# Dynamic Field Theory

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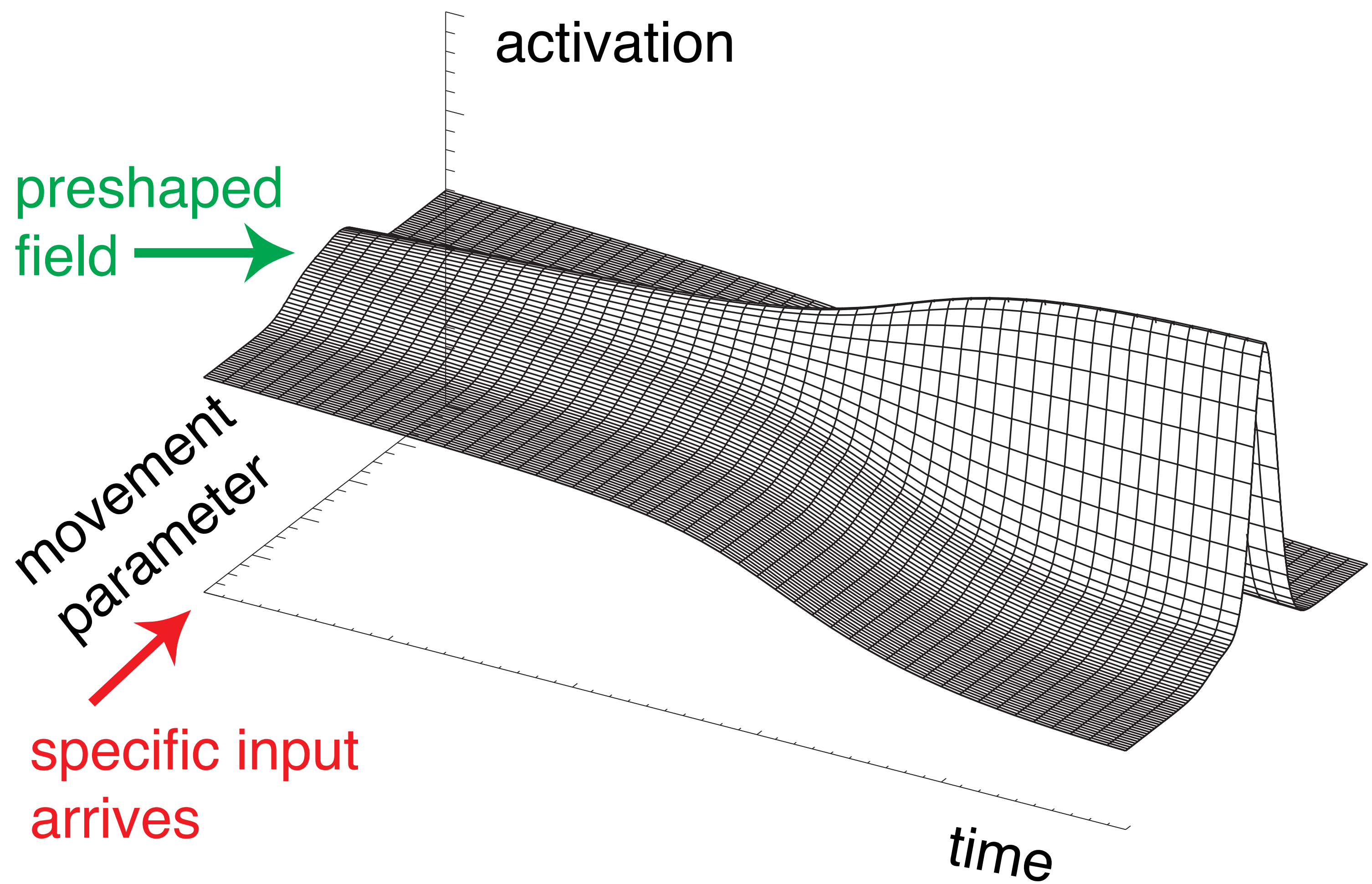
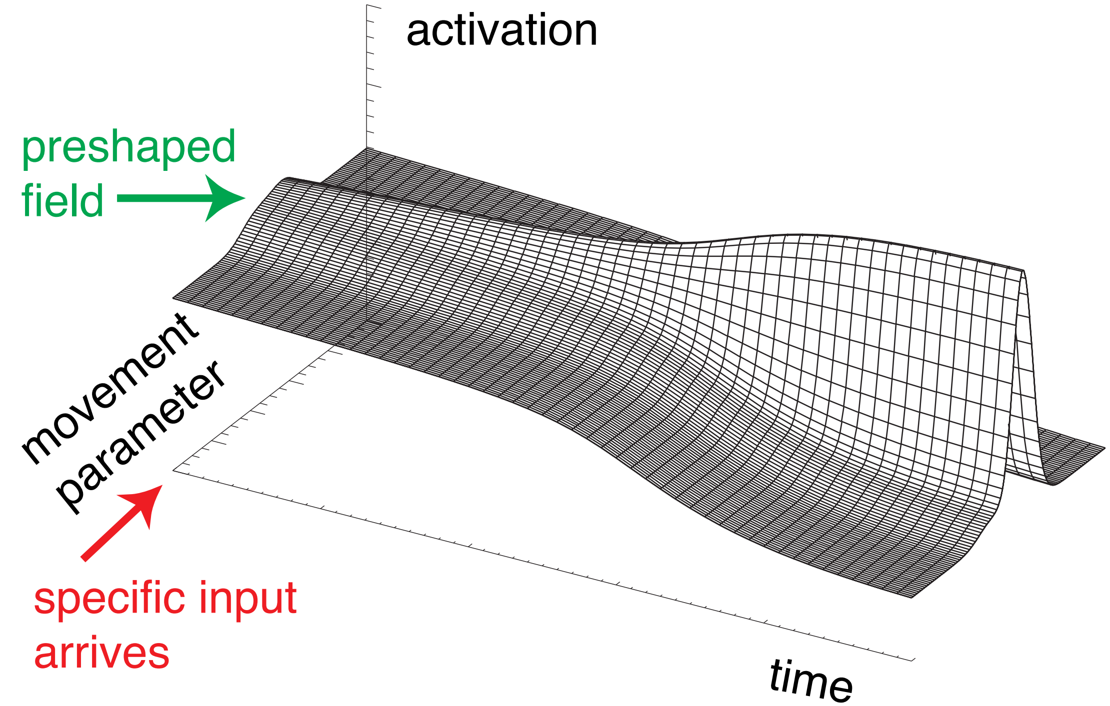
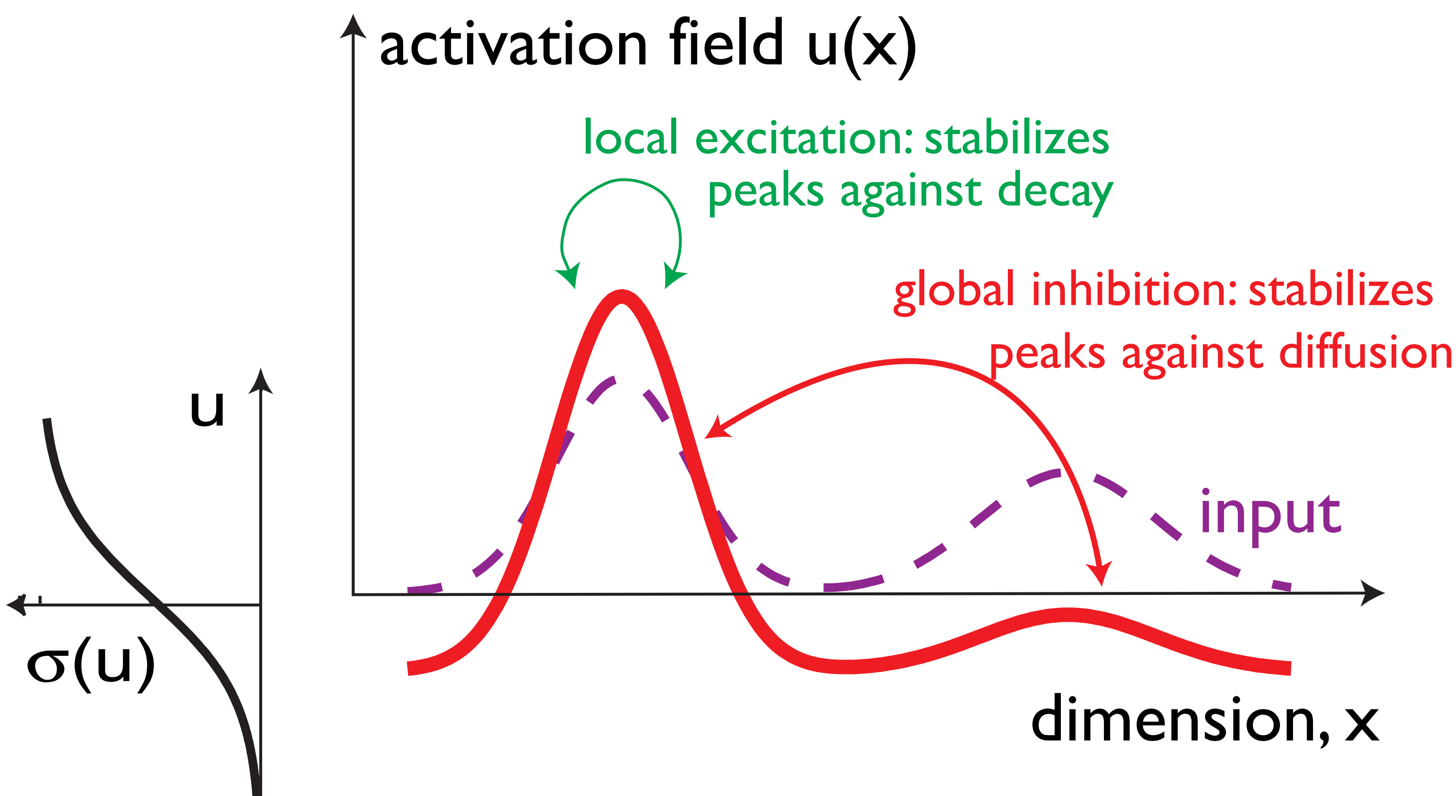
# evolution of activation fields in time: neuronal dynamics



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 $\tau$
- 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

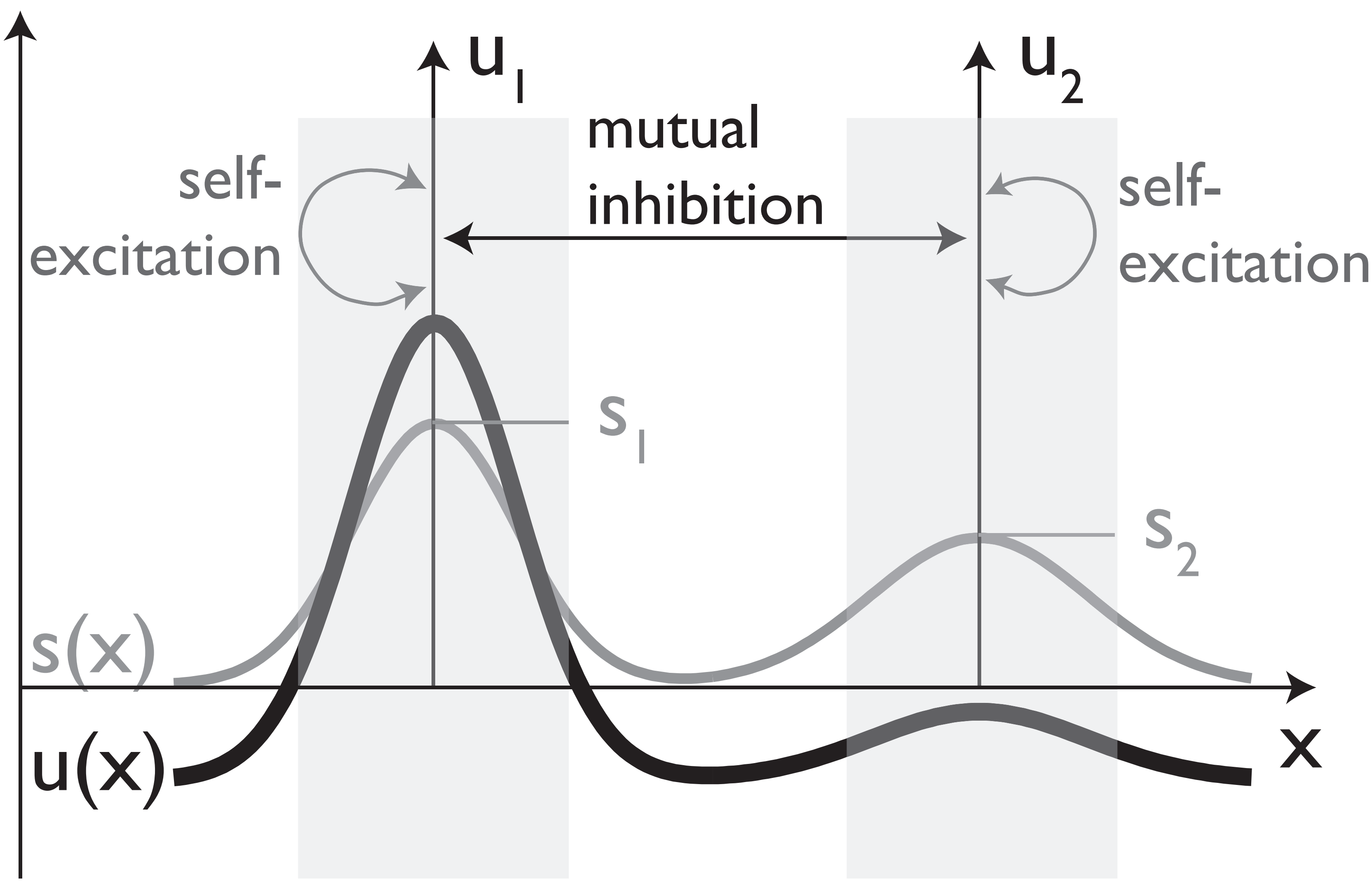
$$\sigma(u) = \frac{1}{1+\exp[-\beta(u-u_0)]}$$

=> simulations

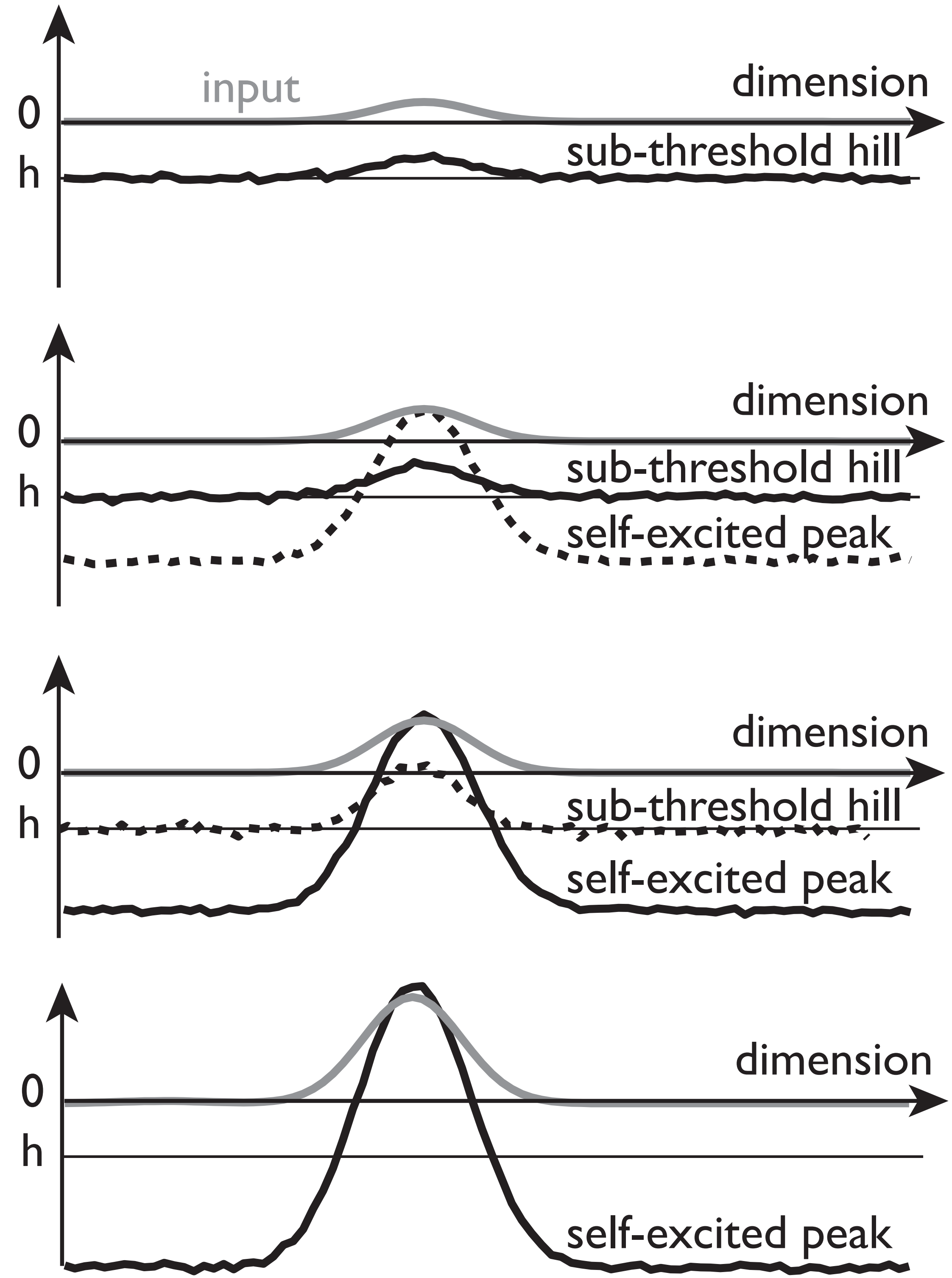
# solutions and instabilities

- 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

# Relationship to the dynamics of discrete activation variables

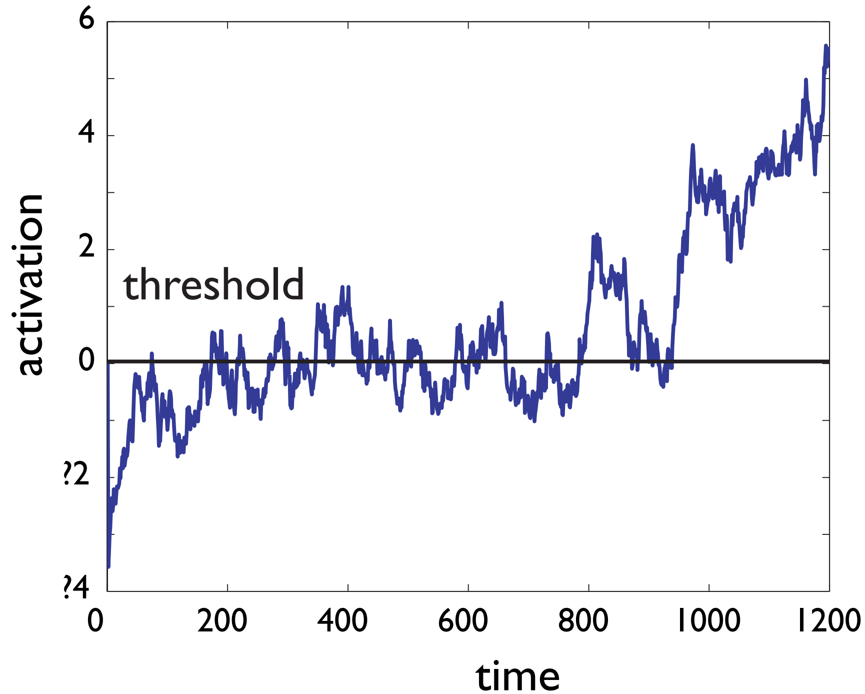


# Detection instability

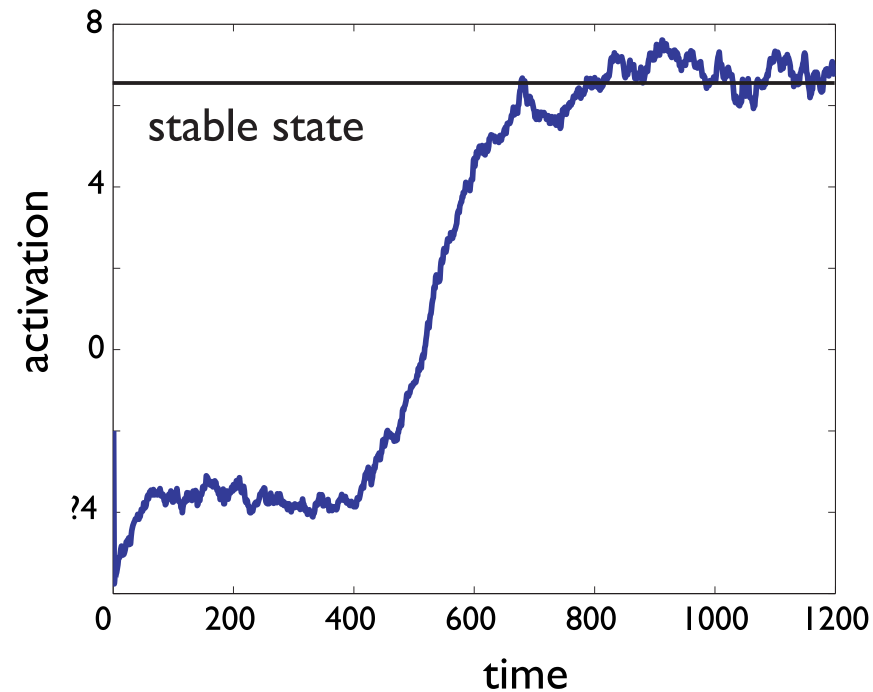


# the detection instability helps stabilize decisions

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

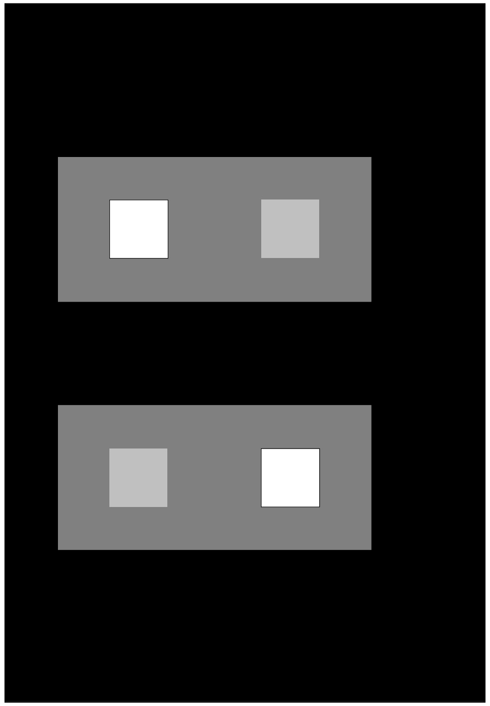
- the detection instability also explains how a time-continuous neuronal dynamics may create macroscopic, time-discrete events

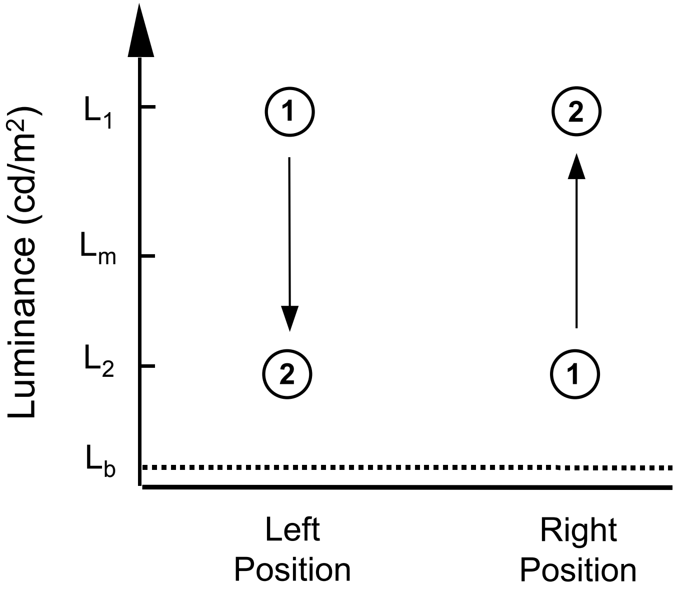
# behavioral signatures of detection decisions

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

# Detection instability

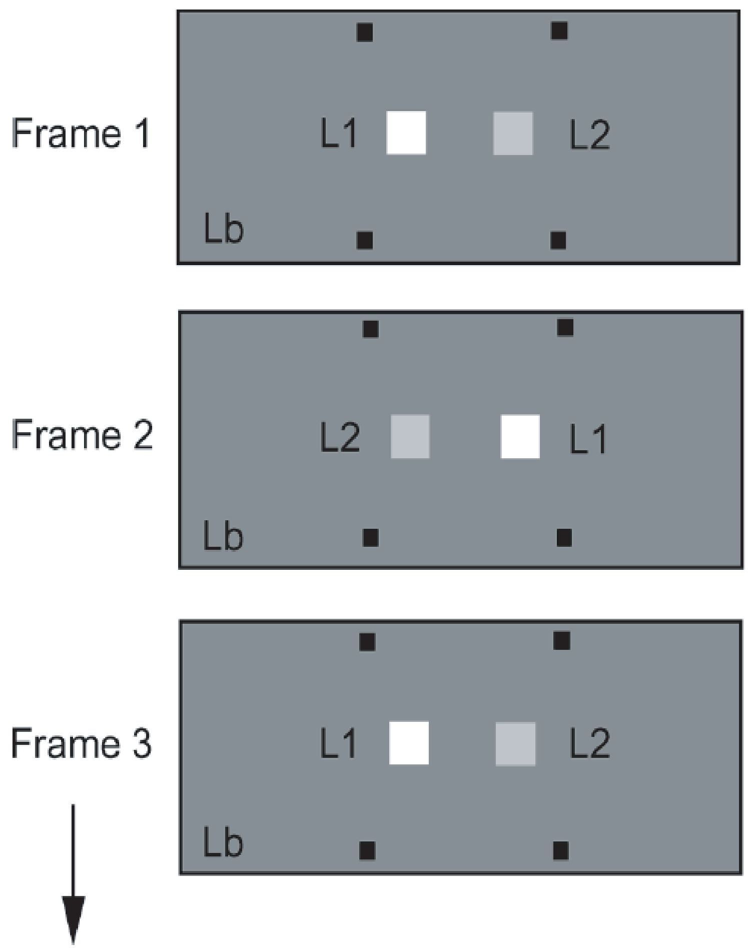
- in the detection of <u>Generalized Apparent Motion</u>





# Detection instability

- varying BRLC



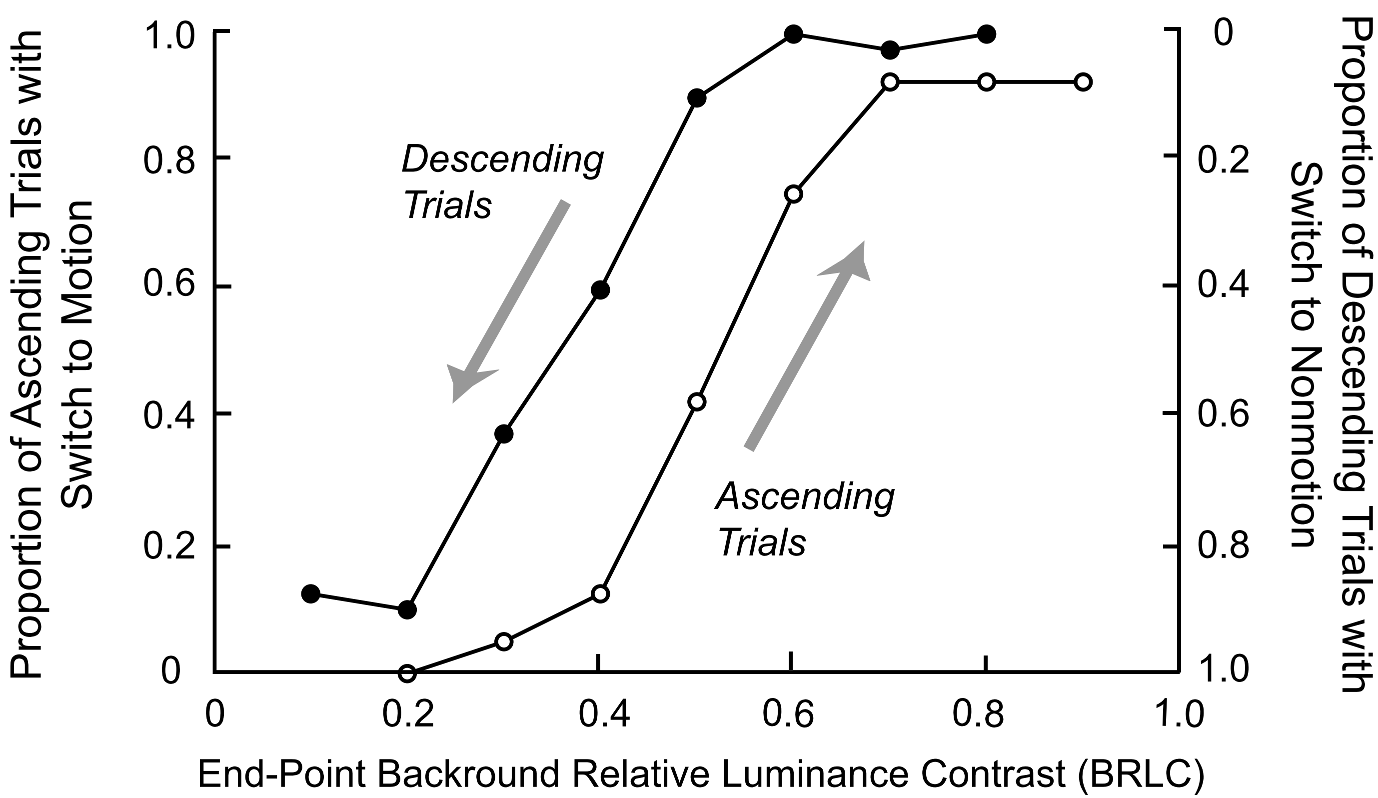

$$Lm = \frac{L1 + L2}{2}$$

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

# Detection instability

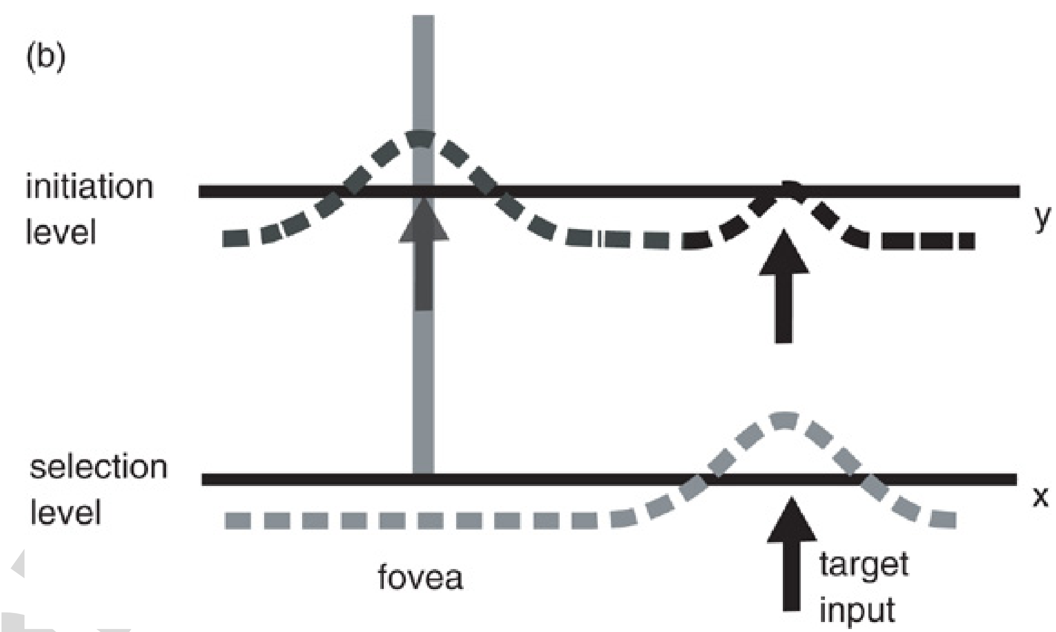
- hysteresis of motion detection as BRLC is varied
- (while response bias is minimized)

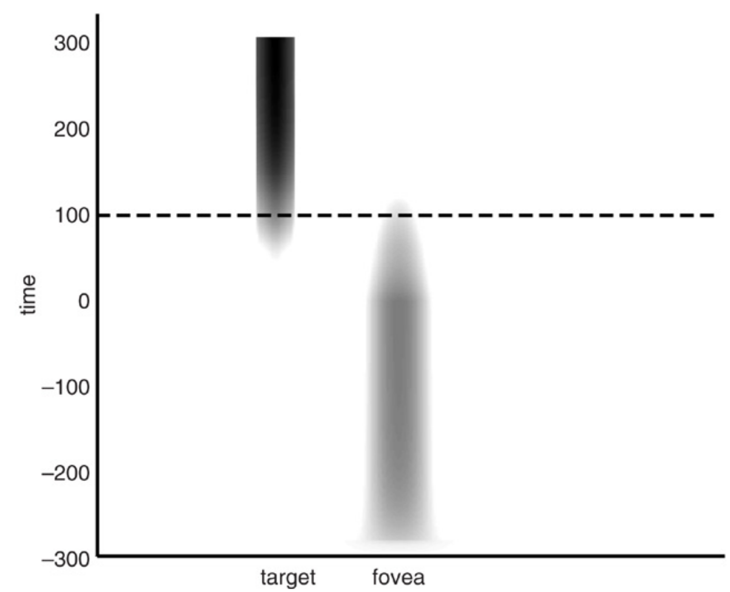
*H. S. Hock, G. Schöner / Seeing and Perceiving 23 (2010) 173–195*



# overcoming fixation

- detection can be like selection: initiating an action means terminating the non-action=fixation or posture
- example: saccade initiation

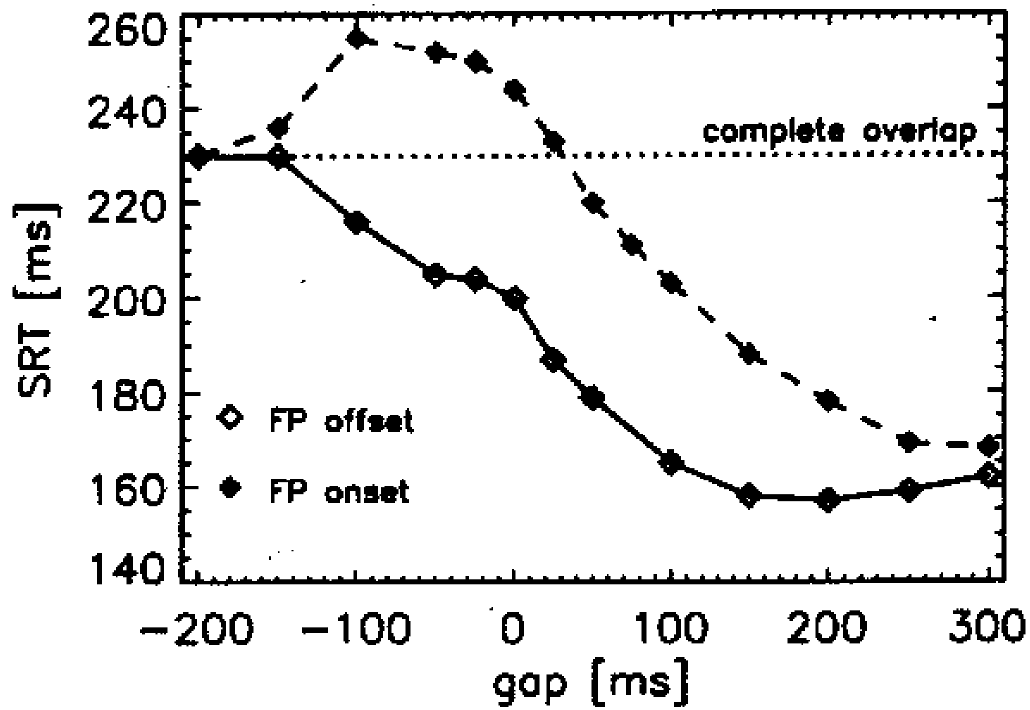


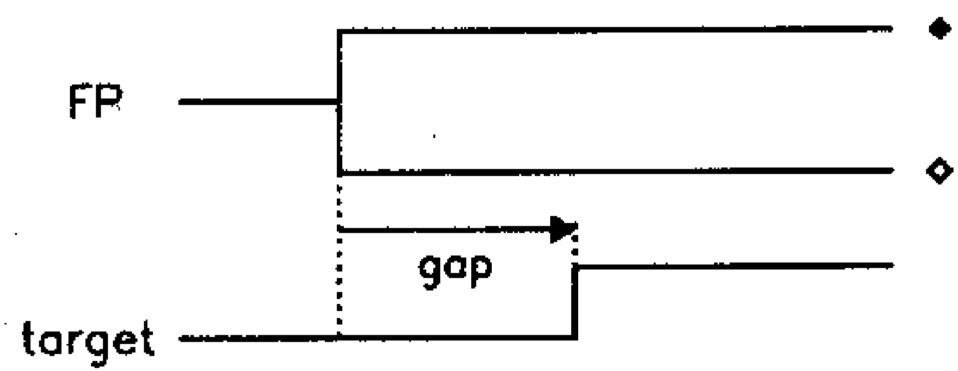




[Wilimizig, Schneider, Schöner, 2006]

# initiation vs. fixation

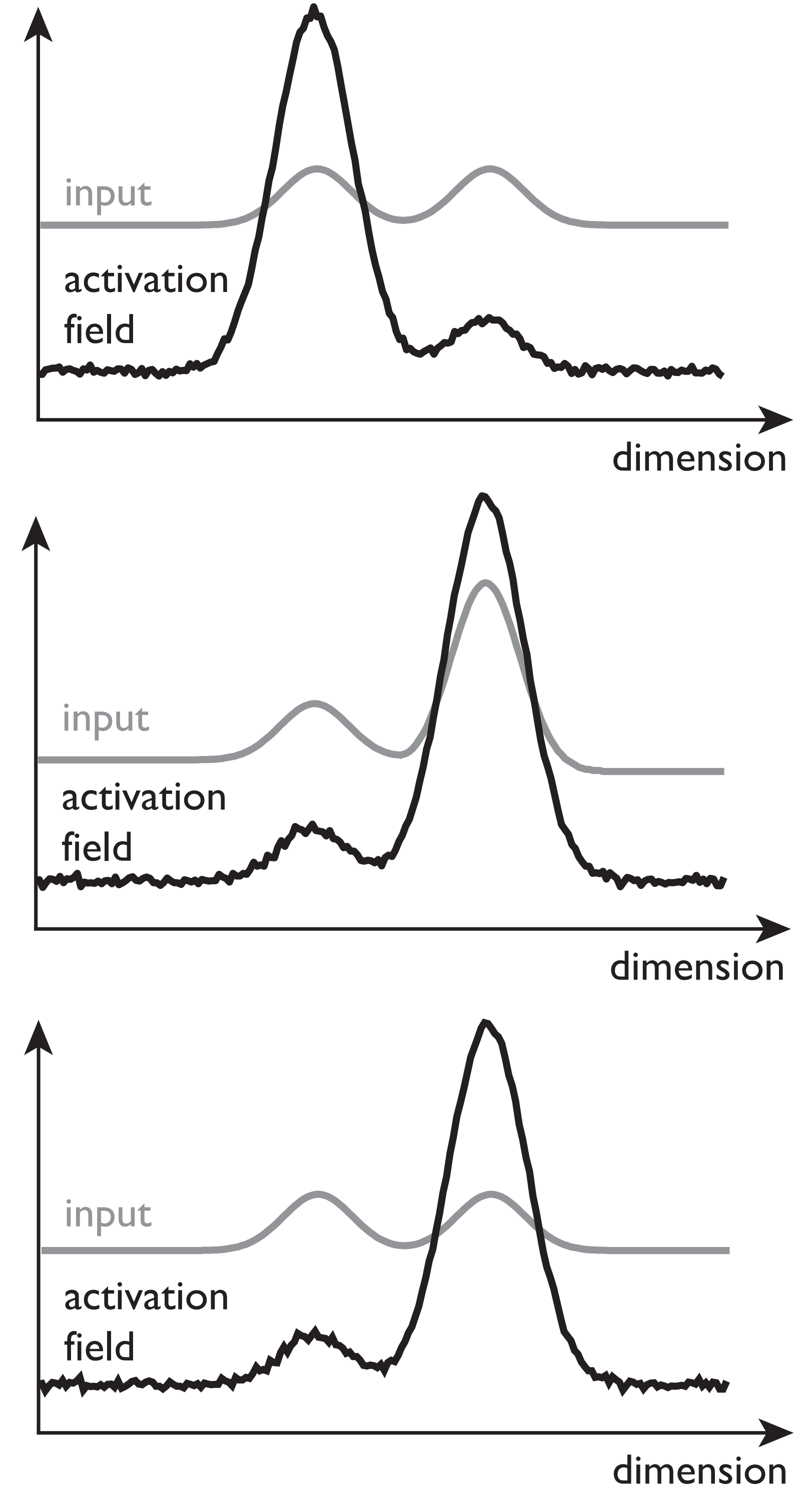
- such models account for the gap-step-overlap effect



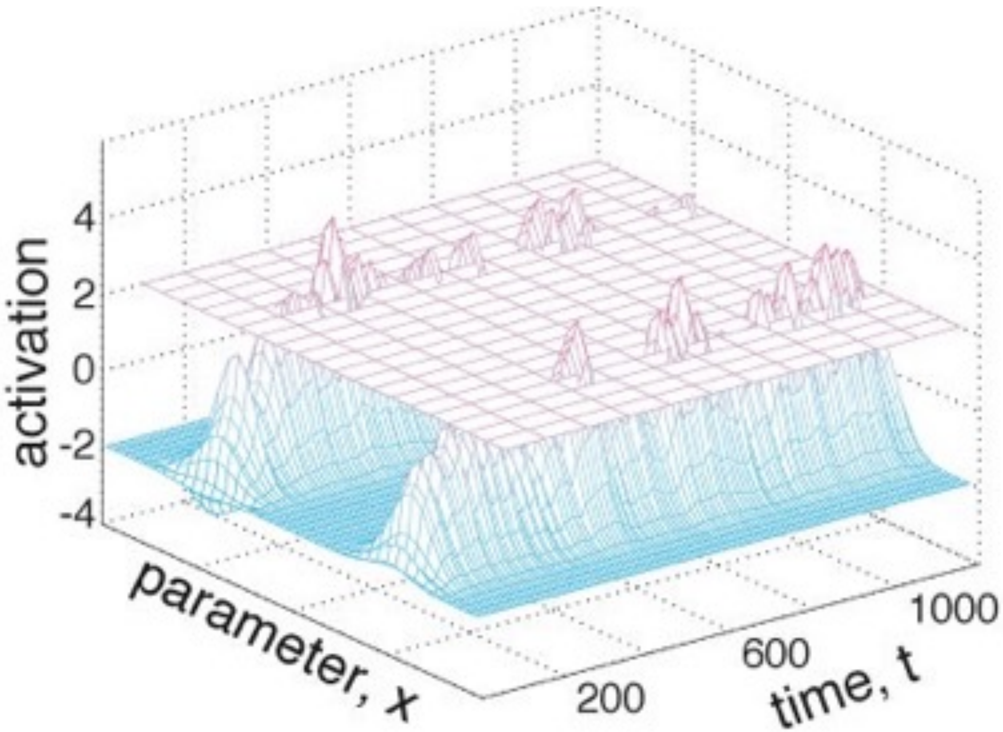



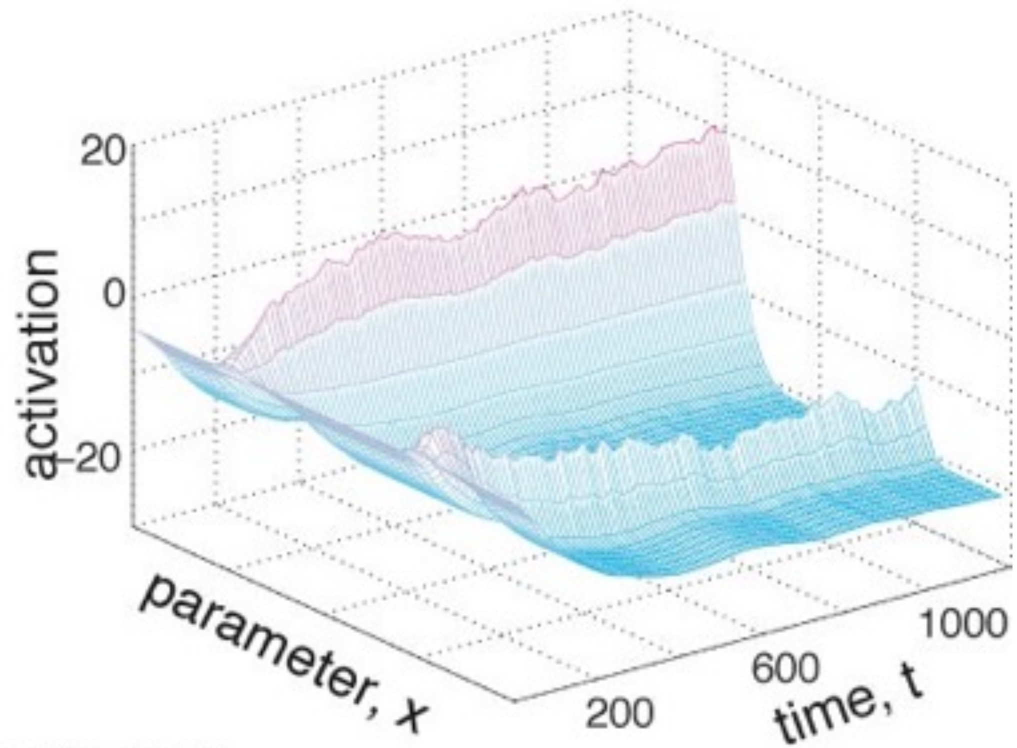

[Kopecz, 95]

# selection instability



# stabilizing selection decisions



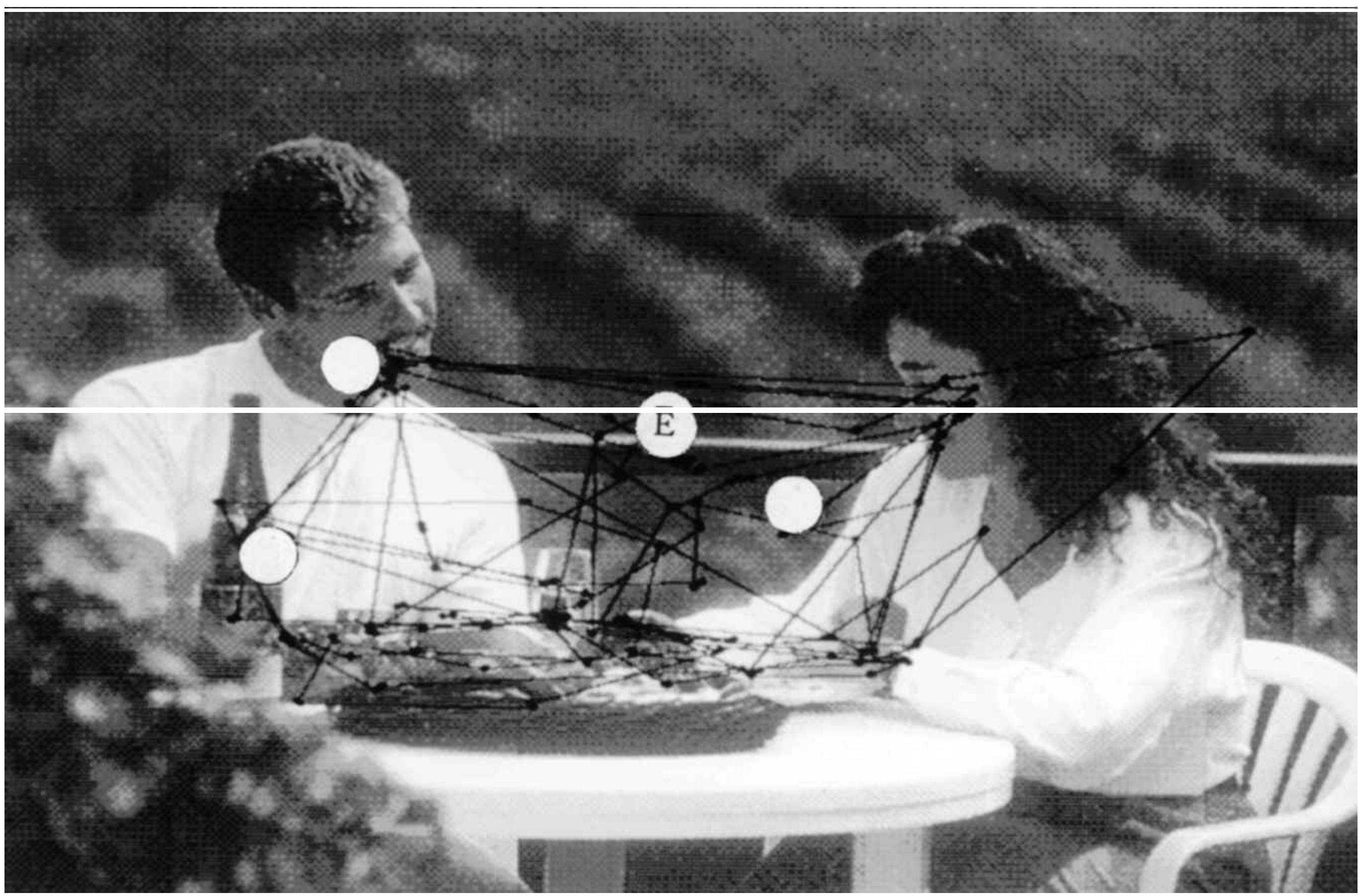

[Wilimzig, Schöner, 2006]

# 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

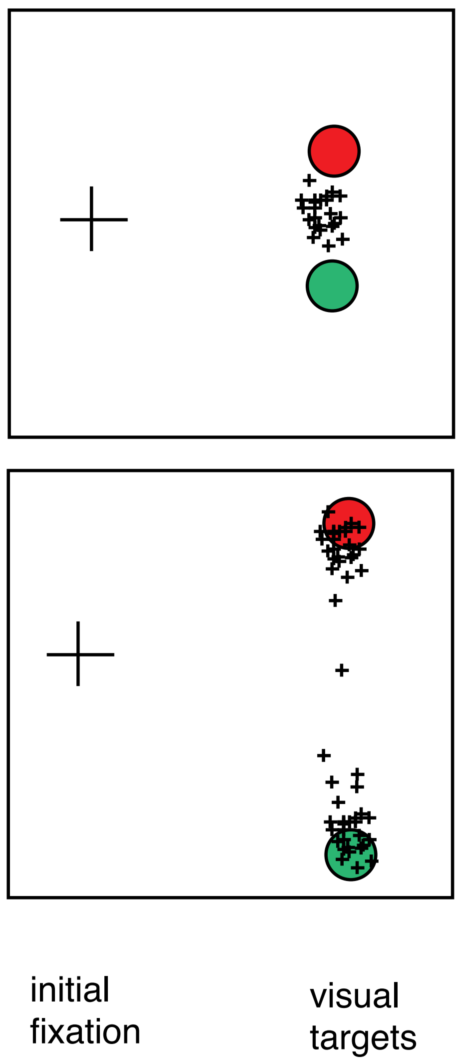
# one system of "free choice"

- selecting a new saccadic location

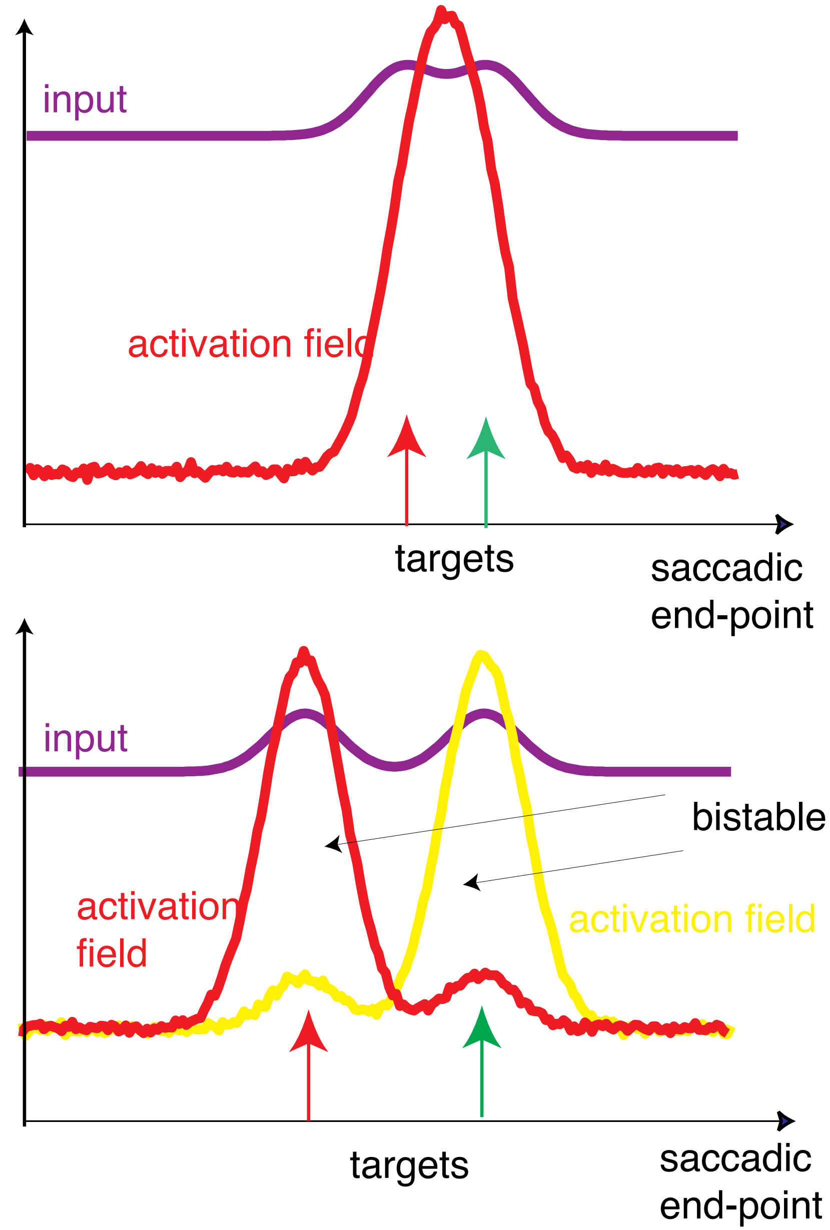



[O'Reagan et al., 2000]

# saccade generation



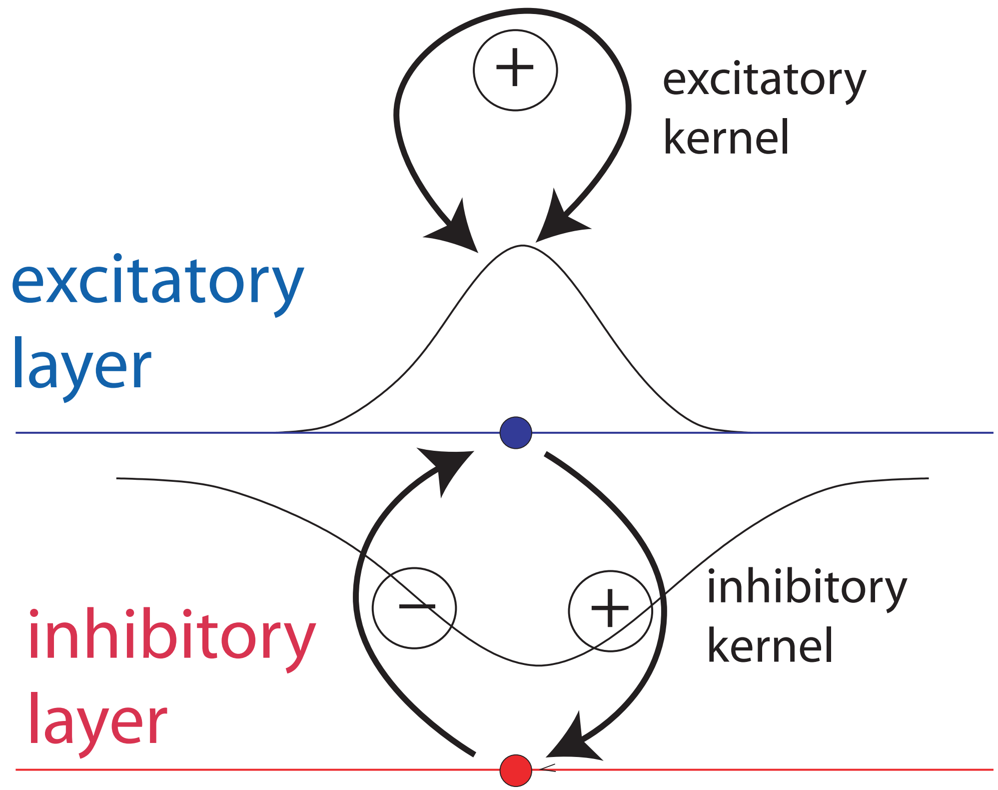

[after: Ottes et al., Vis. Res. 25:825 (85)]




[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)



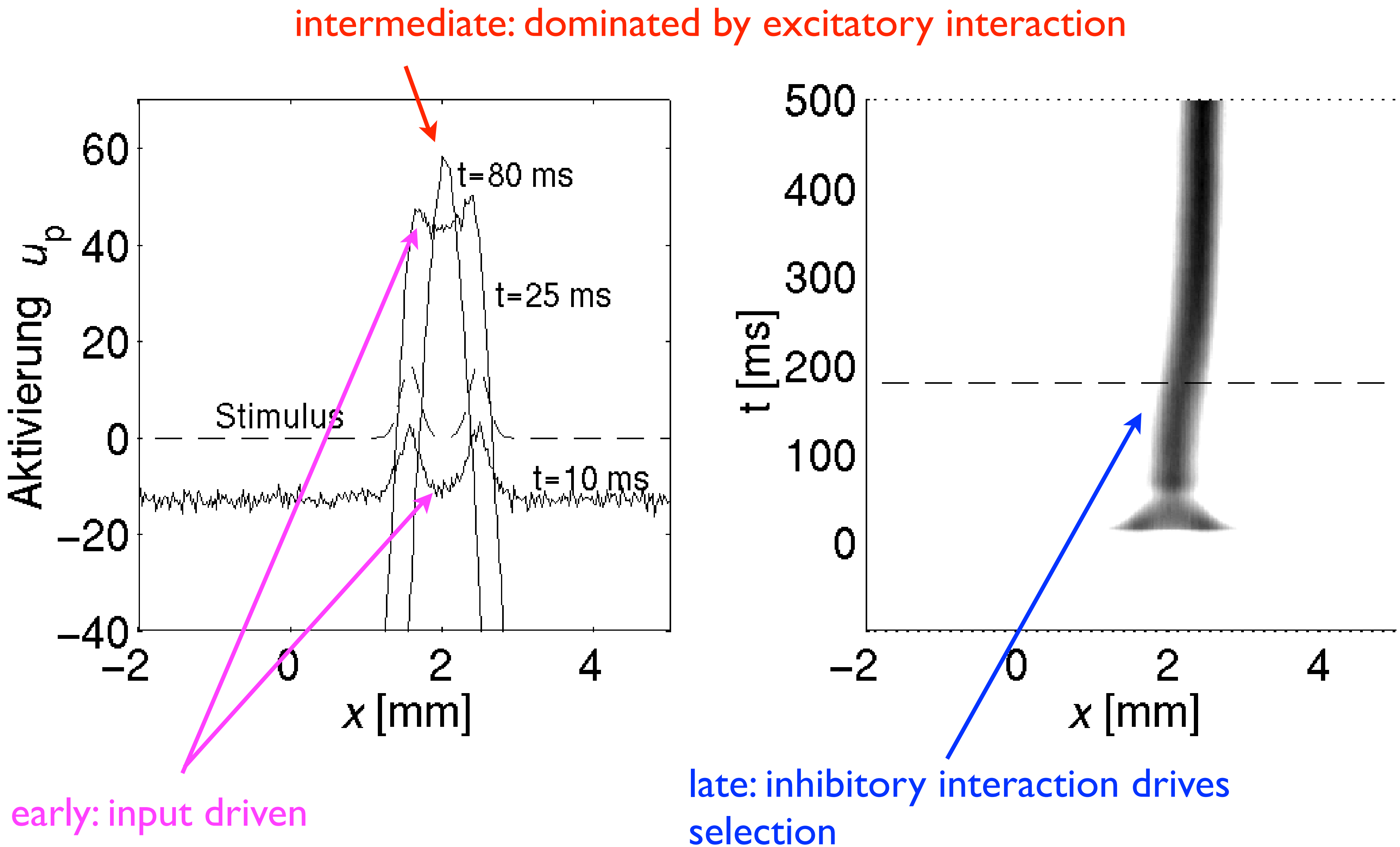

[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

# 2 layer Amari model

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

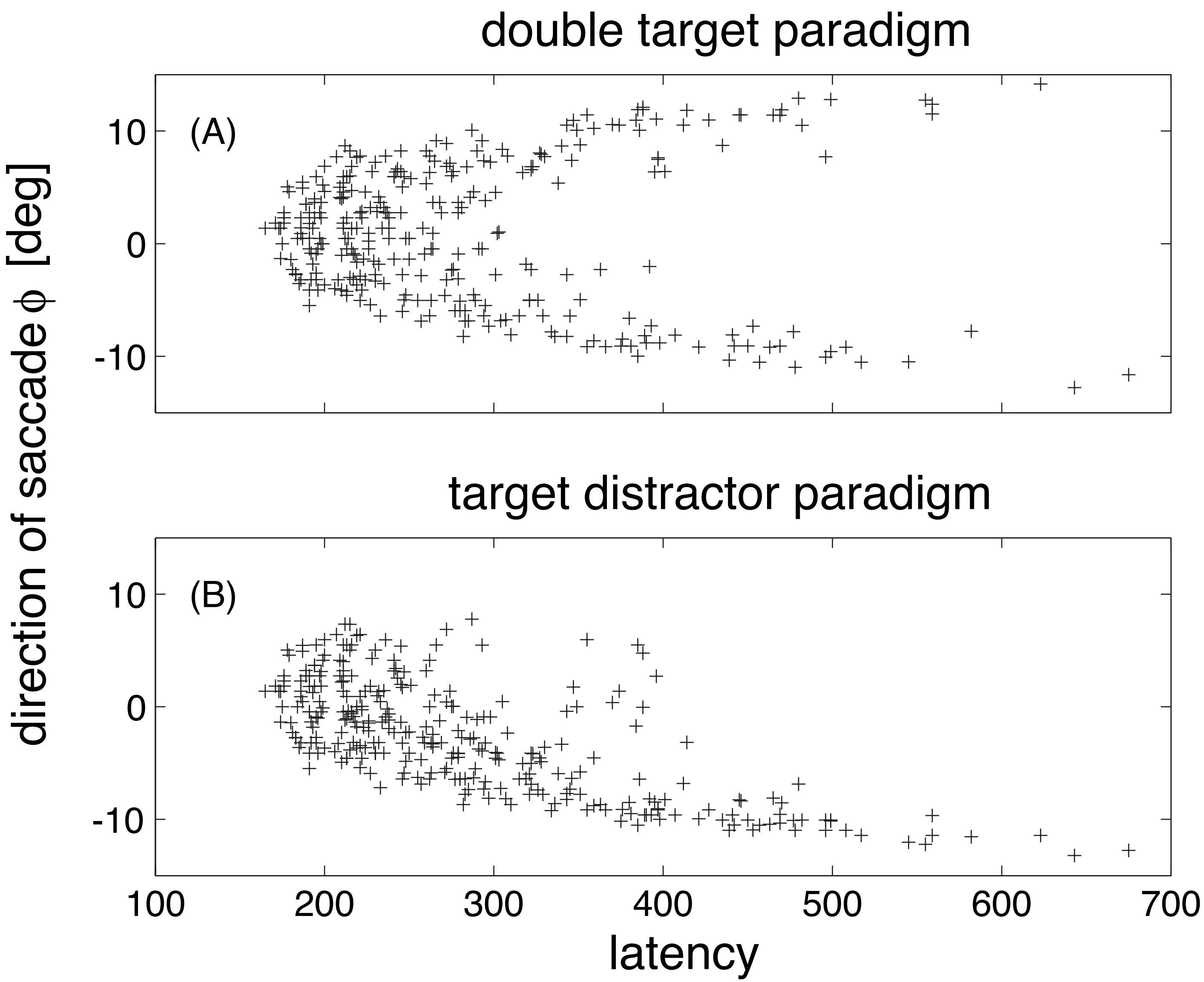
$$c_{ij}(x-x') = c_{i,j,\mathrm{strength}} \; \exp\left[-\frac{(x-x')^2}{2\sigma_{ij}^2}\right]. \qquad \sigma(u) = \frac{1}{1+\exp[-\beta \, u]}.$$

# time course of selection



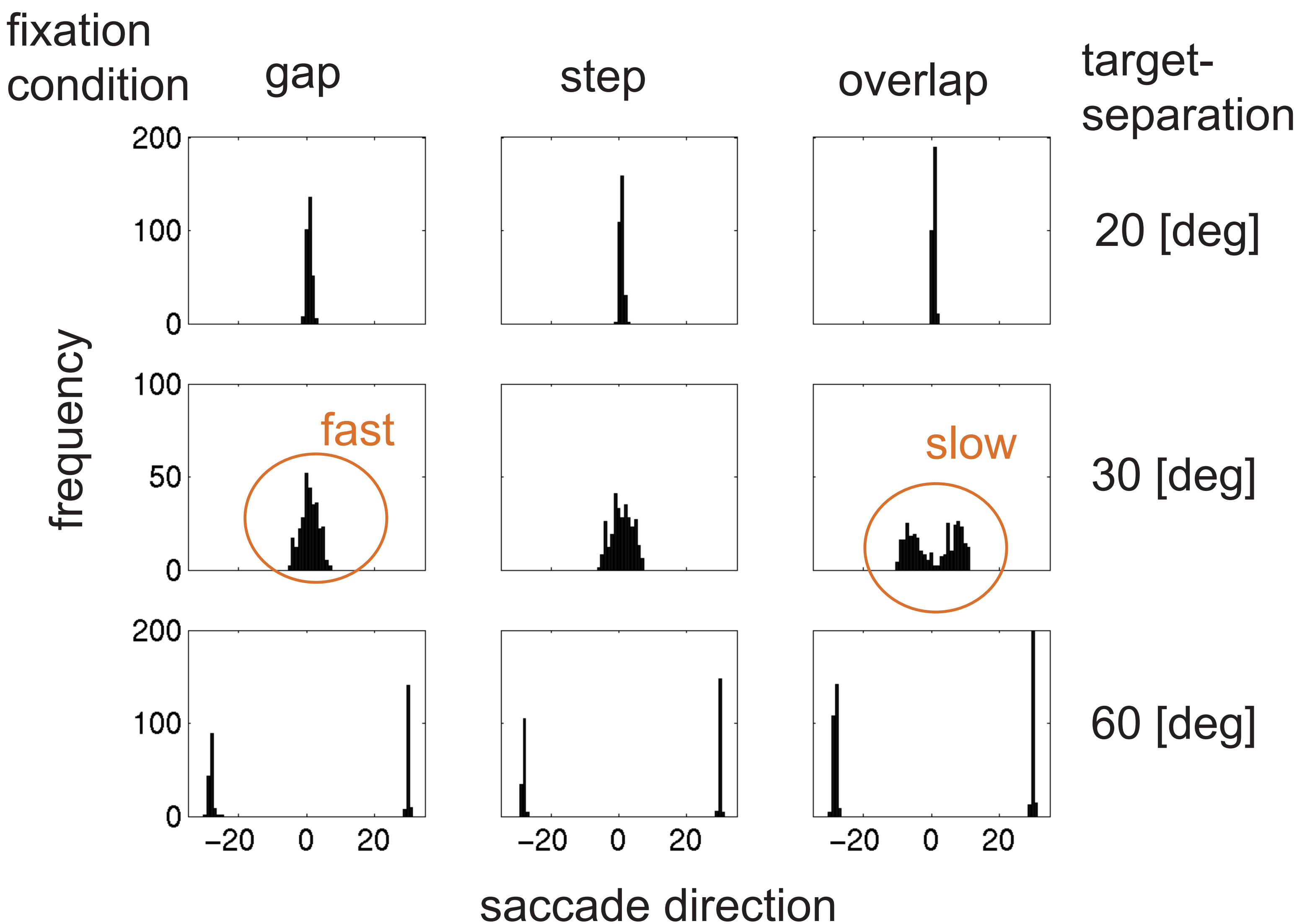

Wilimzig, Schneider, Schöner, Neural Networks, 2006

# => early fusion, late selection



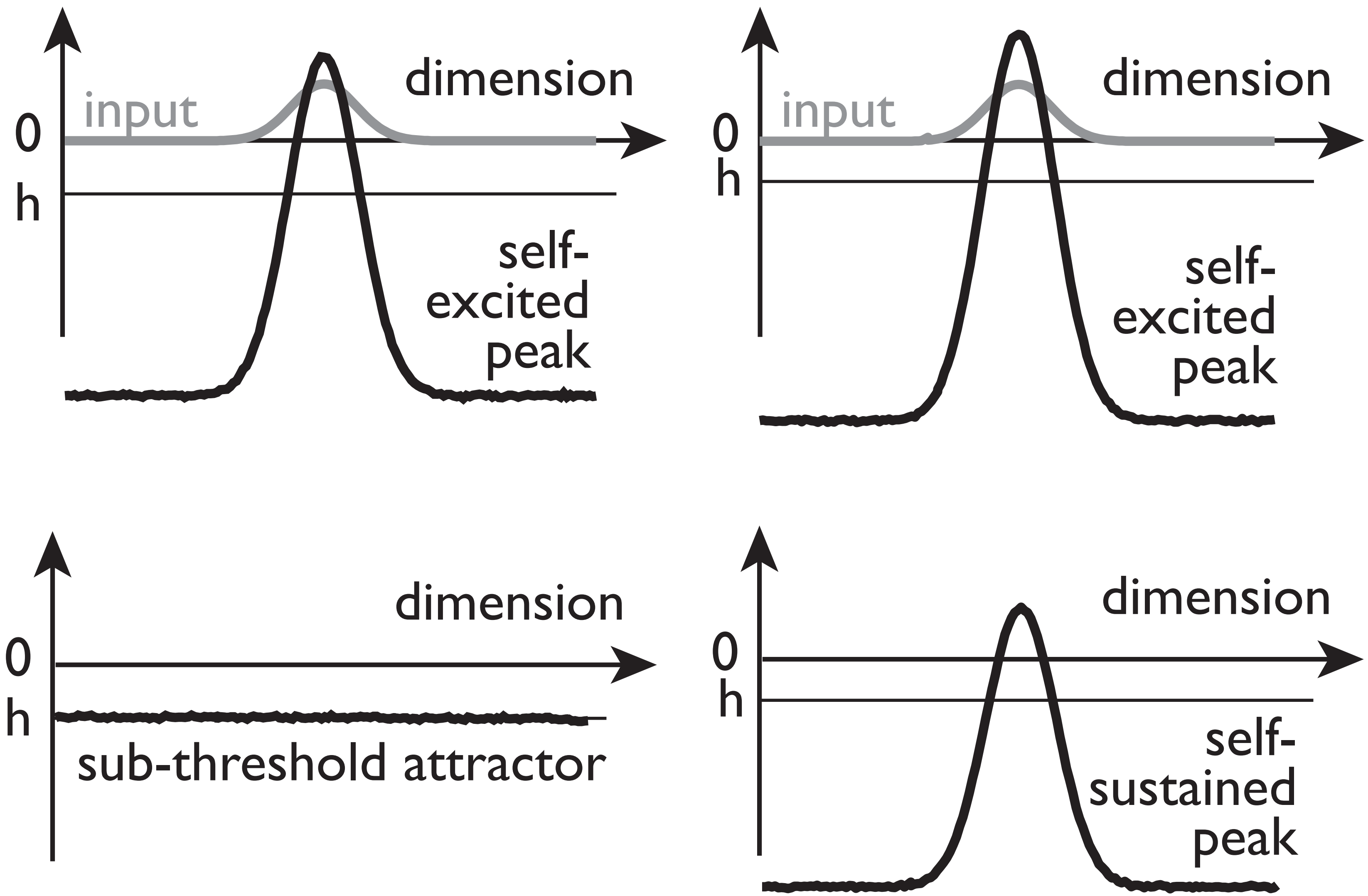

Wilimzig, Schneider, Schöner, Neural Networks, 2006

# fixation and selection

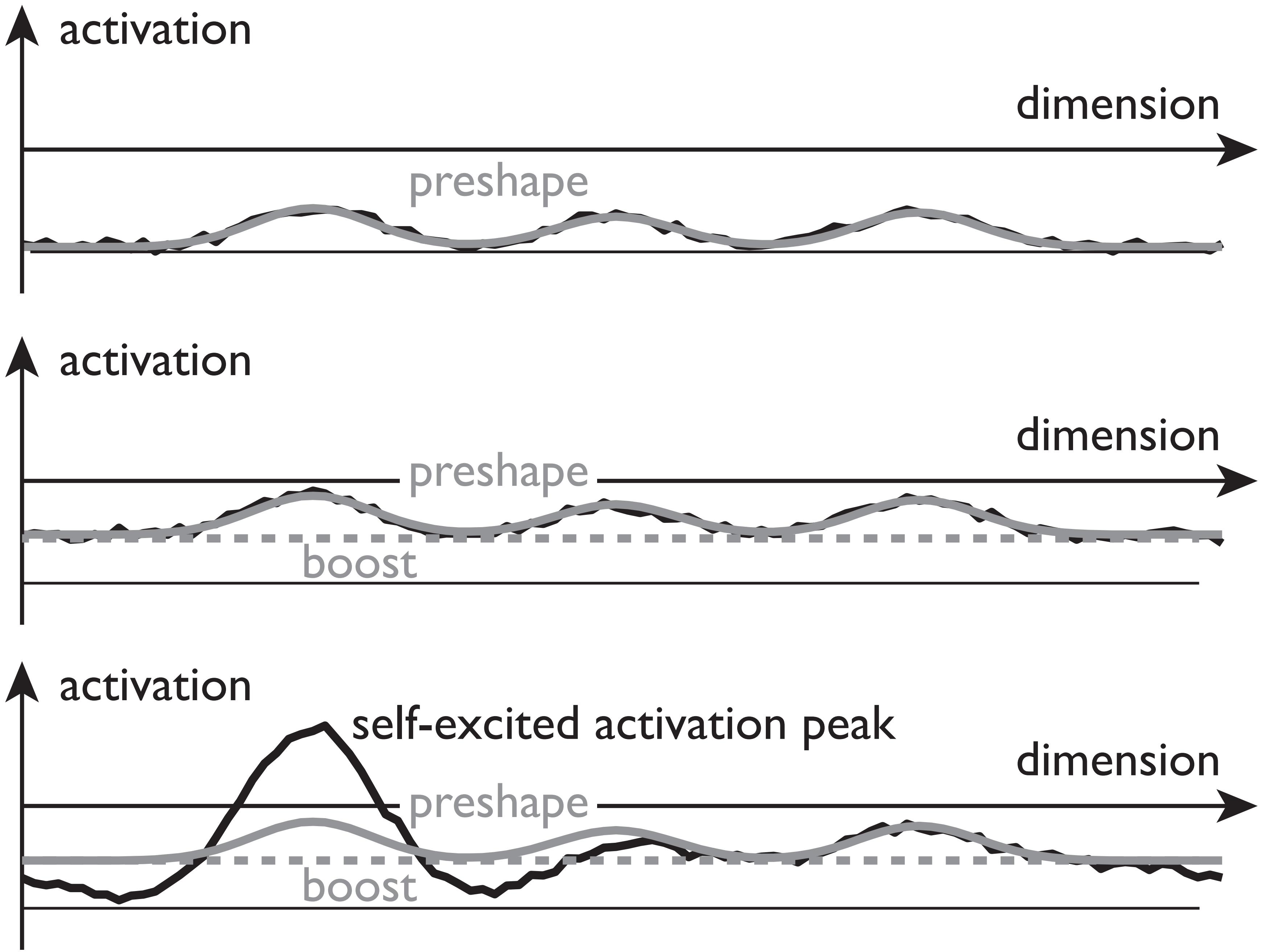



Wilimzig, Schneider, Schöner, Neural Networks, 2006

# Memory instability



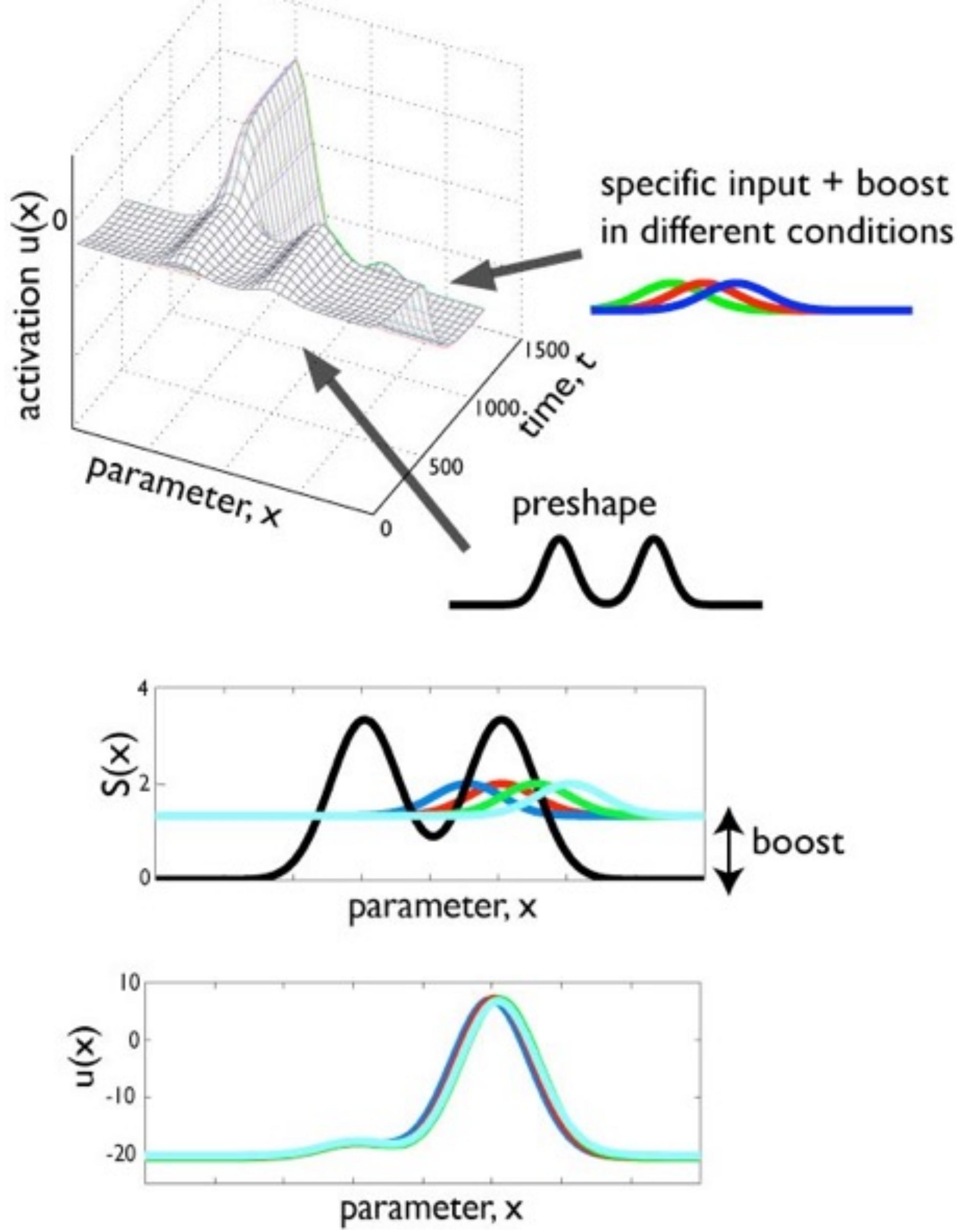
# boost-induced detection instability



# 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

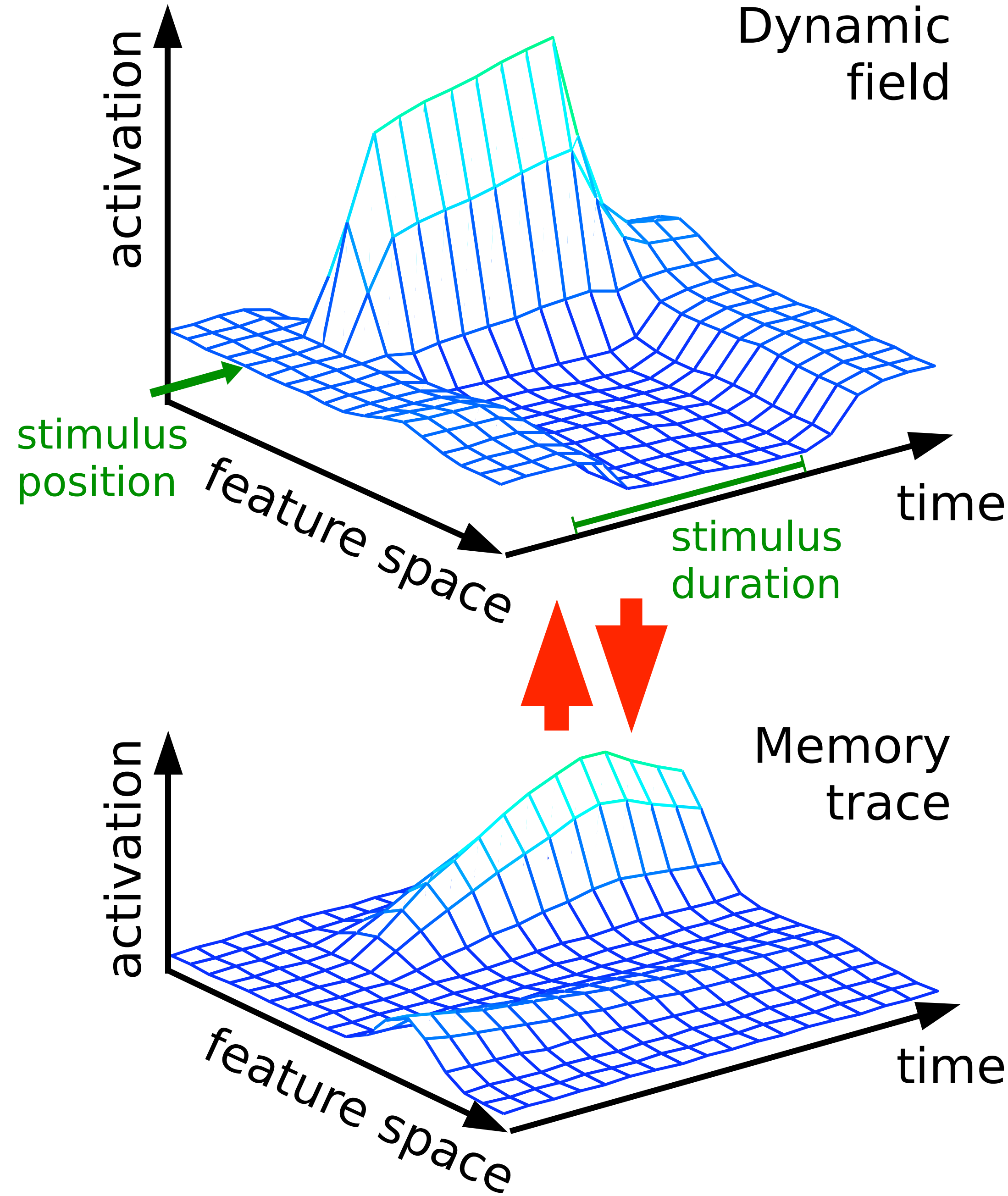
# this supports categorical behavior




- when preshape dominates

[Wilimzig, Schöner, 2006]

# simplest form of learning: the memory trace



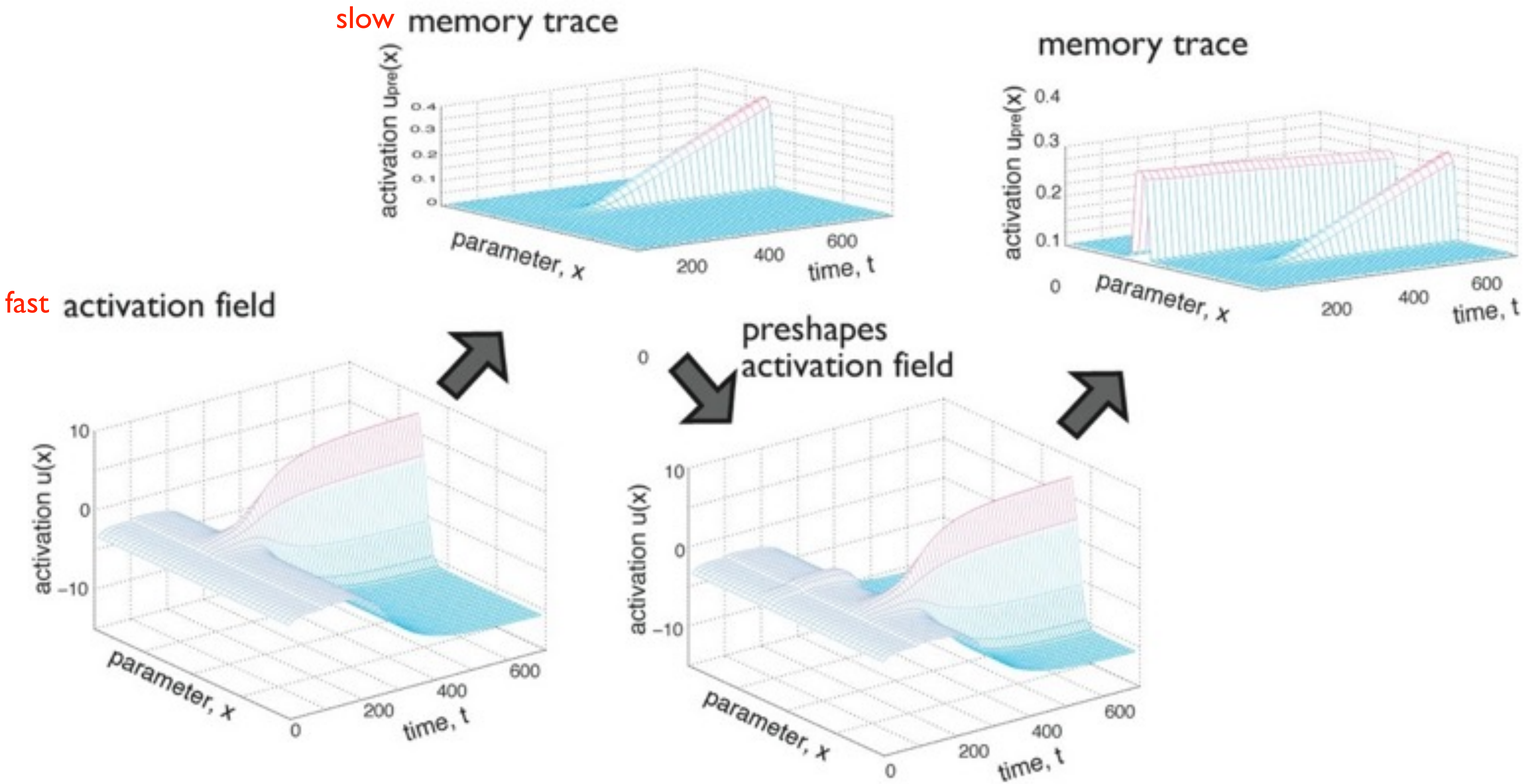

- William James: habit formation as the simplest form of learning
  - (habituation: same for inhibition)

# mathematics of the memory trace

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

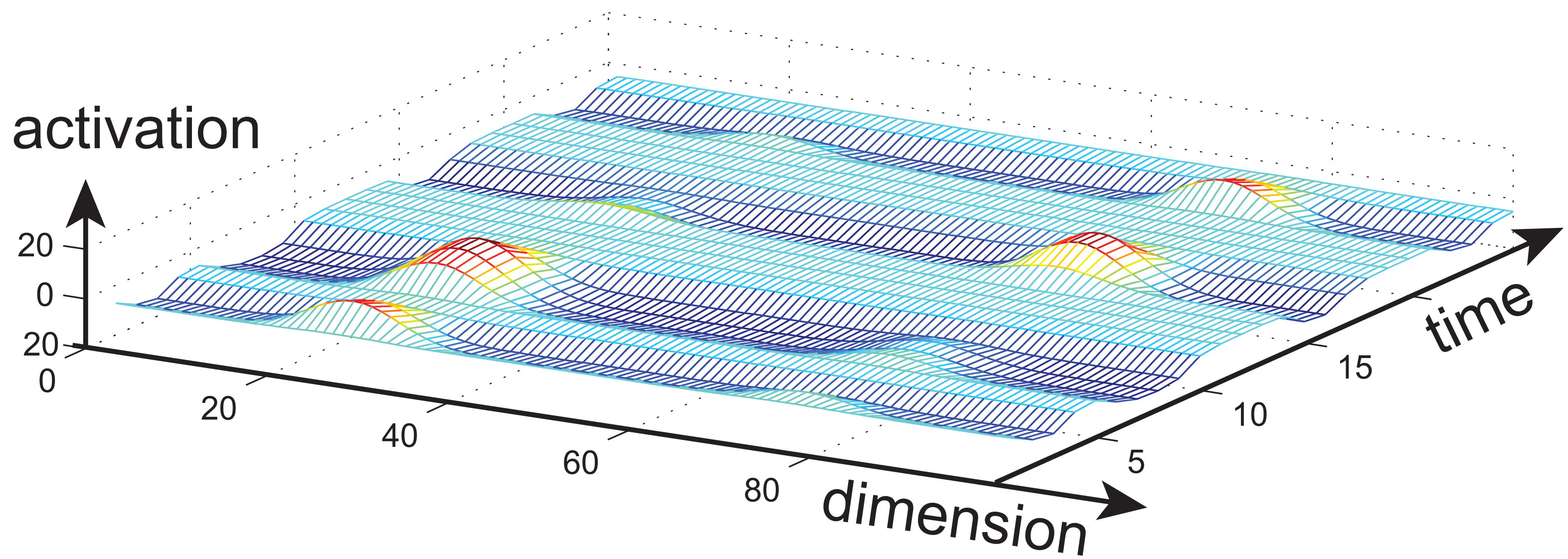
$$\tau_{\text{mem}} \; \dot{u}_{\text{mem}}(x,t) = -u_{\text{mem}}(x,t) + \int dx' \; w_{\text{mem}}(x-x')\sigma(u(x',t))$$

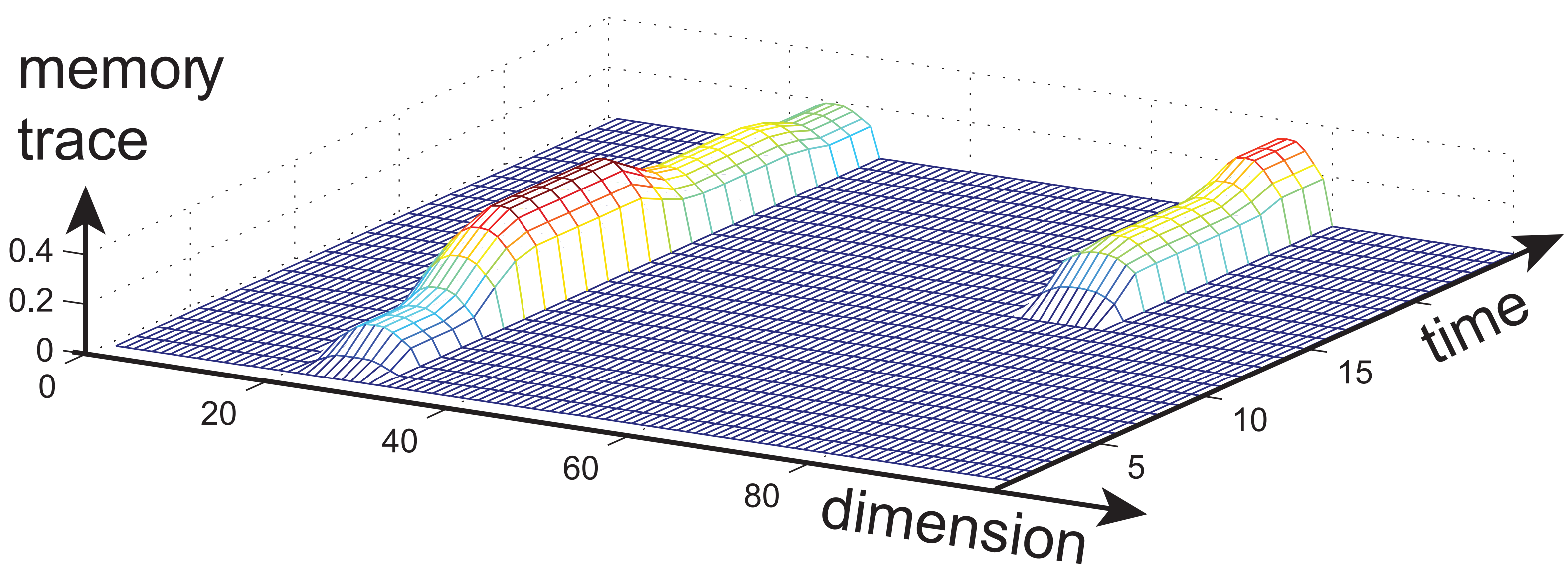
- memory trace only evolves while activation is excited
- potentially different growth and decay rates



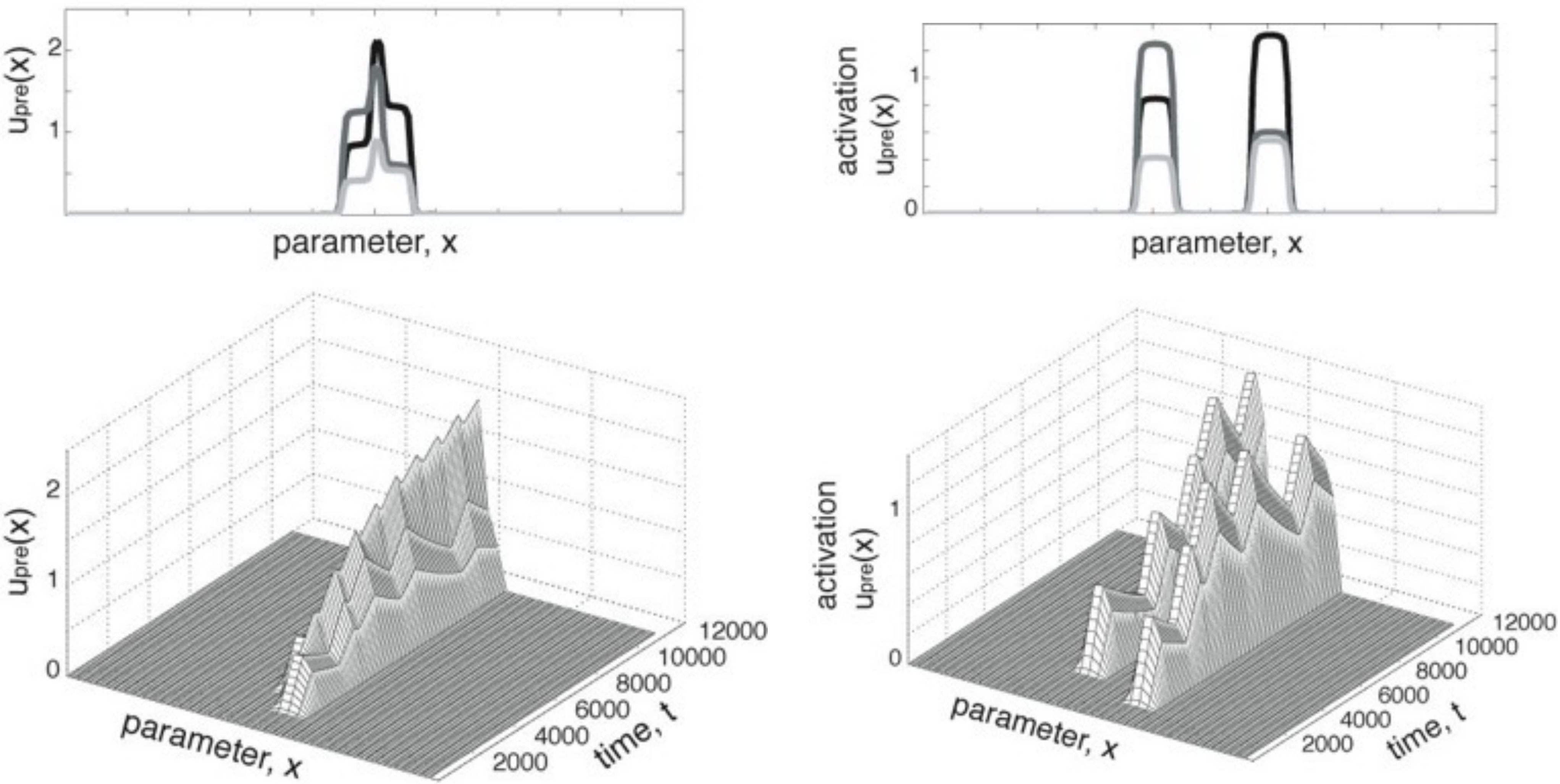

Wilimzig, Schöner 2006

# memory trace reflects history of decisions formation



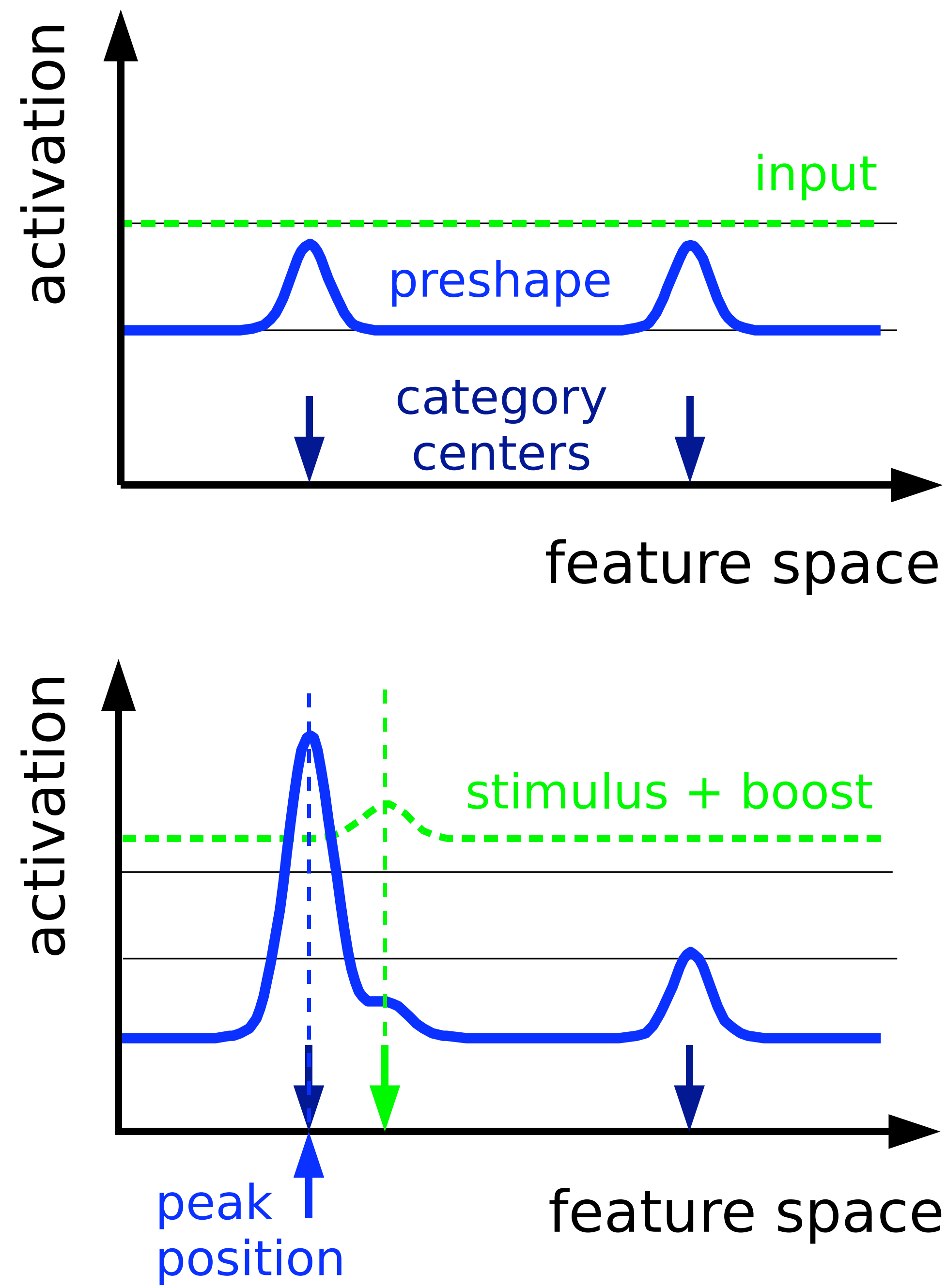
# categories may emerge ...



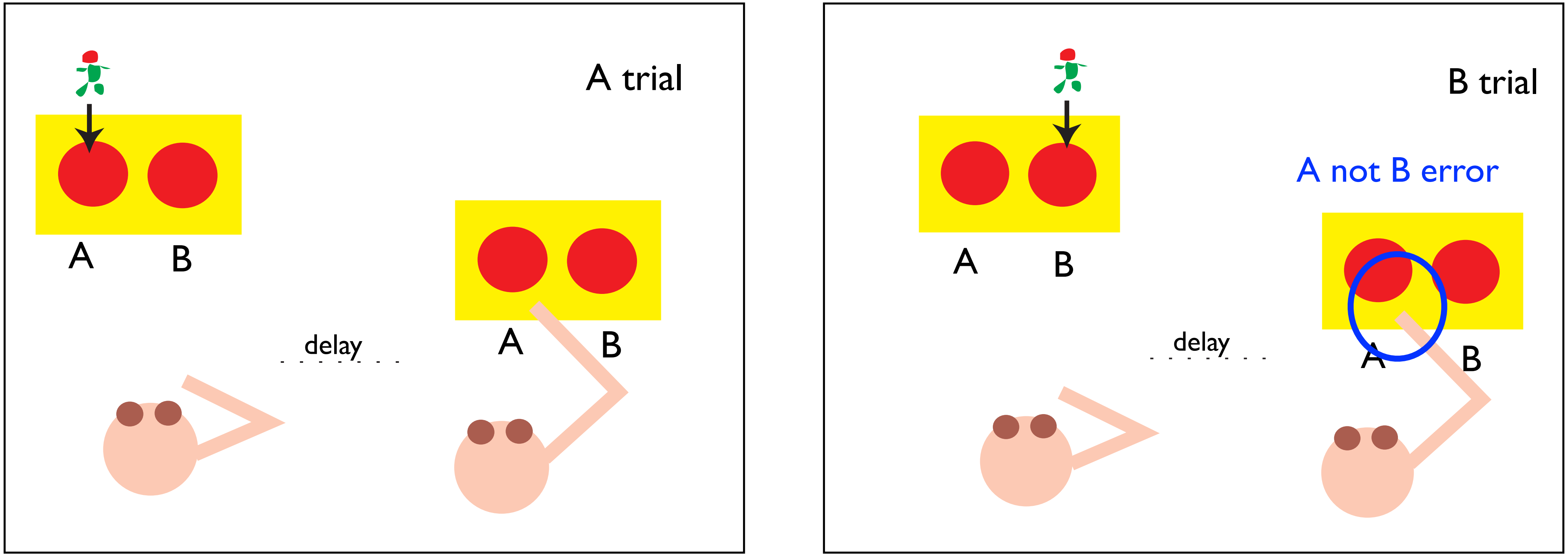

Wilimzig, Schöner 2006

# categories may emerge ...

- based on categorical memory trace and boost-driven detection instability
- => field responds categorically



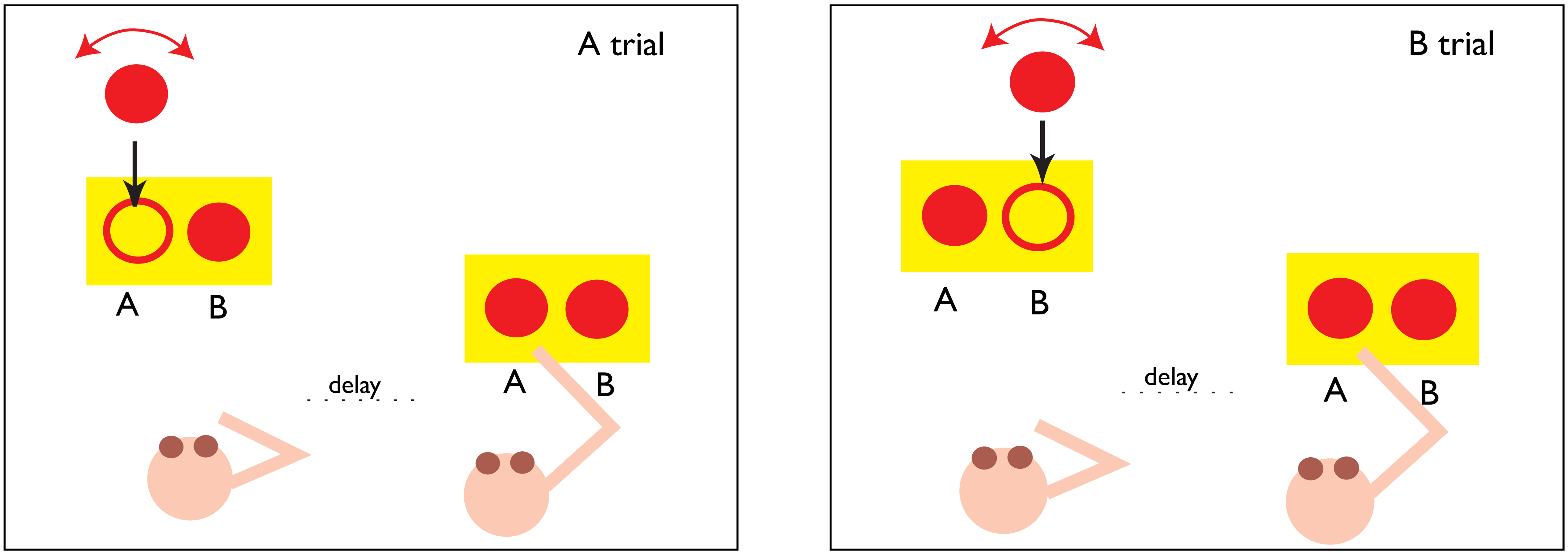
# Piaget's A not B paradigm: "out-of-sight -- out of mind"



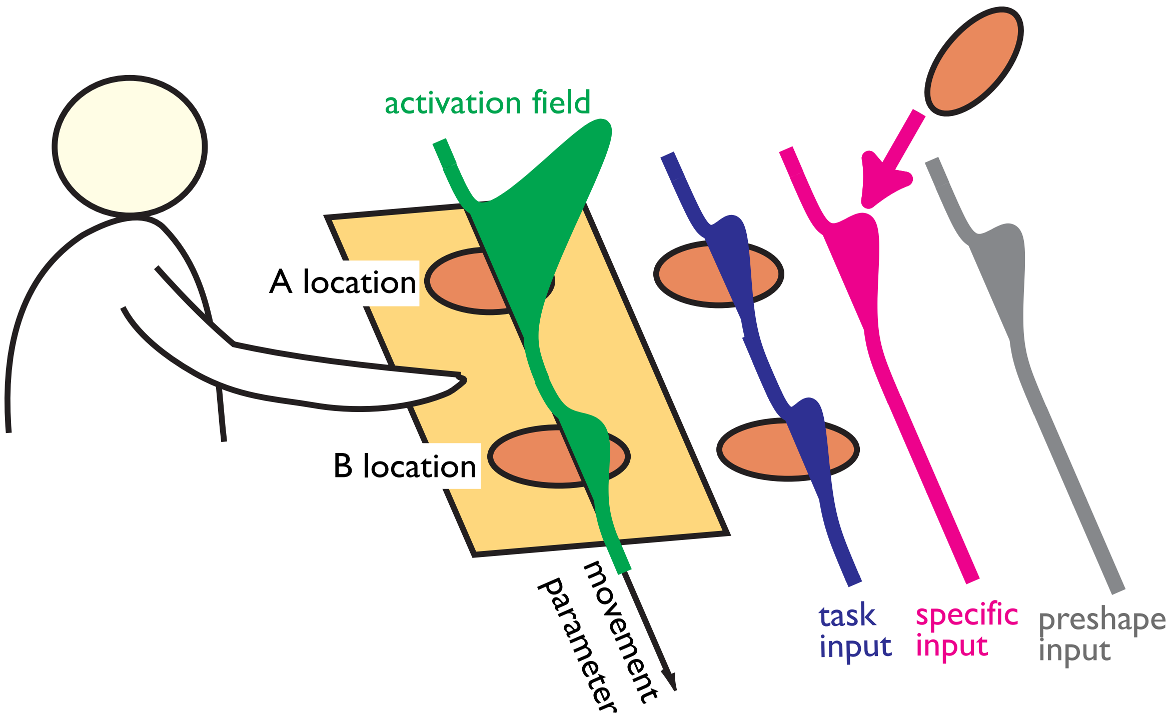
# Toyless variant of A not B task

[Smith, Thelen et al.: Psychological Review (1999)]

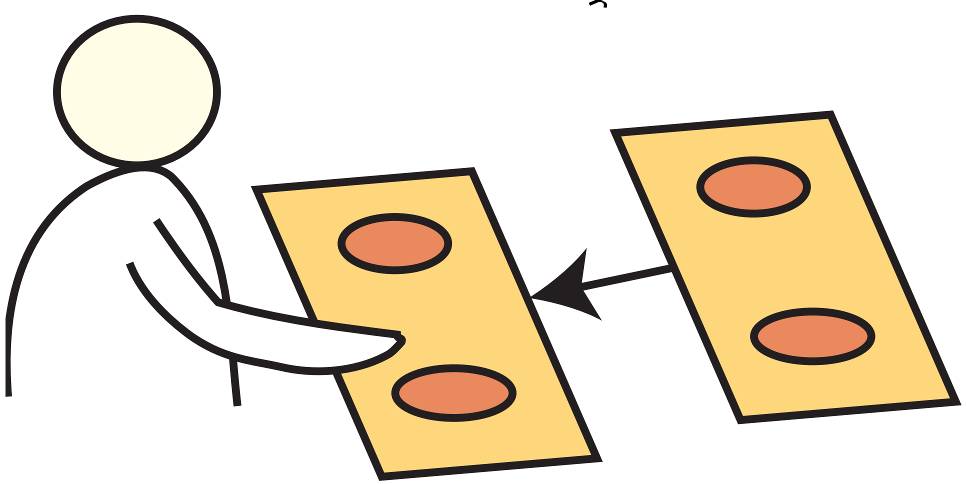
# Toyless variant of A not B task reveals that A not B is essentially a decision task!




[Smith, Thelen et al.: Psychological Review (1999)]



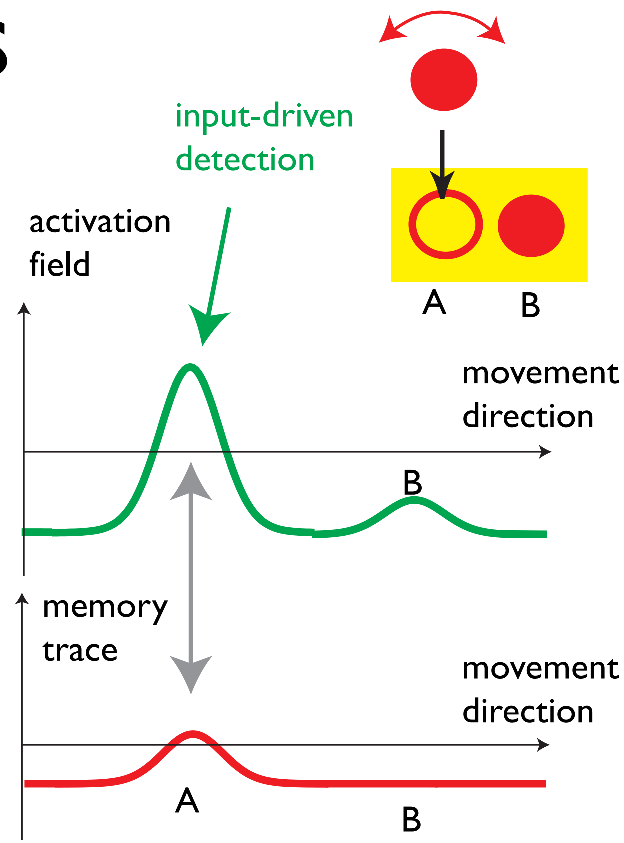

[Thelen, et al., BBS (2001)]



[Dinveva, Schöner, Dev. Science 2007]

# Instabilities

- detection: forming and initiating a movement goal
- selection: making sensori-motor decisions
- (learning: memory trace)
- boost-driven detection: initiating the action
- memory instability: old infants sustain during the delay, young



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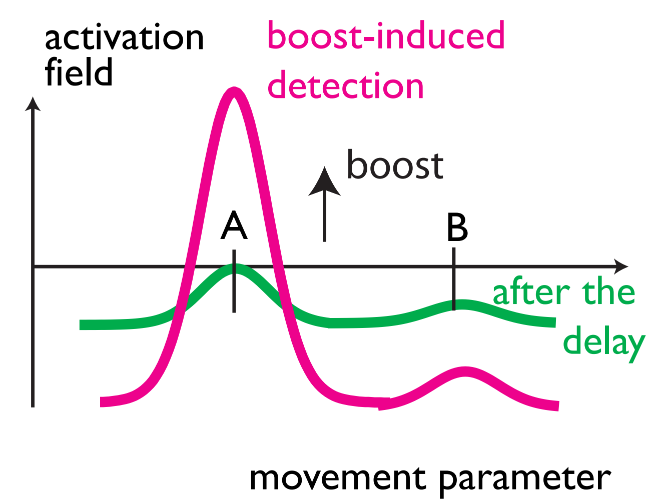

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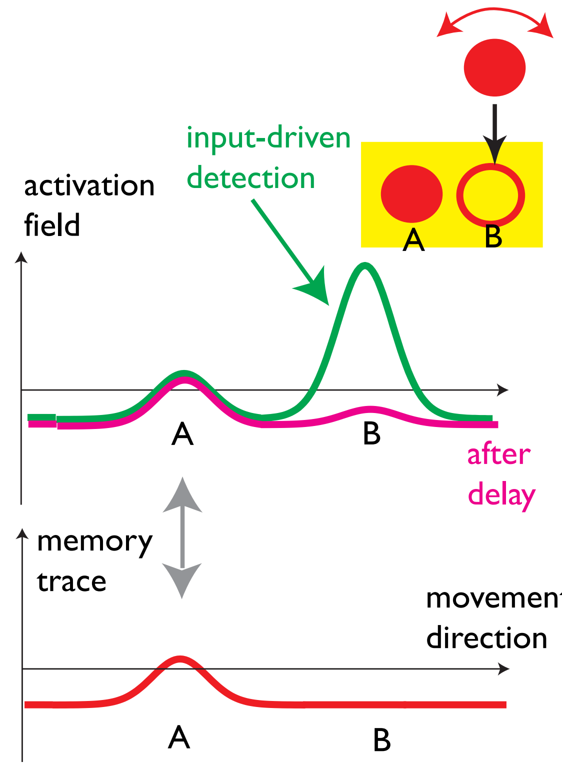
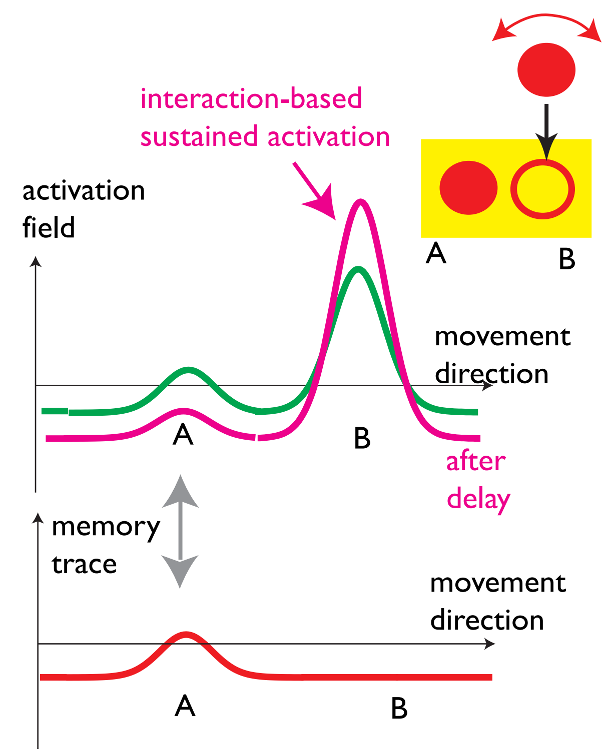
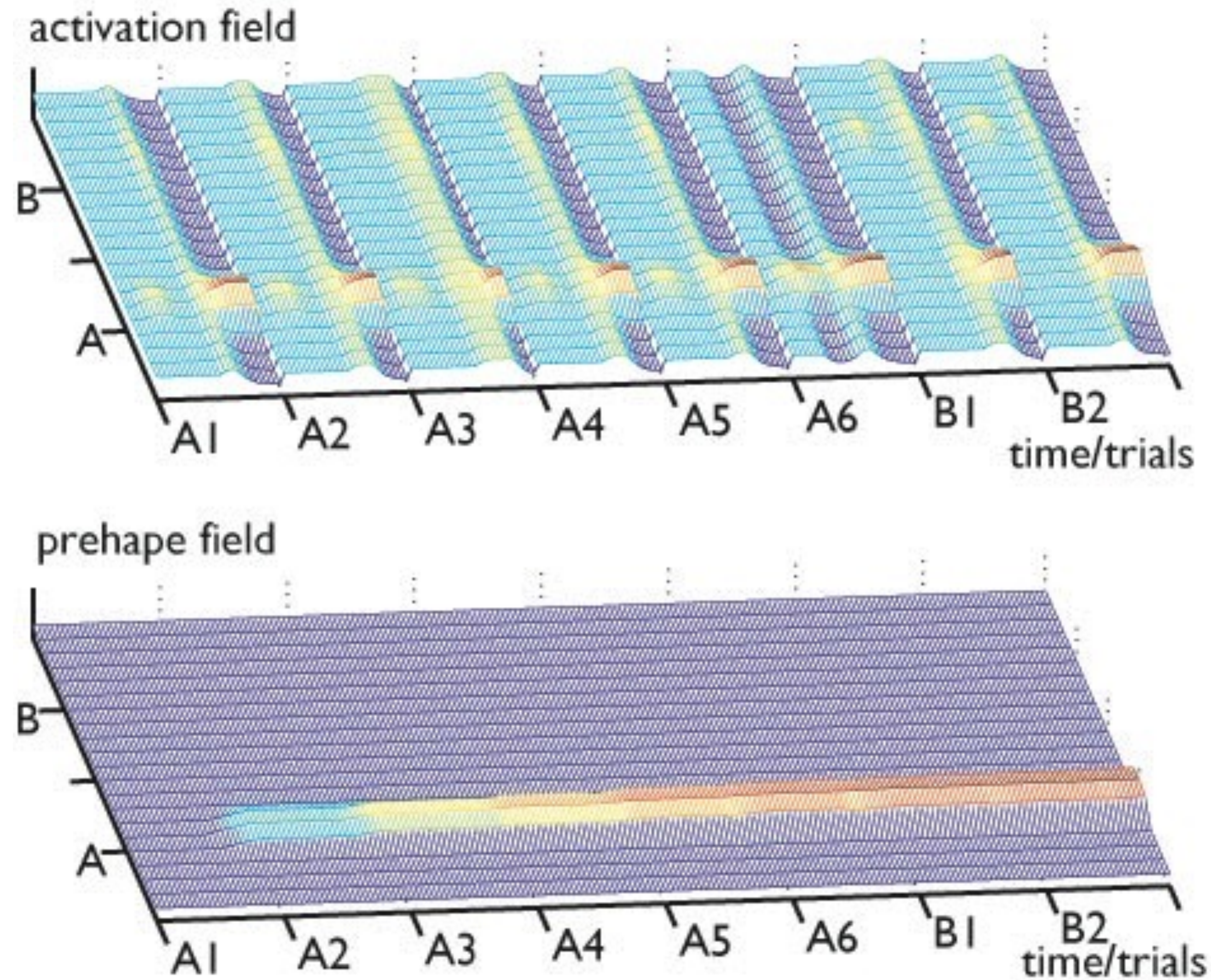
young




old



# DFT of infant perseverative reaching




[Dinveva, Schöner, Dev. Science 2007]

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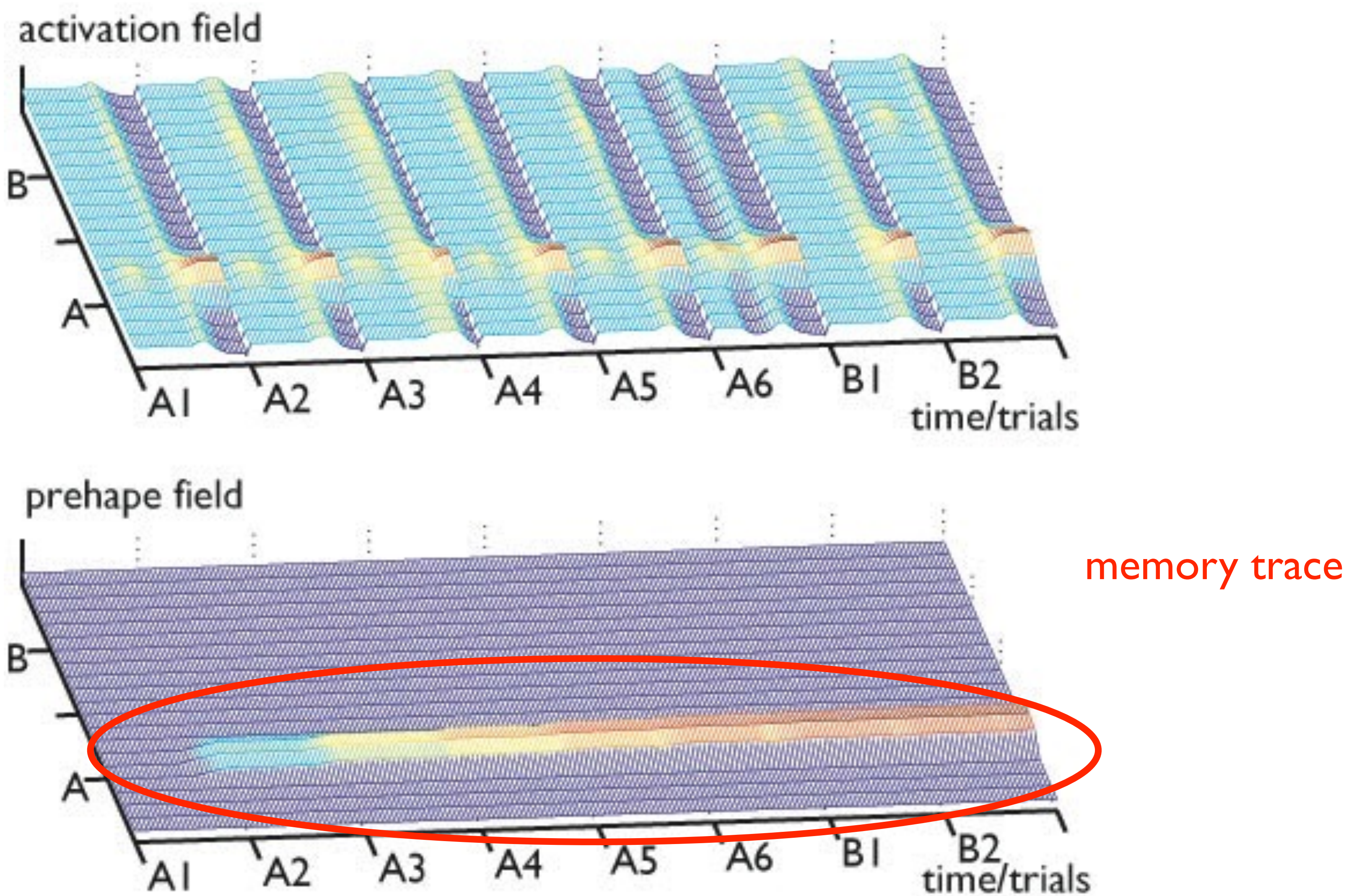


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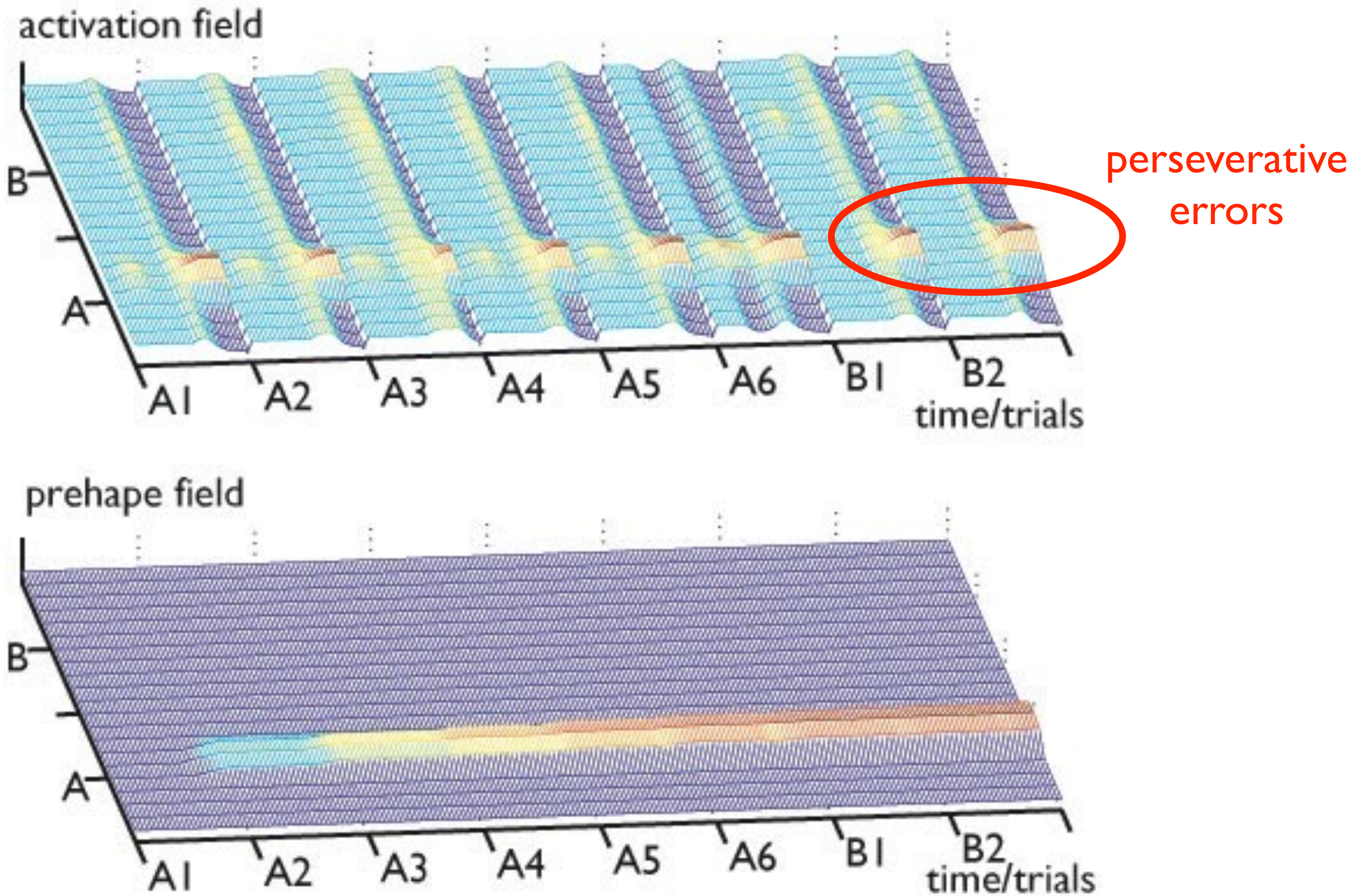
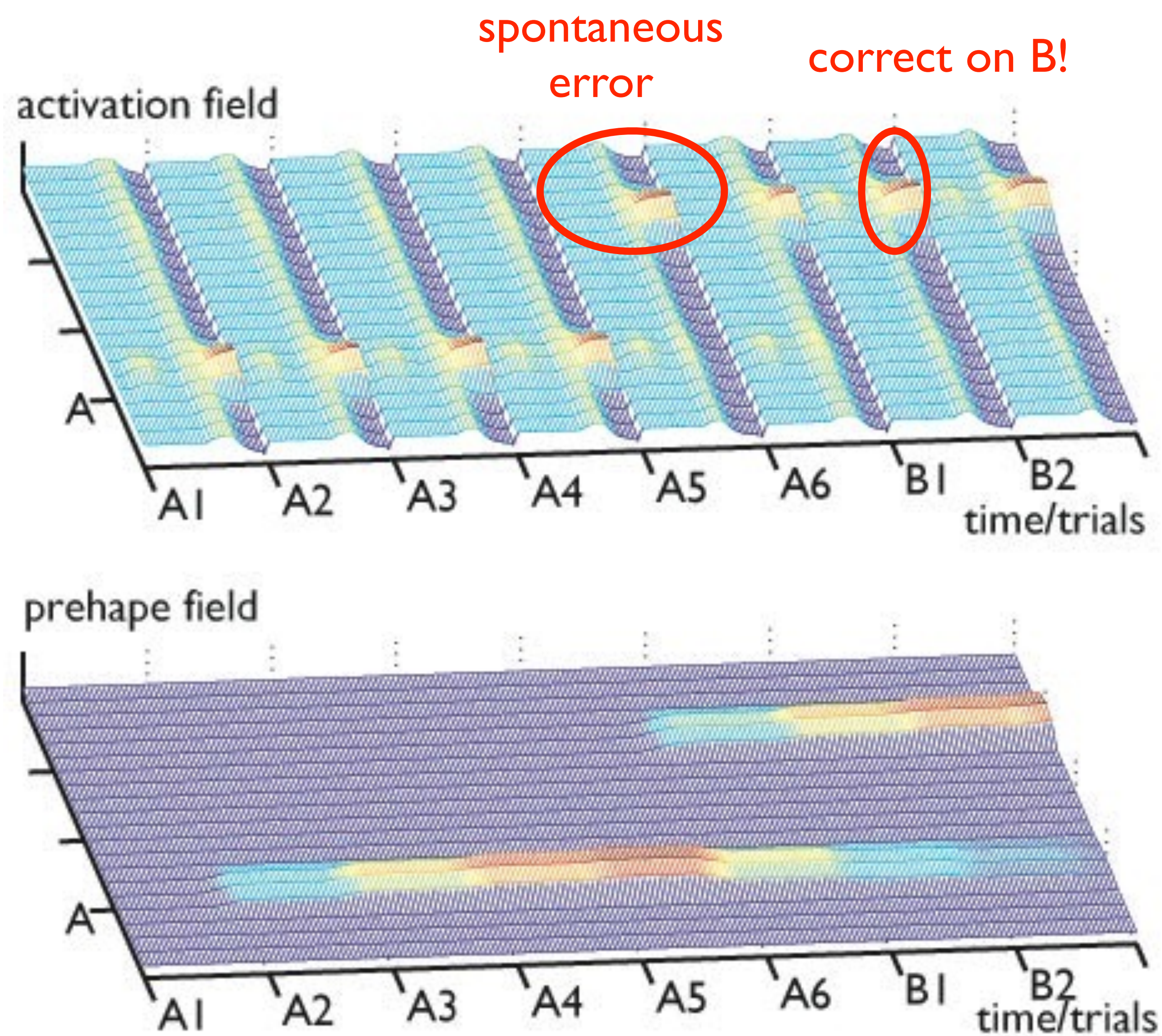



[Dinveva, Schöner, Dev. Science 2007]

# DFT of infant perseverative reaching

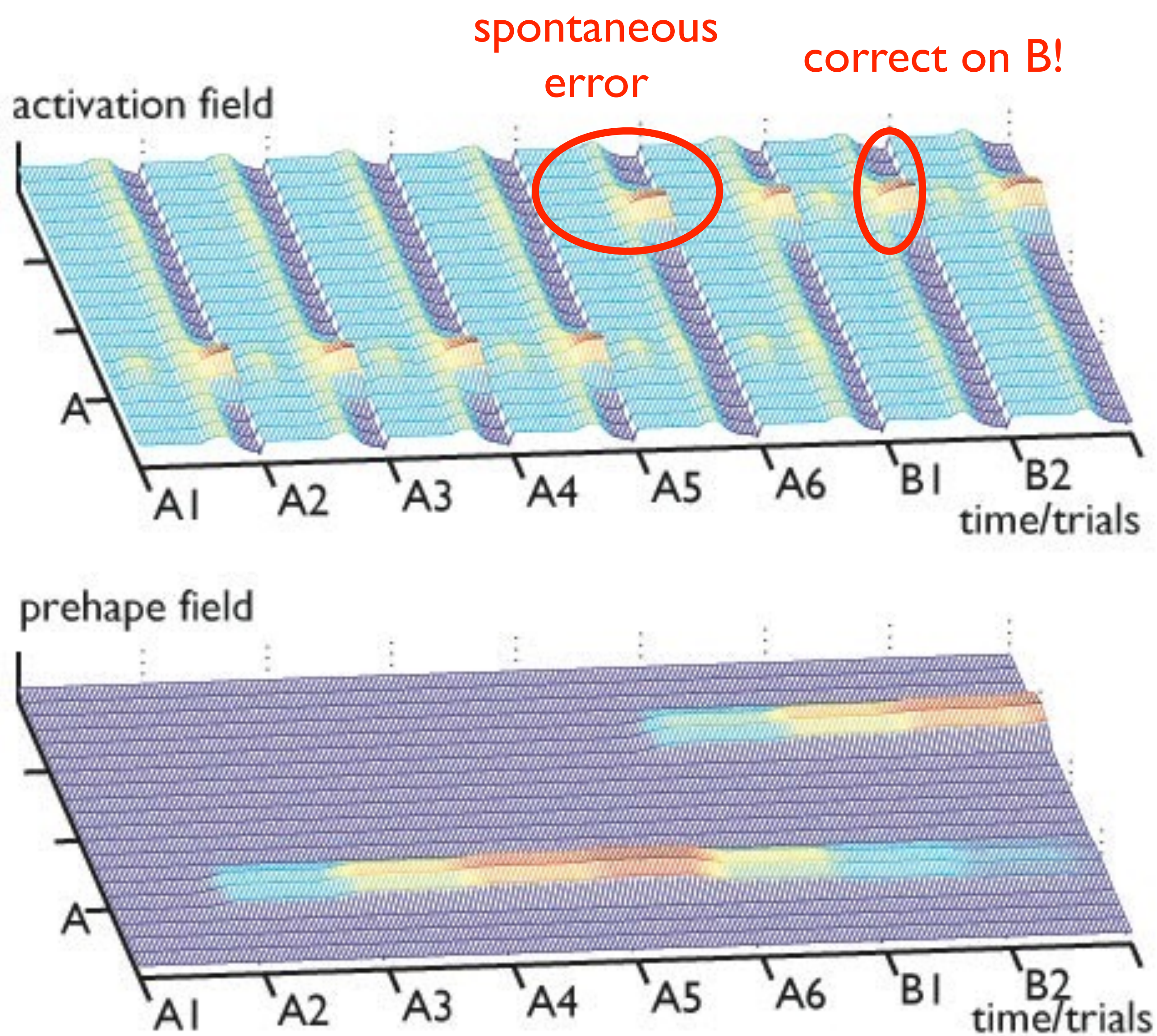
- in spotaneous errors, activation arises at B on an A trial
- which leads to correct reaching on B trial




[Dinveva, Schöner, Dev. Science 2007]

# DFT of infant perseverative reaching

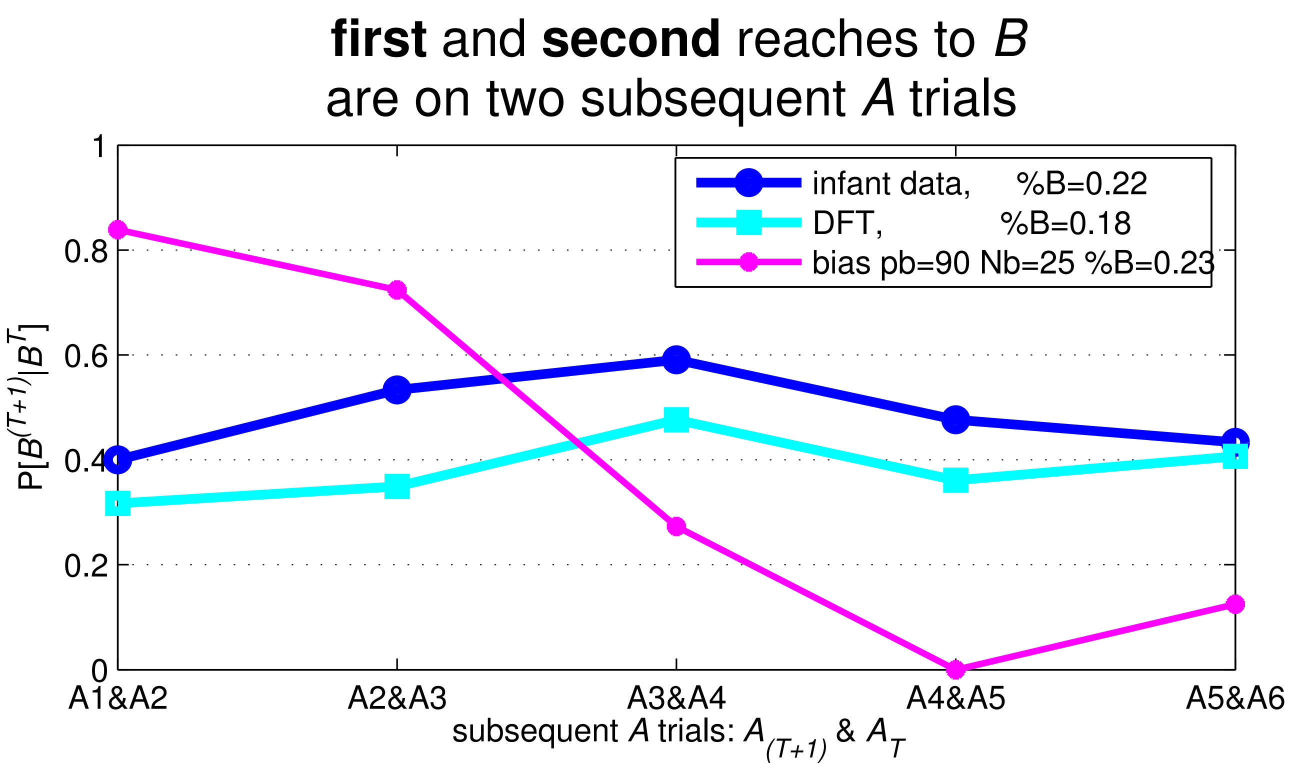
- that is because reaches to B on A trials leave memory trace at B




[Dinveva, Schöner, Dev. Science 2007]

# DFT of infant perseverative reaching

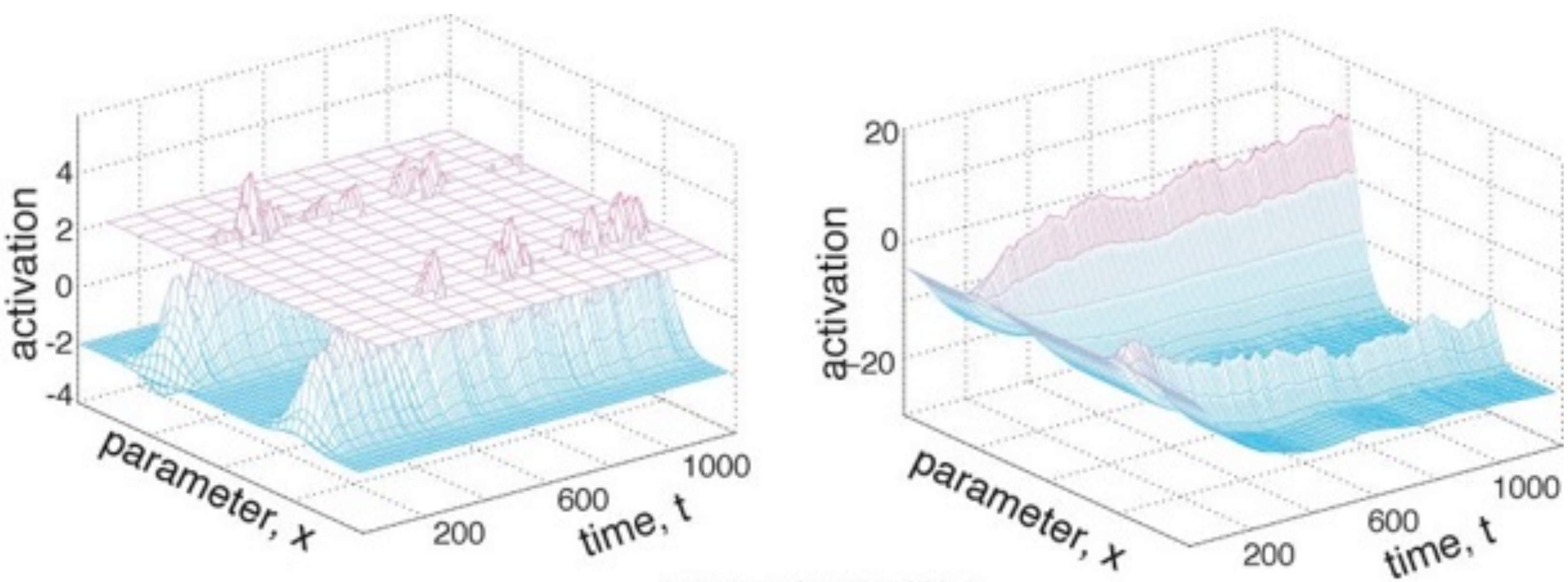
- spontaneous errors promote spontaneous errors




[Dinveva, Schöner, Dev. Science 2007]

# DFT is a neural process model

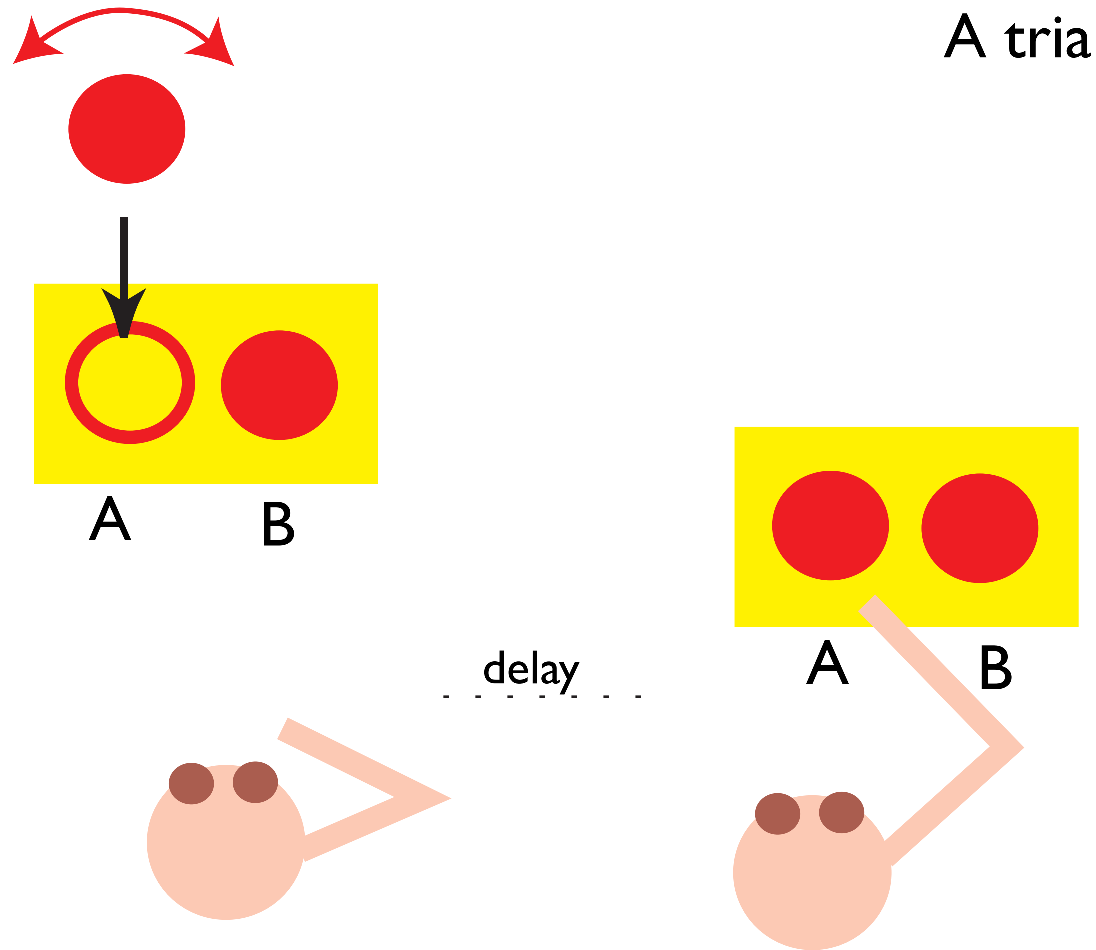
- that makes the decisions in each individual trial, by amplifying small differences into a macroscopic stable state
- and that's how decisions leave traces, have consequences




[Wilimzig, Schöner, 2006]

# summary: instabilities

- detection: forming and initiating a movement goal
- selection: making sensori-motor decisions
- boost-driven detection: initiating the the action
- learning: memory trace
- working memory: sustaining a delay




Toyless version of A not B
(Smith, Thelen, et al., 1999)

# Conclusions

- action, perception, and embodied cognition takes place in continuous spaces. peaks = units of representation are attractors of the neural dynamics
- neural fields link neural representations to these continua
- stable activation peaks are the units of neural representation
- peaks arise and disappear through instabilities through which elementary cognitive functions (e.g. detection, selection, memory) emerge

# The conceptual framework of DFT