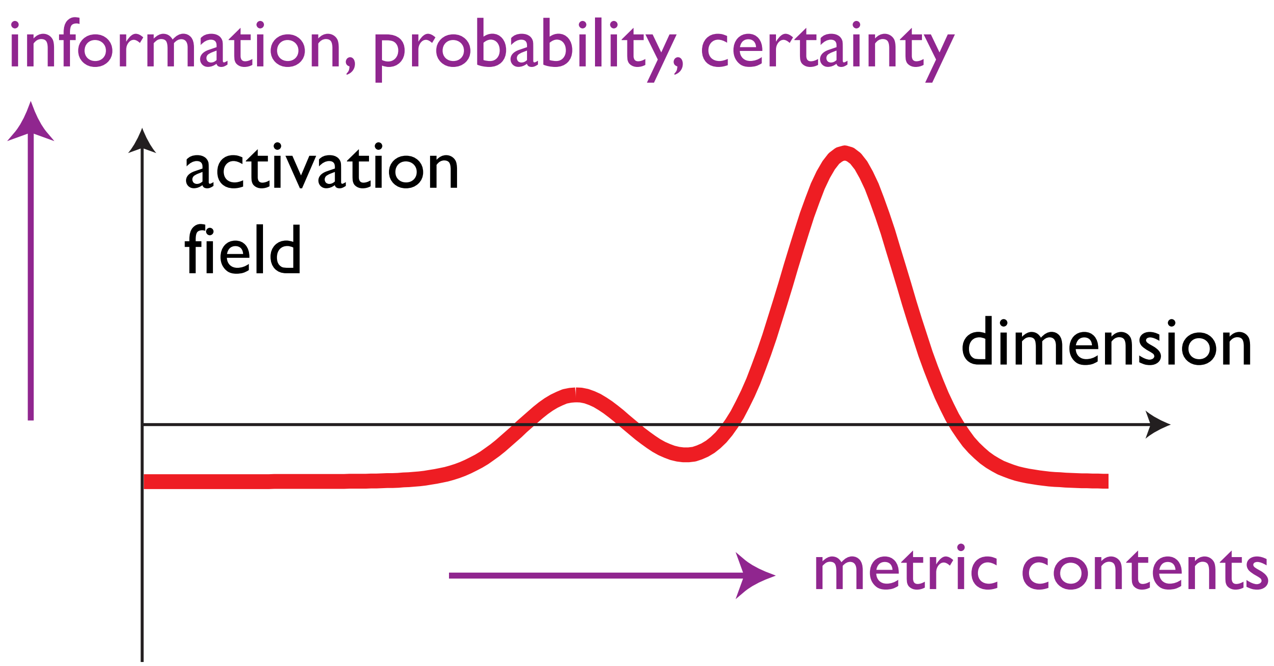
Dynamic Field Theory

Gregor Schöner

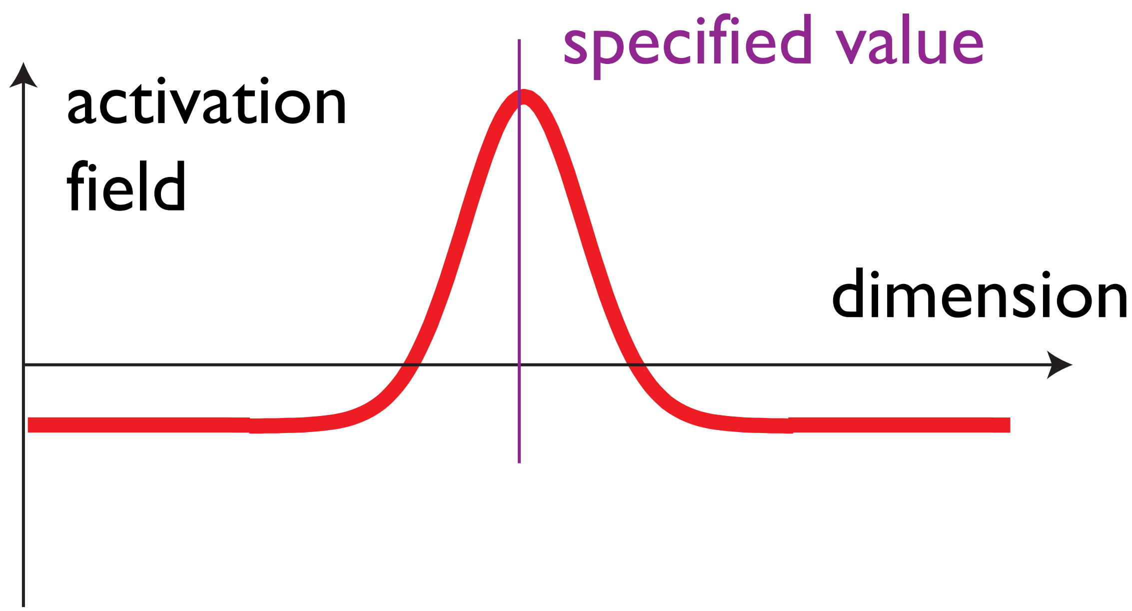
Dynamic Field Theory

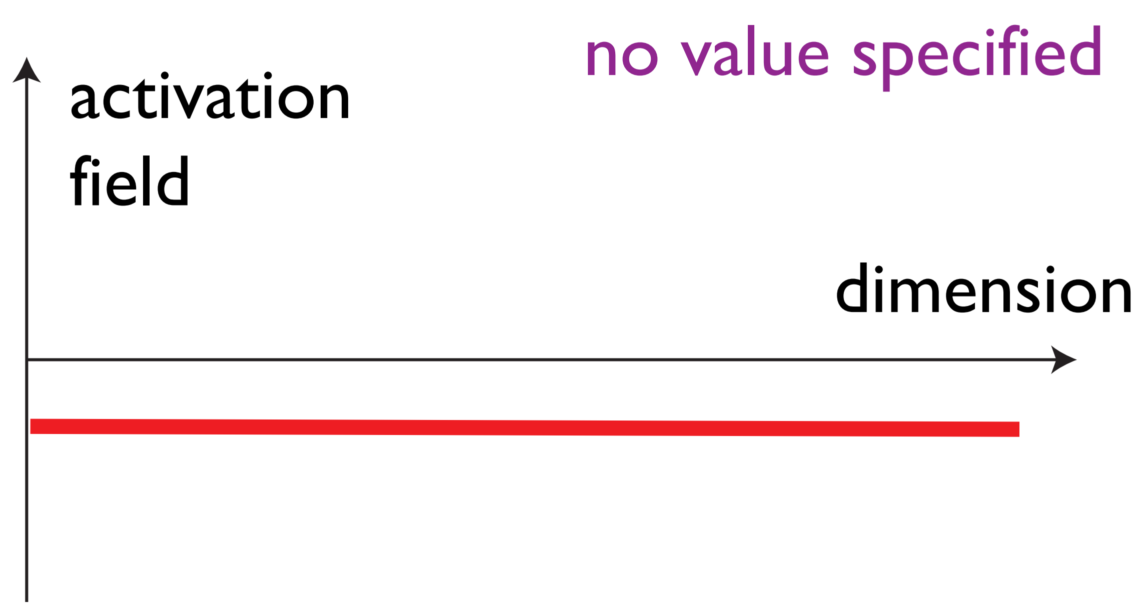
- dimensions
- activation fields
- field dynamics: peaks, instabilities

activation fields

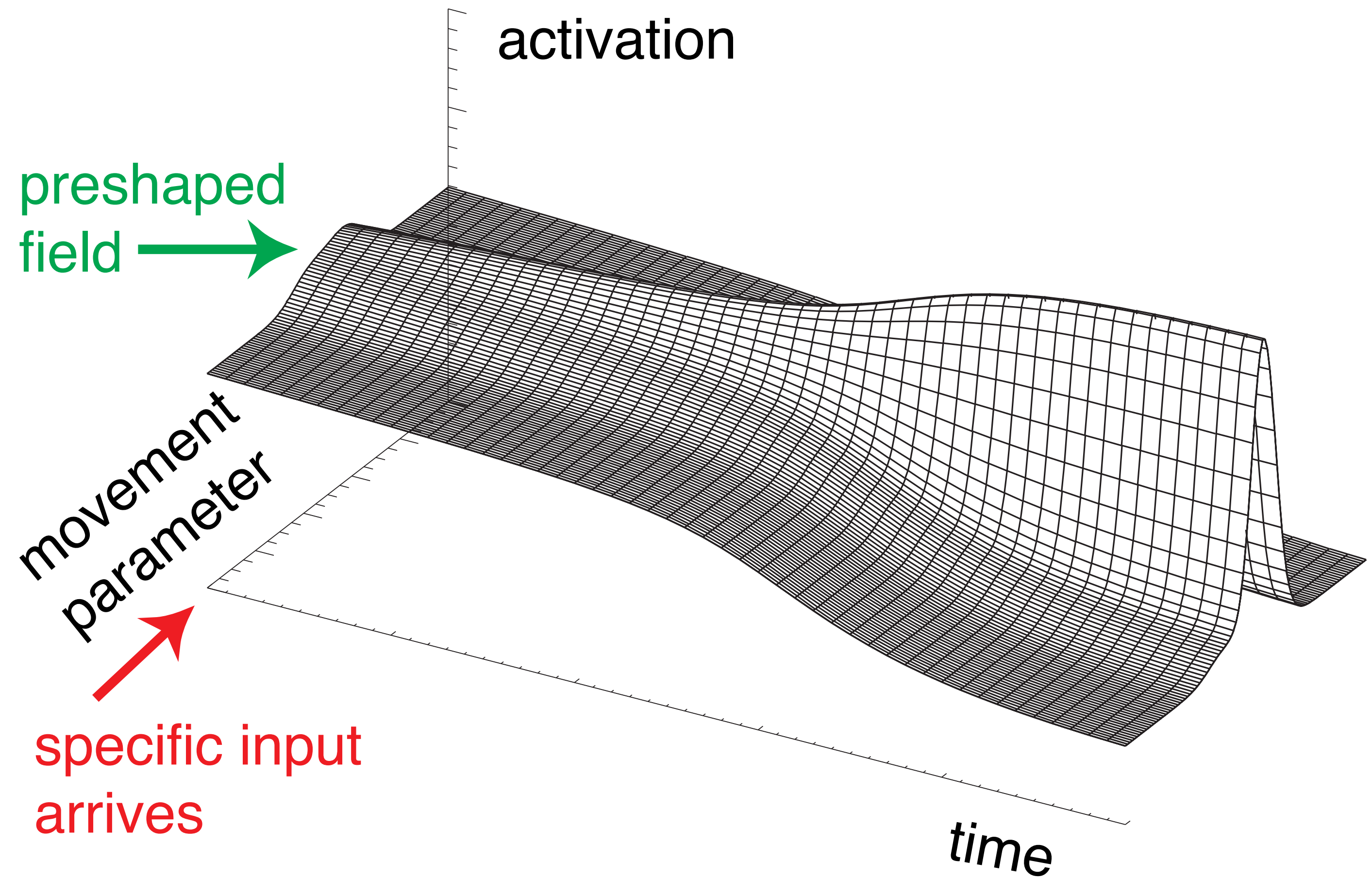


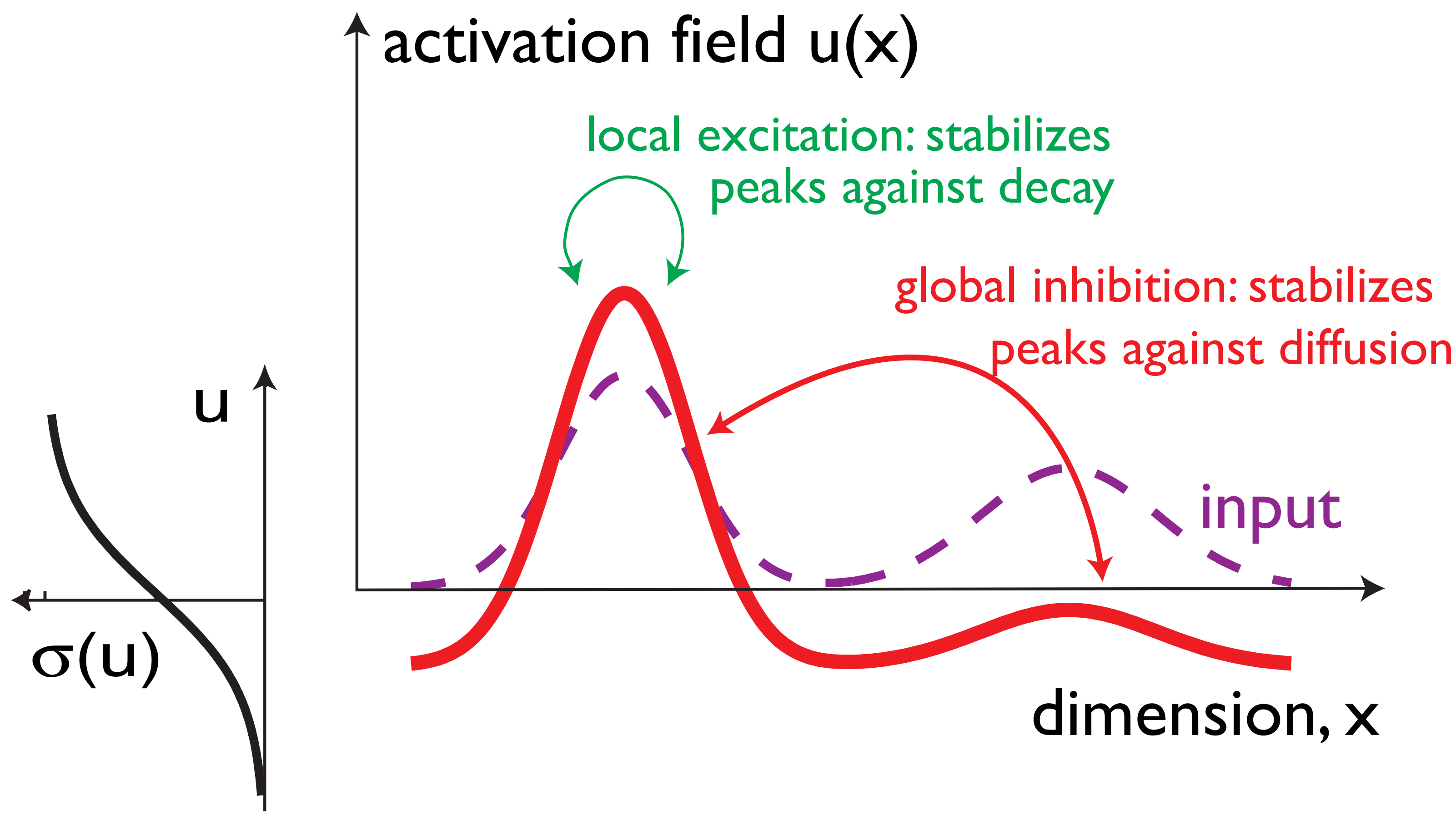
e.g., space, movement parameters, feature dimensions, viewing parameters, ...





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





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

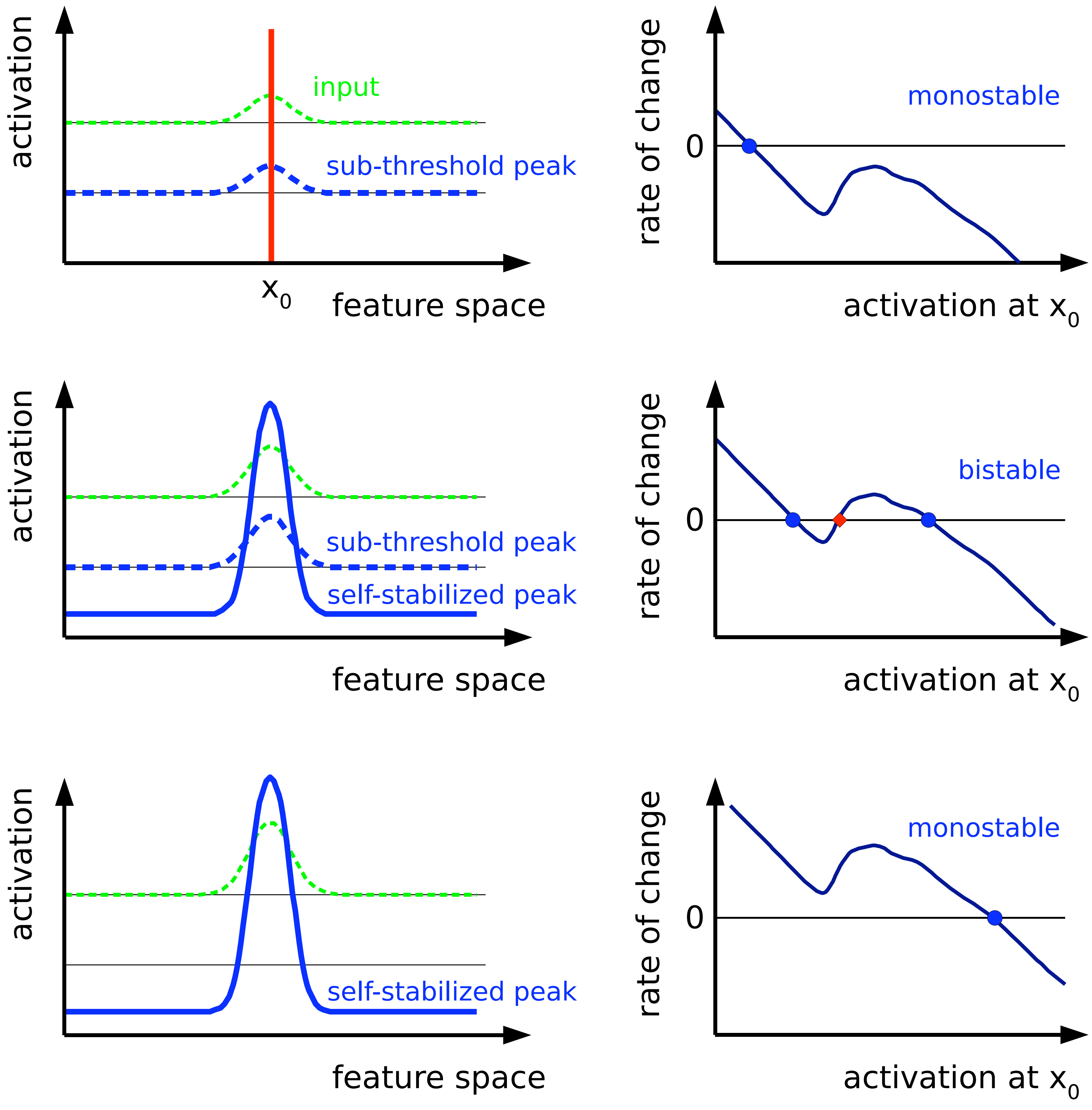
$$w(x-x') = w_i + w_e \exp\left[-\frac{(x-x')^2}{2\sigma_i^2}\right]$$

- sigmoidal nonlinearity is

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

=> simulations

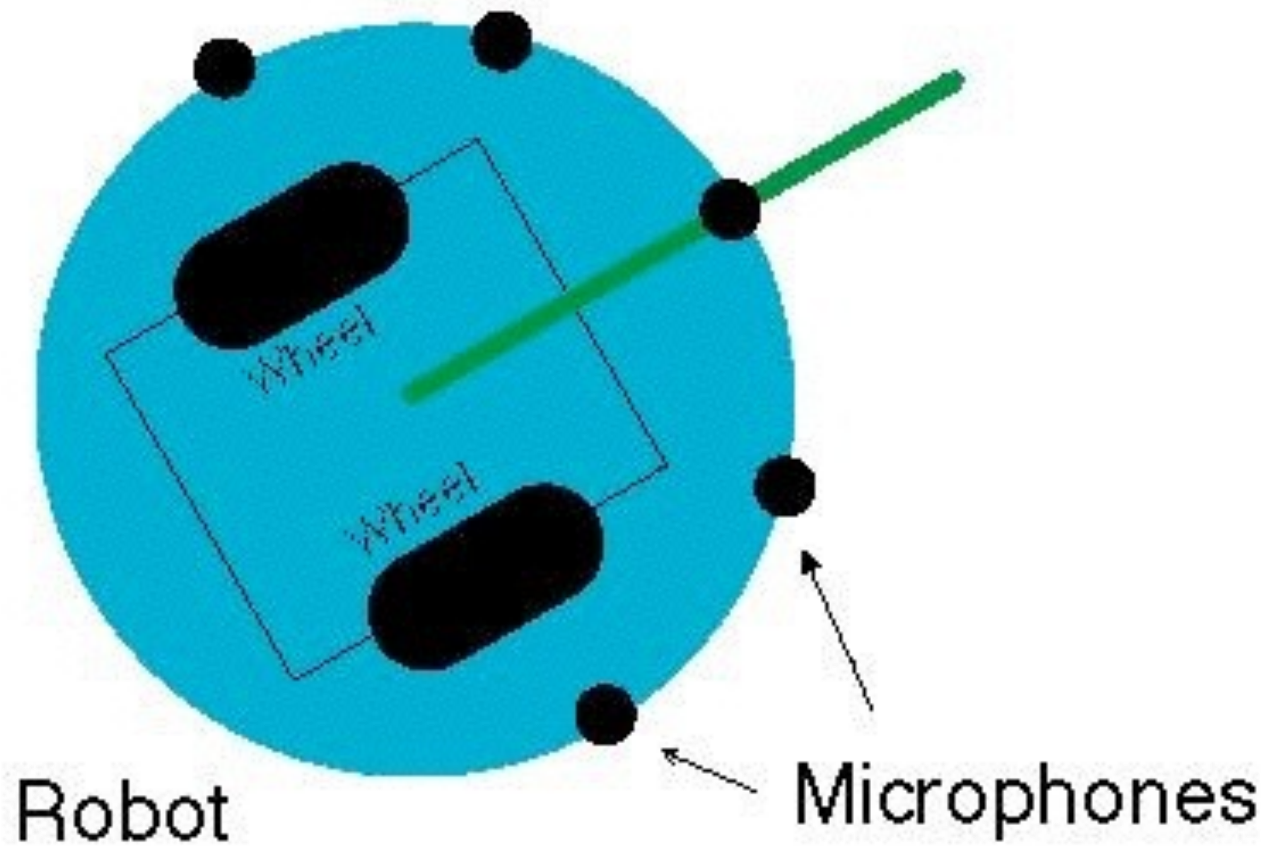
detection instability



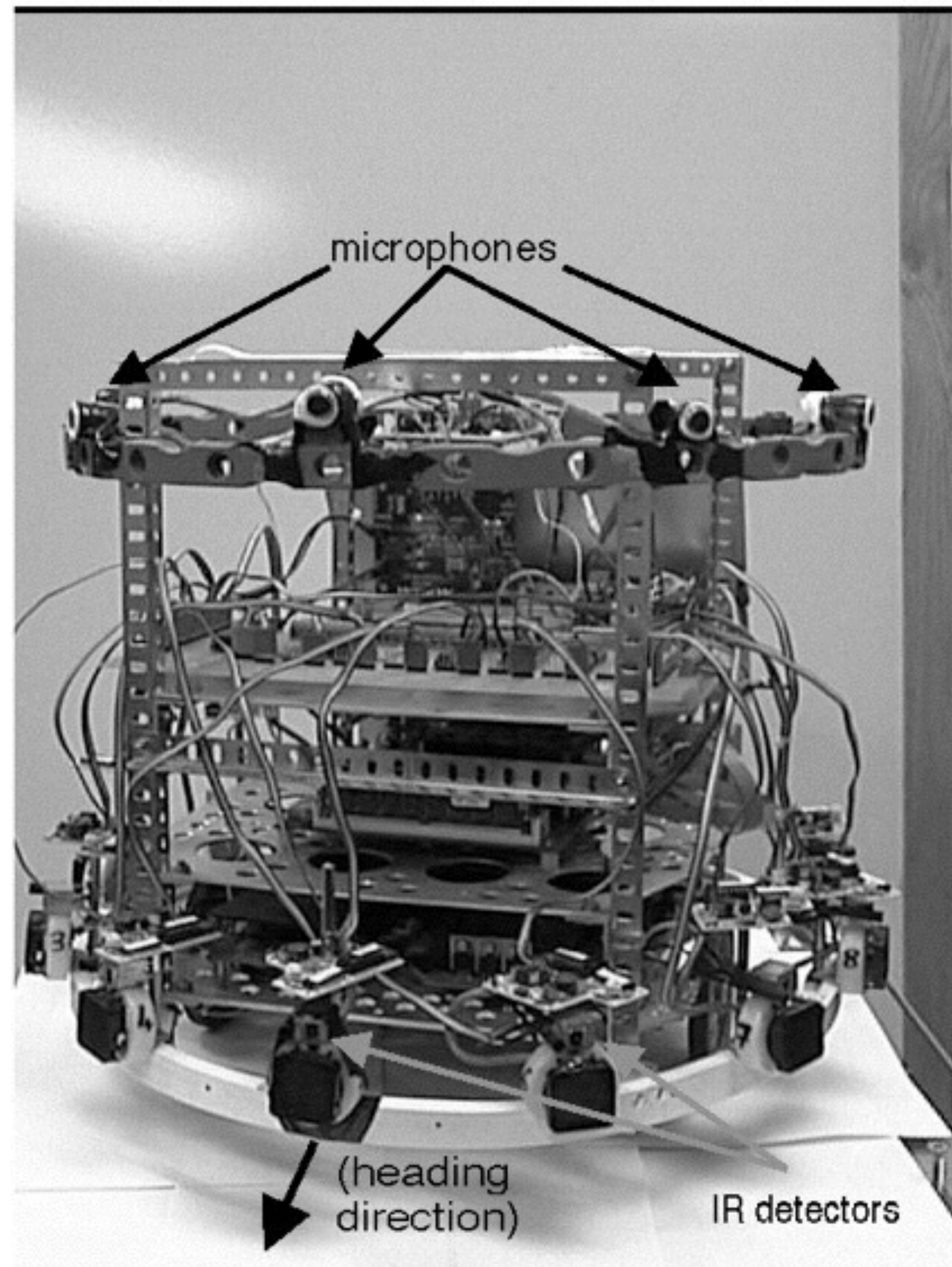
=> the detection instability stabilizes decisions

- self-stabilized peaks are macroscopic neuronal states, capable of impacting on down-stream neuronal systems
- the detection instability also explains how a time-continuous neuronal dynamics may create macroscopic, time-discrete events

Vehicle

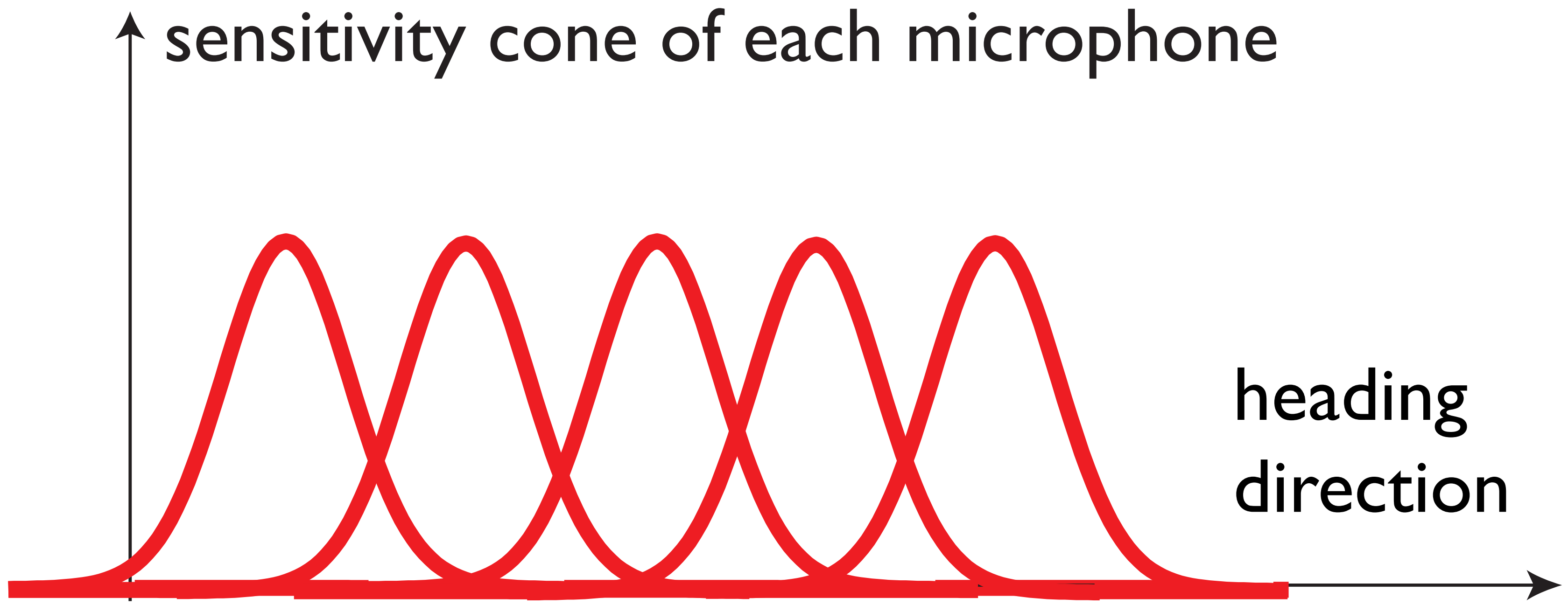


[from Bicho, Mallet, Schöner, Int J Rob Res,2000]

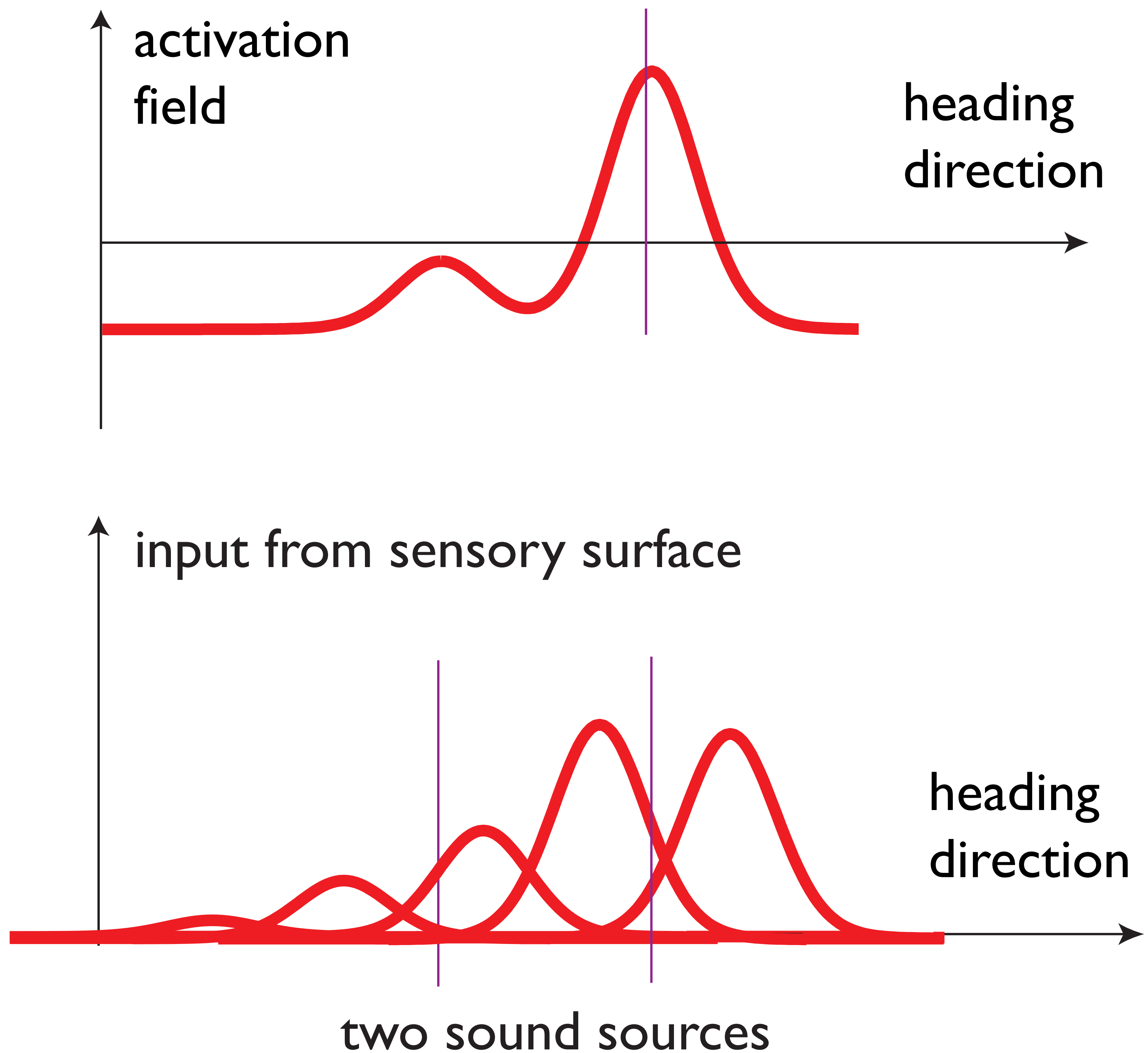


sensory surface

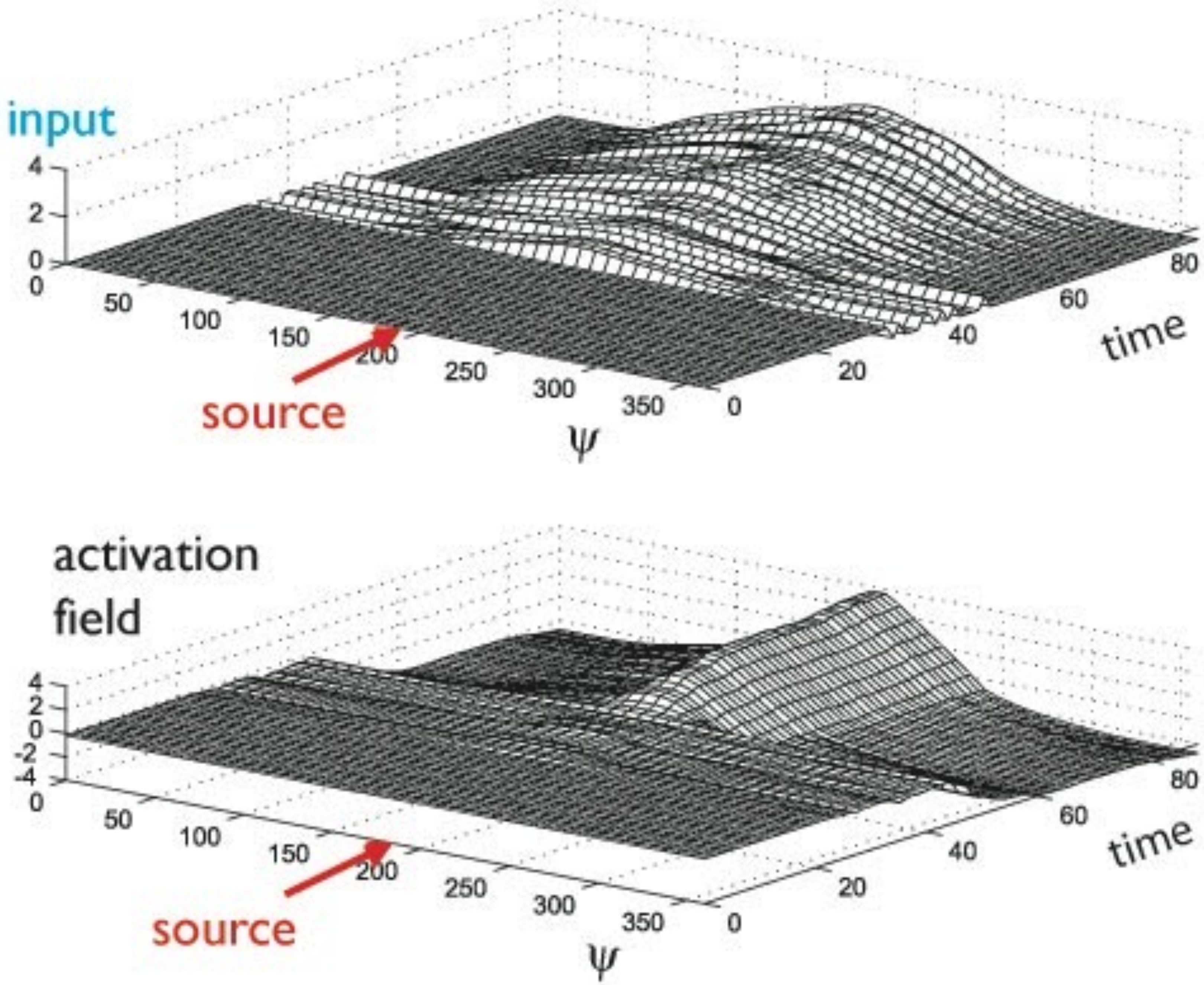
- each microphone samples heading direction

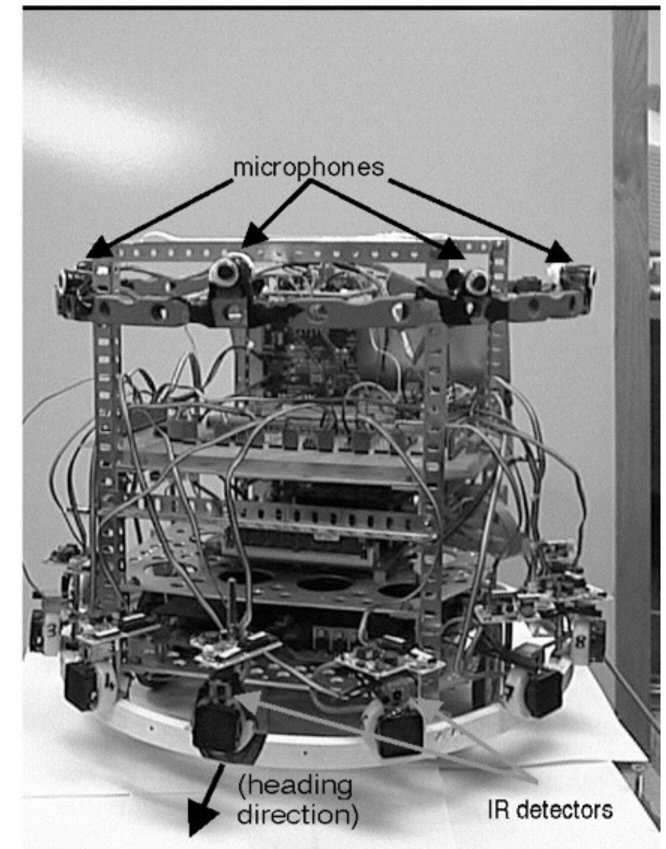


and provides input to the field



detection instability on a phonotaxis robot



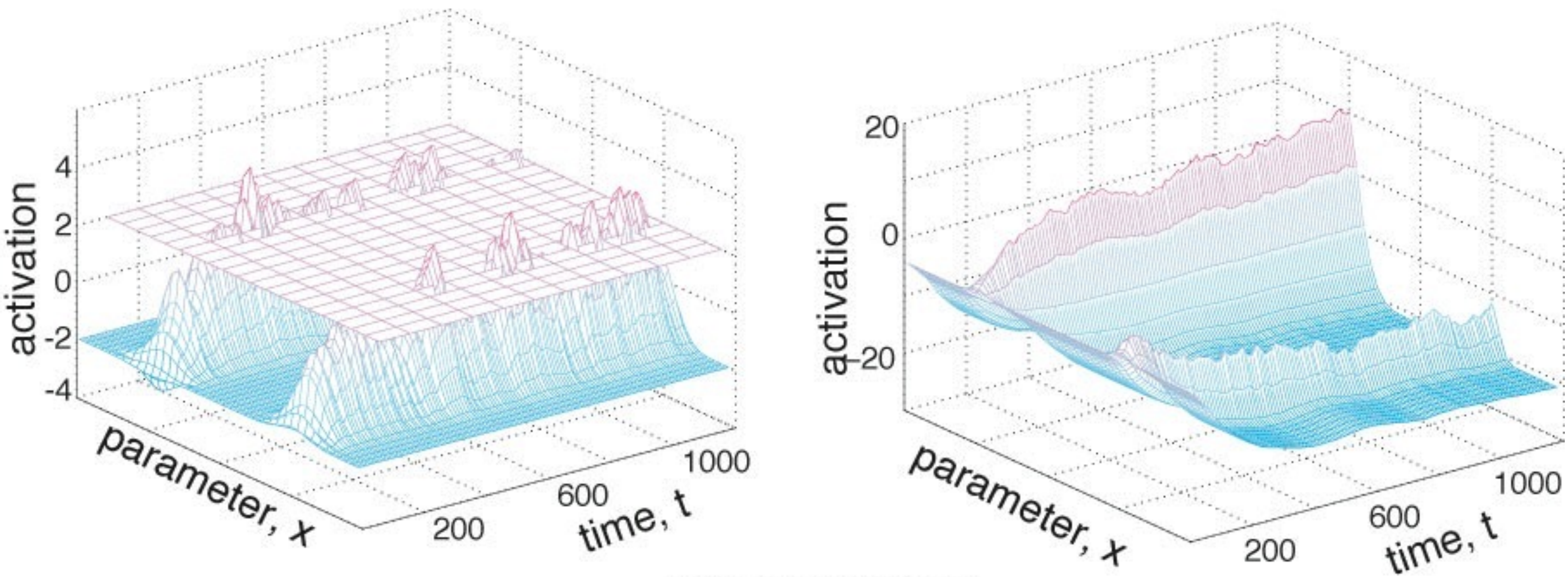


[from Bicho, Mallet, Schöner: Int. J. Rob. Res., 2000]

emergence of time-discrete events

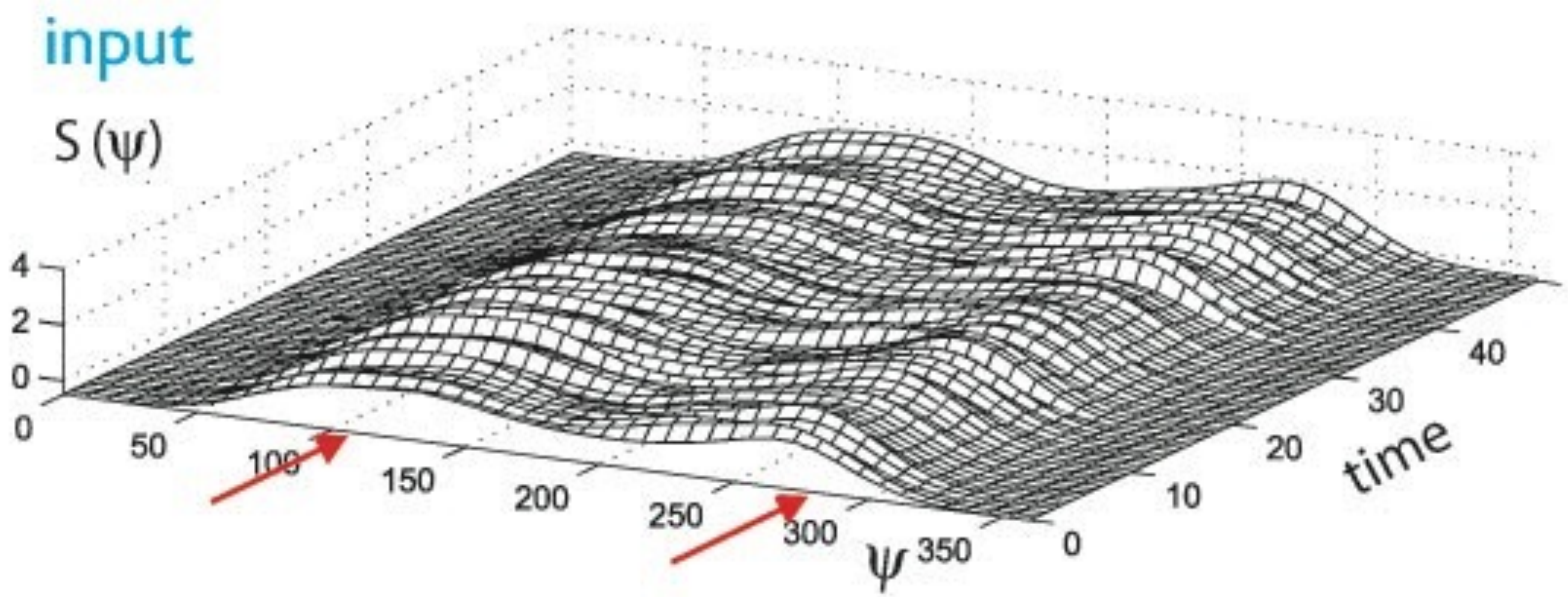
- the detection instability also explains how a time-continuous neuronal dynamics may create macroscopic, time-discrete events

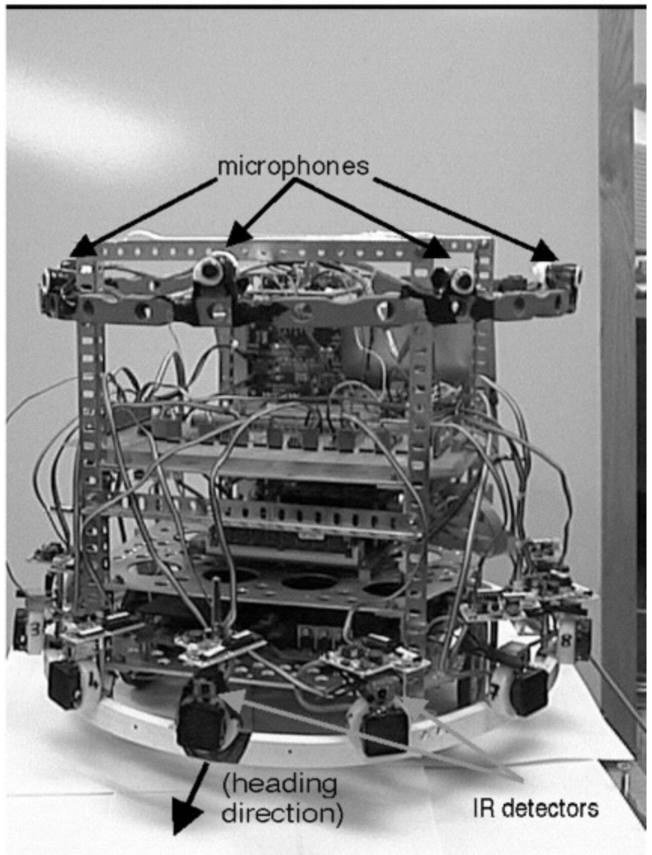
the selection instability stabilizes selection decisions

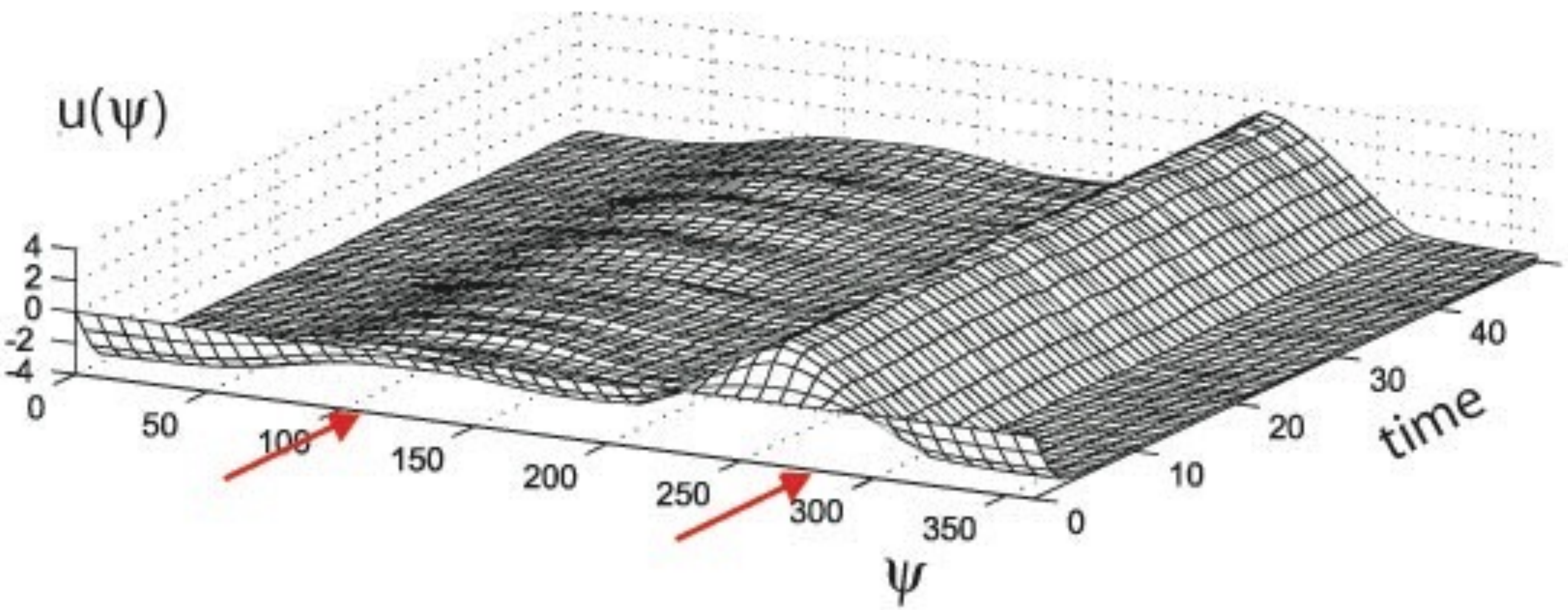


[Wilimzig, Schöner, 2006]

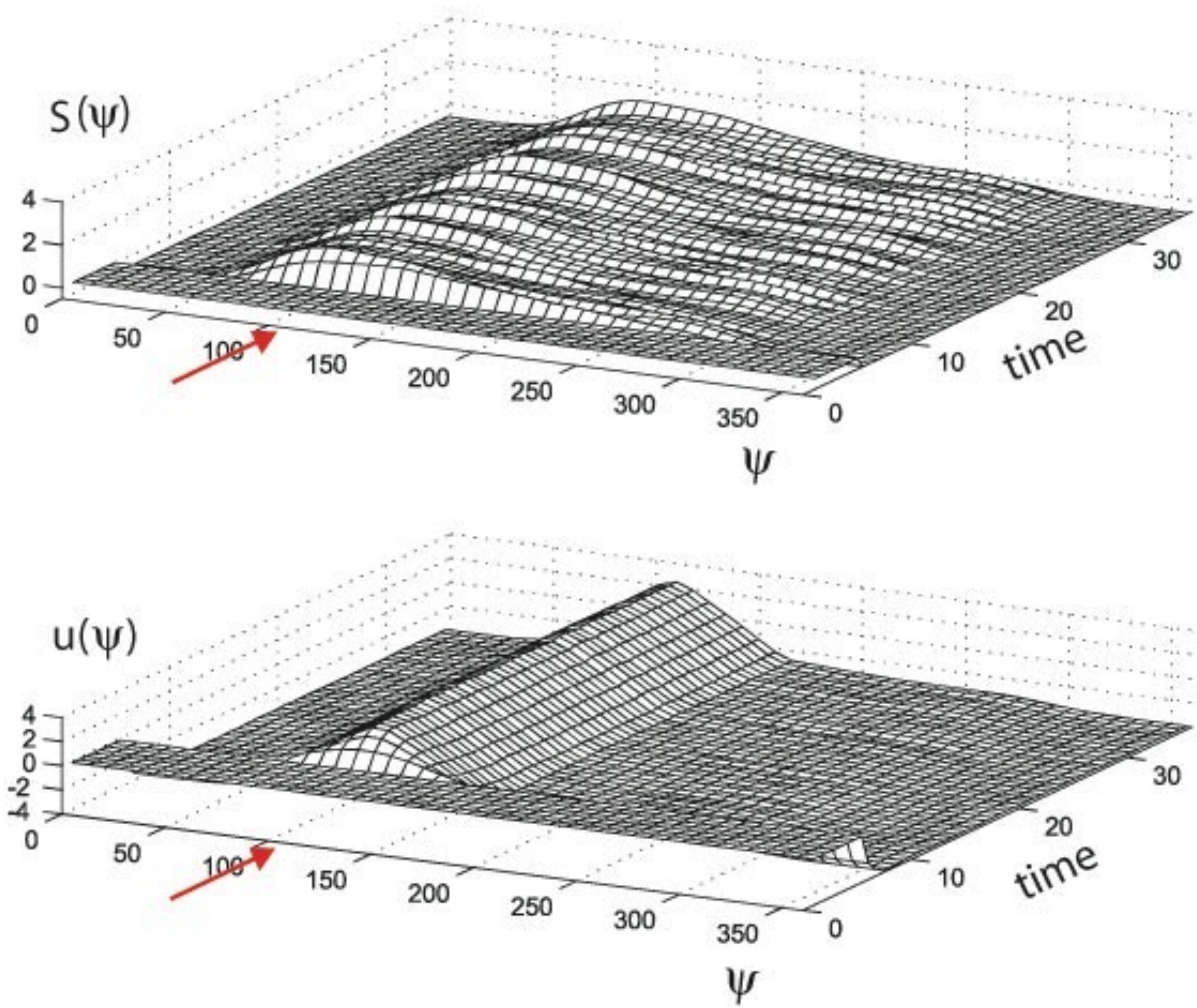
target selection on phonotaxis vehicle



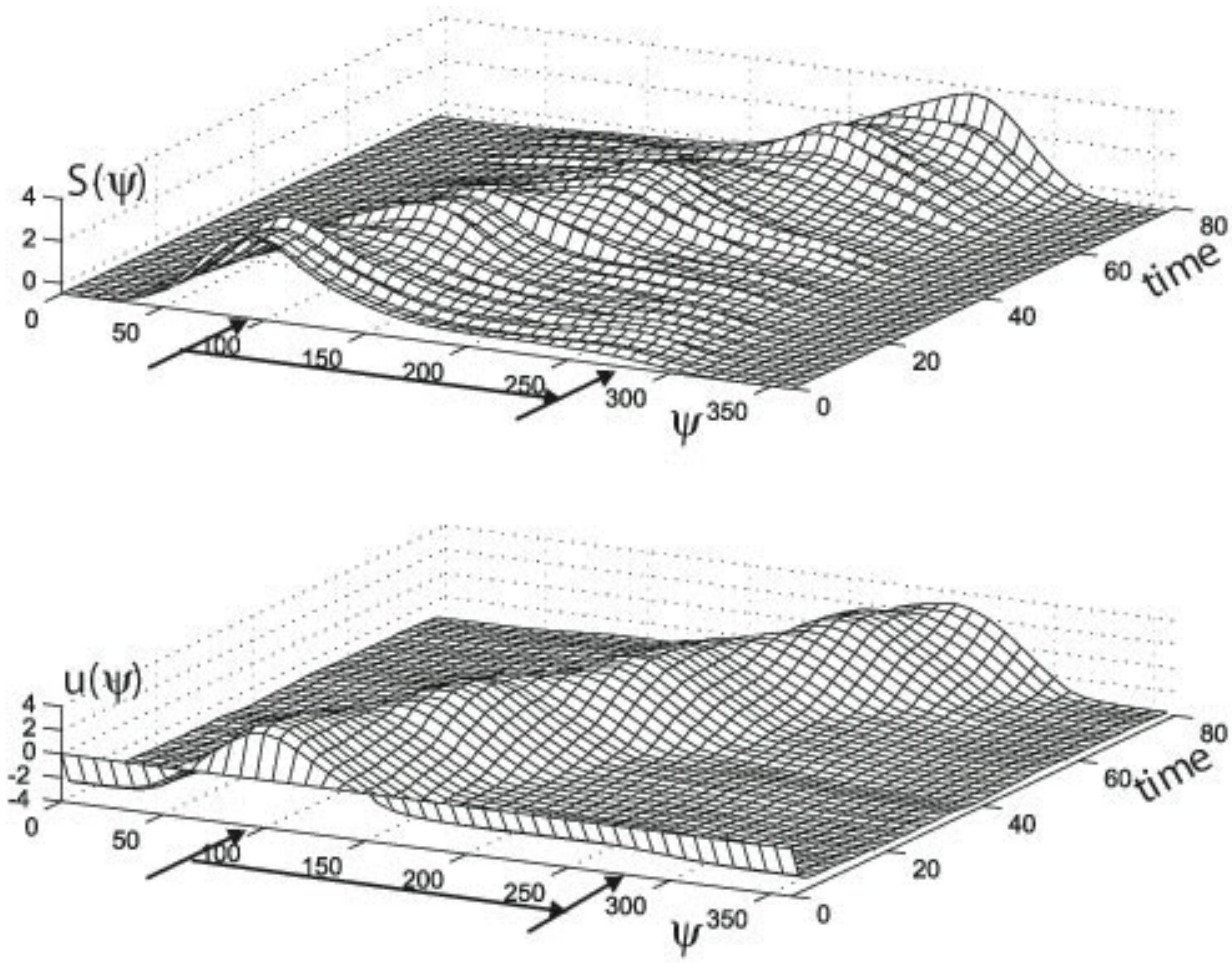




robust estimation

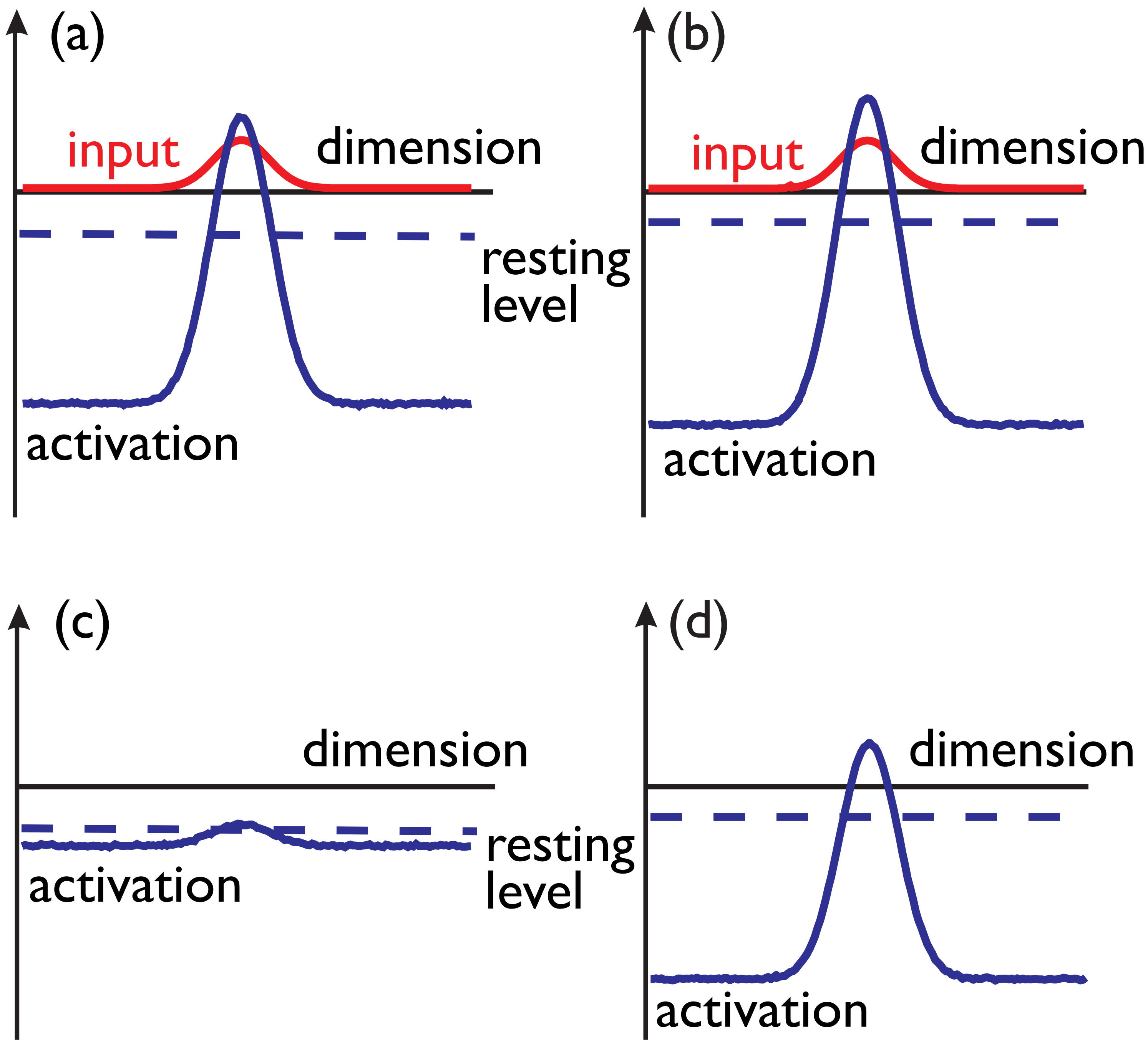


tracking

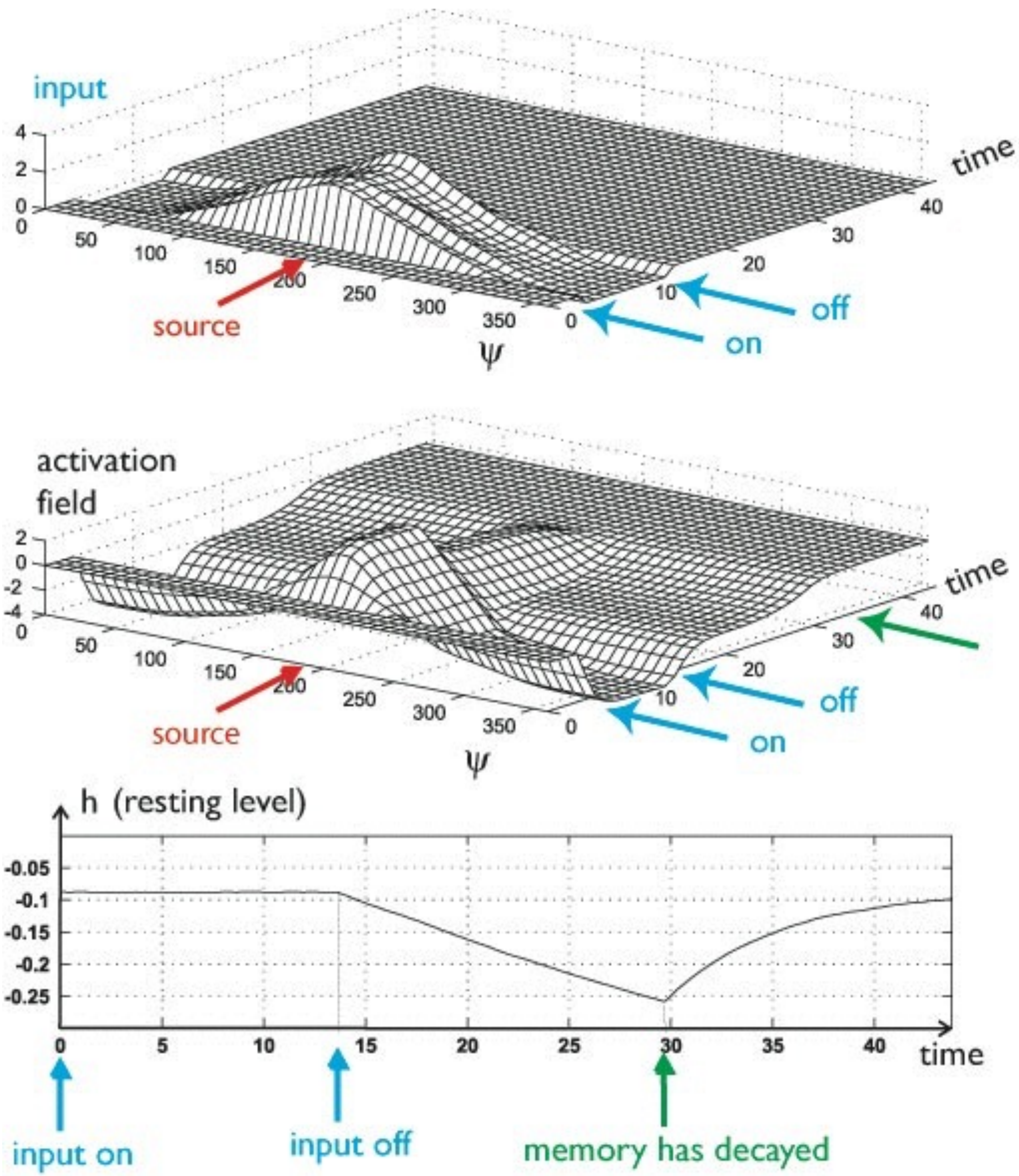

S(ψ)
4
2
0
0
50
100
150
200
250
300
350
ψ
0
20
40
60
80
time
u(ψ)
4
2
0
-2
-4
0
50
100
150
200
250
300
350
ψ
0
20
40
60
80
time

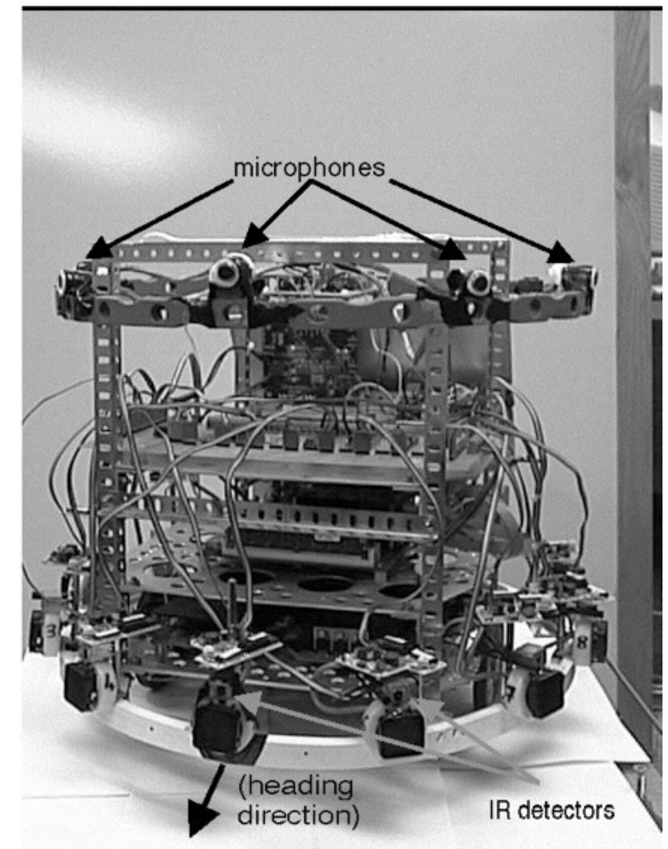
memory instability

- monostable “off” regime vs. bistable regime in which sustained activation provides working memory



memory & forgetting on phonotaxis vehicle



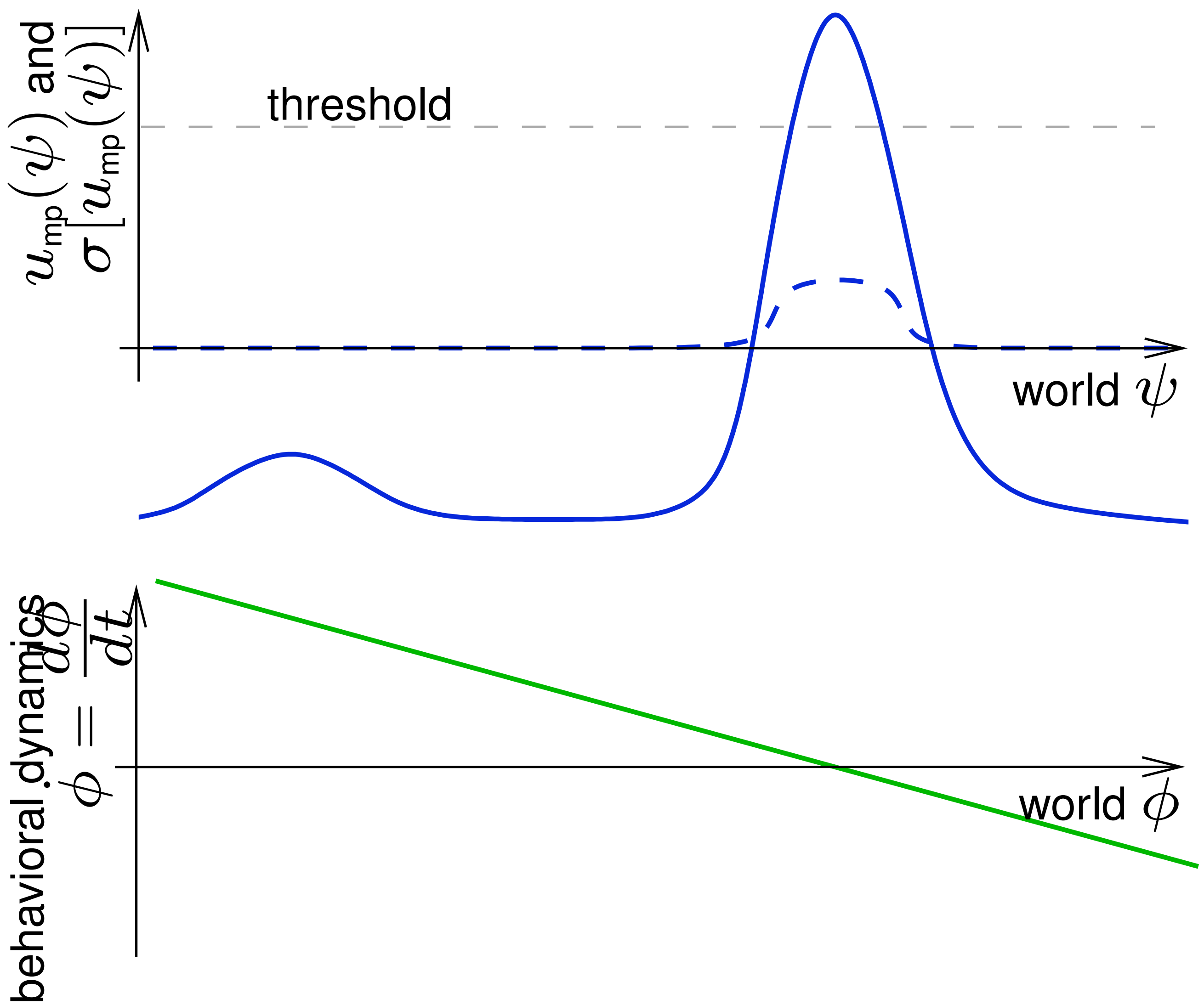


[from Bicho, Mallet, Schöner: Int J Rob Res 19:424(2000)]

a robotic demo of all of instabilities

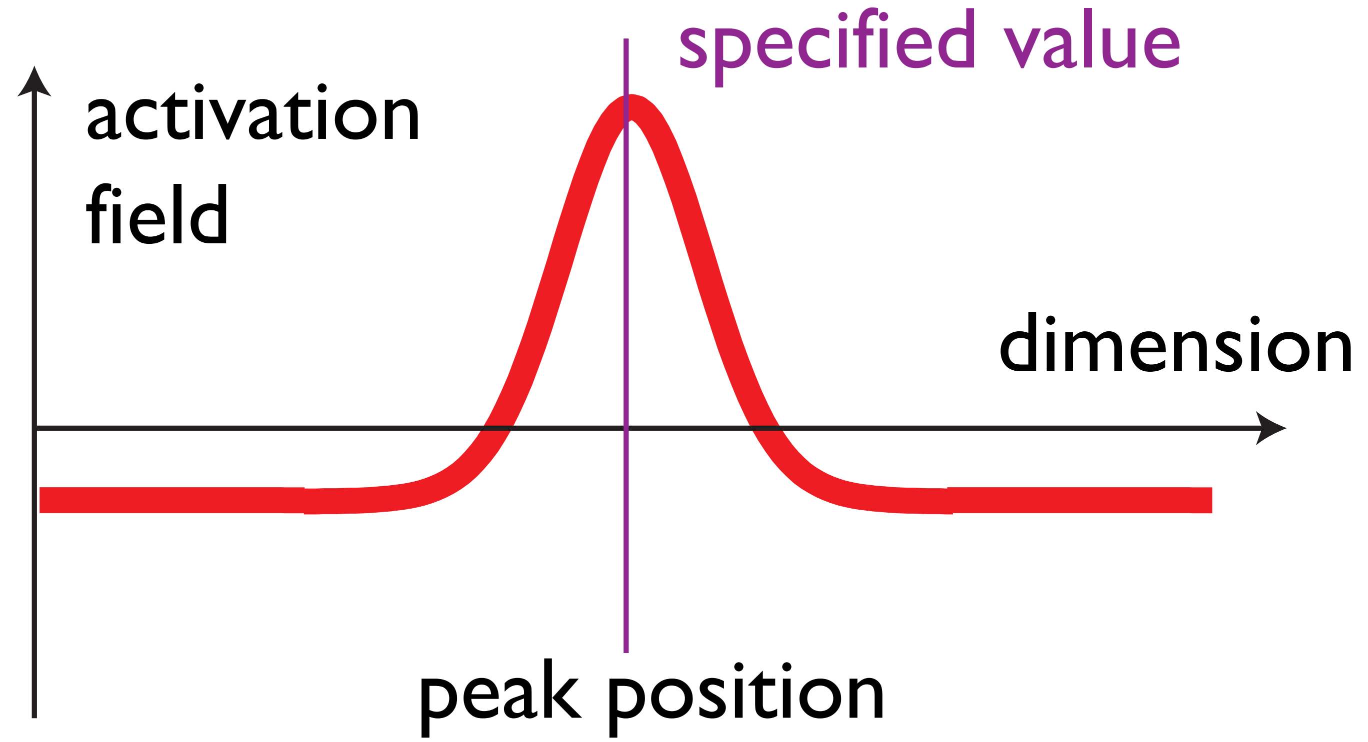
motor dynamics

- couple peak in direction field into dynamics of heading direction as an attractor



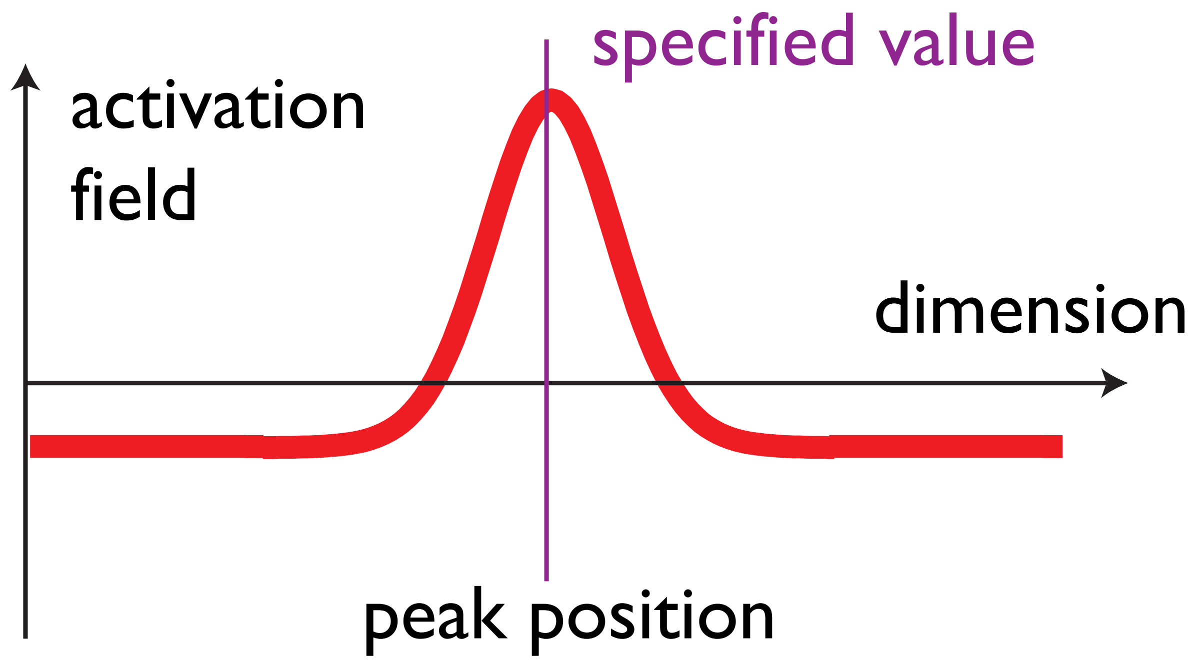
=> transition from DFT to DST

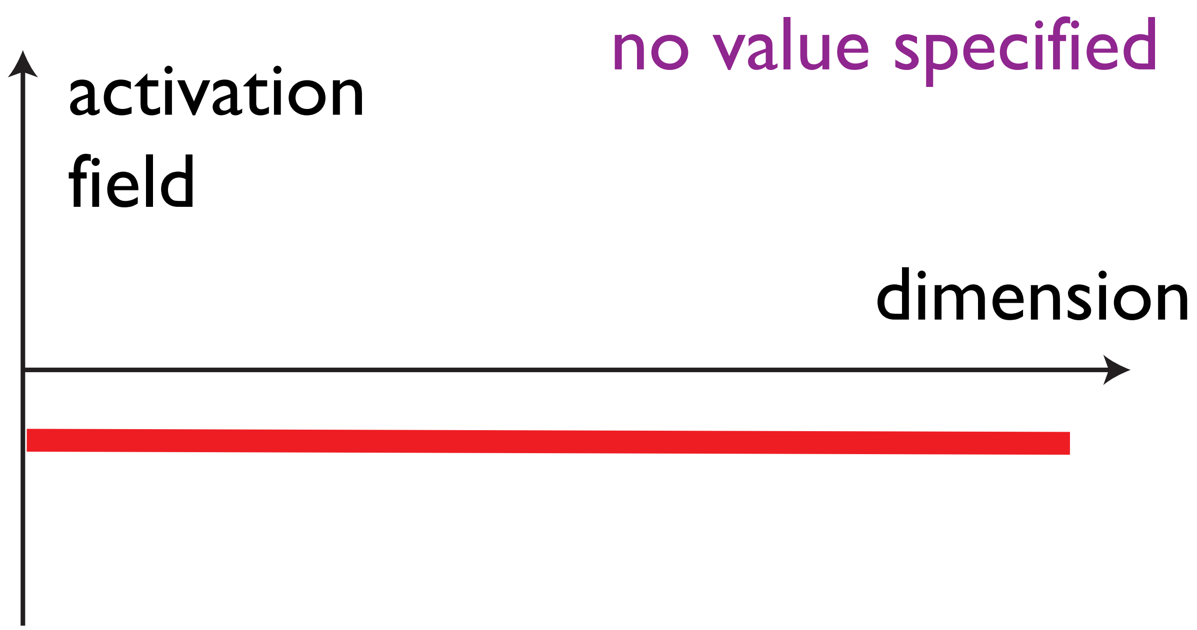
- peak specifies value for a dynamical variable that is congruent to the field dimension



from DFT to DST

- treating sigmoided field as probability: need to normalize
  - => problem when there is no peak: devide by zero!



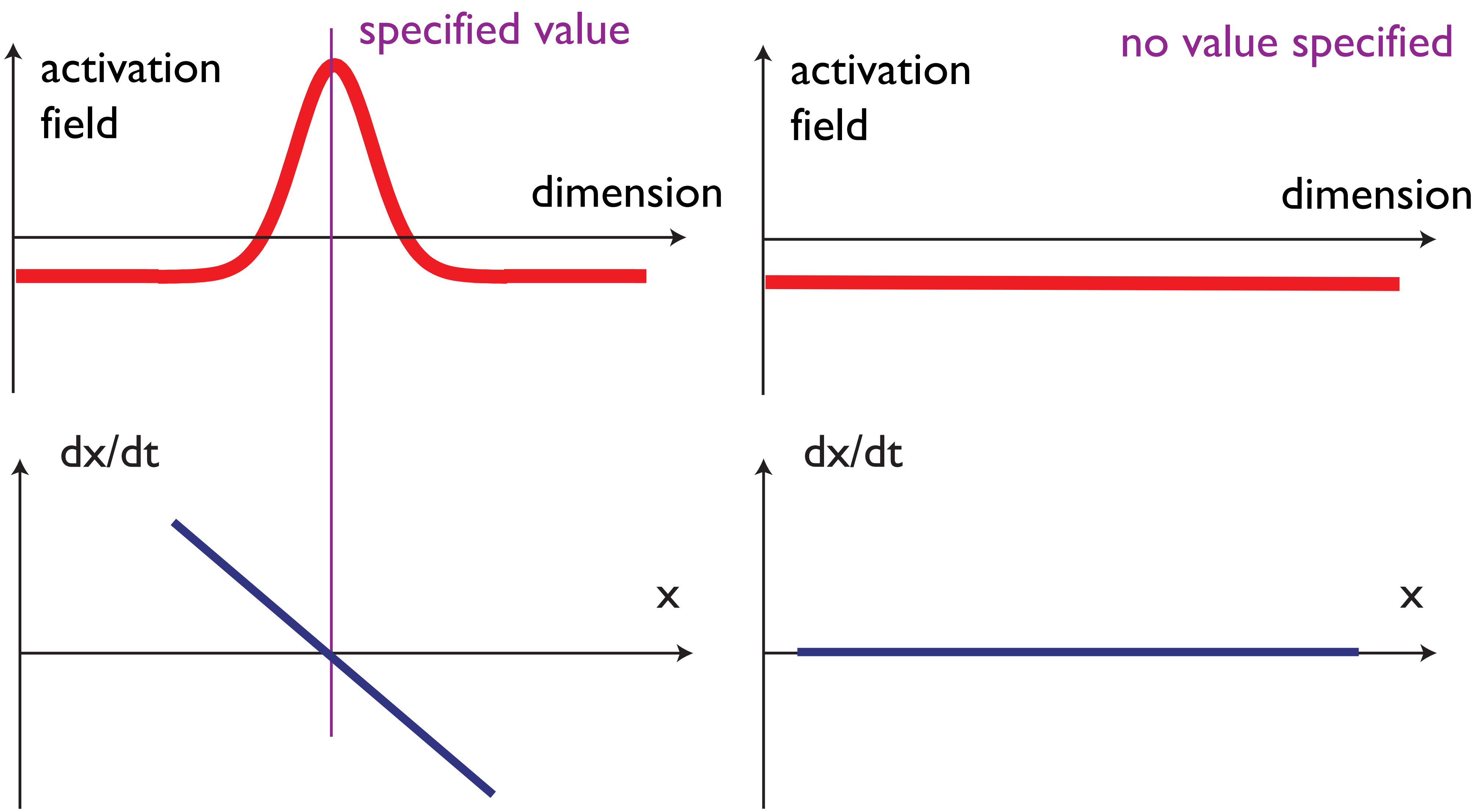


from DFT to DST

- solution: peak sets attractor
  - location of attractor: peak location
  - strength of attractor: summed supra-threshold activation

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

from DFT to DST

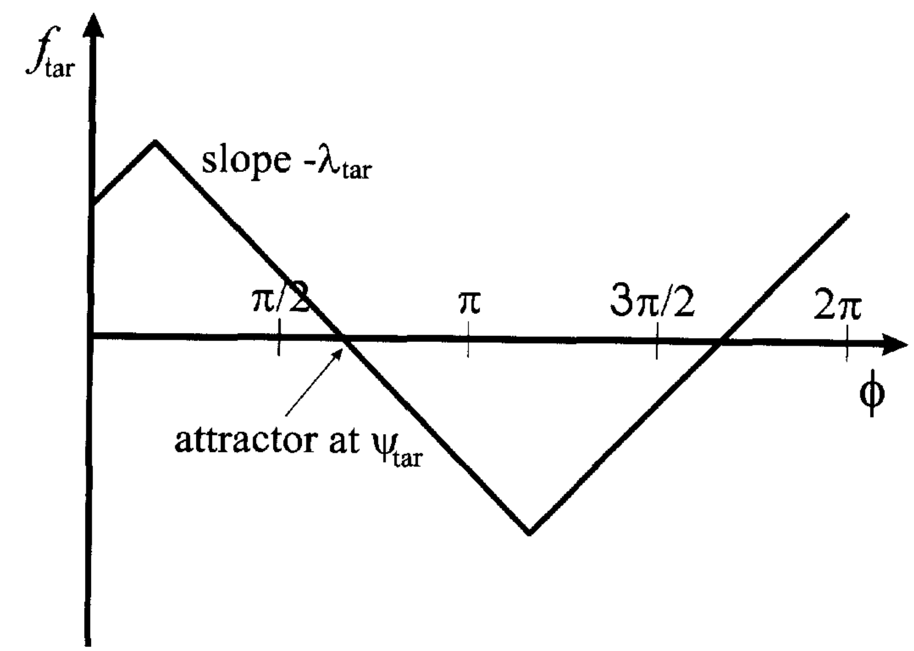


=> Bicho, Mallet, Schöner (2000)

- this is how target acquisition is integrated into obstacle avoidance on the robot

$$\frac{d\phi}{dt} = \sum_{i=1}^{7} f_{\text{obs},i} + f_{\text{tar}}.$$

$$\psi_{\text{tar}} = \int_0^{2\pi} \psi H(u(\psi)) d\psi / N_u$$



$$f_{\text{tar}} = \begin{cases} -\lambda'_{\text{tar}}(N_u\phi - \int_0^{2\pi} (H(u(\psi))\psi) d\psi) \\ \text{for } \psi_{\text{tar}} - \pi/2 < \phi \leq \psi_{\text{tar}} + \pi/2 \\ \lambda'_{\text{tar}}(N_u(\phi - \pi) - \int_0^{2\pi} (H(u(\psi))\psi) d\psi) \\ \text{for } \psi_{\text{tar}} + \pi/2 < \phi \leq \psi_{\text{tar}} + 3\pi/2 \end{cases}$$

The conceptual framework of DFT