COMPLEX ADAPTIVE SYSTEMS:

Approaches to CAS

- intro 2-

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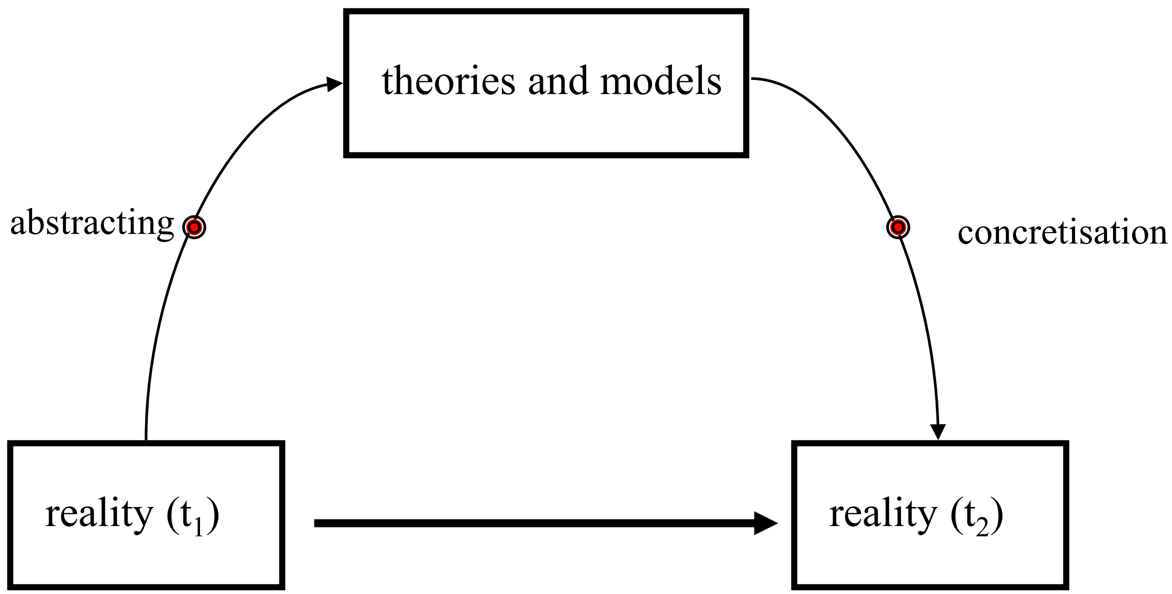
How do we get theories?



positivism :

{theory, model} $\notin$ reality

reality (t_1) ≈ reality (t_2)

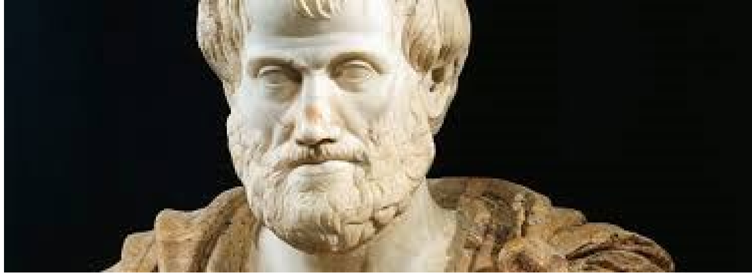
constructionism :

{theory, model} $\in$ reality

reality (t_1) $\neq$ reality (t_2)

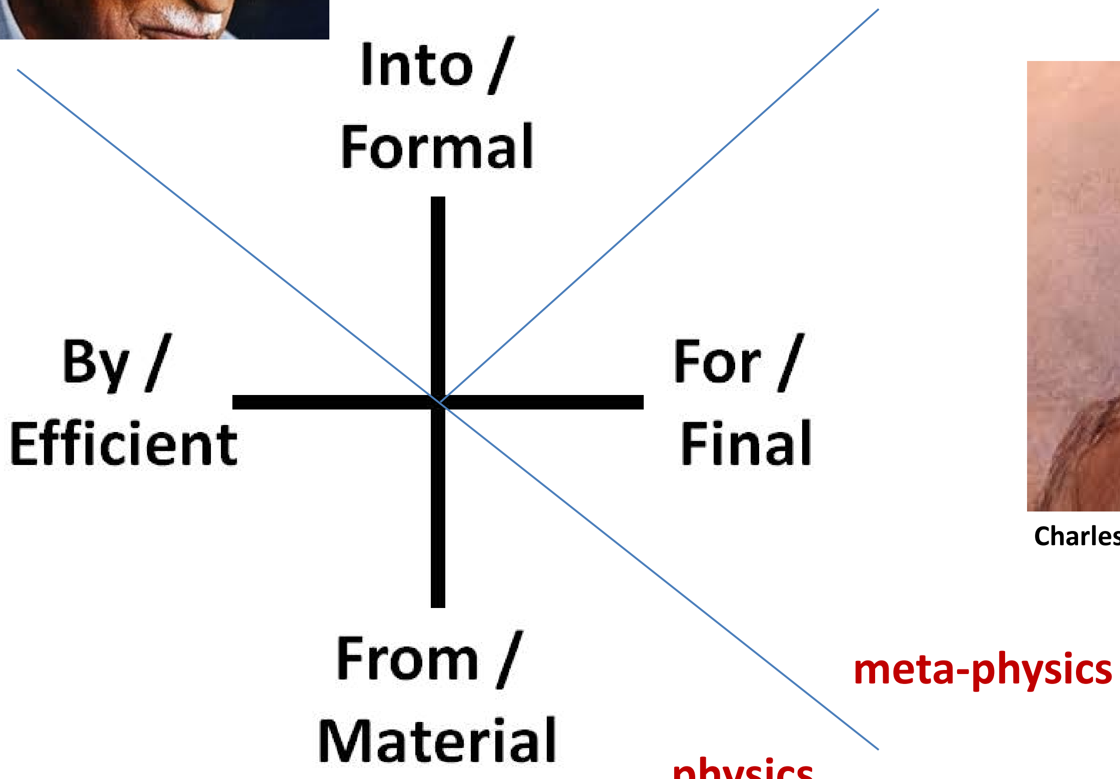
[REF: Rauterberg M. (2006). HCI as an engineering discipline: to be or not to be!?. *African Journal of Information and Communication Technology*, vol. 2, no. 4, pp. 163-184]

The Four Causes

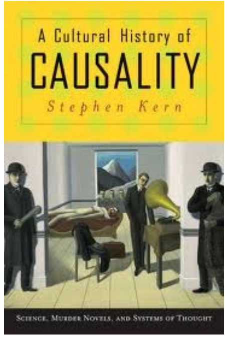


ARISTOTLE [384 – 322 BC]

Carl JUNG [1809–1882]
“archetypes as universal forms”



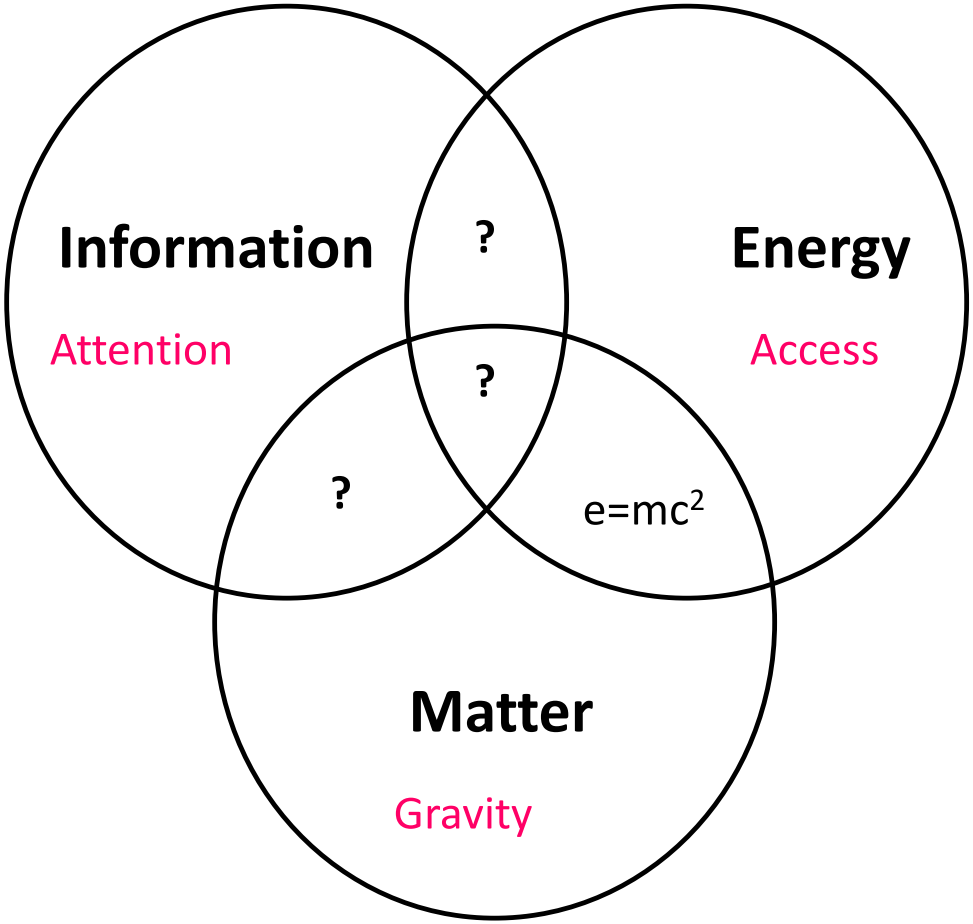
Charles DARWIN [1809–1882]



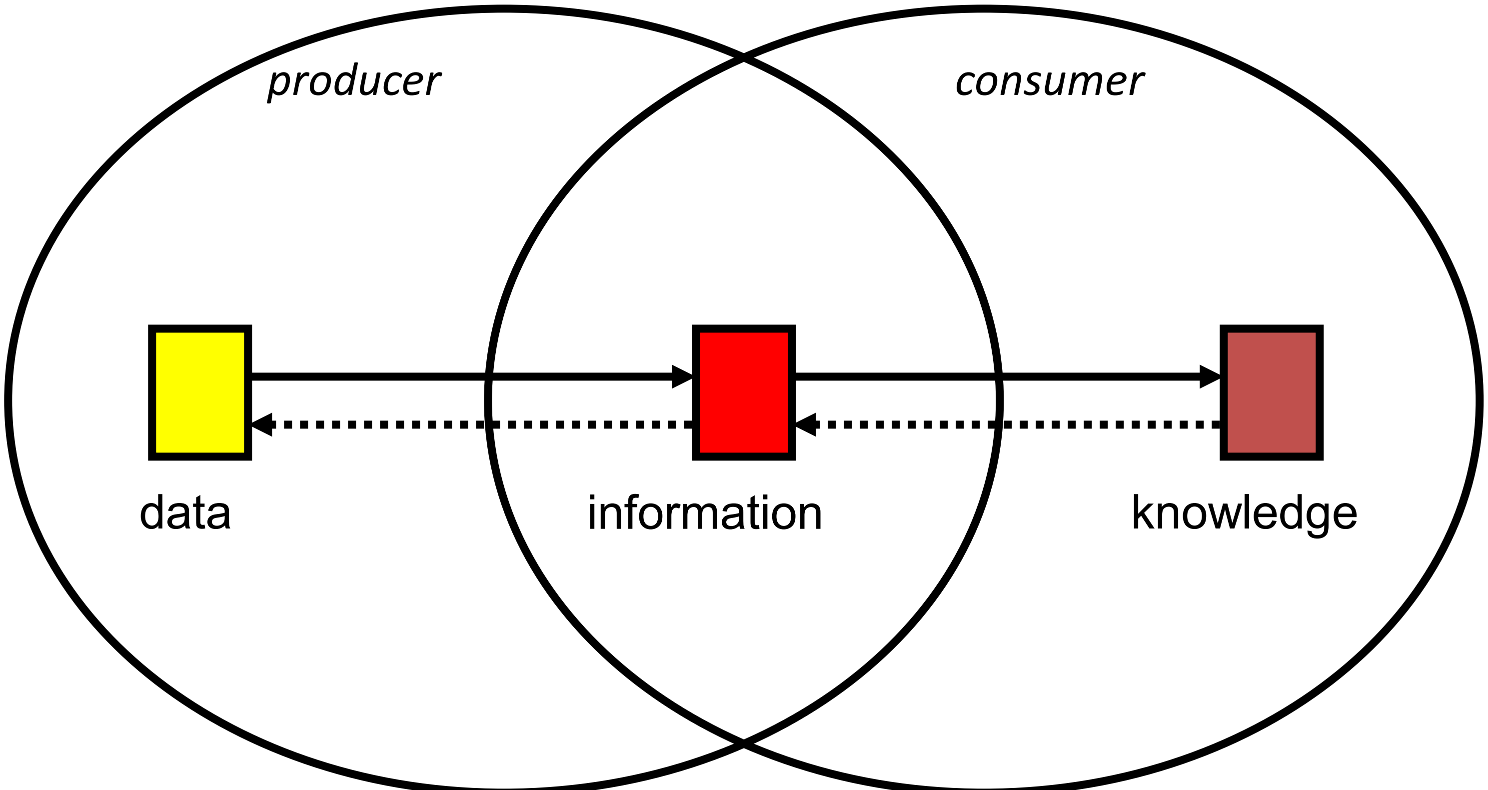
Francis BACON [1561–1626]

Rauterberg M., Feijs L. (2015). Enhanced causation for design. *International Journal of Philosophy Study*, vol. 3, pp. 21-34

The three main ingredients (and the most relevant dimension)…



Data, Information and Knowledge

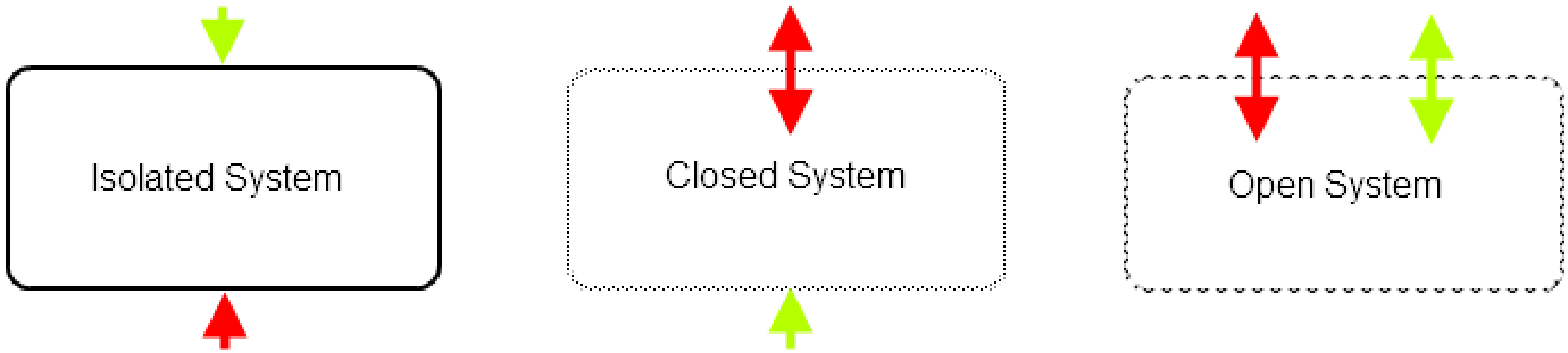


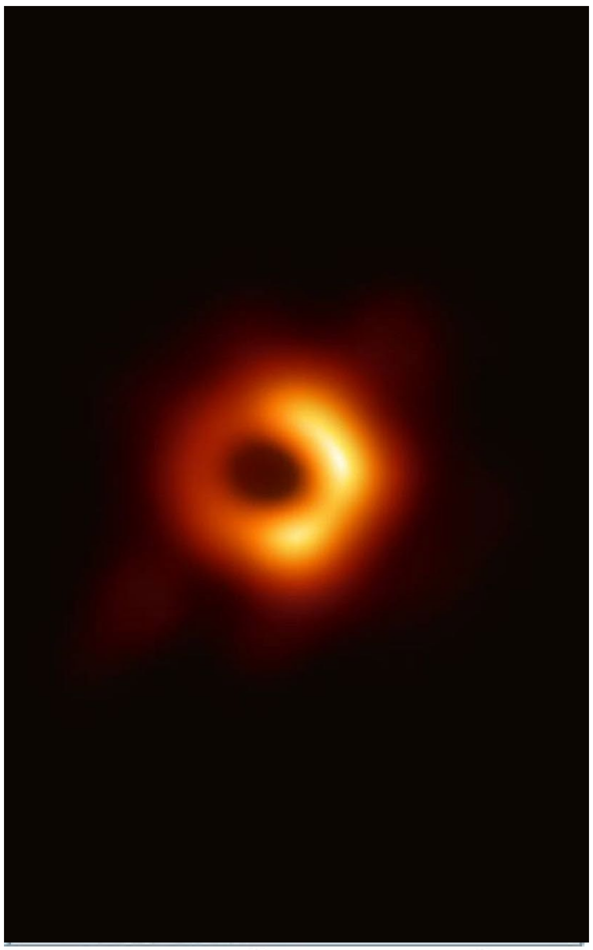
creation
discovery
gathering
storage

presentation
organization
communication

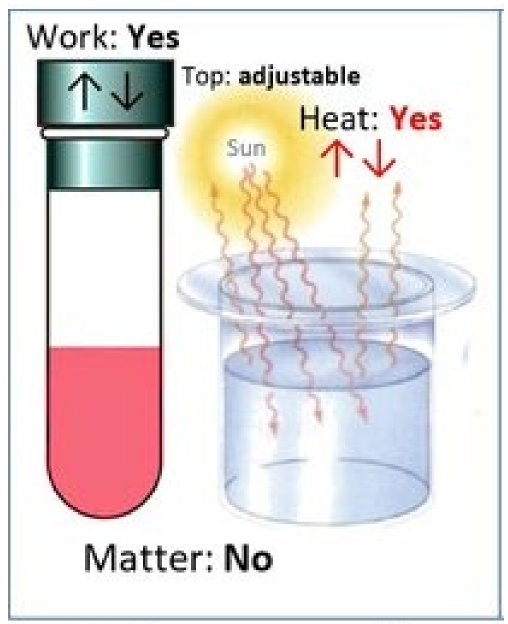
interpretation
evaluation
integration
storage

REF: Rauterberg M. (1995). About a framework for information and information processing of learning systems. In: E. Falkenberg, W. Hesse, A. Olive (eds.), Information System Concepts--Towards a consolidation of views (IFIP Working Group 8.1, pp. 54-69), London: Chapman&Hall.

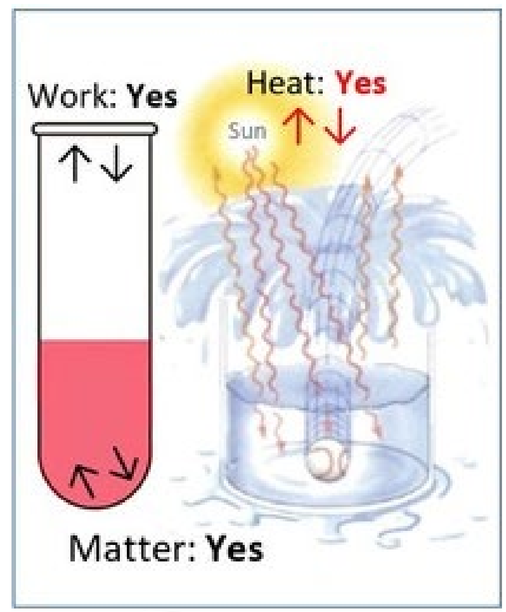




Isolated



Closed



Open

Approaches To CAS

Considering complex adaptive systems, we are interested in:

1. how interactions give rise to patterns of behavior
2. understanding the ways of describing complex systems
3. how complex systems form through pattern formation and evolution
4. how complex systems adapt to their changing environment

How to measure a system's complexity?

- By its unpredictability?
- By how difficult it is to describe?
  - No single model adequate to describe system---the more models that are required, the more complex the system. (Lee Segel)
- By measuring how long before it halts, if ever? By how long until it repeats itself?
- Entropy?
- Multiple levels of organization?
- Number of interdependencies?

CAS: Characteristics

- ***Sub optimal*: A complex adaptive system does not have to be perfect in order for it to thrive within its environment.**
  - It only has to be slightly better than its competitors and any energy used on being better than that is wasted energy.
  - A CAS, once it has reached the state of being good enough, will trade off increased efficiency every time in favor of greater effectiveness.

- ***Requisite Variety*: The greater the variety within the system the stronger it is.**
  - Ambiguity and paradox abound in complex adaptive systems which use contradictions to create new possibilities to co-evolve with their environment.
  - Democracy is a good example in that its strength is derived from its tolerance and even insistence in a variety of political perspectives.

- ***Connectivity*: The ways in which the agents in a system connect and relate to one another is critical to the survival of the system.**
  - It is from these connections that the patterns are formed and the feedback disseminated.
  - The relationships between the agents are generally more important than the agents themselves.

CAS: Characteristics

- ***Simple Rules***:
  - Complex adaptive systems are not complicated. The emerging patterns may have a rich variety, but like a kaleidoscope the rules governing the function of the system are quite simple.
  - A classic example is that all the water systems in the world, all the streams, rivers, lakes, oceans, waterfalls etc with their infinite beauty, power and variety are governed by the simple principle that water finds its own level.
- ***Iteration***:
  - Small changes in the initial conditions of the system can have significant effects after they have passed through the emergence - feedback loop a few times (often referred to as the butterfly effect).
  - A rolling snowball gains on each roll much more snow than it did on the previous roll and very soon a fist sized snowball becomes a giant one.
- ***Self-Organizing***:
  - There is no hierarchy of command and control in a complex adaptive system.
  - There is no planning or managing, but there is a constant re-organizing to find the best fit with the environment.
  - A classic example is that if one were to take any western town and add up all the food in the shops and divide by the number of people in the town there will be near enough two weeks supply of food, but there is no food plan, food manager or any other formal controlling process. The system is continually self organizing through the process of emergence and feedback.

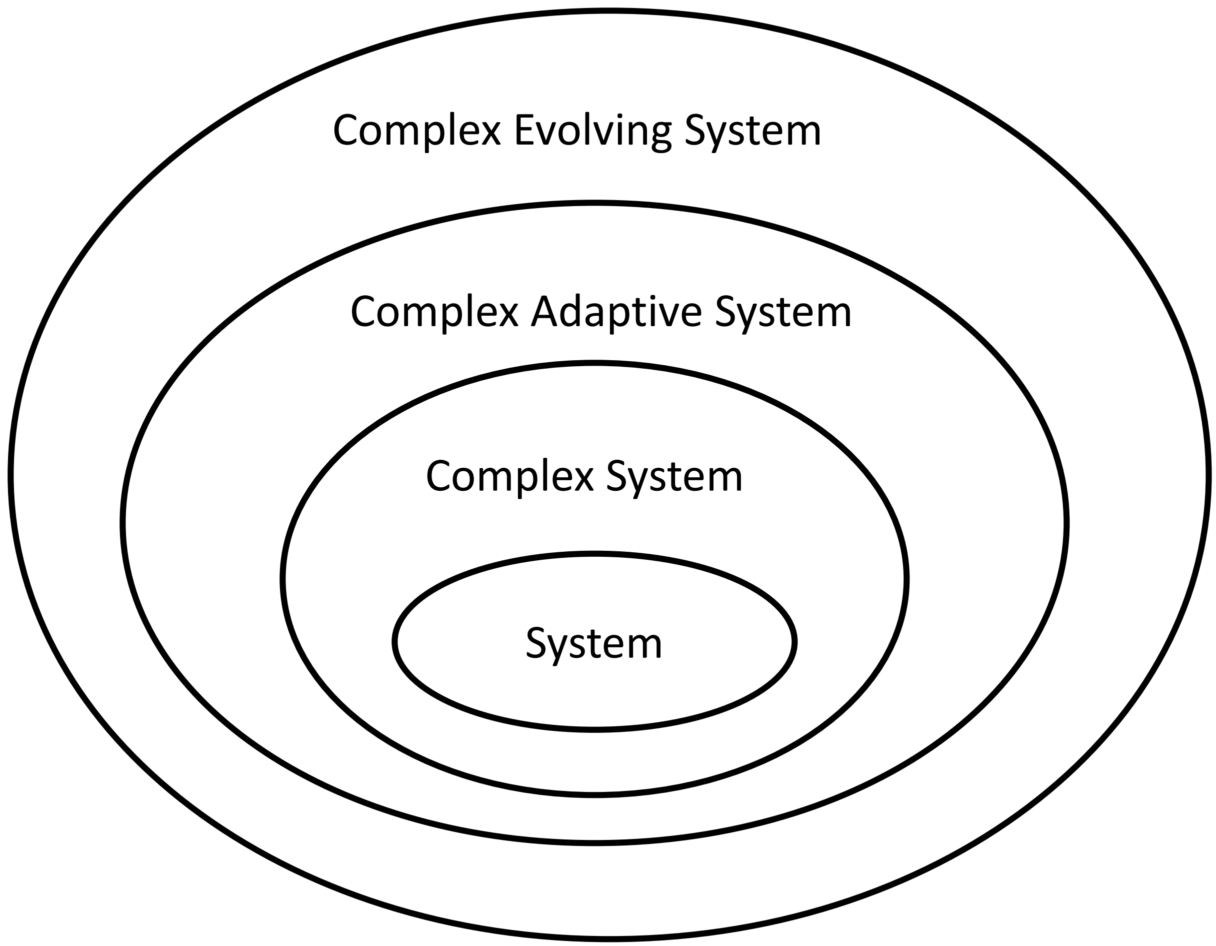
CAS: Characteristics

- ***Edge of Chaos***:
  - Not the same as chaos theory, which is derived from mathematics.
  - Systems exist on a spectrum ranging from equilibrium to chaos.
  - A system in equilibrium does not have the internal dynamics to enable it to respond to its environment and will slowly (or quickly) die.
  - A system in chaos ceases to function as a system.
  - The most productive state to be in is at the edge of chaos where there is maximum variety and creativity, leading to new possibilities.
- ***Nested Systems***:
  - Most systems are nested within other systems and many systems are systems of smaller systems.
  - Consider a food shop. The shop is itself a system with its staff, customers, suppliers, and neighbours.
  - It also belongs the food system of that town and the larger food system of that country. It belongs to the retail system locally and nationally and the economy system locally and nationally, and probably many more.
  - Therefore it is part of many different systems most of which are themselves part of other systems.

Complex Evolving Systems (CES)

- Some people suggest that these type systems continuously learn.
- As Pogo has said (paraphrased):
  - “We have met the future and they are us!” (we, as humans, continuously evolve, not physically in our lifetimes, but emotionally, cognitively, etc.)
- CASs continuously adapt to the changes around them but do not learn from the process.
- CESs learn and evolve from each change enabling them to influence their environment, better predict likely changes in the future, and prepare for them accordingly.

Hierarchy of Systems



What's The Social Science Problem?

- Most pre-computational social science models are linear:
  - Linearity is based on independence of elements
  - Linearity is a good modeling technique for simple systems
  - The linearity assumption implies that the whole is equal to the sum of its parts!
- We know a lot about:
  - Individuals (through surveys)
  - Aggregated as groups and populations
  - On a domain-specific basis
- We know a lot less about interactions among individuals and groups:
  - How social structures form; how protocols emerge and the interactions in large groups and among subgroups
  - How and why do group structures (and their protocols) change
  - What the content of interaction is: influence, power, imitation, exchange, association
- BUT:
  - **Social science systems are not simple,….**
  - **The whole may be greater (or lesser) than the sum of its parts!!**
  - **Modeling the dynamics is (very) hard …**

Why is the Study of CAS Important?

π Problem of *Computational Irreducibility*:

The failure of mathematical models to provide explicit solutions to complex phenomena

Position and velocity can be calculated exactly

Human behaviour is computationally Irreducibile

Studying CAS

- **Multi-scale descriptions are needed to understand complex systems:**
  - Complexity arises at different levels
  - Mathematical tools must scale
  - Need to understand behavior propagation across levels
  - Ex: Weather - (cyclones, tornadoes, dust devils)
- **Fine scales influence large scale behavior:**
  - Ex: Neurophysiology - a nerve cell action triggering a muscle
  - Ex: Economy/society - the relevance of individuals to larger scale behaviors
- **Pattern Formation:**
  - Ex: weather - cells of airflow
  - Ex: Economy/society - patterns of industrial/residential/ commercial areas
- **Multiple (meta)Stable States:**
  - Small displacements (perturbations) lead to recovery; larger ones can lead to radical changes of properties.

Ref: NECSI, http://www.necsi.edu/guide/points.html

Studying CAS

- **Finding a Metric of Complexity**:
  - The amount of information necessary to describe the system.
  - The apparent complexity depends on the scale at which the system is described
- **Behavior Complexity**:
  - How to describe the behavior (actions) of a system acting in response to its environment, where the complexity of the environmental variables are $C(e_i)$ and of the behavior is C(b)
  - The behavior is $b = f_b(e_i)$, so the goal is to determine the nature of f_b
  - Bar-Yam suggests: $C(f_b) = C(b)*2^{C(e(i))}$
    - Is this behavior impossible to determine except for the simplest environments?
- **Emergence**:
  - Parts must be studied "in vivo".
  - Ex (after Bar-Yam): "If you remove a vacuum tube from a radio and the radio squeals do not conclude that the purpose of the tube is to suppress squeals.“
  - The nature of complex systems can be assessed by investigating how changes in one part affect the others, and the behavior of the whole

Ref: NECSI, http://www.necsi.edu/guide/points.html

Studying CAS

- **7+/-2 Rule (Miller 1956):**
  - For a system divided into components, looking at the dependencies between them, when does the state / behavior of one of the components depend on the state of each of the other ones, and not on an average.
  - When does the central limit theorem applies to a number of independent variables (Bar-Yam)
  - Much empirical evidence: structure branching rations in proteins, physiology, brain, and social systems
- **Composition**:
  - To form a new complex system take parts (aspects) of other complex systems and recombine them.
  - Composites allow rapid evolution and can minimize amount of testing
  - Ex: human genome, software/system engineering, creativity
- **Control Hierarchy**:
  - When (if) a single component controls the collective behavior (not the individual behaviors of all the components) of a system, then the collective behavior cannot be more complex than the individual behavior, i.e., there is no emergent complexity.

Ref: NECSI, http://www.necsi.edu/guide/points.html

Wicked Problems

- Wicked problems have incomplete, contradictory, and changing requirements
  - solutions to them are often difficult to recognize as such because of complex interdependencies.
- Rittel and Webber (1973) stated that while attempting to solve a wicked problem, the solution of one of its aspects may reveal or create another, even more complex problems.
- Complexity—systems of systems—is among the factors that makes wicked problems so resistant to analysis and, more importantly, to resolution
- Wicked problems are adaptive, e.g., the (partial) solution changes the problem
  - Is there a restatement of Heisenberg's Hypothesis here??

Wicked Problems

Characteristics (Ritchey 2005):

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rule.
3. Solutions to wicked problems are not true-or-false, but better or worse.
4. There is no immediate and no ultimate test of a solution to a wicked problem.
5. Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The planner has no right to be wrong (planners are liable for the consequences of the actions they generate).

Examples of Wicked Problems

SHK & Associates

- Global Warming
- War on terrorism
- Sprawl and Sustainable Development
- A National Healthcare System for the U.S.
- World Hunger
- Energy Crisis: When the Oil (Coal) Runs Out?
- Large-Scale Software Development
- Epidemic: Worldwide Explosion of Ebola/Marburg/…
- Emergent Systems

- And, your favorite physical or social science problem here!!

Some Open Questions

- If we arbitrarily combine different parts of complex systems, will the result exhibit CAS properties? (Genetics, maybe yes; software, probably not)
- If we combine different parts of complex systems, does the decision process lead to reduction in the complexity of the resulting system?
- Bar-Yam suggests: $C(f_b) = C(b)*2^{C(e(i))}$. Is this behavior impossible to determine except for the simplest environments?
- Is a truly complex system completely irreducible?
  - =>'s cannot derive a model w/out losing some relevant properties
  - Thus, to what extent can we make abstractions (models) of the system's interactions that faithfully reproduces its macroscopic behavior?
  - Can we explain such macroscopic behavior through a set of rules that capture the microscopic interactions?

More Open Issues

John Holland has suggested:

1) All *CAS* exhibit lever points – points where a simple intervention causes a lasting, directed effect.

   Example: vaccines.

   There is no theory that tells us where or how to look for lever points.

2) Open-ended evolution is typical of *CAS* – an initially simple system exhibits increasing diversity of interaction and signaling.

   Example: ecosystems.

   There are no models that exhibit open-ended evolution.

3) All *CAS* have a hierarchical organization of boundaries enclosing boundaries.

   Example: biological cells.

   There is no theory or general model that tells us what mechanisms cause the formation of boundaries in a uniform system.

Introduction - References

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