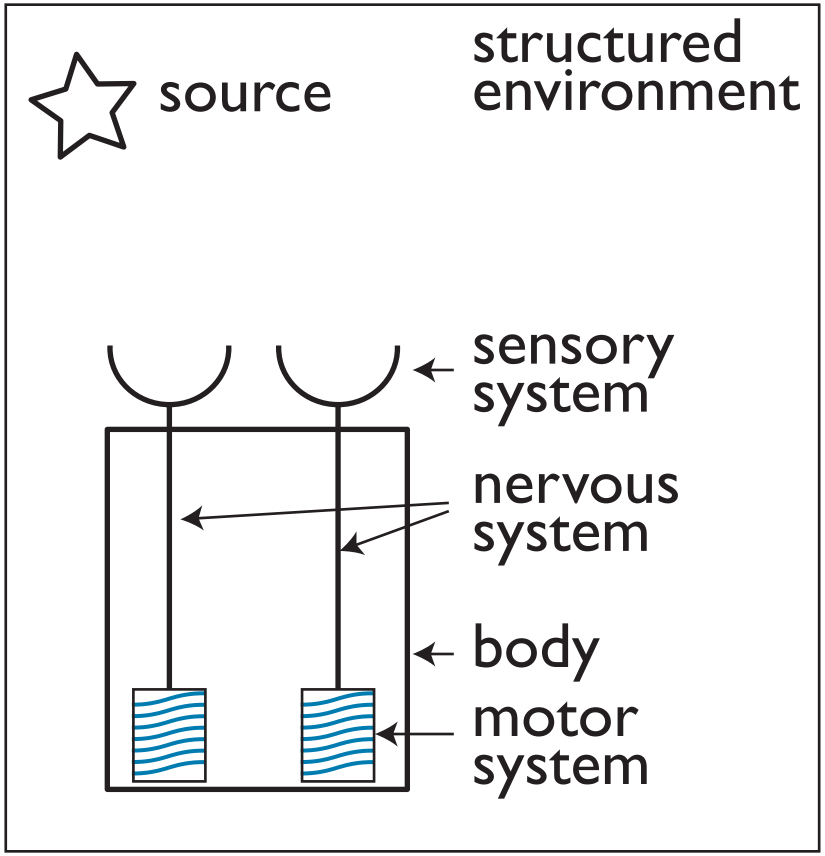
Embodied nervous systems

Gregor Schöner

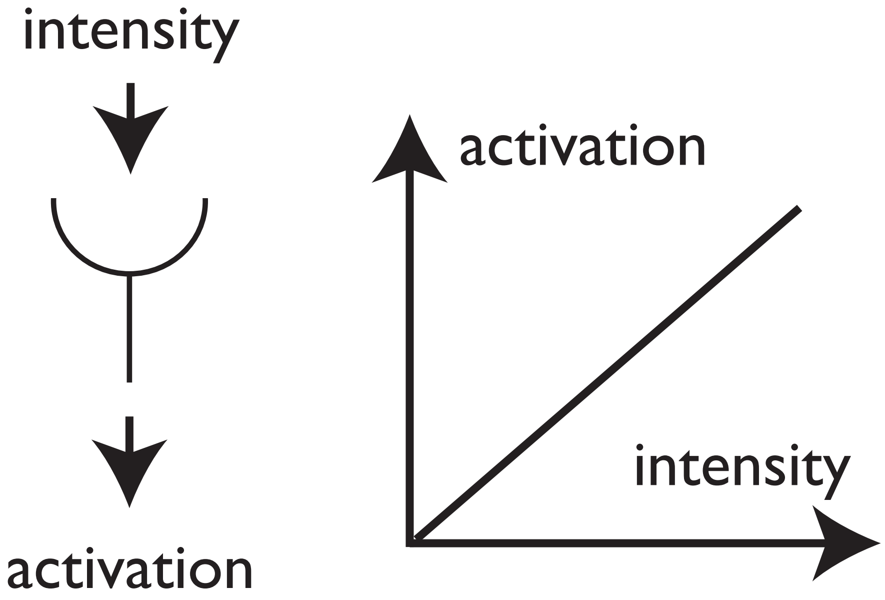
Braitenberg vehicles

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


source
structured environment
sensory system
nervous system
body
motor system

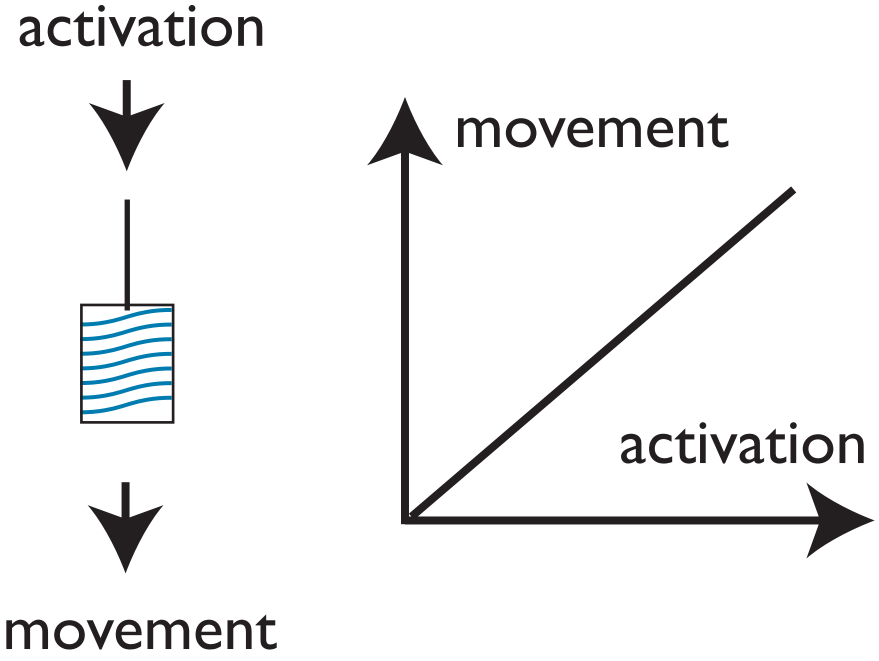
Sensors

- 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”


intensity
activation
activation
intensity

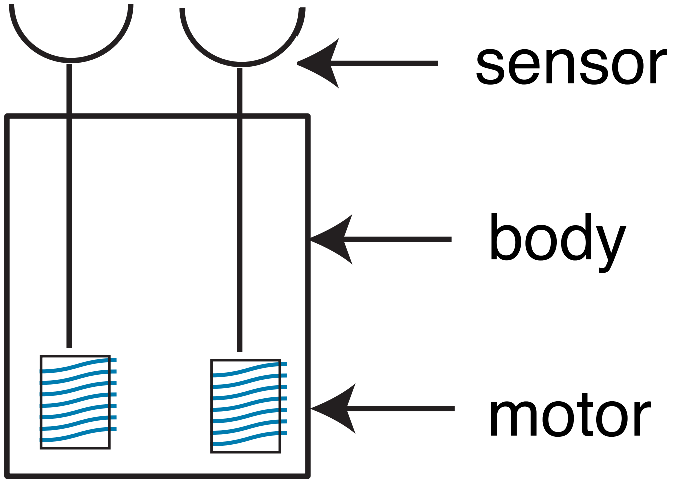
Effectors

- 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, …)


activation
movement
movement
activation

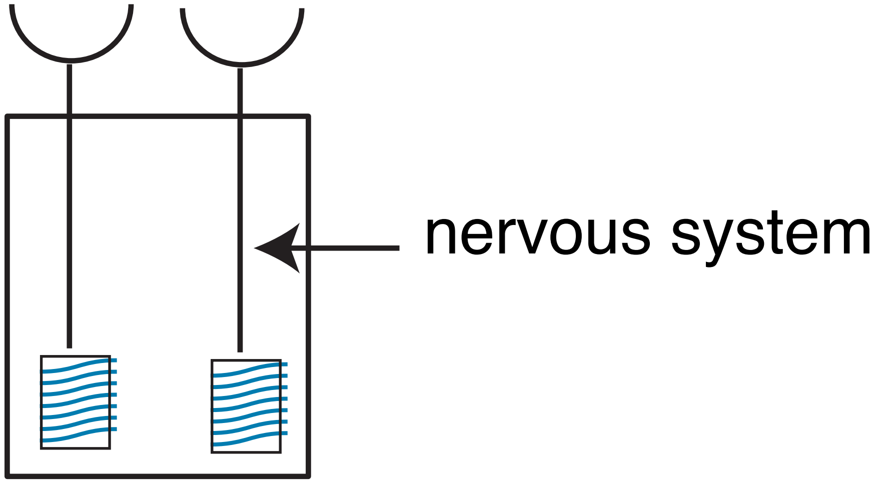
Body

- mechanically links the sensors to effectors

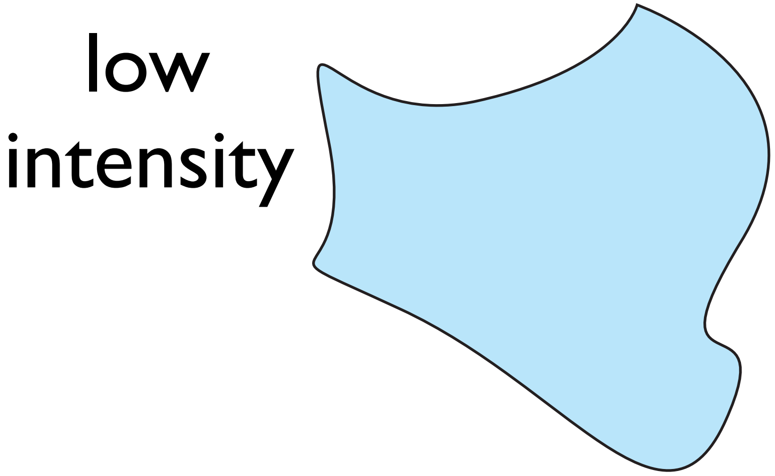

sensor
body
motor

Nervous system

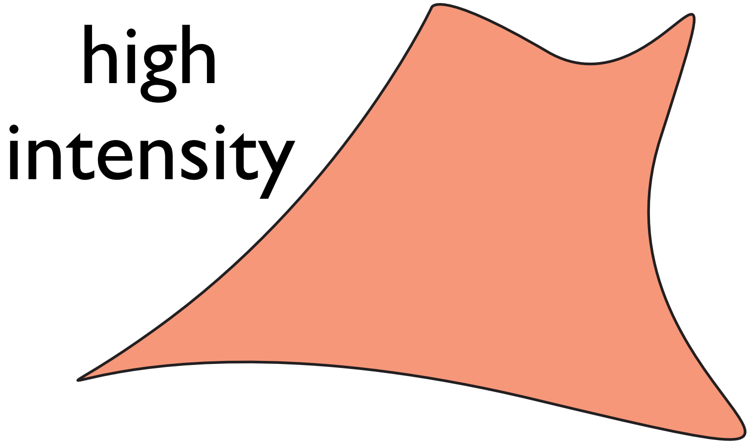
- links sensors to effectors through the inner activation state


nervous system

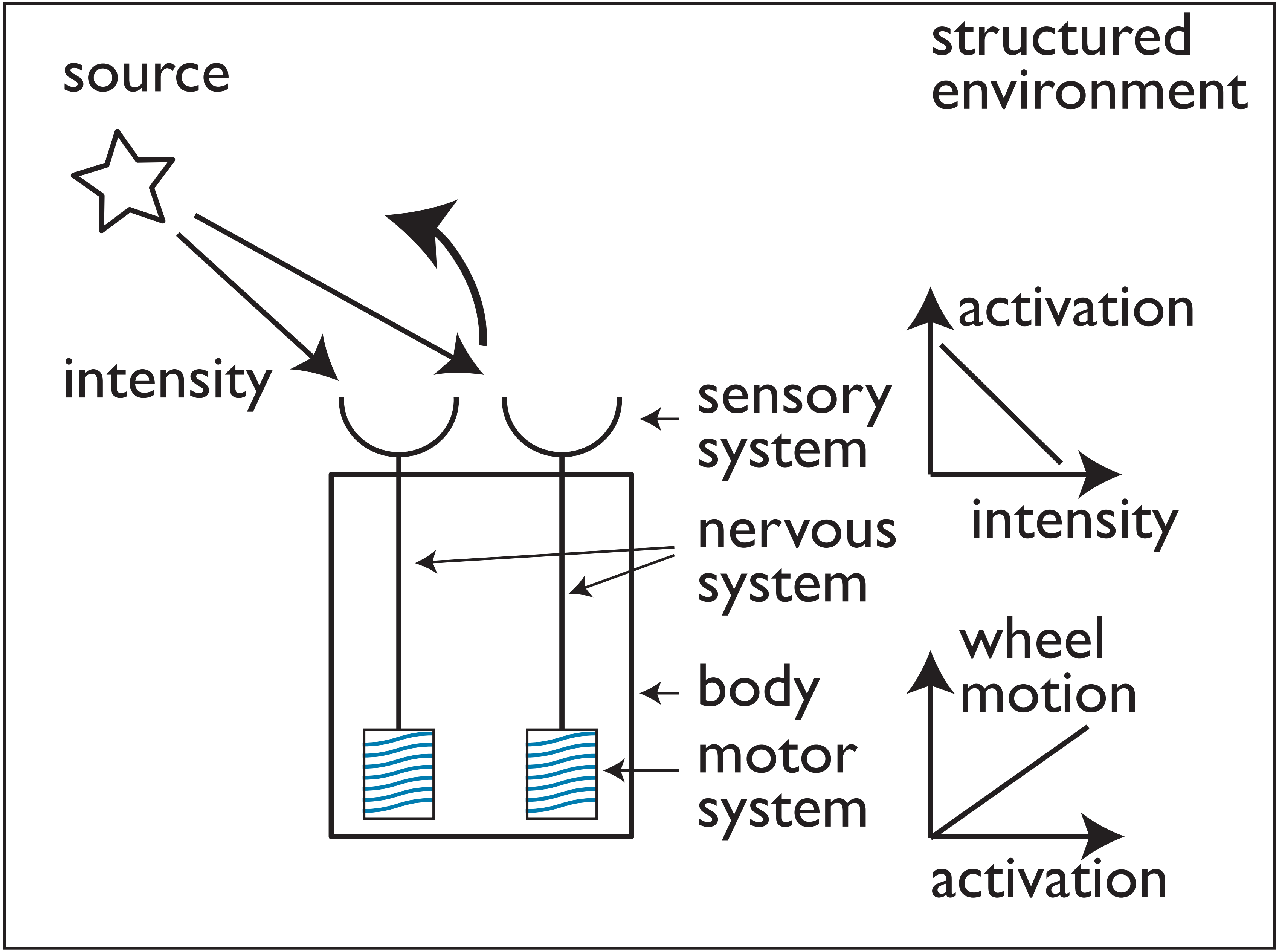
Environment


low
intensity

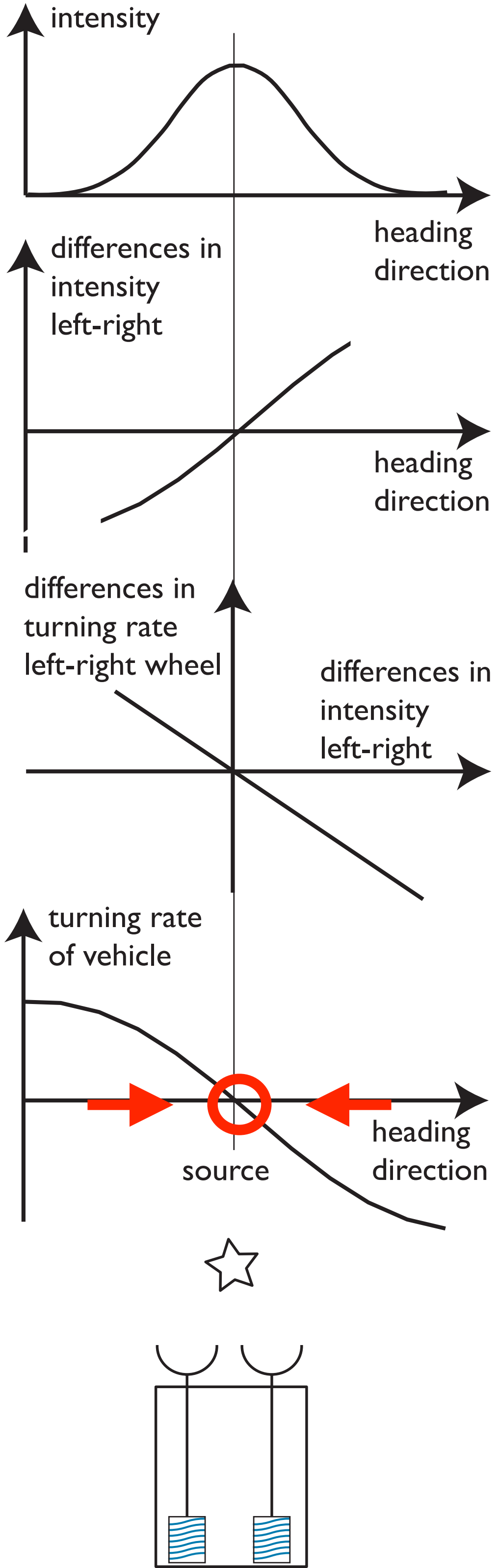
- is structured at a relevant scale in terms of the physical variables to which organism is sensitive


high
intensity

Emergent behavior: taxis


structured
environment
source
intensity
sensory
system
nervous
system
body
motor
system
activation
intensity
wheel
motion
activation

Behavior emerges as the solution of a dynamical system


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
source
heading direction

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

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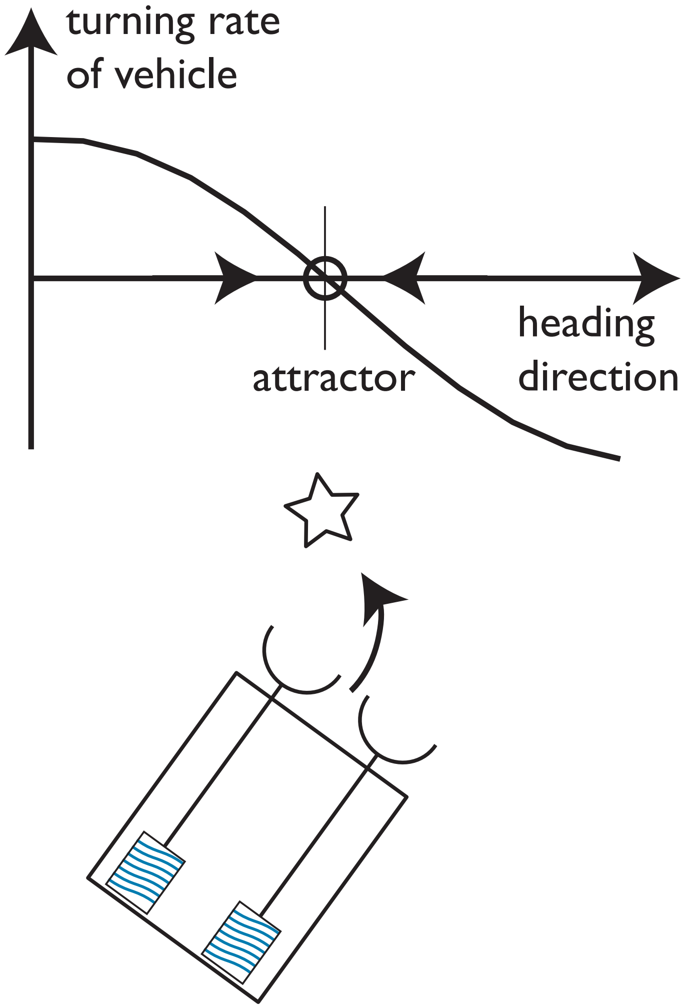
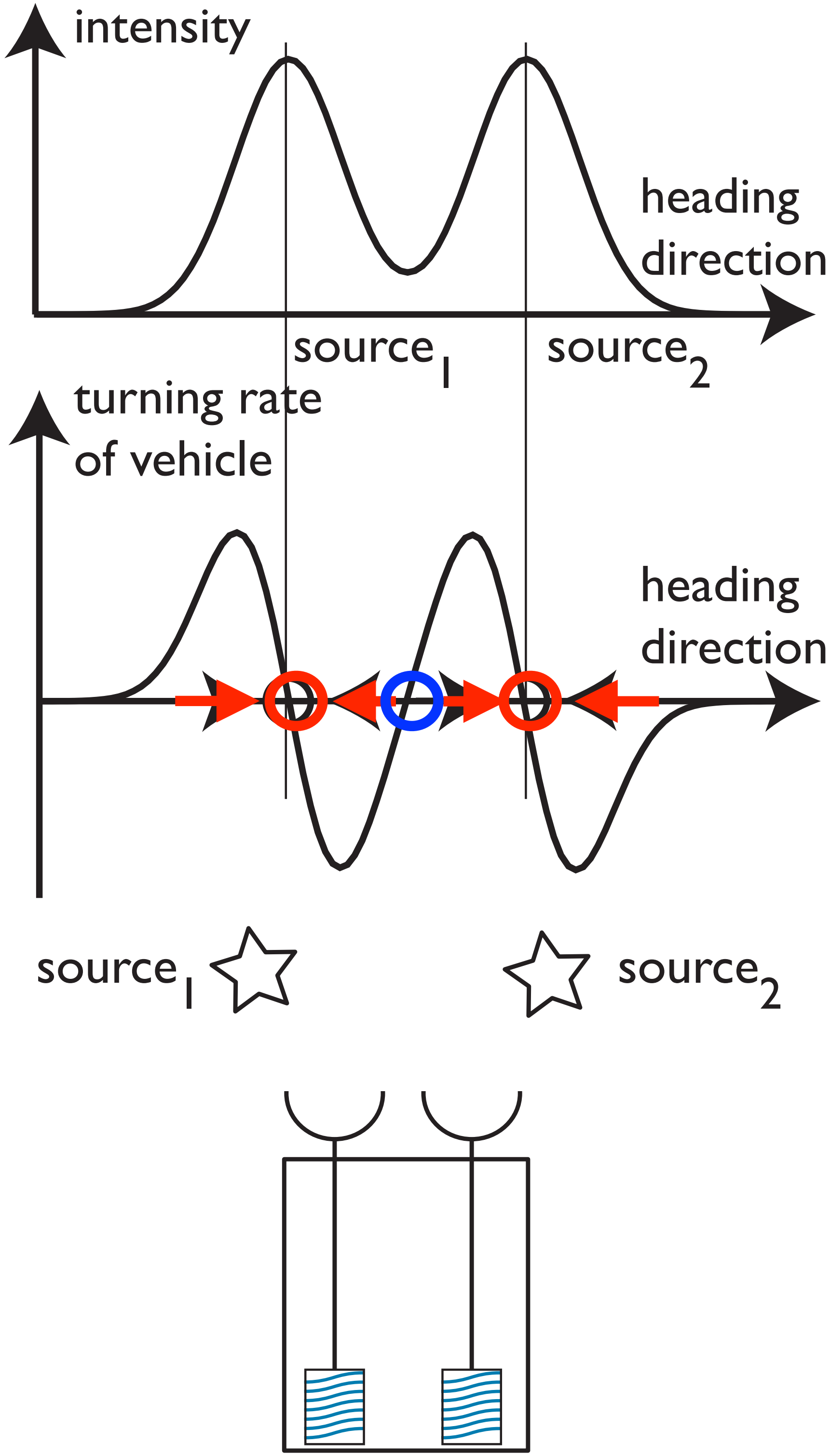
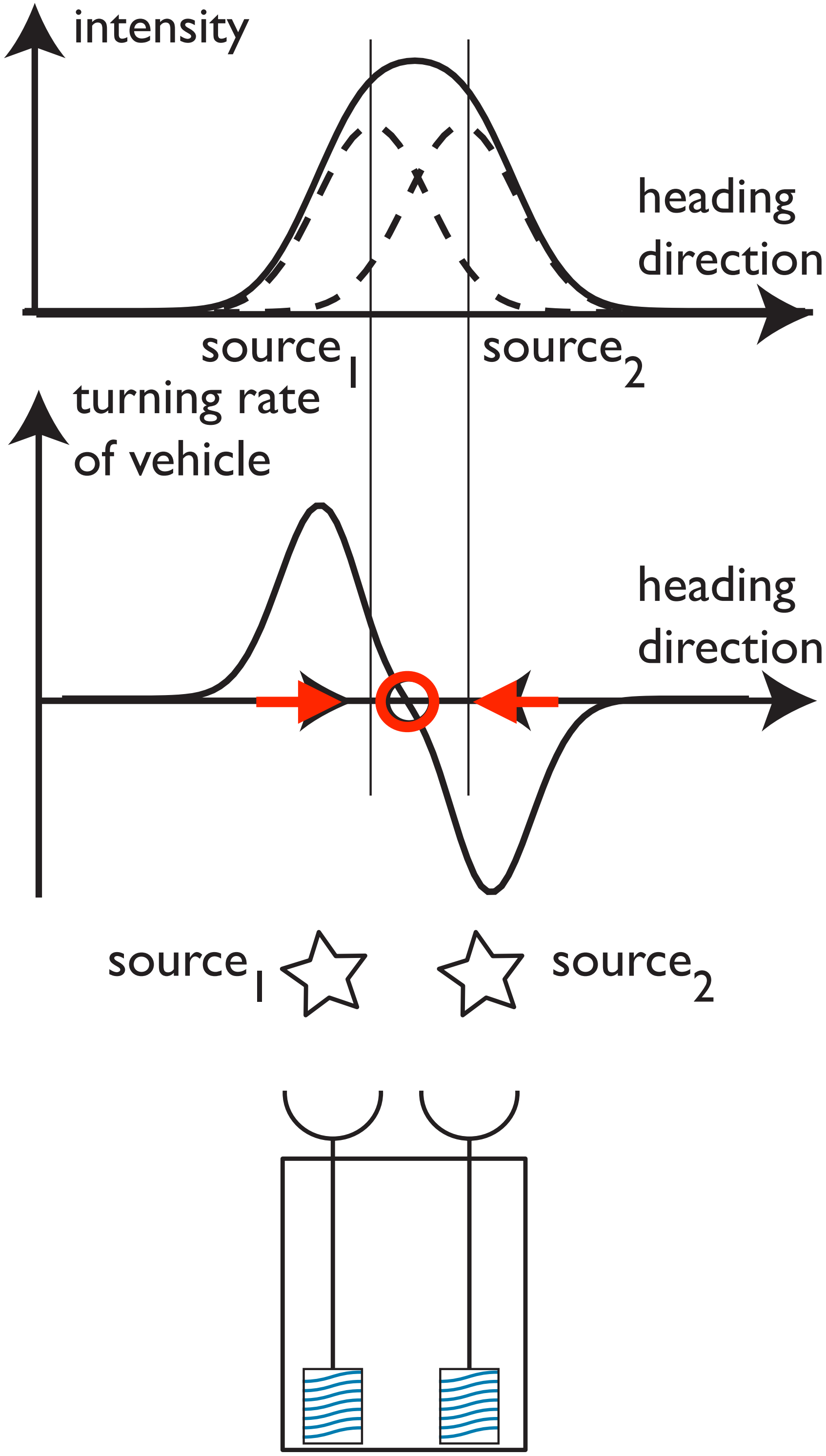

turning rate
of vehicle
attractor
heading
direction

Complex environment => complex dynamics

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


intensity
heading direction
source$_1$
source$_2$
turning rate of vehicle
heading direction
source$_1$
source$_2$


intensity
heading direction
source$_1$
source$_2$
turning rate of vehicle
heading direction
source$_1$
source$_2$

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

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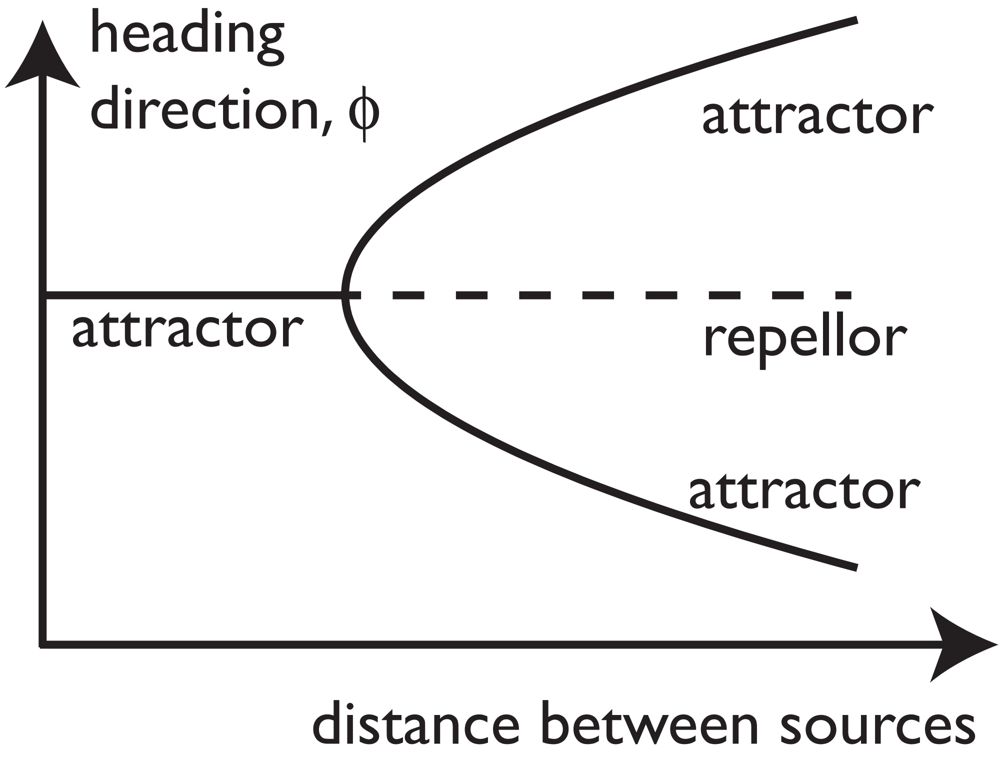
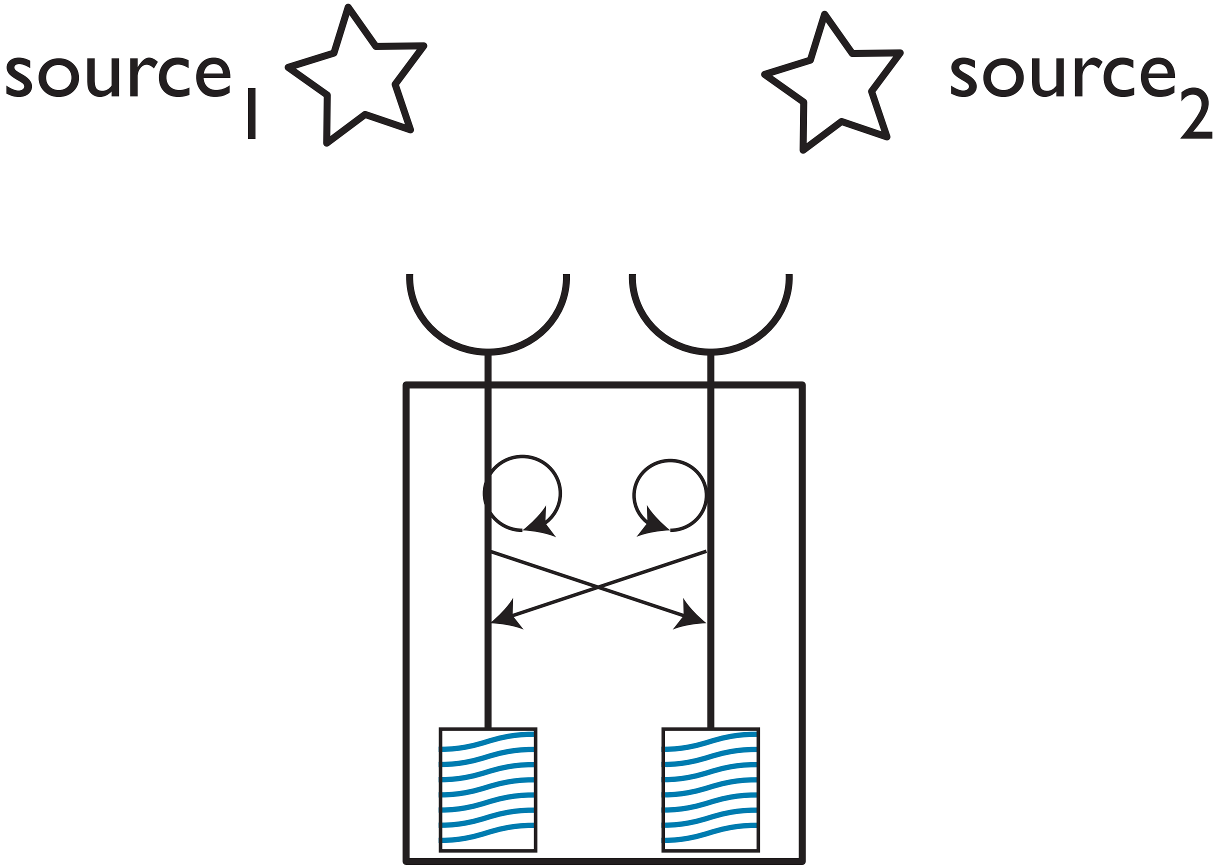
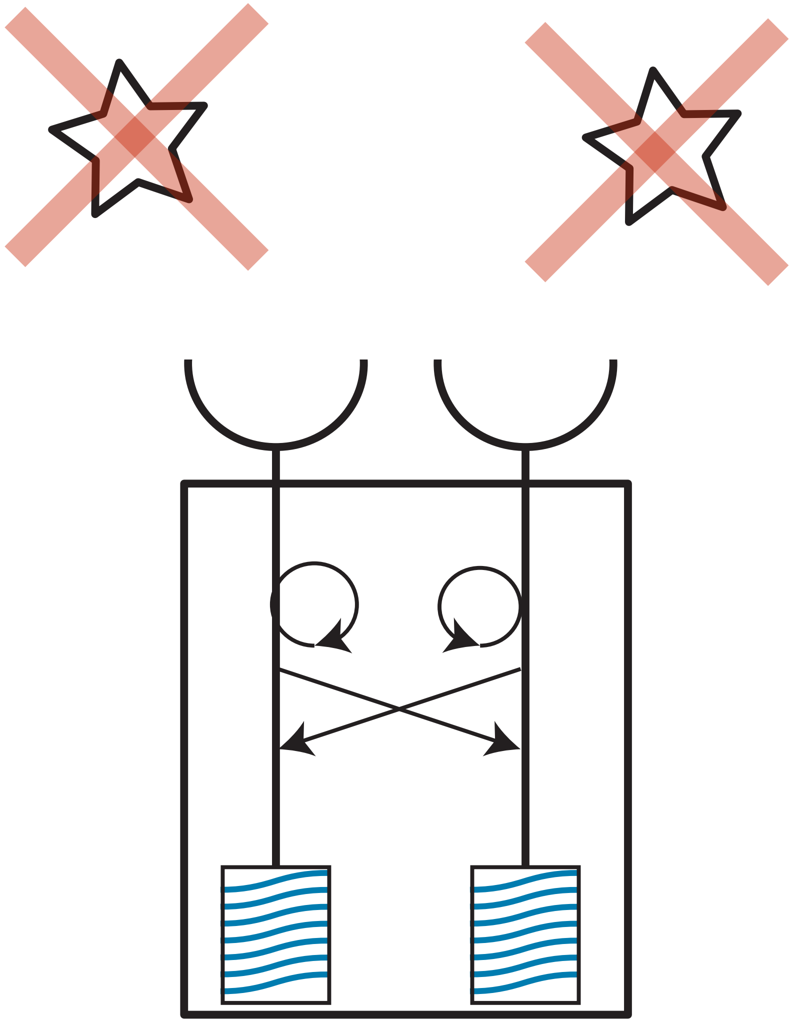

heading direction, ϕ
attractor
attractor
repellor
attractor
distance between sources

Beyond sensory-motor cognition…

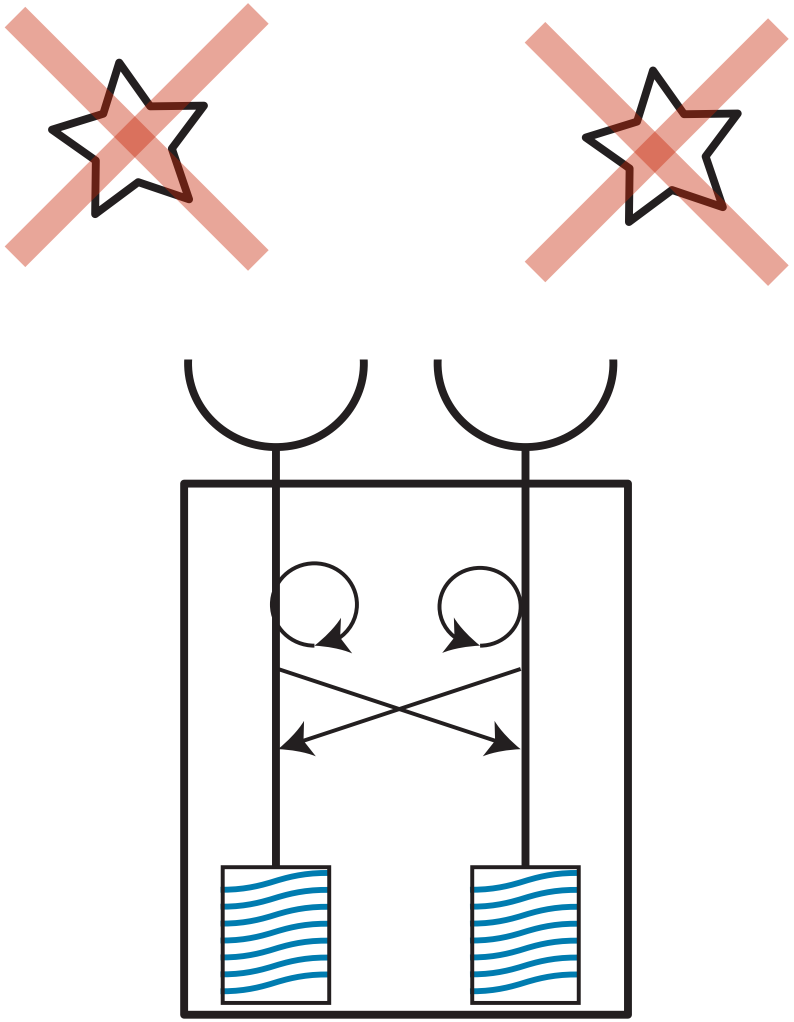

$source_1$
$source_2$

Beyond sensory-motor cognition…



Beyond sensory-motor cognition…

- if sensory information about source not always available on the sensory surface
- => working memory
- need "inner state" that is independent of body or sensors:
- => activation



Braitenberg vehicles

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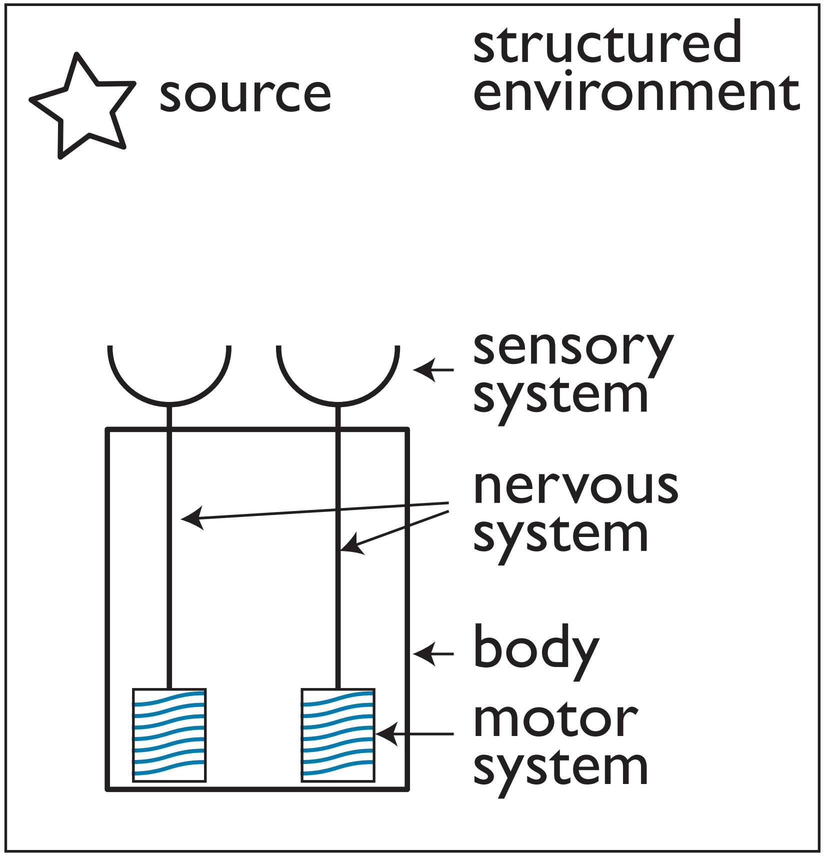
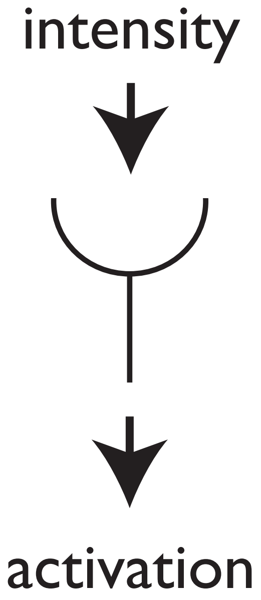
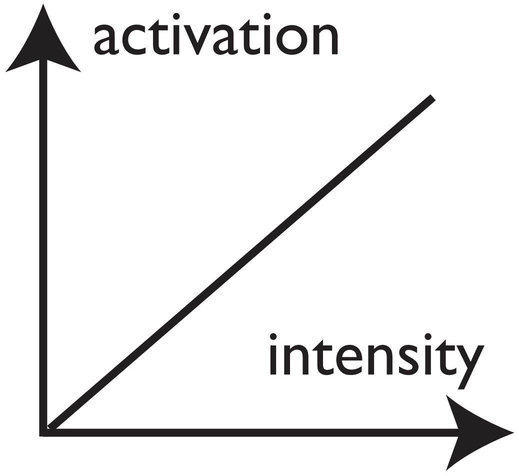
    - sensors
    - a nervous system
    - a body
- + situated in a structured environment
- = emergent function


source
structured environment
sensory system
nervous system
body
motor system

Sensors

- defined by sensor characteristic =relationship between
- the physical stimulus intensity
  - e.g., sound, luminance, chemical concentration, mechanical pressure....
- and an activation variable

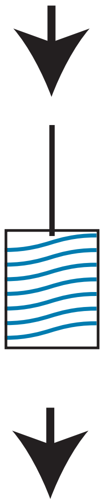

intensity
activation



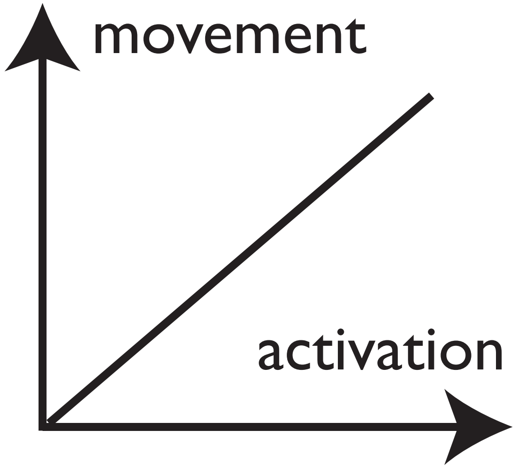
Effectors

- defined by the motor characteristic =functional relationship between
- an activation level
- and a physical effect generated
  - for example: turning rate (rotations per minute rmp), force level, stiffness, ...)

activation

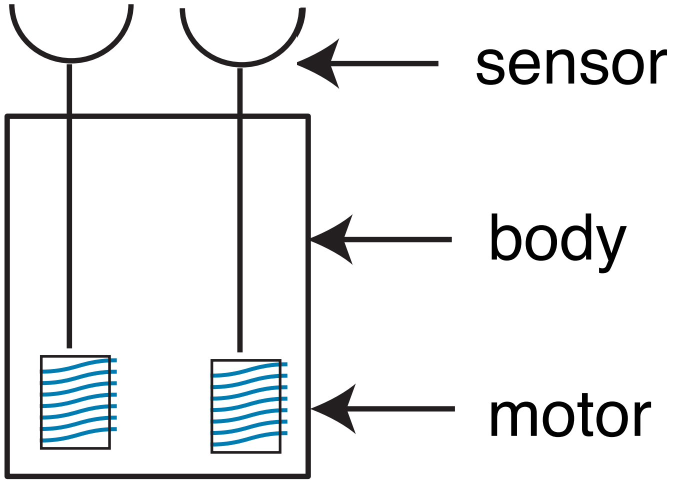


movement



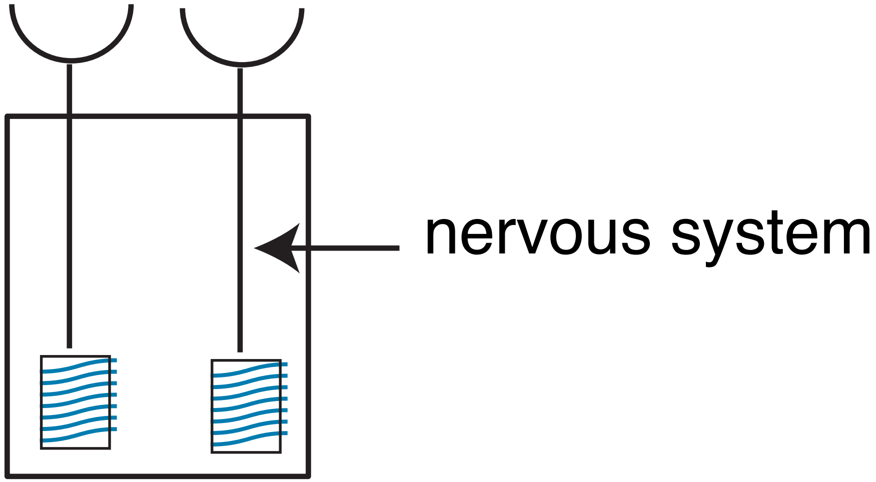
Body

- the body links the sensors and effectors mechanically

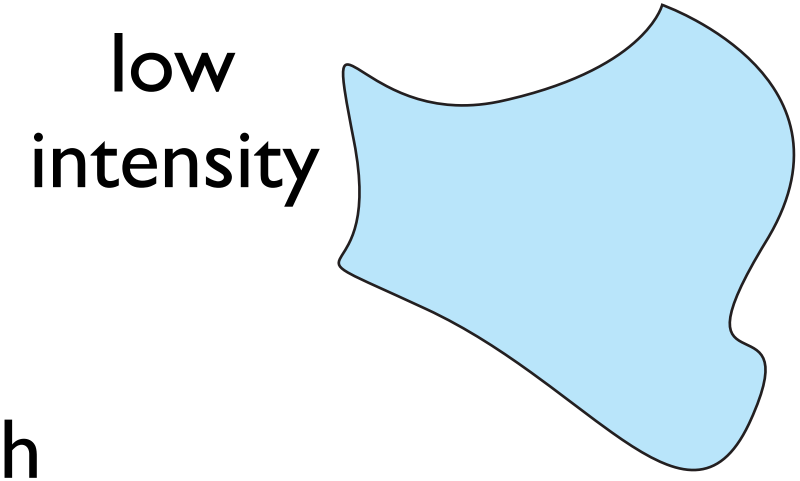

sensor
body
motor

Nervous system

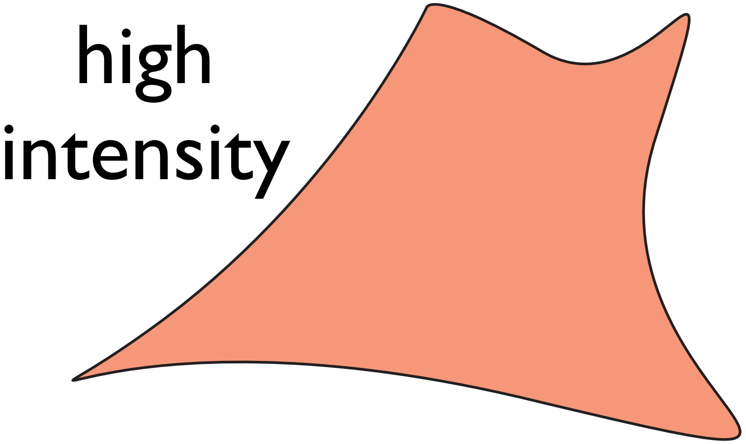
- links sensors to effectors


nervous system

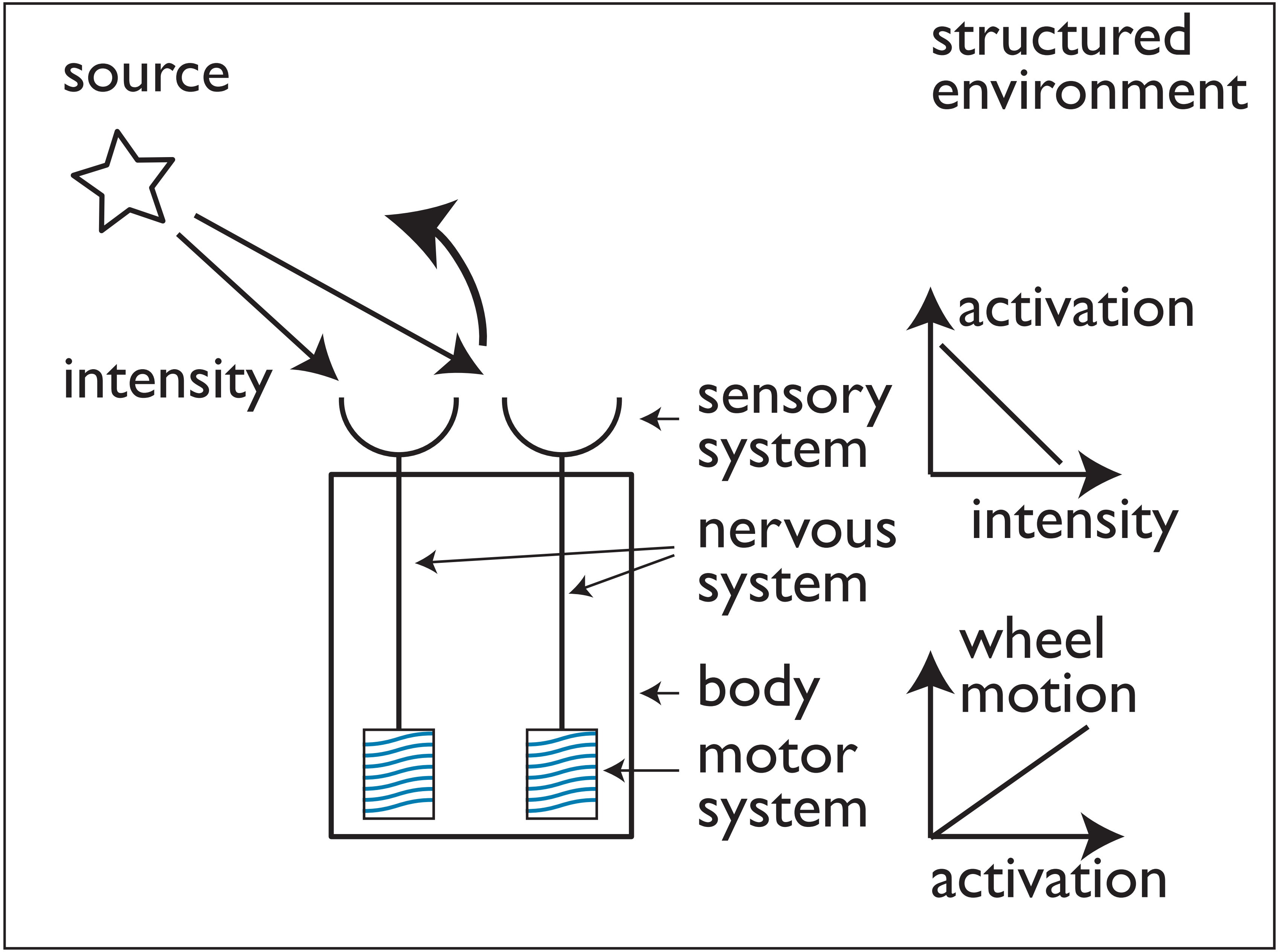
Environment


low
intensity

- non-homogeneous with respect to the physical intensity sensed


high
intensity

Emergent behavior: taxis



source

structured
environment

intensity

sensory
system

nervous
system

body

motor
system

activation

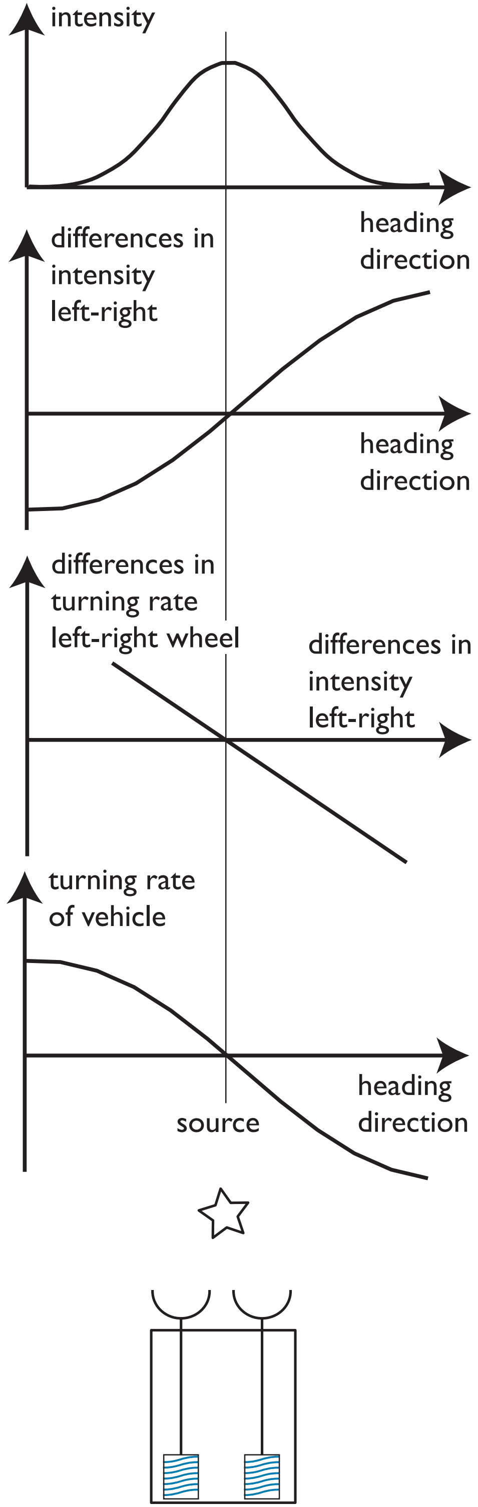
intensity

wheel
motion

activation

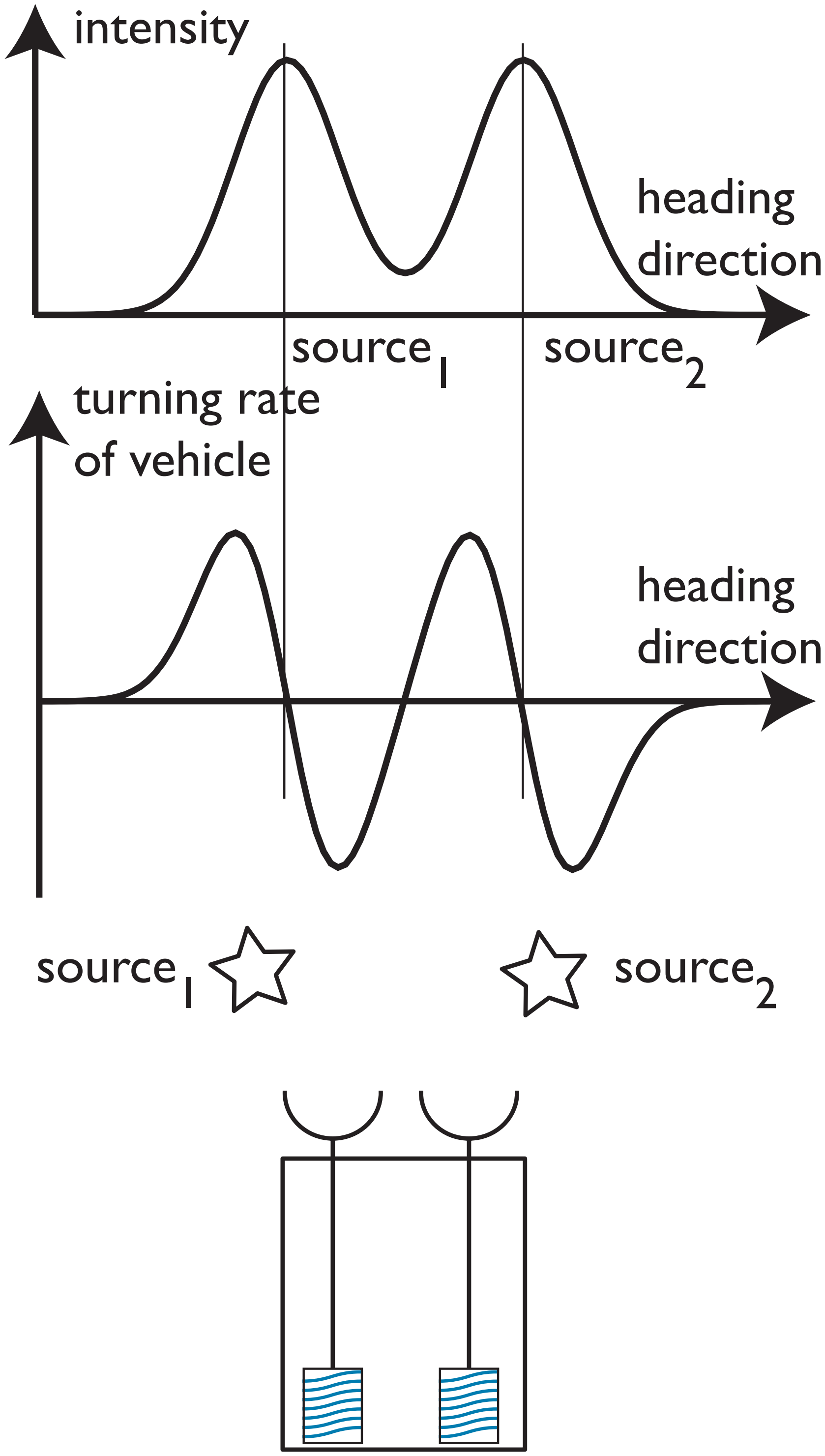
Emergent behavior: this is a dynamics

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


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
source
heading direction

Complex environment => complex dynamics

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


intensity
heading direction
source$_1$
source$_2$
turning rate of vehicle
heading direction
source$_1$
source$_2$

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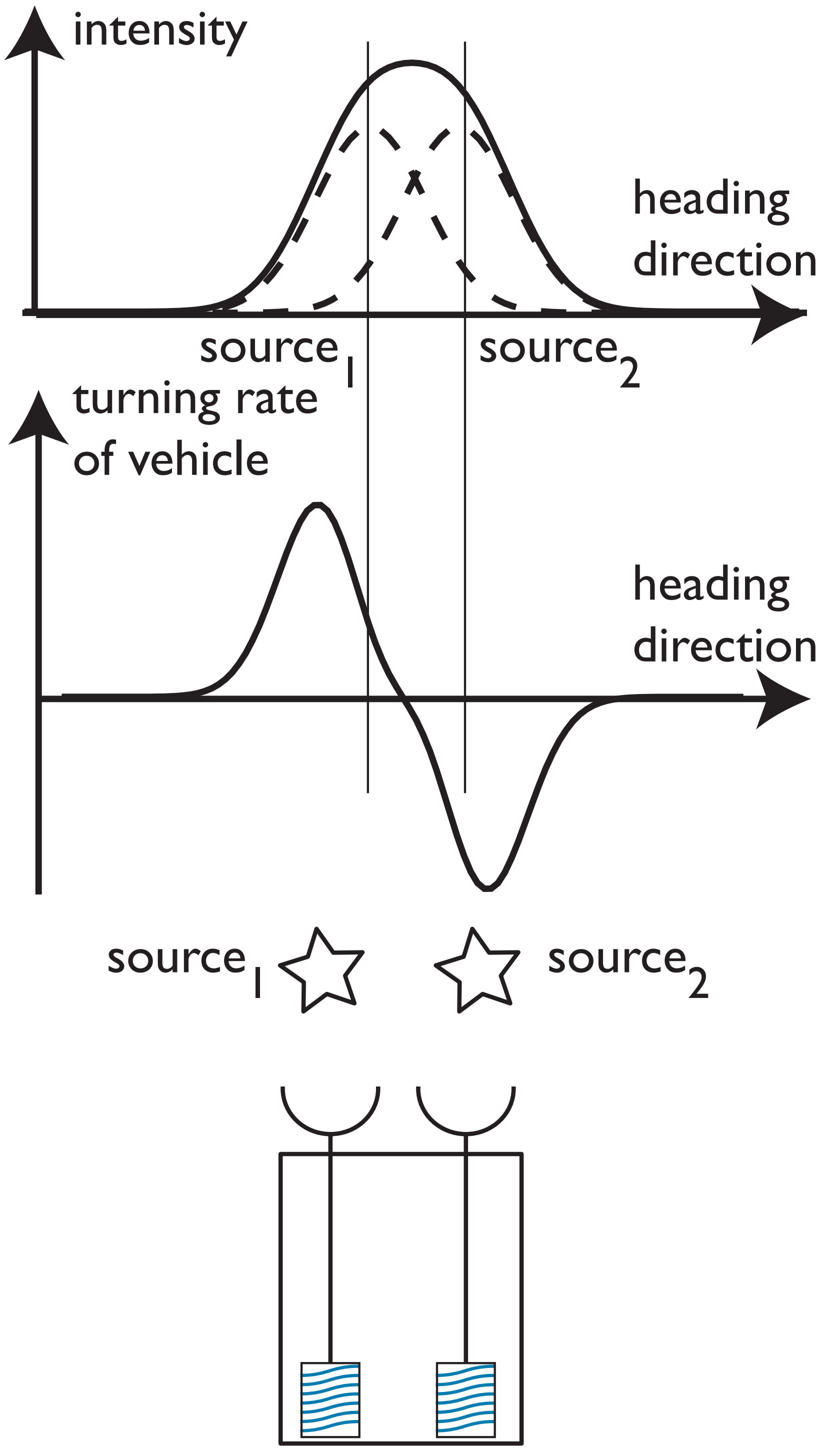
intensity
heading direction
source$_1$
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heading direction
source$_1$
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Complex environment => complex dynamics

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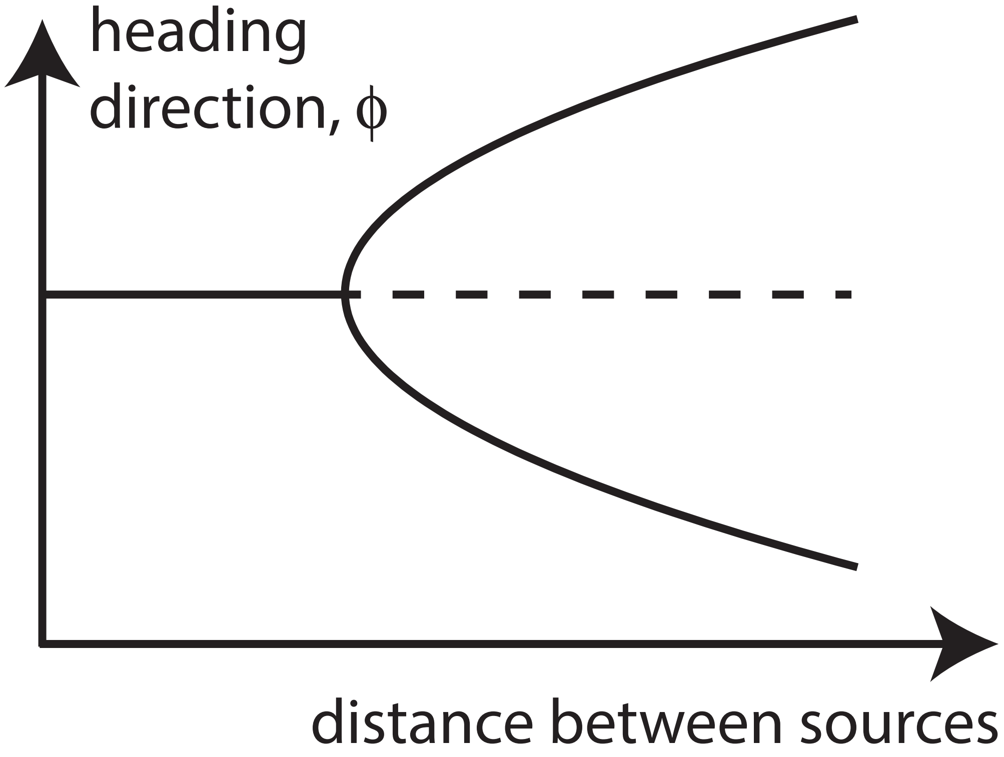
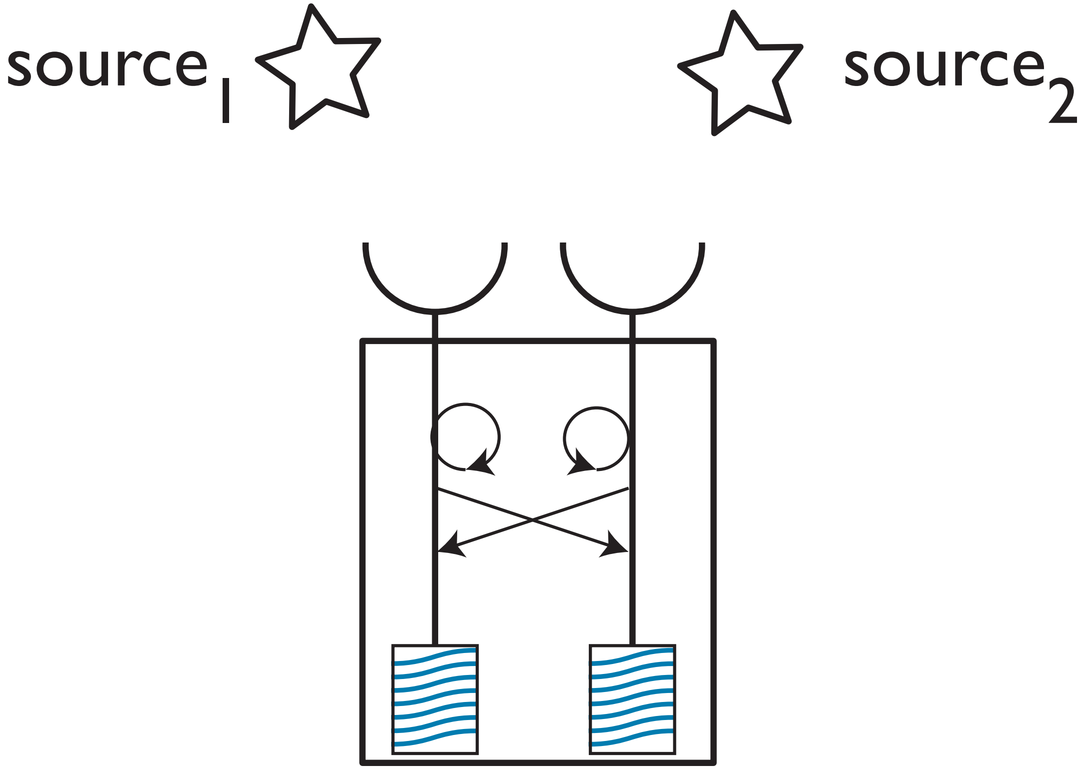

heading direction, ϕ
distance between sources

Internal loops generate neural dynamics


source$_1$
source$_2$

- that generate cognition: internal decisions…
- bifurcations => different cognitive regimes

Internal loops generate neural dynamics

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- need "inner state" that is independent of body or sensors:
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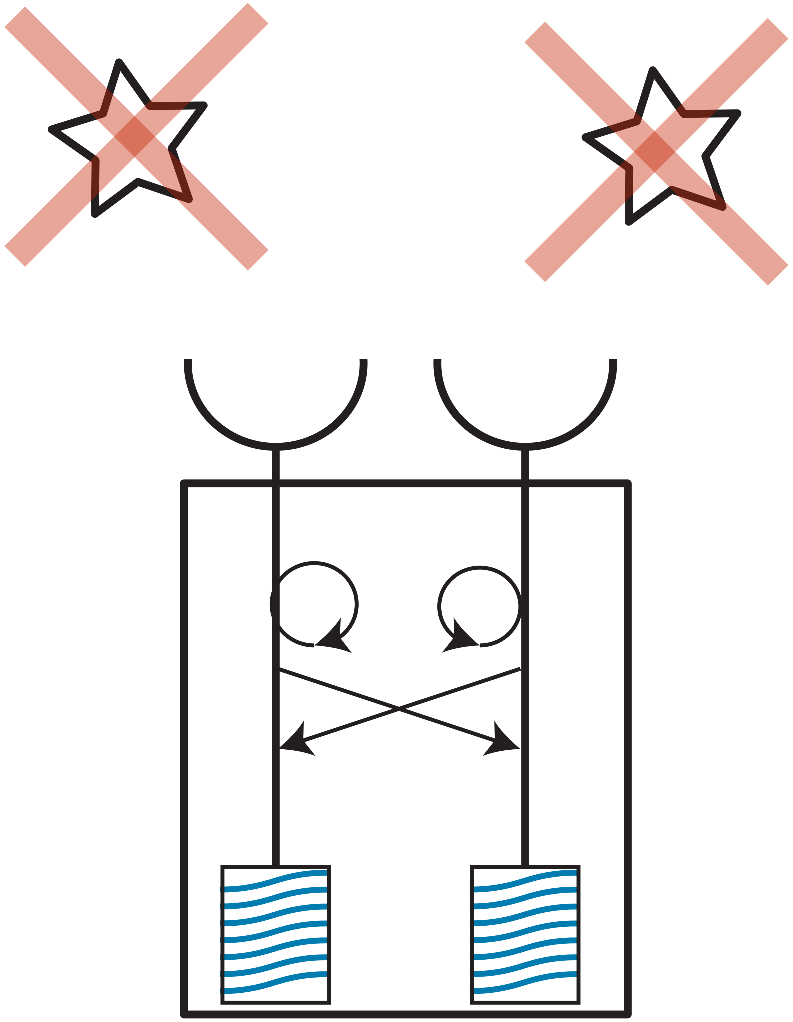
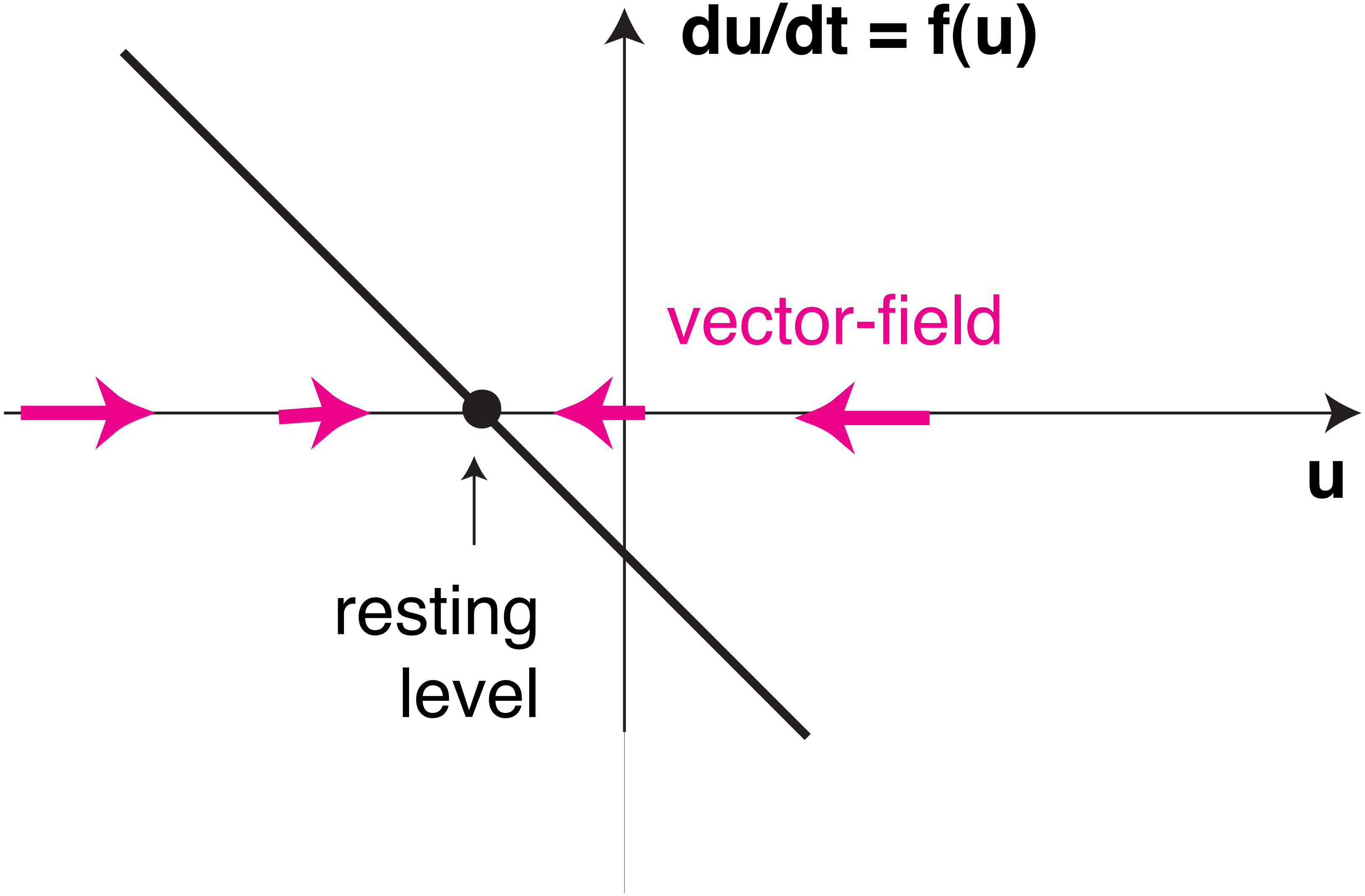
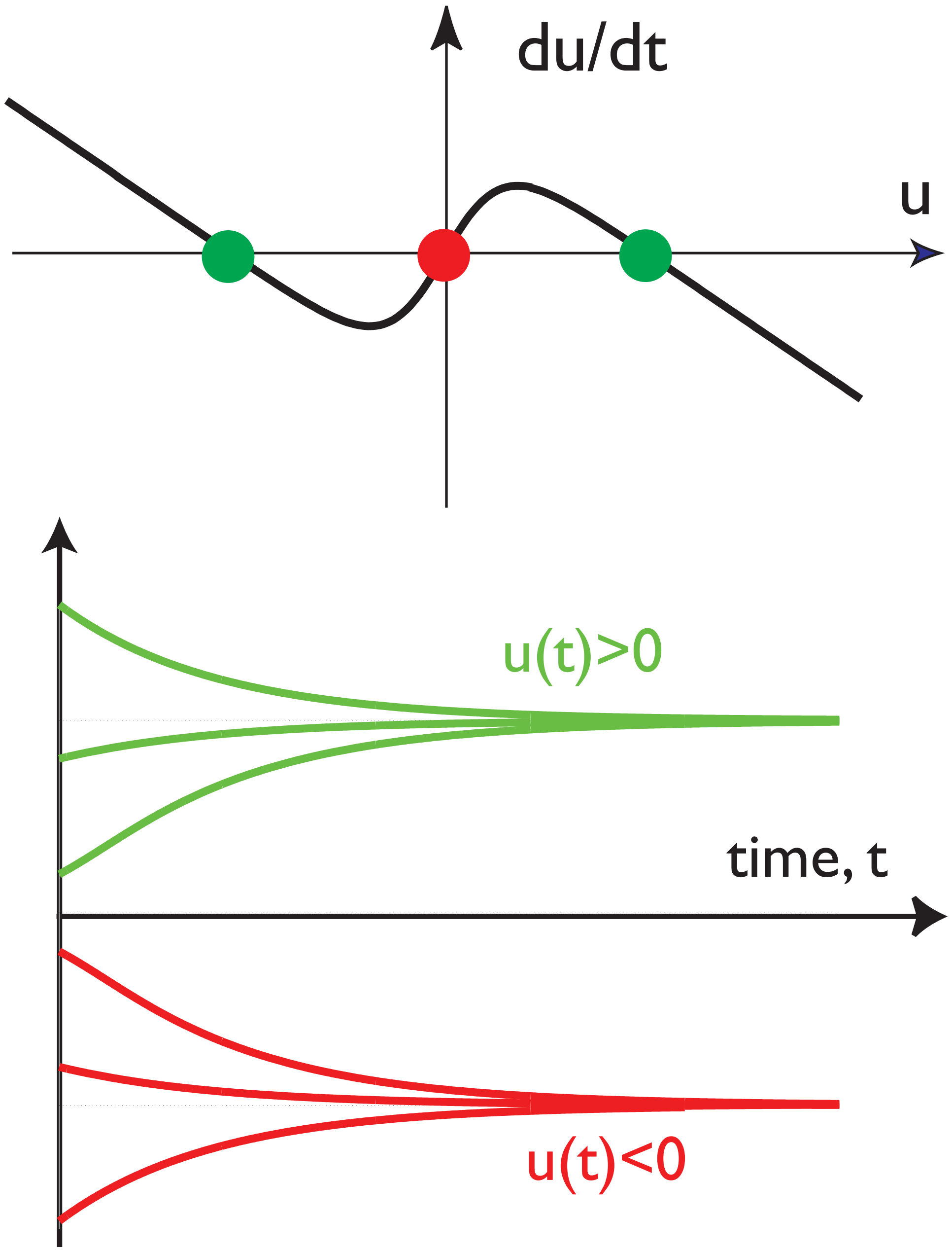


Internal loops generate neural dynamics


du/dt = f(u)
vector-field
u
resting
level

Internal loops generate neural dynamics


du/dt
u
u(t)>0
time, t
u(t)<0

Next…

- neural dynamics