Signal Analysis of “emotivated” Actions

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Exemplar of WP7

An artificial, physically embodied and interacting autonomous agent for which architectures – based on theoretical models – are developed and of which the machinery and behaviour is analysed to study emotion as extended motivation*.

The models are based on ethological and non-linear dynamics approaches and address (among other things) the relations between low level internal dynamics and external activities and the issues this raises for data-analysis.

* **"Emotivation"**

- Connections between: ***dynamical systems models***

cybernetic representation,

WP 3

and

robot architectures

implementation

robot experiments

WP 7

Consequences for data analysis

Suggestions for methods to analyse data from dynamic systems

Analysis of (E

Test-case for how good

For instance, relationship between (continuous) internal variables and (categorical) external variables

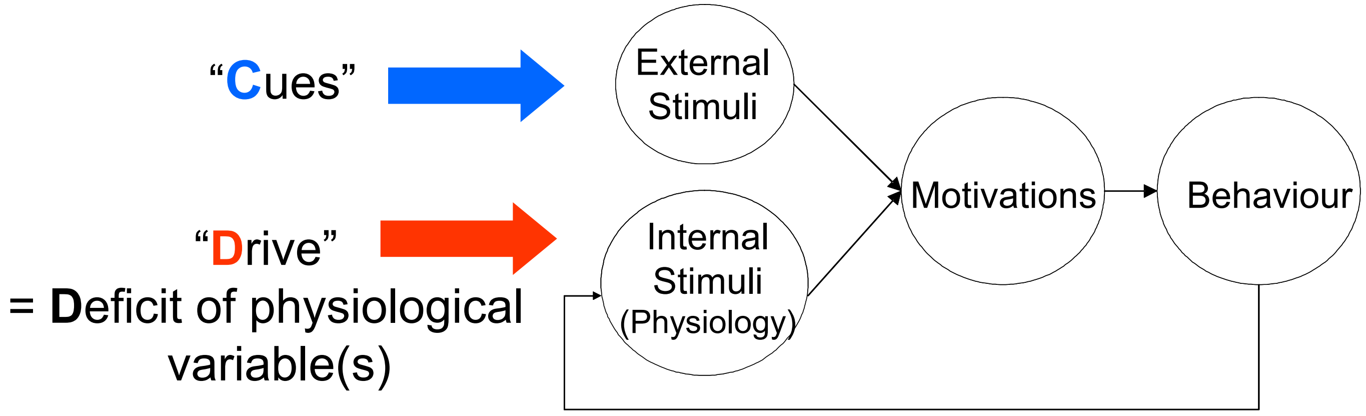
WP 4

(E)motivated Actions

Motivated Actions

"Behaviour" in the ethological sense:

Action Selection Mechanism

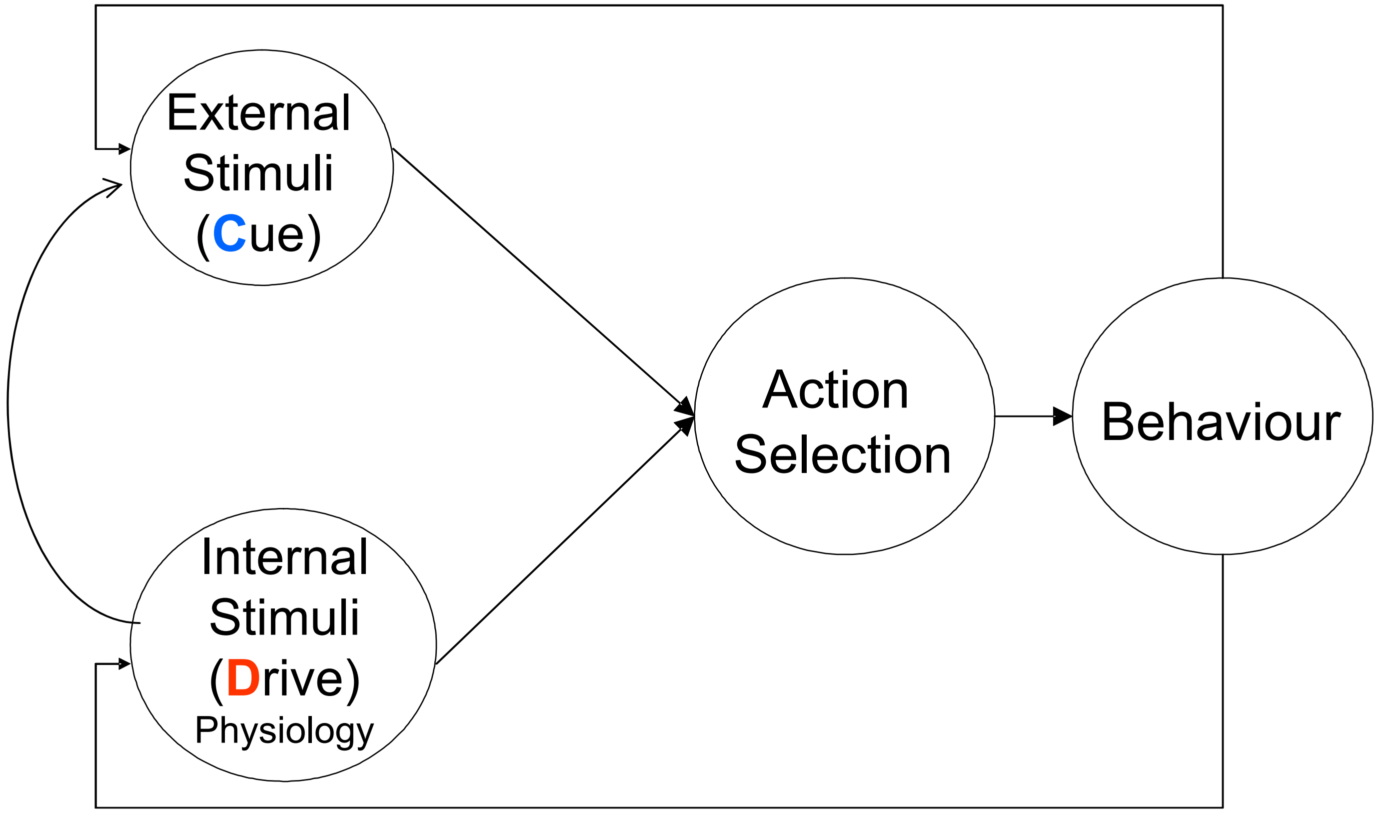


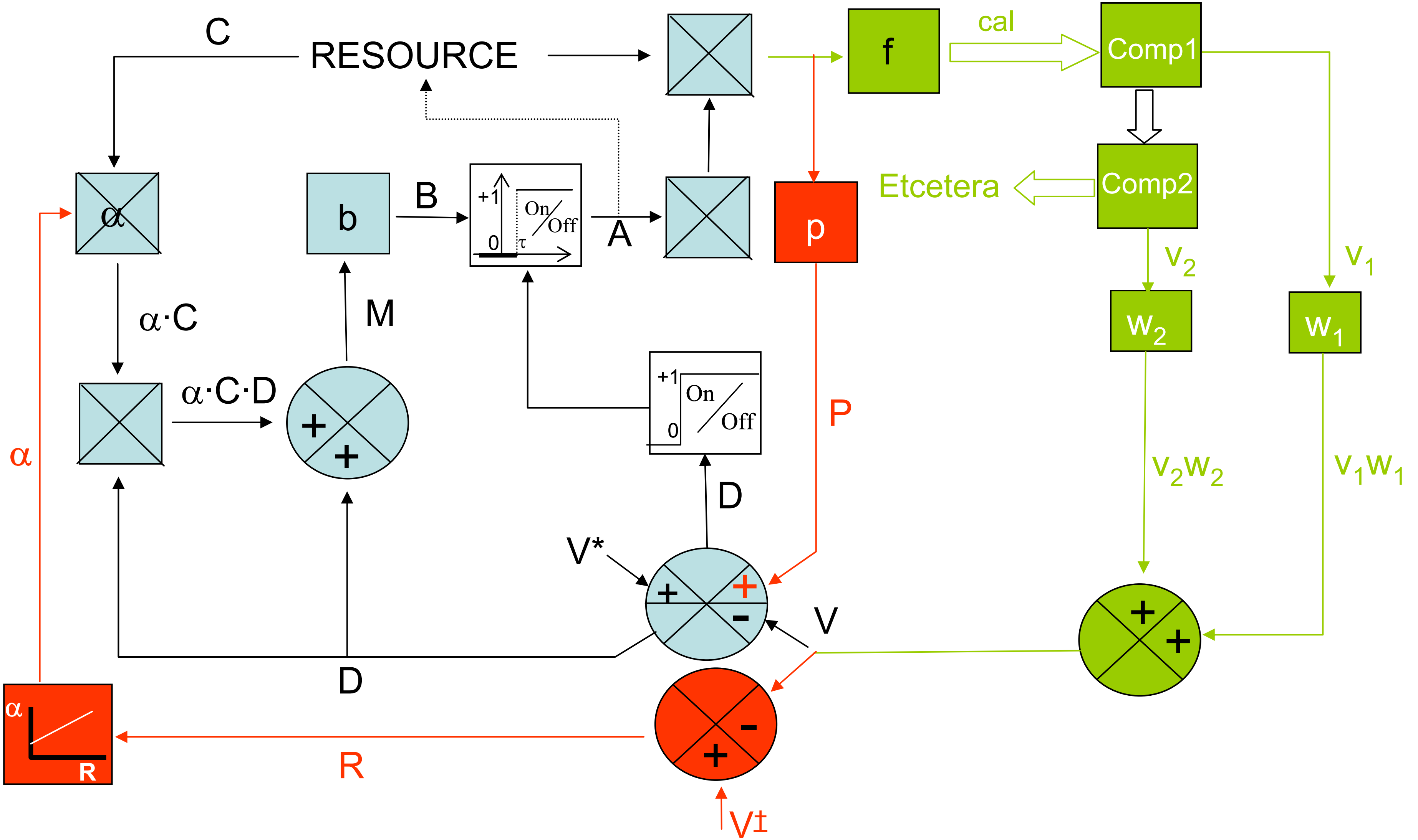
Motivational Strength ("intensity", "tendency")

$$\mathbf{M = D(1 + \alpha \cdot C)}$$

$$\mathbf{0 < \alpha \leq 1, \alpha = weight}$$

Modulation of Sensory Input





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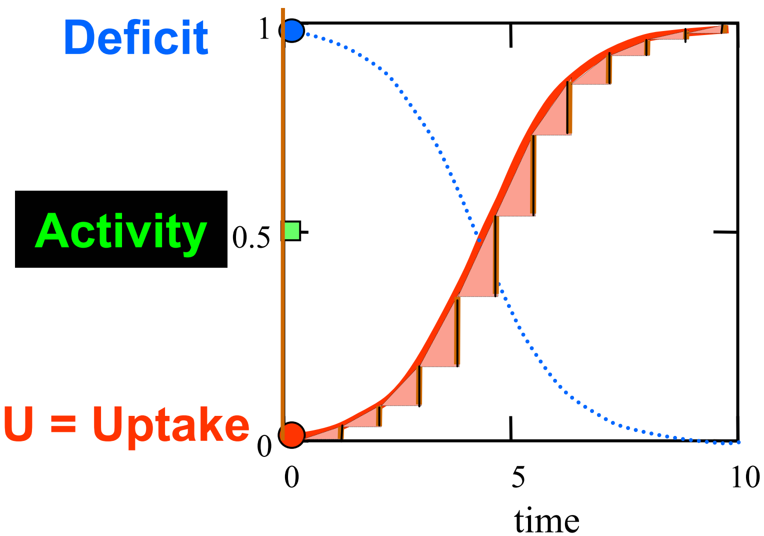
Contribution to WP3

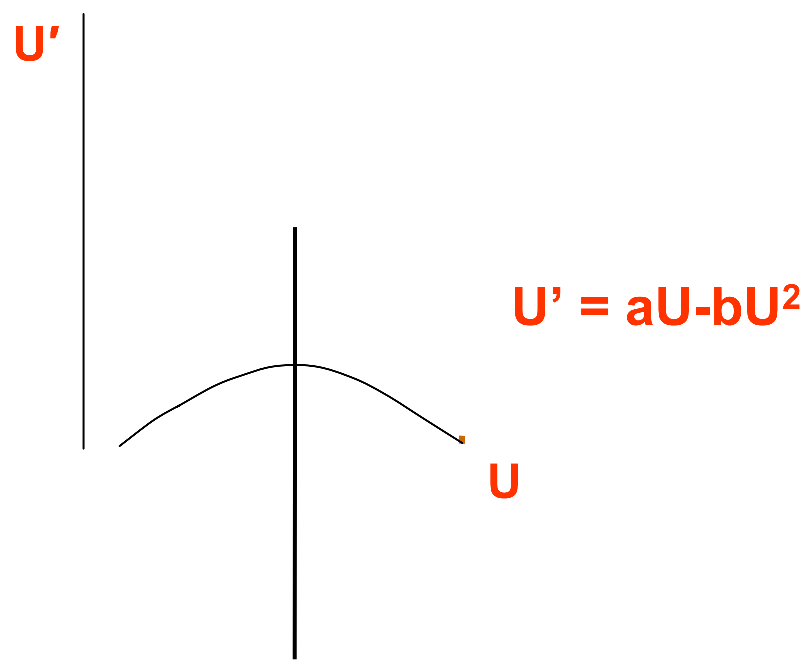
The Simplest Mathematical Formulation

for the Dynamics

… of the simplest version of these models



$$U(t) = \frac{1}{1 + \exp(-(t - a)/r)}$$

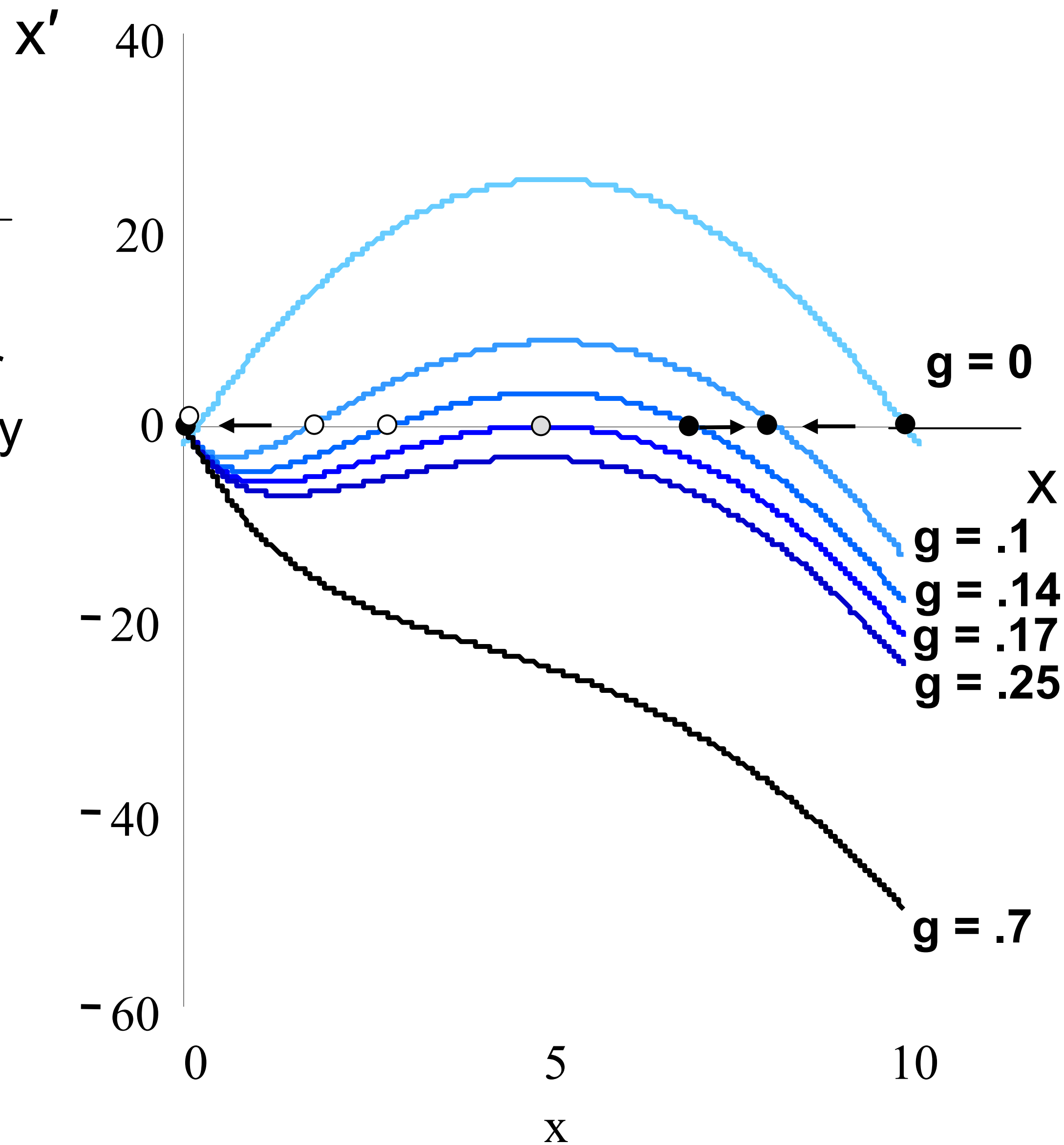


is NON-LINEAR

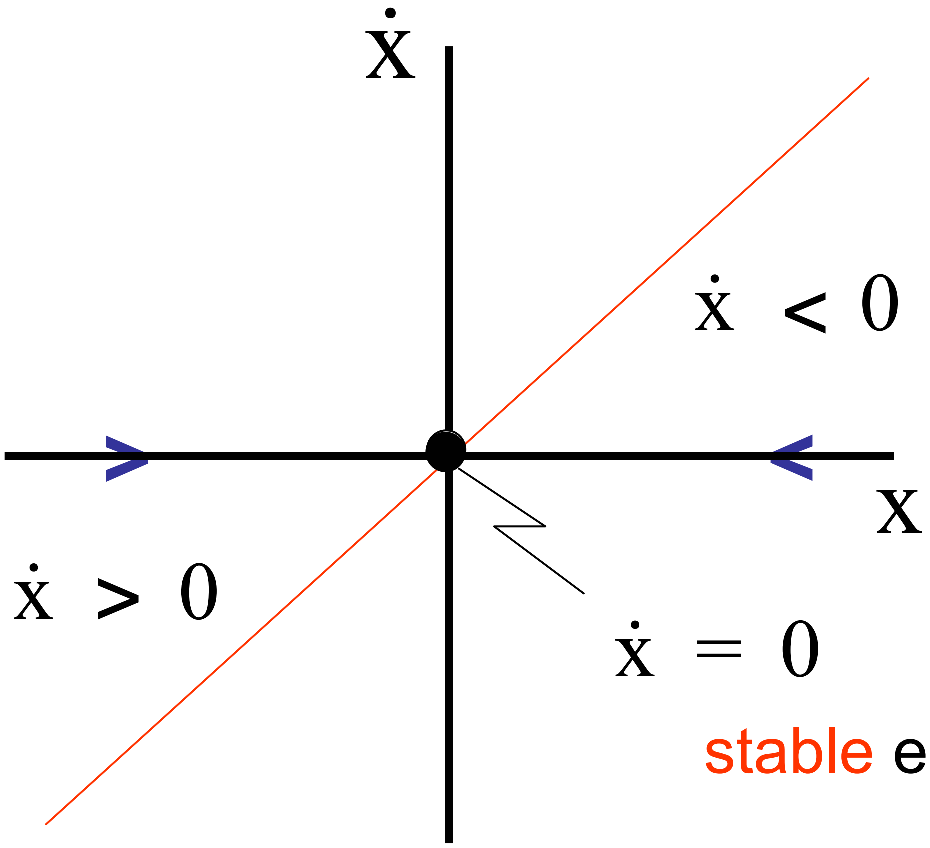
Bifurcation and Multi-stability in a Non-Linear System

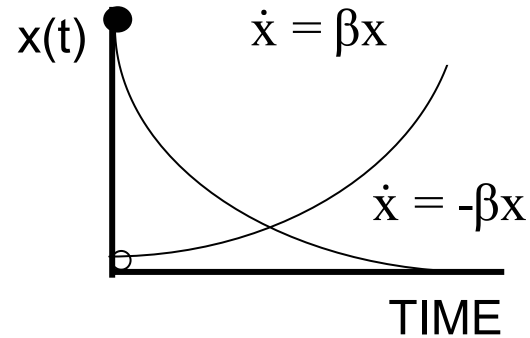
$$x' = \frac{-x^3 + x^2 - g \cdot x}{x + g}$$

Threshold model for motivational intensity



$\dot{x} = -\beta x$ is a linear system:





stable equilibrium

Questions

Does modulated (“emotivated”) behaviour “look” different than non-modulated behaviour?

If so, what is typical for “emotivated” behaviour?

What kind of methods can we use to study this?

especially with respect to ***non-linearity*** *of the dynamics*

Implications for empirical data
Contribution to WP4

To study data from a **dynamical systems perspective**, one should study how **current values** depend on the **past** (*i.e. time series analysis instead of just correlating a bunch of variables*)

How would a dynamical system show up in the data?

Change in x per time interval:

$$\frac{dx(t)}{dt} = \beta x(t) \qquad \dot{x} = \beta x$$

$$x_{t+1} = bx_t$$

differential equation

(continuous)

difference equation

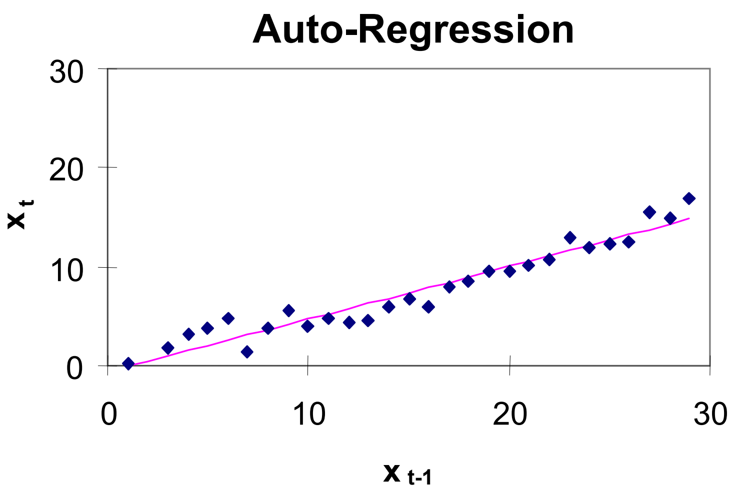
(discrete time steps)

In the Real World:

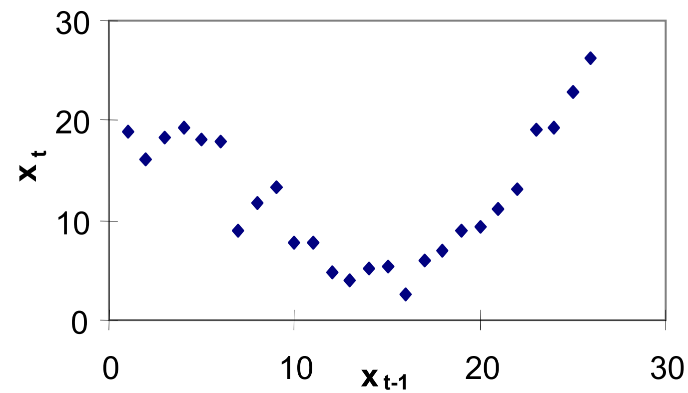
NOT $x_{t+1} = b \cdot x_t$

BUT $x_t = b \cdot x_{t-1} + c + e_t$ **"error" ("noise")**

VERIFICATION



BUT



- Auto-Regression
- Auto-Correlation (r = .96) → **meaningless for nonlinear systems**

- **Non-parametric Auto-Regression**
  (Kernel density smoothing,
  local linear regression)

- **Higher order AR-processes (linear)**

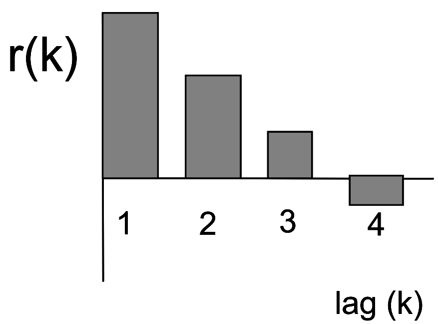
$$x_t = b_1 x_{t-1} + b_2 x_{t-2} + c + e_t \qquad \text{AR (2)}$$

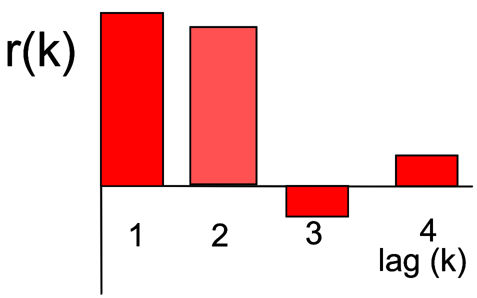
"Real world" representation of the system

$$x' = \alpha y$$
$$y' = -\beta x$$

For certain parameter values: oscillation

Auto-Correlation Function





Partial Auto-Correlation Function

(Dimensionality can be estimated for non-linear systems with non-parametric auto-regression)

- **Cross-correlations**

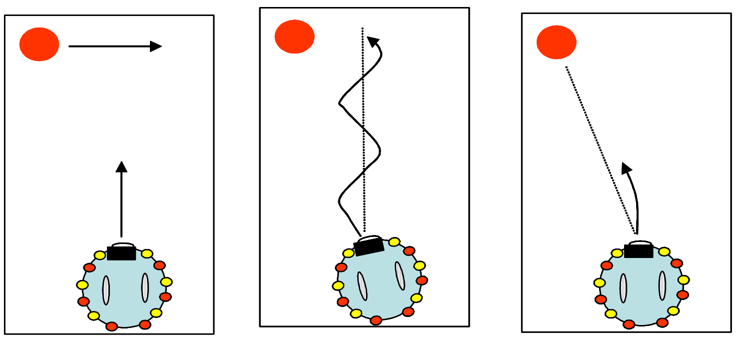
$$x_t = b_1 x_{t-1} + b_2 y_{t-2} + c + e_t$$

• **Change in “correlatedness” among multiple variables**

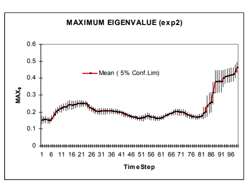
For each time step:
Maximum eigenvalue **of the matrix of weighted (local) correlation coefficients**

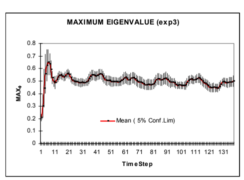
Dimensionality Reduction through Sensor-Motor Control

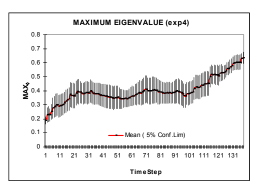
René te Boekhorst, Max Lungarella & Rolf Pfeifer



Moving object Meandering Robot Object focusing



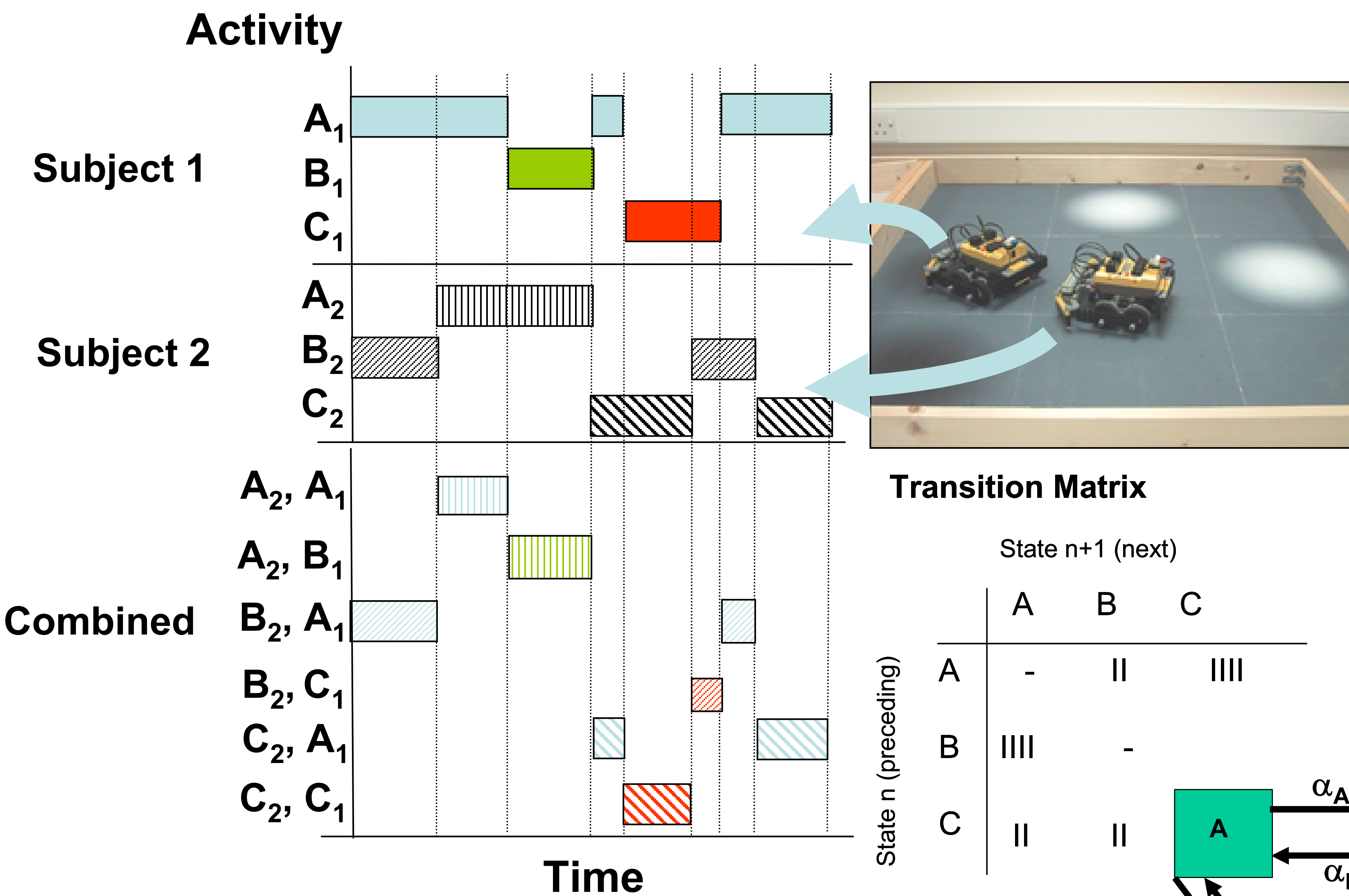




Time series of λ_{max} is a “fingerprint” of the robot-environment interaction

With these tricks we will study the “bio-signals” (“physiological variables”) of our robots

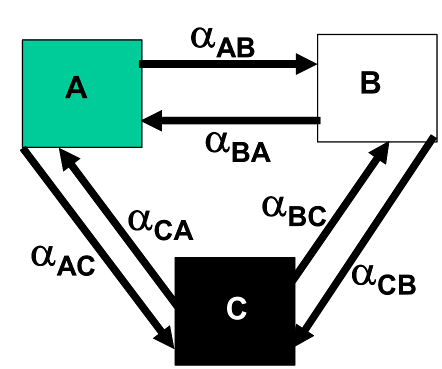
But what about the “outward” signals (“behavioural activities”)?



Transition Matrix

State n+1 (next)

State n (preceding)	A	B	C
A	-	II	IIII
B	IIII	-	
C	II	II	

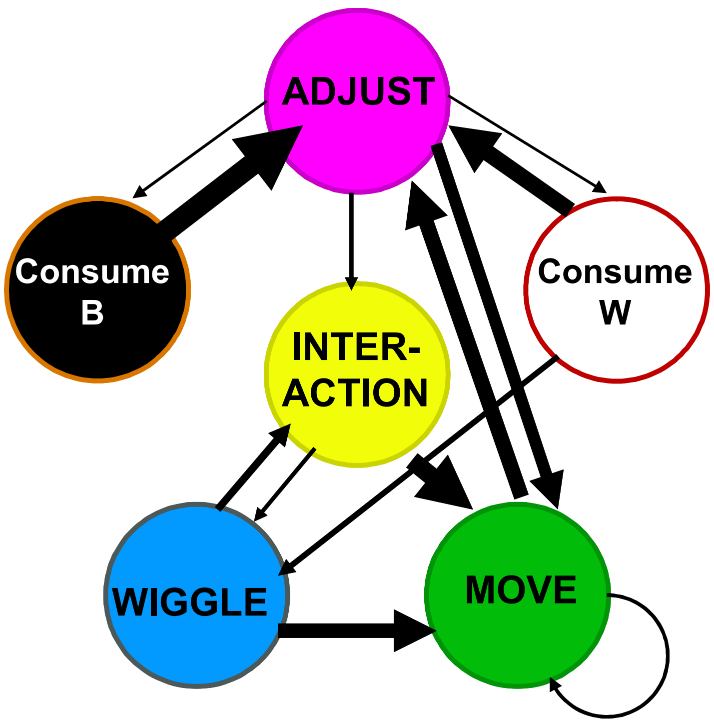


Markov model

χ^2 =	33.94648
DF =	28
P =	0.202641

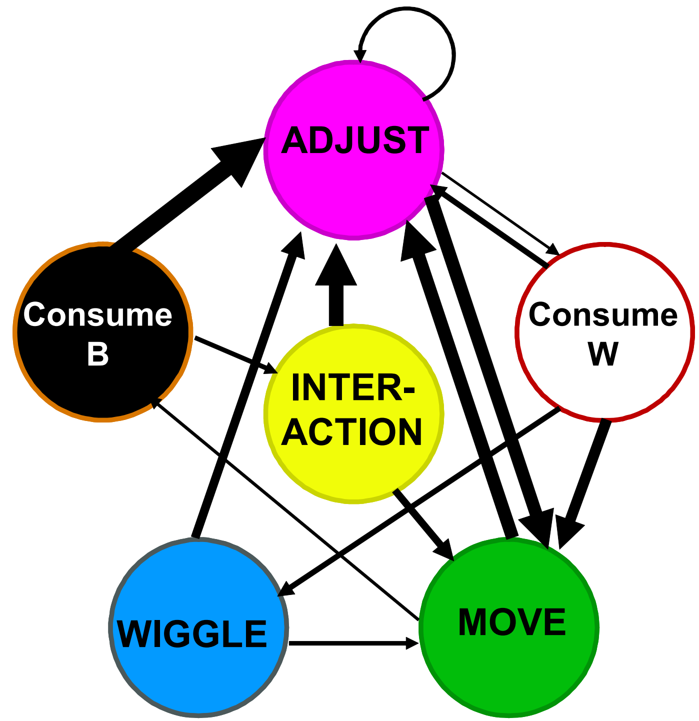
χ^2 =	59.30756
DF =	49
P =	0.148626

Modulated



More directed towards "Move"

Not Modulated



More directed towards "Adjust"

Systematic Experiments (with Orlando Avila-Garcia)

- **Various combinations of partners:**

Robot 1:

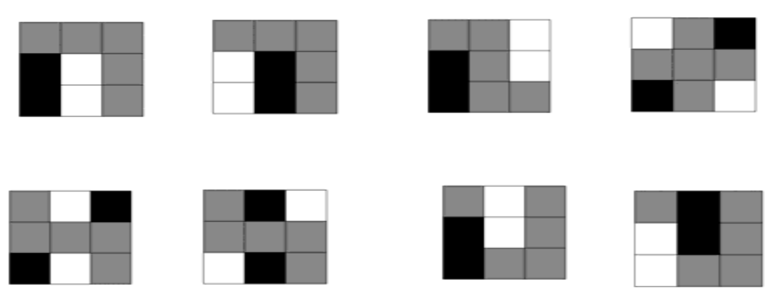
Robot 2:	Modulated	Not Modulated
Modulated	M,M	M, N-M
Not Modulated		N-M, N-M

-

- **Two start conditions:**

  “Head-to-Head” and “Tail-to-Tail”

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



Extensions

General shape of a first-order Markov model:

$$a_n = a_{n-1} + e_n$$

Next activity depends on current activity

Values of variable *a* are discrete activities:

$$a \in A, \qquad A = \{a_1, a_2, \ldots, a_m\}$$

for example, a_1 = “move forward”, a_2 = “turn around” etcetera

Apart from the discontinuous nature of A (non-differentiable), this is a *linear model*

More general approach:

How does the probability distribution of activities as a whole* affect that distribution in the next time interval?

Information Theory:

- In how far does the entropy at time t reduce the uncertainty of a signal at t+1 ?
- In **communication**:
  How strong does the signal entropy of a sender reduce the uncertainty of a given response of a receiver

*(i.e. NOT the parameters typifying that distribution)