

Animals, Robots, Methods and Models:

- Contribution from Ethology to Emotion Research
- A proposition for a dynamic systems formulation

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The Case for Formalisation (Modelling)

The Notion of Emotion is Murky

Explicit modelling brings mental discipline, exposes weaknesses in verbal argumentation and may indicate links between seemingly unrelated concepts (generalisation)

Bateson, 1991

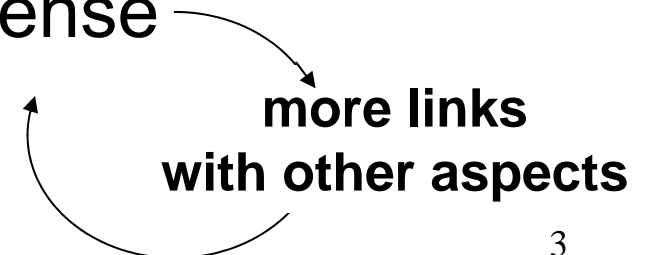
NOT:

Overly concerned with “definitions”

- **Not** trying to find the one-and-only true definition
- **Not** starting with a tight definition in order to make a model

BUT:

A general framework that, while developing it, makes more and more clear how the initially vague notion makes ever more sense



Loose (working-) Descriptions

Damasio¹:

Emotion:

Processes that *guide* behaviour

¹Damasio, A.R. (1999): The feeling of what happens. New York: Harcourt Brace

Emotion

Processes that ***guide*** behaviour
(and *therefore* relate to **motivation**)

Via “**Reward Transmitters**”:

- Dopamine (midbrain)
- Opioids (Enkephalines/Endorphines
a.o. in OrbitoFrontal Cortex)

“**Desire**”,
“**Wanting**”

“**Liking**”

Links with Ethology

Cabanac:

“**Common Currency**” for comparing/
evaluating (conflicting) motivations

Decision making/ Action Selection

Models of Motivation and Behaviour

“Automaton” Models

- Computational Models & A.I
- Cognitive Science
- Neodarwinist Explanations

Meta-physical, idealistic

Functionalist

Top-Down/Analytical

Rationalist-Deductive

Normative

“Mechanistic” Models

- Systems Theory
- Cybernetics
- Neurophysiology

Materialistic

Bottom-up/Synthetic

Inductive

Descriptive

Action Selection

“Automaton” Models



Descartes

Do not accept the obviousness
of your senses (Doubt!)

The correct way to obtain
knowledge is by **reasoning**
(using *ratio*)

Reasoning is beyond perception:

|
Mind-Body Dualism

What did Descartes think about ***behaviour*** ?₇

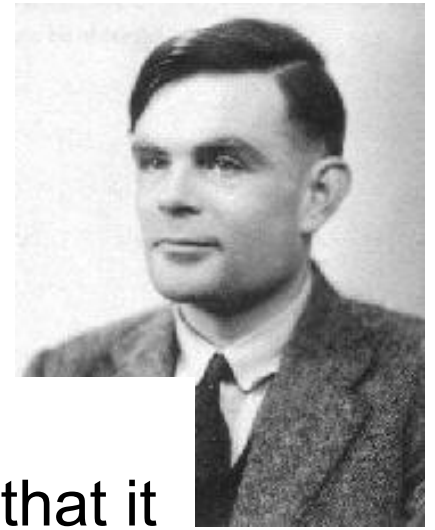
1) If automatons had the shape of animals*, we should have no means of knowing that they did not possess the same nature as animals

2) If automatons perfectly imitated actions of animals*, we would be in no doubt that animals were automatons too

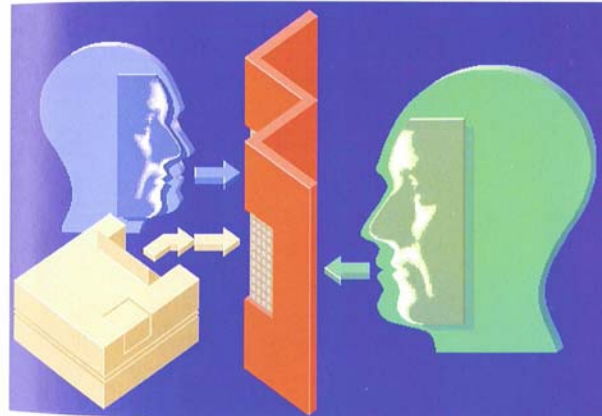
** that lack reason*

***Behaviour could be understood as
an
automaton***

Turing (1950)



If a computer perfectly imitated answers of humans, we should have no means of knowing that it did not possess the same intelligence as humans



Intelligence can be understood as computation

Artificial Intelligence:

Intelligence by Computation

Top-Down

- Initialisation: typical “intelligent” behaviour (e.g. playing chess)
- Implementation: Get it done by effective as possible

algorithms

- Inspiration = ***contemplation***

algorithm following the steps as *we* should do it
to *solve a problem* in the most *economic* way

Independent of Hardware Functionalism

(Putnam, 1975)

- Internalization: propose algorithm as explanation

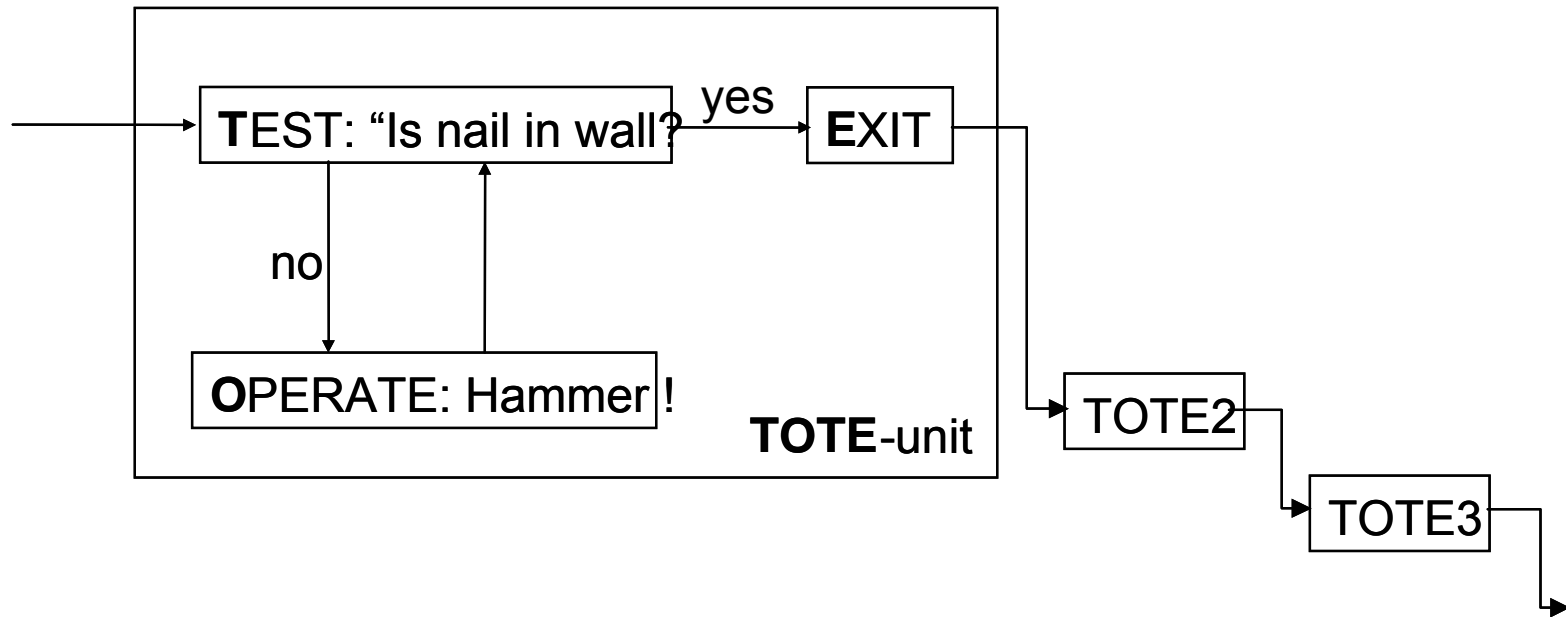
Models of Intelligence or:
Models of ***how we think about*** Intelligence

?

Cognitive Science & Computational Models of Behaviour

Miller, Galanter & Pribram (1960): "Plans and the Structure of Behavior"

- **PLAN:** Any *hierarchical* process in the organism that can *control the order* in which a *sequence of operations* is to be performed



Cognition can be understood algorithmically

Discrete, serial actions. After every act, process is interrupted by a check. Actually, a ***computer program***

```
10 IF StateNail = InWall
20 THEN GOTO 80
30 ELSE
40   BEGIN
50     hammer
60     GOTO 10
70   END;
80 EXIT
```

Algorithmic (Programming) Approach to Behaviour.

Baerends (1976, Anim. Behav.): Motivational dynamics as ***software***,
Behaviour as ***computation***.

Dawkins (1976):

“Animals and computers are both so complex that something on the level of *software explanation* must be appropriate for both of them”

Current Ethology

Computer/Programming metaphors:

- Cognition as **Computation**
- Behaviour as **Problem Solving**
- Capitalizes **Knowledge/Information**



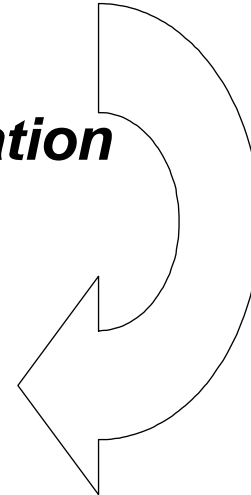
Rational Solutions

Animals “have to” survive

Algorithm: Natural Selection

Evolutionary Ethology

(Neo-Darwinism)



Key concepts: *Problem Solving by Computation; Computation by Algorithms*
Algorithms from Rationalised Contemplation;
Functionalism (independence of physical substrate)

Mechanistic Models

Classical Ethology

(Lorenz: 1937, 1950; Tinbergen: 1951)

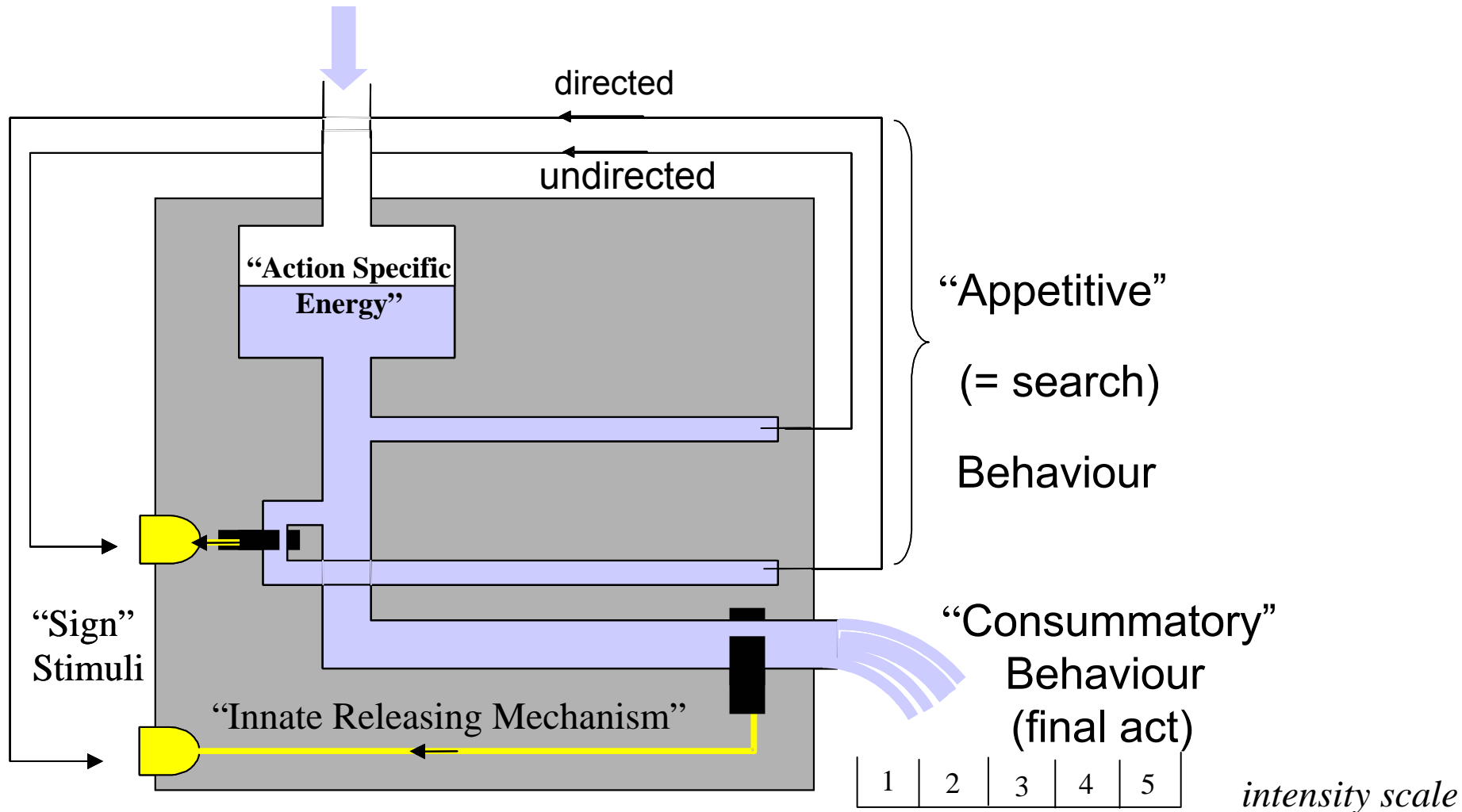
Quasi-technological language

(to make ethology scientifically
acceptable)

Mechano-morphic portrayal of animals*

*E. Crist (Biology & Philosophy, 1998,13)

Classical Ethological Theory of Motivation (“drive”)

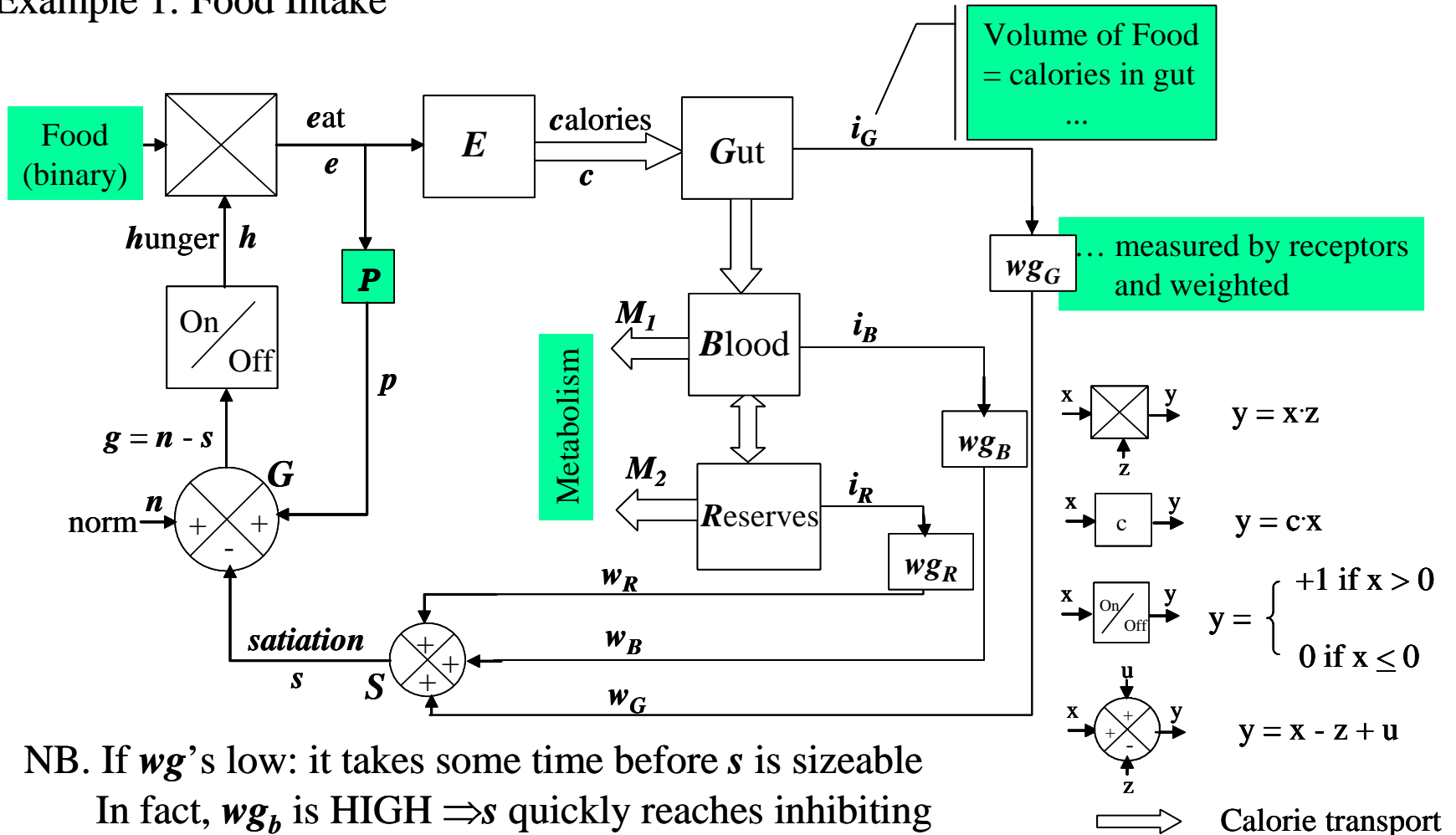


Behaviour can be understood as an energetically driven lock-and-key/ pressure-pull mechanism

Cybernetics & Control Theory (Wiener, 1961)

From Regulation of Fixed Action Pattern to Control of Continuous Behaviour Variables

Example 1: Food Intake



NB. If w_g 's low: it takes some time before s is sizeable
 In fact, w_g_b is HIGH $\Rightarrow s$ quickly reaches inhibiting proportions \Rightarrow "dithering"

Action Selection

Intensity of (final) Behaviour due to **both external stimuli and internal forces** :

Classical

(Lorenz, Tinbergen)

* Level (pressure) of Energy (“Drive”) →

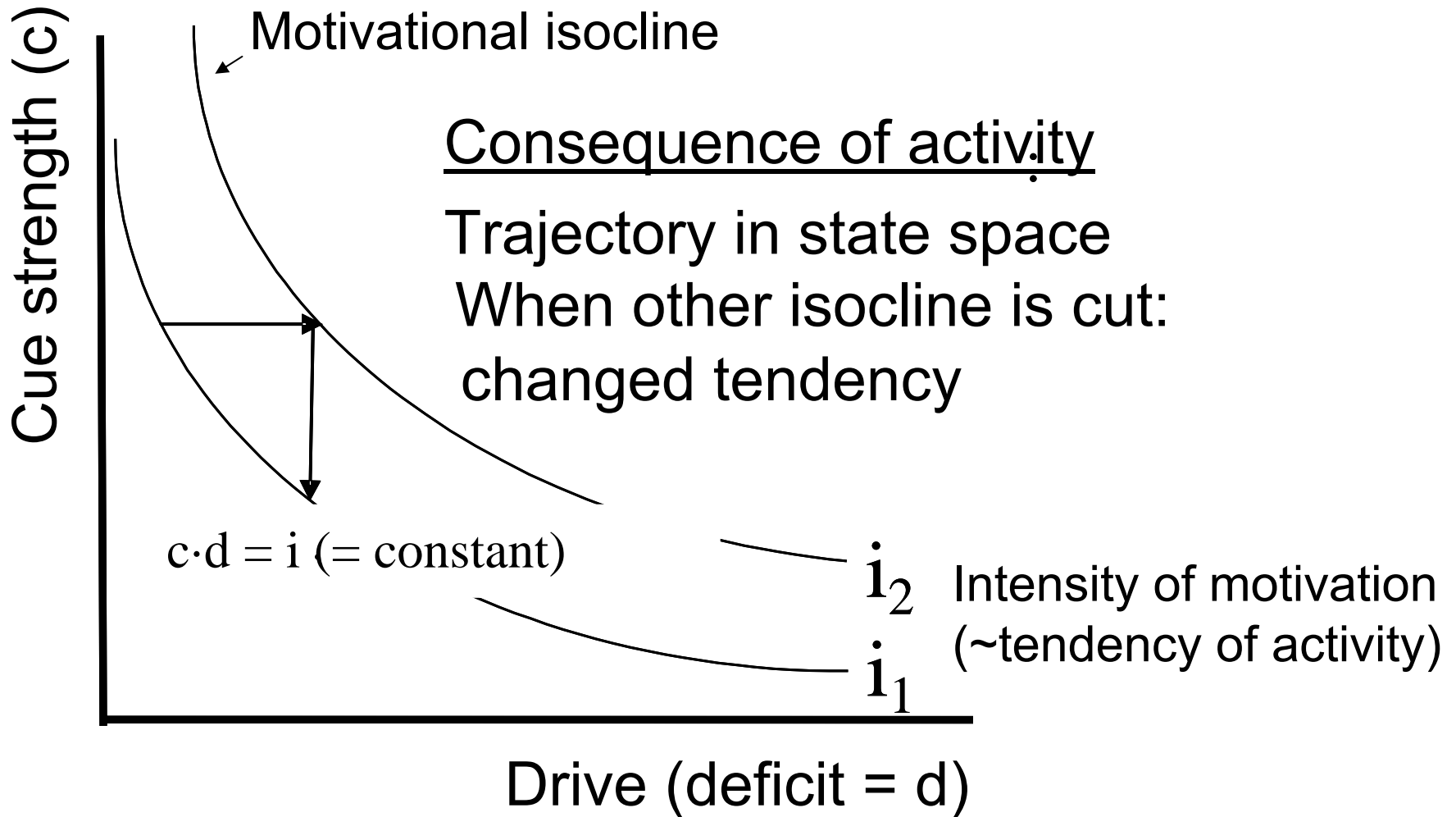
* Pull of Sign Stimuli →

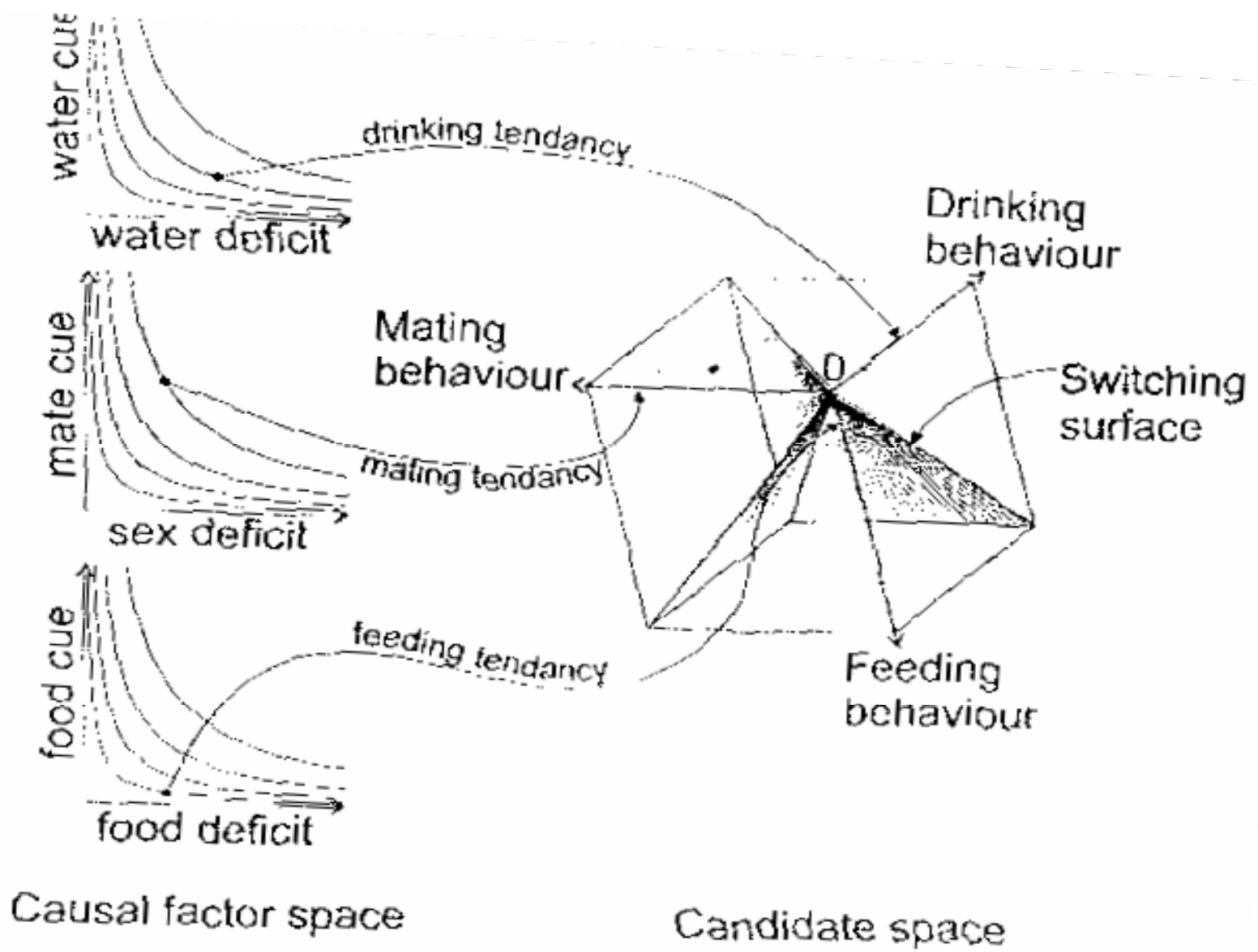
State Space Approach

(McFarland, Houston)

Deficit of
physiological
variables

Cue strength





McFarland & Spiers (1997), Robotics & Autonomous Systems

How Good is the Action Selection Model?

1. Robustness:

2. Explanatory value:

Does it give insight about the complexities of REAL WORLD behaviour?

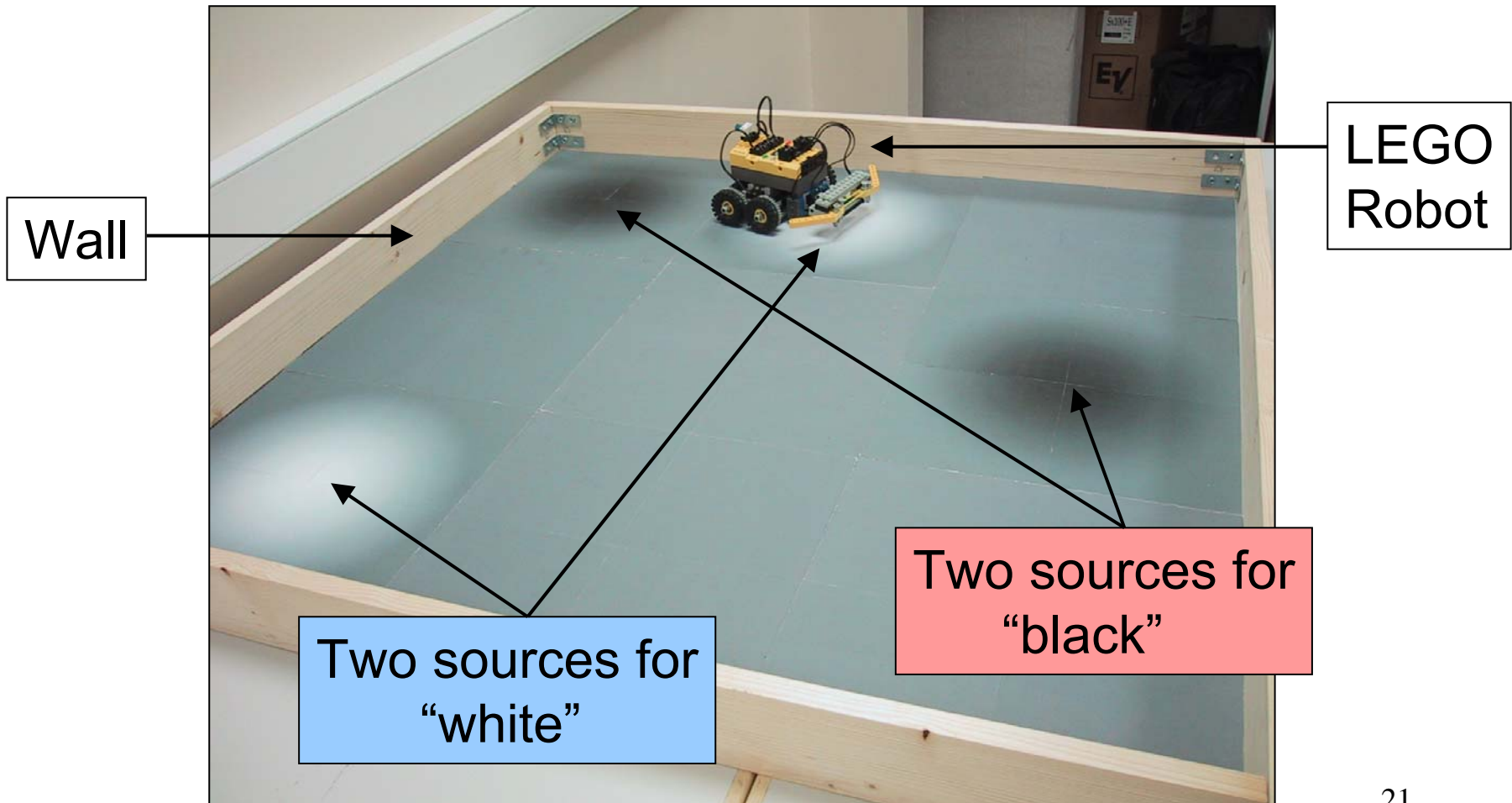
Put it to work in robots

As A Tool for Thought

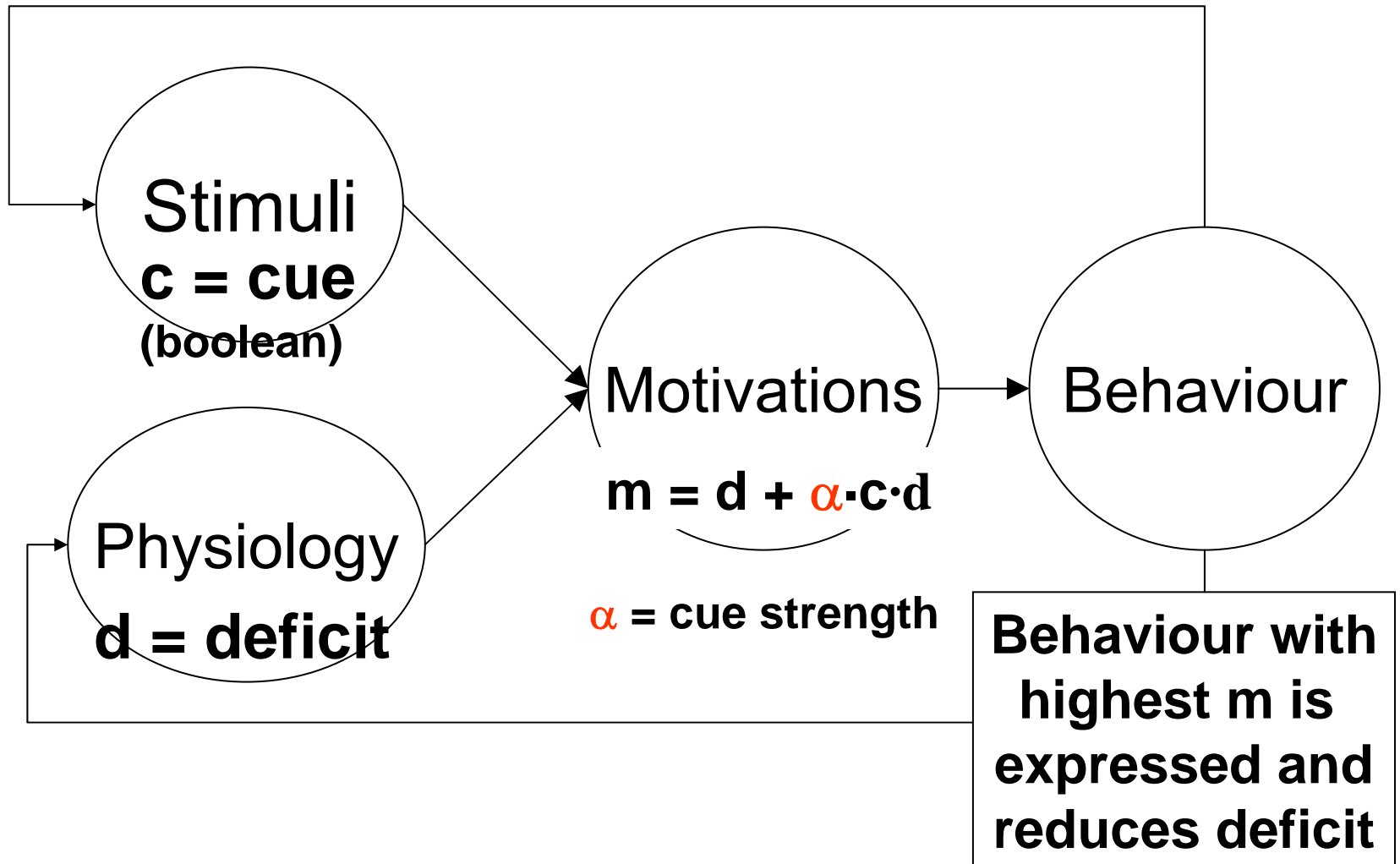
NOT to build emotions!

Put it to work in robots

(Orlando Avilla-Garcia)



Architecture



1. Robustness: Test of Predictions of the Model under variable circumstances

2. Explanatory value:

Does it give insight about the complexities of REAL WORLD behaviour?

Take up Descartes' Challenge: study robots in Action Selection setting AS IF they are animals (i.e. as an ethologist would do)

Prediction:

Basic Cycle of Activities (1)

Spier, E & McFarland, D (1997)

1. Increasing **[White]**

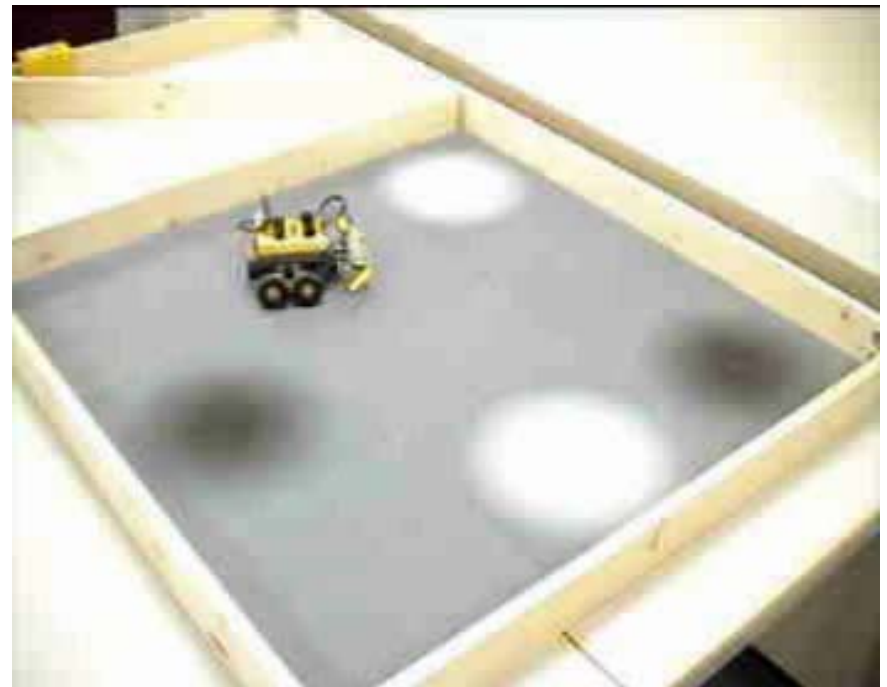
(A) Search Resource White
(appetitive phase)

(B) Uptake White
(consummatory phase)

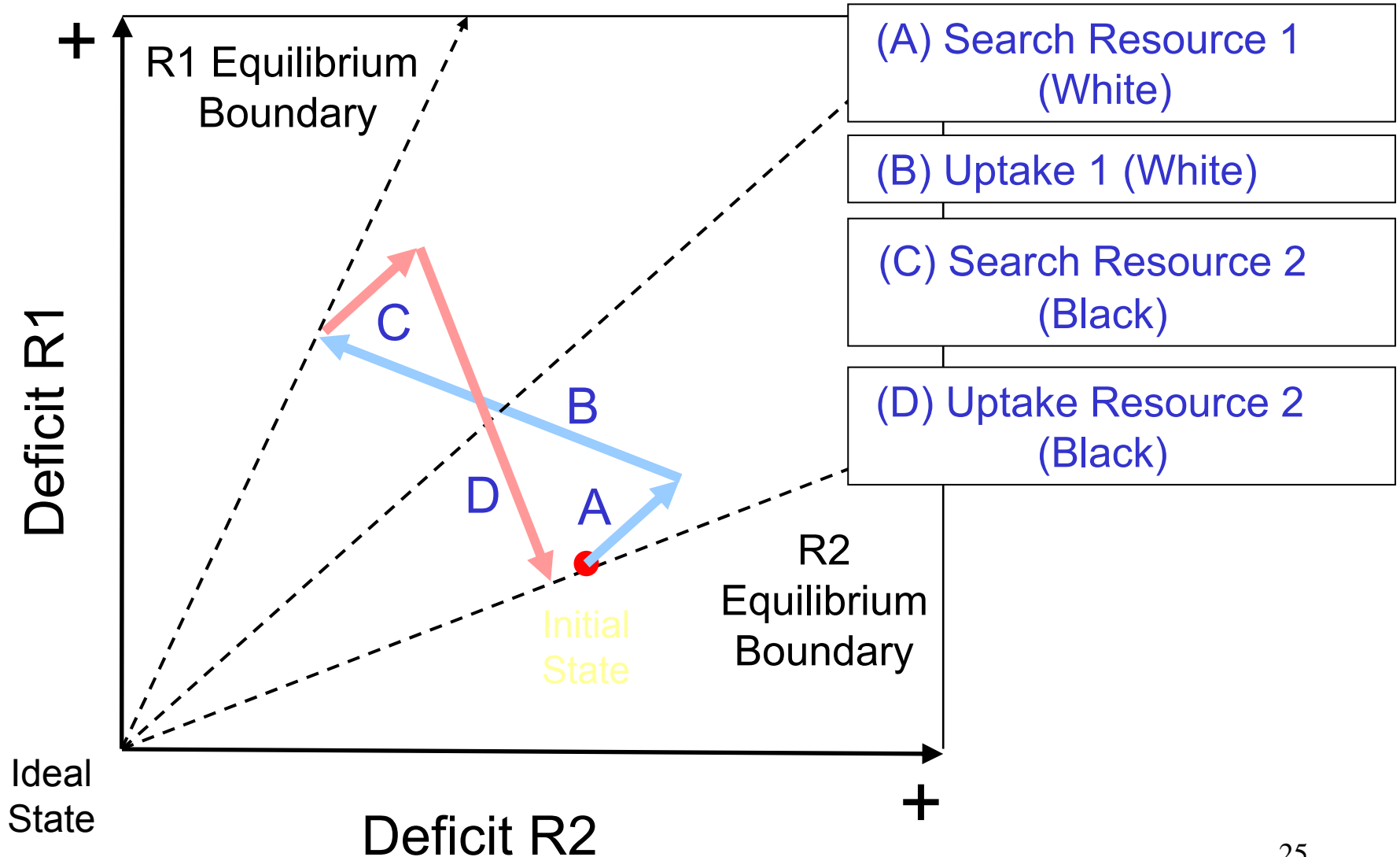
2. Increasing **[Black]**

(C) Search Resource Black
(appetitive phase)

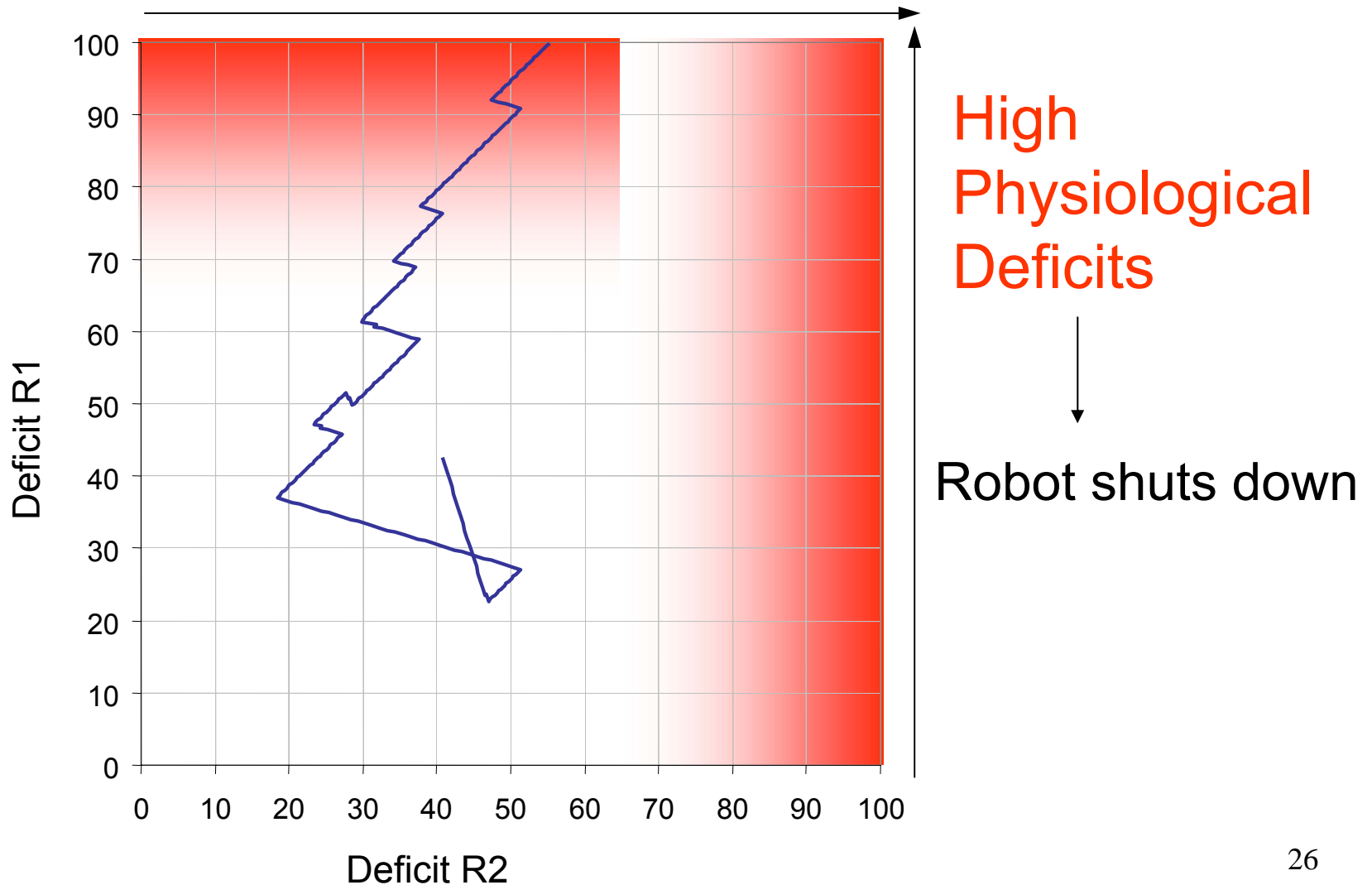
(D) Uptake Black
(consummatory phase)



Basic Cycle of Activities (2)



Robustness: Staying within Survival Region (Viability borders) = stability of the cycle



Test of Robustness: Introducing an extra Robot:

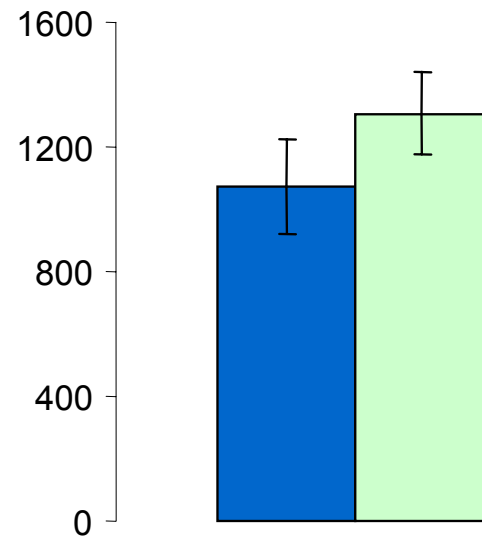
Leads to limited Accessibility & Availability of
Resources

Competition



Effect of Competition

Life Span



■ 2 robots ■ 1 robot

Possible Solution

Dynamic Coupling between Cue and Drive

In robot:

Deficit getting closer to viability border:

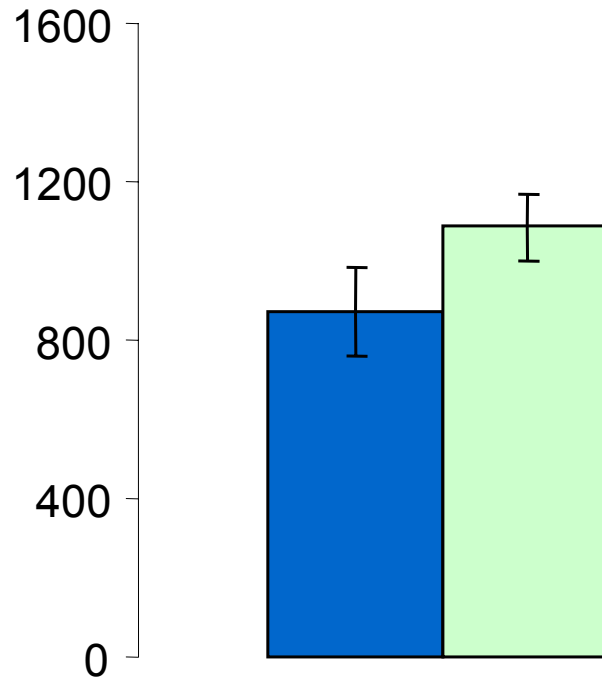
Cue strength (a) decreases, bumper shuts off

In organisms:

Reduced Receptivity
to outside world



Life Span



■ Without Adaptation ■ With Adaptation

How “Good” are the Models (II)?

Take up Descartes’ Challenge:

Build Robots that display seemingly sophisticated behavioural/”decisions”
and study them as if they are animals



Analyse Robot behaviour by means of “Ethological Methods”:

Does Cue-Deficit loop affect the behavioural performance?



Patterns of behavioural activities that can be interpreted by the model

Inverse Problem:

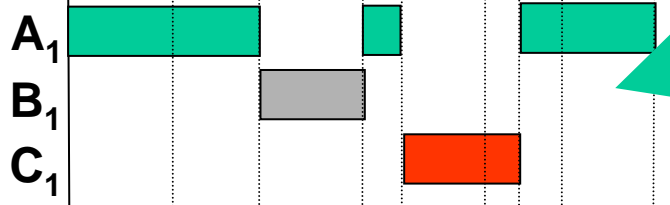
Given (patterns in the) behavioural output, can we infer the motivational “rules”?

Ethological methods

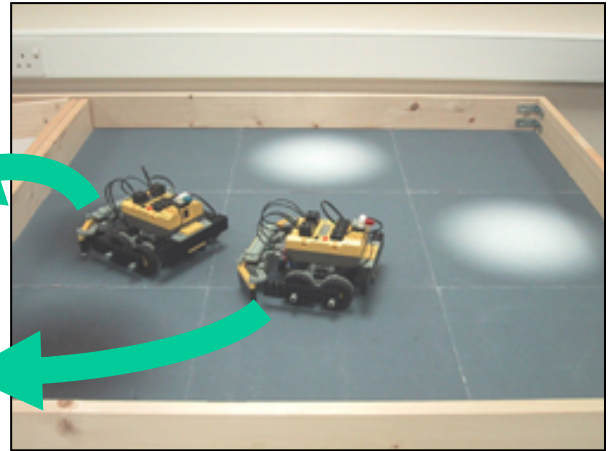
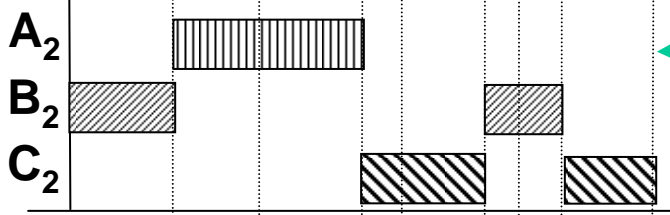
- Define activities, construct transition matrix
- Correlated behavioural profiles (rows in the matrix) reflect motivational states (PCA; Cluster analysis)
- Estimate Rate of Transition of visiting motivational state X from motivational state Y (Markov modelling)

Activity

Subject 1



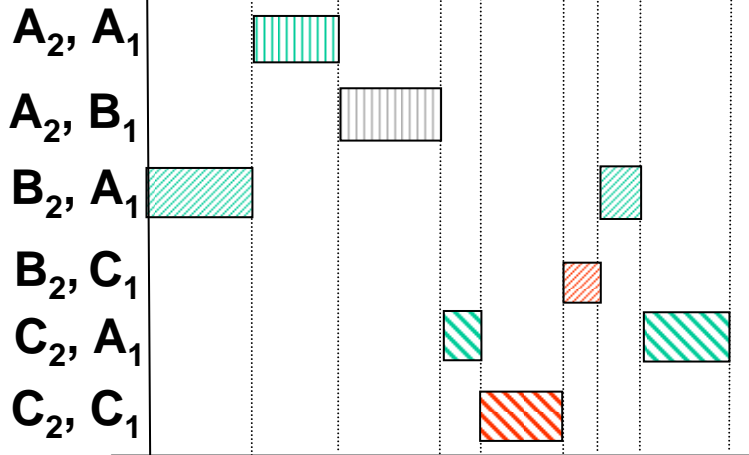
Subject 2



Transition Matrix

		State n+1 (next)		
		A	B	C
State n (preceding)	A	-	II	III
	B	III	-	
	C	II	II	-

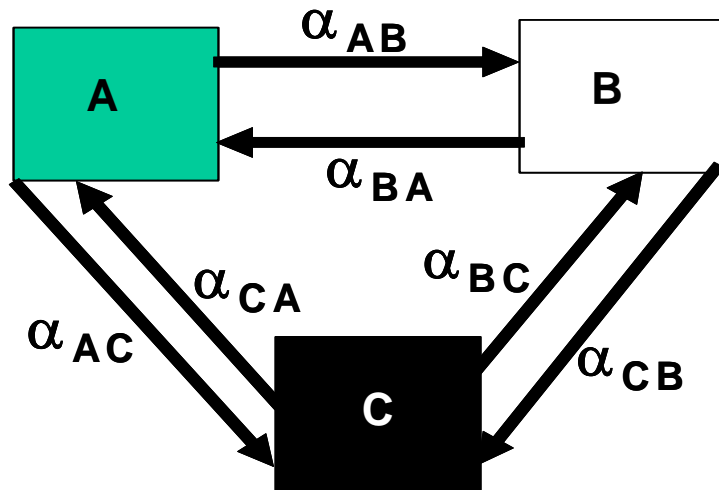
Combined



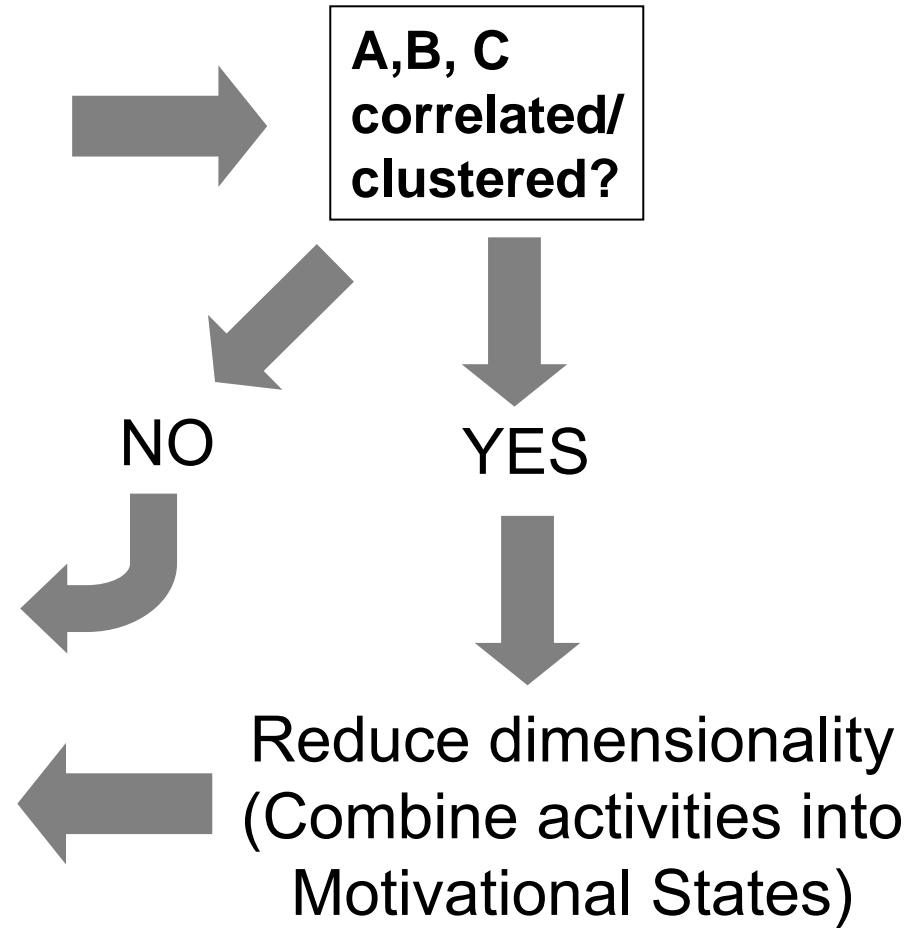
Time

Transition Matrix

		State n+1 (next)		
		A	B	C
State n (preceding)	A	-		
	B		-	
	C			-



Markov model



Systematic Experiments (with Orlando Avila-Garcia)

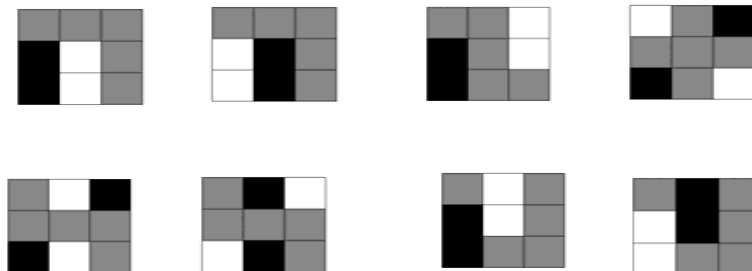
- Various combinations of partners:

		Robot 1:	
		Modulated	Not Modulated
Robot 2:	Modulated	M,M	M, NM
	Not Modulated		N-M, NM

- Two start conditions:

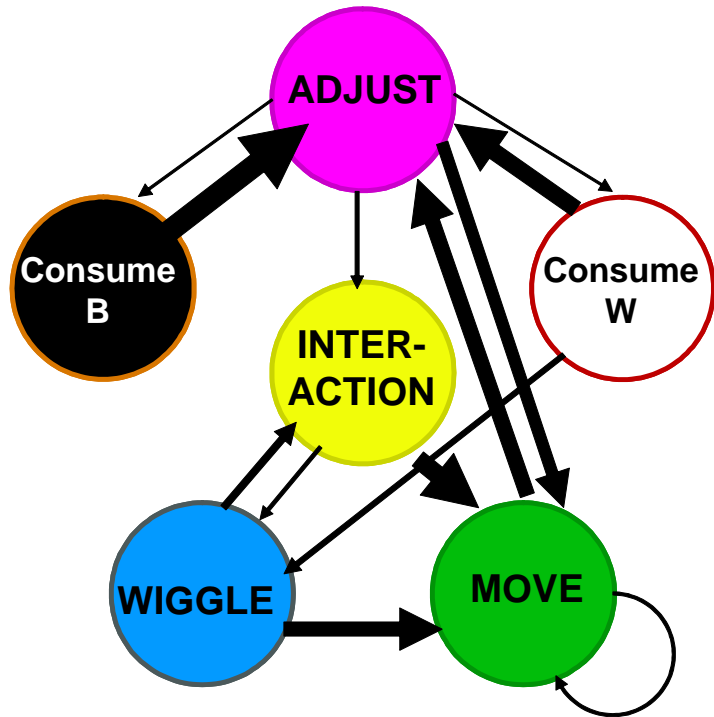
“Head-to-Head” and “Tail-to-Tail”

- Various distributions of “resources” (“Black” and “White”)



$\chi^2 =$	33.94648
DF =	28
P =	0.202641

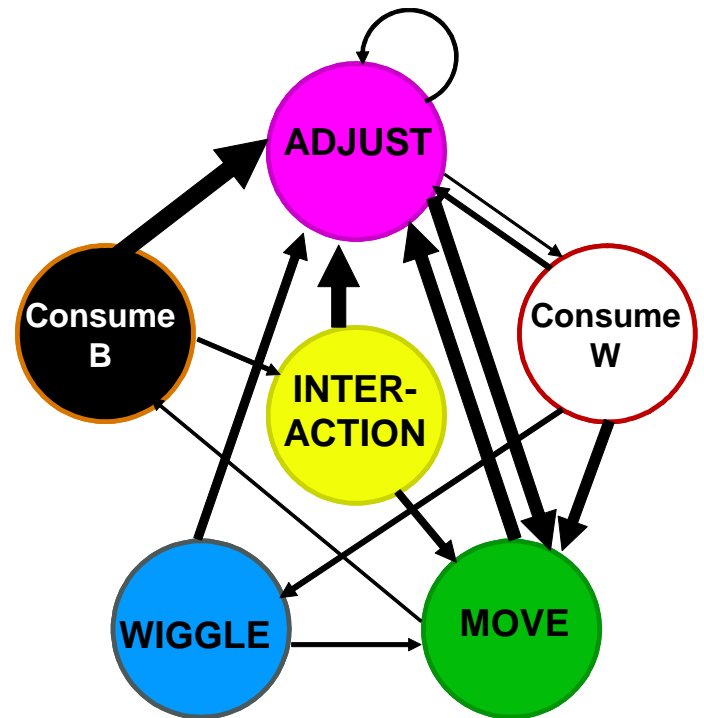
Modulated



More directed towards “Move”

$\chi^2 =$	59.30756
DF =	49
P =	0.148626

Not Modulated



More directed towards “Adjust”

		Adapt. Loop	No Adapt. Loop	Both WITHOUT Adap. Loop		Both WITH Adapt. Loop	
Adjust	Adj	0.0354839	0.0290323	0.03	0.044335	0.015	0.00738
Circle	Cir	0.0225806	0.016129			0.03	0.04797
Corner Avoidance	Cor	0.1258065	0.1258065	0.232	0.1083744	0.129	0.19188
Simple Interaction	Int	0.0387097	0.0548387	0.054	0.0492611	0.018	0.04059
Move Straight	Mov	0.1483871	0.1387097	0.089	0.1625616	0.114	0.17343
Parallel Movement	Par			0.01	0.0197044	0.022	0.02214
Struggling	Str	0.1032258	0.0645161			0.085	0.08118
Traverse Area	Tra	0.0967742	0.1	0.182	0.1674877	0.137	0.07011
Uptake Black	UpB	0.1193548	0.1645161	0.138	0.1428571	0.148	0.14022
Uptake White	UpW	0.1548387	0.1677419	0.079	0.1477833	0.155	0.12546
Wall Avoidance	Wal	0.116129	0.0870968	0.172	0.1034483	0.129	0.09594
Wiggling	Wig	0.0387097	0.0516129	0.015	0.0541872	0.018	0.00369

HOW DO RATIONALIST, TOP-DOWN
ACTION-SELECTION MODELS DEAL WITH
SUCH EMBODIMENT ISSUES
AND SELF-ORGANISATION

?

Critique on Existing Action Selection Model

Actually, **NO declaration** about the **mechanism**

The change from one behaviour to another is
justified by cost/benefit considerations

Rationalist perspective



Decision Theory:

Alternatives can be chosen

independently

Independence of cues and drives

Actually, **NOT dynamical/systemic**

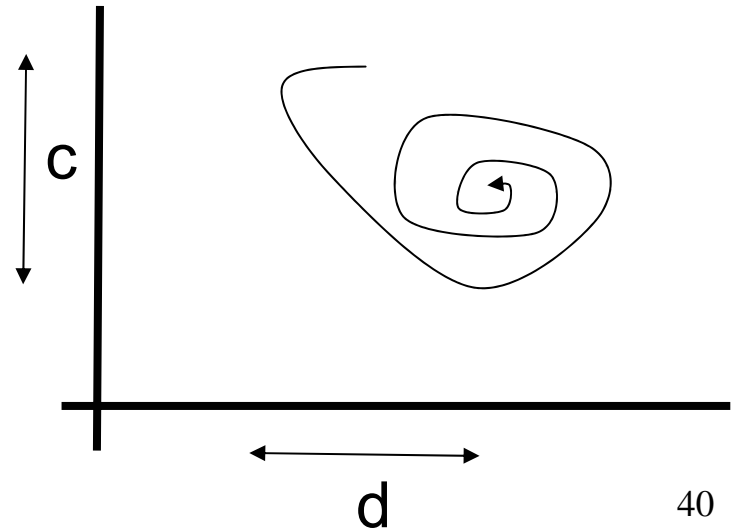
REAL Dynamics

Rules that govern the movement in the Cue-Deficit
State Space

(not just rationalisations about costs and benefit
to go in certain directions)

$$c' = f_c(c, d, \dots)$$

$$d' = f_D(d, c, \dots)$$



A (very simple) Model of Motivational Dynamics

$m(t)$ = Motivational intensity/tendency at time t :

*If nothing else, it decays as: $m'(t) = -d \cdot m(t)$

*Grows by reinforcement: $m'(t) = r \cdot m(t)$

$$m'(t) = r \cdot m(t) - d \cdot m(t)$$
$$\dot{m} = rm - dm$$

****Uses up Energy:*** $E_{used} = c \cdot m(t)$

Amount of Energy left over at time t : $E - E_{used} = E - c \cdot m(t)$

Modulation: Parameter of growth is not constant

Growth is fueled by Energy available:

$$r = f(E - E_{used})$$

Motivational intensity increases in proportion to a fraction (f) of the Energy left over:

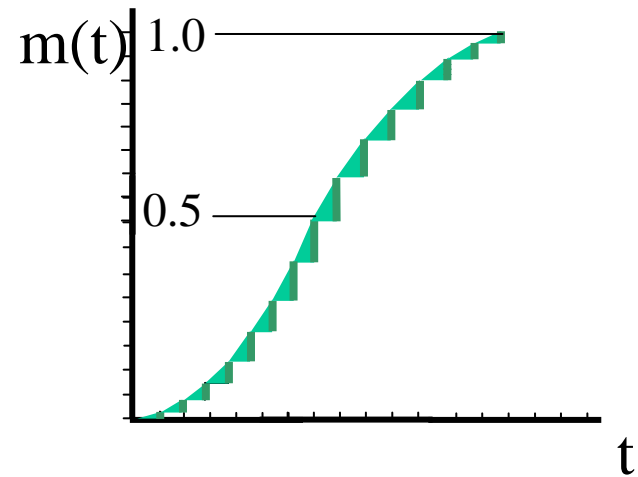
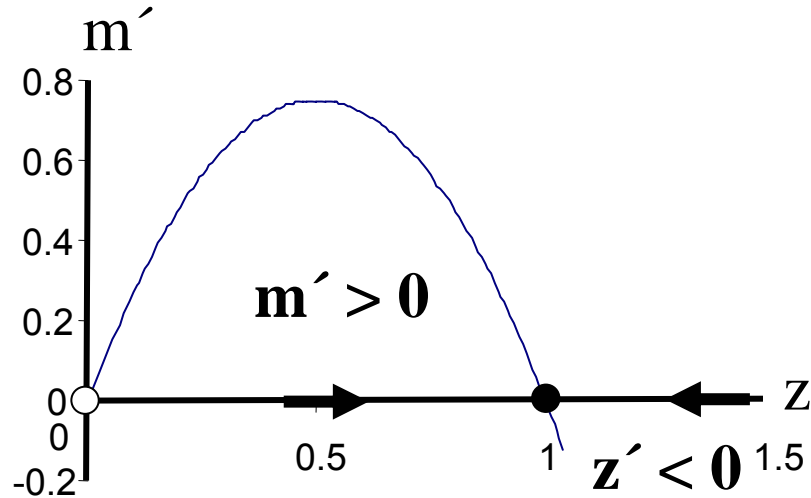
$$m' = f \cdot \underbrace{(E - c \cdot m)}_r \cdot m - dm = (fE - d) \cdot m - fc \cdot m^2$$

$(0 < f \leq 1)$

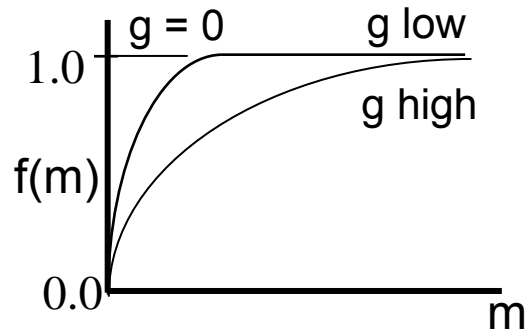
$$m' = \underbrace{(fE-d)}_{\text{Constant}} \cdot m - fc \cdot m^2$$

Constant

Logistic Equation



Extension: When motivation is stronger, a ***larger fraction*** of available Energy is used to fuel further increase



$$f(m) = \frac{m}{m + g}$$

Guarantees $0 < f(m) \leq 1$

\uparrow $g = \infty$ \uparrow $g = 0$

$$\dot{m} = f(m)(E - cm)m - dm$$

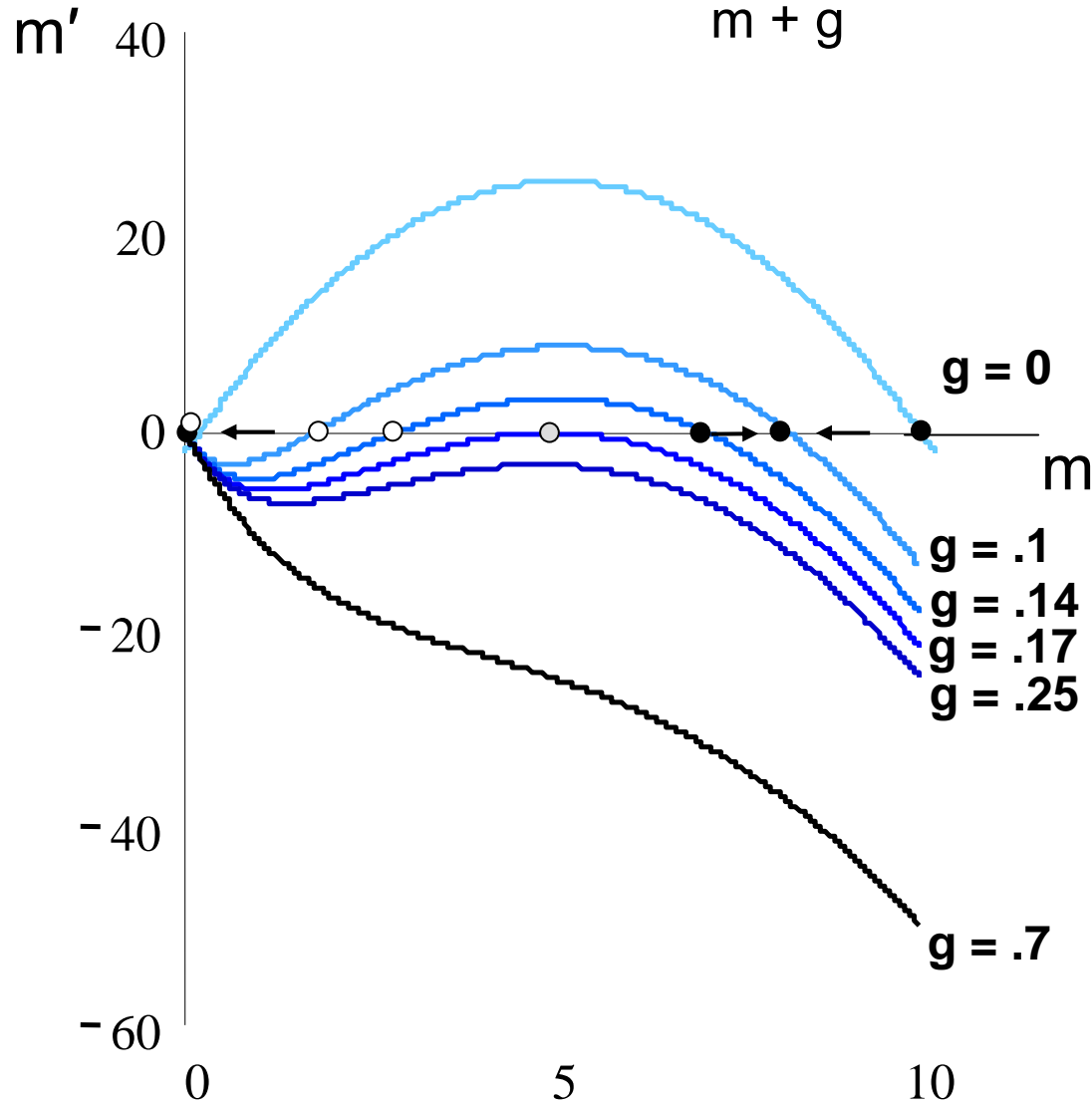
$$\dot{m} = \frac{m}{m + g} (E - cm)m - dm$$

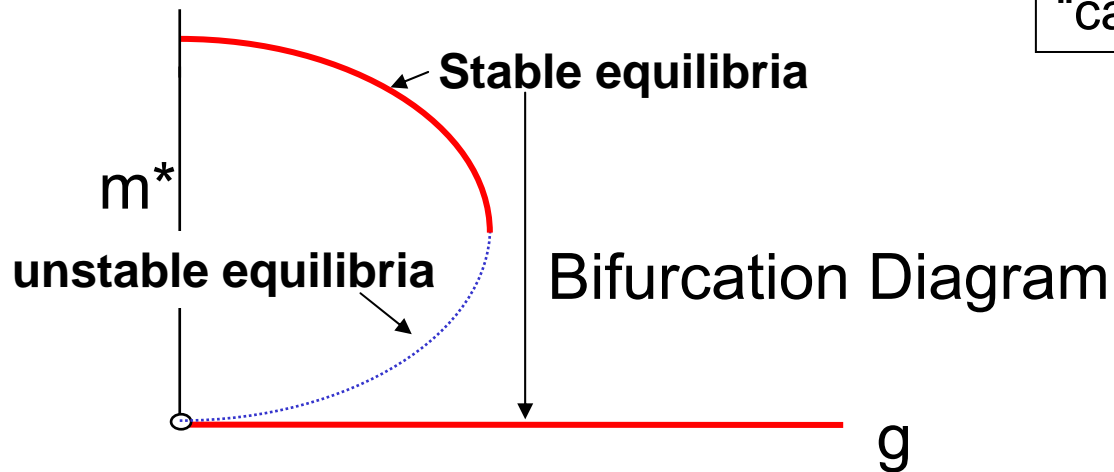
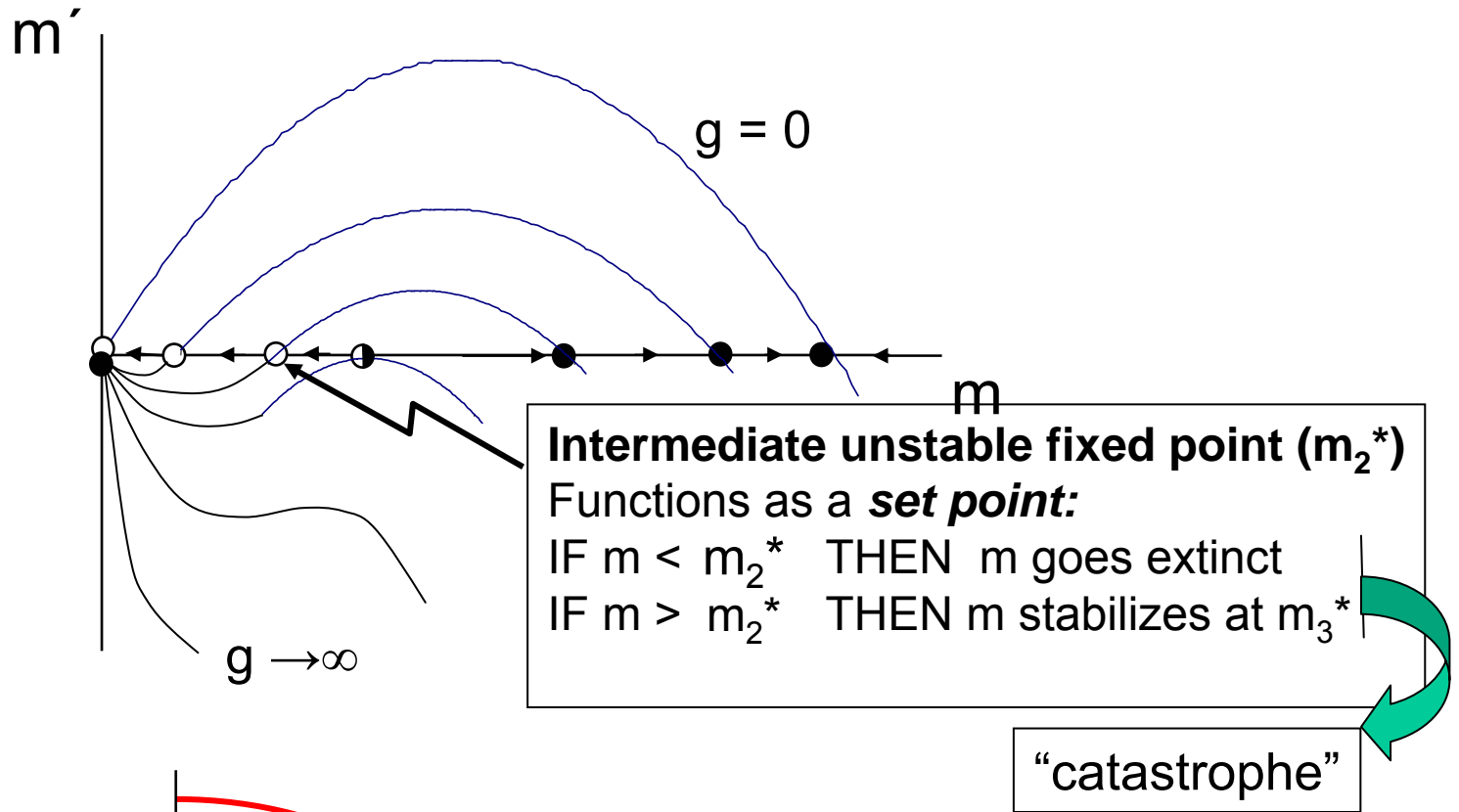
$$= \frac{-cm^3 + (E - d)m^2 - dgm}{m + g}$$

Cubic differential equation

Bifurcation and Multi-stability in a Non-Linear System

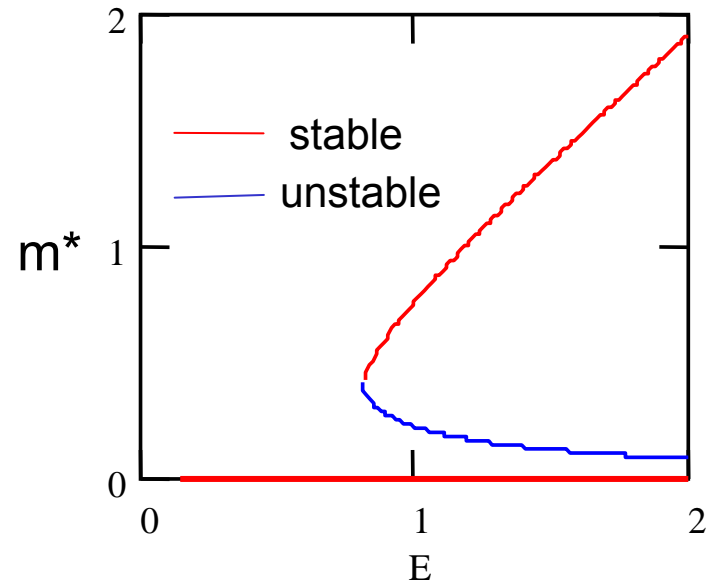
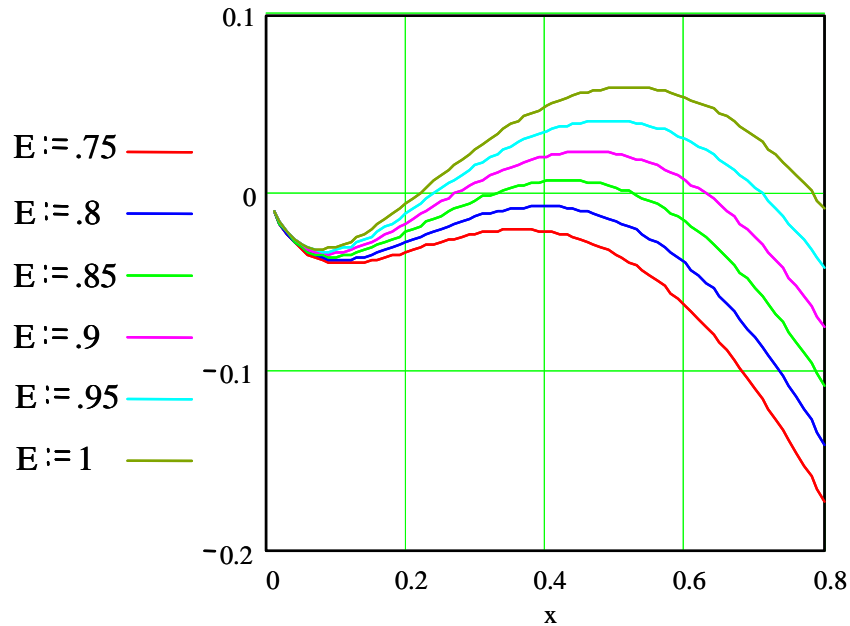
$$m' = \frac{-cm^3 + (E-d)m^2 - dg \cdot m}{m + g}$$





In the model: E is fixed, but Energy *available* ($E - cm$) is not
 Making E “discrete variable” (set lower value after each run):

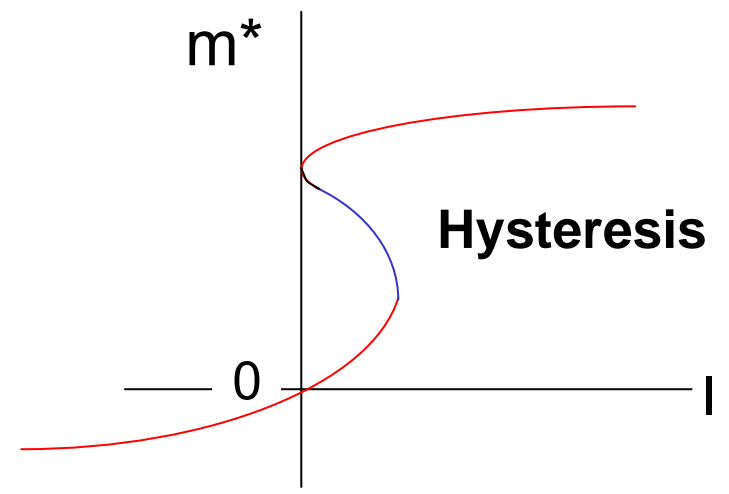
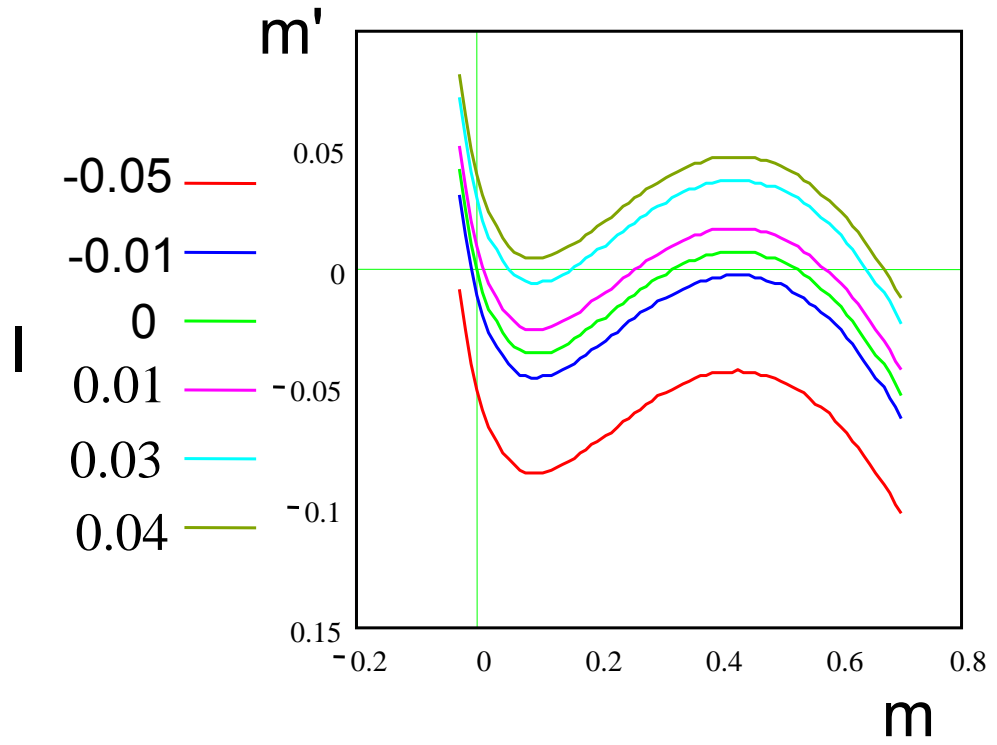
Lower E : moves unstable fp (m_2^*) to the right (= higher threshold)
 and stable fp ($>0 = m_3^*$) to the left (= lower upper asymptote)



Lower E : higher threshold →

Harder to get behaviour expressed

The effect of adding an external stimulus, I , of varying strength



Coupling between two motivations

$$m'_1 = f(m_1)(E - (c_1 m_1 + c_2 m_2)m_1 - d_1 m_1)$$

$$m'_2 = f(m_2)(E - (c_2 m_2 + c_1 m_1)m_2 - d_2 m_2)$$

$$[f(m_1)E - d_1] \cdot m_1 - f_1(m_1)c_1 m_1^2 - f_1(m_1)c_2 \cdot m_1 m_2$$

IF $f(m_i) = \text{constant}$: Lotka-Volterra equations for competing populations with self-damping

Depending on c_1, c_2 : mutual exclusion (Winner Takes All)
or coexistence (conflict behaviour?)

Link with neuro-physiological models

- 1) Structurally very similar to Fitzhugh-Nagumo equation for neurotransmission

Compare:

$$\begin{aligned}x' &= -ax^3 + bx^2 - cx - y + I \\y' &= dx - ey\end{aligned}$$



$$x' = \frac{-ax^3 + bx^2 - cgx + I}{x + g}$$

Limit Cycles and Excitatory Behaviour

2) G. Koob: “Limits To Pleasure”

Dopamine = drive, but there is a “Hedonic set-point”:



feeds back to baseline level of pleasure



- *by depletion*
- *pleasure* also releases stress chemicals → reduces pleasure

Addiction: Misuse of pleasure system leading to troubles
rising above the base line
(more depletion + stress: less pleasure)

If you take too much money from your account, you
run out/go bankrupt

Proposal: E = Endorfine concentration / “drive”

In model: position unstable fixed point (x_2^*) also function of E

When E gets smaller, x_2^* moves up (and at the same time sets x_3^* lower!)



threshold higher, less “satisfaction”

If expression of motivation leads to Endorfine production, then Endorfine concentration $\sim x_3^*$

(to be modelled)

Furthermore, system can be reformulated as:

$$m' = \frac{f(m)[E_0 - cm]m}{-dm} \quad \begin{array}{l} E_0 = \text{Energy constant} \\ E_0 - cm = \text{deficit/depletion/} \\ \text{drive} \end{array}$$

$$= f(m)E_0m - f(m)cm^2$$

$$= \boxed{E(m)m} - \boxed{S(m)m^2} \quad \text{Inhibition by stress}$$

Reinforcement:

Endorfines produced as a function of motivation

Stress is a function of Endorfine production:

$$E(m) = \frac{m}{m+g} E_0$$

$$S(m) = \frac{m}{m+g} c \rightarrow S(m) = E(m) \frac{c}{E_0} = f(E(m))$$