Braitenberg vehicles: embodied nervous systems

Gregor Schöner
Braitenberg vehicles

= embodied nervous systems with:
  - effectors
  - sensors
  - a nervous system
  - a body

+ situated in a structured environment

= emergent function
are characterized by a sensor characteristic= relationship between the physical quantity (e.g. sound, luminance, chemical concentration, mechanical pressure.... ) and an inner state variable: “activation”
Effectors are defined by a motor characteristic = a functional relationship between an inner activation state and a physical effect generated in the world (e.g., turning rate (rotations per minute rmp), force level, stiffness, …)
Body

- mechanically links the sensors to effectors
links sensors to effectors through the inner activation state
is structured at a relevant scale in terms of the physical variables to which organism is sensitive.

Environment

low intensity

high intensity
Emergent behavior: taxis

source

intensity

structured environment

activation

intensity

wheel motion

activation

sensory system

nervous system

body

motor system
Behavior emerges from a dynamical system

- feedforward nervous system
- + closed loop through environment
- => (behavioral) dynamics
Derivation

source

intensity

activation

intensity

wheel motion

activation

wheel motion

intensity

Differences in intensity left-right

differences in turning rate left-right

Turning rate of vehicle

heading direction

differences in intensity left-right

source
Derivation

\[ \omega_l = \omega_0 - cI_l \]
\[ \omega_r = \omega_0 - cI_r \]
\[ \Delta \omega = -c \Delta I \]
Derivation

- Differences in intensity left-right
- Heading direction
- Turning rate of vehicle
- Differences in intensity left-right
- Heading direction
- Source
Derivation

- Differences in intensity left-right
- Differences in turning rate left-right wheel
- Turning rate of vehicle
- Source
- Heading direction
Behavior emerges from a dynamical system

- feedforward nervous system
- + closed loop through environment
- => (behavioral) dynamics
Complex environment $\Rightarrow$ complex dynamics

- bistable dynamics for bimodal intensity distribution
- $\Rightarrow$ nonlinear dynamics makes selection decision
transition to monostable for mono-modal distribution

=> instabilities lead to qualitative change of behavior
Transition to monostable for mono-modal distribution

=> Instabilities lead to qualitative change of behavior
Beyond behavioral dynamics …

- so far: behavioral decision is ``overt”
- => the vehicle’s physical state “stores” the state of that decision
Beyond behavioral dynamics …

- what if we want the vehicle to make a decision for one target, without actually moving so that later, the outcome of that decision can be acted out..

- => “covert” orientation

- need to “store” the state of that decision somewhere other than the physical state of the vehicle: neural state in the neural network
Beyond behavioral dynamics …

- neural state in the neural network: activation concept
- activation dynamics
- competitive/selective
Beyond behavioral dynamics …

neural activation field to represent continuous of possible target orientations
or we want the system to be able to act on the sources after the external sources of stimulation are removed...

=> working memory

need to store the state of that sensory representation in the neural network
store the state of the representation in a neural field as a pattern of sustained activation
Next…

neural dynamics