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)
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 is a powerful theoretical language with which embodied and situated cognitive systems can be designed and modeled.
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

Dynamic Field Theory
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
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

A. TIME SERIES

B. POINT ESTIMATE OF RELATIVE PHASE

[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]
Stability and loss of stability in movement coordination

[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]
Dynamic Field Theory

- extending dynamical systems thinking into cognition
  - Spencer Schöner: formalizing the developmental approach (2003)
A not B.. emergence of competence during development

Experimental data favor an alternative, emergentist account of performance in the A-not-B task that has been developed within Dynamic Field Theory (DFT). This account explains the error through general processes of goal-directed reaching (and indeed is a variant of one model of adult reaching behavior). The model consists of a dynamic field, shown in Figure 1, which corresponds to the activation within a population of neuron-like units, each dynamically representing the direction of a reach. The field integrates multiple sources of relevant information: the immediate events (e.g. hiding the toy), the lids or covers on the table, and the direction of past reaches. The internal activations that produce a directional reach are themselves dynamic events, with rise times, decay rates, amplitudes and varying spatial resolution. Consequently, the model predicts—and experiments have confirmed—fine-grained stimulus, timing and task effects. Because the explanation derives from general models of goal-directed action that are not specific to this task nor to this developmental period, the model makes predictions (tested and confirmed) about similar phenomena (and perseverations) at ages younger than, and considerably older than, the typical age range examined in the standard task.

Indeed, using this model as a guide, experimenters can make the error come and go predictably: by changing the delay, by heightening the attention-grabbing properties of the covers or the hiding event, and by increasing and decreasing the number of prior reaches to A.

The DFT-based model accounts for a wide range of findings showing that variables unrelated to beliefs about the existence of objects can affect the A-not-B error. The model has also been used to predict (correctly) that a reach back to A will occur in some situations when there is no toy hidden. Furthermore, because the dynamic field is viewed as a motor planning field, and thus is tied to the body-centric nature of neural motor plans, the model also makes the novel prediction that perseverative errors should disappear if the motor plan needed for reaching to B is distinctly different from that for reaching to A.

![Figure 1](image)

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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
- 1st 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
spatial language  
[Sandamirskaya, Schneegans, Lipinski]

=> Jonas Lins

[Lipinski, et al., 2012]
... toward cognition

- imitation, action understanding [Bicho, Erlhagen]
Present: robot cooperation

- Bicho, Soares, Monteiro

[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