Computational Neuroscience: Neural Dynamics — Introduction

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Cognition in the wild…

- attention/gaze
- active perception/working memory
- action plans/decisions/ sequences
- goal orientation
- motor control
- background knowledge
- learning from experience

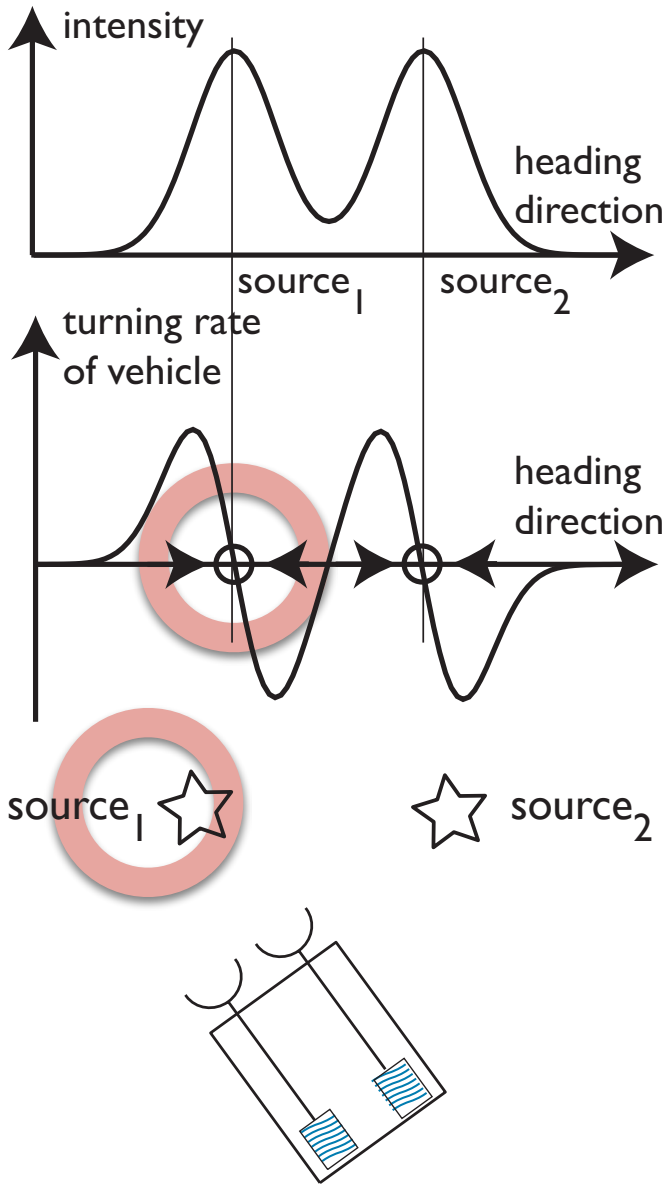
=> implied properties of the underlying neural processes

- graded state
- continuous time
- continuous/intermittent link to the sensory and motor surfaces
- from which discrete events and categorical behavior emerge
- in closed loop
- => states must be stable

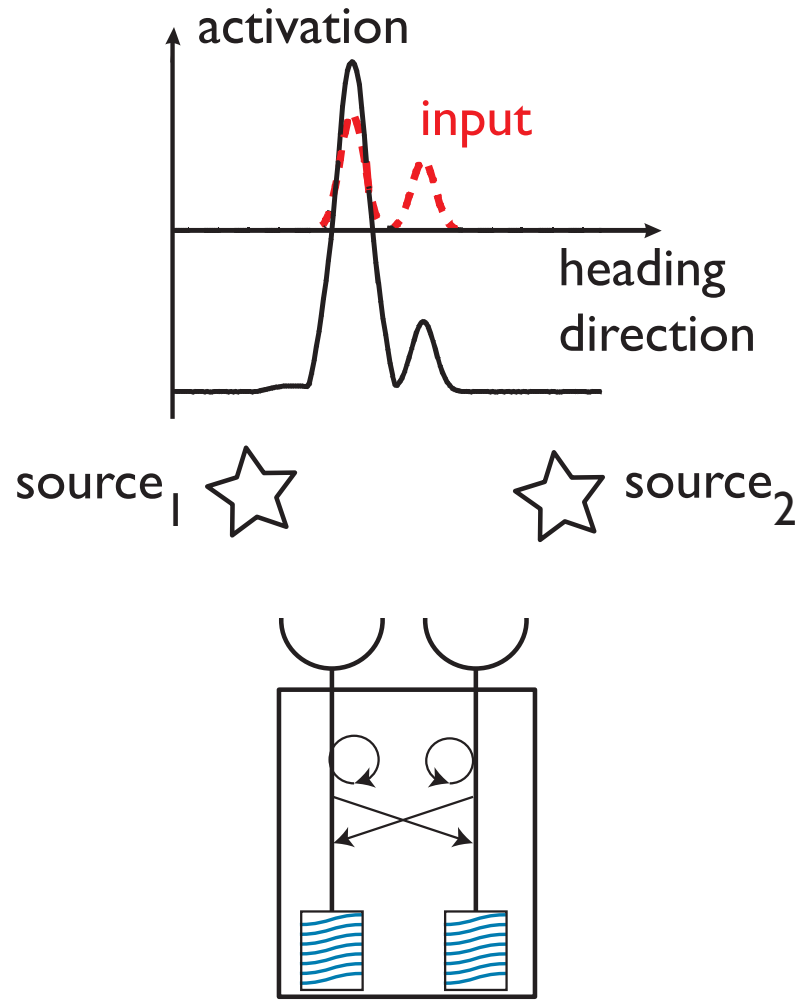
Embodiment hypothesis

- all cognition is like soccer playing = has the properties of embodied cognition
- => there is no particular boundary up to which cognition is embodied and beyond which it is computational/symbolic

Closed loop => dynamics



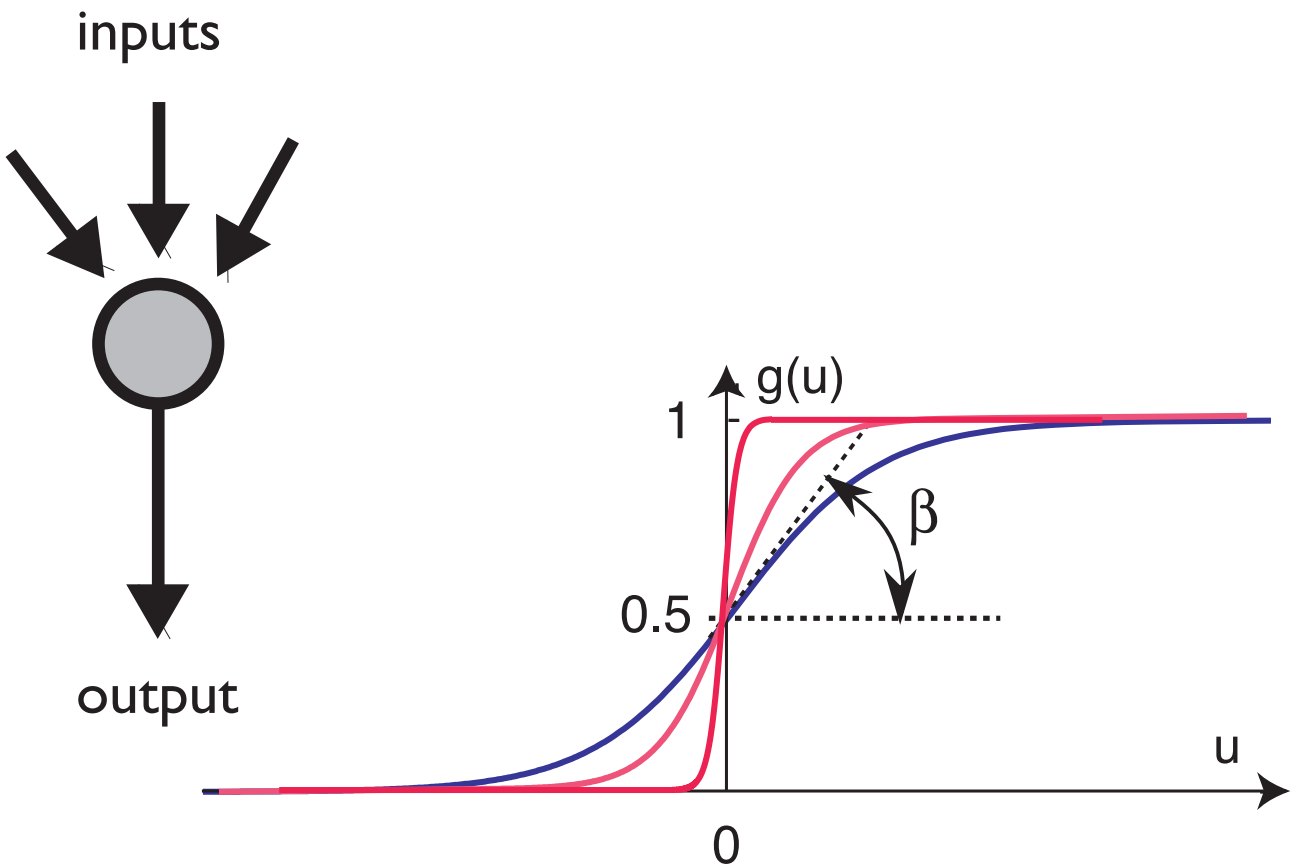
behavioral dynamics

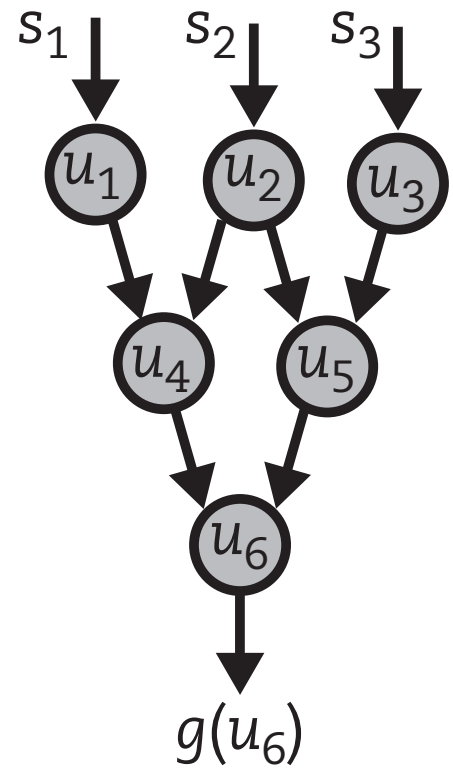


neural dynamics

What does "neural dynamics" mean?

- Neurons as input-output threshold elements that form feed-forward neural networks

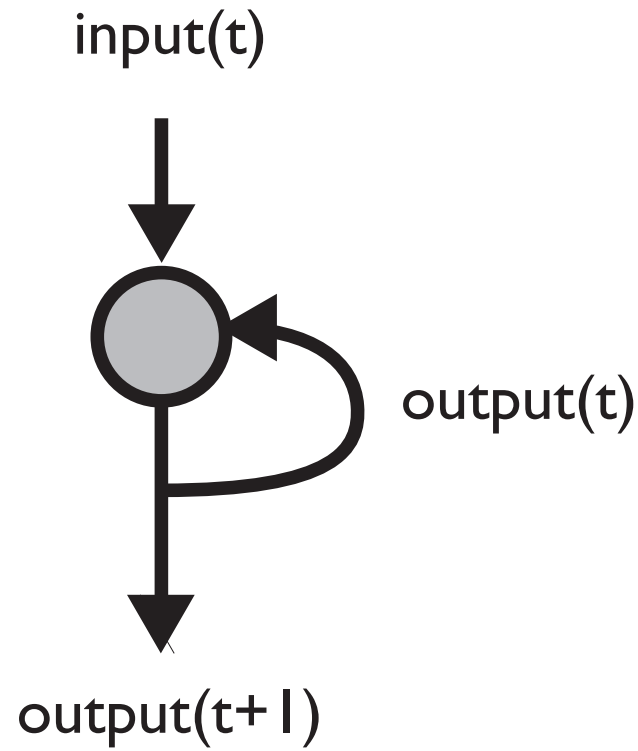




$$\text{output} = g\left(\sum(\text{inputs})\right)$$

What does "neural dynamics" mean?

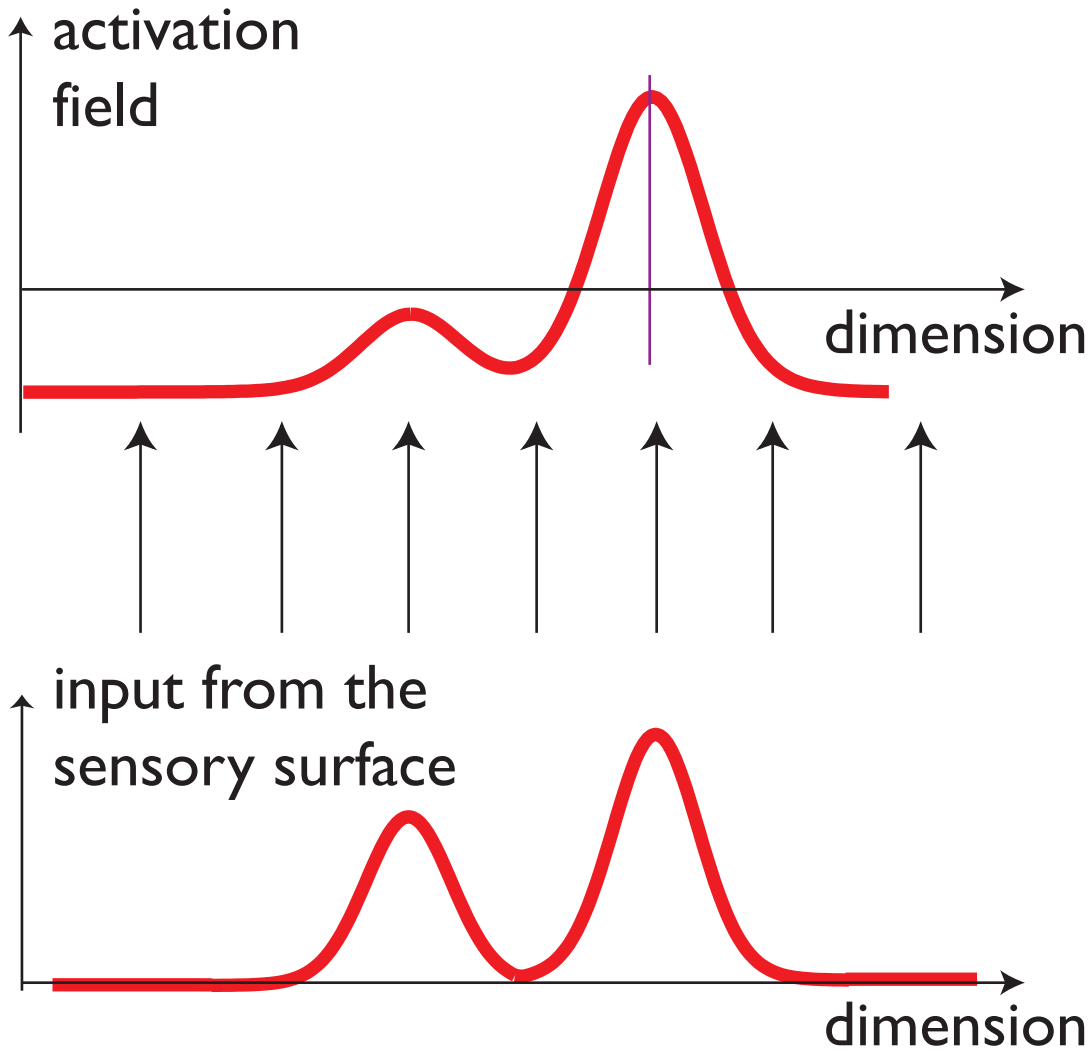
- recurrent neural networks require a concept of time
- time is not discrete (spiking is asynchronous) => neural dynamics…
- requires a concept of activation state, u (membrane potential, spiking rate)



$$\dot{u}(t) = -u(t) + h + \text{input}(t) + g(u(t))$$

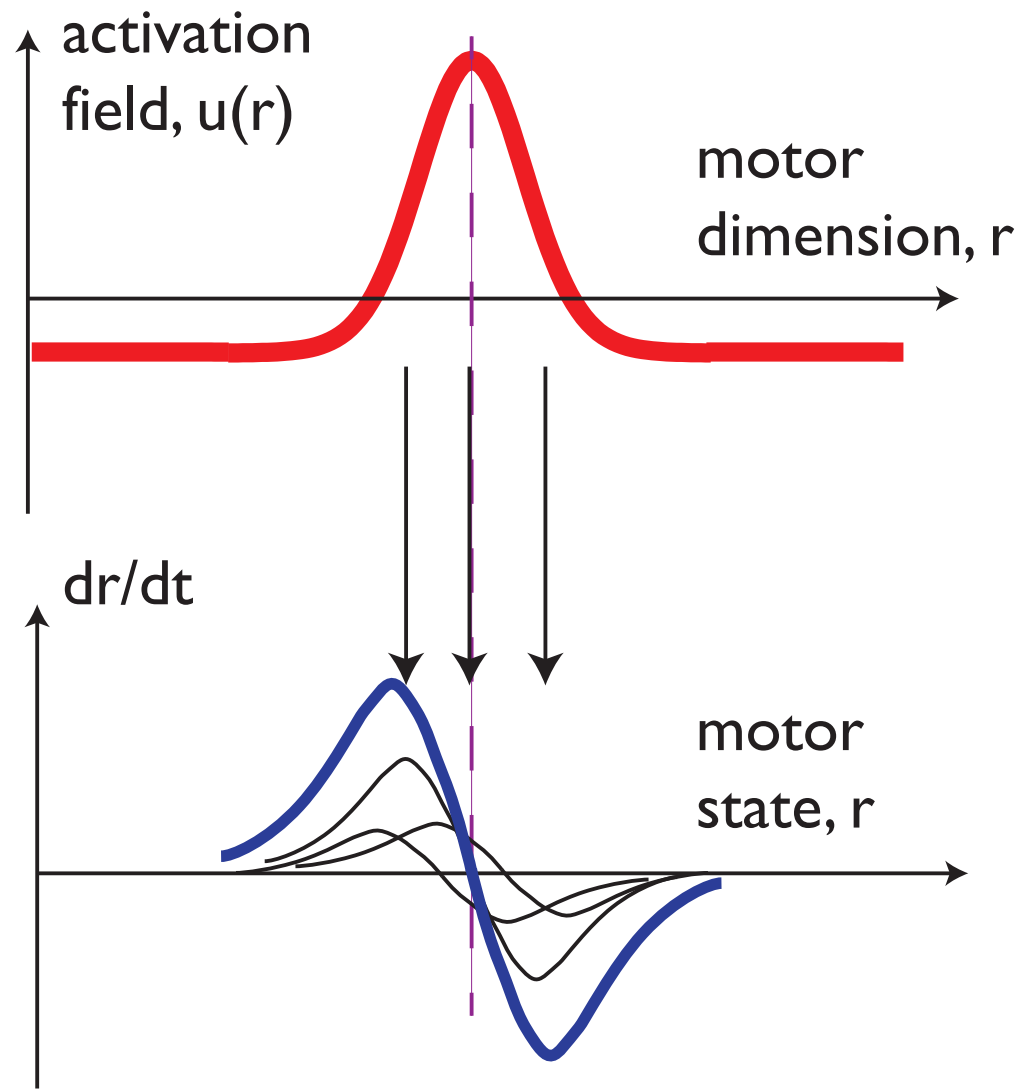
Dynamic fields

- continously many neurons… dynamic fields
- dimensions defined through the forward connectivity from sensory surfaces
  - e.g., feature maps…



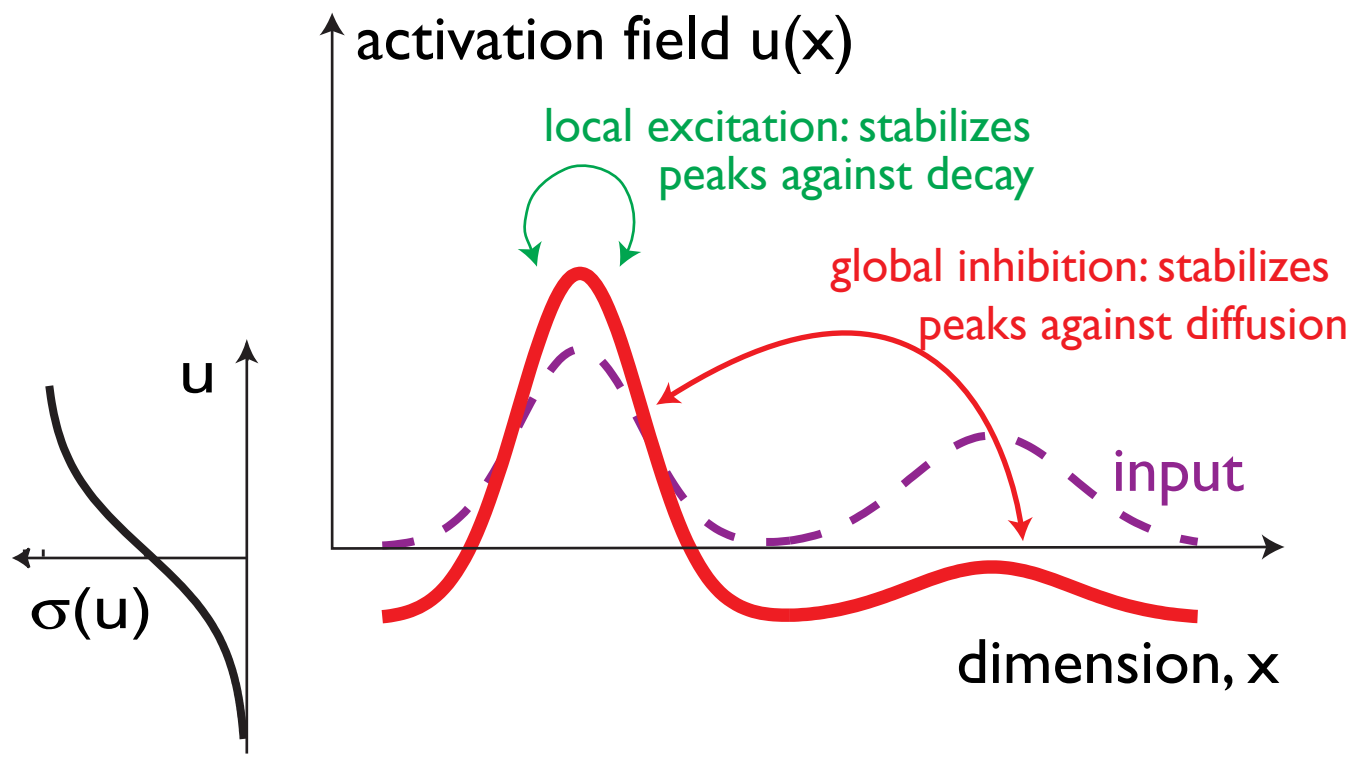
Dynamic fiels

- dimensions may also reflect output to motor surfaces… => behavioral dynamics
  - e.g., through peripheral reflex loops



Dynamic Fields

- regular recurrent connectivity (interaction) leads to localized activation patterns as attractor states:
  - stabilized by excitatory coupling against decay
  - stabilized by inhibitory coupling against diffusive spread



Theoretical research program

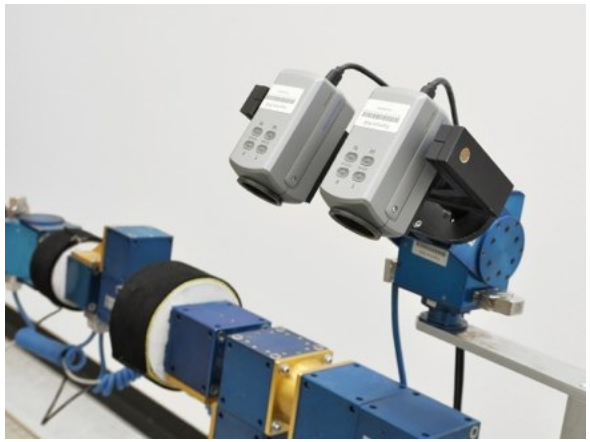
- theory of behavior and thinking…
  emergence from the sensory-motor domain
- process accounts based on neural principles
- naturalistic tasks that connect to elementary behaviors and elementary forms of cognition

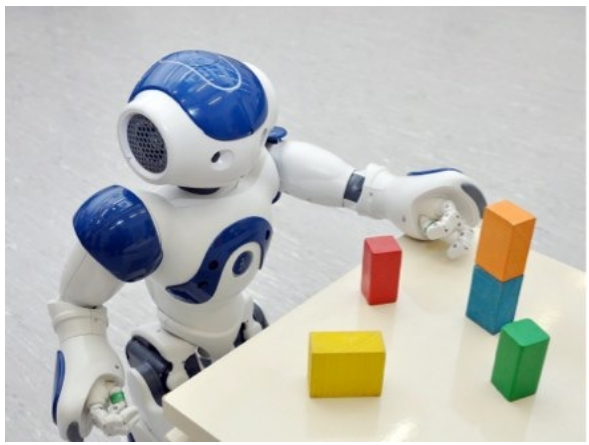
Experimental research program

- look for behavioral signatures of the postulated neural principles
  - e.g. metric effects, role of time, context, online updating
- study links between different domains

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 devices to demonstrate process accounts





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
  - rate code, neural maps
  - population code
  - neurophysics

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

Syllabus

- 1) Dynamical systems tutorial
  - a very brief conceptual survey over the basis concepts of dynamical systems, including attractors and instabilities
- 2) Braitenberg vehicles
  - a simple demonstration of synthetic psychology/ neuroscience: how behavior emerges from simple embodied situated nervous systems

Syllabus

- 3) Neurophysics
  - a very brief survey over basic concepts of the nervous systems: neurons, spiking, networks, learning, neural networks, the brain
- 4) Neural dynamics
  - the core dynamical systems properties of recurrent neural networks: single neuron with self-excitation and two competing neurons

Syllabus

- 5) Dynamic neural fields
  - the key instabilities in dynamic neural fields
  - detection
  - selection
  - memory
  - the memory trace

Syllabus

- 6) Higher dimensional fields
  - joint representations
  - visual search
  - binding
  - coordinate transforms
  - grounding
  - mental maps

Syllabus

- 7) sequences
  - condition of satisfaction
  - action initiation/termination
- 8) intentional systems
  - architectures
- 9) relation to other neural theories of cognition