

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

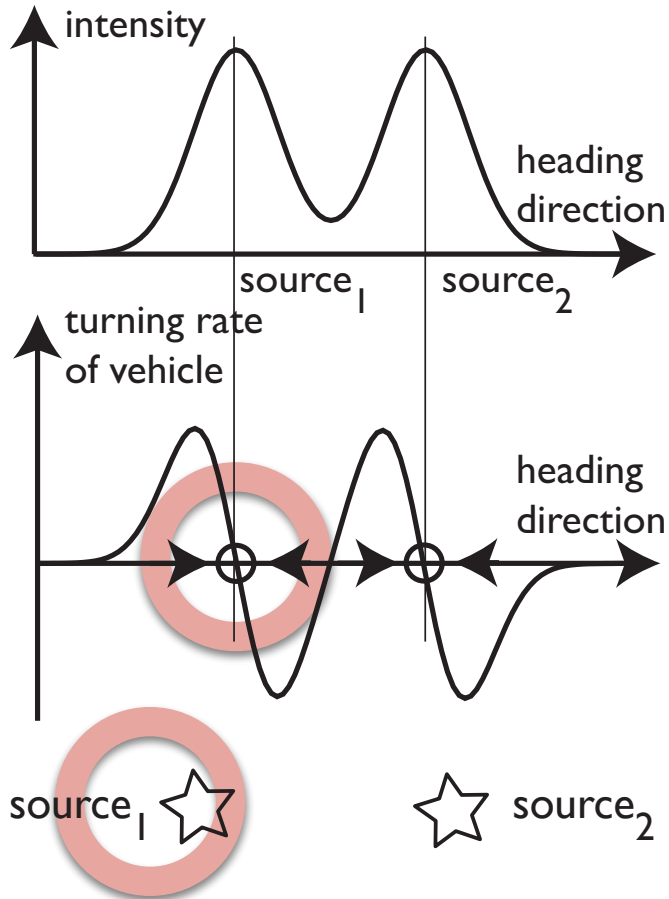


Embodiment hypothesis

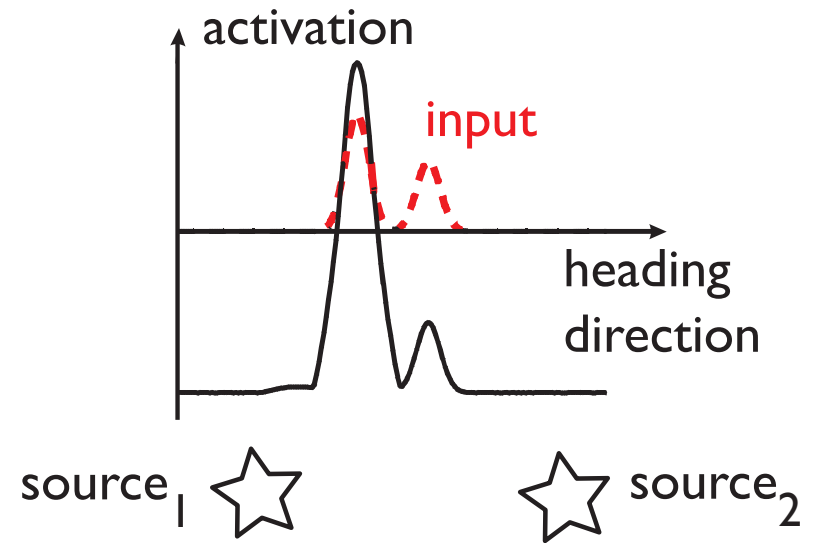
- all cognition is like soccer playing = has the properties of embodied cognition
- => there is no particular boundary up to which cognition is embodied and beyond which it is computational/symbolic



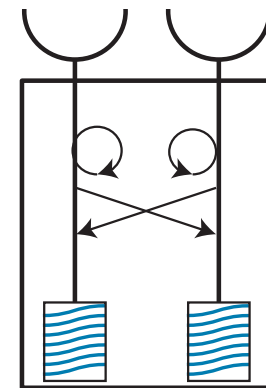
Closed loop => dynamics



behavioral dynamics

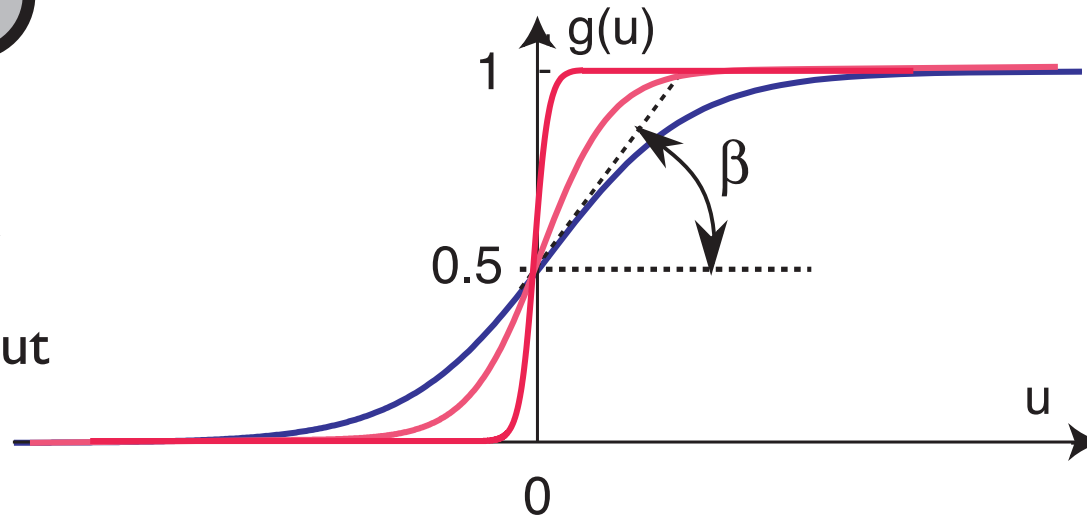
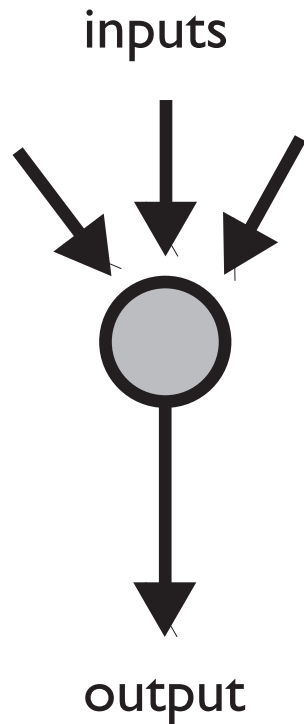


neural dynamics

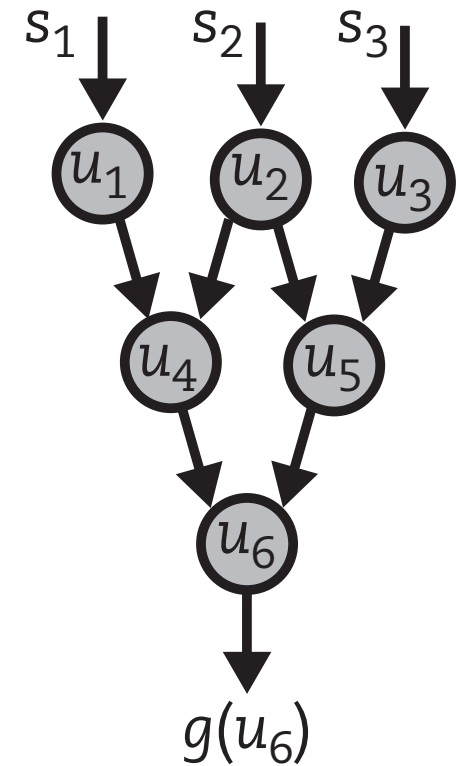


What does “neural dynamics” mean?

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

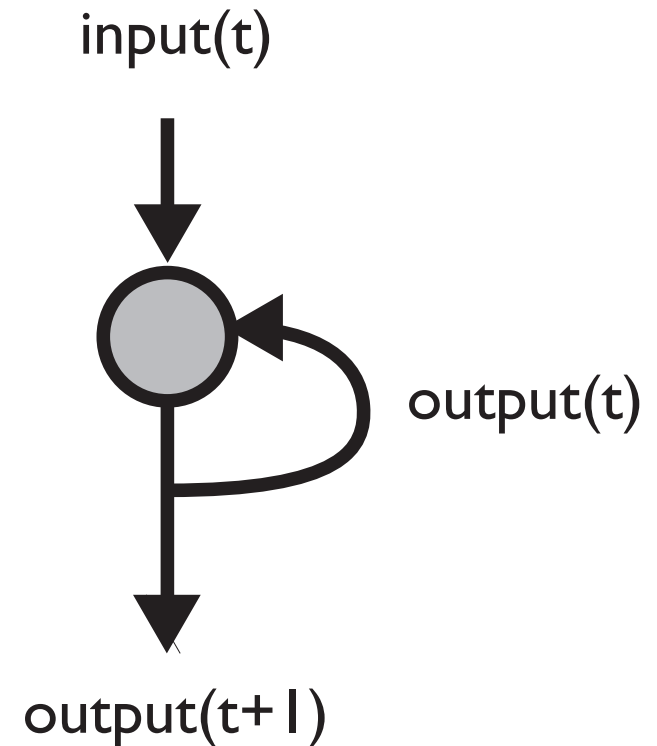


$$\text{output} = g \left(\sum (\text{inputs}) \right)$$



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)



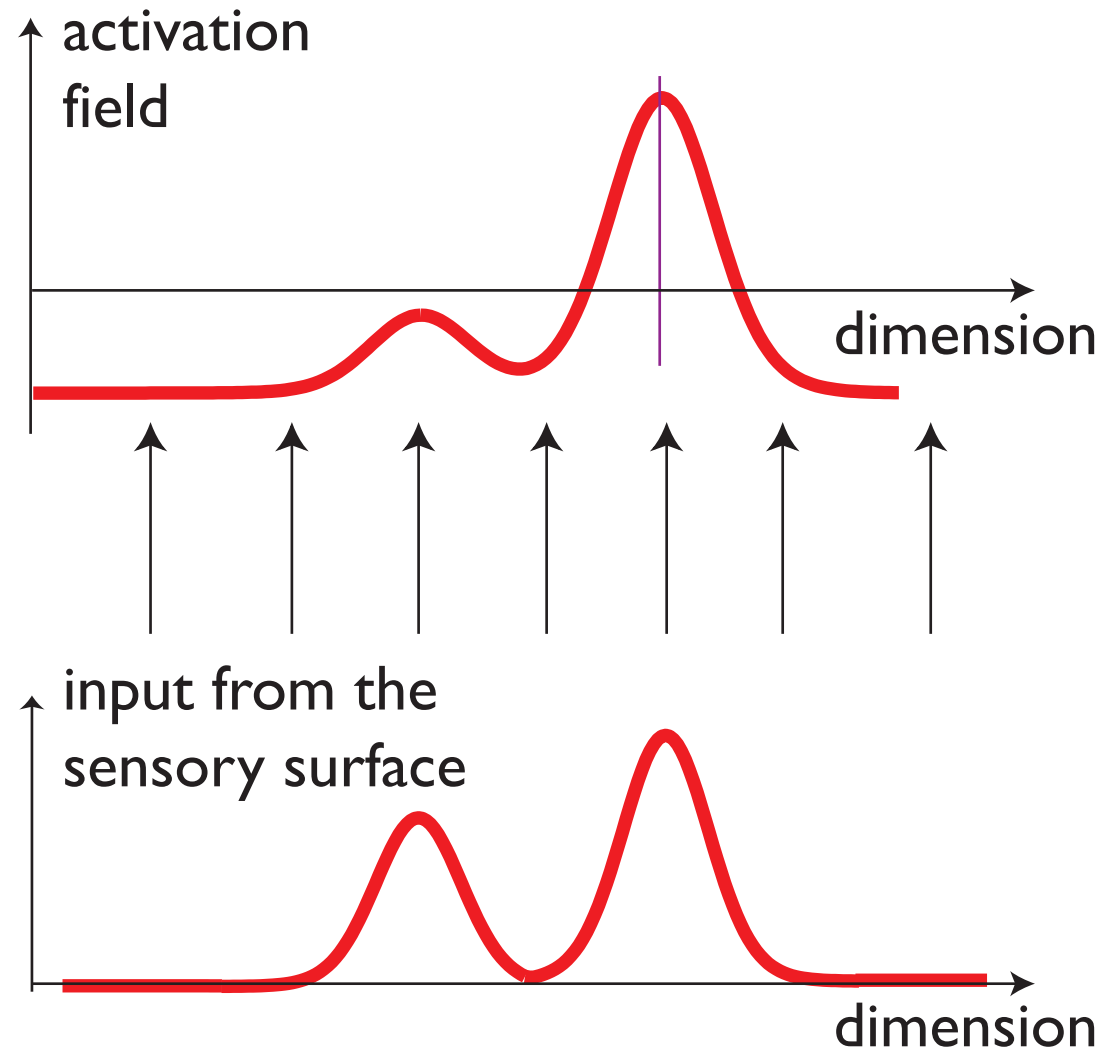
$$\dot{u}(t) = -u(t) + h + \text{input}(t) + g(u(t))$$

Dynamic fields

- continuously many neurons... dynamic fields

- dimensions defined through the forward connectivity from sensory surfaces

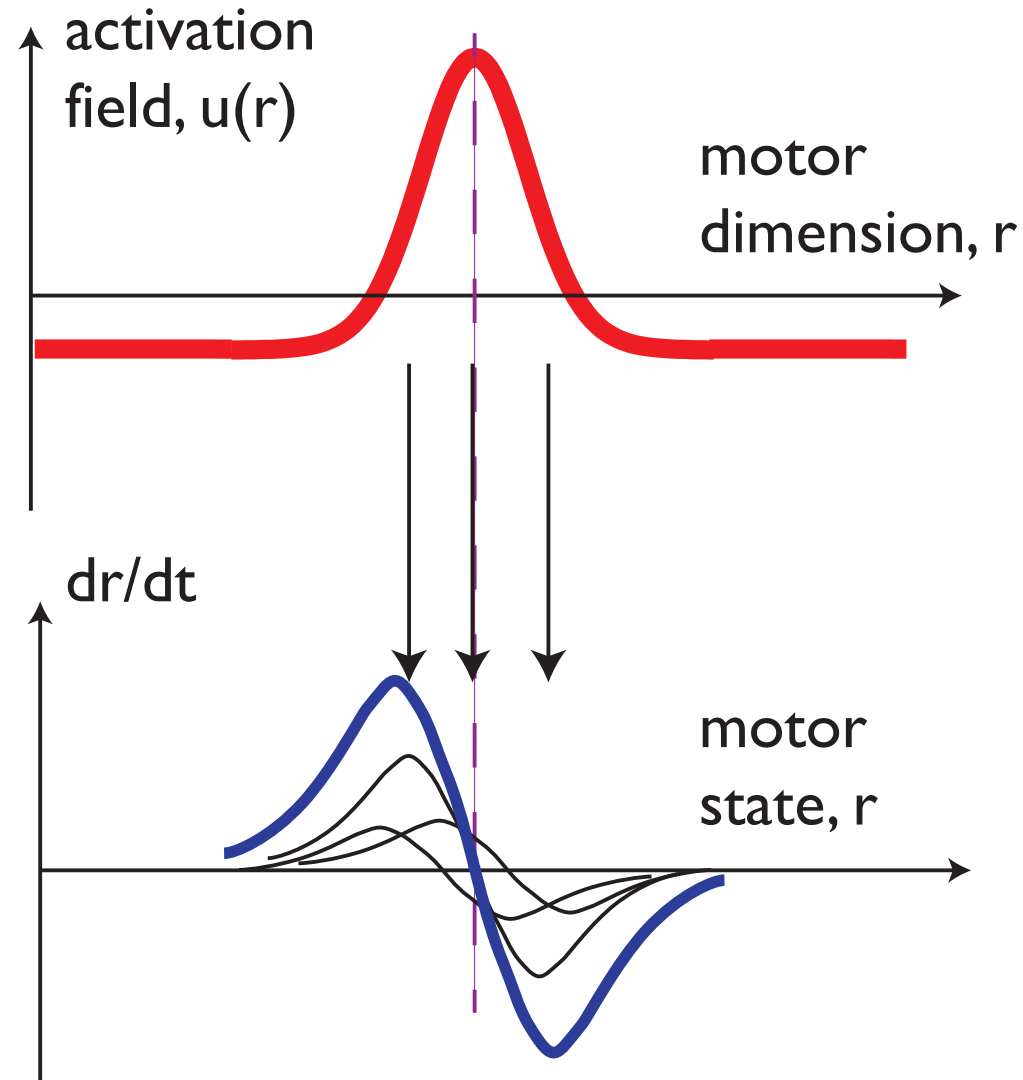
- e.g., feature maps...



Dynamic fields

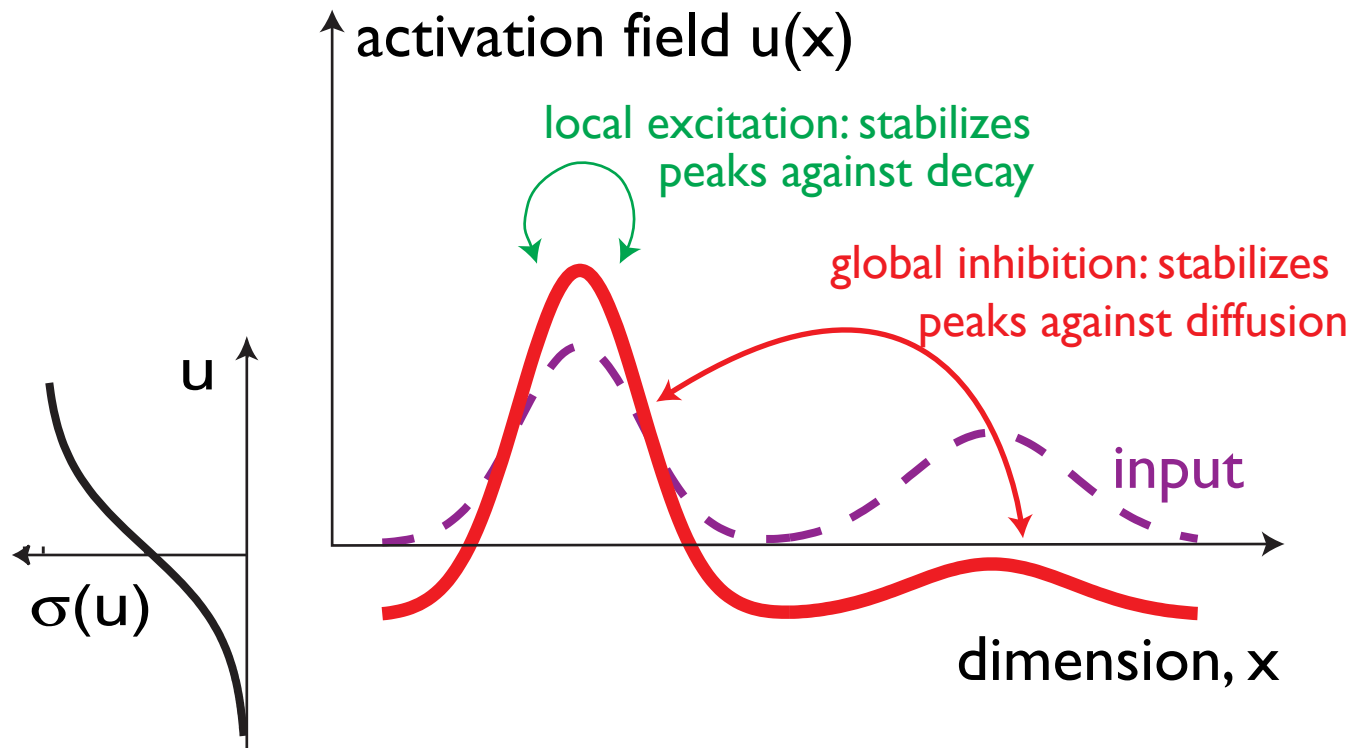
■ dimensions may also reflect output to motor surfaces... => behavioral dynamics

■ 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

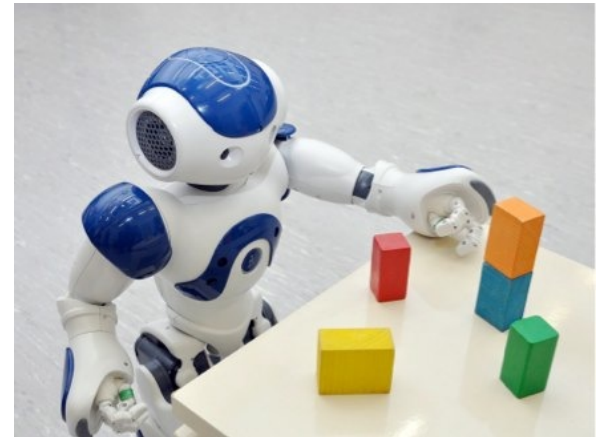
- theory of behavior and thinking...
emergence from the sensory-motor domain
- process accounts based on neural principles
- naturalistic tasks that connect to elementary behaviors and elementary forms of cognition

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