Elastic Systems: Role of Models and Control

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Neocybernetic starting points – summary

- The details (along time axis) are abstracted away, holistic view from the above is applied
- There exist local actions only, there are no structures of centralized control
- It is assumed that the underlying interactions and feedbacks are consistent, maintaining the system integrity
- This means that one can assume *stationarity* and *dynamic balance* in the system in varying environmental conditions
- An additional assumption: Linearity is pursued as long as it is reasonable



Sounds simple – are there any new intuitions available?

HELSINKI UNIVERSITY OF TECHNOLOGY Control Engineering Laboratory Cybemetics Group Strong guiding principles for modeling

Elastic model structures – summary

 Evolutionary optimum = maximum coupling between the system and its environment



Coupling between the system and environment

• Exploitation.

• It turns out that the evolutionarily beneficial neocybernetic strategy maps the environmental resources into the system as

$$\overline{x} = \mathbf{E}\left\{\overline{x}\overline{x}^{T}\right\}^{-1}\mathbf{E}\left\{\overline{x}u^{T}\right\}u$$

• Exhaustion.

• Simultaneously, the environmental resources are used up correspondingly, so that the resources are exhausted according to the following formula

$$\hat{u} = \mathbf{E}\left\{\overline{x}u^{T}\right\}^{T} \mathbf{E}\left\{\overline{x}\overline{x}^{T}\right\}^{-1} \overline{x}$$

• Feedback.

• There is a two-way interaction between the system and its environment – indeed, there is a *balancing negative feedback* ...

Another view: Model based control

• Model.

• It turns out that the neocybernetic strategy constructs the best possible (in the quadratic sense) description of the environment; the *PSA latent variables* are

$$\overline{x} = \mathbf{E}\left\{\overline{x}\overline{x}^{T}\right\}^{-1}\mathbf{E}\left\{\overline{x}u^{T}\right\}u$$

A cybernetic system constructs a "mirror image" of its environment!

• Estimate.

 It turns out that the neocybernetic strategy constructs the best possible (in the quadratic sense) estimate of the environment state; LS regression estimate is

$$\hat{u} = \mathbf{E}\left\{\overline{x}u^{T}\right\}^{T} \mathbf{E}\left\{\overline{x}\overline{x}^{T}\right\}^{-1} \overline{x}$$

• Control.

• When combined, it turns out that the neocybernetic strategy integrates modeling and estimation to maximally eliminate variation in the environment.

System as a controller

Heraclitus: "The way up and the way down ..."!

- The dualism between information vs. matter/energy (traditionally mind vs. matter) deserves to be studied closer
- The age-old dilemma of dualism is solved in a peculiar way in a cybernetic system: "Marriage of information and matter"
- Extraction of information from a real-life system necessitates exploitation of matter/energy

Upstream: Construction of a model = information flow *Downstream*: Construction of feedback = matter/energy flow

• Full closed loop control system is constituted only if both mechanisms are present

Abstract flows in a cybernetic system

Extra intuition: Adaptive control

- Adaptation is the key property in truly cybernetic systems = they are *adaptive control systems*, trying to implement more efficient controls
- This is yet another benefit if one has control engineering background: One can understand what happens in truly cybernetic systems
- Why are adaptive controllers notorious in control engineering? Why do they behave in a pathological way?
- The reason for "explosions" is *loss of excitation*: Good control eliminates information (variation) in data
- This takes place in all loops of simultaneous model identification and control that is based on that model

- For some reason, massive extinctions seem to take place in 62 million year cycles
- Dinosaurs died about
 62 million years ago …
- Do you need some meteors to explain extinctions? Or is this simply because of evolution dynamics?

Rohde and Muller (2005): Cycles in fossil diversity. Nature 434

More intuitions ...

• Towards intersubjectivity:

- When individual minds apply the same principles for modeling the world, the relevant structures do have correspondences
- The subjective worlds can become shared, there can exist common language
- This can be extended to human-machine and even to machine-machine interaction

• Towards interobjectivity:

- Nature tries to find models of environments to maximally eliminate variation
- When humans model natural systems, what is the difference as compared to nature-made models?
- Contrary to traditional thinking, models are not only shadows of reality they can capture the *essence* of systems

Power of mathematics

- It has always been wondered why (simple) mathematics is so powerful in representing Nature
- There are now some fresh points of view available –
- To start with, the cybernetic phenomena *are* simple, being characterized in terms of correlations, etc.
- But what is more fundamental it seems that system complexity and analyzability go hand in hand:

If Nature has been able to construct sophisticated model structures, why not us?

• The positivistic claim here also is that *cybernetic systems* can always be modeled

HELSINKI UNIVERSITY OF TECHNOLOGY Control Engineering Laboratory Cybernetics Group Cybernetic thinking offers many new intuitions to modeling work

Control engineering rehabilitated

- Mathematics gives the language for discussing philosophies
- Control understanding gives the meaning and relevance to the philosophical discussions

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Further: Ideal mixers vs. idea mixers

 Cybernetic models define a framework for studying whirls in the flow of entropy – WHAT?

Many systems with cumulating improbability can be studied

Paradox of entropy

- Two classes of systems – normal and abnormal: Either energy is used for increasing entropy or it is used for decreasing entropy
- Compare to sublunar and translunar physics: Planetary motions are divine?

• There are some intuitive misconceptions

- Entropy ever increases = "arrow of time" !!
- "Universe must be expanding otherwise time would go backwards" ??
- For example, is *symmetry* a sign of entropy or neg-entropy?
 - First intuition: Symmetry means *structure* and *order* negative entropy
 - However, a completely unordered set of particles meaning high entropy level – is most symmetric, as any of the particles can be interchanged
- Intuitions are problematic and contradictory
 - Simplicity of symmetric patterns is an illusion, being caused by our mental machinery that exploits existing mental models to interpret symmetries
- The thermodynamic and information theoretic entropia seem to be mutually incompatible but now these will be united ...

!!!

- In a cybernetic system information = variation, or deviation from balance
- Goal of cybernetic system: Balance = loss of information = maximum probability = (local) heat death on the lower level
- The control structure implemented by the cybernetic system thus boosts entropy the faster, the better the control is
- Emergence of structure on the higher level is also **not** against the arrow of entropy on the contrary:

Emergence of structures is *caused* **by entropy pursuit**

this entropy being equally meaningful in the thermodynamic and information theoretic setting.

• In the long run, the cybernetic control maximizes entropy!

Conclusion

- Heraclitus' Logos is not "fire" but "fire extinguisher": The incoming variation is being eliminated by the systems
- There is no "Intelligent Designer" but a "Hardworking Idiot": The local optimizations result in extreme inconsistency

