Anticipation in cybernetic systems: A case against mindless antirepresentationalism

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Kunstmatige Intelligentie / RuG

Overview

- From data to explanation: competing theories
- Neural representations
- Anticipation and attention: phenomena requiring representation
- Conclusions

War of worlds/words

- behavorism & associationism

$$Stim \rightarrow Resp$$

- traditional symbolistic cognitive science

$$Act = Cogn(Perc)$$

- ecological approaches

$$Act \Leftrightarrow Perc$$

- the brain-imaging revolution

$$Act = Brain(Perc)$$

Cognitive theories vs(?) Non-linear dynamic systems theories

- Grey Walter (1948)

  Emergent behavior in Turtle bots

- JJ Gibson (1960-1970)

  Ecological perception & action

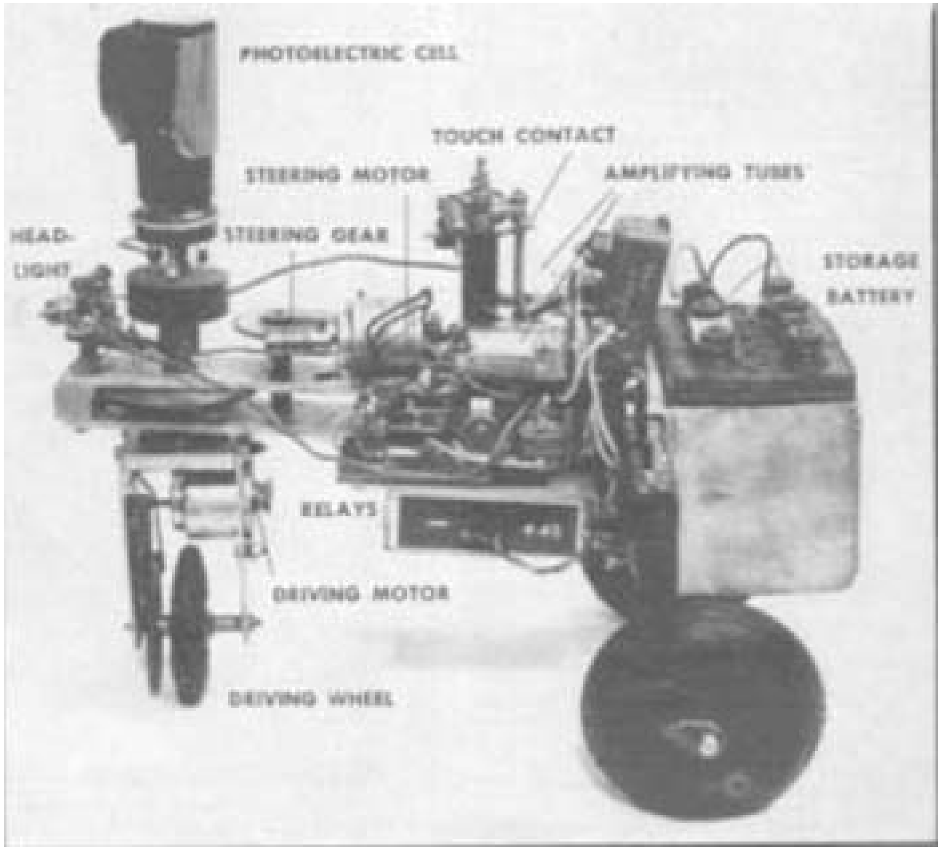
- Scott Kelso (198x)

  Action-Perception as a pattern formation process

- Rodney Brooks (1991)

  Intelligence without representation

Grey Walter (194x): behavioral complexity through simple perception/action mechanisms



"Elsie the artificial tortoise"

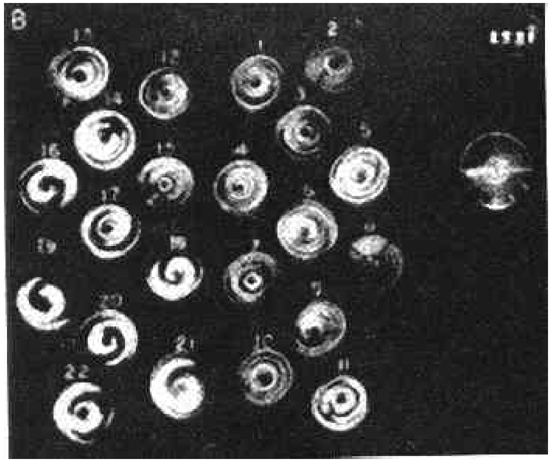
- -light sensor
- -thermionic valve
- -simple steering

-Nonlinearity, e.g.: go towards faint light, avoid bright light

Grey Walter (194x): turtle dance

two electromechanical turtles, each with a non-linear light sensor and a light source over its shell, produce a strange movement,
"**like the mating behavior of animals**"

Grey Walter, Wiener et al. 40’s/50’s…



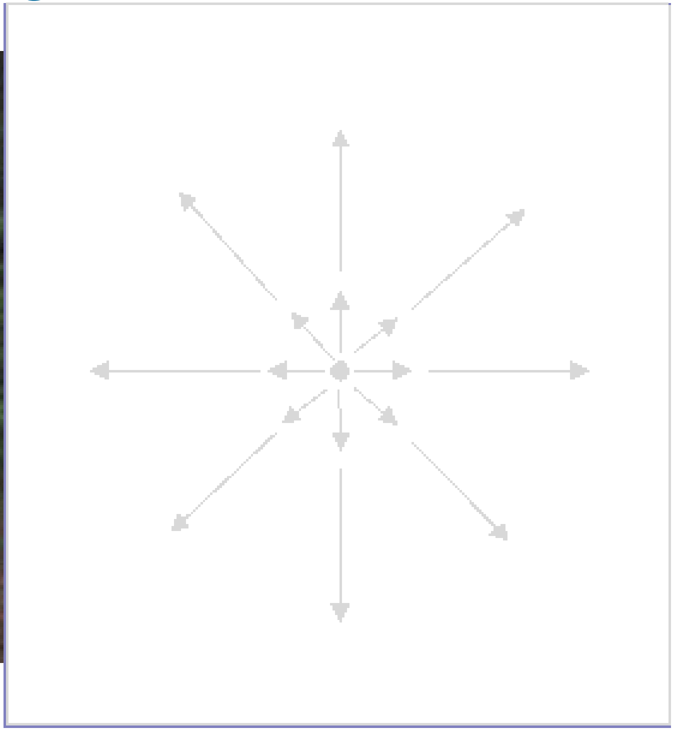
even in the early days there is a strong sense of friction between *“behavioral complexity through a few simple rules”*

and

“brain complexity through many simple neurons”

JJ Gibson 70's, Scott Kelso, 80's

- Perception/Action: seamless integration into the world. Example: ego motion and optic flow



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JJ Gibson 70's, Scott Kelso, 80's

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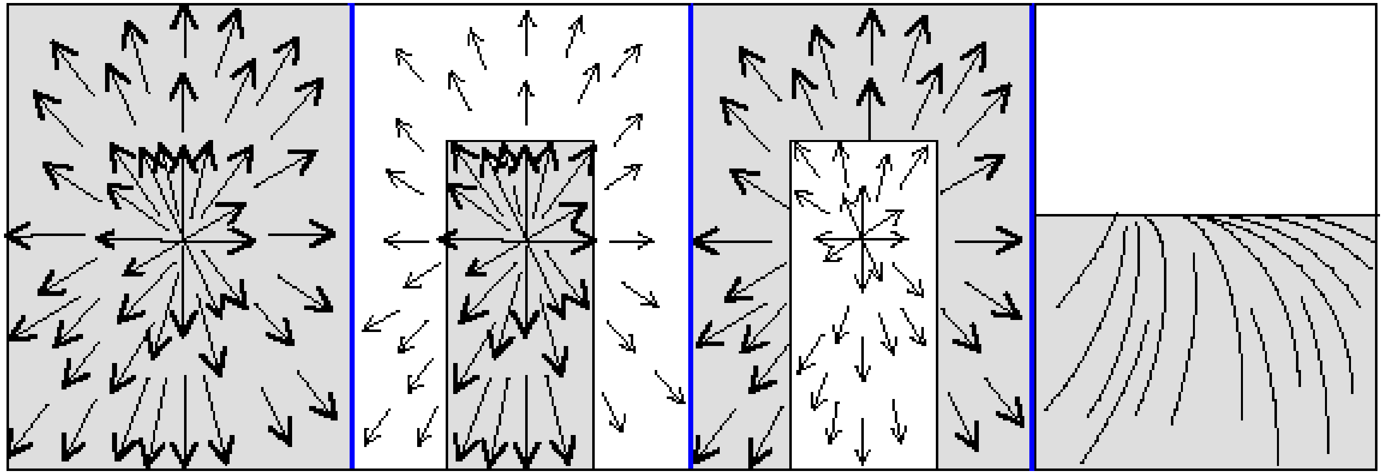

Approach | Approach obstacle | Approach hole | Curvilinear heading

JJ Gibson 70’s, Scott Kelso, 80’s

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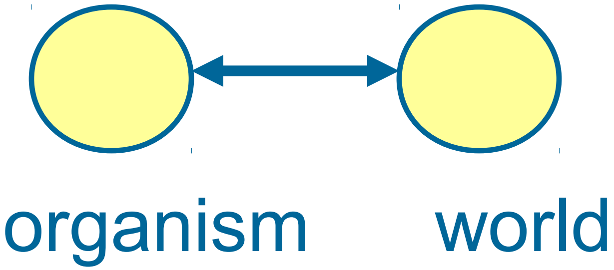

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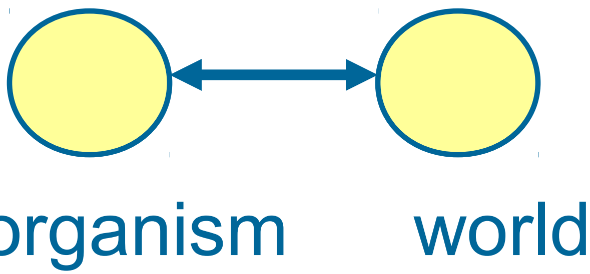
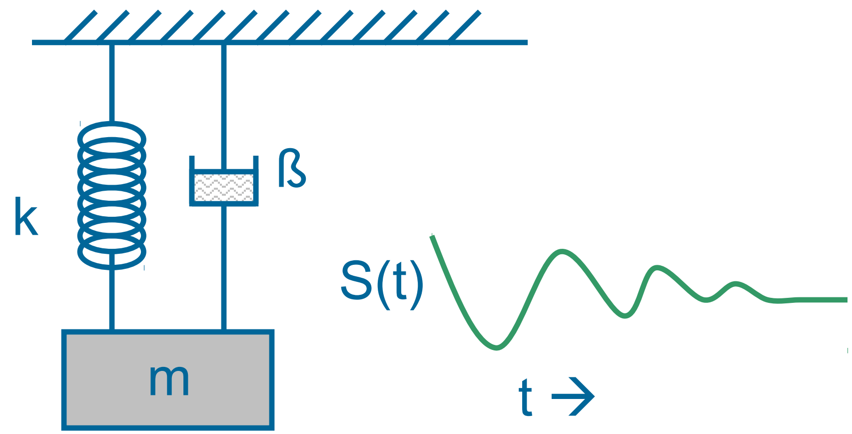
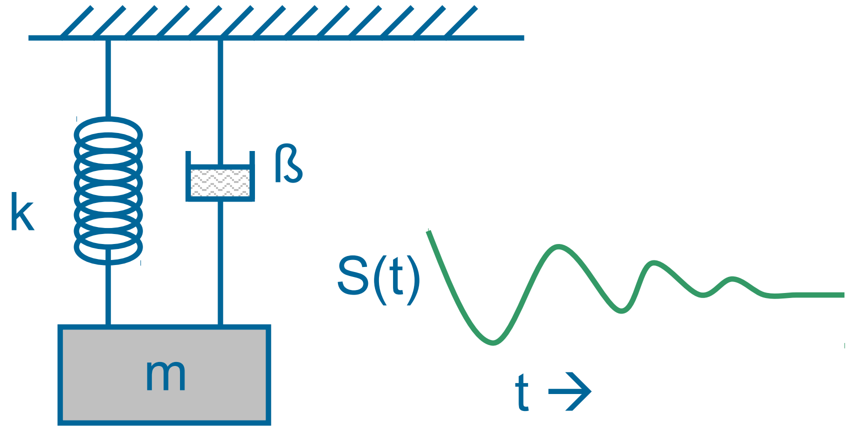




Like in: mass, spring & friction: what causes the motion?

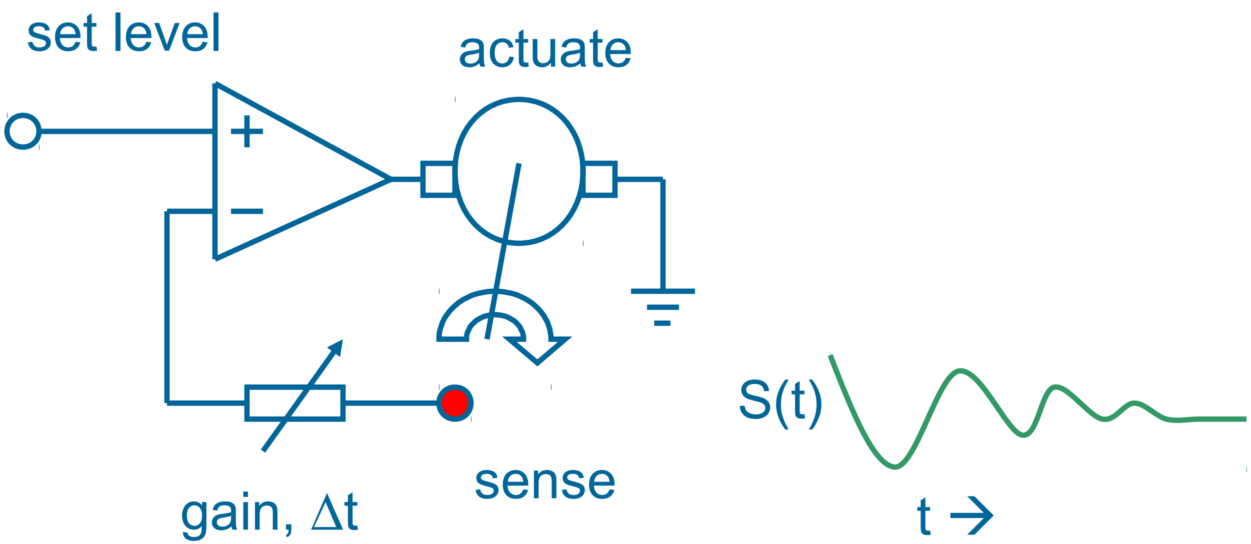
$$mx''_t + \beta x'_t + kx_t = c$$

Physics



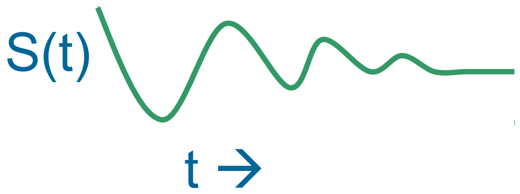
$$mx''_t + \beta x'_t + kx_t = c$$

Cybernetics

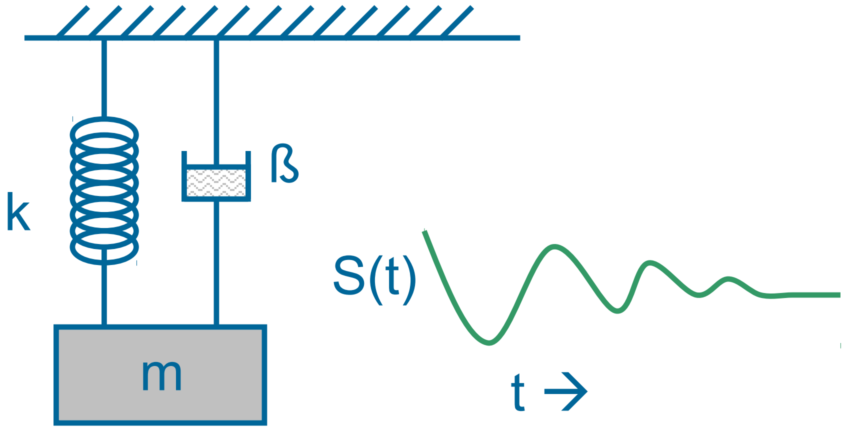


Informatics

```
while (true) {
    S := sense(state);
    if ( S < set_level ) {
        actuate(s + gain * ( set_level - S));
    }
    sleep(dt);
}
```



Physics… but in a wholistic sense



$$mx''_t + \beta x'_t + kx_t = c$$

cf. Example by van Gelder, Watt's governor: no representation, still behavior

meanwhile, in AI

- Cognitive Science & AI:
  Perception → **Cognition** → Action

- … does not seem to **work** that well in robotics

- Brooks: GOFAI needs representations & logic, but that does not help me in creating robots with believable intelligent behaviors

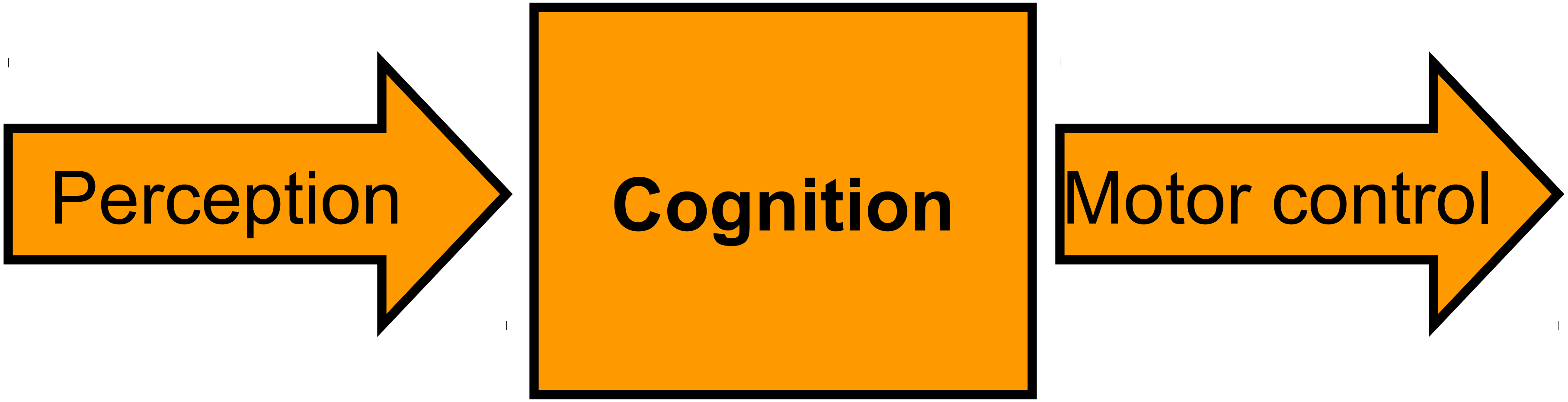
(*Elephants don't play chess,* Brooks, 1990)

late 1990's

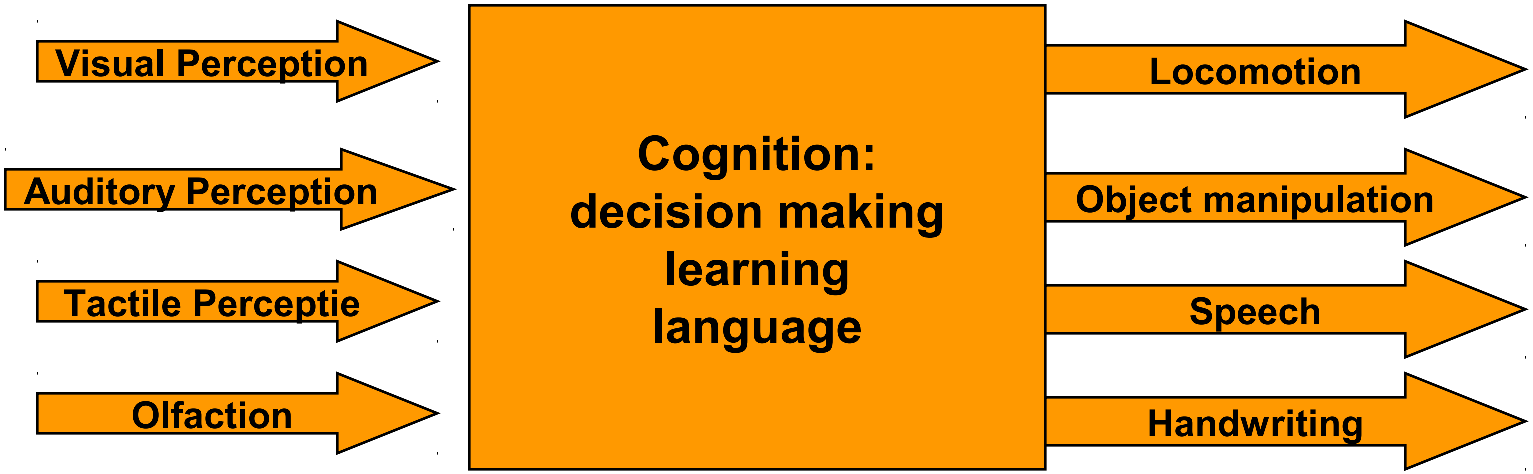
- ➔ behavior-based robotics
- ➔ Artificial Life

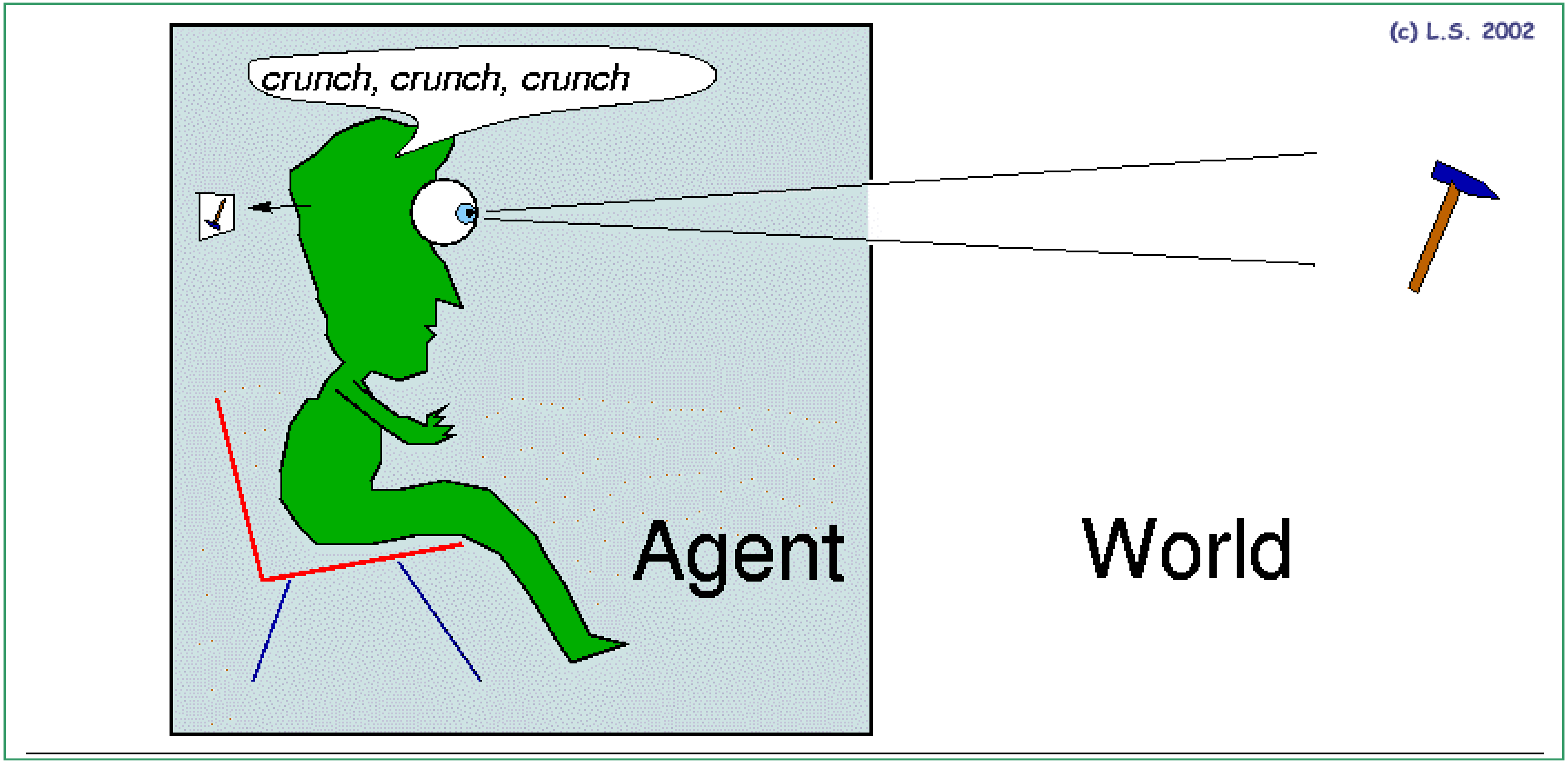
- ➔ representation avoiders

Traditional paradigm

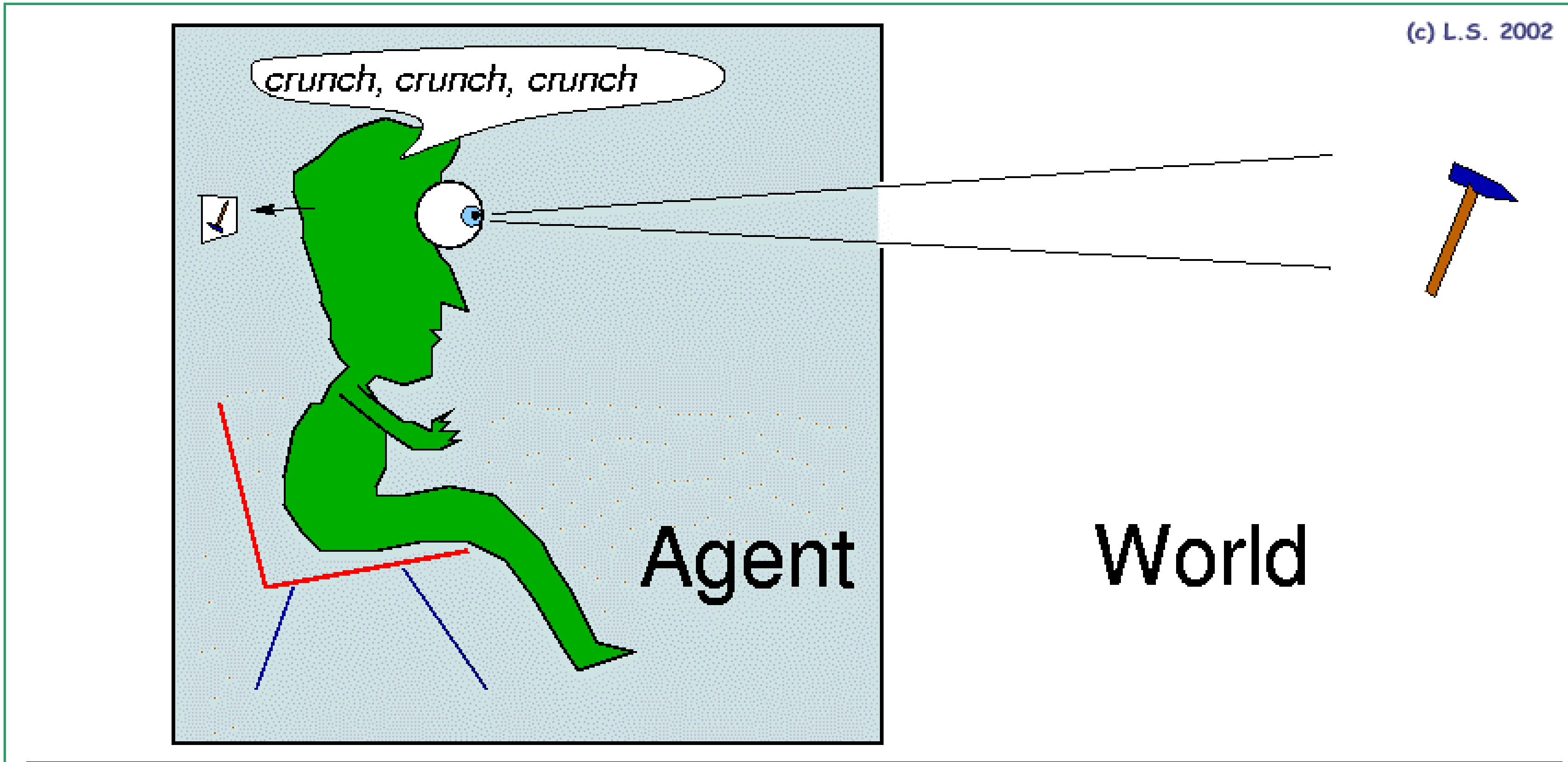


Epistemological Overspecialisation





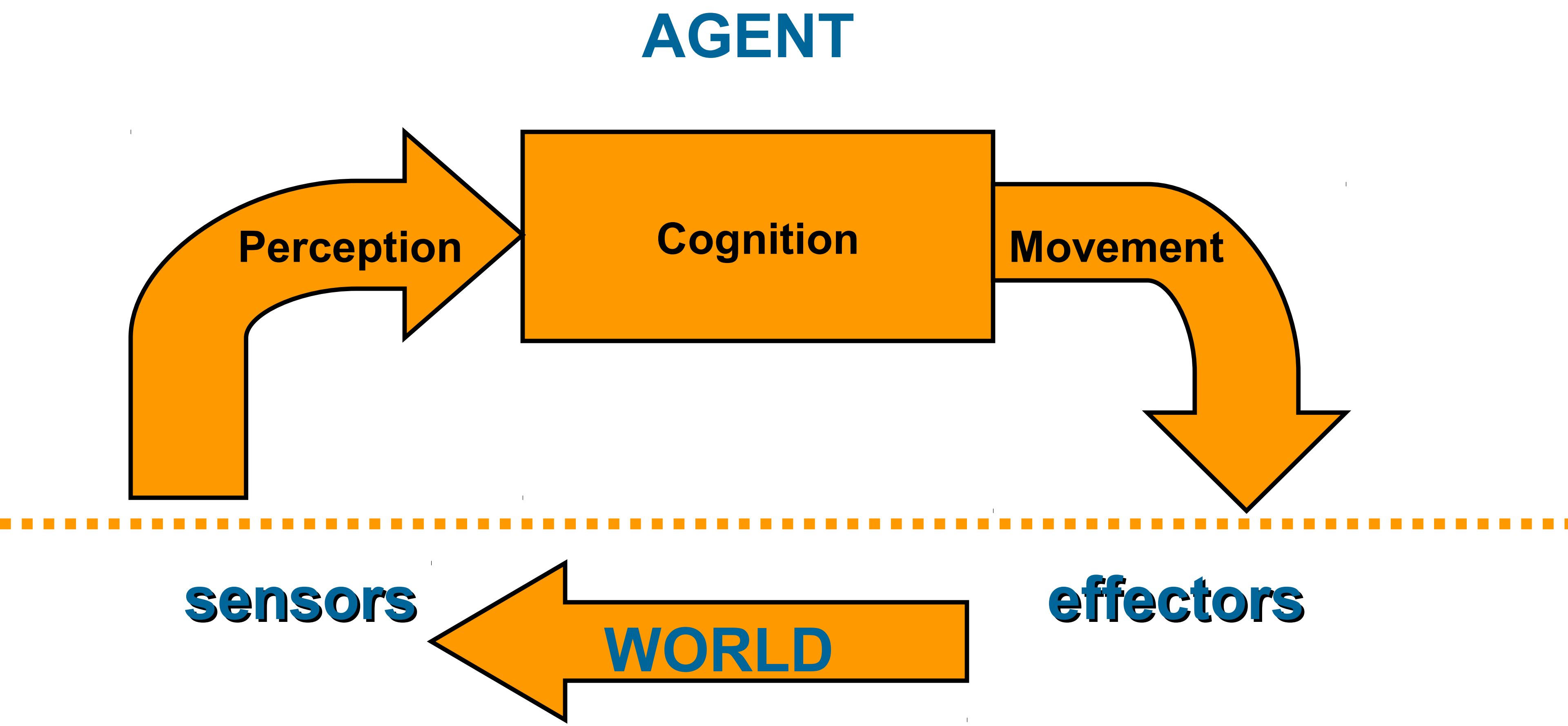
How Visual Perception is viewed



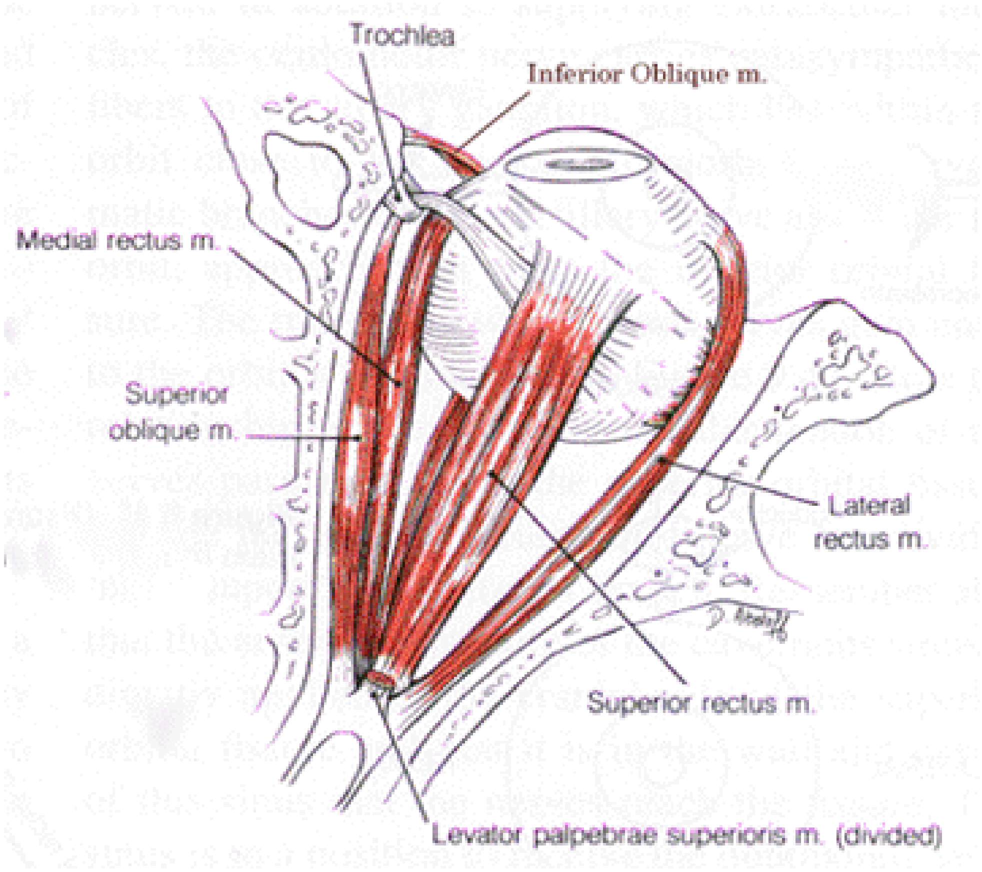
Couch–potato Peep–hole Perception

➔ a common paradigm in experimental psychology AND in computer vision!

Situated & Embodied systems: Close the Loop!



Input/Output are codependent



Input/Output are codependent

late 1990's

- ➔ behavior-based robotics
- ➔ Artificial Life

- ➔ representation avoiders

beware!

Representation in neural systems

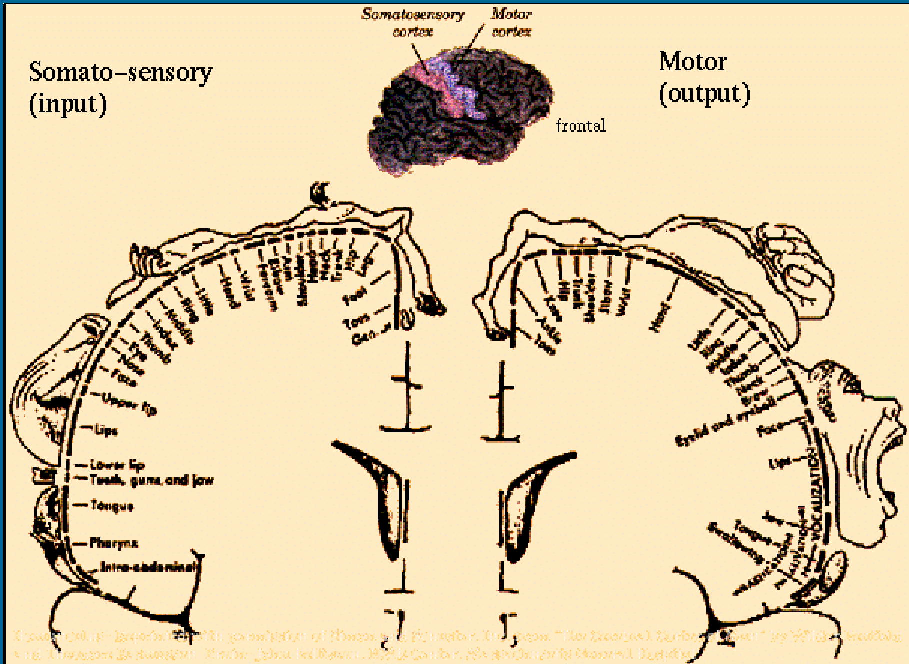
- Antirepresentationalists may throw away the baby with the bath water

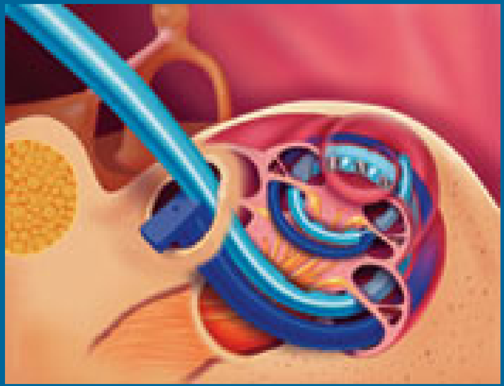
- Representations are abundant in neural systems

- In order to apply simple rules, one may need complex representations!

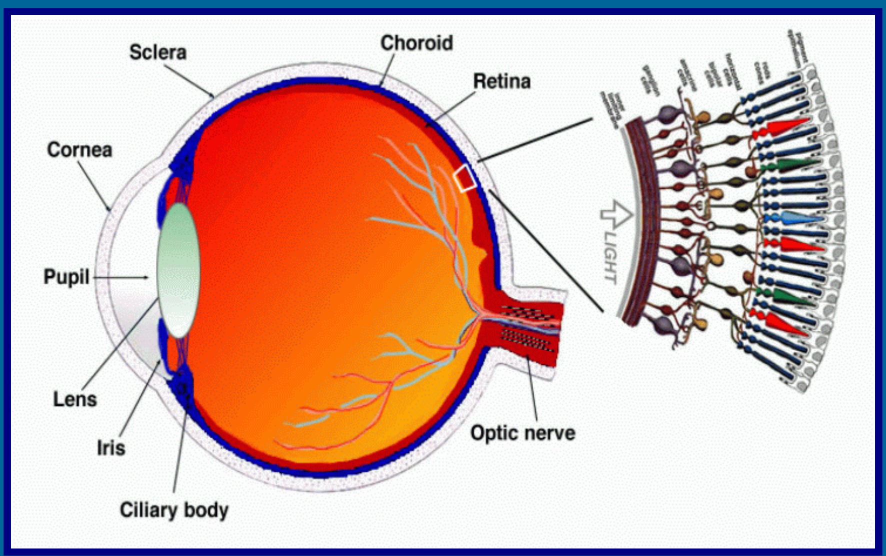
Neural representations

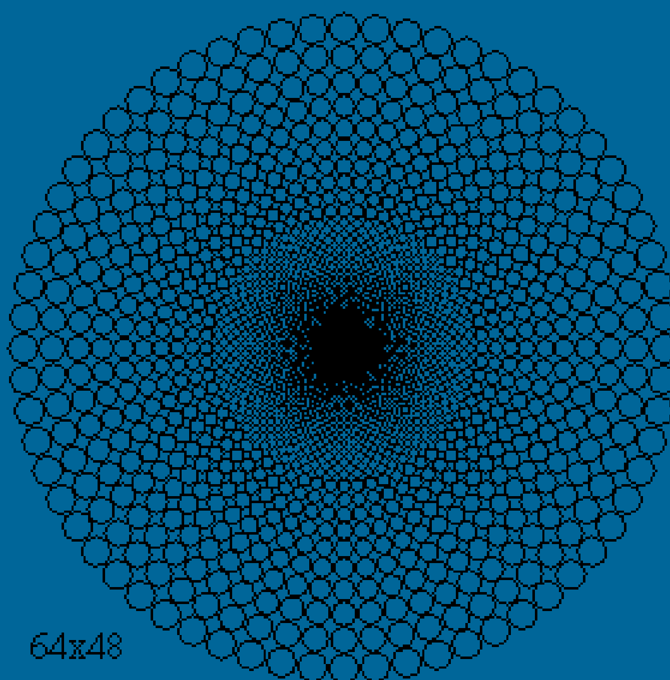
- Topological: vision, hearing, tactile sensing
- Quantity coding: firing rate and recruitment
- Distributed representations
- Timing, vetoing, synchronisation,coherence



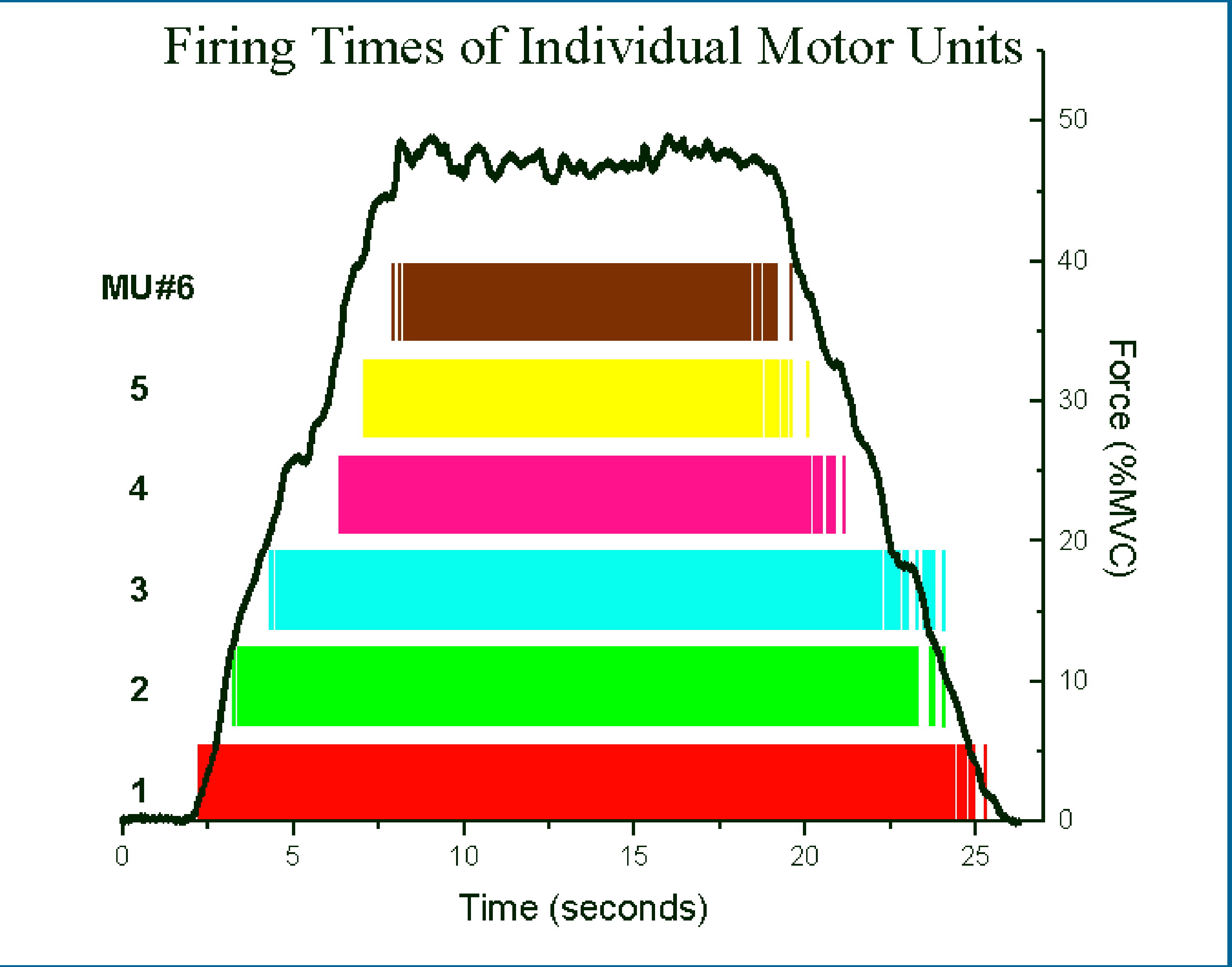


cochlea ~= G(f)





x,y → log(r), phi

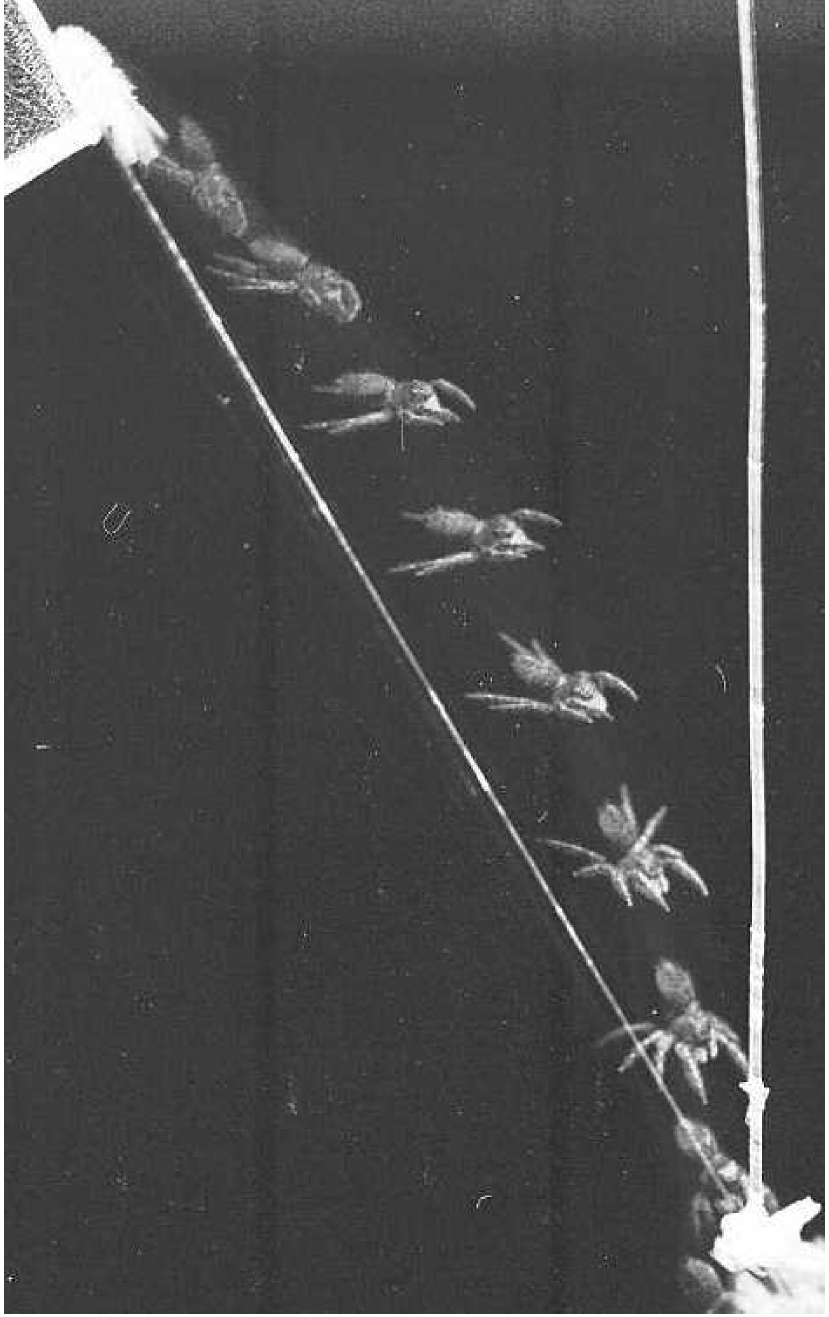


(Fig: neuromuscular research center)

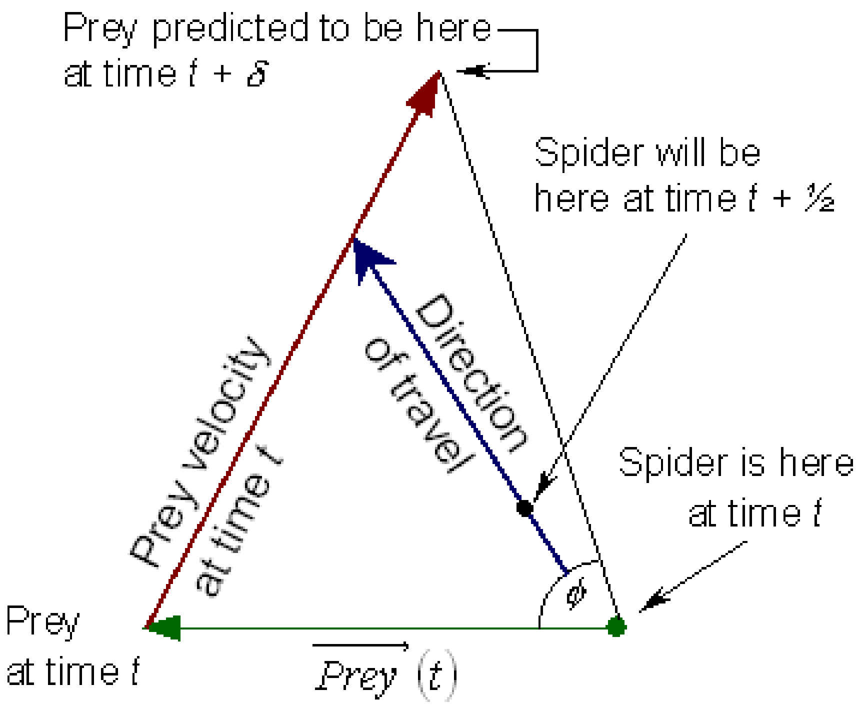
"Quantity" = #units active (coarse control)

& their firing rate (fine control)

(Hill, 2001)



(Hill, 2001)

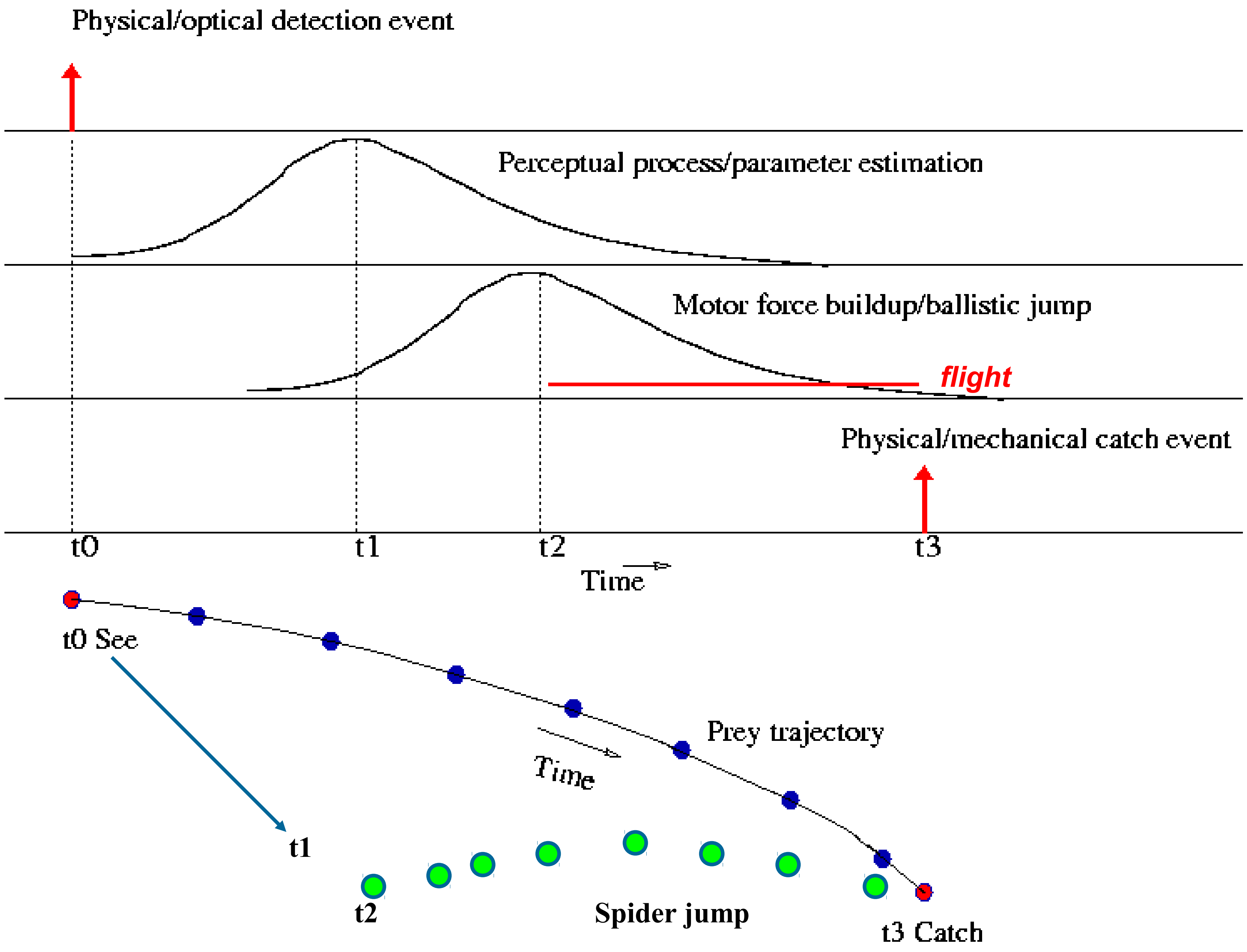


(Forster & Forster, 1999)

Properties of the spider jump

- Determination of prey velocity on the basis of optic flow
- **Preparation** of the muscle contraction amplitude, direction and timing,

  in advance
- Jump
- Flight (almost no trajectory corrections possible!)
- Catch or miss



Physical/optical detection event
Perceptual process/parameter estimation
Motor force buildup/ballistic jump
flight
Physical/mechanical catch event
t0
t1
t2
t3
Time
t0 See
Prey trajectory
Time
t1
t2
Spider jump
t3 Catch

The spider jump …

- is **not** purely reactive (i.e. non Brooksian)
- the jump is planned in a **pro-active** manner
- towards a position where there is
  no visual percept of the prey
- estimating a future time of arrival

- ➔ there must be a represented estimate
  of a predicted state in the future

System models: stateless, reactive

- $A = F(P)$

Reactive, with perceptual memory

- $A = F(P_{[t0,t]})$

reactive with perceptual and action memory

- $A = F(P_{[t0,t]}, A_{[t0,t-\Delta t]})$

proactive, with perceptual and action memory and prediction window for perception and action

- $A = F(P_{[t0,t]}, A_{[t0,t-\Delta t]}, P_{[t,t+dt]}, A_{[t,t+dt]})$

proactive, with perceptual and action memory and prediction window for perception and action

- $A = F(P_{[t0,t]}, A_{[t0,t-\Delta t]}, P_{[t,t+dt]}, A_{[t,t+dt]})$

Prediction of the future perceptual and motor state is essential when there is any form of time delay within or outside the agent.

System models

- $A = F(P)$
- $A = F(P_{[t0,t]})$
- $A = F(P_{[t0,t]}, A_{[t0,t-\Delta t]},)$
- $A = F(P_{[t0,t]}, A_{[t0,t-\Delta t]}, P_{[t,...]}, A_{[t,...]})$

cf: frontal and prefrontal cortex in primates

Example: The non-linear IIR

IIR = infinite impulse response

$$y(t+\Delta t) = \mathbf{F} \left(\sum_{\tau} w_{\tau} x(t-\tau), \sum_{\tau} v_{\tau} y(t-\tau) \right)$$

Example: The multipurpose non-linear IIR

$$\mathbf{y}(t+\Delta t) = \mathbf{F} \quad (\textstyle\sum_\tau w_\tau \mathbf{x}(t-\tau), \sum_\tau v_\tau \mathbf{y}(t-\boldsymbol{\tau}))$$

"the next action is a non-linear function
of (1) the weighted sum of *things x seen until now*
and (2) the weighted sum of *things y done until now*"

Example: The multipurpose non-linear IIR

$$\mathbf{y}(t+\Delta t) = \mathbf{F} \quad (\sum_{\tau} \alpha_{\tau} \mathbf{x}(t-\tau), \sum_{\tau} \beta_{\tau} \mathbf{y}(t-\tau))$$

"the next action is a non-linear function of (1) the weighted sum of *things **x** seen until now* and (2) the weighted sum of *things **y** done until now*"

(it can be used for modeling a plethora of processes in physics, engineering and biology)

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Conclusion (1)

- Behavior may be determined by simple rules
- *but the complexity of the brain is apparent (?)*

- Some may want to do away with representation
- *but neural representation is the essence of cognitive neuroscience*

Conclusion (2)

- Even “simple” animals may need to estimate the state of the world in the future

this can only be realized if a persistent representation of the relevant facets of that world is available for prediction