Neural Dynamics
Part I

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recall: Braitenberg vehicles...
behavioral dynamics

- turning rate of vehicle
- heading direction
- attractor

Diagram showing the dynamics of a vehicle's turning rate and heading direction, with an attractor point.
**Selection**

- bistable dynamics for bimodal intensity distribution => bistable (nonlinear) dynamics makes selection decision
... with more complex nervous system

source_1

source_2
…keep selection decision “in mind”?
...keep selection decision “in mind”?  

- when sensory information is removed => keep decision in working memory  
- for this need an “inner state” of the nervous system that “stores” that decision => neural activation
Activation

- neural state variable activation
  - linked to membrane potential of neurons in some accounts
  - linked to spiking rate in our account
  - through: population activation... (later)
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)
  - quite different... really a function that measures how far a module is from emitting its output...
Activation dynamics

- activation evolves in continuous time

- no evidence for a discretization of time, for spike timing to matter for behavior
Activation dynamics

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

$$\tau \frac{du(t)}{dt} = f(u)$$

- what function $f$?
Activation dynamics

- start with $f=0$

\[ \tau \dot{u} = \xi_t \]
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**

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$$\frac{du(t)}{dt} = \dot{u}(t) = -u(t) + h \quad (h < 0)$$
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

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

**Diagram:**
- Time scale
- Vector-field
- Resting level
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
- $\tau \frac{du(t)}{dt} = -u(t) + h + \text{inputs}(t)$