Introduction

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What is this school about?

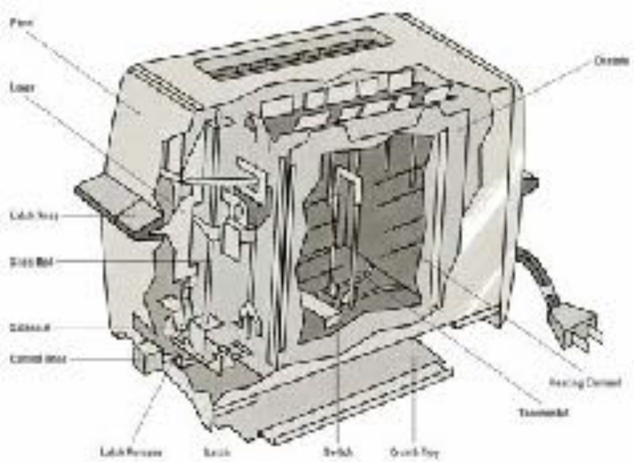
- embodiment
- neural dynamics
- autonomous behavior

Soccer as a form of cognition

- perception: recognize the ball and the other players, estimate their velocities, perceive the scene
- attention: select and track a visual target, controlling gaze
- working memory: to predict where you need to look to update your scene understanding
- plan and control own action, running, kicking, tackling, updating movement plans any time
- pursue goals, make decisions
- learning: get better at playing
- background knowledge: know the goal of the game/rules, know how hard the ball is, how fast players are

Much cognition contains

- perception: explore scene, recognize screws, while keeping track of spatial arrangement
- attention: fixate on relevant part, visually search tool
- working memory: use to efficiently find tools and places to act on, update with toaster pose
- plan: manipulating cover, taking it off, recognizing spring, re-attaching it, mounting cover back on, generating the correct action sequence
- pursue goals
- learning: get better at this
- background knowledge: know about cover, screws, how hard to turn or press



[image: HowStuffWorks]

[image: mystery fandom theater 3000]

Embodied cognition

- Properties of sensorimotor processes
  - continuous link to the sensory and motor surfaces
  - temporal continuity in state
  - stabilization of states against sensor and motor noise
  - unfolding of processes in closed loop with the environment
  - sensitive to the structure of the environment

Embodied cognition

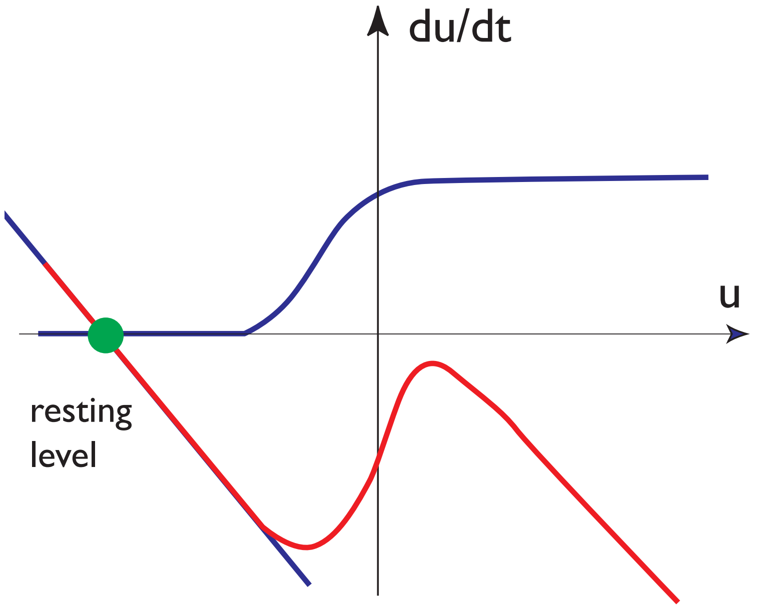
- Embodied cognition emerges from sensorimotor processes
  - through decision making
  - working memory
  - autonomous sequence generation
  - achieving invariance through coordinate transforms

Neural dynamics hypothesis

- embodied cognition
  - unfolds continuously in time
  - with internal closed loops: prediction/planning
  - in closed loops with the environment
- => embodied cognition requires stability
- embodied cognitive processes must be characterized as dynamical systems
  - behavioral dynamics
  - neural dynamics

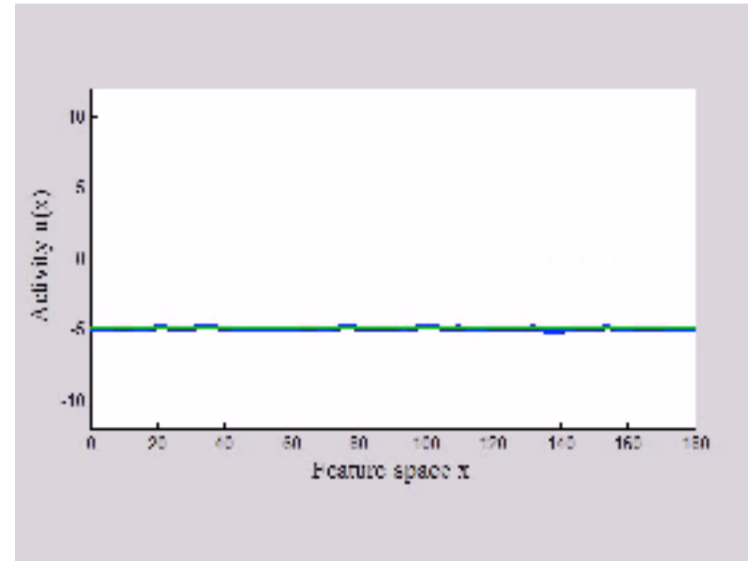
Neural dynamics hypothesis

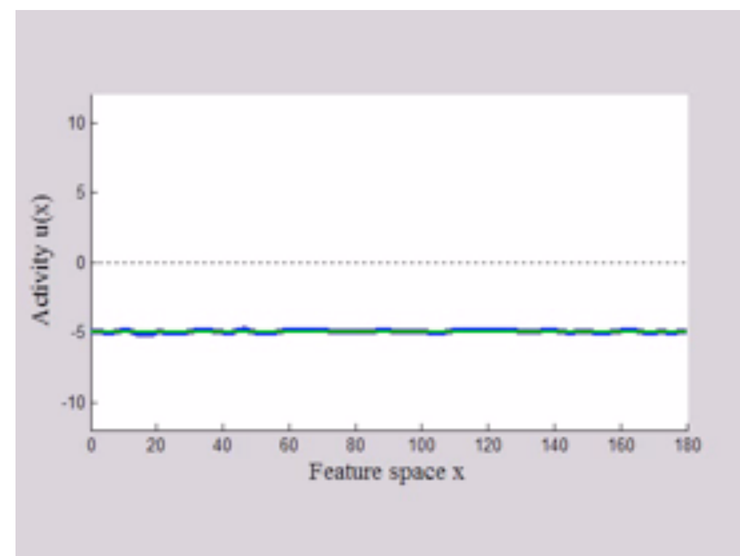
- the theoretical language of neural dynamics captures the fundamental stability requirement of embodied cognitive systems…
- from instabilities in neural dynamics, new qualities emerge that go beyond the control theoretical aspects of dynamics



Dynamic Field Theory

- is a branch of neural dynamics that is particularly suited to understand neural cognitive architectures
- focusses on the functional significance of neuronal activity
- abstracting from the functionally insignificant discrete spatial and temporal structure of neuronal activity





The strong embodiment hypothesis

- embodied cognitive processes are characterized by the stability/instability and the link to sensorimotor processes
- Hypothesis: there is no particular boundary up to which, cognition is embodied, but beyond which cognition loses the properties of embodiment

Neural dynamics + strong embodiment hypotheses

- => all cognition processes have the properties of embodied cognition:
  - stability
  - potential link to sensorimotor processes
  - instabilities at original of new qualitites
- => understanding cognition requires the theoretical framework of neural dynamics

Implications

- when studying cognitive competences, keep the links to the sensorimotor domain in view, both experimentally and theoretically
- tasks create context, study behavior and cognition in naturalistic tasks that connect to elementary behaviors
- keep conceptual commitments made in one domain when studying other domains: stability

Theoretical research program

- develop a set of theoretical concepts that are necessary … to fulfill constraints
- probe how the set is sufficient to account for behavior and cognition
- be conservative: only introduce new theoretical concepts when forced to …
- be mindful of neural constraints

Experimental research program

- look for metric effects
- study role of time
- look for online updating

Robotic research program

- autonomous robots: actively generate behavior, initiating, selecting, terminating actions based on the system's own perceptual processes
- use autonomous robots as heuristic devicdes
- the demonstrate that a link to the sensorimotor domain is possible
- they may uncover overlooked processes and constraints
- they may review that certain processes are not necessary

A short history of thought

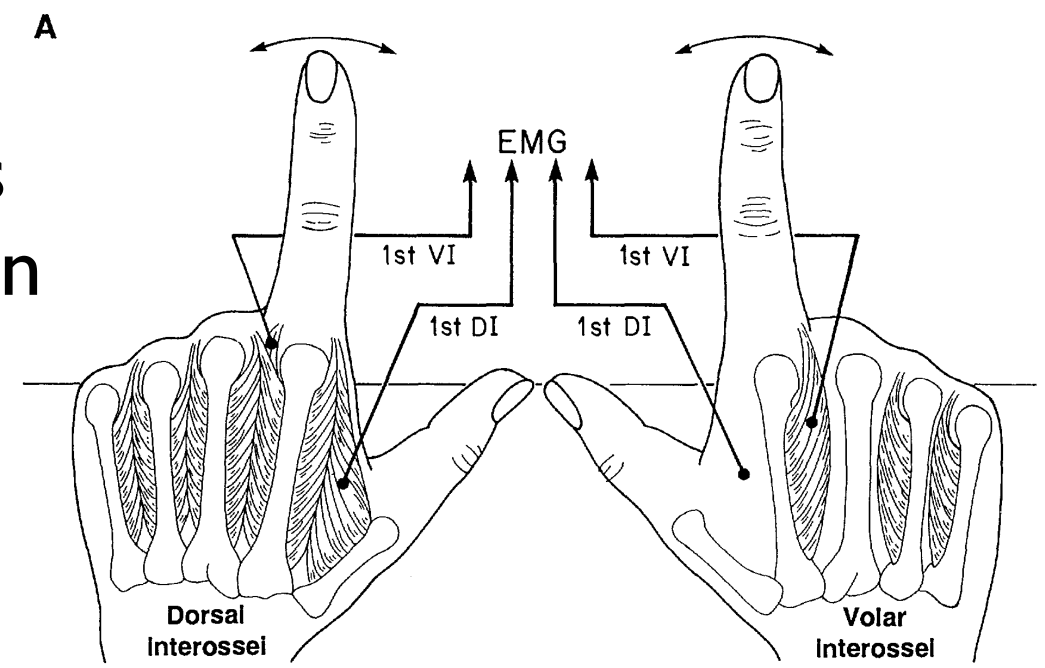
- dynamical systems thinking
- dynamical field theory
- attractor dynamics approach

Dynamical systems thinking (DST)

- beginnings in ecological psychology: Turvey, Kugler, Kelso
  - emergency of behavior/coordination from dynamics
- metaphor: movement is like going to a minimum
  - a link to Anatol Feldman's ideas of Equilibrium Point Theory

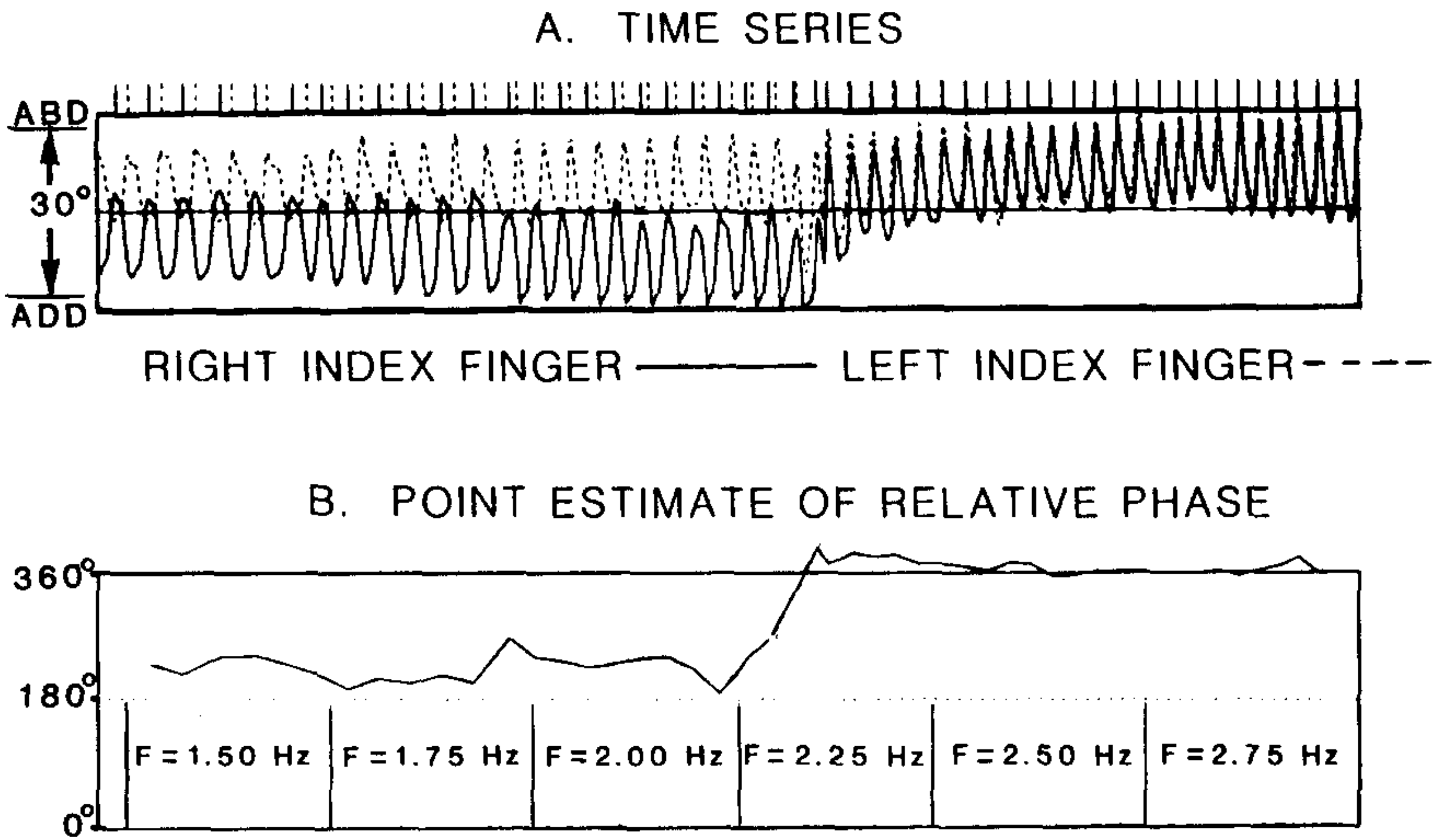
Stability and loss of stability in movement coordination

- stability of relative phase is constitutive of coordination
- loss of stability (enhanced variance, relaxation time) leads to change of coordination pattern



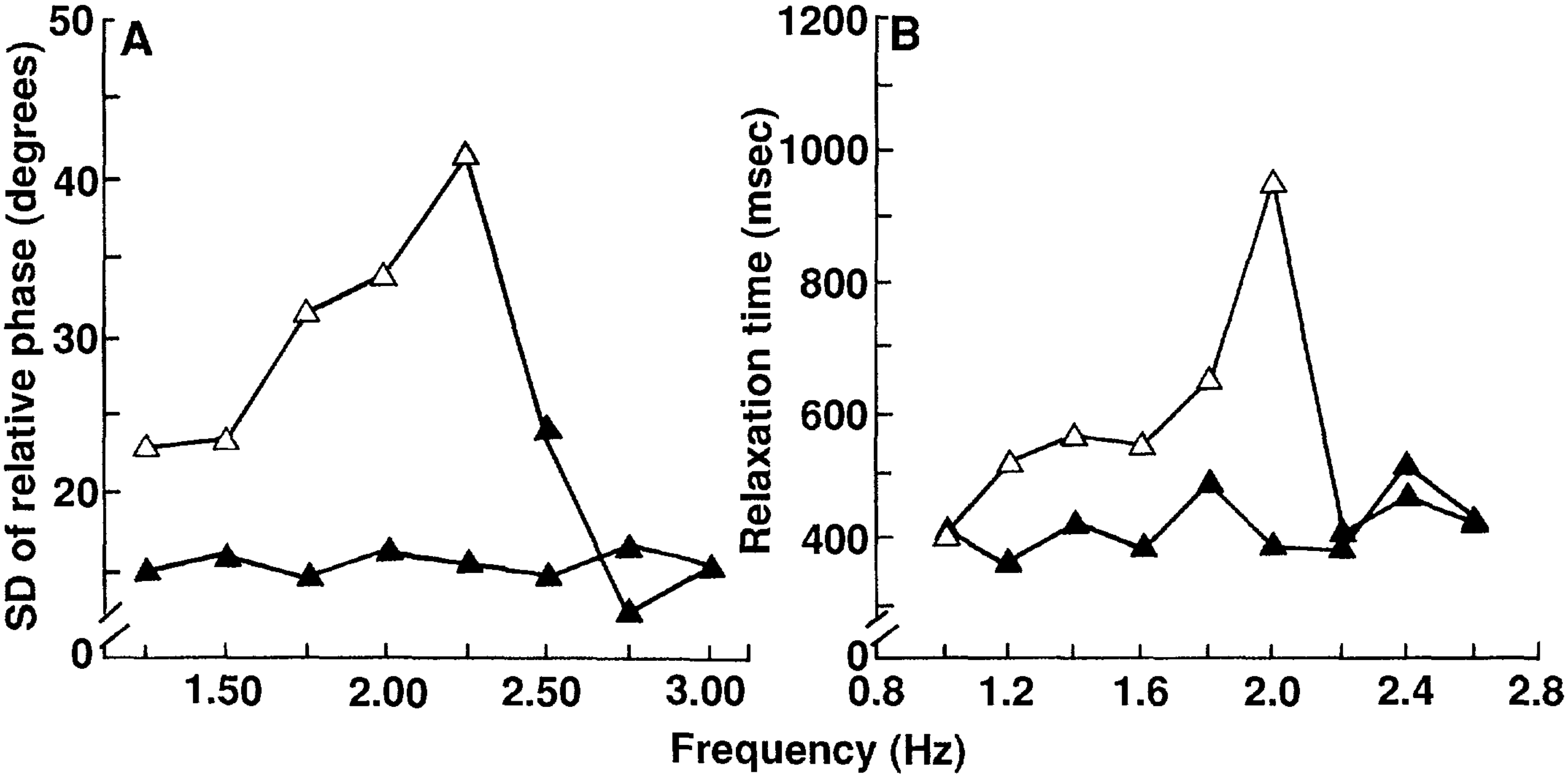
[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]

Stability and loss of stability in movement coordination



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

Stability and loss of stability in movement coordination



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

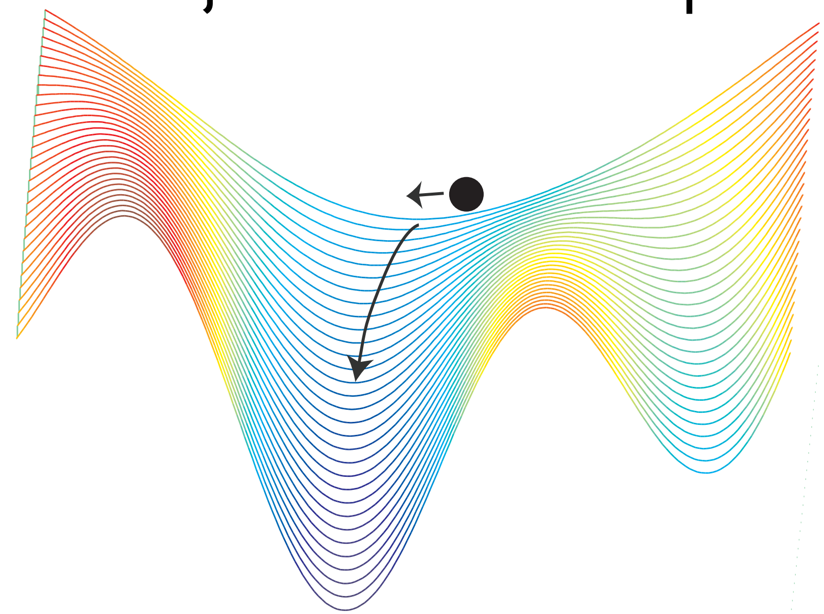
Stability and loss of stability in movement coordination

- => stability is both necessary and sufficient for the emergence of coordination patterns

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

Thelen, Smith: dynamical systems thinking as metaphor in development

- embodiment/situatedness
  - development is driven by experience, in which cognition is closely linked to sensory and motor behavior afforded by the structure of the environment
- emergence
  - competences emerge in the here and now in real time
  - multi-causality, soft-causation, soft-assembly
- time
  - behavioral history in the task matters
  - developmental history matters: individual trajectories of development

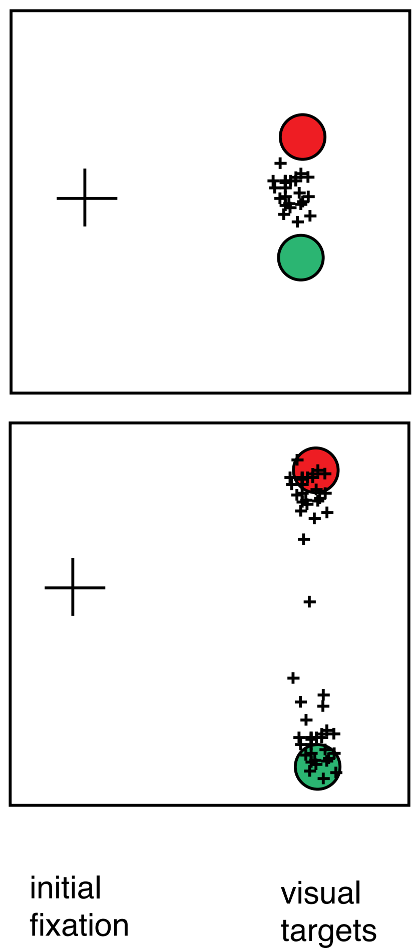


Dynamic Field Theory

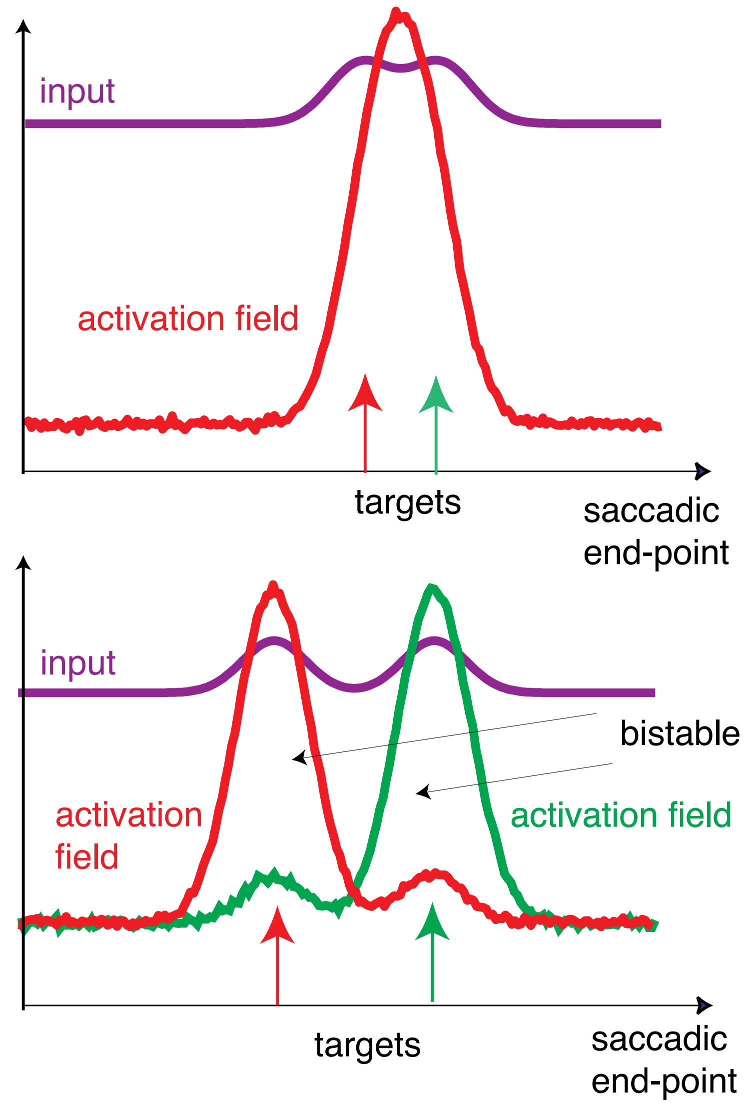
- from metaphor toward mathematically formalized theory
- beyond the motor domain, toward embodied cognition

Dynamic Field Theory

- Kopecz Schöner (1995): saccadic target selection as sensorimotor decision



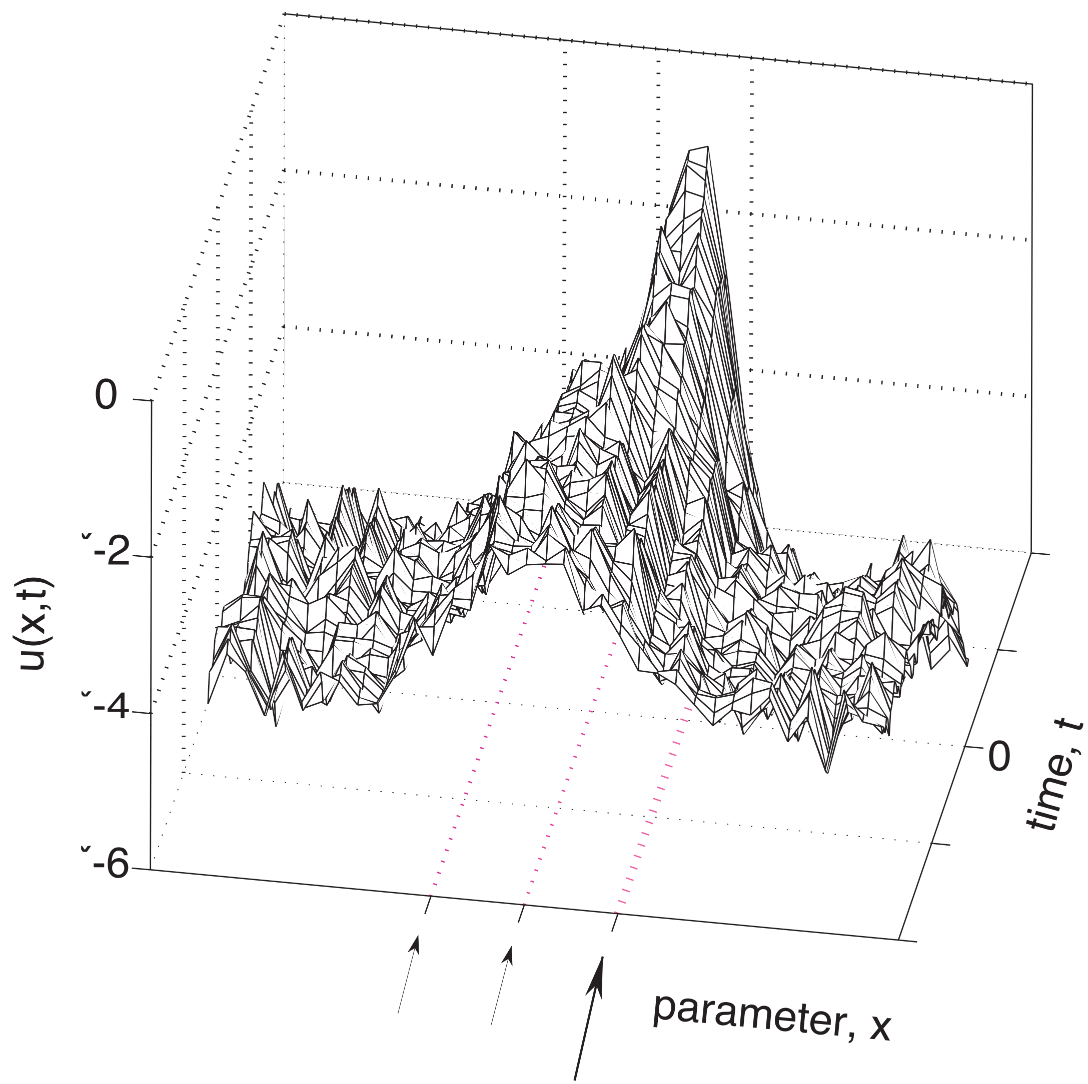
[after: Ottes et al., Vis. Res. 25:825 (85)]



[after Kopecz, Schöner: Biol Cybern 73:49 (95)]

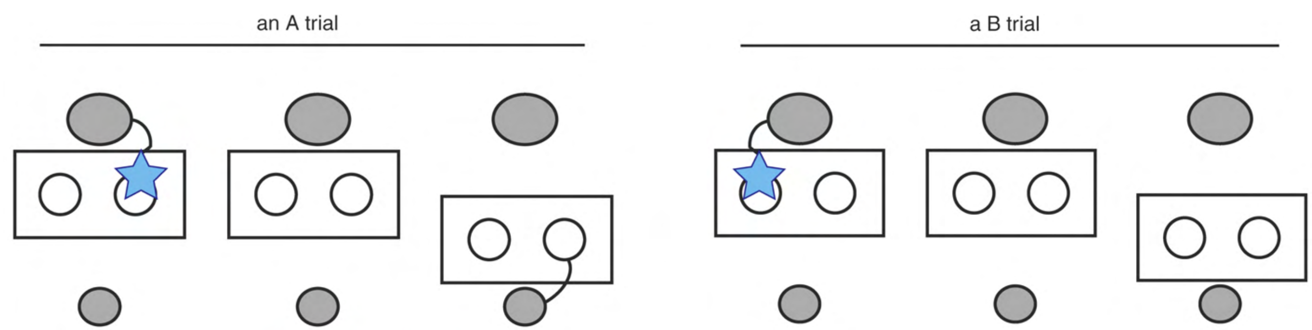
Dynamic Field Theory

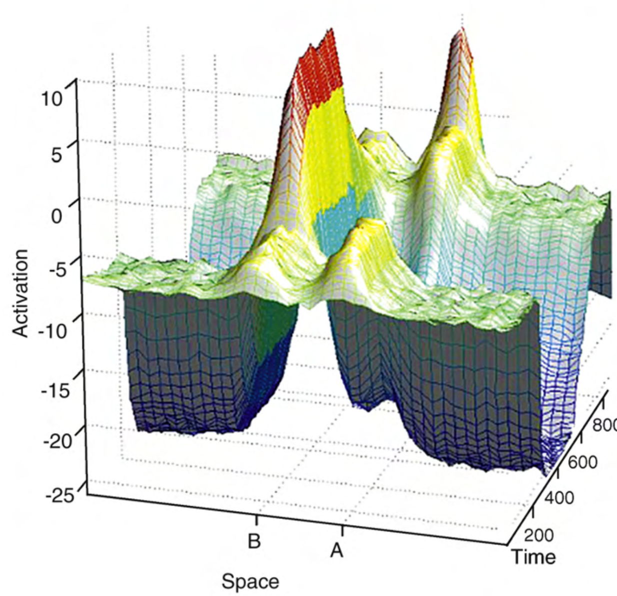
- Erlhagen Schöner: movement preparation (1997, 2002)



Dynamic Field Theory

- Thelen, Smith, Schöner (2001) Perseverative reaching as sensorimotor decision making





Dynamic Field Theory

- Spencer Schöner (2003): refuting the anti-representationalist stance of some proponents of dynamical systems thinking

Dynamic Field Theory

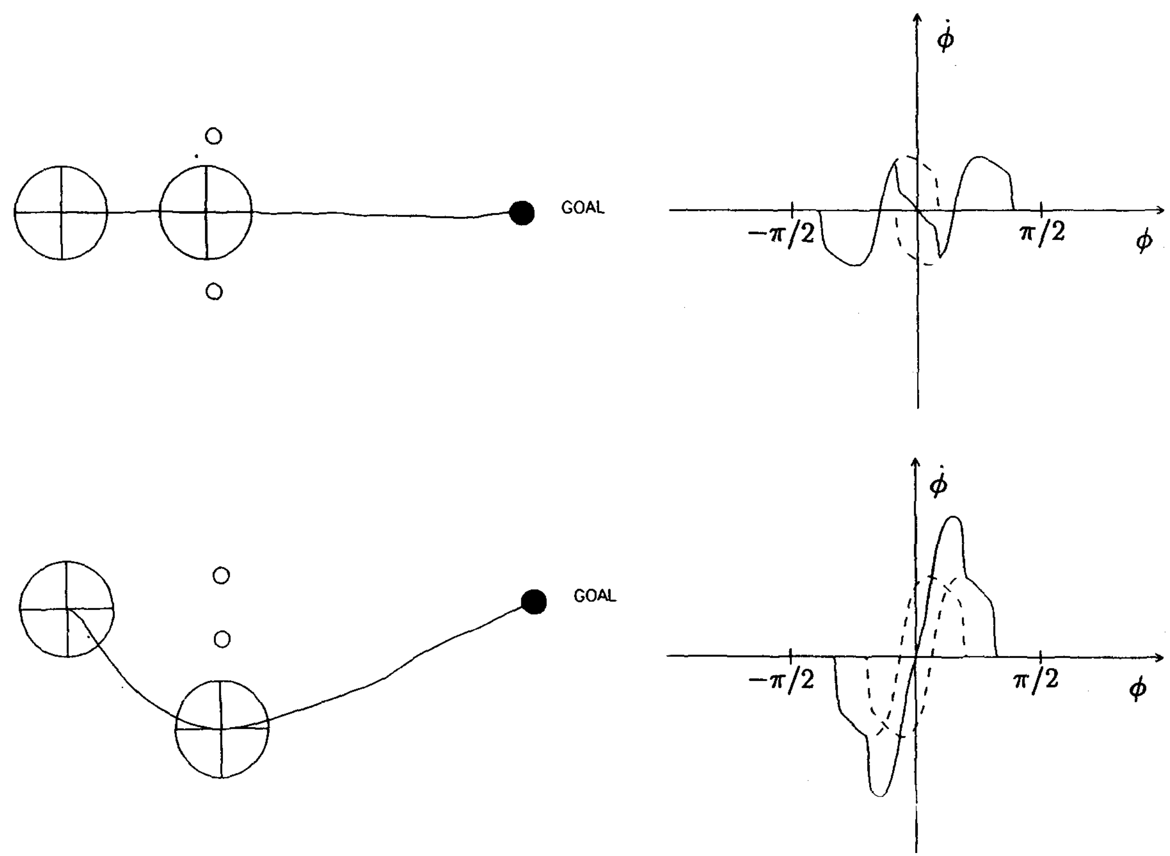
- … the rest of that history … emerges over this week…
- … that is the "neural dynamics" strand of DST

Attractor dynamics approach

- a second strand of formalization of DST

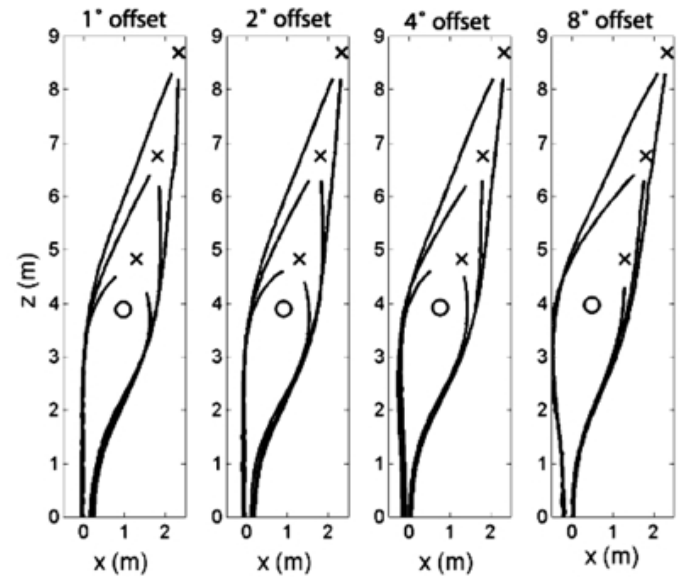
Attractor dynamics approach

- Schöner, Dose, 92;
  - behavioral variables: capture state of a system in the environment
  - behavior emerges from attractors
  - avoidance from repellors
  - instabilities lead to new dynamic regimes: decisions



Attractor dynamics approach

- describes human visually guided steering!
- Fajen, Warren, 2003



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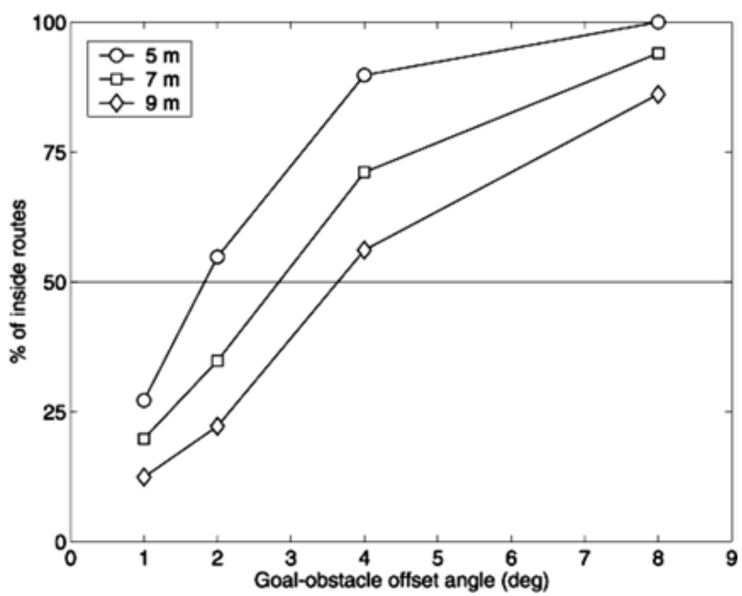


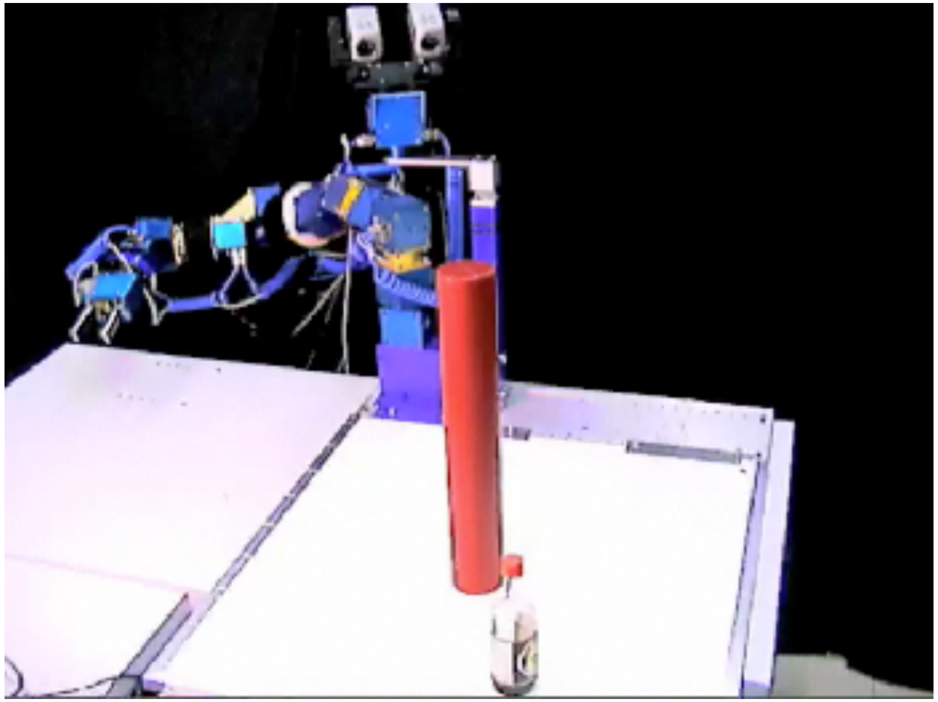
(b)

Behavior based attractor dynamics

- attractor dynamics driven by low-level sensory input
  - Bicho, Schöner 1997: 2nd order dynamics
  - Mallet, Bicho, Schöner 2000: first order dynamics on a wheelchair

Attractor dynamics for arm movement

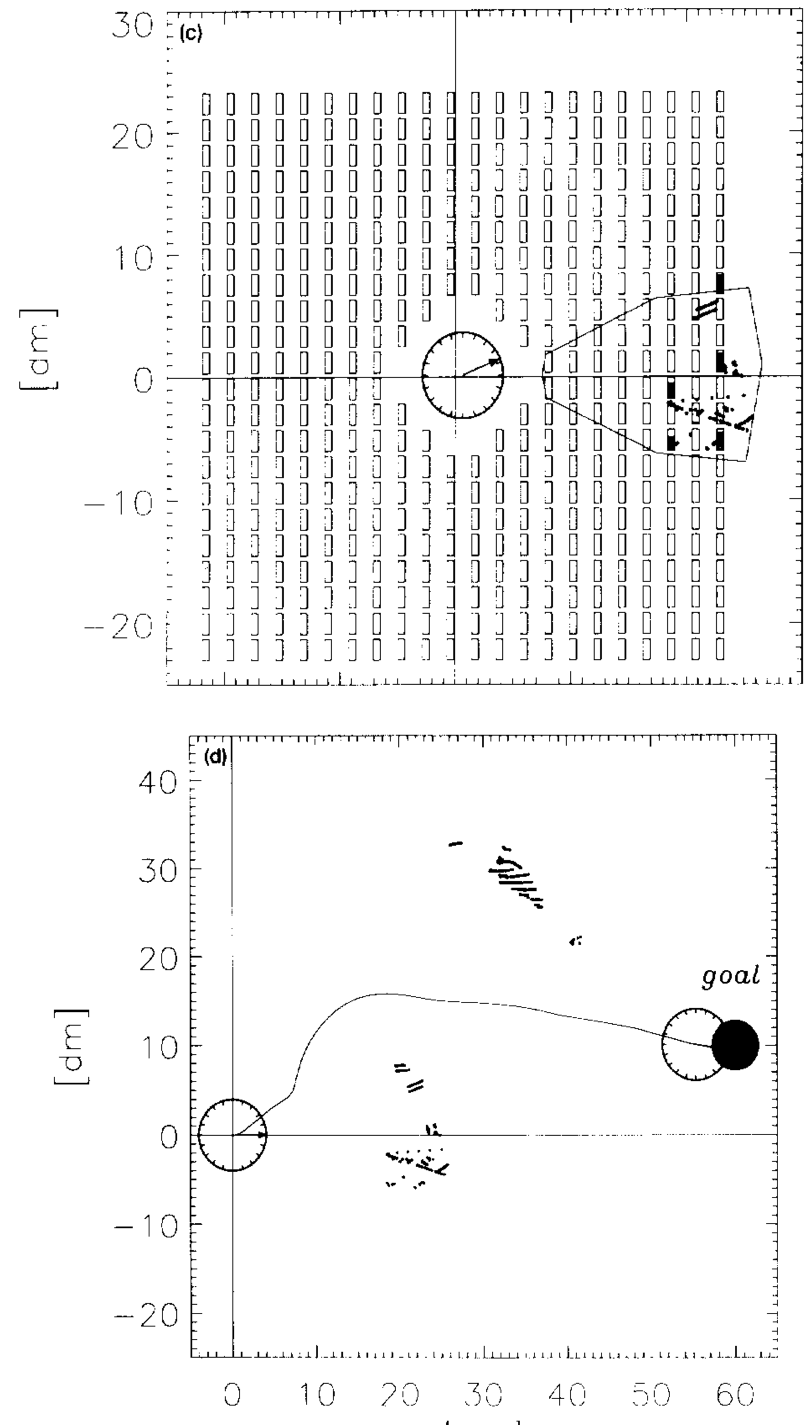
- Iossifidis et al.
- Jokeit, Reimann, Schöner



Linking attractor dynamics and neural dynamics

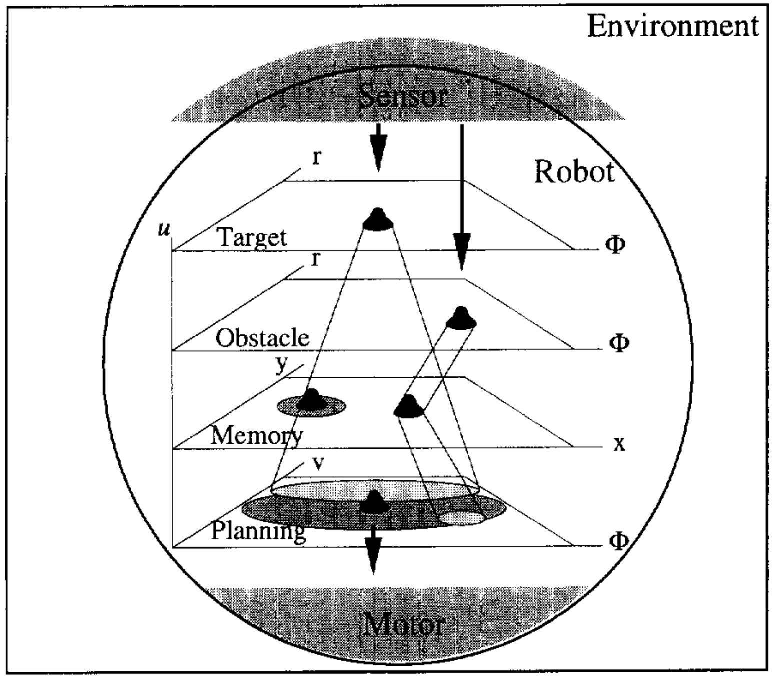
Linking attractor dynamics and neural dynamics

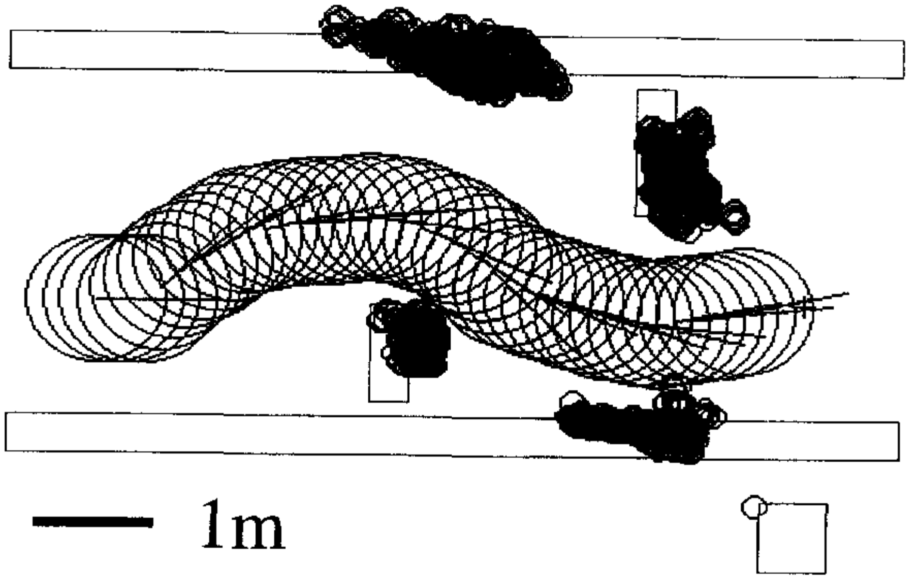
- even Schöner, Dose 1992 hat first elements of representation: discrete neurons select representative obstacles

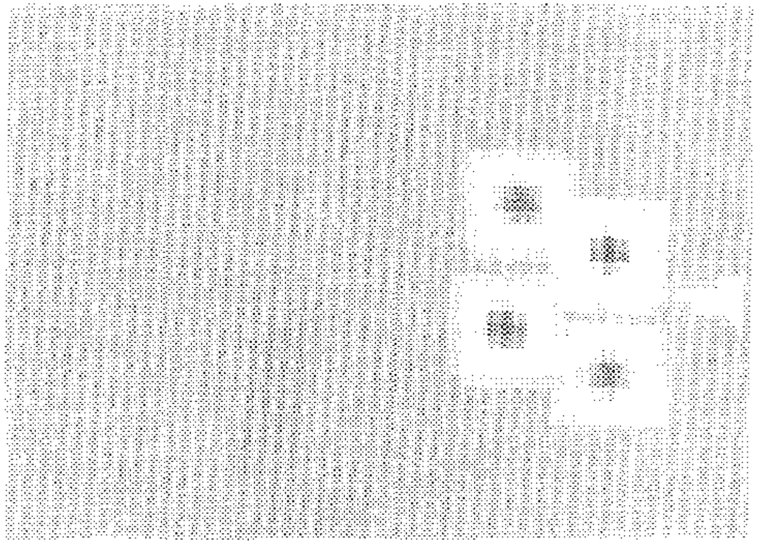


Linking attractor dynamics and neural dynamics

- Neural fields for obstacle avoidance… in an architecture: Engels, Schöner, 1995

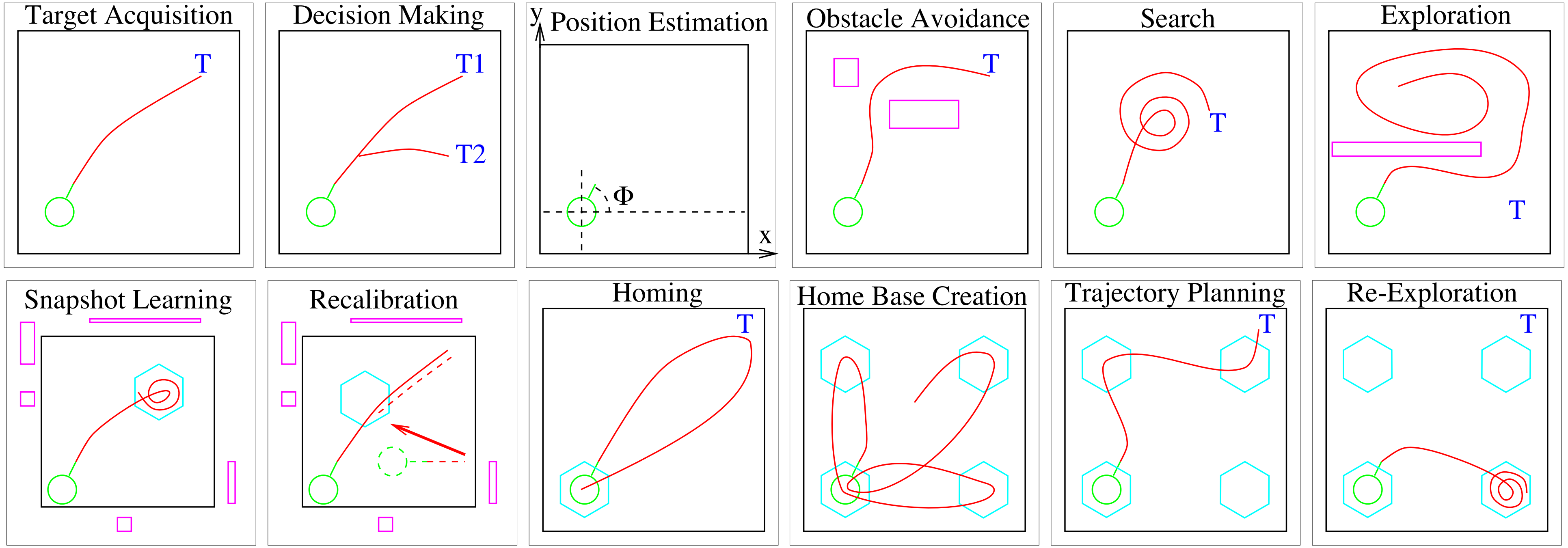






Linking attractor dynamics and neural dynamics

- competitive dynamics to select behaviors in seuquences: Steinhage, Schöner, 1997



Linking attractor dynamics and neural dynamics

- DFT for target representation in phono-taxis from low-level sensors: Bicho, Mallet, Schöner (2000)

How is DFT embedded in the broader history of thought?

- connectionism
- deep networks
- computational neuroscience
- probabilistic thinking

How is DFT embedded in the broader history of thought?

- … let’s do that when we have learned about DFT in some depth… at the end of the tutorial lectures…

What I'll do in my core/ tutorial lectures

- Braitenberg vehicles: to create an intuition how behavior emerges from dynamics… and to position neural relative to behavioral dynamics
- Neural dynamics: to formalize the concepts of dynamics in the context of individual "neurons" and the strongly recurrent neural networks they form

What I'll do in my core/ tutorial lectures

- Dynamic Field Theory 1: show how "neurons" come to represent sensory or motor states and ground neural dynamics in neurophysiology
- and discuss the instabilities of DFT and link them to different behavioral signatures

What I'll do in my core/ tutorial lectures

- Dynamic Field Theory: Il introduce the memory trace, link to autonomous learning, and use A not B as a model case
- Dynamic Field Theory and behavioral dynamics: show how fields can be linked to attractor dynamics to generate motor behavior

What I'll do in my core/ tutorial lectures

- Higher dimensional fields: show how new functions become possible when the number of represented dimensions is increased: biased competition, coordinate transforms
- Multi-layer fields: expand the dynamic repertoire by introduces inhibitory interneurons, linking to neural timers/oscillators and active transients

What I'll do in my core/ tutorial lectures

- Show how sequential behavior and sequential activation states emerge in DFT
- link to architectures …

Advanced lectures

- Raul Grieben: a DFT architecture of scene representation
  - feature space representation of objects
  - visual search
  - scene memory
  - change detection and updating

Advanced lectures

- Mathis Richter: a DFT architecture for the perceptual grounding of relational concepts as an example of "higher cognition"
  - spatial language, movement concepts
  - perceptual grounding vs. generating descriptions
  - coordinate transforms to generalize neural operators
  - mental maps?

Advanced lectures

- Jonas Lins: mouse tracking provides experimental signatures of DFT principles of selection
  - experiments on the grounding of relational concepts
  - establish sensorimotor link of a DFT model of higher cognition

Advanced lectures

- Jan Tekülve: a DFT architecture for the generation of movement directed at objects in the visual surround
  - integrates many of the modules laid out previously
  - pulls many methods from the neural dynamic tool kit: selection, coordinate transform, sequence generation, neural timers, link to attractor dynamics
  - robotic demonstration