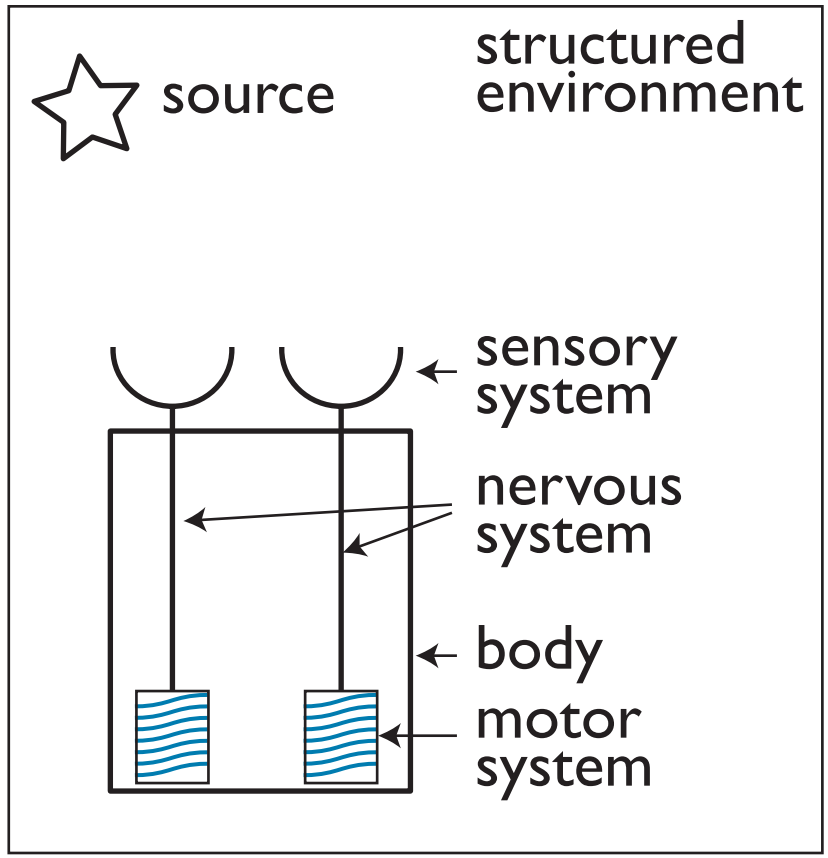
Braitenberg vehicles: embodied nervous systems

Gregor Schöner

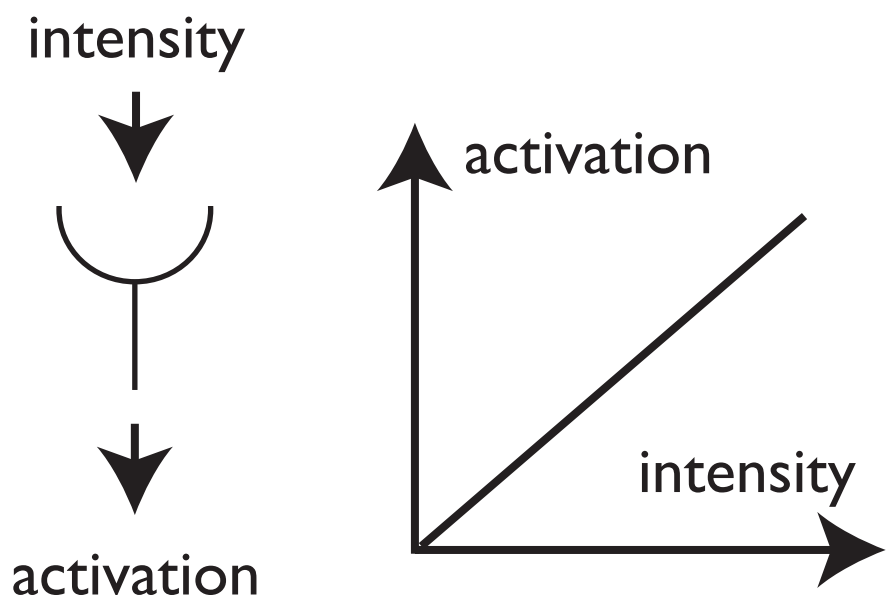
Braitenberg vehicles

- =embodied nervous systems with:
  - effectors
  - sensors
  - a nervous system
  - a body
- + situated in a structured environment
- = emergent function



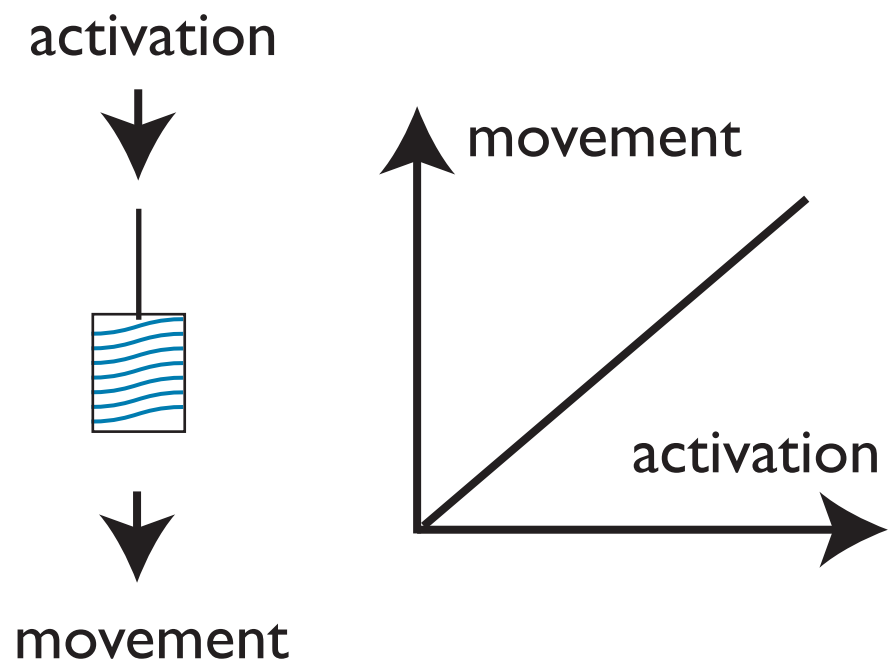
Sensors

- 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"



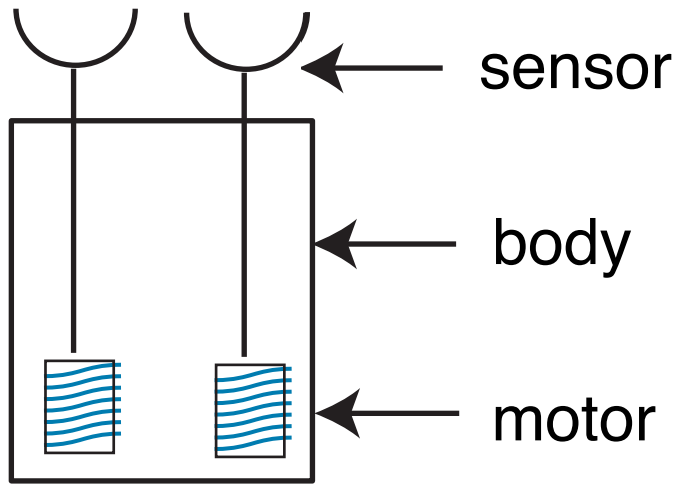
Effectors

- 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, …)



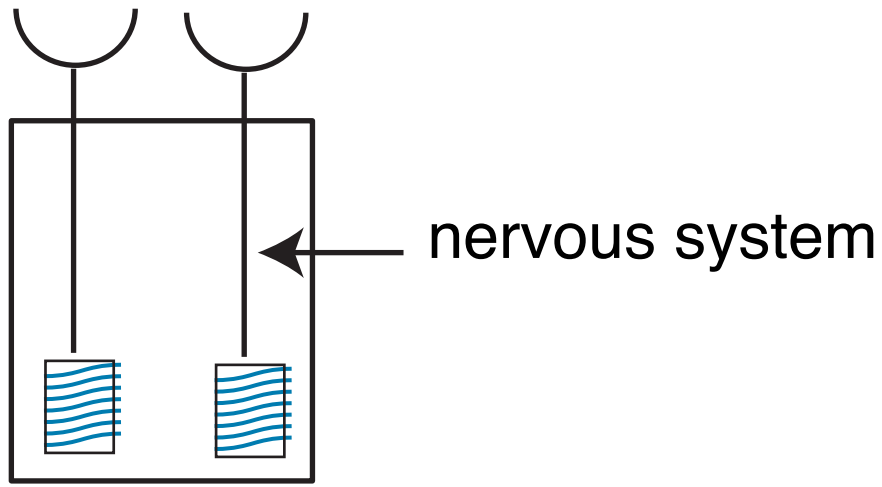
Body

- mechanically links the sensors to effectors



Nervous system

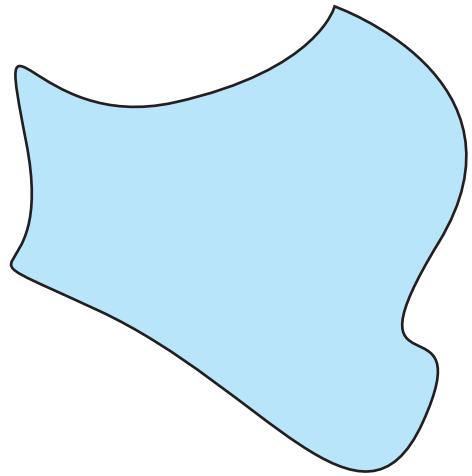
- links sensors to effectors through the inner activation state



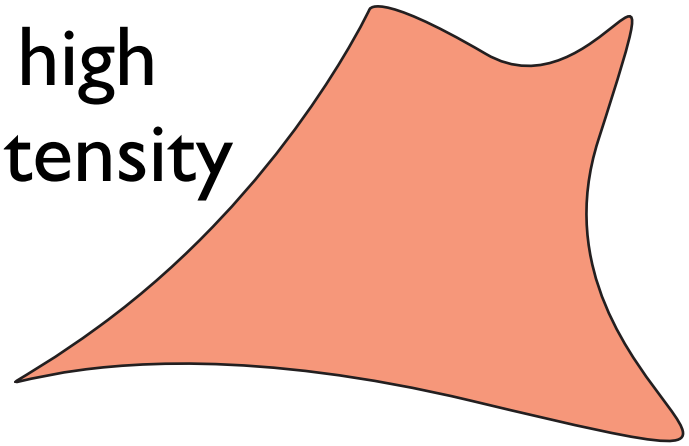
Environment

- is structured at a relevant scale in terms of the physical variables to which organism is sensitive

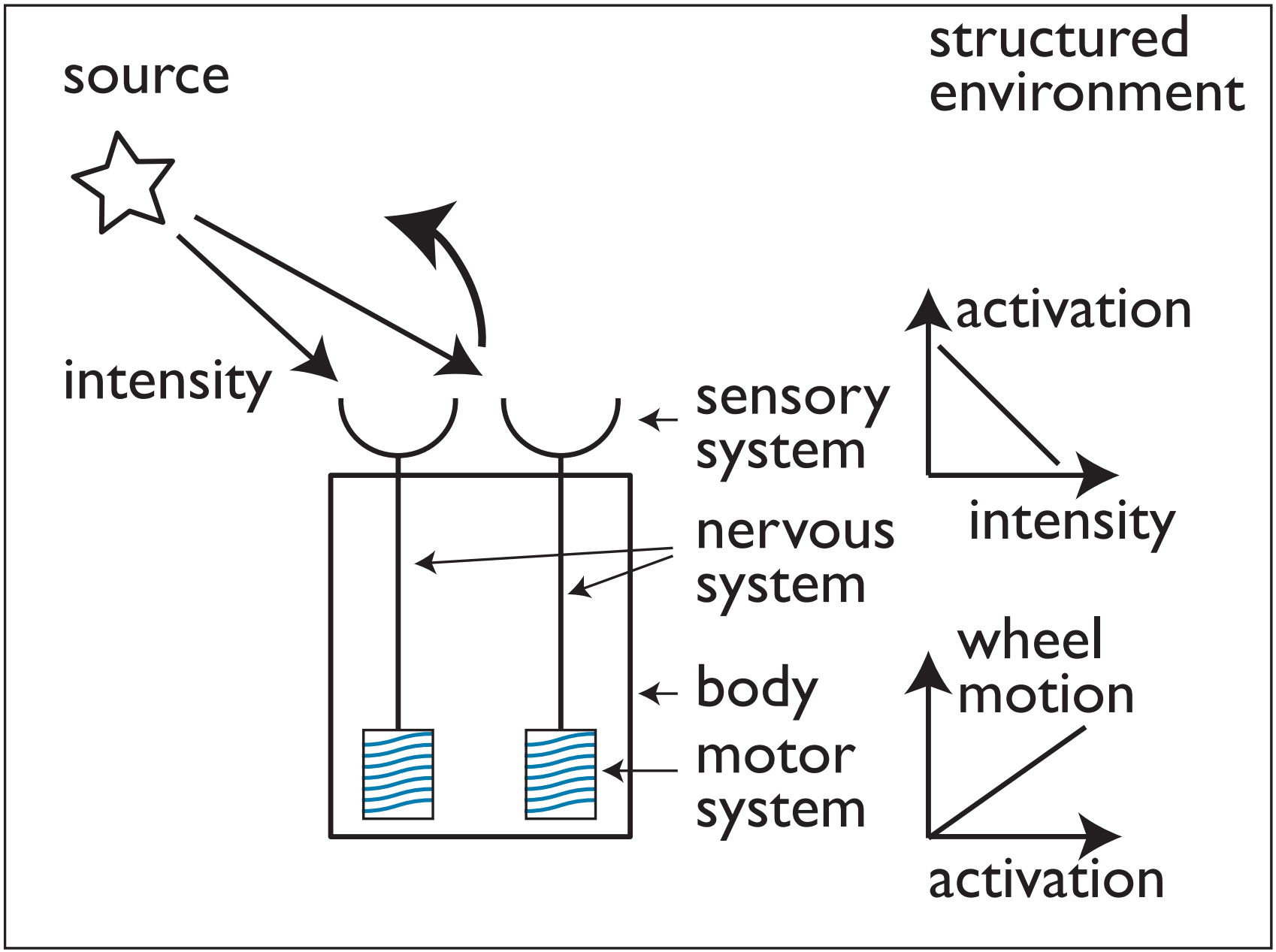
low intensity



high intensity

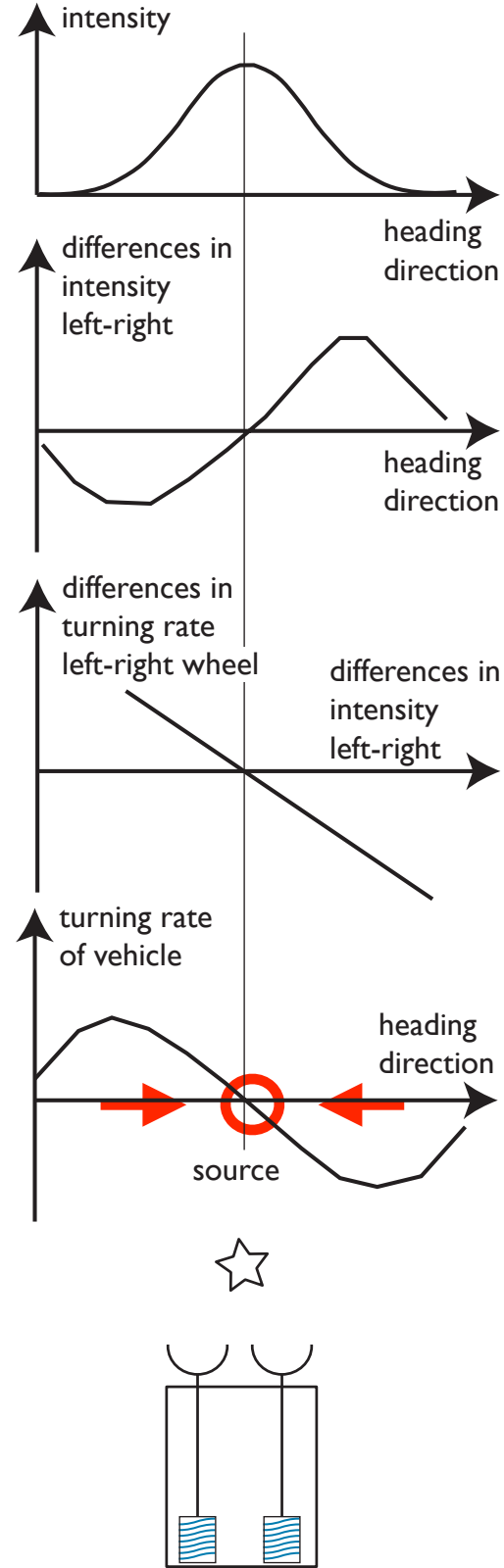


Emergent behavior: taxis

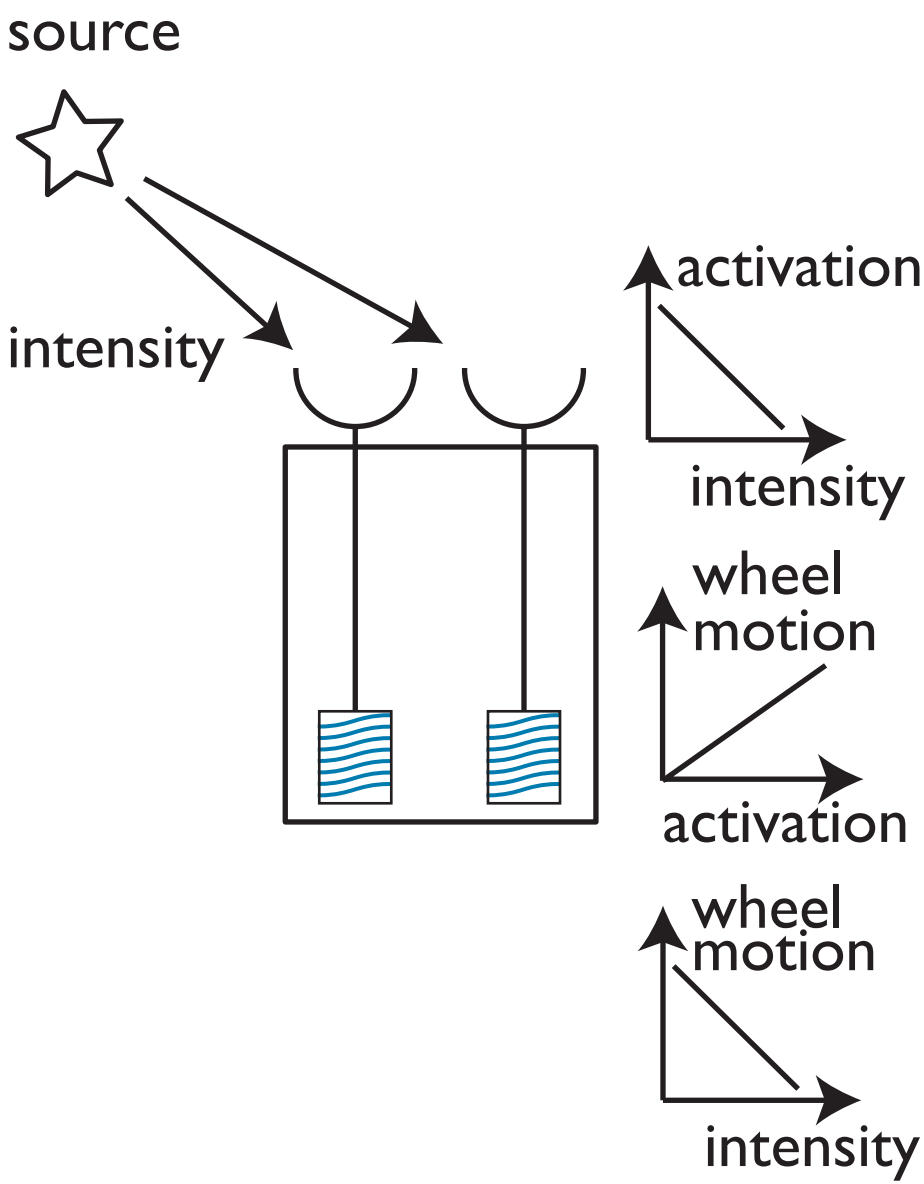


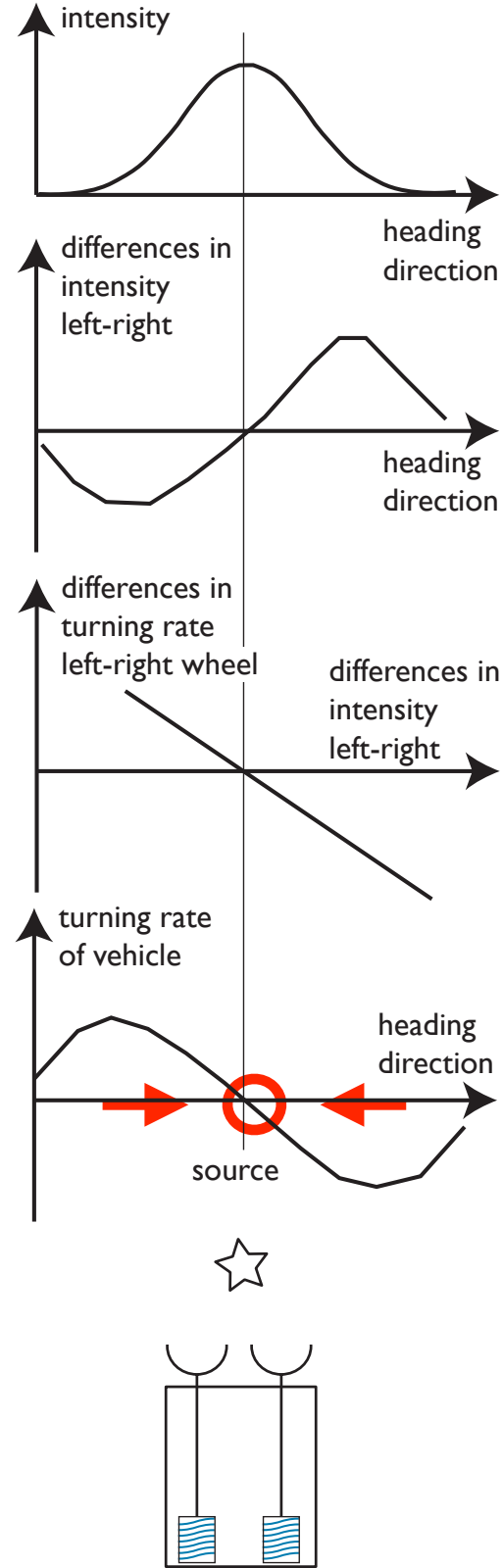
Behavior emerges from a dynamical system

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



Derivation


source
intensity
activation
intensity
wheel
motion
activation
wheel
motion
intensity

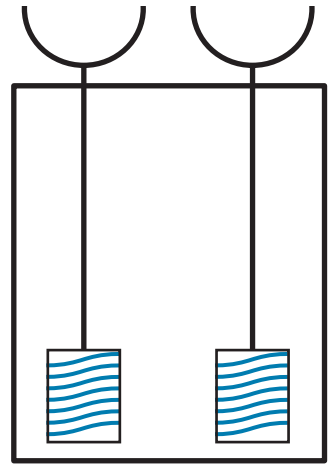

intensity
heading
direction
differences in
intensity
left-right
heading
direction
differences in
turning rate
left-right wheel
differences in
intensity
left-right
turning rate
of vehicle
heading
direction
source

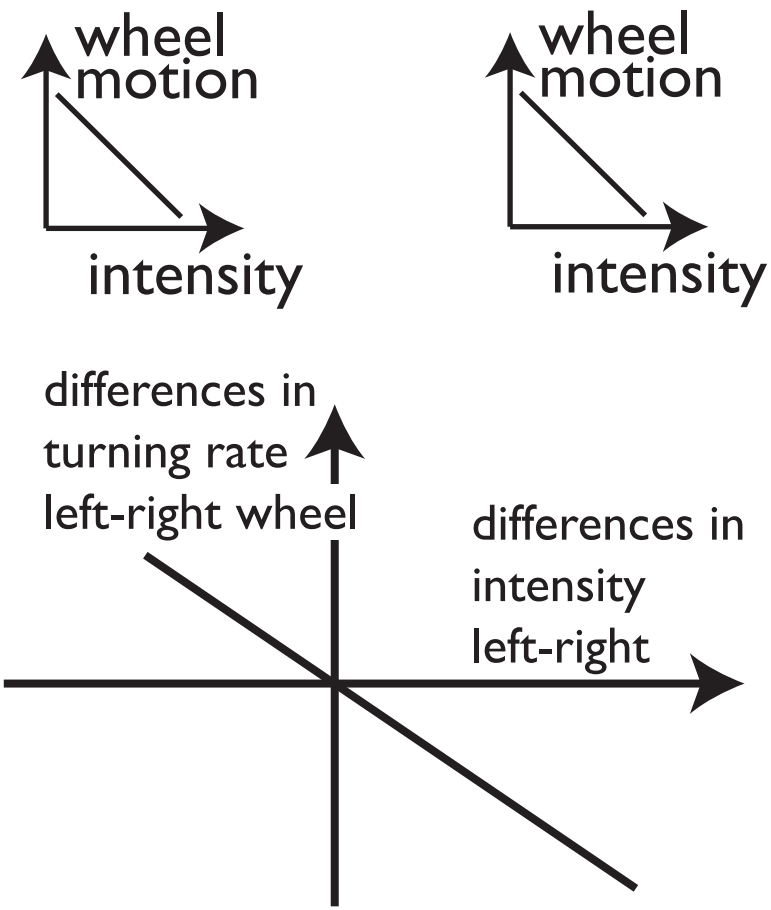
Derivation

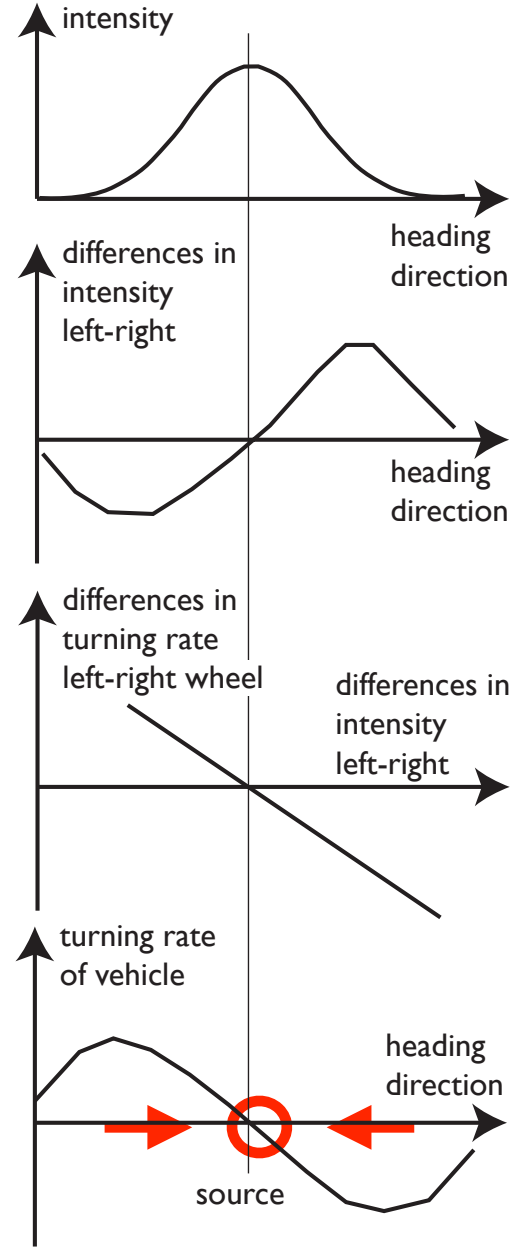
$$\omega_l = \omega_0 - cI_l$$

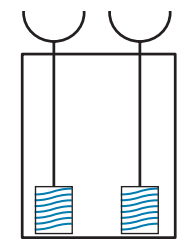
$$\omega_r = \omega_0 - cI_r$$

$$\Delta\omega = -c\Delta I$$

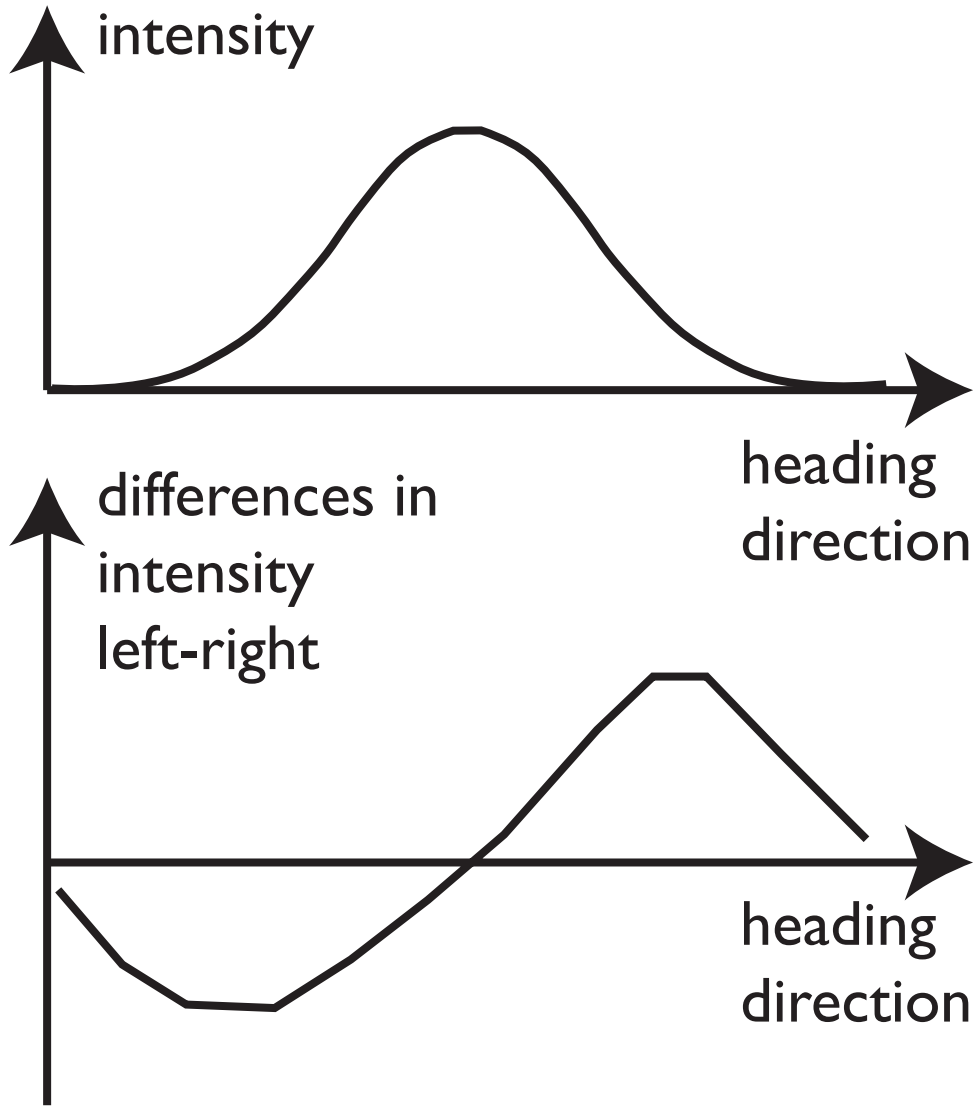


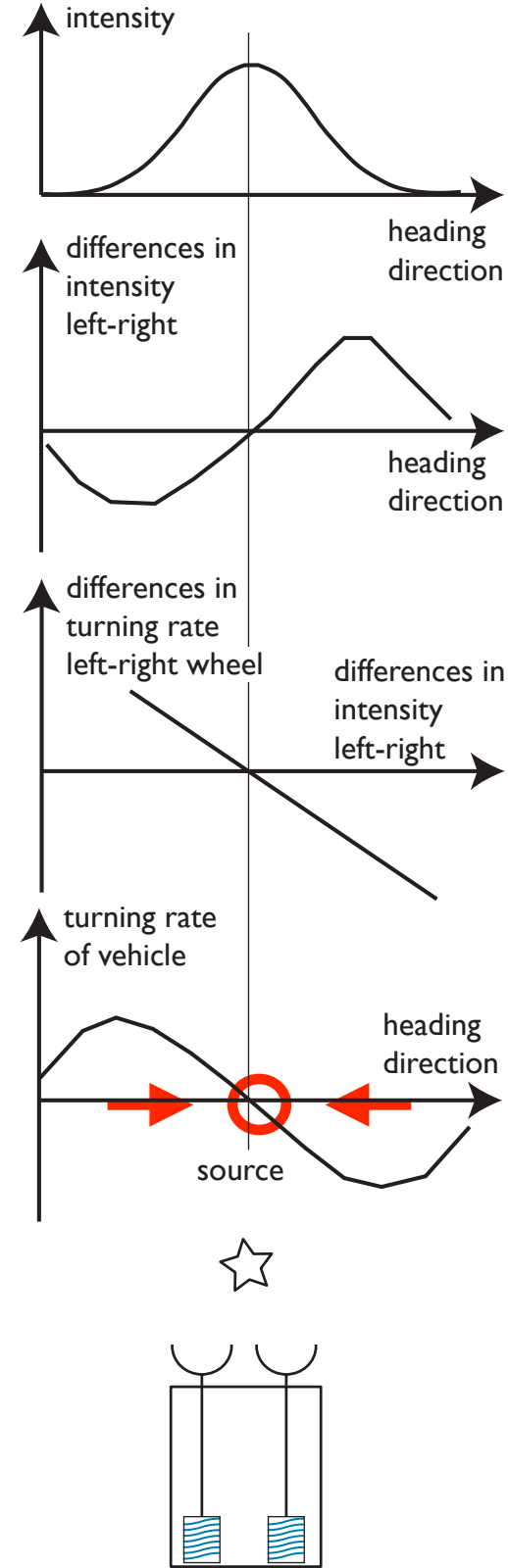




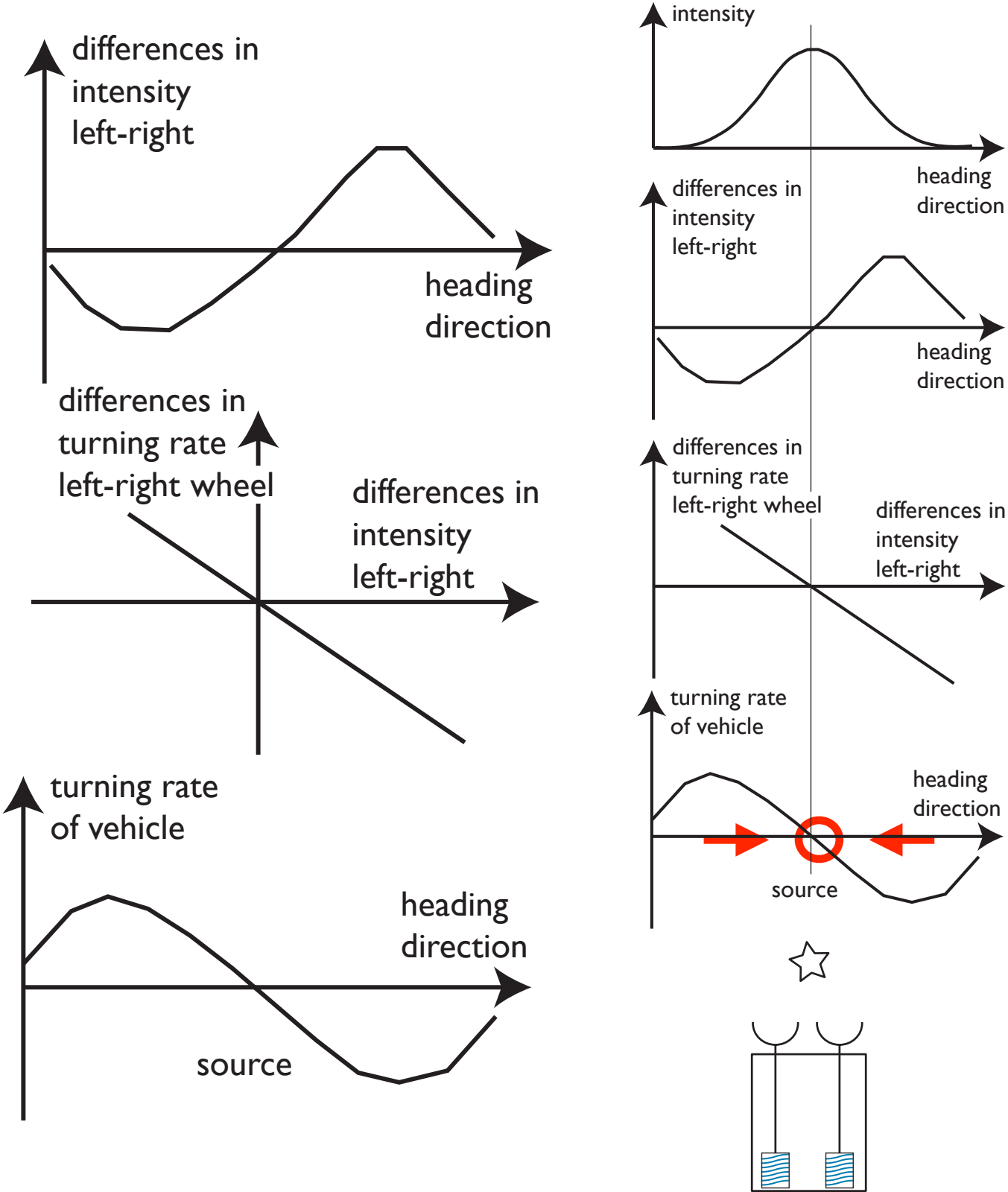


Derivation


intensity
heading
direction
differences in
intensity
left-right
heading
direction


intensity
heading
direction
differences in
intensity
left-right
heading
direction
differences in
turning rate
left-right wheel
differences in
intensity
left-right
turning rate
of vehicle
heading
direction
source

Derivation


differences in
intensity
left-right
heading
direction
differences in
turning rate
left-right wheel
differences in
intensity
left-right
turning rate
of vehicle
heading
direction
source
intensity
heading
direction
differences in
intensity
left-right
heading
direction
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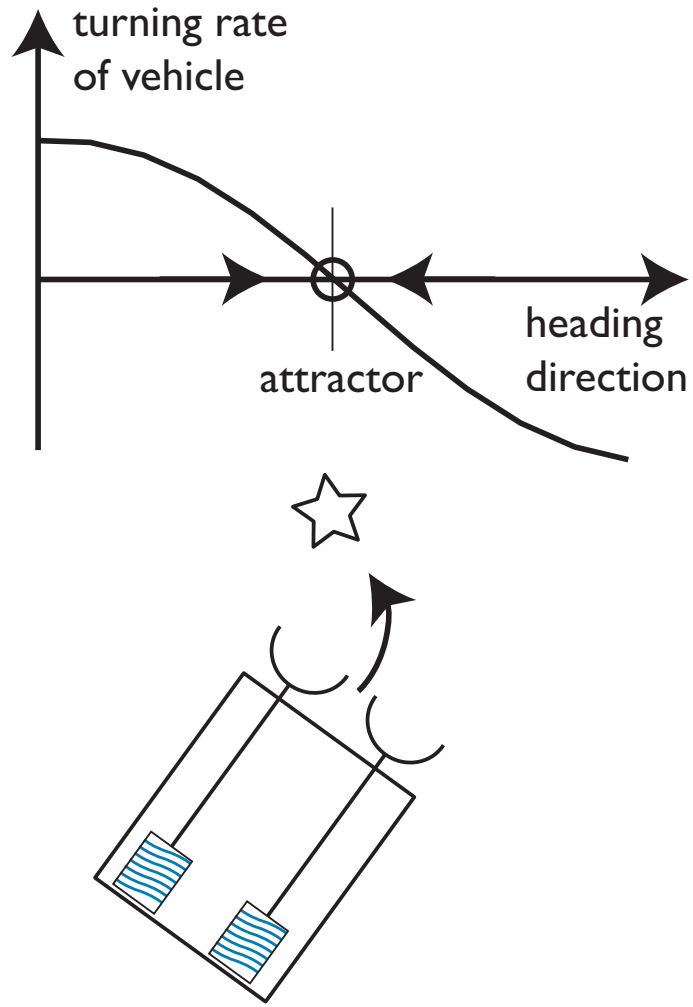
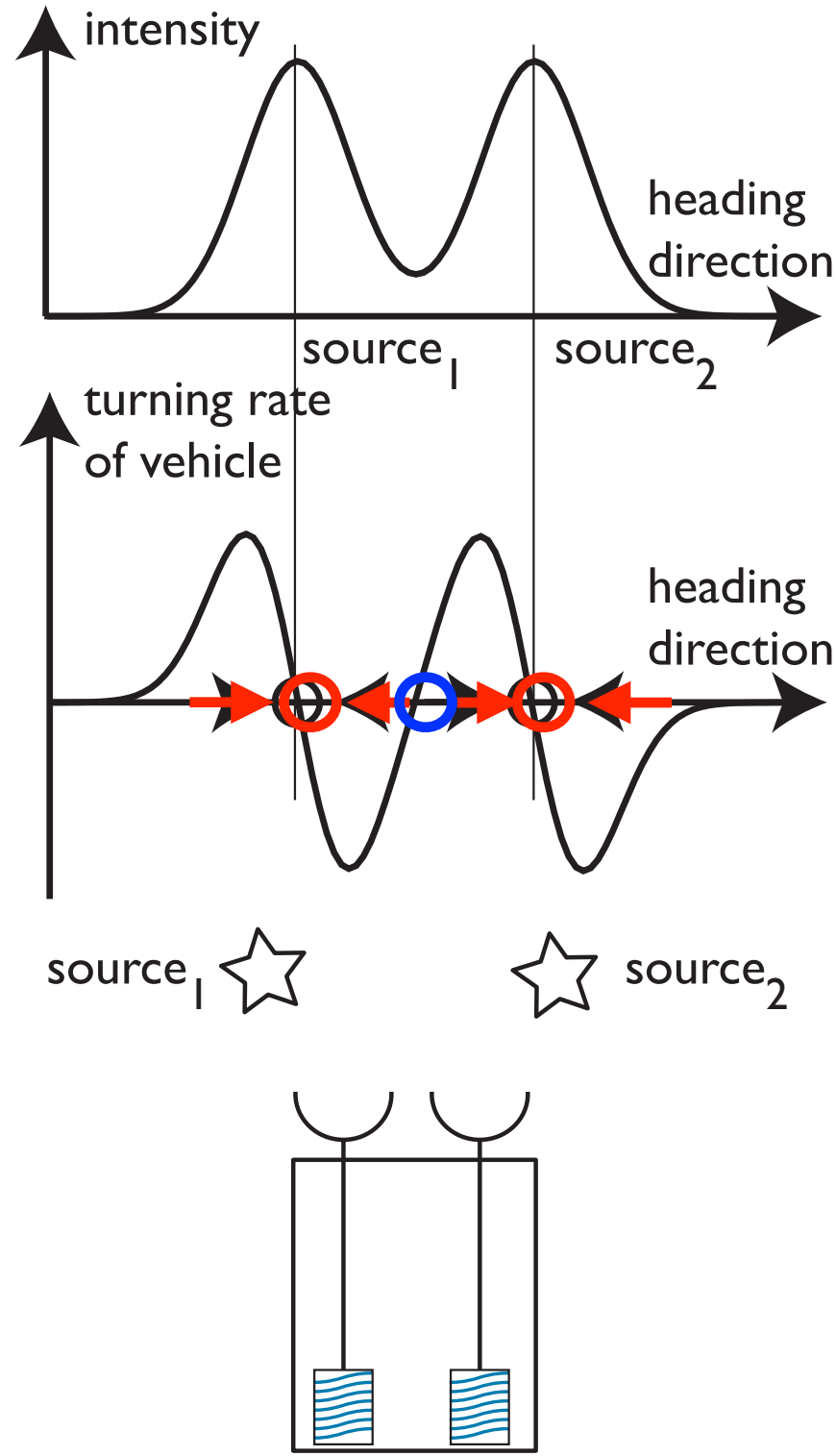
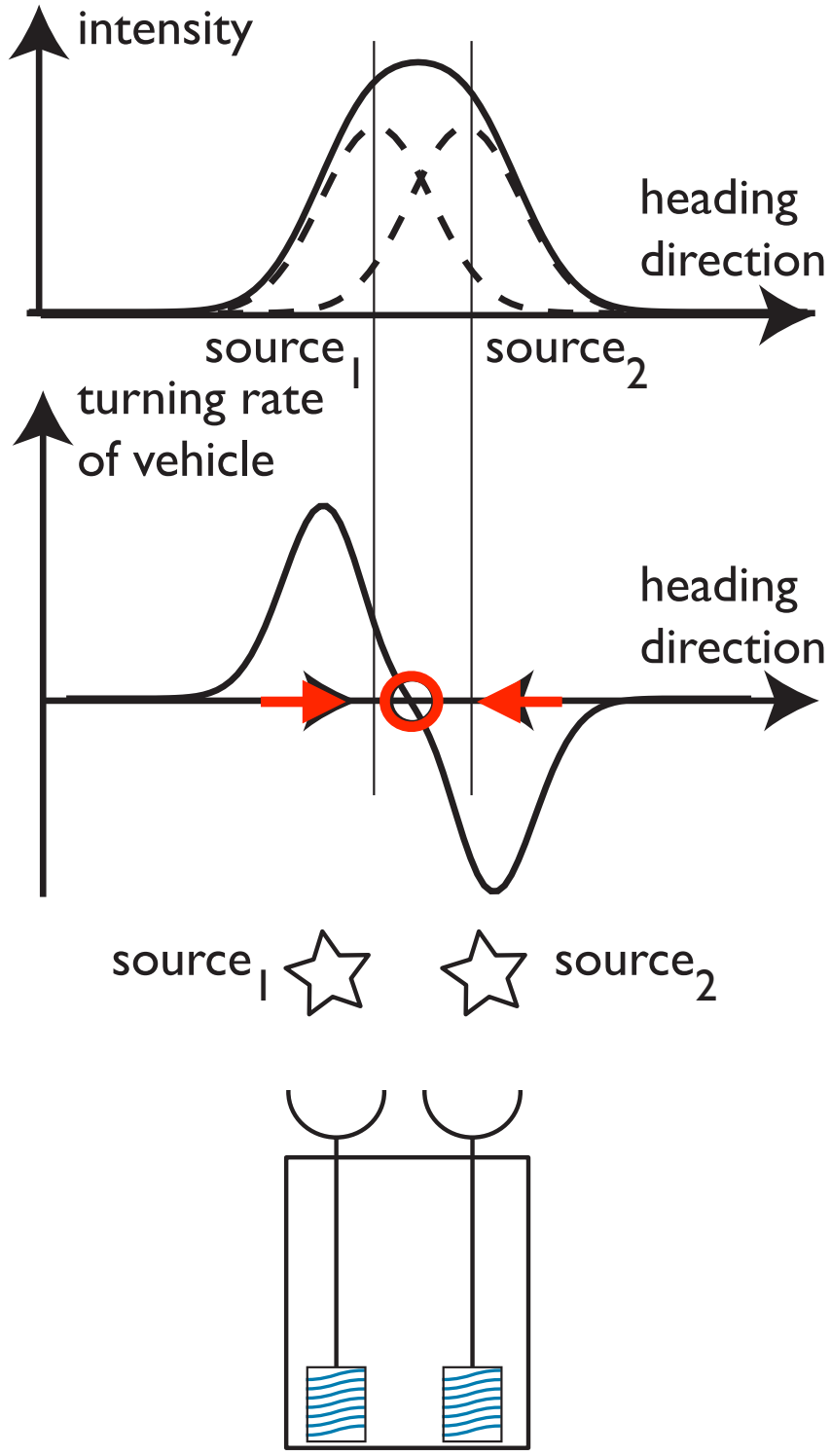


Complex environment => complex dynamics

- bistable dynamics for bimodal intensity distribution
- => nonlinear dynamics makes selection decision



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



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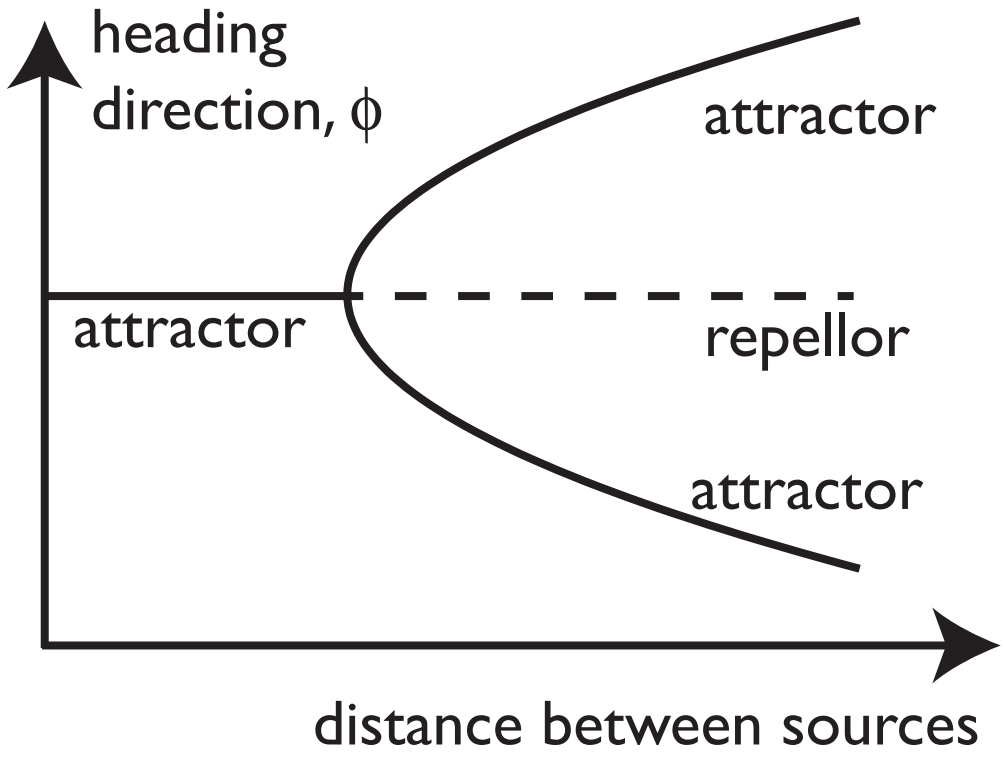
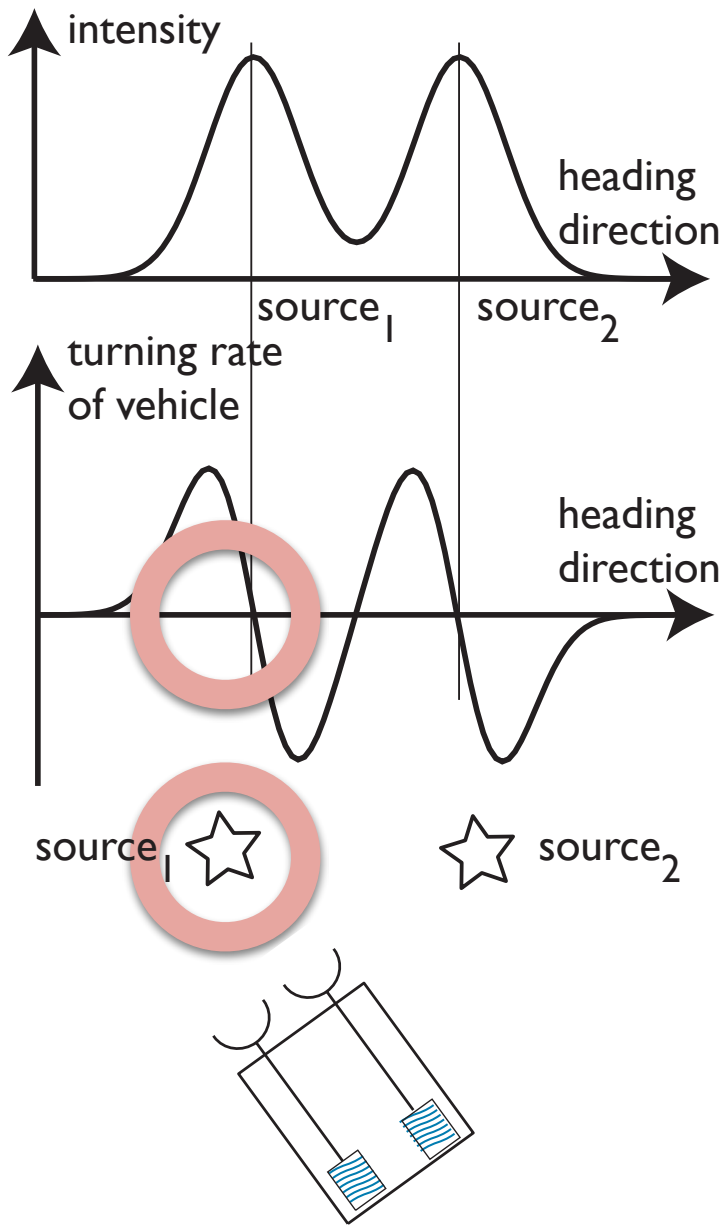


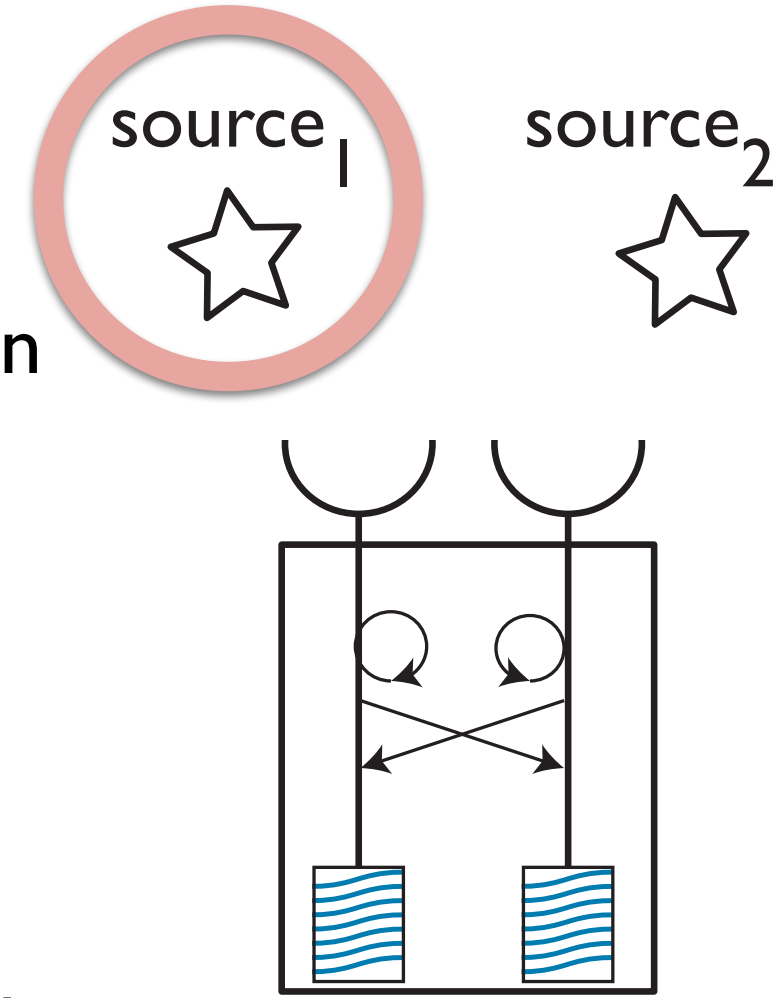
Beyond behavioral dynamics …

- 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



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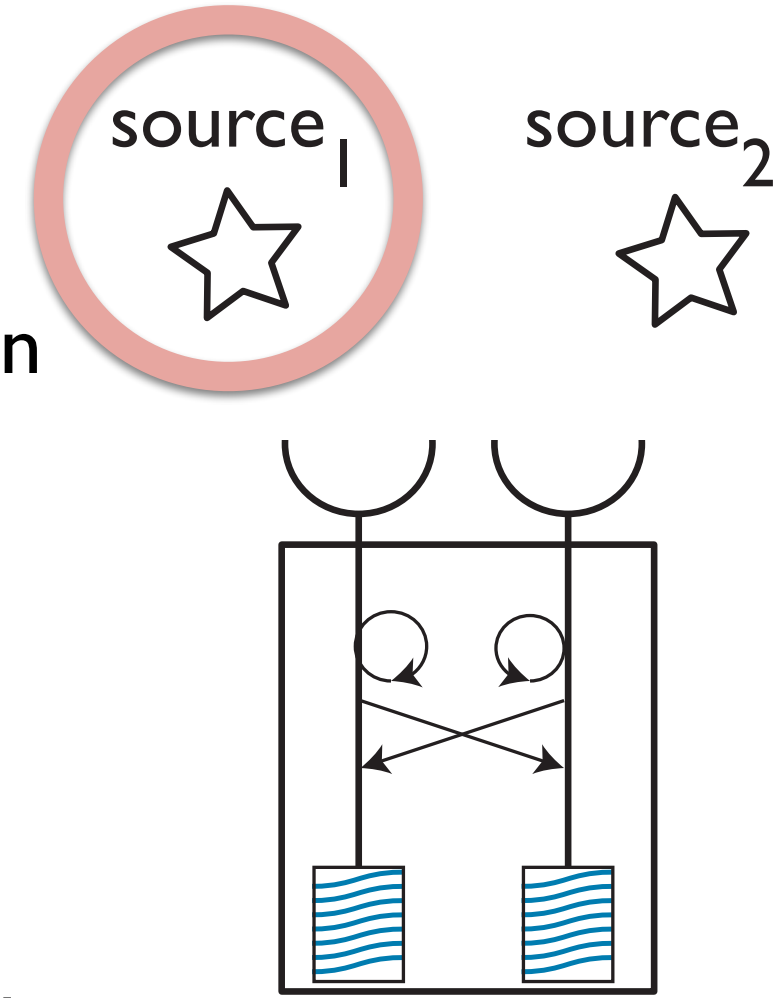
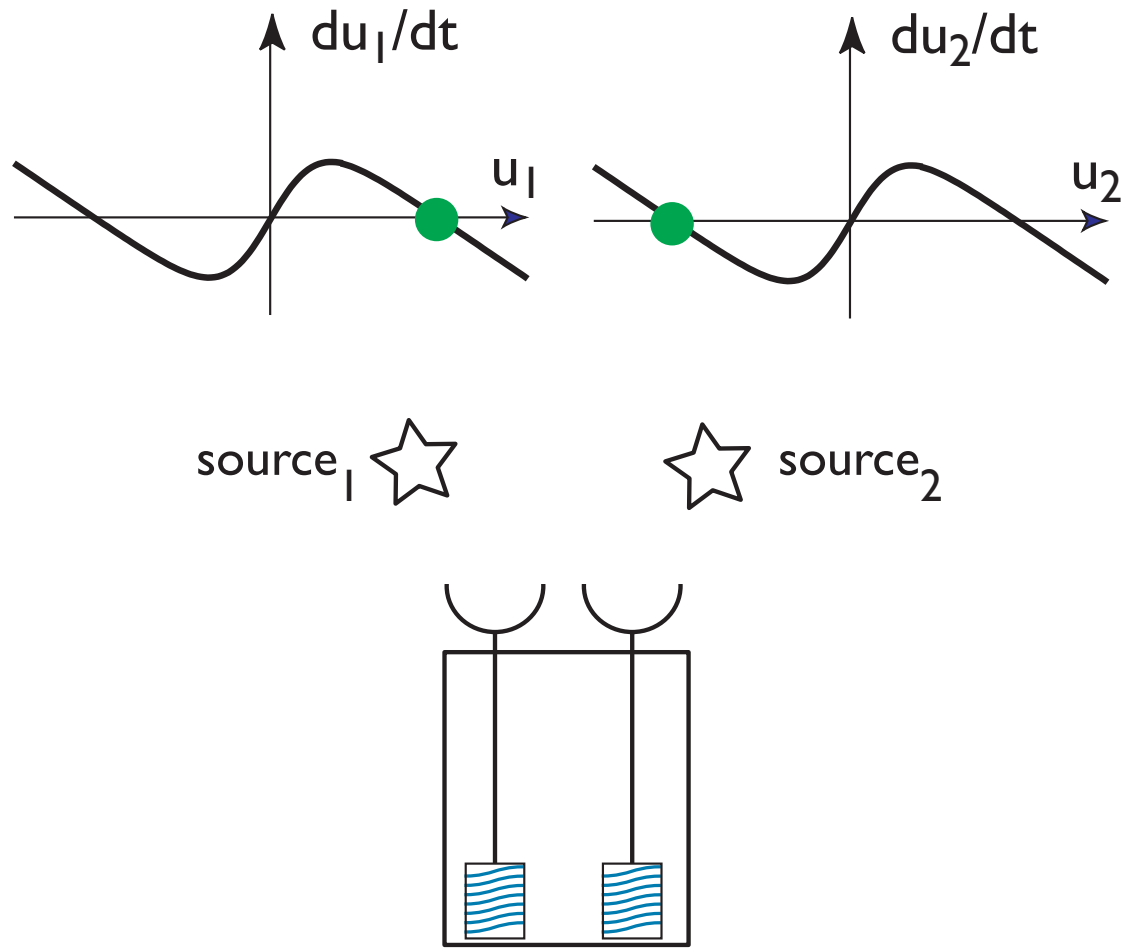


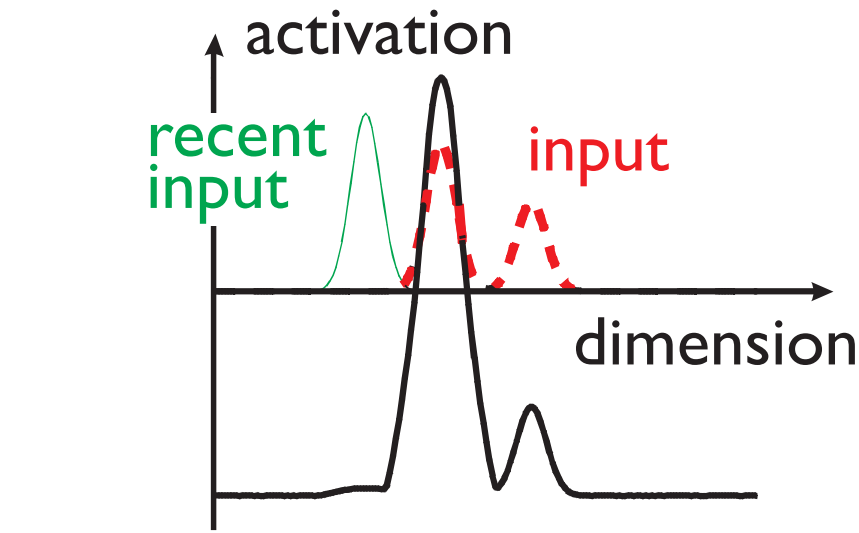
Beyond behavioral dynamics …

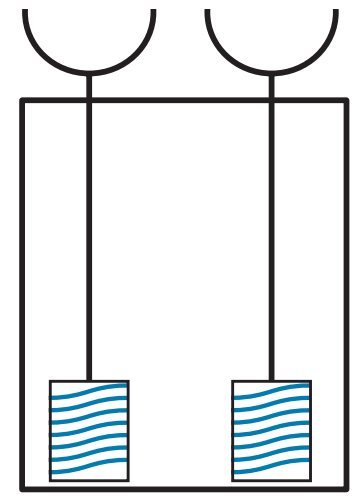
- neural state in the neural network: activation concept
- activation dynamics
- competitive/selective



Beyond behavioral dynamics …

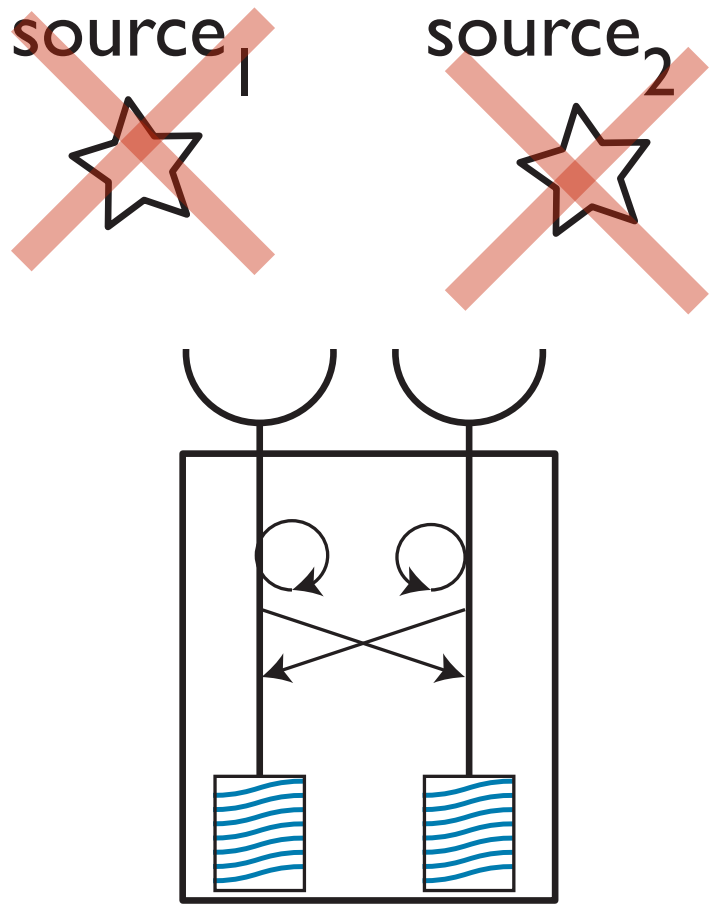
- neural activation field to represent continuous of possible target orientations





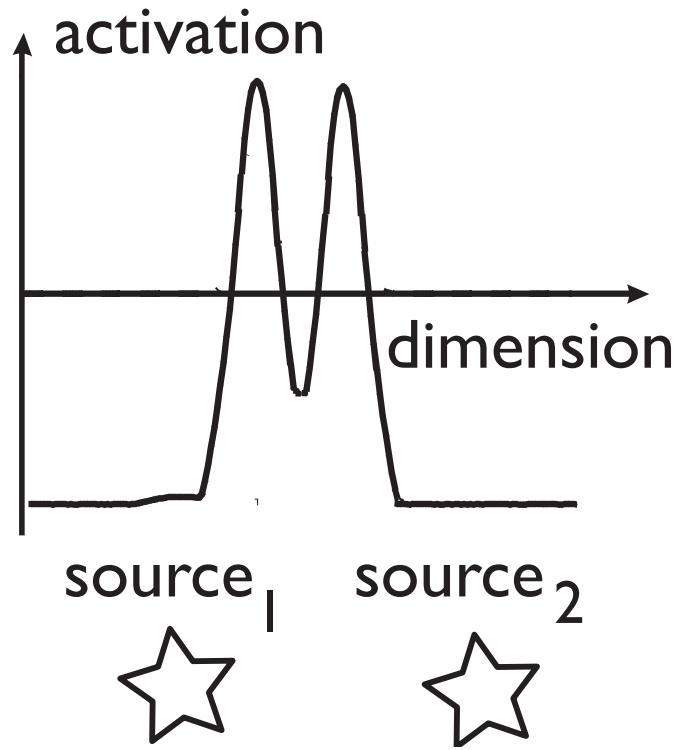
Beyond behavioral dynamics …

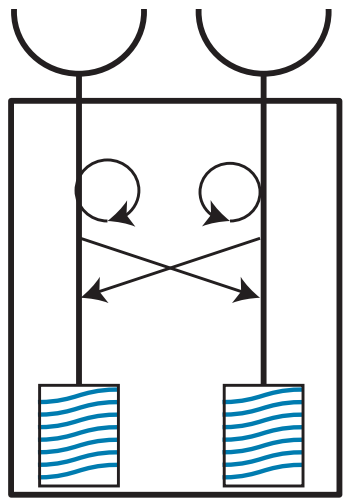
- or we want the system to be able to act on the sources after the external sources of stimulation are removed…
- => working memory
- need to store the state of that sensory representation in the neural network



Beyond behavioral dynamics …

- store the state of the representation in a neural field as a pattern of sustained activation





Next…

- neural dynamics