Dynamic Field Theory: Linking back to motor behavior

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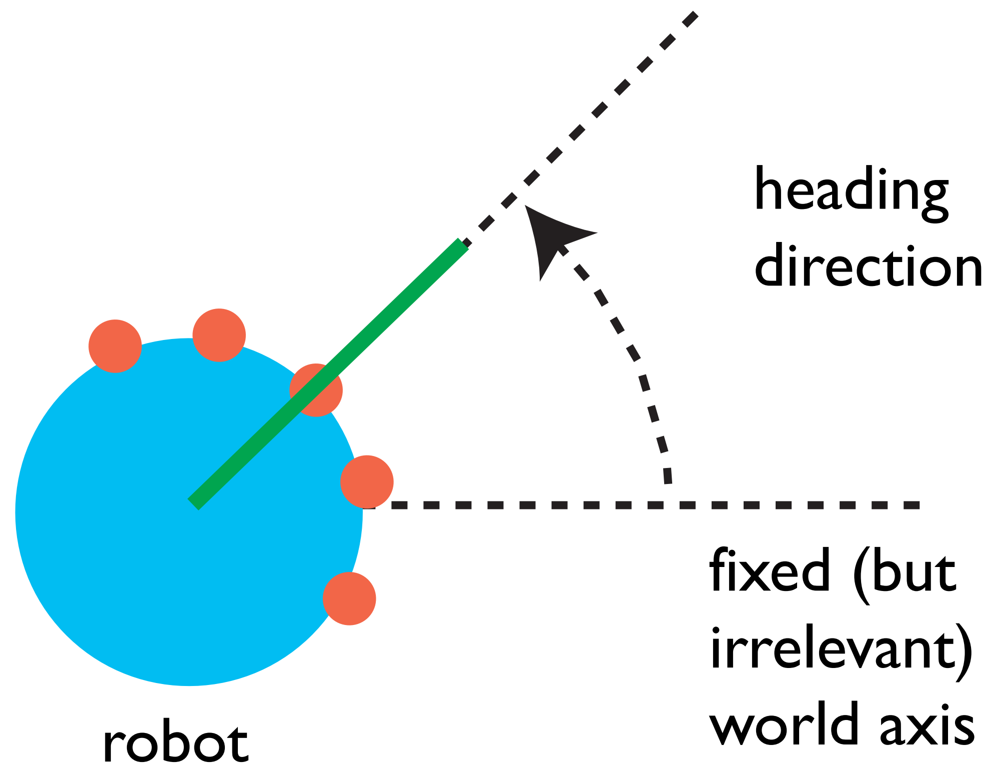
Generating motor behavior

- > behavioral dynamics

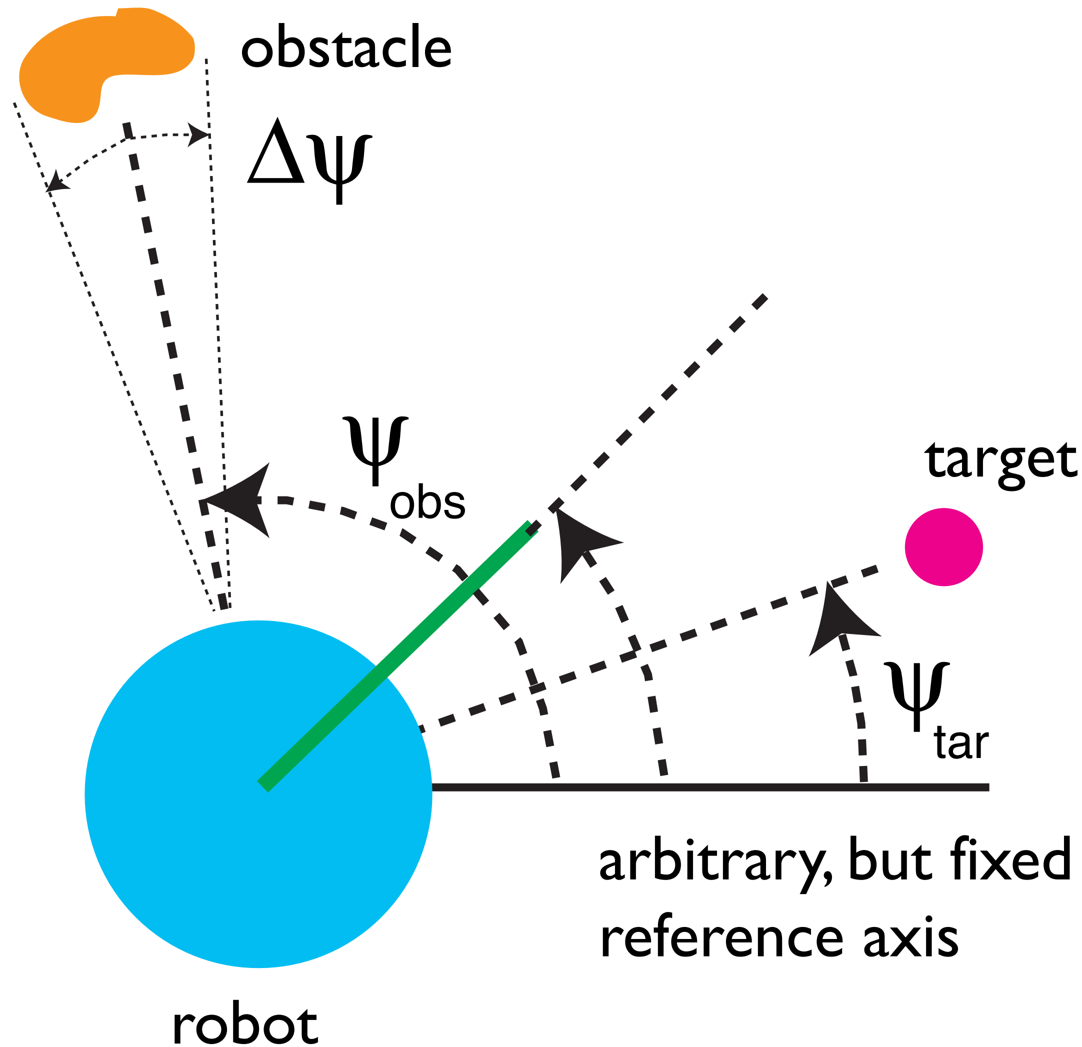
Behavioral variables: example

- vehicle moving in 2D: heading direction



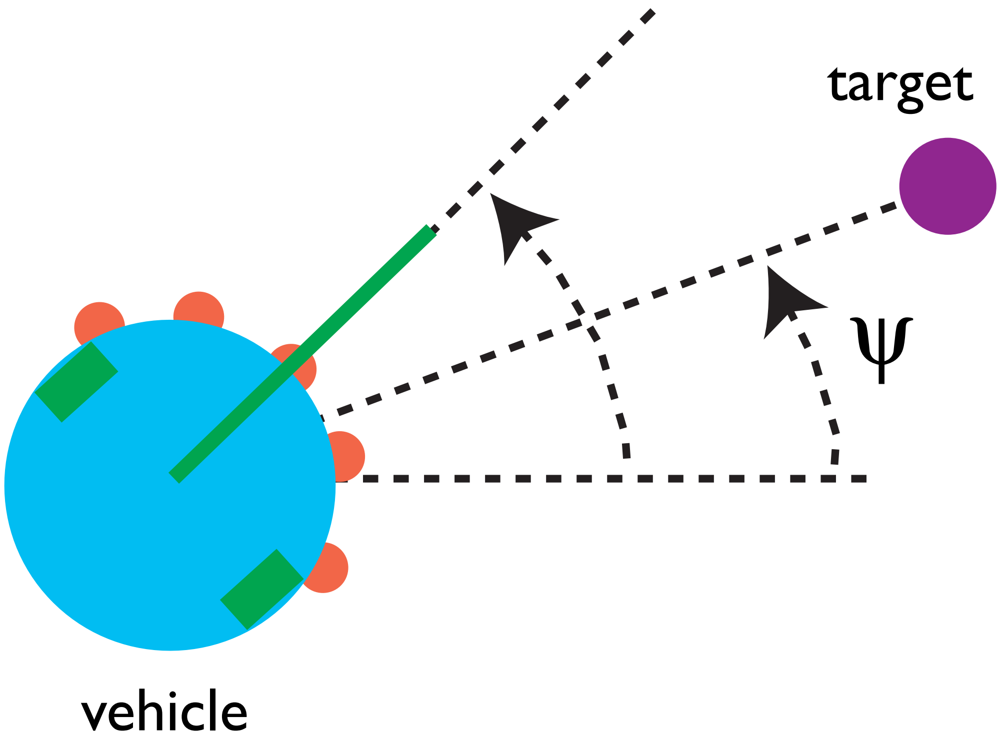
Behavioral variables: example

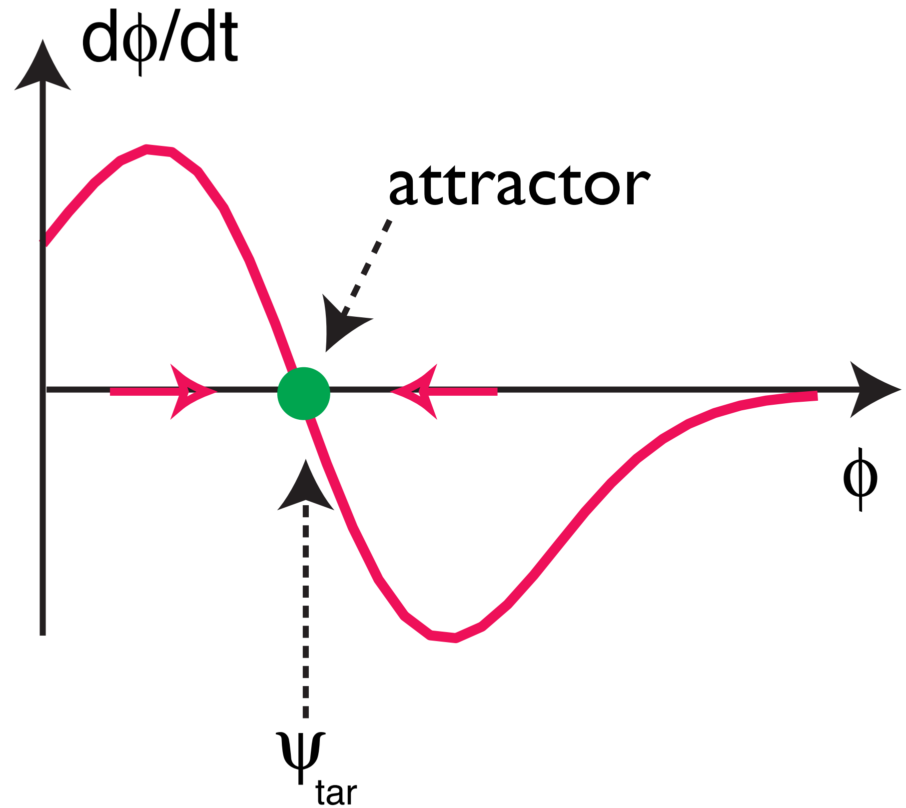
- constraints: obstacle avoidance and target acquisition



Behavioral dynamics: example

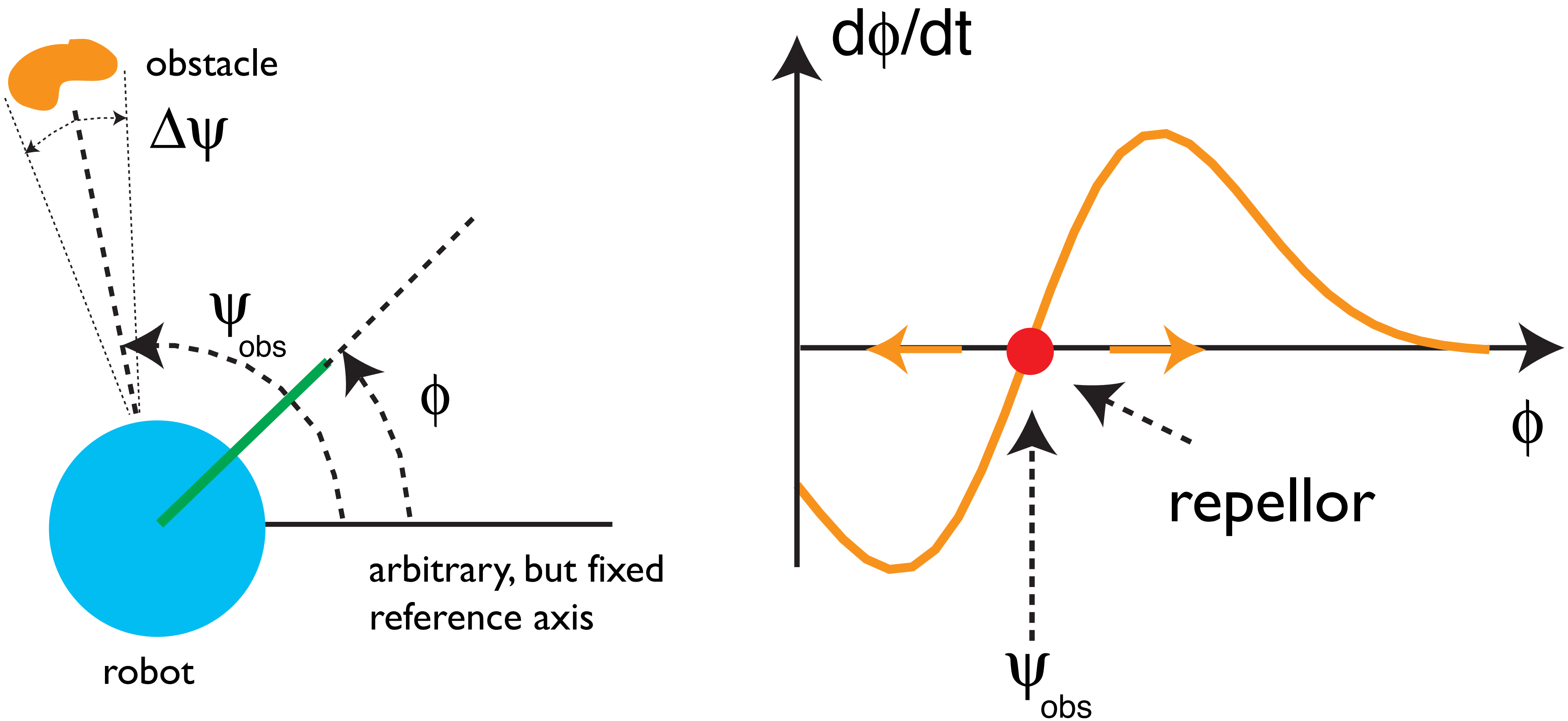
- behavioral constraint: target acquisition





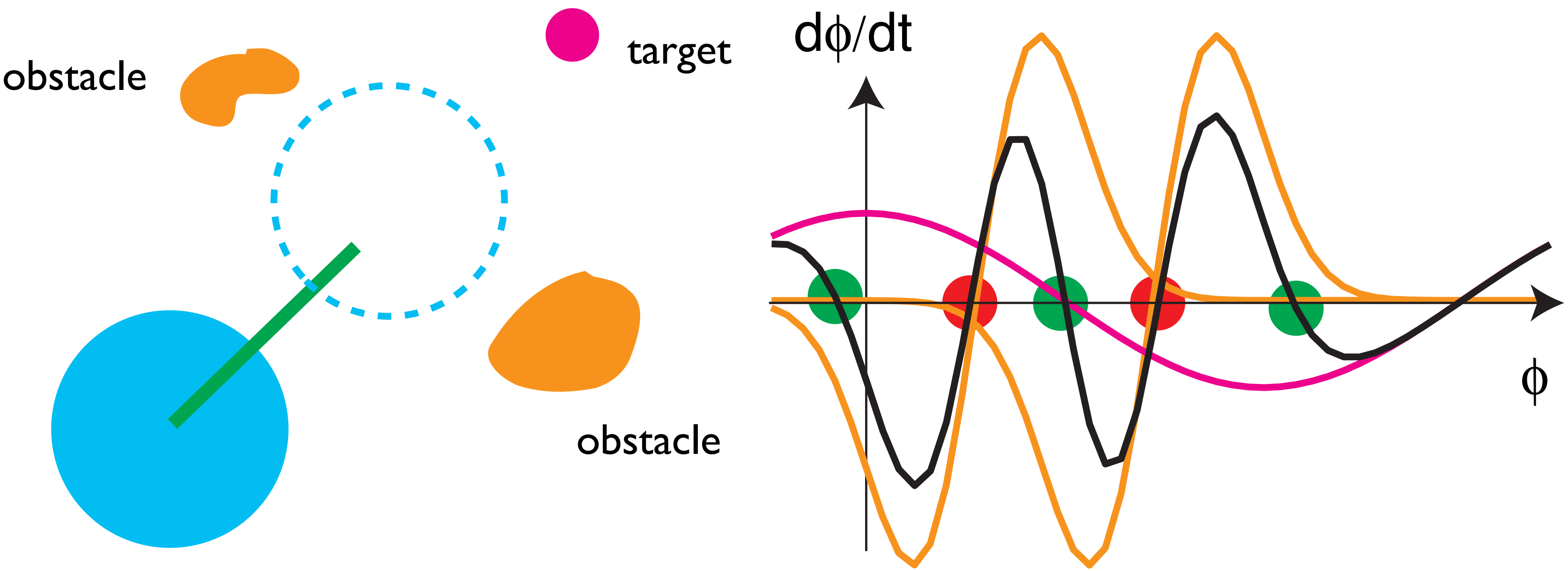
Behavioral dynamics: example

- behavioral constraint: obstacle avoidance



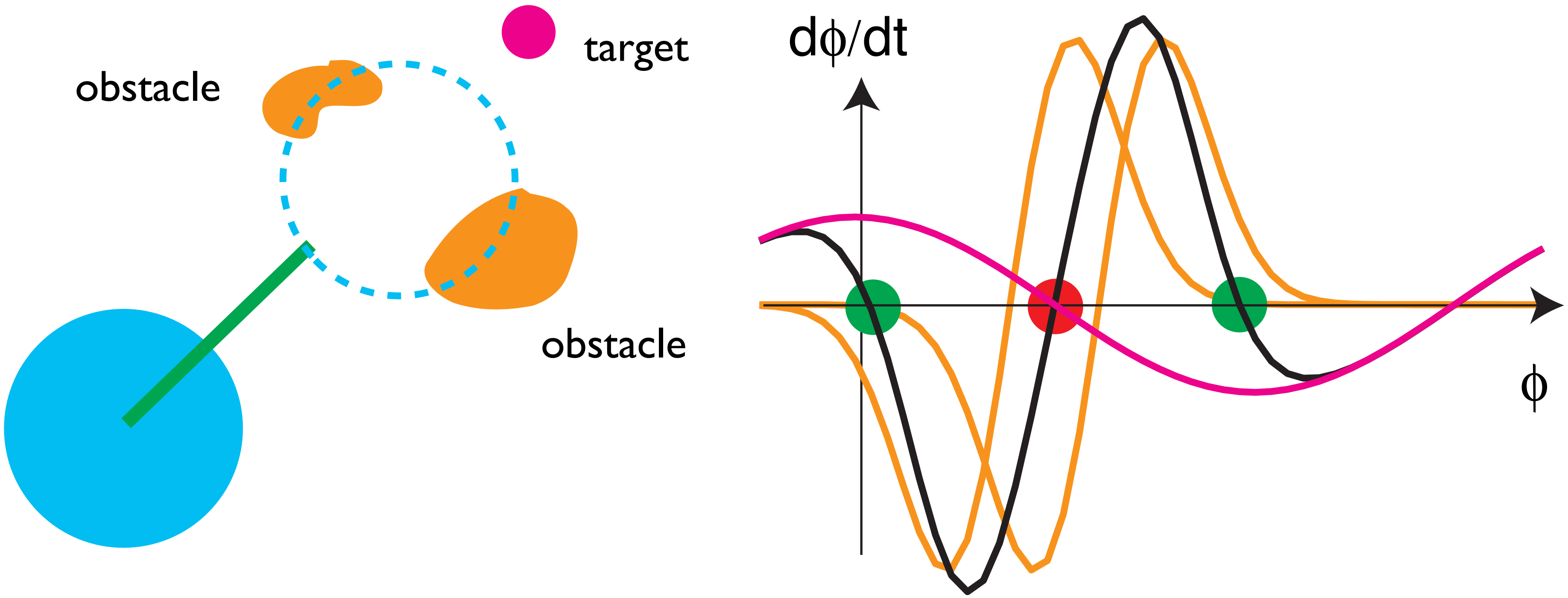
Behavioral dynamics

- bifurcations in obstacle avoidance and target acquisition
- constraints not in conflict



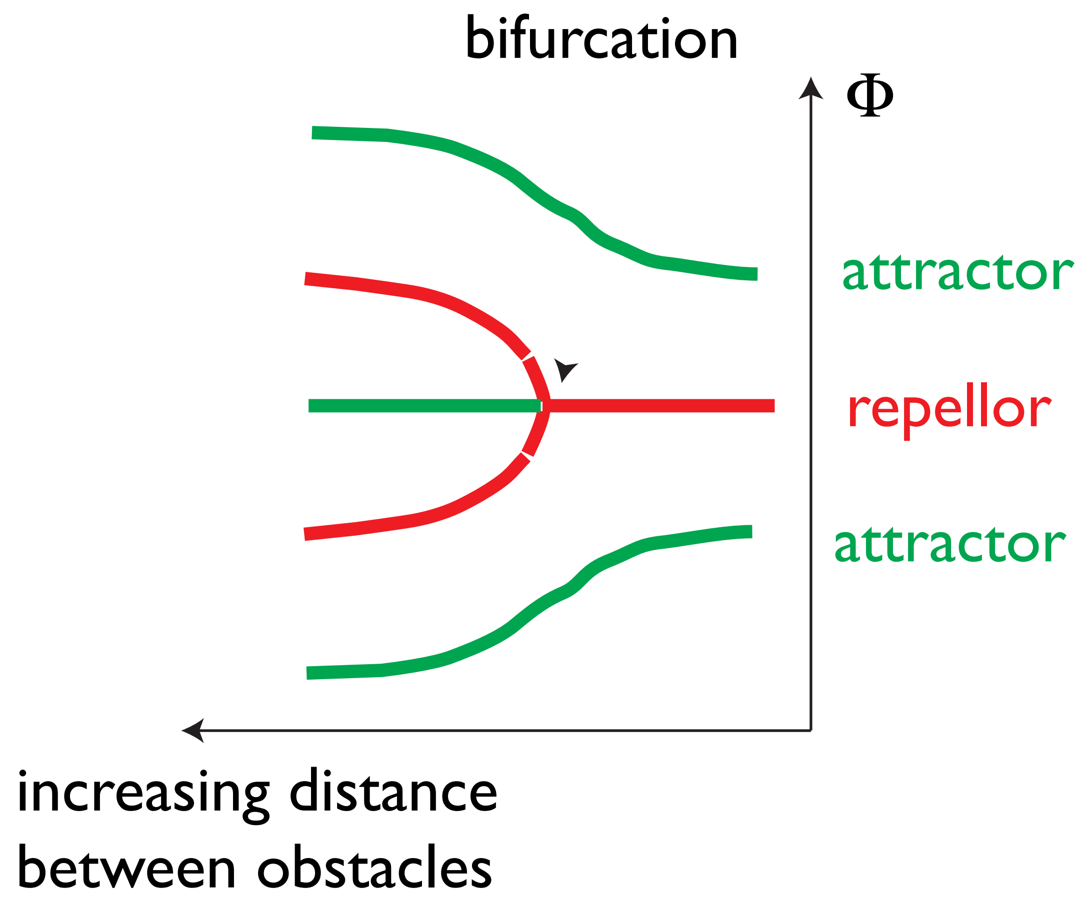
Behavioral dynamics

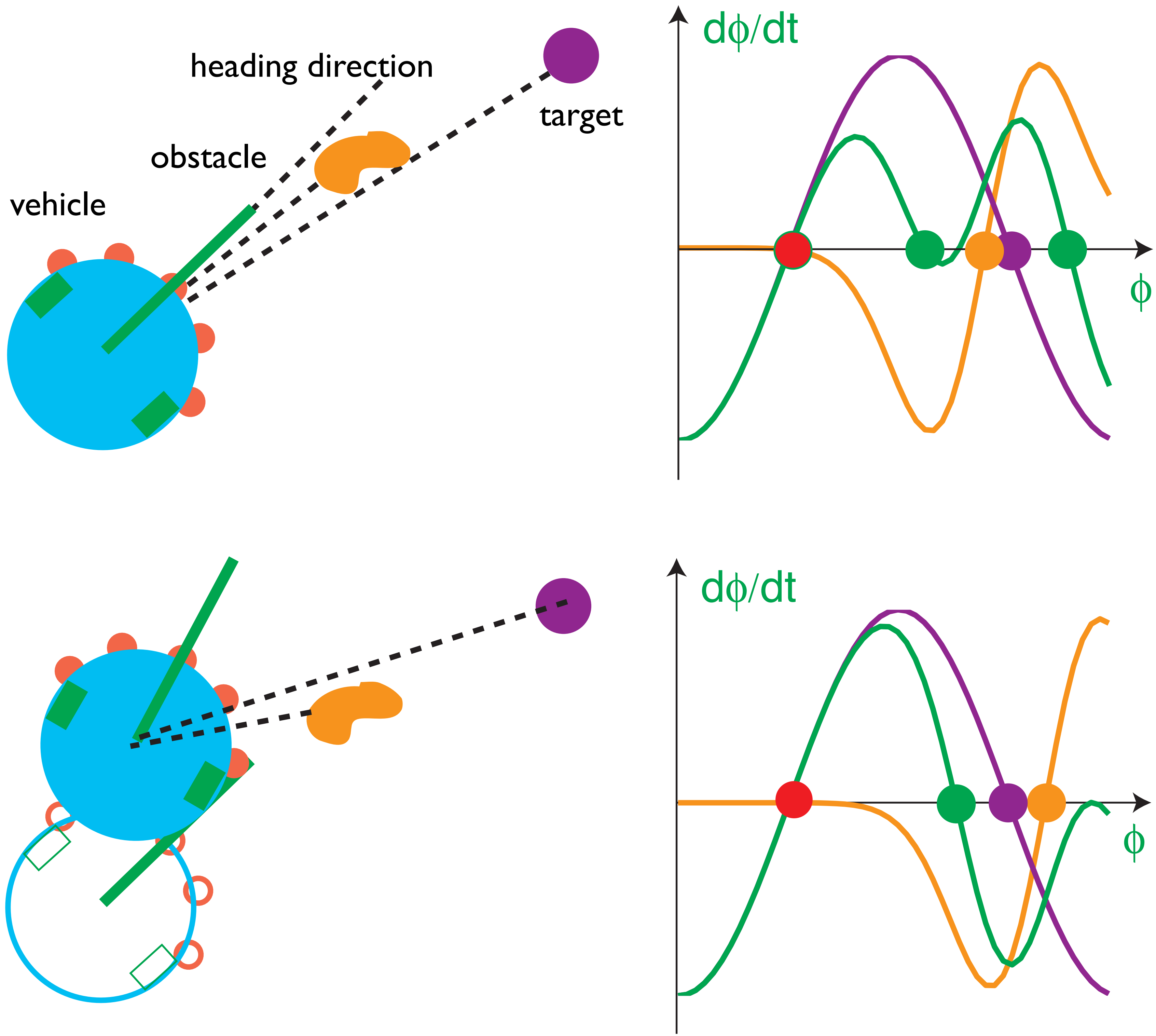
- constraints in conflict



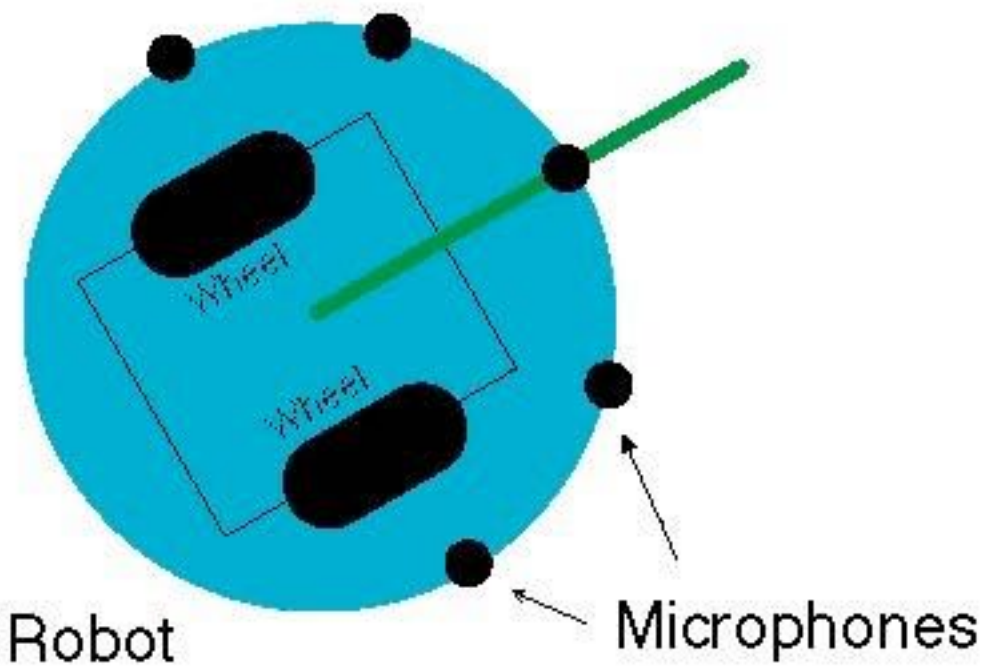
Behavioral dynamics

- transition from “constraints not in conflict” to “constraints in conflict” is a bifurcation

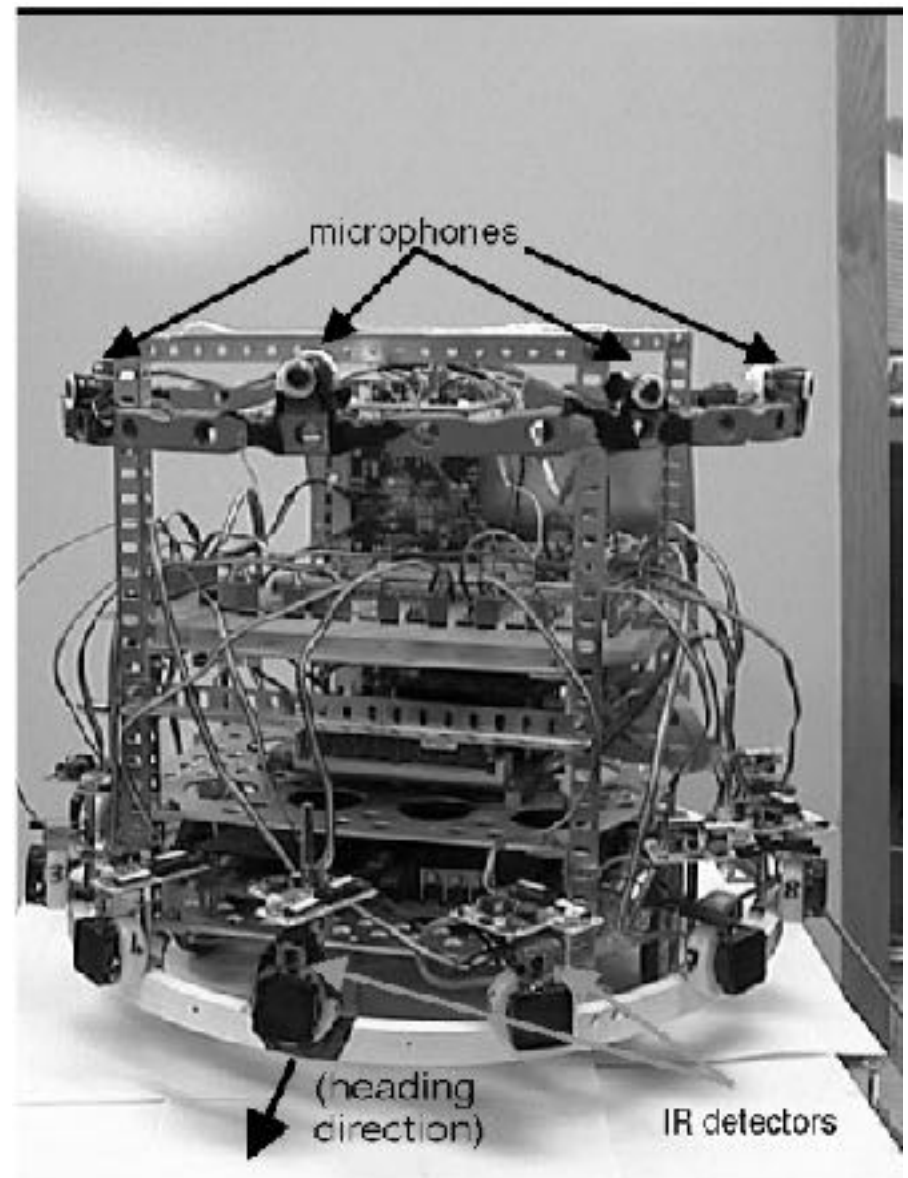



heading direction
target
obstacle
vehicle
dφ/dt
φ
dφ/dt
φ

Vehicle

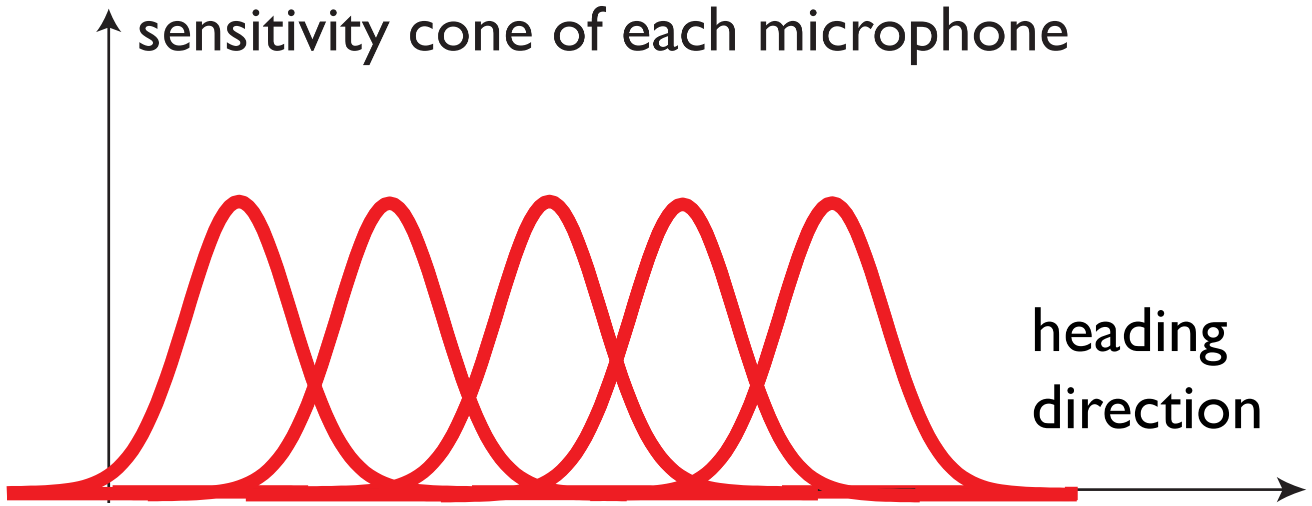


[from Bicho, Mallet, Schöner, Int J Rob Res,2000]

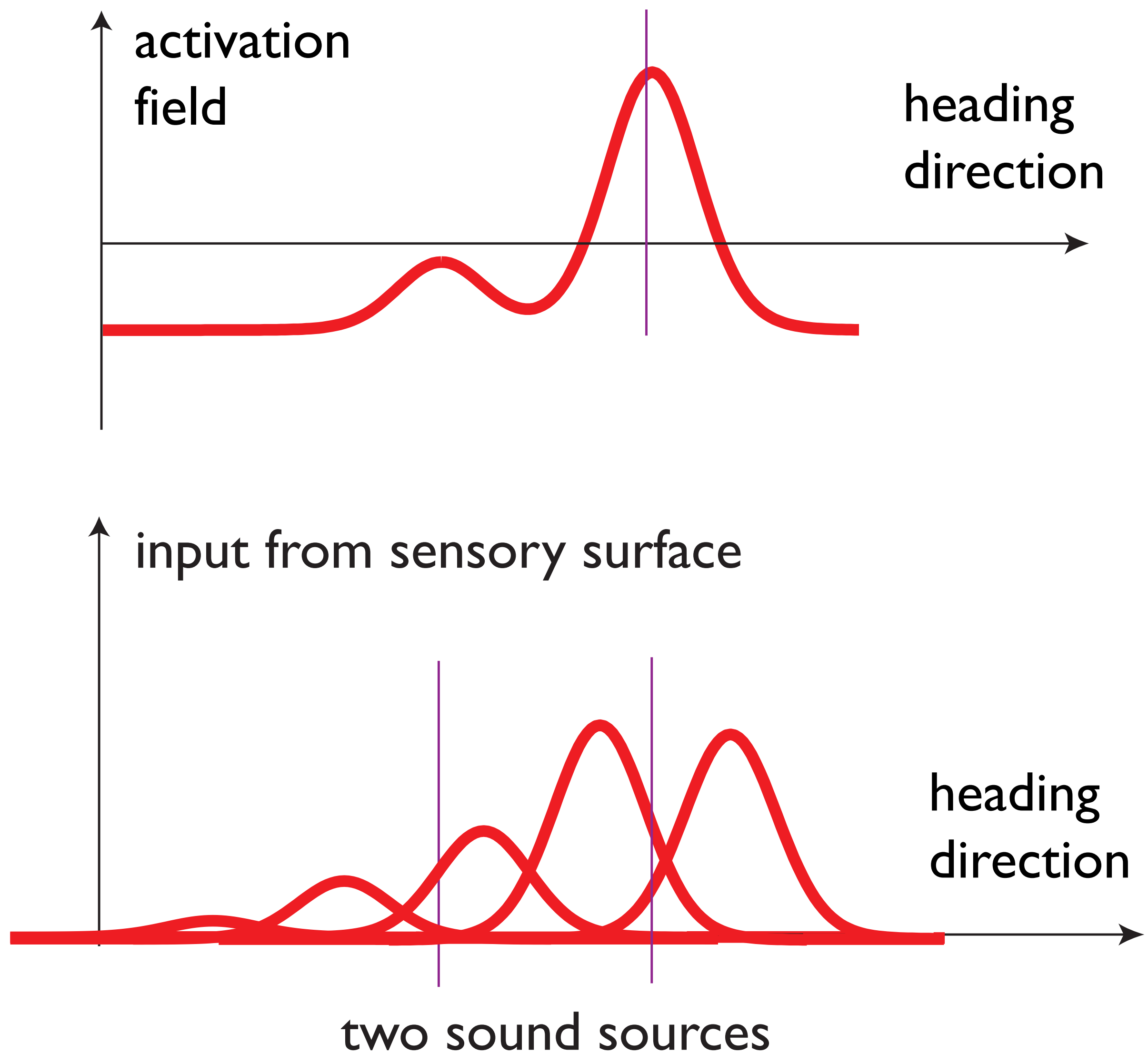


sensory surface

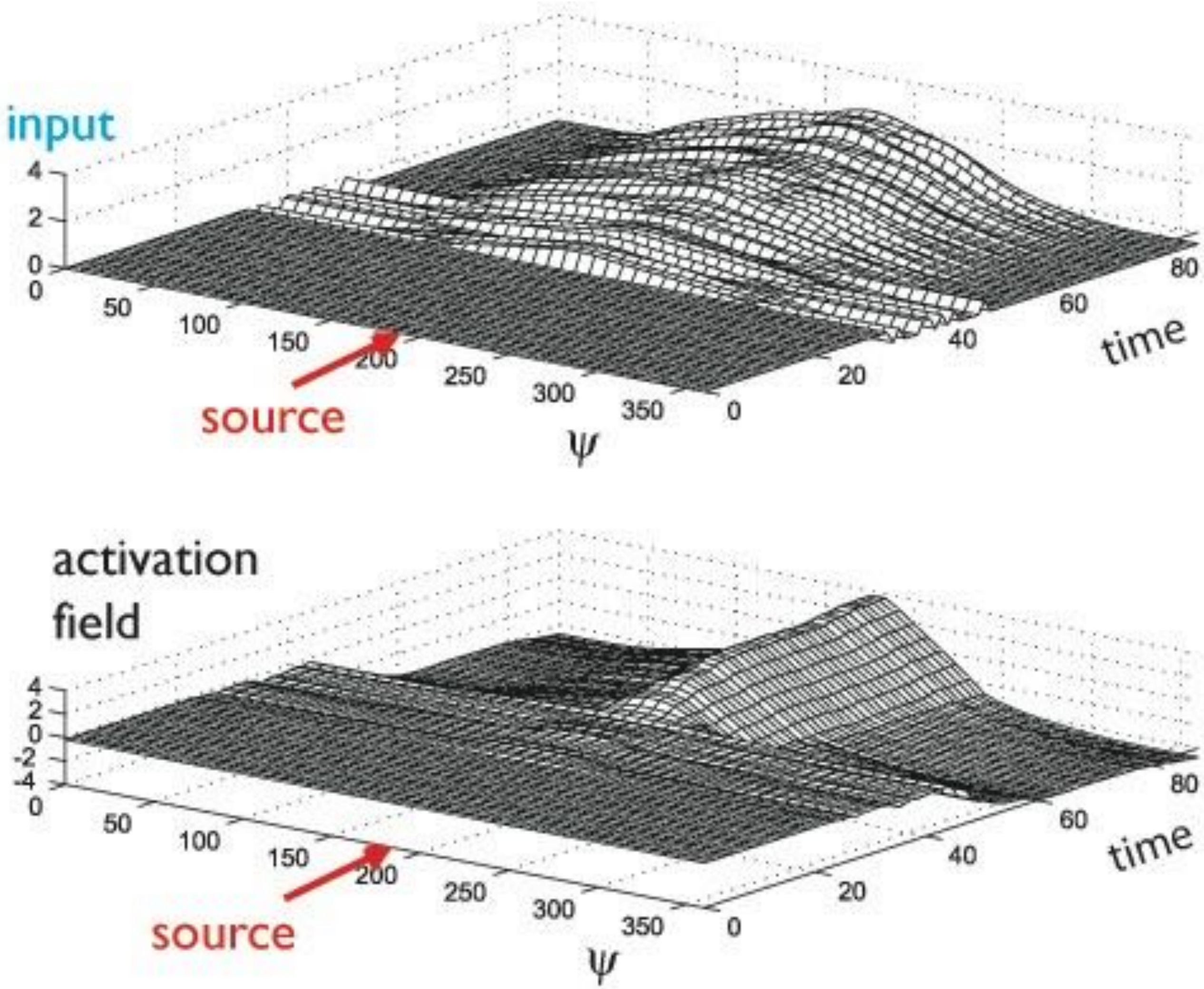
- each microphone samples heading direction

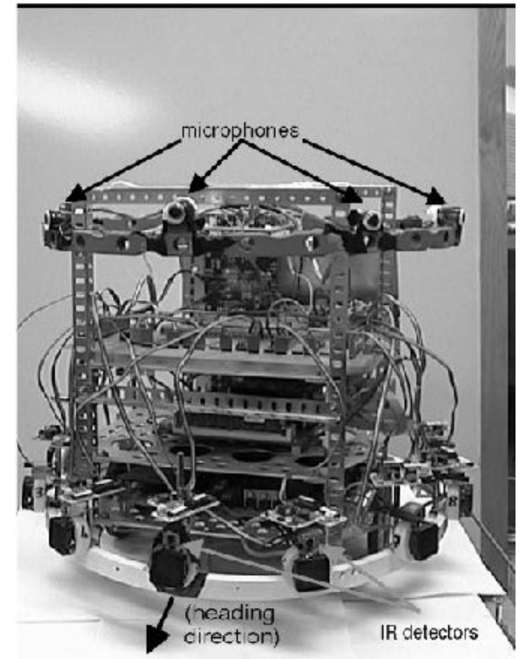


and provides input to the field



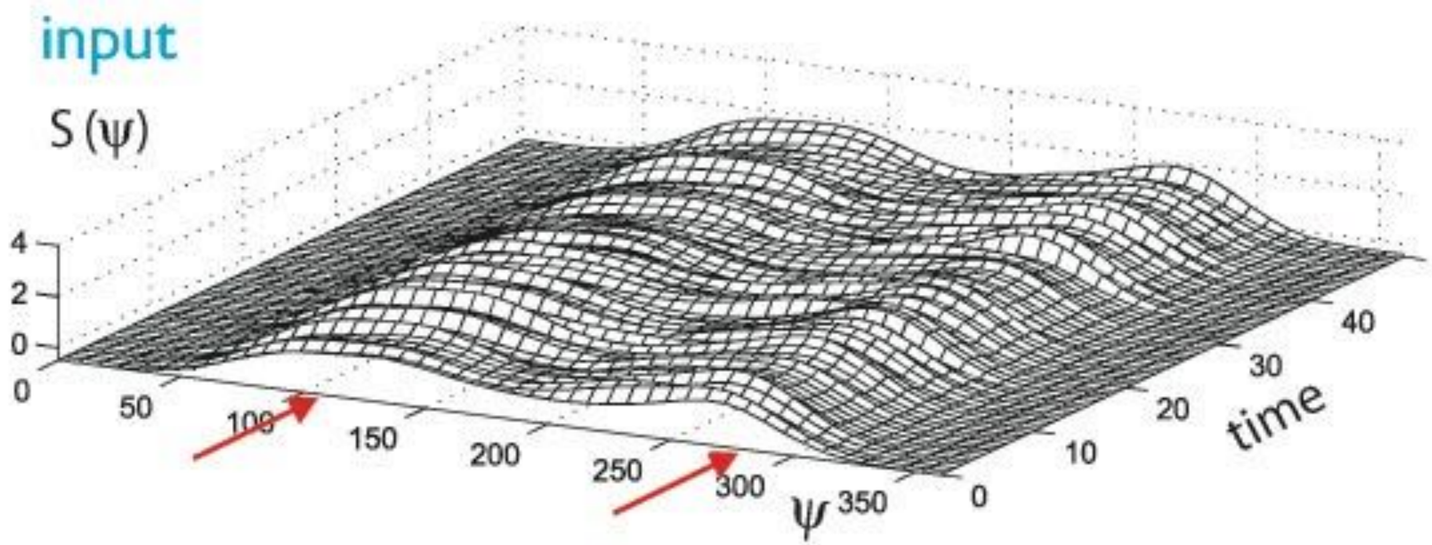
detection instability on a phonotaxis robot

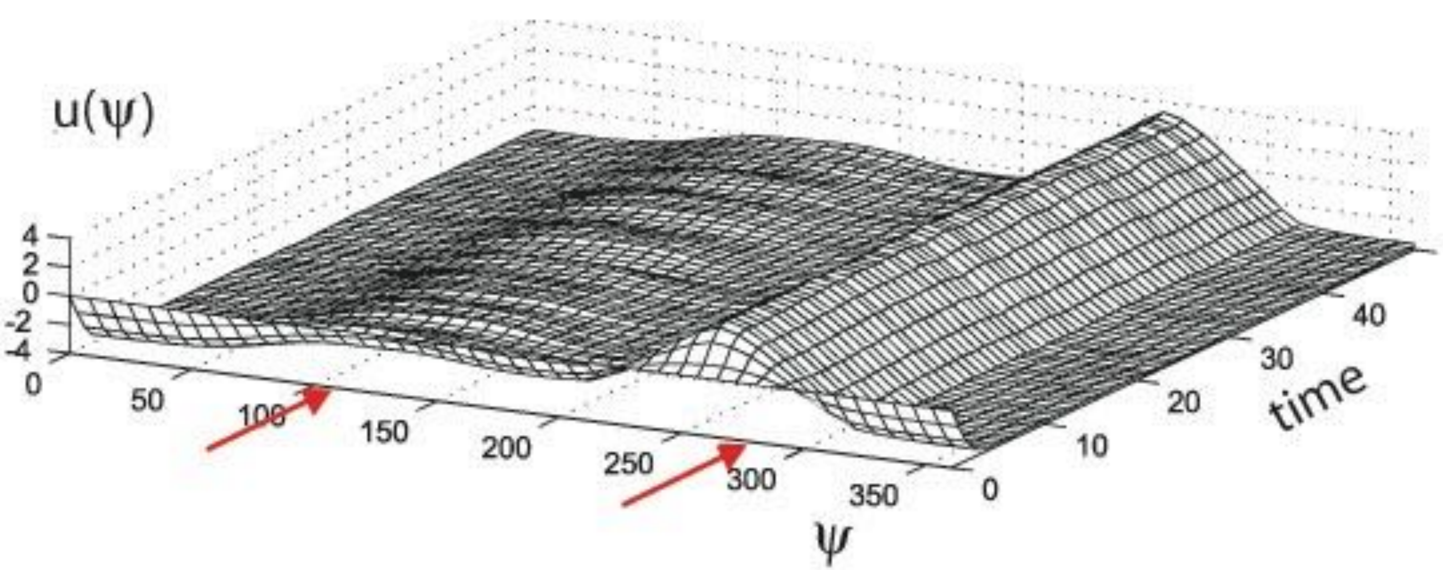


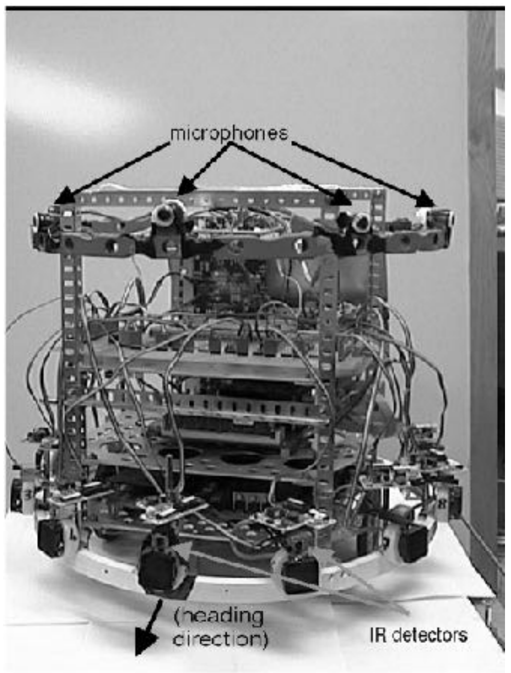


[from Bicho, Mallet, Schöner: Int. J. Rob. Res., 2000]

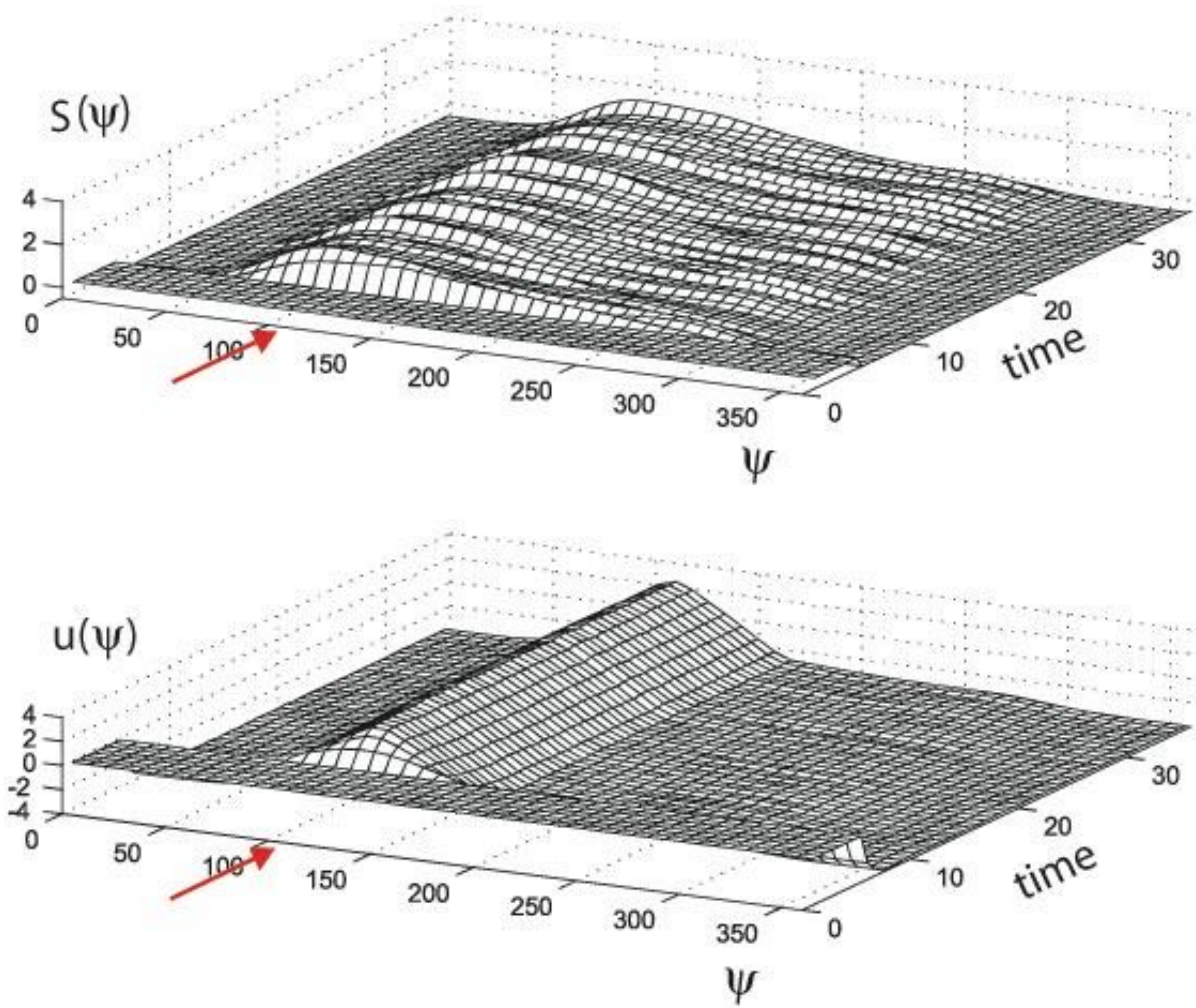
target selection on phonotaxis vehicle



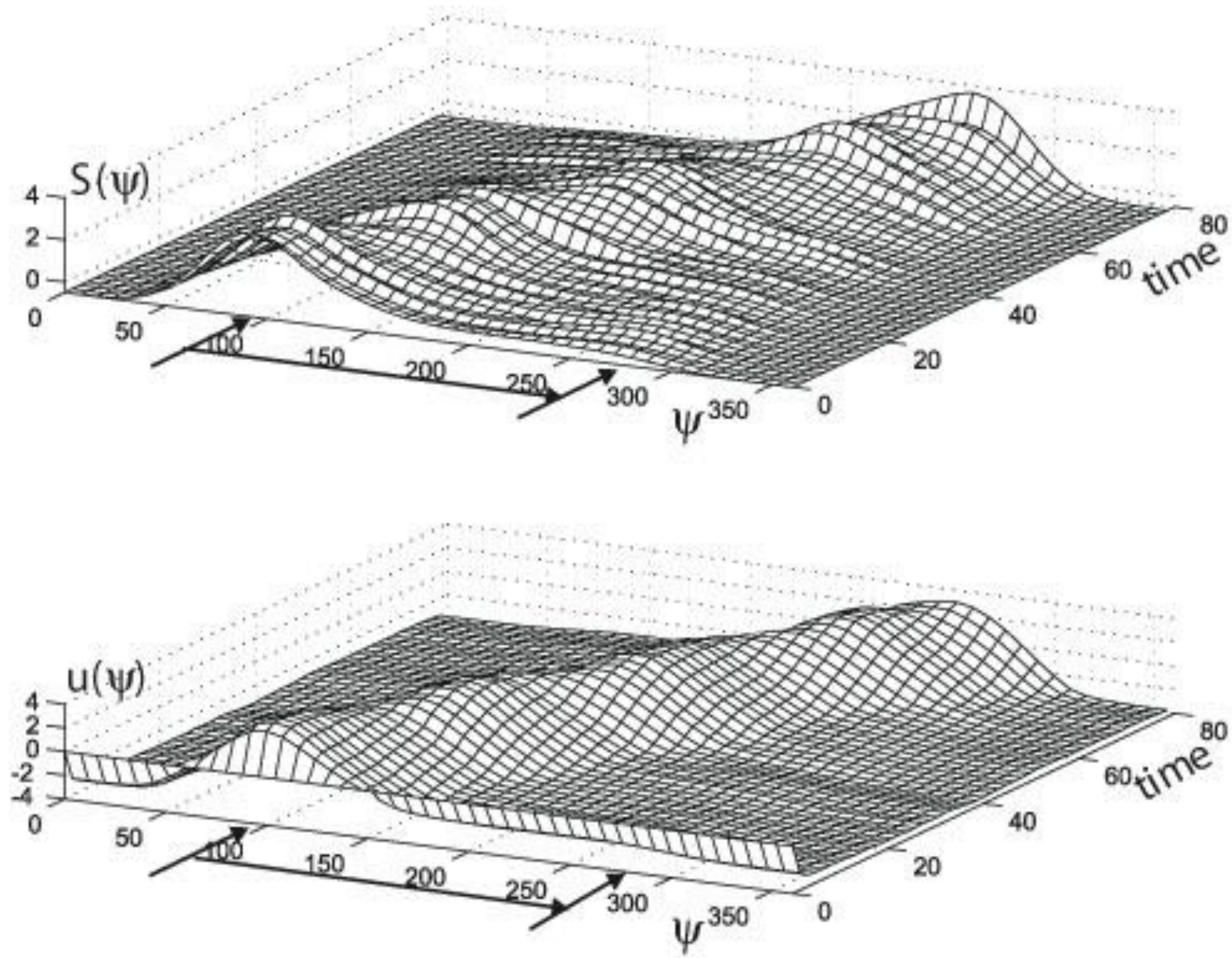




robust estimation

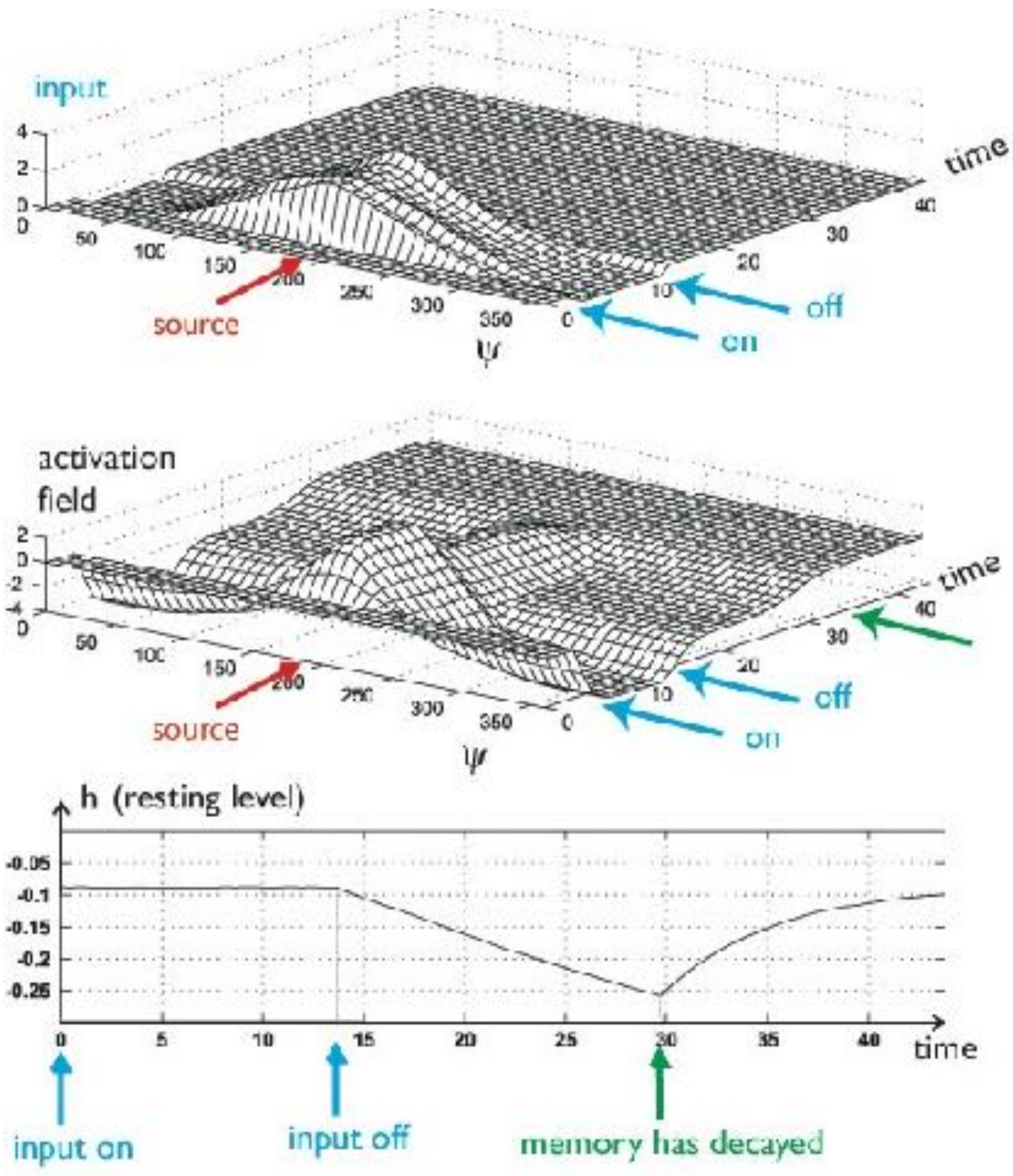


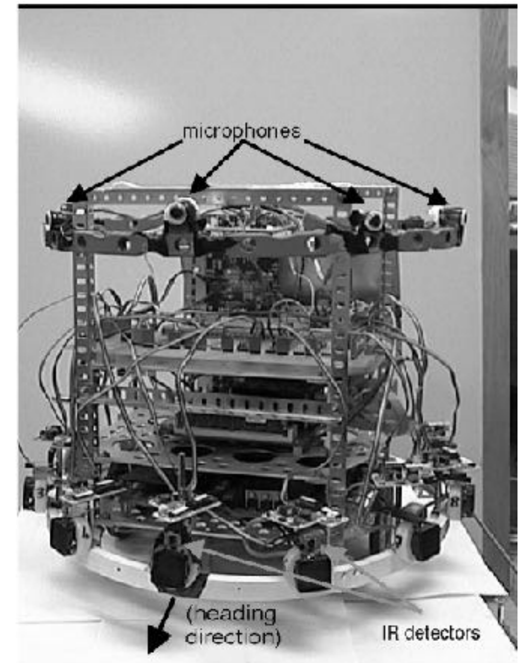
tracking



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

memory & forgetting on phonotaxis vehicle



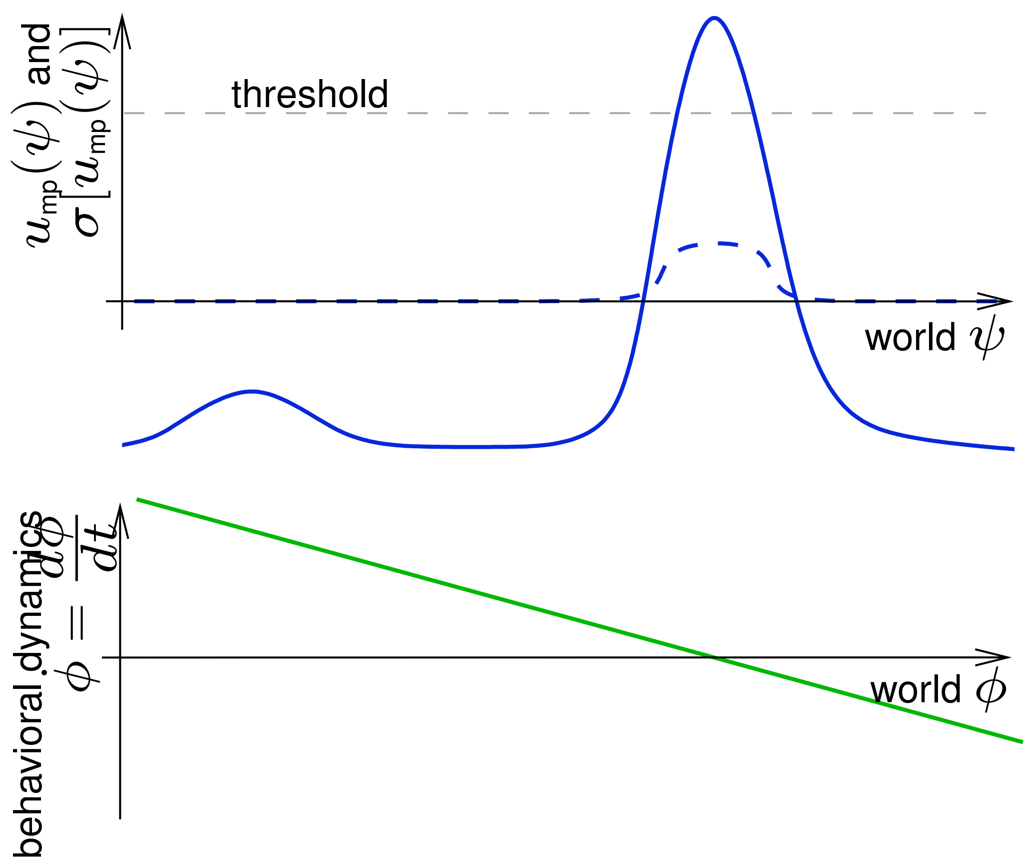


[from Bicho, Mallet, Schöner: Int J Rob Res 19:424(2000)]

a robotic demo of all of instabilities

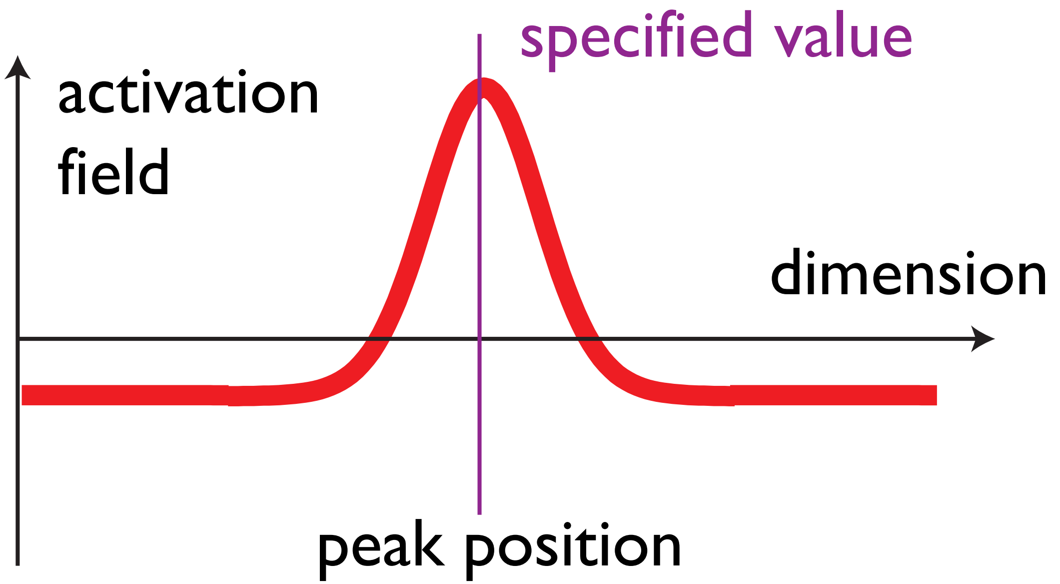
back to attractor dynamics of heading

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



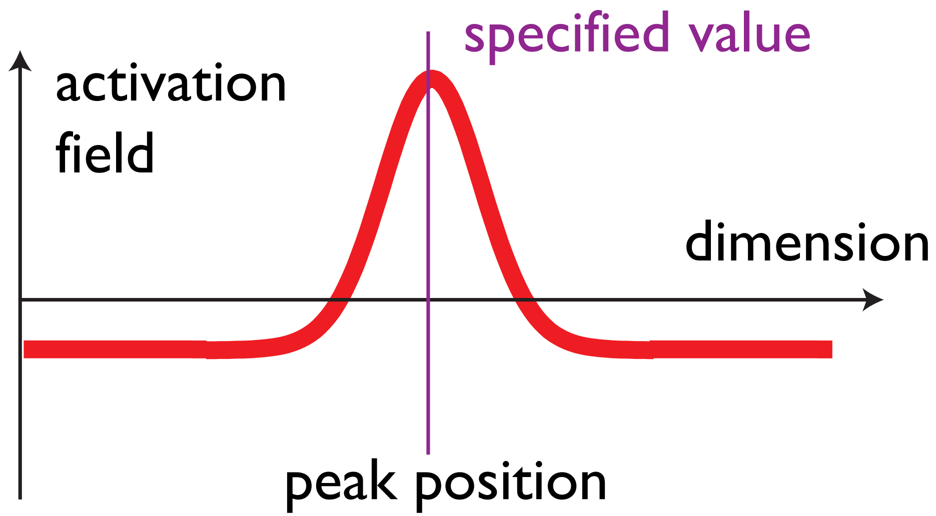
=> transition from DFT to DST

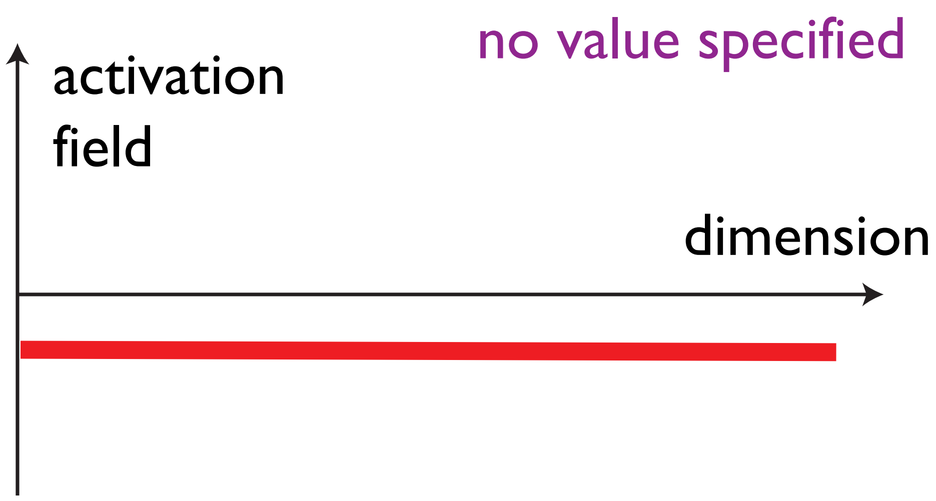
- peak specifies value for a dynamical variable that is congruent to the field dimension



from DFT to DST

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



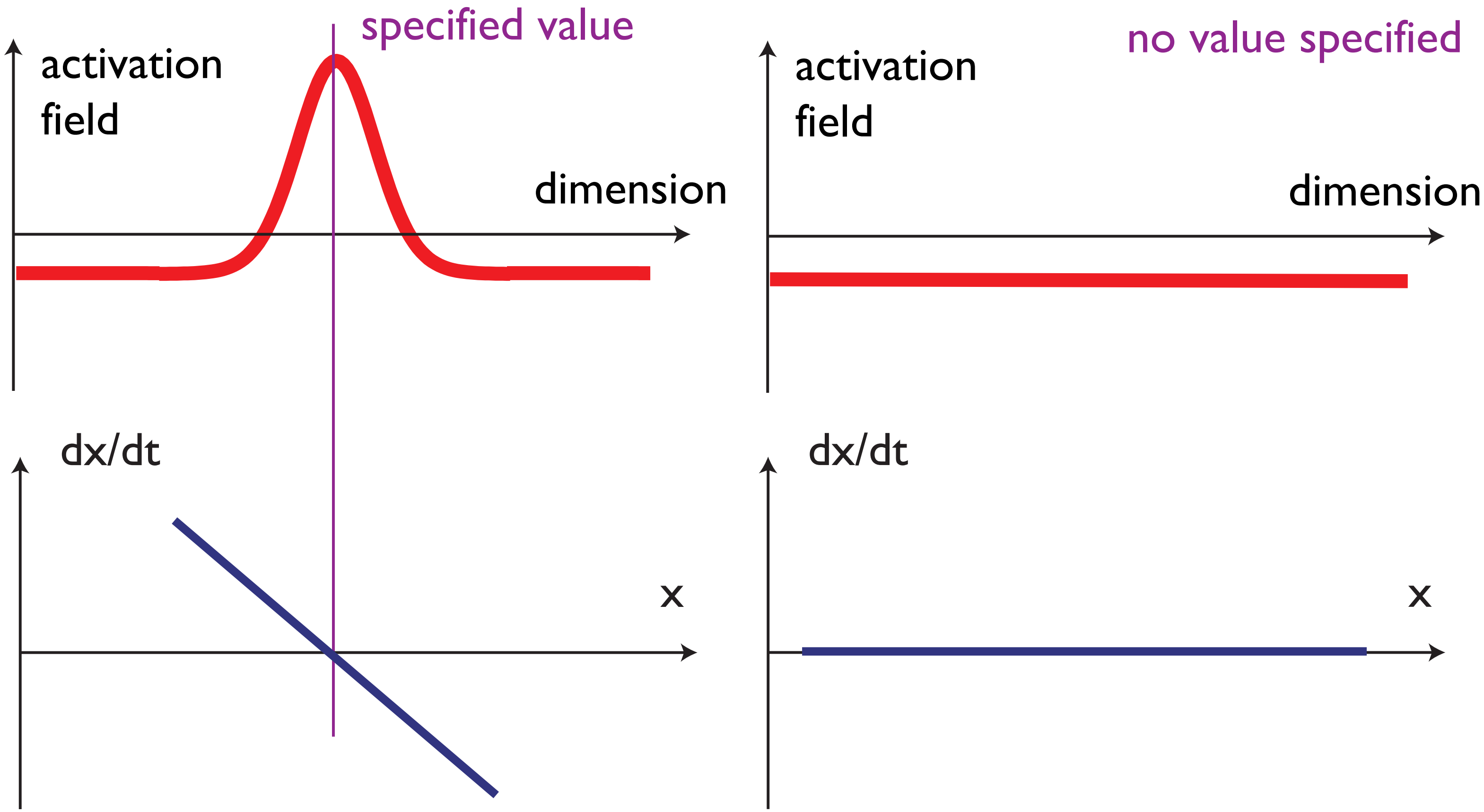


from DFT to DST

- 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

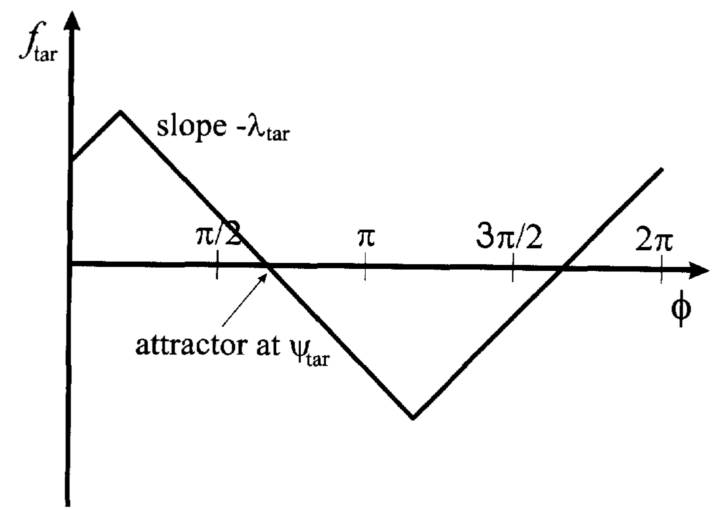


=> Bicho, Mallet, Schöner (2000)

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

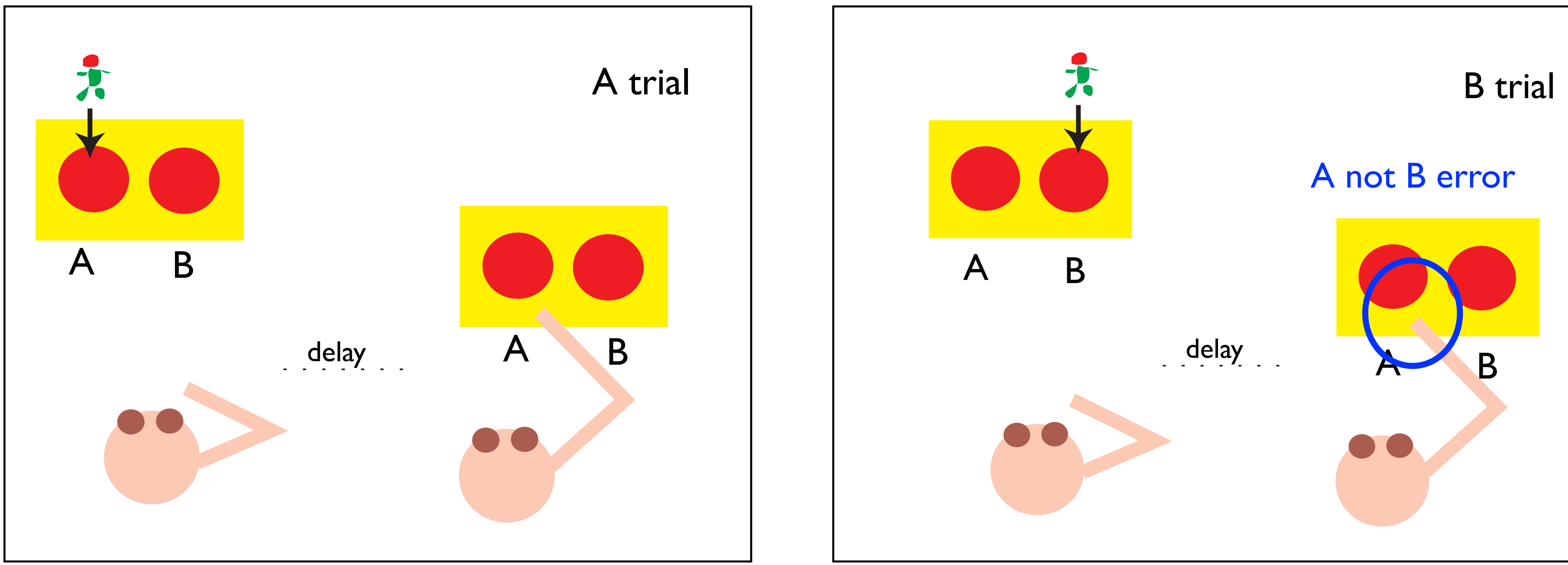
$$\frac{d\phi}{dt} = \sum_{i=1}^{7} f_{\text{obs},i} + f_{\text{tar}}.$$

$$\psi_{\text{tar}} = \int_{0}^{2\pi} \psi H(u(\psi)) d\psi / N_u$$



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

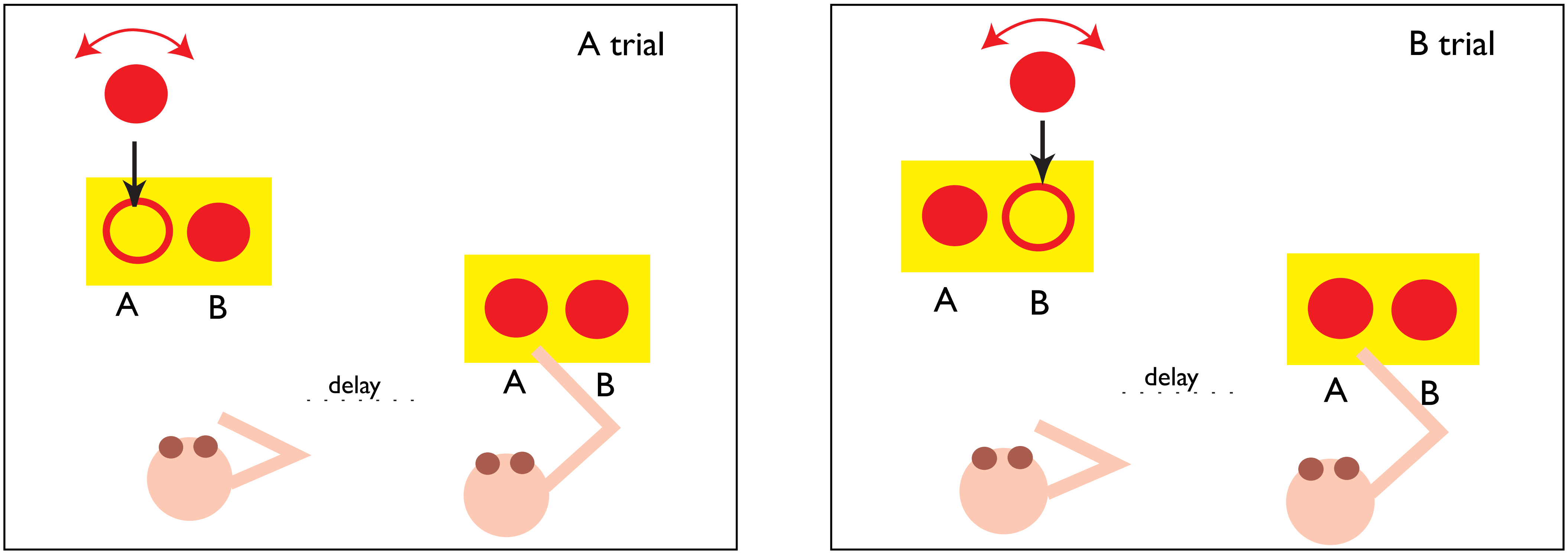
Piaget's A not B paradigm: "out-of-sight -- out of mind"



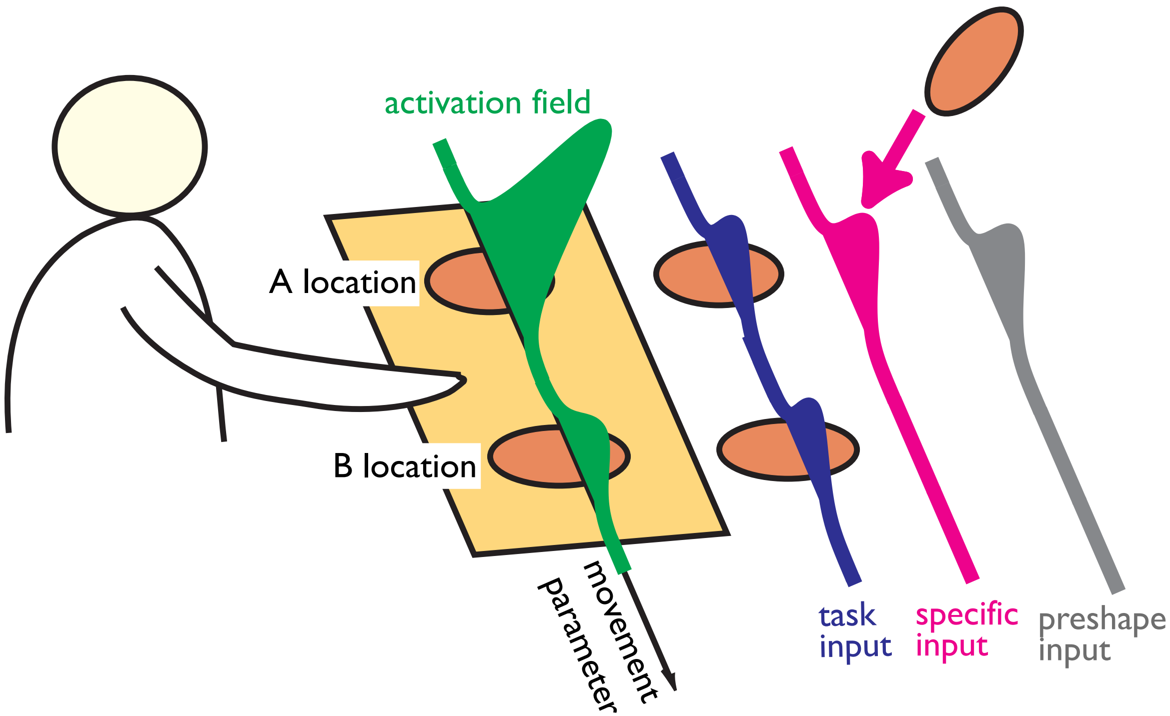
Toyless variant of A not B task

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

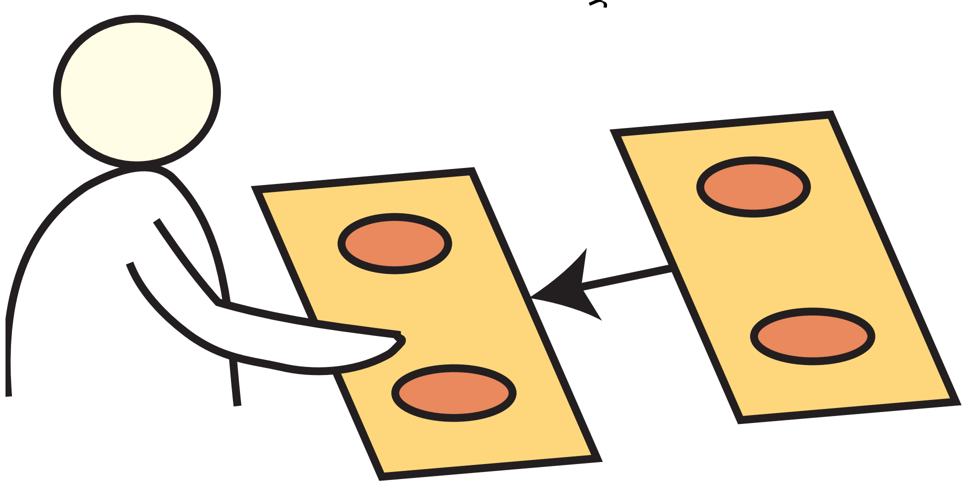
Toyless variant of A not B task reveals that A not B is essentially a decision task!



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



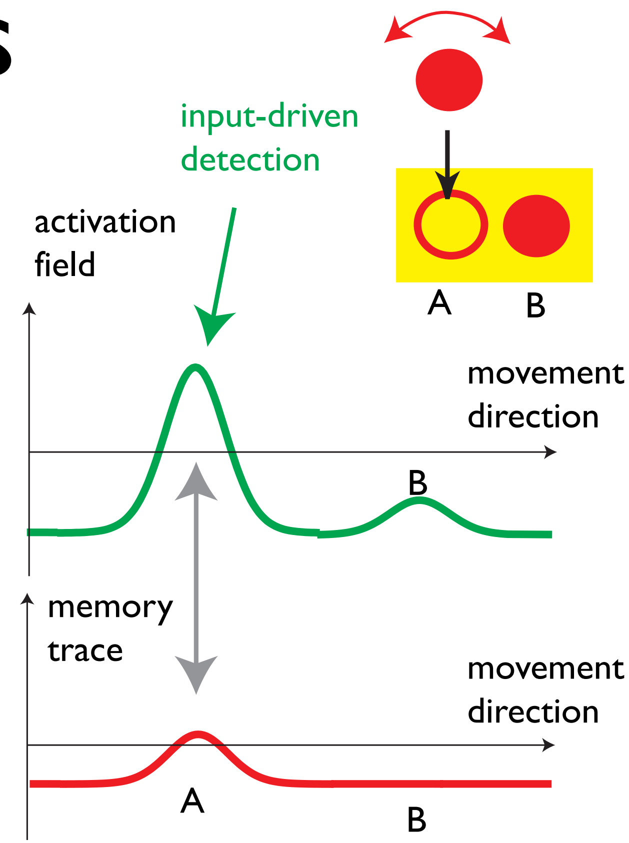
[Thelen, et al., BBS (2001)]



[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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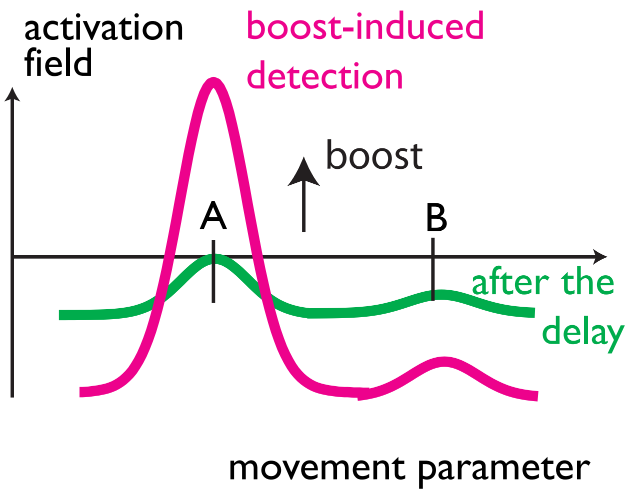

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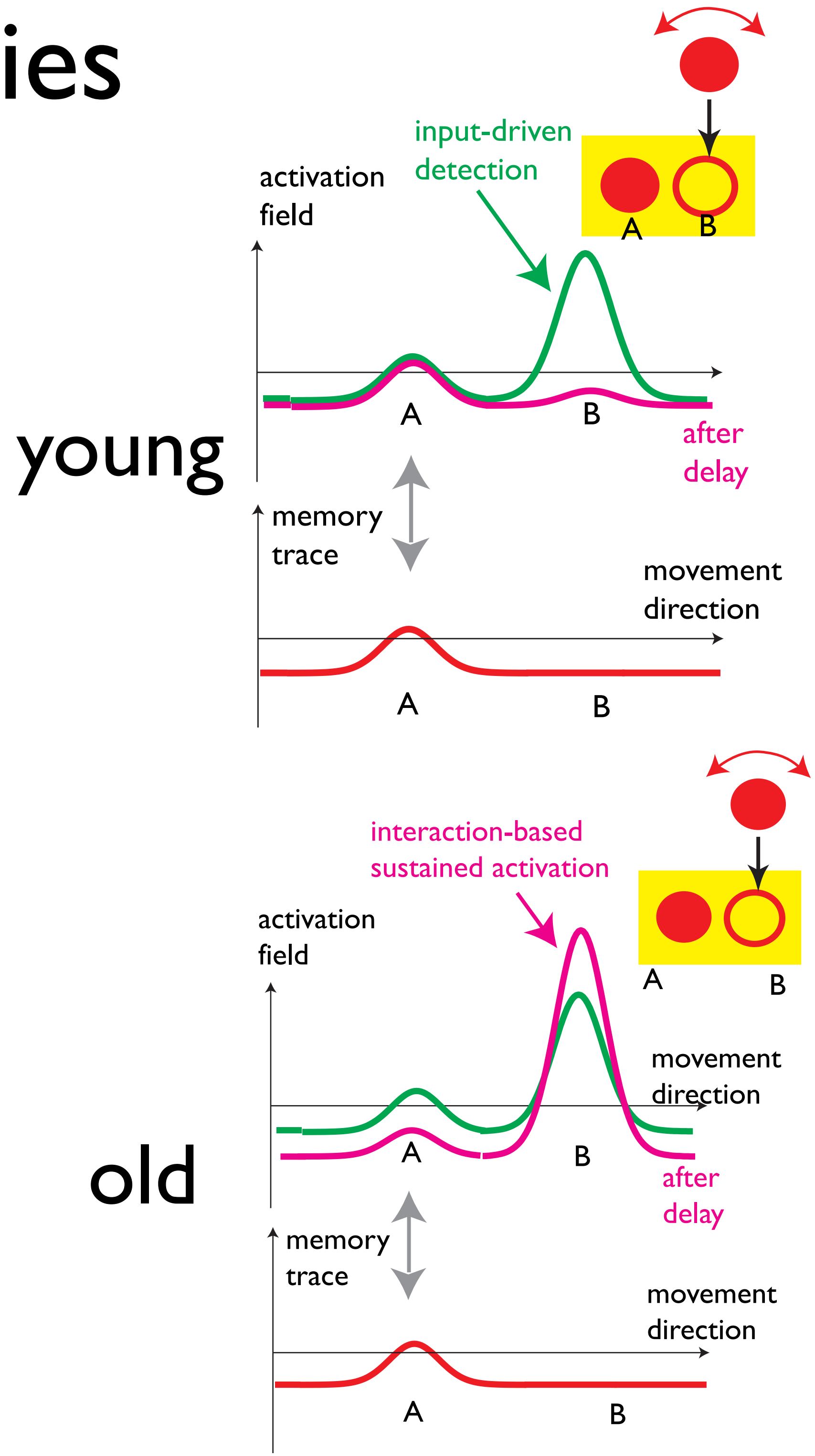
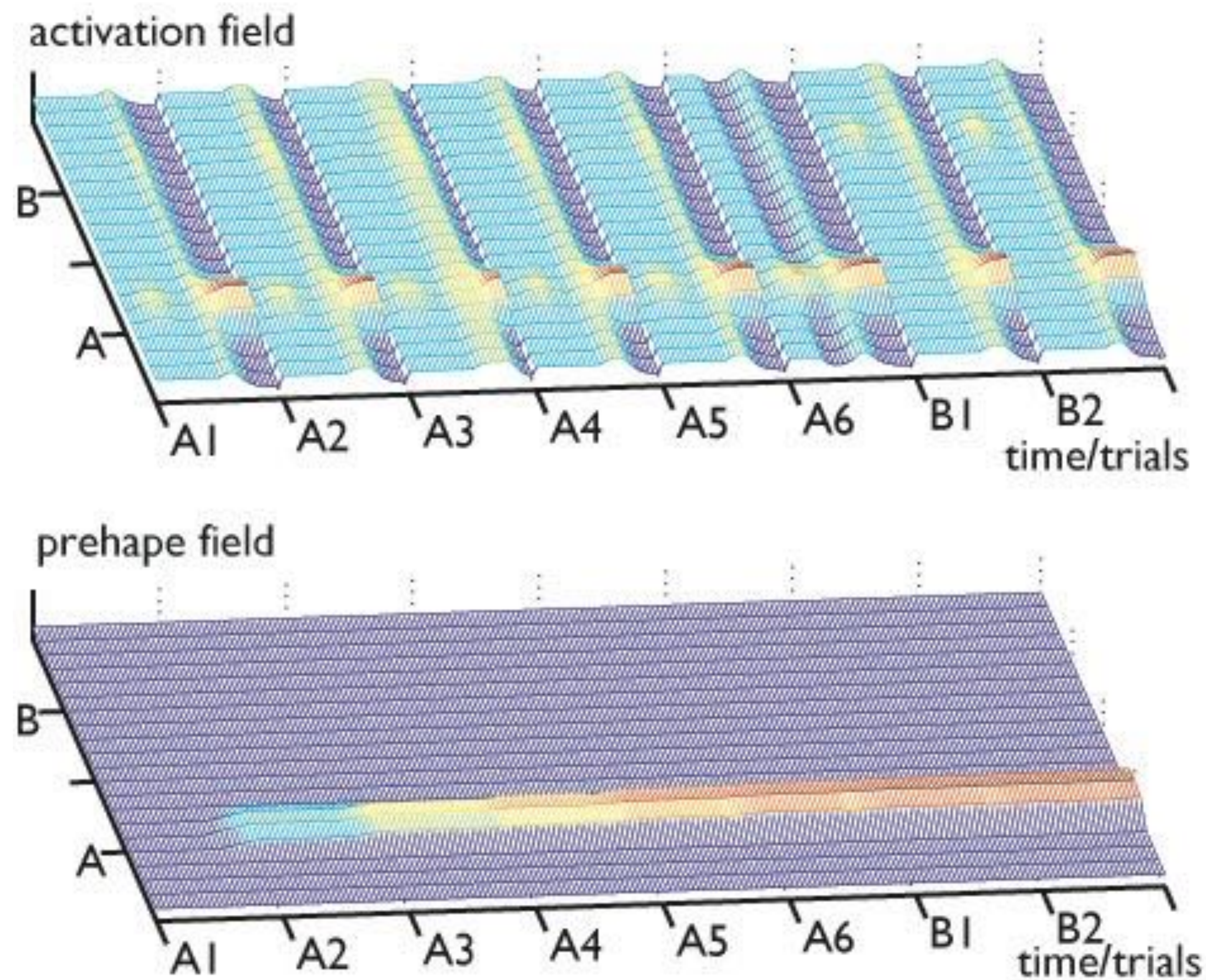
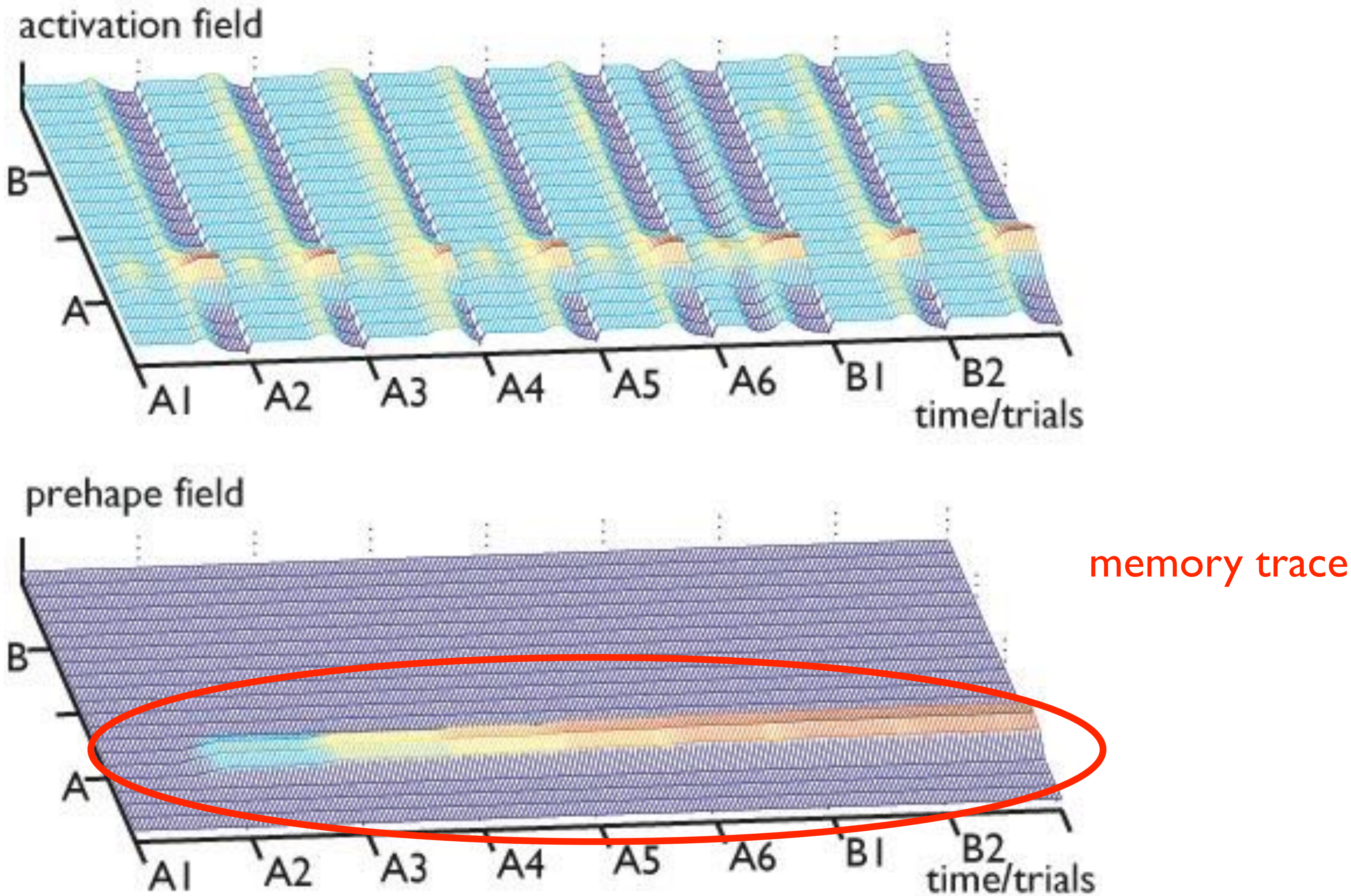


DFT of infant perseverative reaching



[Dinveva, Schöner, Dev. Science 2007]

DFT of infant perseverative reaching



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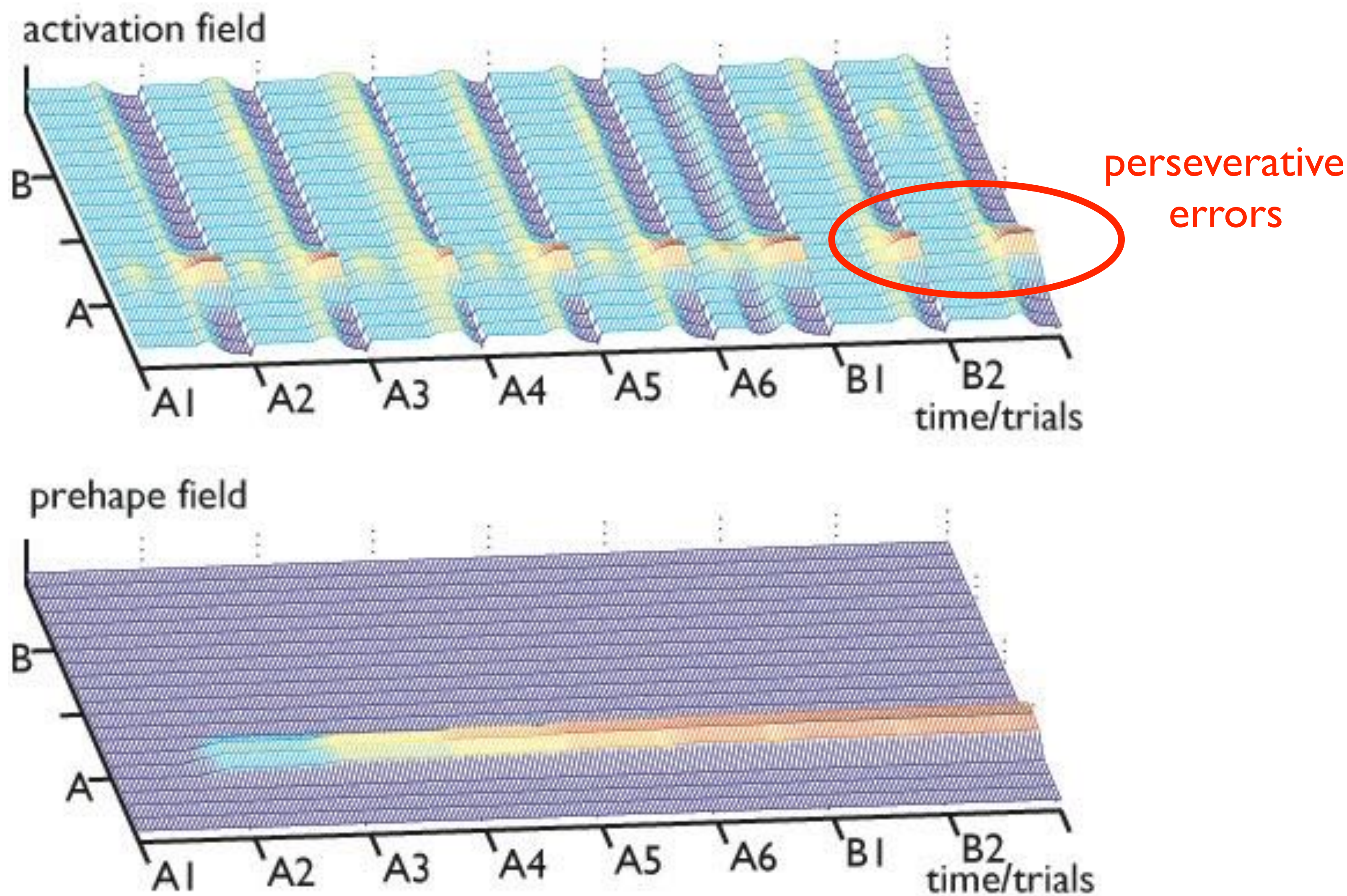
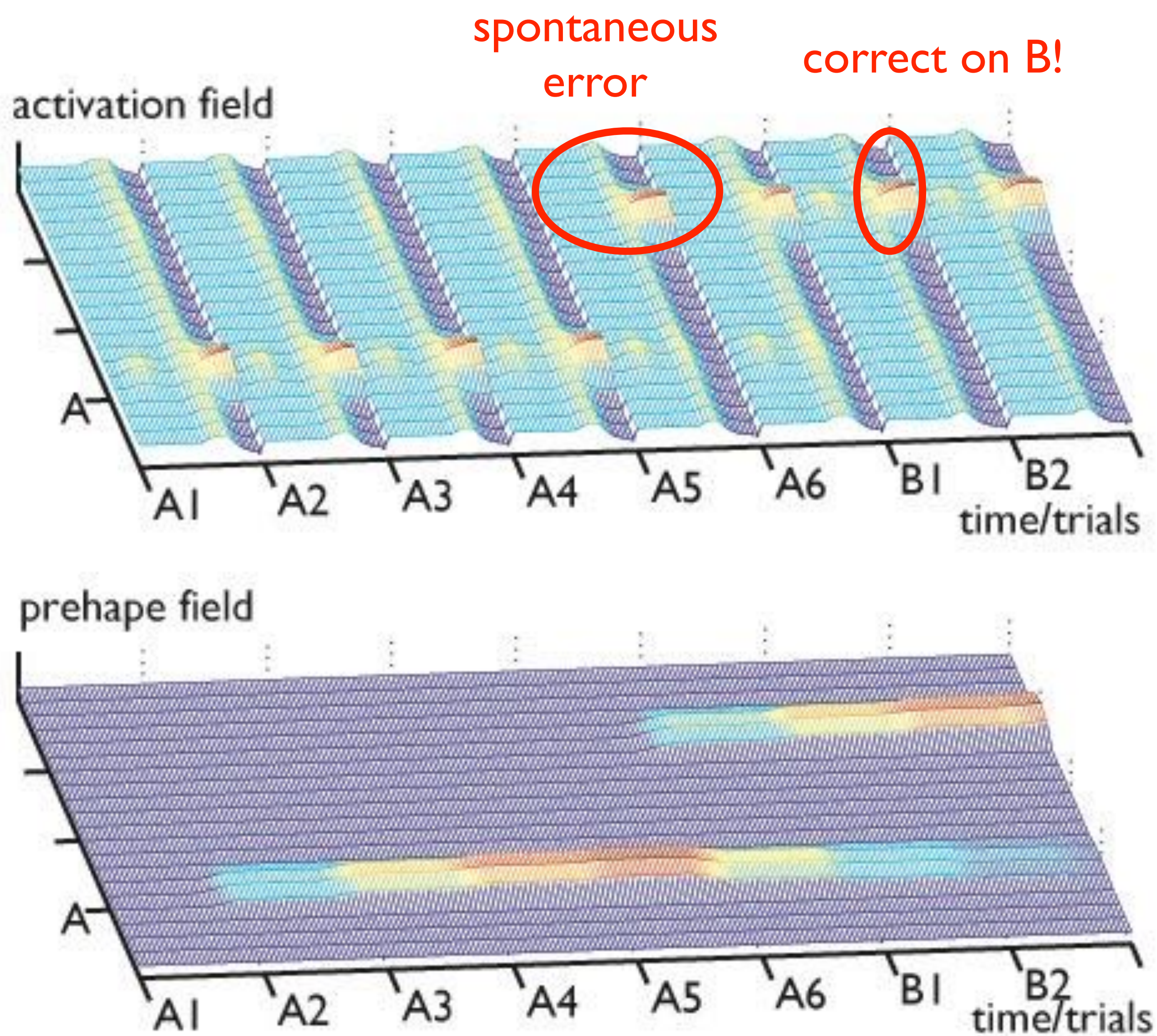


[Dinveva, Schöner, Dev. Science 2007]

DFT of infant perseverative reaching

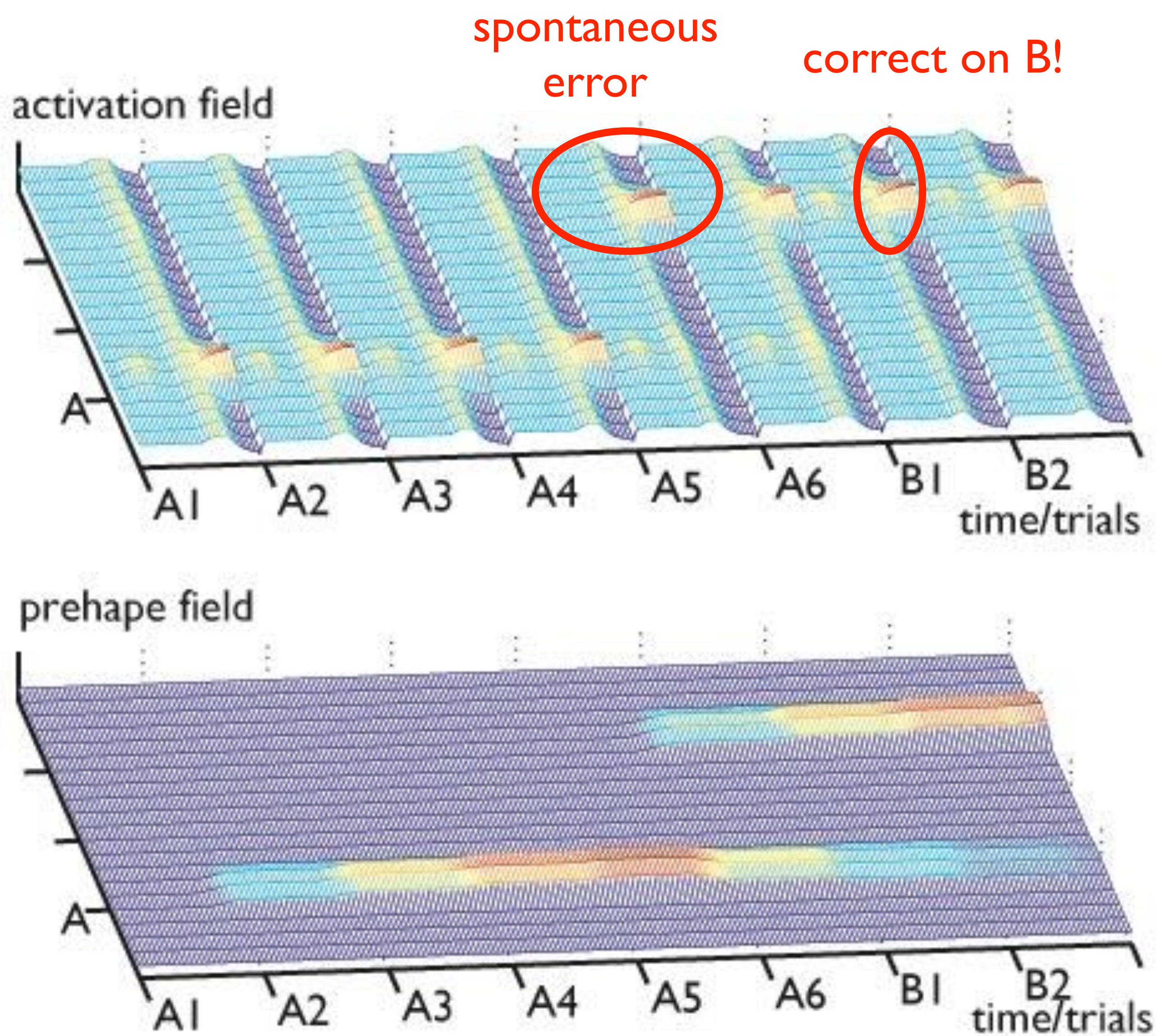
- in spotaneous errors, activation arises at B on an A trial
- which leads to correct reaching on B trial



[Dinveva, Schöner, Dev. Science 2007]

DFT of infant perseverative reaching

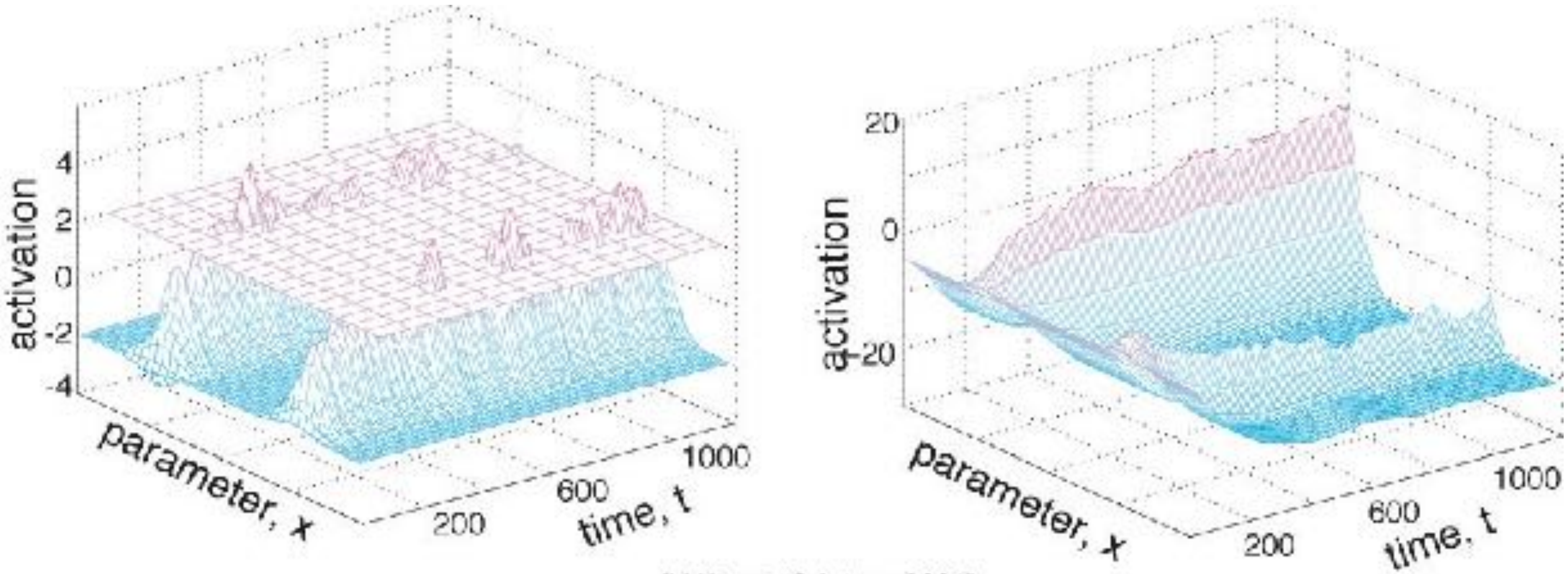
- that is because reaches to B on A trials leave memory trace at B



[Dinveva, Schöner, Dev. Science 2007]

DFT is a neural process model

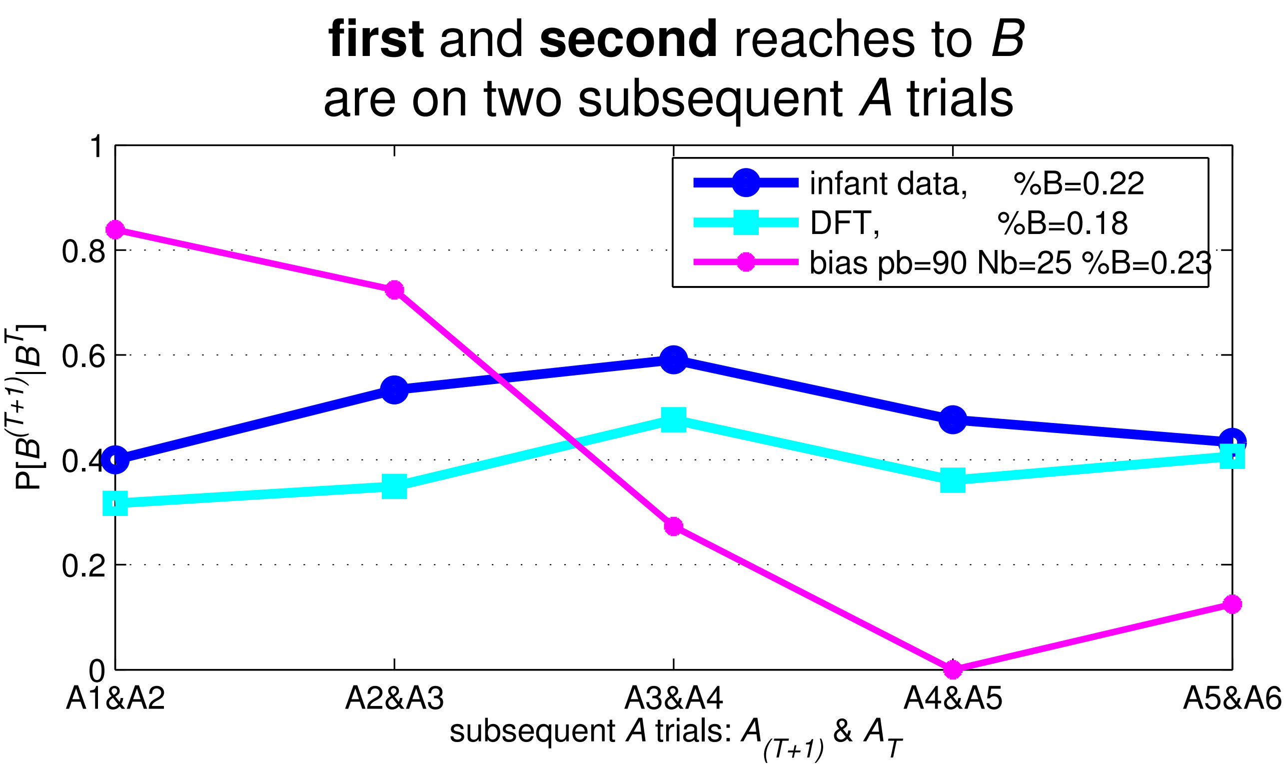
- that makes the decisions in each individual trial, by amplifying small differences into a macroscopic stable state
- and that's how decisions leave traces, have consequences



[Wilimzig, Schoner, 2006]

DFT of infant perseverative reaching

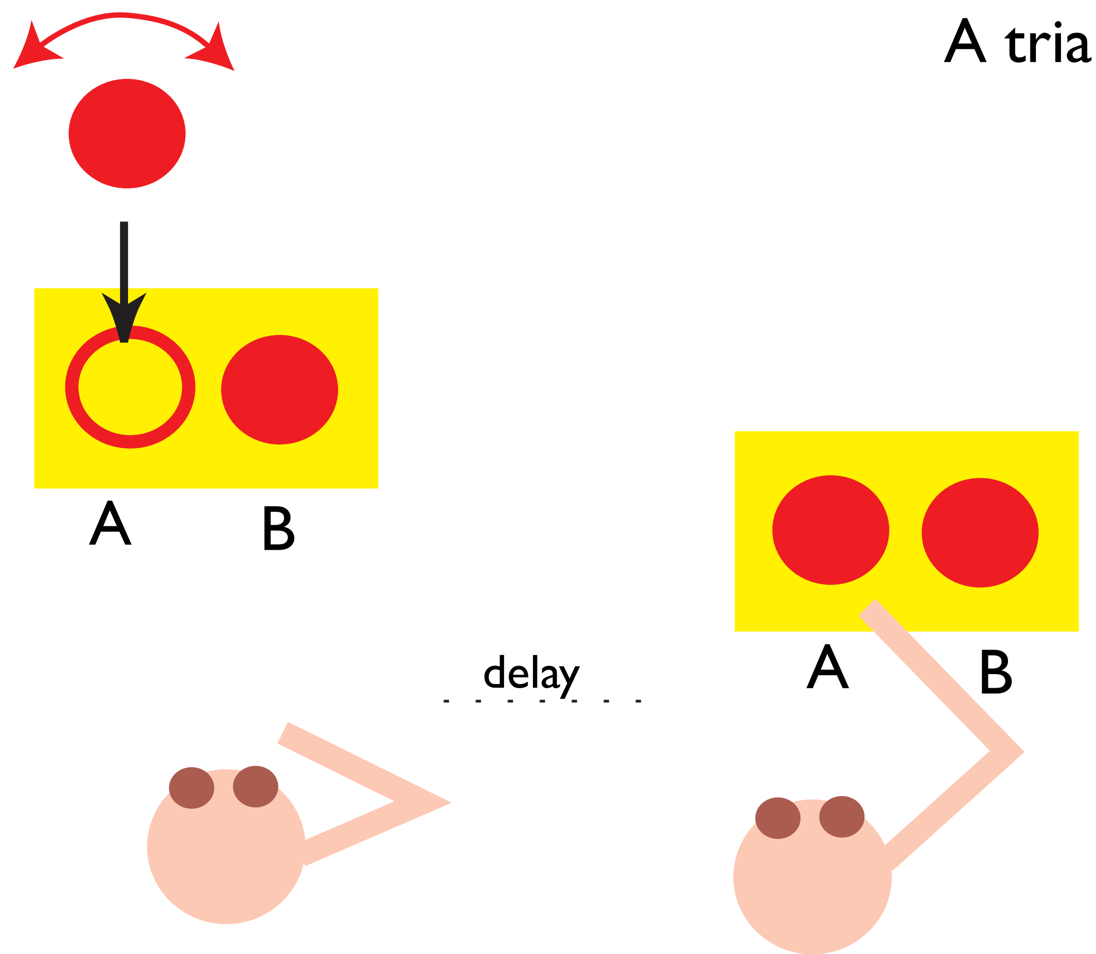
- spontaneous errors promote spontaneous errors



[Dinveva, Schöner, Dev. Science 2007]

summary: instabilities

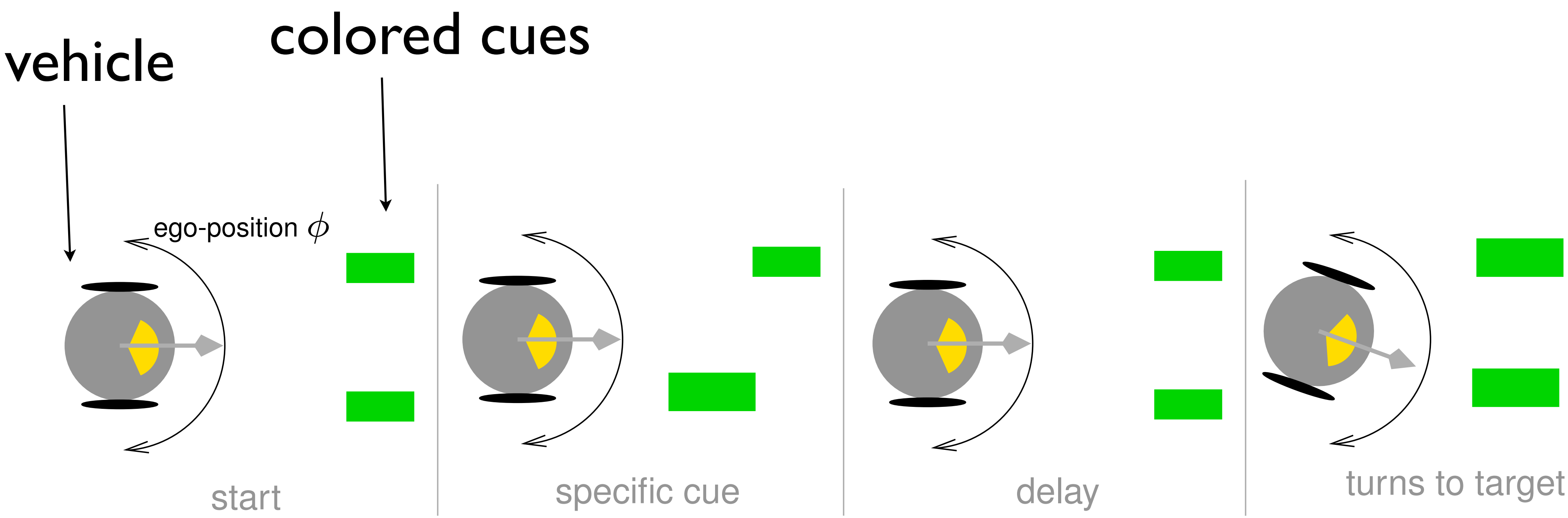
- detection: forming and initiating a movement goal
- selection: making sensori-motor decisions
- boost-driven detection: initiating the the action
- learning: memory trace
- working memory: sustaining a delay



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

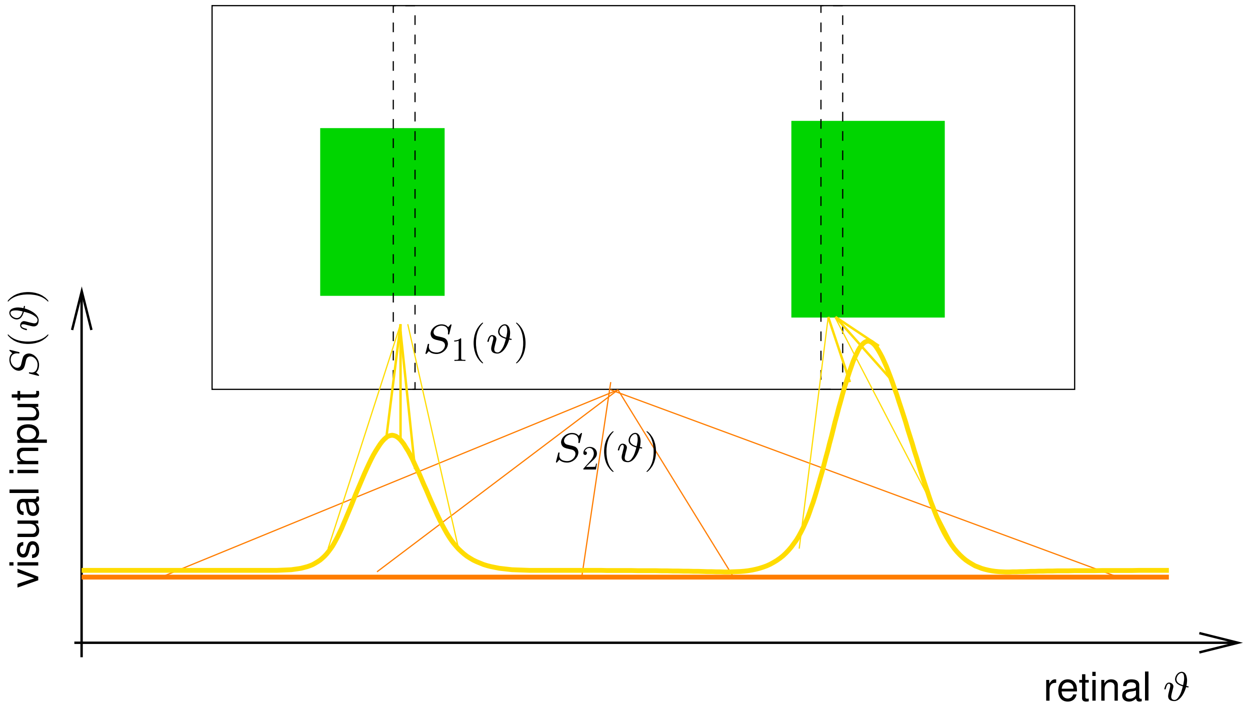
Embodied A not B

- implementing the A not B model on a autonomous robot with continuous link to sensory and motor surfaces...



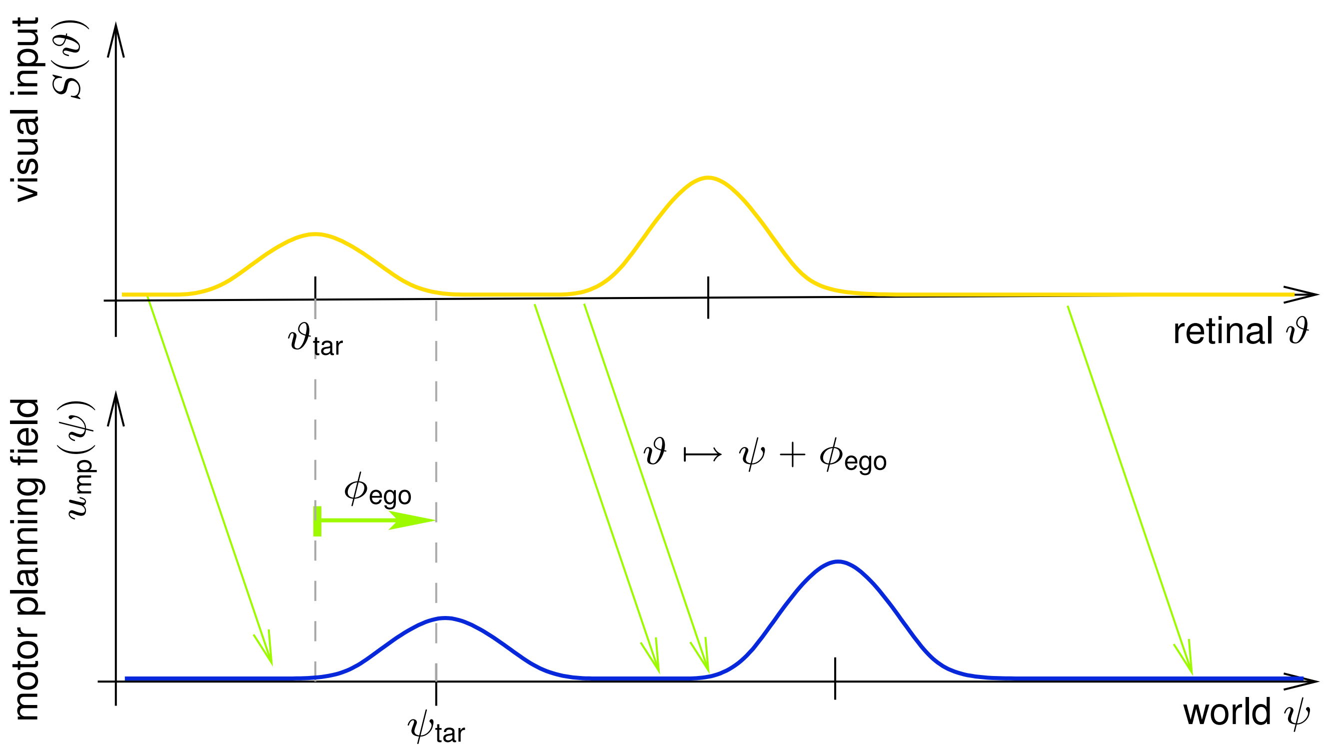
Visual input

- color-based segmentation
- summing color pixels within color slot along the vertical
- spatially filter at two resolutions



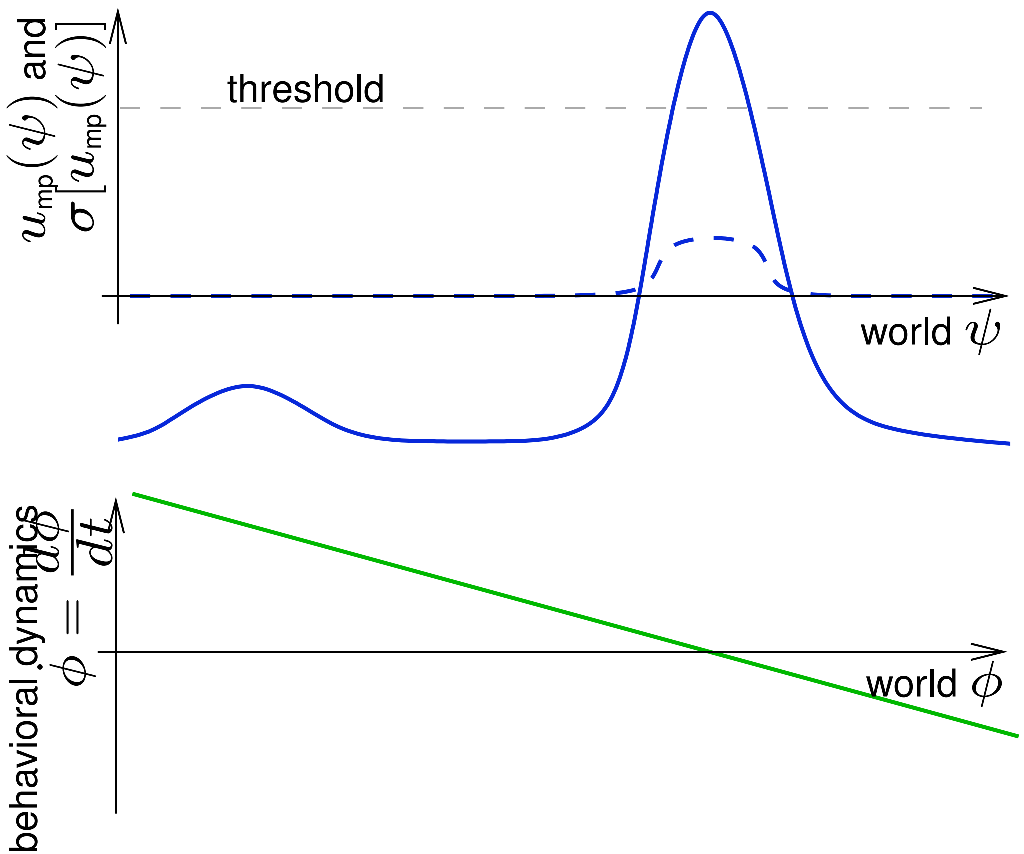
Dynamic field

- defined over direction in the world
- (requires coordinate transform from retina based on dead-reckoning)



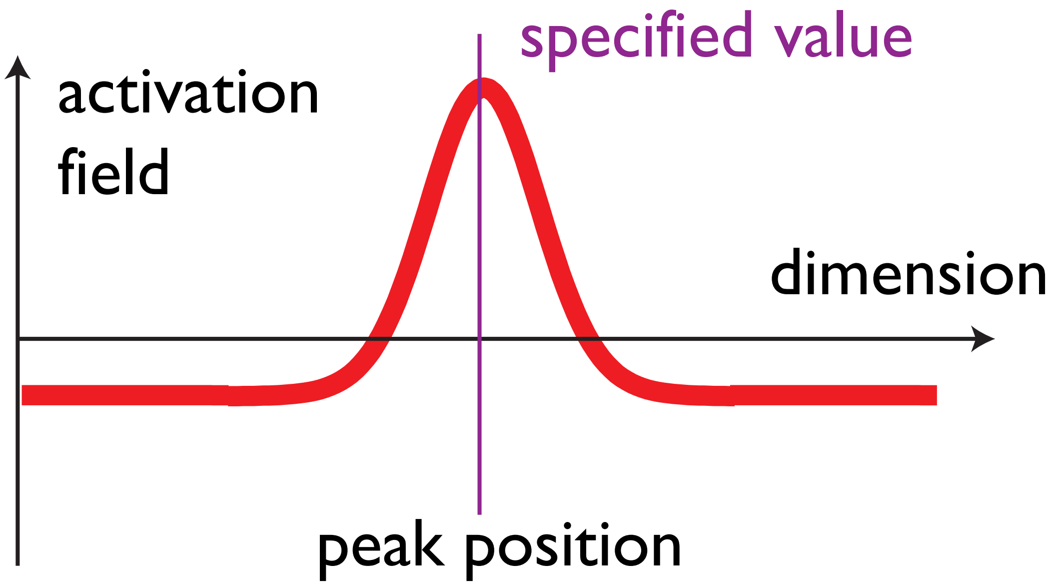
Motor dynamics

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



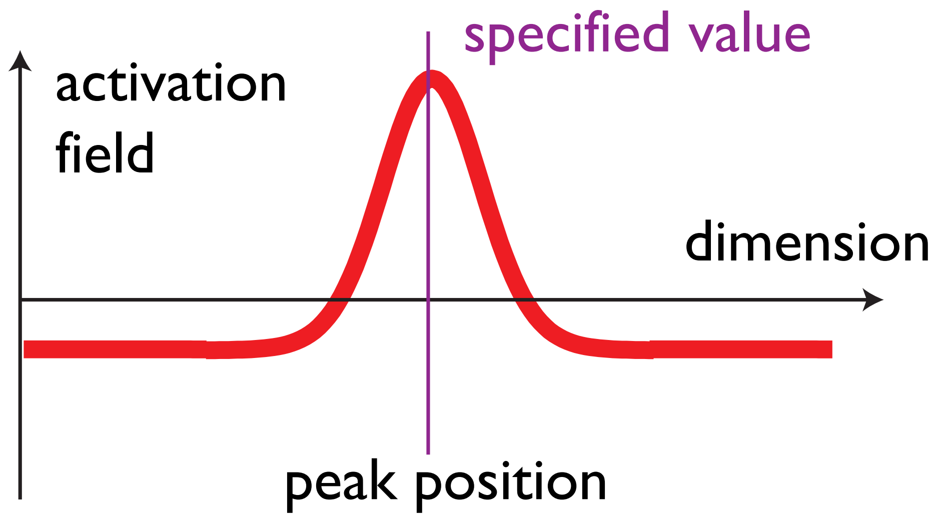
"Read-out" by generating attractor dynamics for motor system

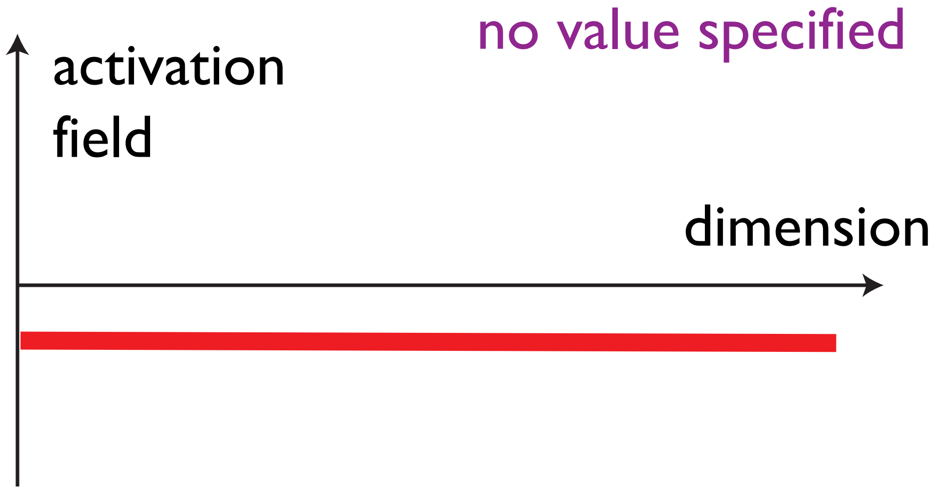
- peak specifies value for a dynamical variable that is congruent to the field dimension



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

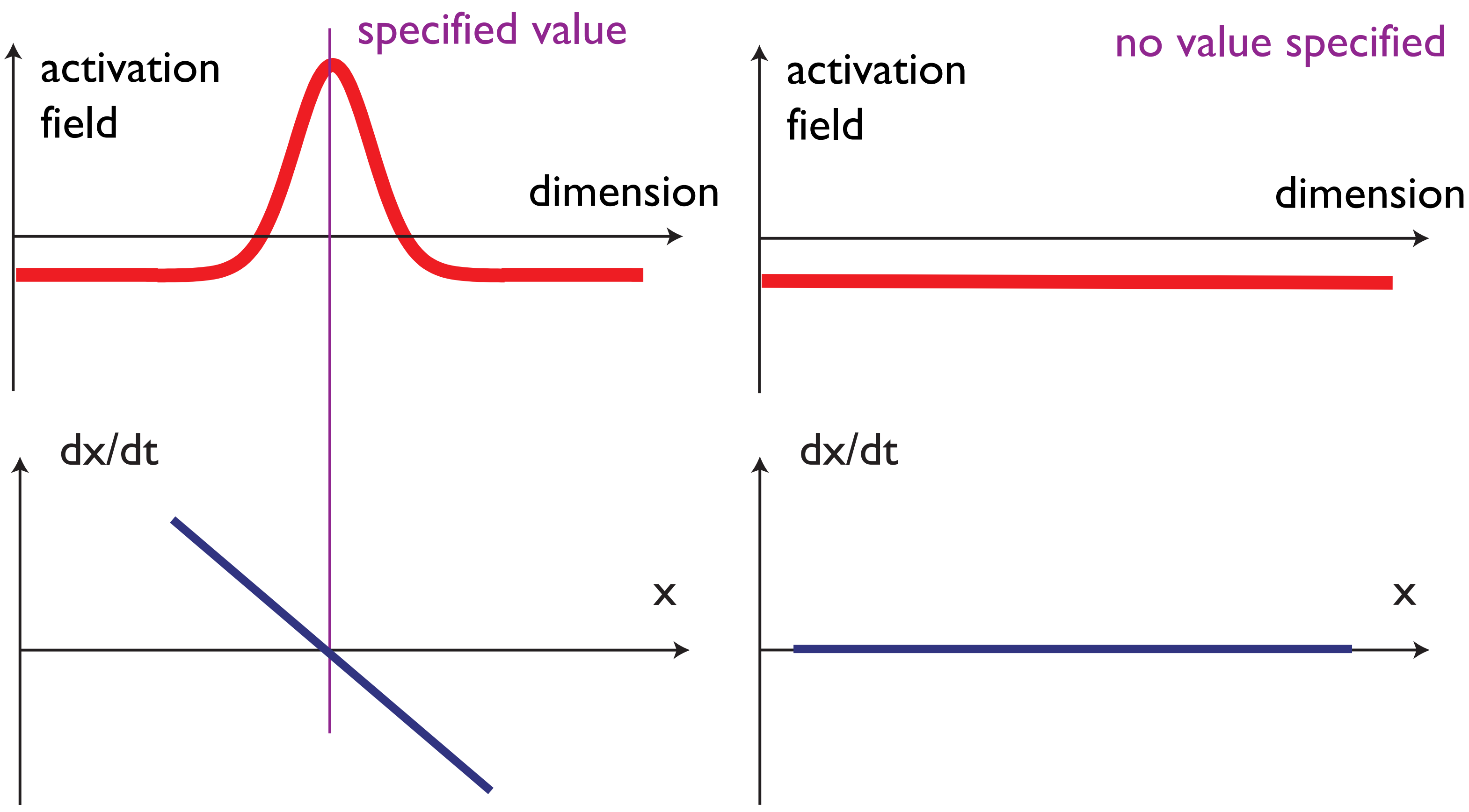
$$x_{\text{peak}} = \frac{\int dx' \; \sigma(u(x',t))x'}{\int dx' \; \sigma(u(x',t))}$$





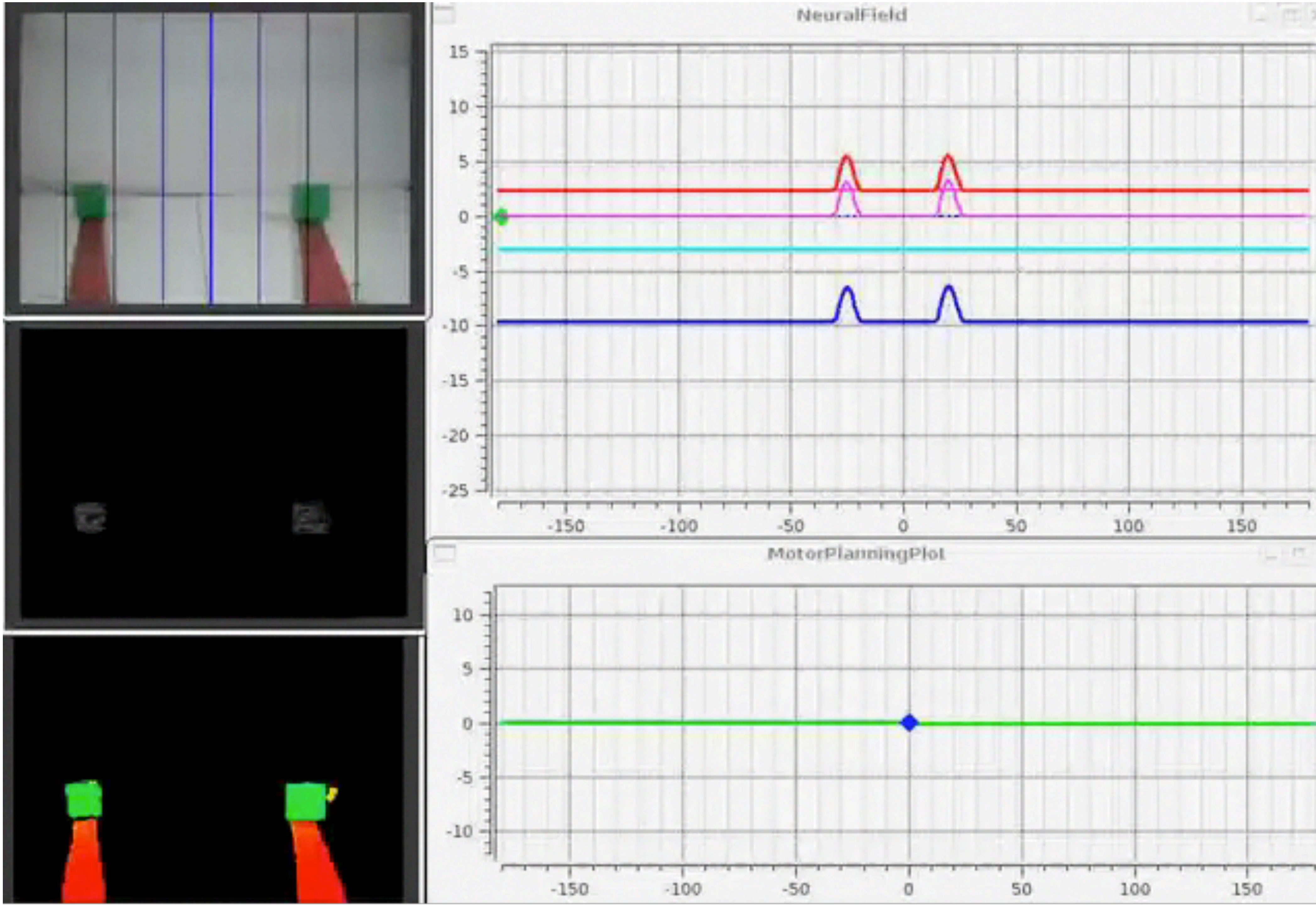
instead:

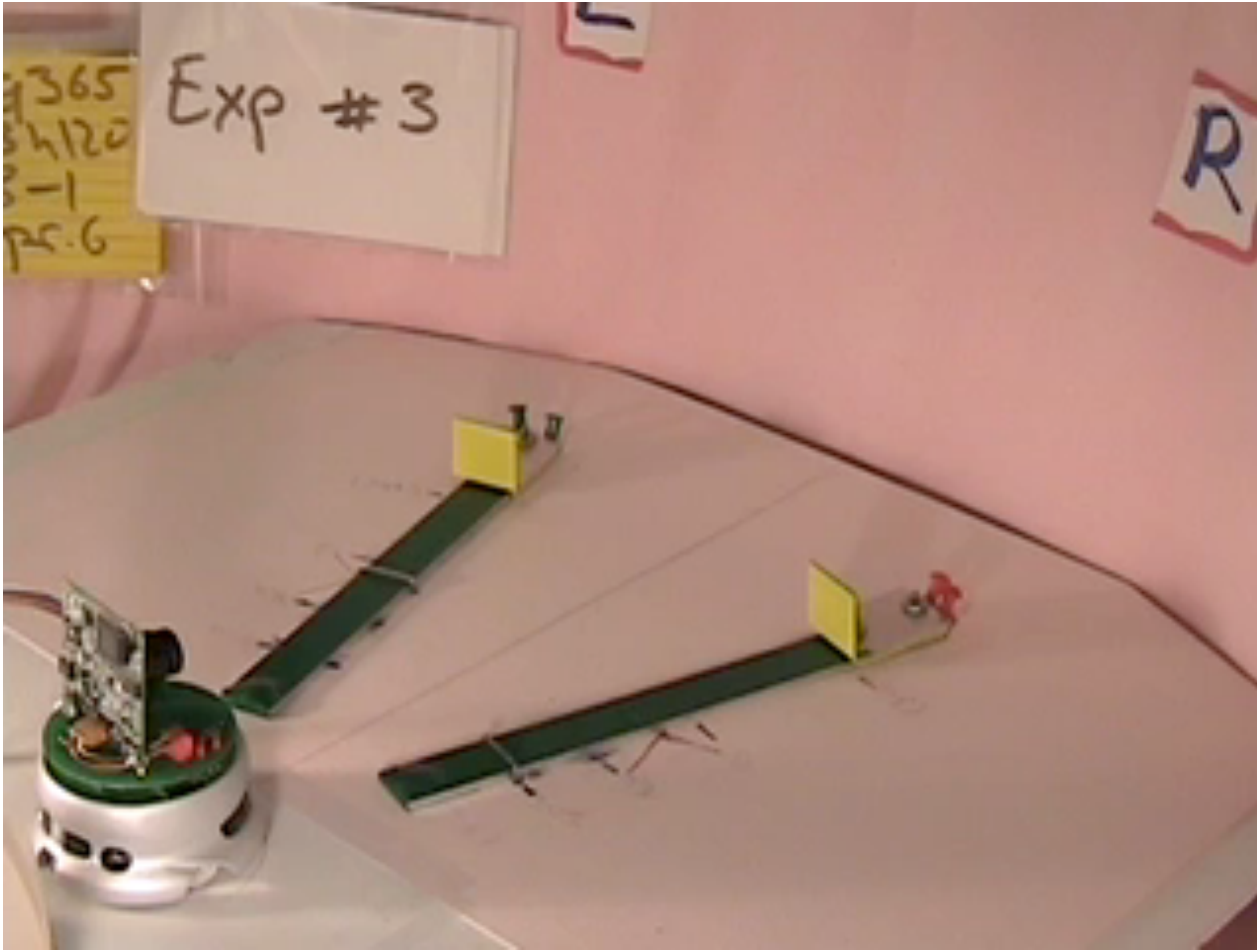
- create attractor



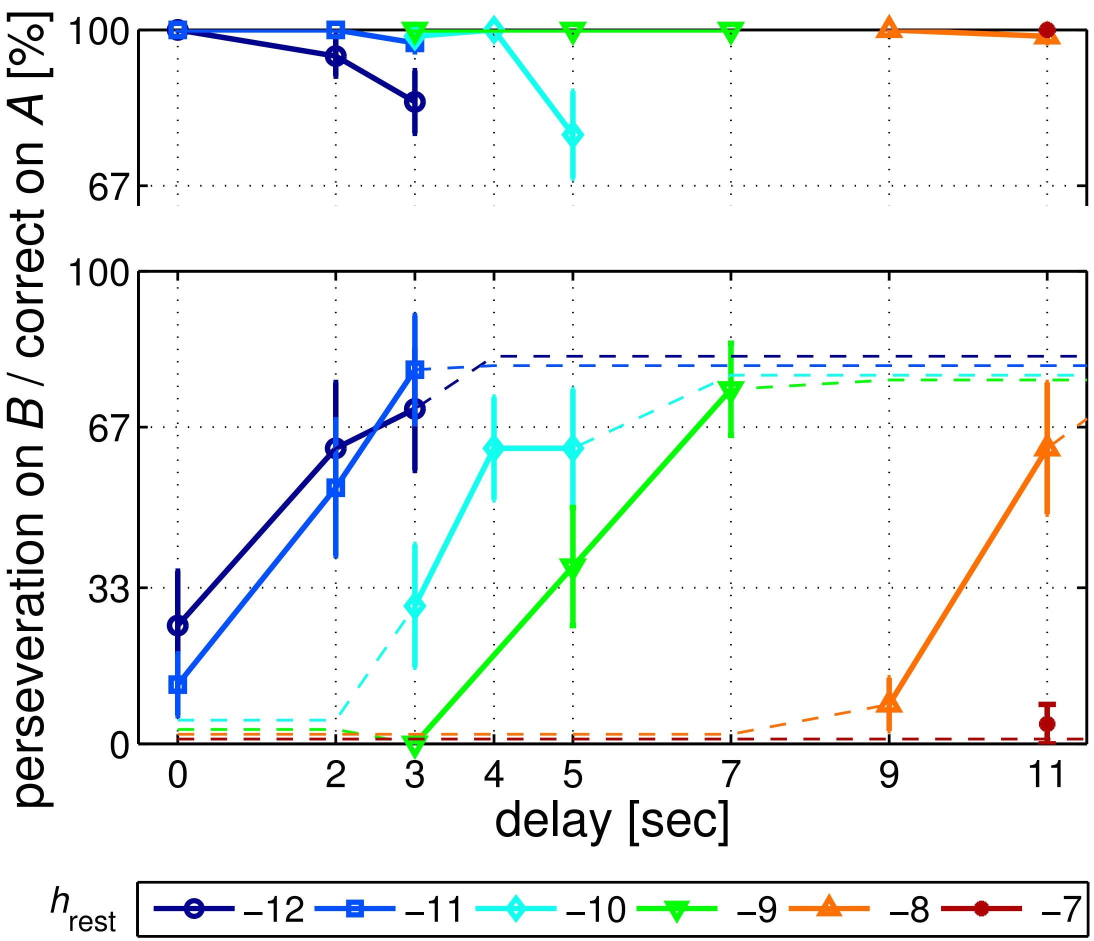
- solution: peak sets attractor
  - location of attractor: peak location
  - strength of attractor: summed supra-threshold activation

$$
\begin{aligned}
x_{\text{peak}} &= \frac{\int dx' \; \sigma(u(x',t))x'}{\int dx' \; \sigma(u(x',t))} \\
\dot{x} &= -\int dx' \; \sigma(u(x',t)) \, (x - x_{\text{peak}}) \\
&= -\left[\int dx' \; \sigma(u(x',t)) \; x - \int dx' \; \sigma(u(x',t)) \; x_{\text{peak}}\right] \\
&= -\left[\int dx' \; \sigma(u(x',t)) \; x - \int dx' \; \sigma(u(x',t)) \; x'\right] \\
&= -\int dx' \; \sigma(u(x',t)) \, (x - x')
\end{aligned}
$$


NeuralField
MotorPlanningPlot

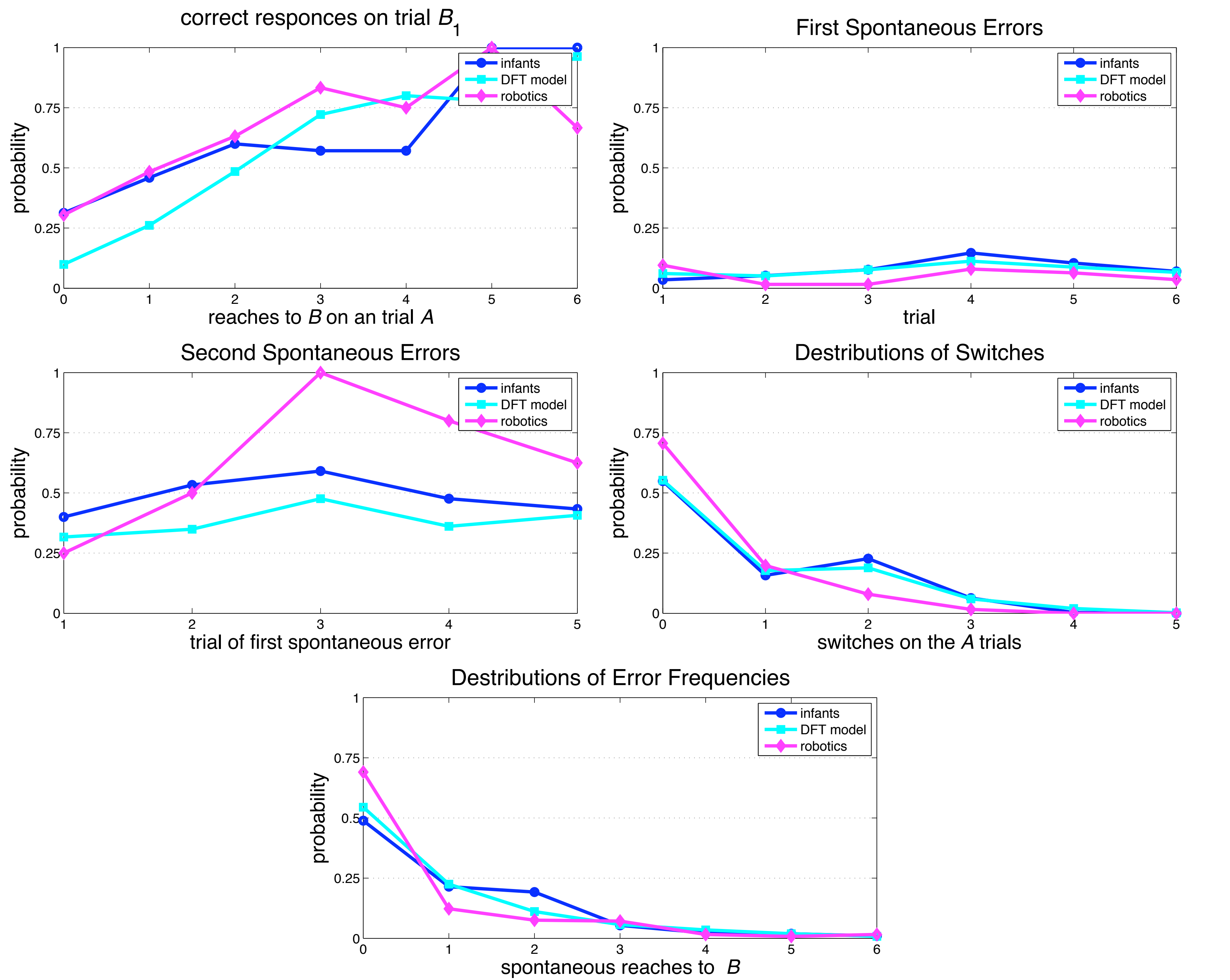

Exp #3
R

result: reproduce fundamental age-delay trade-off in A not B



young

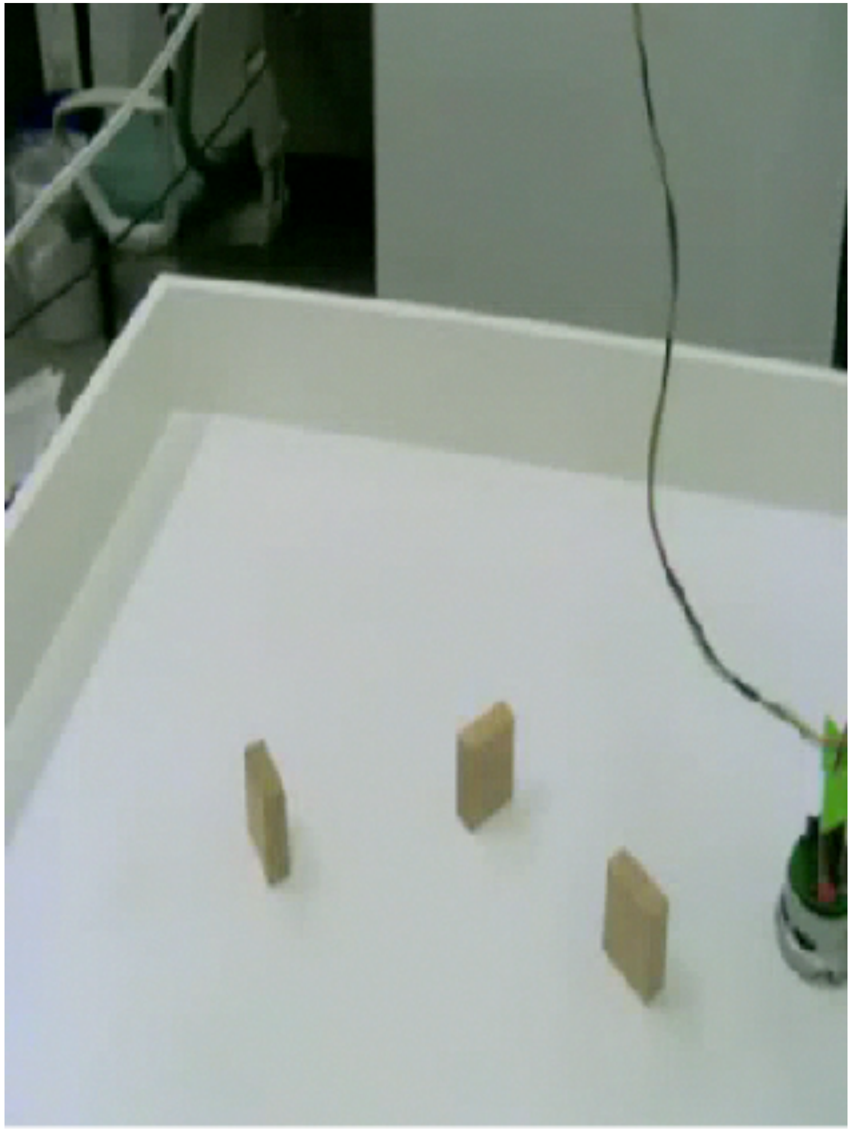
old


correct responces on trial B1
reaches to B on an trial A
First Spontaneous Errors
trial
Second Spontaneous Errors
trial of first spontaneous error
Destributions of Switches
switches on the A trials
Destributions of Error Frequencies
spontaneous reaches to B
probability
infants
DFT model
robotics

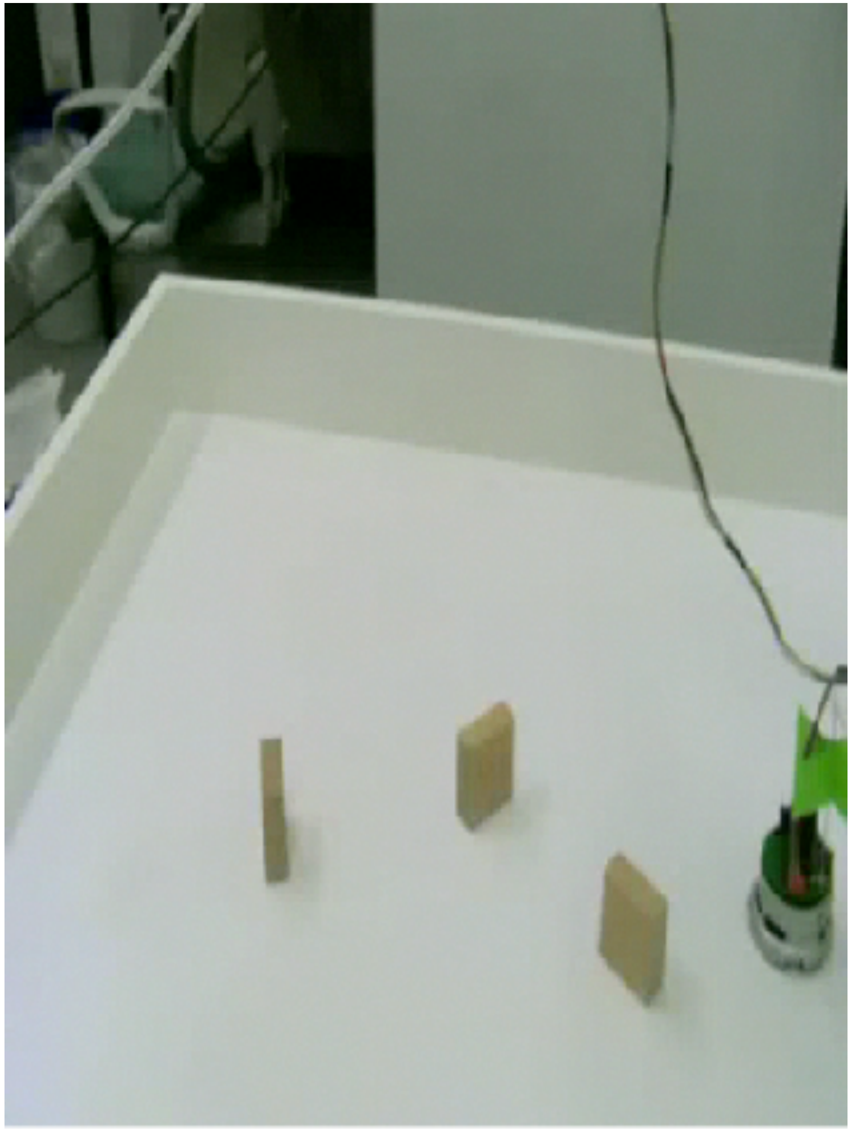
“young” robot

“old” robot

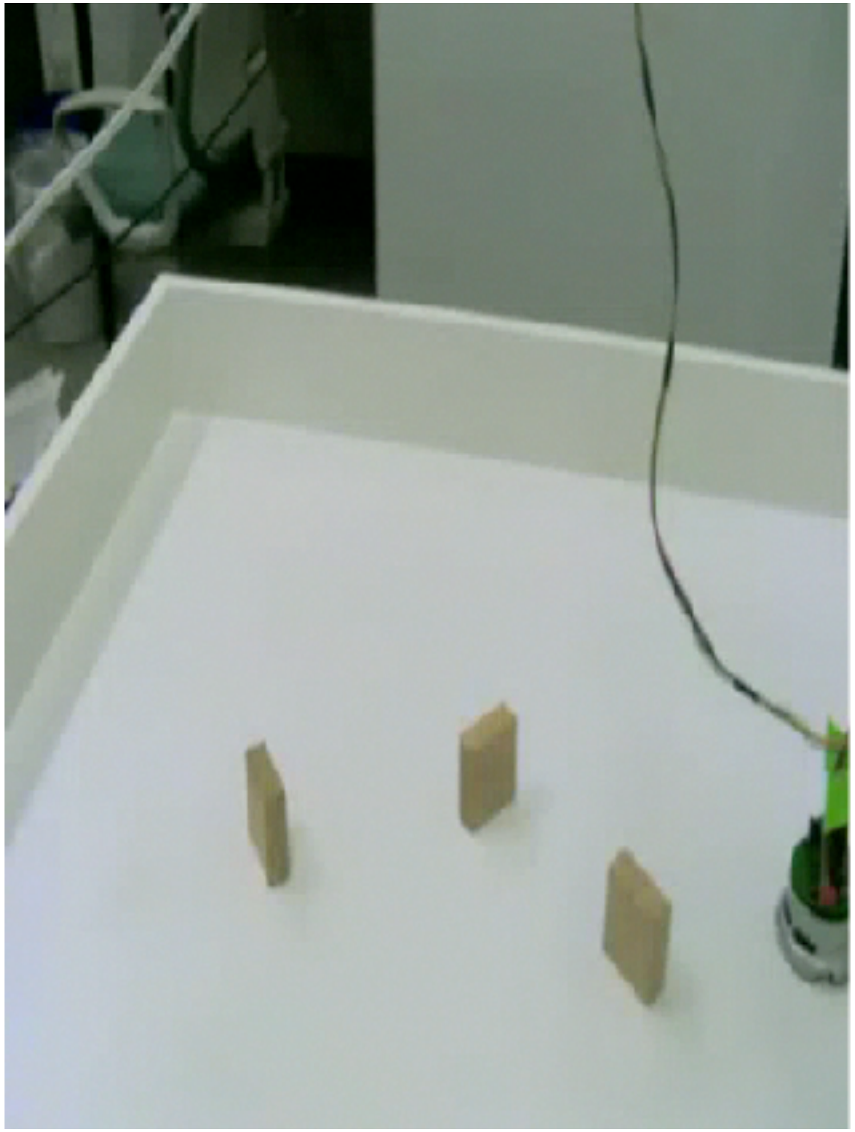
target



target

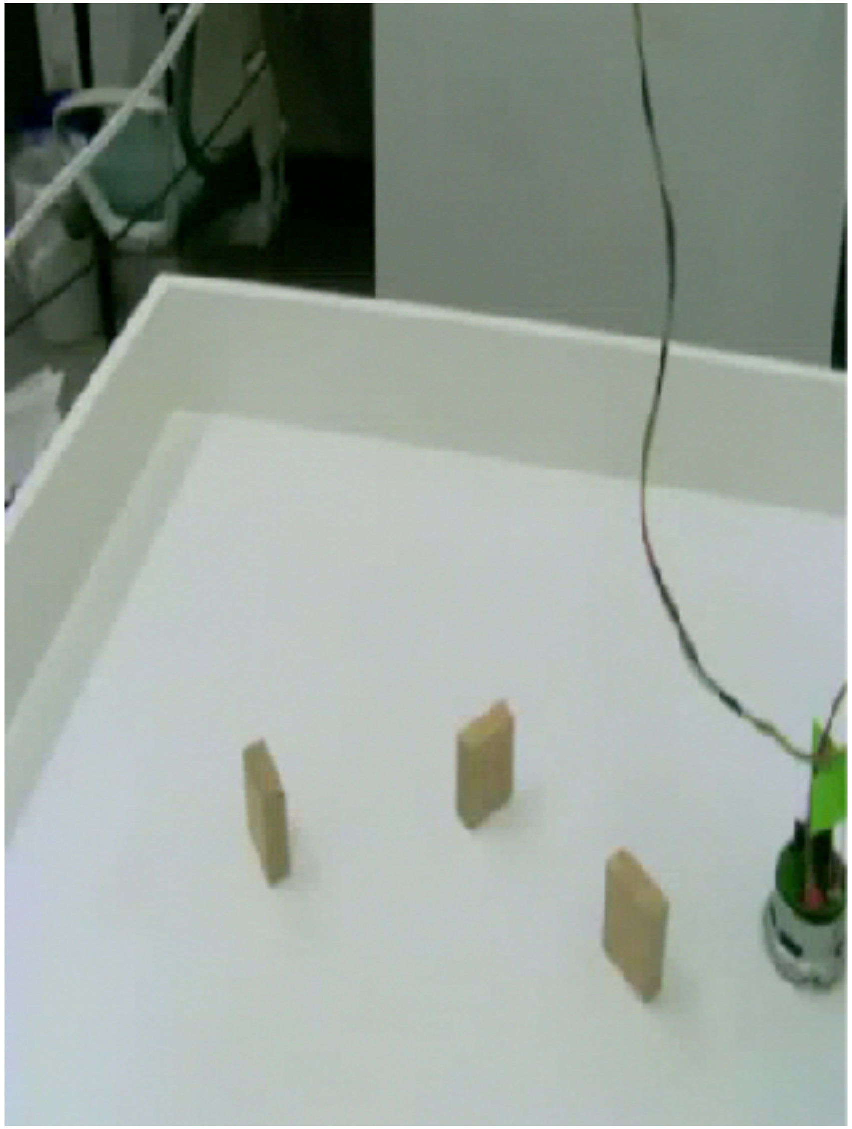


“young” robot



target

“young” robot with memory trace



target

DFT models can be embodied

- stabilization of decisions is critical
- (when we failed to do so, by just "reading out" the location with maximal activation after the delay, that location fluctuate from moment to moment leading to meandering of the robot in an averaged direction)