From General Systems Theory to Cyber-Physical System

The theory that is shaping our world …

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Topic

1. Theory of Systems (L.Von Bertalanffy,1972)

2. Real-Time Systems (Quest for Stability or Optimum State)

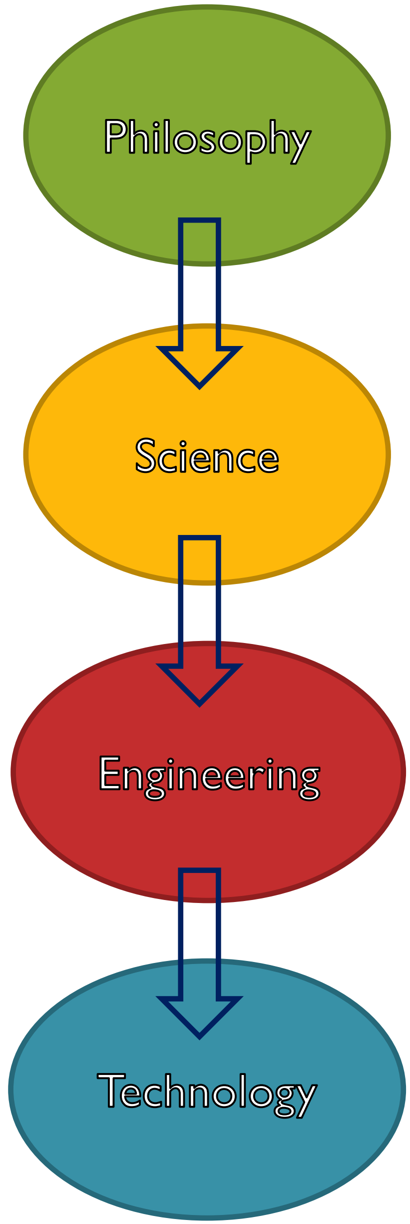


Fig 1

Prelude (L. Von Bertalanffy)

- Post Socrates Greek Philosophy
- There is an order or *Cosmos: intelligible* → *controllable by rational actions*
- Aristotle : *"The **Whole** is more than **sum its parts***
- Eastern Philosophers and Experimental, Scientists Avecina, Khawrazmi, Toosi, Khayyam, … linked philosophy to science – Mathematics
- Medieval thinker Cusa (15th cent): *coincidentia oppositorum* a fight amongst the parts within the whole
- In the west Galilean conceptions
- Newtonian Mechanical approach

Creation of Causal events described in mathematical language

Origins of Systems Modelling

- Second Maxim of Descartes *"Discourse de la Methode"*
- To understand the *Whole* we must know both parts of the relations
- We are now used to breaking down problems – isolating them
- However the challenge to the principles of isolating the components of complex problems is not new
- The *"How"* to integrate isolated systems is a major challenge for engineers!
- Simultaneous differential equations
- Continuous vs Discrete
- …

Purpose

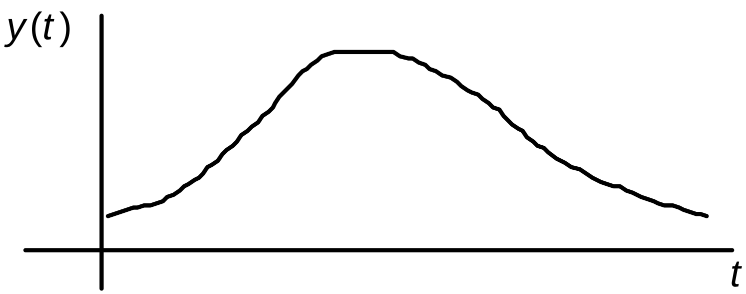
- To understand (i.e. be able to explain)
- To relate excitation with behaviour
- To predict (what happens?)
- To stabilise (Control)
- To optimise (Operational Research)

Why do you want to know about a system?

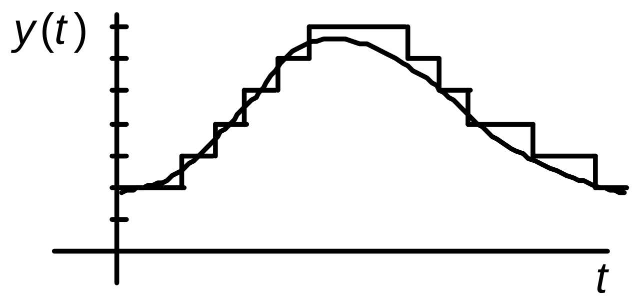
Observing Systems

- Continuous Analysis

- Discrete Analysis



(a) continuous time analog signal



(b) continuous time quantized signal

$$y^*(kT) = y(kT) \quad k = 0, 1, 2, 3, \ldots$$

Types of Systems

- Mechanist → Total sum of members

Repetitive, Algorithmic, Stable Environment, Minimal Adaptability

- Organists → survival of the fittest (adaptation)

Darwinian, Adaptive, Responsive, Reactionary, Low Level of Intelligence, Optimisation, Customisation, Stochastic-Determinsitic

- Viable/Sustainable Systems

All capabilities of organic system + High levels of intelligence, governs complex interactions, Active Learning, continuous monitoring & control, and aggressive prediction

- influence and change the environment to their advantage

- Reinvention – Creativity – Innovation

Adaptation + Sustainability

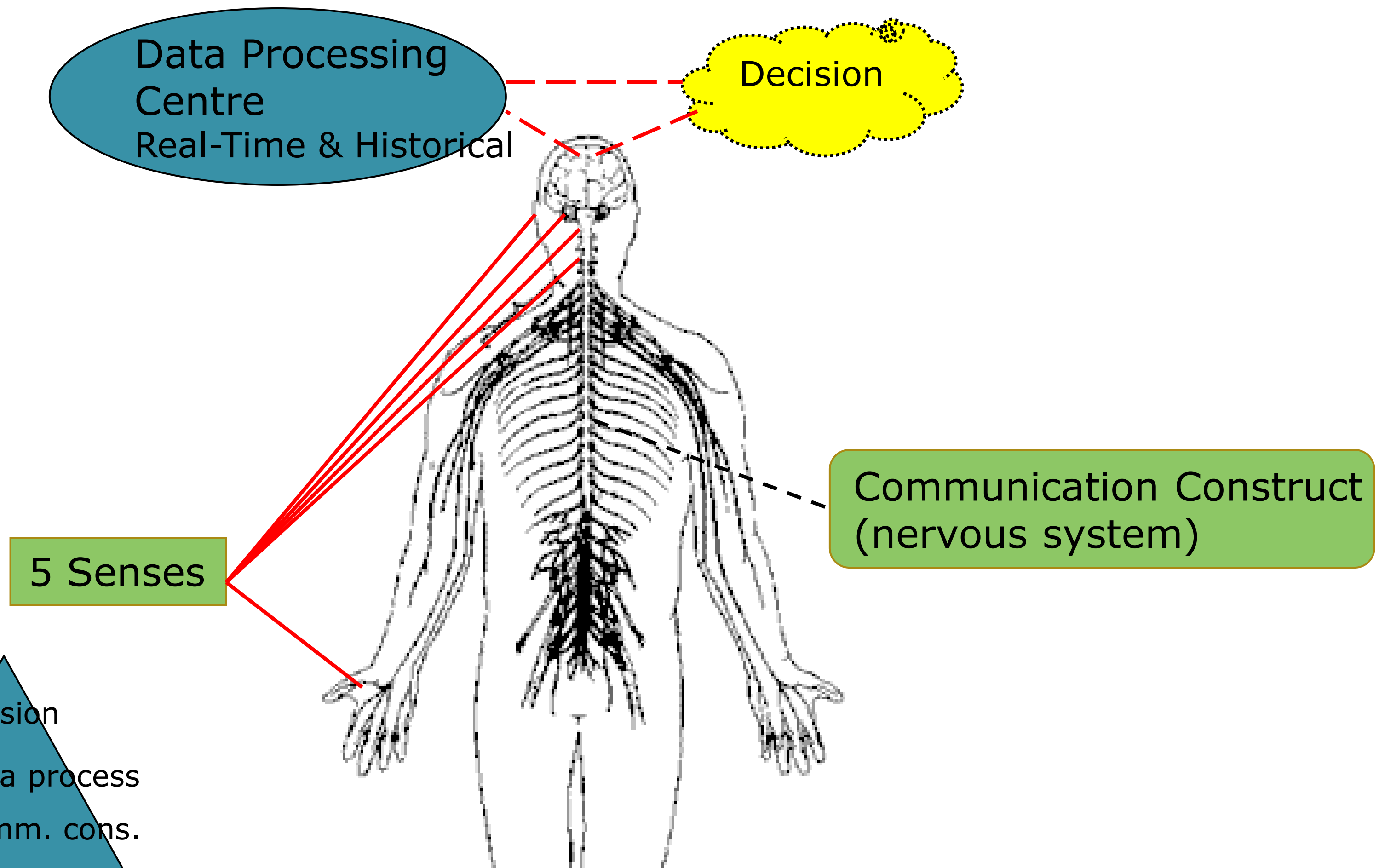
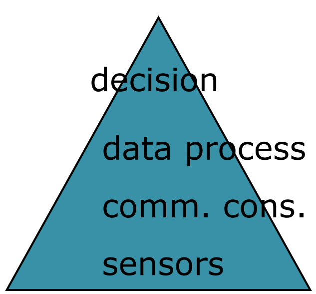


Figure 2



Information pyramid

Data Modelling & System Performance Analysis (Descriptive)

- Data modelling is the process of preparing and translating ***input data*** into ***meaningful information*** in a specified ***time span***
- There are various technique:
  - As simple as logical *AND, OR and IF* for binary systems
  - Complex data mining techniques such as; Statistical Process Analysis, Transfer Functions, Genetic Programming, Fuzzy Inference Analysis, Bayesian Belief Networks, …

Attributes of Real-Time Data

- Created, Consumed, Collected by embedded systems
- Devices, Plants normally have SCADA systems
- Challenge is to make sense of it soon and take corrective action

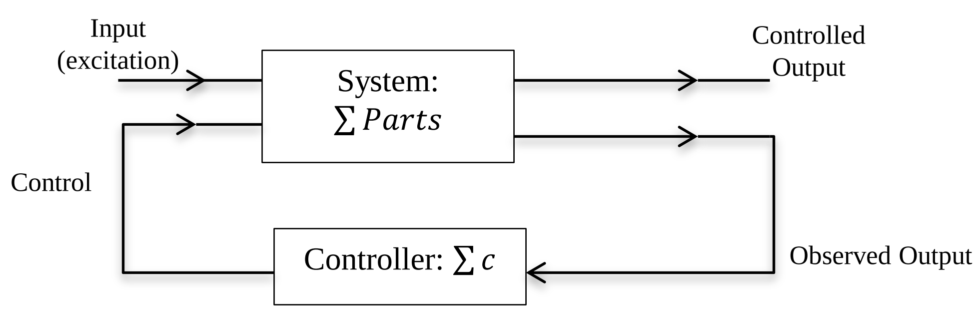


Fig 3

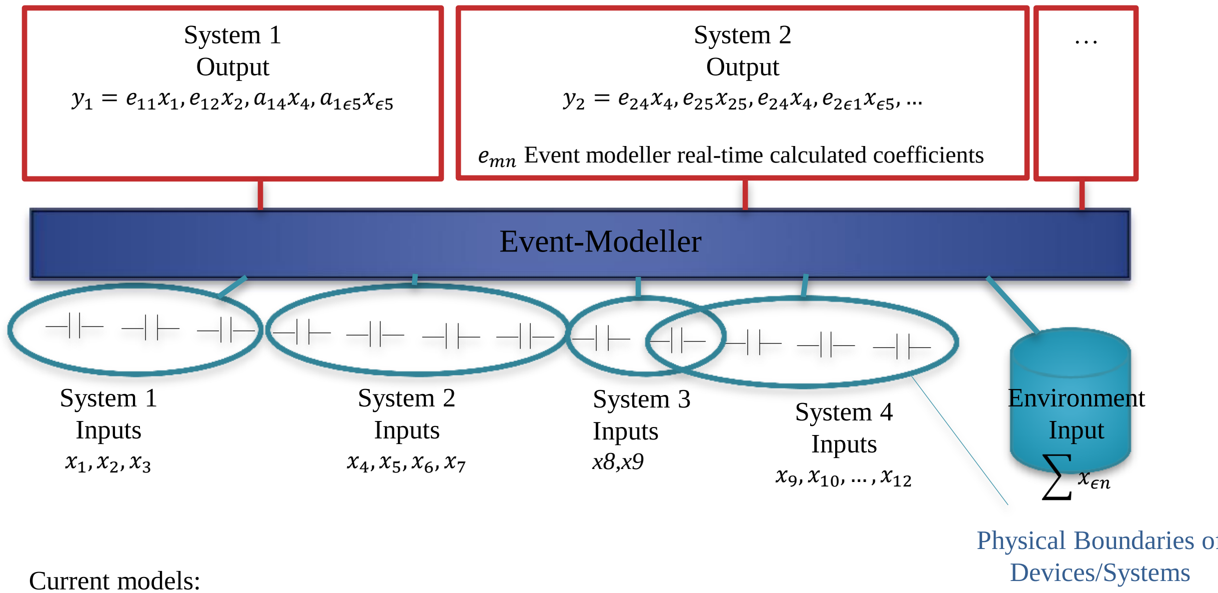
Event-Modelling (Mousavi et al 2013-14)

- The underpinning philosophy of the proposed technology is based on Decartes' philosophy of *"Discours de la Methode"*,
- *"breakdown every problem into as many separate elements as possible"*, and then **reassemble** it in the form of **eco-system of causality** of the smallest units.
- We also Borrow the concept of *"coincidentia opposittorum"* or the *"fight among parts" from* Cusa, and interpret the concept as the *causal interrelationships* of parts in the whole.
- In the language of engineering, how the excitation of the system driven by events and demonstrated by measurable inputs that contribute/affect the behaviour, stability and safety of a system.

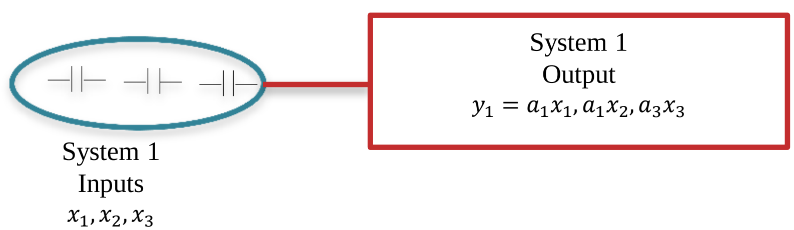
(back to Fig 3)

- Also Lorenzo's butterfly effect

Event-Modeller (tracker+cluster)

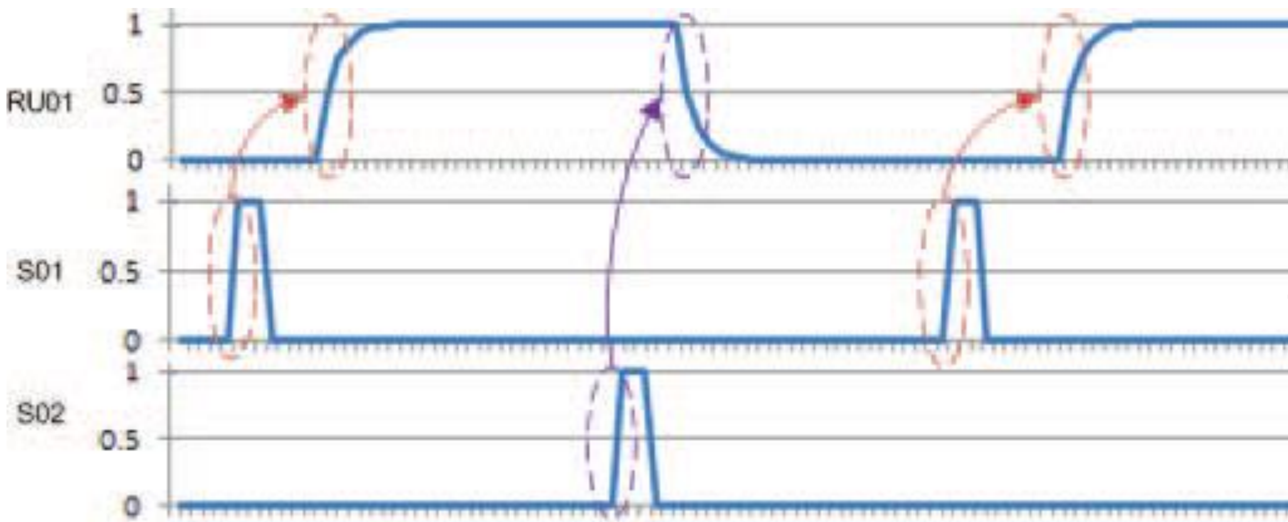


Current models:



a_n known or historically calculated coefficients

Event Tracker



Event Data

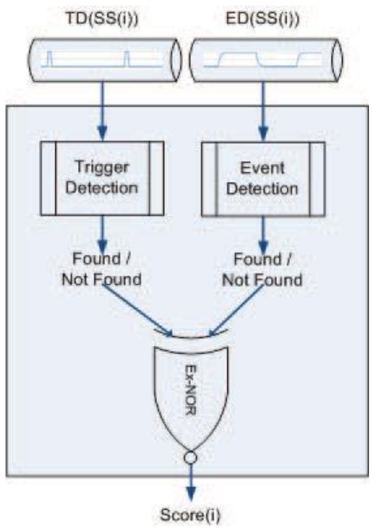
Trigger Data

Event-Modeller Parameters

1. ***Search slot (SS):*** a fixed time in which batches of TD and ED are captured (system dependent)
2. ***Analysis Span (AS):*** the time period that a sensitivity analysis is conducted (AS contains a number of SS)
3. ***Event Threshold (ET):*** expressed as a percentage is the level of change in the value of an event determines whether a genuine event has occurred or not (e.g. change in flow rate)
4. ***Trigger threshold (TT):*** expressed as a percentage is the level of change in the value of a trigger determines whether a genuine event has occurred or not (e.g. sensor high/low)

The algorithm

1: Stepwise Scan & TT detection



2: Two-way Matching

Input 1	Input 2	Output
0	0	+1
0	1	-1
1	0	-1
1	1	+1

3: Summation of two-way matching (Sensitivity Index at time *t*)

$$SI_{(t)} = \sum_{1}^{n} Search\ Slot\ Scores$$

Where *n is number of Search Slot in an Analysis Span*

Algorithm continued

4. Normalisation:

$$\tilde{S} = \frac{SI - l}{u - l}$$

Sensitivity index

Upper Bound

Lower Bound

An example for 10 search slot, 1 event and 3 sensors

1. Detected Events

2. Two-Way Matching Scores

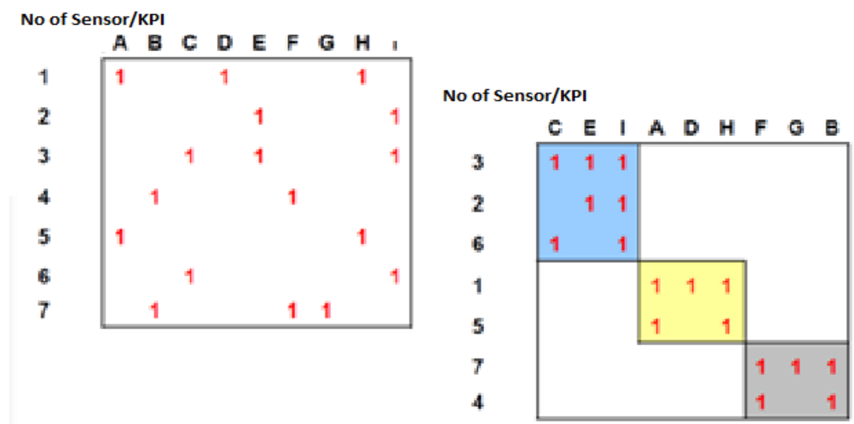
Search Slot	0	1	2	3	4	5	6	7	8	9	10
ED	*	*		*		*	*	*		*	*
TD1			*			*			*	*	*
S1	-1	-1	-1	-1	1	1	-1	-1	-1	1	1
SI1	-1	-2	-3	-4	-3	-2	-3	-4	-5	-4	-3
SIn1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TD2	*				*	*	*	*		*	
S2	1	-1	1	-1	-1	1	1	1	1	1	-1
SI2	1	0	1	0	-1	0	1	2	3	4	3
SIn2	1.00	1.00	1.00	0.67	0.33	0.33	0.67	0.75	0.80	0.80	0.75
TD3		*		*		*		*		*	
S3	-1	1	1	1	1	1	-1	1	1	1	-1
SI3	-1	0	1	2	3	4	3	4	5	6	5
SIn3	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

ED is most sensitive to TD3 and shows no sensitivity to TD1

3. Summation of two-way matches

4. Normalised sensitivity index

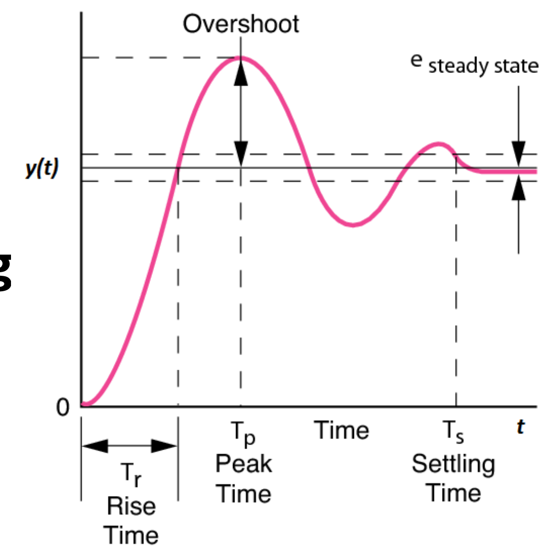
Event Cluster



- Group and linking a set of inputs to any given output
- Tests with 200 sensors and 2 Key performance indicators in Cement (energy & production output)
- 43000 real-time samples over 30 days
- Grouped all the relevant inputs to the 2 outputs.
- EventTracker and Event Cluster return the same results

Potentials and Future Work

- Use the technique to improve control transfer models and character equations
- Use the technique to deal with *Known-Unknowns* and potentially the *Unknown-Unknowns!*
- Technically and in real-time (**Engineering and Not Mathematically**) use the I/O relations to stabilise the system
- Optimise process by identifying the best process points and then adjusting the inputs to reach the desired output.
- Intelligent-Autonomous Control for Complex Systems



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