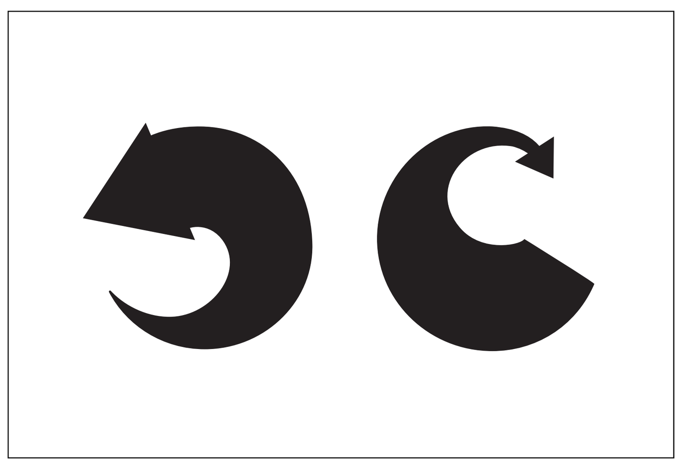
THE VISUAL REPRESENTATION OF COMPLEXITY

Definitions, Examples & Learning Points

Sustainability practitioners have long relied on images to display relationships in complex adaptive systems on various scales and across different domains. These images facilitate communication, learning, collaboration and evaluation as they contribute to shared understanding of systemic processes. This research addresses the need for images that are widely understood across different fields and sectors for researchers, policy makers, design practitioners and evaluators with varying degrees of familiarity with the complexity sciences. The research identifies, defines and illustrates 16 key features of complex systems and contributes to an evolving visual language of complexity. Ultimately the work supports learning as a basis for informed decision-making at CECAN (Centre for the Evalutation of Complexity Across the Nexus) and other communities engaged with the analysis of complex problems.

A research process was designed to identify sixteen key characteristics of complexity and to inform the development of new images and descriptions. In order to gather ideas from academics, sustainability practitioners and designers with expertise in the complexity sciences, systems mapping and design, I collected 50 surveys at The Environment, Economy, Democracy: Flourishing Together RSD6 (Relating Systems Thinking and Design) conference in Oslo (October 2017) and ran two participatory workshop in London (November and December 2017). The images, definitions, examples and learning points were developed with this research process. The text below was written with Alex Penn, Pete Barbrook-Johnson, Martha Bicket and Dione Hills. Many thanks to RSD6 organisers and all who contributed images and ideas in the surveys and workshops.

Introductory text by Dr. Joanna Boehnert

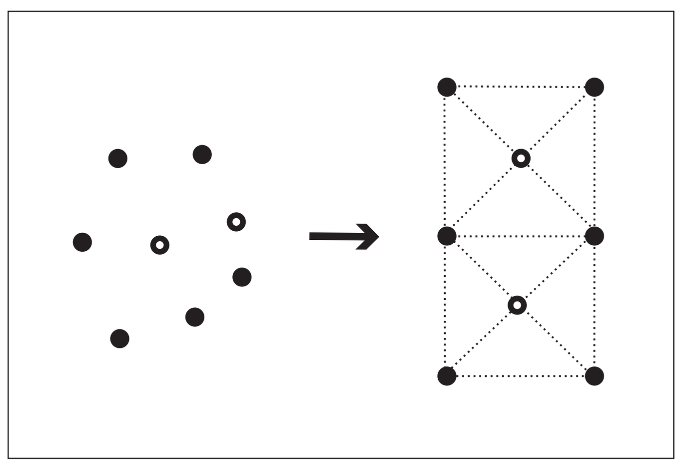


1. Feedback

When a result or output of a process influences the input either directly or indirectly. These can accelerate or suppress change.

EXAMPLES
- A stampede in a crowd, as individuals panic, others around them panic more (positive feedback).
- We sweat or shiver to maintain a constant body temperature (negative feedback).
- As the climate changes, permafrosts melts and releases more greenhouse gases. These feedback into the climate system (posivite feedback).

LEARNING POINTS
- Feedback loops can lead to runaway effects, or can create inertia through dampening of effects - two extremes.
- Positive feedbacks are reinforcing and accelerate change.
- Negative feedback suppress change and are stabilising/regulating.

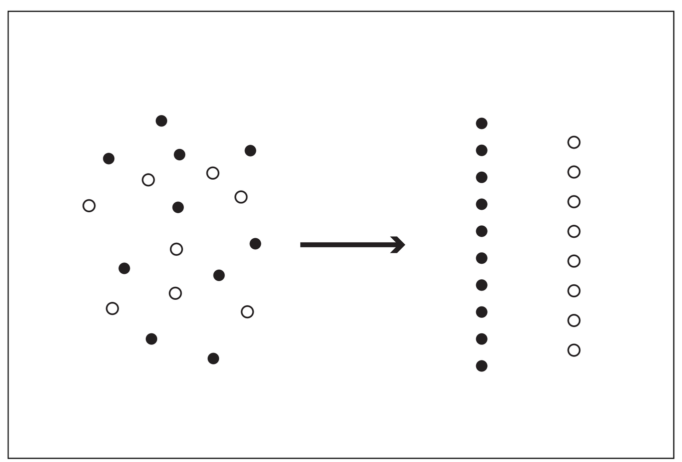


2. Emergence

New, unexpected higher-level properties can arise from the interaction of components. These properties are said to be emergent if they cannot easily be described, explained, or predicted from the properties of the lower level components.

EXAMPLES
- A market price is an emergent property, arising from the interaction of many buyers & sellers.
- A traffic jam is an emergent phenomena, caused by the interaction of drivers,
- Consciousness is an emergent property of the interactions of the neurons in our brain.

LEARNING POINTS
- Completely new and unexpected properties or things can arise simply from the interaction of lower level entities. These new properties can be difficult and sometimes impossible to predict.
- Consider how to understand unpredictable emergent phenomena in your domain.

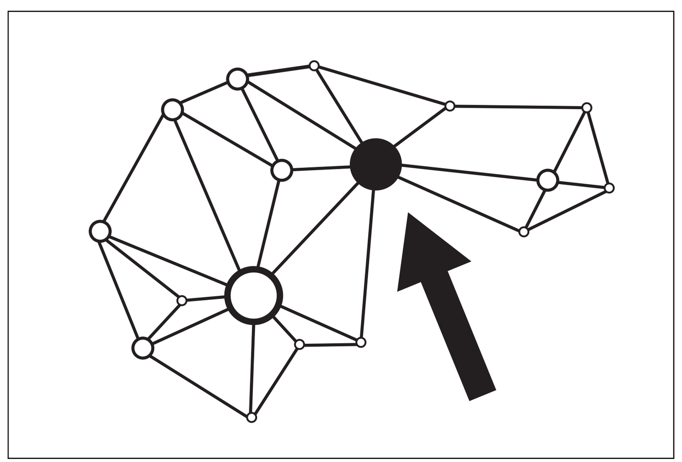


3. Self-organisation

Regularities or higher-level patterns can arise from the local interaction of autonomous lower-level components.

EXAMPLES
- Shoals of fish, flocking of birds
- The formation of lines of people moving in opposite directions on a crowded pavement

LEARNING POINTS
- Simple and autonomous behaviour can create order at larger scales.
- This higher level order requires only local (or lower-level) interactions.
- Order arises spontaneously without top down control and hence can often remain in place even if part of the system is disrupted.
- Emergence and self-organisation are closely related concepts. Self-organisation can cause emergent phenomena, but emergent phenomena do not have to be self-organised.

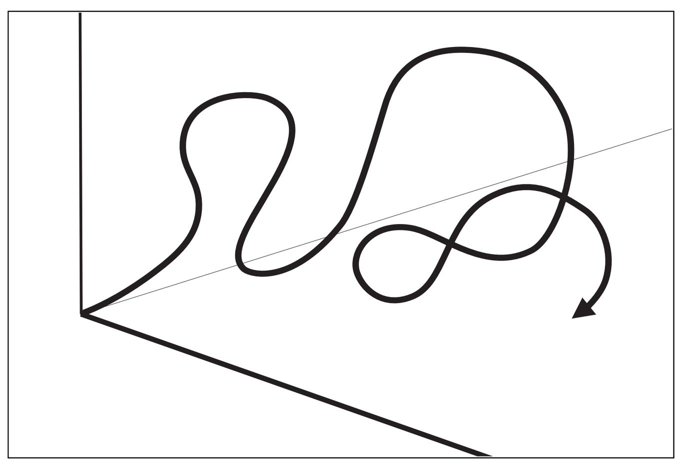


4. Levers and hubs

There may be components of a system that have a disproportionate influence because of the structure of their connections. How these behave can help to mobilise change, but their behaviour may also make a system vulnerable to disruption.

EXAMPLES
- A community champion can be a hub, but if she leaves, an initiative may stop being promoted.
- If a keystone species becomes extinct there may be cascading extinctions amongst other species.
- A bank collapsing may lead to multiple knock-on effects across the financial system.

LEARNING POINTS:
- Identifying hubs and levers can help identify best places to intervene in complex systems.
- Structure matters; knowing the structure of interactions in a system is crucial to understanding how it will behave, change or fail.

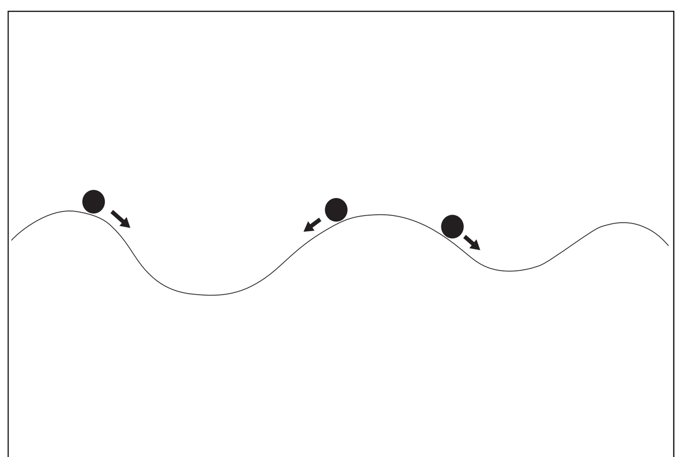


5. Non-linearity

A system is non-linear when the effect of inputs on outcomes are not proportional. The behaviour of a system may exhibit exponential changes, or changes in direction (i.e., increases in some measure becoming decreases), despite small or consistent changes in inputs.

EXAMPLES
- Braking distance in a car at 30MpH is more than twice that at 20MpH
- A new product may be slow to take-off but after a point sales will accelerate, before slowing again.

LEARNING POINTS
- In social settings, few things are actually linear
- Non-linearity can mean that the relationships between things can be just as powerful in determining outcomes as the structure of interactions. • In non-linear systems when we double or half an input, the output will not be double or half its original value, and may be completely different.

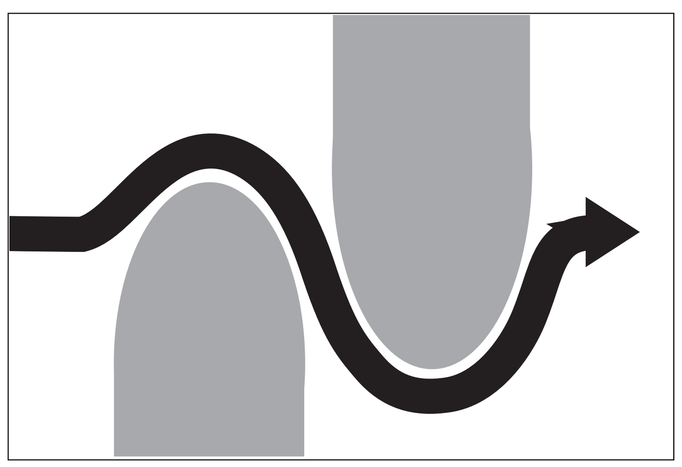


6. Domains of stability

Complex systems may have multiple stable states which can change as the context evolves. Systems gravitate towards such states, remaining there unless significantly perturbed. If change in a system passes a threshold, it may slide rapidly into another stable state, making change very difficult to reverse.

EXAMPLES • The melting of Antarctic ice: The planet may be stable with or without ice caps, but not at intermediate states. • Poverty traps: Low or reasonable incomes are stable, but not intermediates

LEARNING POINTS • Knowledge of domains of stability can be used to effect change in a system. If we can push a system into a different, more desirable, stable state with a policy intervention then we have changed the system in a robust way. • We do not need to put in continuous effort to keep the system in the new state. • We may try to use policy to change the positions of domains of stability. • What is possible in a system is often discontinuous and sticky. Not everything is stable.

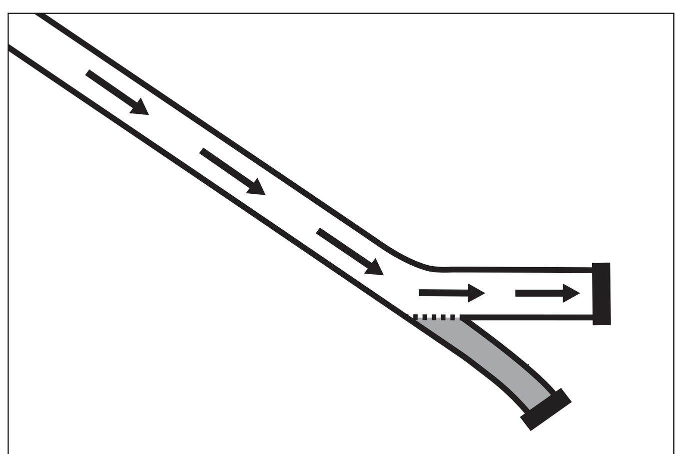


7. Adaptation

Components or actors within the system are capable of learning or evolving, changing how the system behaves in response to interventions as they are applied. So, for example, in social systems people may communicate, interpret and behave strategically to anticipate future situations. In biological systems, species will evolve in response to change.

EXAMPLES • Bacteria evolve to become resistant to antibiotics.
- A new tax/regulation is circumvented.

LEARNING POINTS:
- The rules of the game change as you play it. • We have to be prepared to adapt our interventions in response to how the system reacts to previous input. • We should be aware of the pressures to adapt that we are putting in place in systems. • We also need to be prepared for individuals - and systems - to adapt in response to an intervention in ways we didn't anticipate.

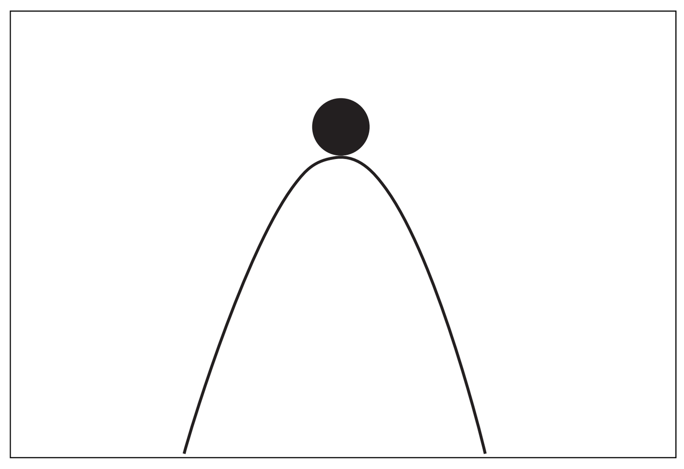


8. Path dependency

Current and future states, actions, or decisions depend on the sequence of states, actions, or decisions that preceded them – namely their (typically temporal) path.

EXAMPLES
- The first fold of a piece of origami paper will determine which final shapes are possible; origami is therefore a path dependent art.
- The organisation chosen to lead a new policy initiative influences which other organisations also become involved.
- VHS + Betamax, or railways + gauges -> once one option is adopted it would be impractical to switch.

LEARNING POINTS
- What paths are we 'locked-into'? What paths might our actions lock us into? What is it that makes a particular change impossible because of path dependency? Which 'lock-ins' might shift soon?

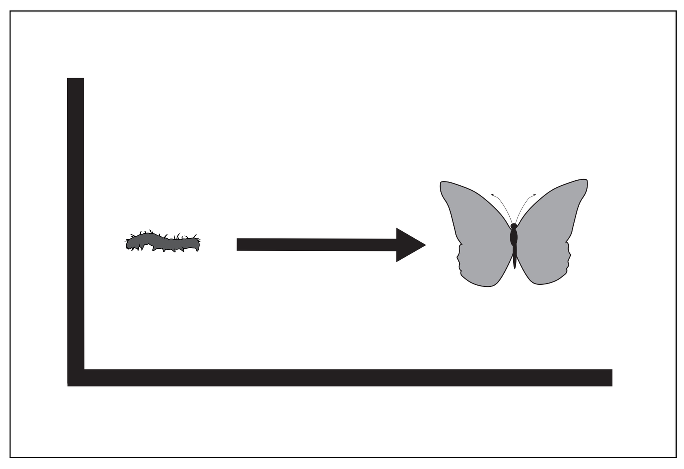


9. Tipping points

The point beyond which system outcomes change dramatically. Change may take place slowly initially, but suddenly increase in pace. A threshold is the point beyond which system behavior suddenly changes.

Examples
- The gradual, then sudden gentrification of a neighbourhood
- Social unrest increasing leading to a regime change
- A species' population reducing in numbers such to the extent that it cannot re-establish itself in the wild.

Learning points
- Sudden change can happen and we might not know it is coming.
- Knowledge of tipping points can be used to affect change in a system. We can aim to get a system past a tipping point (as also described in the 'domains of stability' definition).
- A system may be pushed towards and past a tipping point by positive feedback of some kind.

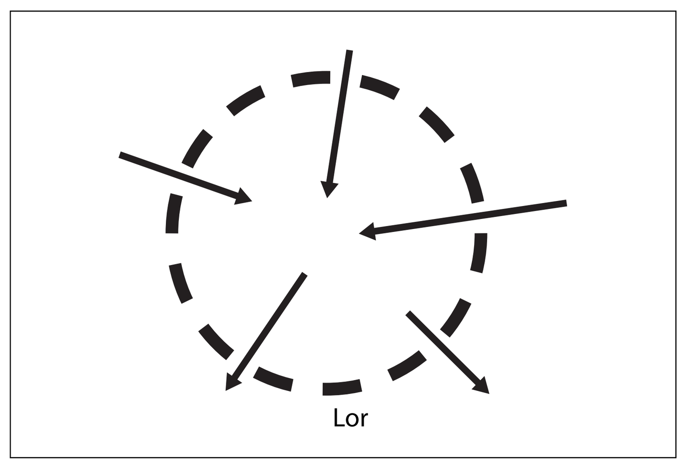


10. Change over time

Complex systems inevitably develop and change their behaviour over time. This is due to their openness and the adaption of their components, but also the fact that these systems are usually out of equilibrium and are continuously changing.

EXAMPLES
- A local community partnership changes direction when one of the constituent partners changes its policies. Social norms evolve over time.
- What constitutes the political 'centre', or what is viewed as 'politically correct', shifts over time.
- Ecosystems undergo succession over time: e.g. from annual plants, to scrub, to woodland.

LEARNING POINTS
- We cannot automatically assume that complex systems have reached a stable state.
- Do not rely on the system being the same in the future.

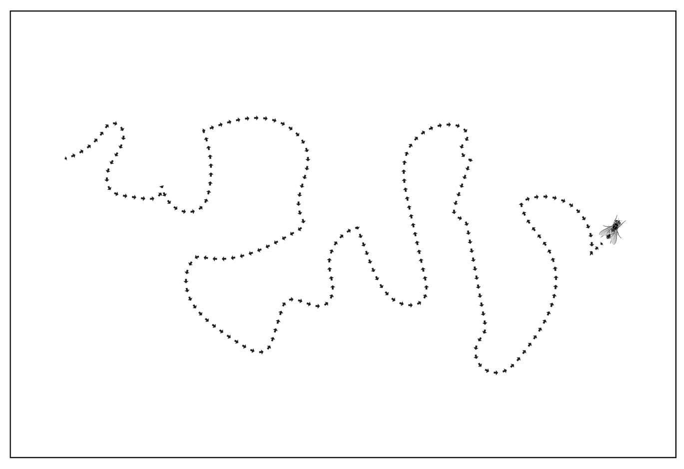


11. Open system

An open system is a system that has external interactions. These can take the form of information, energy, or material transfers into or out of the system boundary. In the social sciences an open system is a process that exchanges material, energy, people, capital and information with its environment.

EXAMPLES
- A food production company changes in response to changes in food fashions or in the cost and availability of ingredients.

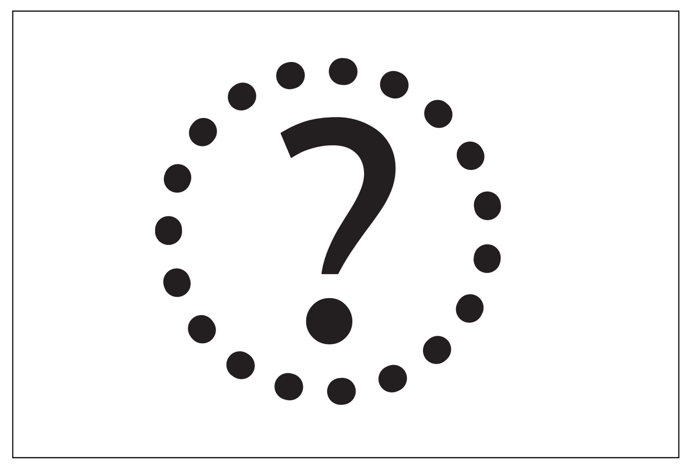
LEARNING POINTS
- Open systems are impossible to bound.
- Open systems mean that we must be alert to outside influences.



12. Unpredictability

A complex system is fundamentally unpredictable. The number and interaction of inputs/ causes/ mechanisms and feedbacks mean it is impossible to accurately forecast with precision. Random noise can have a large effect. Complex systems are fundamentally unknowable at any point in time - i.e. it is impossible to gather, store & use all the information about the state of a complex systems.

EXAMPLES and LEARNING POINTS:
- In the economy and other systems, it is impossible to know the intentions and interactions of all actors.
- We can't forecast the future, instead we must explore uncertainty with rigour.
- Predictive models will always be limited in complex systems, however they can be used to explore and compare potential scenarios, and system behaviours.
- Precise prediction is impossible in the long term.

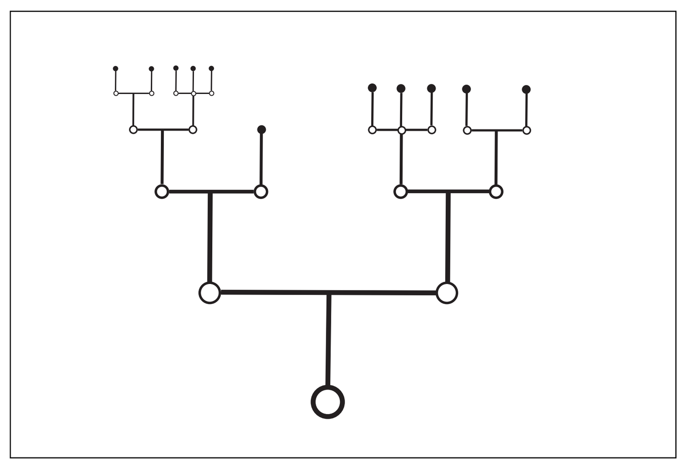


13. Unknowns

Because of their complex causal structure and openness, there are many factors which influence (or can influence) a system of which we are not aware. The inevitable existence of such unknowns mean we often see unexpected indirect effects of our interventions.

EXAMPLES
- A powerful social grouping operating in a policy area not anticipated by a policy maker.
- An undiscovered plant in a rainforest with numerous potential health applications.

LEARNING POINTS
- Expect the unexpected.
- Be prepared to learn as the system unfolds it will become apparent that it might influence or be influenced by completely unexpected things.
- A new technology might enable a fundamental change, leading to widespread social effects.

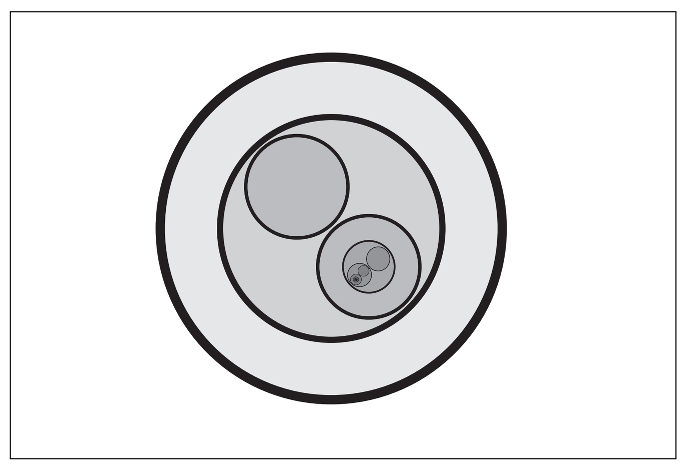


14. Distributed control

Control of a system is distributed amongst many actors. No one actor has total control. Each actor may only have access to local information.

EXAMPLES
- A smoking cessation intervention's success may be determined by the many health professionals 'on the ground' running events and offering advice, rather than the central agency.
- Political parties' local groups and government may have differing views to the central parliamentary party. The central and distributed groups may conduct political work in contradictory ways.

LEARNING POINTS
- There is no top down control in complex systems. Decisions and reactions happen locally and the interactions of all these lower-level decisions can give us system-level properties such as stability, resilience, adaptation or whole system emergent regulation.
- The best we can do is to "steer" the system.

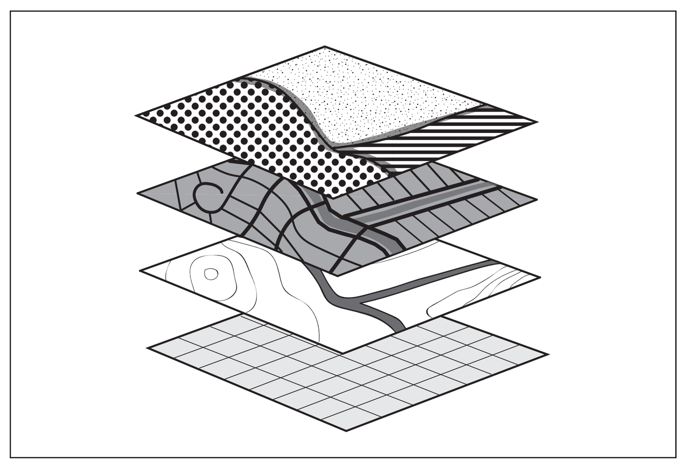


15. Nested systems

Complex systems are often nested hierarchies of complex systems (so-called 'systems of systems').

EXAMPLES
- Brain -> person -> society -> planet
- An ecosystem is made up of organisms, made up of cells, made up of organelles which were once free-living bacteria, made up of complex metabolic processes intertwined with genetic systems (each nested level is a complex system).

LEARNING POINTS
- When studying a particular system, it is useful to be aware of the larger system of which it is part, or the smaller systems operating within it.
- Mechanisms of change (as in realist evaluation) may be taking place at a higher or lower level to the one where an intervention is taking place.



16. Multiple scales and levels

Actors and interactions in complex systems can operate across scales and levels. For this reason systems must be studied and understood from multiple perspectives simultaneously.

EXAMPLES
- Health issues can be considered at the scale of the individual physiology or behaviour, the household, community, society (social norms) or nation (economy, health system). Usually more than one domain is required to fully understand a problem.

LEARNING POINTS
- Tackling obesity requires thinking about individuals' eating habits and activity, but also social norms, economic factors and even town planning. No one level is sufficient. • We need to think broadly about systems at multiple scales and fields as properties or dynamics of one scale often feed up or down to affect others domains.

cecan
Centre for the Evaluation of Complexity Across the Nexus

ESRC ECONOMIC & SOCIAL RESEARCH COUNCIL

NERC SCIENCE OF THE ENVIRONMENT

CECAN project funding did not cover the full costs for the production of this research. Many thanks to the organisers and participants of the Relating Systems Thinking and Design conference **RSD6** for their support, including waving conference fees.

Project mentors :
Dr. Alex Penn
Dr. Pete Barbrook-Johnson
Martha Bicket
Dr. Dione Hills
www.cecan.ac.uk

Research and design by
Dr. Joanna Boehnert
j.boehnert@eco-labs.org
@EcoLabs + @Ecocene
www.ecolabsblog.com
www.ecocene.net