32nd Annual INCOSE international symposium

hybrid event

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What Systems Engineers Should Know About Emergence

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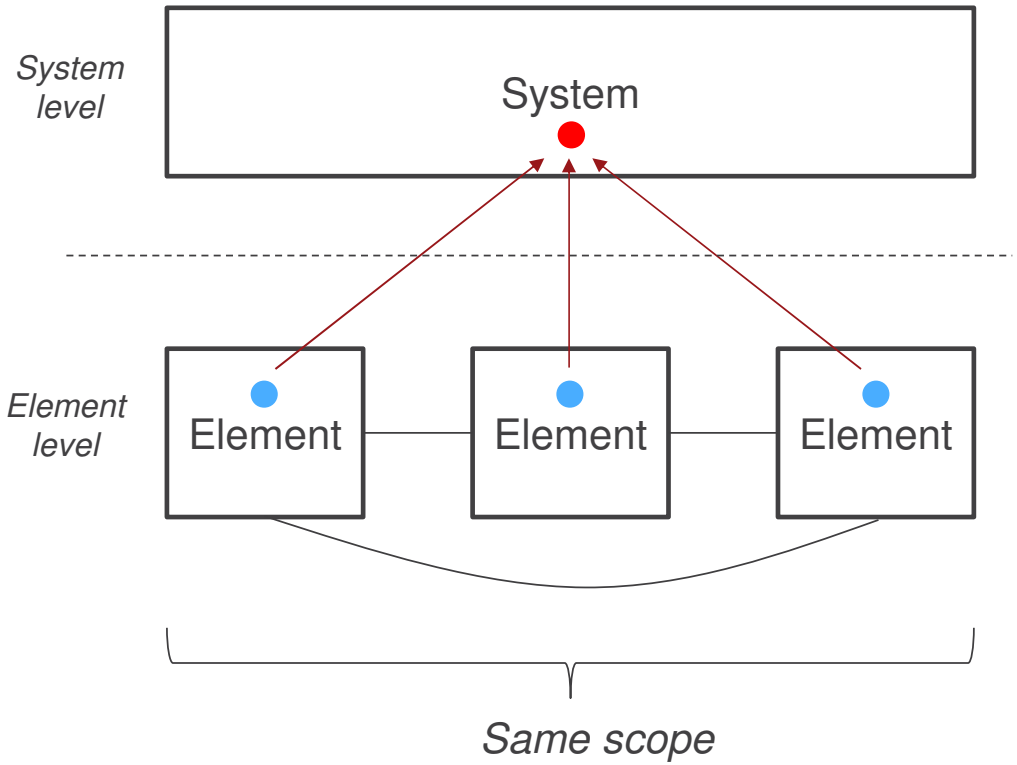
Introduction

- Why care about “emergence”?
  - Fundamental concept in systems
  - Widely, but shallowly, referred to in, e.g., INCOSE handbook
  - Key concept in systems-of-systems engineering
- Systems theoretical foundation of SE not leveraged
- Overview of paper:
  - History of emergence
  - Highlights from the philosophical debate
  - The role of the observer
  - Consequences on SE

Intuitive definition of emergence



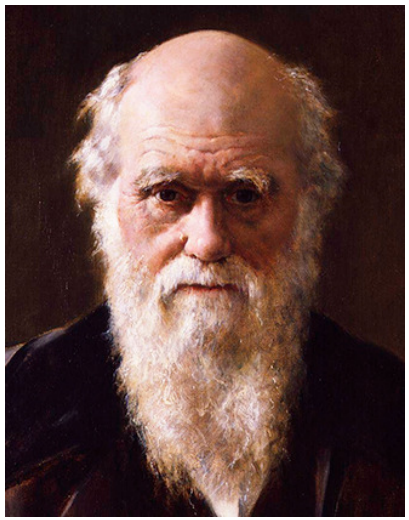
- The *levels* describe the same thing but with different levels of detail
- *Properties* describe a state
- *Behavior* describes state changes over time
- *Phenomena* is used to denote patterns both in properties and behavior
- *Emergence* denotes phenomena on system level not present in individual elements

History: Three waves of interest in emergence

Ca 500 BC - 1600

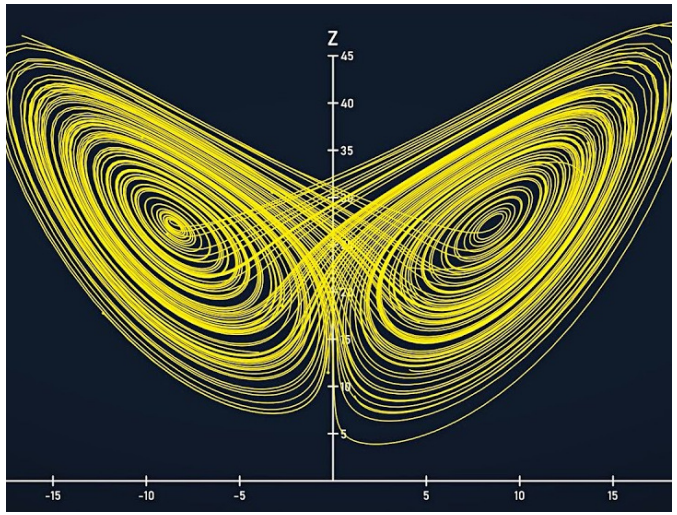
Aristotle (to the right of Plato): ”The whole is other than the sum of the parts”

Ca 1875 - 1920



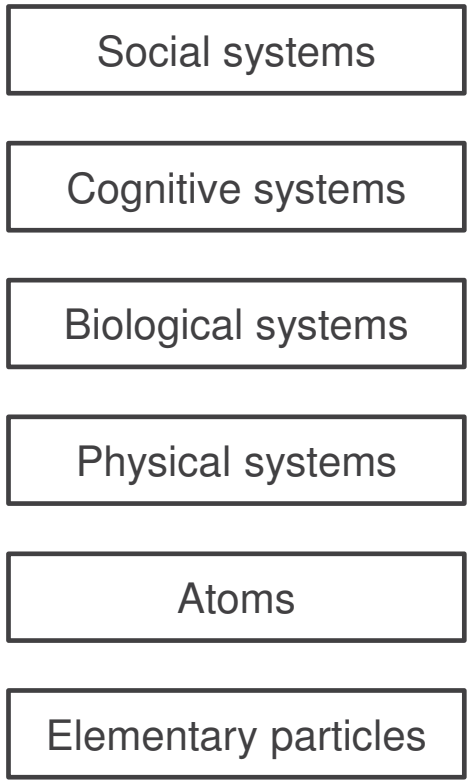
Could Darwin really be right? Doesn’t nature change faster than possible under pure natural selection?

Ca 1975-



Chaos theory and complex adaptive systems

Tacit assumptions in most philosophical work



Tacit assumptions:

1. The levels are given
2. There should be a universal emergence theory applicable from quarks to society

Is this reasonable?

In particular, there may be a divider when cognition is included (which it is in SoS but not in all SE).

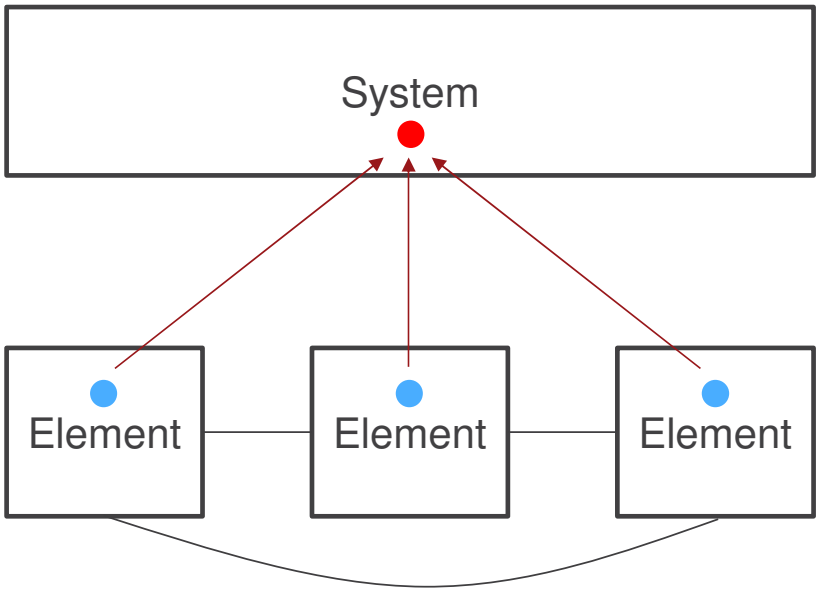
Philosophical controversies

1. Must there be an observer for emergence to exist?
2. What phenomena should be called emergent?
3. Is emergence predictable?
4. Can system-level phenomena affect element-level phenomena?

Does the observer matter?

- Does an emergent phenomenon exist at all if no-one is observing it?
- For a particular observer/agent, it does not really matter if it exists if it cannot be perceived
- SE observers: Stakeholders
- It becomes much easier to explain emergence if an observer is assumed!

Dependence and autonomy

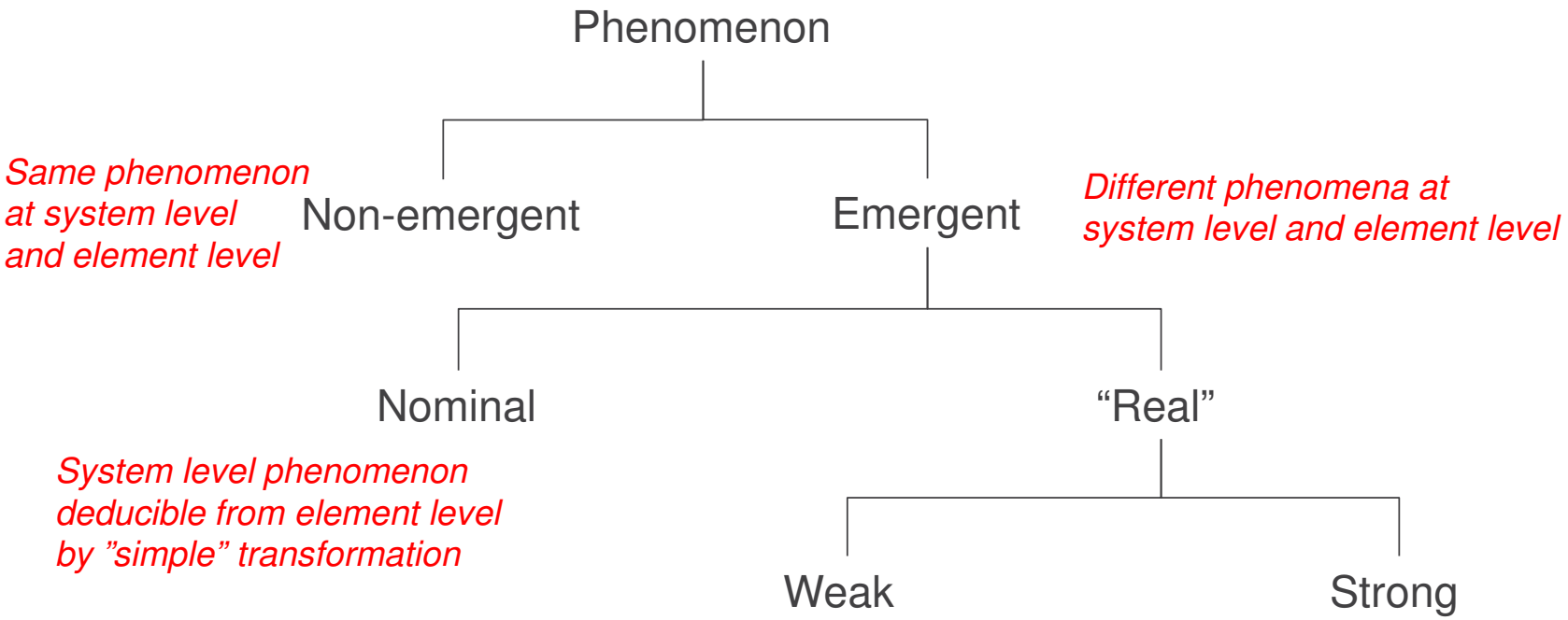


- *Dependence*: Change on system level can only happen if something changes on element level
- *Autonomy*: Many different arrangements of elements may give rise to same system level phenomenon

Debate:

- Autonomy is against principles of science!?
- Emergence is a provisional construct, used because the true laws have not yet been found?

Taxonomy based on computational complexity



Same phenomenon at system level and element level

Different phenomena at system level and element level

System level phenomenon deducible from element level by "simple" transformation

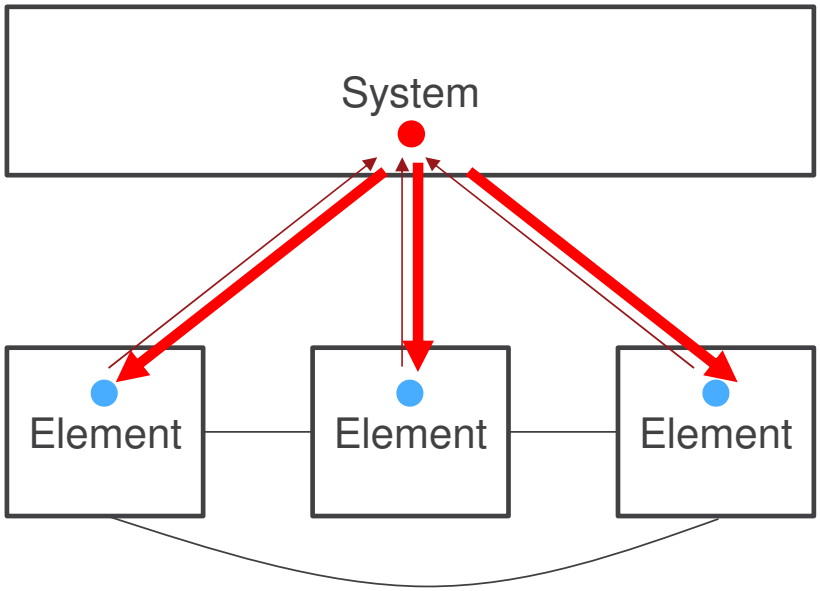
System level phenomenon deducible from element level only by simulation

System level phenomenon not even in principle deducible from element level (does this even exist at all?)

Predictable or surprise?

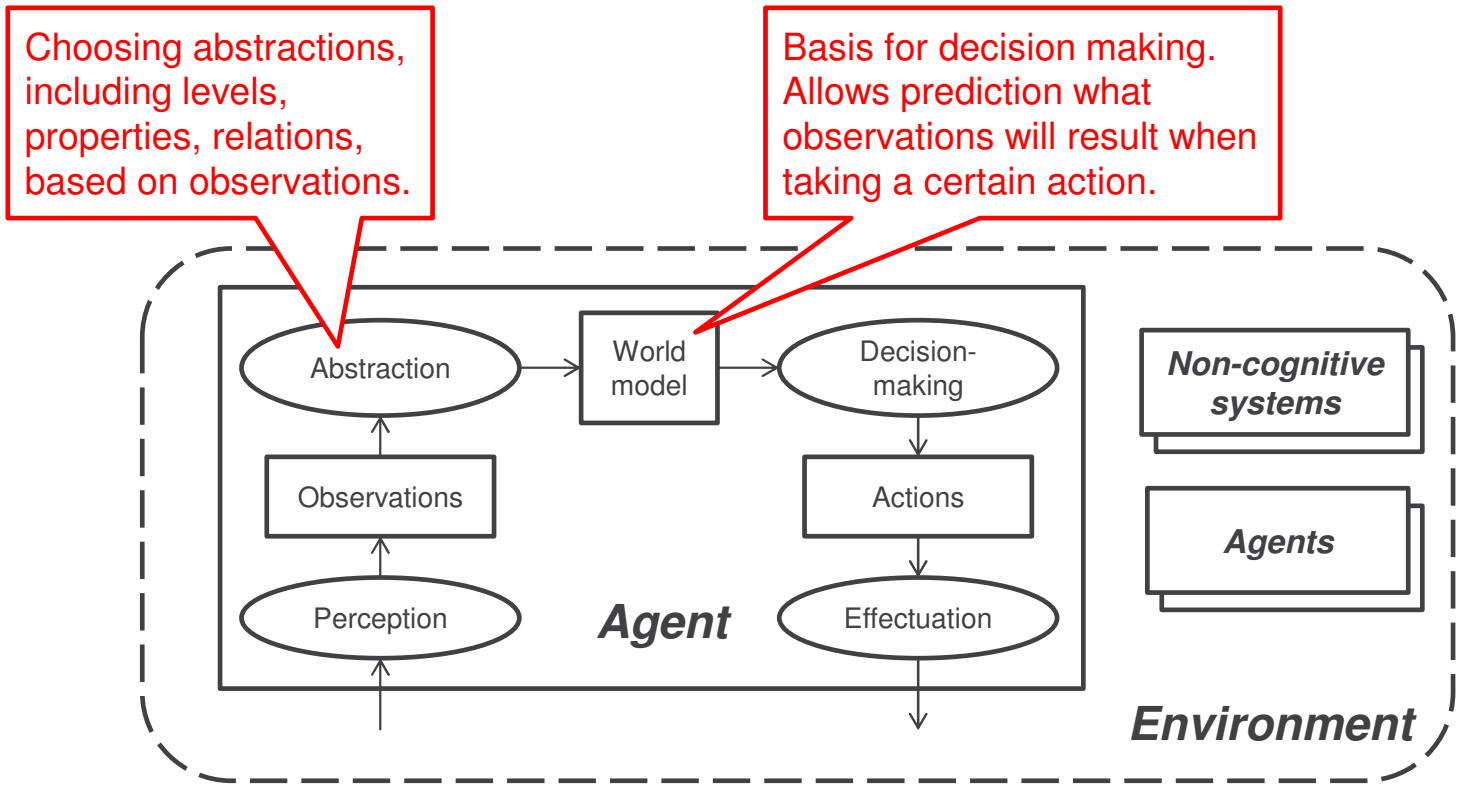
- Emerge = to become visible
- Depends on prior knowledge:
  - Surprise first time, but hardly second
  - Learning about phenomenon in other ways than direct observation

Downward causation



- Can element level phenomena be affected by system level emergent phenomena?
- Seems plausible when cognitive agents are involved!
- Also applies to SoS (since the constituent systems can be seen as cognitive agents)
- Note that the observer then is inside the system, not outside!

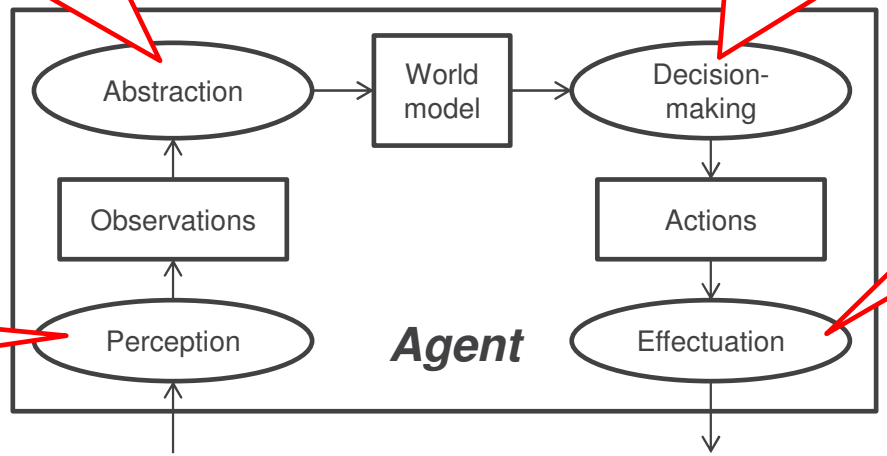
Conceptualizing observers



Tactics for dealing with emergent phenomena

Model-based SE on three levels:
1. Context models
2. System-of-interest
3. Elements of system

- Reduce strength of emergence → reduced complexity
- Exploit downward causation through communication/mediators



- Dynamic control strategies
- Collaborate with other systems to control emergence on SoS level

- Multidisciplinarity
- Organizational learning

Conclusions

- Many difficulties with emergence are resolved by making observer explicit
- By conceptualizing the observer as a cognitive agent, different aspects of emergence can be clarified, and tactics for dealing with them identified

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