Dynamic field theory (DFT) … attractor dynamics for perception and cognition

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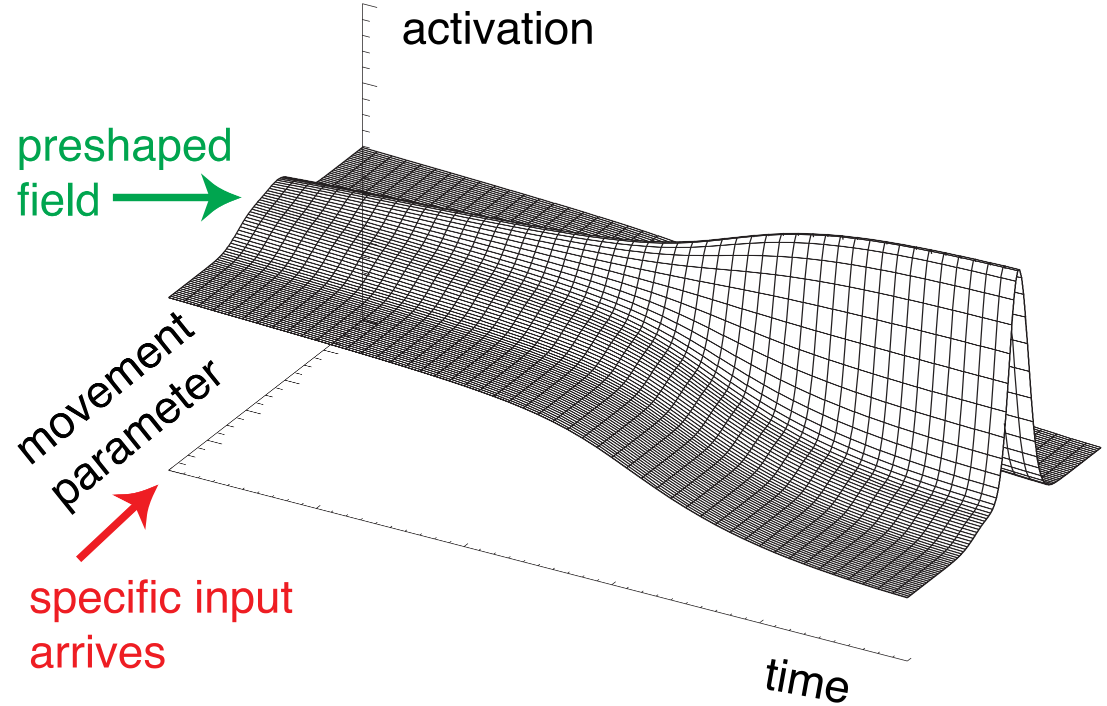
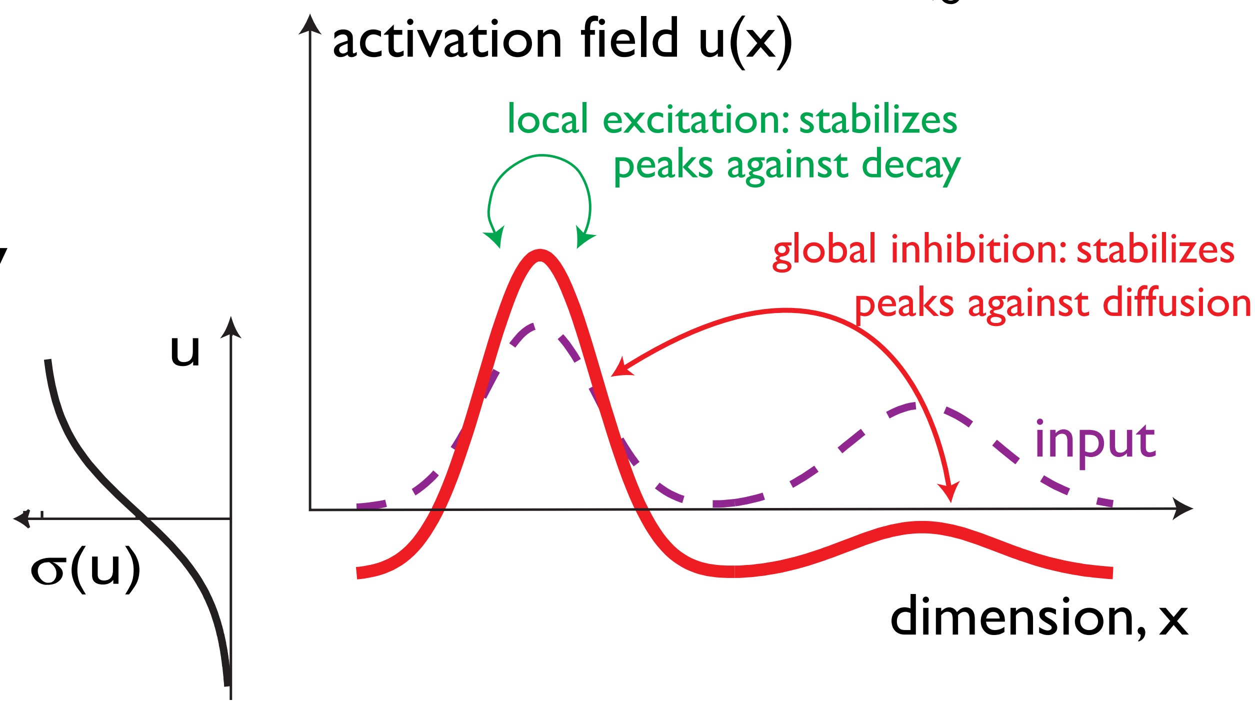
The dynamics activation fields

- field dynamics combines input
- with strong interaction:
  - local excitation
  - global inhibition
- => generates stability of peaks





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

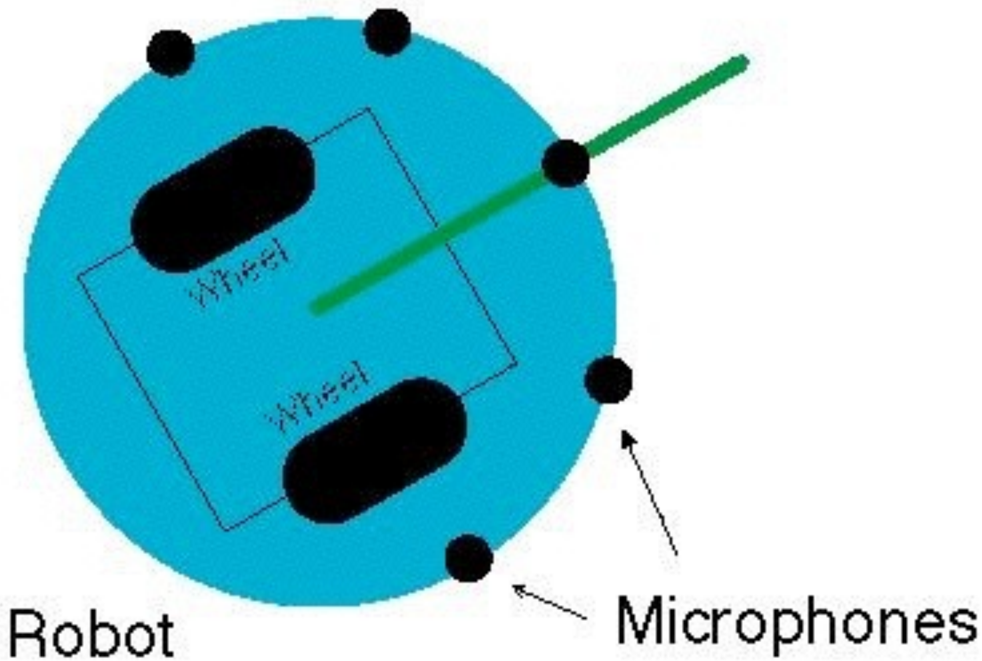
$$\sigma(u) = \frac{1}{1+\exp[-\beta(u-u_0)]}$$

=> simulations

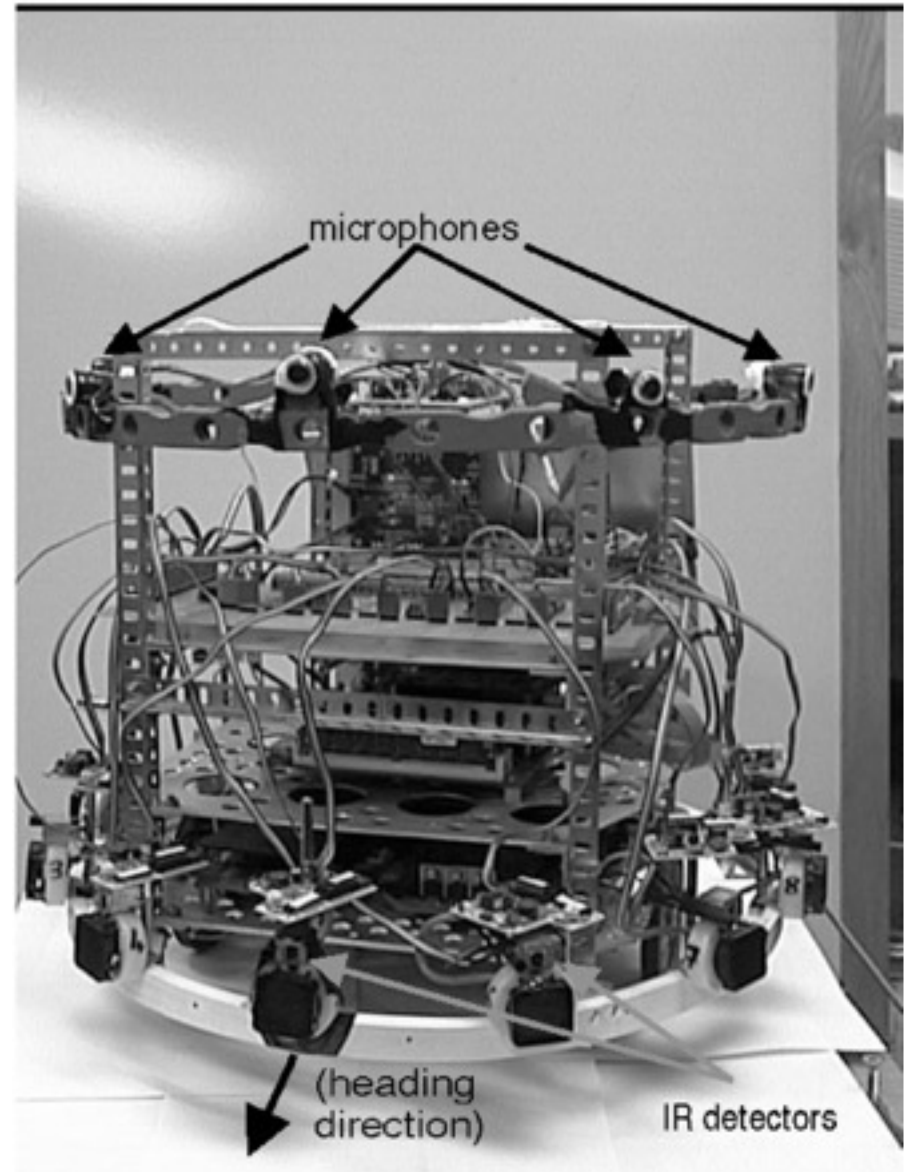
=>

- attractor states
  - input driven solution (sub-threshold)
  - self-stabilized solution (peak, supra-threshold)
- instabilities
  - detection instability (from localize input or boost)
  - reverse detection instability
  - selection instability
  - memory instability

Vehicle

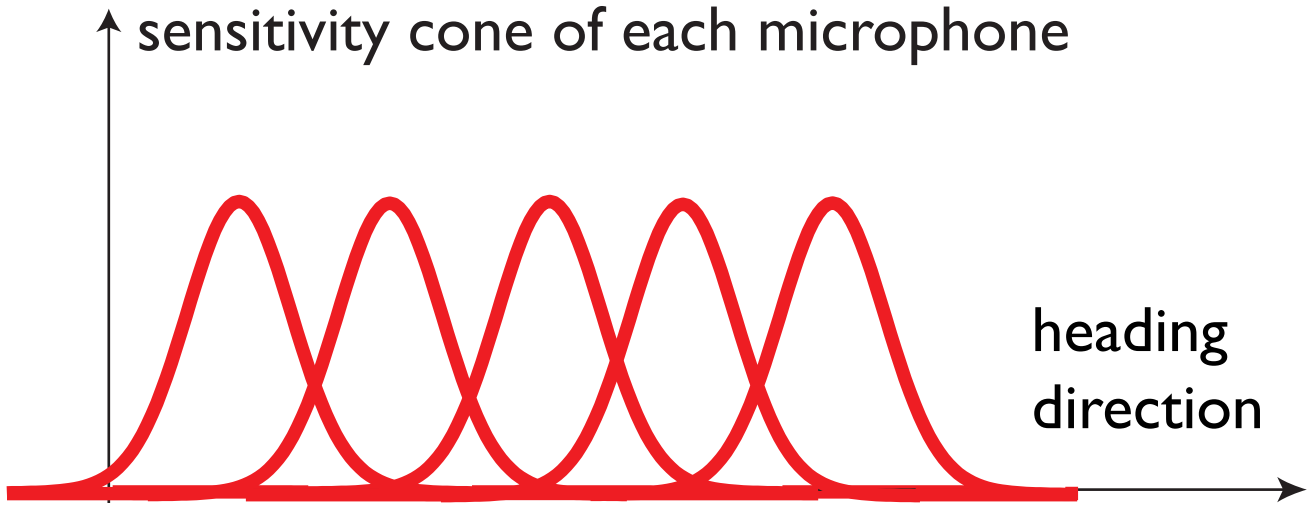


[from Bicho, Mallet, Schöner, Int J Rob Res,2000]

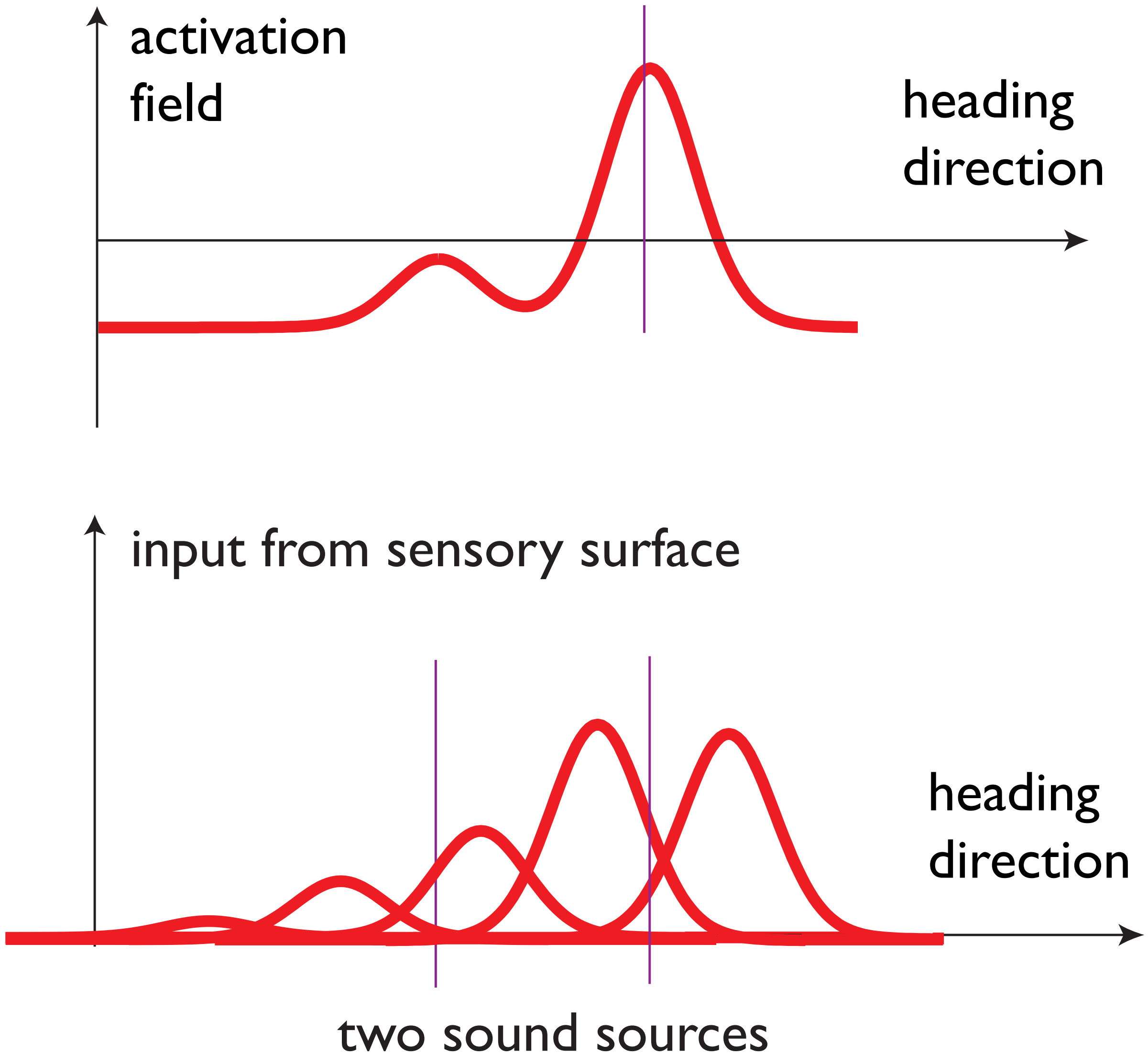


sensory surface

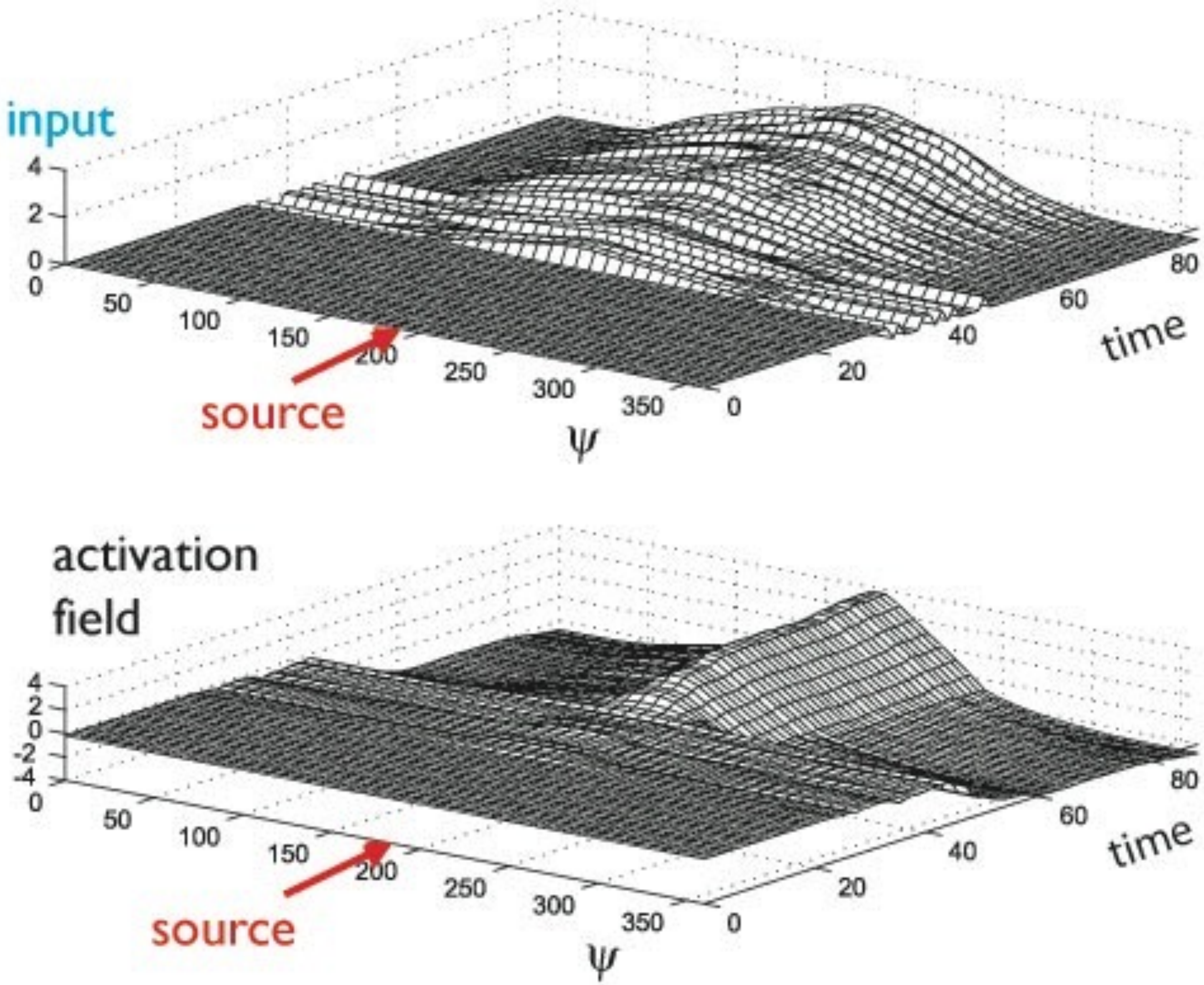
- each microphone samples heading direction

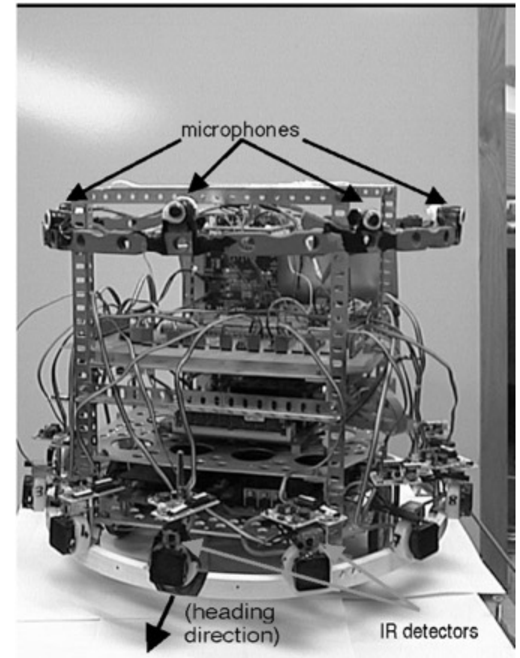


and provides input to the field



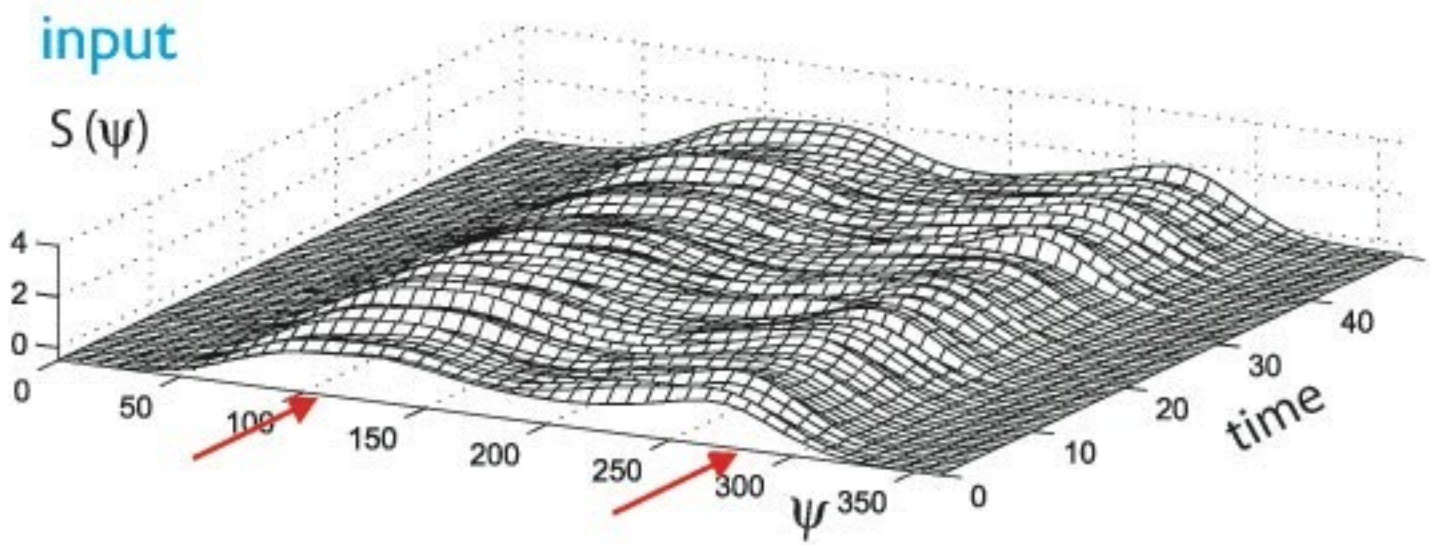
detection instability on a phonotaxis robot

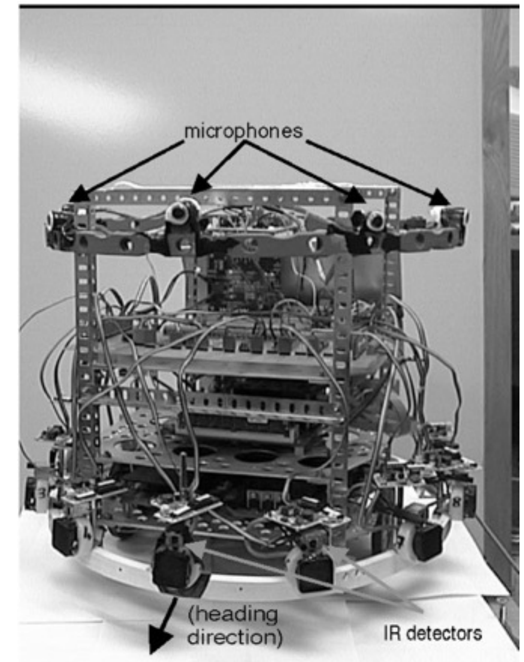


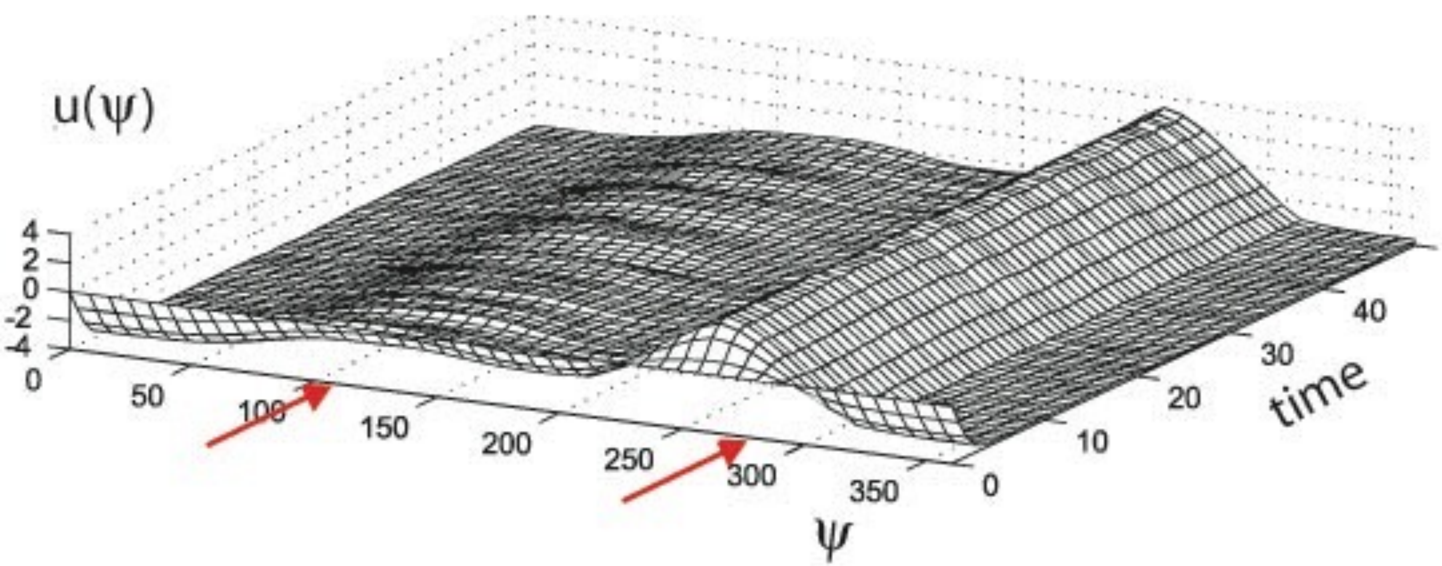


[from Bicho, Mallet, Schöner: Int. J. Rob. Res., 2000]

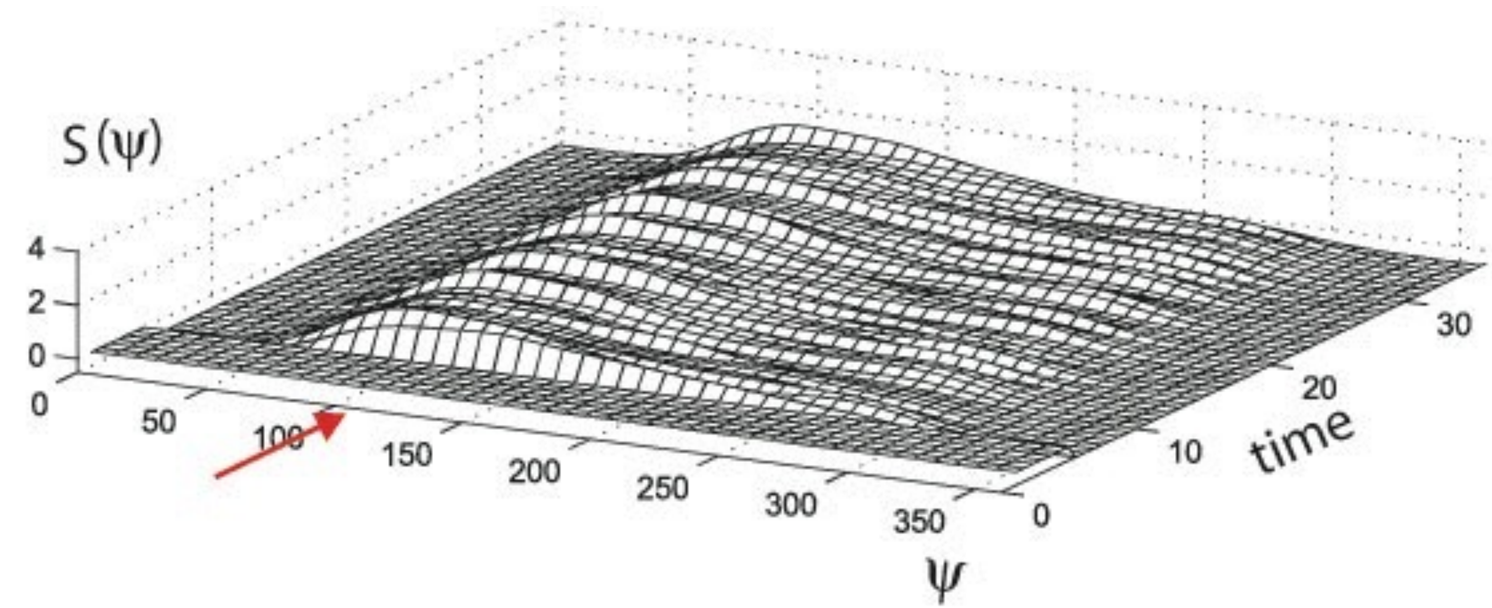
target selection on phonotaxis vehicle

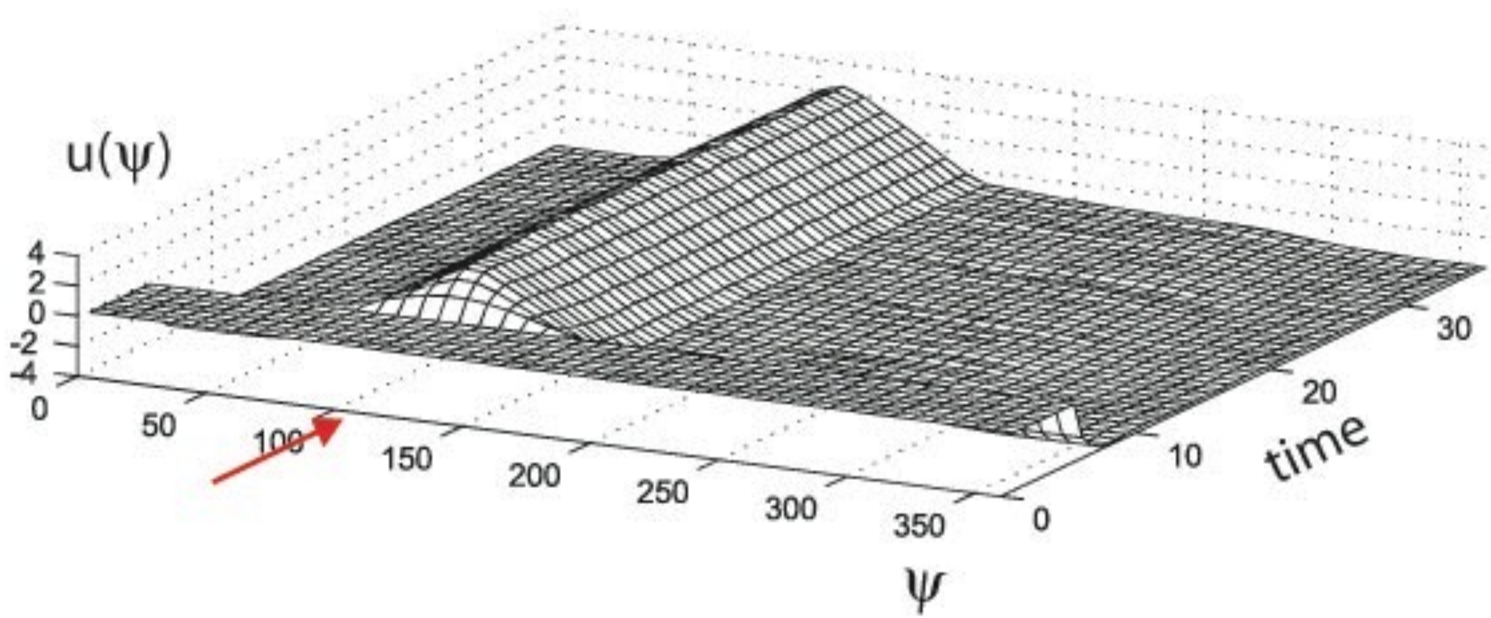




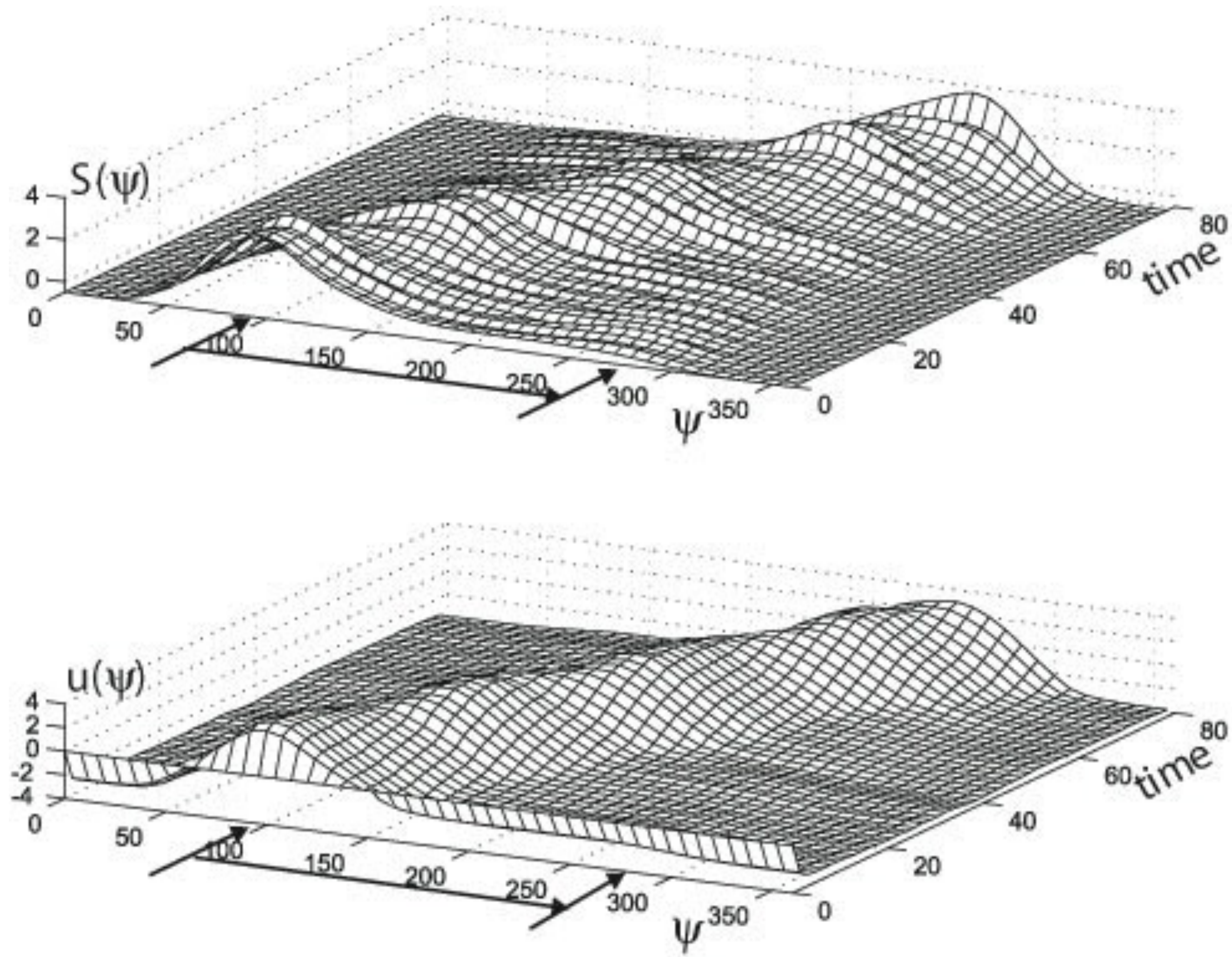


robust estimation





tracking



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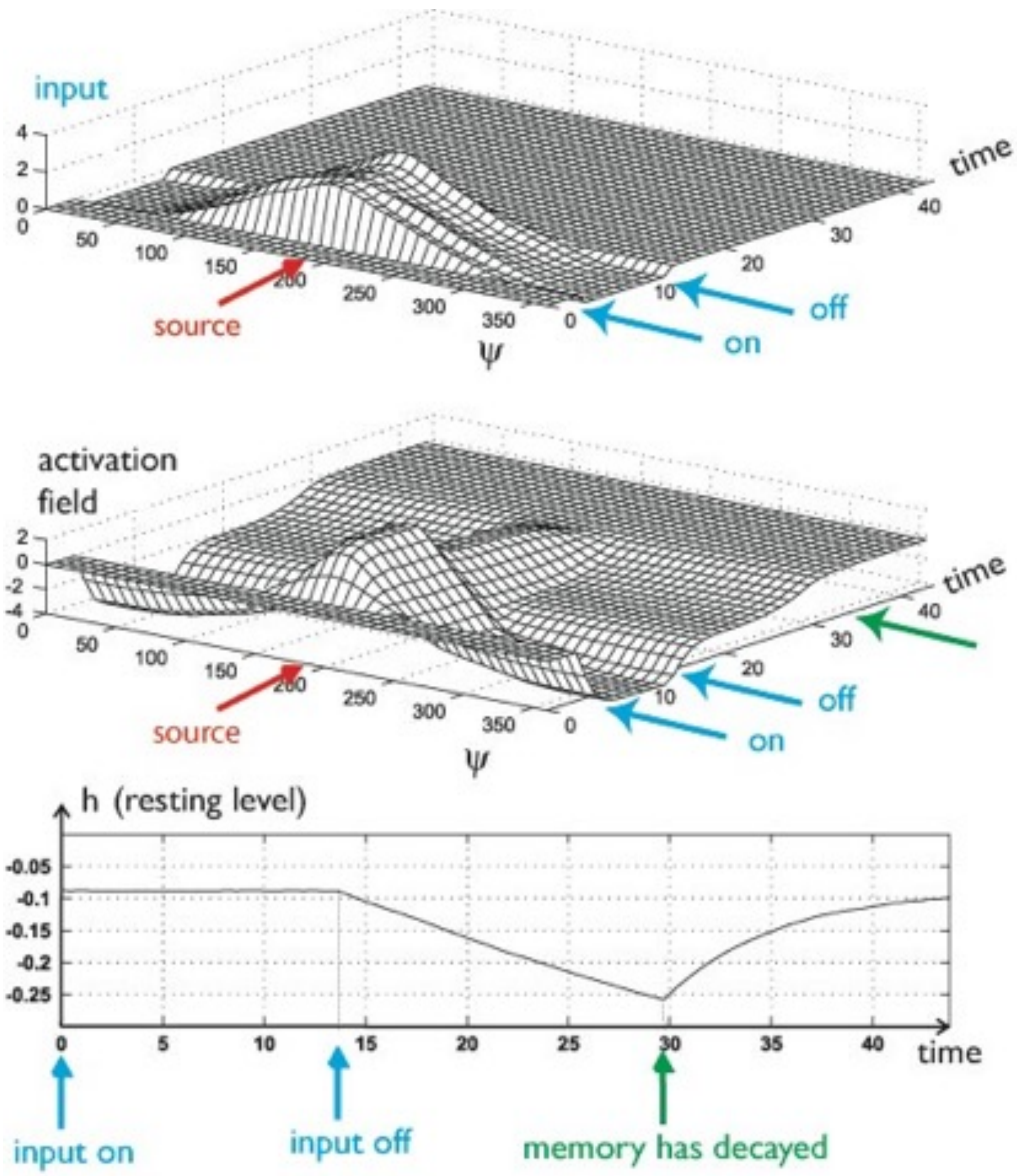
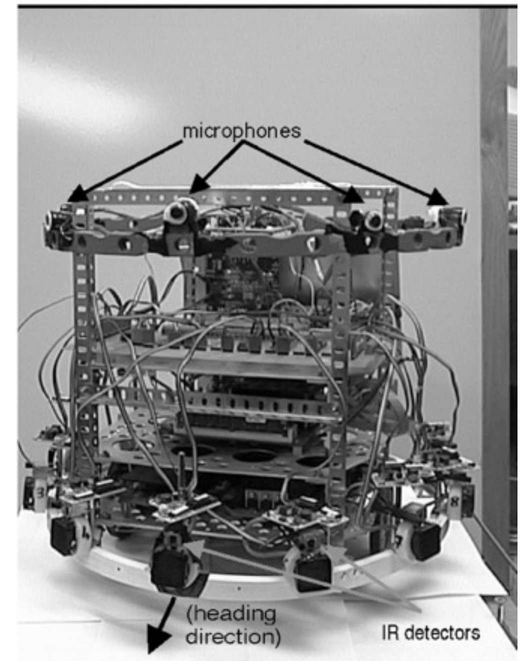
60
80
time

memory & forgetting on phonotaxis vehicle



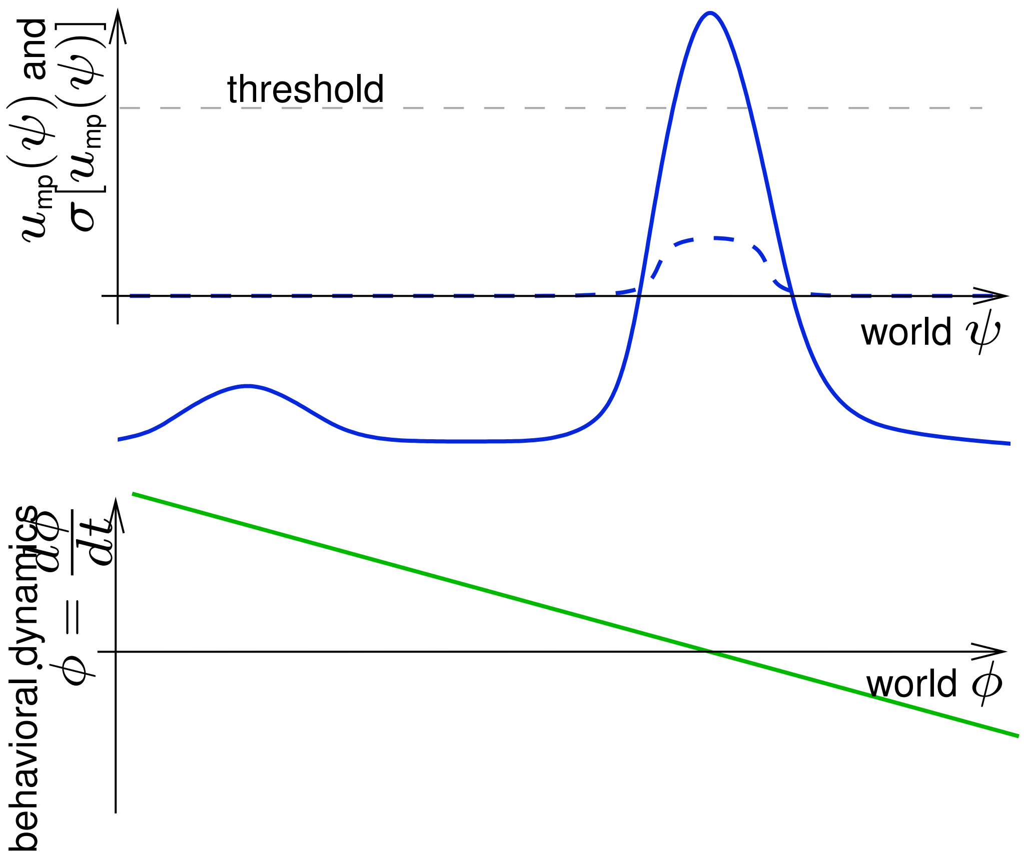


[from Bicho, Mallet, Schöner: Int J Rob Res 19:424(2000)]

a robotic demo of all of instabilities

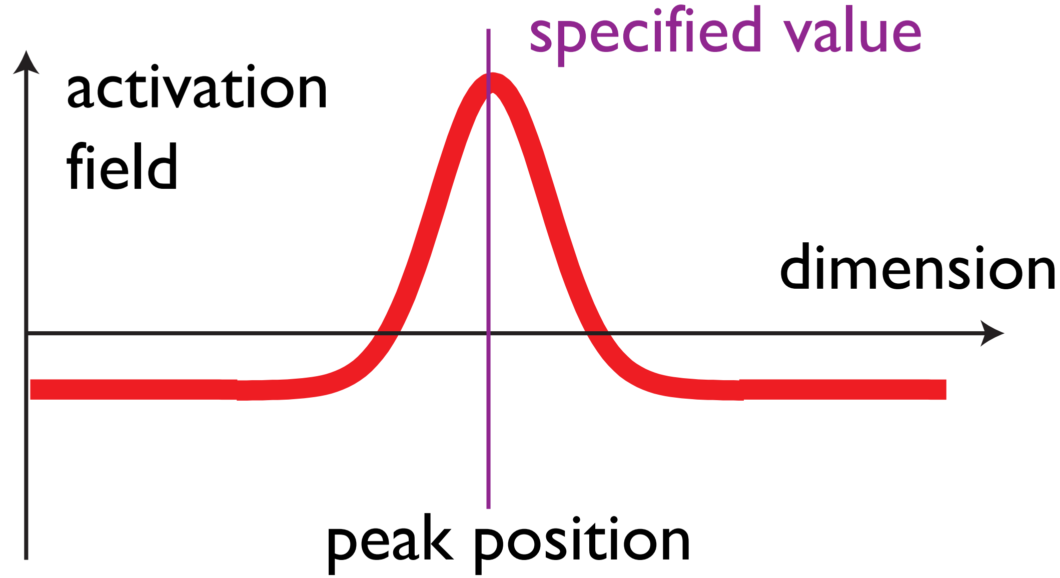
back to attractor dynamics of heading

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



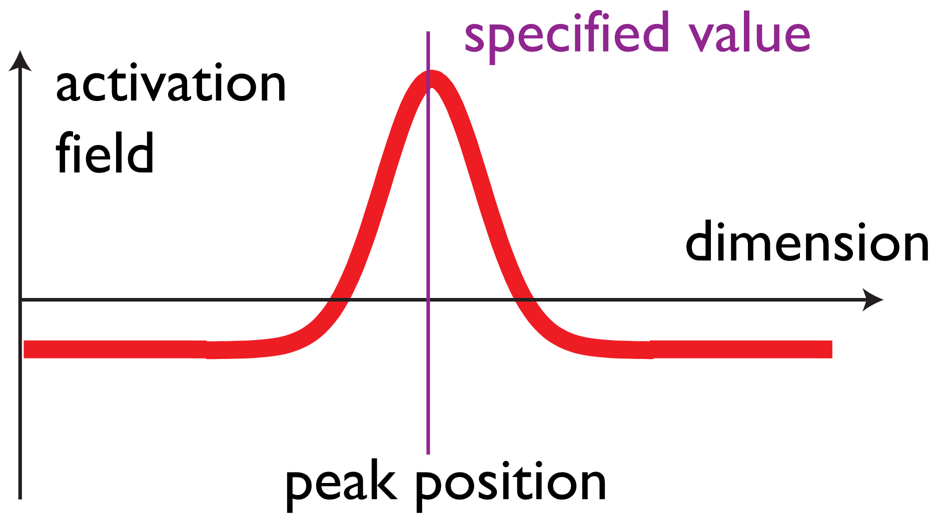
=> transition from DFT to DST

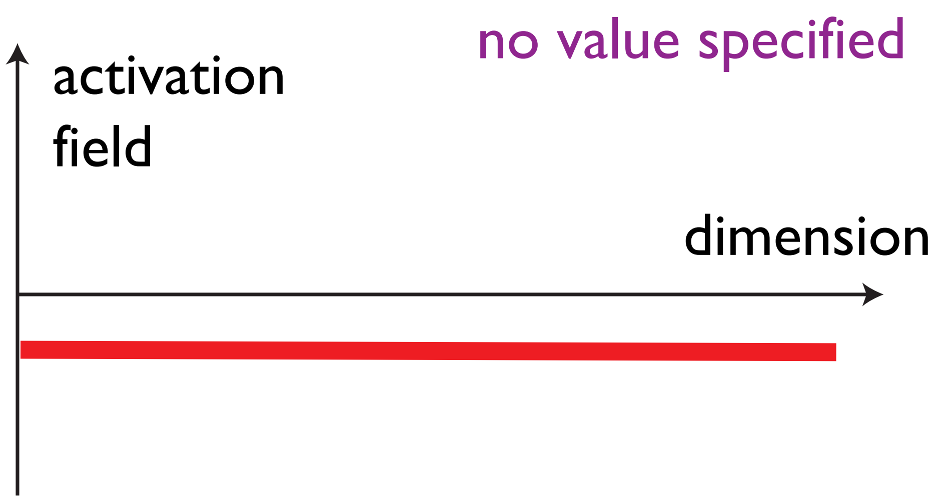
- peak specifies value for a dynamical variable that is congruent to the field dimension



from DFT to DST

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



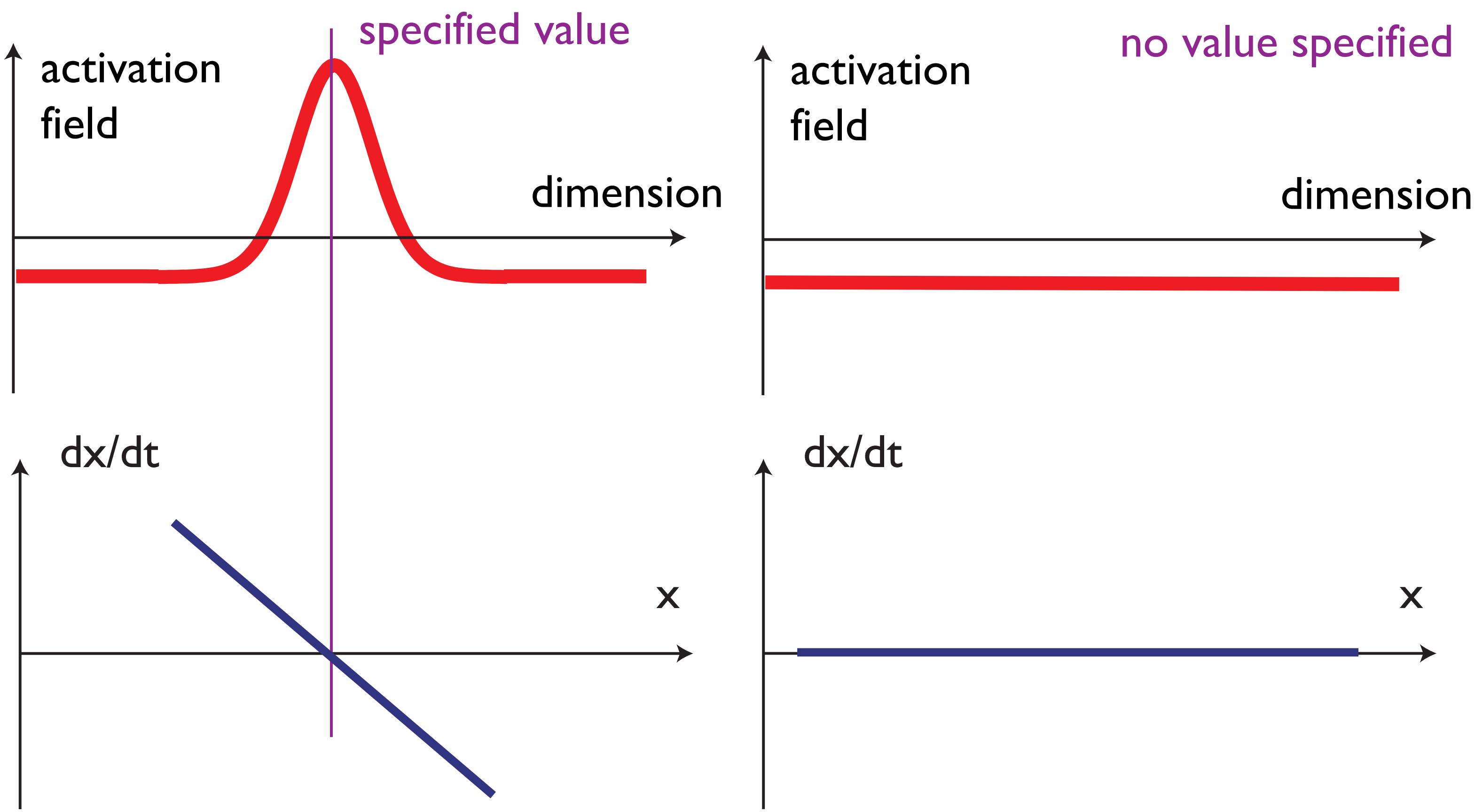


from DFT to DST

- 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

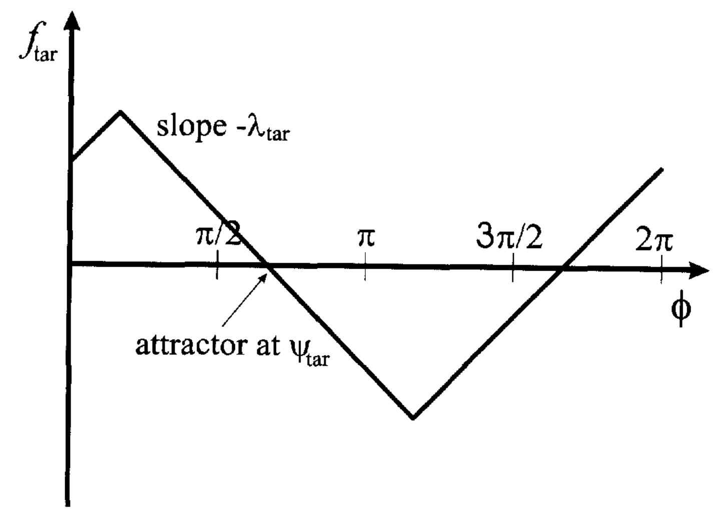


=> Bicho, Mallet, Schöner (2000)

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

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

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



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

Conclusion

- Neural dynamics for the inner loops that endow perception and cognition with stability
- Behavioral dynamics for the outer loops that generate behavior in closed loop….
- So far: all in closed loop: sensor moves with the actuator…
- Next: look at situations in which that is not the case: grasp an object…