Computational Neuroscience: Neural Dynamics

What is this school about?

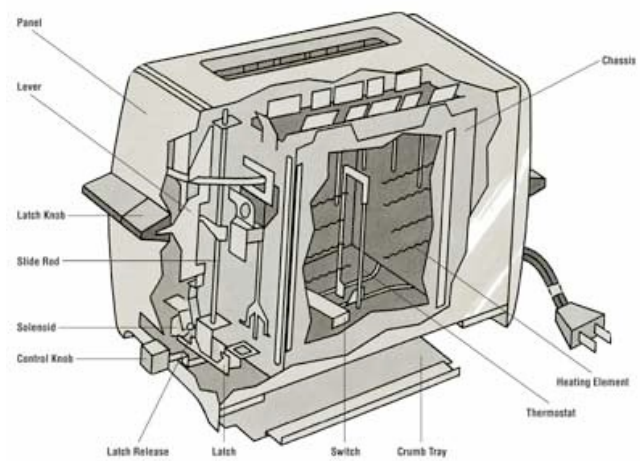
- embodiment
- neural dynamics
- autonomous behavior

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]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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

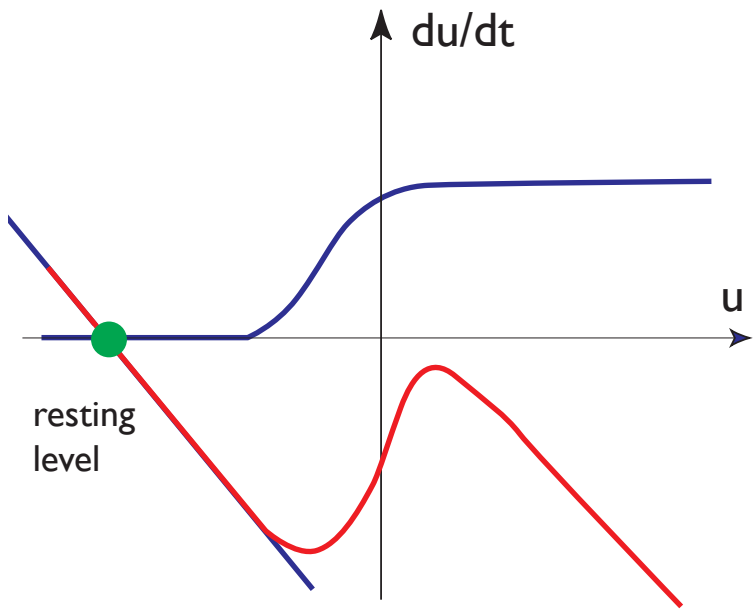
- Embodied cognition emerges from sensorimotor processes
  - through decision making
  - working memory
  - autonomous sequence generation
  - achieving invariance through coordinate transforms

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

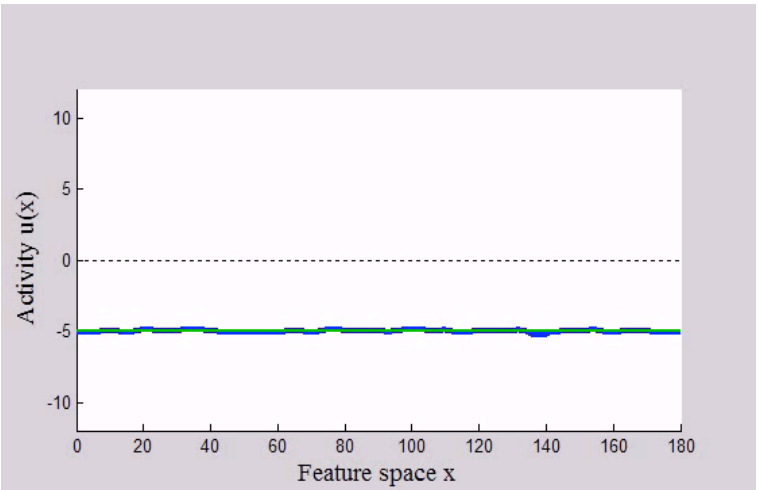
Neural dynamics hypothesis

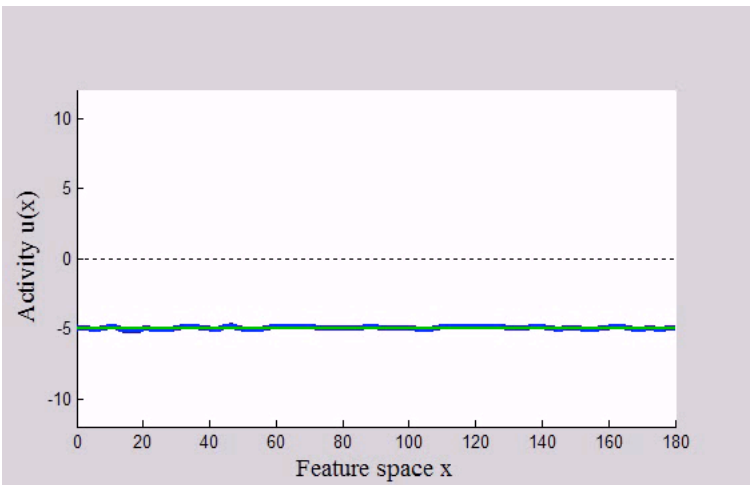
- the theoretical language of neural dynamics captures the fundamental stability requirement of embodied cognitive systems…
- from instabilities in neural dynamics, new qualities emerge that go beyond the control theoretical aspects of dynamics



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

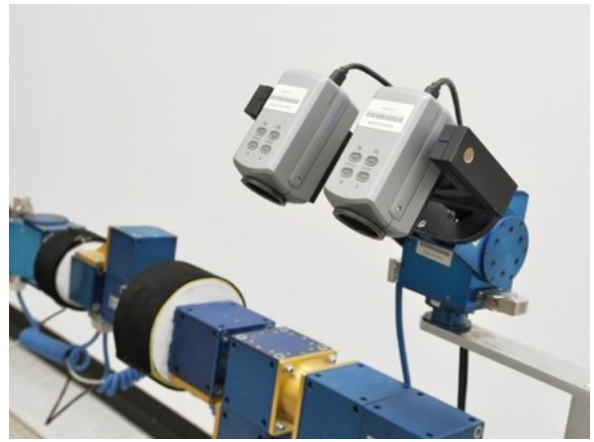
- develop a set of theoretical concepts that are necessary … to fulfill constraints
- probe how the set is sufficient to account for behavior and cognition
- be conservative: only introduce new theoretical concepts when forced to …
- be mindful of neural constraints

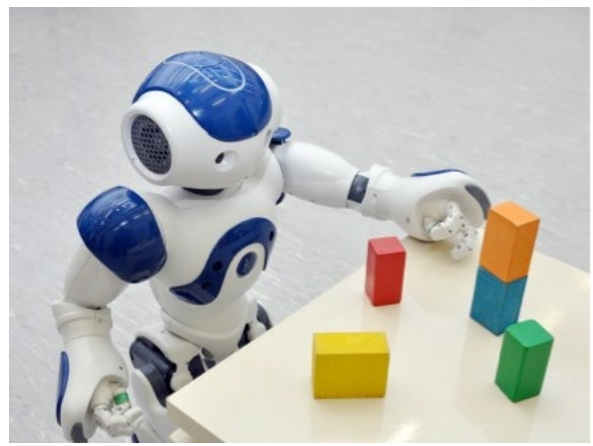
Experimental research program

- 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





What contents do you learn?

- elements of embodied cognition
  - detection decisions
  - selection decisions
  - working memory for metric information
  - memory trace

What contents do you learn?

- theoretical concepts
  - behavioral dynamics
  - neural dynamics
  - dynamic neural fields
  - Dynamic Field Theory

What contents do you learn?

- neural foundations
  - Braitenberg vehicles
  - rate code
  - population code

What contents do you learn?

- mathematic concepts
  - dynamical systems
  - stability, attractors, instabilities
  - numerical solution of differential equations

What contents do you learn?

- theory-experiment relationships
  - accounting for neural and behavioral data
  - accounting for behavior in process models

What contents do you learn?

- robotic and simulated behavior
  - as a heuristic tool
  - to demonstrate function from neural dynamics
  - to uncover overlooked problems

What skills do you learn?

- academic skills
  - read and understand scientific texts
  - write technical texts, using mathematical concepts and illustrations

What skills do you learn?

- mathematical skills
  - conceptual understanding of dynamical systems
  - capacity to read differential equations and illustrate them
  - perform “mental simulation” of differential equations
  - use numerical simulation to test ideas about an equation

What skills do you learn?

- interdisciplinary skills
  - handle concepts from a different discipline
  - handle things that you don’t understand
  - sharpen sense of what you understand and what not