Neural Dynamics

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Activation

- how to represent the inner state of the Central Nervous System?
- => activation concept
Activation

neural state variables

- membrane potential of neurons?
- spiking rate?
- ... population activation...
Activation

- Activation as a real number, abstracting from biophysical details

- Low levels of activation: not transmitted to other systems (e.g., to motor systems)

- High levels of activation: transmitted to other systems

- As described by sigmoidal threshold function

- Zero activation defined as threshold of that function
Activation

- compare to connectionist notion of activation:
  - same idea, but tied to individual neurons

- compare to abstract activation of production systems (ACT-R, SOAR)
  - different... really a function that measures how far a module is from emitting its output...
  - but related: sigmoidal function gives meaning to activation
Activation dynamics

- activation variables $u(t)$ as time continuous functions...

$$\tau \ddot{u}(t) = f(u)$$

- what function $f$?
Activation dynamics

- start with $f=0$

$$\tau \dot{u} = \xi_t$$

- probability distribution of perturbations
Activation dynamics

Need stabilization

\[ \tau \dot{u} = -u + h + \xi_t. \]
In a dynamical system, the present predicts the future: given the initial level of activation $u(0)$, the activation at time $t$: $u(t)$ is uniquely determined

\[ \frac{du(t)}{dt} = \dot{u}(t) = -u(t) + h \quad (h < 0) \]
Neural dynamics

- stationary state: fixed point = constant solution
- stable fixed point: nearby solutions converge to the fixed point = attractor

\[ \frac{du(t)}{dt} = \dot{u}(t) = -u(t) + h \quad (h < 0) \]
Neural dynamics

- exponential relaxation to fixed-point attractors
- $\tau \dot{u}(t) = -u(t) + h$

$u(0)/e \rightarrow u(t) \rightarrow u(\tau)$

resting level

vector-field

du/dt = f(u)
Neural dynamics

- attractor structures ensemble of solutions = flow

\[ \tau \dot{u}(t) = -u(t) + h \]
**Neuronal dynamics**

- Inputs = contributions to the rate of change
  - Positive: excitatory
  - Negative: inhibitory
- => shifts the attractor
- Activation tracks this shift (stability)

\[ \tau \frac{du(t)}{dt} = -u(t) + h + \text{inputs}(t) \]
=> simulation in live exercise session
Neuronal dynamics with self-excitation

\[ \tau \dot{u}(t) = -u(t) + h + s(t) + c \, g(u(t)) \]
Neuronal dynamics with self-excitation

\[ \tau \dot{u}(t) = -u(t) + h + s(t) + c \, g(u(t)) \]

=> nonlinear dynamics!
Neuronal dynamics with self-excitation

\[ \tau \dot{u}(t) = -u(t) + h + s(t) + c \, g(u(t)) \]
Neuronal dynamics with self-excitation

- At intermediate stimulus strength: bistable
- “On” vs “off” state

\[ \tau \dot{u}(t) = -u(t) + h + s(t) + c \, g(u(t)) \]
Neuronal dynamics with self-excitation

- Increasing input strength => detection instability
Neuronal dynamics with self-excitation

- decreasing input strength
  => reverse detection instability

\[ \text{resting level, } h \]
\[ \text{input strength} \]
\[ \text{stimulus strength} \]
\[ \text{fixed point} \]
\[ \text{stable} \]
\[ \text{unstable} \]
Neuronal dynamics with self-excitation

- The detection and the reverse detection instability create discrete events out of input that changes continuously in time.
simulation in live exercise session