Computational Neuroscience: Neural Dynamics
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 $\Rightarrow$ dynamics

- behavioral dynamics
- neural dynamics

intensity

heading direction

turning rate of vehicle

heading direction

source $1$

source $2$

activation

input

source $1$

source $2$

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)
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)

\[
\dot{u}(t) = -u(t) + h + \text{input}(t) + g(u(t))
\]
Neural dynamics

- localized activation patterns as attractor states:
  - stabilized by excitatory coupling against decay
  - stabilized by inhibitory coupling against diffusive spread

=> embedded in low-dimensional space to enable such regular patterns of connectivity/interaction
Interface with sensory surfaces

- Dimensions reflect forward connectivity from sensory
- E.g., feature maps…
Interface with motor surfaces

- Dimensions may reflect output to motor surfaces... => behavioral dynamics
- E.g., through peripheral reflex loops
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
Theoretical research program

- when studying cognitive competences, keep the links to the sensorimotor domain in view, both experimentally and theoretically.
- because 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.
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 devices

- 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