Dynamic field theory (DFT) … attractor dynamics for perception and cognition

Gregor Schöner
behavioral attractor dynamics

- generate time courses of behavioral variables to steer a system toward desired states while satisfying constraints
perception/cognition

- need perception and cognition to autonomous generated behavior:
  - detect targets, obstacles
  - estimate direction to target etc.
  - select objects, recognize objects, etc

=> perception = extract information about the world from sensory signals

=> cognition: plan actions, action sequences, motor goals, etc.
detection

detection = decide if a particular signal/object etc is present

examples:
- target detection from radar signals
- detection of communication signals from radio waves

theoretical approaches:
- signal detection theory, with varying amounts of prior information about signals and noise (models)
- framework: statistical hypothesis testing
estimation

- estimation = determine the value of a continuously valued parameter from data, given the presence of a signal (which was detected)

- tracking: do some continuously in time, updating estimates…

- examples:
  - navigation: determine ego-position from distance sensors, maps, beacons
  - control: estimate parameters of plant
  - motion planning constraints: estimate pose and position of targets
estimation

- theoretical approaches
  - (optimal) estimation theory based on various amounts of a priori knowledge about the system
  - Optimal filtering, Kalman filtering, particle filters
classification

given that a signal has been detected, assign that signal to one class within a set of discrete classes

examples:
- binary classification (target yes or no)
- decoding in (digital) telecommunication
- recognition: letters, speech, objects, ...
classification

- theoretical approaches:
  - statistical hypothesis testing within metrics of feature/code space to separate distributions (discrimination)
  - (detection being a special case of classification)
  - neural networks, learning
  - statistical learning theory: support vector machines
  - link to coding: optimal code that maximize distances in code space between classes
The neural dynamics approach to perception and cognition: Dynamic Field Theory

- dimensions
- activation fields
- field dynamics: peaks, instabilities
Dimensions

different categories of behavior and percepts each form continua, embedded in spaces

- e.g., the space of possible reaching movements: spanned by the direction in space of the hands velocity

- e.g., the spaces of possible shapes, colors, poses of a segmented visual object
Activation

- activation: the notion of an “inner” state of a neural network that is used to mark what is significant about neural activity (=has impact)
  - membrane potential of neurons
  - spiking rate?
  - ... population activation… elaborated in lecture course of the WS on neural dynamics
Activation

- activation: a real number that characterizes the inner state of a “neuron”, and abstracts from biophysical details

- low levels of activation: state of the “neuron” is not transmitted to other systems (e.g., to motor systems)

- high levels of activation: state is transmitted to other systems

=> sigmoidal threshold function

![Diagram of sigmoid function with parameters}\( g(u) \) and \( \beta \) showing the transition from low to high activation levels. The graph illustrates the sigmoidal curve with a threshold at 0.5, and the steepness is adjusted by \( \beta \).
Activation fields

- combine activation and dimensions

information, probability, certainty

activation field

dimension

metric contents

e.g., retinal space, movement parameters, feature dimensions, viewing parameters, ...
Activation fields

may represent different states of affairs:

- localized activation peak: a specific value along the dimension is specified and information about the dimension is thus available
  - had been detected/instantiated
  - and has been estimated/planned
- flat, sub-threshold activation: no information is available, no value is specified
The dynamics activation fields

- **Field dynamics** combines input
- with strong interaction:
  - local excitation
  - global inhibition
- => generates stability of peaks

**Activation field** $u(x)$

- local excitation: stabilizes peaks against decay
- global inhibition: stabilizes peaks against diffusion

**Graph**

- Activation field $u(x)$
- Movement parameter
- Time
- Dimension, $x$
- Specific input arrives
- Preshaped field

**Diagram**

- Graph showing activation and movement parameter with time.
Amari equation

\[ \tau \dot{u}(x, t) = -u(x, t) + h + S(x, t) + \int w(x - x') \sigma(u(x', t)) \, dx' \]

where

- time scale is \( \tau \)
- resting level is \( h < 0 \)
- input is \( S(x, t) \)
- interaction kernel is

\[ w(x - x') = w_i + w_e \exp \left[ -\frac{(x - x')^2}{2\sigma_i^2} \right] \]

- sigmoidal nonlinearity is

\[ \sigma(u) = \frac{1}{1 + \exp[-\beta(u - u_0)]} \]
=> simulations
attractor states
- input driven solution (sub-threshold)
- self-stabilized solution (peak, supra-threshold)

instabilities
- detection instability (from localize input or boost)
- reverse detection instability
- selection instability
- memory instability