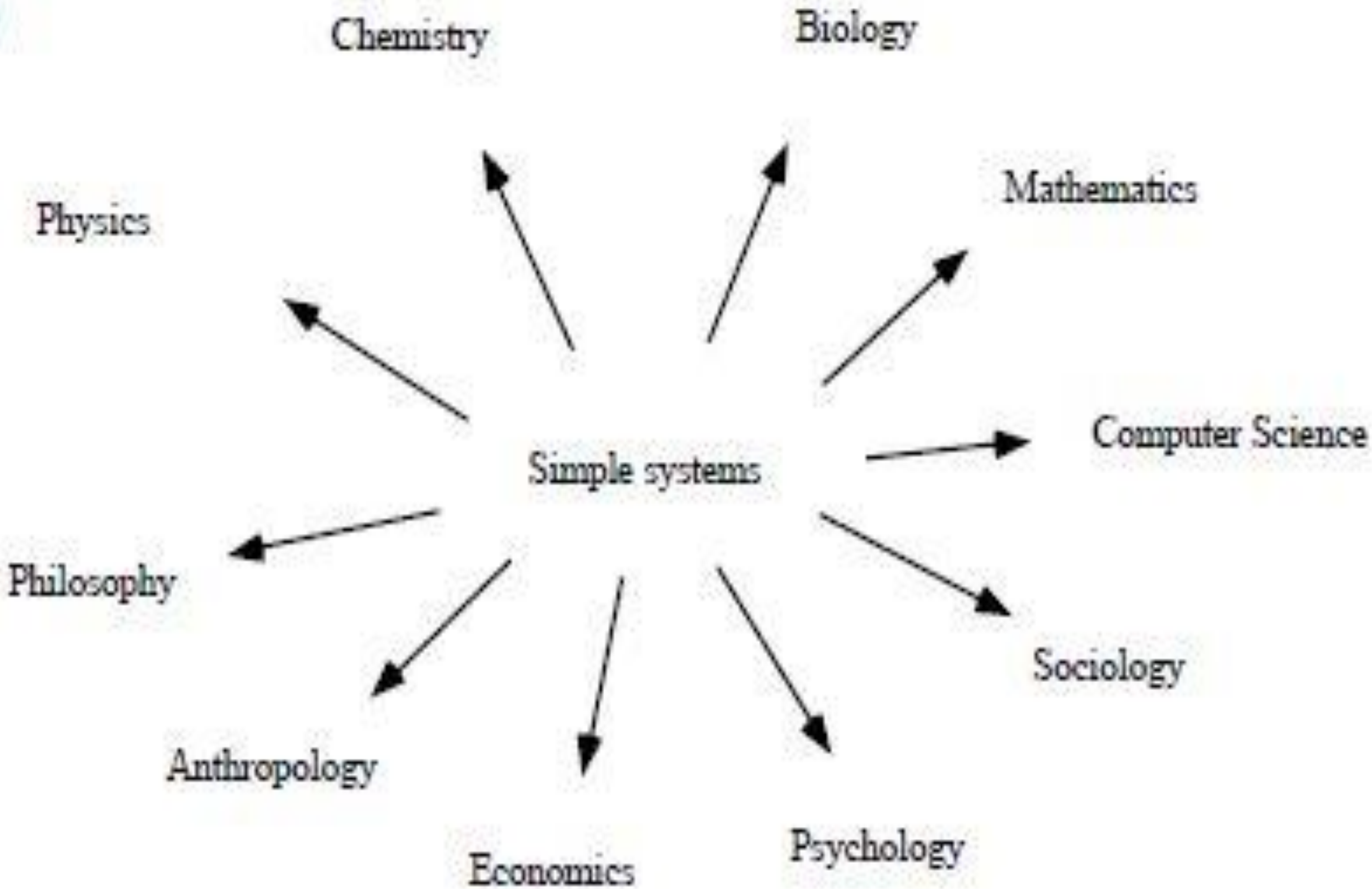
We are ready for definition of features of a complex system and its evolution (the identikit)

- it is typically open (matter, energy, information fluxes): all real system are open
- it contains a set of many interacting objects, or "agents" (physical interaction, group interaction, information exchange, …, networks): generally non-linear Interactions; delayed effects
- repetitive (gas, water) and non-repetitive (nervous central systems, neurons, cellular enzyme ensemble)
- the behavior is conditioned by memory (negative and positive feedback cycles)
- it presents stability and robustness (perturbation damping) and differentiated sensibility (presence of critical points relative to external injury)
- it is adaptive (CAS): agents can modify their strategies
- hierarchical organization (each sub-system is also complex): an organized system is able to evolve more faster
- partial agents autonomy
- presence of paradoxes

Cfr. Gandolfi, 2014

(a)



Chemistry
Biology
Physics
Mathematics
Computer Science
Simple systems
Philosophy
Sociology
Anthropology
Psychology
Economics

MULTIDISCPLINARY
THINKING
MENTAL MODELS
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Hindsight Bias
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Prospect Theory
Over-confidence
Reciprocation
Contrast effect
Association
Morals
Ethics
Wisdom traditions
Supply
Demand
Utility
Comparative Advantage
Trade-offs
Tragedy of Commons
Game Theory
Feedback Loops
Sunk Cost
Redundancy
Breakpoints
Margin of Safety
5 Forces of Porter
Brands
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Autocatalysis
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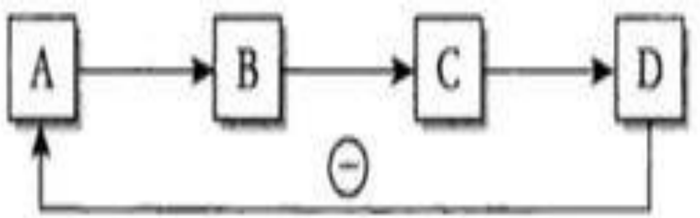
Open systems

- von Bartalanffy, founder of General Systems Theory, distinguishes carefully between open and closed systems.
- matter, energy, information fluxes
- generally dissipative (Prigogine)
- often unknown distribution and elaboration of energy

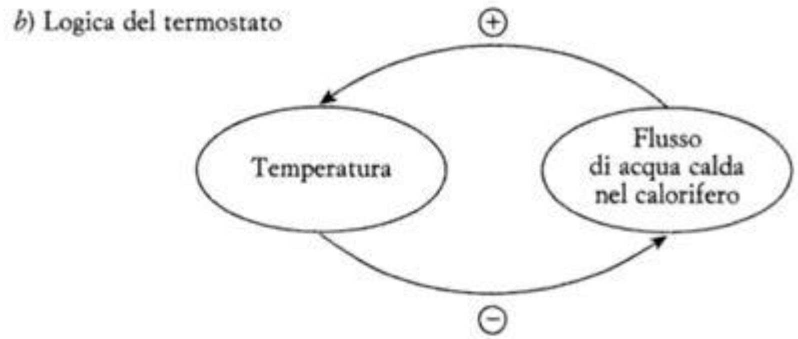
Many interacting objects, or “agents”

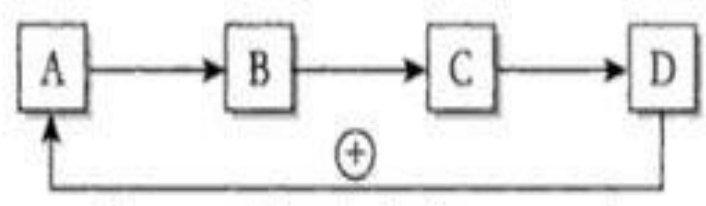
- simple or complex (often biological)
- repetitive (gas, liquid, crystals), non-repetitive (nervous central systems, neurons, cellular enzyme ensemble)
- physical interaction (simples rules, but emergence of complex and unpredictable behavior): termitarium
- information exchange (coherent, with program)
- networks
- non-linear interaction
- time and delayed effects

The behavior is conditioned by memory (feedback)

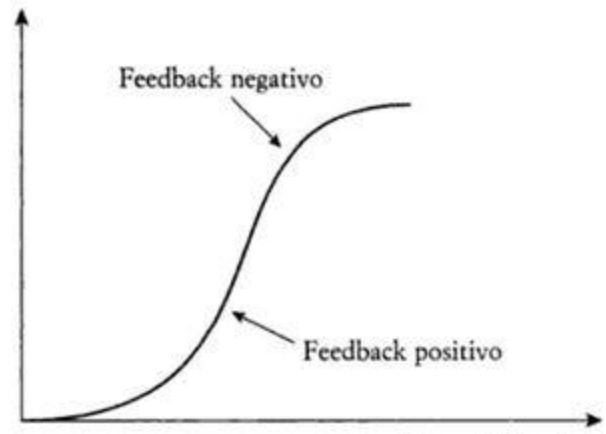


Negative feedback (stabilizing)





Positive feedback (destabilizing, often chaos source)



Norbert Wiener, Cybernetics founder, introduces feedback notion
Positive feedback followed by negative feedback
(bacterial cultures, populations of predators and prey, snowflakes, oscillating reactions); Volterra-Lotka equations

Cycles, ipercycles, complex catalysis (homeostasis)

Cfr.Gandolfi, 2014

Hierarchical organization

- Hierarchy Meaning: the control of a system composed of many interacting elements that must act in a coordinated and harmonious manner
- nesting progressive
- principle of enslavement (Haken and Synergetics, lasers)
- drastic reduction of theoretical freedom: the organization imposes constraints that inhibit certain capabilities that are found in various parts (Morin)
- black box an bottom-up approach (strategy not always useful)

Self-organization- From disorder to the order

- repetitive objects (gas, liquid): external conditions can influence local order of a set of objects (Bénard cells
- self-organization occurs when the system exceeds a critical threshold of complexity(Bak)
- irreversible process that, by means the action of cooperative subsystems leads to more complex structures in the global system (Ebeling, 1991)
- catastrophic bifurcations: not predictable or calculable theoretically because the evolution of the entire system depends on the minimum random fluctuations, that in a situation of stability should be often negligible
- paradoxal semplification of the system: a new level of organization thus involves a simplification of the system structure , but also involves the beginning of a progressive complexification (Lazslo, 1986)

Stability and robustness

- perturbation damping: It bears with extreme flexibility external injuries, without collapsing: due to redundancy and preparation to frequent errors, but significant energy consumption
- differentiated sensibility: very variable sensitivity to external and internal stimuli of the different parts or regions of the system; presence of critical points relative to external injury)

Complex Adaptive Systems

A complex adaptive system (CAS) is an open system, made up of several elements that interact with each other in a non- linear manner and which constitute a single entity, organized and dynamic, able to evolve and adapt to the environment agents can modify their strategies.

- creativity, innovation, unpredictability (constantly production of not existing structures and functions)
- partial agents autonomy
- presence of paradoxes (co-existence of fast and slow movements or oscillations or of regular and irregular shapes, or even of stability and instability)

What about evolution

- it appears like “living” system (its behavior is absolutely non-trivial)
- it gives rise to emergent phenomena, often astonishing and sometime extreme (creativity, innovation, unpredictability, no control)
- auto-organization (no external intervention)
- it alternates ordered and chaotic behavior in a complicated way
- simple agents interconnected can produce a large spectrum of realistic results: this is the complexity essence, sometime a slap to the reductionist approach to the knowledge of the world.

Therefore, we can say that the key difference between a generic system, more o less complicated, and a complex system is in the fact that the relationship between its parts is more important than part constitution

Complicated vs Complex

Cum + plicatus

"Piegato insieme" (folded together)

Can be "s-piegato" (explained)

A complicated system can be decomposed into subparts and understood by analyzing each of them

- many elements
- generally simple elements
- linear interactions between elements
- high predictability
- no evolution. Static system
- connected in series
- low or no redundancy
- low robustness/flexibility

Cum + plexus

"Intrecciato insieme" (interconnected)

Can not be "s-piegato" (explained)

A complex system can be understood only considering it as a whole and in particular by observing interaction between its elements

- many elements
- often complex
- non linear interactions between elements
- low or no predictability
- high evolution. Dynamical system
- often parallel networks
- high redundancy
- high robustness/flexibility

A complicated pattern is one that is intricate in the number of parts and their hidden relationships to each other. Such a system appears to be “folded” so that parts are hidden from view. To understand such a system, the parts must be separated from each other and the relationships clearly defined. Though it may take a long time and much effort, a complicated system can be understood in terms of its parts.

Reductionism is an effective method of investigating the nature and function of a complicated system.

A complex pattern, on the other hand, involves the weaving together of parts into and intricate whole. Each part is massively entangled with others, and the emergent (complex) pattern cannot be discerned from its components. The whole emerges from the interaction of the parts. In the same way that a tapestry depends on the relationships among threads of various colors, other complex systems derive from the parts AND their intricate relationships to each other.

If a system can be understood in terms of its parts, then it is a complicated system.

If the whole of the system is different from the sum of its parts, then it is complex.

This distinction is important in evaluation practice because complicated and complex systems require different methods of analysis. Good evaluation of a complicated system involves repetition, replication, predictability, and infinite detail. Good evaluation of a complex system involves pattern description, contextualization, and dynamic Evolution.

Complicated vs Complex

(examples)

- High dimension software
- automation systems in a factory
- administrative procedures in a Country
- space shuttle
- artificial satellites
- rockets
- pile of sand
- low or no redundancy
- low robustness/flexibility
- traffic control system

- ecosystem
- economic system
- brain
- society
- DNA
- company
- group of friends
- ant and termitarium (very complex)
- bacterium
- metabolism control system

Main deep deductible consequences

- giving up the principle of “cause-effect”
- giving up the concept “*tertium non datur*”
- acceptance of unpredictability and uncertainty
- deep differences between complicated (explicable) and complex
- observer's interference
- understanding as compression (information or data)

What results from this series of new awareness in the development of science, in our (observers) world view, operating within it, and in the rational “exact” construction of technology and scientific predictions?

cfr. Eletti, 2010

Some initials conclusions to retain

► CAS is when you bring together many elements (simple or complex in their turn) connected between them in a network (feedback loop, cycles and enzymatic hypercycles, non-linearity of the system) regulated by local simple laws, and when the system as a whole is in a non-equilibrium state (dynamical, turbulent state, at the edge of chaos) and in an exchange condition with the environment (open, dissipative system)

► In any field of science or disciplines, we are experiencing recurring features, among which in particular:

● reversal of the entropic process, with the creation of order instead of the natural tendency to disorder in a limited area in time and space (system-environment, as a whole, instead continue to respect the second law of thermodynamics, so total entropy grows) (*apparent paradoxes and deviations*);

● disappearance of linear and direct relationship between causes and effects, so the events, configurations and system developments over time (delayed effects) and space (probabilistic localization of effects);

● emergence at system level of unforeseeable features from the observation of individual elements (the whole is greater than the sum of its parts);

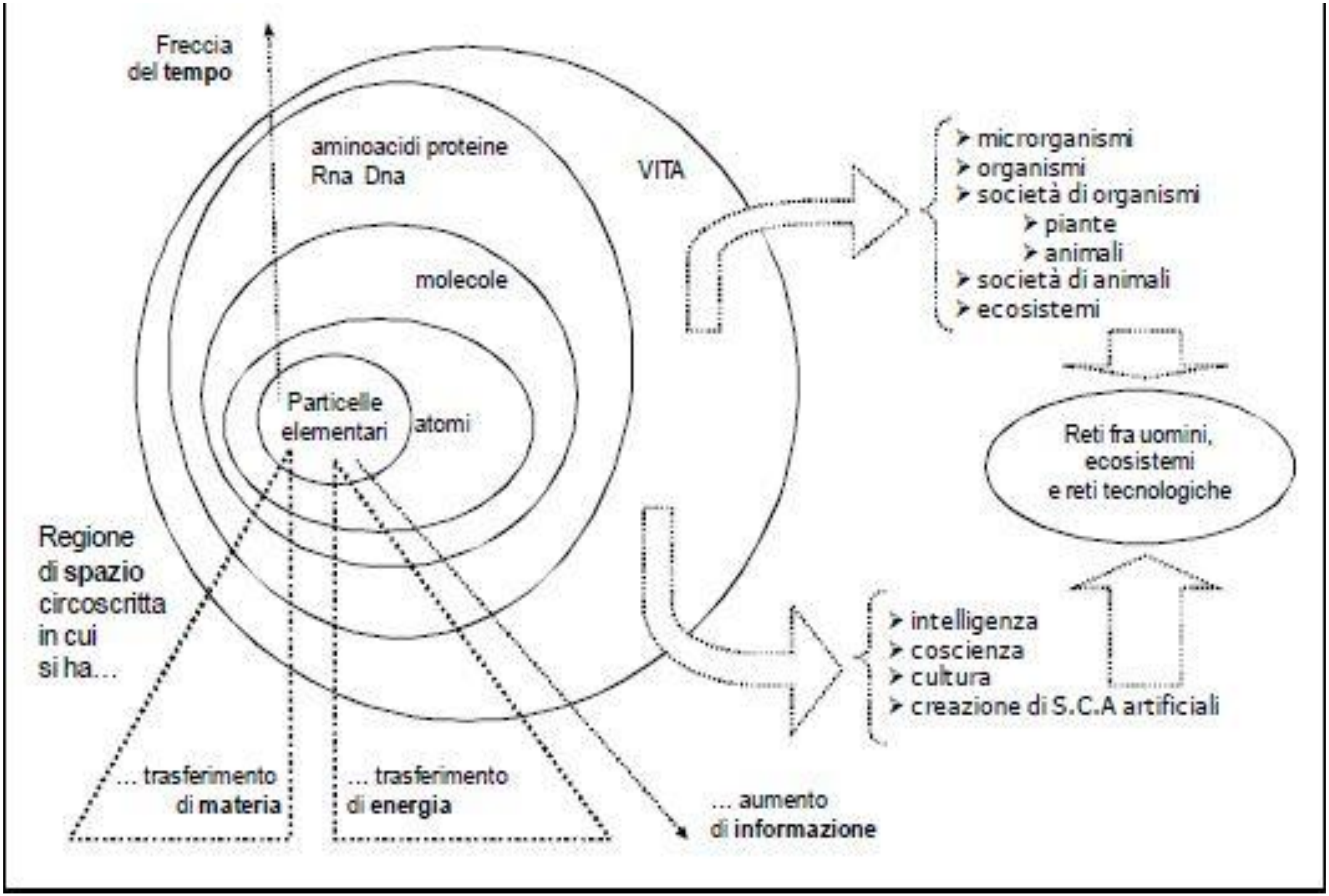
cfr. Eletti, 2010

► ability to generate over time hierarchies gradually higher in complexity: elementary particles > atoms > molecules > amino acids > proteins > RNA > DNA ... from which what we call life: cells > microorganisms > multicellular beings and organs > plants, animals > basic forms of intelligence > society > ecosystems ... and in the specific field of our species: brain > mind, thought, conscience ... from which entails new complex "artificial" systems as the financial market, business organization, politics, urban planning,

knowledge systems (cultural and meme systems [Dawkin]), computer networks, life and artificial intelligence ... until to the possible (probable) emergence of a new conscious and living organism, of scale greater than our own?

► From these considerations the answer immediately follows to the question: why deal with complex systems? For we ourselves are CAS, formed by CAS, nested in an environment consisting of CAS in continuous interaction between them and permanent evolutionary adaptation to their environments . Moreover, thanks to the abilities emerged from the complexity of the synapses of our brain, we are able to create and add new CAS to the environment in which we live ; and we are able to observe (and partly "to understand") some of the complexity hierarchies that are "below" and "above" our own ...

cfr. Eletti, 2010



cfr. Eletti, 2010