

# Braitenberg vehicles: embodied nervous systems

Gregor Schöner

# Braitenberg vehicles

■ =embodied nervous systems  
with:

■ effectors

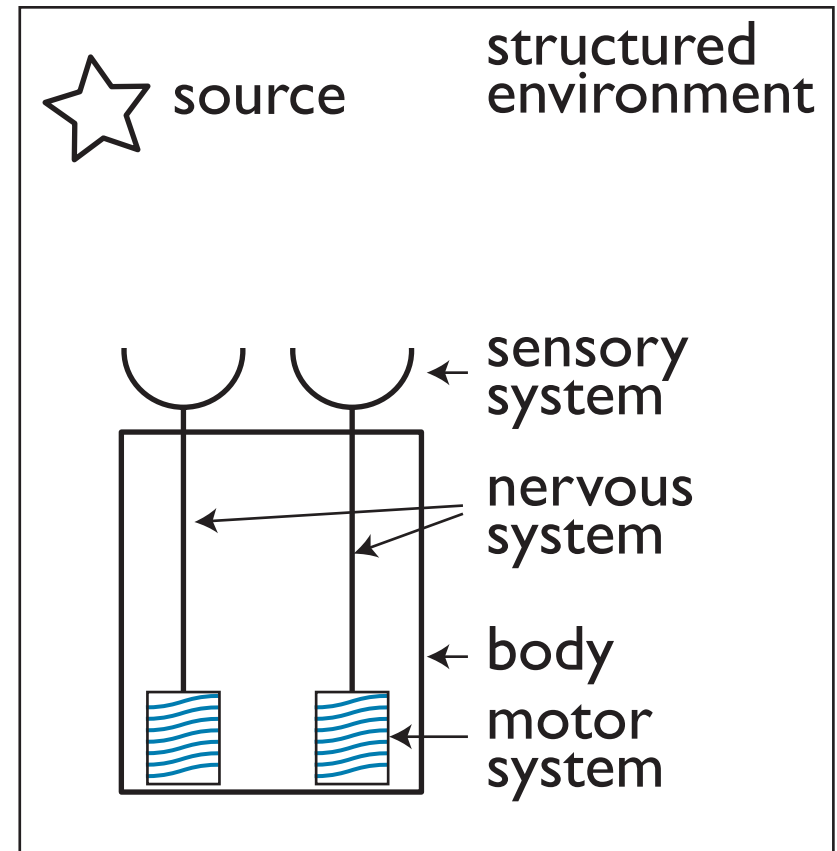
■ sensors

■ a nervous system

■ a body

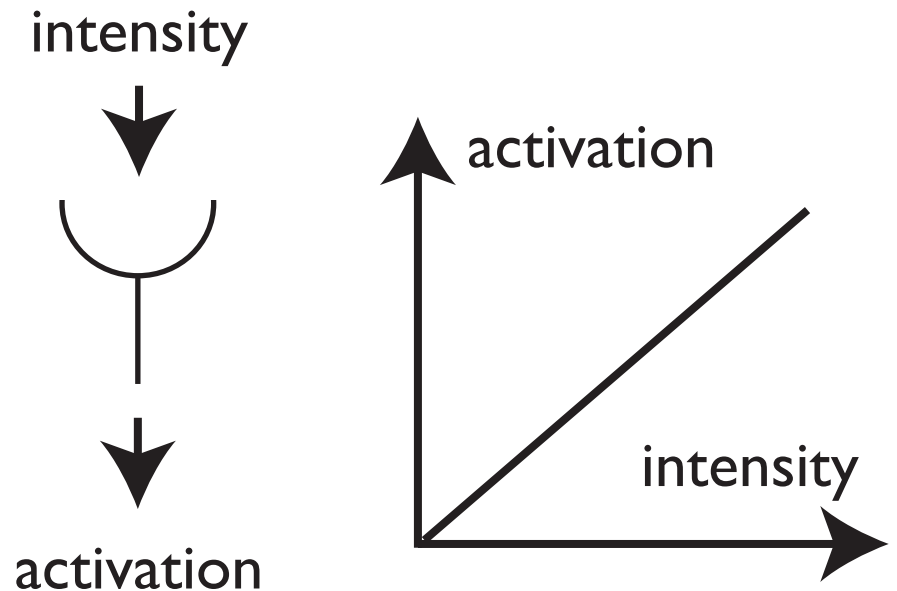
■ + situated in a structured environment

■ = emergent function



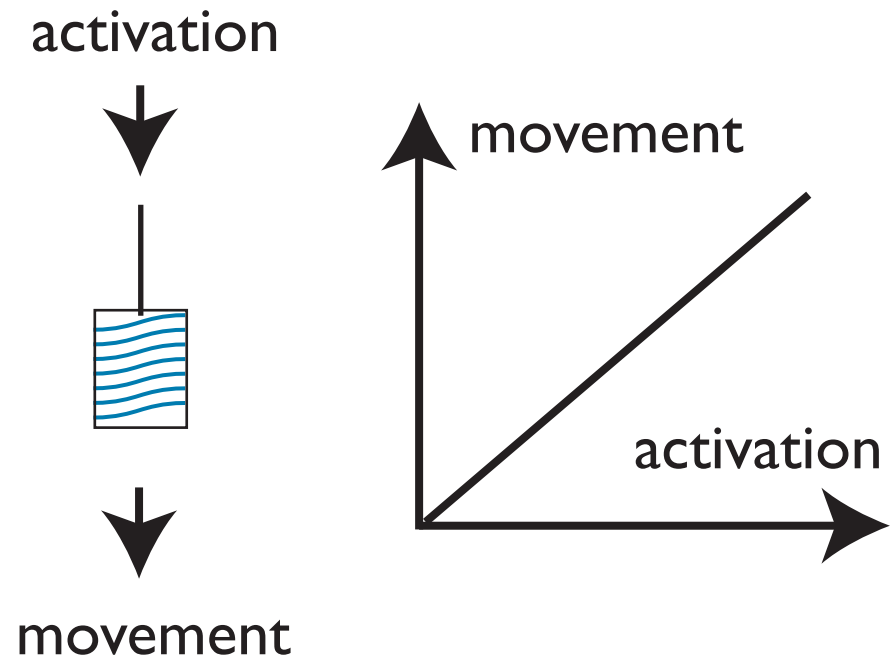
# Sensors

- 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”



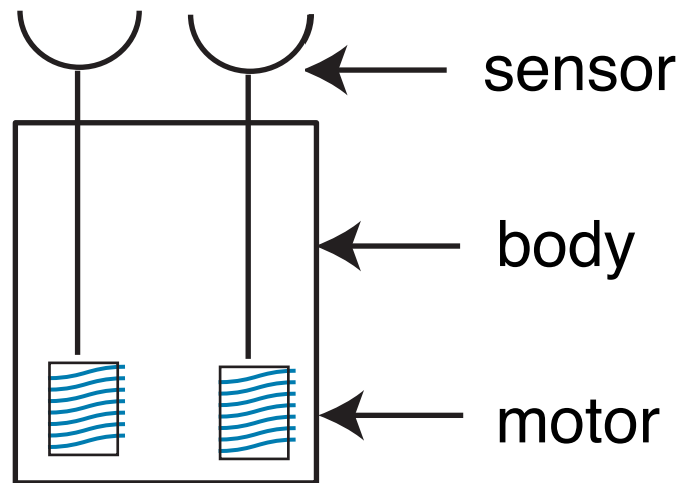
# Effectors

- 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, ...)



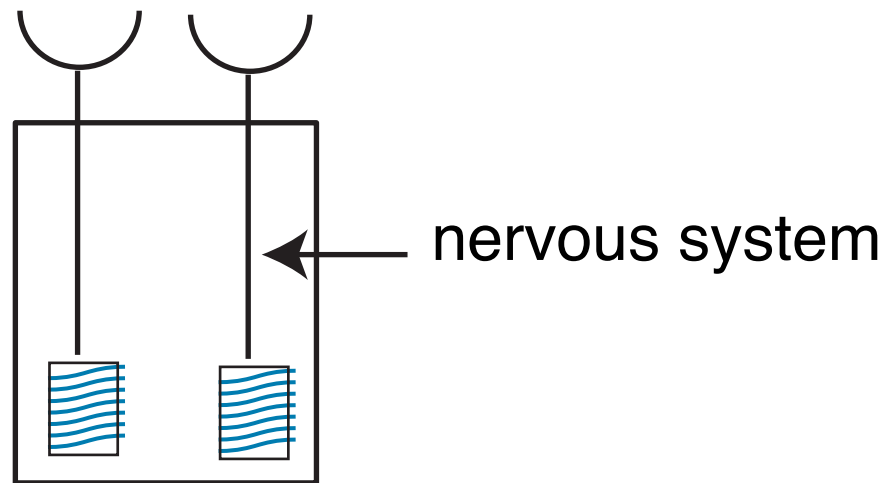
# Body

- mechanically links the sensors to effectors



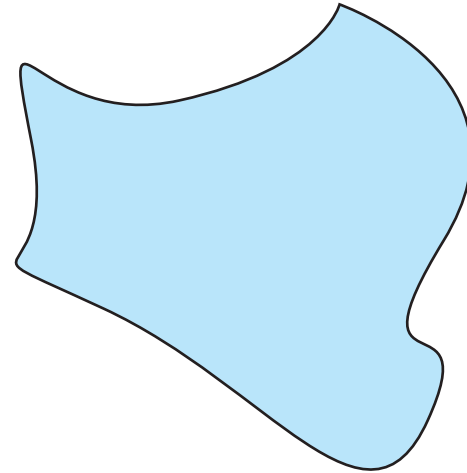
# Nervous system

- links sensors to effectors through the inner activation state



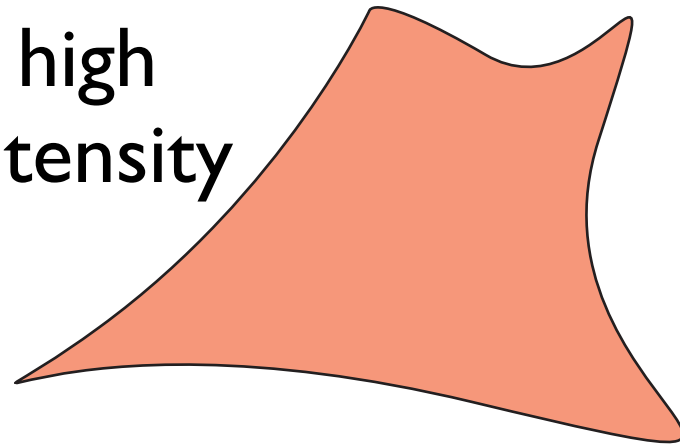
# Environment

low  
intensity

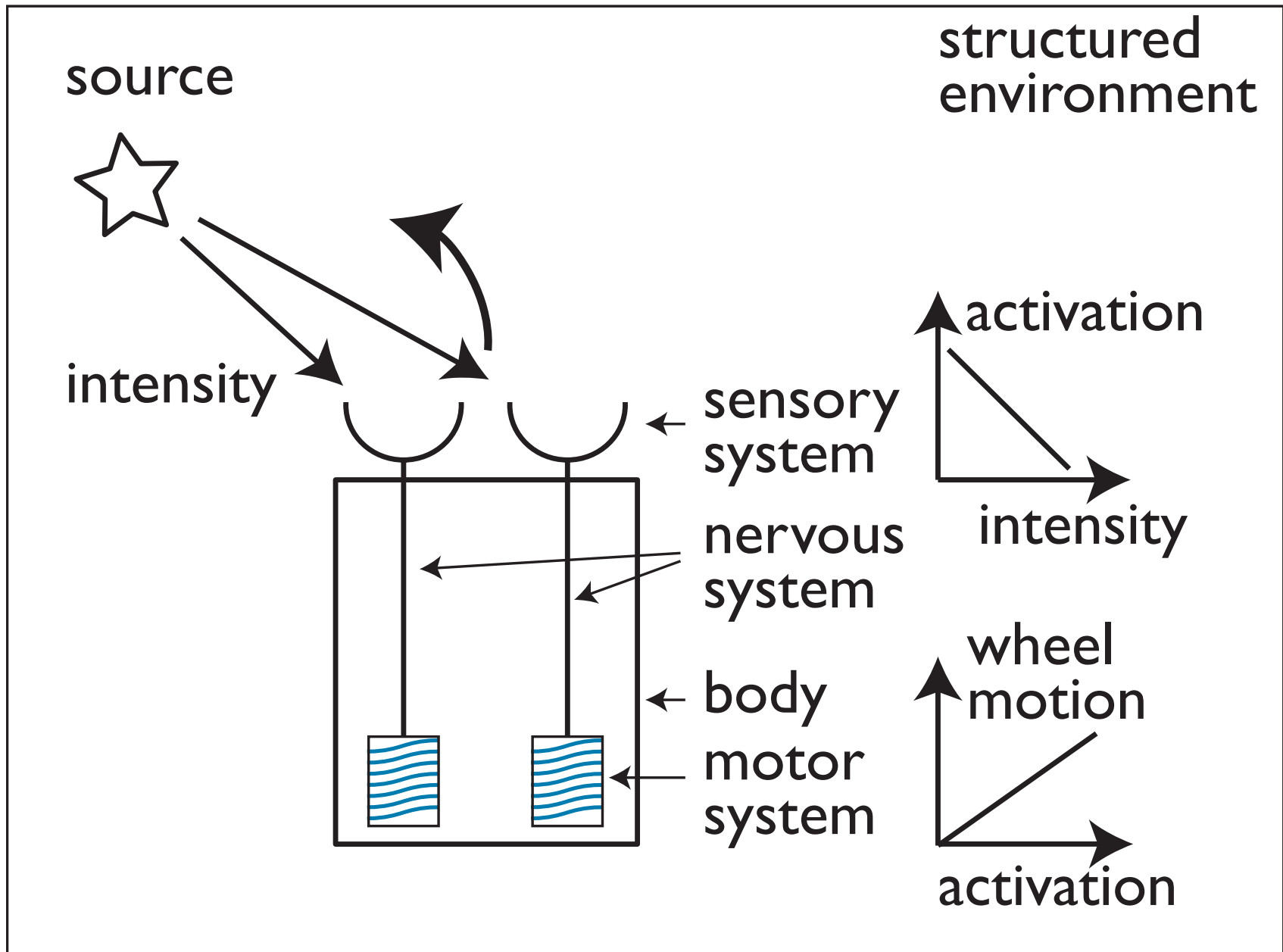


- is structured at a relevant scale in terms of the physical variables to which organism is sensitive

high  
intensity



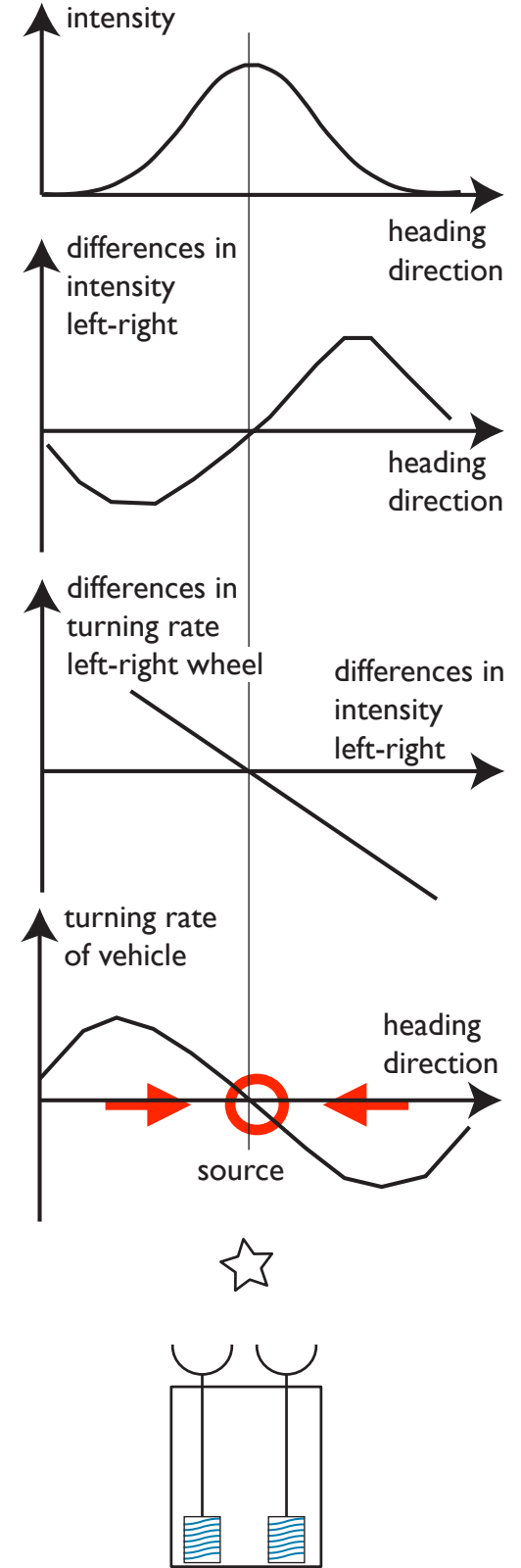
# Emergent behavior: taxis





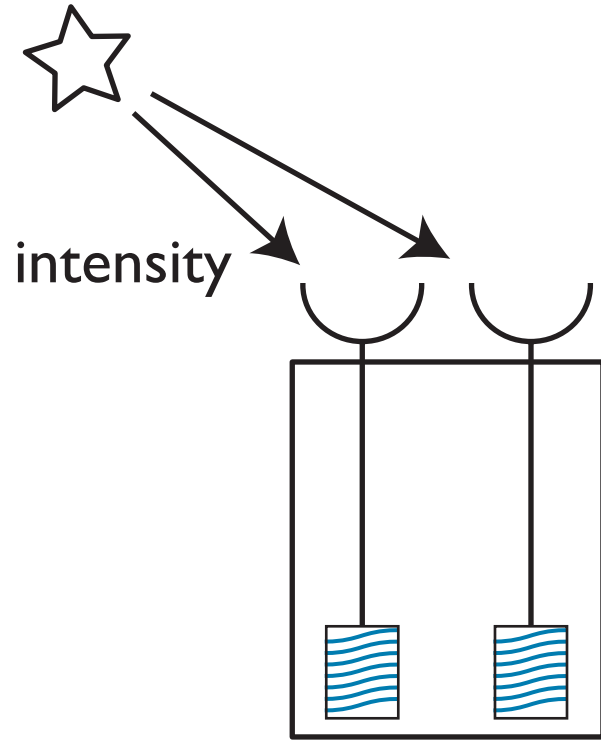
# Behavior emerges from a dynamical system

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

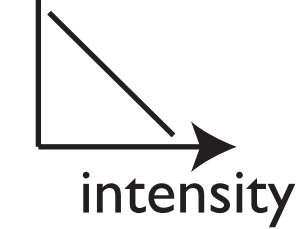


# Derivation

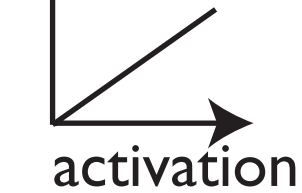
source



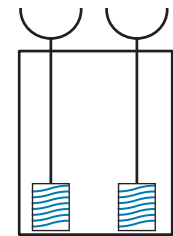
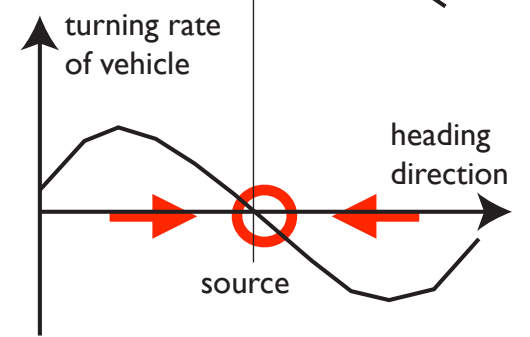
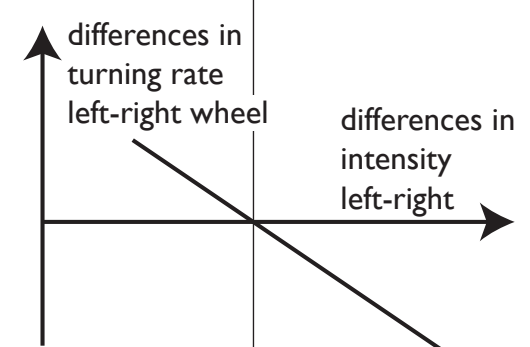
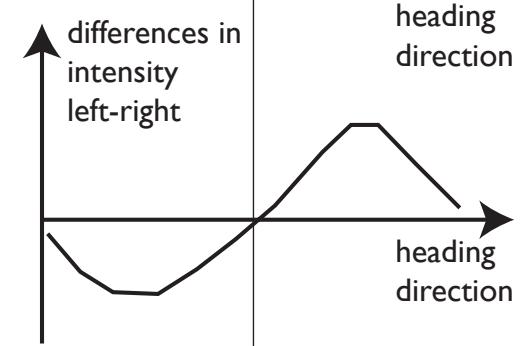
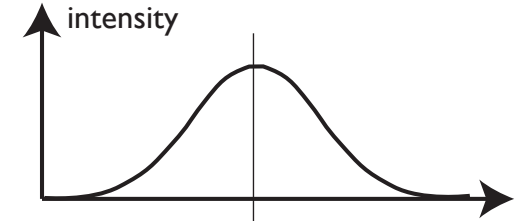
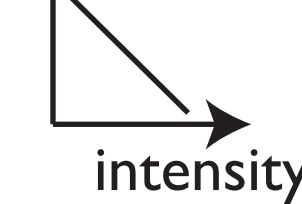
activation



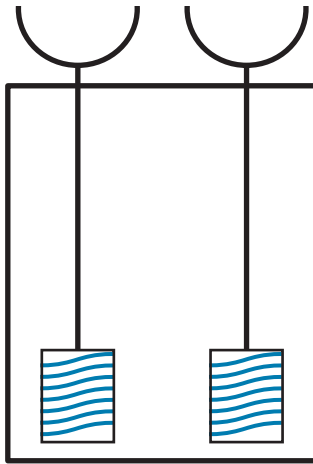
wheel motion



wheel motion



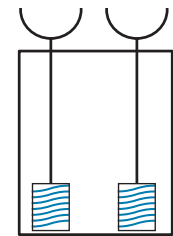
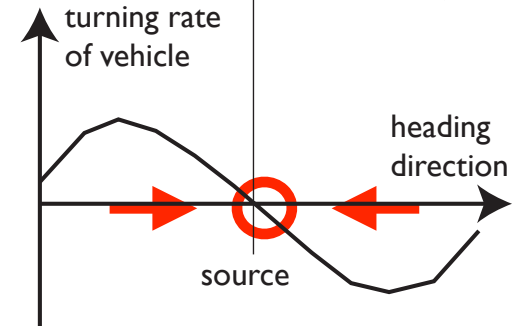
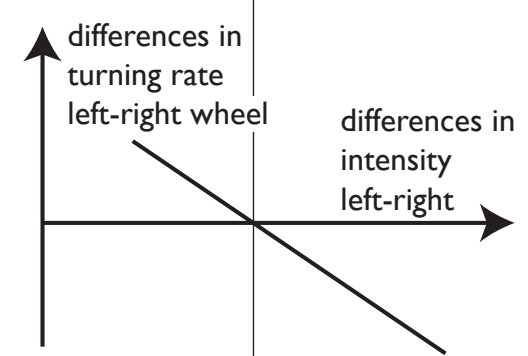
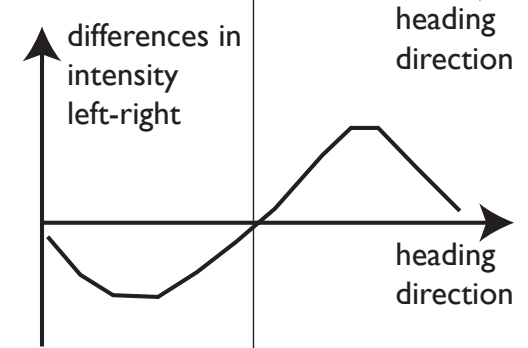
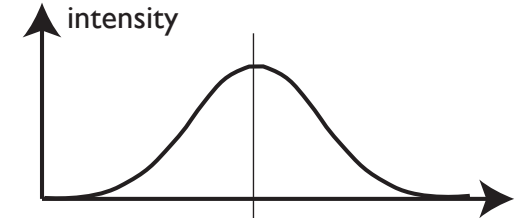
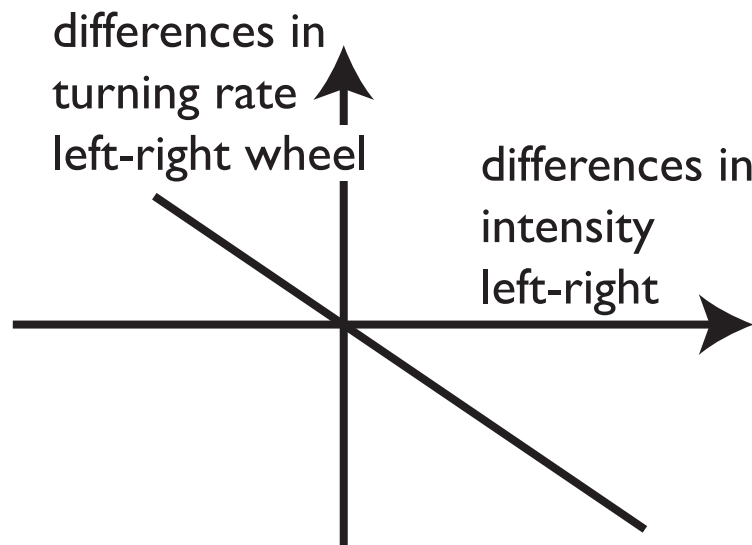
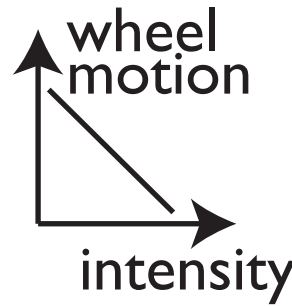
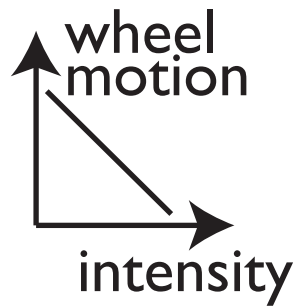
# Derivation



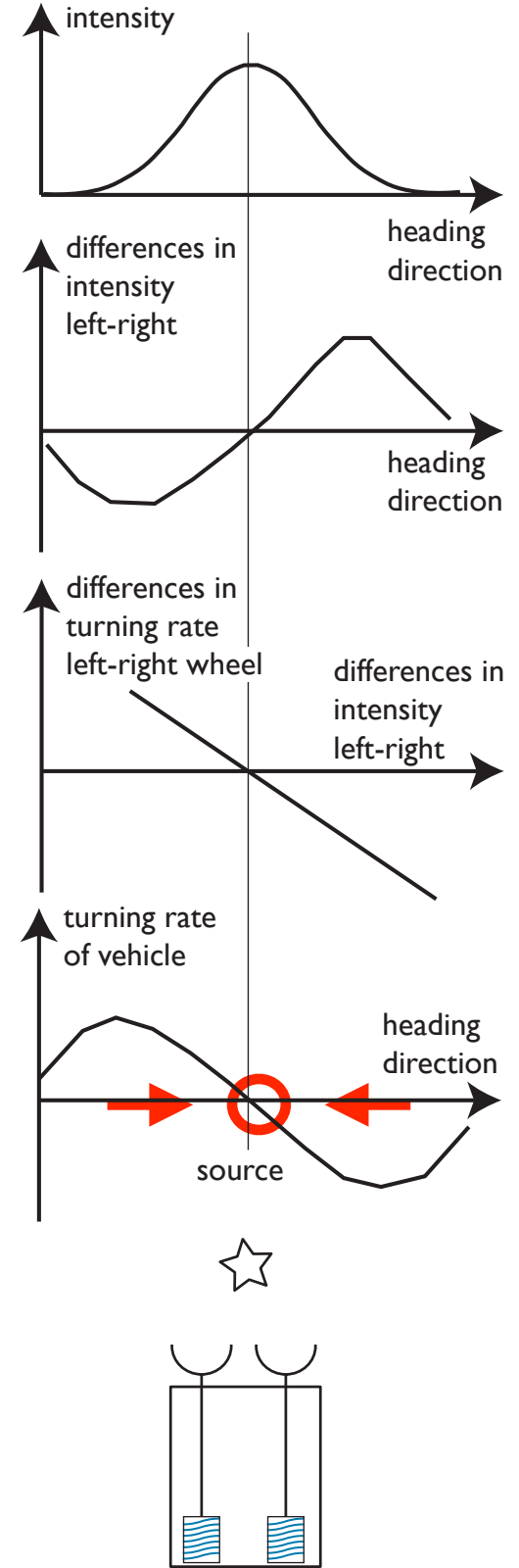
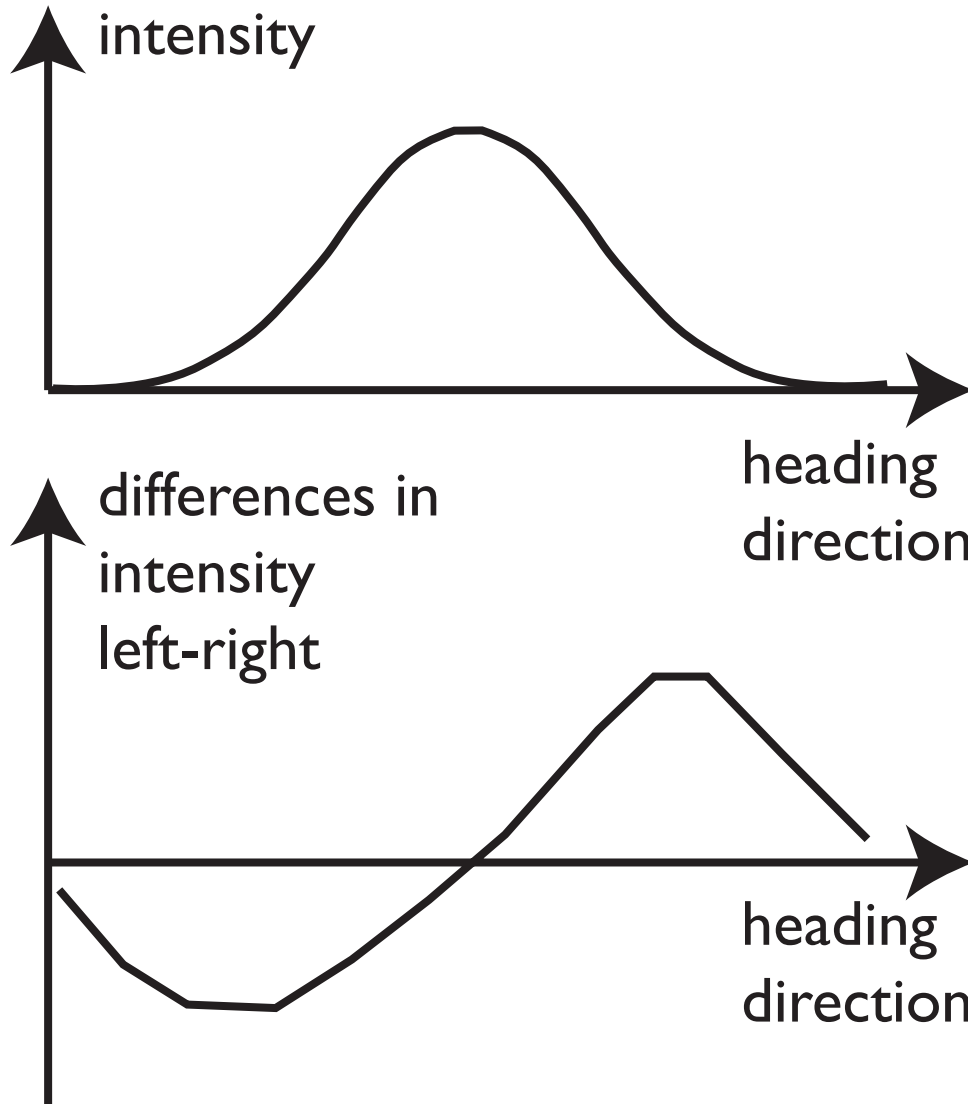
$$\omega_l = \omega_0 - cI_l$$

$$\omega_r = \omega_0 - cI_r$$

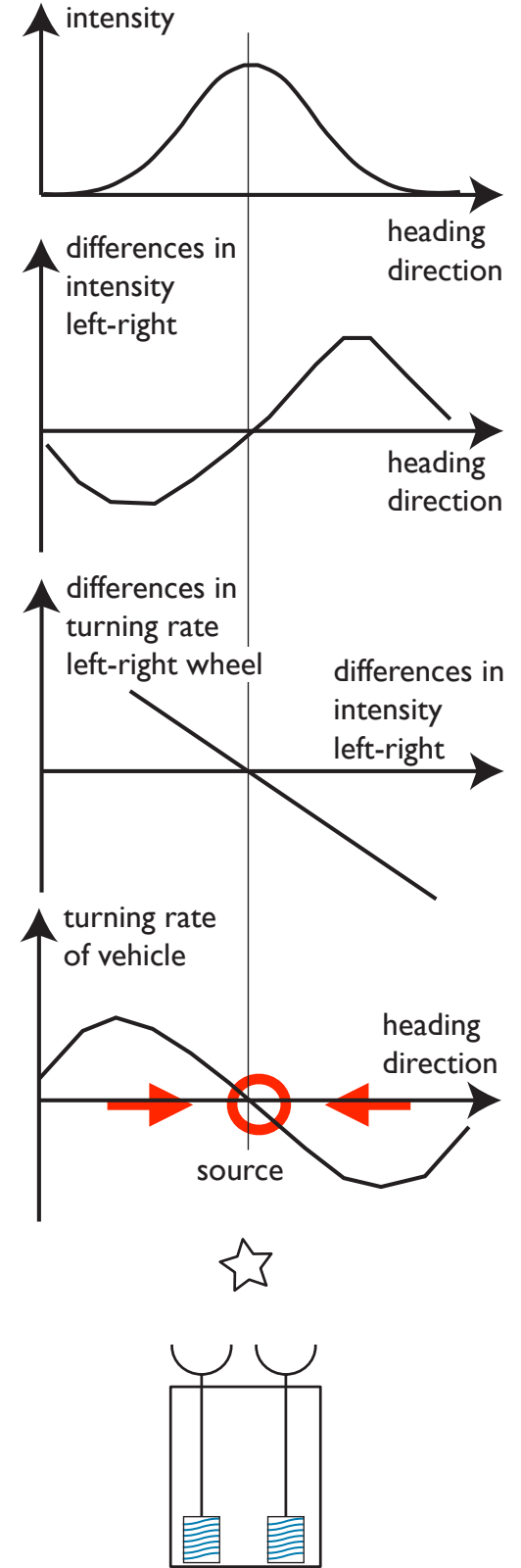
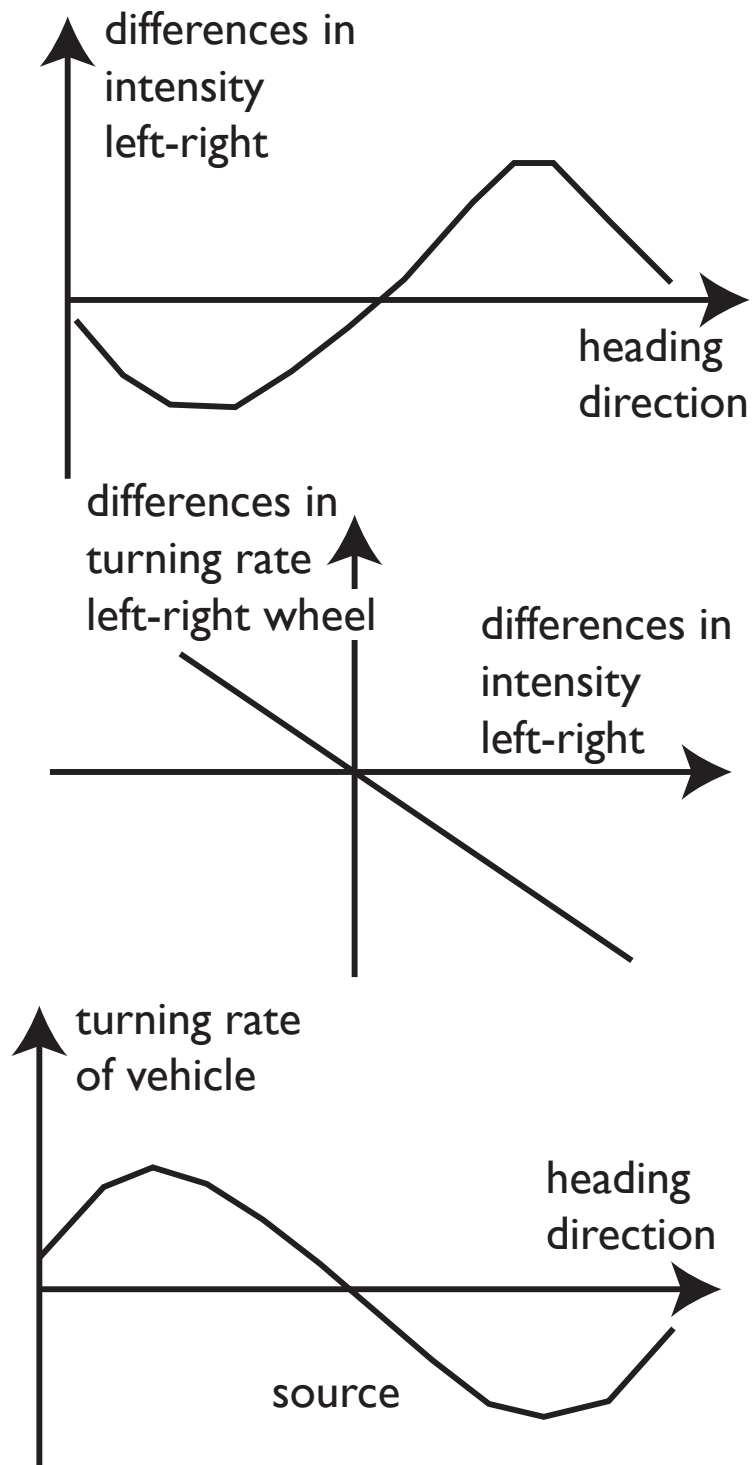
$$\Delta\omega = -c\Delta I$$



# Derivation

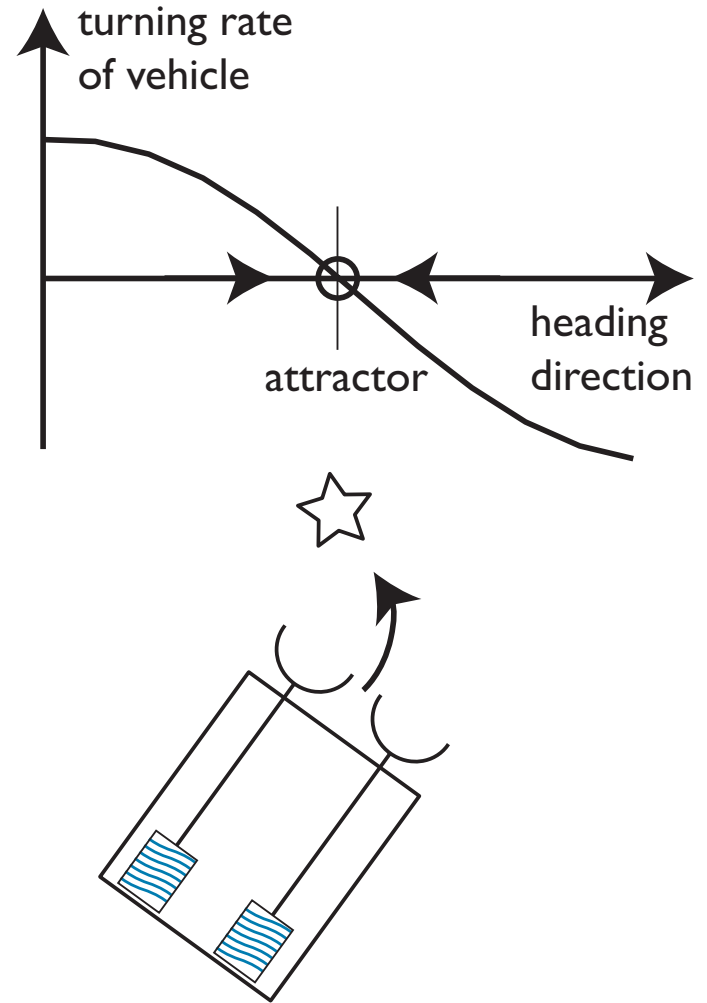


# Derivation



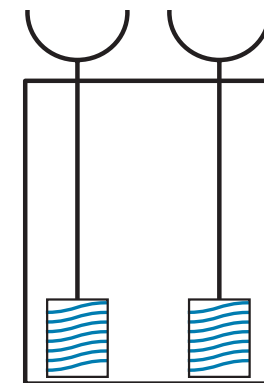
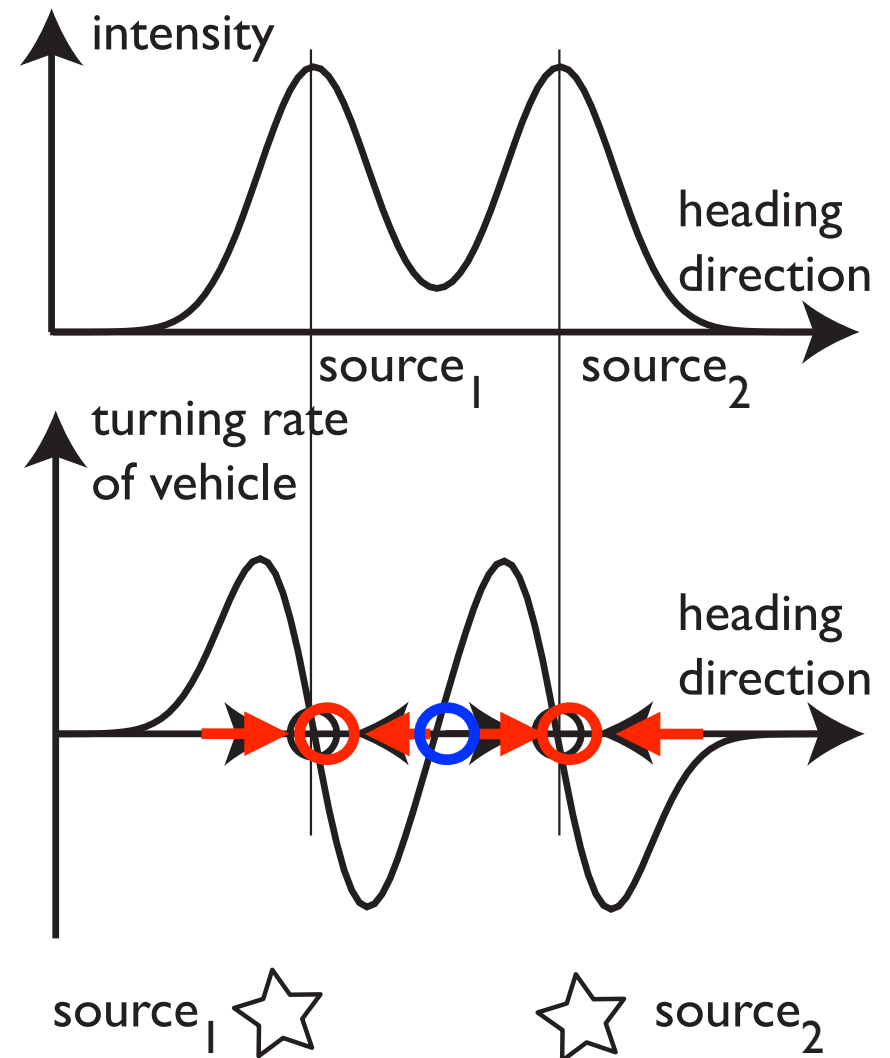
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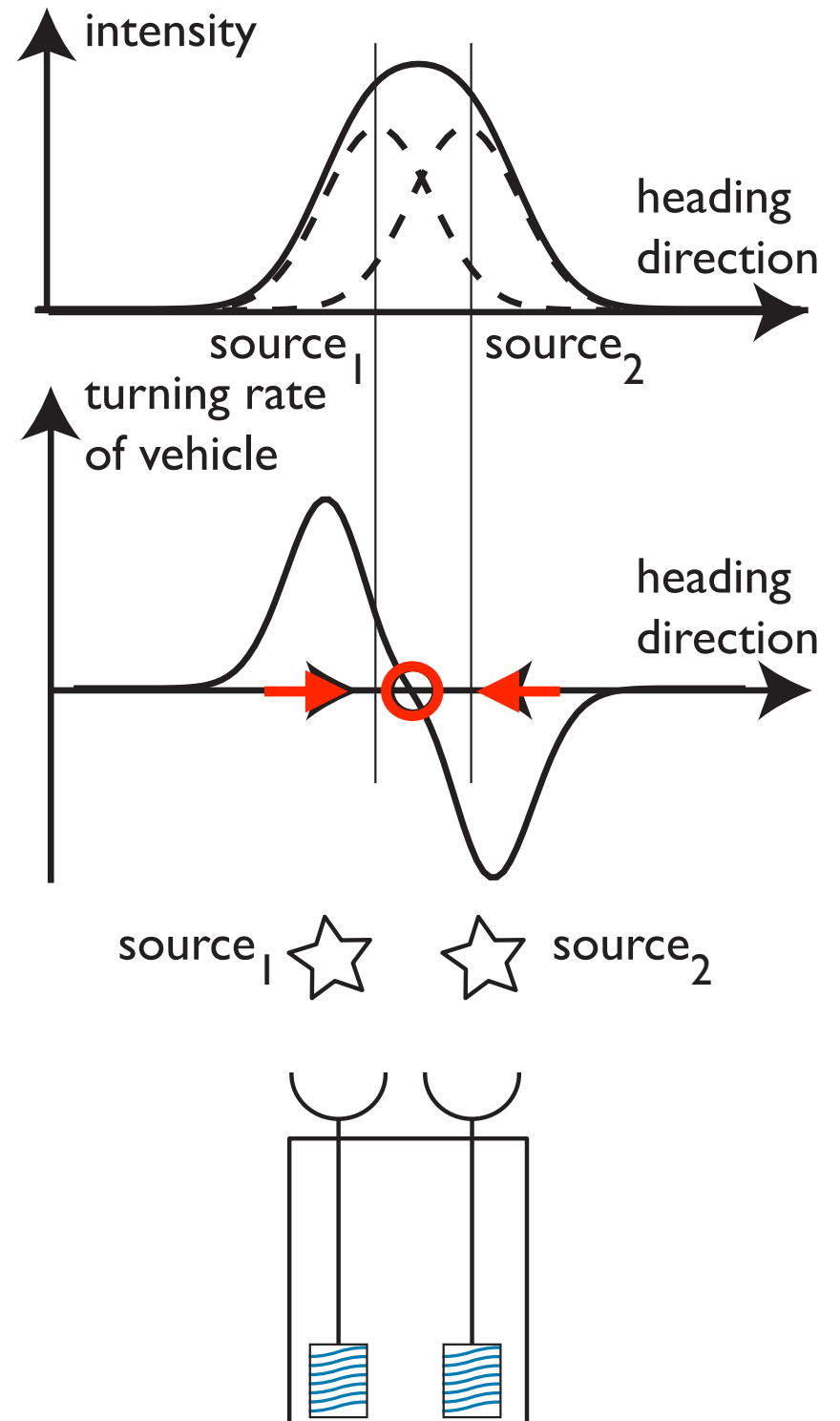


# Complex environment => complex dynamics

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



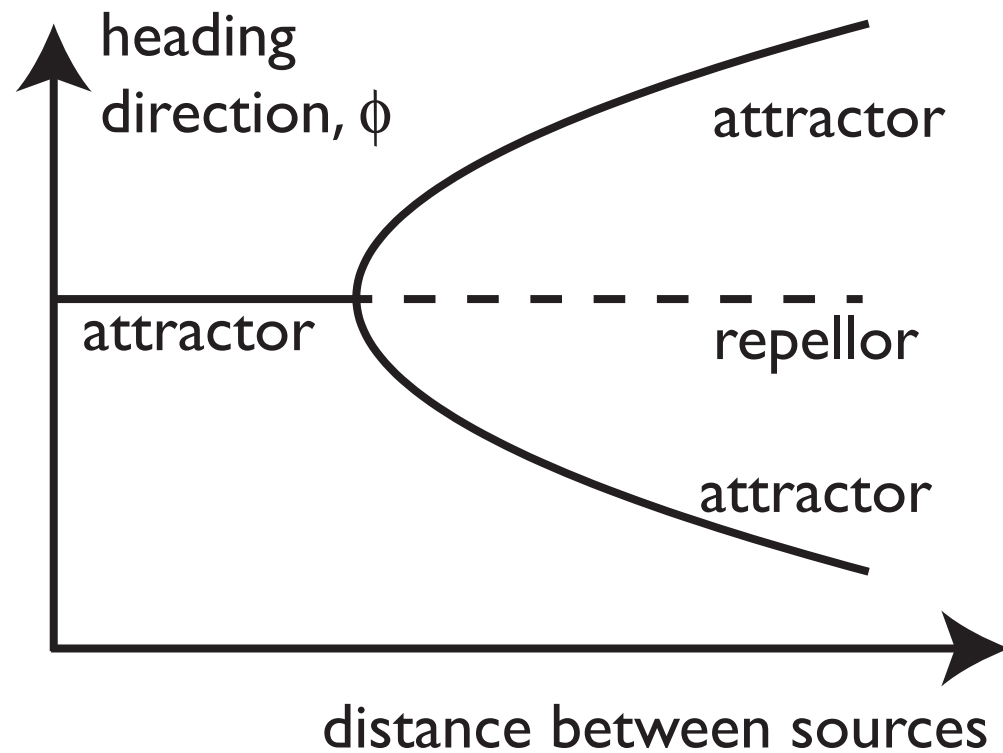
- transition to monostable for mono-modal distribution
- => instabilities lead to qualitative change of behavior





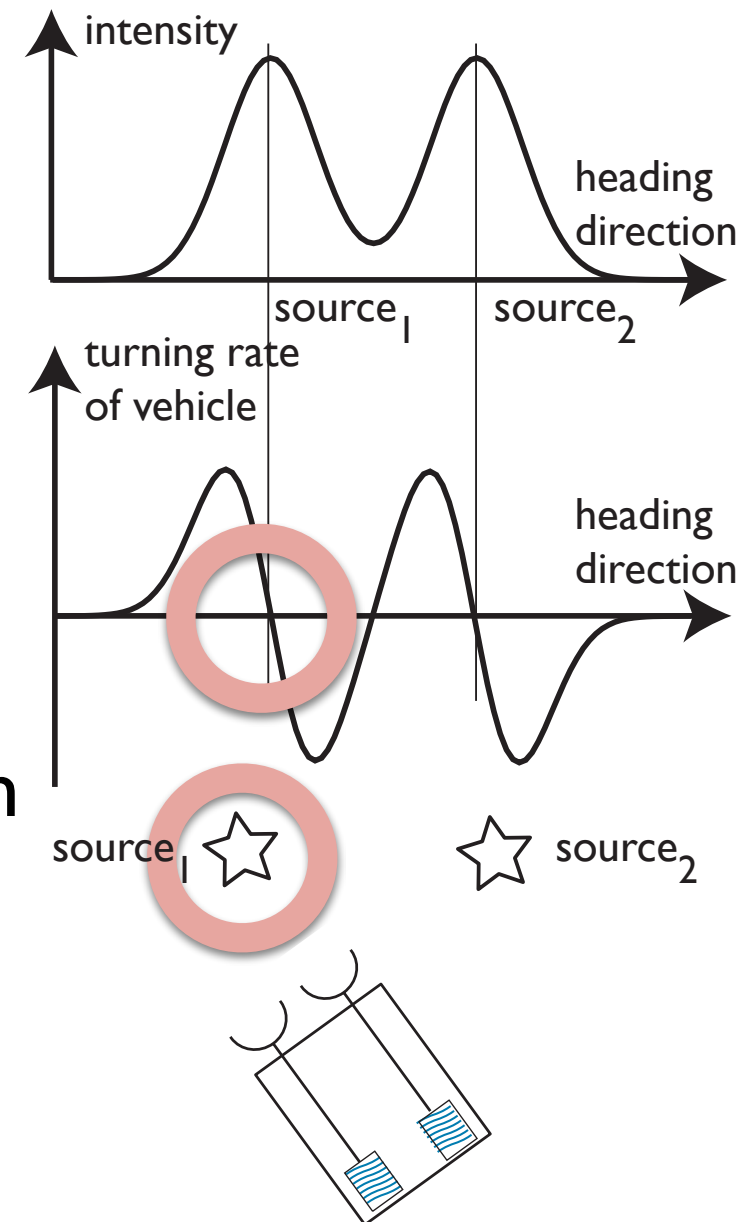
■ transition to monostable for mono-modal distribution

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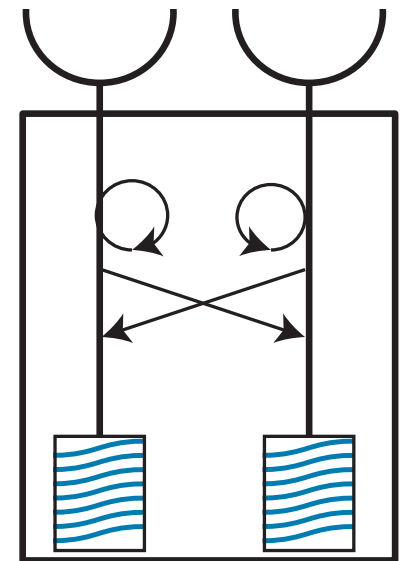
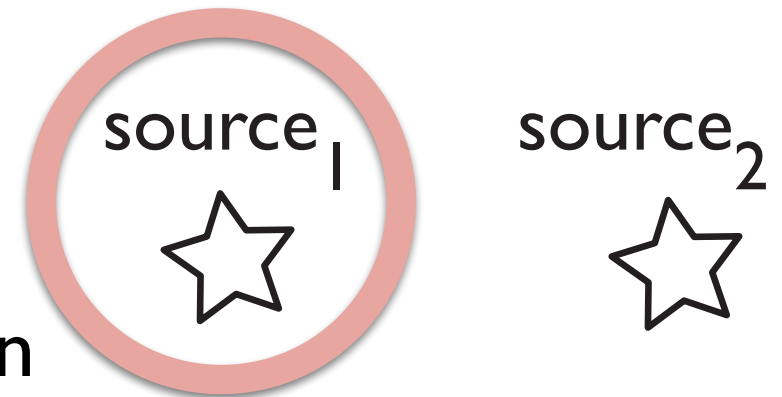
# Beyond behavioral dynamics ...

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



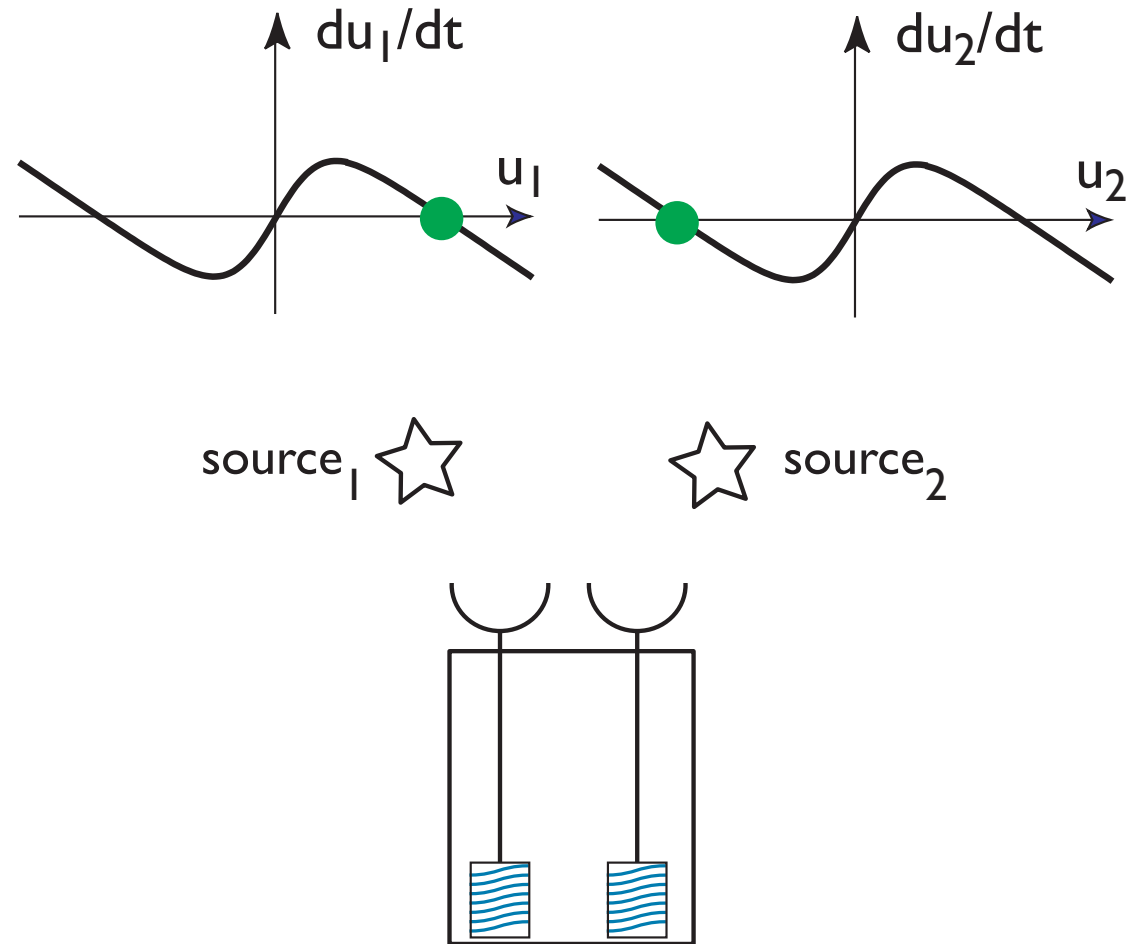
# Beyond behavioral dynamics ...

- 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



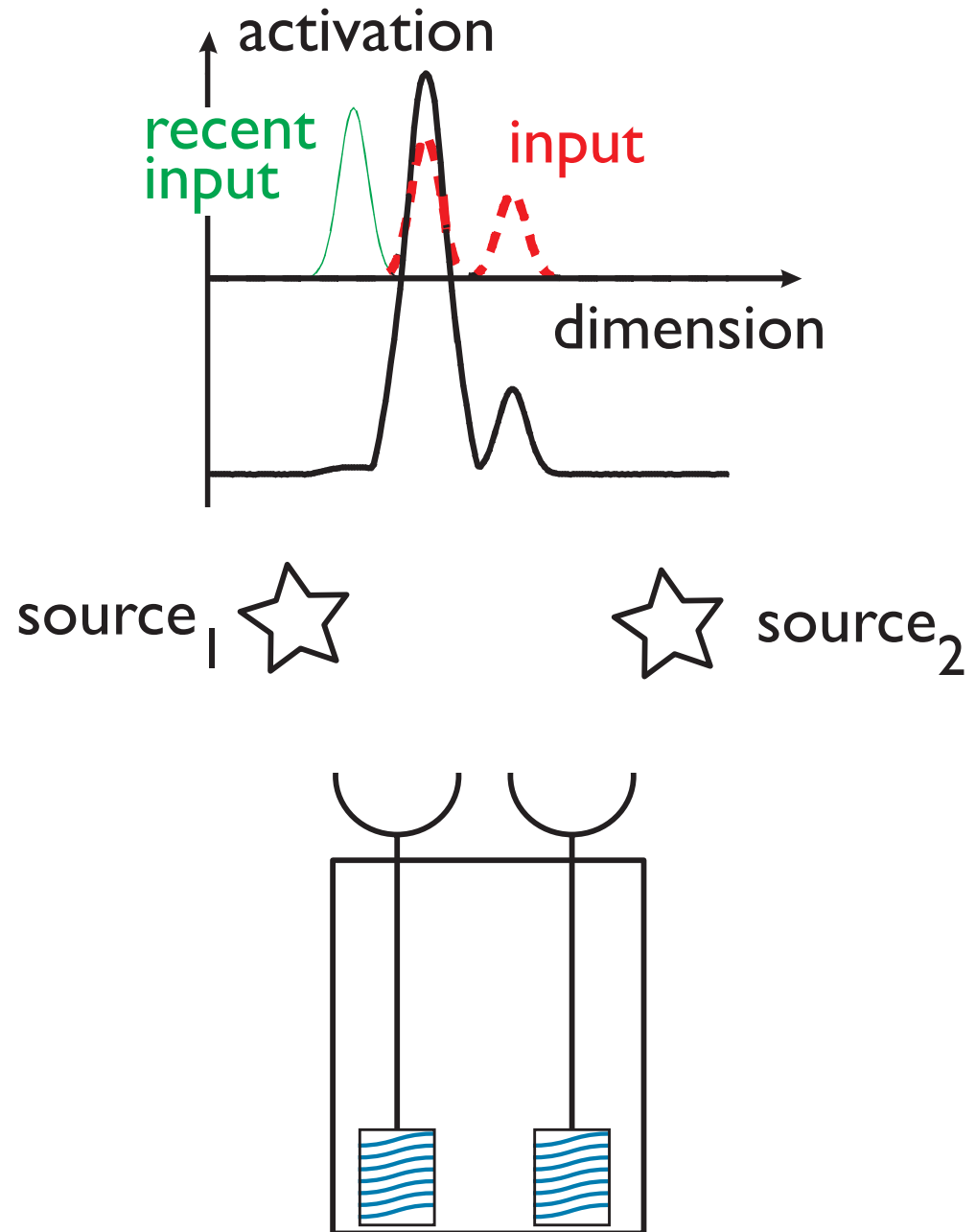
# Beyond behavioral dynamics ...

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



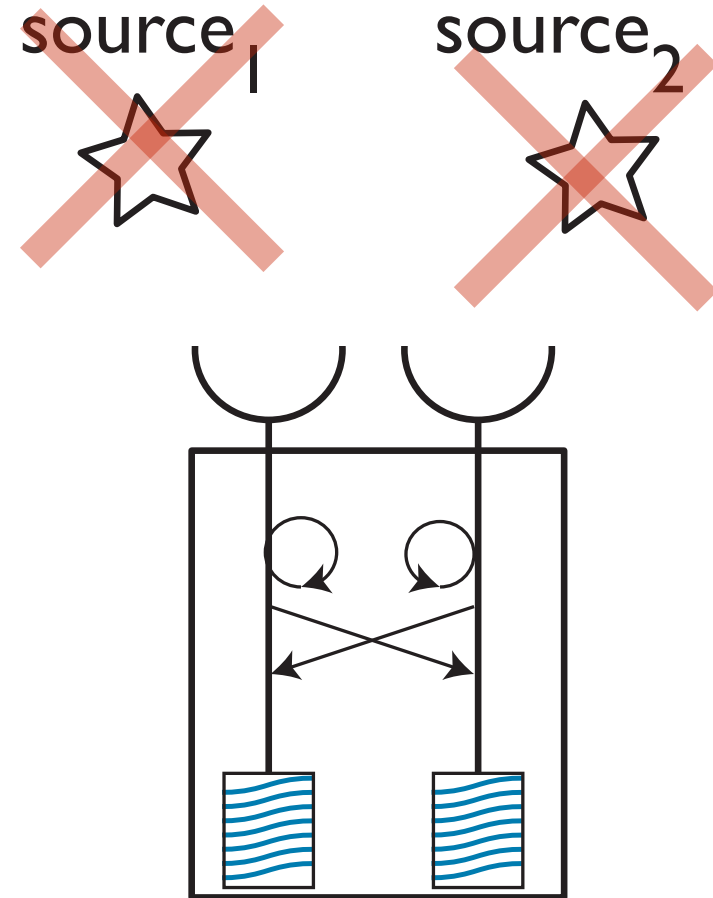
# Beyond behavioral dynamics ...

- neural activation field to represent continuous of possible target orientations



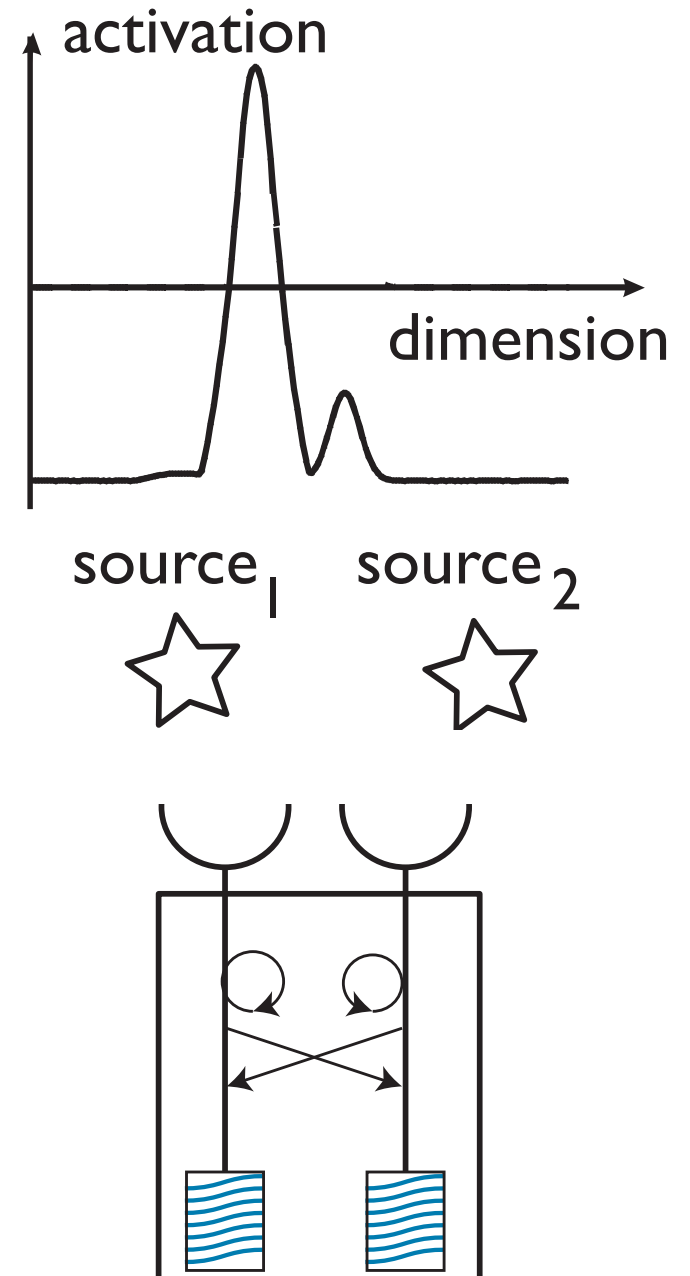
# Beyond behavioral dynamics ...

- 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