Summary

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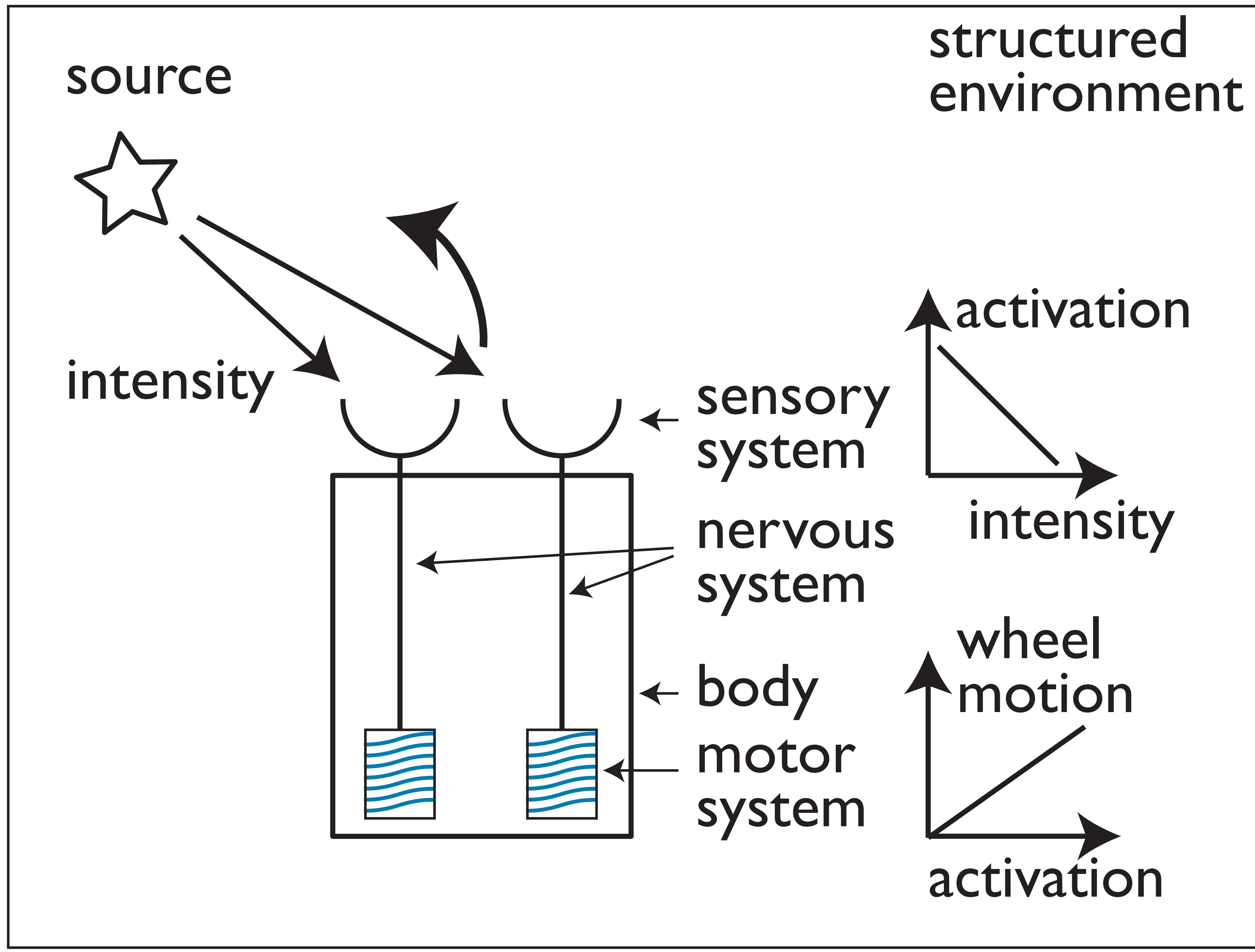
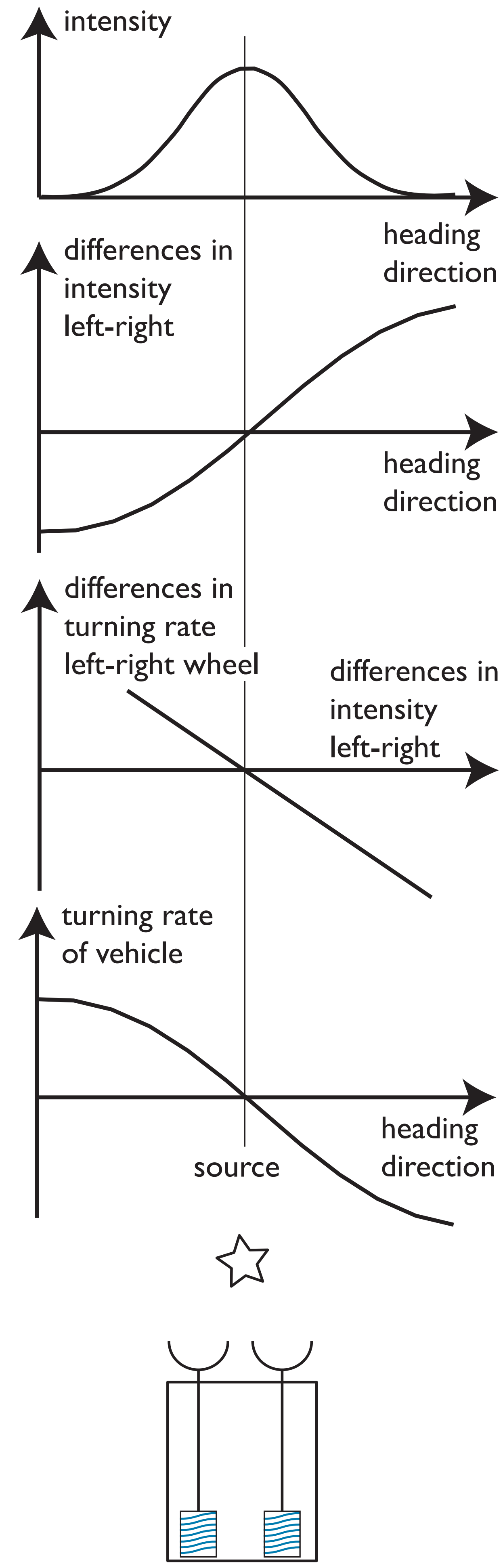
Five things needed to generate behavior

- sensors
- motors
- linked by a nervous system
- linked physically by a body
- an appropriately structured environment



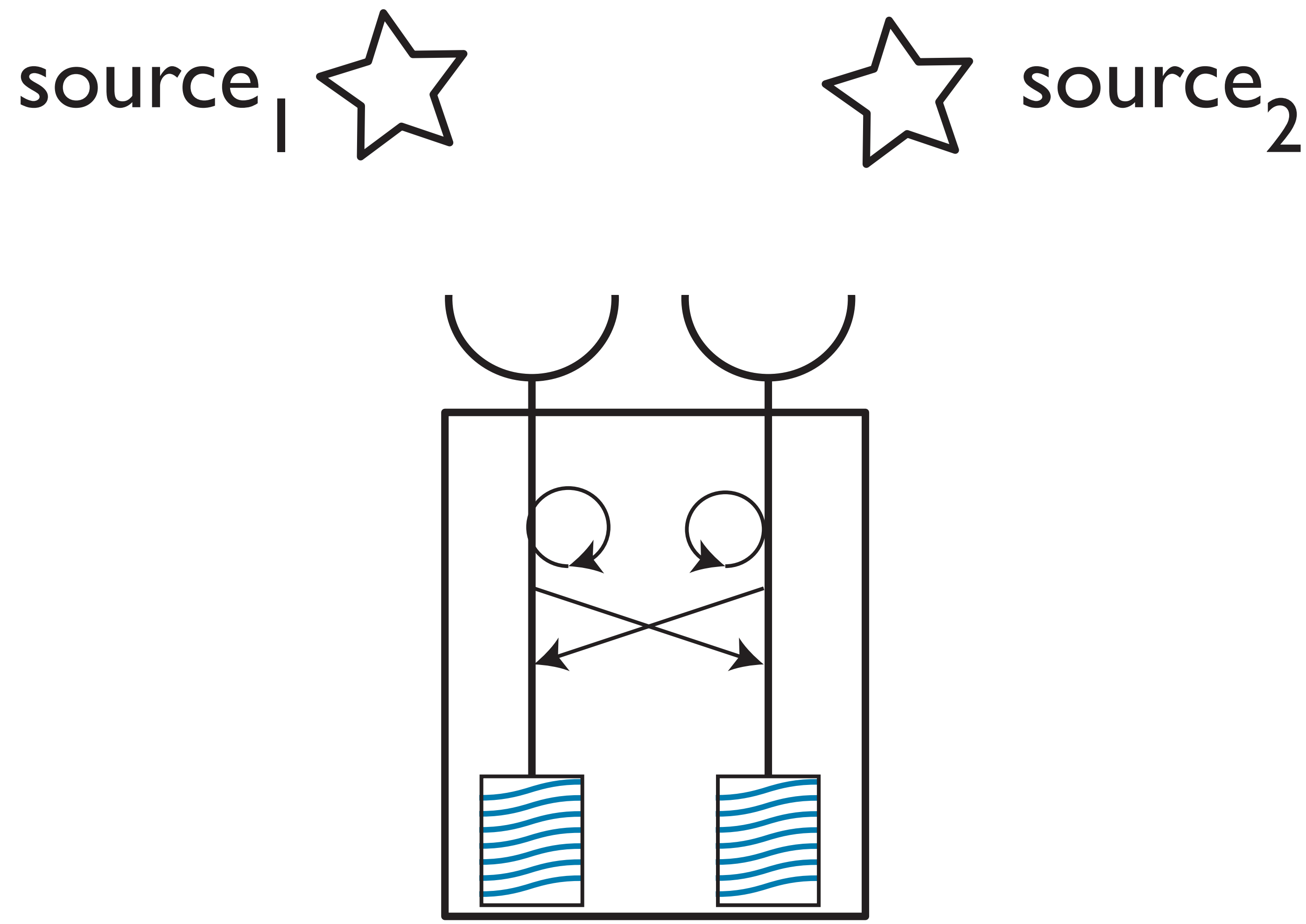
Emergent behavior: this is a dynamics

- feedforward nervous system
- + closed loop through environment
- => (behavioral) dynamics



Internal loops generate neural dynamics

- that generate cognition: internal decisions…
- bifurcations => different cognitive regimes

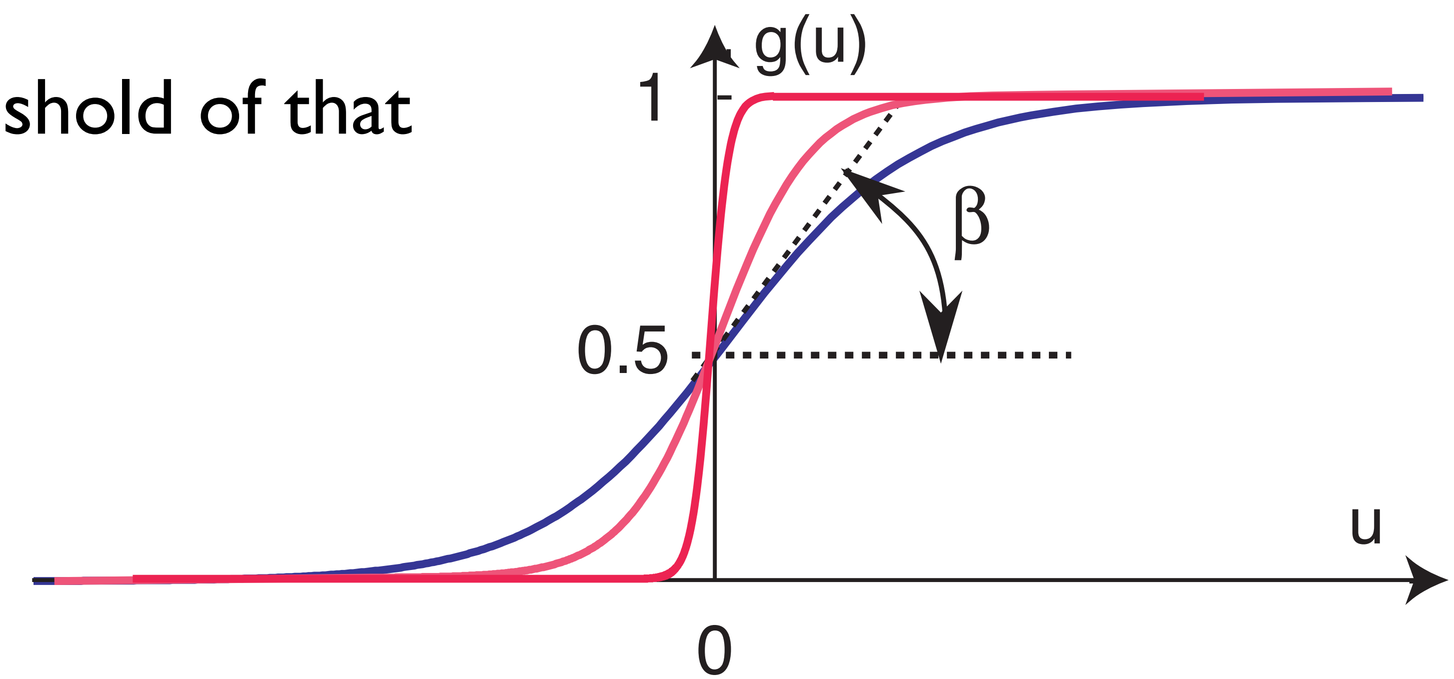


Activation

- neural state variable activation
  - linked to membrane potential of neurons in some accounts
  - linked to spiking rate in our account
  - through: population activation... (later)

Activation

- activation as a real number, abstracting from biophysical details
  - low levels of activation: not transmitted to other systems (e.g., to motor systems)
  - high levels of activation: transmitted to other systems
  - as described by sigmoidal threshold function
  - zero activation defined as threshold of that function

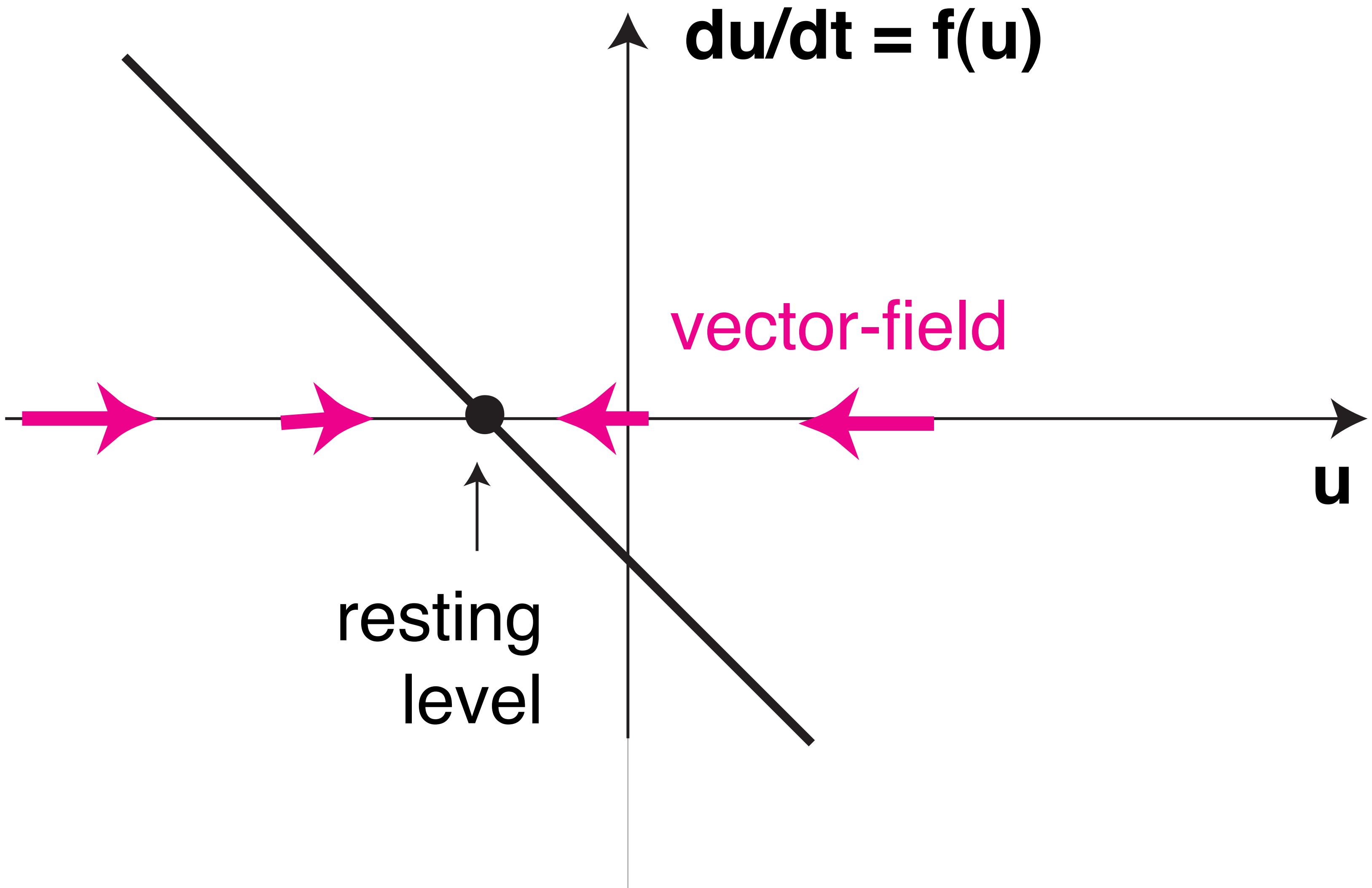


Activation dynamics

- activation evolves in continuous time
  - no evidence for a discretization of time, for spike timing to matter for behavior

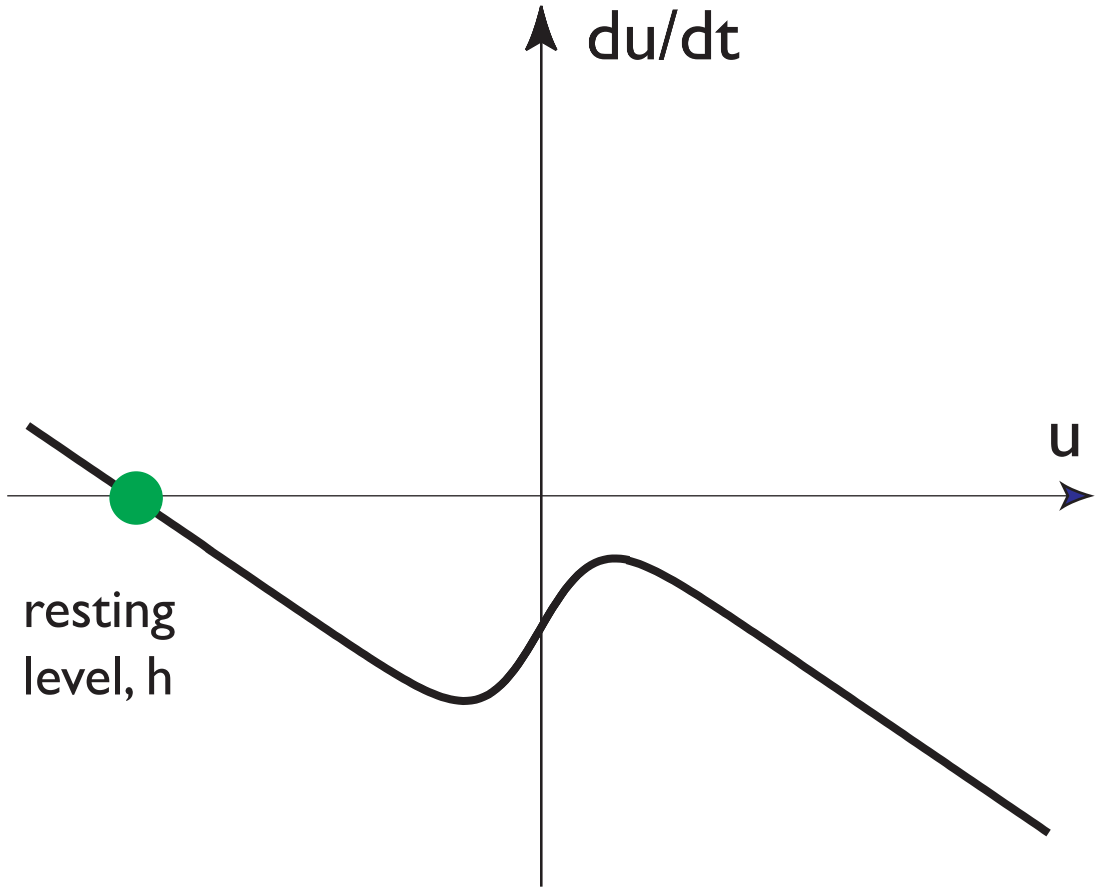
Neural dynamics

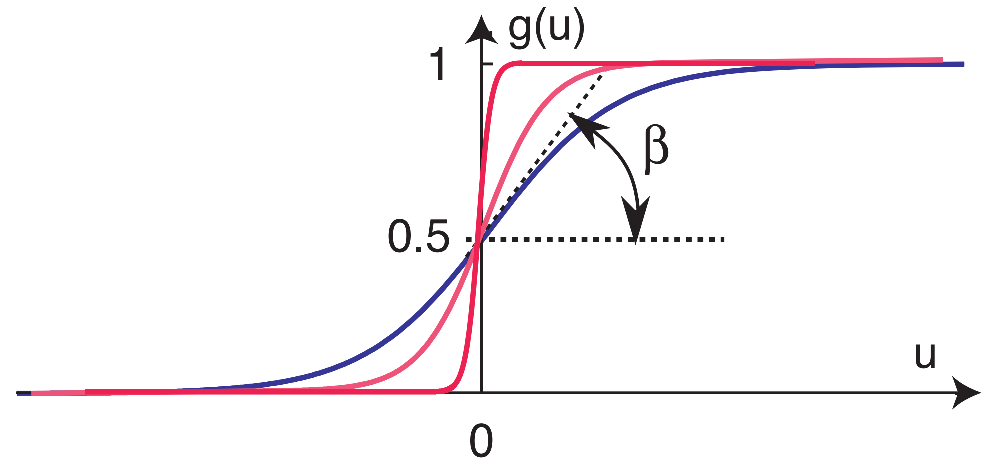
- stationary state=fixed point= constant solution
- stable fixed point: nearby solutions converge to the fixed point=attractor



$$\frac{du(t)}{dt} = \dot{u}(t) = -u(t) + h \qquad (h < 0)$$

Neuronal dynamics with self-excitation

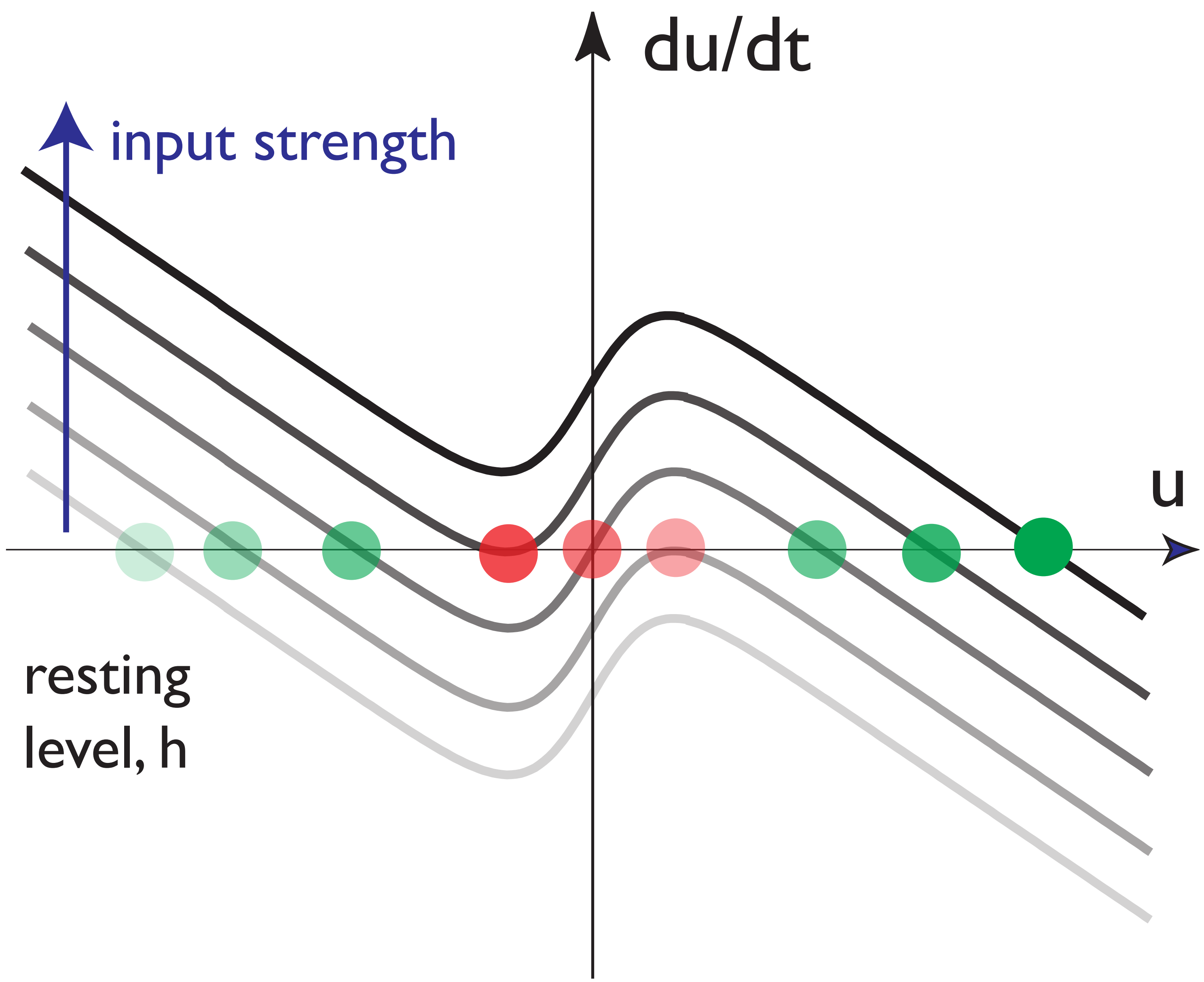




$$\tau \dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

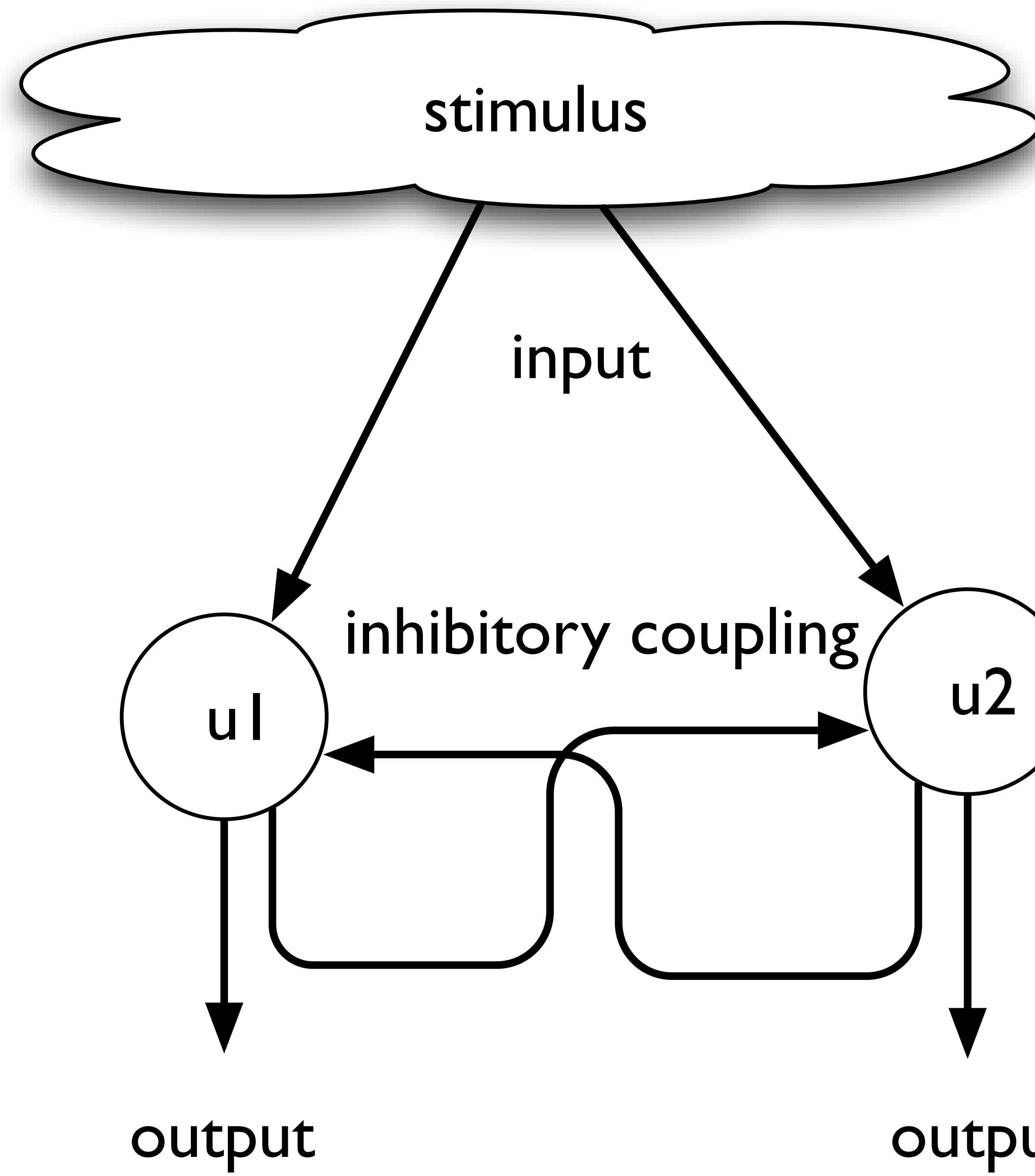
Neuronal dynamics with self-excitation

- stimulus input



$$\tau\dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

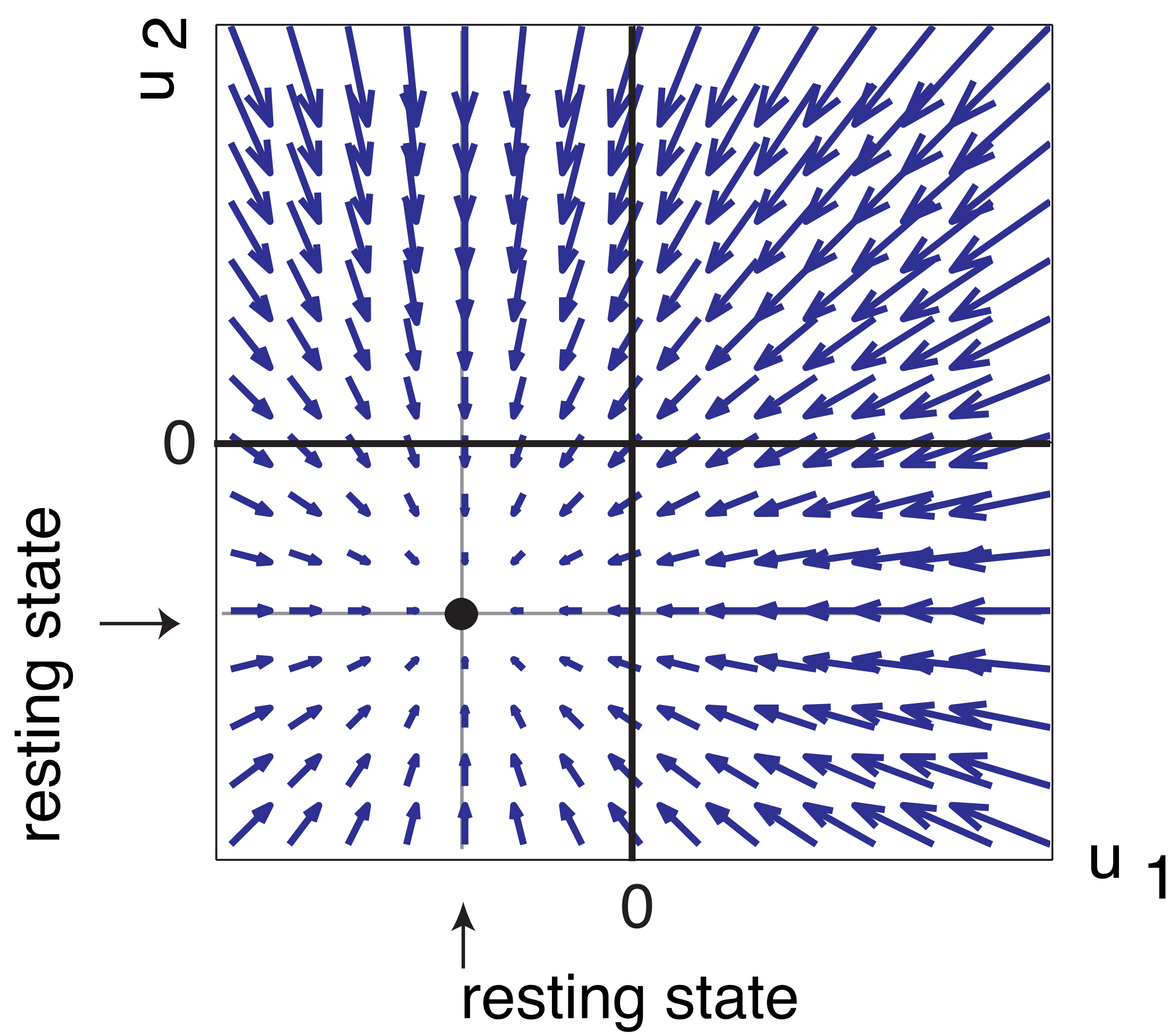
Neuronal dynamics with competition



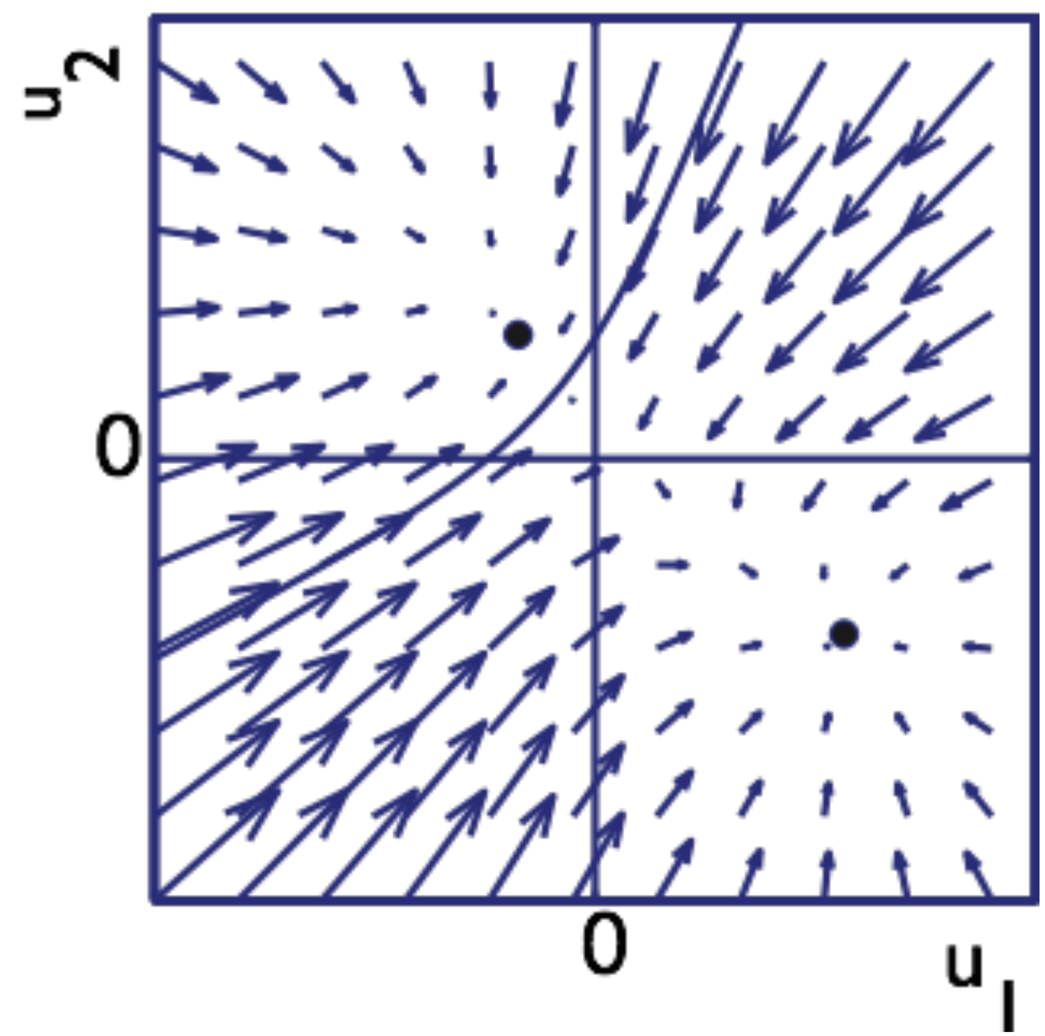
$$\tau \dot{u}_1(t) = -u_1(t) + h - \sigma(u_2(t)) + S_1$$
$$\tau \dot{u}_2(t) = -u_2(t) + h - \sigma(u_1(t)) + S_2$$

Neuronal dynamics with competition =>biased competition

before input is presented

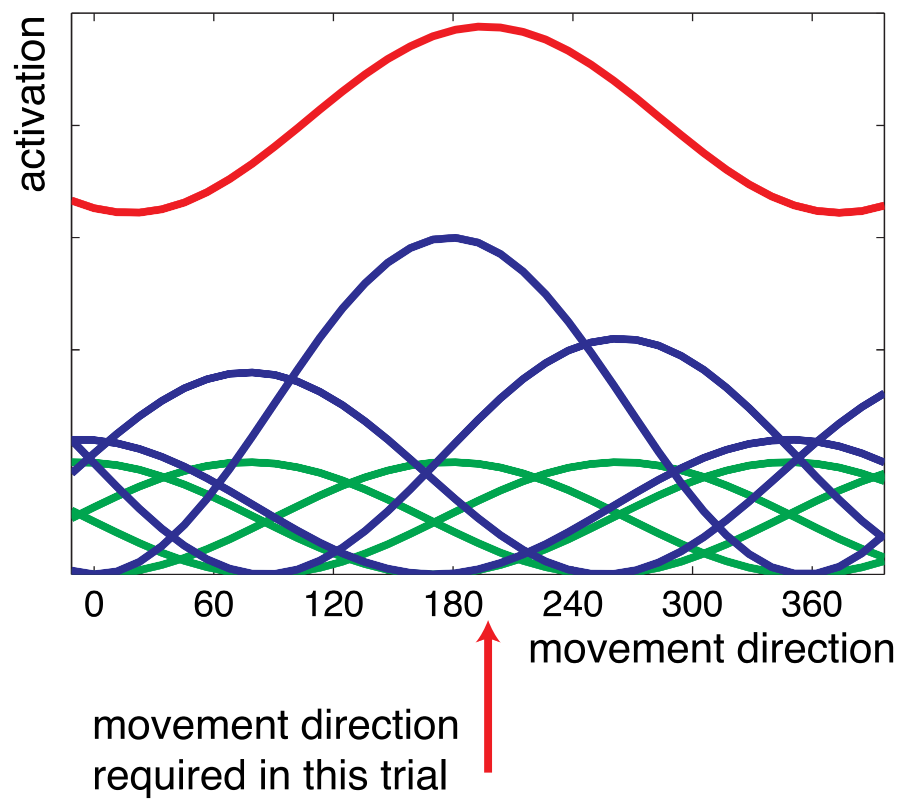


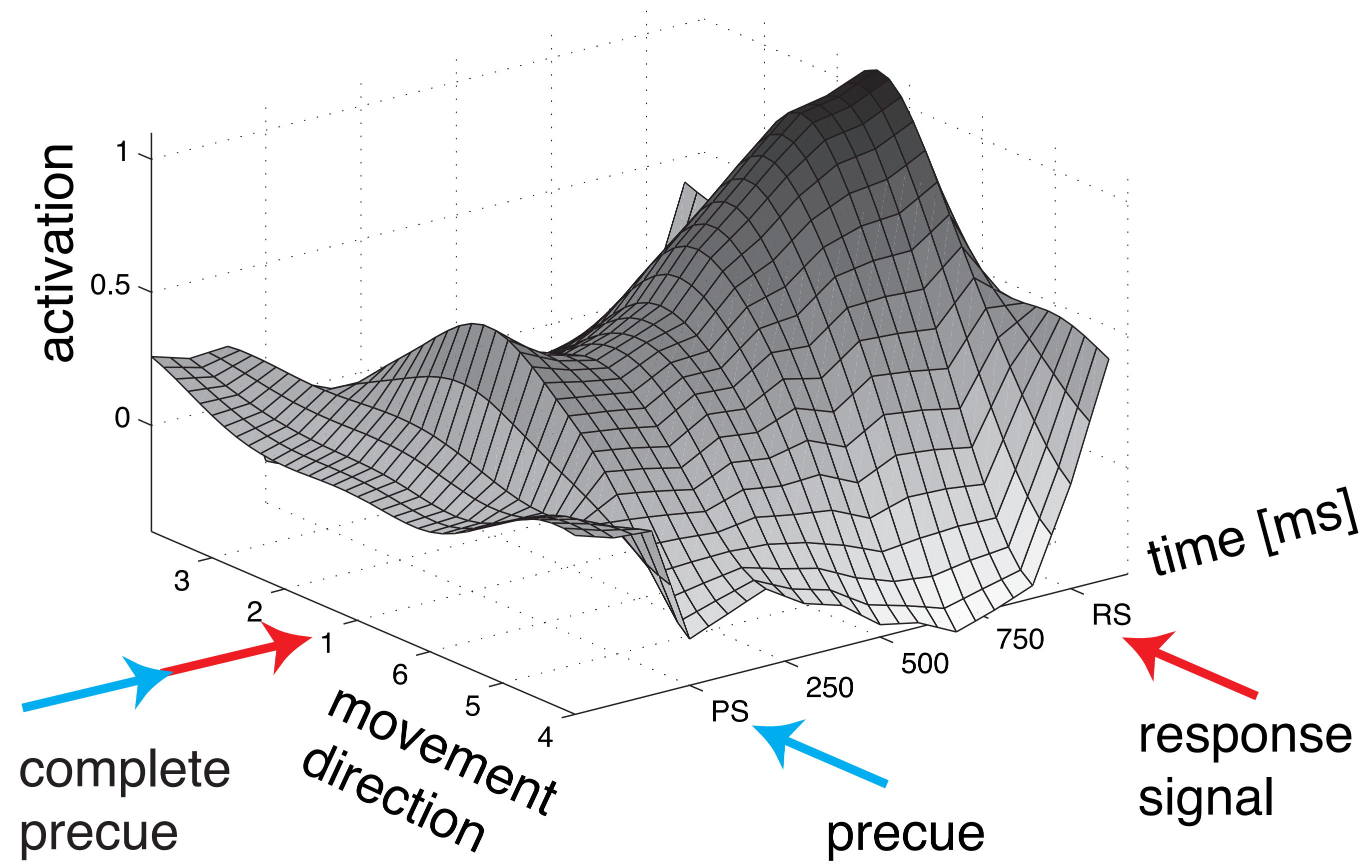
after input is presented



Distribution of Population Activation (DPA)

Distribution of population activation = $\sum_{\text{neurons}}$ tuning curve * current firing rate

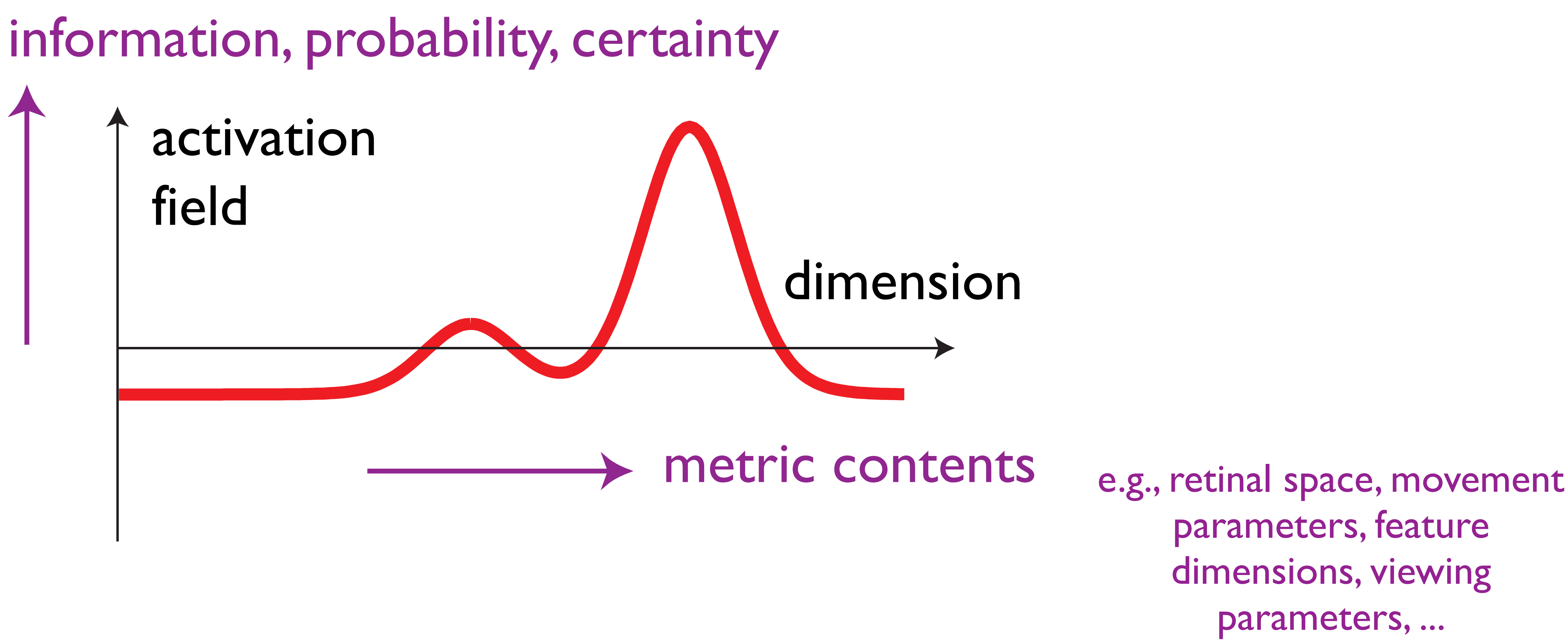




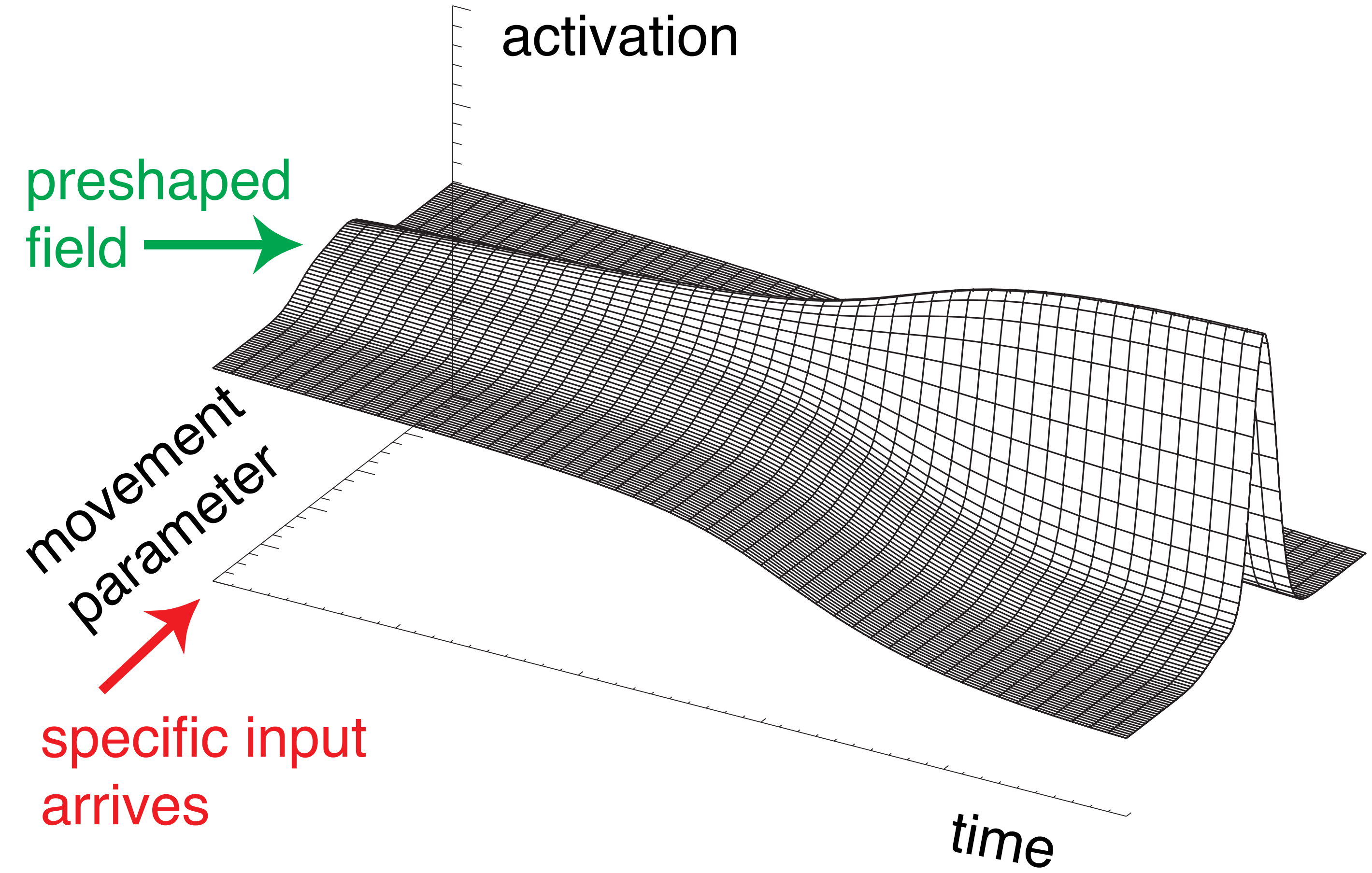
[Bastian, Riehle, Schöner, 2003]

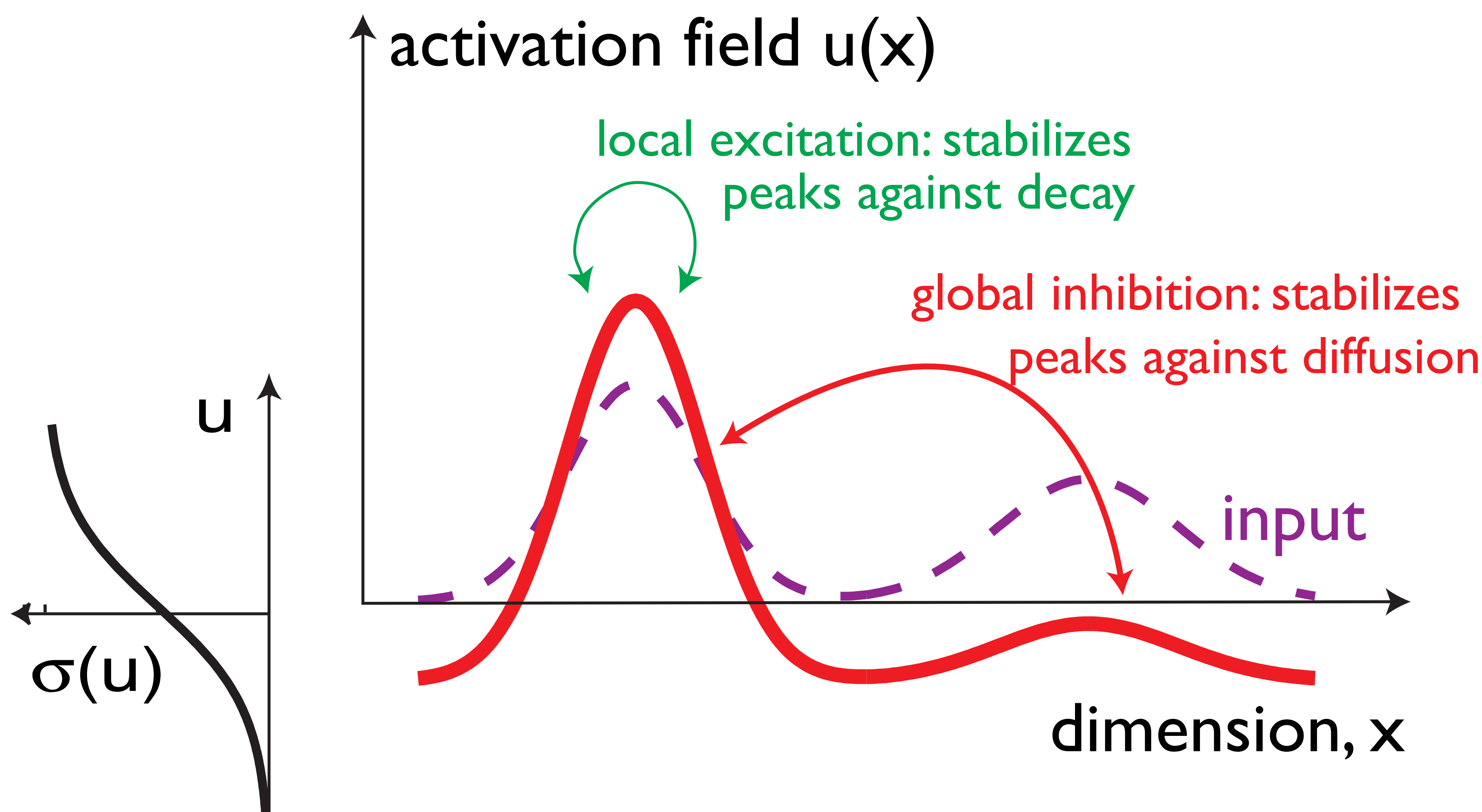
Dynamical Field Theory: space

- fields: continuous activation variables defined over continuous spaces



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

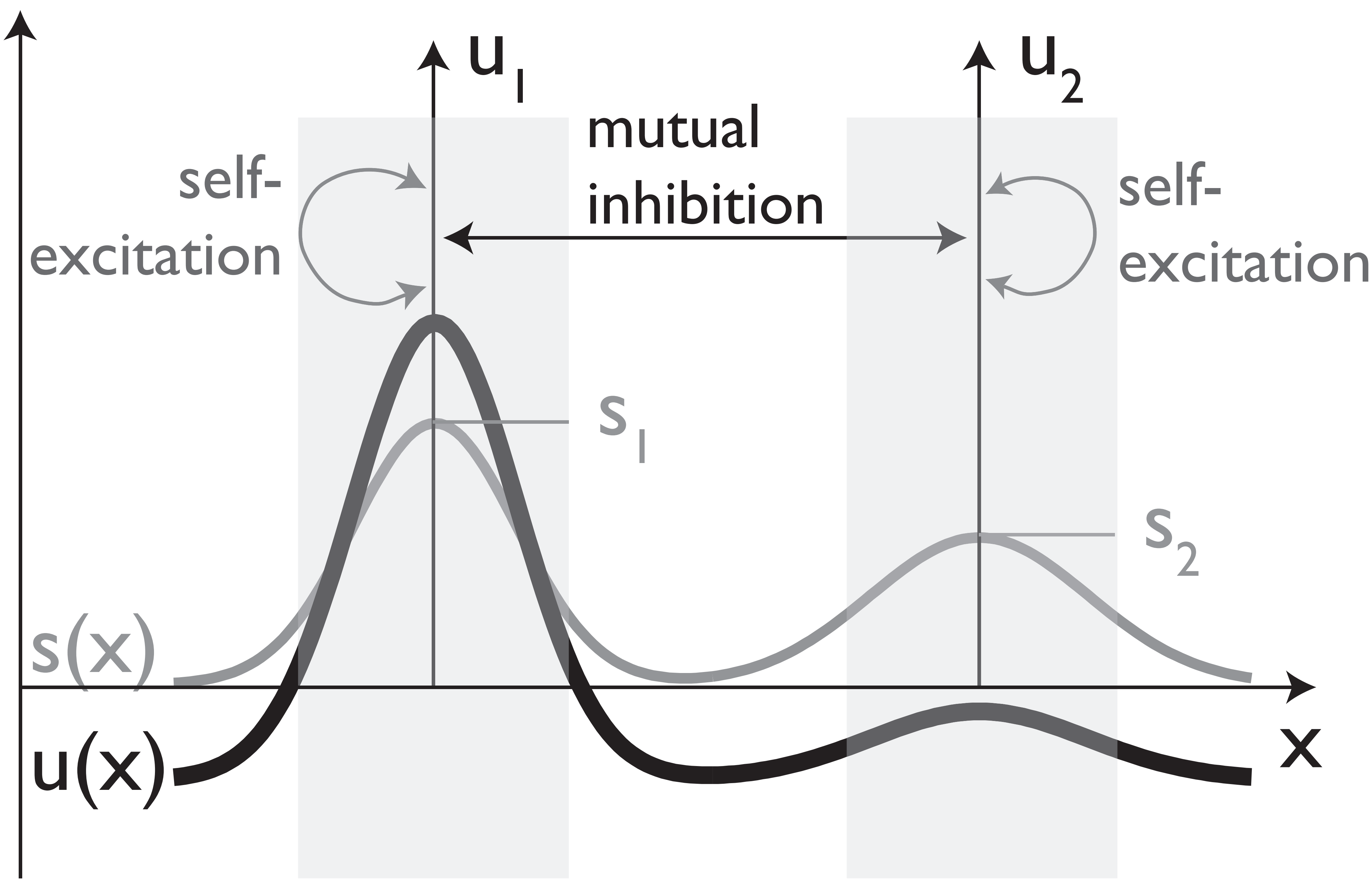
- time scale is τ
- resting level is $h < 0$
- input is $S(x,t)$
- interaction kernel is

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

- sigmoidal nonlinearity is

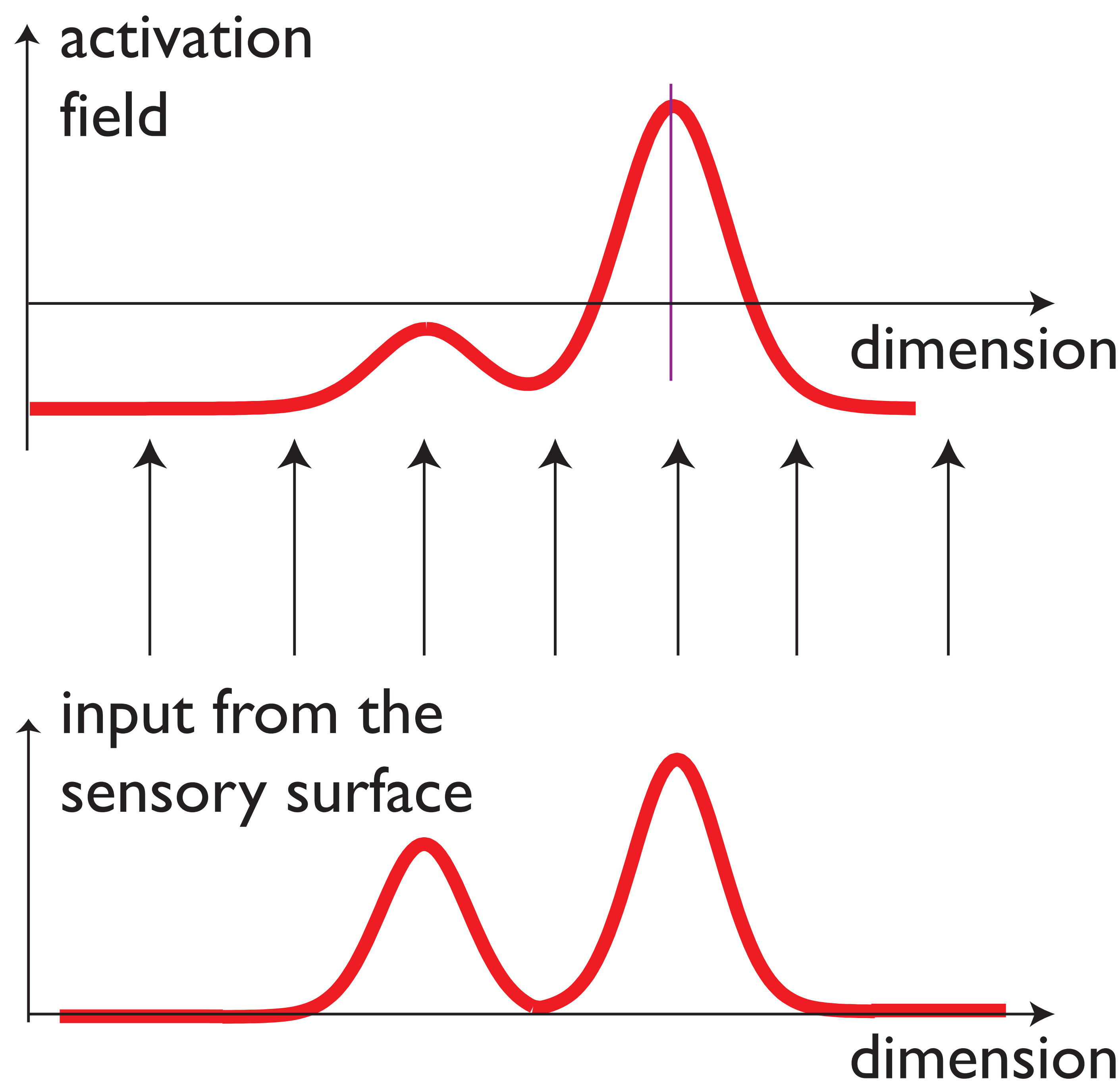
$$\sigma(u) = \frac{1}{1+\exp[-\beta(u-u_0)]}$$

Relationship to the dynamics of discrete activation variables

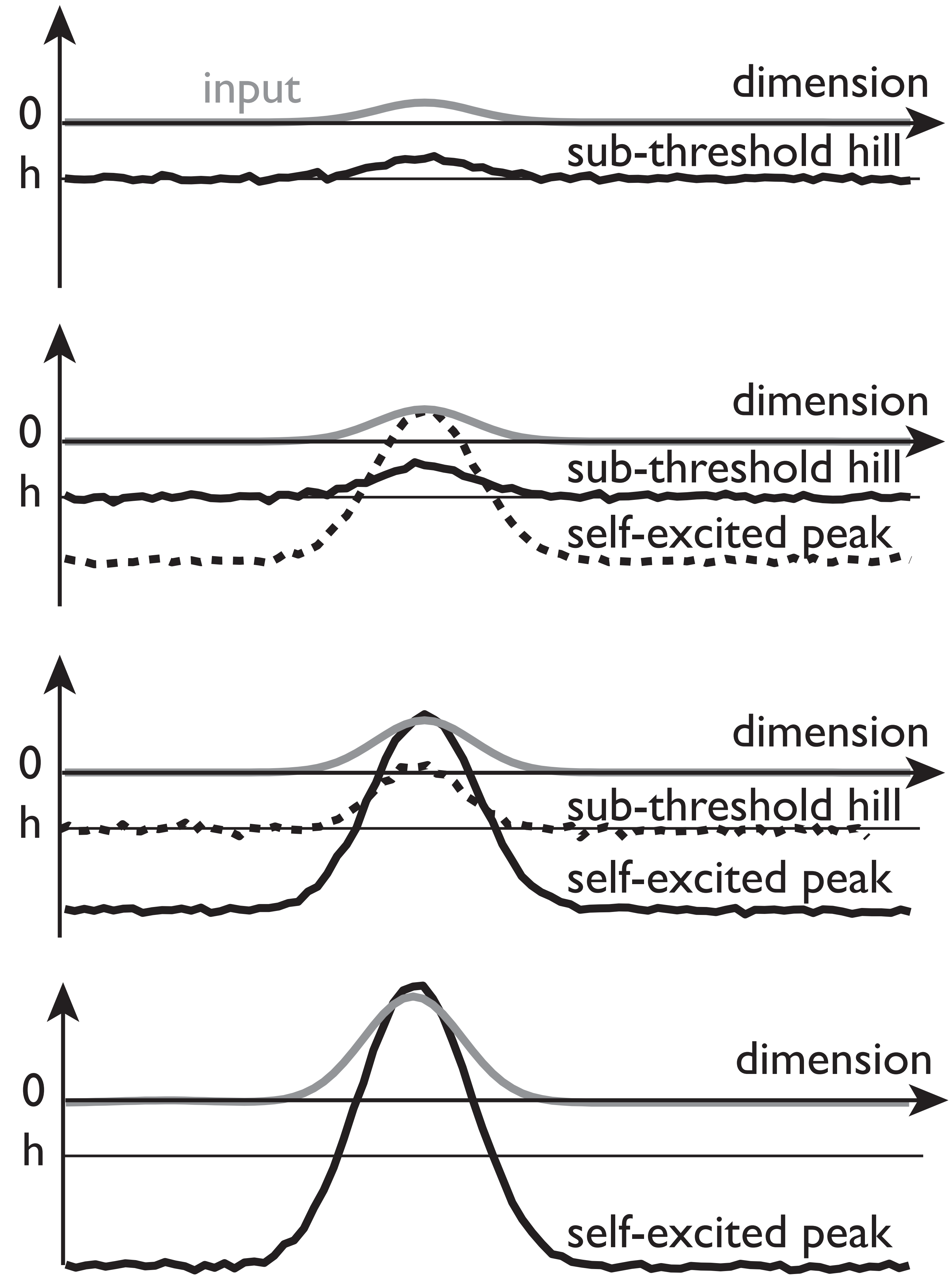


How does a field come to stand for "its" dimension?

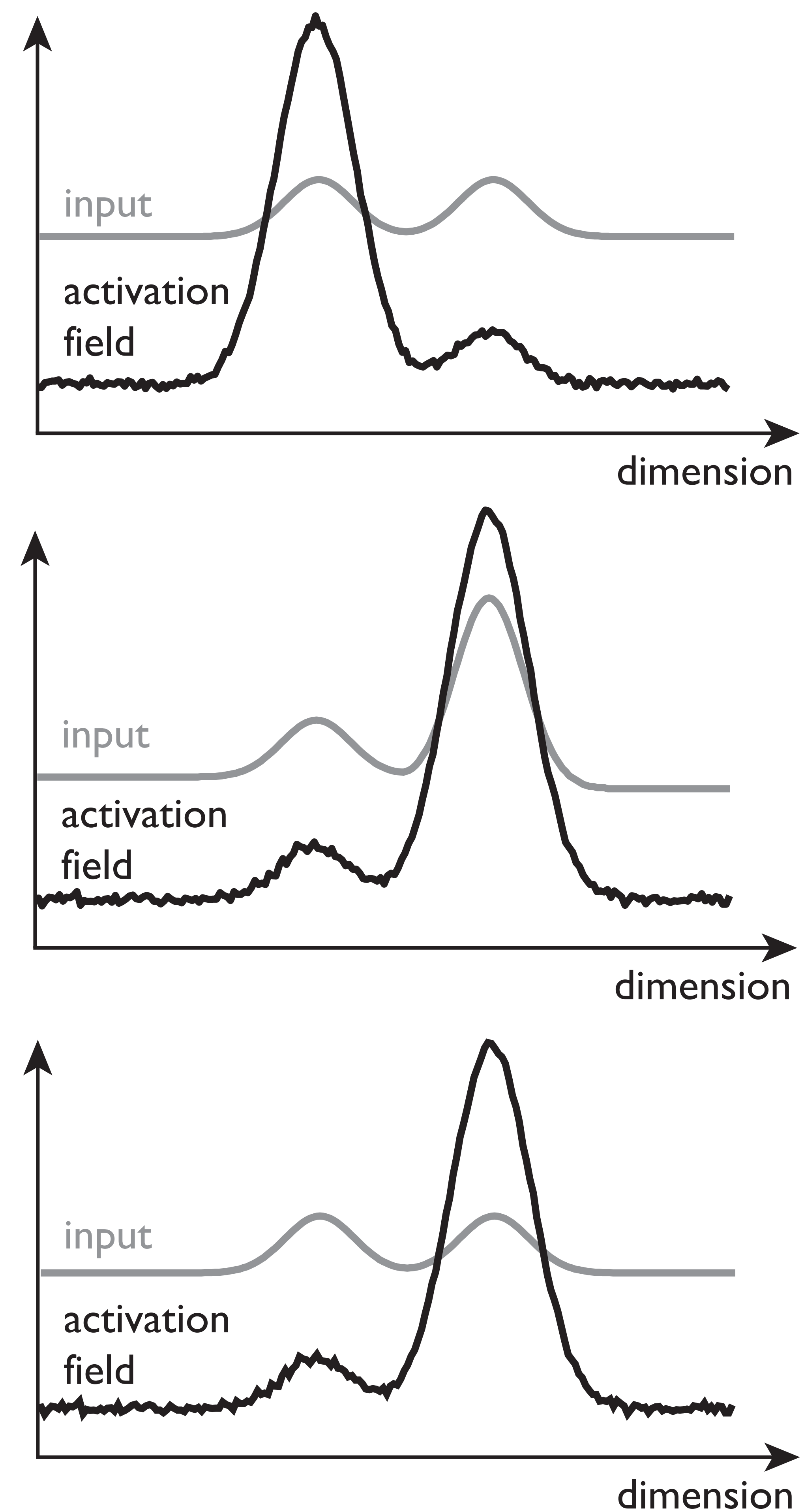
- => by its input/output connectivity…



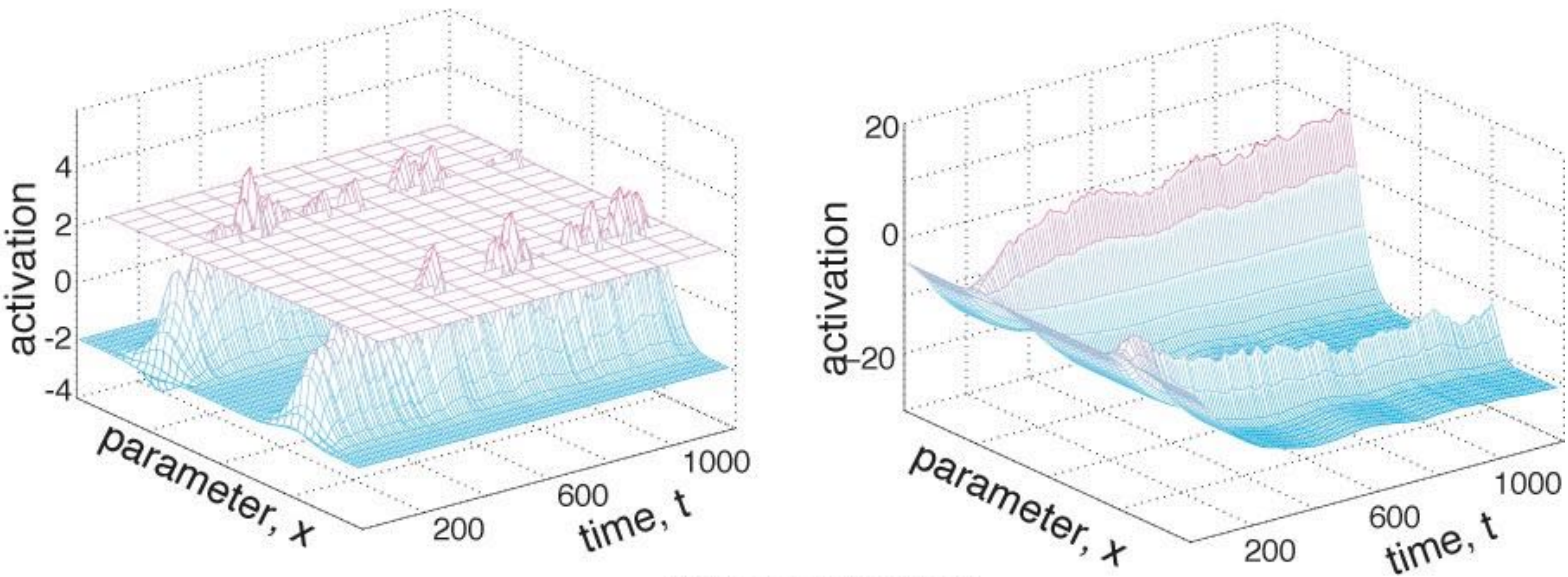
Detection instability



selection instability



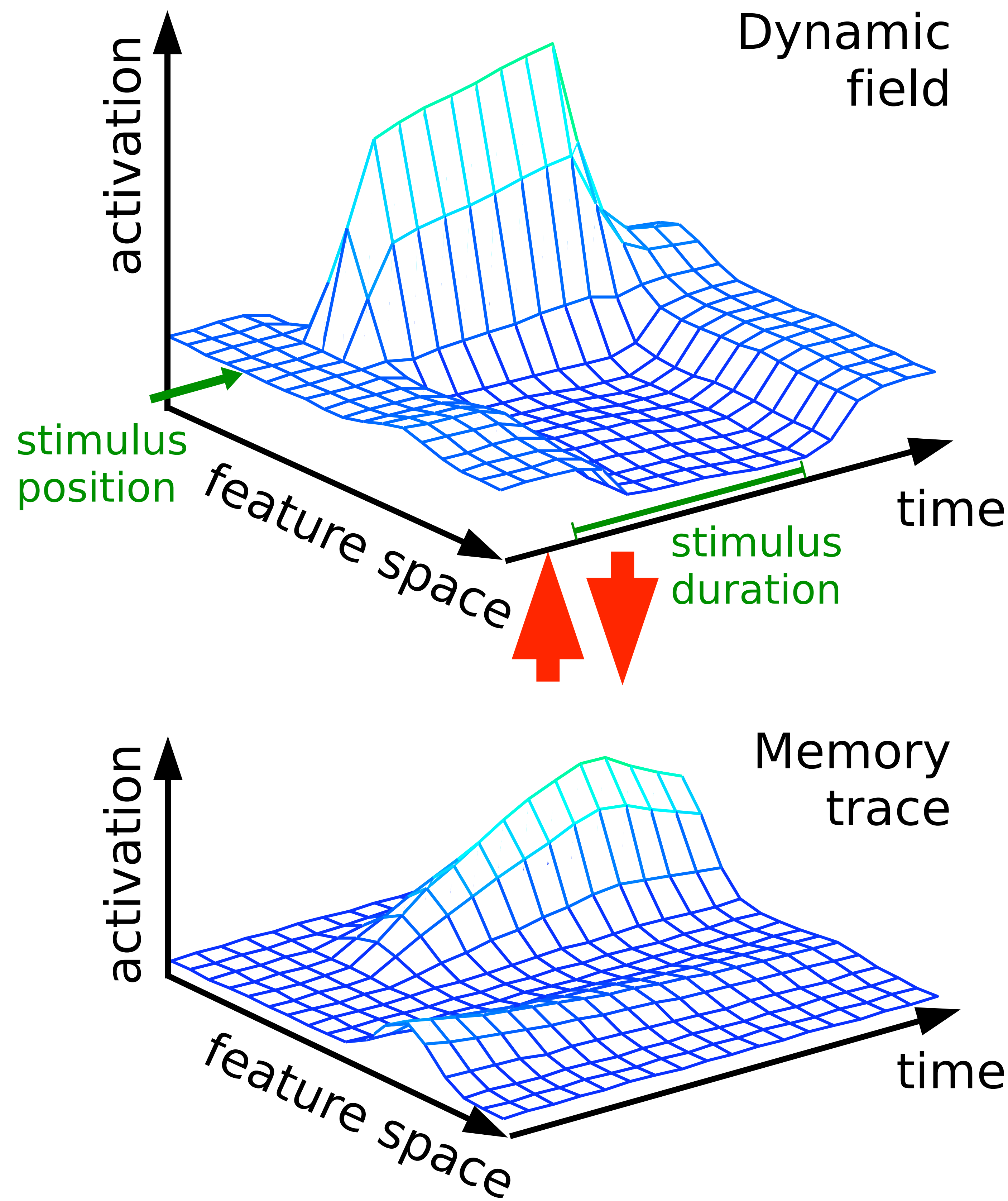
Stabilizing selection decisions



[Wilimzig, Schöner, 2006]

The memory trace

- activation leaves a trace that may influence the activation dynamics later…
- a simplest form of learning
- relevant in DFT because the detection instability may amplify the slightly inhomogeneous activation patterns induced by the memory trace into peaks of activation



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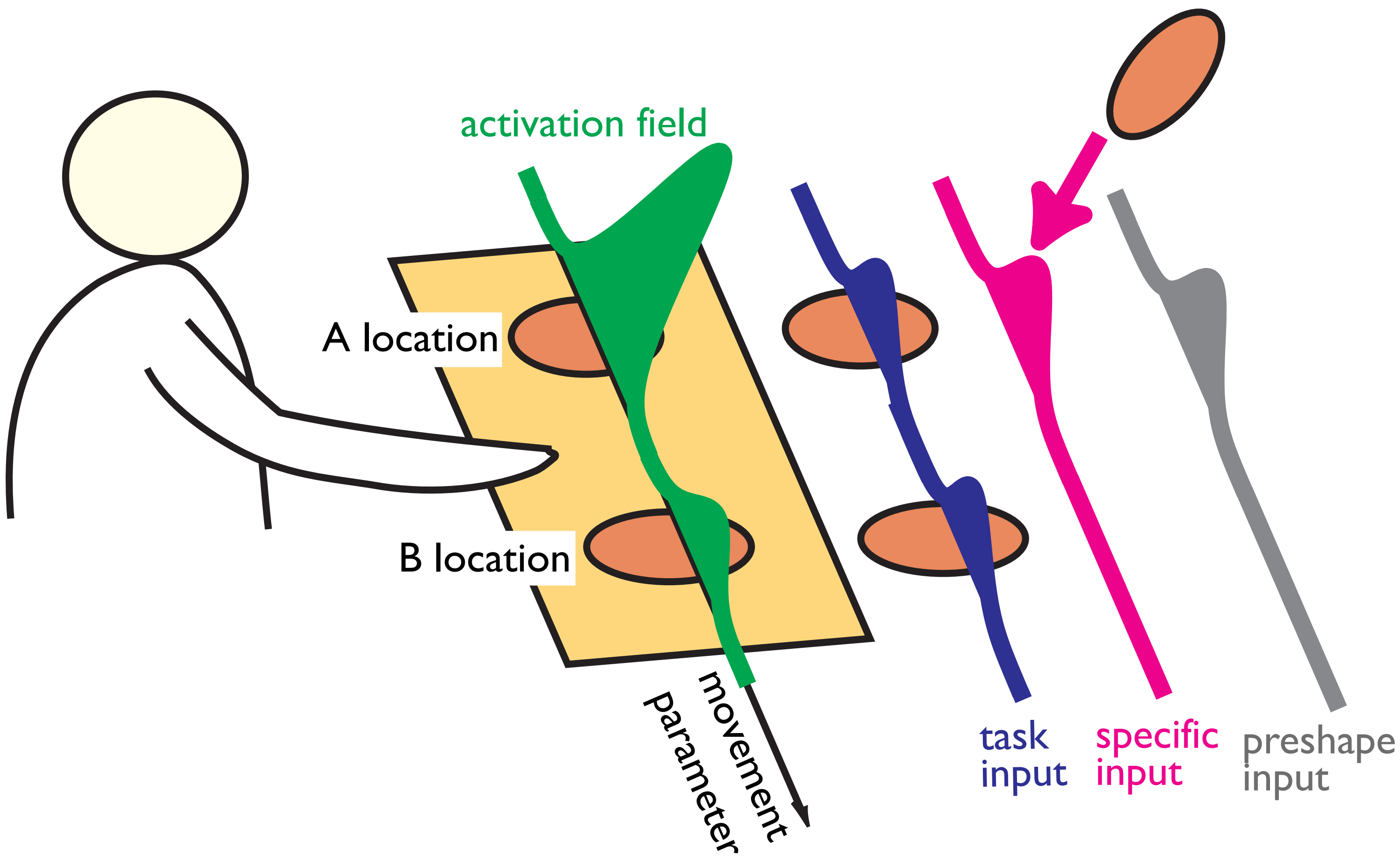
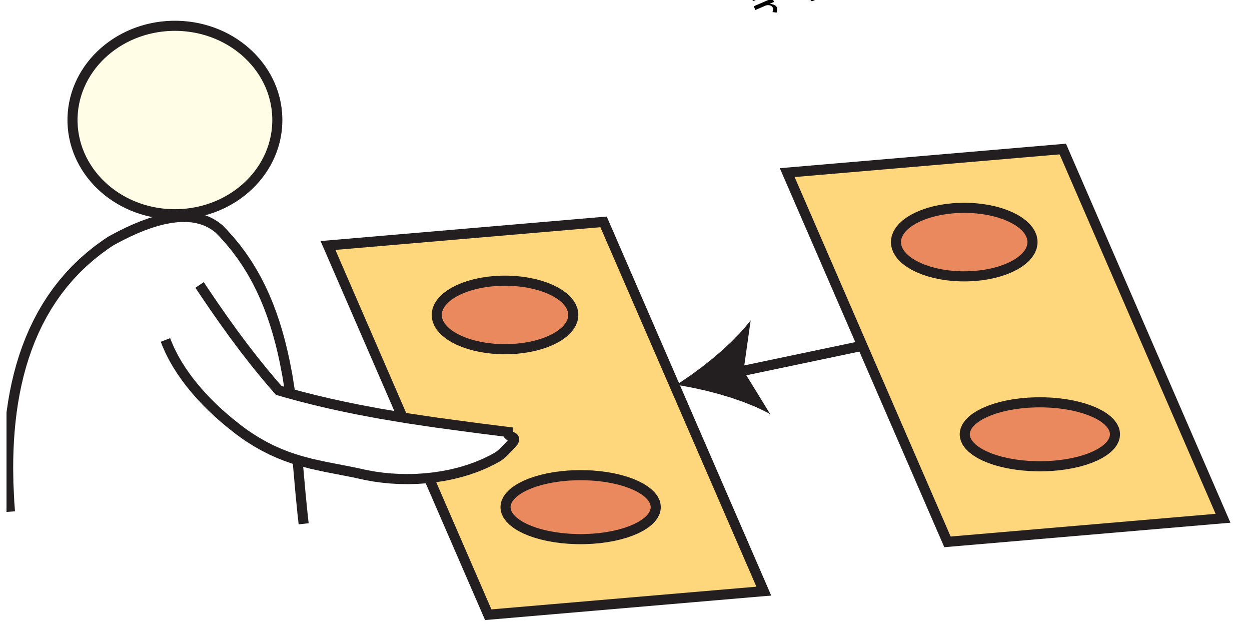


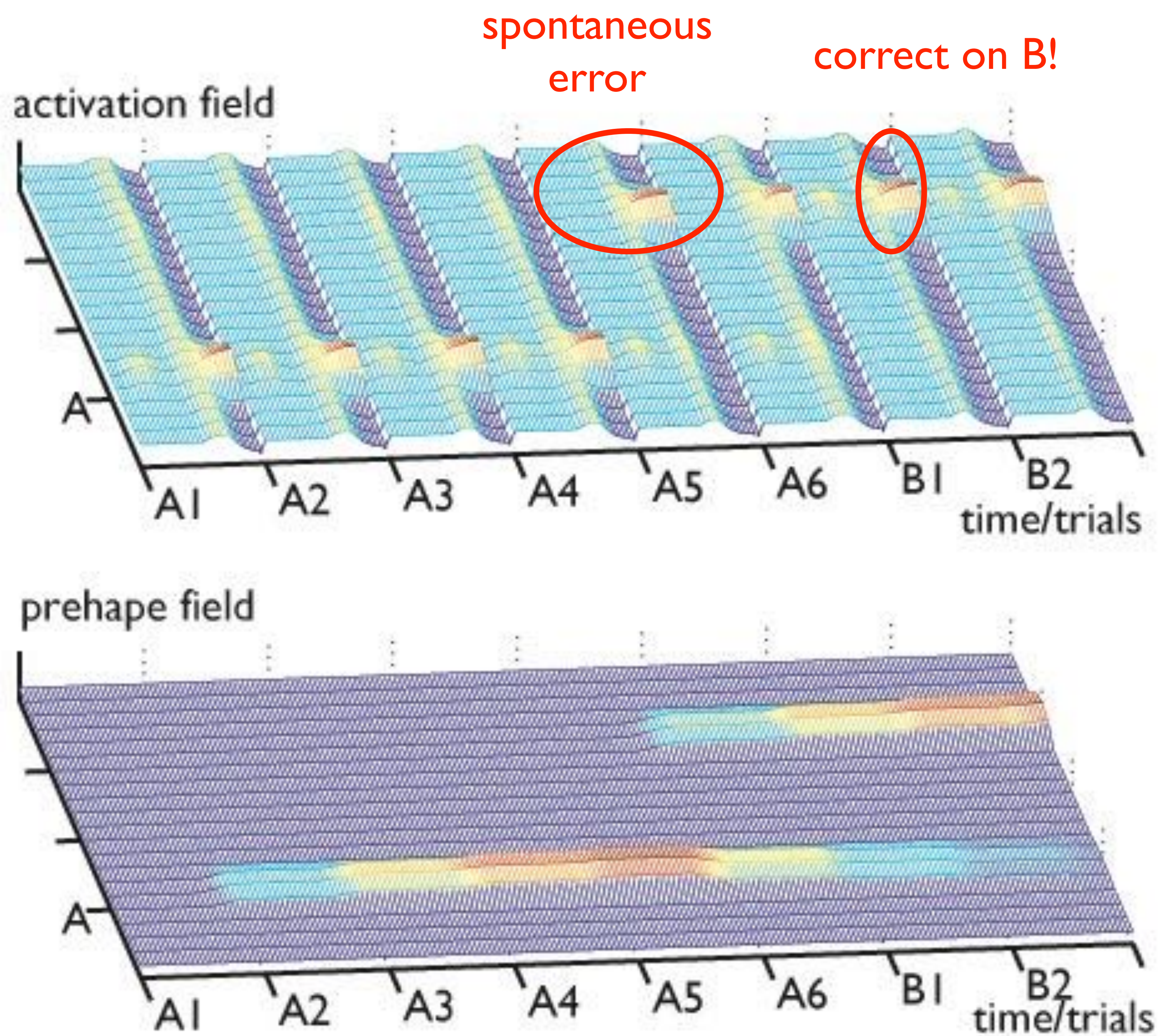
[Thelen, et al., BBS (2001)]



[Dinveva, Schöner, Dev. Science 2007]

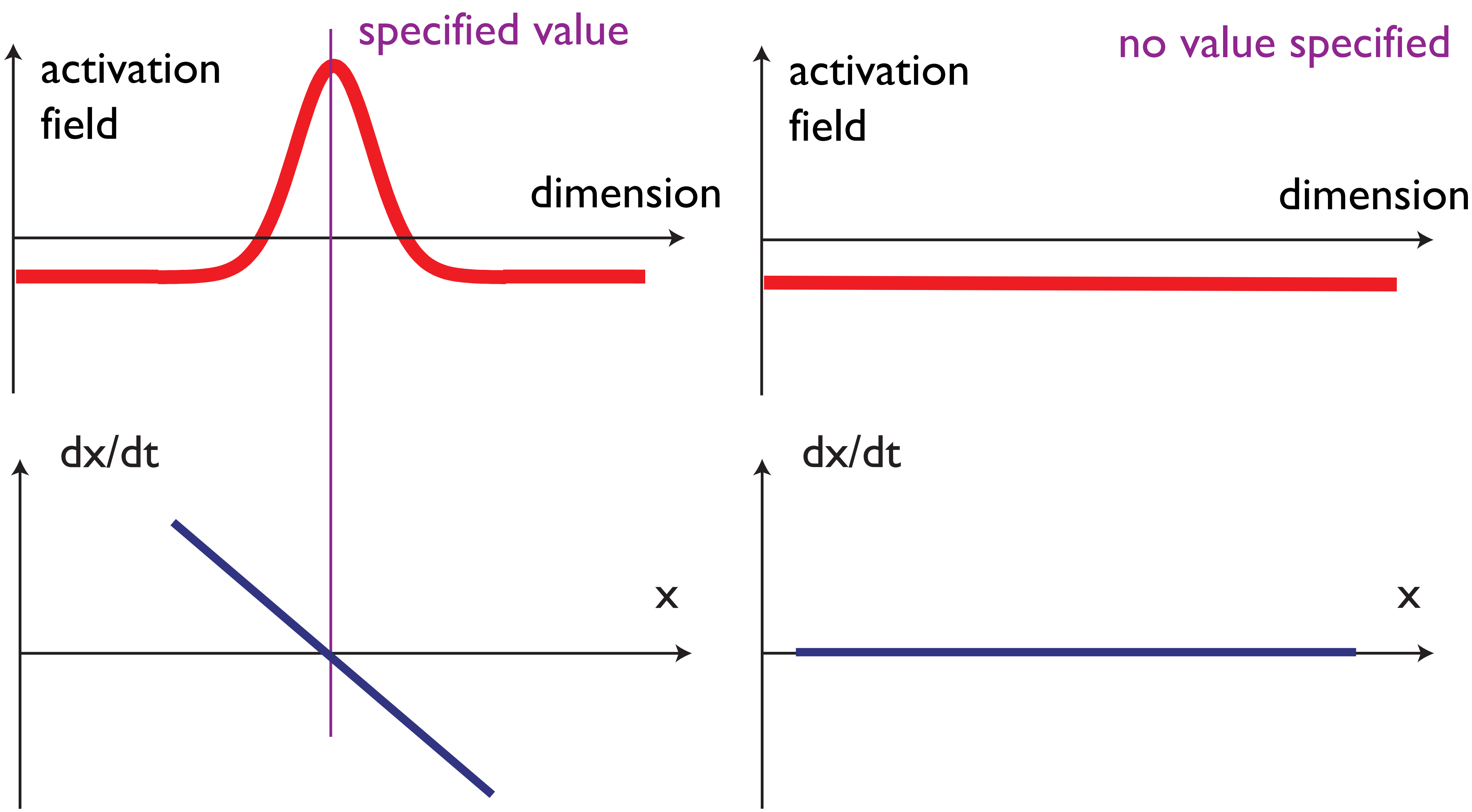
DFT of infant perseverative reaching

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



[Dinveva, Schöner, Dev. Science 2007]

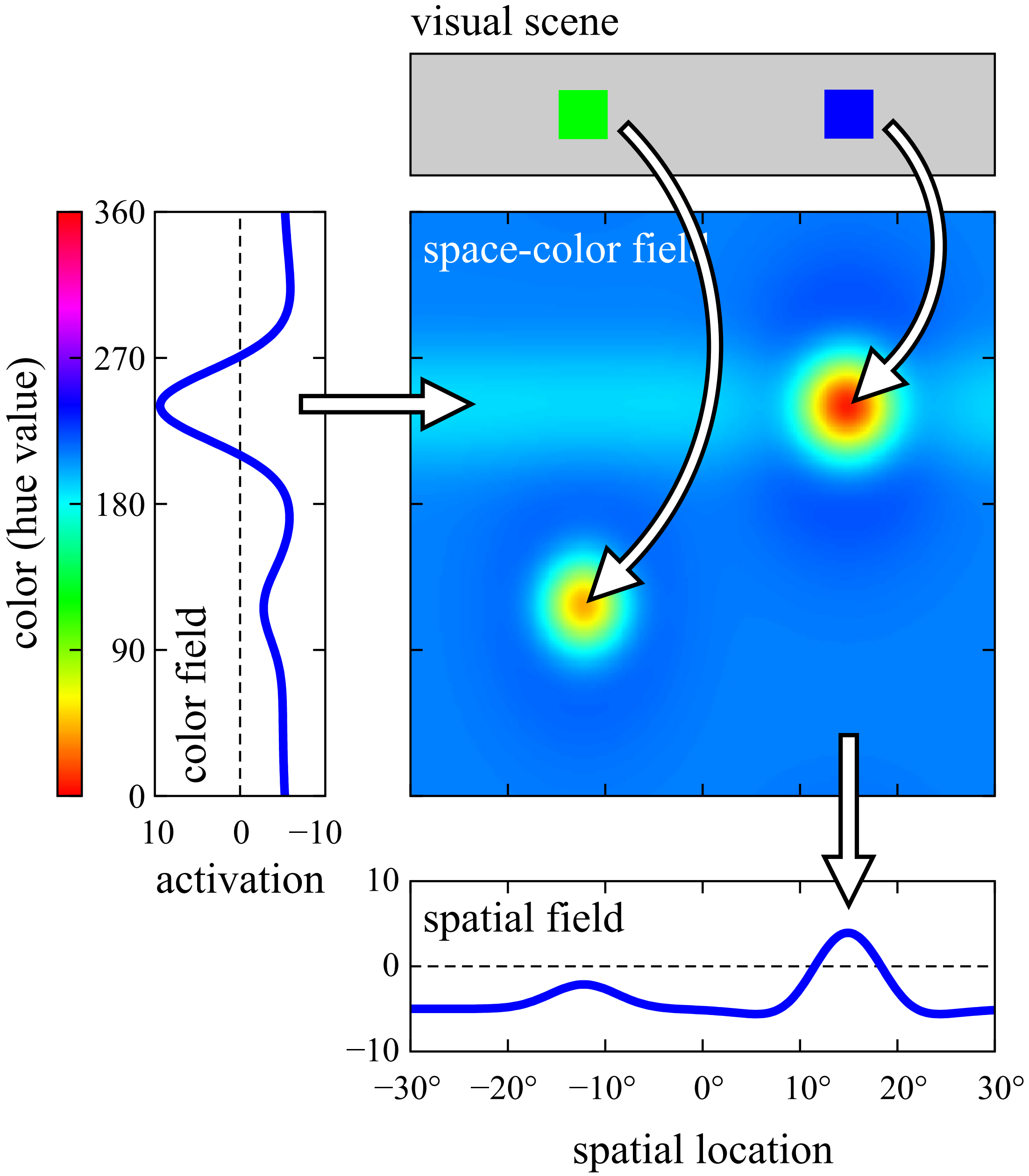
From neural to behavioral dynamics



$$
\begin{aligned}
x_{\text{peak}} &= \frac{\int dx\; x\; \sigma(u(x,t))}{\int dx\; \sigma(u(x,t))} \\
\dot{x} &= -\left[\int dx\; \sigma(u(x,t))\right](x - x_{\text{peak}}) \\
\Rightarrow \dot{x} &= -\left[\int dx\; \sigma(u(x,t))\right]\; x + \left[\int dx\; x\; \sigma(u(x,t))\right]
\end{aligned}
$$

New functions from higher-dimensional fields

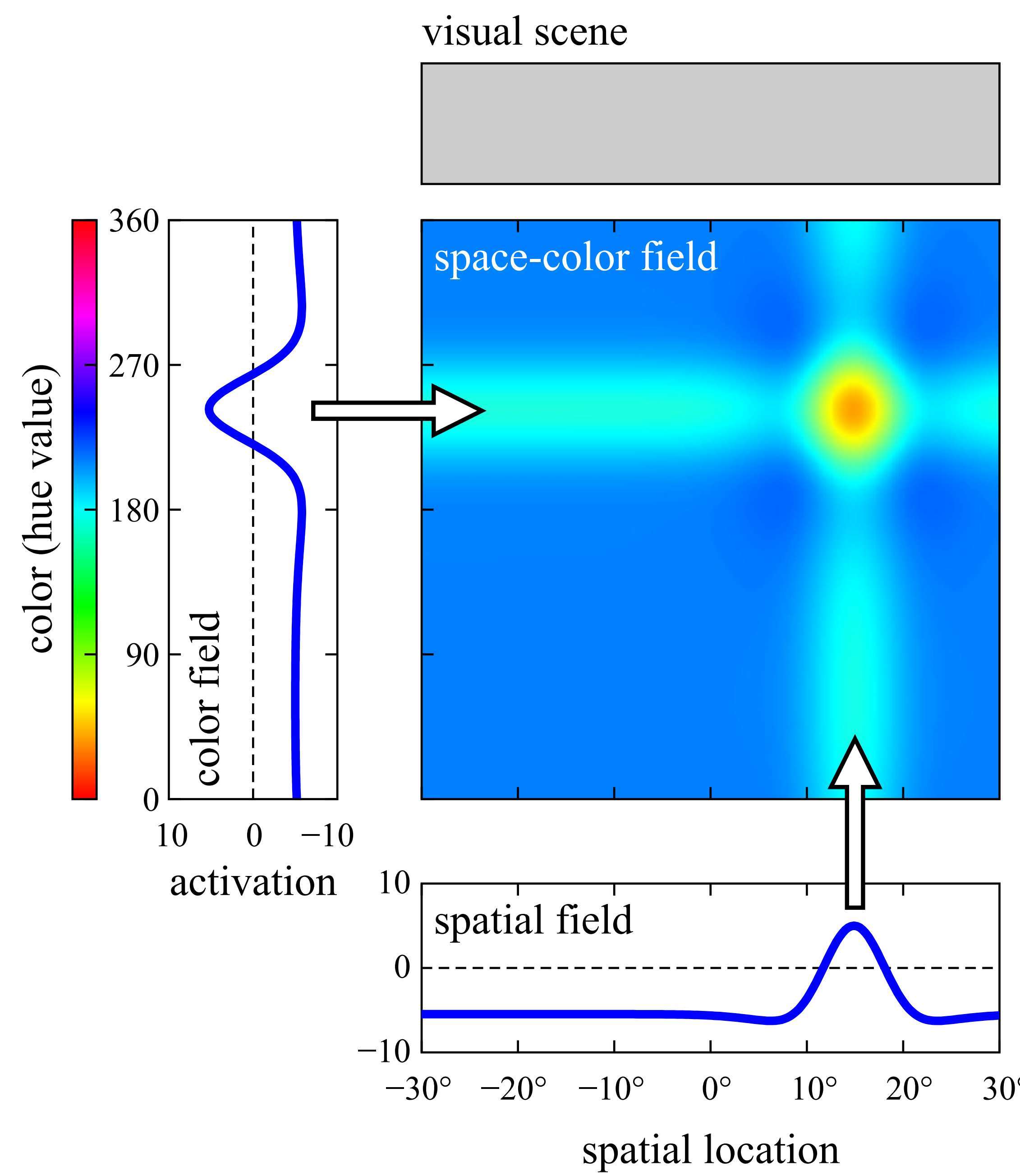
- visual search: combine ridge input with 2D input..



[Slides adapted from Sebastian Schneegans,
see Schneegans, Lins, Spencer, Chapter 5 of Dynamic Field Theory-A Primer, OUP, 2015]

New functions from higher-dimensional fields

- peaks at intersections of ridges: bind two dimensions



[Slides adapted from Sebastian Schneegans,
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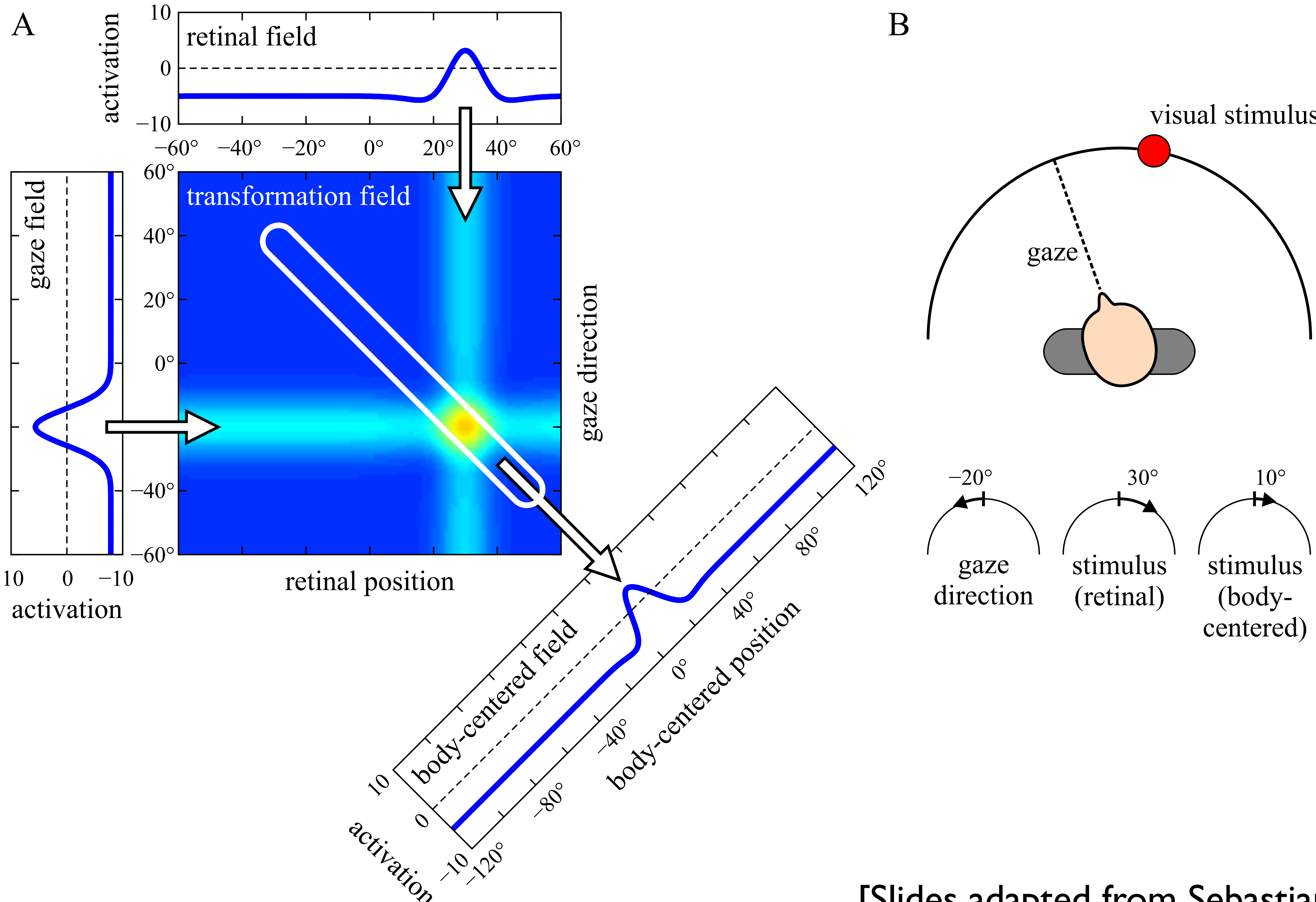
New functions from higher-dimensional fields: coordinate transforms



[Slides adapted from Sebastian Schneegans, see Schneegans, Chapter 7 of Dynamic Field Theory-A Primer, OUP, 2015]

Toward higher cognition: Grounding spatial concepts

- bring objects into foreground
- make coordinate transformation
- apply comparison operators

[Lipinski et al: JEP:LMC (2011)]