DFT embodied

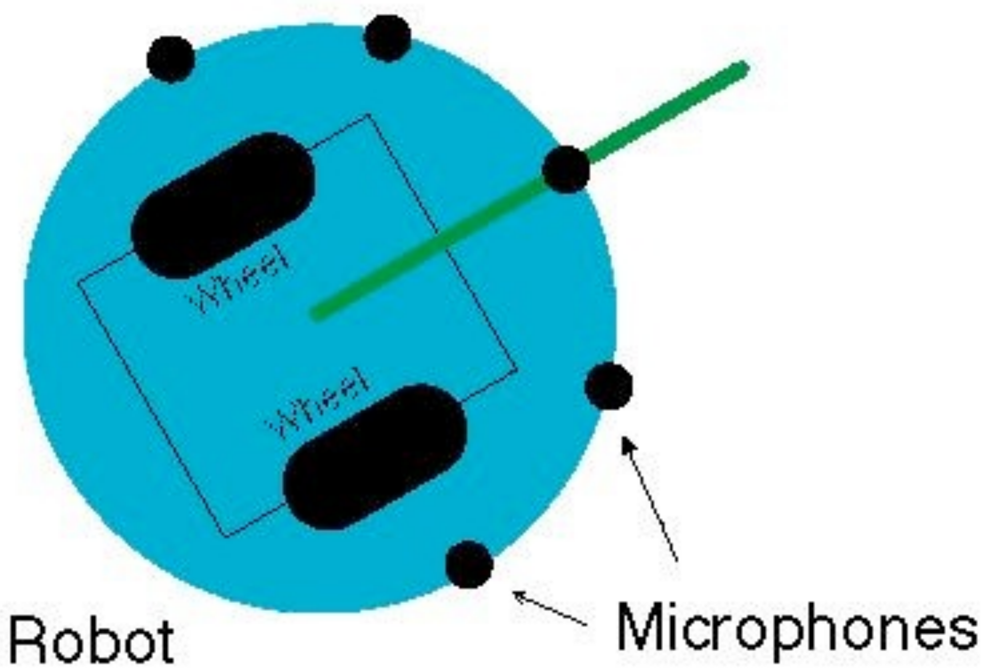
Gregor Schöner, INI, RUB

Goal

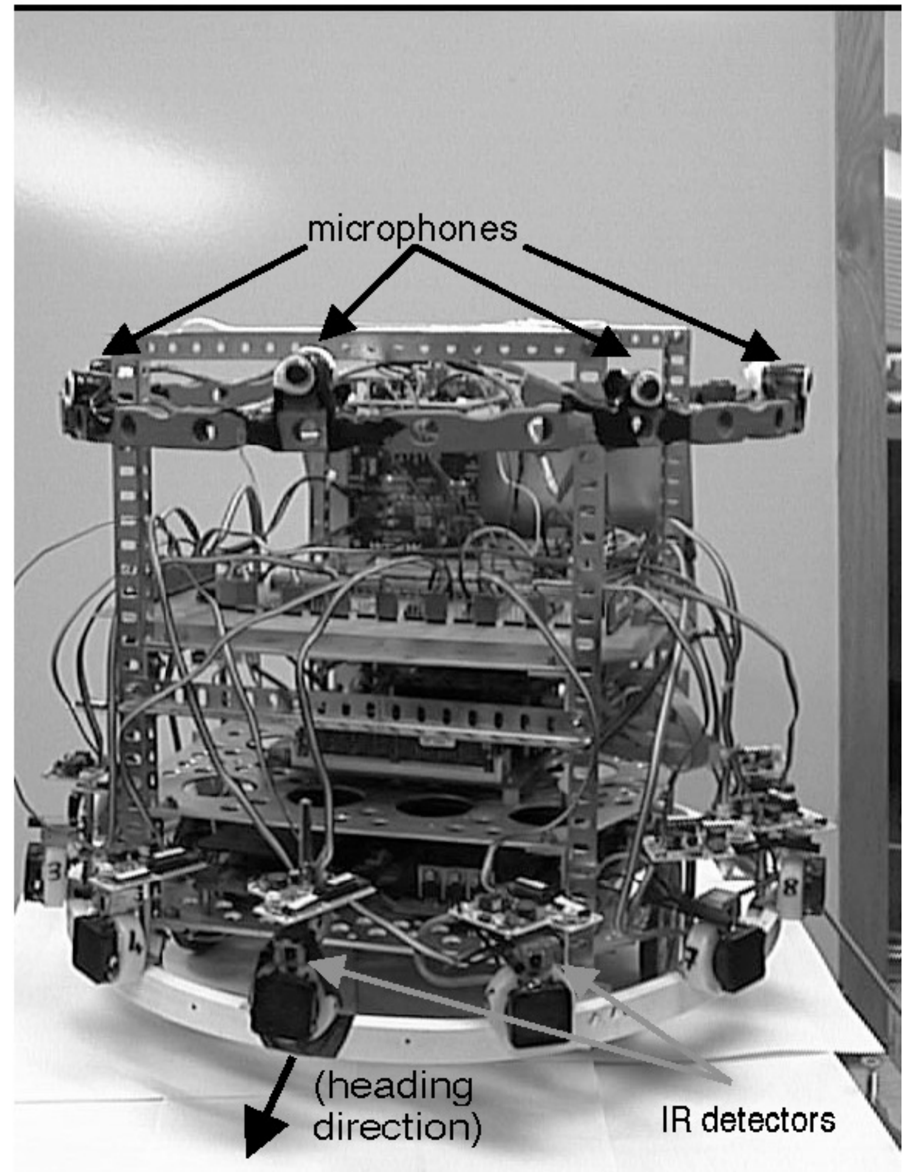
- show how
  - 1) neural dynamic fields can be coupled to time-varying sensory inputs
  - 2) neural dynamic fields can control motor systems in closed loop

Driving fields from sensory signals

- robot that orients toward sound sources

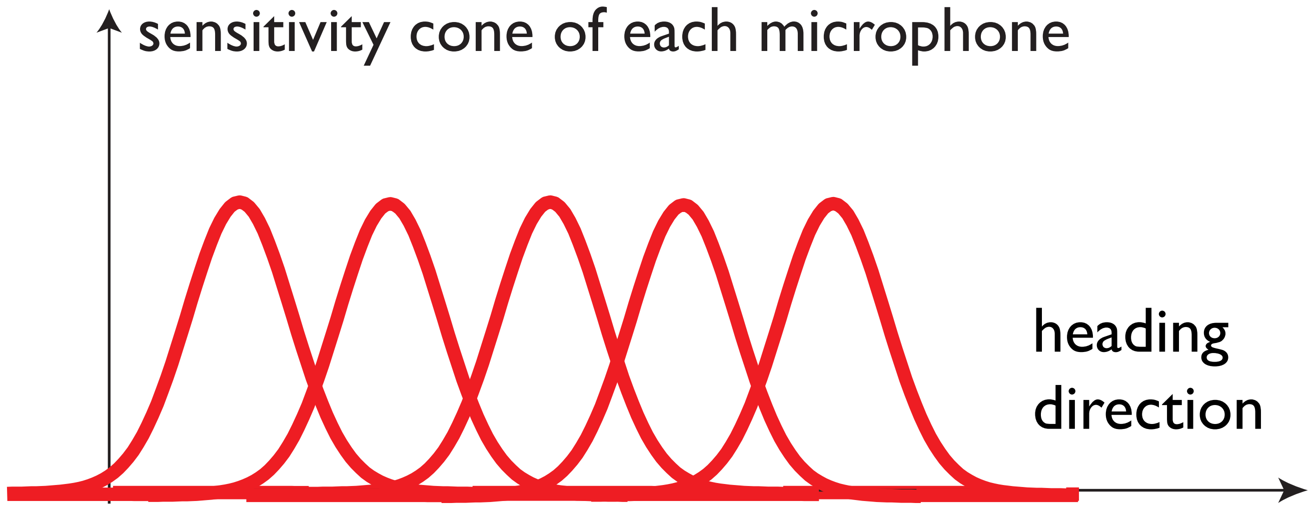


[from Bicho, Mallet, Schöner, Int J Rob Res,2000]



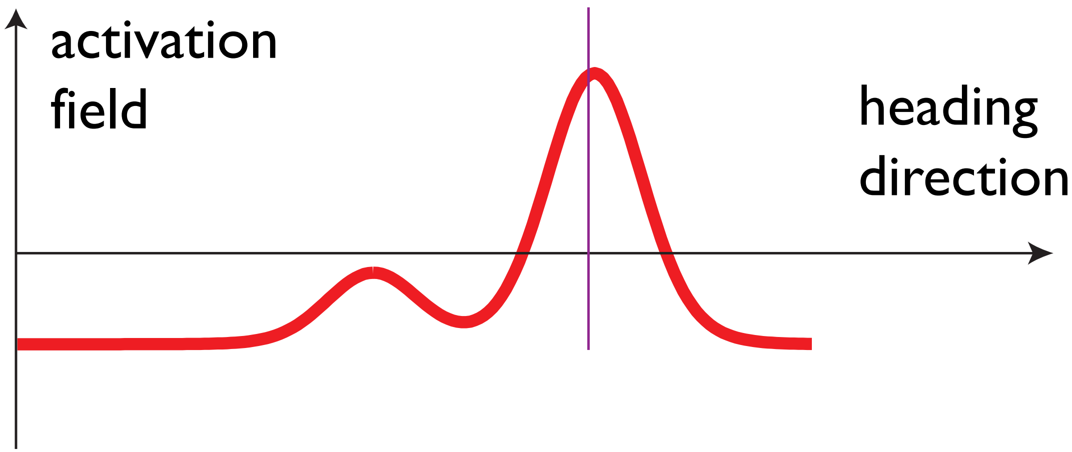
Sensory surface

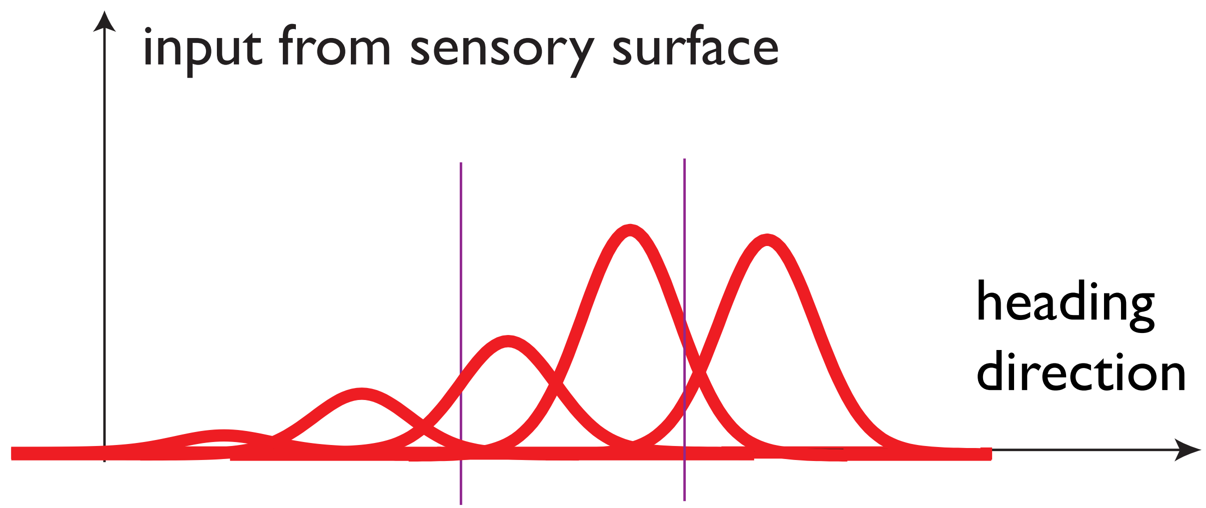
- each microphone samples heading direction



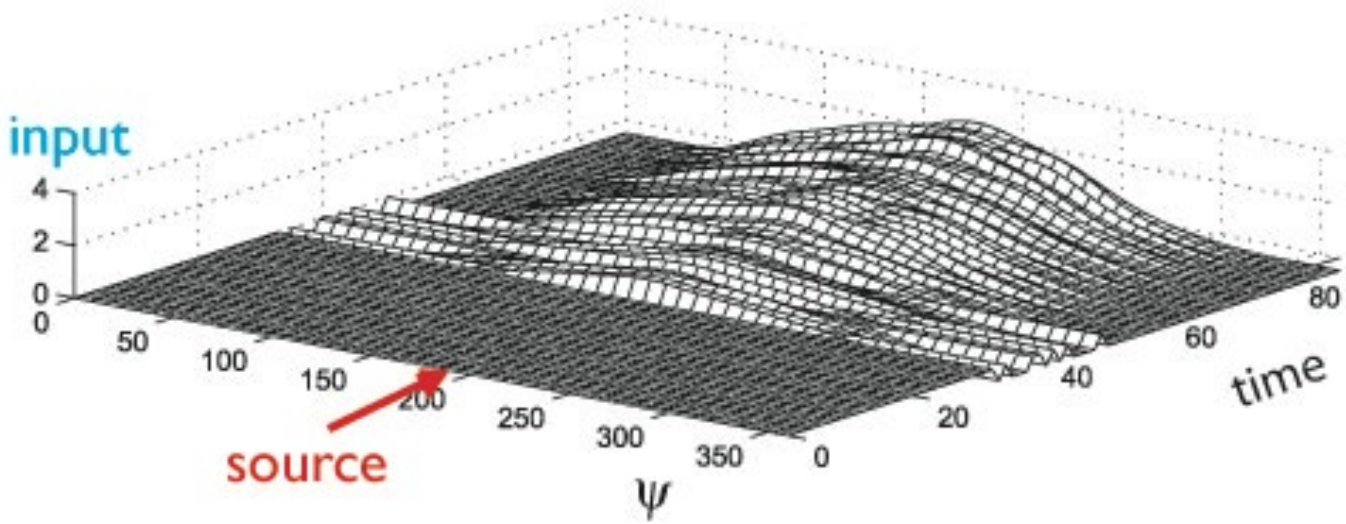
Sensory input

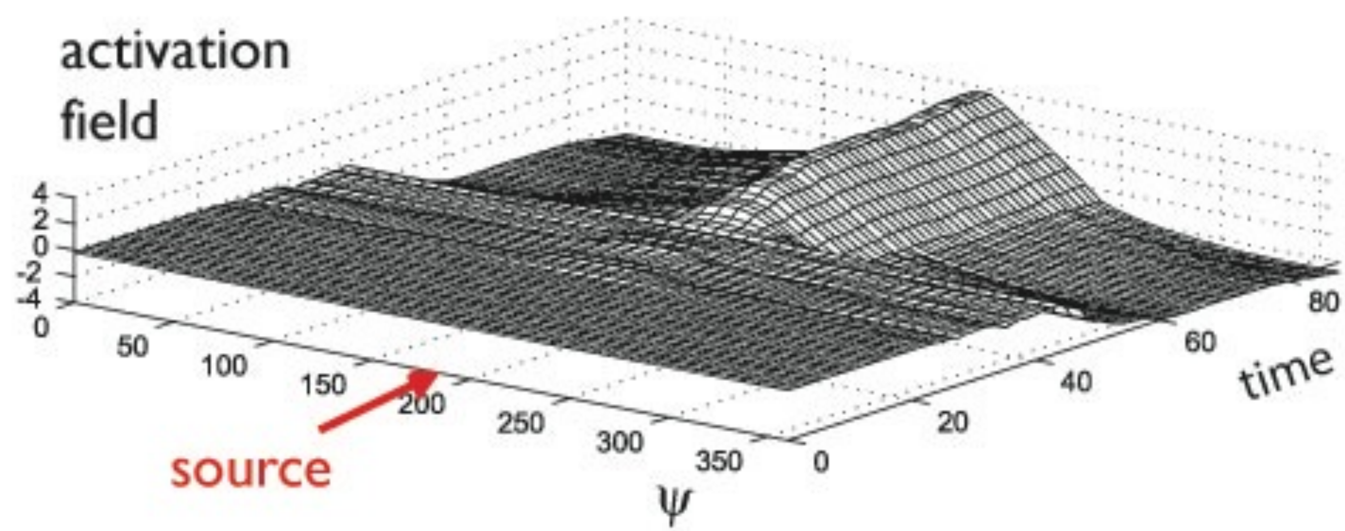
- each microphone provides input to the field = loudness * sensitivity cone



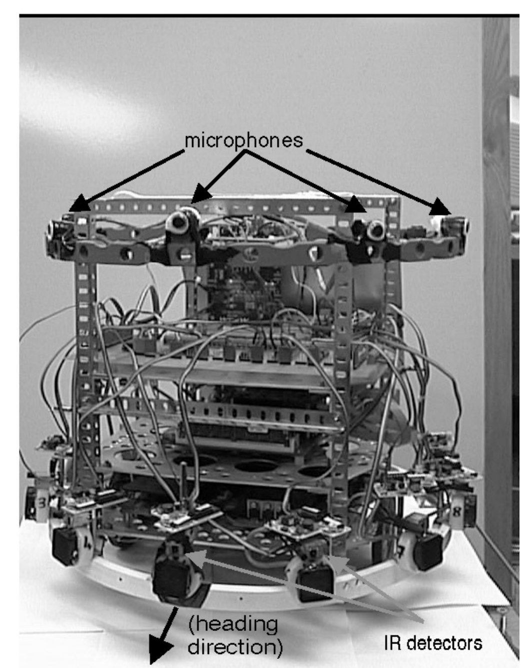


Detection instability as intensity of sound source increases

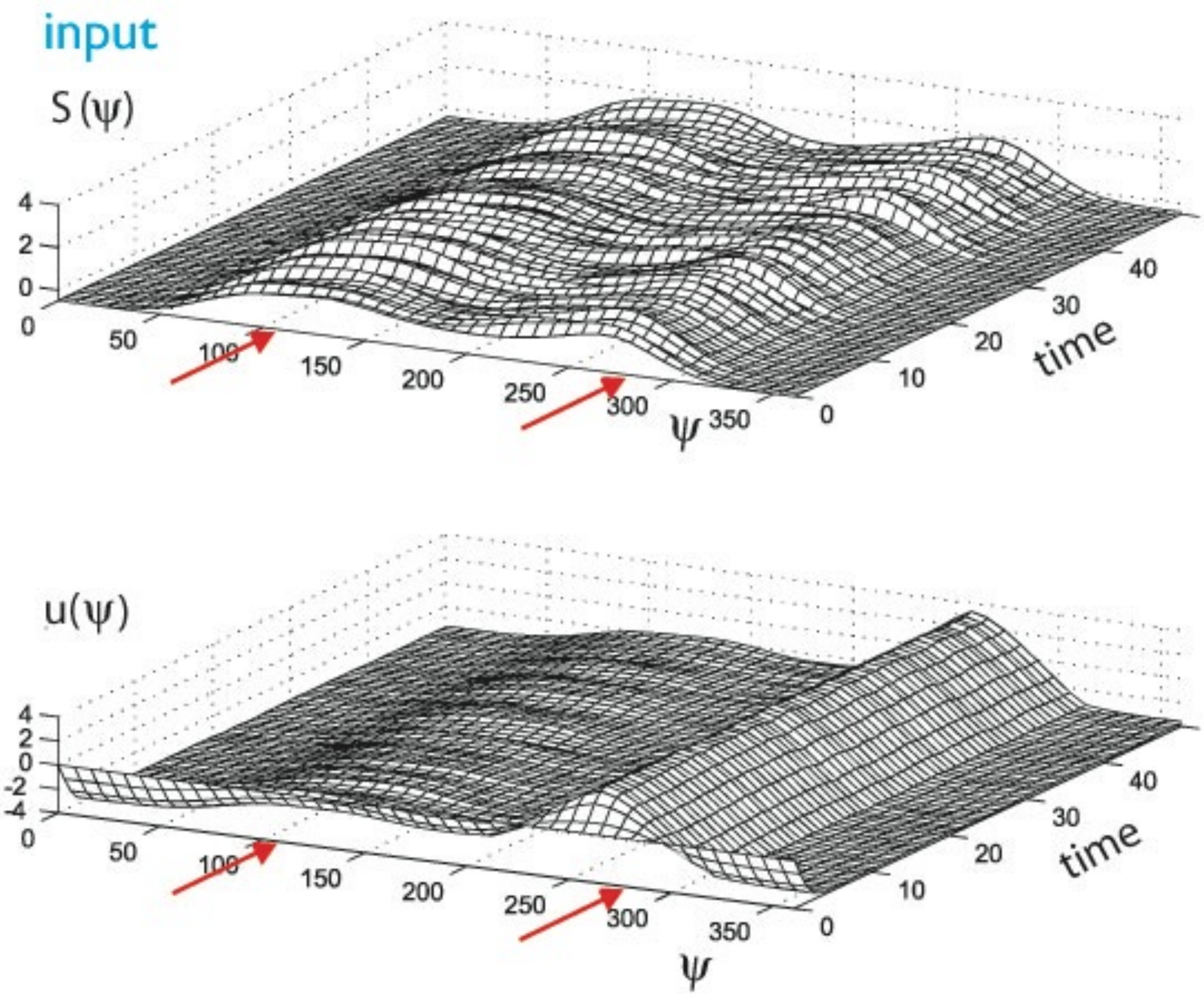




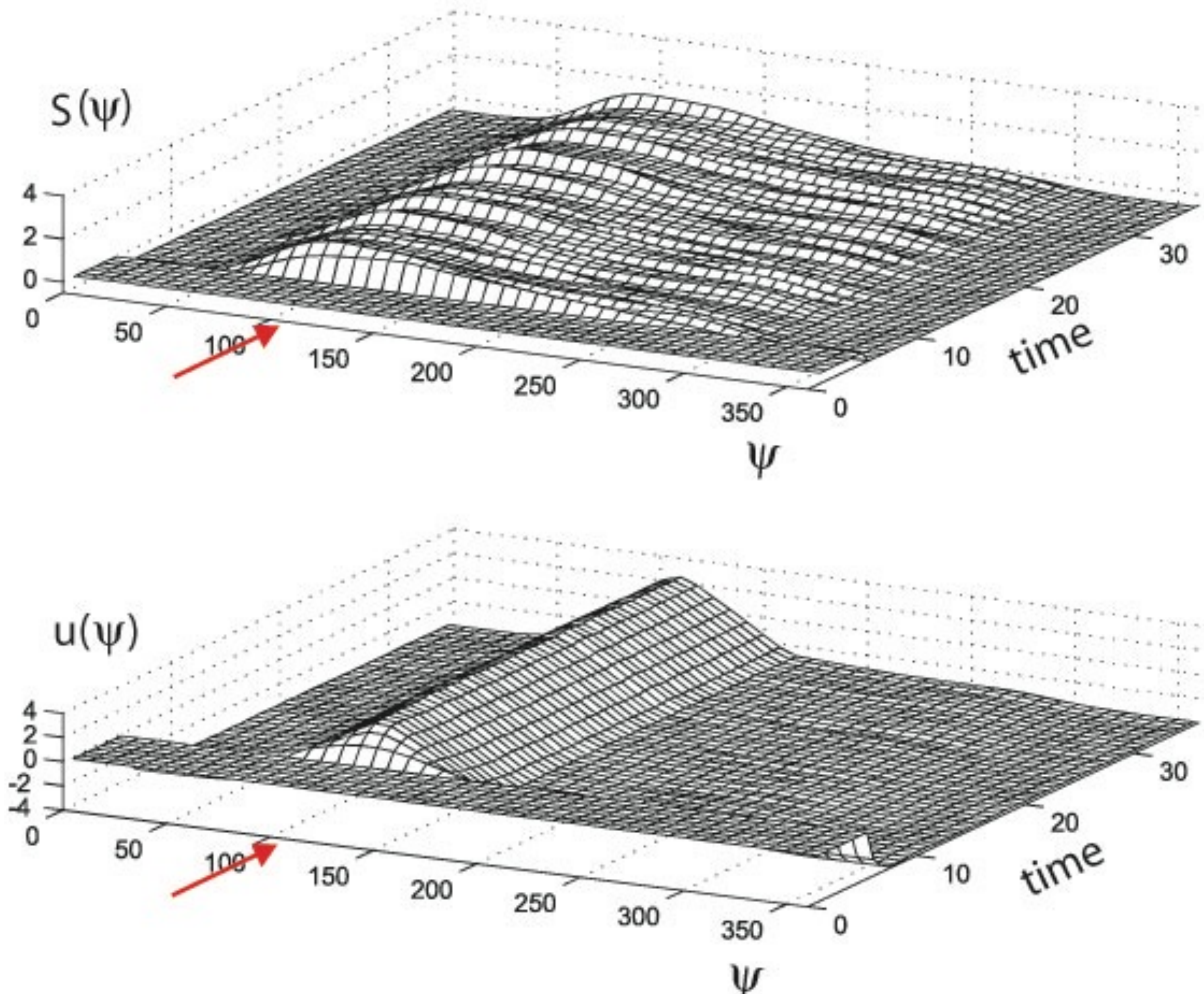
[from Bicho, Mallet, Schöner: Int. J. Rob. Res., 2000]



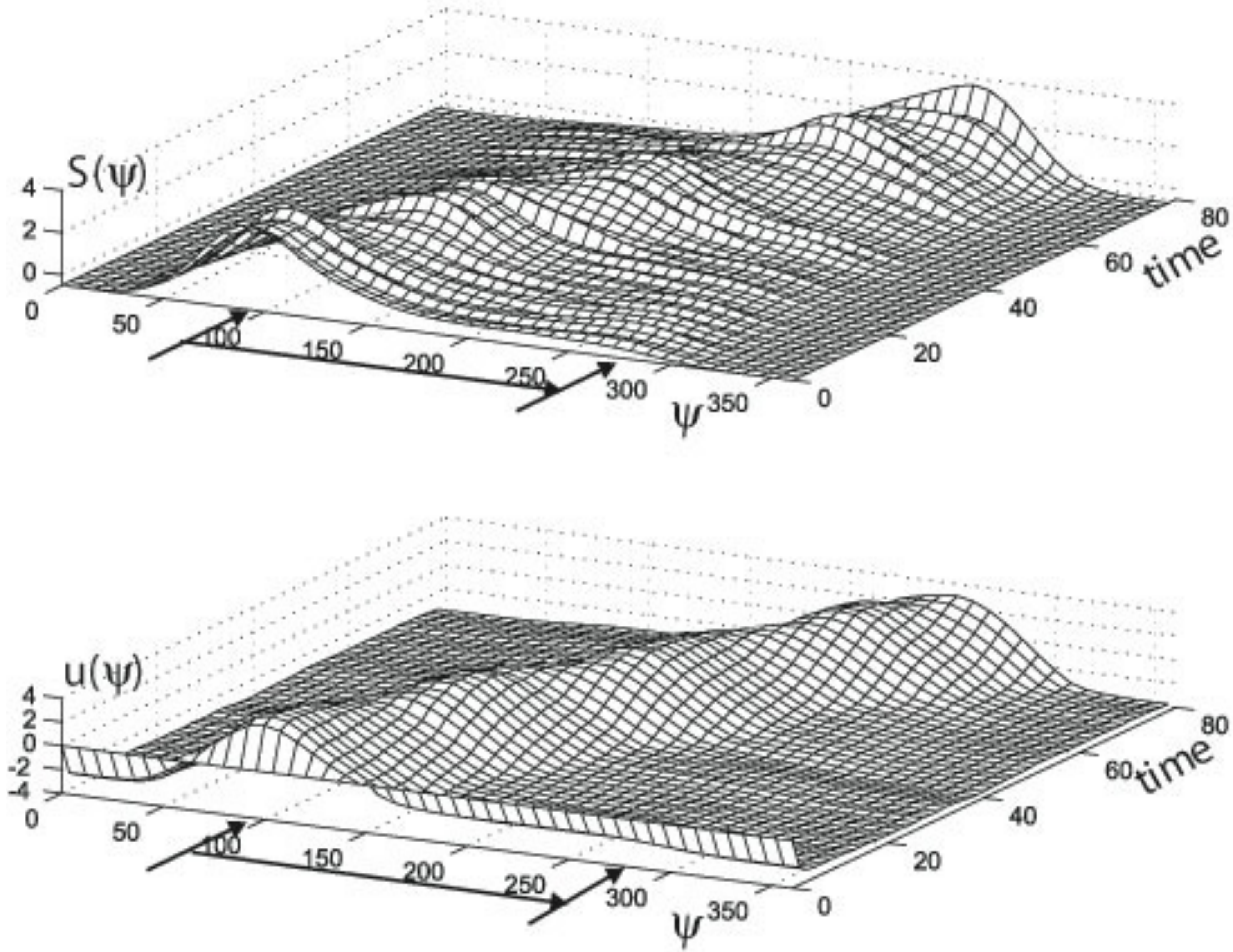
Target selection in the presence of two sources



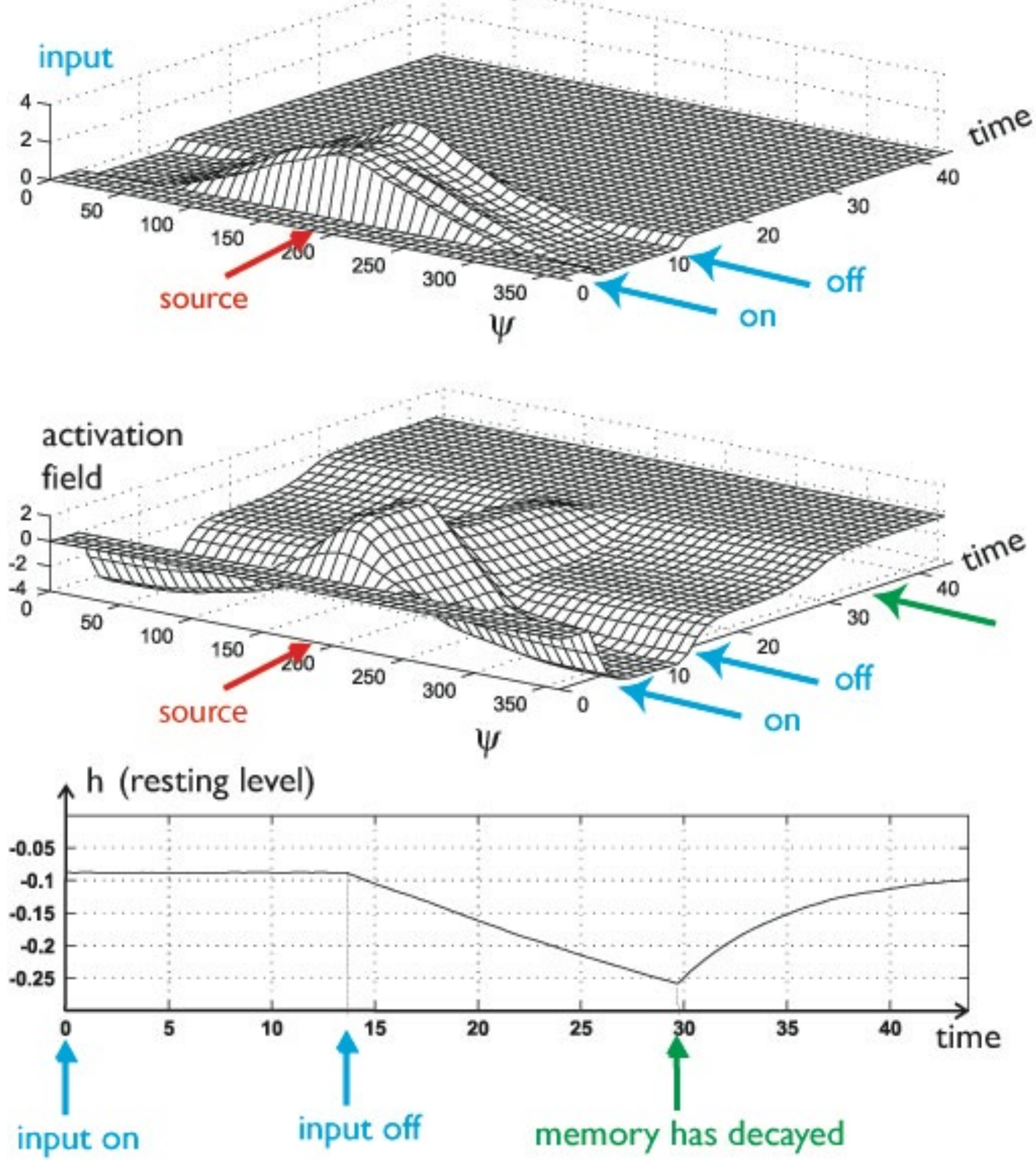
Robust estimation in the presence of outliers



Tracking moving sound source



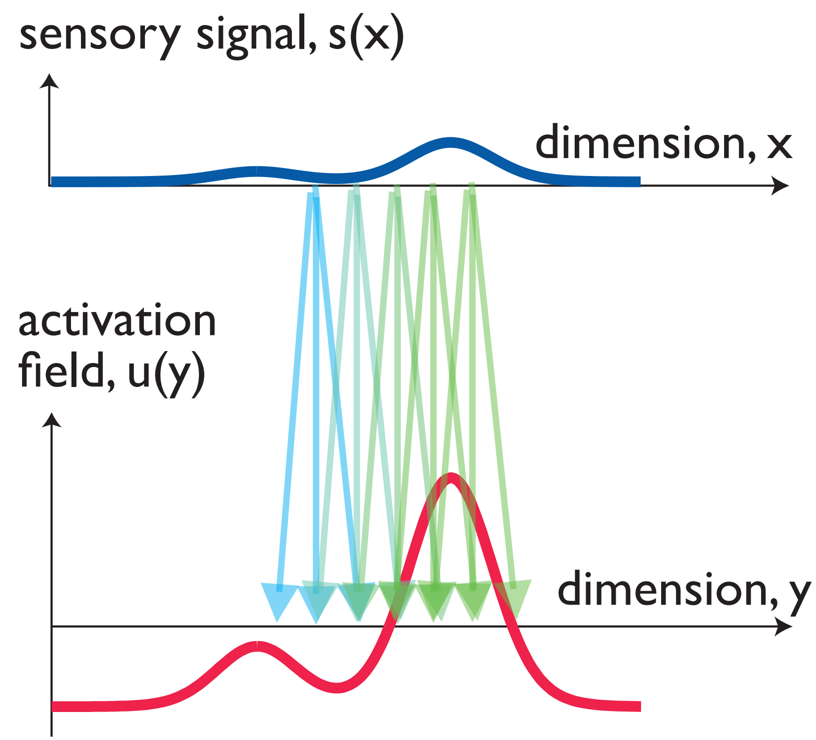
Working memory



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

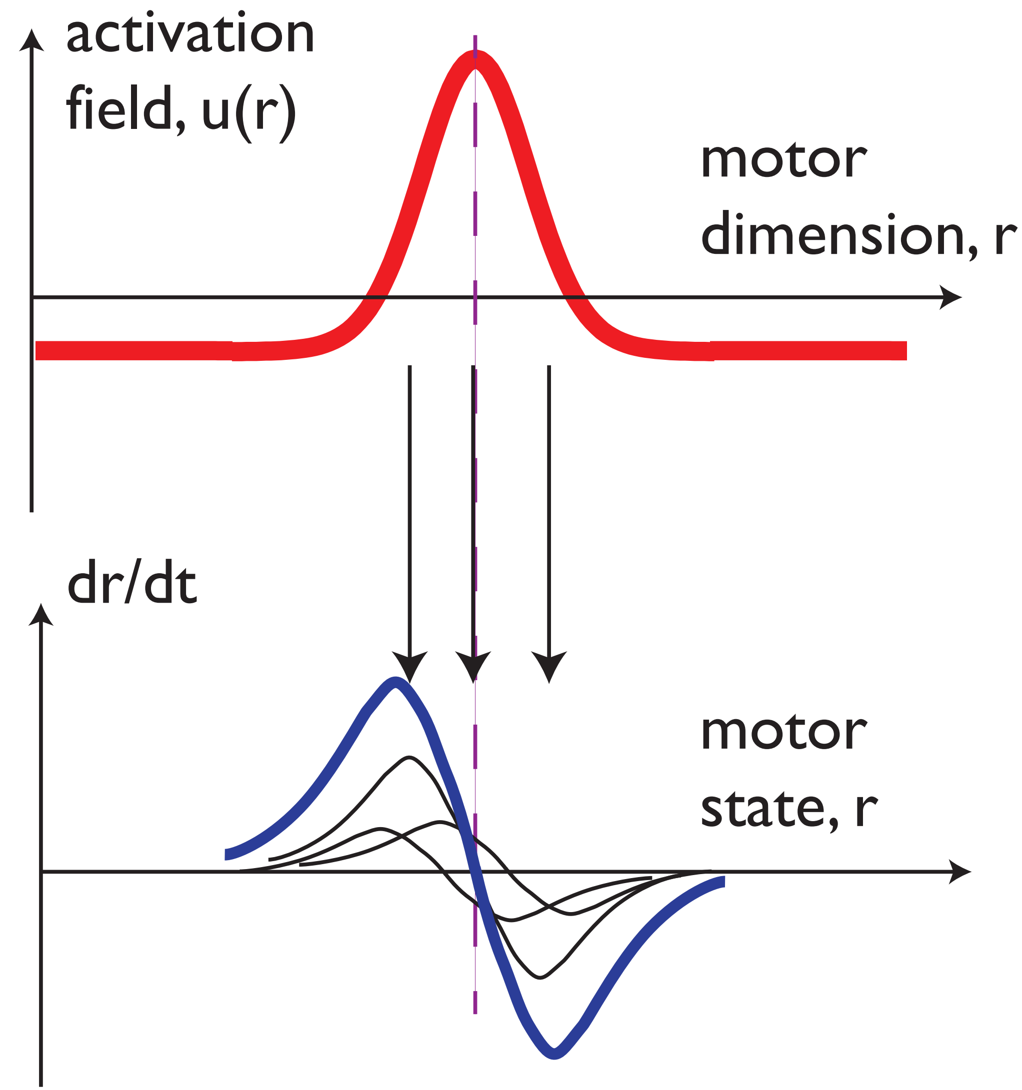
Conclusion 1

- Neural dynamic fields can be directly driven from time-varying sensory inputs
- the attractor states and their bifurcations enable
  - detection
  - robust estimation, tracking
  - selection
  - working memory



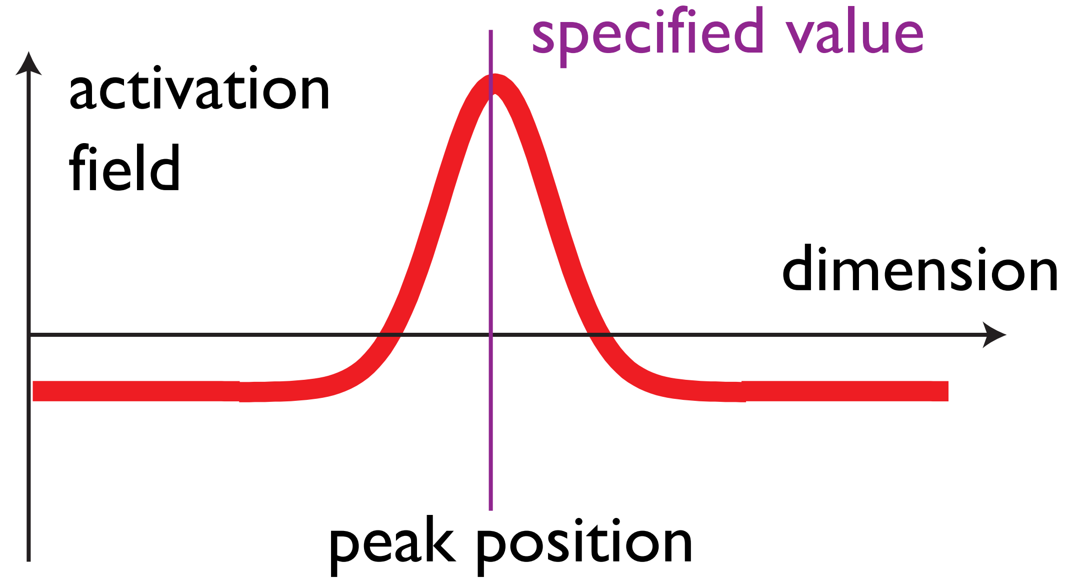
How may neural dynamic fields generate the behavior?

- challenge 1: generating behavior involves "behavioral dynamics" (Braitenberg)



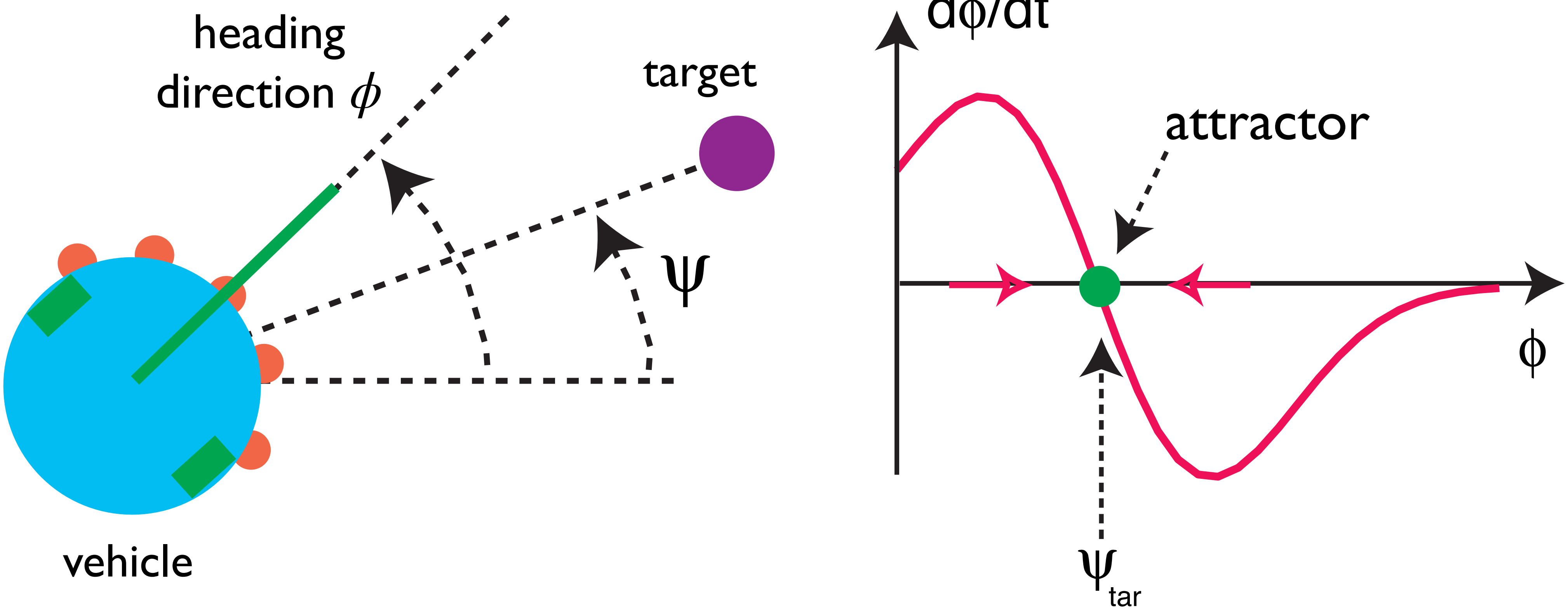
How may neural dynamic fields generate the behavior?

- note the mere "reading out" of a peak's location…



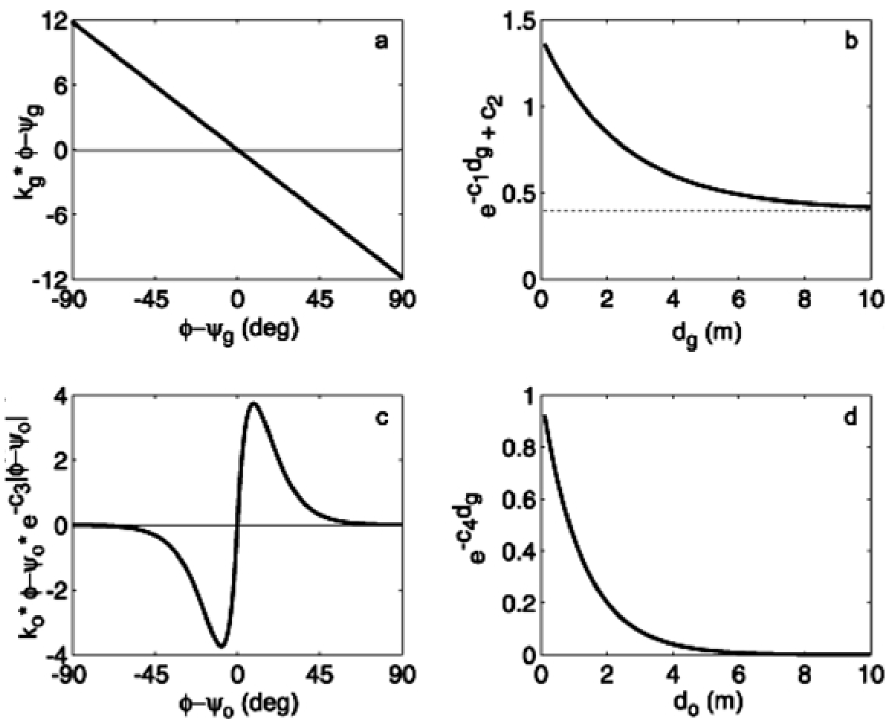
Generating behavior entails dynamics

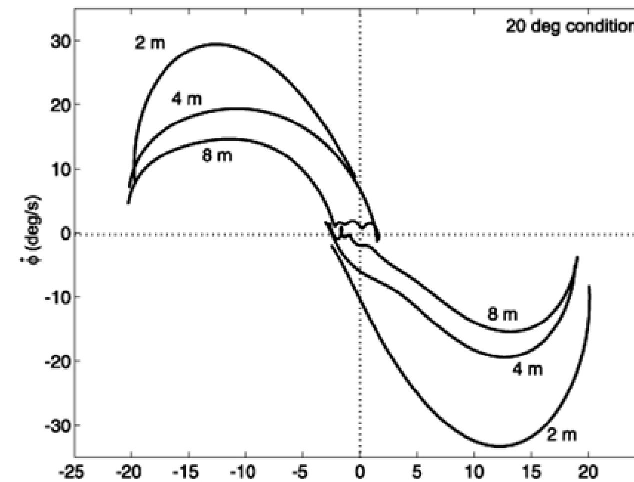
- behavioral dynamics of a vehicle
- with an attractor at desired heading

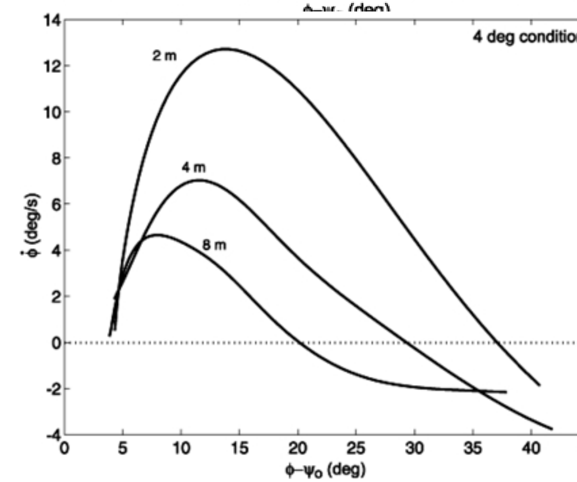


Human locomotion described by dynamics of heading direction

- humans walking in virtual reality under the influence of targets and obstacles



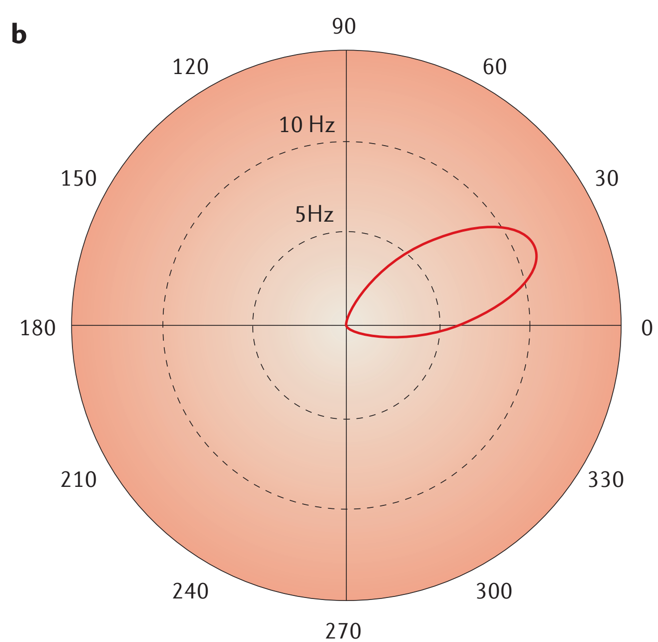


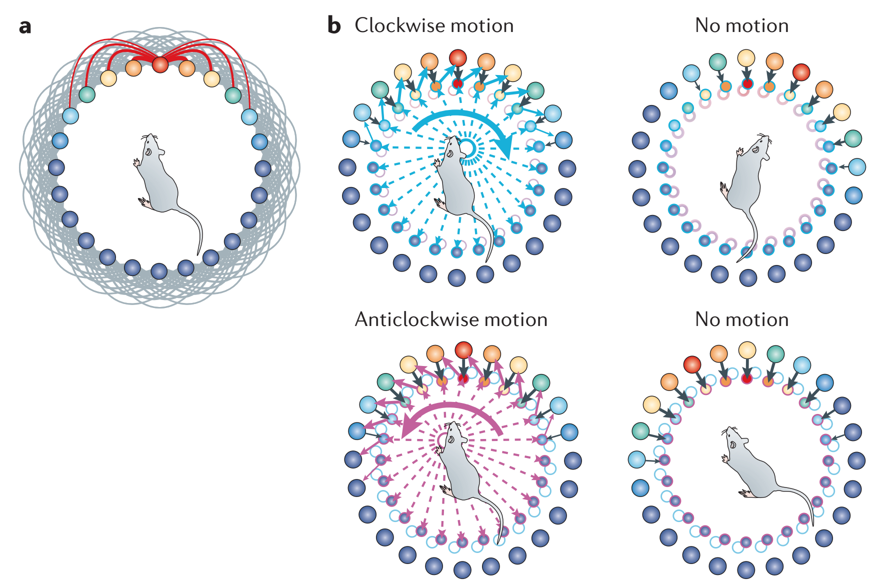


[Warren, Fajen et al, 2003]

Heading direction

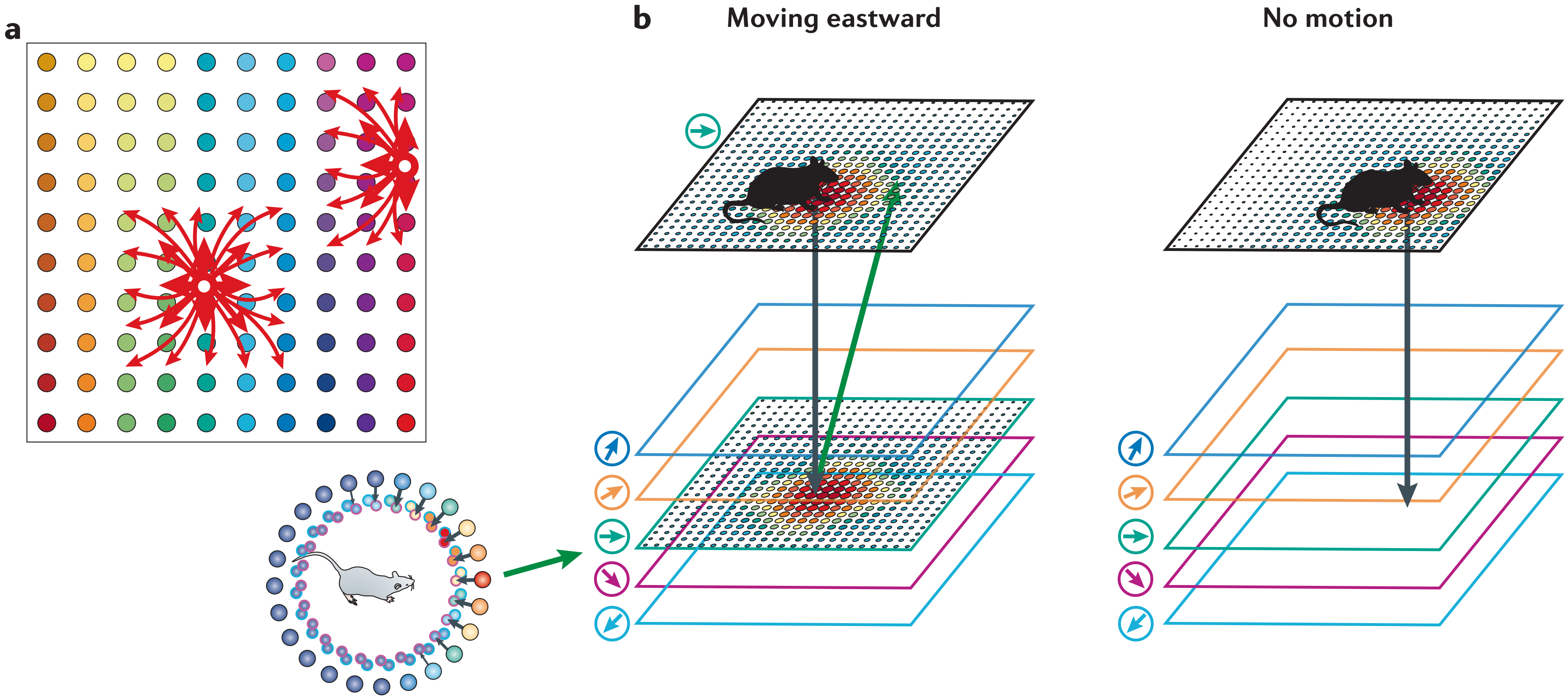
- Neural evidence for head-orientation cells… that function as heading direction representation
- Neural attractor dynamics (neural field) for heading direction





[McNaughton et al., *Nature reviews neuroscience* 2006]

Neural dynamics of path integration

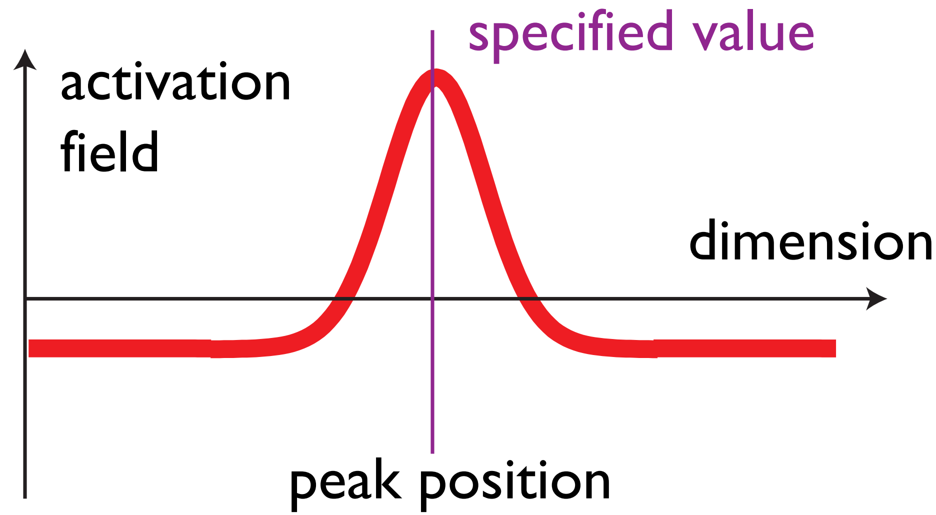


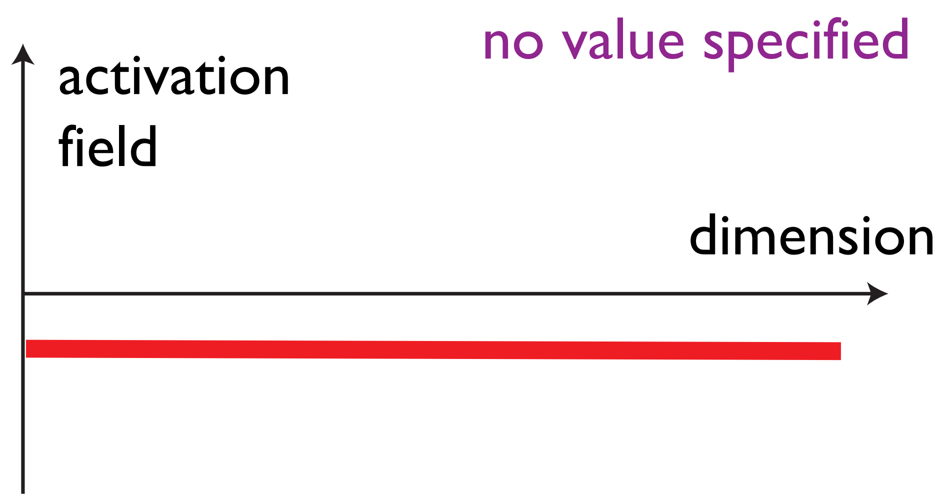
[McNaughton et al., *Nature reviews neuroscience* 2006]

From field to behavioral dynamics

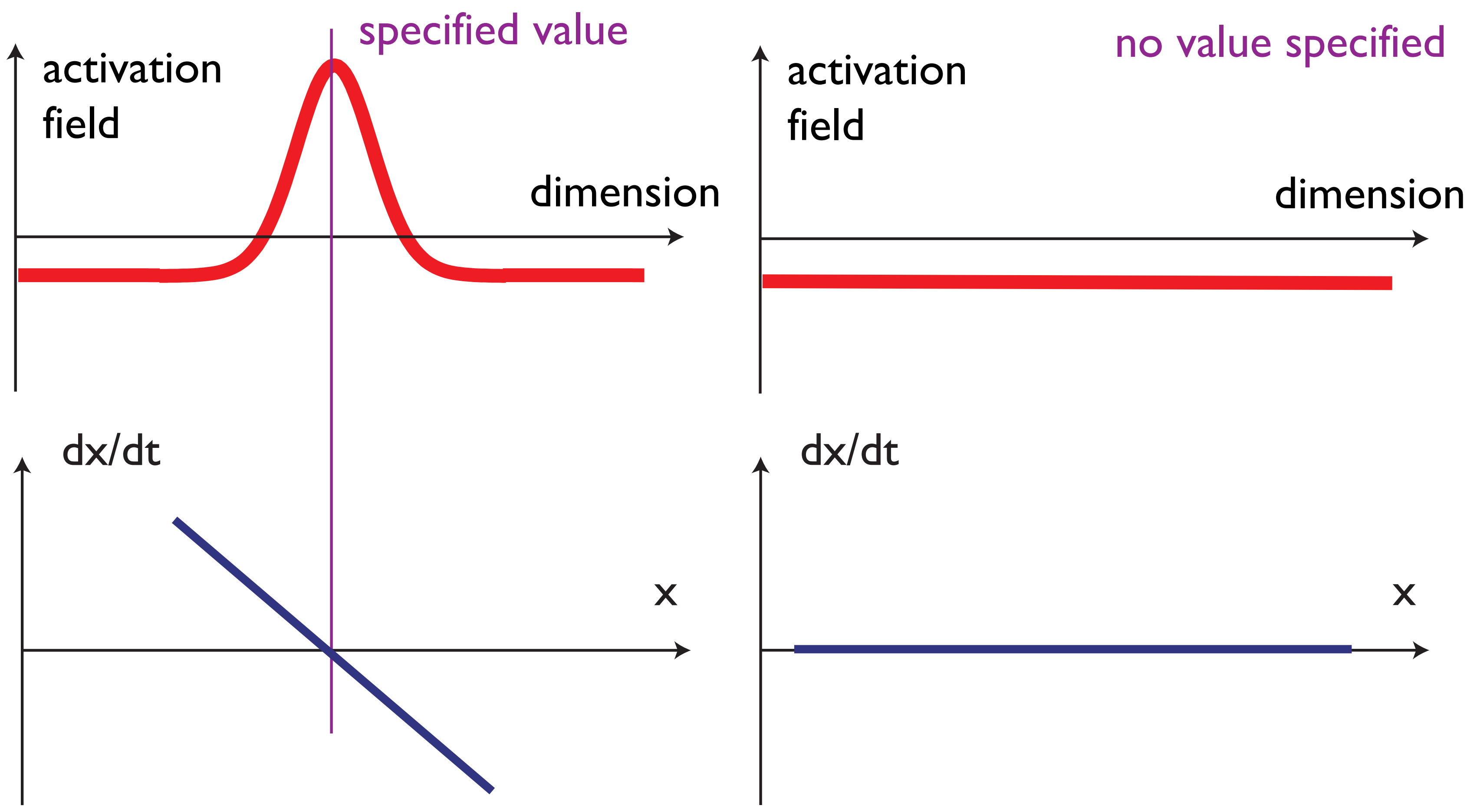
- standard idea: $\sigma(u)$~ probability density
- but: normalization!
- => problem when there is no peak: divide by zero!

$$\phi_{\text{peak}} = \frac{\int d\phi \ \phi \ \sigma(u(\phi,t))}{\int d\phi' \ \sigma(u(\phi',t))}$$



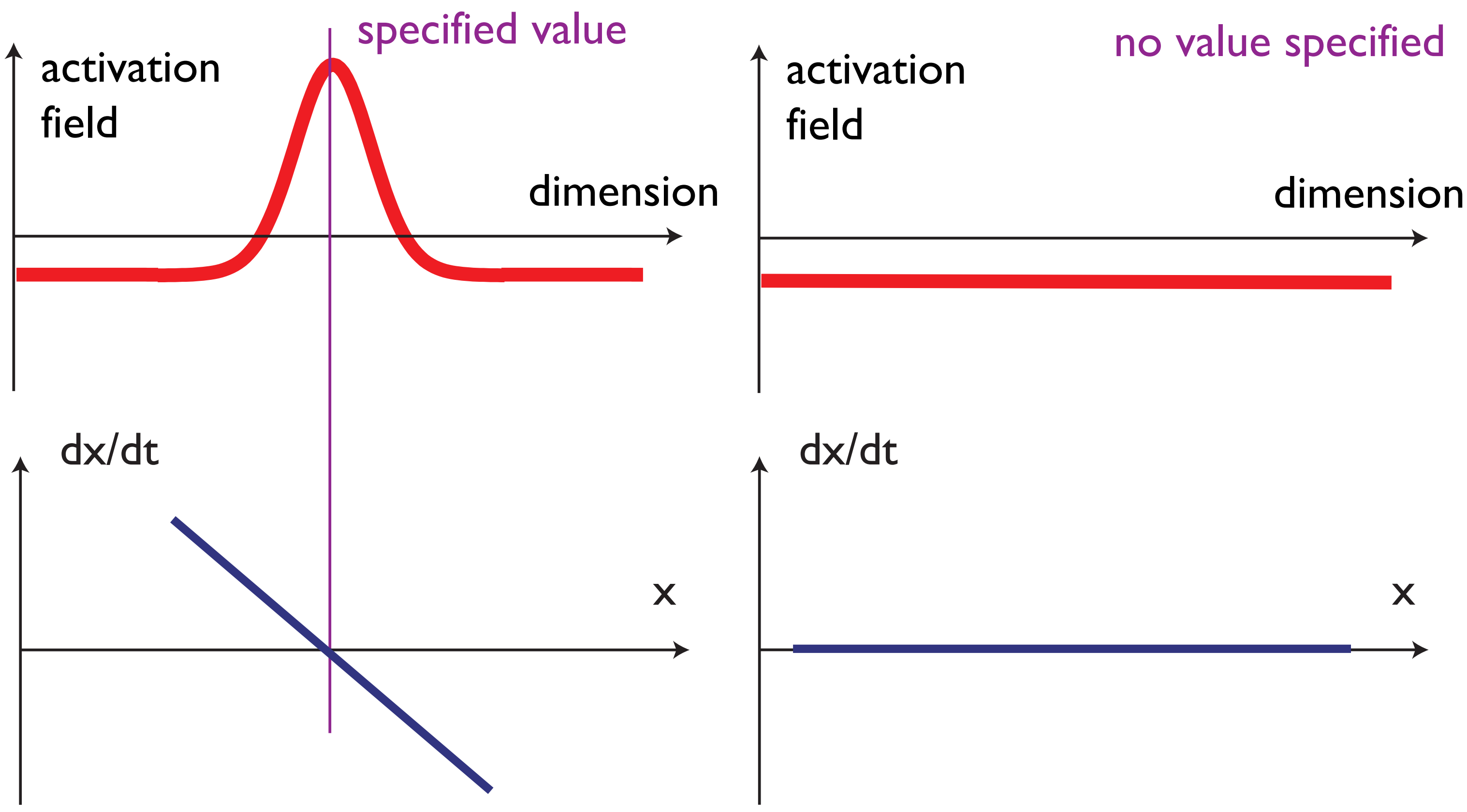


Erect an attractor rather than “read out”



$$\dot{\phi} = - \left[\int d\phi' \sigma(u(\phi', t)) \right] (\phi - \phi_{\text{peak}})$$

$$= - \int d\phi' \, (\phi - \phi') \, \sigma(u(\phi', t))$$



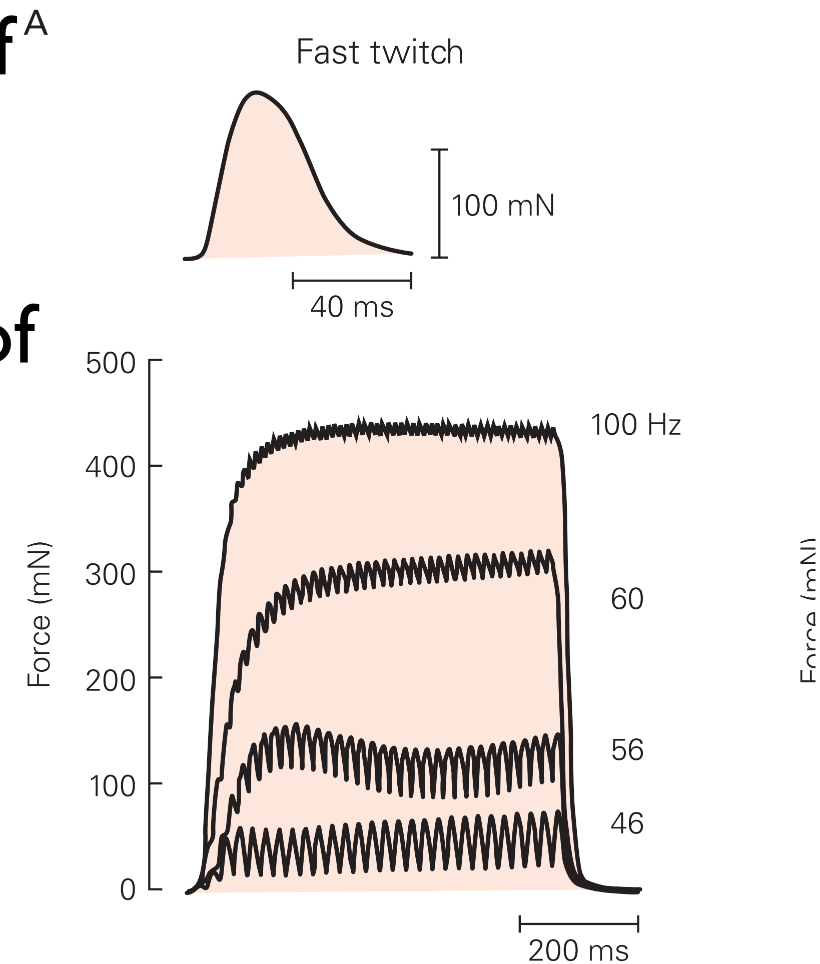
Challenge

- In organism (rather than vehicles), movement is generated by muscles which receive descending activation that is graded (rate code)… and temporally structured (timing)

Rate code in motor neurons

- a single action potential of a motor neuron elicits a transient force pulse in a “fast twitch” motor unit of a muscle

- higher firing rates of the motor neuron induce higher peak force of the motor unit

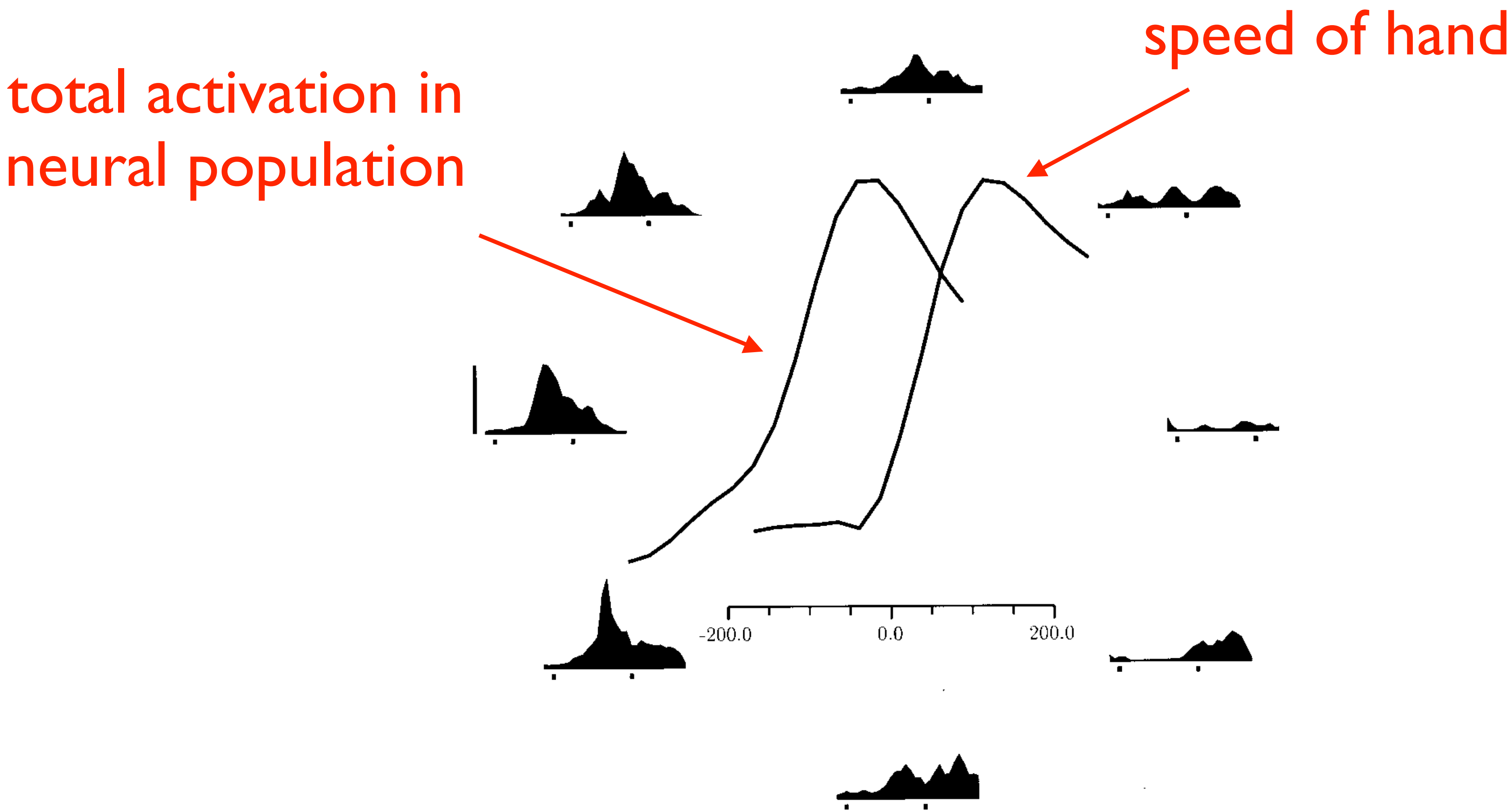


[Kandel, Schwartz et al, 2021]

So movement involves

- generation of a neural activity pattern that rises and falls to generate transient muscle activity…
- => “translation into rate code”

Motor cortical neural timers

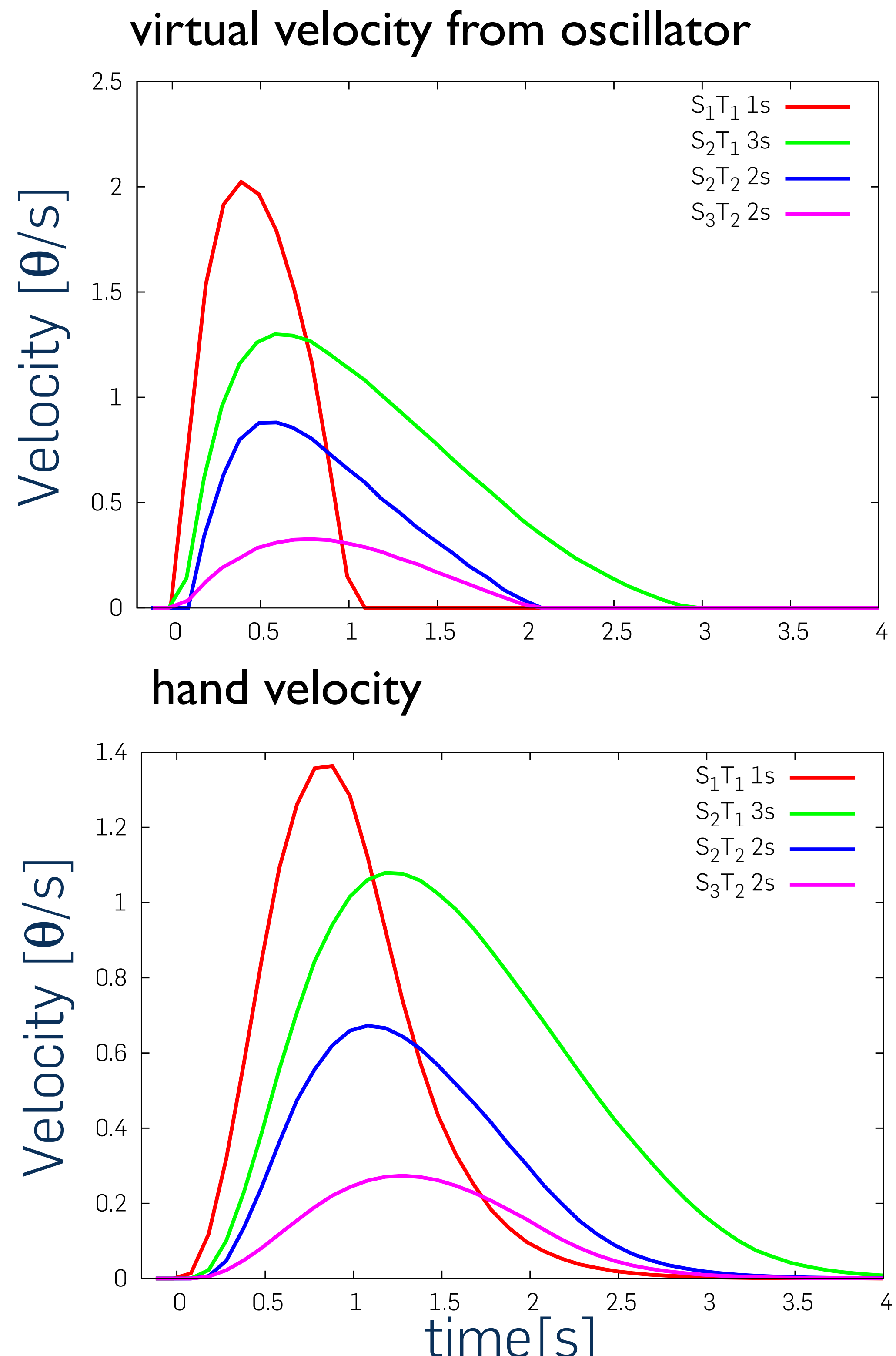


[Moran, Schwartz, J Neurophys 1999]

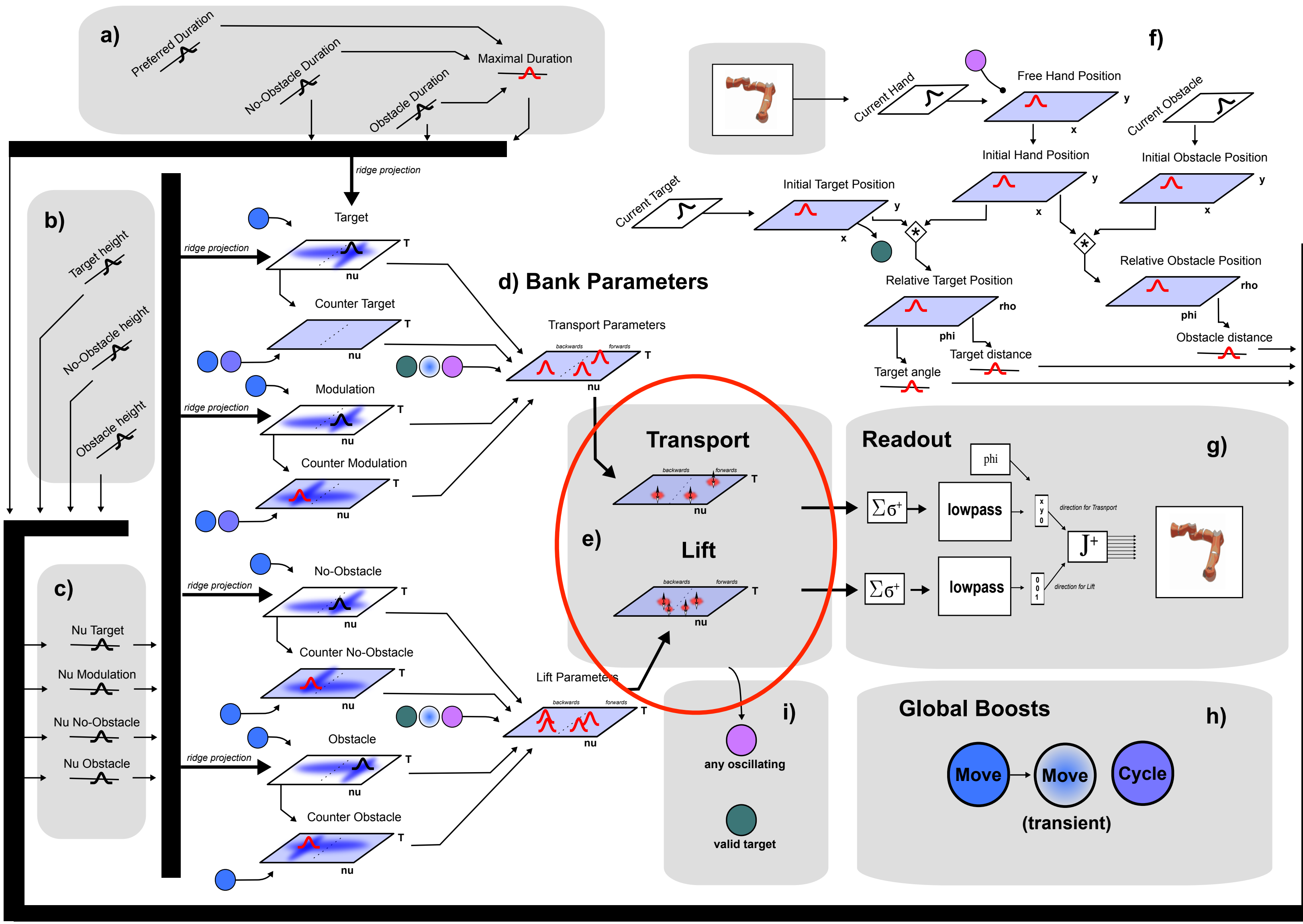
Neural oscillator model of timing

- standard excitatory-inhibitory neural population dynamics => oscillations/active transients
- field of such oscillators for different peak velocities/ amplitudes

[Zibner, Tekülve, Schöner, ICDL 2015; Schöner, Tekülve, Zibner, 2019]]

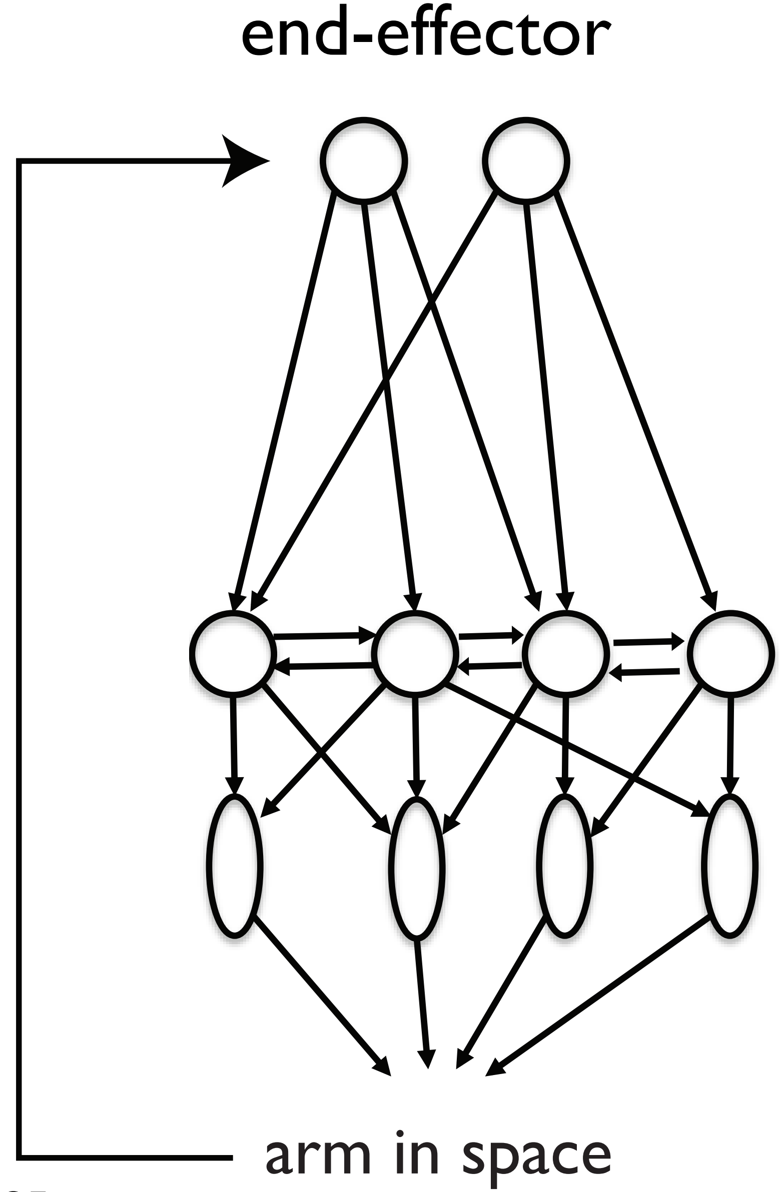


Localized input triggers transients/ oscillations in such fields



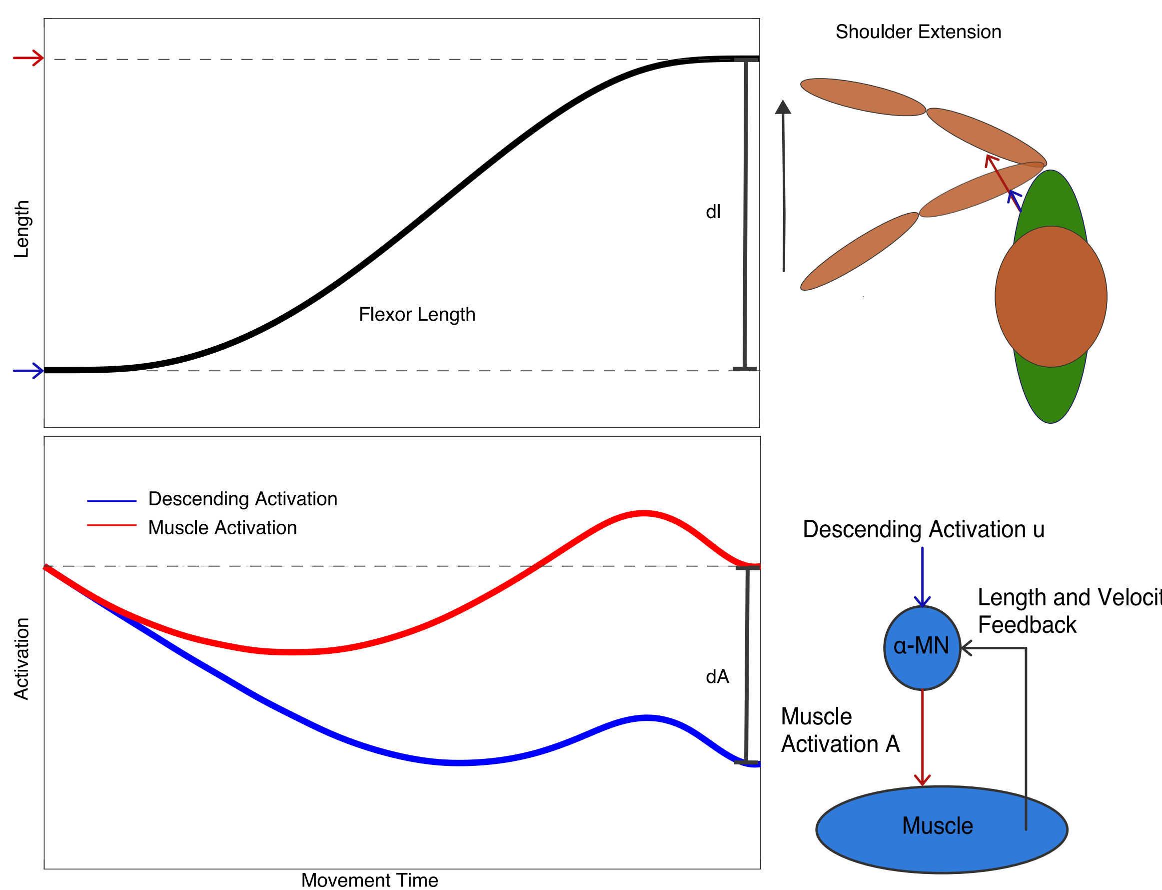
[J-S Jokeit dissertation 2022]

Descending activation: DoF problem



[Martin, Scholz, Schöner. *Neural Computation* (2009]
[Martin, Reimann, Schöner *Biological Cybernetics* 2019]

Muscles generate force in closed loop: behavioral dynamics



[Ramadan et al, 2022]

Conclusion 2

- Neural dynamics drive behavior by steering a behavioral dynamics