Introduction

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What is this workshop about?

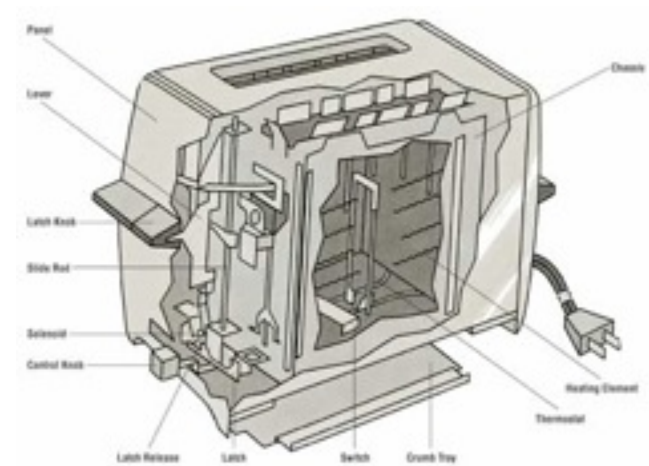
Embodied cognition vs. Information processing

Soccer playing contains a lot of cognition

- see and recognize the ball and the other players, estimate their velocities (perception, scene representation)
- select a visual target, track it, controlling gaze (attention)
- use working memory when players are out of view to predict where you need to look to update (working memory)
- plan and control own motion, initiate and control kick, update movement plans any time (planning)
- get better at playing (learning)
- know goal of the game/rules, how hard the ball is, how fast players are (background knowledge)

Cognition contains a lot of embodiment

- explore scene, recognize screws, while keeping track of spatial arrangement (scene representation, coordinate transforms)
- plan action, find tools, apply them to remembered locations, updated by current pose of toaster (working memory, scene representation)
- manipulating cover, taking it off, recognizing spring, re-attaching it (goal-directed action plan)
- mounting cover back on, generating the correct action sequence (sequence generation)
- get better at this (learning)
- know about cover, screws, hard to turn (background knowledge)



[image: HowStuffWorks]

[image: mystery fandom theater 3000]

Embodied cognition implies constraints

- active perception for a purpose through which perceptual objects are grounded: sensory autonomy
- cognitive processes continuously updated and continuously linkable to motor processes: stability
- invariance and abstraction must retain this linkage to the sensory and motor surfaces
- cognition is sensitive to behavioral history, environmental context: learning, adaptation
- (cognition arises from neural systems)
- build in "back-ground knowledge" (Searle)

The embodiment hypothesis

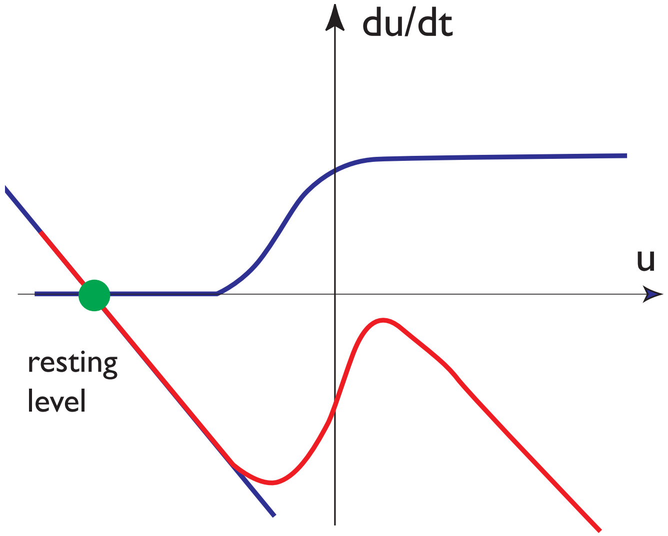
- there is no particular boundary
  - up to which, cognition is embodied
  - beyond which cognition loses the properties of embodiment
- => all cognition shares properties of embodied cognition

Neural dynamics hypothesis

- because embodied cognition unfolds in time, in interaction among processes, including often interaction (loop) between organisms and their environment
- => embodied cognition requires dynamics...

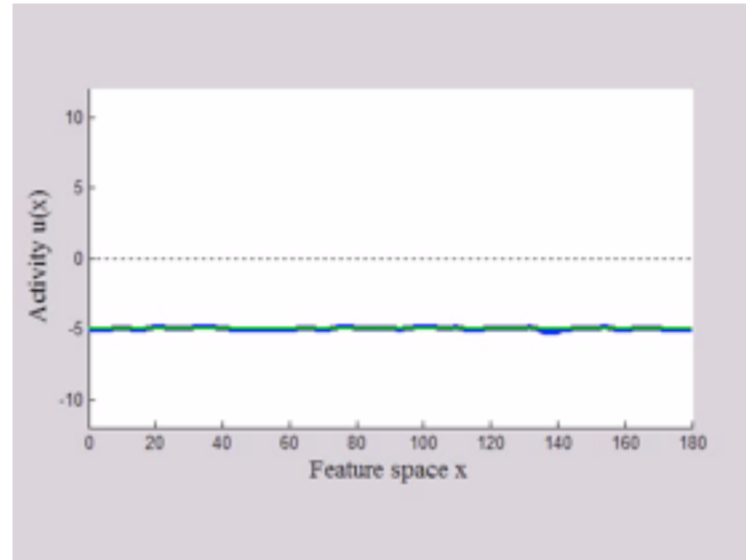
Neural dynamics hypothesis

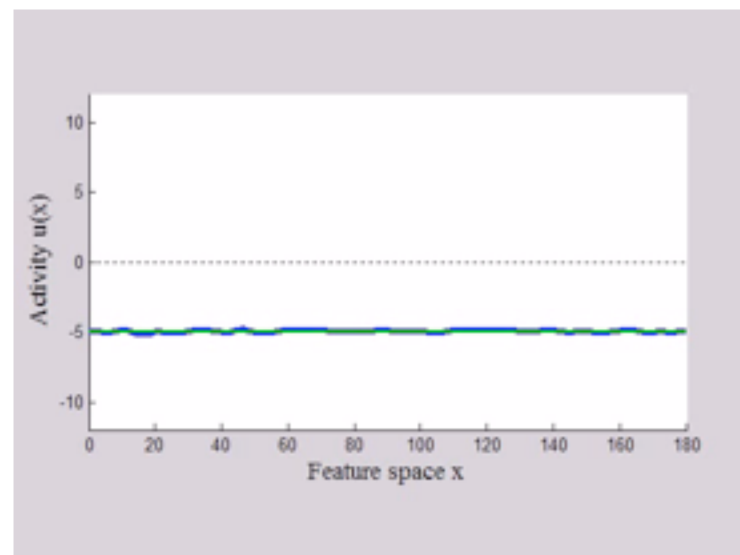
- neural dynamics is a powerful theoretical language with which embodied and situated cognitive systems can be designed and modeled



Dynamic Field Theory

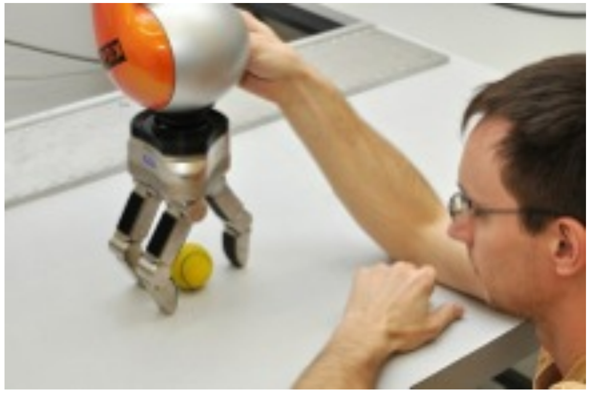
- the most conceptually consistent branch of this language
- which focusses purely on the functional significance of neuronal activity
- abstracting from the functionally insignificant discrete spatial and temporal structure of neuronal computation





Autonomous cognitive robots

- autonomy: actively generate behavior, initiating, selecting, terminating actions based on the system's own perceptual processes
- autonomous robots are model systems on which ideas of embodied (and general) cognition may be tested, evaluated, and heuristically expanded
- autonomous robots are also artificial embodied cognitive systems of interest in their own right.

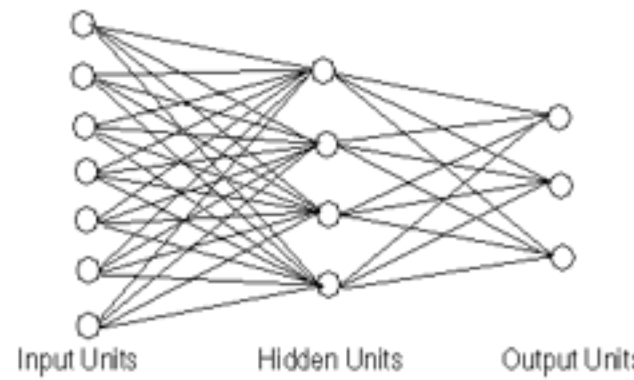


… a little history of

- dynamical systems thinking
- dynamical field theory
- the attractor dynamics approach to behavior generation

… in psychology

- connectionism
  - graded, distributed representations in connectionist networks
  - neural principle: only the connectivity implements function, generalization challenging
  - so far: little autonomy, largely feed-forward stimulus driven
  - and: interfaces with sensors/motor systems hide important problems .... that why you don't see many connectionist robots

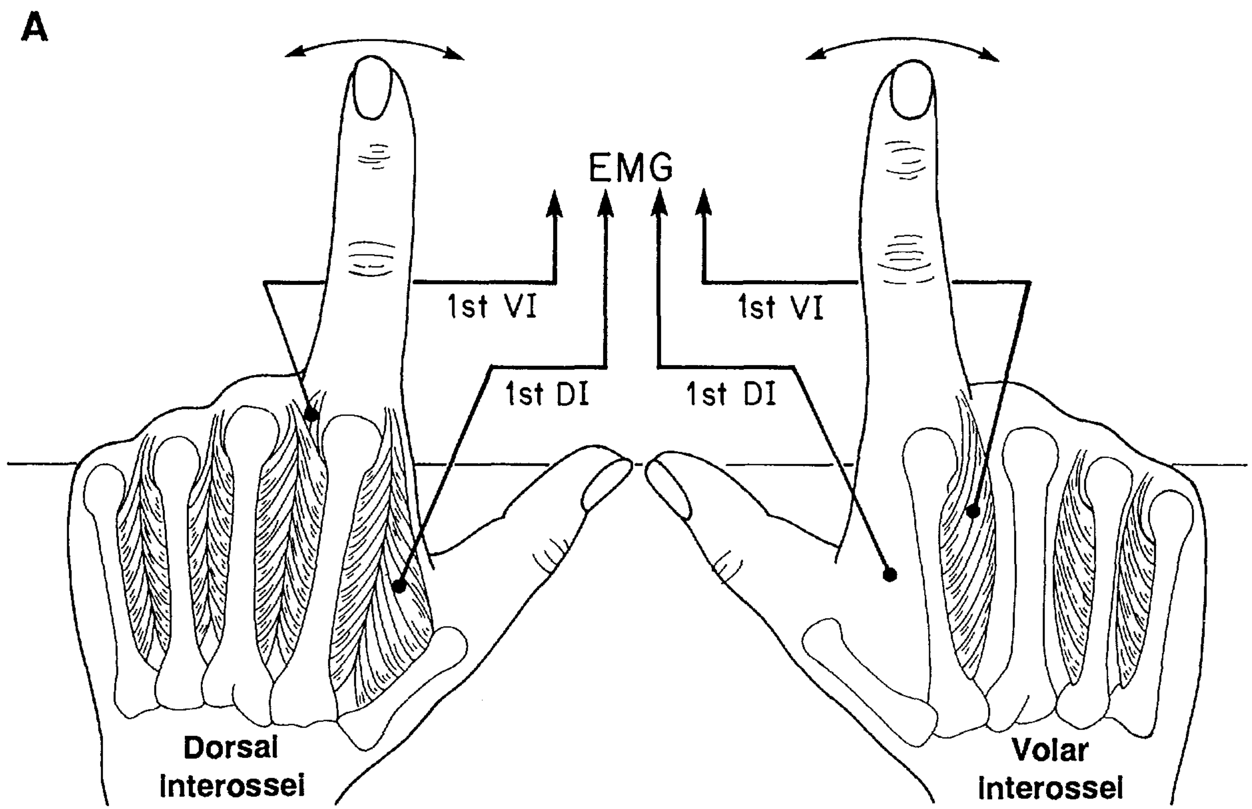


[Stanford Encyclopedia of Philosophy]

dynamical systems thinking

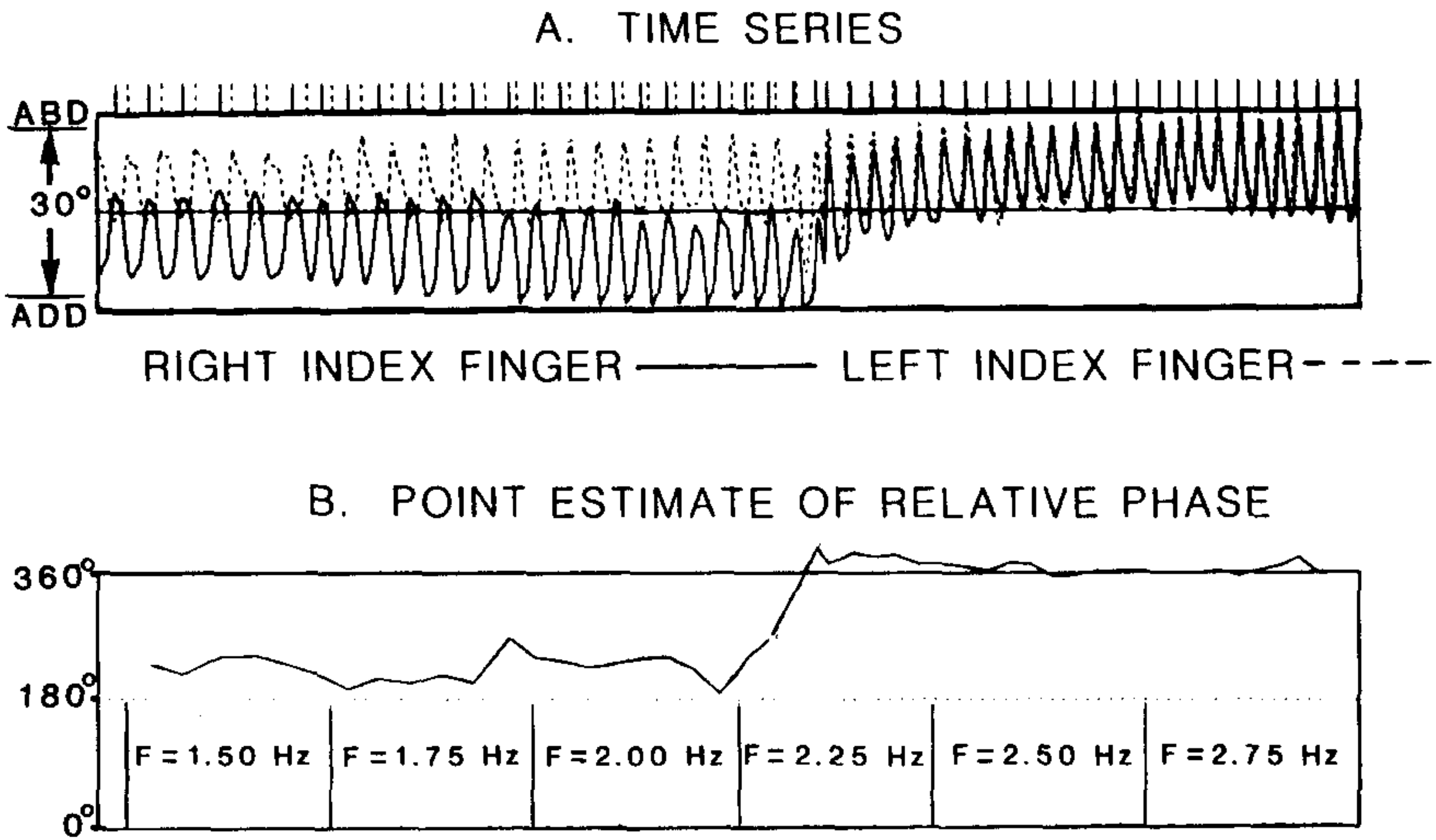
- beginnings in ecological psychology: Turvey, Kugler, Kelso
  - emergency of behavior/coordination from dynamics
- movement coordination: Kelso, Schöner
  - evidence that stability is critical

Stability and loss of stability in movement coordination



[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]

Stability and loss of stability in movement coordination



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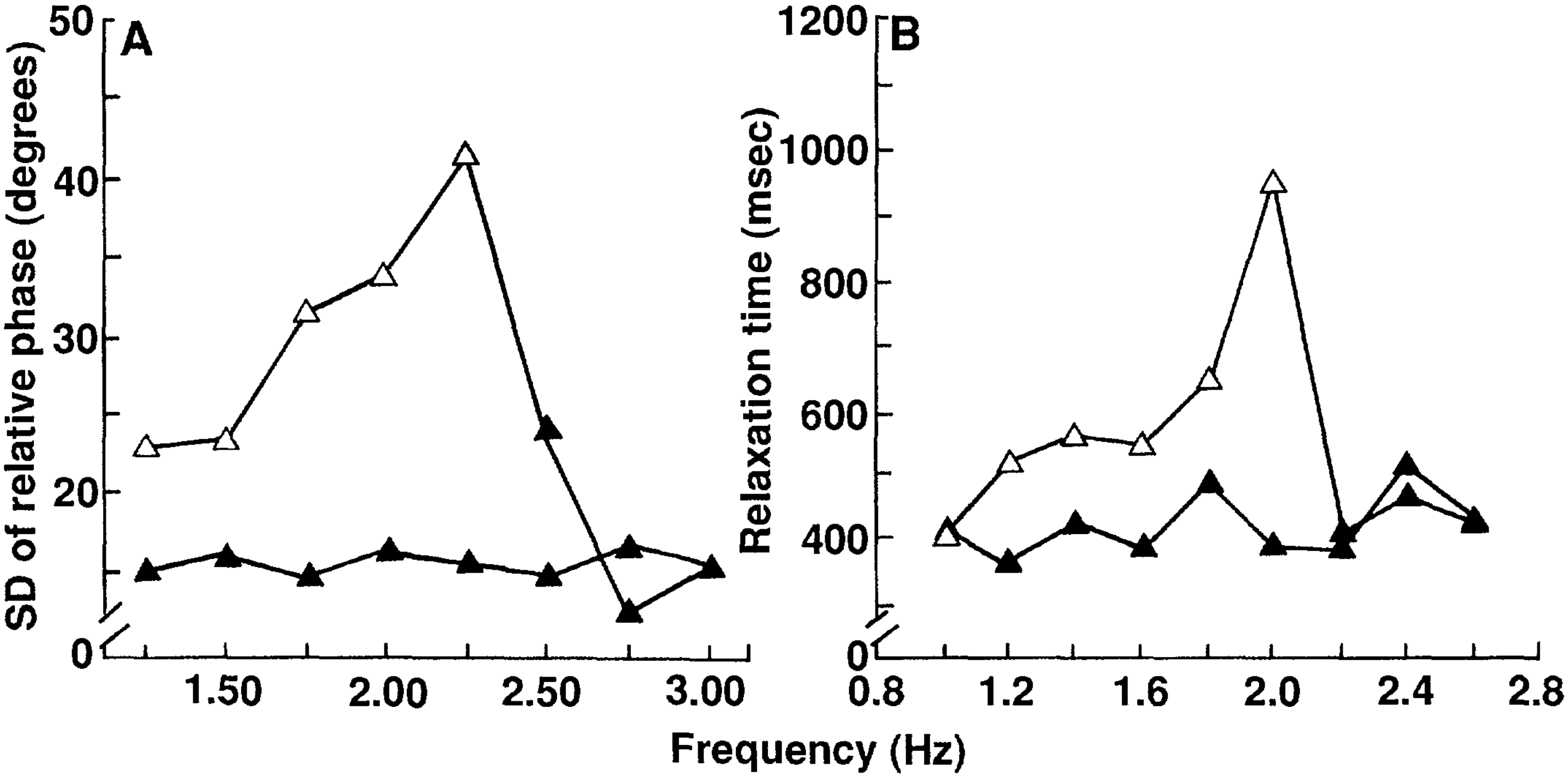
Stability and loss of stability in movement coordination



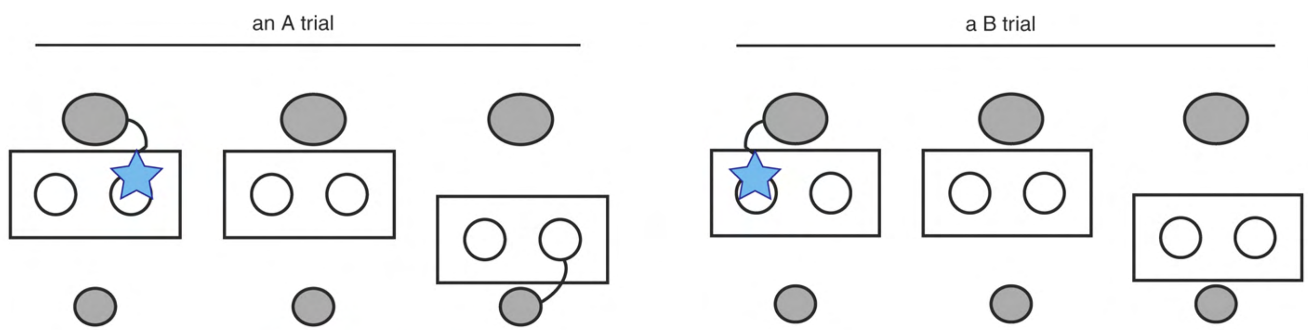
[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]

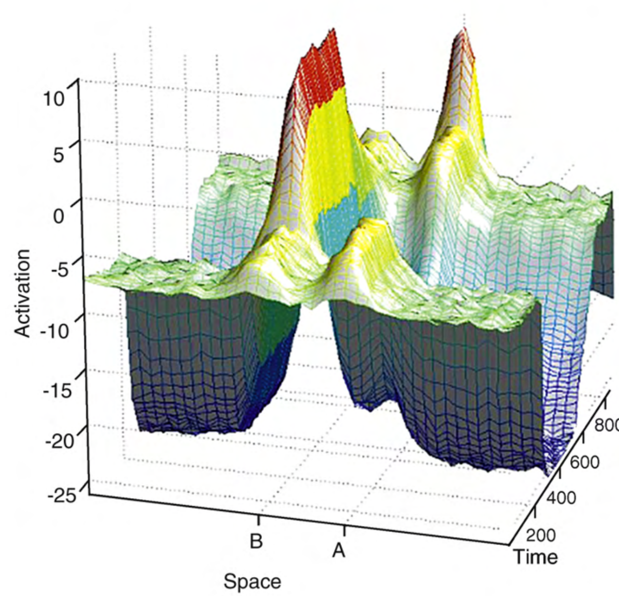
Dynamic Field Theory

- extending dynamical systems thinking into cognition
  - Kopecz Schöner: saccade selection (1995)
  - Erlhagen Schöner: movement preparation (1997, 2002)
  - Spencer Schöner: formalizing the developmental approach (2003)

dynamical systems thinking

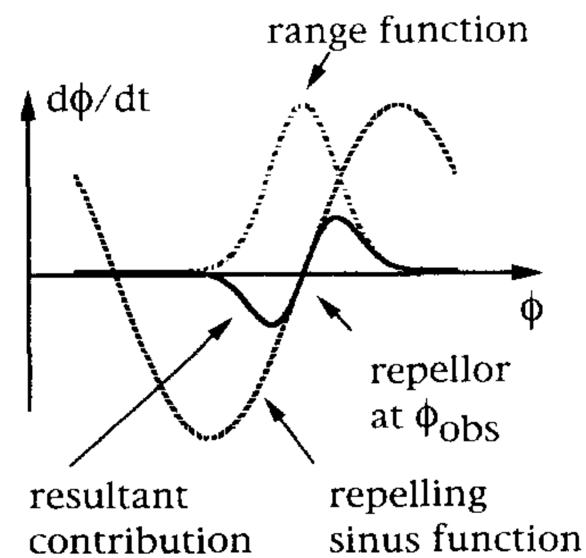
- development: Thelen, Smith, Schöner (2001)
  - A not B.. emergence of competence during development

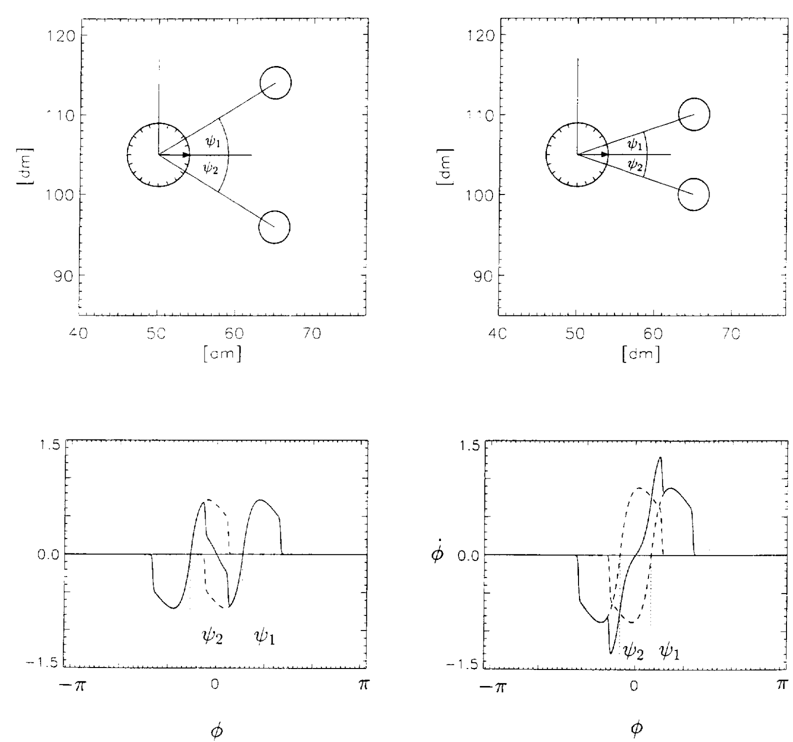




Attractor dynamics approach

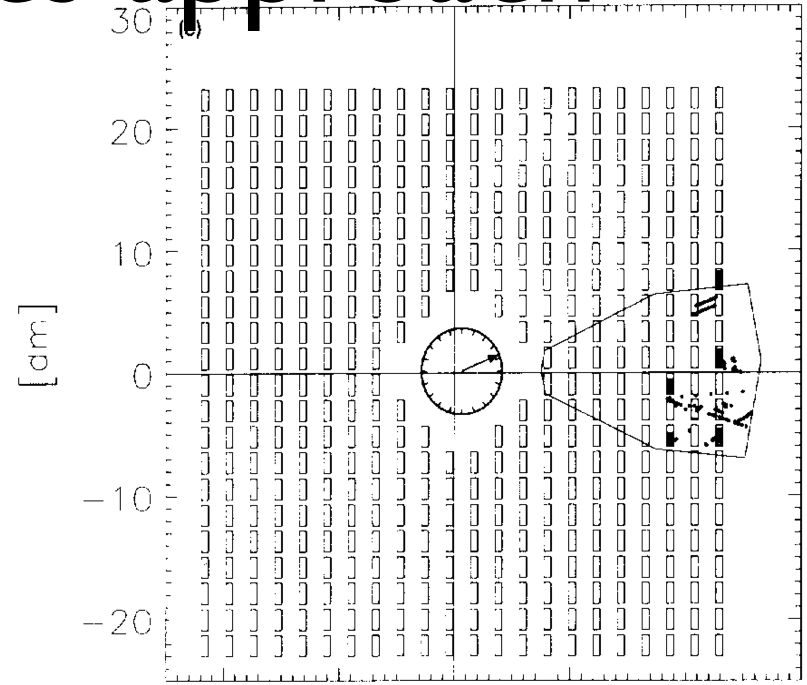
- Schöner, Dose, 92
  - behavioral variables
  - stable states
  - instabilities at decision points
  - similar: Christensen, Large
- related to, but different from potential field approach

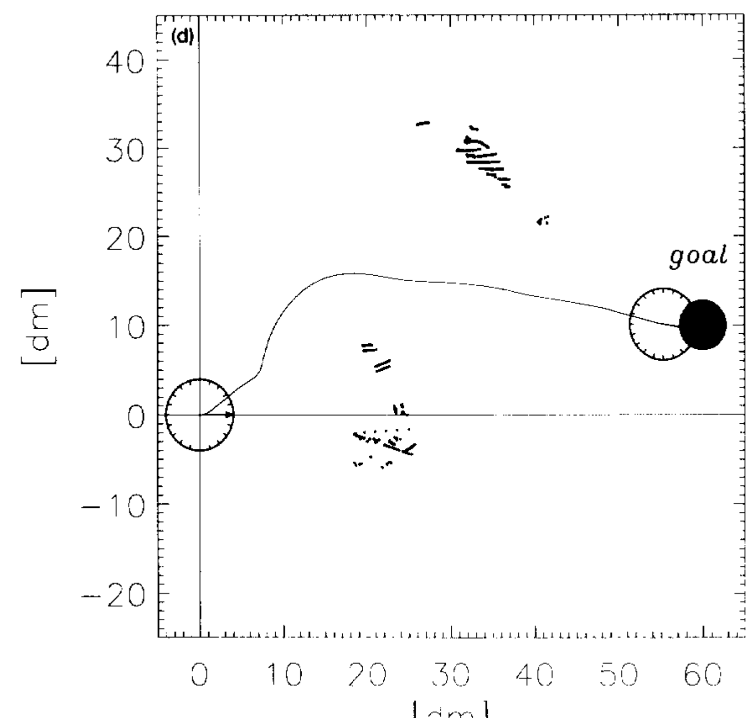




Attractor dynamics approach

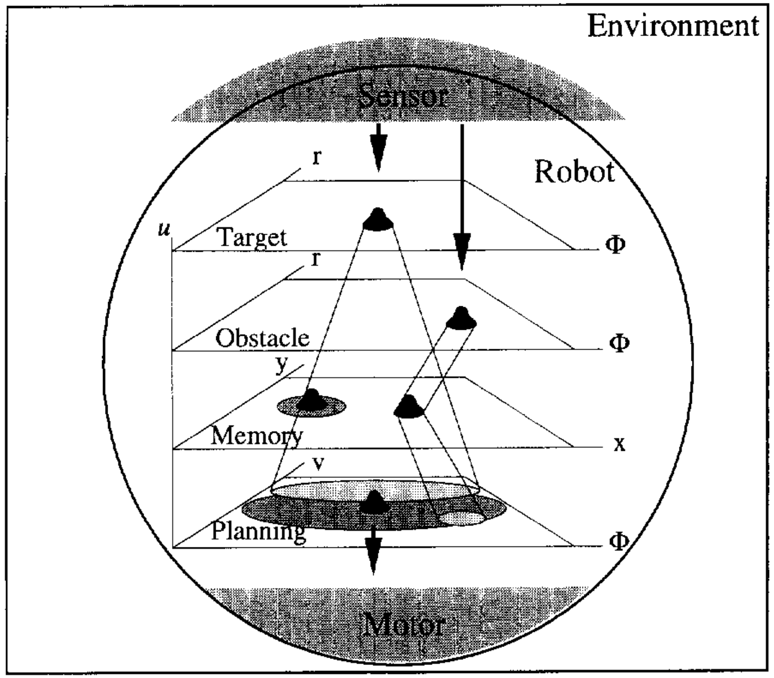
- first elements of representation: discrete neurons select representative obstacles

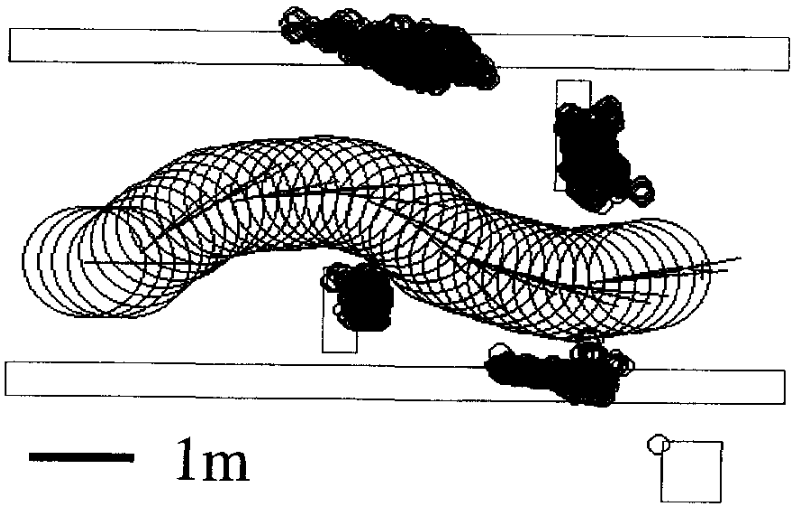


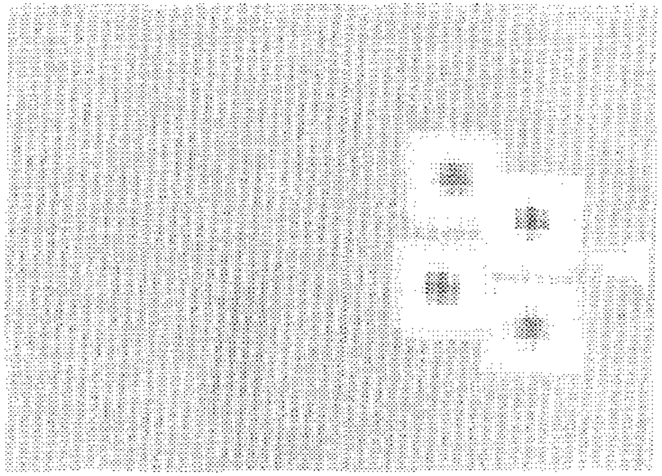


Dynamic Field Theory

- DFT for obstacle avoidance: Engels, Schöner, 95

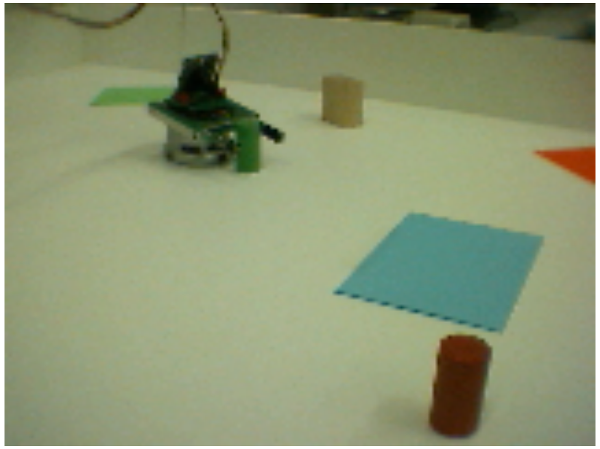


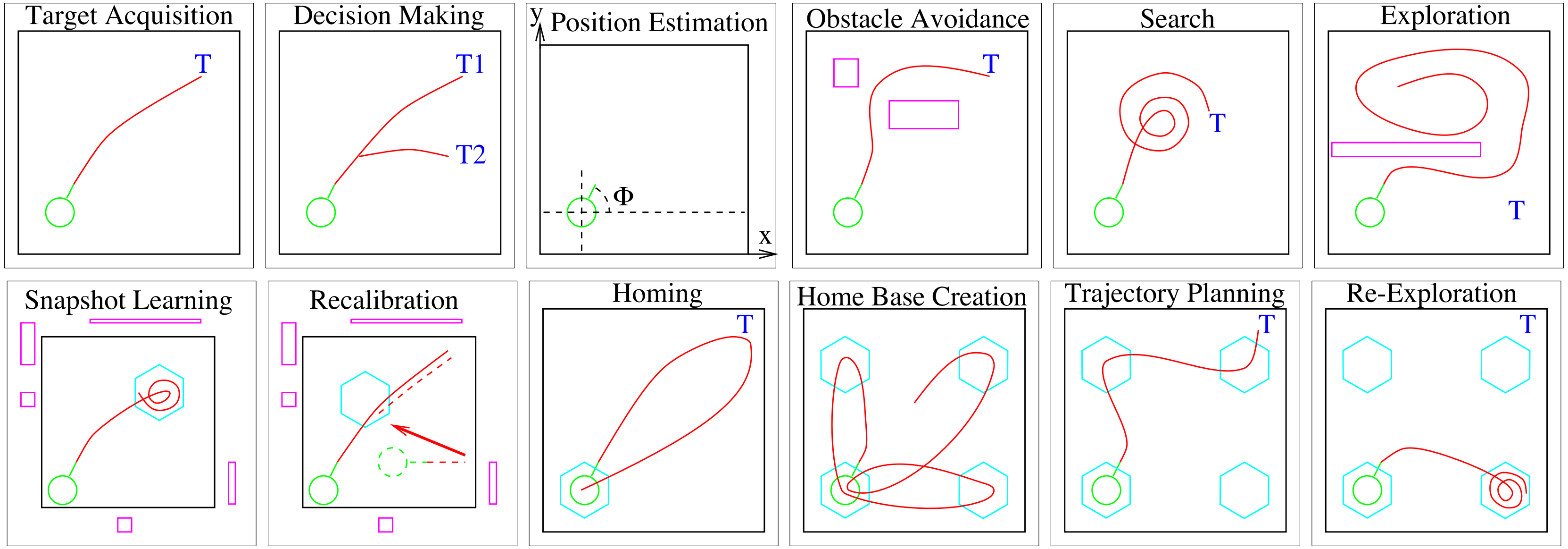




Attractor dynamics approach

- neural dynamics for behavioral organization: Steinhage, Schöner, 97: competition to select behaviors





Behavior based attractor dynamics

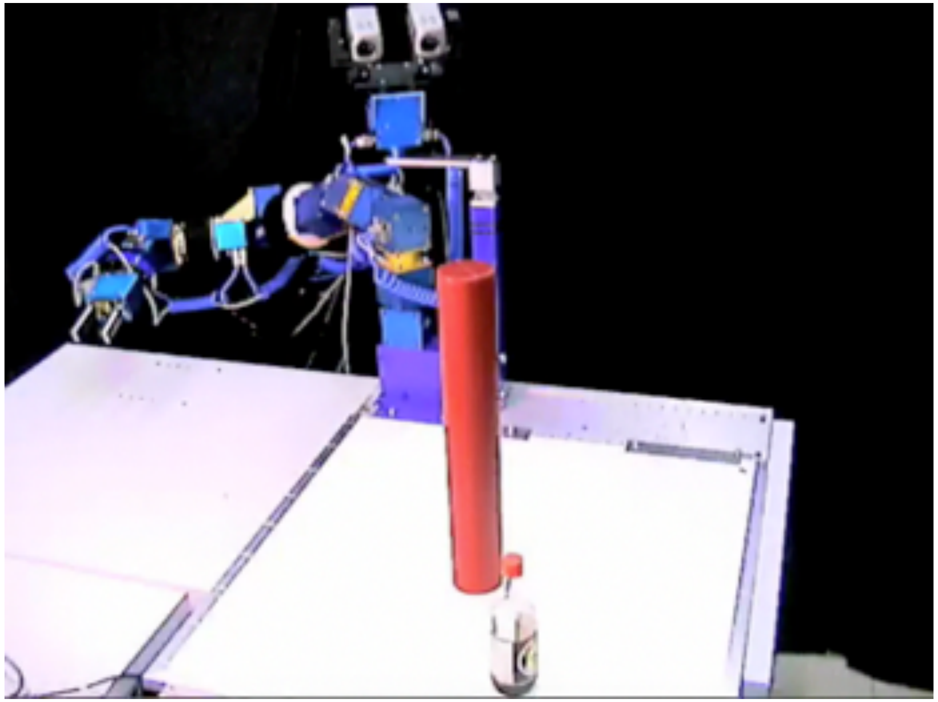
- attractor dynamics on low level vehicles: Bicho, Mallet, Schöner 97-2000
  - 2nd order dynamics
  - first order dynamics, wheelchair

Behavior based attractor dynamics

- DFT on low level system: Bicho, Mallet, Schöner
  - target representation in phono-taxis

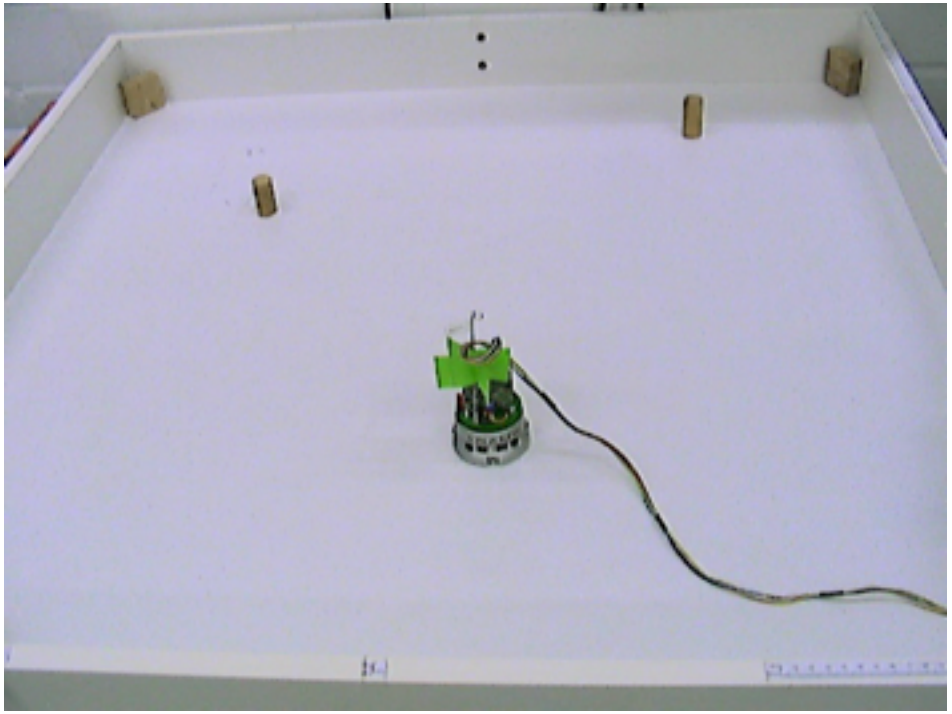
toward complex action

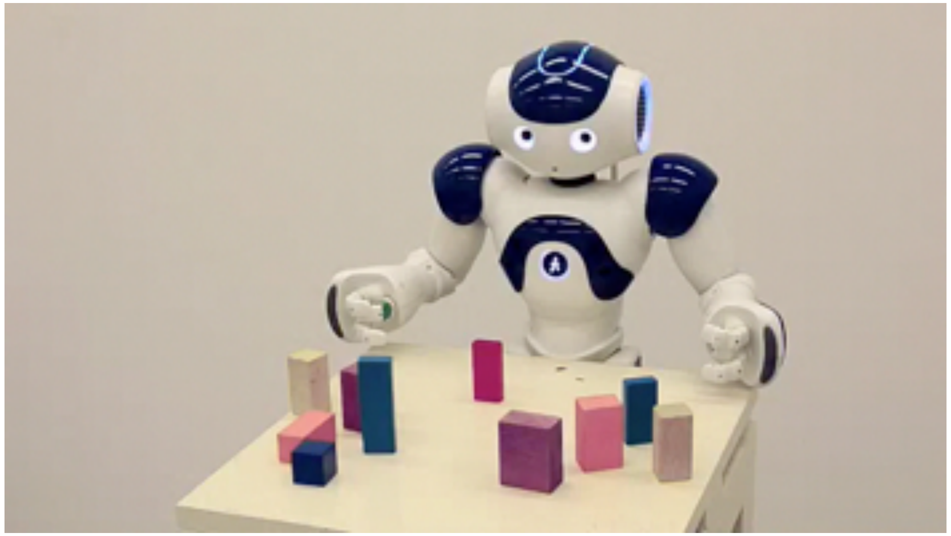
- Attractor dynamics for arms: Jokeit, Reimann, Schöner
    - multi-degree of freedom arm trajectory formation



…toward cognition

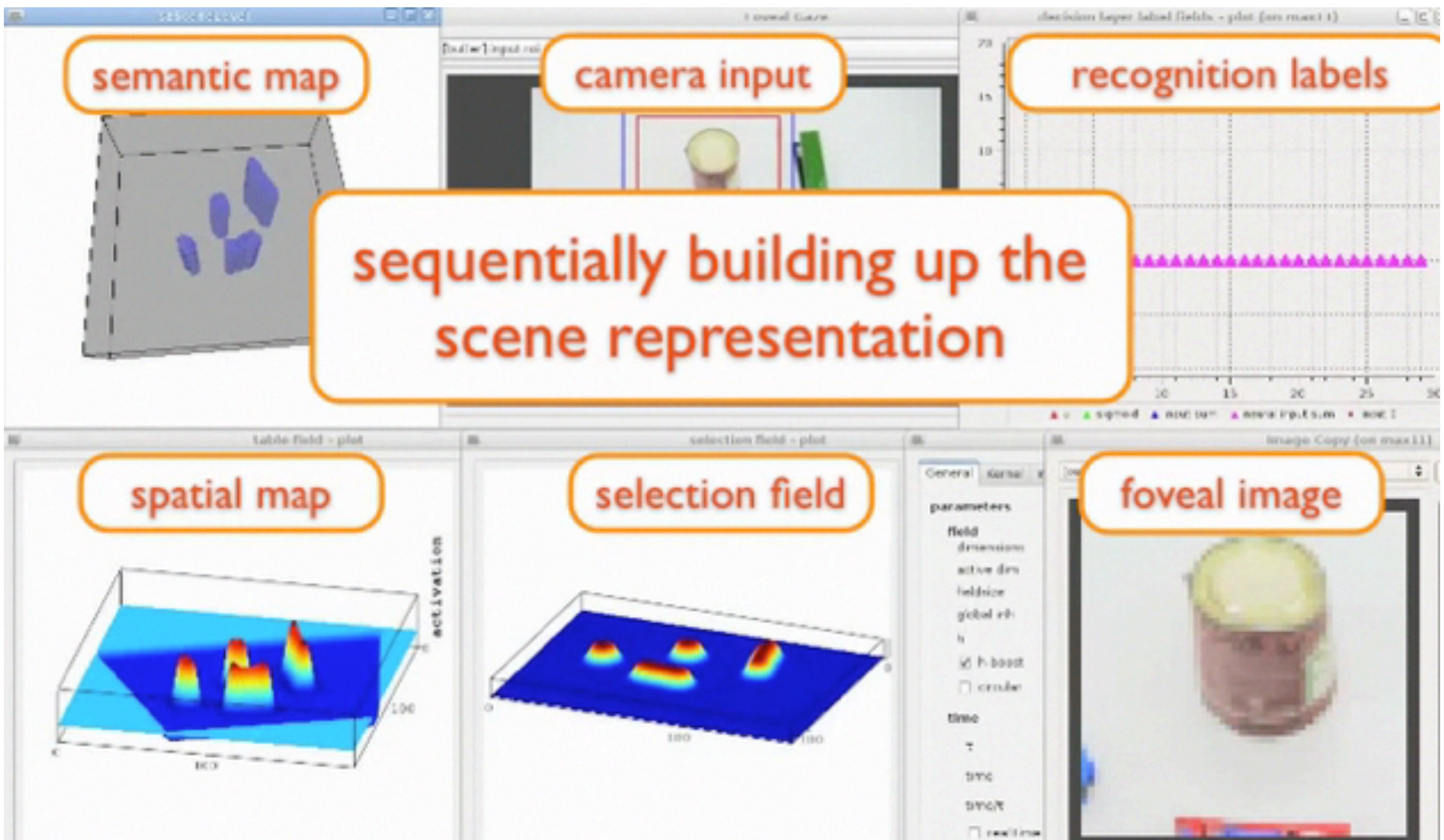
- DFT for sequence generation: Sandamirskaya
- DFT for behavioral organization: => Mathis Richter, Sandamirskaya





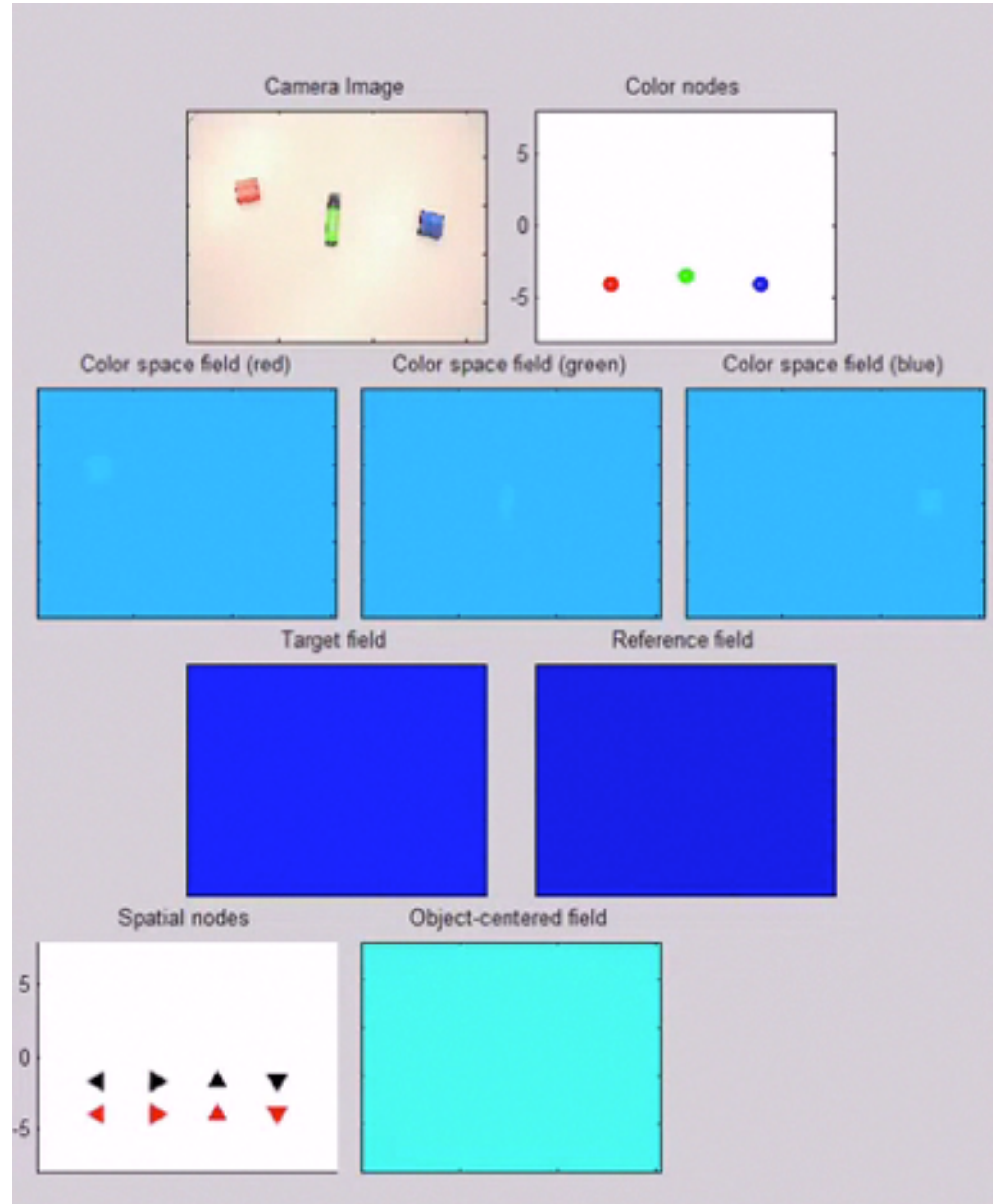
toward cognition

- DFT for perception
  - scene representation: => Stephan Zibner, Faubel
  - object learning: Faubel => Oliver Lomp



… toward cognition

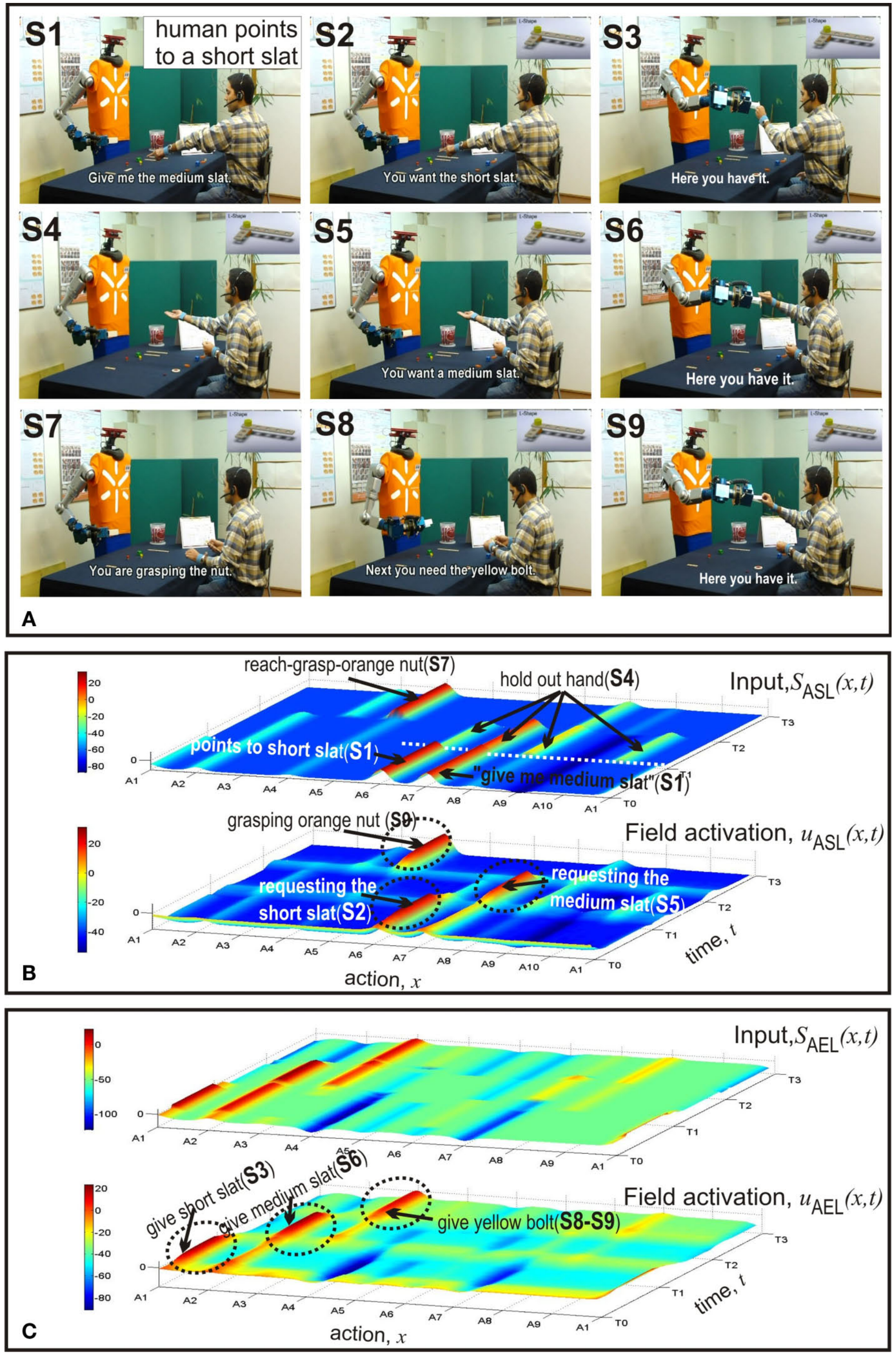
- spatial language [Sandamirskaya, Schneegans, Lipinski]
- => Jonas Lins



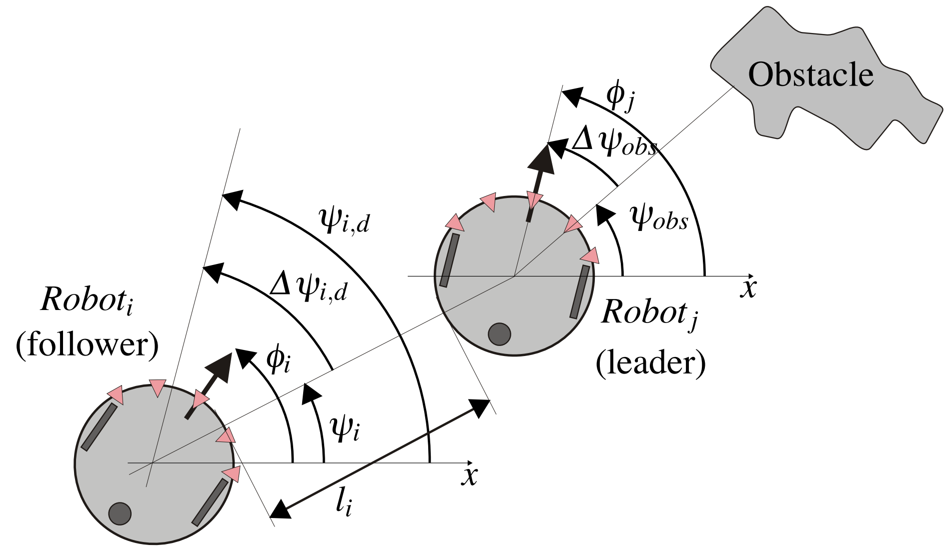
[Lipinski, et al., 2012]

… toward cognition

- imitation, action understanding [Bicho, Erlhagen]



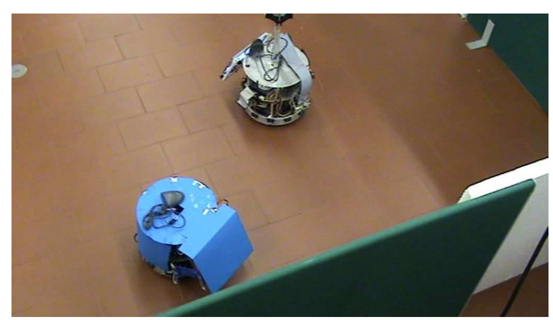
Present: robot cooperation

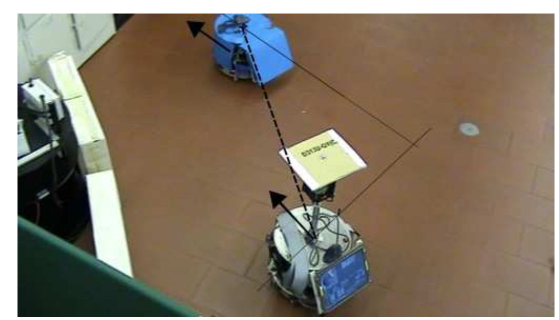


- Bicho, Soares, Monteiro

(i) $t = 66$ *sec*

(j) $t = 77$ *sec*: near stabilizing the formation





[Monteiro, Bicho, 2010]

What I'll do in my core lectures

- Braitenberg vehicles: give an intuition for why dynamics is important
- Attractor dynamics approach: formalizes how behavior emerges in closed loop
- Neural dynamics: formalizes recurrent neural networks
- Dynamic Field Theory: introduce the core notions