Affective Decision Making in Robots

Lola Cañamero
L.Canamero@herts.ac.uk
www.emotion-modeling.info
Room LC254

Additional reading

- From the textbooks:
  - From *Behavior-Based Robotics*: Chapters 3, 4 (sections 4.1 to 4.4)
  - From *Understanding Intelligence*: Chapters 7, 11
- Papers available on Canvas:
  - Paper by Rodney Brooks
  - Avila-García, O., Cañamero, L. (2004): Using Hormonal Feedback to Modulate Action Selection in a Competitive Scenario. In: Proc. 8thIntl. Conf. Simulation of Adaptive Behavior (SAB 2004), pp. 243–252. MIT Press, Cambridge, MA.
  - Cañamero, Lola, Avila-García, Orlando (2007): A Bottom-Up Investigation of Emotional Modulation in Competitive Scenarios. In: Paiva, Ana,Prada, Rui, Picard, Rosalind W. (eds.) ACII 2007 - Affective Computing and Intelligent Interaction, Second International Conference September 12-14, 2007, Lisbon, Portugal. pp. 398-409.

Architectures for behavior/action selection

- **Behavior selection problem:** given an agent with multiple time-varying goals, a repertoire of behaviors (some executable), and specific sensor data, *what actions should this agent take next* so as to best satisfy the achievement of its goals?
- **How can an agent decide what to do next** so as to further the progress toward its multiple time-varying goals?
  - How can it deal with contingencies and opportunities?
  - How can it arbitrate among conflicting goals?
  - How can it deal with noisy sensors and actuators?
- **Sub-problems** to deal with:
  - what is the nature of goals?
  - what is the nature of sensor data?
  - what are the arbitration and command fusion mechanisms?

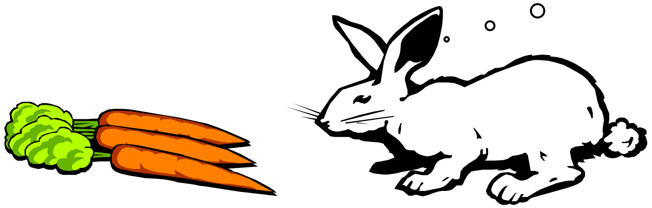
Requirements on behavior selection

1. Favor actions contributing to the goals
2. Deal flexibly with *opportunities* and *contingencies*
3. Be *real time* (fast enough for the dynamics of environment)
4. *Minimize* unnecessary *switching* between behaviors/goals
5. *Improve* with experience
6. *Graceful degradation* when components break down or unexpected changes happen
7. *Never get completely stuck* in a loop or deadlock situation
8. *Do not* mindlessly *pursue unachievable goal*
9. Be "*good enough*" for environment & task at hand:
   a. agent achieves its goals within constraints (adequacy)
   b. "optimize" behavior w.r.t. selective pressures (ecological evaluation)

Affective decision making systems

1 ...

Carrots … Eat !!

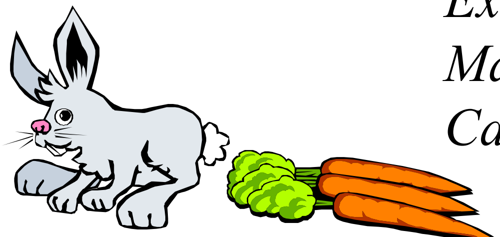


Reactive system

Examples:
Braitenberg Vehicles;
Subsumption architecture

2 ...

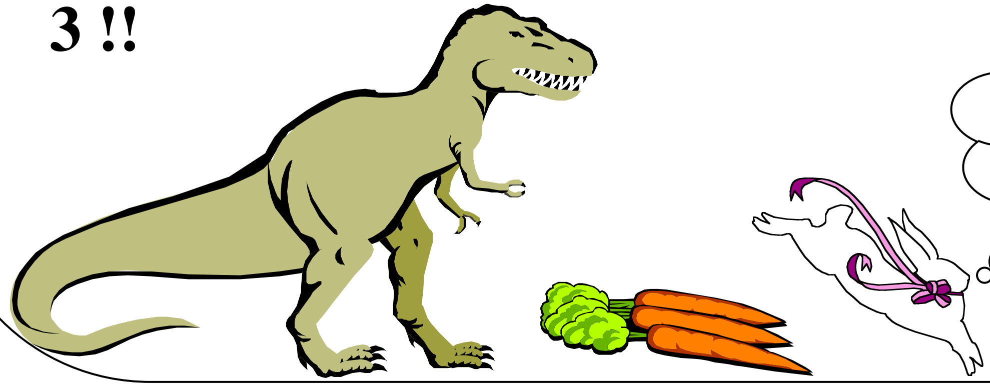
I am starving … Where had I seen those carrots?



Motivated system

Examples:
Maes' AS architecture;
Cañamero's AS architecture

3 !!



I am starving, but this might not be the right moment!!!

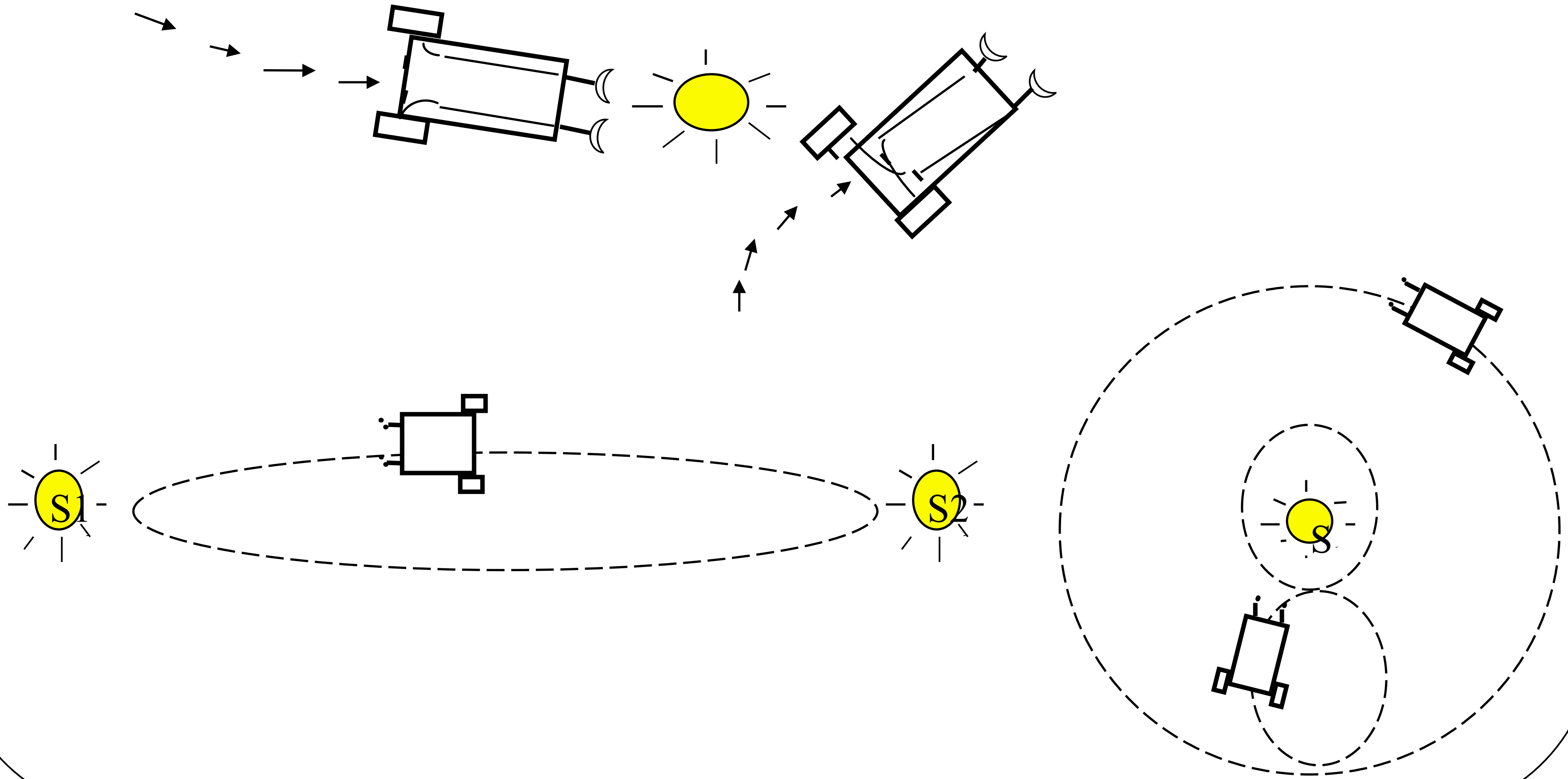
Emotional system

Examples:
Cañamero's AS architectures

Reactive decision-making systems

- Direct coupling of perception and action fosters timely robot response in dynamic and unstructured worlds.
- Typically in the context of motor behaviors, but can also be in other areas (e.g. social interaction)
- Reactive behavior control is the simplest type of affective behavior and affective decision making (e.g., fear-like aversive behaviors)
- Reactive control architectures can be based either on continuous or on discrete mappings between sensors and actuators. Architectures based on discrete mappings are also called behavior-based architectures.
- Examples of continuous mappings: simple behaviors like taxis and kinesis; **Braitenberg Vehicles**
- A prominent example of discrete mapping / behavior-based reactive control is Rodney Brooks' **Subsumption Architecture**.

Braitenberg Vehicles (cf. Lecture 2b)



Layered reactive control, subsumption:

Priority of behaviors

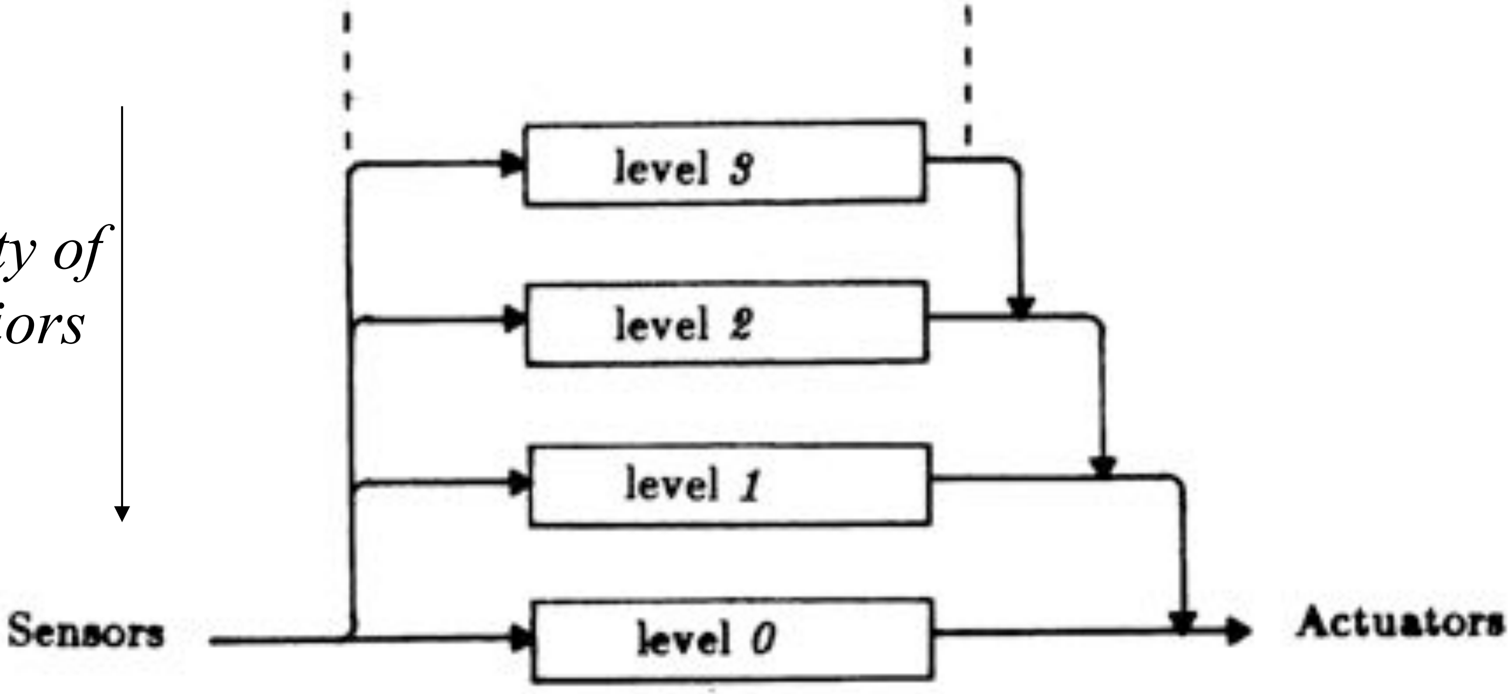
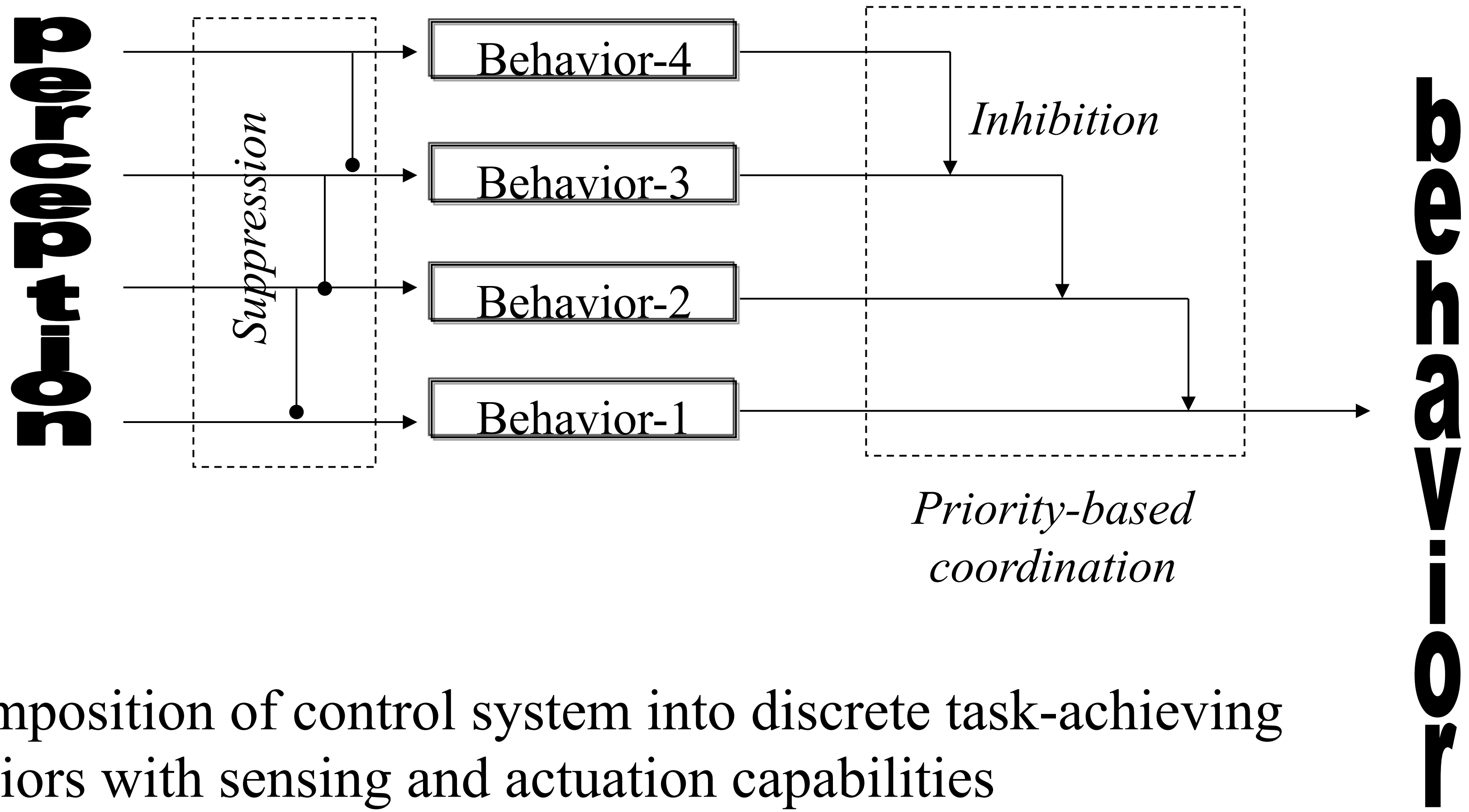


Figure 3. Control is layered with higher level layers subsuming the roles of lower level layers when they wish to take control. The system can be partioned at any level, and the layers below form a complete operational control system.

R. Brooks' Subsumption architecture



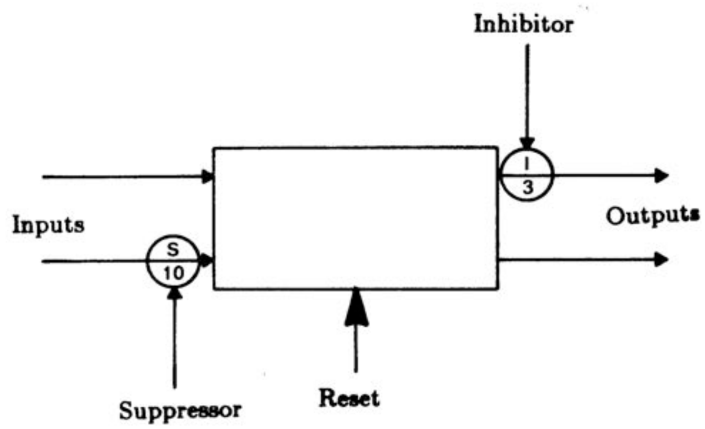
- Decomposition of control system into discrete task-achieving behaviors with sensing and actuation capabilities
- Main problem: these architectures can be difficult to engineer

Main features of Subsumption architecture

- **Additivity**:
  - Layered control: incrementally “higher” levels of competence to achieve increasingly complex behavior
  - Higher levels/layers subsume lower levels/layers without changing them
- **Multiple goals**:
  - Individual layers working on individual “goals” concurrently
  - Suppression mechanism mediates the actions that are taken
- **Multiple sensors**:
  - Avoids sensor fusion problems
  - Not all sensor readings used by all layers; layers use “relevant” sensor readings
- **Robustness**:
  - Provided by multiple sensors / redundancy
  - Also as lower layers continue to function if higher layers misfunction

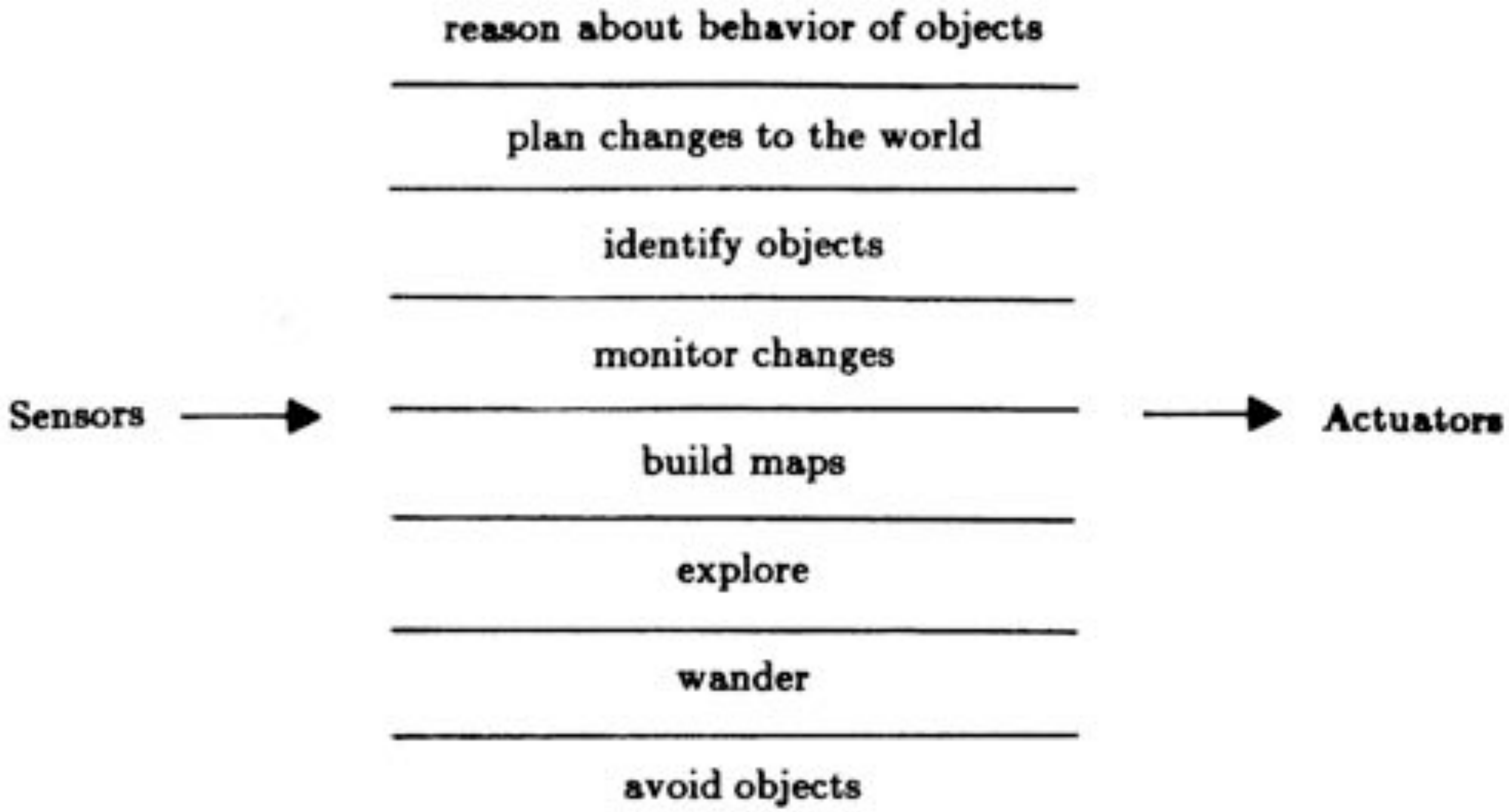
Implementation of SA: AFSM

- Brooks' early architectures implemented in hardware: connected "wires" "pass messages" within and across layers; inhibition and suppression mechanisms
- Layers composed of "modules" of AFSM
- AFSM: augmented finite state machines, FSM augmented with timer
- Very complex and tricky to implement, many AFSM required to implement "competences" / "behaviors"



Mobile robot example

- Example from R.A. Brooks (1985), "A Robust Layered Control System for a Mobile Robot". MIT AI-Memo 864.
- A robot wanders and explores the environment avoiding obstacles (3 bottom layers)



Level 0 competence: “avoid”

- Ensures that the robot does not come in contact with other objects
- Will avoid stationary objects
- Will flee from moving obstacles
- Consists of a number of mini-modules, including “sonar”, “collide”, “feelforce”, “runaway”, “turn”, and “forward”
- The latter two interact directly with the robot

Level 0 competence

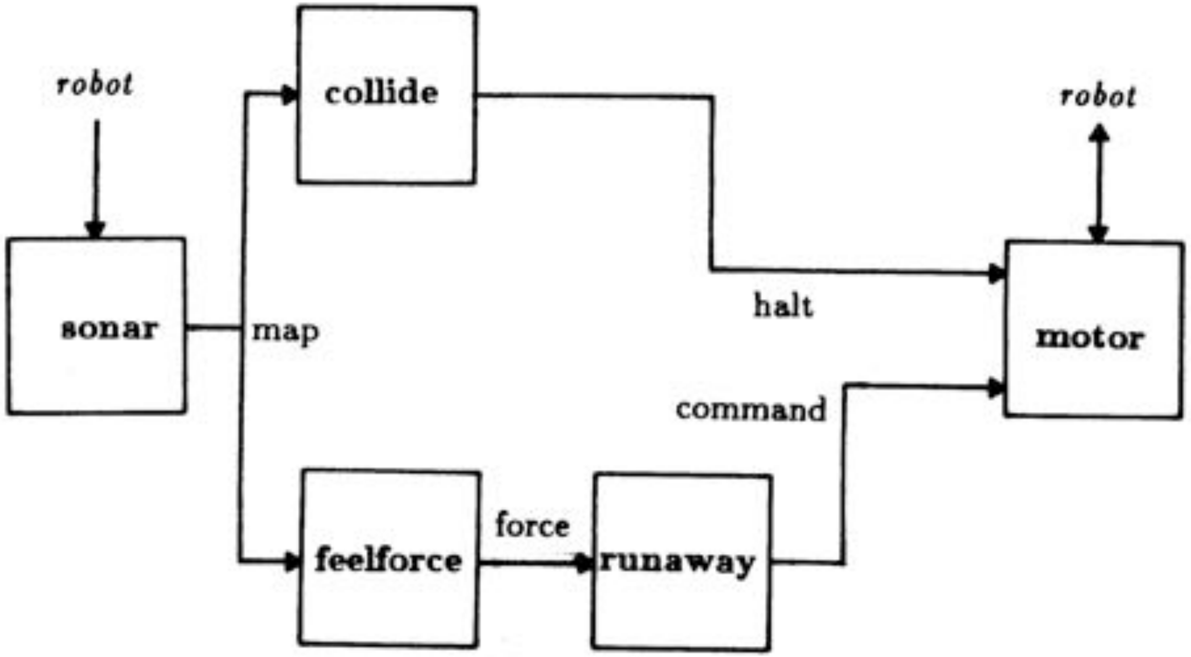
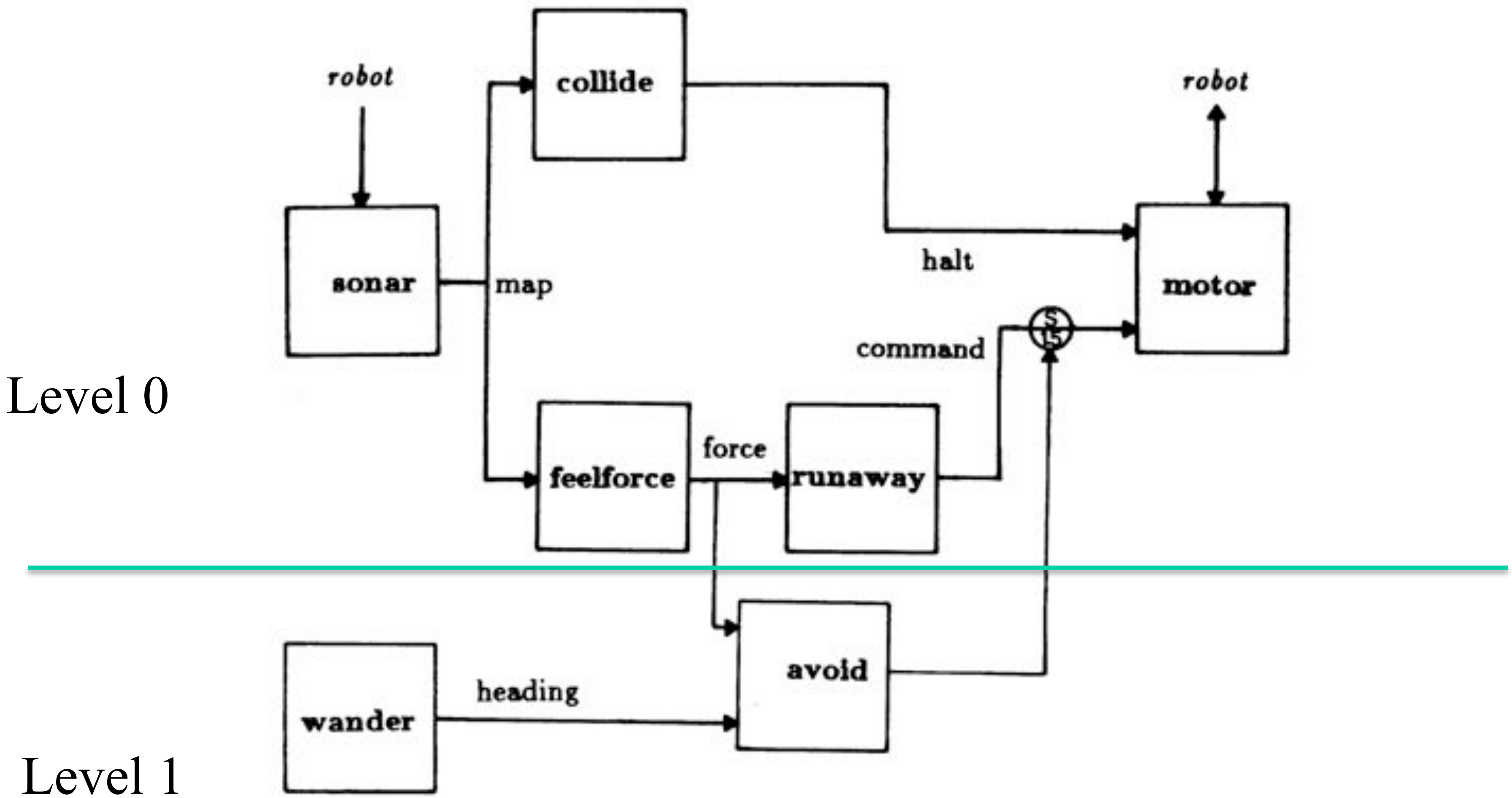


Figure 5. The level *0* control system.

Level 1 competence: “wander”

- Creates a new destination for the robot every few seconds
- Relies on 0-level functionality to avoid obstacles
- Adds two mini-modules to the system: “Wander”, and “Avoid”

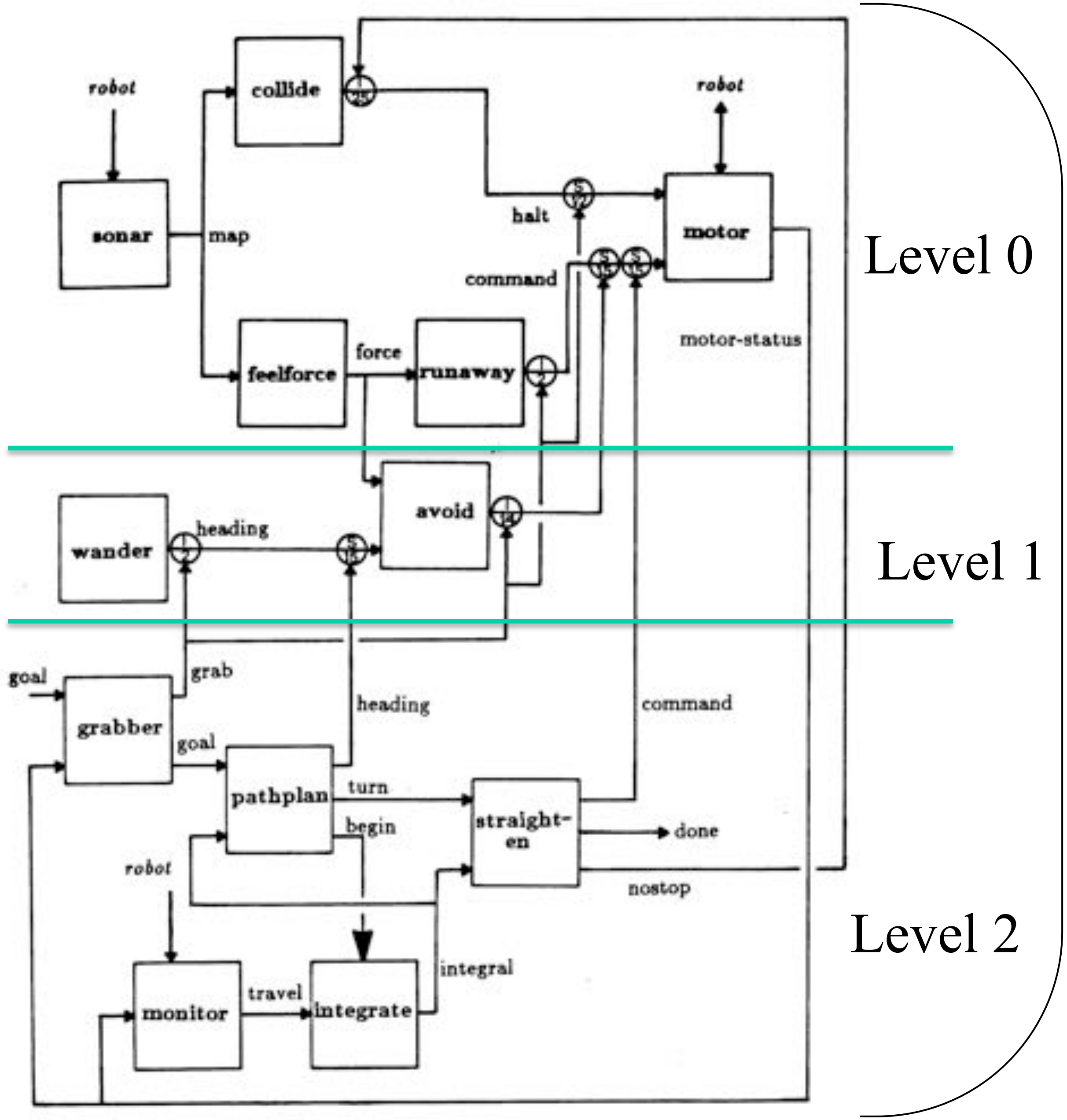
Level 1 competence + level 0 competence



Level 2 competence: “explore”

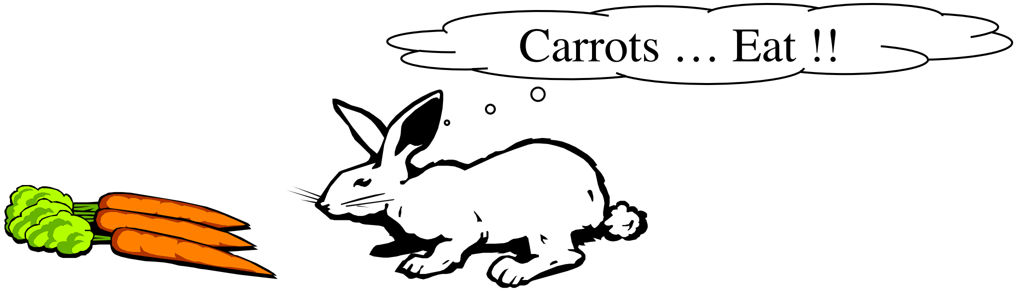
- Allows the robot to seek out interesting places to visit
- Adds the mini-modules “Stereo”, “Look”, “Pathplan”, “Integrate”, and “Whenlook”
- Impedes output of level 1 layer to reach its goal (inhibition)

Level 2 competence + level 1 competence + level 0 competence



Affective decision making: motivated

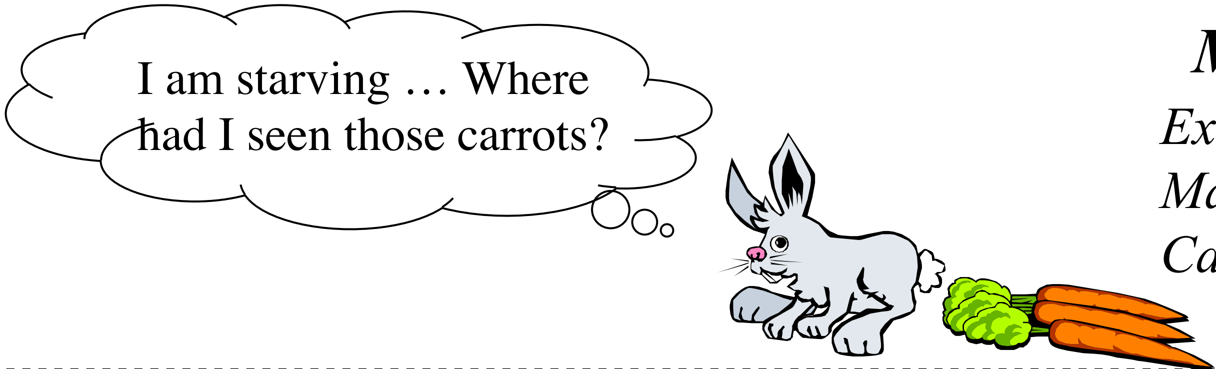
1 ...



Reactive system

Examples:
Braitenberg Vehicles;
Subsumption architecture

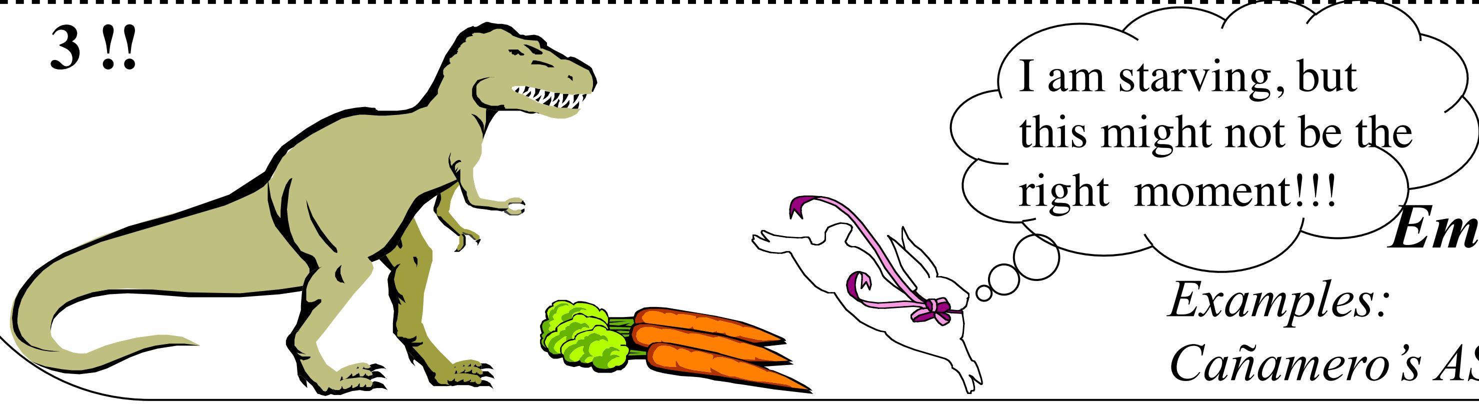
2 ...



Motivated system

Examples:
Maes' AS architecture;
Cañamero's AS architecture

3 !!



Emotional system

Examples:
Cañamero's AS architectures

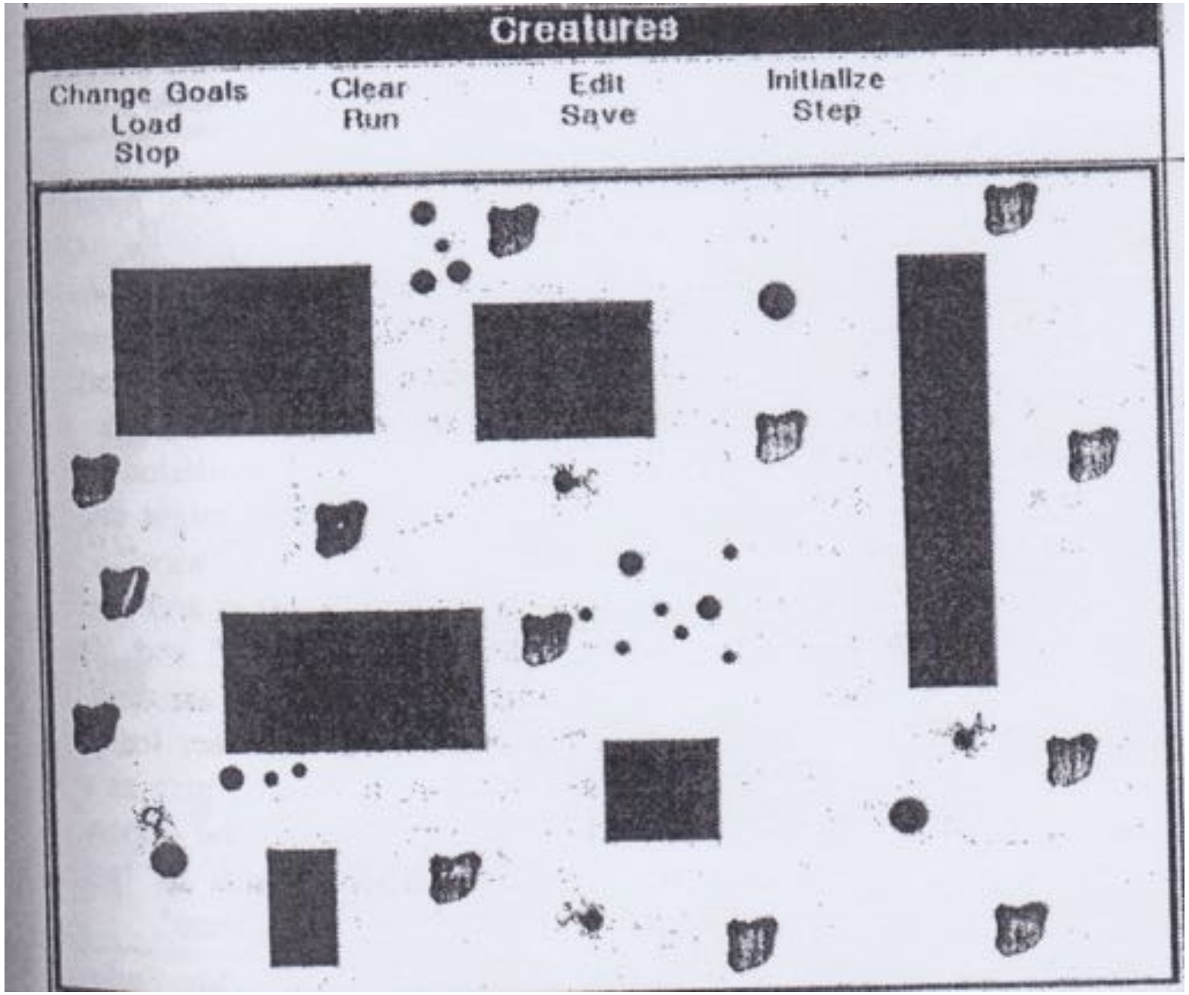
Maes' hybrid AS architecture: Combining Nnets, Symbolic AI and Embodied AI

- **From NNets / reactive systems**: inherits intrinsic parallelism, fault tolerance, and global emergent computation from local interacting units
  - Robustness
  - Adaptability
  - Reactivity, fast response
- **From embodied AI**: complete creature principles
  - Complete embodied creature that must adapt to its environment to survive
  - Creature has multiple behavioral competencies
- **From symbolic AI**: it uses representations and structured principles:
  - Network is prewired
  - Nodes are meaningful => understandability, explanation facilities, programmability

Pattie Maes' hybrid AS architecture

- Agent seen as a collection of competencies (modules)
- Action Selection is emergent property of activation/inhibition dynamics among those competencies (spreading of activation)
- AS algorithm combines features of reactive systems and traditional planners:
  - Produces fast and robust activity in tight loop of interaction with environment
  - While allowing for some prediction and planning
- Global parameters permit to adapt AS behavior to environment.
- Interesting trade-offs possible:
  - Goal-orientedness vs. situation-orientedness
  - Bias towards ongoing plans (inertia, persistence) vs. adaptivity
  - Thoughtfulness vs. speed
  - Adjust sensitivity to goal conflicts

The environment of the creatures



Creatures' consummatory behaviors and motivations

avoid-obstacle	safety
explore	curiosity
fight	aggression
flee-from-creature	fear
eat	hunger
sleep	lazyness
drink	thirst

Fig. 4. The consummatory behaviors of the creature and the motivations they are associated with.

Behaviors linked in a flat network

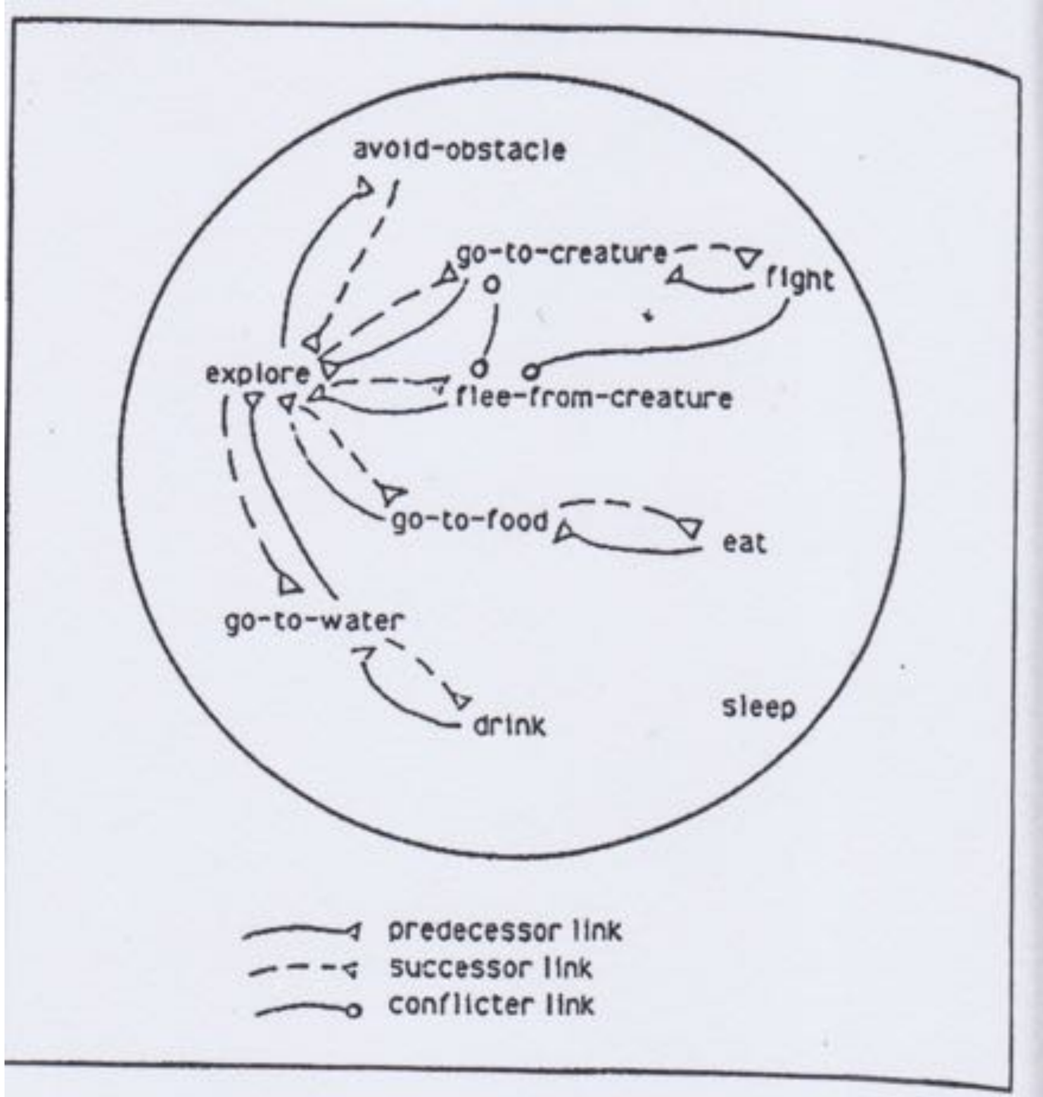


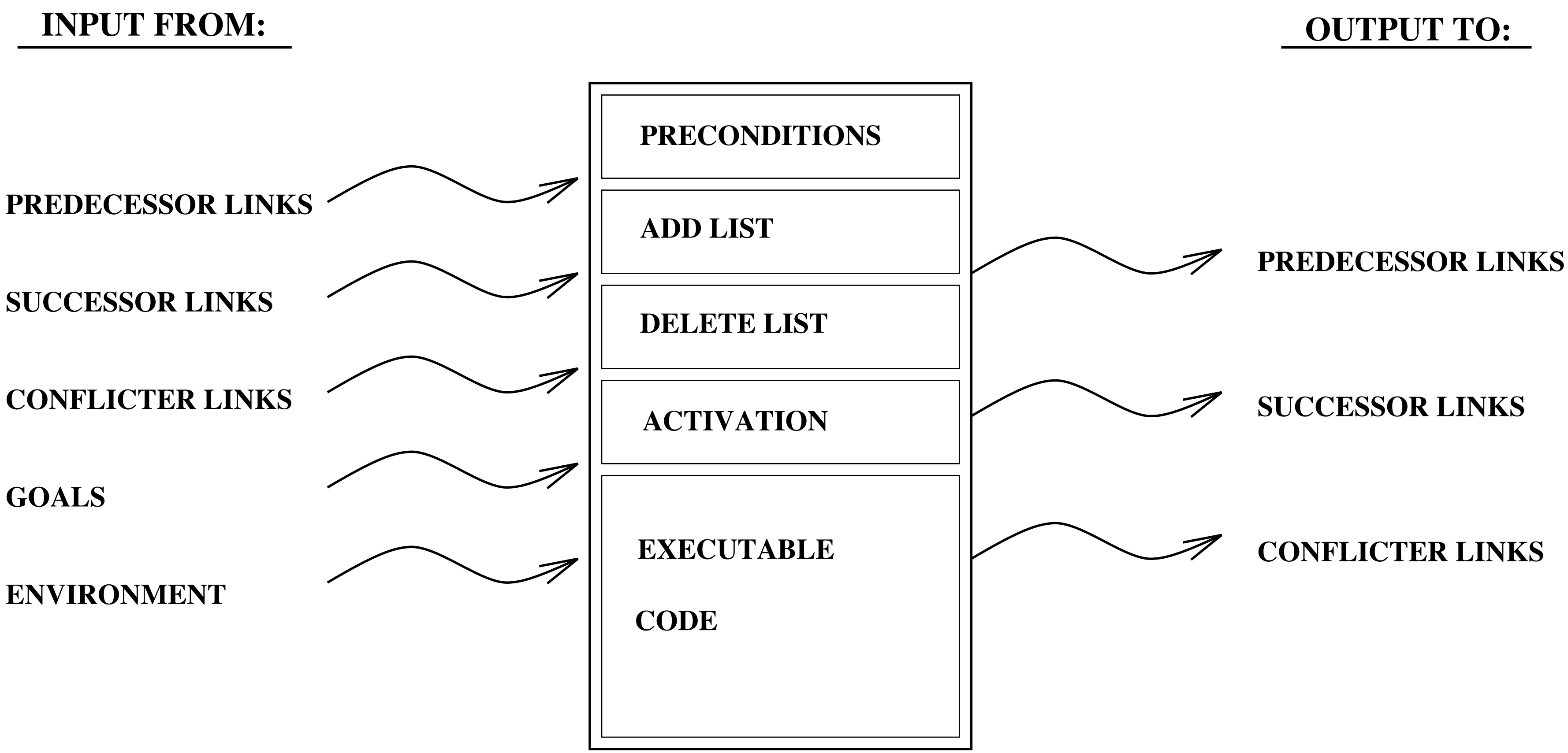
Fig. 3. The behaviors inside a creature are linked through predecessor, successor and conflicter links.

Maes's competence modules

- A creature consists of a set of **competence modules** (behaviors and motivations) organized in a **"flat" network**:
  - Modules connected though "predecessor", "successor" and "conflictor" links
  - "Energy" (activation) is spread in the network through those links (parallel computation)
    - Activation from state of world + activation from goals + inhibition by protected goals
  - Highest activated behavior (over a threshold) is executed
  - Behavior selection is dynamic, an emergent property of the network
- Modules implemented as **extended strips operators**, e.g.:

  Behavior feed:
    - Activation level: 78.3
    - Preconditions: food-within-reach
    - Processes: <a set of processes implementing the feeding activity>
    - Add list: <a set of facts that hold after the behavior is executed>
    - Delete list: <a set of facts that do not hold anymore after behavior execution>

A Maes' network competence module/node



Spreading of activation: snapshot

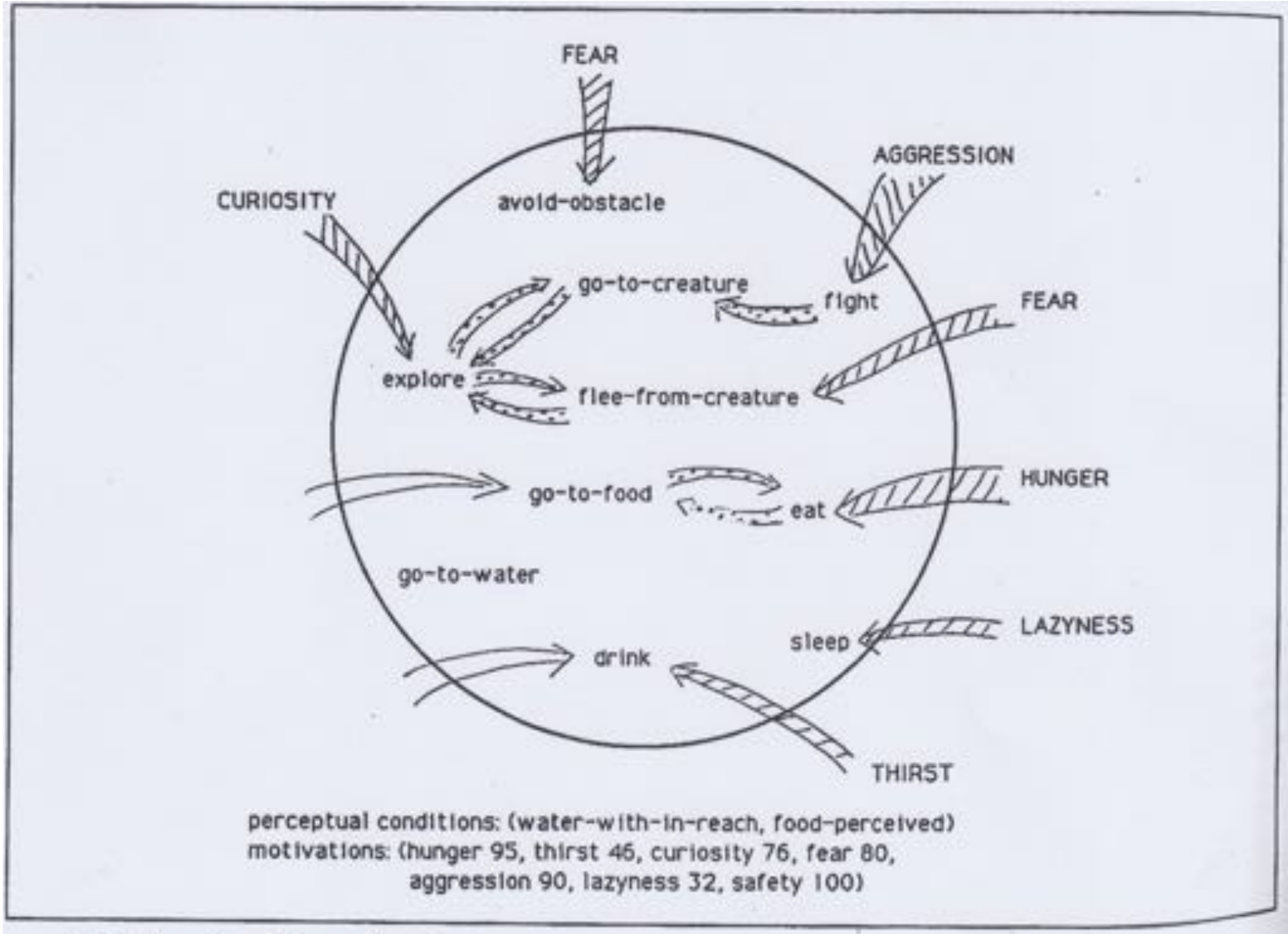
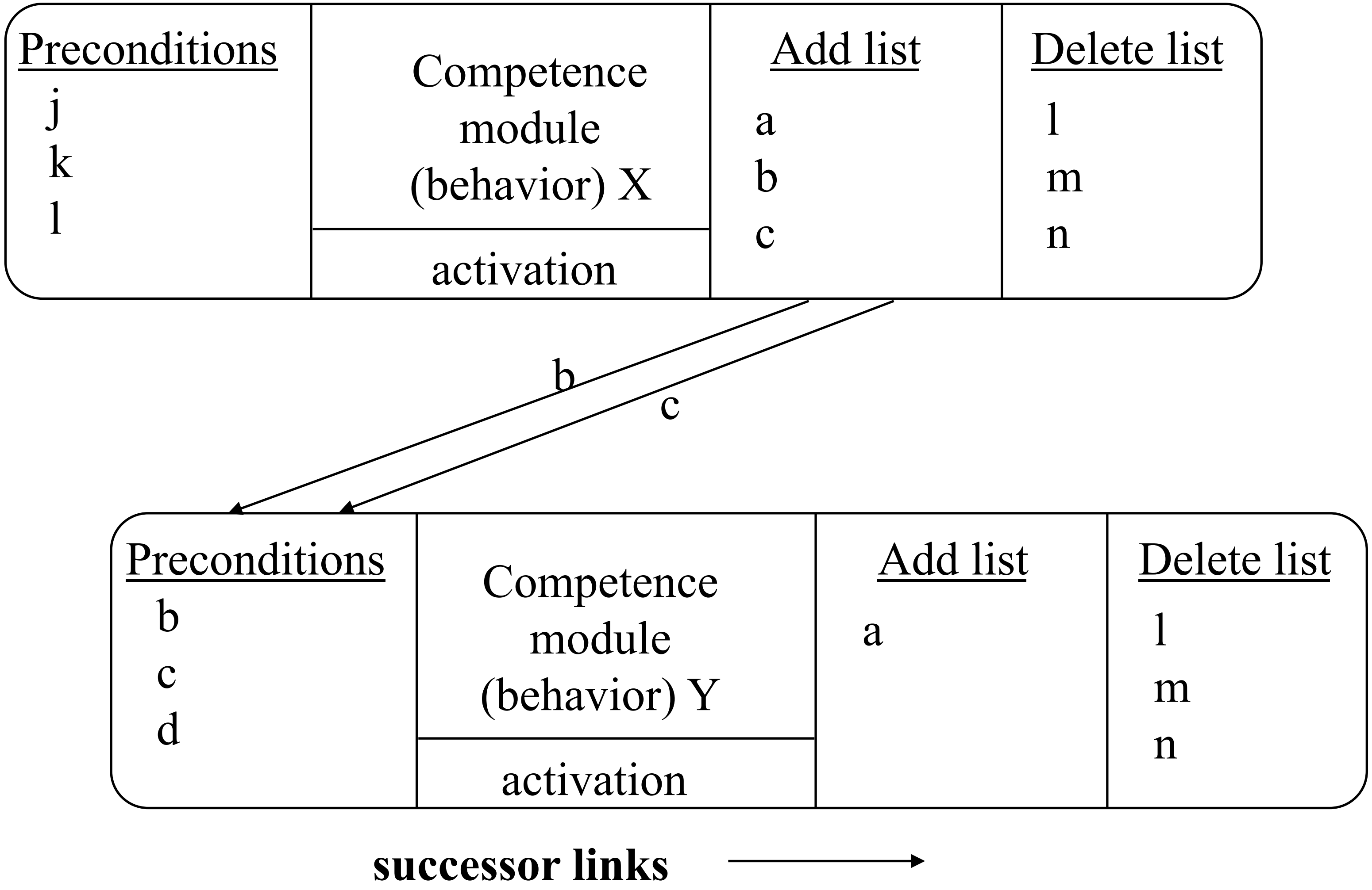
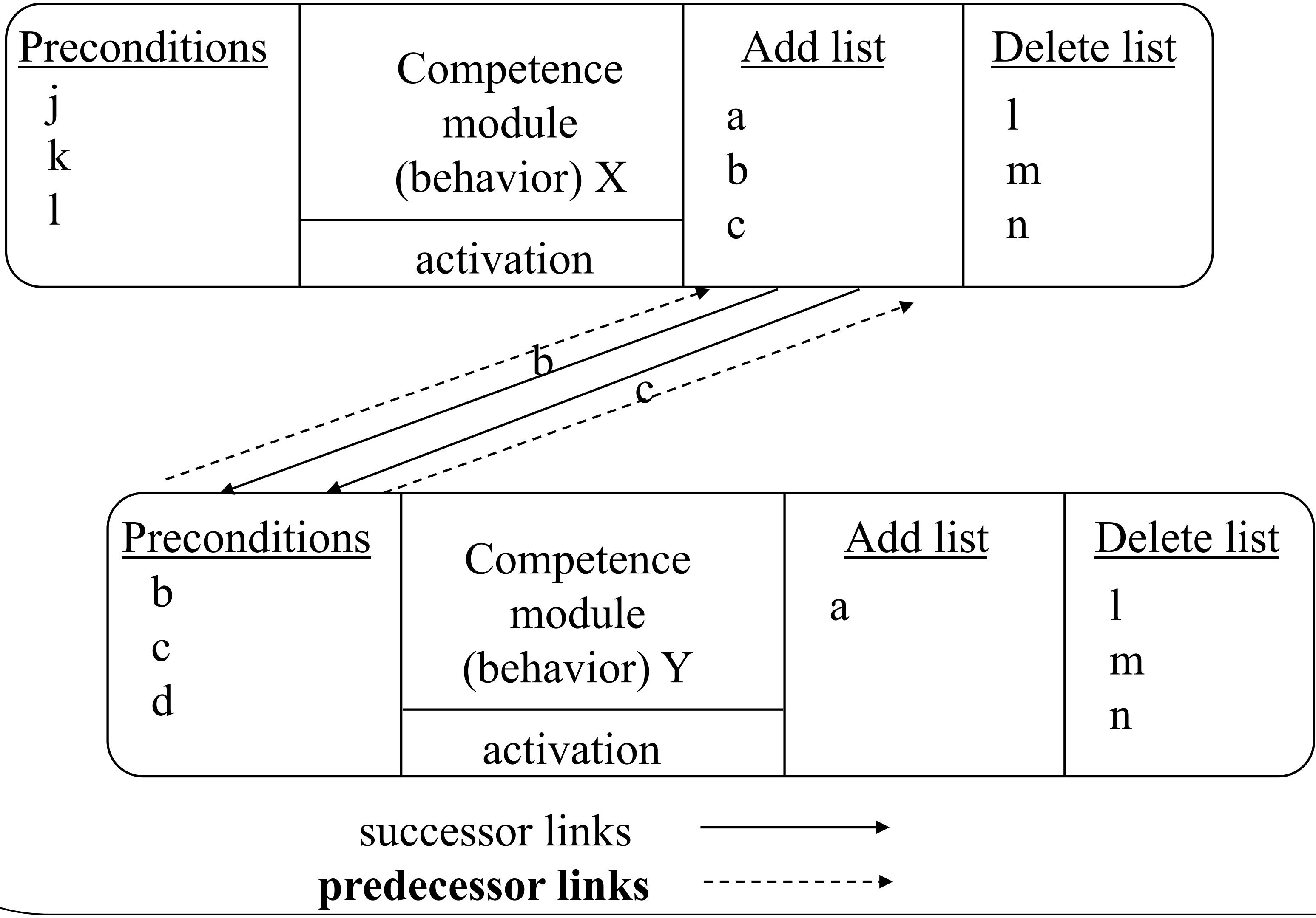


Fig. 5. A snapshot of the spreading activation process.

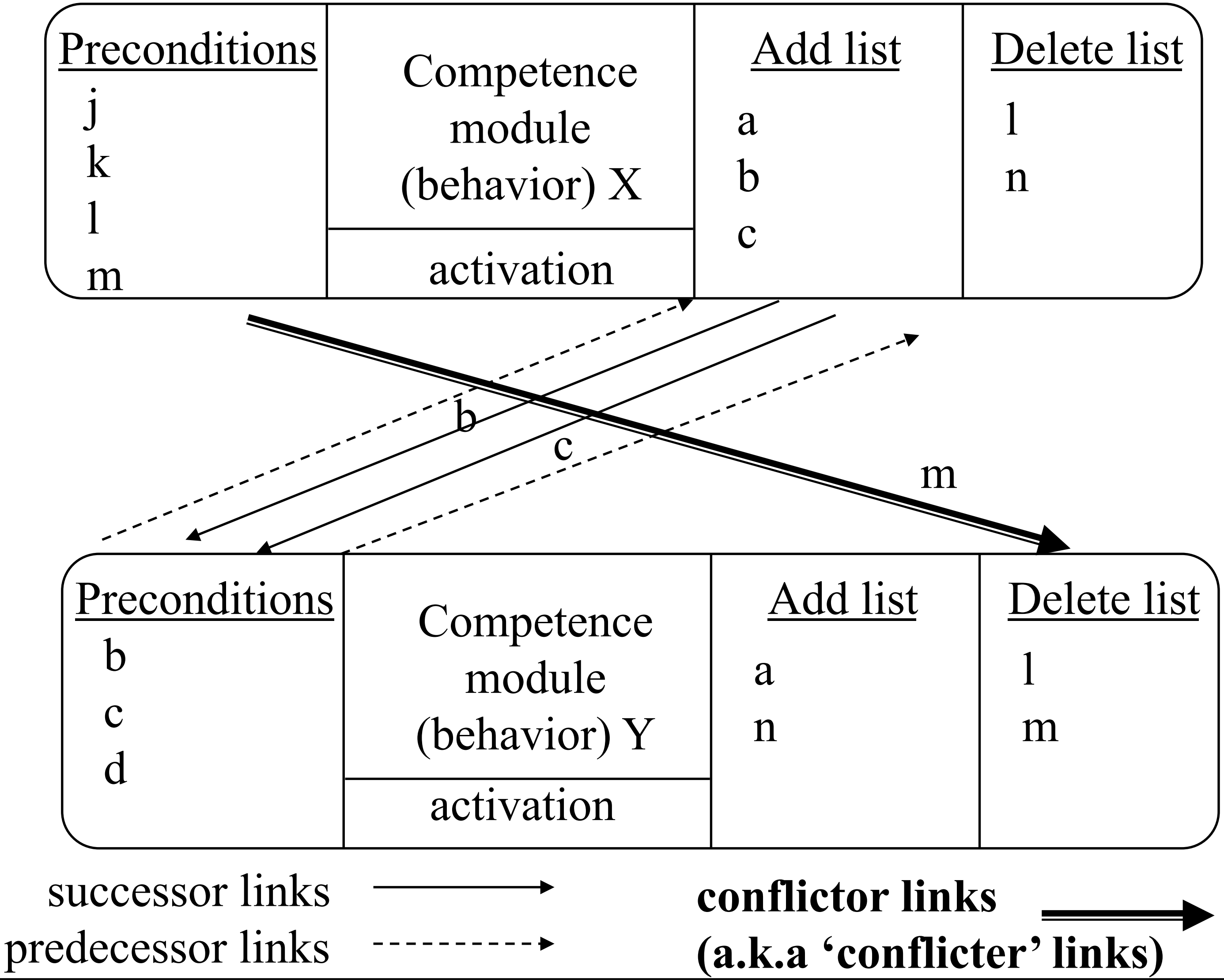
Spreading activation: successor links



Spreading activation: predecessor links



Spreading activation: conflictor links



Behavior selection loop (Maes)

Loop forever:

1. Add activation from environment and goals
2. Spread activation forward and backward among competence modules
3. Activation decay – total activation remains constant
4. A competence module fires if:
   i. It's executable and
   ii. It's over threshold and
   iii. It's the one with highest activation
5. If one competence module fires, its activation goes to 0, and all thresholds return to their normal value
6. If none fires, reduce all thresholds by 10%

Spreading of activation: snapshot

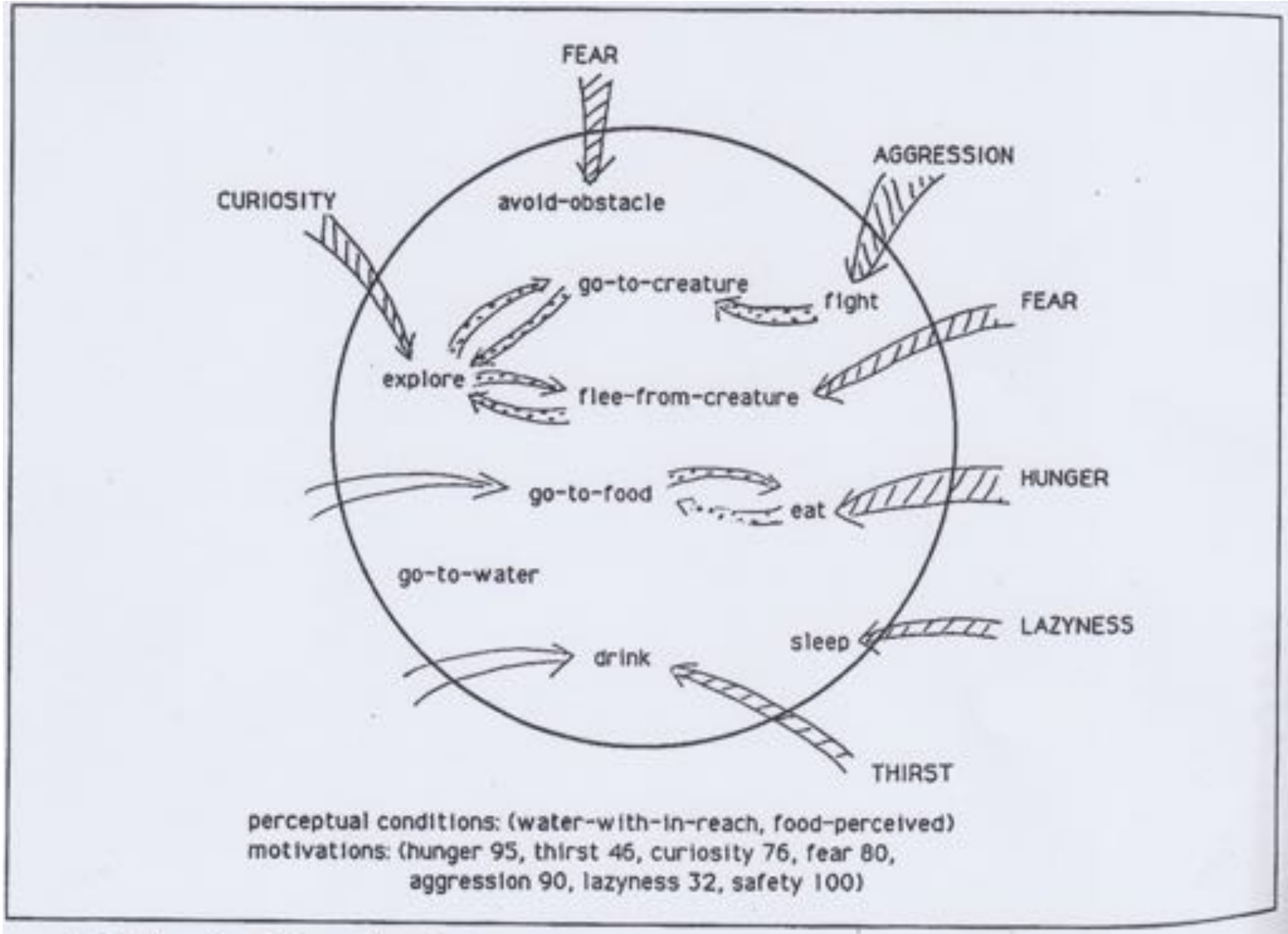
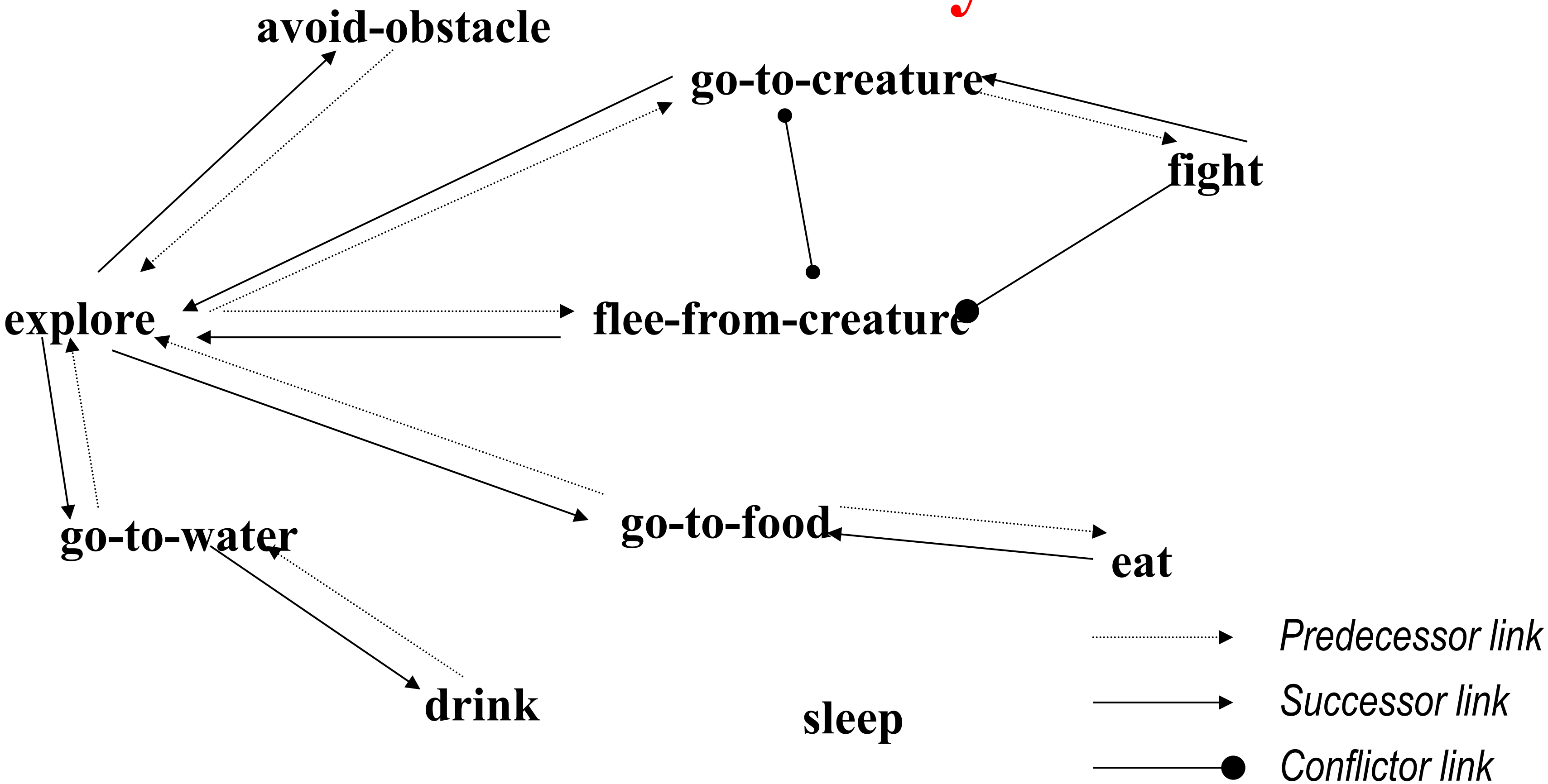


Fig. 5. A snapshot of the spreading activation process.

Behavior selection dynamics



THINKING EXERCISE FOR YOU: think of 'preconditions' and 'add' and 'delete' postconditions for some of these behaviors linked by successor, predecessor, and conflictor links, and how they would relate.

Global parameters to tune AS

- Four global parameters can be used to “tune” the spreading activation dynamics, and therefore the AS behavior of the agent.
- These parameters also determine the amount of activation spread (fwd, bkwd, or away) by competence modules.

1. θ, the threshold for becoming active, and related to it, π the mean level of activation. θ is lowered with 10% each time none of the modules could be selected. It is reset to its initial value when a module could be selected.
2. ϕ, the amount of activation energy a proposition that is observed to be true injects into the network.
3. γ, the amount of activation energy a goal injects into the network.
4. δ, the amount of activation energy a protected goal takes away from the network.

Inspecting the creature's internal state

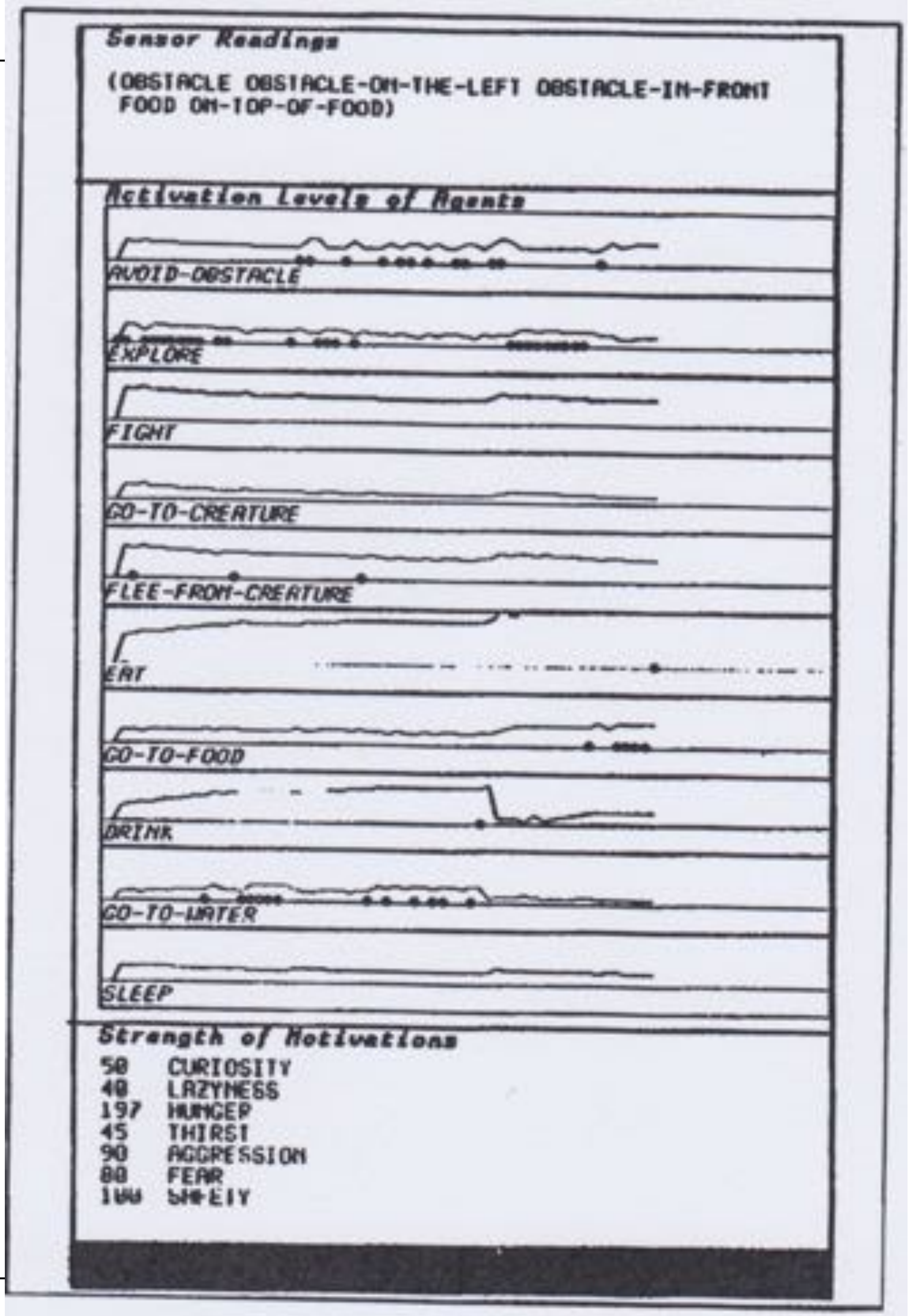


Fig. 2. The internal structure of an example creature.

Environments and inspection facilities

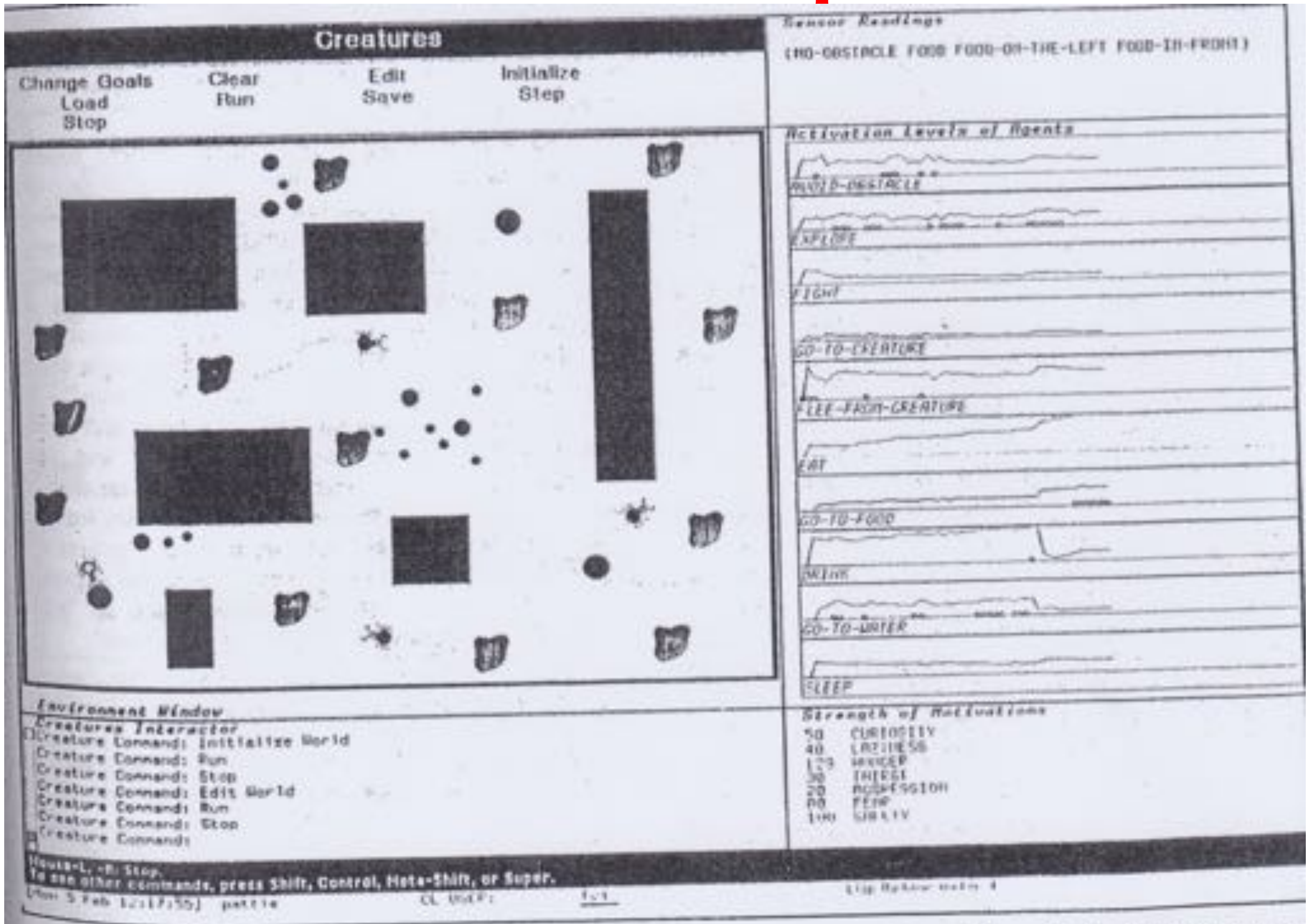


Fig. 6. The creatures in their 2-dimensional environment. The windows on the right show the internal state of the creature with a white cross on its back.

Example of opportunistic behavior

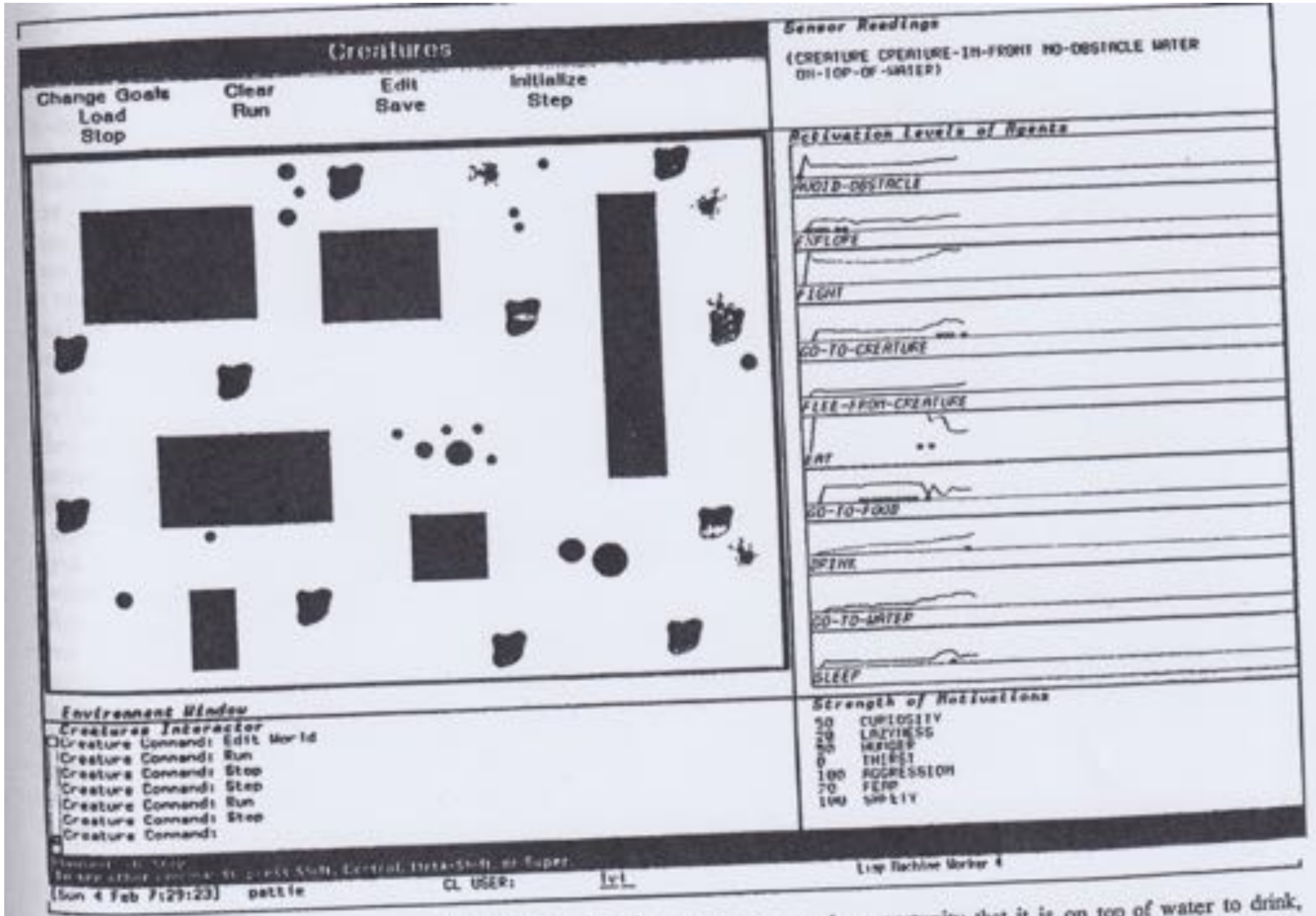
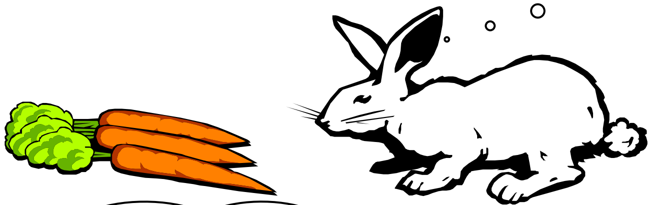


Fig. 7. An example of opportunistic behavior: the creature chooses to use the opportunity that it is on top of water to drink, while it is chasing another creature to fight with it. The strength of drink is rest to 0 (it was 40 before the drink behavior was selected).

Affective decision making: “wanting” & “liking”

1 …

Carrots … Eat !!



Reactive system

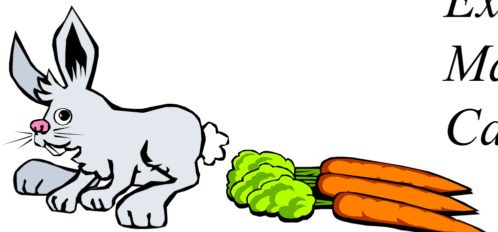
Examples:

Braitenberg Vehicles;

Subsumption architecture

2 …

I am starving … Where had I seen those carrots?



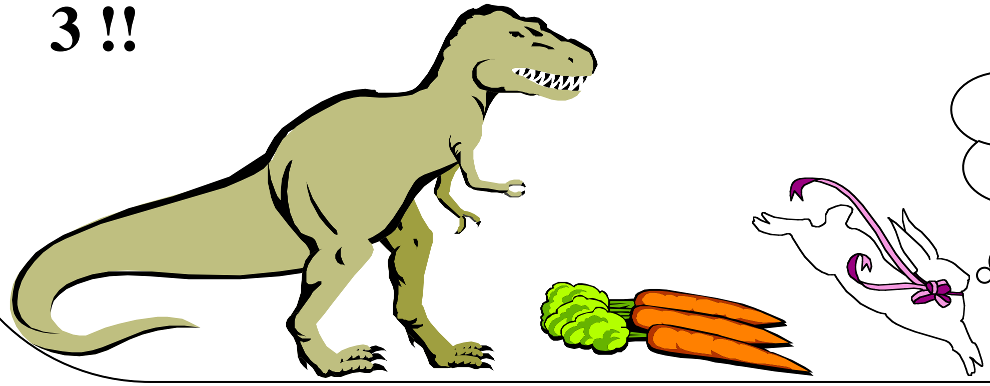
Motivated system

Examples:

Maes’ AS architecture;

Cañamero’s AS architecture

3 !!



I am starving, but this might not be the right moment!!!

Emotional system

Examples:

Cañamero’s AS architectures

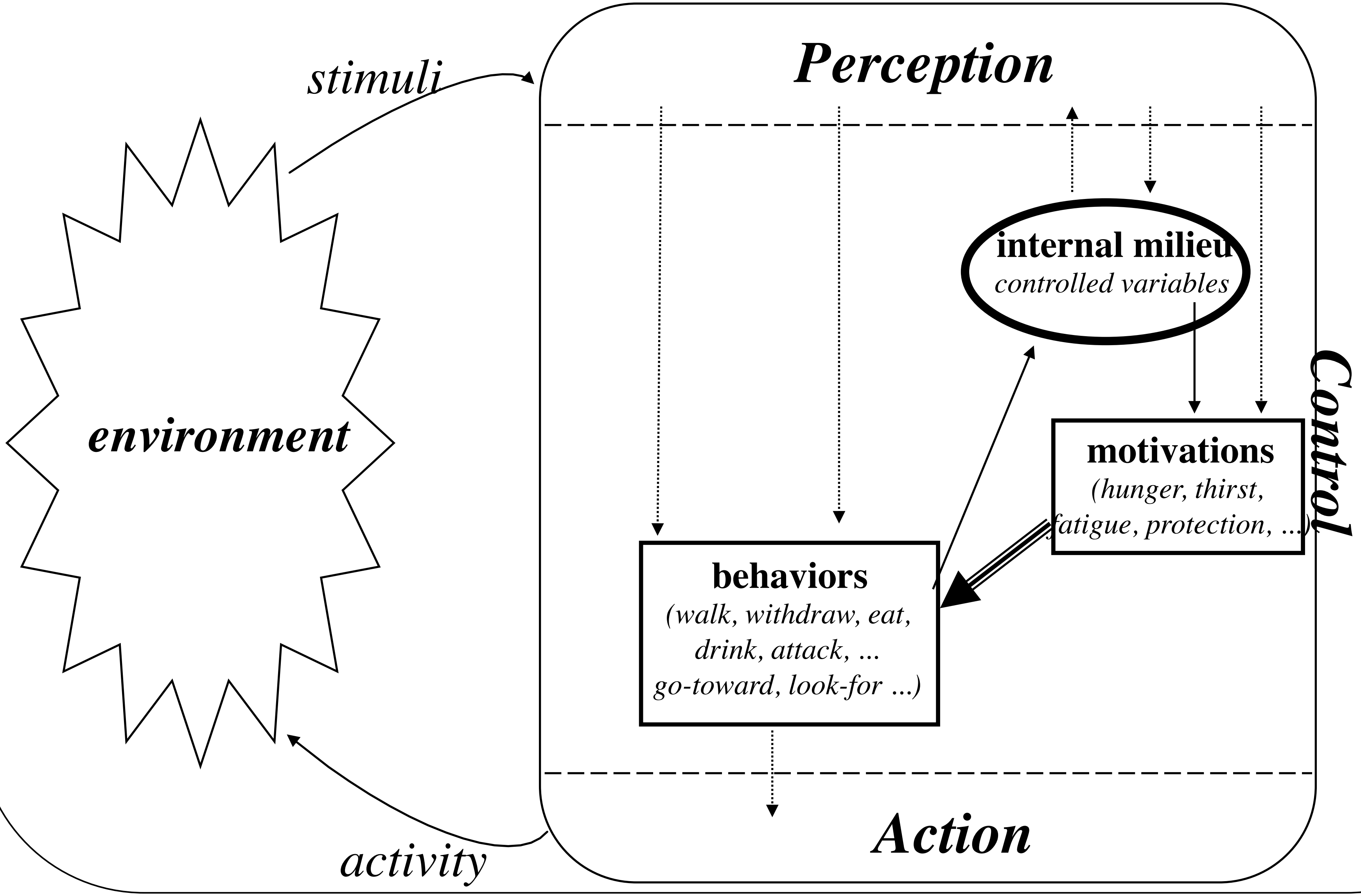
How are motivations defined & calculated?

- Motivations can be defined in terms of different factors, e.g.,:
  - Internal signals, internal states (drives) only: these systems are less responsive to what happens in the environment
  - External stimuli only: systems are more “opportunistic” & somewhat similar to reactive systems
  - Internal and external stimuli combined: more balanced and adaptive decisions that take into account both internal (e.g., survival-related, cognitive, social) needs and what is happening in the surrounding environment.
  - The behavior that is currently being executed, in conjunction with internal signals, external stimuli, or both: these systems will show more persistence in working towards satisfying the need that they have already started to work towards.
  - Personal preferences (e.g. food preferences), cultural elements, social norms, etc. These elements are important in social affective robots.
- These different ways of defining motivations can be translated into specific mathematical formulas when implemented in robots
- Different ways of calculating motivations have an impact on the behavior that the robot shows and the decisions it will make => ***THINKING EXERCISE FOR YOU: think of an action selection example and analyze and compare some of the above “definitions” in terms of the resulting behavior and decisions of the robot.***

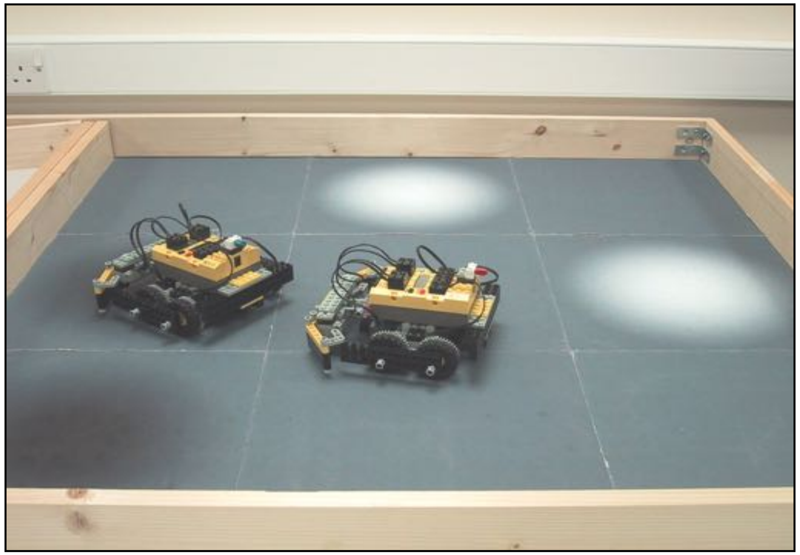
Motivational states

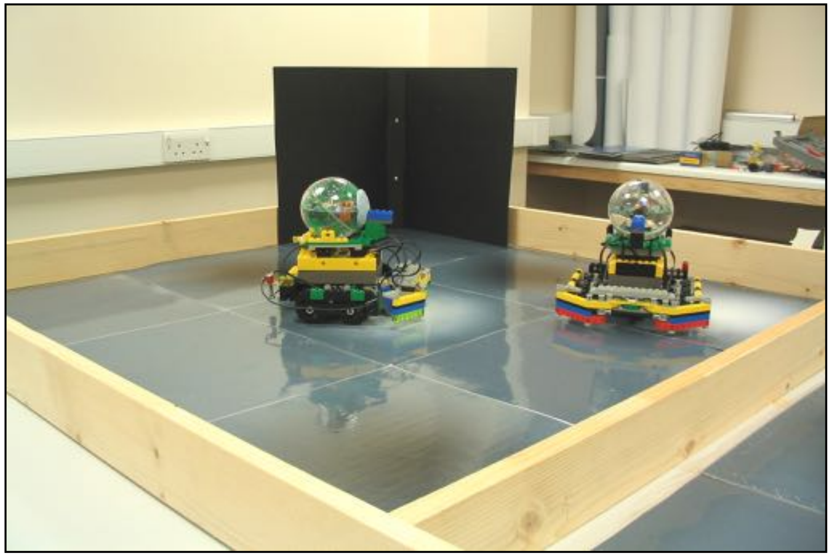
- Internal states postulated to explain the variability of behavioral responses that cannot be accounted for only by observable stimuli.
- These states or drives constitute urges to action based on bodily needs related to self-sufficiency and survival. They can also be social, cognitive, etc.
- Can be seen as homeostatic processes which maintain a controlled physiological variable within a certain range:
  - An error detector generates an error signal— the drive—when the value of this variable does not match the ideal value or set point,
  - Error signal triggers inhibitory and excitatory controlling elements to adjust the variable in the adequate direction, such as feeding or fleeing behaviors.
- External (incentive) stimuli, "innate" or learned, can also motivate/drive behavior.
- Three main functions:
  - (a) directing function: they steer behavior toward, or away from, a specific goal;
  - (b) activating function: they increase general alertness and energize the individual to action;
  - (c) organizing function: they combine individual behavioral components into a coherent goal-oriented behavioral sequence

Motivational AS architecture (Cañamero)



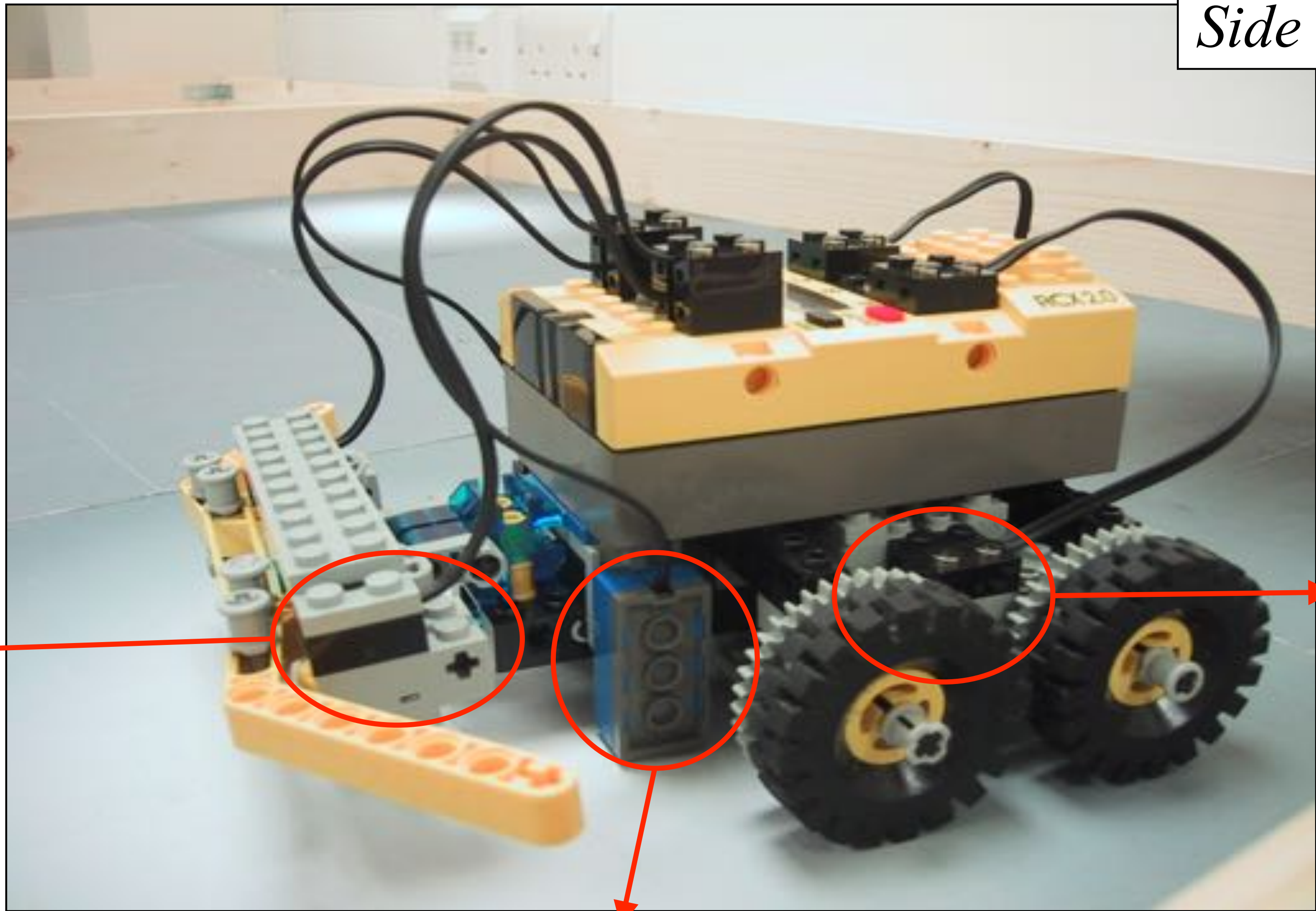
Robots "want" & "like": decision making





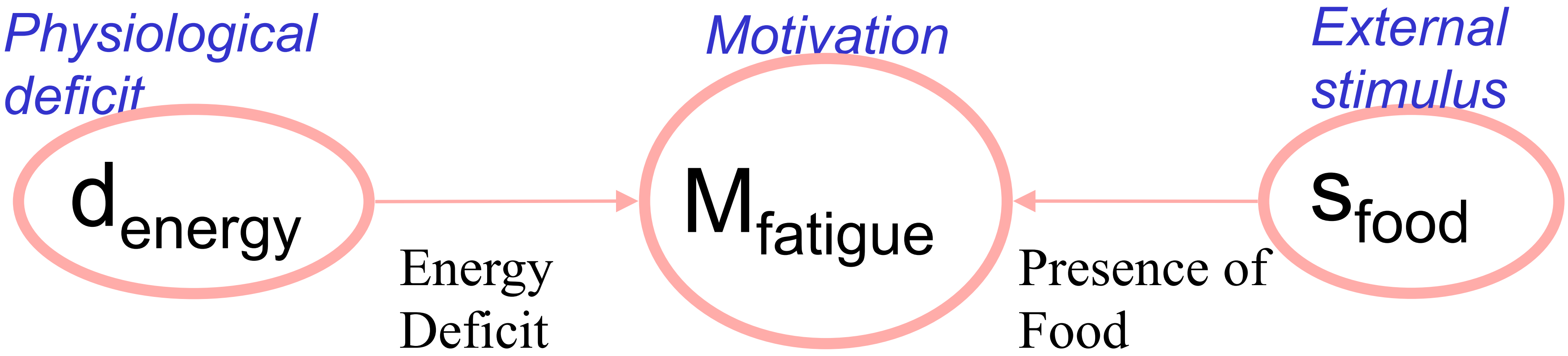
- Avila-García, O., Cañamero, L.: Using Hormonal Feedback to Modulate Action Selection in a Competitive Scenario. In: Proc. Eight Intl. Conf. Simulation of Adaptive Behavior (SAB 2004), pp. 243–252. MIT Press, Cambridge, MA (2004).
- Cañamero L., Avila-García O. (2007) A Bottom-Up Investigation of Emotional Modulation in Competitive Scenarios. In: Paiva A.C.R., Prada R., Picard R.W. (eds) Affective Computing and Intelligent Interaction. ACII 2007. Lecture Notes in Computer Science, vol 4738. Springer, Berlin, Heidelberg

The robot: perception and action



“Wanting”?

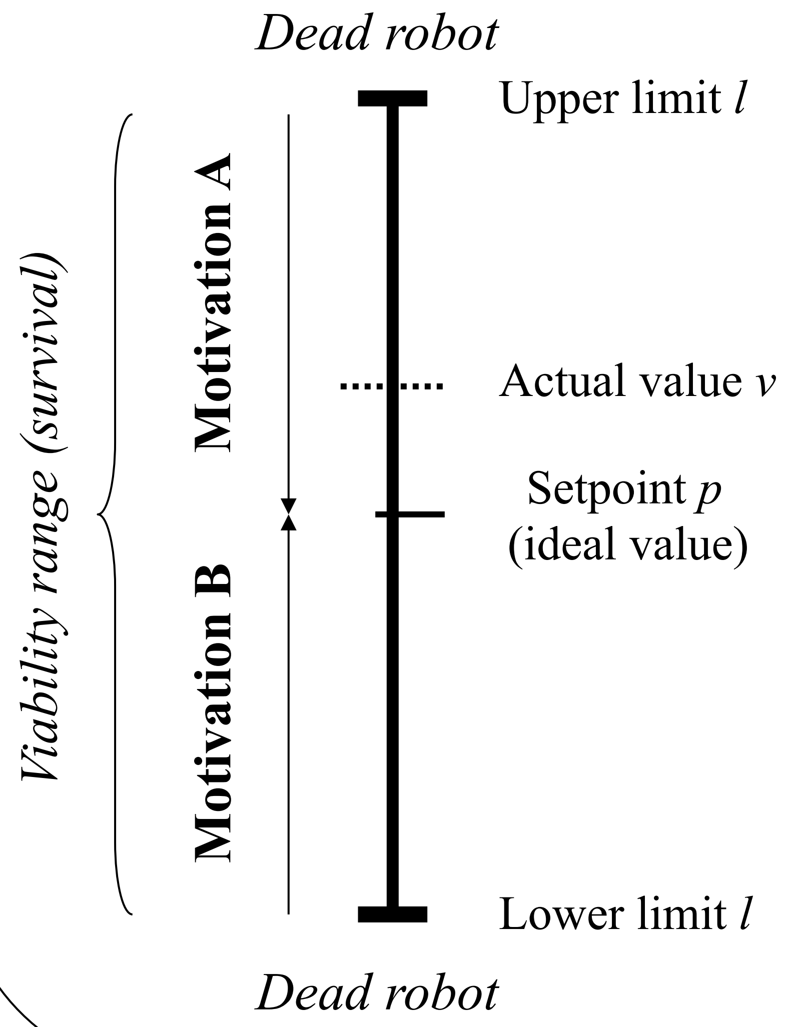
Motivations: urges to action based on bodily needs and influenced by external stimuli



$$\boxed{\text{Motivation} = \text{deficit} + (\text{deficit} \bullet \text{stimulus})}$$

Tyrrell, T (1993)
Spier, E & McFarland, D (1997)

Calculating the error (homeostasis)

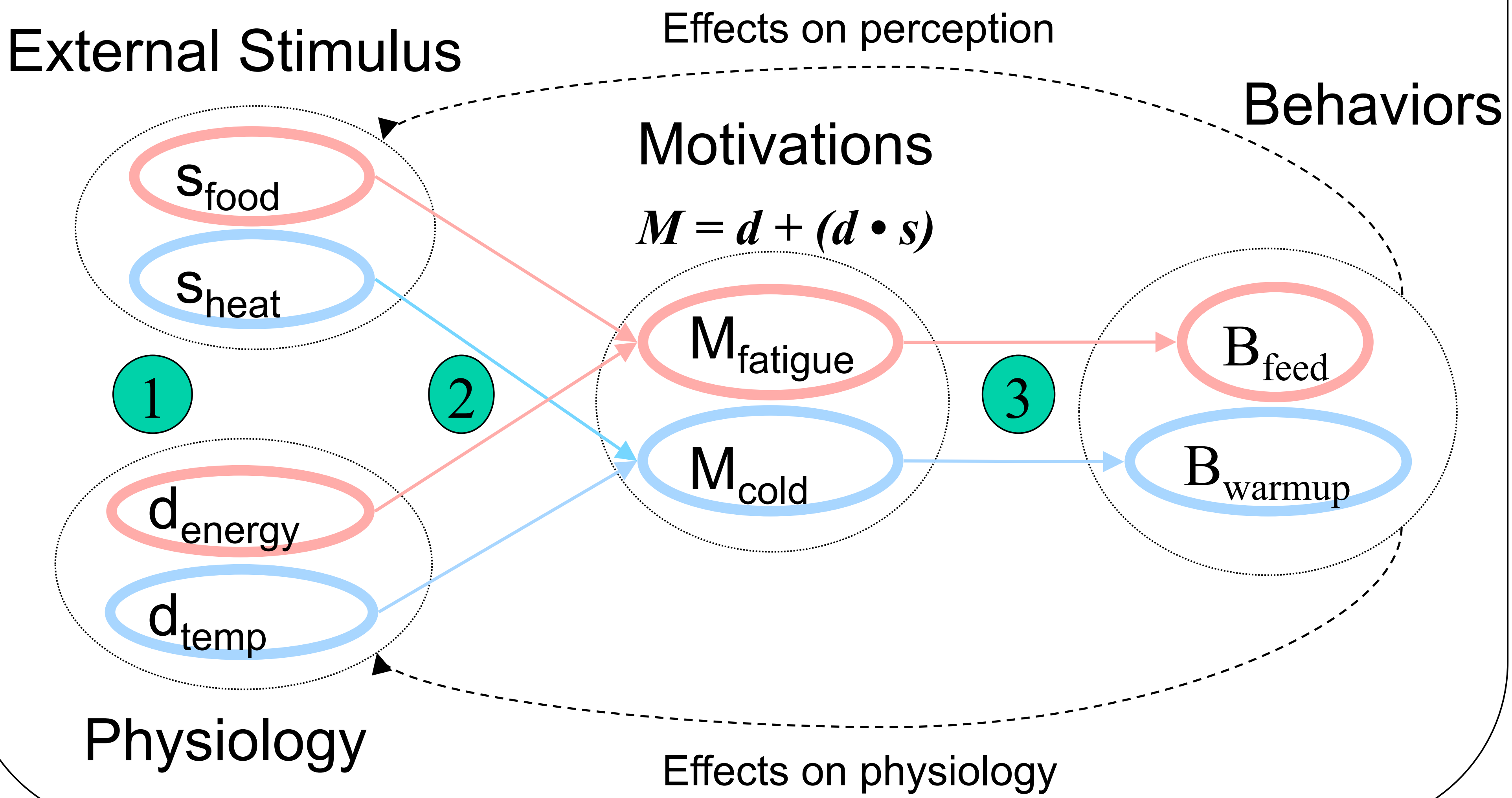


- The error is a number normalized in [0,1], where 0 is no error and 1 results when actual value overflows / underflows the upper / lower limit of the variable (and the robot dies!!)
- The error is calculated as:

1. Calculate the distance between the setpoint and the limit: $ld_v = abs(l_v - p_v)$.
2. Calculate the distance between the actual variable value and the setpoint: $vd_v = abs(v_v - p_v)$
3. Calculate normalized error:

$$e_v = \begin{cases} vd_v / ld_v & \text{if } ld_v > abs(l_v - v_v) \\ 0 & \text{otherwise} \end{cases}$$

Robots that "want"

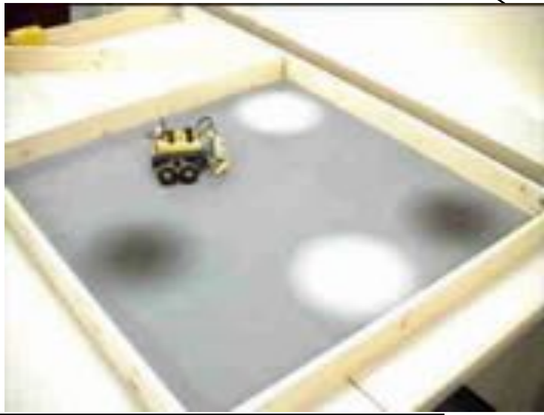


Viability (performance) indicators

- **Life Span:** The time that the robot survived (remained viable) during each run in simulation steps normalized with the total simulation time.
- **Overall Comfort:** The average level of satisfaction of all the essential variables.
- **Physiological Balance:** The homogeneity with which the different physiological needs are satisfied (variance).
- **Management of Risk of Death:** The amount of time during which an architecture keeps the highest physiological need within different regions of the viability zone.
- **Activity cycles**: cycles of activities reflected in the physiological space

2RP: Basic cycle of activities

(Spier & McFarland, 1997)

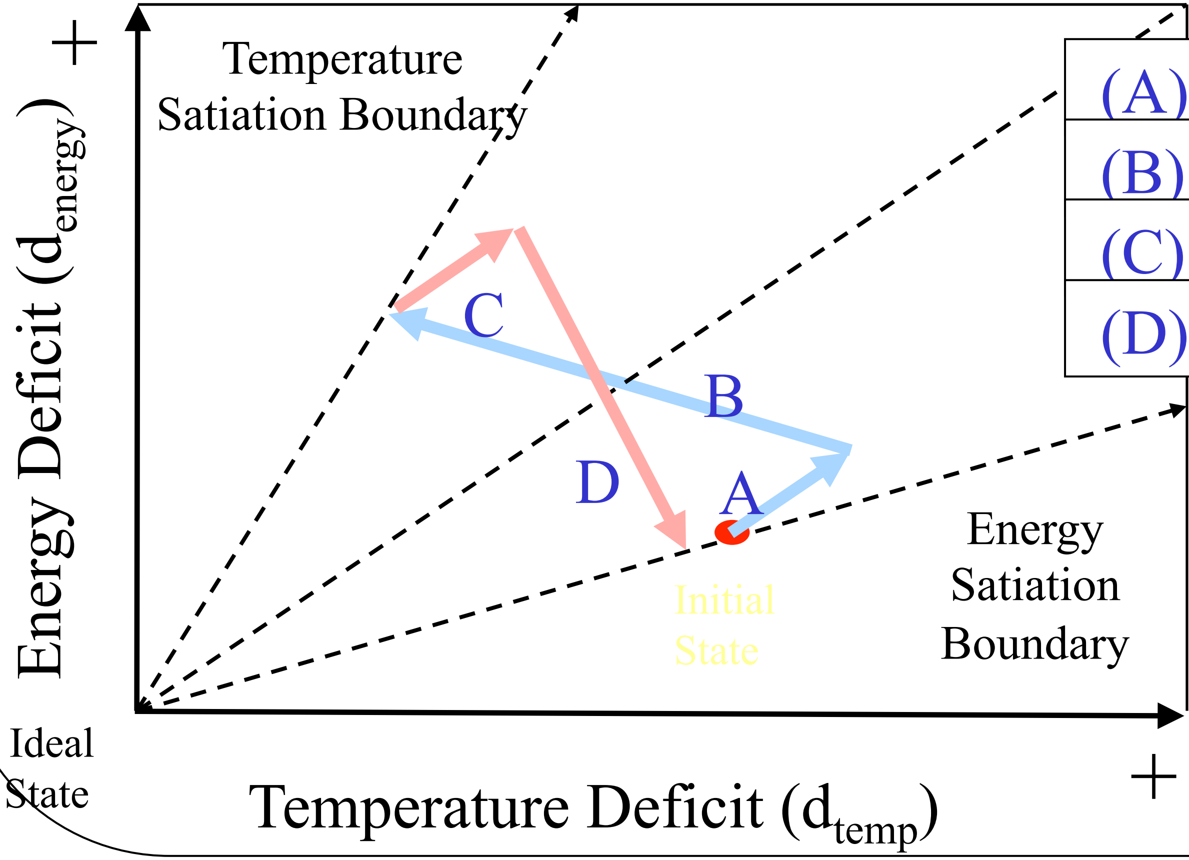


(A) Look-For-Heat,

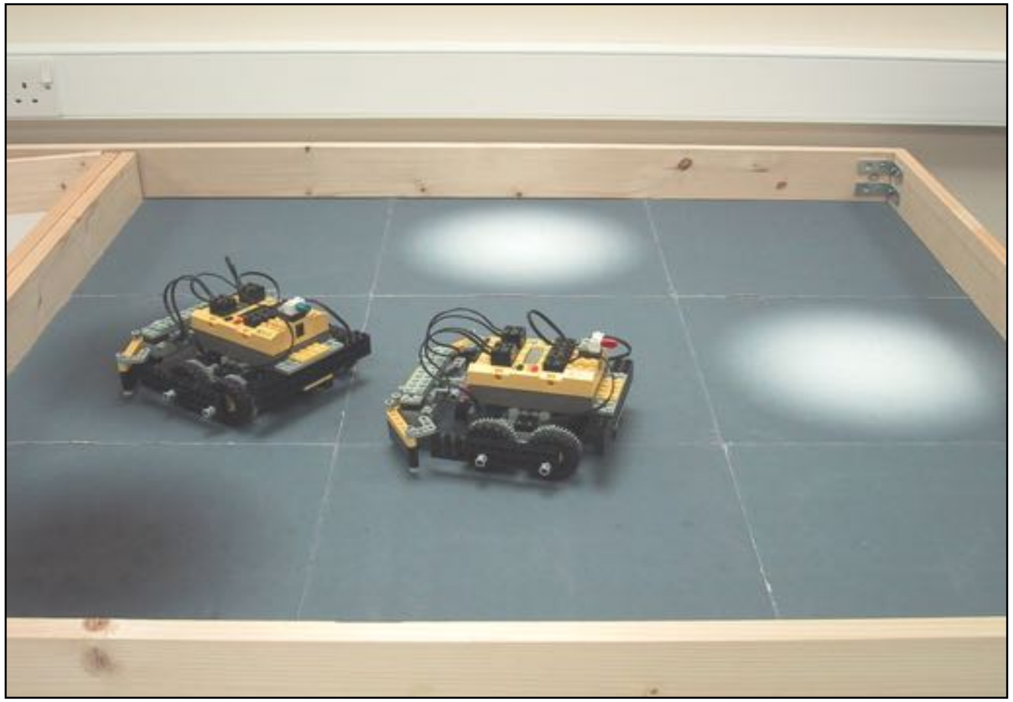
(B) WarmUp,

(C) Look-For-Food,

(D) Feed



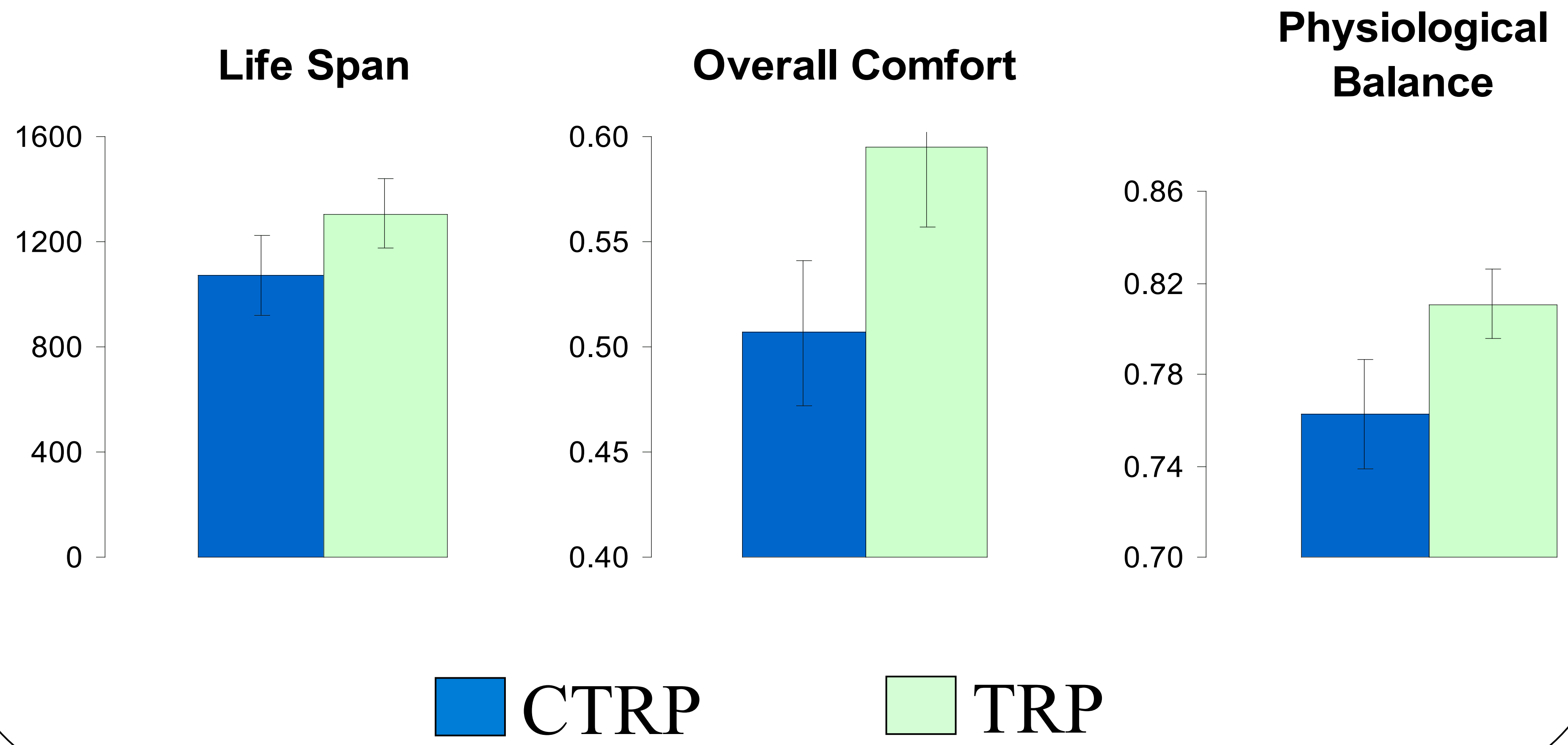
Competitive Two-Resource Problem



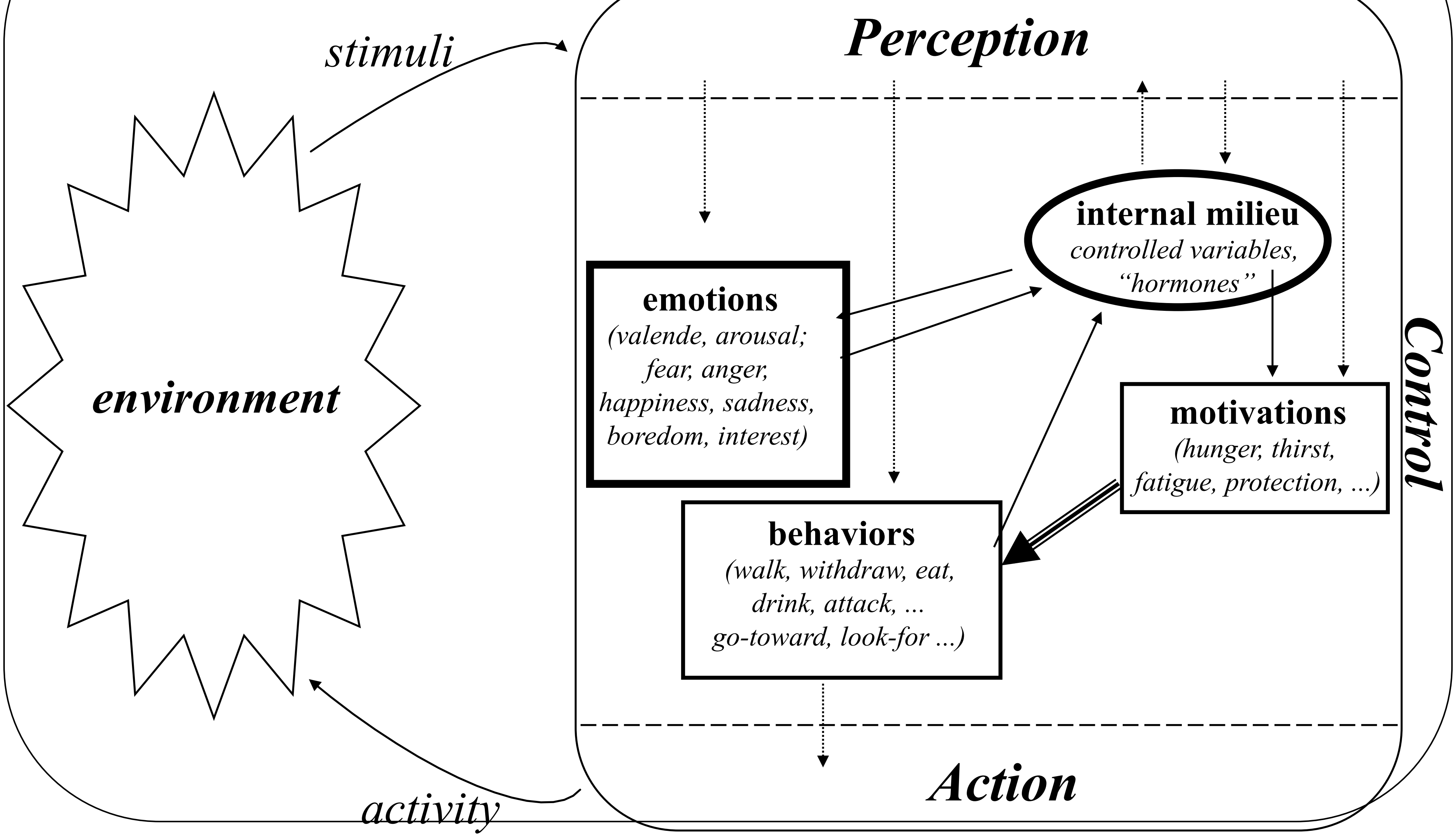
- Two robots in same environment
- What happens when the other robot is on the resource you want?
  - Push it out if you can! (“aggression”)
  - Give up eating is you are weaker! (“fear”)

Avila-Garcia, O. & Cañamero, L. (2004). Proc. SAB 2004.

Comparing static and dynamic TRP

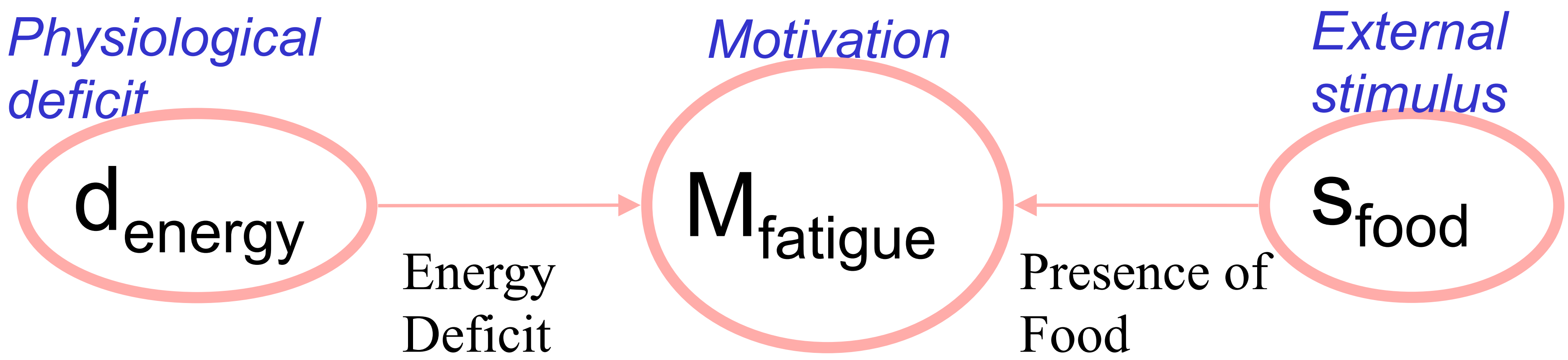


Full affective AS architecture (Cañamero)



“Wanting” modulated by “liking”

Motivations: urges to action based on bodily needs and influenced by external stimuli

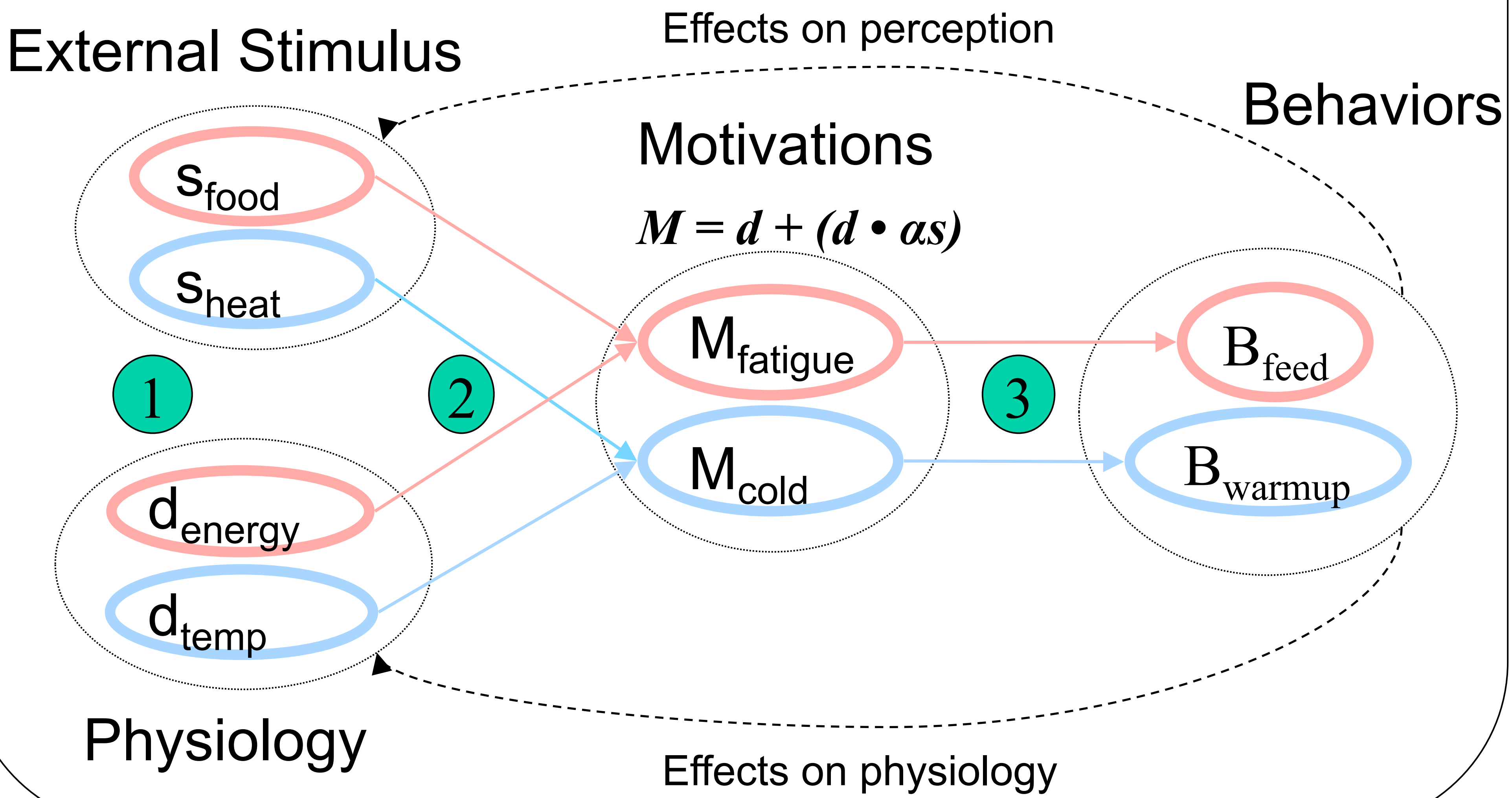


$$\boxed{\text{Motivation} = \text{deficit} + (\text{deficit} \bullet \alpha \text{ stimulus})}$$

weighting factor

Tyrrell, T (1993)
Spier, E & McFarland, D (1997)

Robots that "want" modulated by "liking"

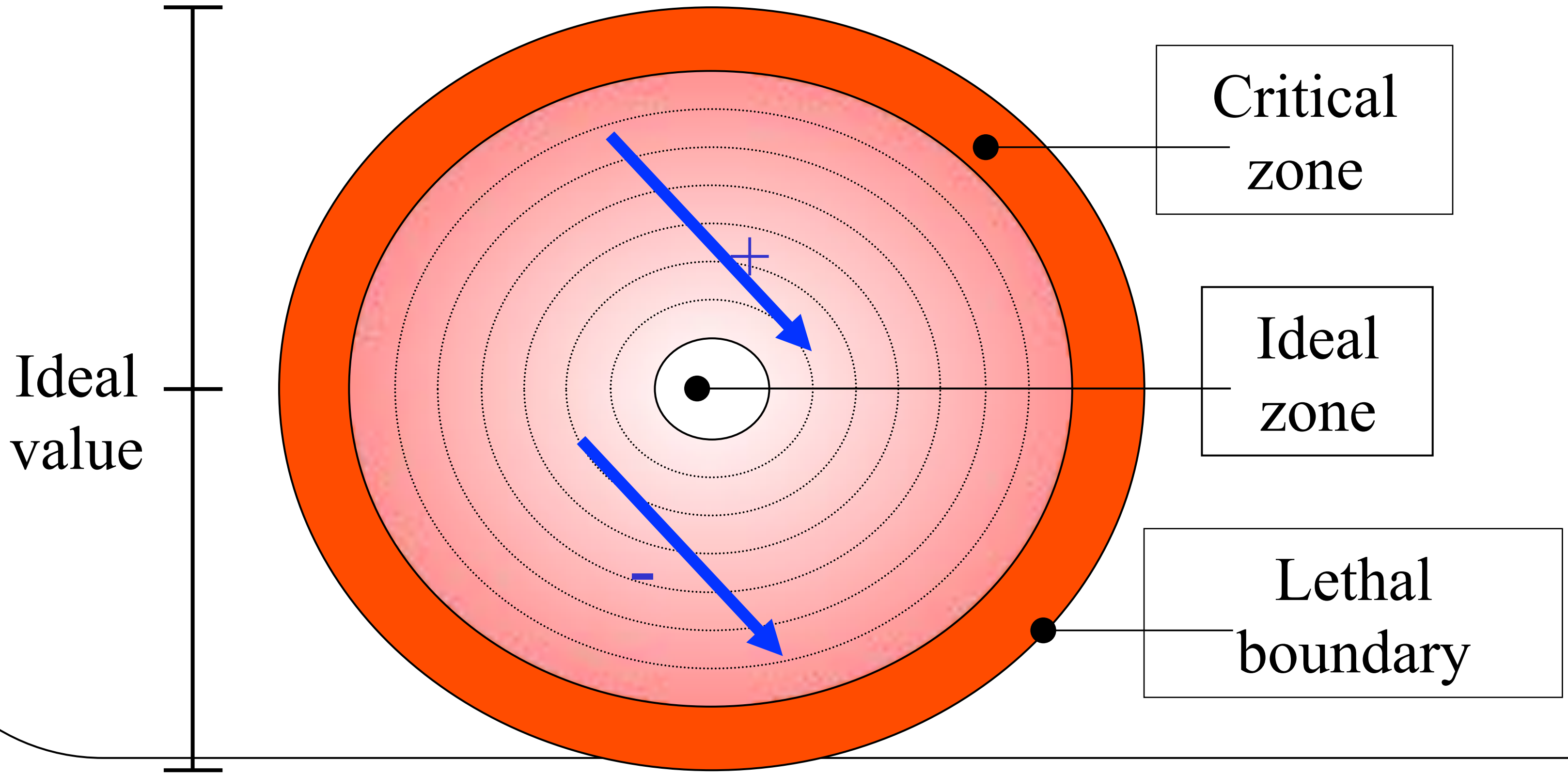


Robots that "like" ("pleasure")

Lewis, M., & Cañamero L. (2016). Hedonic quality or reward? A study of basic pleasure in homeostasis and decision making of a motivated autonomous robot. *Adaptive Behavior*. 24(5), 267–291.

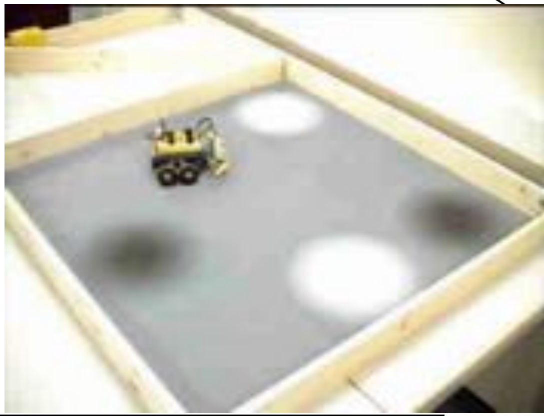
Trajectories in physiological (or sensory) space:

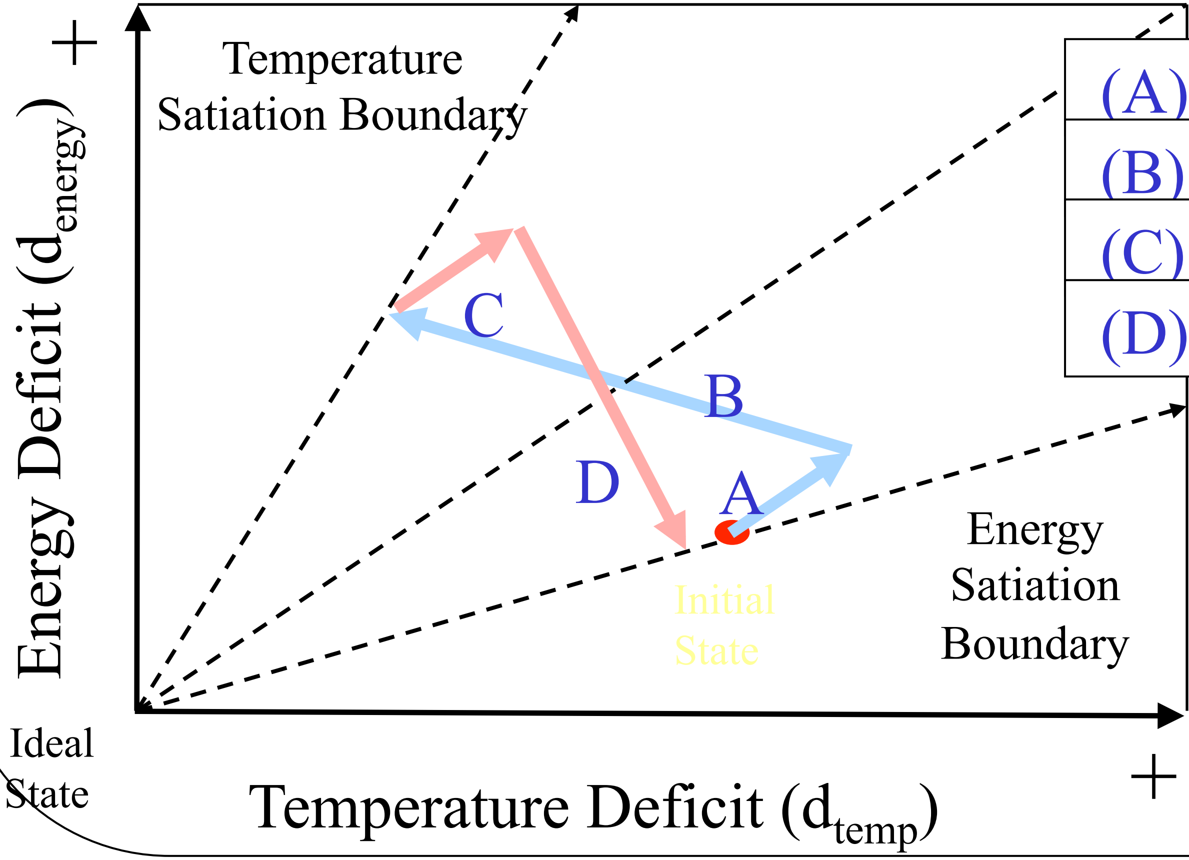
- Need satisfaction / well-being
- Simulated "pleasure hormone"



2RP: Basic cycle of activities

(Spier & McFarland, 1997)



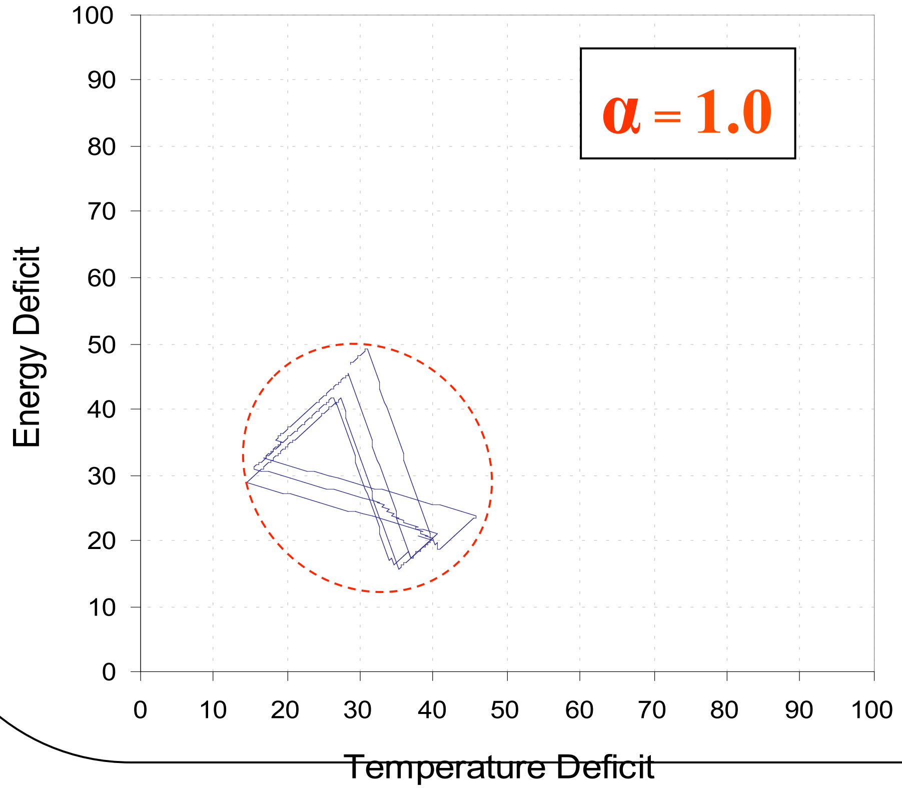


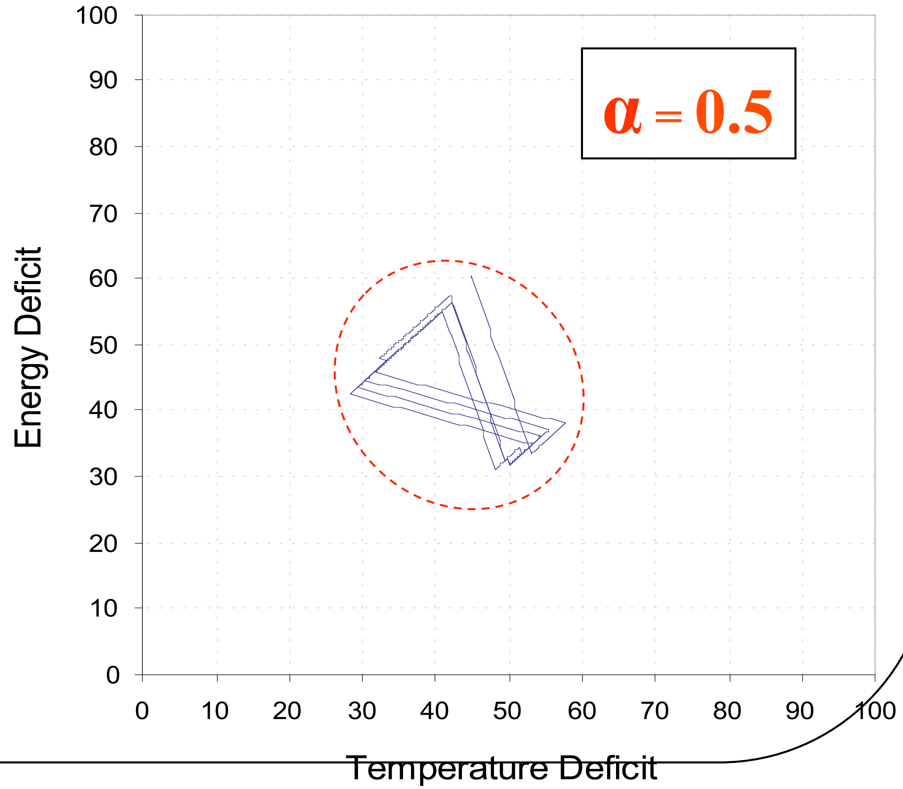
(A) Look-For-Heat,
(B) WarmUp,
(C) Look-For-Food,
(D) Feed

The slope of the satiation boundaries depends on **α**!

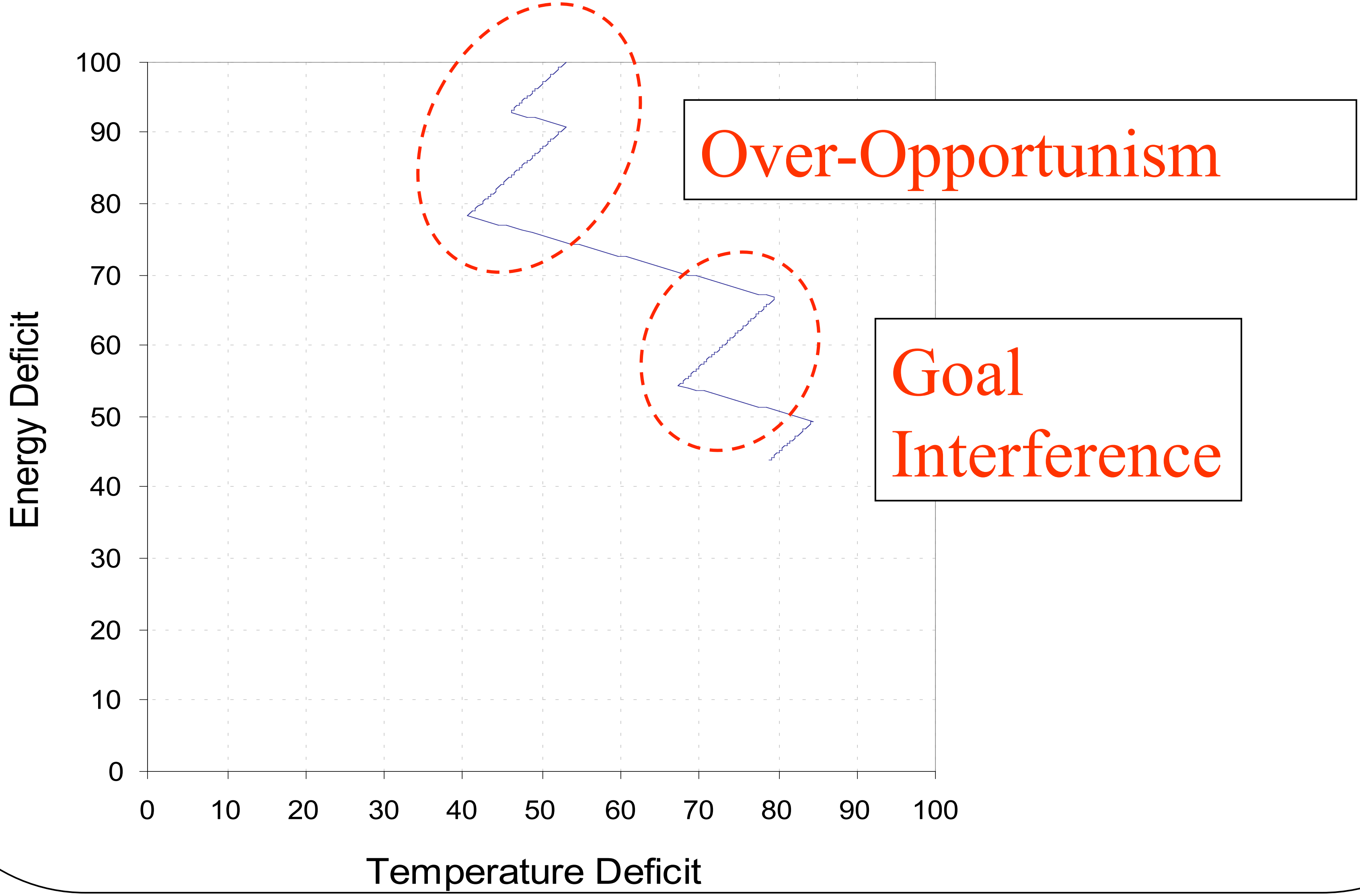
Modulation of perception

Modulating (α) the influence that external stimuli have on motivations we are able to influence activity cycles

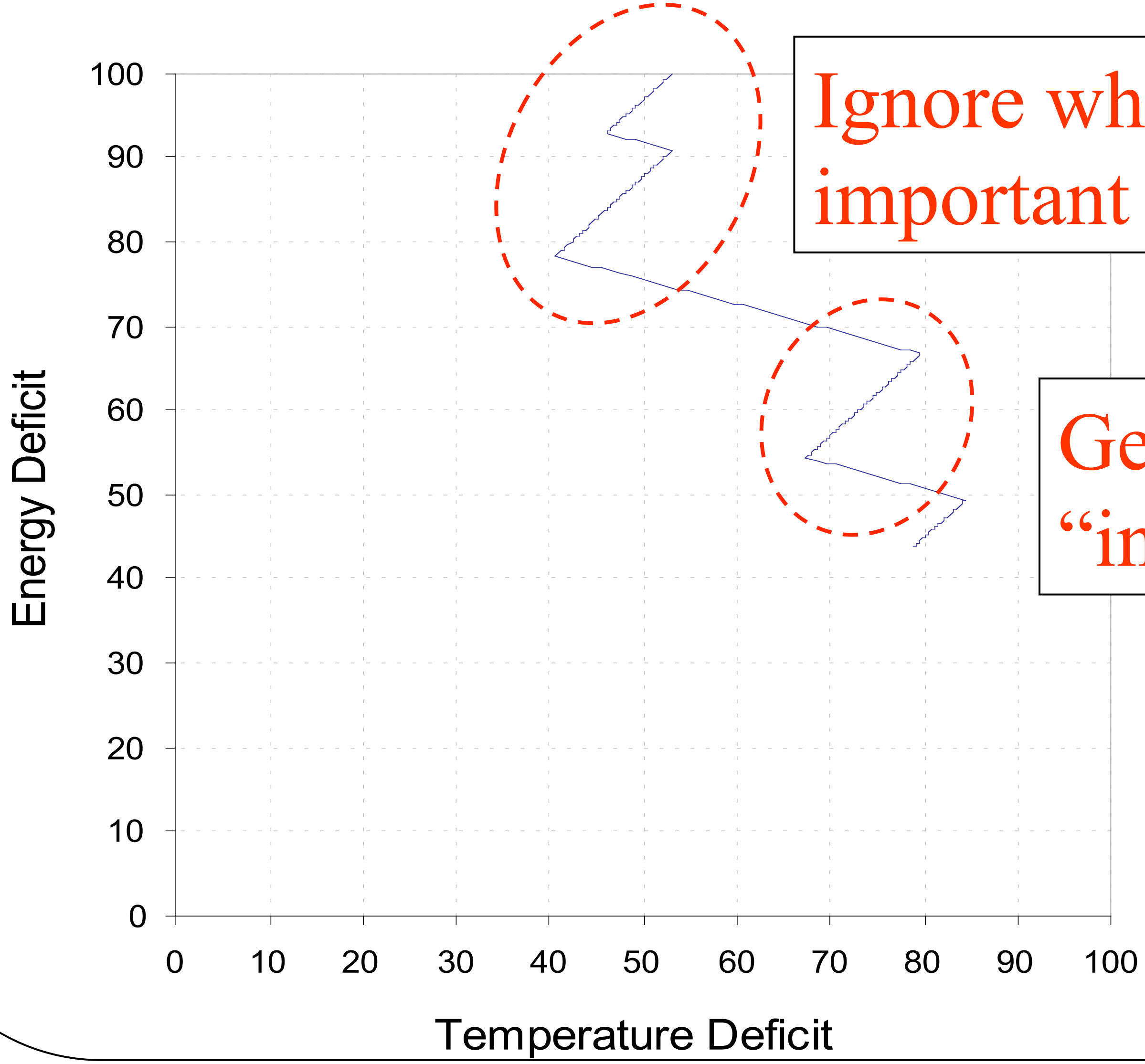




Problems with activity cycles



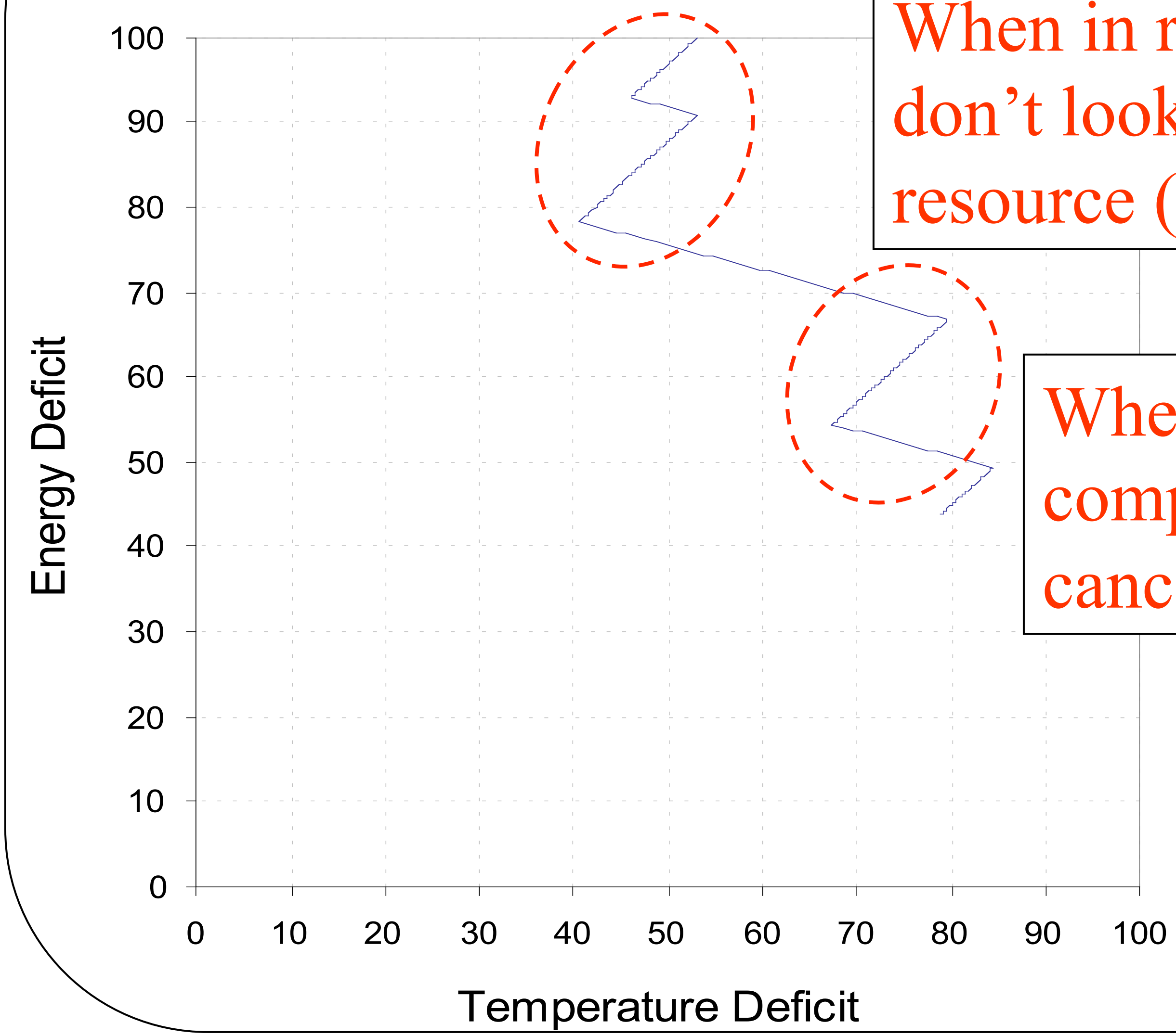
Typical solutions



Ignore what's not important

Get rid of "intruder"

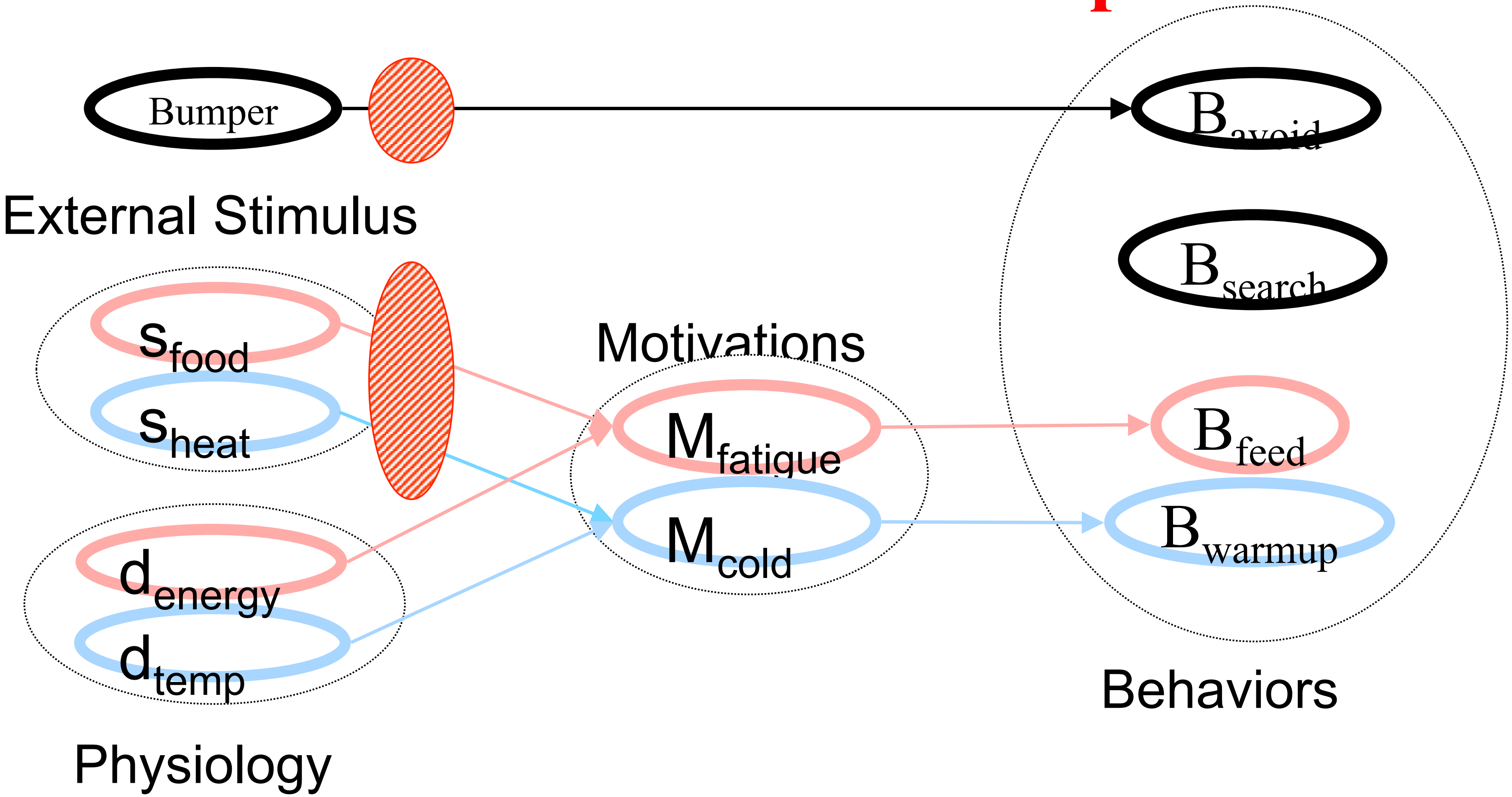
Hormonal modulation of perception



When in risk of death, don't look at "wrong" resource (α)

When in presence of competitor, no RoD, cancel bumpers

Modulation of exteroception



- Hormone concentration is a function of intensity of stimulus (competitor) + RoD from physiological deficits

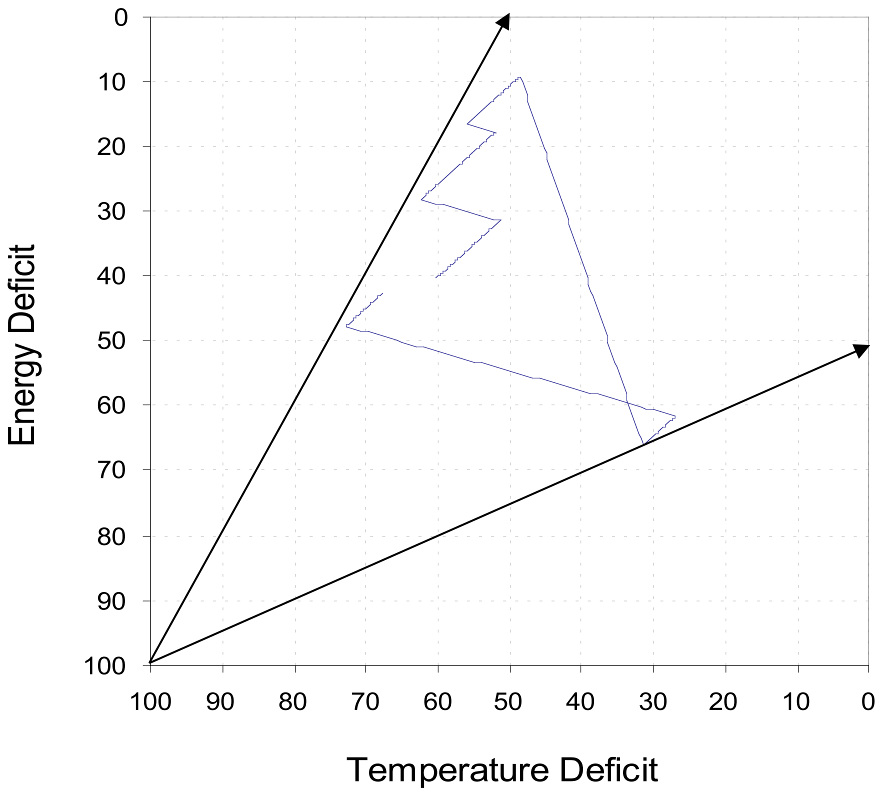
Effects on behavior

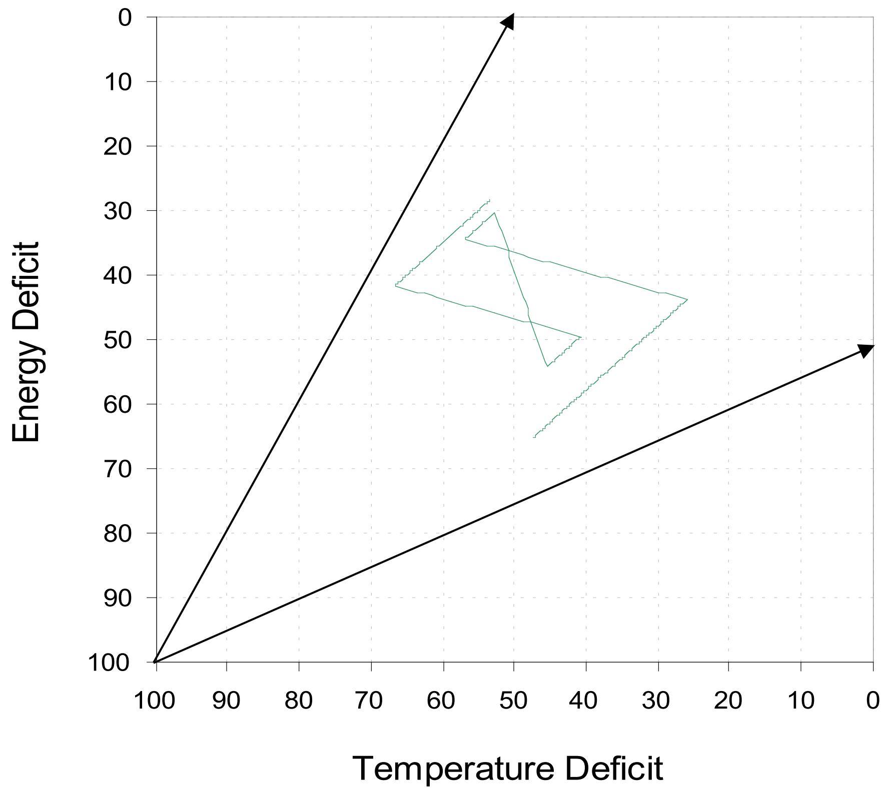
- Different functions (behavior) from the same anatomical "neural" circuit
- Stop consuming resources when competitor approaches
  - Abandonment of situation
- Robot goes towards other robot and …
  - If RoD high, bumpers not cancelled => avoid other robot

  (observer's point of view: "fear")
  - If no RoD, bumpers cancelled => "push" other robot, enhanced "competition skills"

  (observer's point of view: aggression, protection of resources)

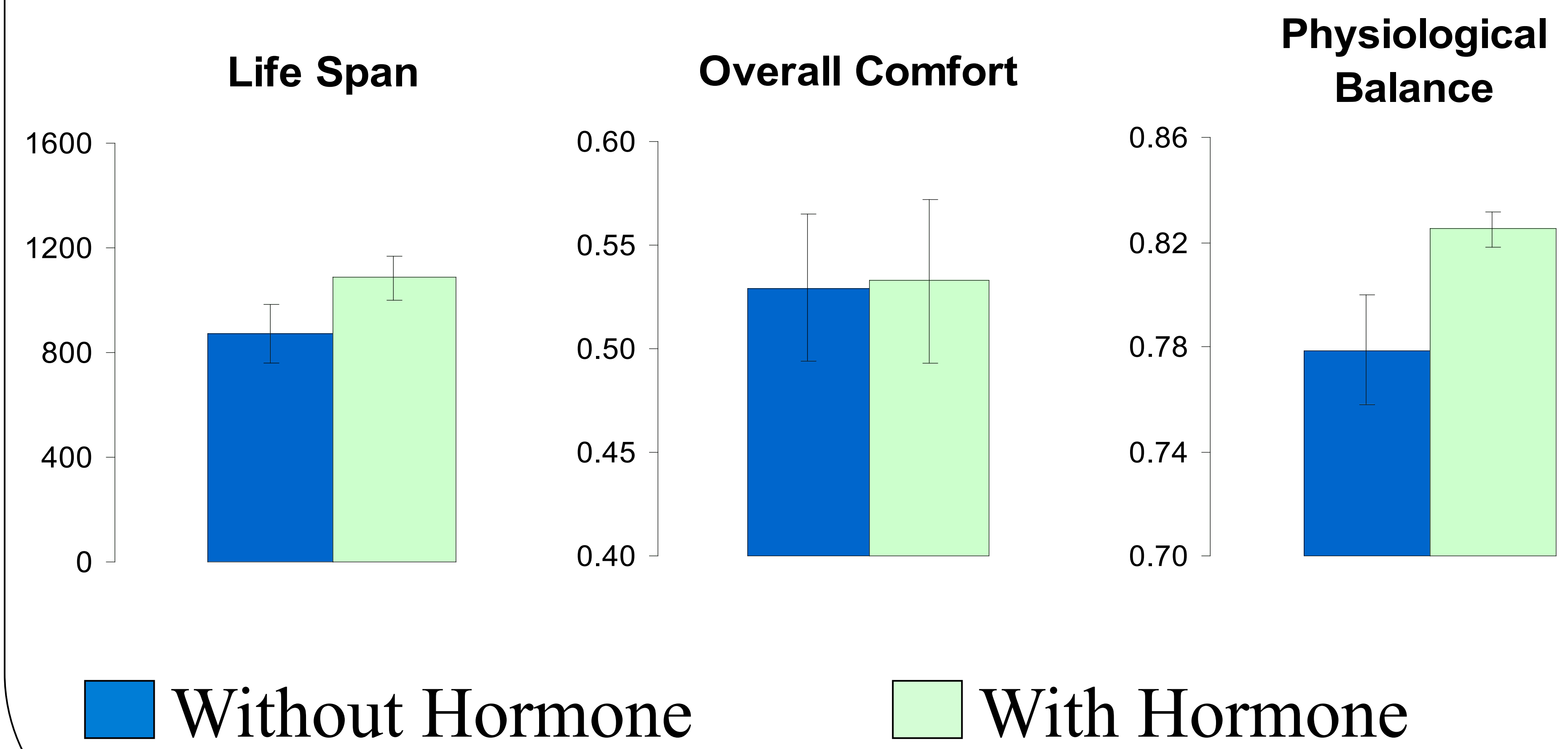
Modulation of exteroception & activity cycles



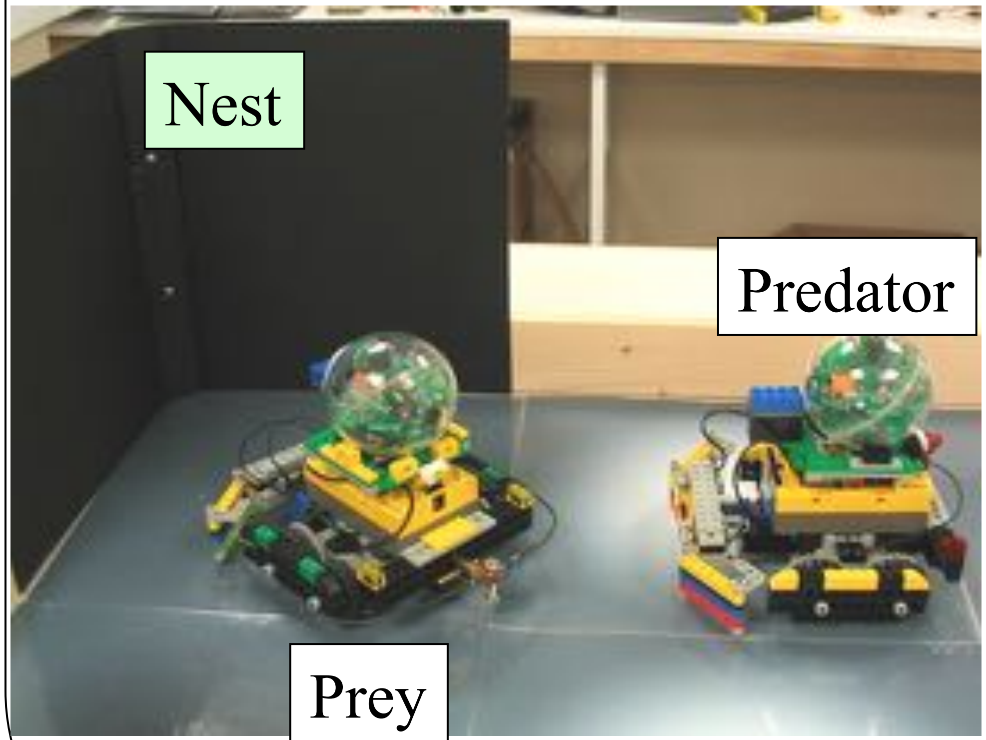


Without Hormone With Hormone

Results in CTRP



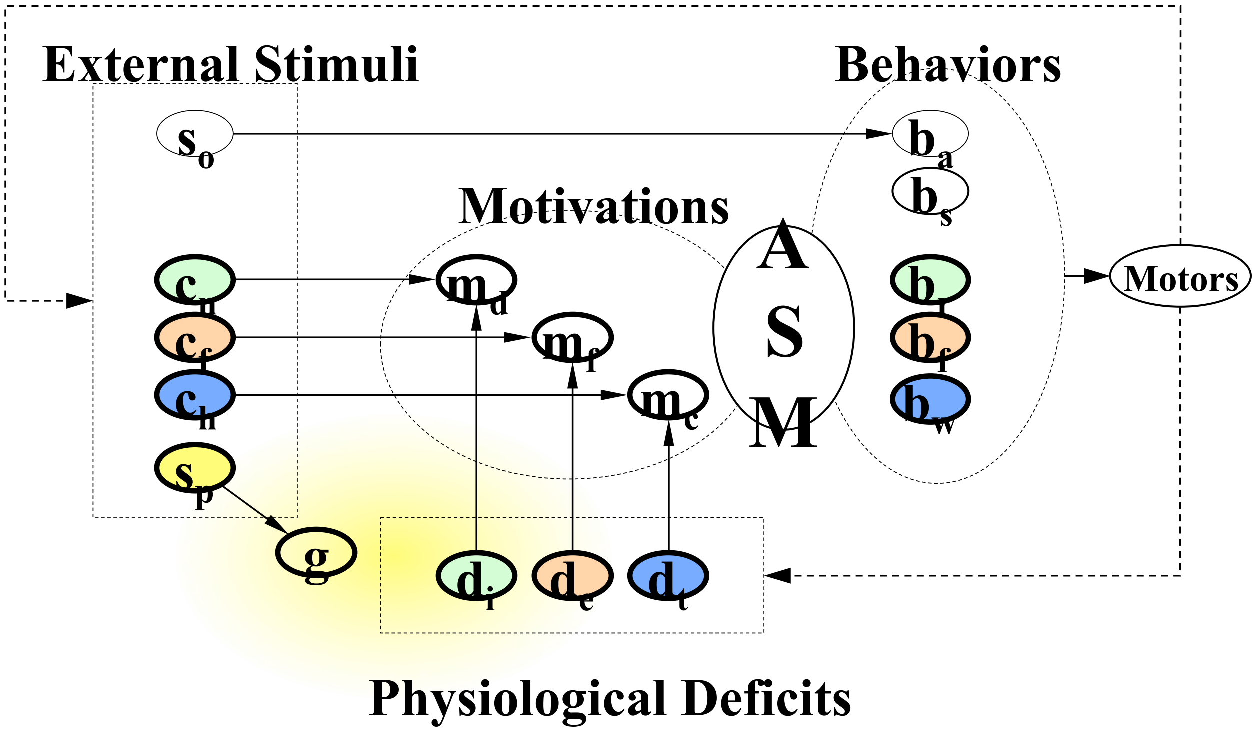
Hazardous 3-Resource Problem



- Prey has new physiological variable: integrity
- Prey can recover integrity by resting at nest
- Limited perception of predator: punctual, “too late”

Cañamero, L. & Avila-Garcia, O. (2007). Proc. ACII 2007
O’Bryne, C. & Cañamero, L. (2009, 2010). Proc. ACII 2009; Proc. ALIFE 2010.

Modulation of interoception



- Longer-term changes in behavior (temporal dynamics of hormones)
- Increased sensitivity to integrity deficit, increased attention to "risk of predation" *(observer: "apprehension", "fleeing")*
- Interruption of other activities before satiation