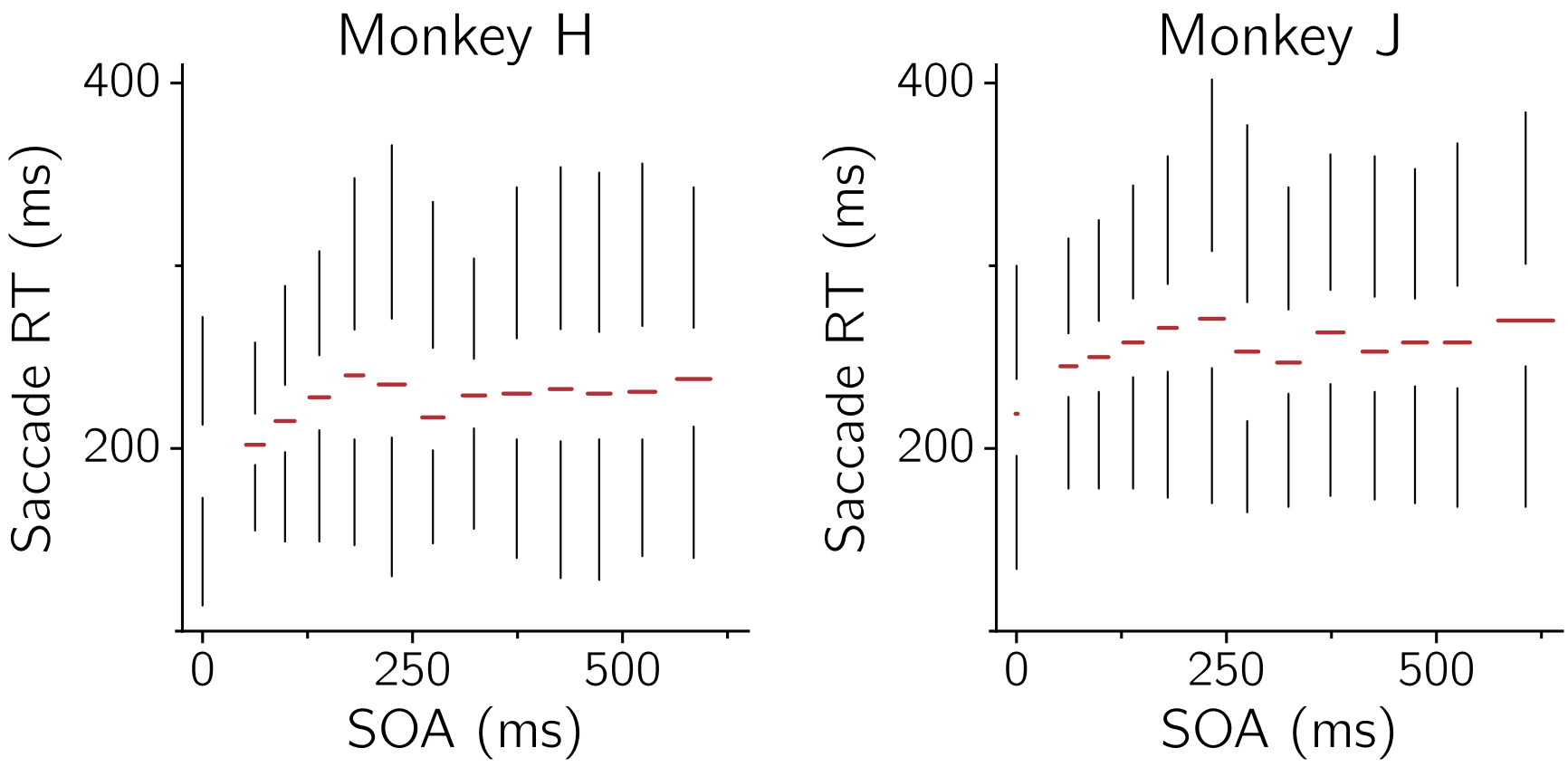
Pesaran lab

Heather Dean
Bijan Pesaran
Maureen Hagan
Eva Tsui

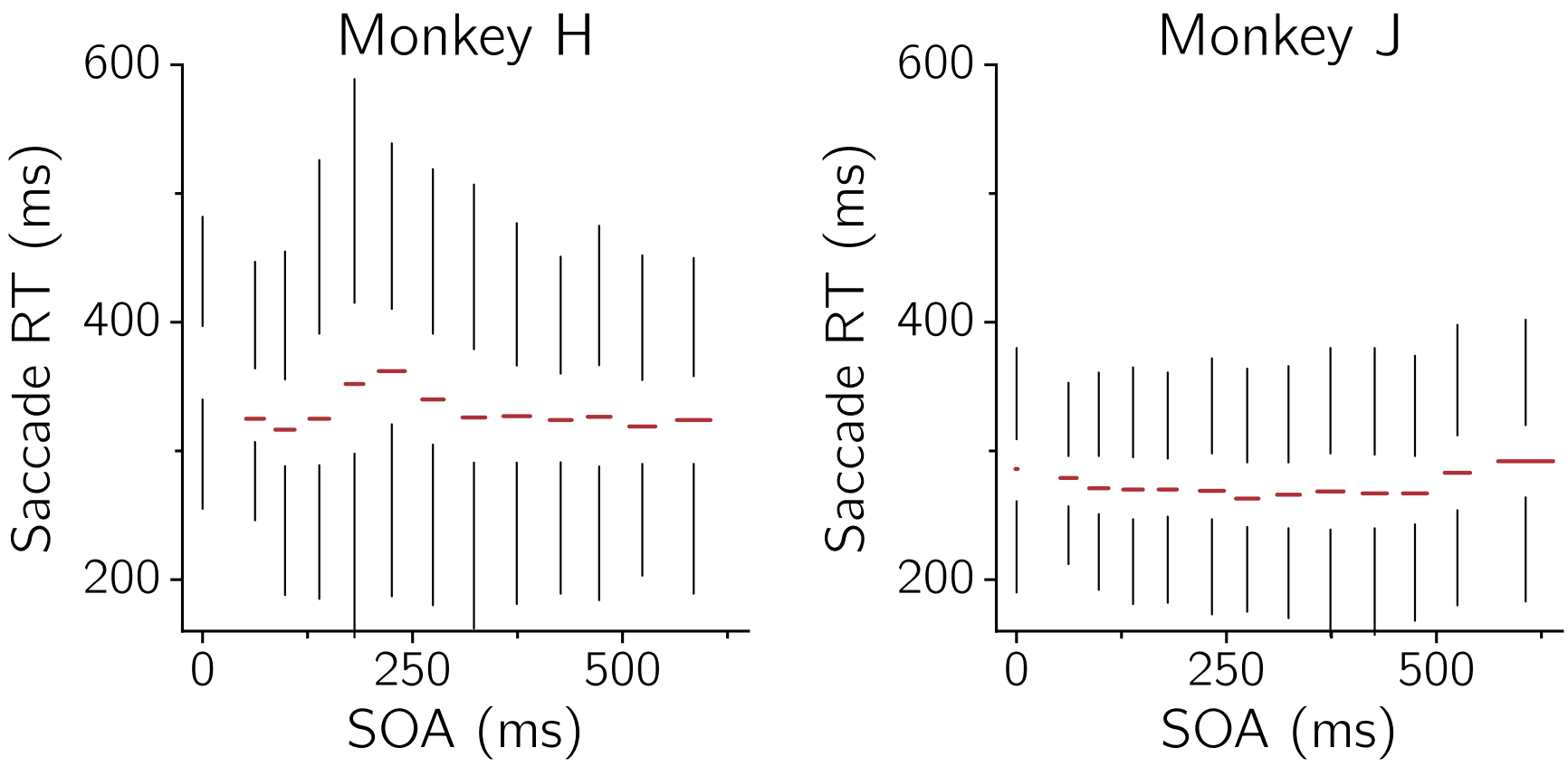
Funding

Swartz Foundation

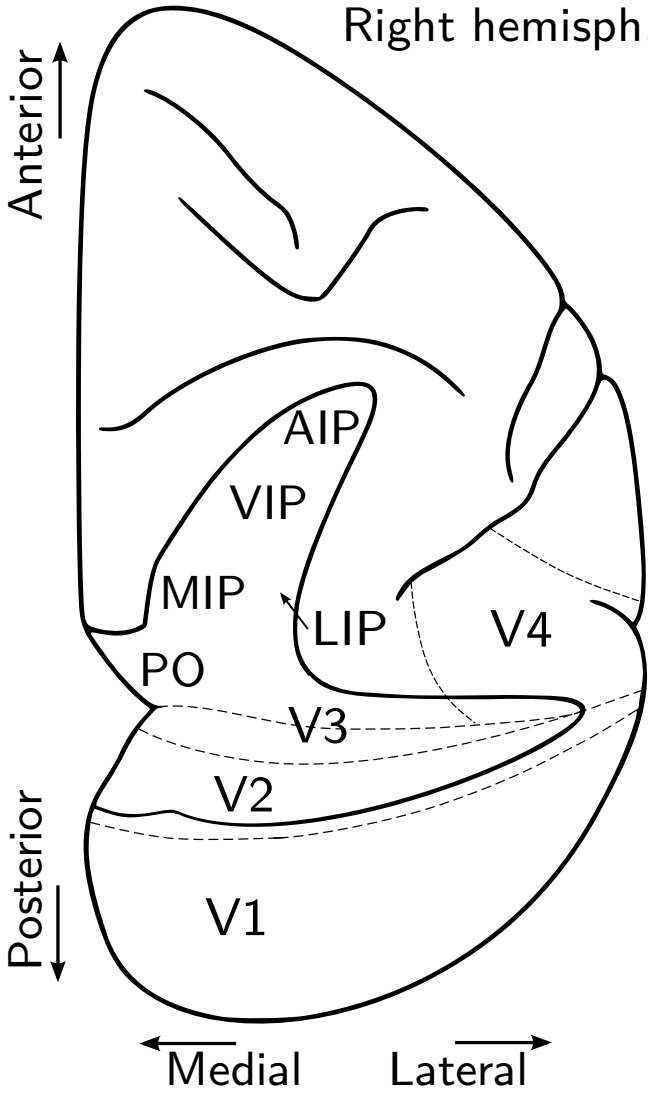
Box plots of saccade RTs versus SOA



Box plots of reach RTs versus SOA



Motor Planning in Parietal Cortex

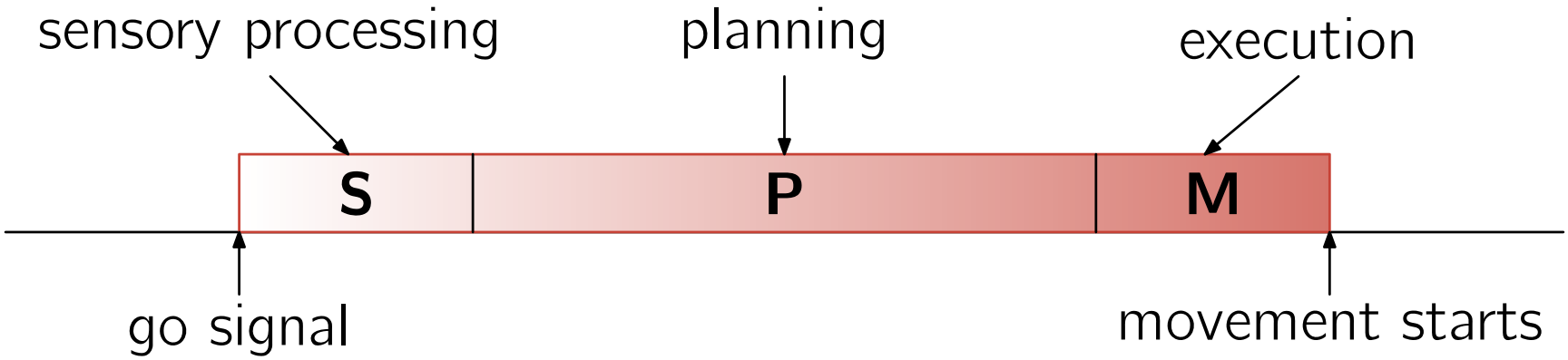


Adapted from Colby CL, Neuron 1998

Posterior Parietal Cortex (PPC):

- Motor planning:
  - Saccadic eye movements (lateral intraparietal area)
  - Reach movements (medial-posterior area)
  - Grasping mov. (anterior area)
- Spatial reference frames
  - eye-centered (LIP)
  - arm-centered (MIP–PO)
  - head-centered (VIP)

Stages of Movement Initiation



- Total reaction time as a sum of a number of successive times (Donders 1868),

$$\mathbf{T} = \mathbf{S} + \mathbf{P} + \mathbf{M} \equiv \mathbf{P} + \mathbf{R}$$

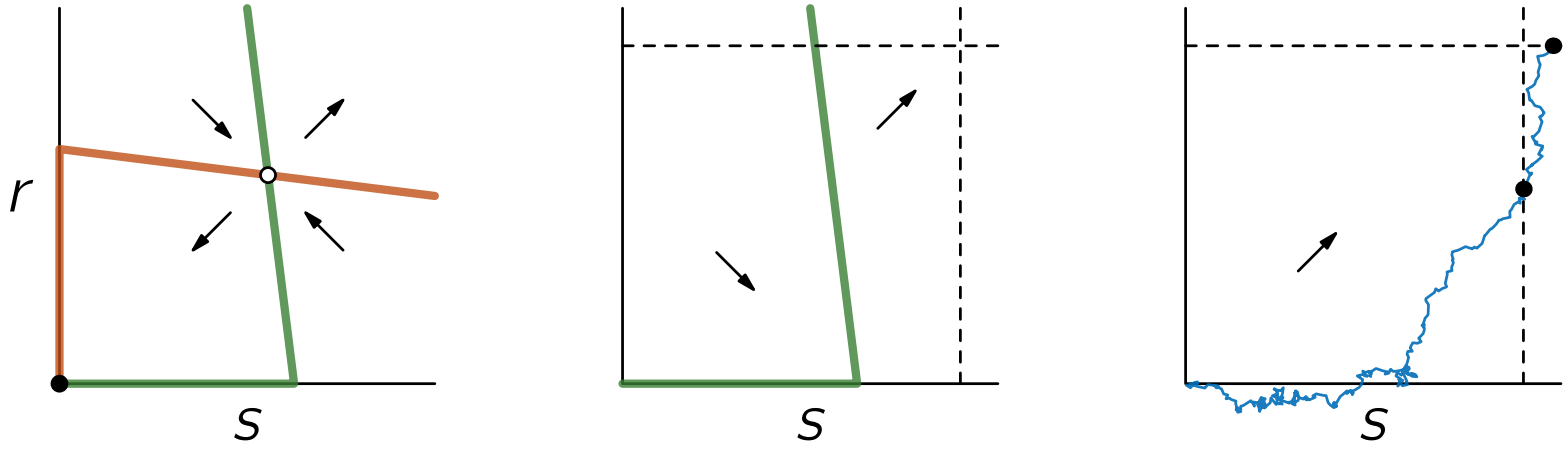
- Difficult to disambiguate the different stages.
- It is commonly assumed that most of the variability stems from the planning stage,

$$\mathrm{var}(\mathbf{T}) \approx \mathrm{var}(\mathbf{P}), \quad \mathbf{T} = \mathbf{P} + r,$$

Model: Phase Plane

- Stable fixed point when inputs are turned off.
- Trajectories go randomly to infinity (or saturation) along the direction (1,1) when inputs are on.

  For $f(I) = [I - \theta]_+$:



- Correlations in both reaction times will depend on the difference of input onsets (i.e., the SOA)