Dynamic Field Theory: Part 2: dynamics of activation fields

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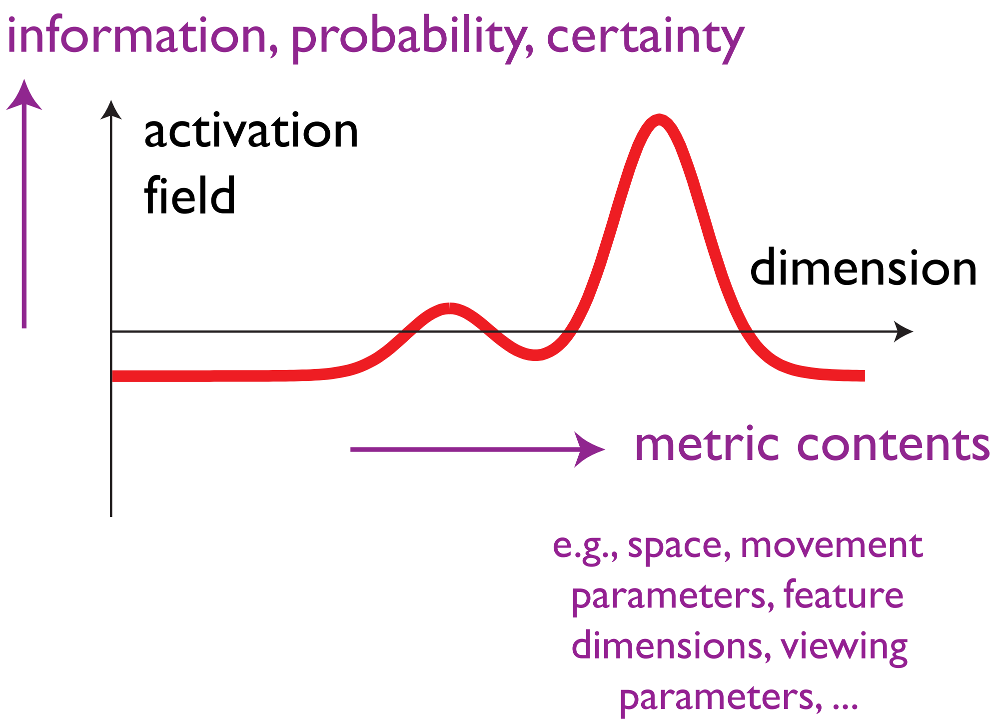
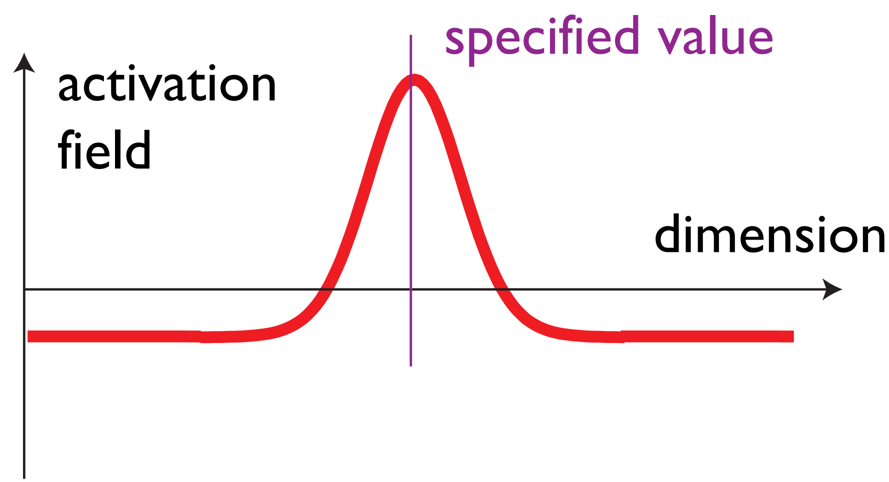
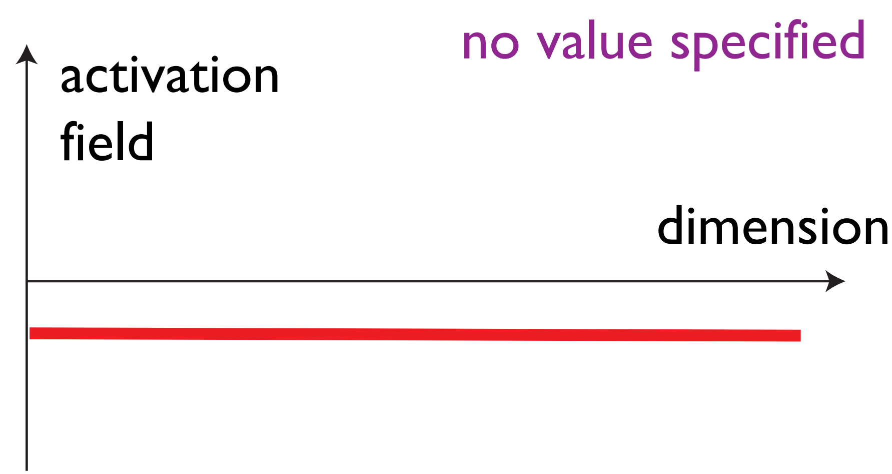
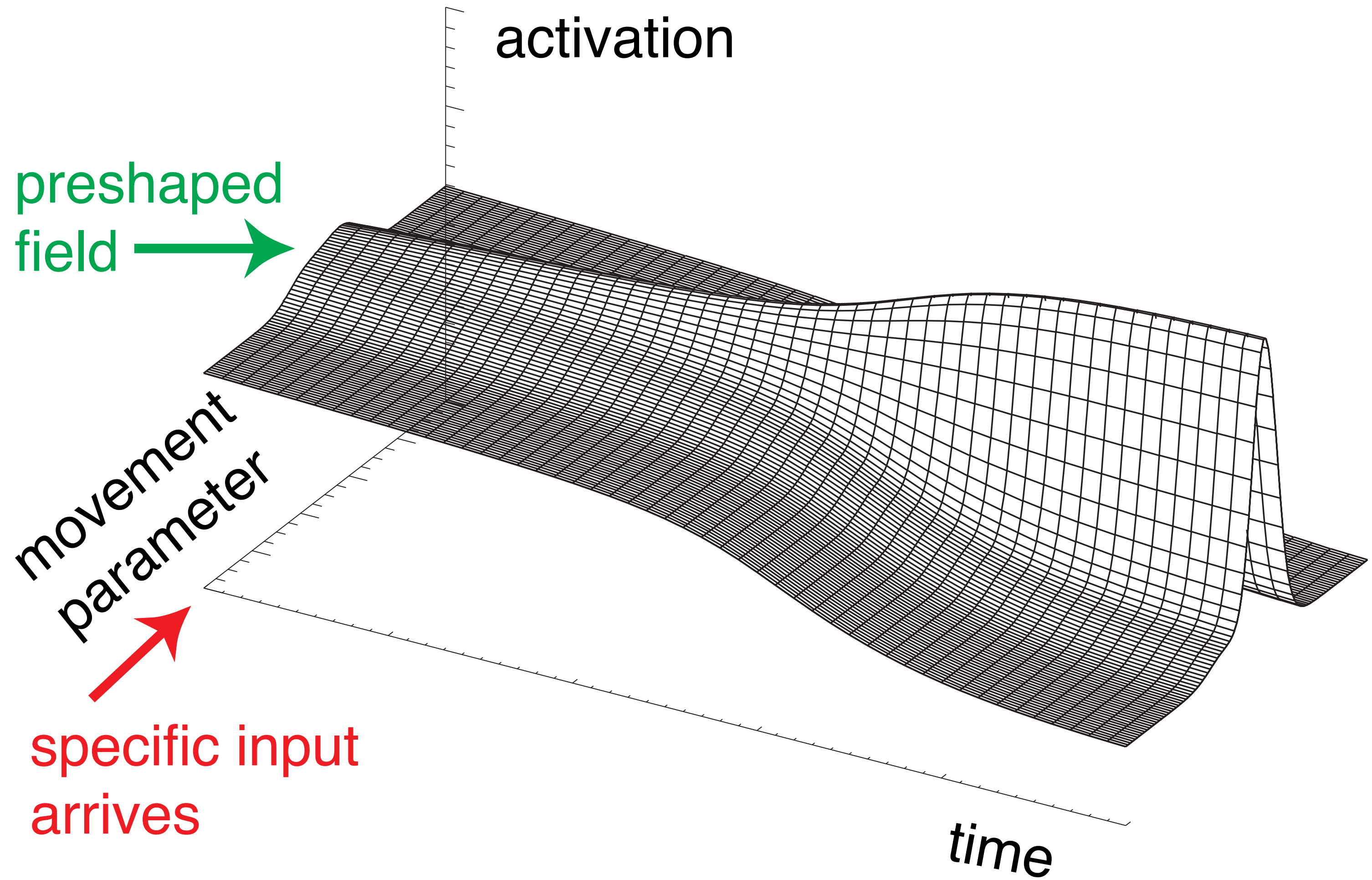
activation fields



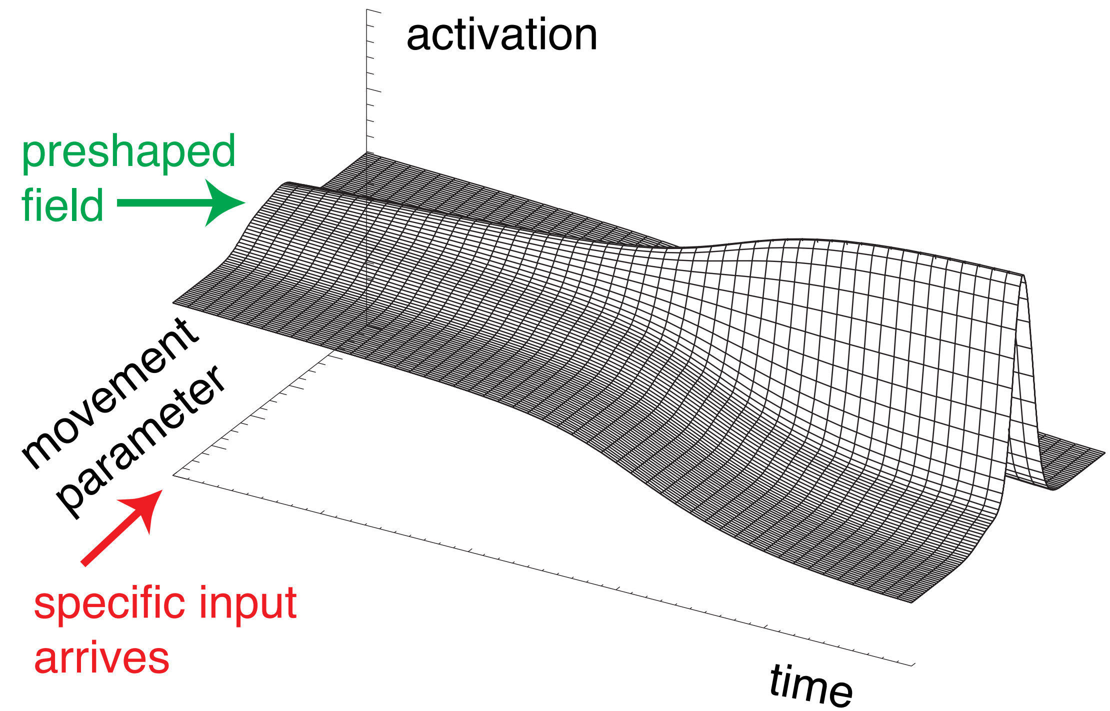


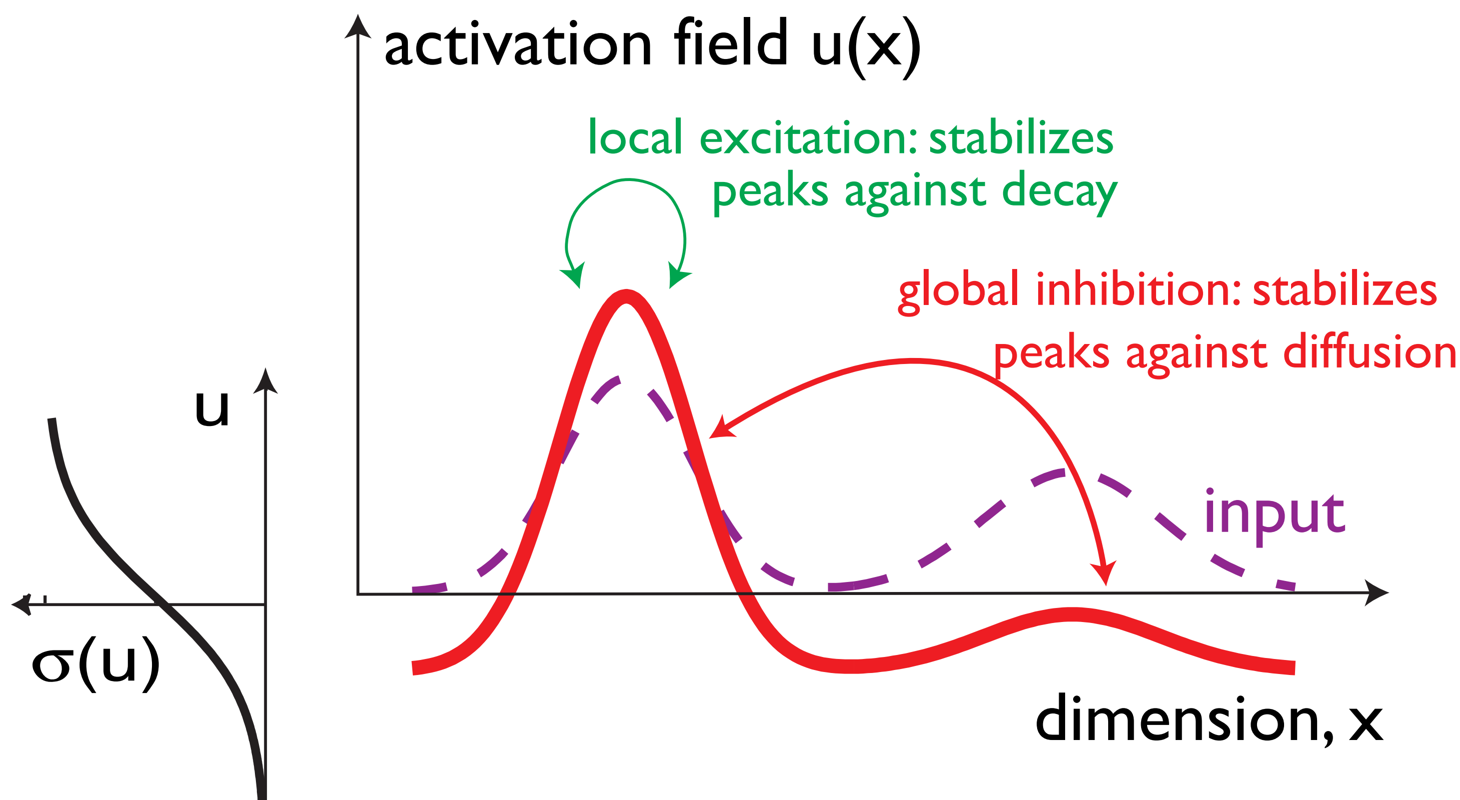


evolution of activation fields in time: neuronal dynamics



the dynamics such activation fields is structured so that localized peaks emerge as attractor solutions





mathematical formalization

Amari equation

$$\tau \dot{u}(x,t) = -u(x,t) + h + S(x,t) + \int w(x-x')\sigma(u(x',t))\,dx'$$

where

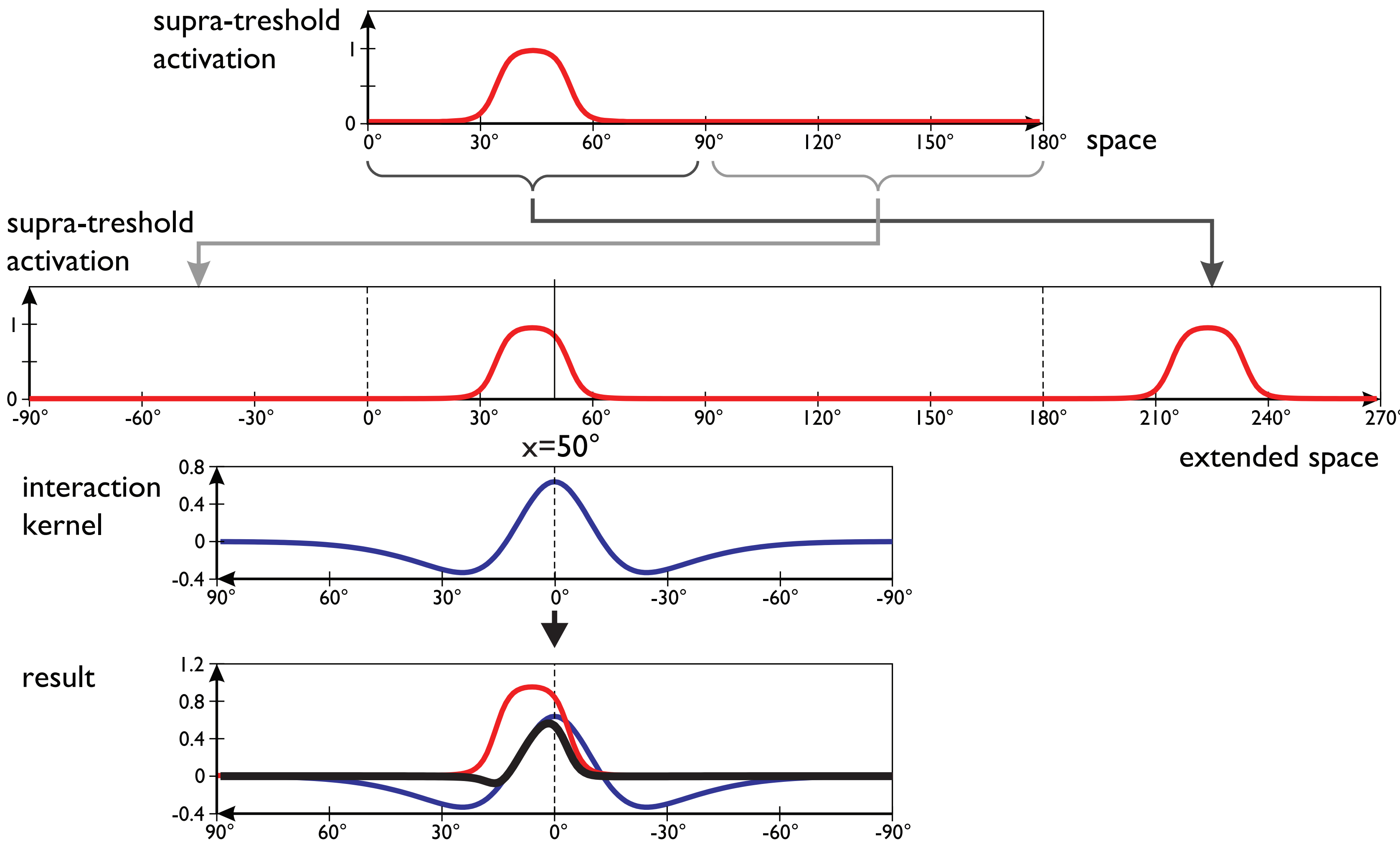
- time scale is τ
- resting level is $h < 0$
- input is $S(x,t)$
- interaction kernel is

$$w(x-x') = w_i + w_e \exp\left[-\frac{(x-x')^2}{2\sigma_i^2}\right]$$

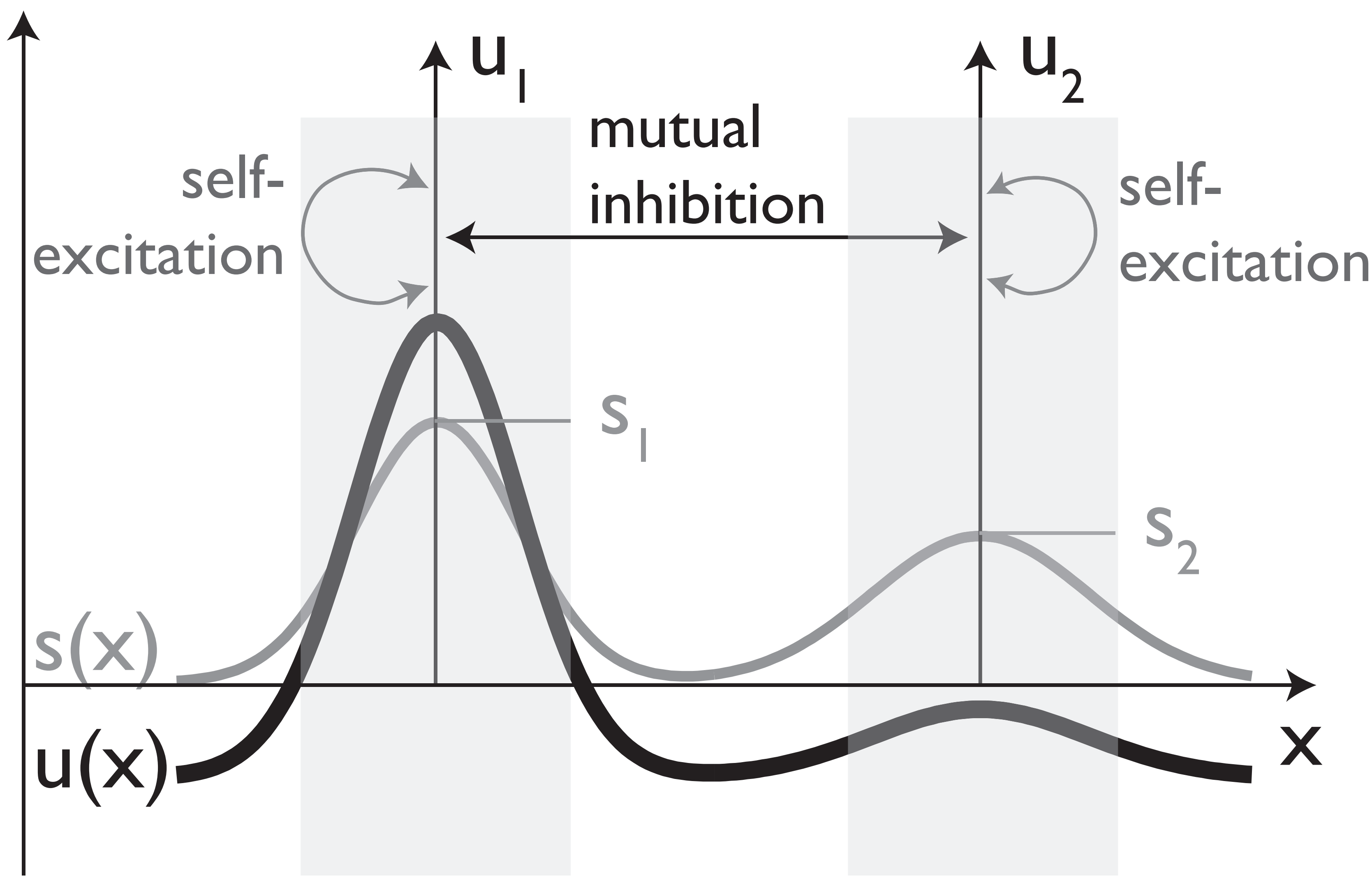
- sigmoidal nonlinearity is

$$\sigma(u) = \frac{1}{1 + \exp[-\beta(u-u_0)]}$$

Interaction: convolution



Relationship to the dynamics of discrete activation variables

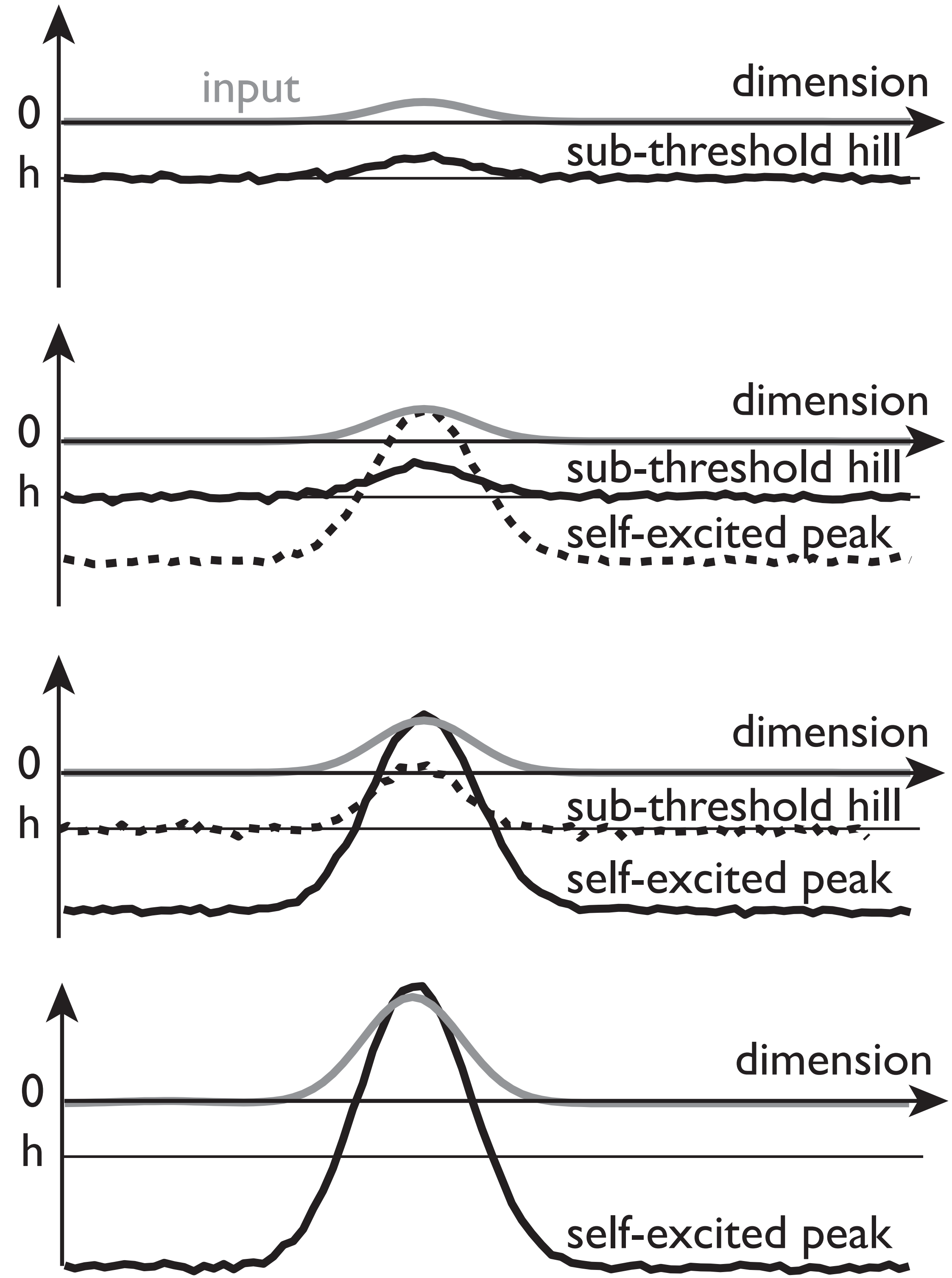


=> simulations

solutions and instabilities

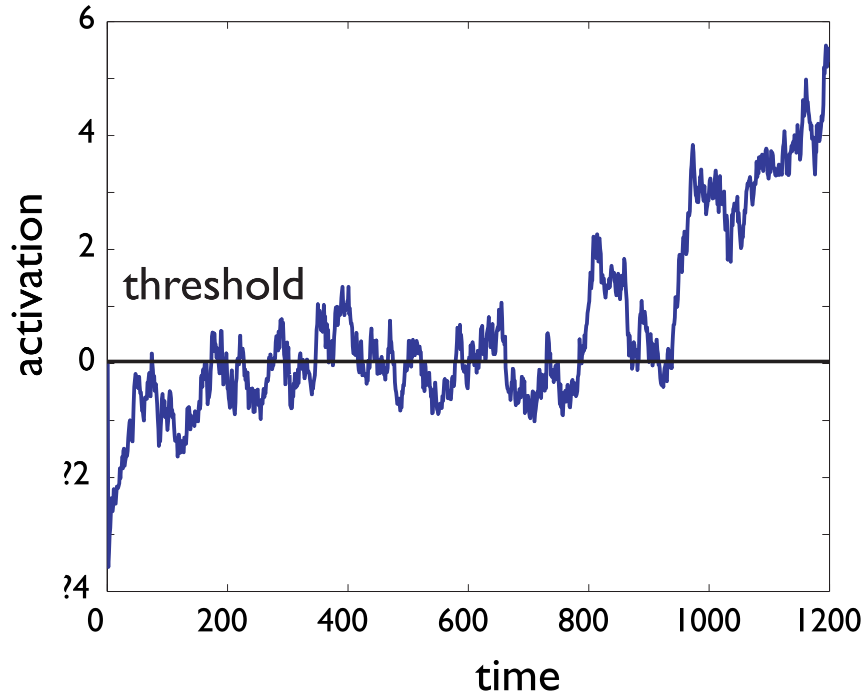
- input driven solution (sub-threshold) vs. self-stabilized solution (peak, supra-threshold)
- detection instability
- reverse detection instability
- selection
- selection instability
- memory instability
- detection instability from boost

Detection instability

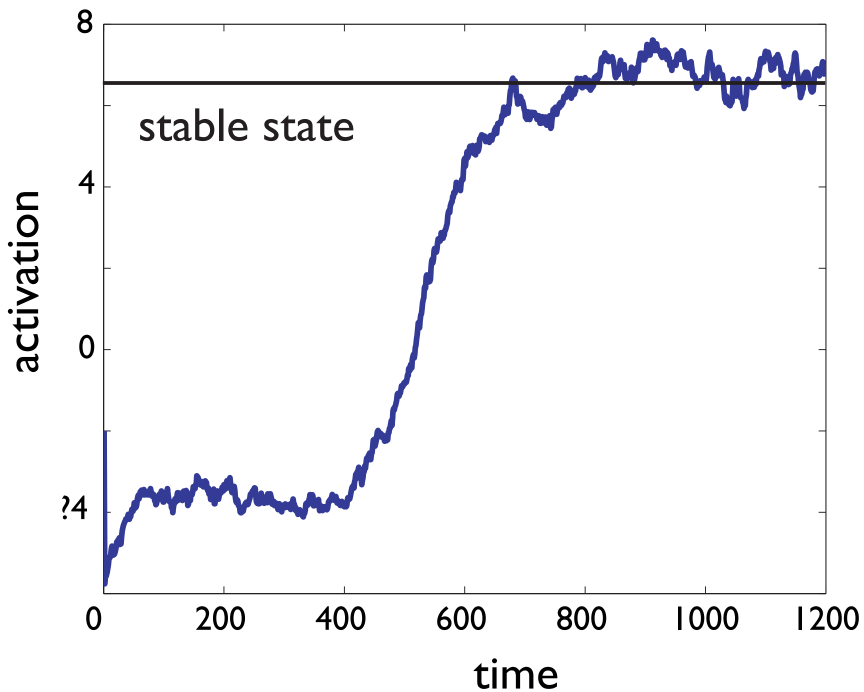


the detection instability helps stabilize decisions

threshold piercing



detection instability



the detection instability helps stabilize decisions

- self-stabilized peaks are macroscopic neuronal states, capable of impacting on down-stream neuronal systems
- (unlike the microscopic neuronal activation that just exceeds a threshold)

emergence of time-discrete events

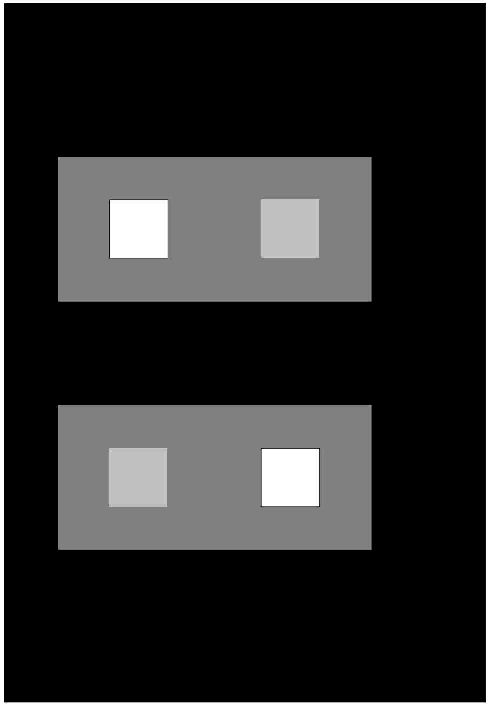
- the detection instability also explains how a time-continuous neuronal dynamics may create macroscopic, time-discrete events

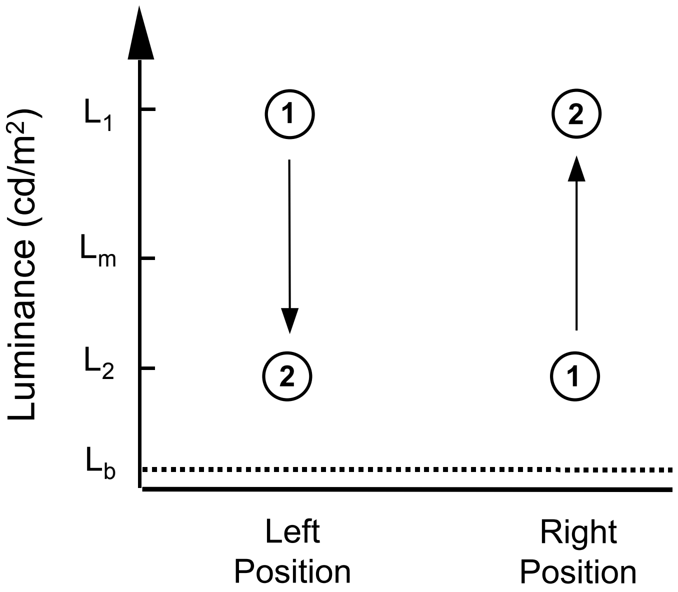
behavioral signatures of detection decisions

- detection in psychophysical paradigms is rife with hysteresis
- but: minimize response bias

Detection instability

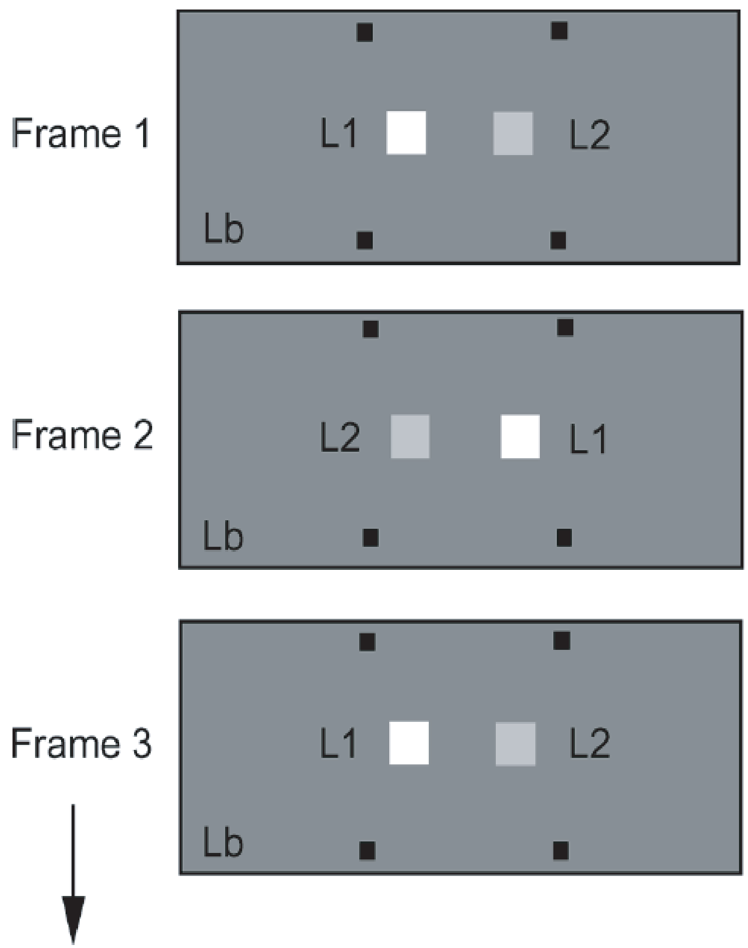
- in the detection of Generalized Apparent Motion





Detection instability

- varying BRLC



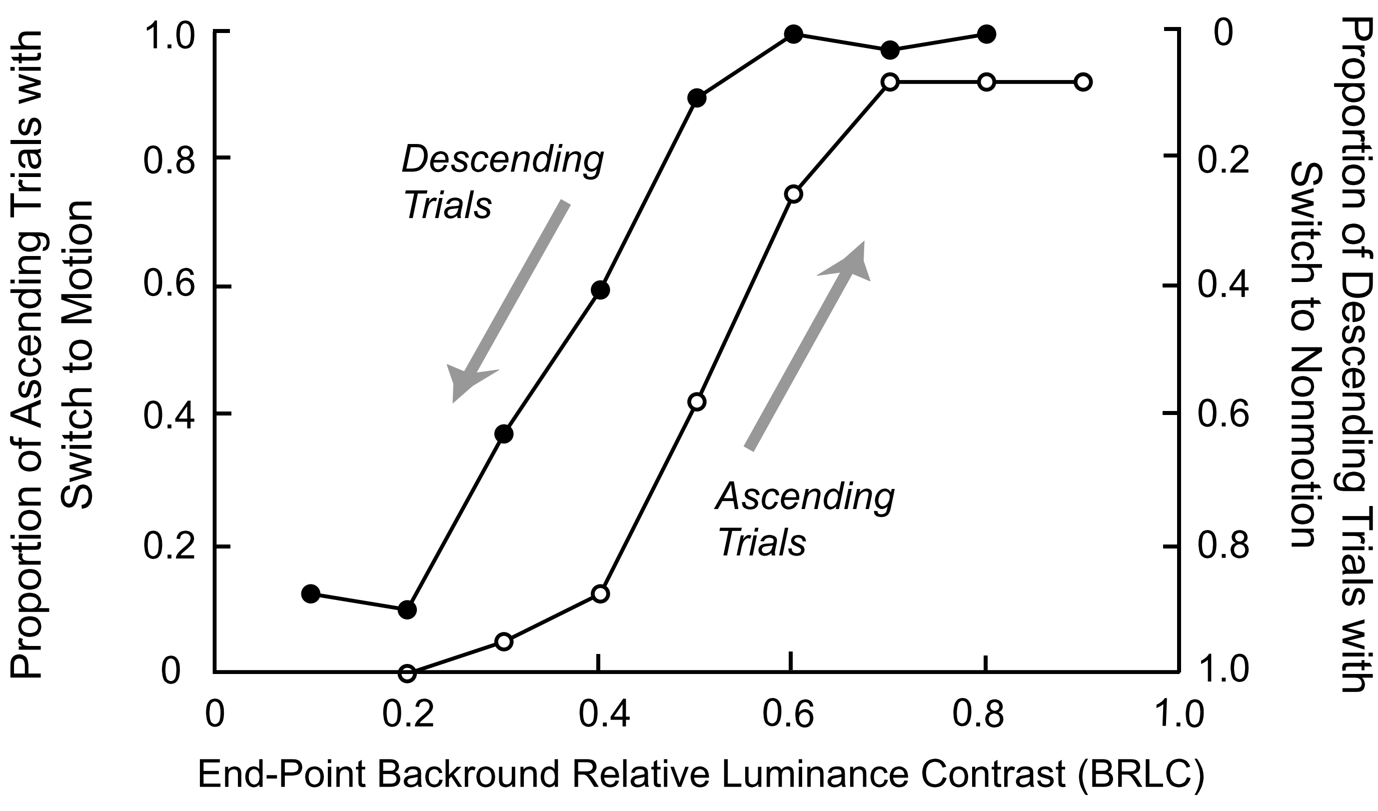
$$Lm = \frac{L1 + L2}{2}$$

$$\text{Background-Relative Luminance Change (BRLC)} = \frac{L1 - L2}{Lm - Lb}$$

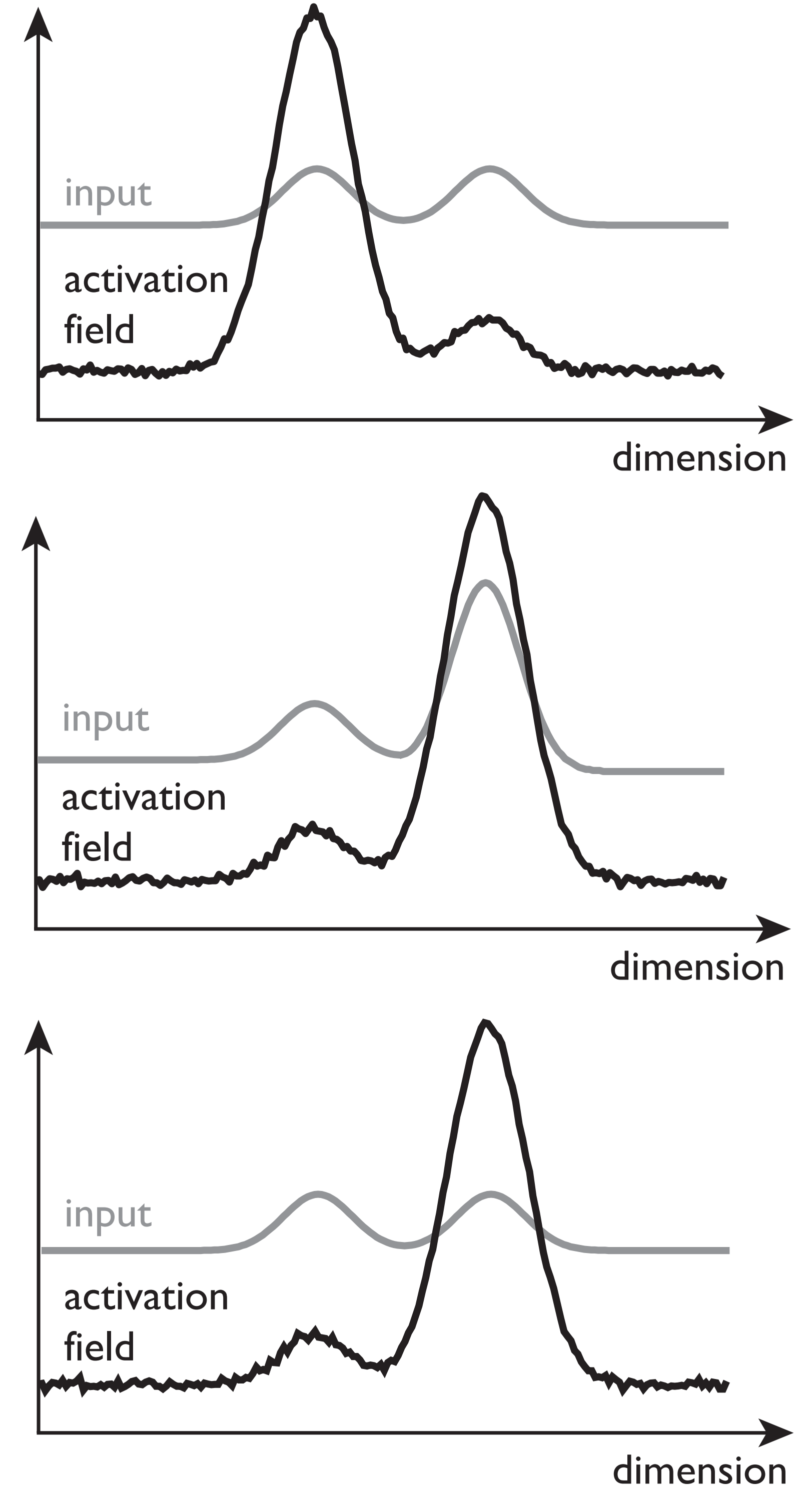
Detection instability

- hysteresis of motion detection as BRLC is varied
- (while response bias is minimized)

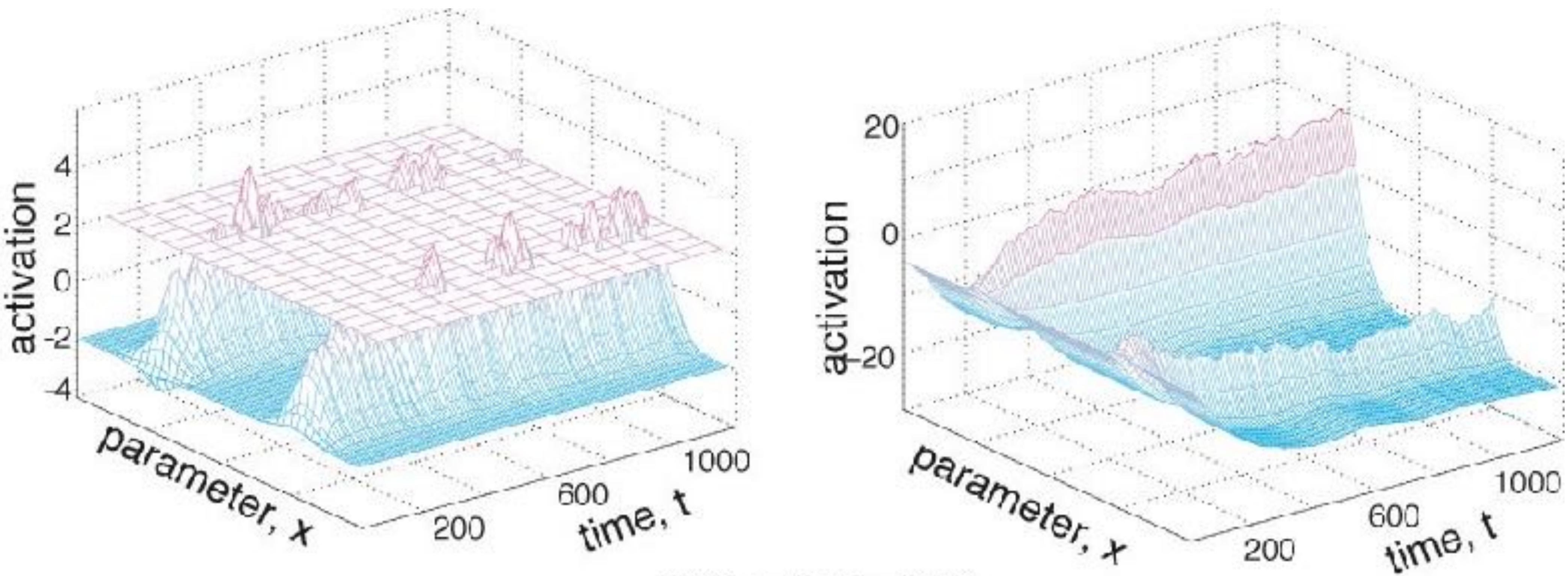
H. S. Hock, G. Schöner / Seeing and Perceiving 23 (2010) 173–195



selection instability



stabilizing selection decisions



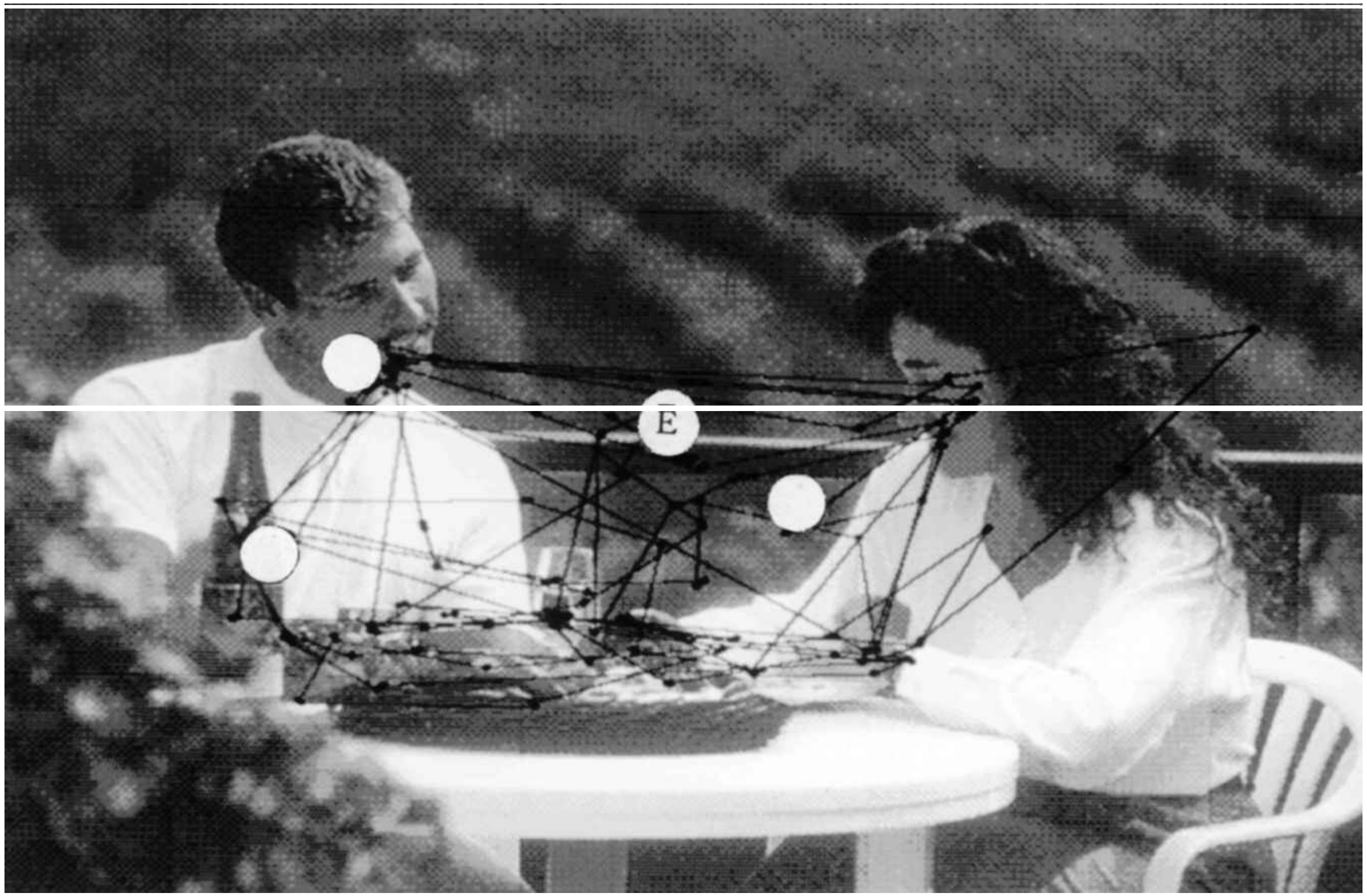
[Wilimzig, Schöner, 2006]

behavioral signatures of selection decisions

- in most experimental situations, the correct selection decision is cued by an "imperative signal" leaving no actual freedom of "choice" to the participant (only the freedom of "error")
- reasons are experimental
- when performance approaches chance level, then close to "free choice"
- because task set plays a major role in such tasks, I will discuss these only a little later

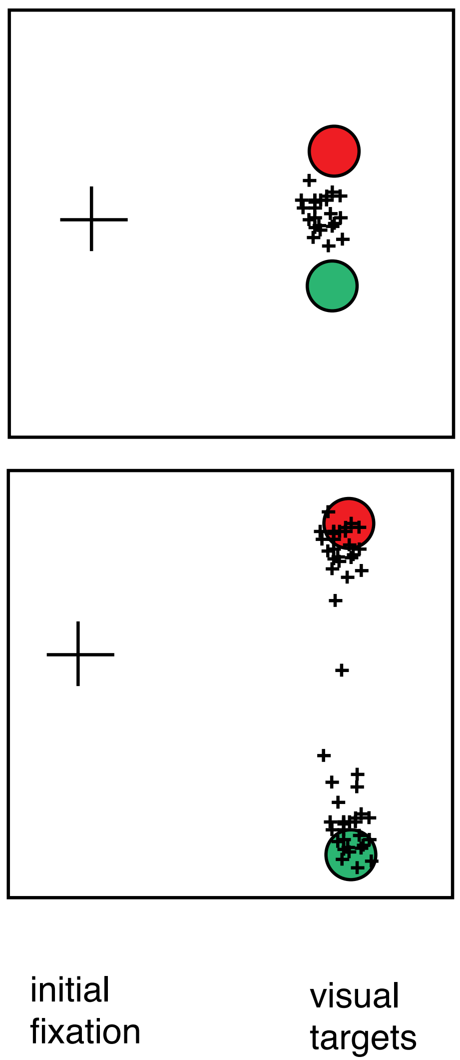
one system of "free choice"

- selecting a new saccadic location

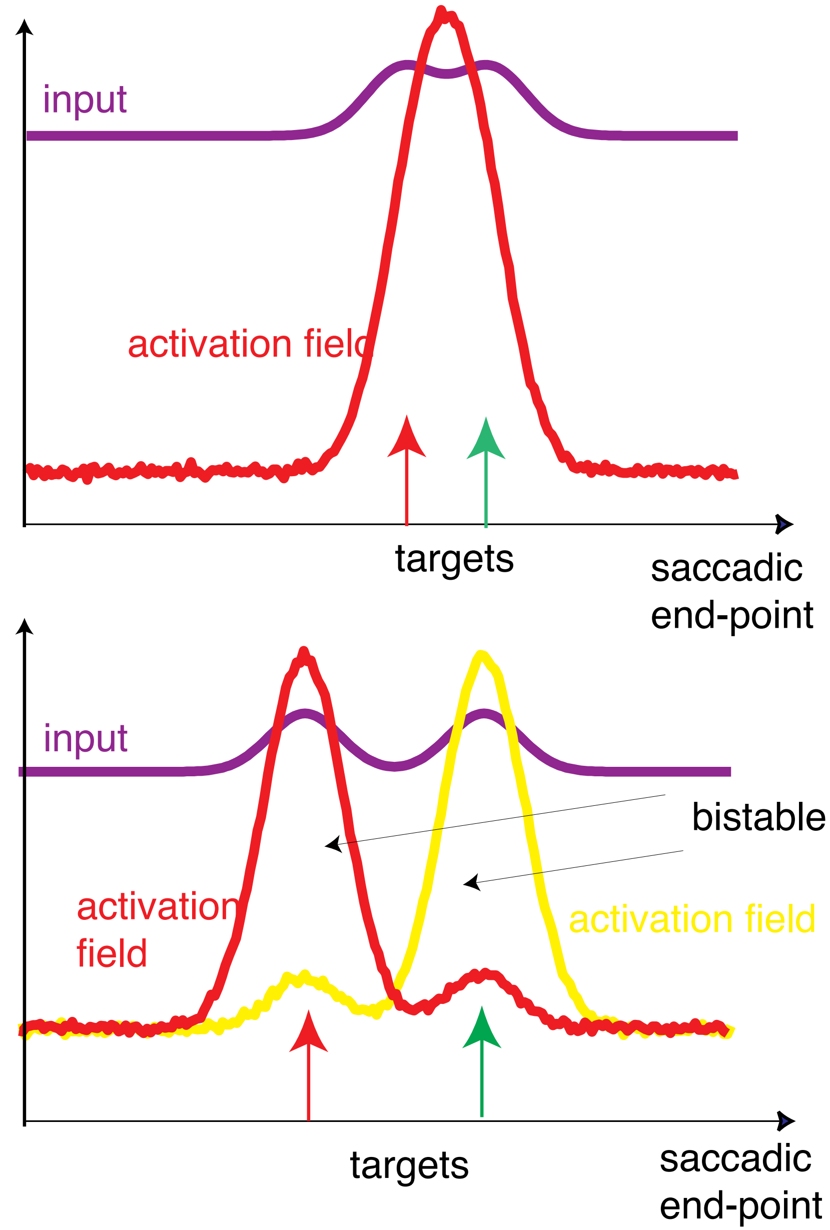


[O'Reagan et al., 2000]

saccade generation



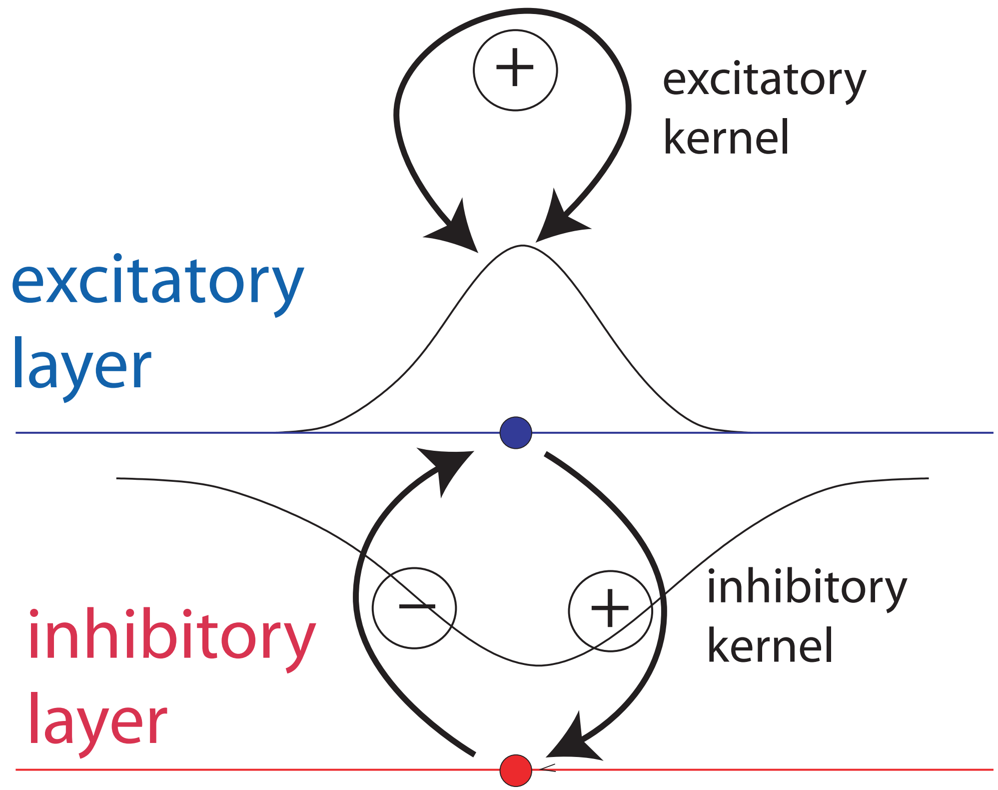
[after: Ottes et al., Vis. Res. 25:825 (85)]



[after Kopecz, Schöner: Biol Cybern 73:49 (95)]

2 layer Amari fields

- to comply with Dale's law
- and account for difference in time course of excitation (early) and inhibition (late)



[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

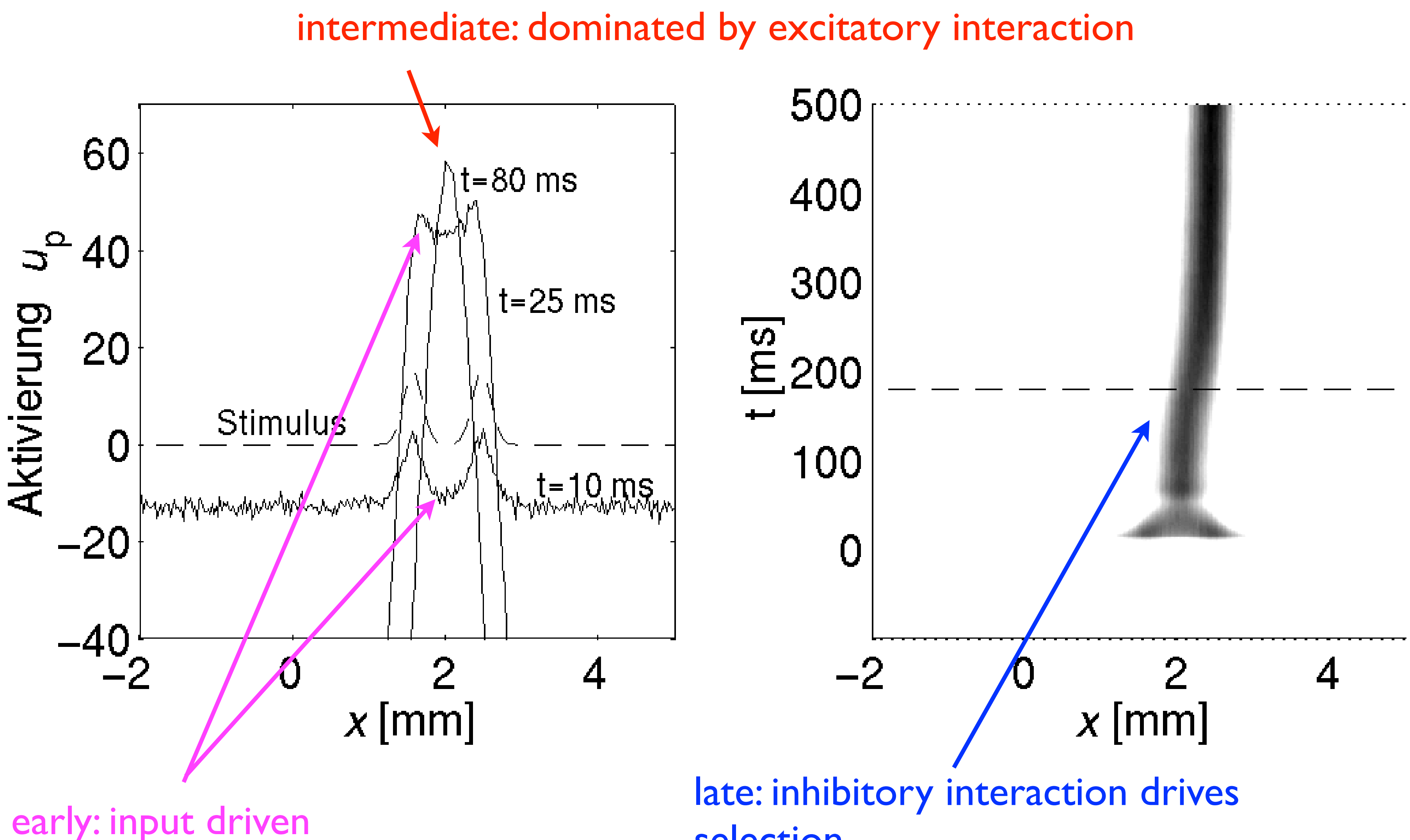
2 layer Amari model

$$\begin{aligned}
\tau \dot{u}(x,t) &= -u(x,t) + h_u + S(x,t) + \int dx'\; c_{\mathrm{uu}}(x-x')\; \sigma(u(x',t)) \\
&- \int dx'\; c_{\mathrm{uv}}(x-x')\; \sigma(v(x',t)) \\
\tau \dot{v}(x,t) &= -v(x,t) + h_v + \int dx'\; c_{\mathrm{vu}}(x-x')\; \sigma(u(x',t))
\end{aligned}$$

$$c_{ij}(x-x') = c_{i,j,\mathrm{strength}}\; \exp\left[-\frac{(x-x')^2}{2\sigma_{ij}^2}\right].$$

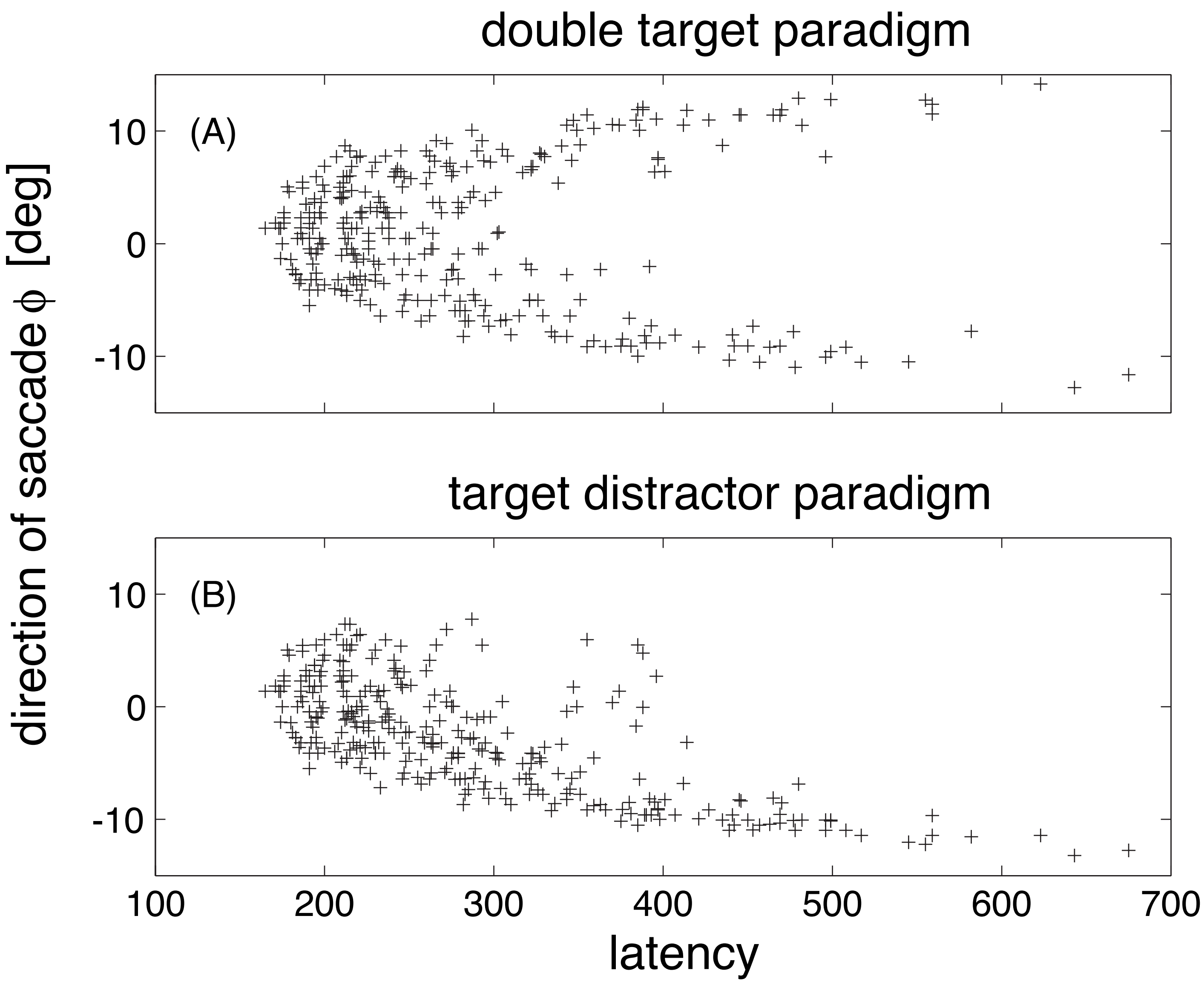
$$\sigma(u) = \frac{1}{1+\exp[-\beta\; u]}.$$

time course of selection



Wilimzig, Schneider, Schöner, Neural Networks, 2006

=> early fusion, late selection

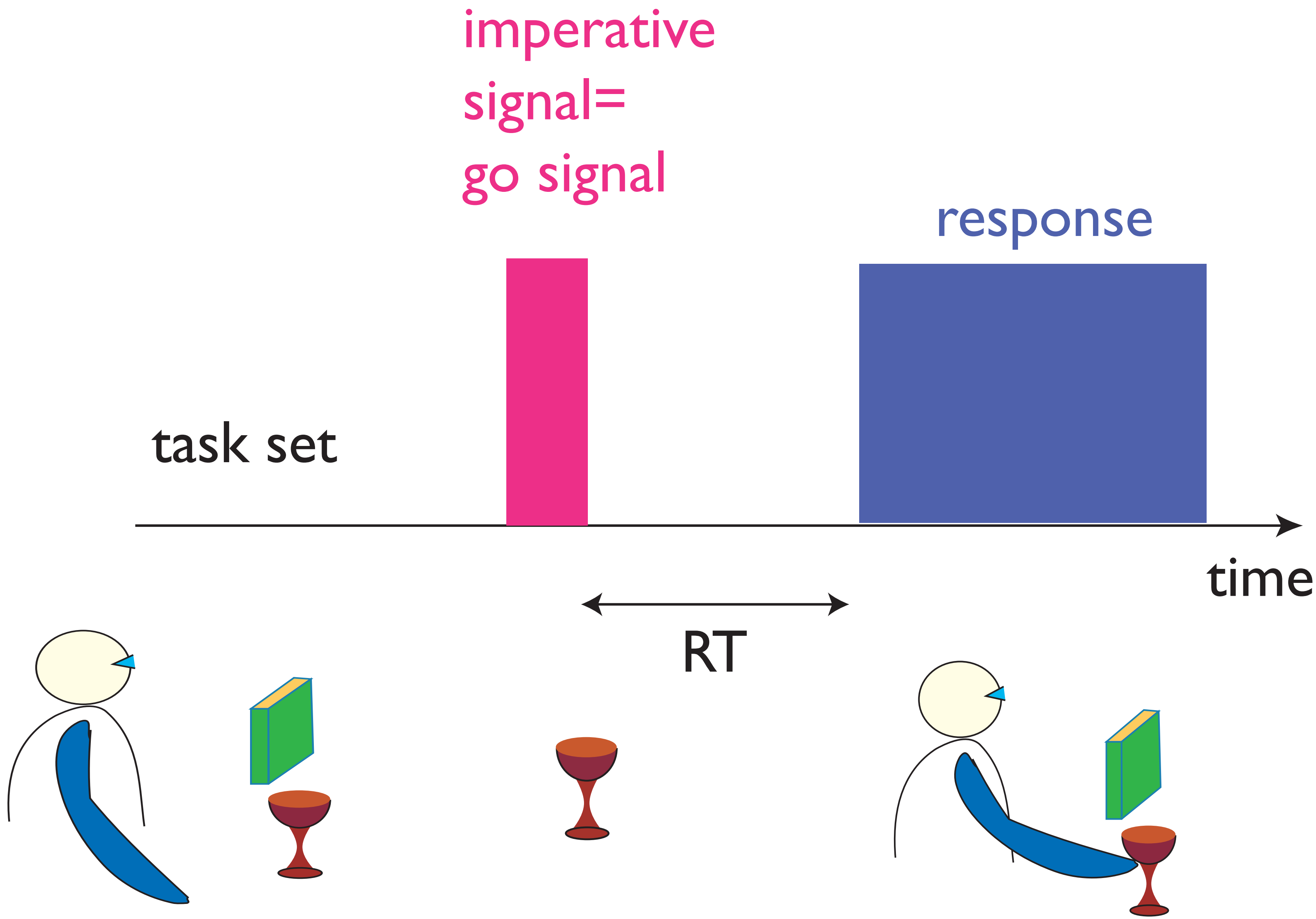


Wilimzig, Schneider, Schöner, Neural Networks, 2006

studying selection decisions in the laboratory

- using an imperative signal...

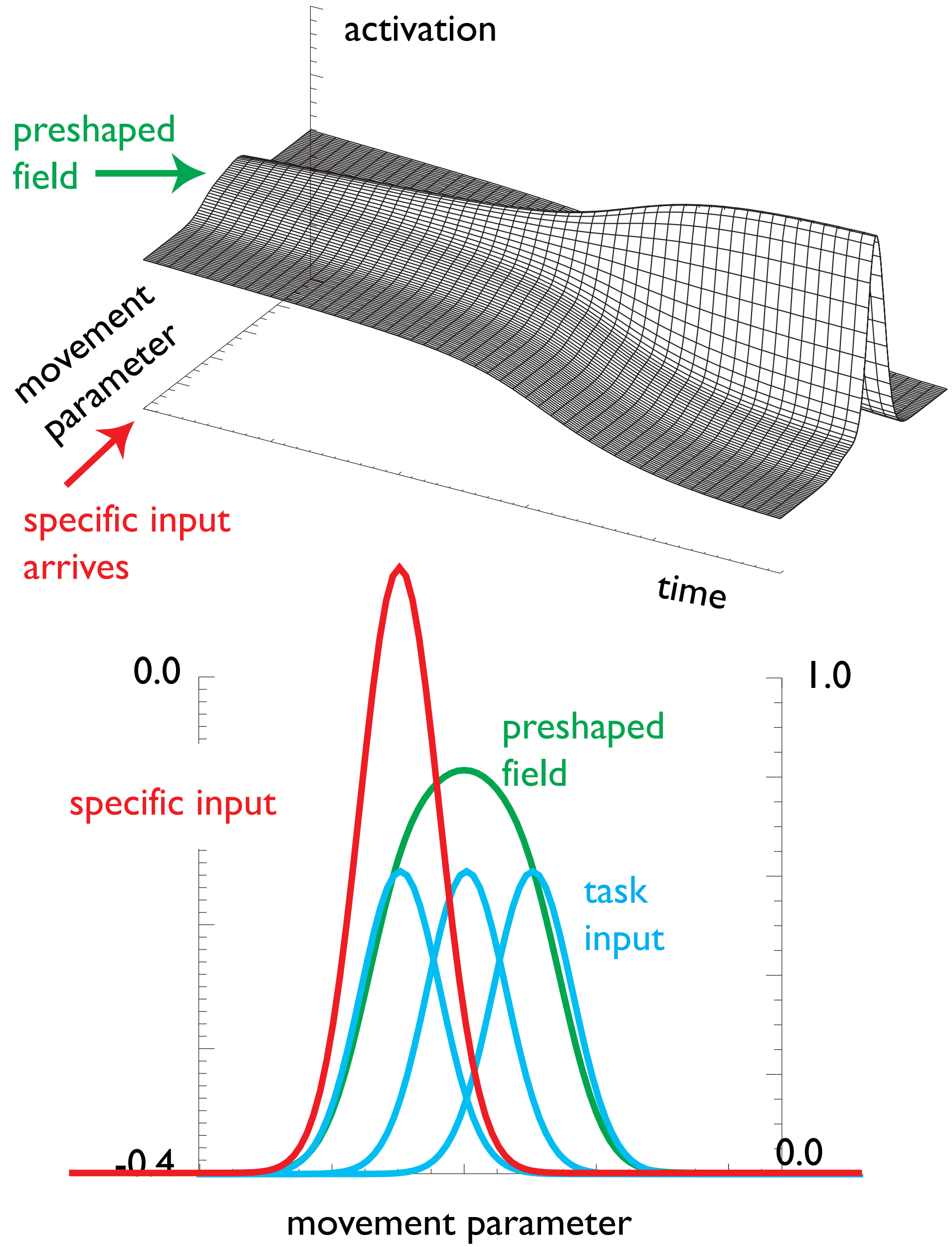
reaction time (RT) paradigm



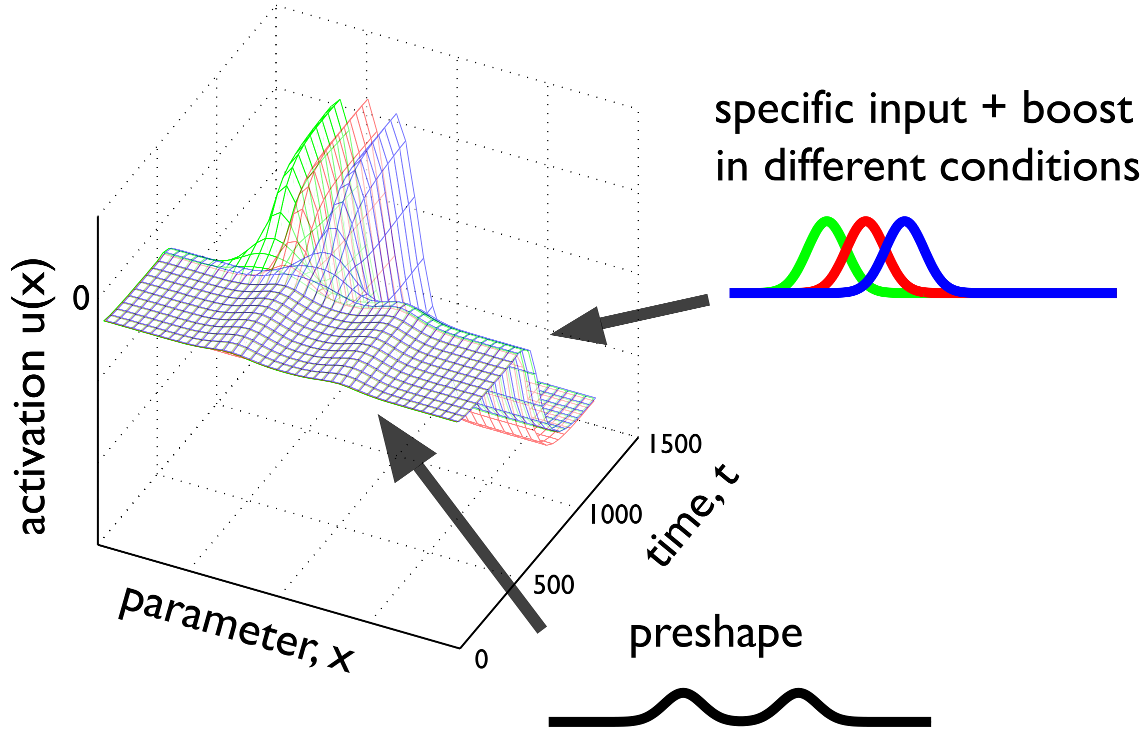
task set

- that is the critical factor in most studies of selection!
  - for example, the classical Hick law, that the number of choices affects RT, is based on the task set specifying a number of choices
- (although the form in which the imperative signal is given is varied as well...)
- how do neuronal representations reflect the task set?

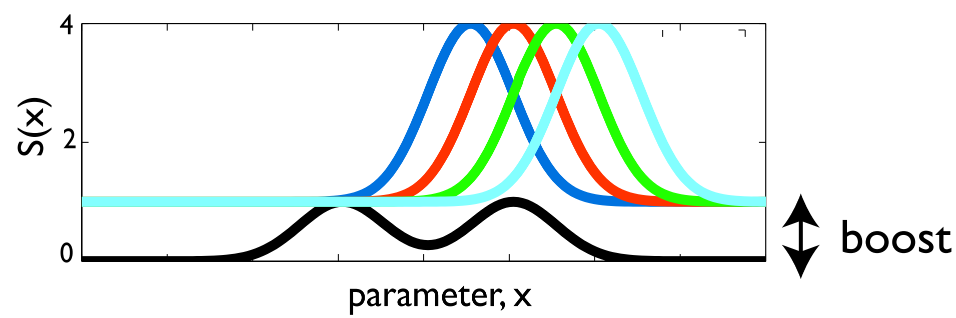
notion of preshape

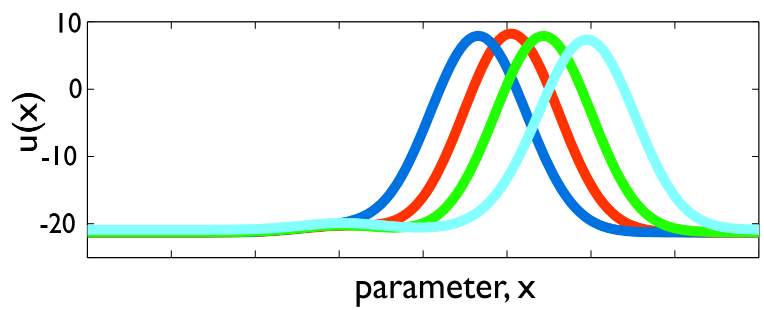


weak preshape in selection



- specific (imperative) input dominates and drives detection instability

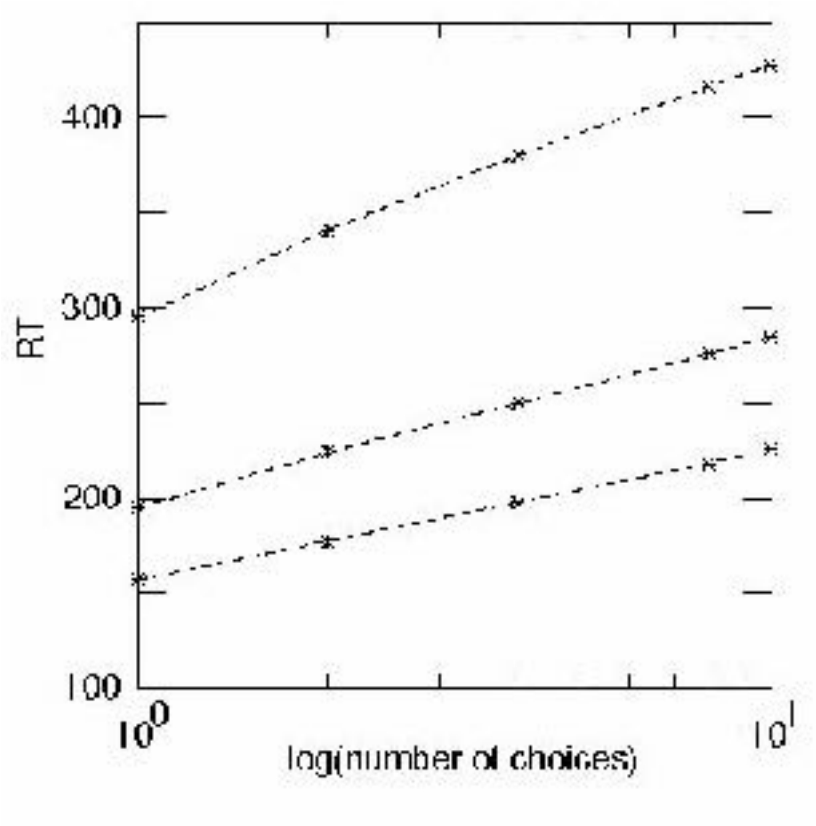


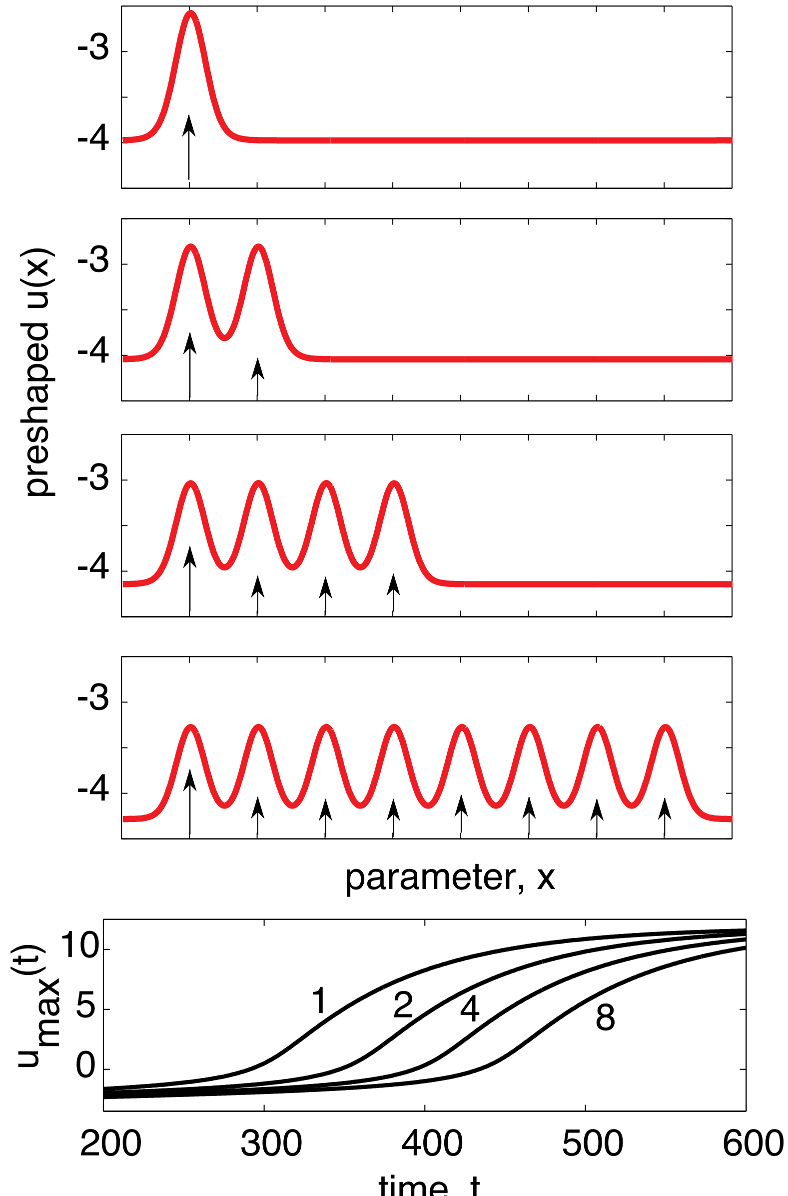


[Wilimzig, Schöner, 2006]

using preshape to account for classical RT data

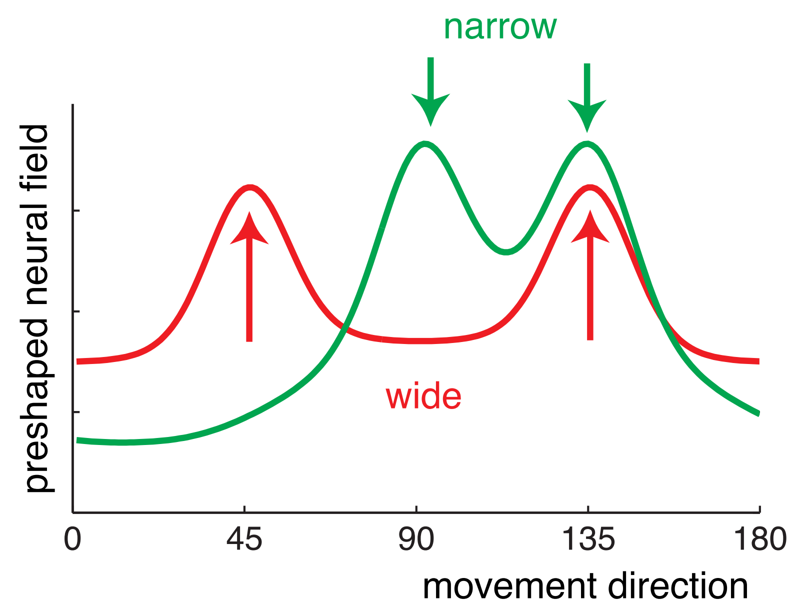
- Hick's law: RT increases with the number of choices



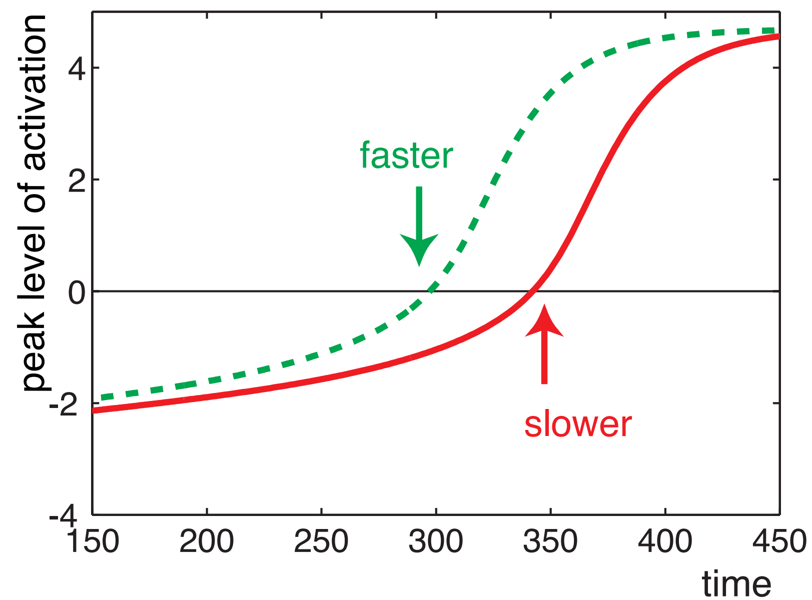


[Erlhagen, Schöner, Psych Rev 2002]

metric effect

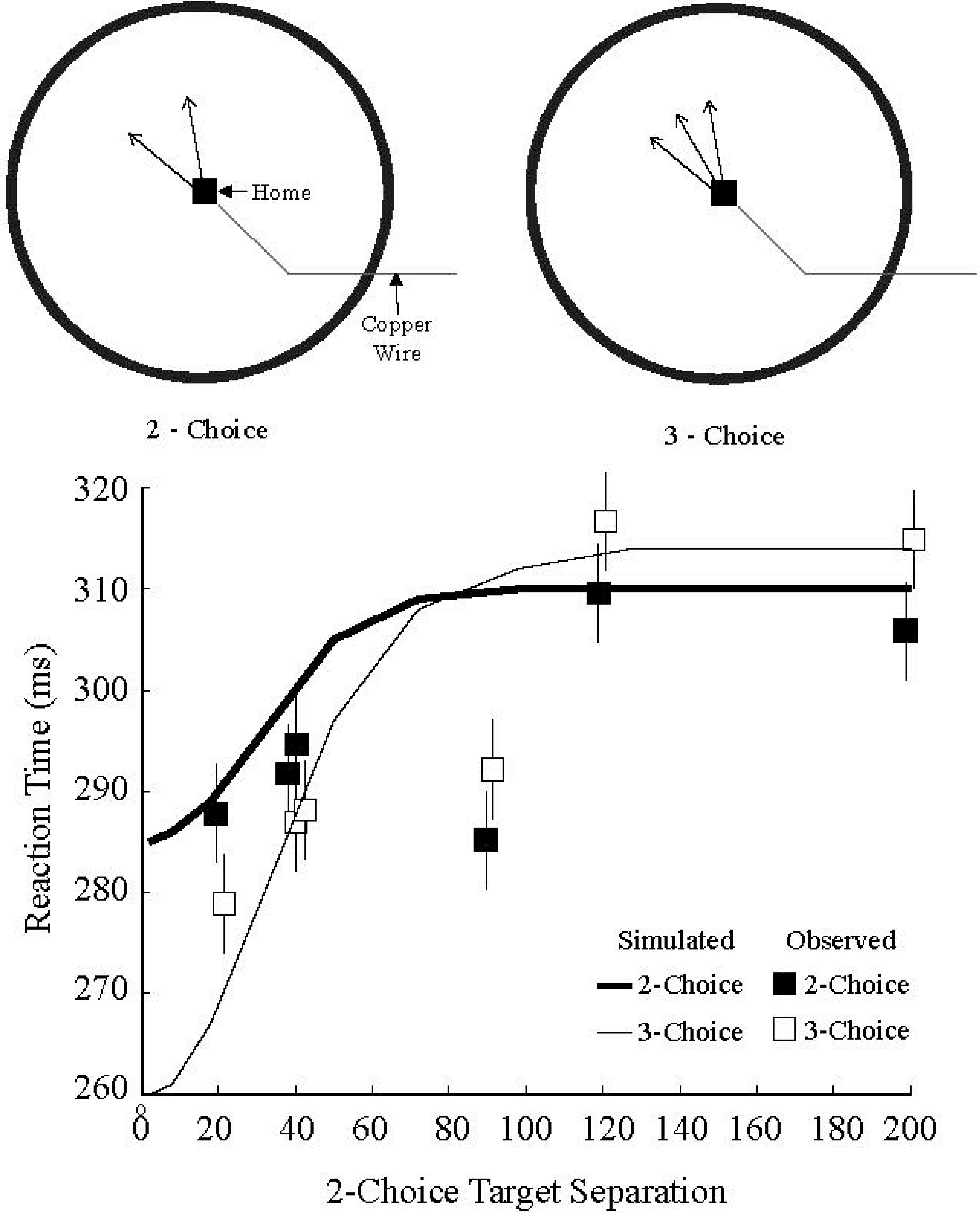


- predict faster response times for metrically close than for metrically far choices

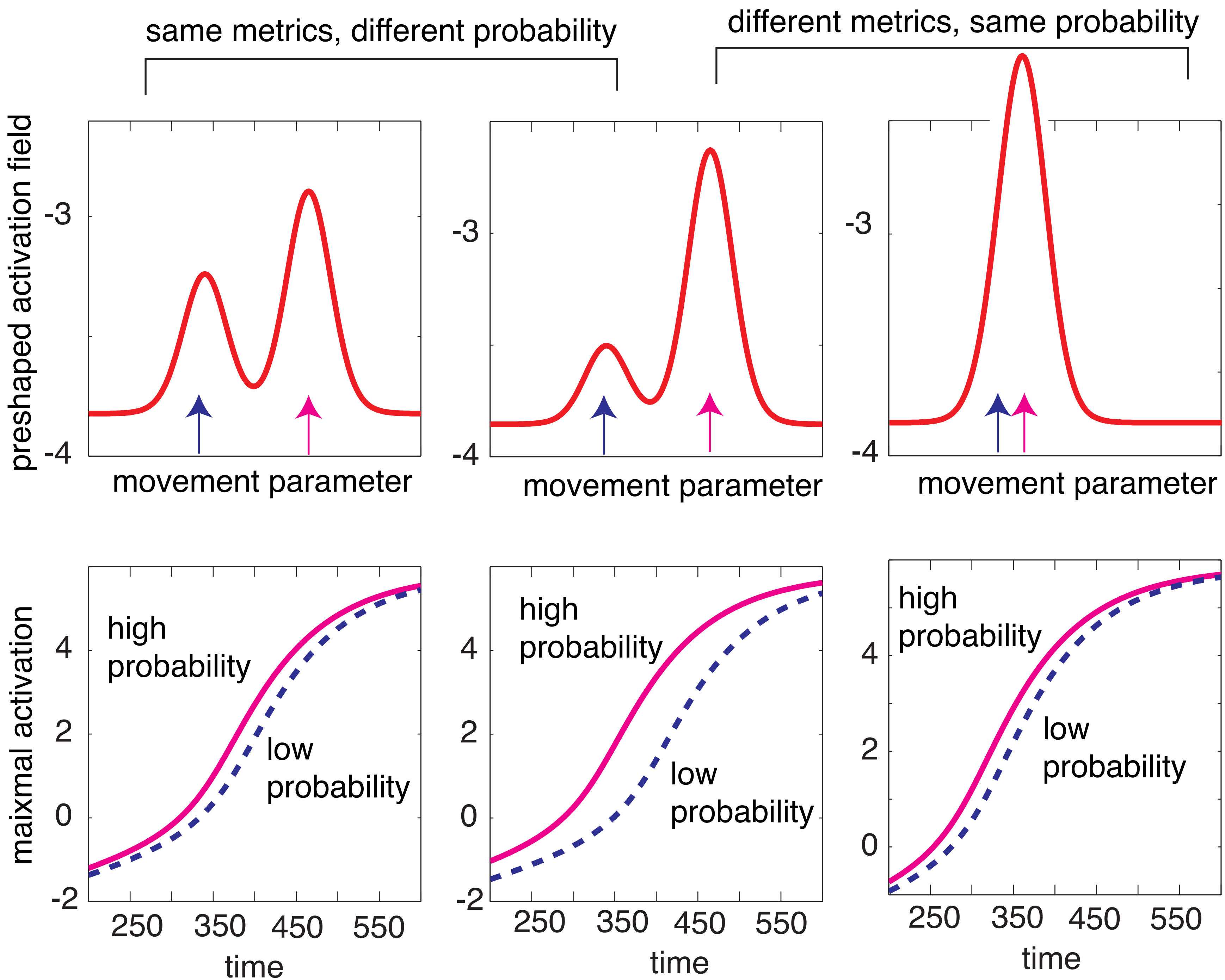


[from Schöner, Kopecz, Erlhagen, 1997]

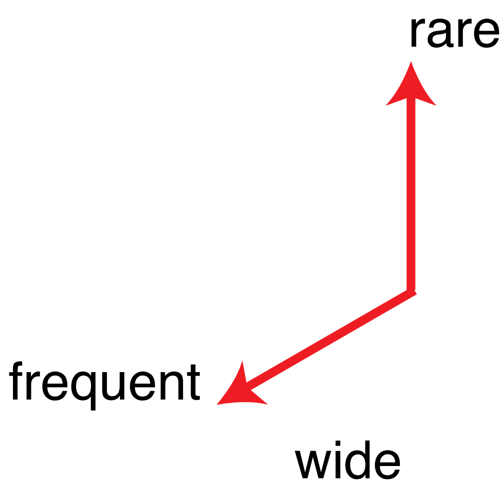
experiment: metric effect

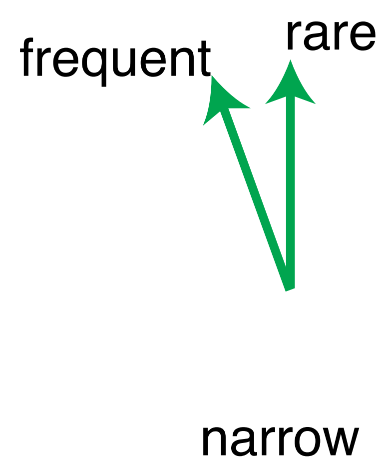


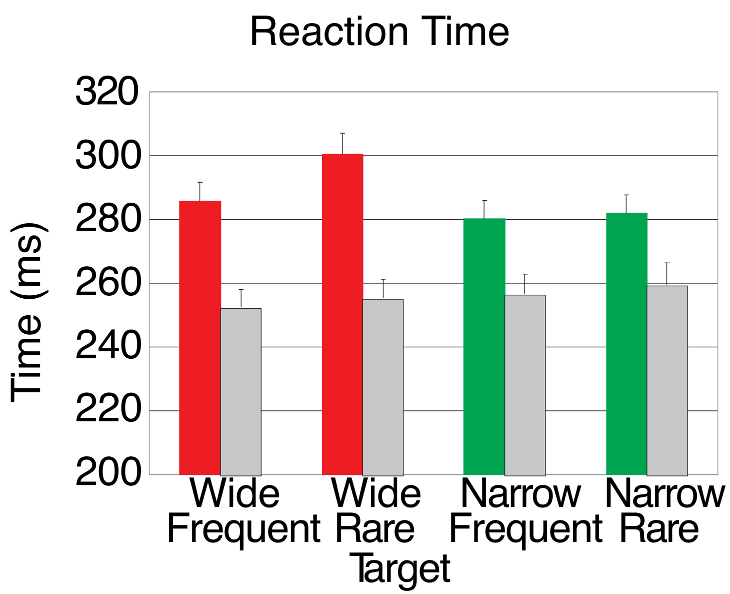
[McDowell, Jeka, Schöner]

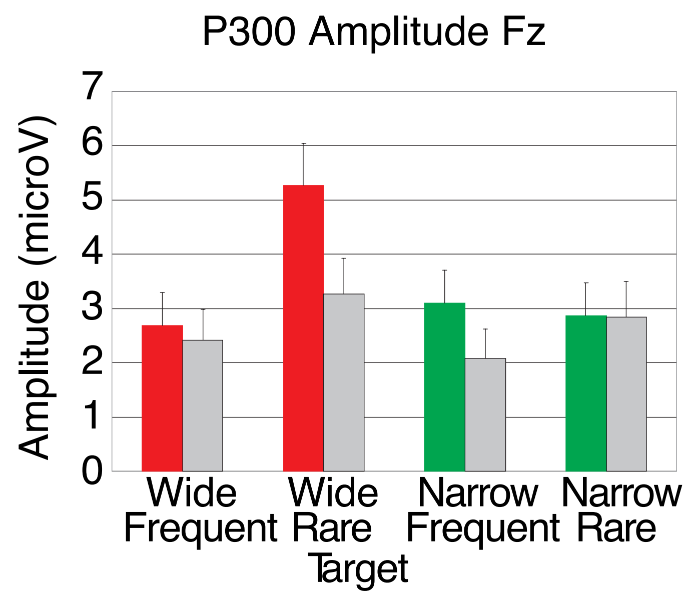


[from Erlhagen, Schöner: Psych. Rev. 2002]



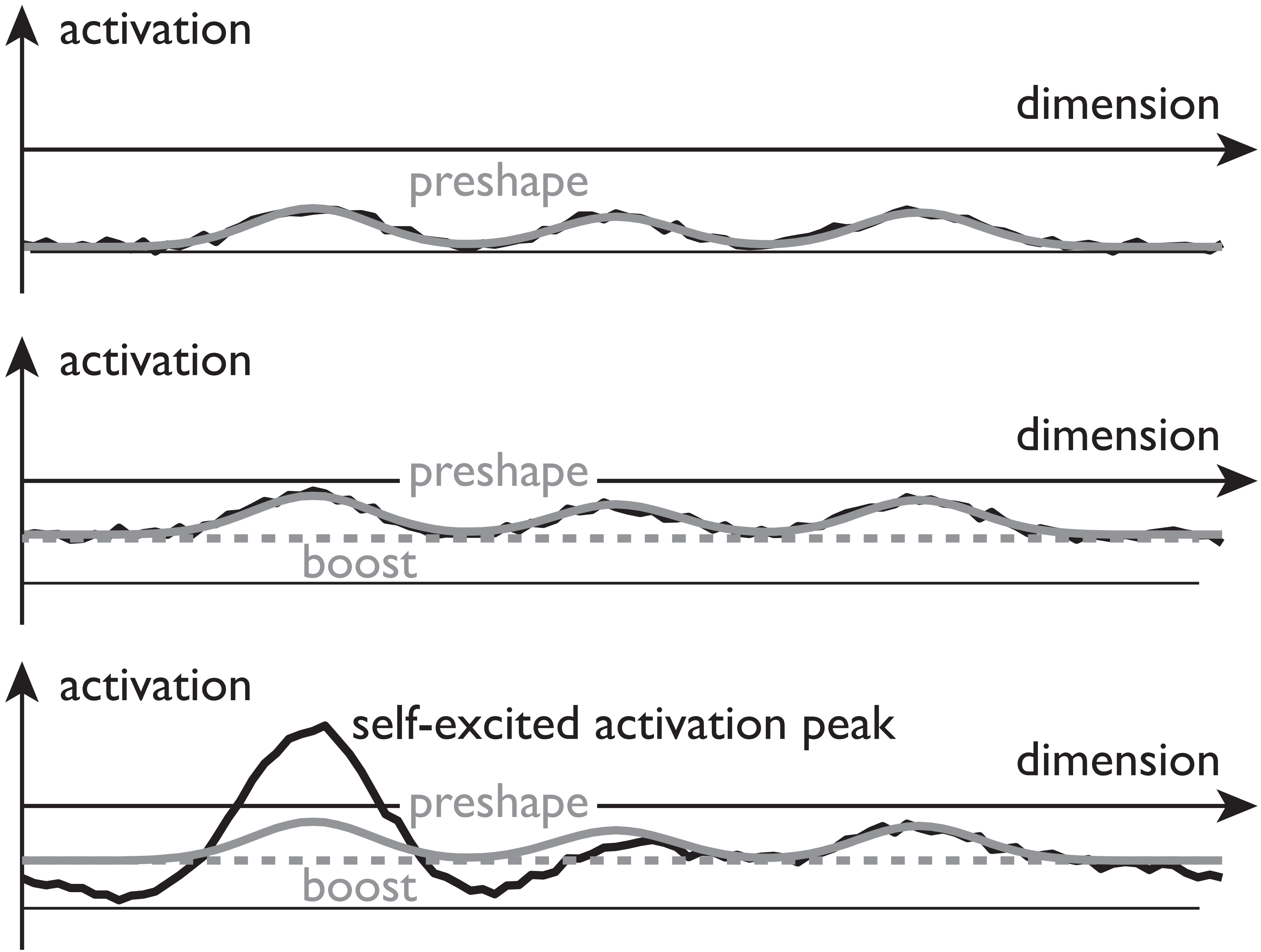






[from McDowell, Jeka, Schöner, Hatfield, 2002]

boost-induced detection instability

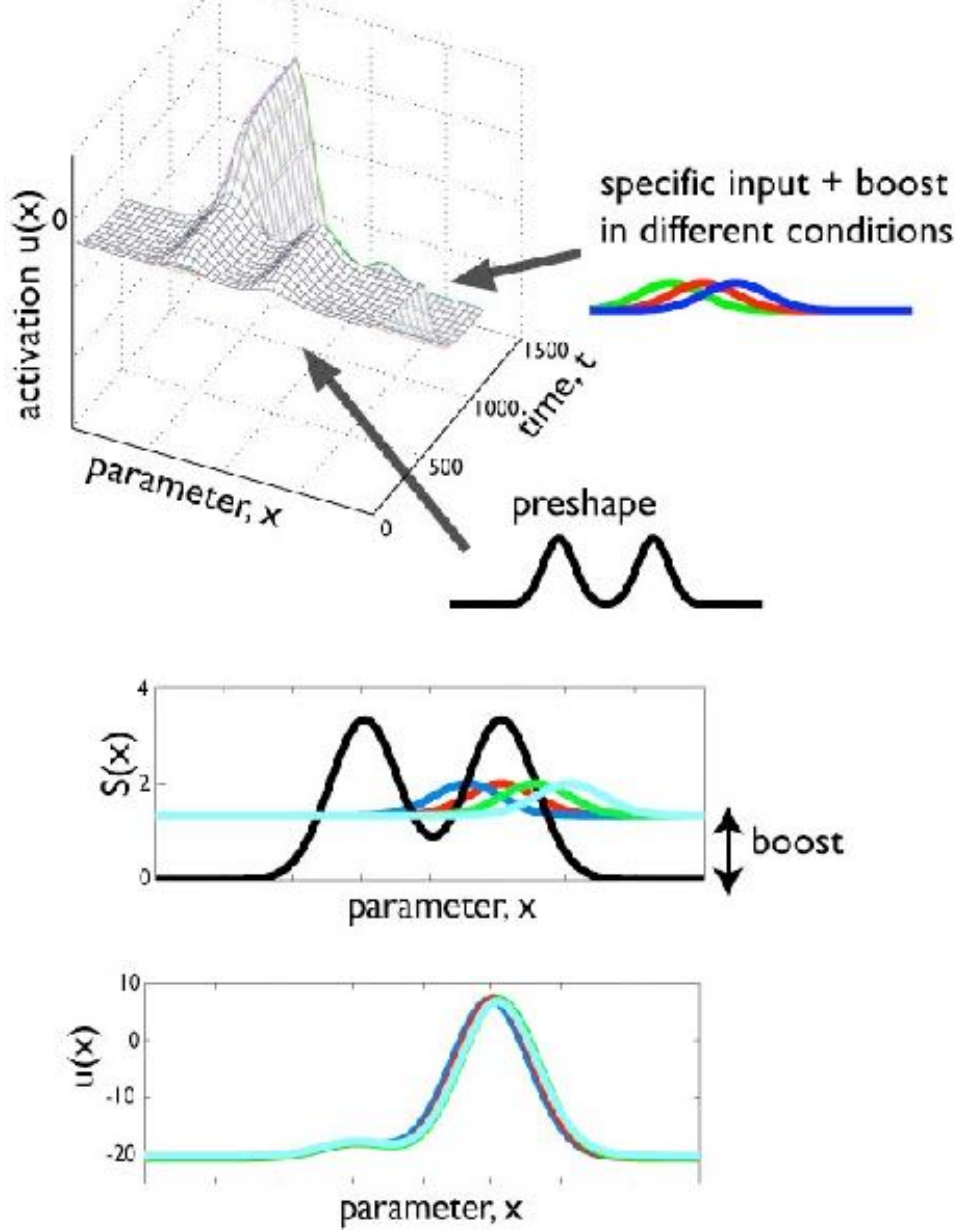


boost-driven detection instability

- inhomogeneities in the field existing prior to a signal/stimulus that leads to a macroscopic response="preshape"
- the boost-driven detection instability amplifies preshape into macroscopic selection decisions

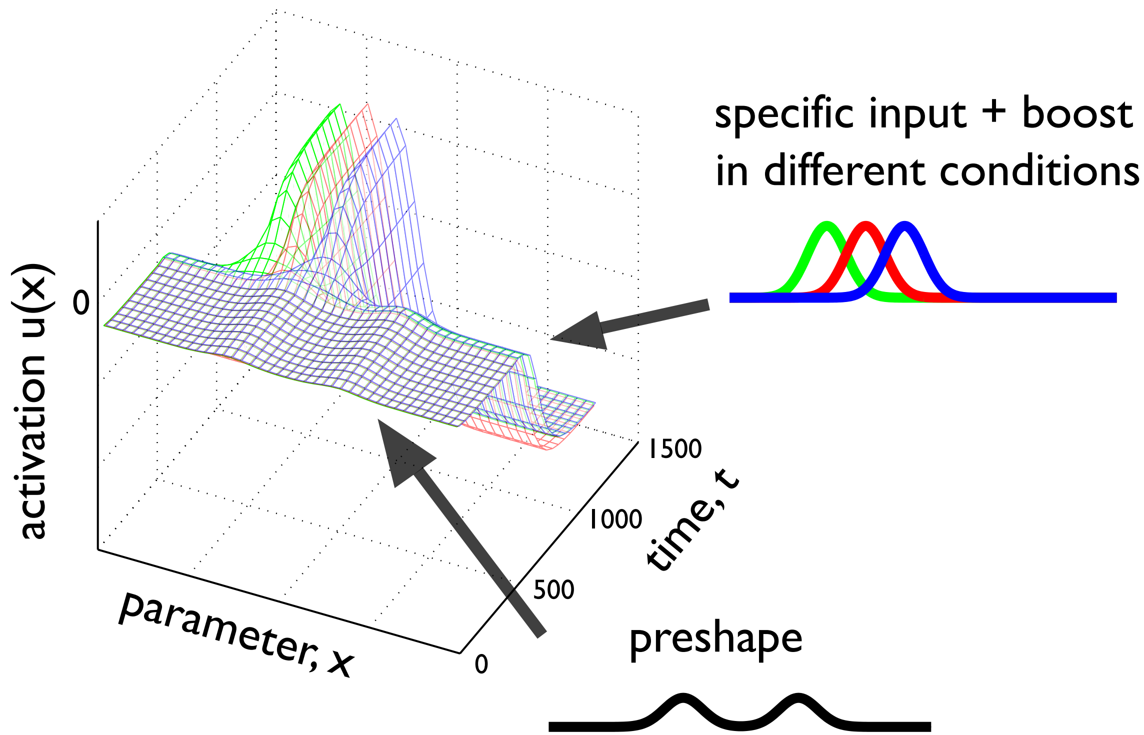
this supports categorical behavior

- when preshape dominates



[Wilimzig, Schöner, 2006]

weak preshape in selection



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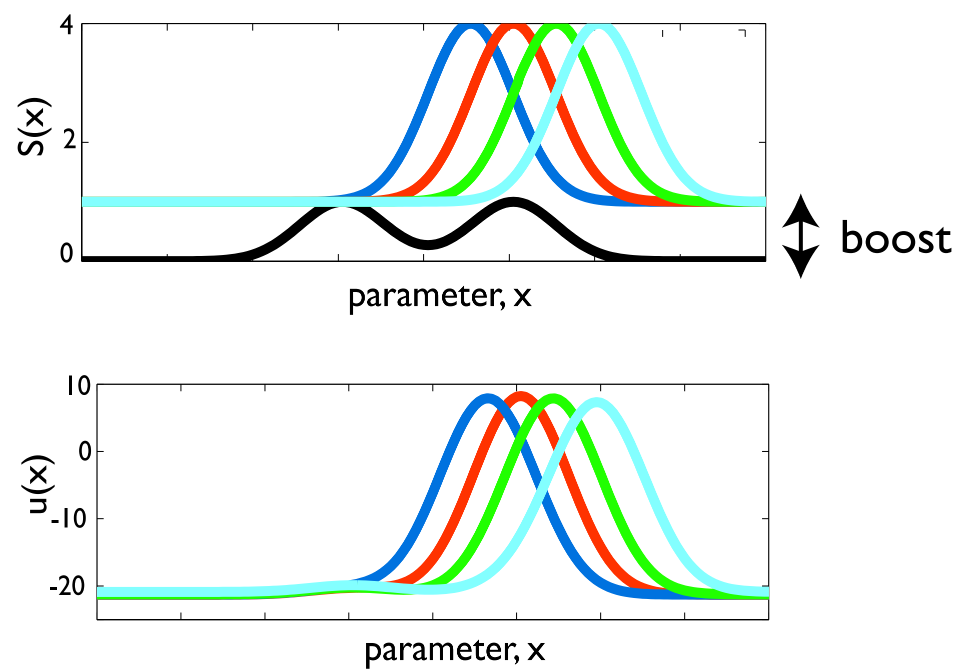


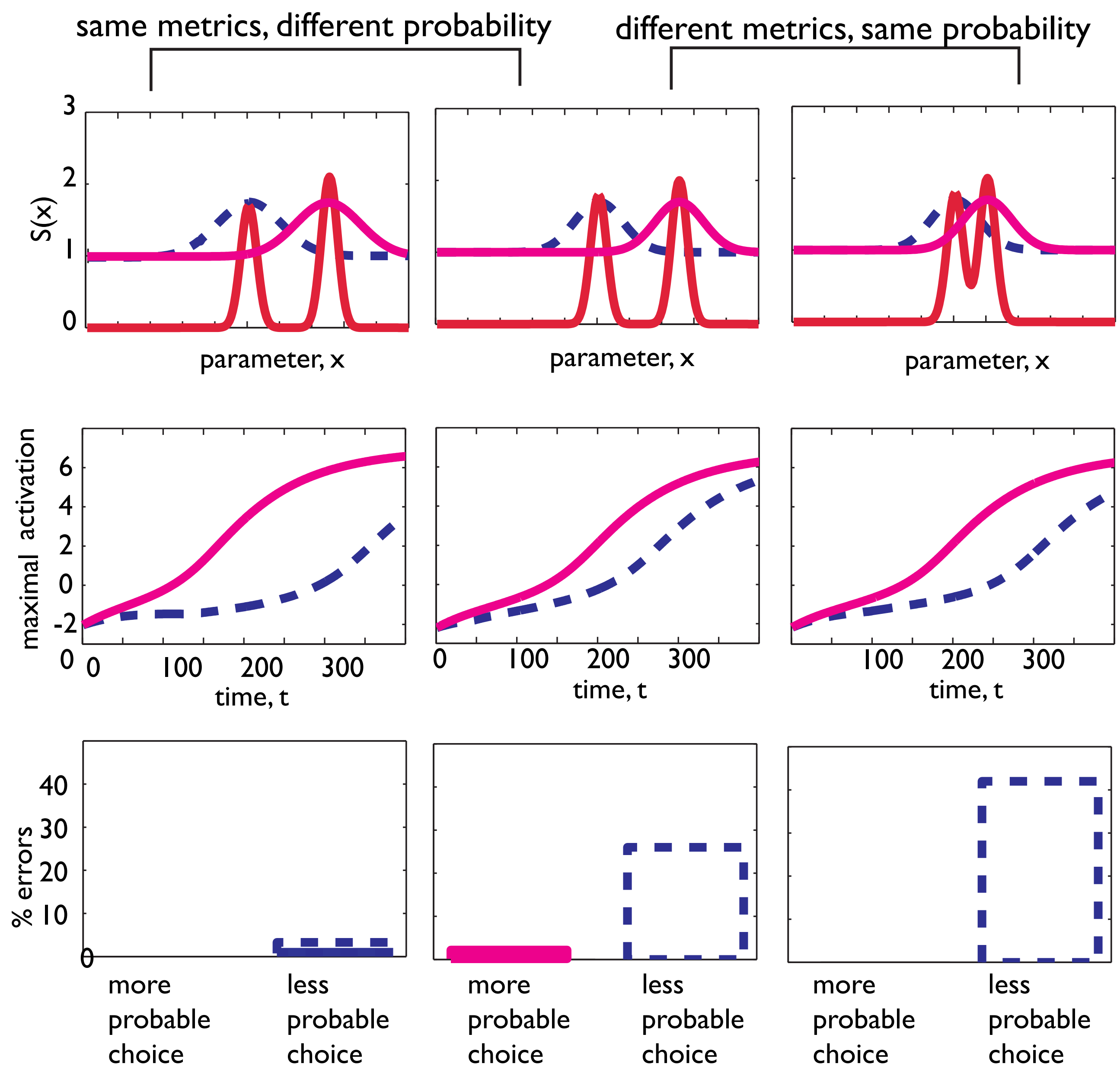
[Wilimzig, Schöner, 2006]

distance effect

- common in categorical tasks
  - e.g., decide which of two sticks is longer... RT is larger when sticks are more similar in length

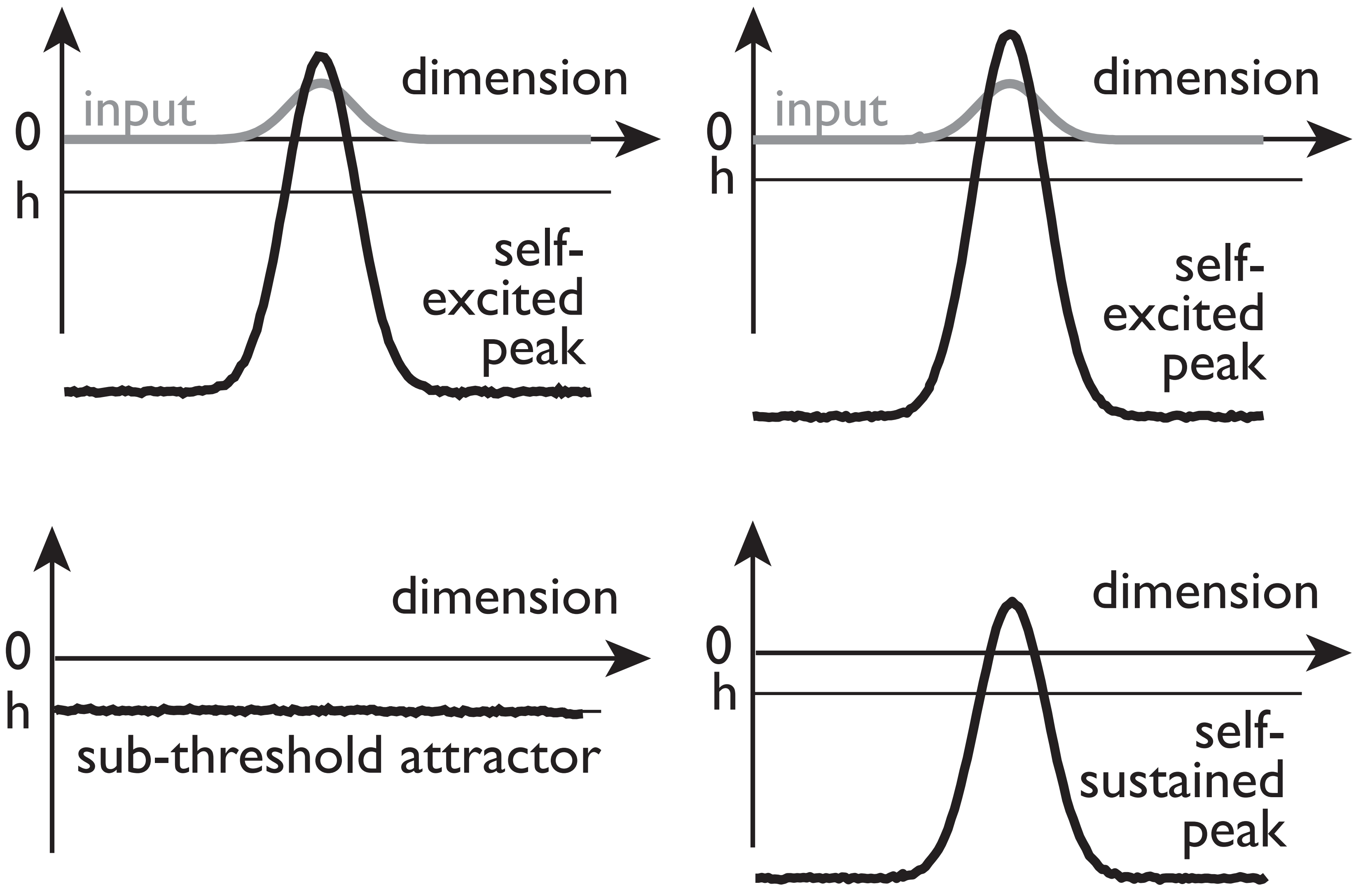
interaction metrics-probability

- opposite to that predicted for input-driven detection instabilities:
- metrically close choices show larger effect of probability

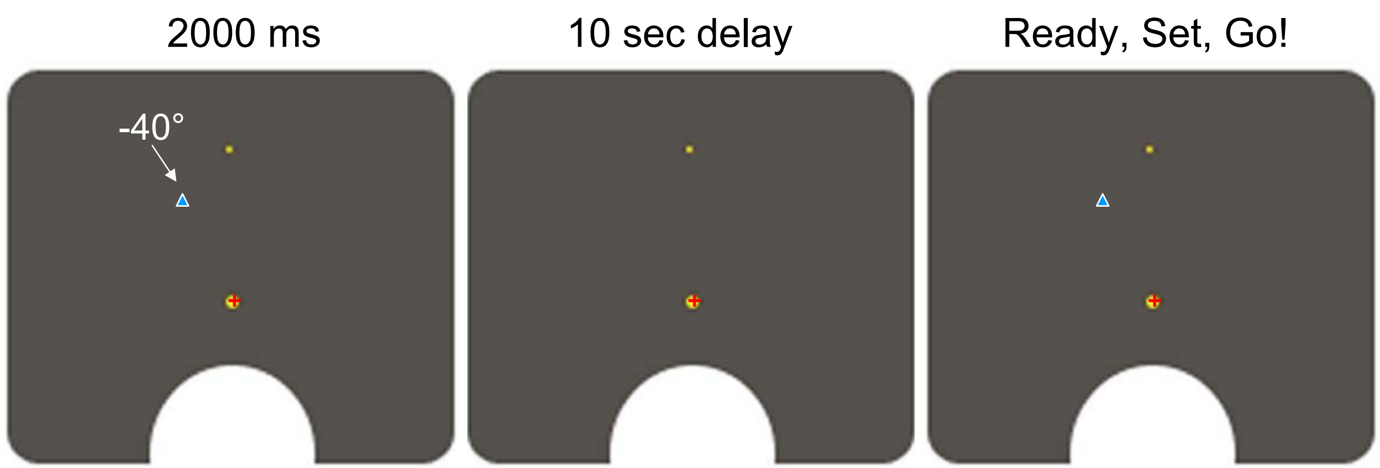


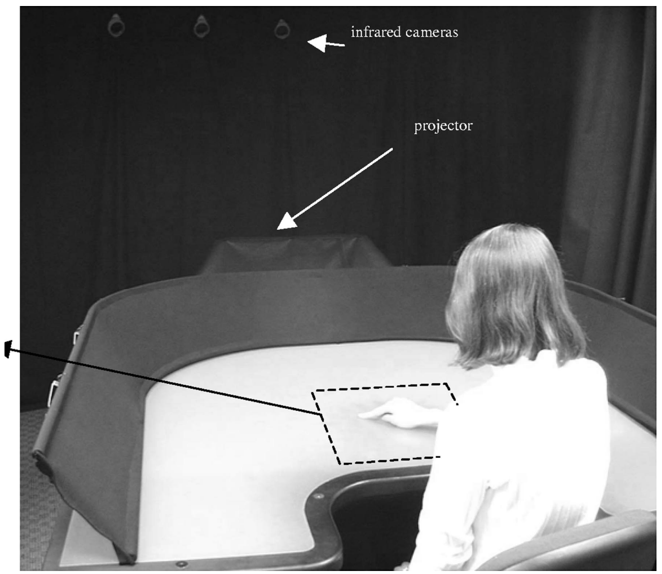
Wilimzig, Schöner, 2006

Memory instability



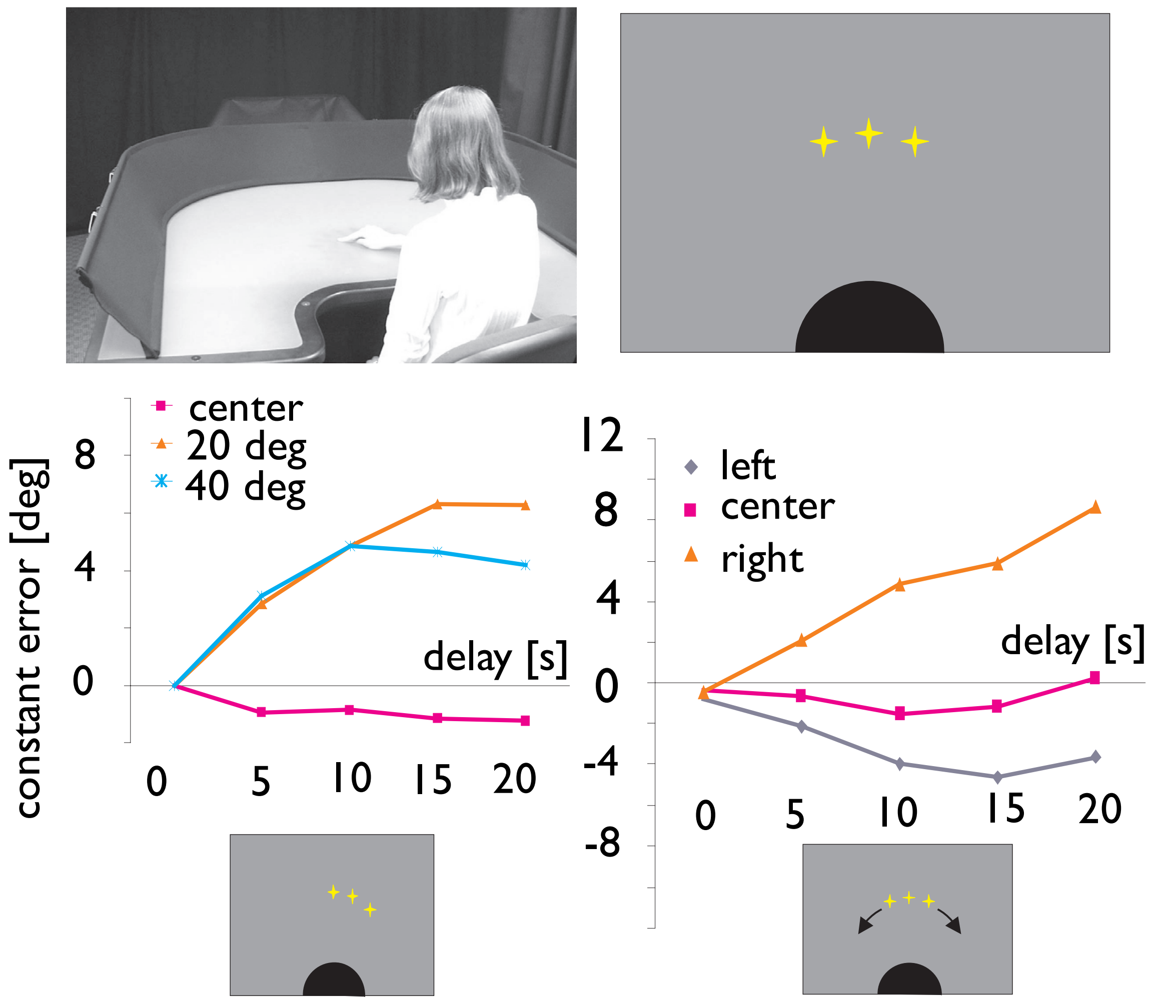
- “space ship” task probing spatial working memory





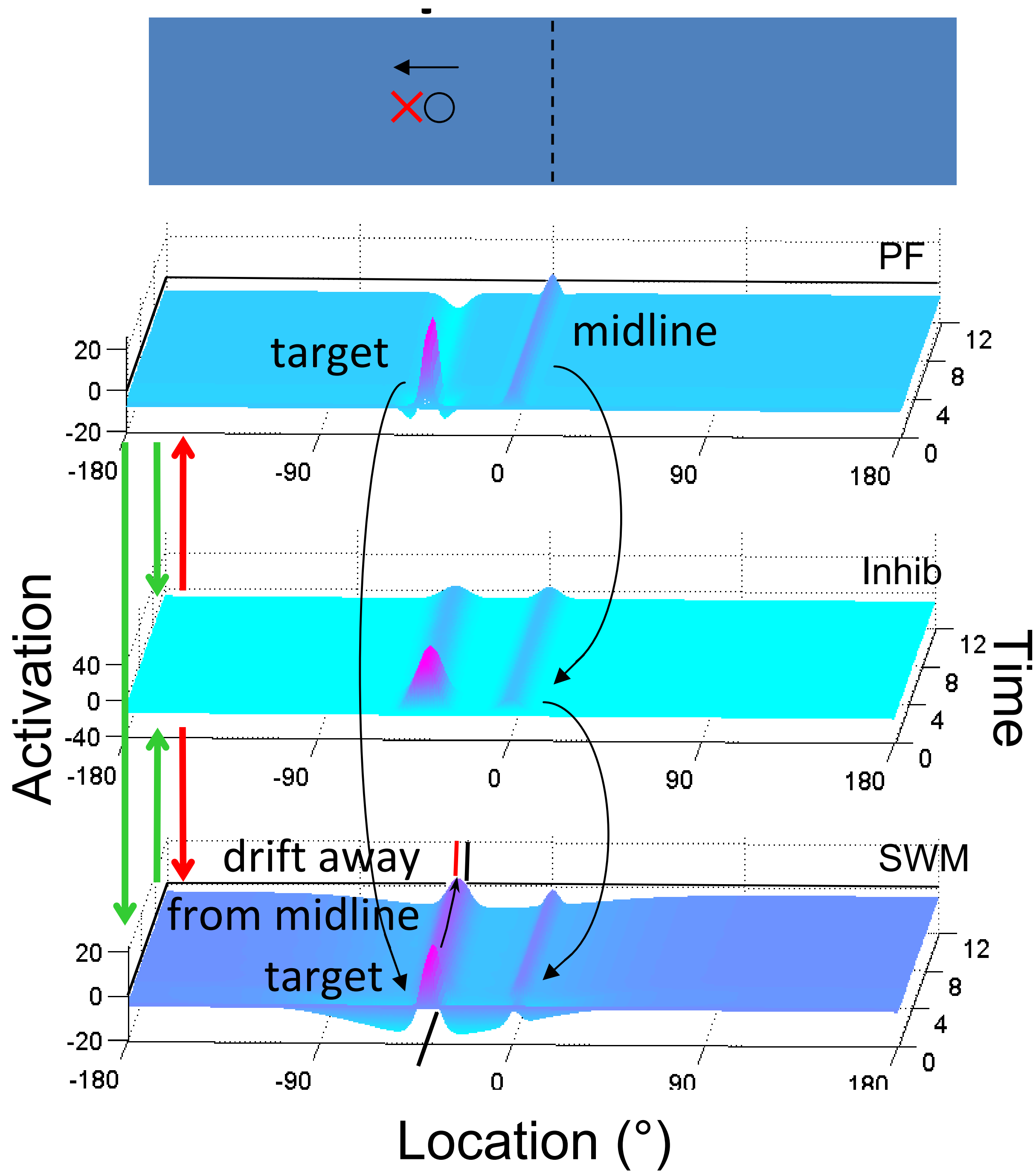
[Schutte, Spencer, JEP:HPP 2009]

repulsion from midline/landmarks



[Schutte, Spencer, JEP:HPP 2009]

- DFT account of repulsion: inhibitory interaction with peak representing landmark



[Simmering, Schutte, Spencer: Brain Research, 2007]

Working memory as sustained peaks

- implies metric drift of WM, which is a marginally stable state (one direction in which it is not asymptotically stable)
- => empirically real..