Complexity: the good, the bad, and the ugly

... I didn't find a better title

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Outline

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Introduction

- Edmonds (1996) surveys different definitions (and their shortcomings): concluding that "complexity necessarily depends on the *language* that is used to *model* the system" (here, system = computer networks)
- Many formalism to characterize complexity (computational complexity, Kolmogorov complexity, information complexity) $\rightarrow$ *criteria*, *metrics*, *etc*.

- Dependencies (affecting system's function, structure, and behaviour) ?
- Which language ?
- Which model ?

Source: Edmonds B. (1996), What is Complexity?, F. Heylighen and D. Aerts (eds.), The Evolution of Complexity (Kluwer, Dordrecht)

Outline

Example (1)

Initially: Single queue with FIFO discipline + drop-tail
Today: Hierarchical queues with advanced scheduling (rate-based, deadline-based, etc.) + AQM

- Other dependencies ?
- Which language: Markov chains, Stochastic process/network calculus (deterministic network calculus + statistical multiplexing)
- Which model: Markov model, (fractional) Brownian motion / Fluid flow model (taken out physics)

Language evolution

Languages themselves evolve over time:

Requirements	Queueing networks	Effective bandwidth	Network calculus	Stochastic network calculus
Traffic classes (incl. self-similar, heavy-tailed)	Limited	Broad	Broad (but loose)	Broad
Scheduling	Limited	No	Yes	Yes
QoS (bounds on loss, throughput delay)	Very limited	Loss, throughput	Deterministic	Yes
Statistical Multiplexing	Some	Yes	No	Yes

Source: A Statistical Network Calculus for Computer Networks, J.Liebeherr, 2005.

Example (2)

Initially: adaptive (deterministic) routing + manual configuration
Today: self-adaptive stochastic routing + automated (re-)configuration

- Other dependencies ? routing algorithmic, topology and policy dynamics, etc.
- Which language: control theory (P.S.Laplace, A.Lyapunov, L.Pontryagin, etc.)
- Which model: feedback loop + adaptive loop + model-reference + predictive

Example (2)

Initially: adaptive (deterministic) routing + manual configuration
Tomorrow: so-called "self-organizing" systems

- Other dependencies ? routing algorithmic, topology and policy dynamics, etc.
- Which language: (S)PDE
- Which model: epidemiology model, kinetic model, multi-cellular model, etc.

Outline

1. Introduction
2. Examples
3. Complexity characterization and dependencies
4. Conclusion

Characterization

- *Emergence*
  - Information (= structure/pattern) at a higher scale that is not present at a lower scale
  - Concept can be generalized in terms of computation, i.e., information transformation
  - $\rightarrow E = \frac{I_{out}}{I_{in}}$ where, $I_{out} = f(I_{in})$
- *Self-organization*
  - Measured as change over time in organization (opposite of information)
  - If information is reduced, then self-organization occurs (high organization (order) is characterized by a low information and low organization is characterized by a high information)
  - $\rightarrow S = I_{in} - I_{out}$

Complexity and Analysis

Following [Lopez-Ruiz,1995], one can then define:

Complexity C

Complexity $C = S \times E$ (in bit units)

Analysis

- High E implies a low S (and vice versa)
- High C (complex systems) can occur only when balance between order (high S) and chaos (high E)

Further Characterization

- *Homeostasis*: capacity to remain in "viable" zone
  - High homeostatic capacity: maintain system's dynamics close to a certain state or states (attractors). When perturbations or environmental changes occur, the system adapts to face the changes within the viability zone, i.e. without breaking [Ashby, 1947]
  - High homeostatis indicates stability $\rightarrow$ no change, i.e. information is maintained
  - Notion closely related to sensitivity to initial conditions (high sensitivity to initial conditions is a signature of chaotic dynamics)
- *Apoptosis*:
  - No element part of the system is indispensable
  - Maintaining and/or protecting the system must be given to every part of the system, incl. element(s) that may represent the threat $\rightarrow$ remove obsolete portions of the system

Outline

Conclusion ... if any

- Which parts/aspects (function, structure, behaviour) of a system are worth modelling ?

Critical questions

- Holistic approach (is it possible ?) vs. atomistic (is it sufficient ?)
- Who "decides" which parts are in or out (subjective)

  - Note: requires also to "agree" on system properties (robustness, resilience, etc.)

- Requires to elaborate on "functions" of the system and their degree of independence (architectural complexity)
- Characterization of "objective" complexity taking into account: spatial scale (local vs. global, node vs. network, etc.) and temporal scale dimension (short-term dynamics vs. long-term evolution)

References and reading list

- Edmonds B., What is Complexity?, *The Evolution of Complexity*, Kluwer, Dordrecht, 1996.
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- Cook, S., *An overview of computational complexity*, Communications of the ACM, 26(6), pp.400-408, 1983.