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

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

motor dimension, r

activation field, u(r)

dr/dt

motor state, r
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