CLIMAT ACADEMY®

The Scientific Supplement

Chapter Nine

Paradigm Shift - Science Complexity

Summary

This supplement challenges the comforting story that the world is moving smoothly from old energy sources to new ones. It argues that historical evidence shows not simple replacement, but "energy addition": coal, oil, gas, nuclear and renewables tend to accumulate rather than neatly displace one another. By looking at industrial history, the text shows that wood did not vanish when coal rose, and oil did not eliminate coal. Each new energy source often expanded the overall scale of energy use. The supplement also points toward the rebound effect, where efficiency gains or new technologies can stimulate greater total consumption instead of reducing it. This makes the phrase "energy transition" more problematic than it first appears. The chapter's wider warning about physical tipping points is therefore sharpened: without confronting absolute demand, infrastructure lock-in and material throughput, societies can mistake technological change for real climate progress while still driving the Earth system toward dangerous thresholds.

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In 2008 was published “Thinking in Systems” by Donella H. Meadows, an MIT researcher author of the resounding “Limits to Growth”. With the help of her experience as an analyst, Donella Meadows brings her knowledge of mathematical and computer systems to the real world.

The science of complex systems concerns the multiple relationships existing in a system between the components themselves, and between the components and their environment. The functioning of these systems is said to allow a “whole greater than the sum of all its parts”.

It is usually enough in simple systems to understand the individual properties of the components to infer or predict the properties of the system. The state of the system, i.e. the set of all variables that characterize it, changes as its parameters.

A change of frame

Before a brief overview of complex systems, it is needed to clarify what is not, and what the science of complexity cannot be used for. In opposition with what scientists generally pursue in their respective disciplinary fields, the goal here is not to predict and control the course or outcome of a process.

Science of complexity incorporates **unpredictability** and accepts the **lack of control** of the system. This is one of the most significant scientific paradigms shift since the Copernican revolution.

From a dynamic point of view, complex systems can be described as **non-linear systems**; changes in the system’s components can lead to disproportionate outcomes.

Tipping points are a possible manifestation of minimal changes occurring in system parameters that can drastically alter the overall behaviour of the system.

Establishing architectural models of complex systems is an important aspect of complexity science; human societies, nerve or immune cells, climate change, ecosystems and macroeconomics are all practical examples of complex systems.

There are generally four characteristics of complex systems that are identified:

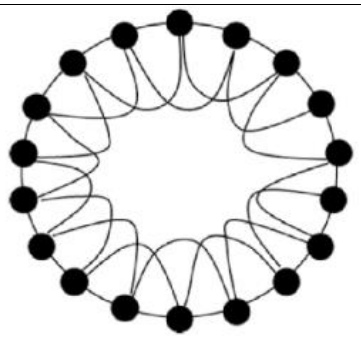
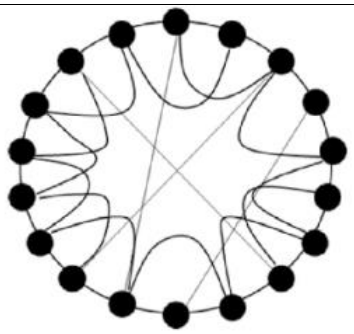
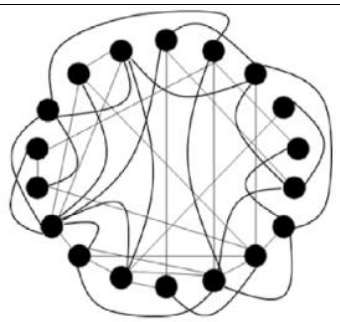
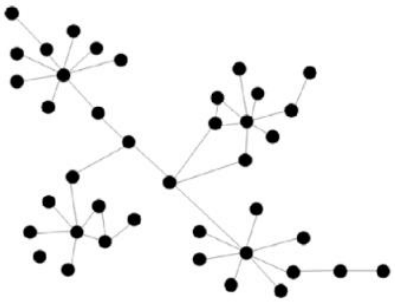
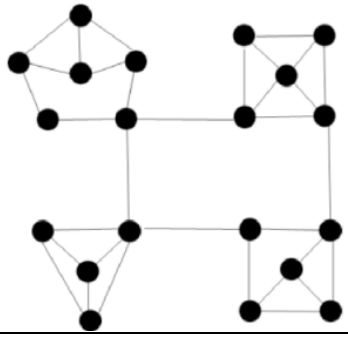
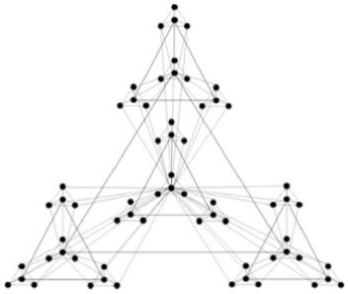
1. Organized in a network, with **nodes** and **interconnections.**
2. They are beyond the thermodynamic equilibrium, by the fact that they are open systems constantly exchanging energy and matter with their environment.
3. The **existence of emergent properties**. The entire system is not only greater than the sum of all its components, but also very different. Like ants and the complex functioning of an anthill.
4. Unpredictability

If we consider the brain as a complex system, then neurons would be the nodes and synapses the connection links.

Depending on the number of nodes and connections but also the distance between the nodes as well as the clustering of the nodes, the Italian professor P. L. Gentili proposes 6 architectural models of complex networks.

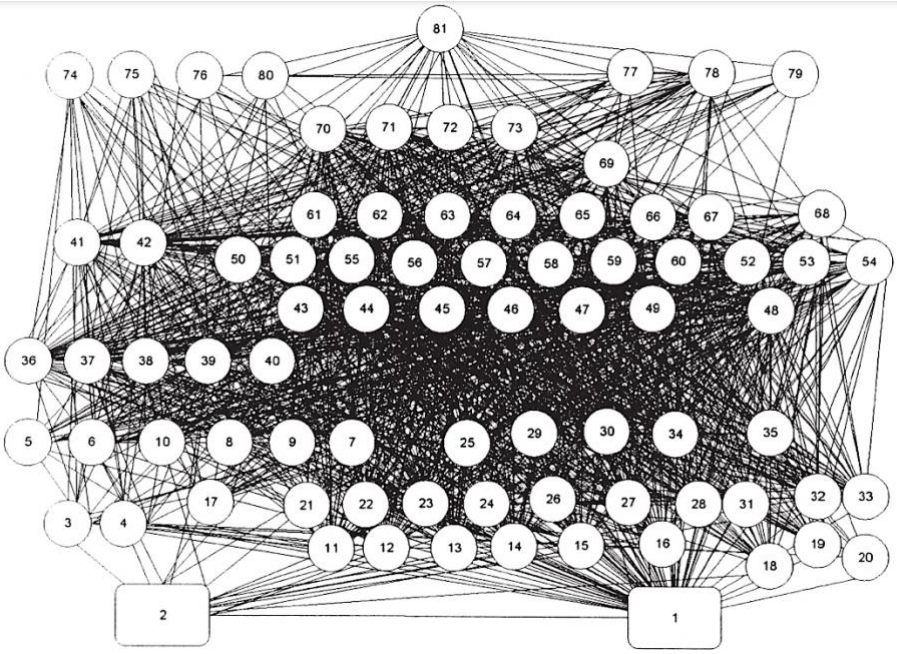
Gentili, P. L. (2021, 27 janvier). Why is Complexity Science valuable for reaching the goals of the UN 2030 Agenda ? Rendiconti lincei. Scienze fisiche e naturali, 32(1), 117-134. https://doi.org/10.1007/s12210-020-00972-0

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Regular Network	“Small-World” Network	Random Network
		
“Scale Free” Network	Modular Network	Hierarchical Network

These models can be applied to all complex systems. Thus, climate can be considered as a set of geographical locations (nodes) and physico-chemical data (connections), which correspond to a “small world” architecture. An in-depth study of this model reveals a high efficiency in the propagation of signals as well as in synchronization of events. The work of complex systems scientists would be to match complex systems with an architectural model representation that will help to understand and identify the characteristics of that system. To repeat the words of George Box: “All models are wrong, but some are useful”.

To further emphasize the importance of modelling complex systems, it is interesting to mention a 2003 research paper on the North Atlantic marine ecosystem and fisheries resource management.



The boxes represent:

- (1) Litter
- (2) Phytoplankton

The circles represent the upper trophic levels of species or group of species, and the circle 81 represent the humans.

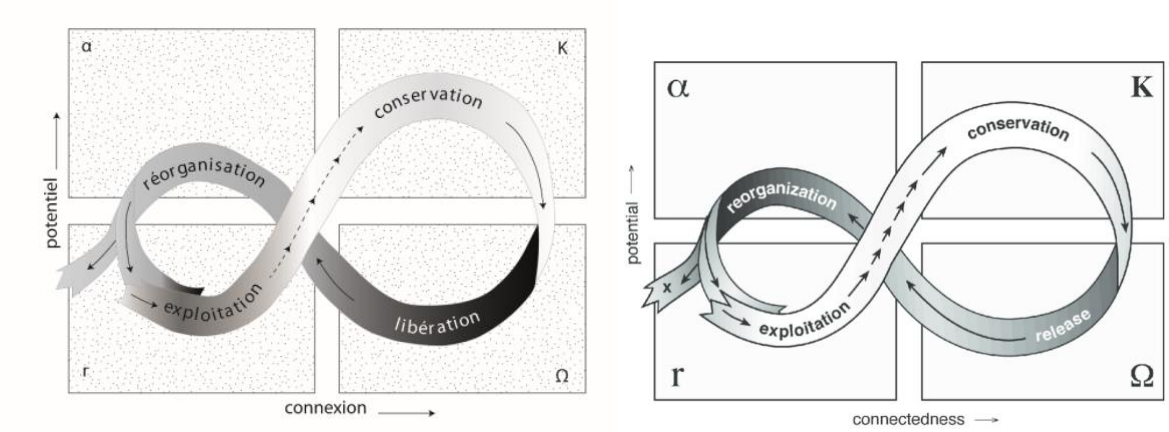
The left part of the network contains the representations of pelagic organisms and the right and middle part the benthic and demersal organisms (that live on the bottom of the ocean)

Sissenwine, M., & Mace, P. M. (2003, 1 janvier). 21 Governance for Responsible Fisheries : an Ecosystem Approach. ResearchGate. https://www.researchgate.net/publication/237474239

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Panarchy

When the science of complexity int integrates time into the study of complex systems, it is possible to find patterns for the evolution of the stability of complex systems. One of the most relevant models is the model of **adaptive cycles**. In opposition with hierarchical structures that are by definition fixed, panarchy focuses on the transitions between change, resilience and stability.



The adaptive cycle

First, there is the phase of **exploitation** (**r**) which corresponds to the implantation of pioneer organisms in a biotope. These organisms will then develop strategies of reproduction allowing them to quickly **colonize** space. Then comes a phase of **consolidation** (**K**) during which biomass and nutrients will slowly **accumulate**, interactions between species are strengthened and the system enters a **period of stability**. If external forces such as droughts, fires or diseases for example intervene, the system will be destabilized and switch to a phase of **release** (**Ω**) of the accumulated resources. The potential of use for these resources drops violently until they are **reorganized** (phase **α**), i.e. other organisms will exploit them again (back to phase **r**).

Such functioning can be qualified of **sustainable**, but unfortunately, if during the phase of release (Ω), most or all of the accumulated resources are lost, there is no possible reorganization.

Resilience Alliance - Panarchy. (s. d.). https://www.resalliance.org/index.php/panarchy
Gunderson, L. H., & Holling, C. S. (2002b). Panarchy : Understanding Transformations in Human and Natural Systems. Island Press.

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