DFT School 2020 Introduction

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Ultimate goal

- … ultimately, we all try to understand how the central nervous system fused with our body and embedded in structured environments generates behavior and thought…
- … some of us seek ideas for how to build artificial cognitive systems that may perceive, act, and think on their own

Cognition

- much of an organism's behavior can be understood in terms of relatively simple perception-action patterns…
- a simple-minded, but useful, perspective posits, that cognition is whatever comes between sensing and motor behavior..
  - the more invariant against changes of sensory input, against delay, against changes in effector configuration… the more cognitive
  - the more indeterminate the behavior from the proximal stimulus.. .the more cognitive

Cognition as computation

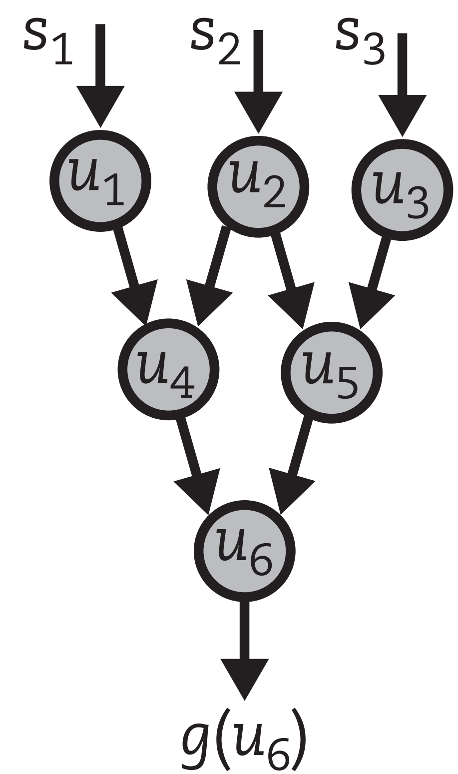
- the “classical” approach to cognition … emphasizes
  - the capacity to generalize: abstraction/invariance… and systematicity/rules
  - the capacity to generate unboundedly many different thoughts.. productivity/compositionality
- => cognition as symbol manipulation
- which entails symbol instantiation (the grounding problem)

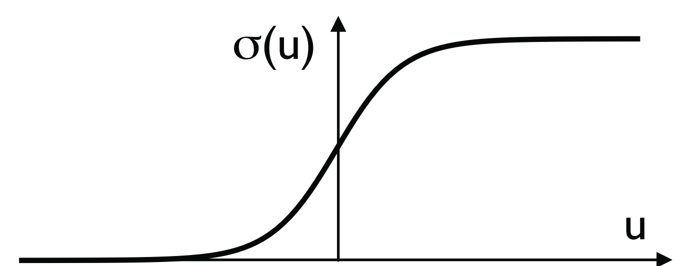
Cognition as computation

- which leads to the view of cognition as computation (information processing)
- at the core of which is function evaluation
  - for example, in relational cognition: to-the-right-off(target position, reference position) returns “true” or “false” or a probability
- and the nesting/concatenation of such function calls
  - for example, in parsing language

Neural basis of cognition

- the connectionist view of neural function:
  - neurons as input-output threshold elements
  - that form (essentially feed-forward neural networks
- these neural networks may contain recurrent loops
  - but the functional significance of the networks typically still derives from the overall "output=function(input)" characterization





$$\text{output} = g\left(\sum(\text{inputs})\right)$$

Neural basis of cognition

- so, although connectionism calls into question the hypothesis, that symbols are instantiated and manipulated
- connectionism still lends itself to a *function evaluation* perceptive on cognition
- (with the computational black boxes replaced by clouds of neural networks)

But: Cognition emerges in evolution and development from the sensorimotor domain

- for example, memory emerges in evolution from spatial navigation: knowing where you are and how to get somewhere
- decision making emerges from action selection: knowing what to do
- => cognition *for* action, behavior, survival

Sensorimotor cognition

- the sensorimotor origin of cognition is evident in the structure of the brain
  - that has evolved in a graded way
  - with many subsystems highly invariant
  - e.g. basal ganglia as the basis for action selection from lamprey to human over 500 million years (Grillner, Robertson, *Current Biology* 2016)
- => seek a neural account of cognition that is *specific* to our evolutionary repertoire of forms of cognition

Sensorimotor cognition

- attention/gaze
- active perception/working memory
- action plans/decisions/sequences
- goal orientation
- social interaction
- background knowledge
- learning from experience

Properties of sensorimotor cognition

- graded state
- continuous time
- continuous/intermittent link to the sensory and motor surfaces
- from which discrete events and categorical behavior emerge
- closed loop
- => dynamics
- => need for stability

Embodiment hypothesis

- cognition inherits the properties of embodied cognition
- => dynamics rather than function evaluation

Embodiment hypothesis (radical form)

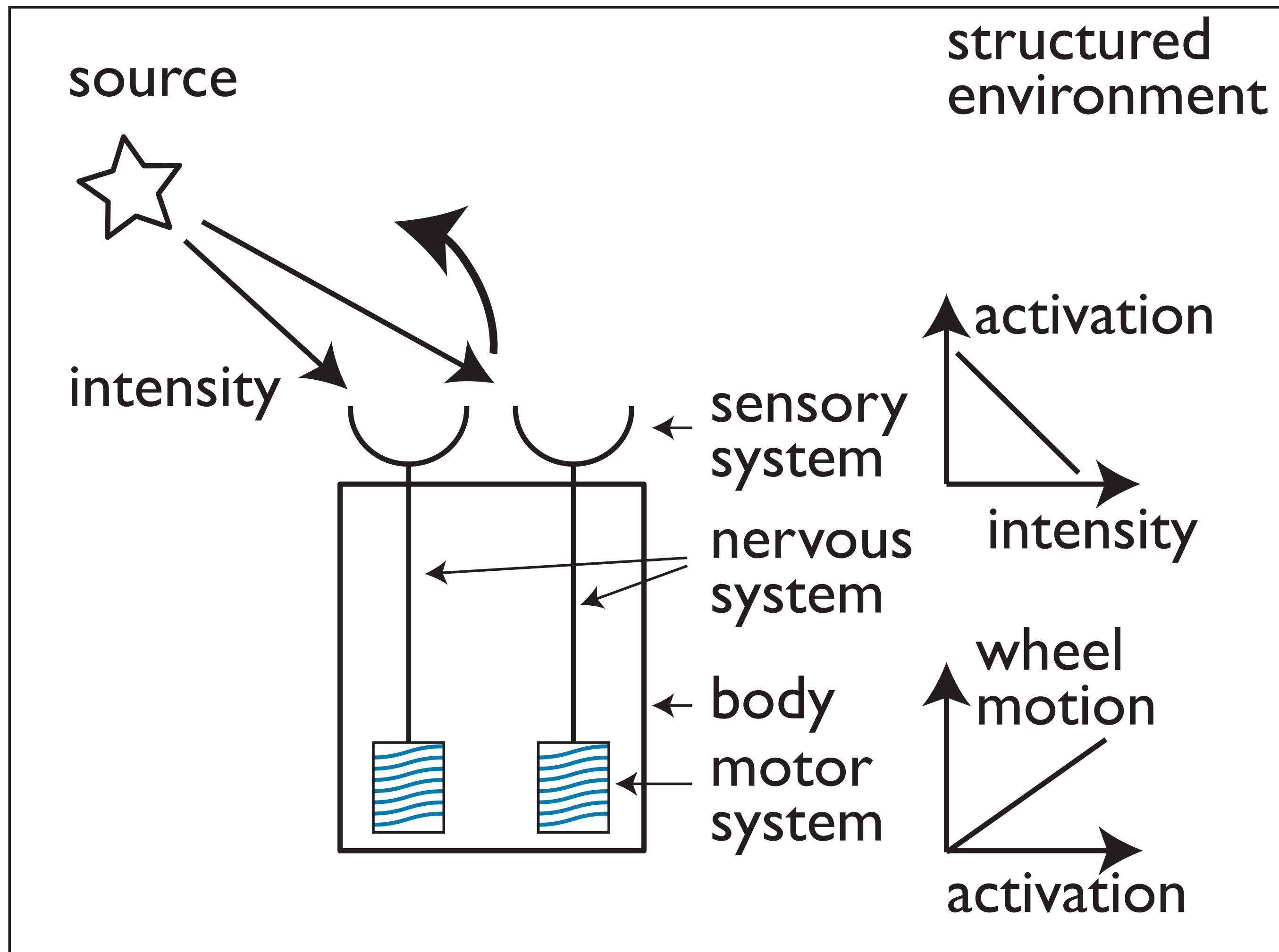
- all cognition has these dynamic properties…
- there is no boundary, beyond which these properties can be neglected…

Dynamics

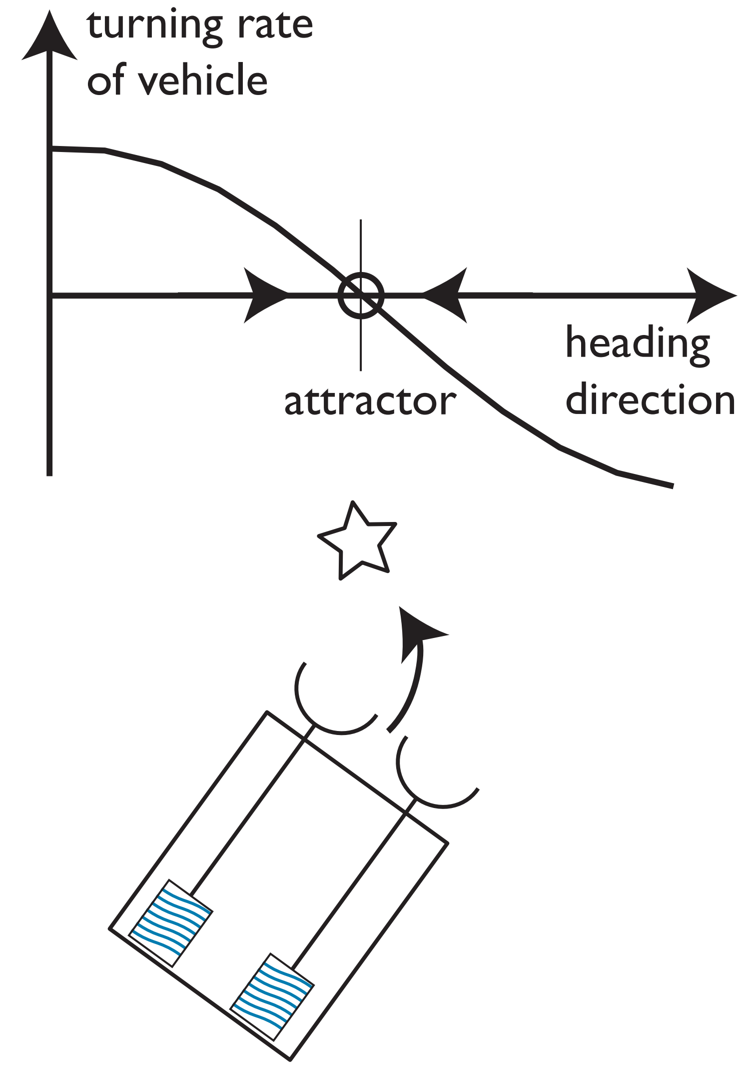
- what is "dynamics"… ?

Braitenberg's vehicle metaphor

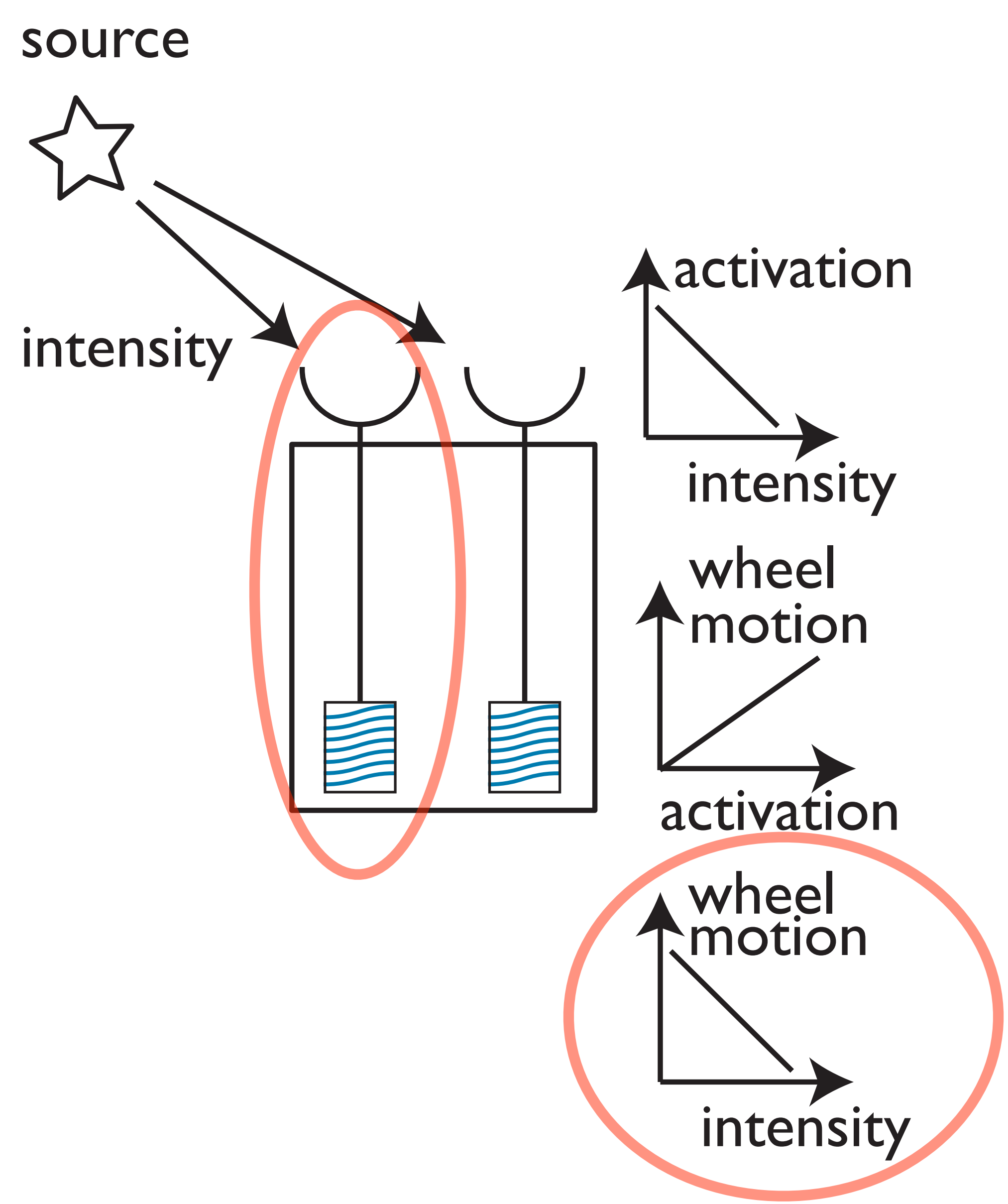
- vehicle=organism whose body moves its sensors and motor systems through its environment



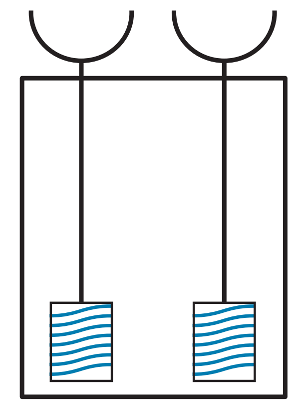
The vehicles' behavior emerges from the attractor of a dynamical system



Input-output description of the feed-forward paths of the vehicle's nervous system

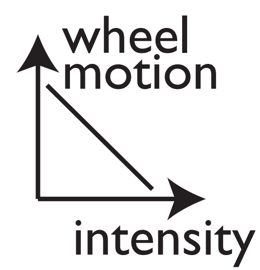


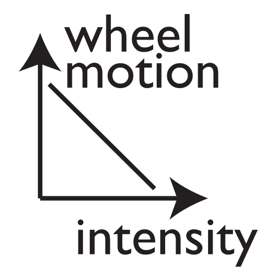
Input-output description of the vehicle's nervous system for body rotation

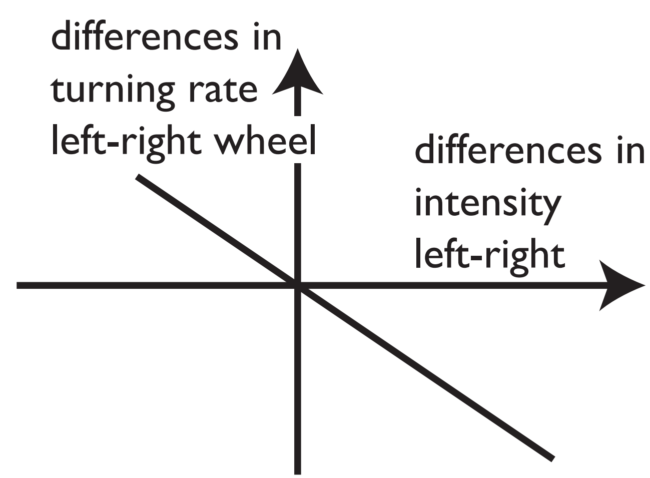


$$\omega_l = \omega_0 - cI_l$$

$$\omega_r = \omega_0 - cI_r$$



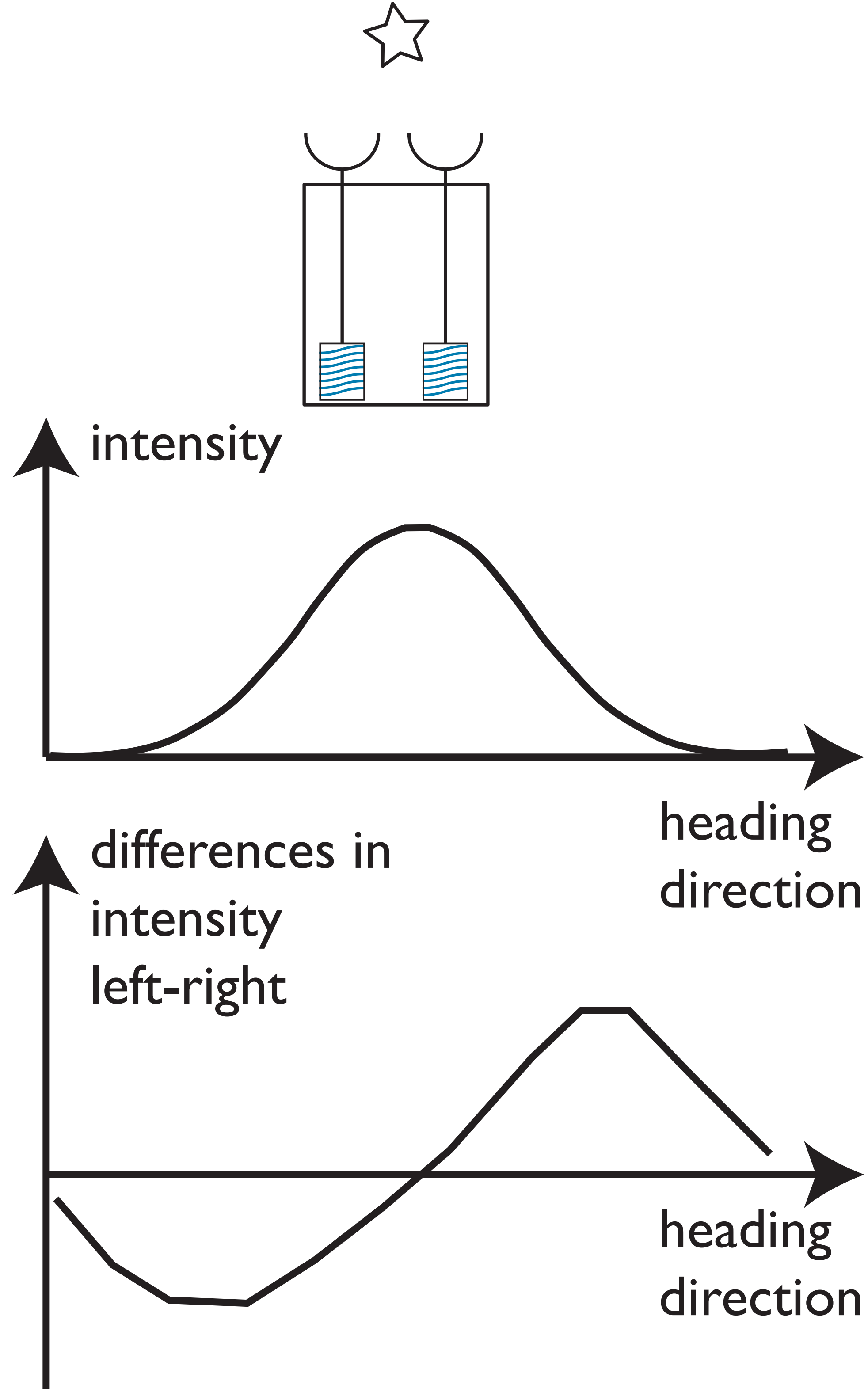




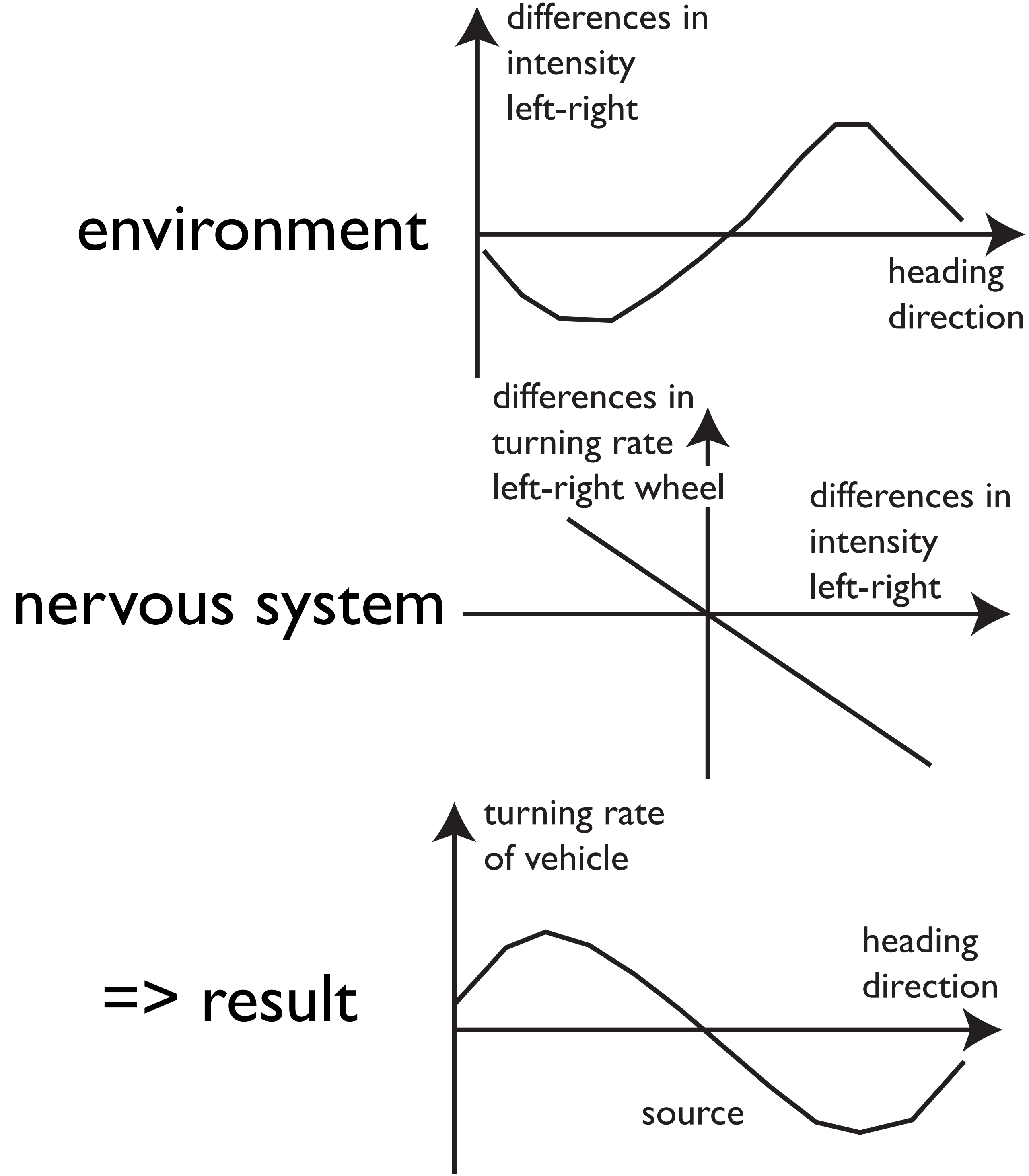
$$\Delta\omega = -\,c\Delta I$$

output input

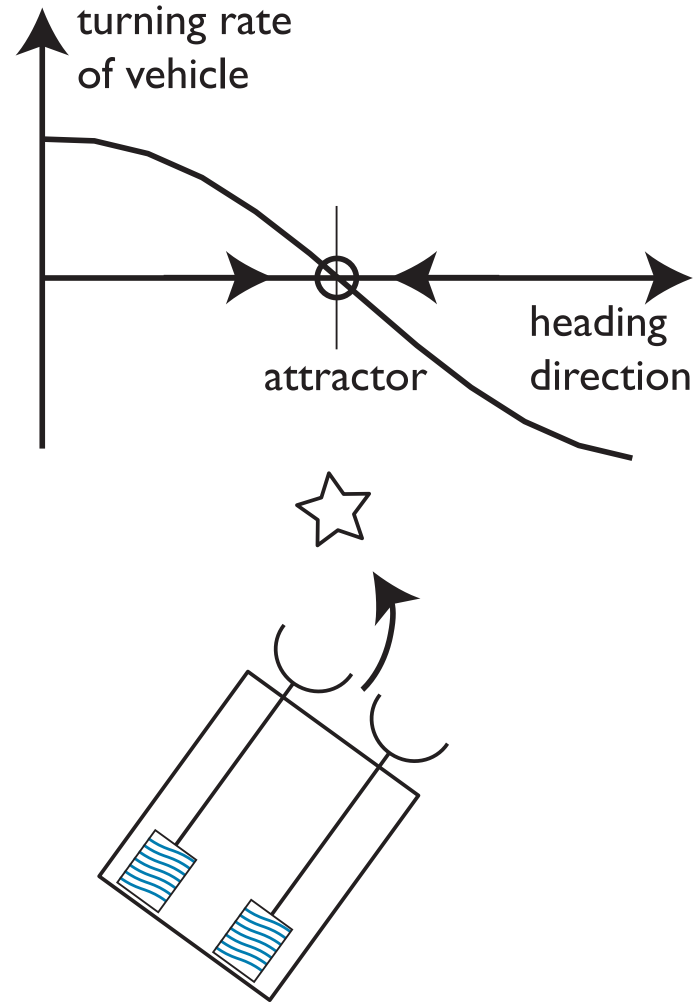
Model of the environment



Concatenate the model of the environment with the model of the nervous system

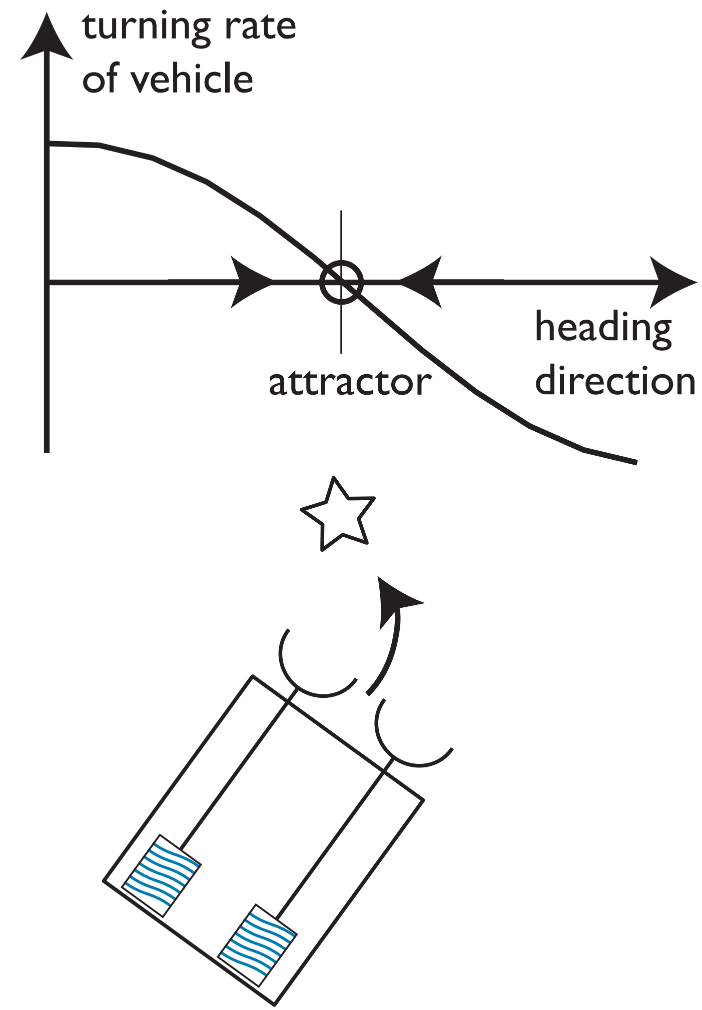


- feedforward nervous system
- + closed loop through environment
- => (behavioral) dynamics



Cybernetic reading of dynamics

- the CNS reduces the deviation from the desired behavioral state to zero
- by its sensors measuring the "error"
- and the CNS sending a feedback control signal to its actuators to reduce the error



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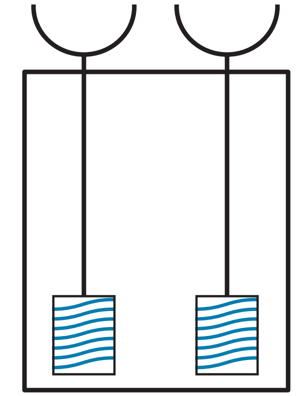
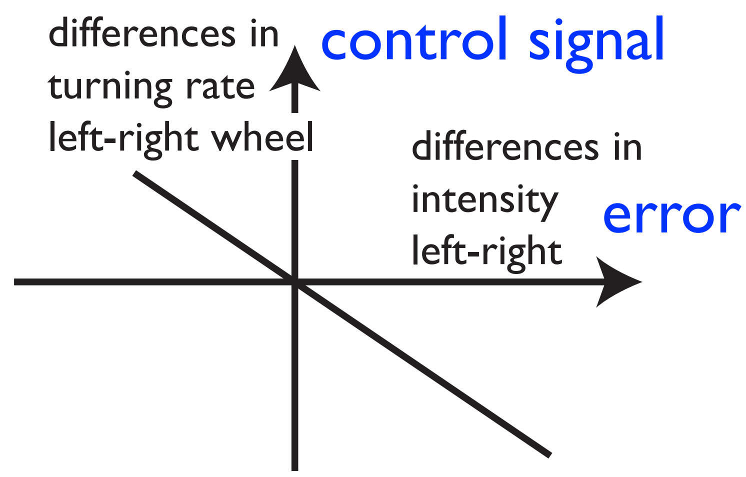
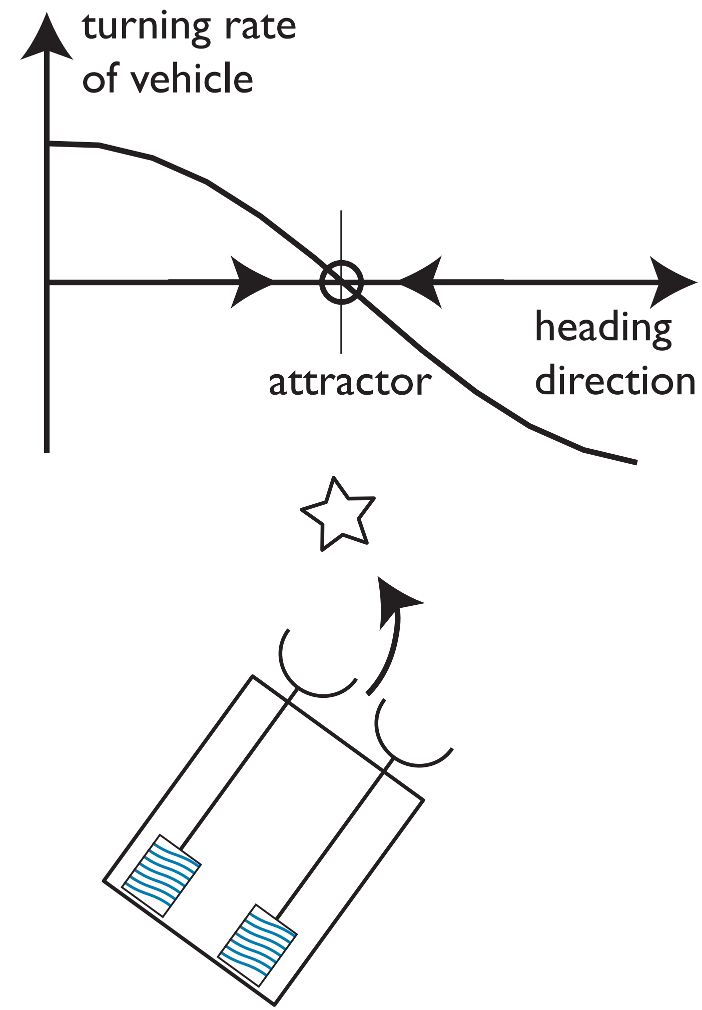




$$\Delta\omega = -c\Delta I$$

Cybernetic reading of dynamics

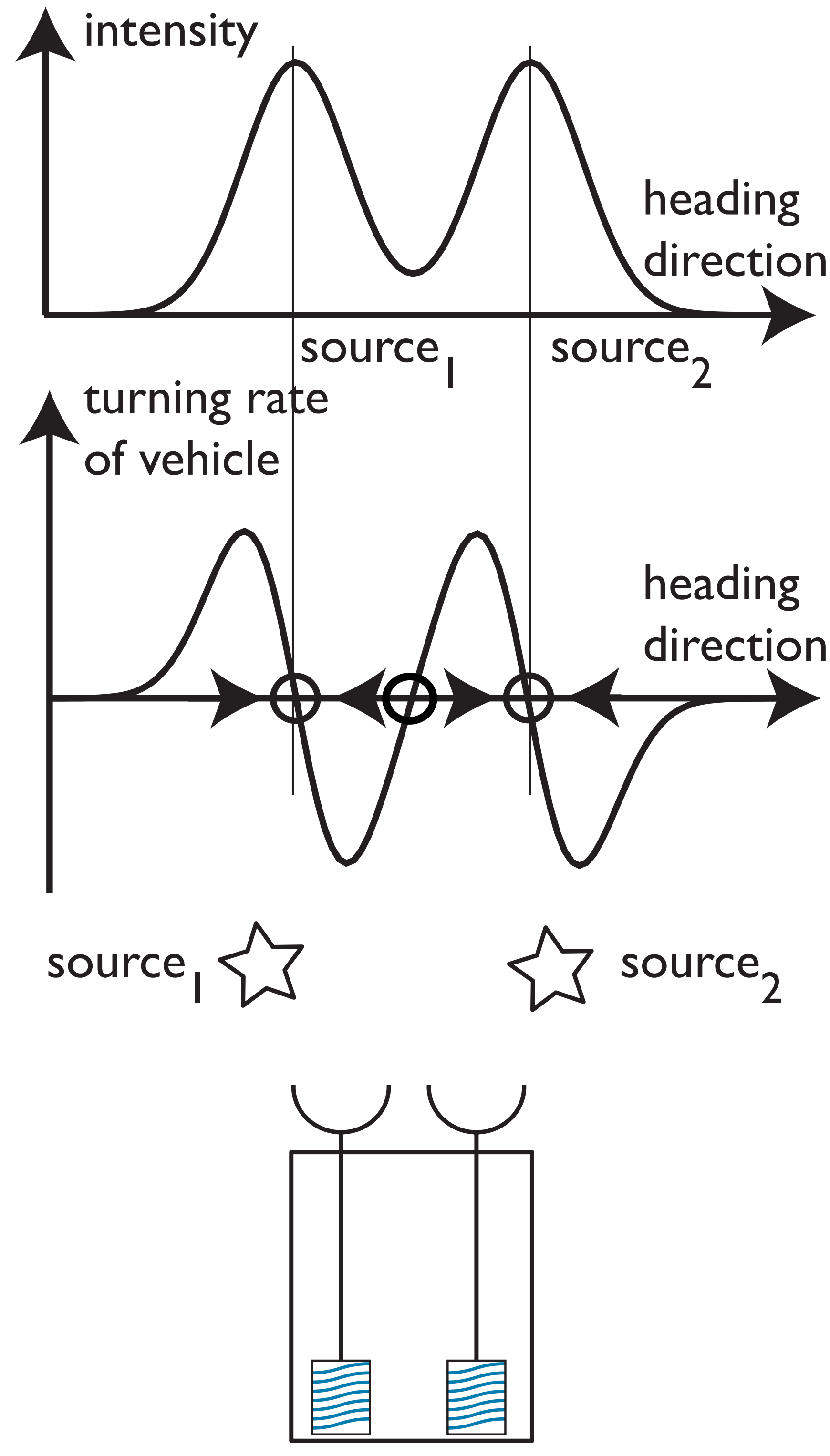
- … depends critically on the *closed loop*: the body's movement changes the sensory information..
- this is a loop through the environment
- the state of the dynamics is the body's physical state in the environment



Limits of the cybernetic view of dynamics

- presumes there is a single "goal" or set-point

- two sources
- bimodal distribution
- => bistable (non-linar) dynamics
- => selection decision



Limits of the cybernetic view of dynamics

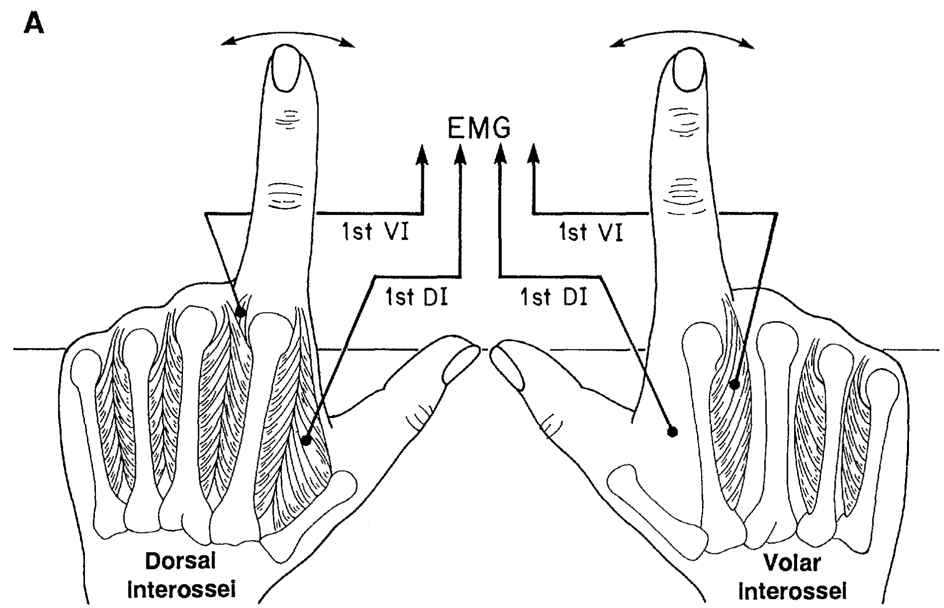
- far reaching implications …
- for the nature of the perceptual variables (not "error-signals")
- for the nature of the state variables (not "error-correcting-control-signals")
- => dynamics $\neq$ cybernetics/control theory

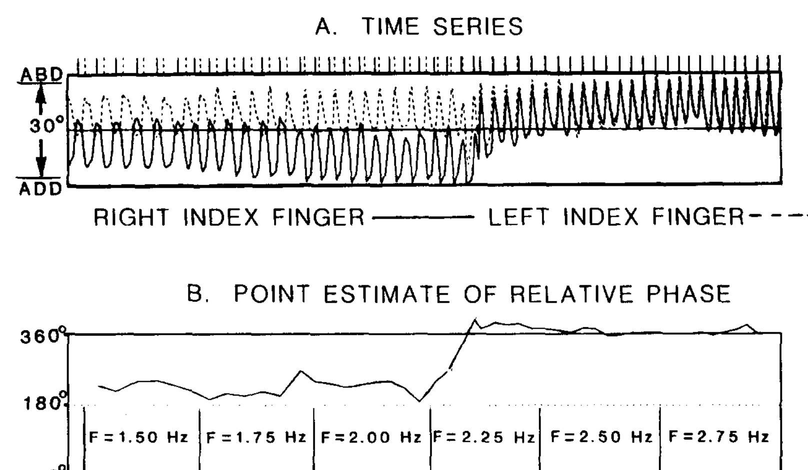
Why is stability important for behavioral dynamics?

- because it is sufficient… stability brings about the behavior…
- because it is necessary… without stability no behavior (not the correct behavior)

Stability and loss of stability in movement coordination

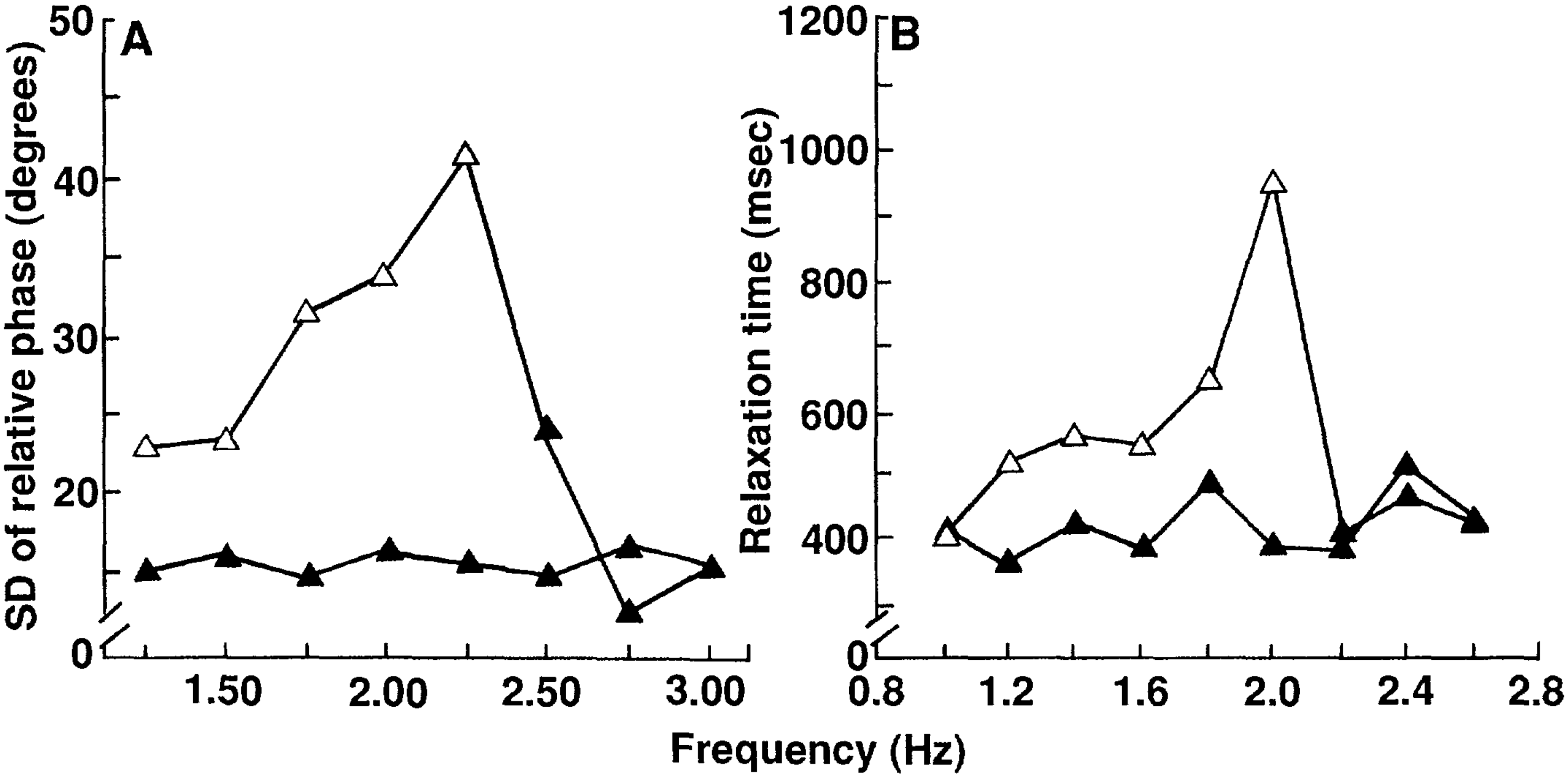
- stability of relative phase is constitutive of coordination
- loss of stability (enhanced variance, relaxation time) leads to change of coordination pattern





[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]

Stability and loss of stability in movement coordination



[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]

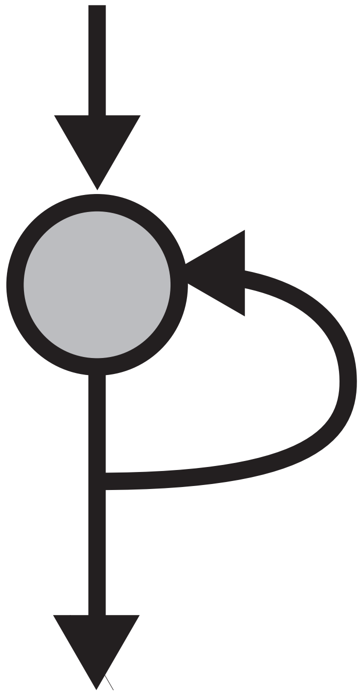
Stability and loss of stability in movement coordination

- => stability is both necessary and sufficient for the emergence of coordination patterns

[Kelso, Scholz, Schöner, 86; Schöner, Kelso, 88]

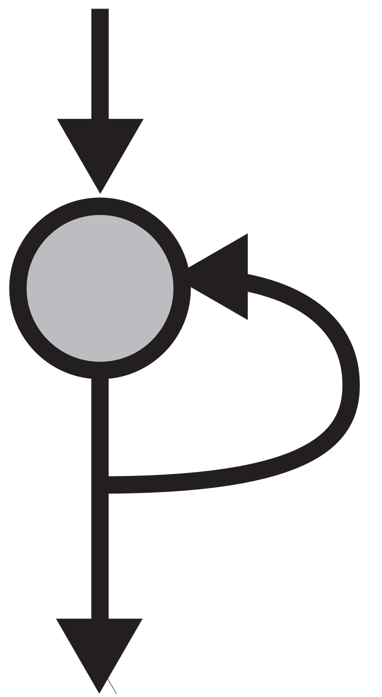
What about “internal” loops?

- internal to the nervous system …



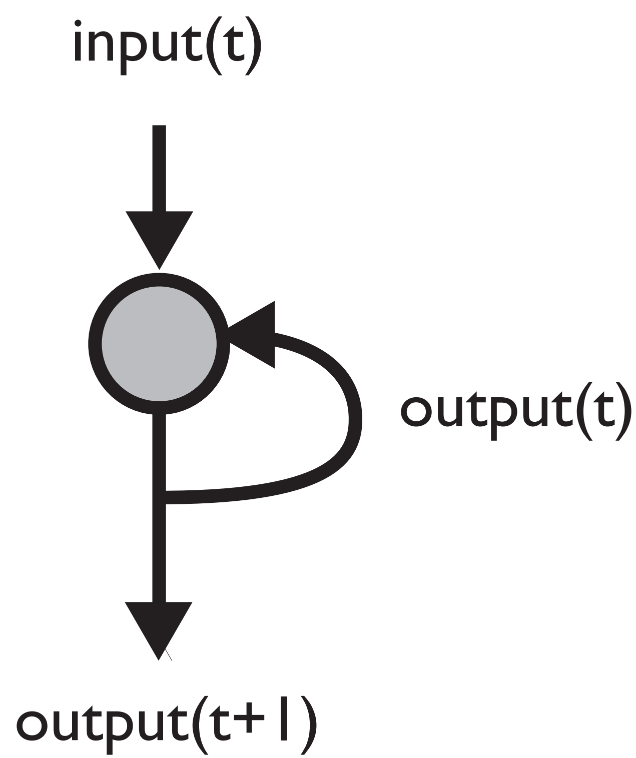
Internal loops

- internal loops are conceptually important to move beyond the framing of input/output function evaluation
- because they make it possible that neural activation arises or persists in the absence of input
  - examples: movement generation, working memory, sequences generation



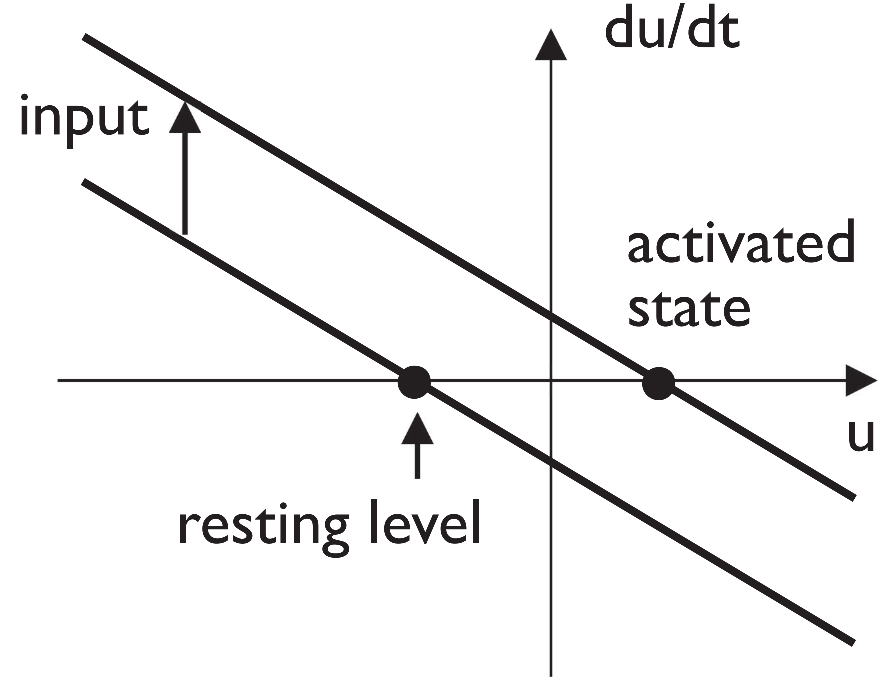
Internal loops

- ~ recurrence in neural network terms
- => implies time



Internal loops => neural dynamics

- time is not discrete (and spiking is asynchronous)
- => dynamics of the neural activation state, u: neural dynamics
- the "-u" term, inherited from membrane dynamics, is the source of stability



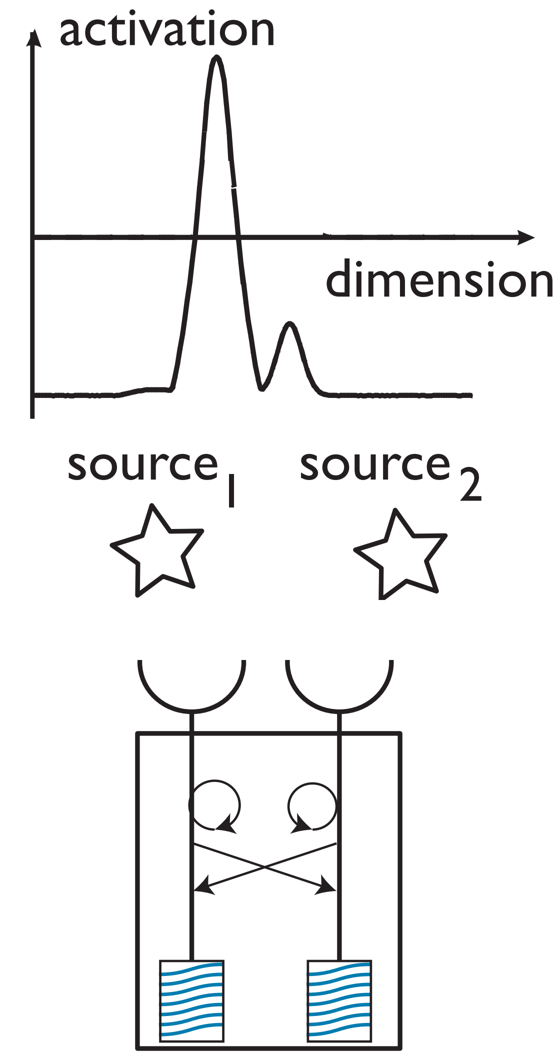
$$\dot{u}(t) = -u(t) + \text{resting level} + \text{input}(t)$$

Why is stability important in neural dynamics?

- because it is sufficient… as you will see..
- instabilities demarcate different cognitive functions… as you will see..

Why is stability important in neural dynamics?

- more intuitively: stability is resistance to change under perturbation, change of conditions/inputs..
    - e.g. resistance to distractor input… in a selection decision
- dense neural connectivity => in any given neural state, many connections provide “distractor input”.. that must be resisted



Neural dynamics

- as used in Dynamic Field Theory is a *sub-set of general neural network theory* (!)
- in which additional principles / constraints are imposed
  - stability
  - low-dimensionality
  - regular interaction functions
  - dynamic instabilities
  - active transients
- … and that is what this course is about