CAS applied to Innovation

Globelics Academy 2022

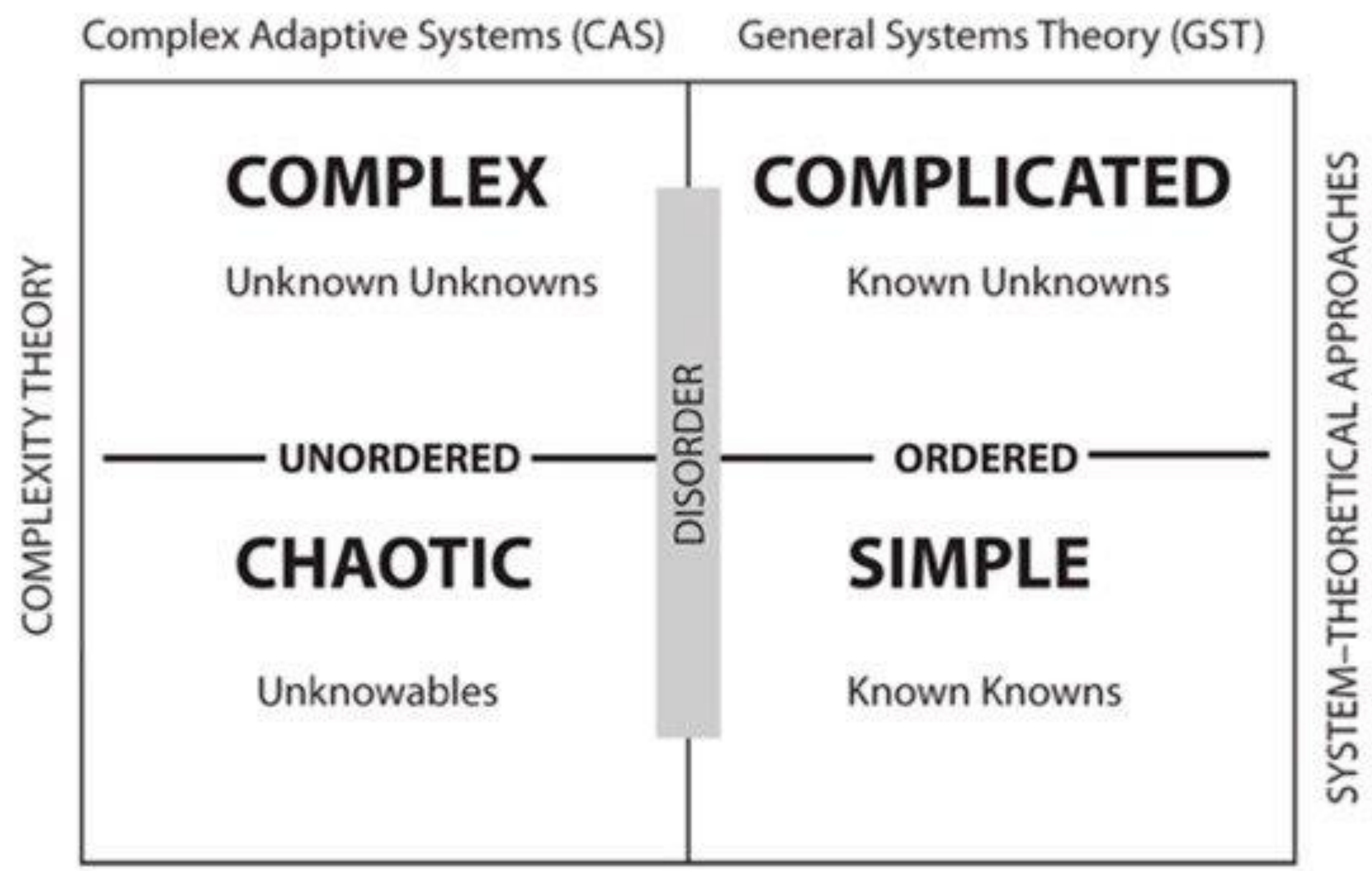
19/08/2022

Dr. Danilo Spinola

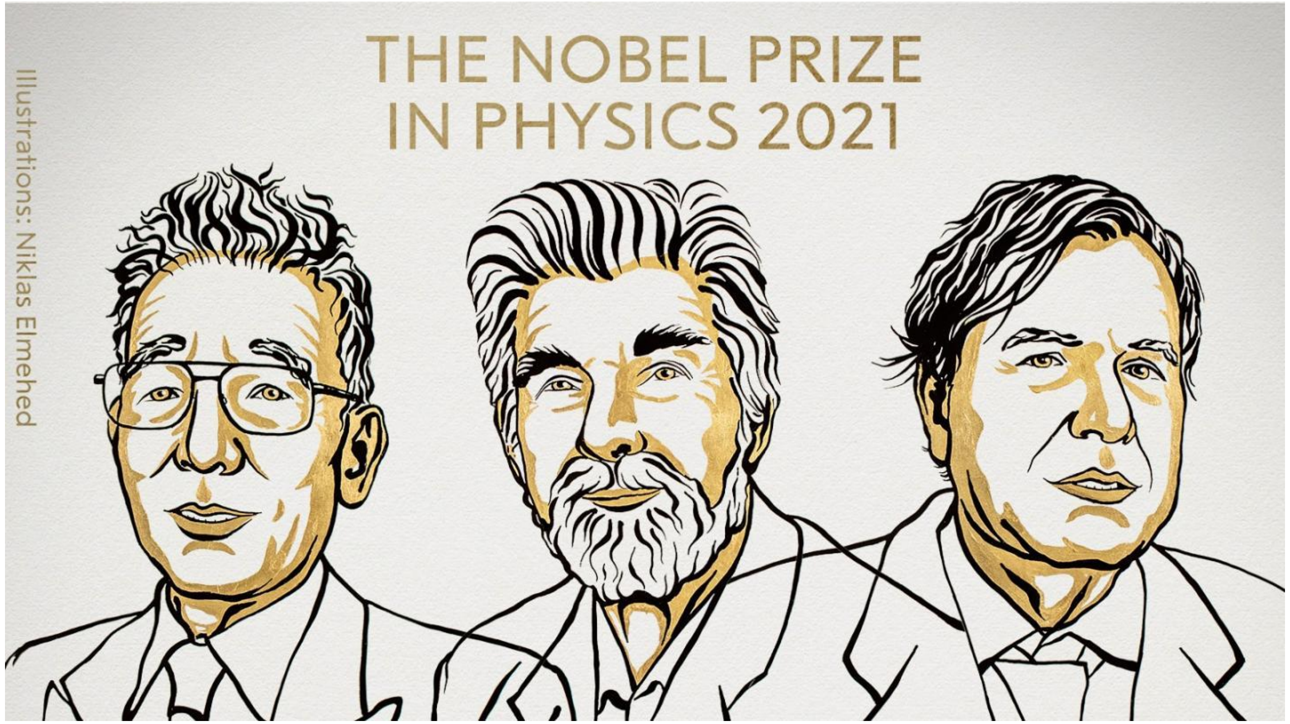
What is complexity?

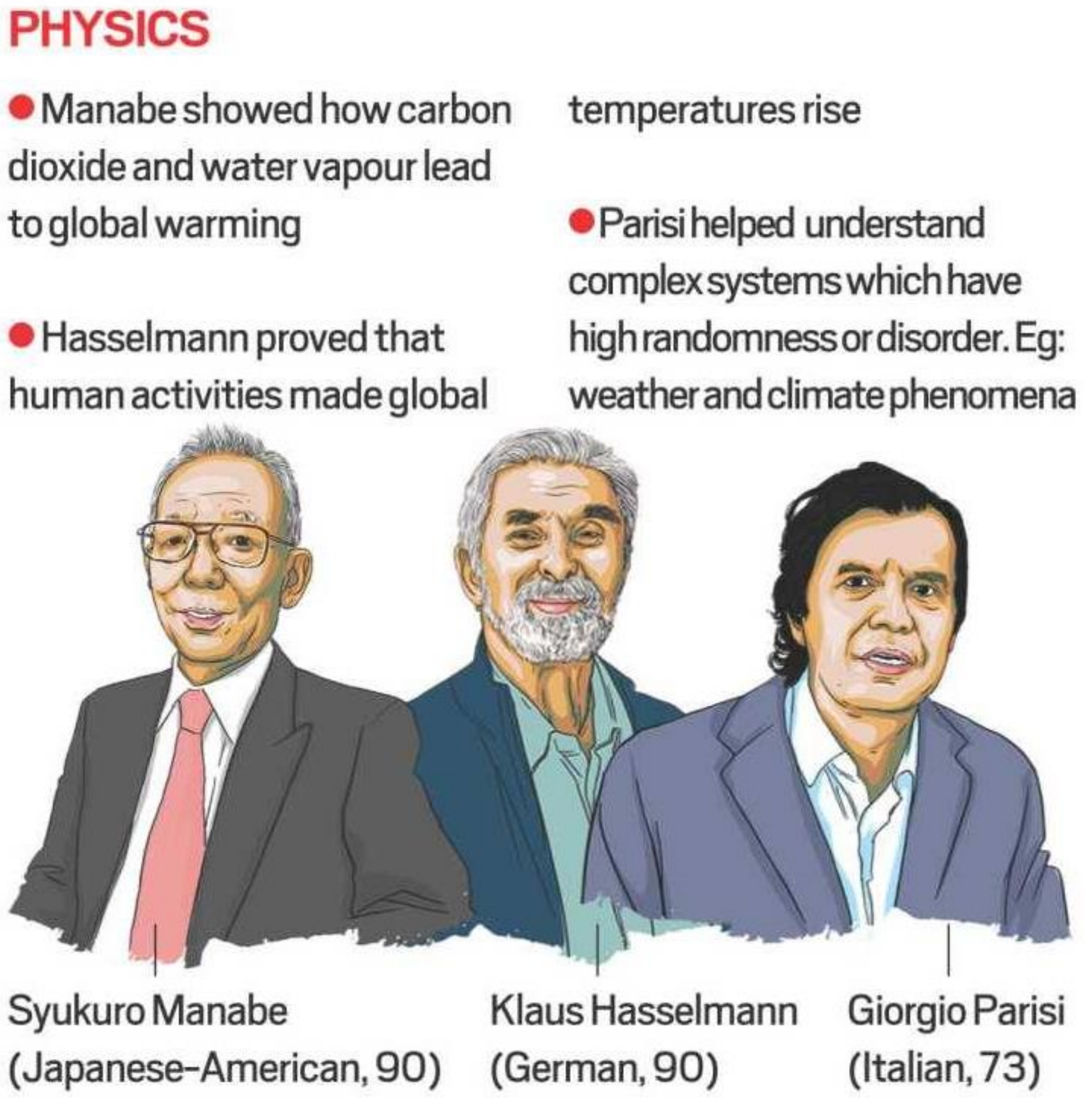
What is complexity?

- Approach to the human behavior around a system composed of interrelated parts that, when as a set, exhibit properties and behaviors that are not evident from the sum of the individual parts.
- Complex is not "complicated"


Complex Adaptive Systems (CAS)
General Systems Theory (GST)
COMPLEXITY THEORY
SYSTEM–THEORETICAL APPROACHES
COMPLEX
Unknown Unknowns
COMPLICATED
Known Unknowns
UNORDERED
DISORDER
ORDERED
CHAOTIC
Unknowables
SIMPLE
Known Knowns

Complexity and the Nobel Prize 2021





Santa Fe Institute

Community of scholars interested in studying complexity theory.

Central contributions to Economics of Innovation.

- Path Dependence Concept (W. Brian Arthur). QWERTY.

www.santafe.edu

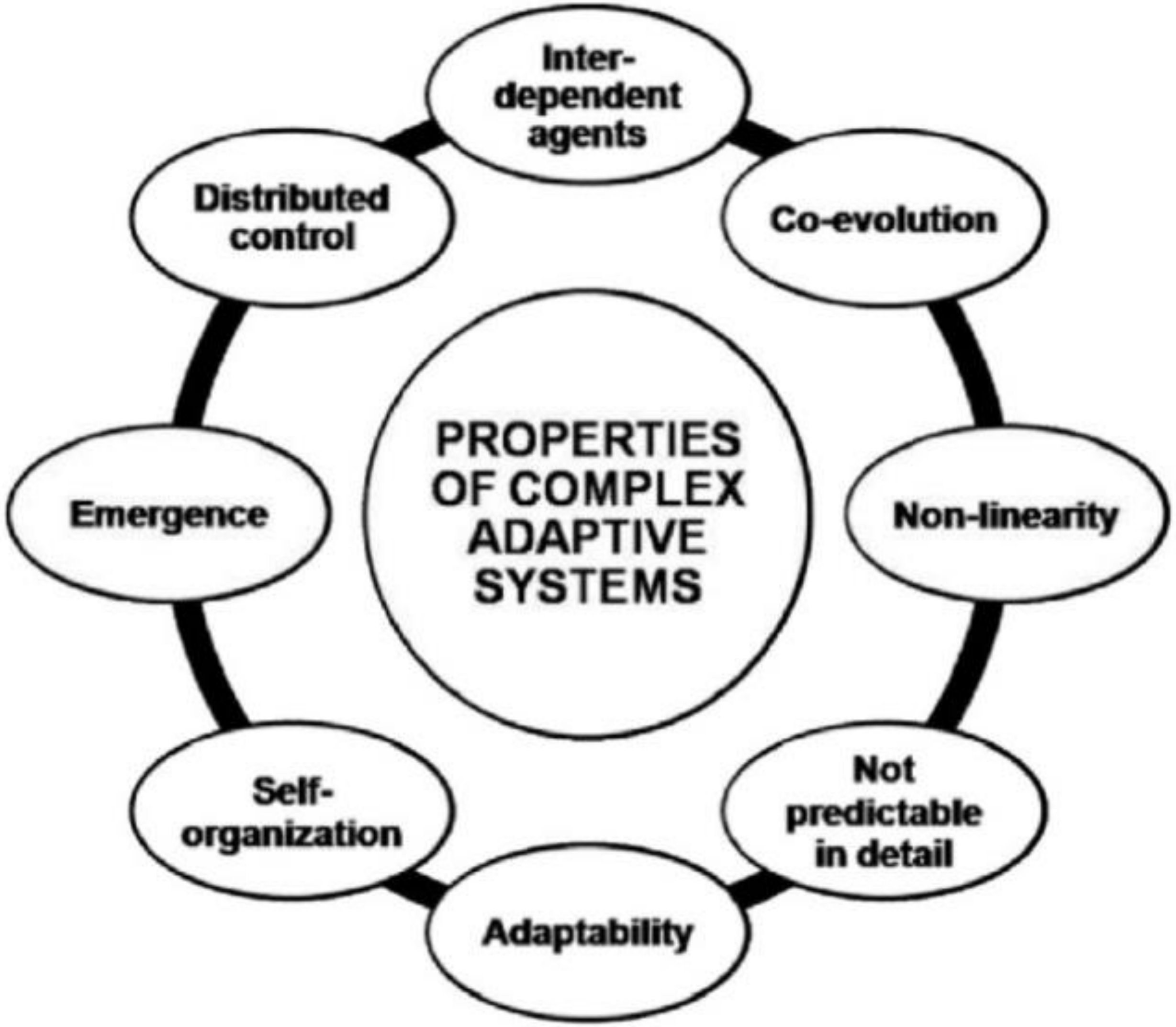
http://necsi.org/

Complex Systems

- A complex system is a system composed of interrelated parts that as a set exhibit properties and behaviors not evident from the sum of the individual parts.
- The characteristics of complex systems (such as interdependence, diversity and adaptability of agents, etc.), challenge the basic assumptions of traditional theories.

Characteristics

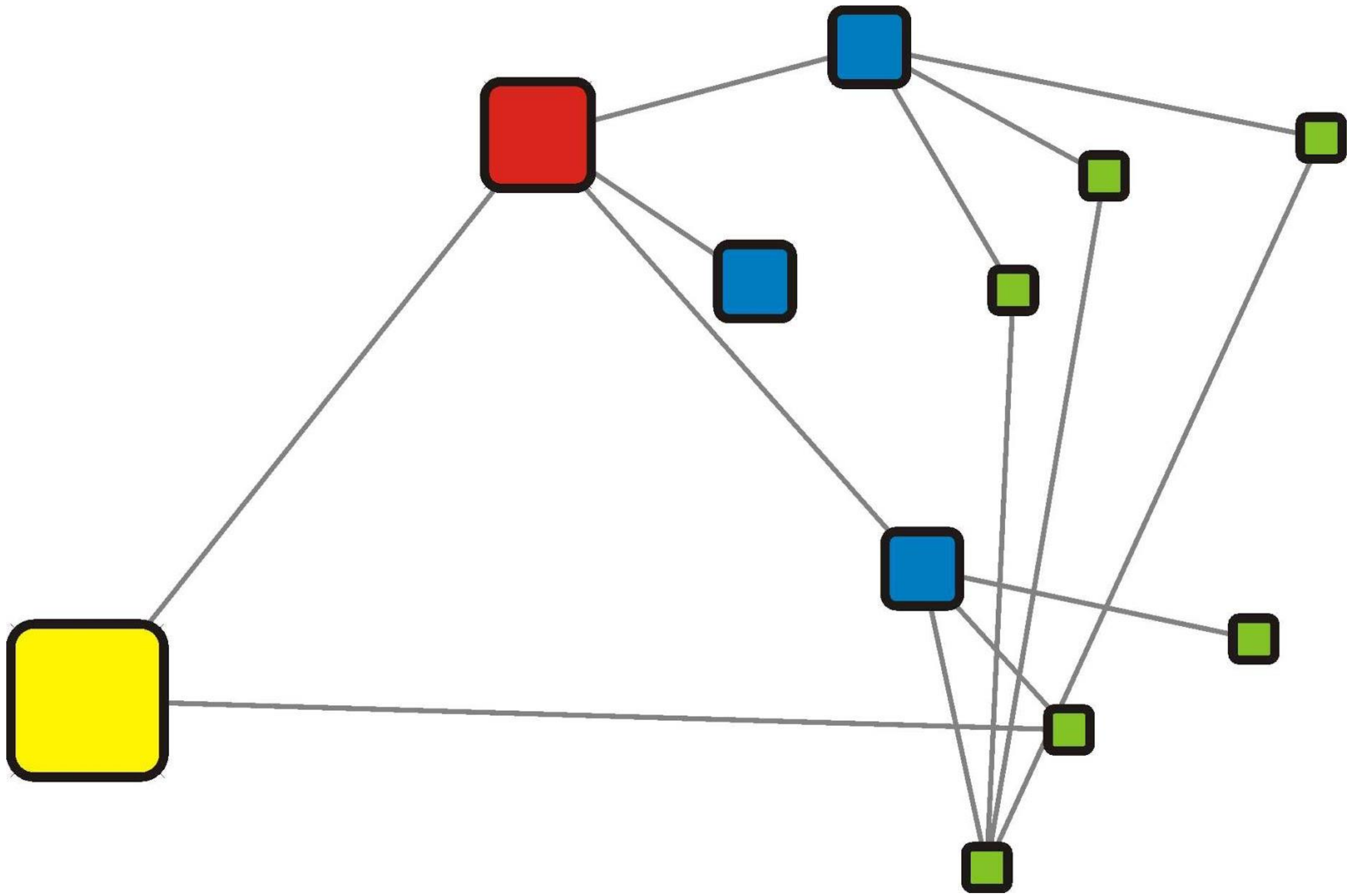
- Systems composed of connected, interdependent, diverse, adaptive, and path-following agents whose interactions result in emerging phenomena.
- The dynamics of development are full of complexities. The characteristics of complex systems (such as the interdependence, diversity and adaptability of agents, etc.), challenge the basic assumptions of traditional theories (such as independent agents (i.i.d.) or fixed patterns of growth, etc.).



Source: Palmberg (2009, p. 21)

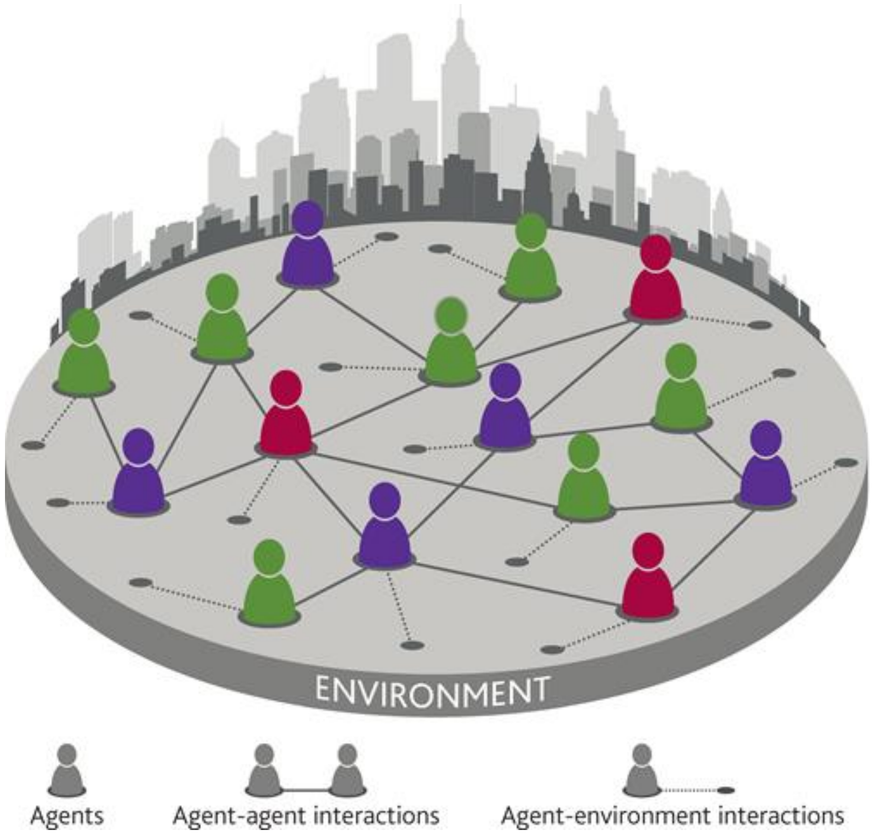
Connected and Interdependent

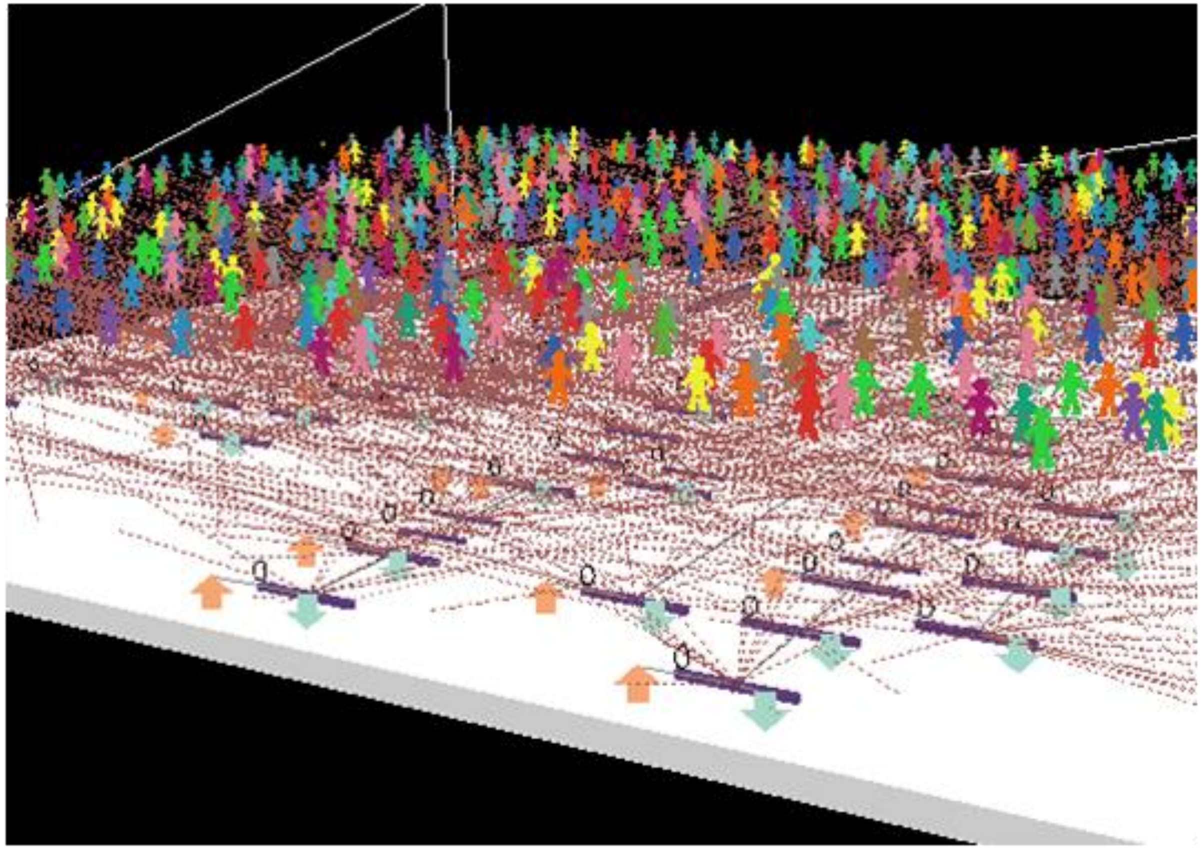
- The idea of connectivity, according to Waldrop (Complexity. The Emerging Science at the edge of order and chaos, 1992), is that of a set of inter-acting agents participating in a network of nodes linked by connections.
- Neural Networks and Immune System - structure of Nodes-and-Connections. Nodes can be the different types of messages and Connections the Classification Rules of the same.



Complex Adaptive Systems

Adaptive, because it changes and learns from experience





Self Organization

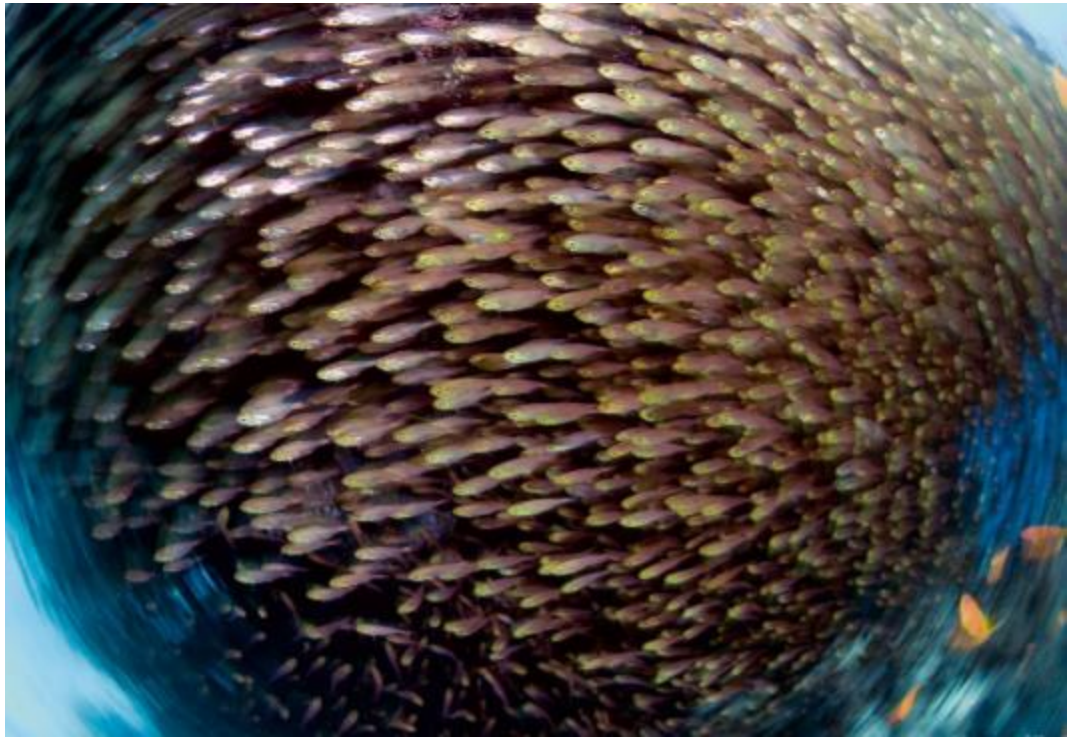
A global form of order/coordination that arises from the local interactions between components of an initially disordered system.

Spontaneous process: is not directed or controlled by any agent or subsystem inside or outside the system. The process is usually triggered by random fluctuations that are amplified by positive feedback. The resulting organization is completely decentralized or distributed over all components of the system; this organization is typically very robust, able to survive and self-repair substantial damage or disturbance.

Self Organization

Behavior is a product primarily of interactions:

- Not from a single element or from an external source.
- Examples of self-organizing systems: cells, brains, cities, the Internet, a stock market, an insect colony, an ecosystem, a biosphere, a national innovation system.
- Design of self-organizing systems: Focus on the behavior of components, so that, through their interactions, they perform the function of the system, without designing it directly. Elements are constantly looking for solutions. When you change the problem, the system adapts.



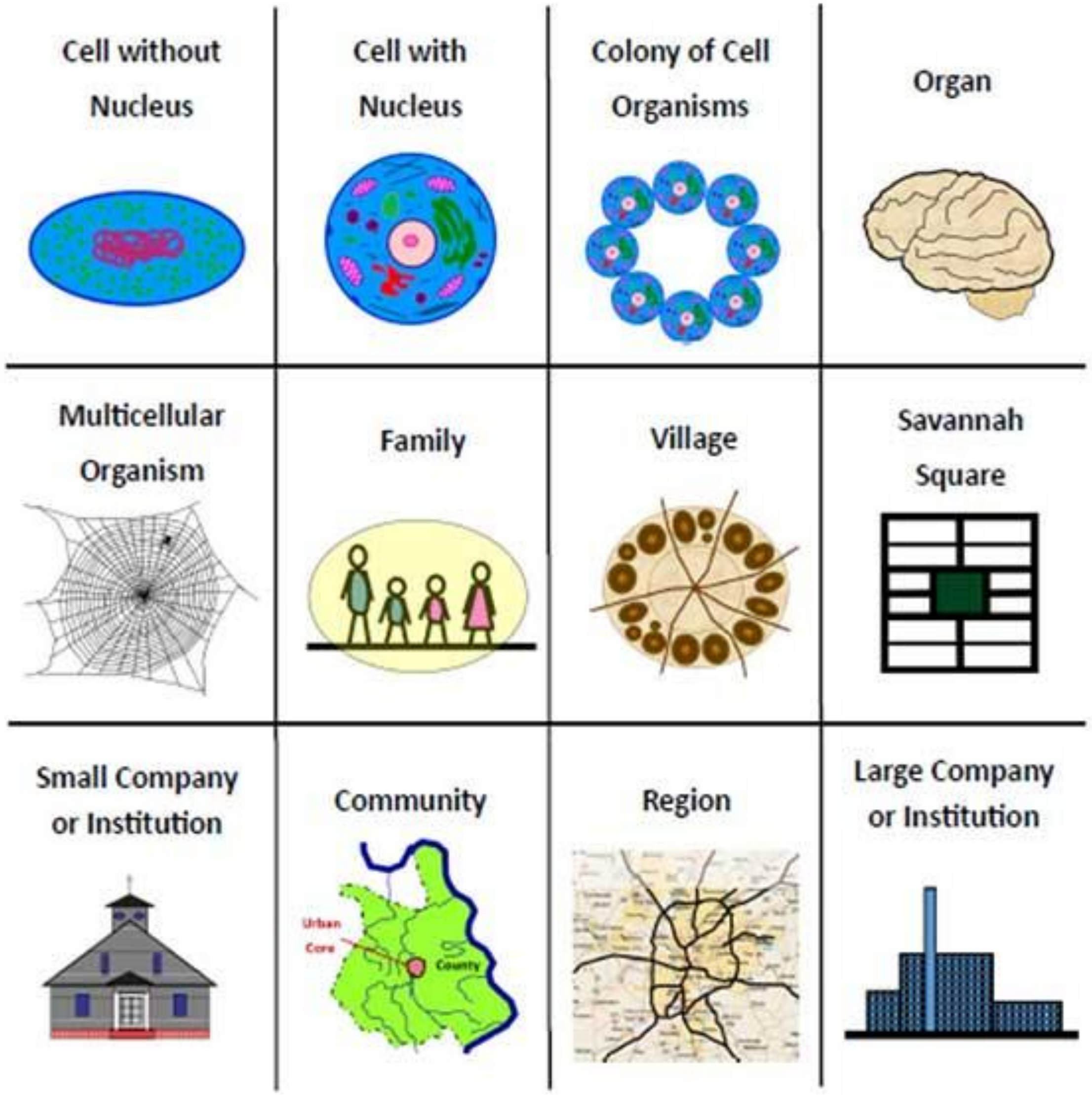
Emergence

Emergence refers to those properties or processes of a system not reducible to the properties or processes of its constituent parts.

The mind, for example, is considered by many as an emergent phenomenon, since it arises from the distributed interaction between various neural processes (including also some corporeal and environmental) without being able to be reduced to any of the components involved in the process (none of the neurons separately is conscious).

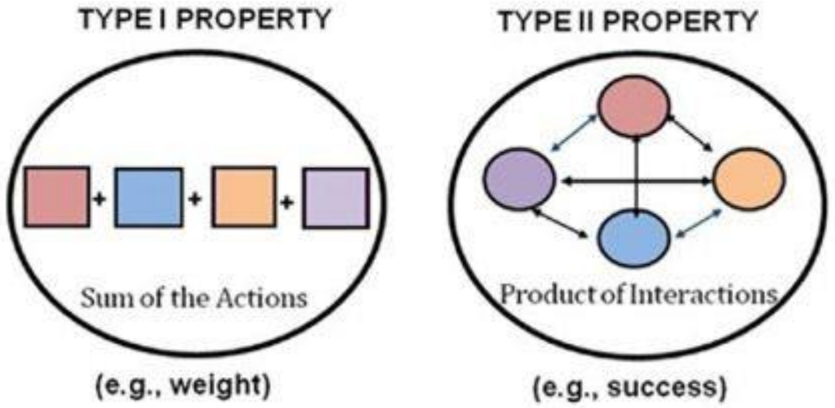
Idea of artificial intelligence.

Examples of Living Systems



EMERGENT PROPERTY

Properties of the Whole VS. Properties of the Parts

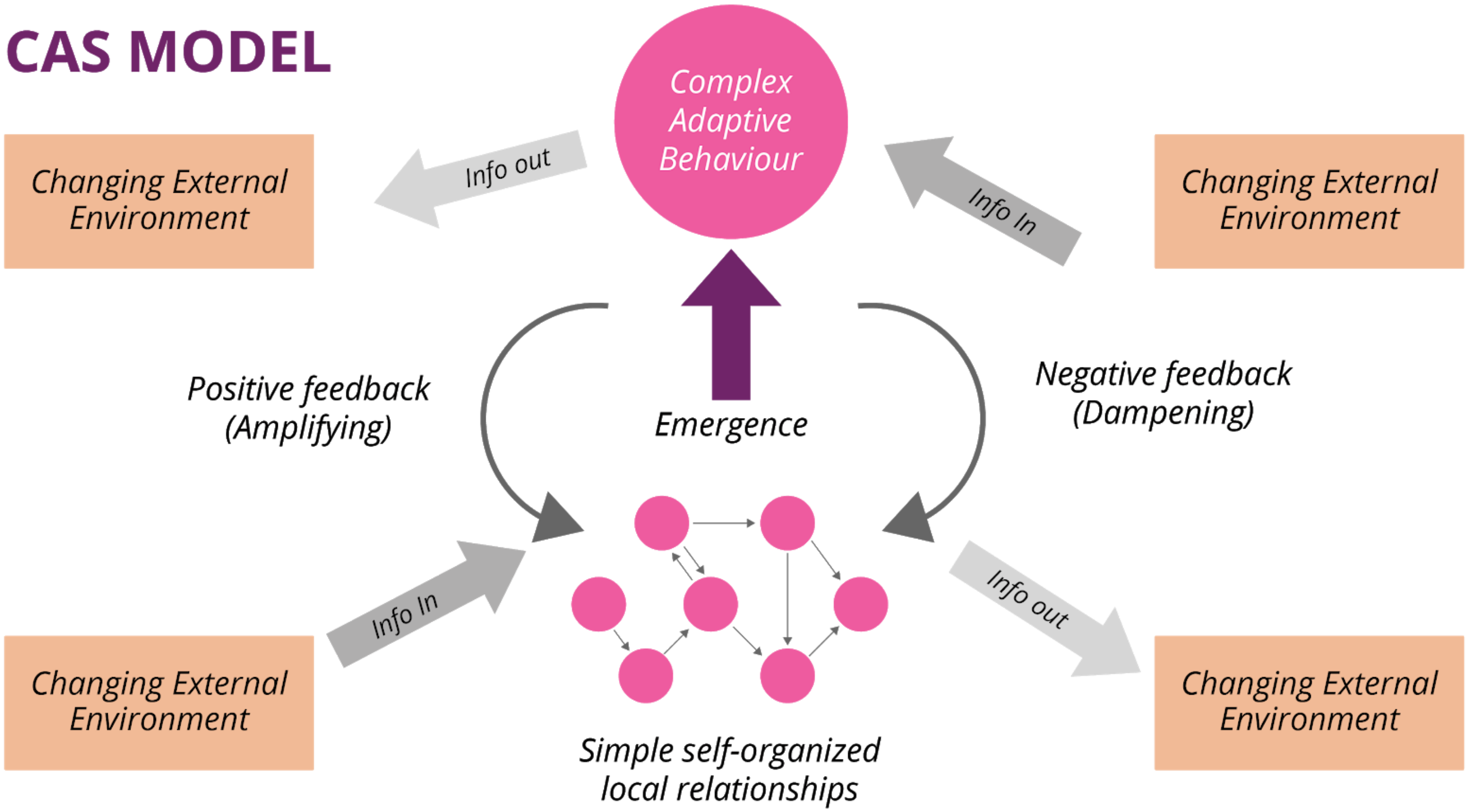


THE ALL-STAR TEAM IS NOT NECESSARILY THE BEST TEAM

Adaptation

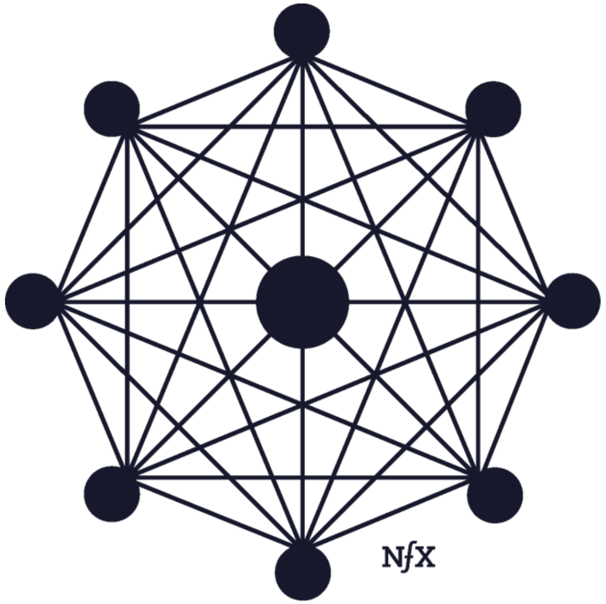
- Ability of a system to change behavior in the presence of a disturbance.
- Prediction tries to act before a disturbance affects the expected behavior of a system. Adaptation as a prediction/anticipation generalization.
- Living systems as inspiration.
- Adaptation as creativity: systems seek solutions to unknown problems.

CAS MODEL

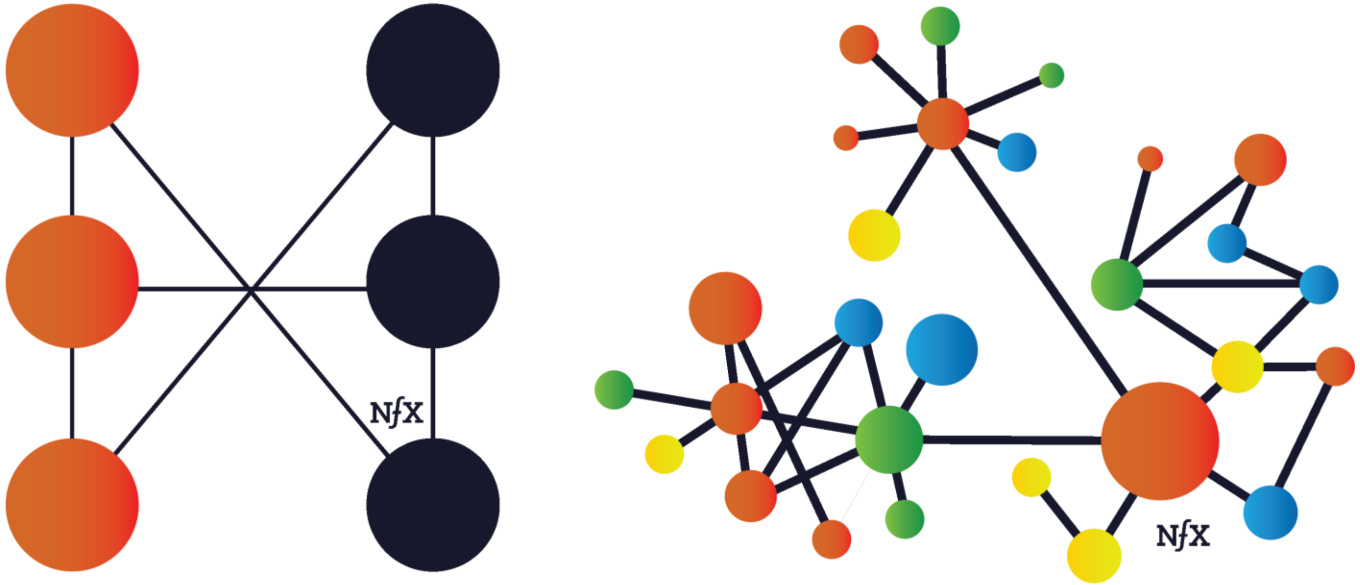

Complex Adaptive Behaviour
Changing External Environment
Info out
Info In
Changing External Environment
Positive feedback (Amplifying)
Emergence
Negative feedback (Dampening)
Info In
Info out
Changing External Environment
Simple self-organized local relationships
Changing External Environment

Heterogeneity / Diversity

- Agents are different, have different characteristics, resulting in different forms of organization
- Complementarity.
- Recombination.



Homogeneous Network



Heterogeneous Networks

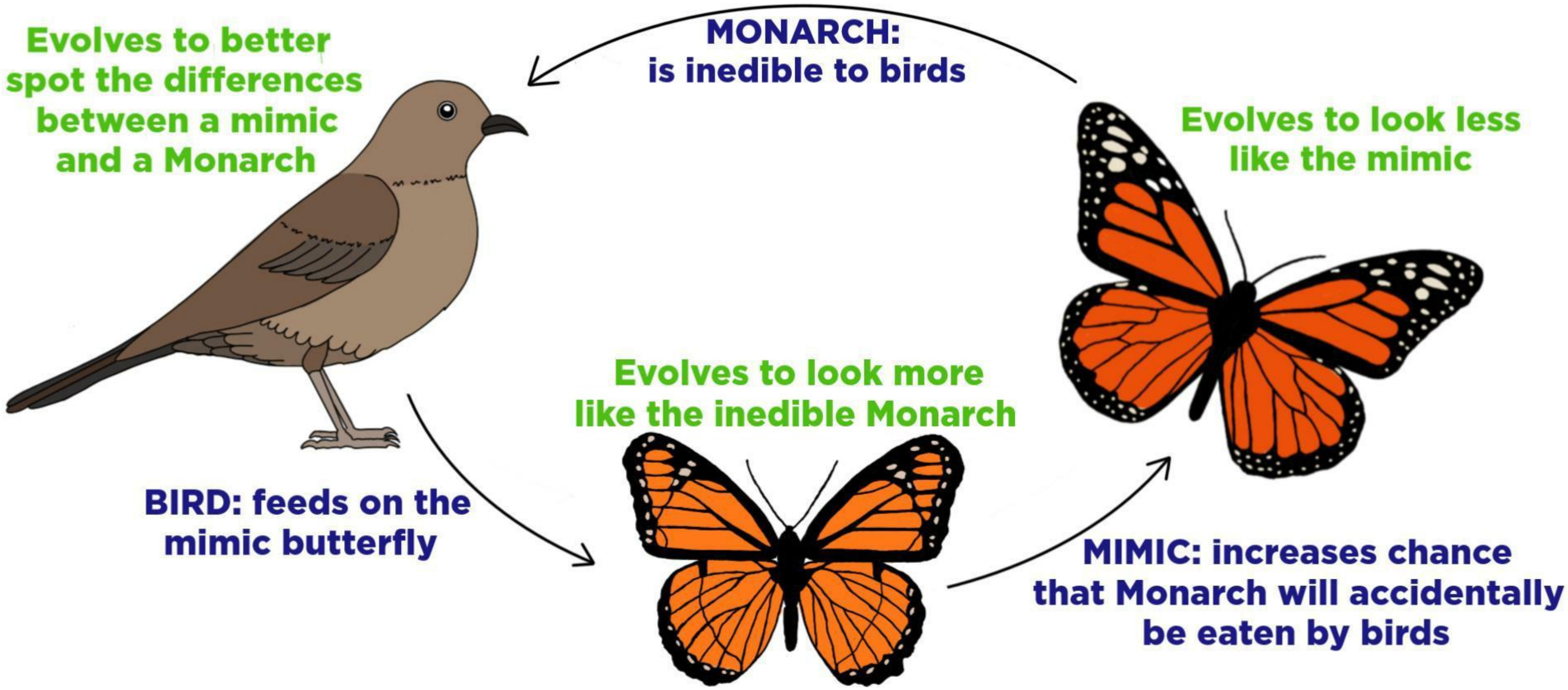
Co-evolution

Process of reciprocal evolutionary and adaptive change between interacting species.

As interactions between species, developed by reciprocal actions of different intensity, shape behavior, shape context, and persist in space and time even if they undergo constant and normally rapid evolutionary change.

Transfer these concepts to the socio-ecological sphere to understand in detail the impact of integration and interdependence on the essential dimensions of development.

COEVOLUTION EXAMPLE: BUTTERFLIES AND BIRDS



Chaos

Chaos theory: branch of mathematics, physics and other sciences (biology, meteorology, economics, among others) that deals with certain types of complex systems and nonlinear dynamical systems which are very sensitive to variations in initial conditions.

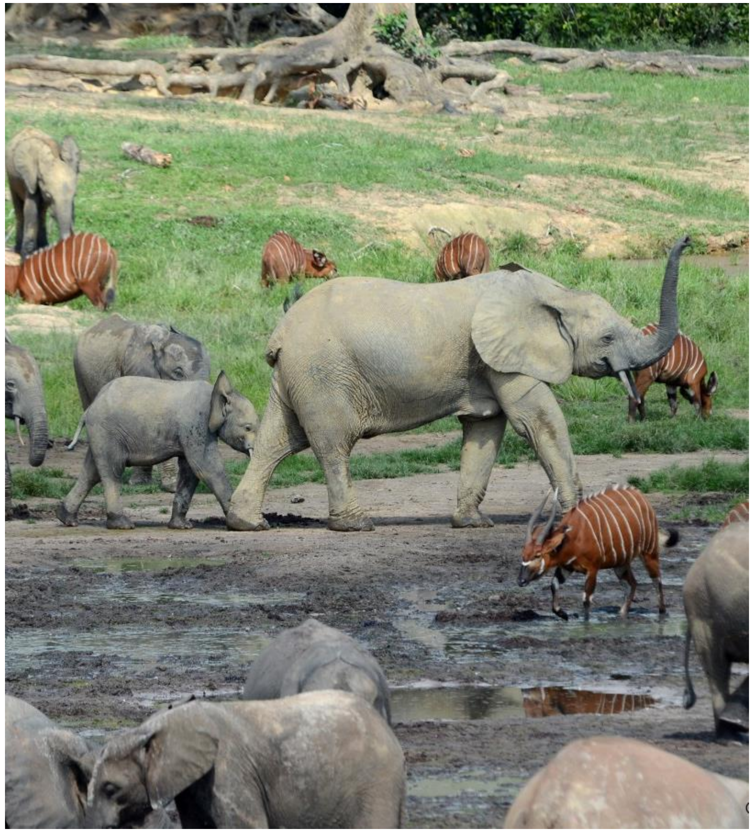
- Small variations in these initial conditions can imply large differences in future behavior, making short-term prediction impossible. This happens although these systems are strictly deterministic, that is; their behavior can be completely determined by knowing their initial conditions.

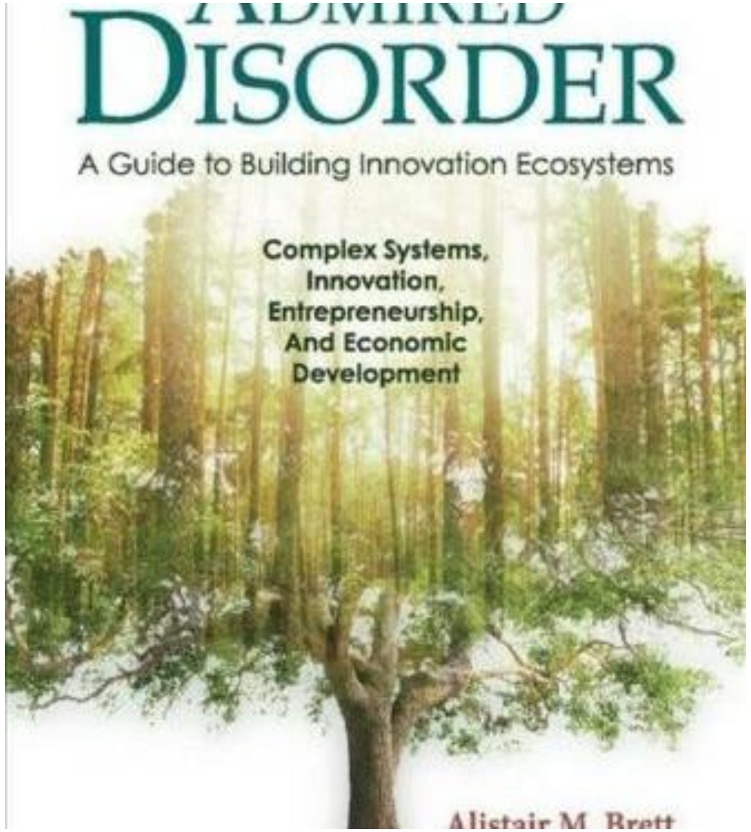
Dynamic Systems (Butterfly Effect)

Strong sensitive dependence on initial conditions.

Any small discrepancy between two situations with a small variation in the initial conditions, will end up giving rise to situations where both systems evolve in certain aspects in a completely different way (it should be noted that without a doubt and without scientific explanation).

This implies that if a small initial disturbance occurs in a system, through an amplification process, it can generate a considerably large effect in the short or medium term. It is a concept of chaos theory.

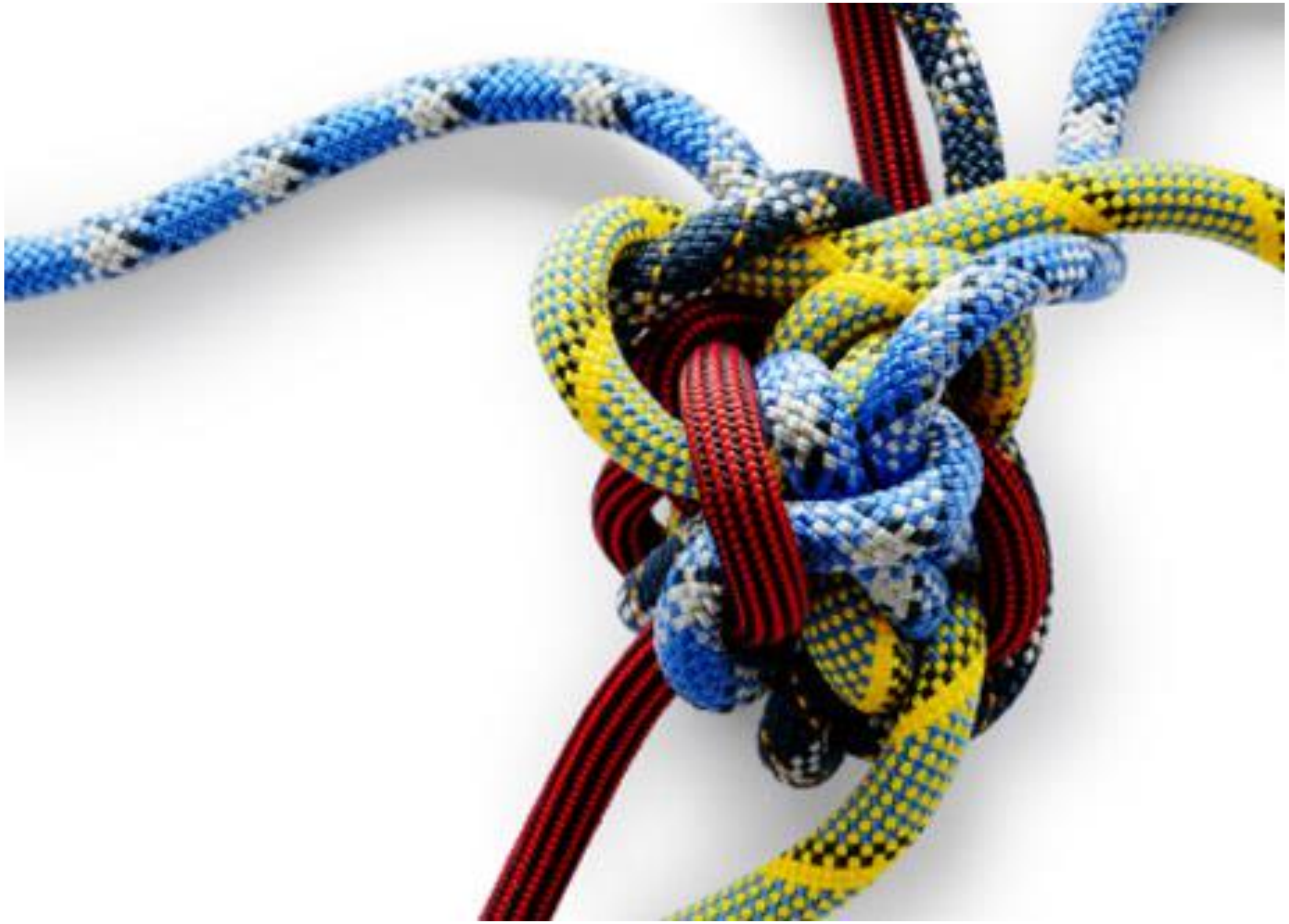




Ecosystem

- COMPLEX ADAPTIVE SYSTEM

- ADAPTATION, COEVOLUTION, DIVERSITY, SELF-ORGANIZATION, EMERGENCE.

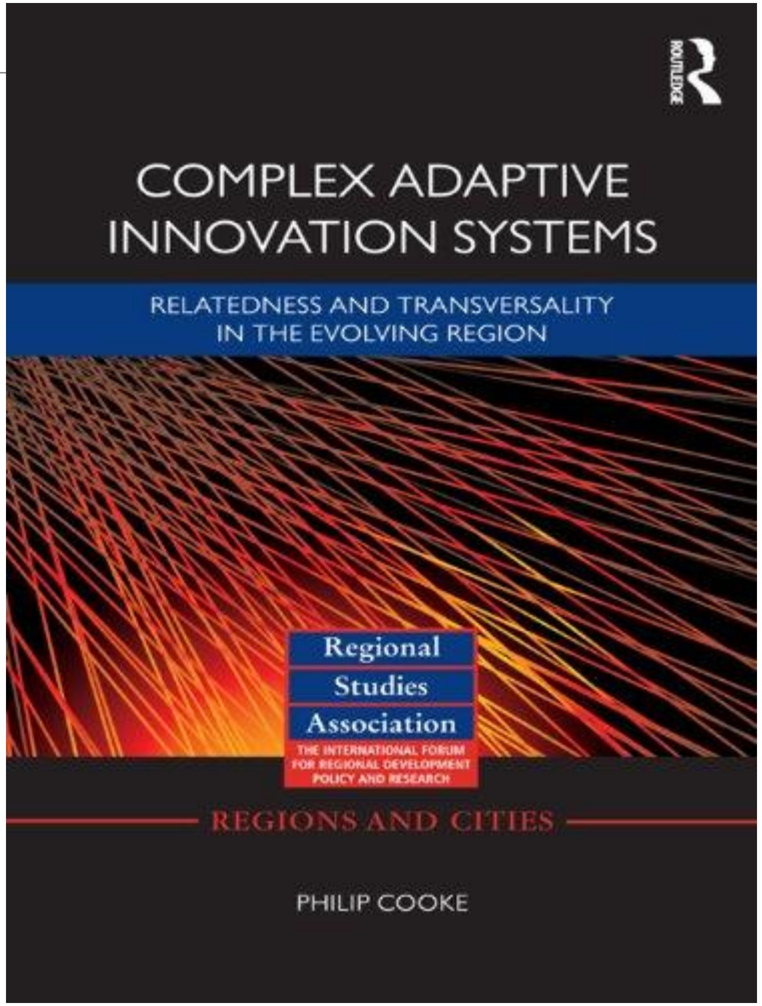


Complexity Applied to Economics of Innovation

Innovation Systems as a Complex Systems

Innovation is a response obtained from the analysis of complex relationships between firms and the environment and between firms and its members, since it is the interactivity between them that generates the knowledge - that innovation uses for its final product.

Firms: complex systems with characteristics of self-organization, creativity, lack of linearity, memory and adaptability. Agent is capable of managing complexity and organizing knowledge to innovate and survive in the environment.

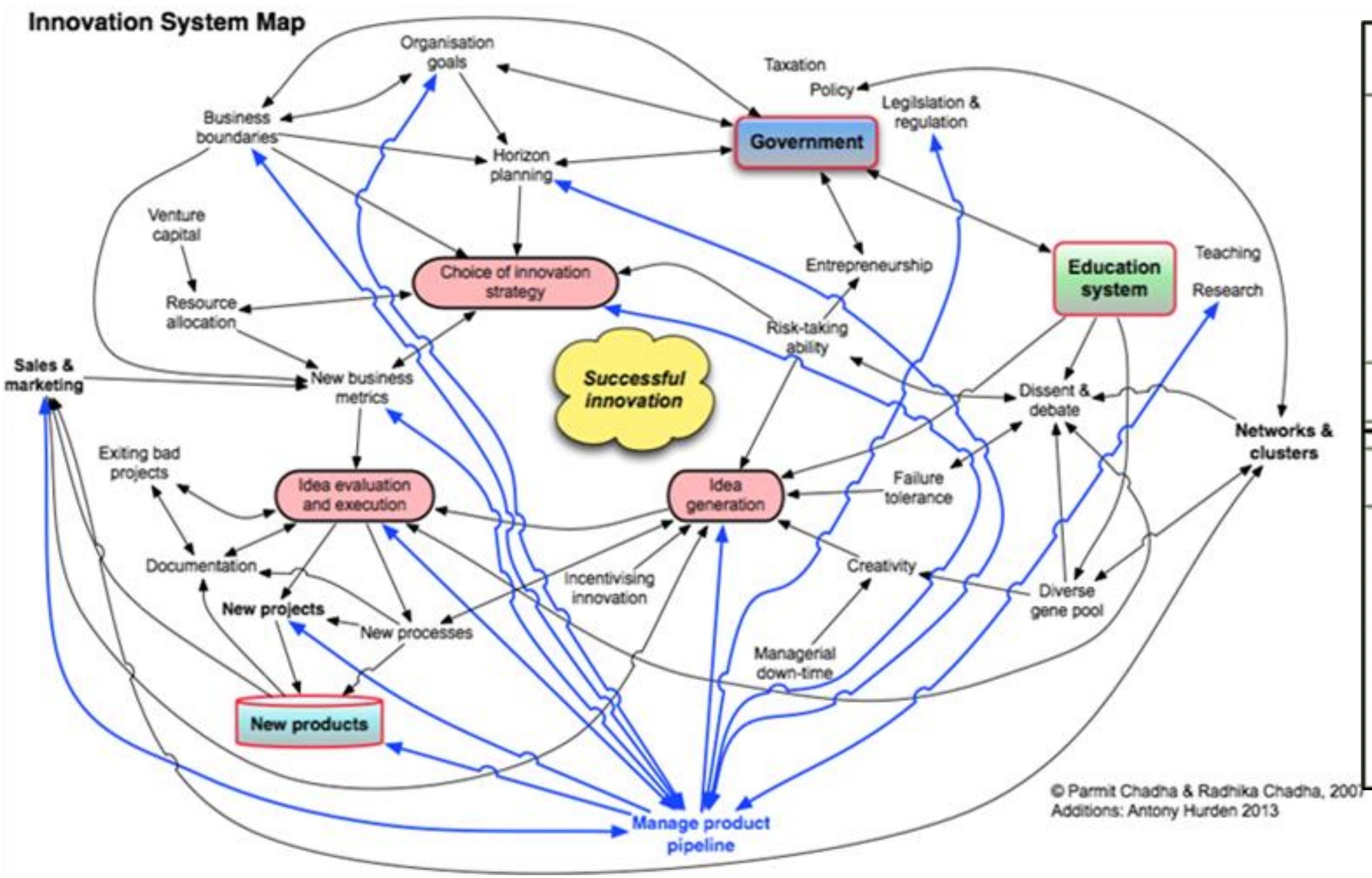


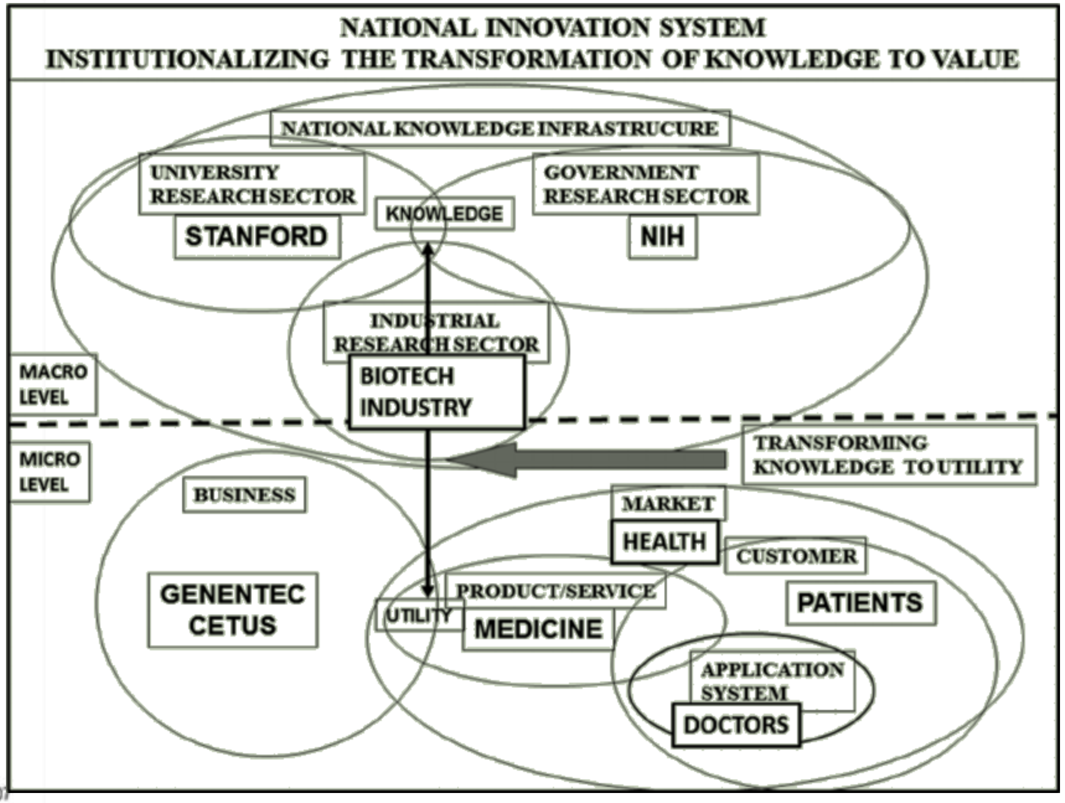
National Innovation System and Complexity

Productive and innovation system: complex, whose components - companies and institutions (generically organizations) - interact, learn and develop absorption and connectivity capacities. Interactions between system components result in changes in their capabilities and in their location in the connection space.

This means that the absorptive capacity and linkages that firms engage in co-evolve over time. Both capabilities and feedback mechanisms induce companies to generate different responses, creative or adaptive (Schumpeter, 1947), which explain, in part, their innovative behavior as an emerging property of the system (Antonelli, 2011).

Innovation System as a Complex Adaptive System





Studies in Complexity Economics

- Simon (1969): Theory of modular systems and distributed systems.
- **Complex architecture:** existence of a hierarchy of systems and differential relationships between and within the subsystems of an economic system.
- Allow to analyze the economic system without splitting the macro from the micro - focus on the continuous interaction between micro and macro, on the basis of hierarchical structures.
- During the 1980s, the idea of self-organization, linked to the study of technological diffusion, was used by several authors who emphasized historical time and the heterogeneity of firms in terms of capabilities and strategies. (Silverberg, Dosi, Orsenigo, 1988; Arthur, 1999).

Complexity and Innovation

Schumpeter's legacy (**Antonelli 2007, Metcalfe, 2007; Dosi and Kaniovski, 1994; Dosi and Nelson, 1994; Foster, 1993 and 2005; Saviotti, 2001; Witt, 1997**) used the complex systems approach to account for different aspects of the innovation economy.

Evolutionary framework of variation, selection and retention - relationship between innovation and productive transformation.

- (i) Innovation activities carried out by organizations
- (ii) Changes in organizational routines and learning processes
- (iii) Knowledge interactions that firms maintain with each other and with other organizations.

The common idea that brings together this group of authors is that the complex systems approach helps to understand the non-linear and imbalanced dynamics that characterize the self-transformation of economic systems.

Complex systems theory and innovation

(i) Schumpeterian ideas of evolution and capitalist dynamics as an open process of qualitative change led by innovation **(Fagerberg, 2003)**

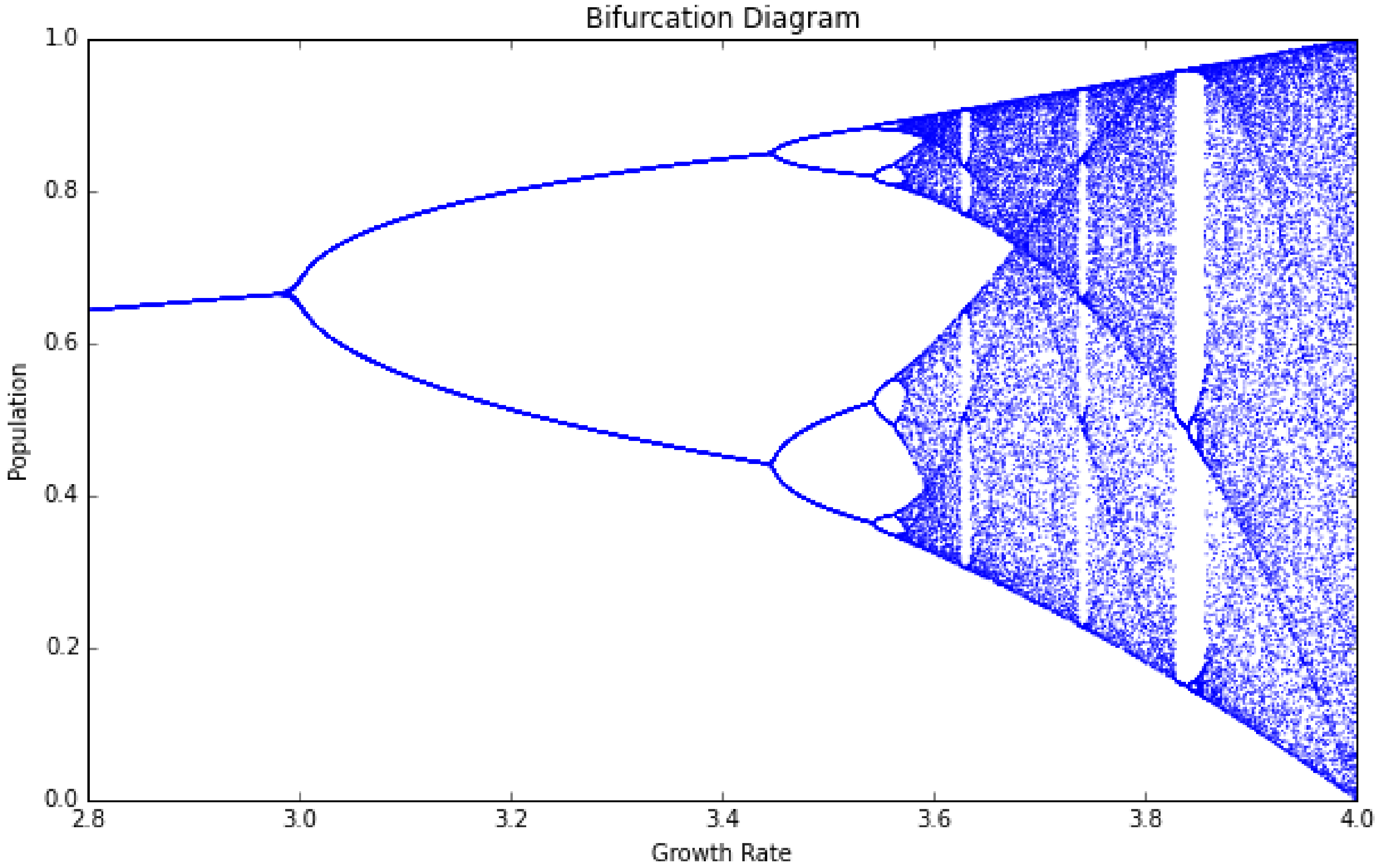
(ii) Changing and self-organizing nature of capitalist productive structures. **Antonelli (2007)** and **Metcalfe (2007)** also explain the differential dynamics of production systems under the assumption of the existence of heterogeneous firms endowed with creative capacity.

This means that their reactions **cannot be reduced** to automatic behaviors according to the given conditions, but that each firm or organization is able to react creatively and diversely to similar circumstances.

Complexity in EoI

Evolutionary line of thought:

1) Long waves of the economy (Silverberg, 2003)
2) Economic growth and the dynamics of competition (Metcalfe, Foster and Ramlogan, 2006)
3) Changes in technological paradigms, resorting to the notions of self-organization, dynamics far from equilibrium, emergence and self-organized criticality (Prigogine and Stengers, 1985; Kauffman, 1993; among others).



Disequilibrium

Authors from the Santa Fe Institute (Arthur, Durlauf and Lane, 1997), have applied complexity to economics to explain the feedback dynamics and out the equilibrium of economic systems.

Feedback, which can even be perceived at the institutional level. In this direction, the works of Arthur (1989) on the dissemination and adoption of competitive standards and technologies, as well as the economics of David's qwerty (1985), stand out.

Analytical framework of complexity in economics

- Economic agents (companies, consumers, investors) .
- Change of actions and strategies in response to the outcome they mutually create. This further changes the outcome, requiring them to adjust again.
- Agents live in a world where their beliefs and strategies are constantly being "tested" for survival within an outcome or "ecology" that these beliefs and strategies create together.
- Economics has largely avoided this view of non-equilibrium, but if we allow it, we see patterns or phenomena that are not visible to equilibrium analysis.
- We also see the economy not as something given and existing, but is formed from a set of technological innovations, institutions and arrangements in constant development that generate more innovations, institutions and arrangements.

Path Dependence

Small shocks at a given time affect the long-term trajectory in an irreversible and significant way (Arthur, 1989). This occurs when trajectories emerge from points close to each other in an exponential way over time. Then, when insignificant fluctuations occur in appropriate circumstances that invade the entire system, a new system is generated.

Path-dependence explains why these systems are not only sensitive to initial conditions, but also to disturbances along their path. This leads to a diversity of behavioral patterns that affect the long-term dynamics of the global system (Dosi and Kaniovski, 1994; Antonelli 2007).

Complex systems help to understand why initial differences may tend to increase over time rather than shrink, as the neoclassical convergence hypothesis suggests.

	Complexity Economics	Traditional Economics
Dynamics	Open, dynamic, non-linear systems, far from the break-even point.	Closed, static, linear and equilibrium systems.
Agents	Individually modeled; using inductive rules to make decisions; have incomplete information; they make mistakes and are prejudiced; learn to adapt over time; Heterogeneous.	Modeled collectively; use complex deductive calculations to make decisions; they have all the necessary information; they do not make mistakes and are not prejudiced; they do not learn or need to (they are already perfect); mostly homogeneous.
Networks	Explicitly models bi-lateral interactions between individual agents; networks of relationships change over time.	It assumes that agents only interact indirectly through market mechanisms (e.g. auctions).
Emergence	It makes no distinction between macro and microeconomics; macro patterns are an emergent result of the interactions and behaviors of micro levels.	Macro and microeconomics remain separate disciplines.
Evolution	The evolutionary process of differentiation, selection and amplification provides the system with innovation and is responsible for its growth in order and complexity.	There is no endogenous mechanism for creating innovation, growth, order or complexity.
Technology	It is fluid and endogenous to the system.	The technology is given or selected on an economic basis.
Preferences	The creation of preferences is central; individuals are not necessarily selfish.	Preferences are already given; individuals are selfish.
Origins of Physical Sciences	Based on biology (structure, pattern, self-organization, life cycle).	Based on nineteenth-century physics (balance, stability, deterministic dynamics).
Elements	Patterns and possibilities.	Price and quantity.

Source: https://es-academic.com/dic.nsf/eswiki/399312

Methods of analysis in complexity Economics

Social Networks

Agent-based models

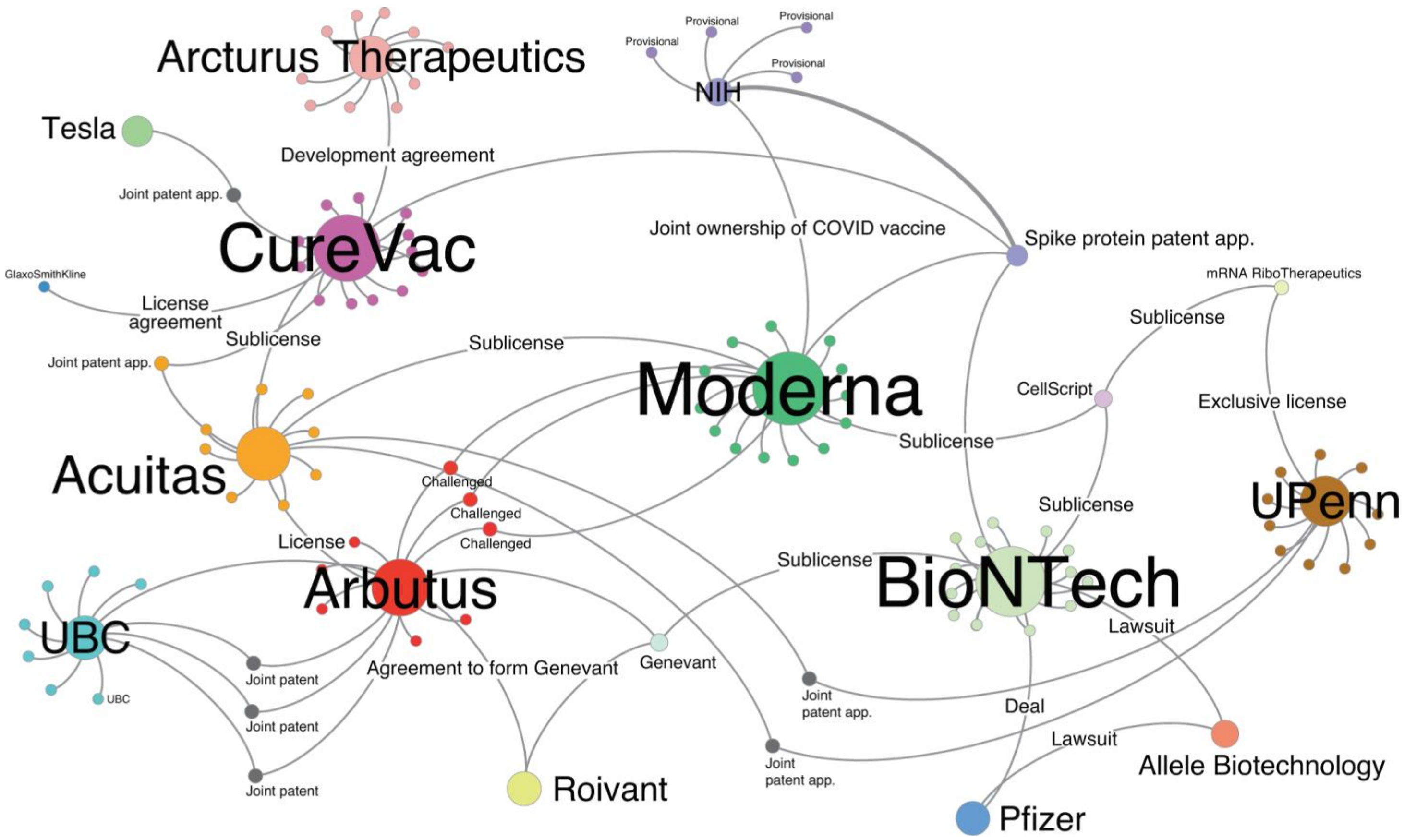
Product Space Theory

1. Social Network Analysis

Integrated techniques to represent the relationships between actors and analyze the social structures that arise from the recurrence of these relationships. Analysis of the relationships between entities. Relational data organized in the form of a matrix.

If actors are represented as nodes and their relationships as lines between pairs of nodes, the concept of social network goes from being a metaphor to an operational analytical tool that uses the mathematical language of graph theory and matrix and relational algebra.

R&D Collaboration Network

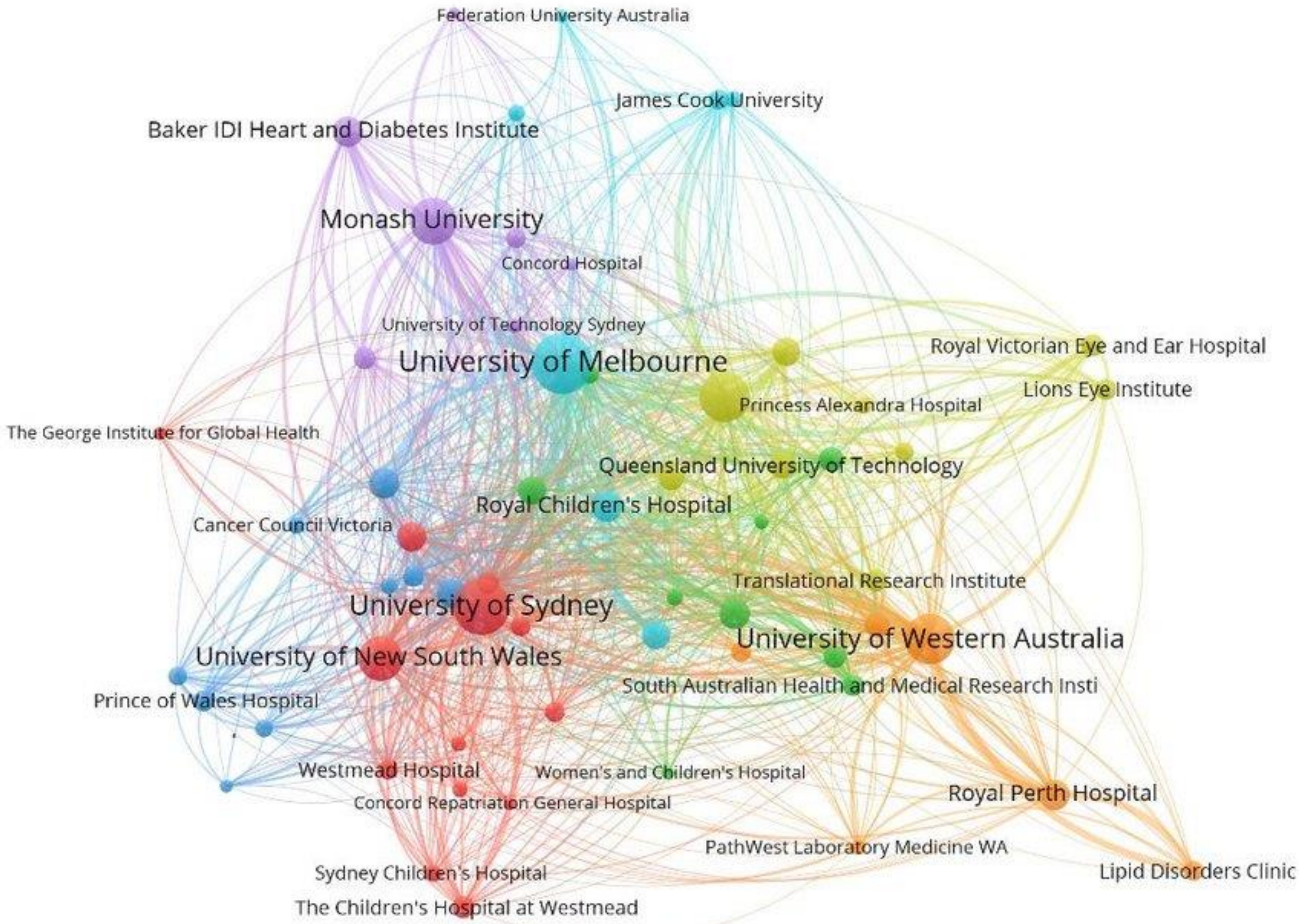


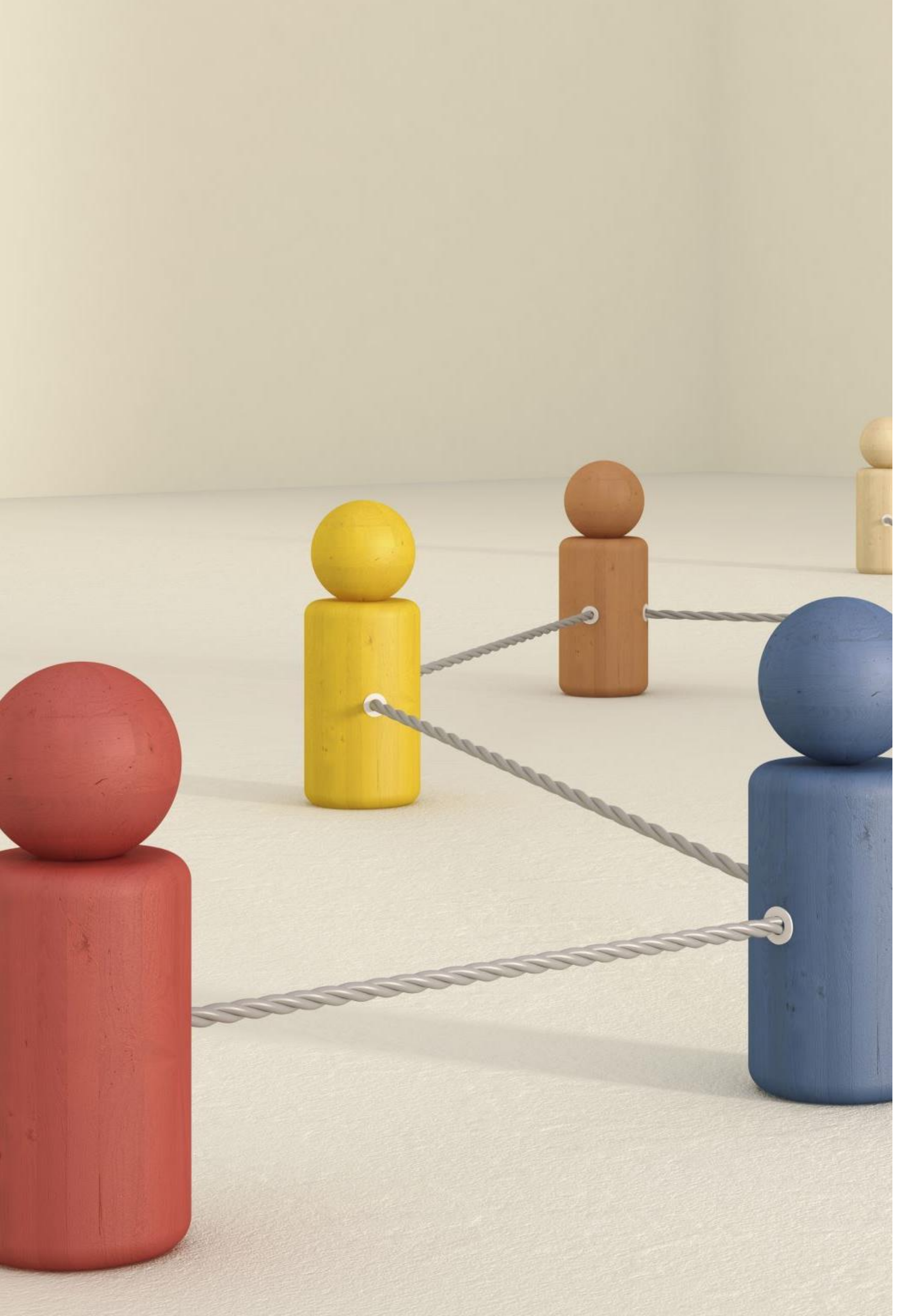
Gaviria, M.; Cilic, B. (2021). A network analysis of COVID-19 mRNA vaccine patents”. Nature Biotechnology

Innovation networks

Current techno-economic context (ICT): interconnection, integration, cooperative relations, alliances between organizations (public or private), countries and communities, has impacted on work, seen in the framework of a networked environment has had its implications of change.

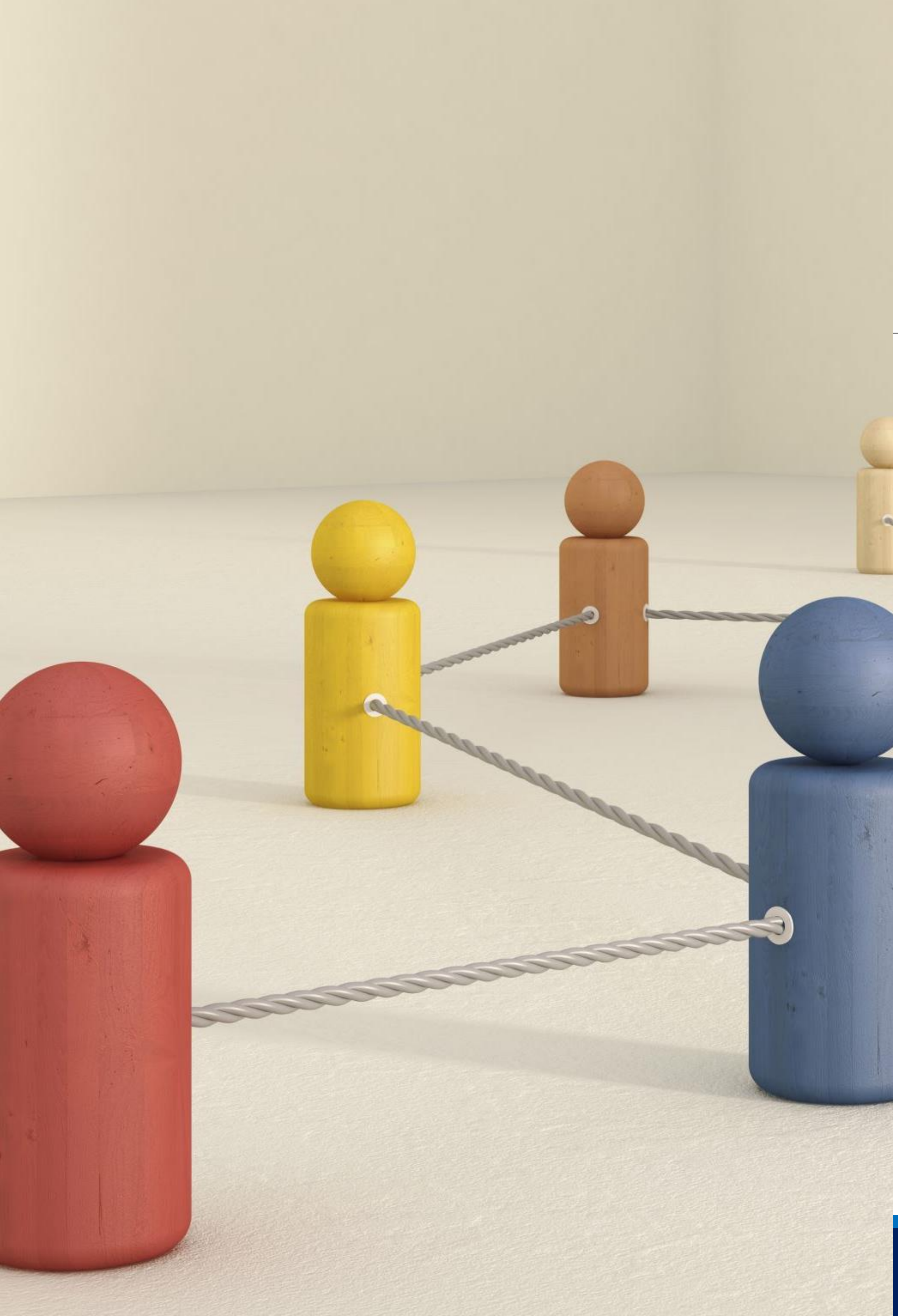
Precisely, networking is basically associated with a modality of interacting in a cooperative way; to create bridges, shared information flows and communication towards a common purpose.


Federation University Australia
James Cook University
Baker IDI Heart and Diabetes Institute
Monash University
Concord Hospital
University of Technology Sydney
University of Melbourne
Royal Victorian Eye and Ear Hospital
Lions Eye Institute
Princess Alexandra Hospital
The George Institute for Global Health
Queensland University of Technology
Royal Children's Hospital
Cancer Council Victoria
Translational Research Institute
University of Sydney
University of Western Australia
University of New South Wales
South Australian Health and Medical Research Insti
Prince of Wales Hospital
Westmead Hospital
Women's and Children's Hospital
Concord Repatriation General Hospital
Royal Perth Hospital
PathWest Laboratory Medicine WA
Lipid Disorders Clinic
Sydney Children's Hospital
The Children's Hospital at Westmead



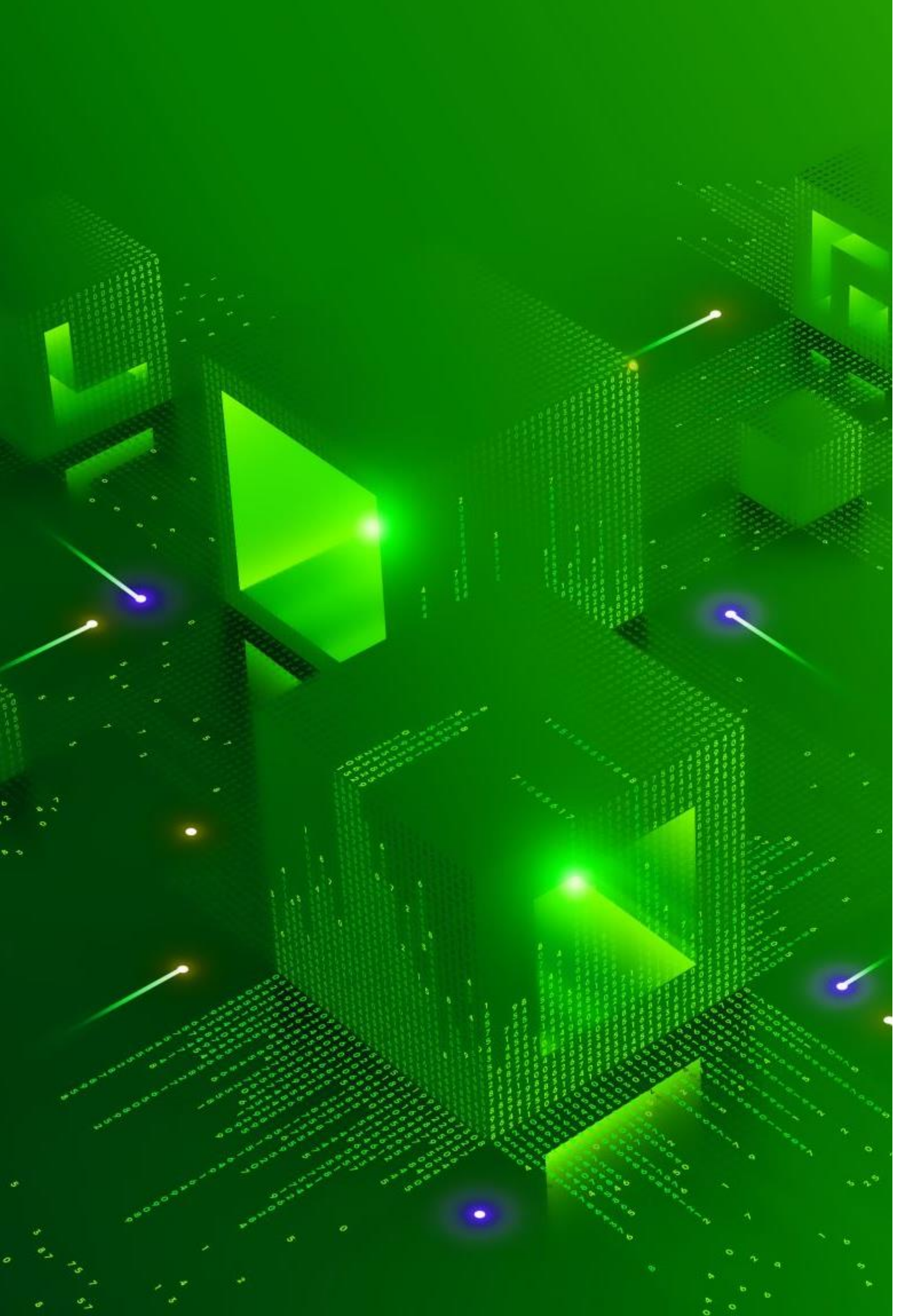
Economics of Social Networks

1. Recognize, evaluate, define and represent underlying social structures based on the relationships established between people. Search for the structural determinations of human action, and not for the individual or collective motivations of individuals.
2. Concept of structure presupposes that structures manifest themselves in the form of the LINKS (edges) existing between the differentiated elements (nodes) that make up a social system, these nodes being "social actors" or any type of significant social entities (individuals, groups, organizations, classes). **Social networks are the set of links between nodes**.
3. Relational analysis presupposes that the structural characteristics of the networks of social relations discovered in the course of the analysis determine the behaviors of the individuals involved in them.



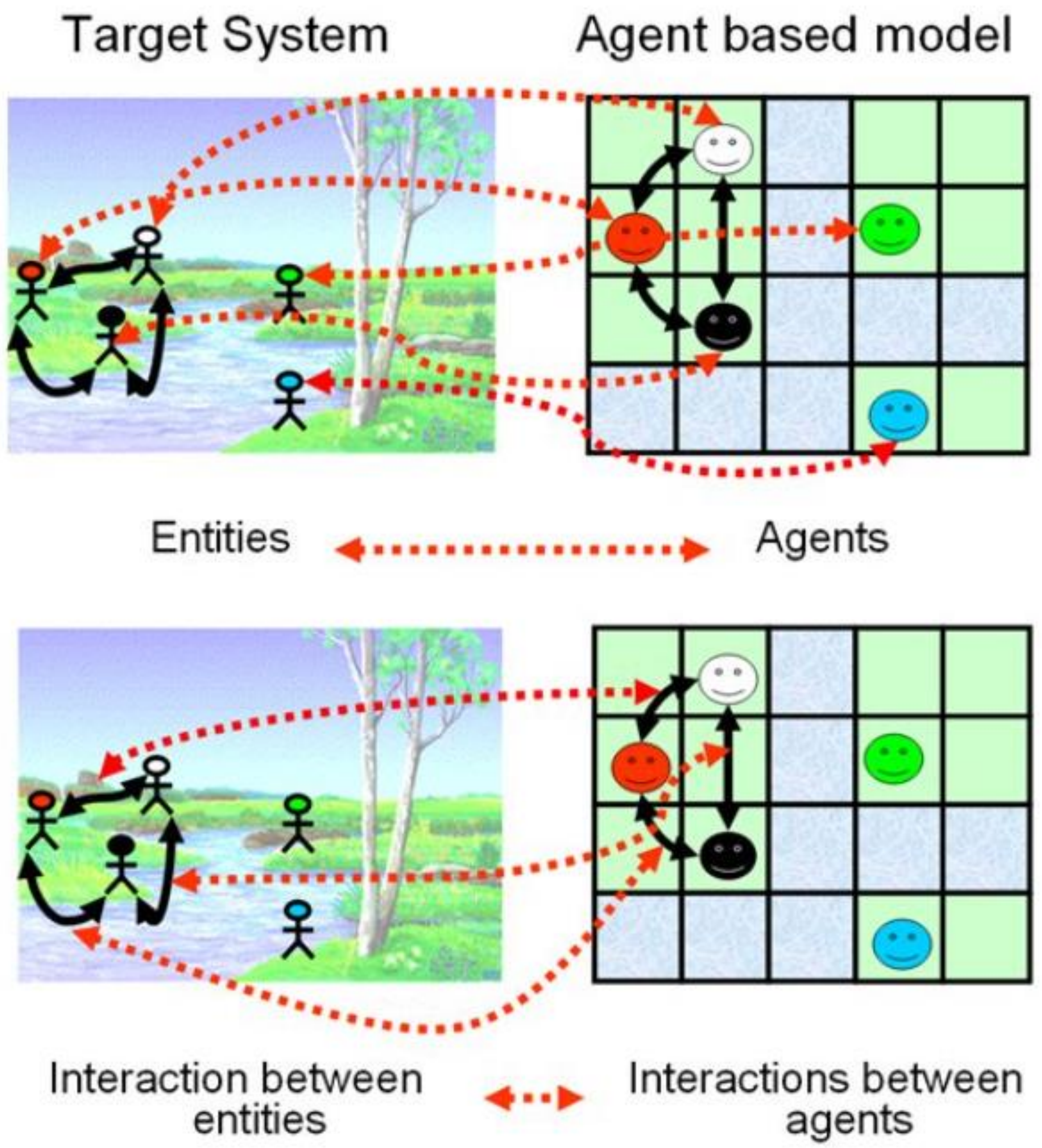
Economics of Social Networks

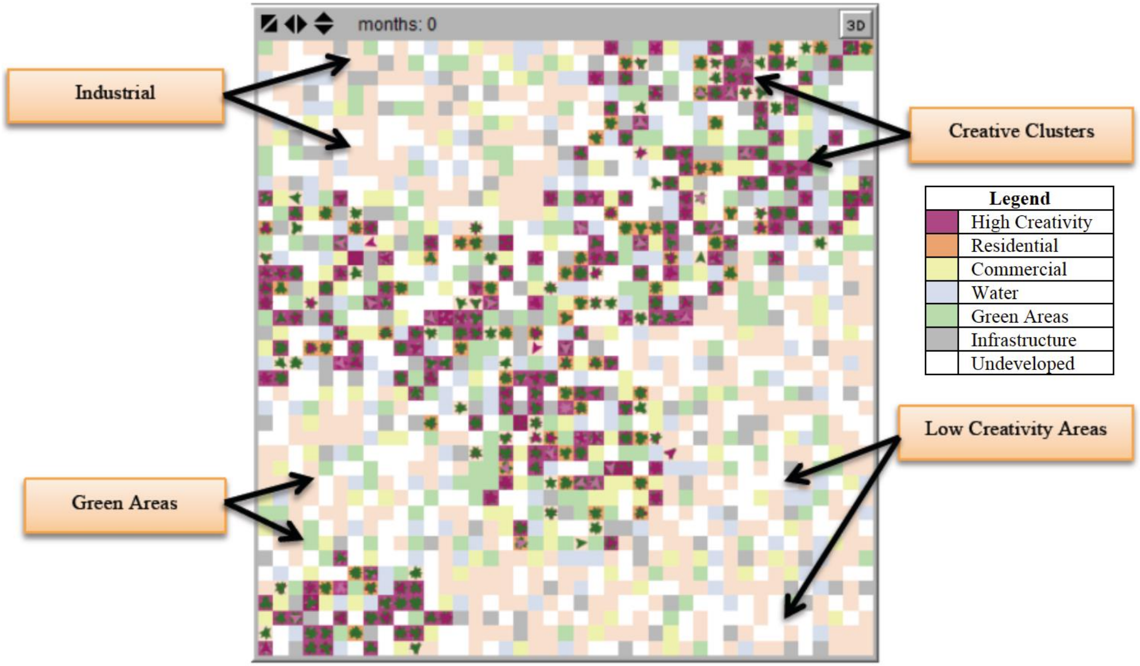
4. Social systems as networks of social relations, rather than as a set of individuals whose behavior is regularized by a set of internalized norms and values, by individual attributes or by mere dyadic relationships. Links are not necessarily diadic and reticular analysis considers the links between links as an essential element of structure.
5. Structured set of social positions: the concept of role appears as a variable dependent on the position itself and not as the one that designates the significant units of social systems. Consequently, the evaluative and normative dimensions of behavior are, for the reticular analysis, like the other dimensions of motivation, rather effects that it causes..
6. The links between the nodes that define a social lattice are flows of information, goods, or influence.



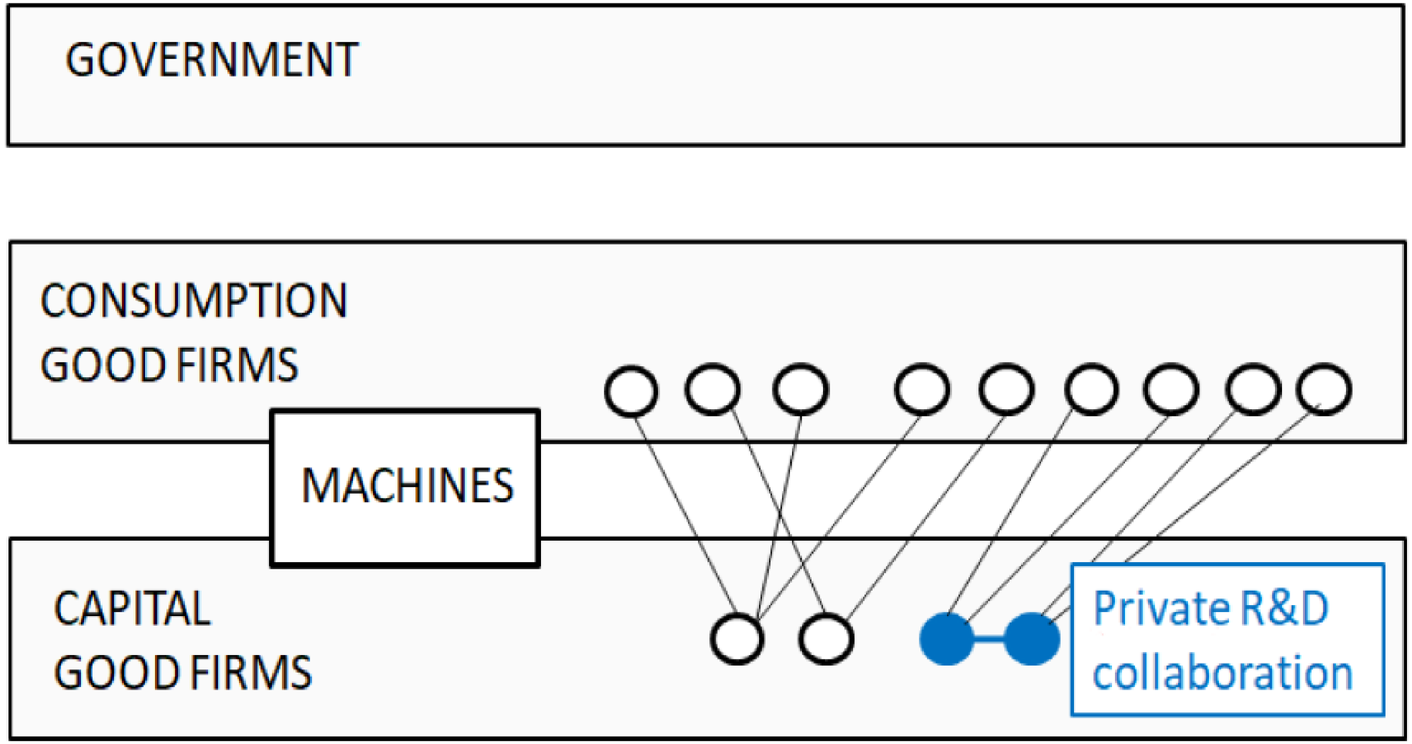
2. Agent-based models (ABM)

- Computational modeling/simulation method for the study of the organization and dynamics of complex systems.
- ABM constitutes an artificial society composed of autonomous and heterogeneous agents that interact in a non-trivial way with each other and with the environment, according to certain rules.
- Computational simulation allows to explore in real time the dynamic interaction between agents and simulate the process by which patterns and structures emerge in the macro environment that are not reducible to the properties of the agents in the micro.


Target System
Agent based model
Entities
Agents
Interaction between entities
Interactions between agents


months: 0
3D
Industrial
Creative Clusters
Legend
High Creativity
Residential
Commercial
Water
Green Areas
Infrastructure
Undeveloped
Low Creativity Areas
Green Areas

K+S Model (Agent Based Model)



Micro-macro economic model. Dynamics of innovation, imitation and diffusion.

2 sectors

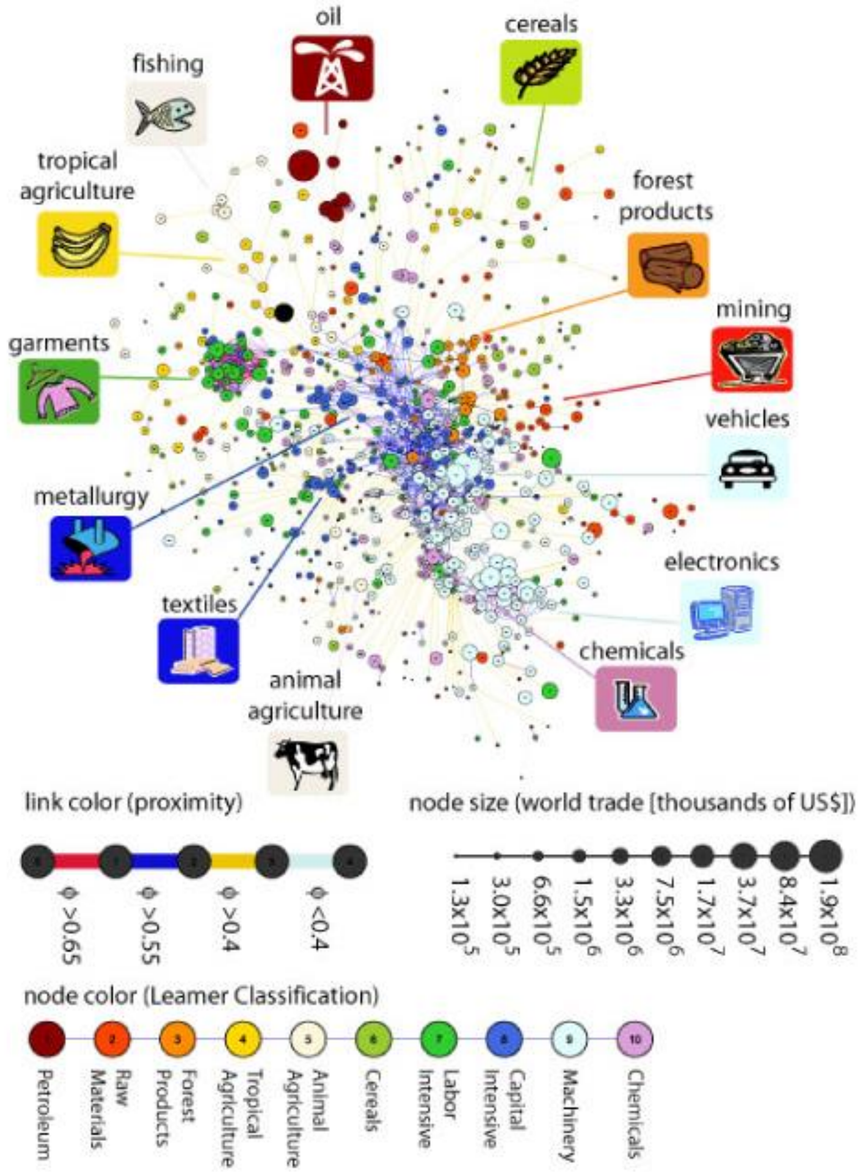
Capital goods (technological innovation))

- Consumer goods (dissemination)
- Labour market and government dynamics

Spinola, D; Treibich, T; Lamperti, F.; Mohnen; P. Roventini, A . (2022). Private R&D collaboration ,innovation and competition - an agent-based exploration. Growinpro Project.

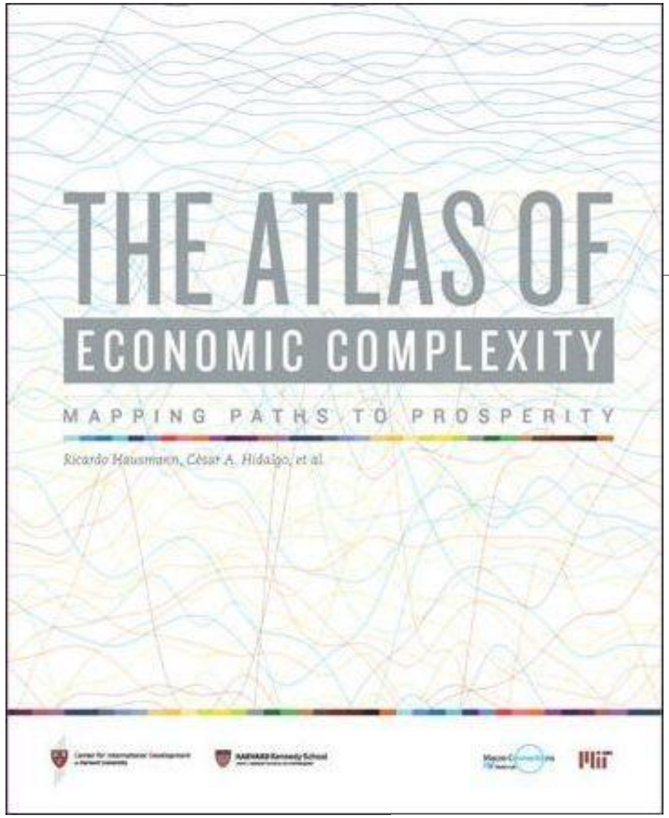
3. Product Space Theory

Particular view of complexity that many consider as "the" vision of complexity.



Atlas of Economic Complexity

Expression of the productive knowledge of a society, measured by the degree of sophistication of the products it manufactures. It starts from the principle of division of labor, based on the idea that society as a whole can achieve a greater amount of knowledge than anyone could have individually.




Ricardo Hausmann


Cesar Hidalgo

Atlas of Economic Complexity

But the fundamental thing is not only the amount but how diversified a society is, since complex economies are those capable of weaving large amounts of relevant knowledge and the countries that have greater capacities are those that can manufacture the greatest diversity of products. In turn, greater economic complexity is necessary for society to maintain and use a greater amount of productive knowledge.

https://atlas.cid.harvard.edu/

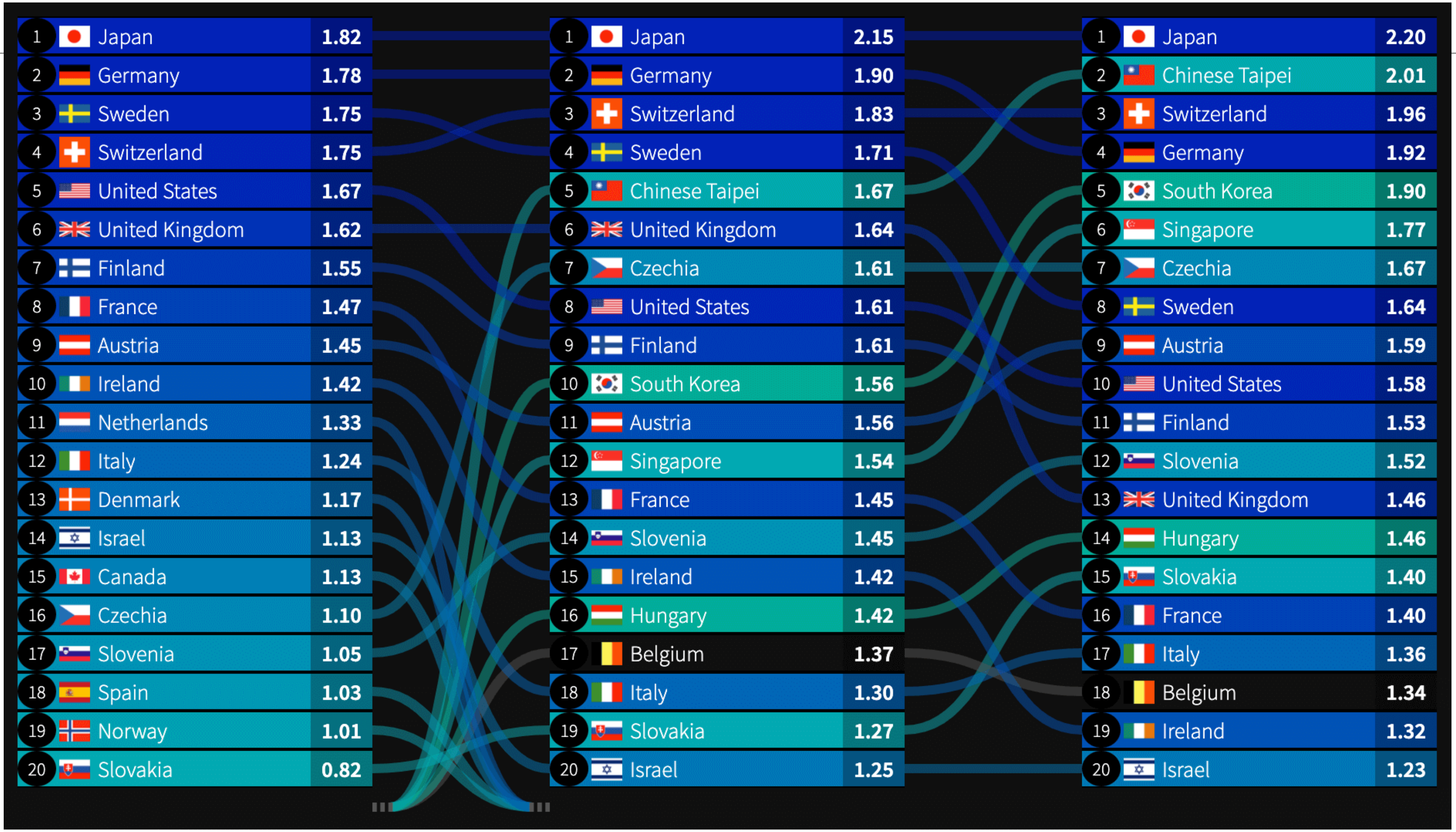
Economic Complexity Index

Number of different products that the country can manufacture (diversity of the country) and the number of countries capable of producing a certain product (ubiquity of the product) and in turn, how complex these are.

A product is more or less complex depending on how many countries are able to produce it, how complex these are, and how much technical knowledge is required to manufacture it.

It allows countries to be listed according to how diversified and complex their export basket is.

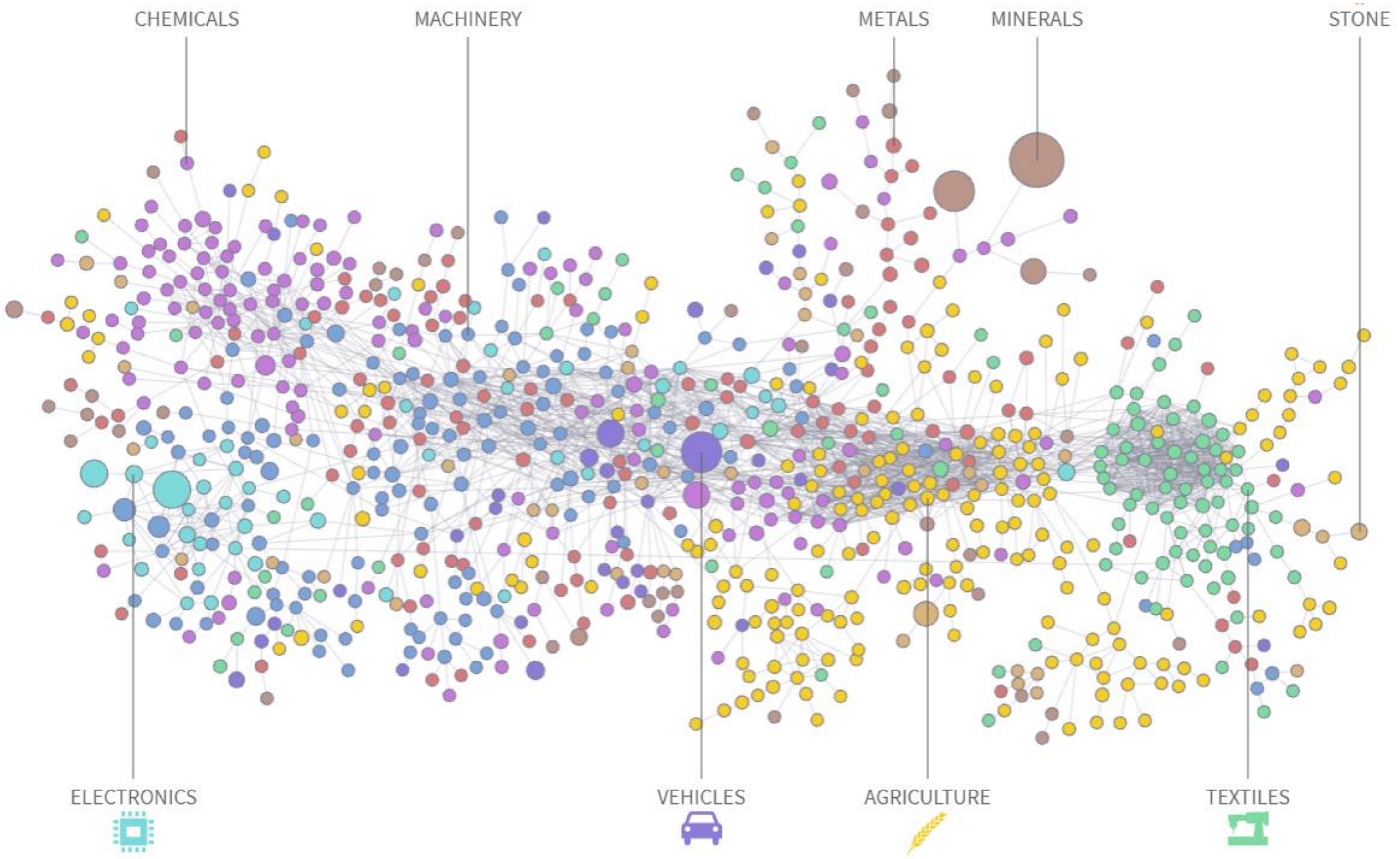
EC index by country



Diversification strategy (Public policies)

Focus will depend on whether or not the country has many opportunities, and how complex are its products:

1. Parsimonious industrial policy approach: there are limited opportunities where bottlenecks need to be addressed and thus be able to jump short distances on related products.
2. Soft touch approach: There is ample room for diversification by leveraging existing success to move to more complex production.
3. Strategic betting approach: Few close opportunities for chaining require coordinated long jumps into strategic areas with potential for future diversification.
4. Technological frontier approach: all possible production advantages have already been exploited and where the profits from more complex production would only come in the development of new products.


CHEMICALS
MACHINERY
METALS
MINERALS
STONE
ELECTRONICS
VEHICLES
AGRICULTURE
TEXTILES

https://oec.world/

https://atlas.cid.harvard.edu/

	Complexity Economics	Traditional Economics
Dynamics	Open, dynamic, non-linear systems, far from the break-even point.	Closed, static, linear and equilibrium systems.
Agents	Individually modeled; using inductive rules to make decisions; have incomplete information; they make mistakes and are prejudiced; learn to adapt over time; Heterogeneous.	Modeled collectively; use complex deductive calculations to make decisions; they have all the necessary information; they do not make mistakes and are not prejudiced; they do not learn or need to (they are already perfect); mostly homogeneous.
Networks	Explicitly models bi-lateral interactions between individual agents; networks of relationships change over time.	It assumes that agents only interact indirectly through market mechanisms (e.g. auctions).
Emergence	It makes no distinction between macro and microeconomics; macro patterns are an emergent result of the interactions and behaviors of micro levels.	Macro and microeconomics remain separate disciplines.
Evolution	The evolutionary process of differentiation, selection and amplification provides the system with innovation and is responsible for its growth in order and complexity.	There is no endogenous mechanism for creating innovation, growth, order or complexity.
Technology	It is fluid and endogenous to the system.	The technology is given or selected on an economic basis.
Preferences	The creation of preferences is central; individuals are not necessarily selfish.	Preferences are already given; individuals are selfish.
Origins of Physical Sciences	Based on biology (structure, pattern, self-organization, life cycle).	Based on nineteenth-century physics (balance, stability, deterministic dynamics).
Elements	Patterns and possibilities.	Price and quantity.

Source: https://es-academic.com/dic.nsf/eswiki/399312