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Systems Thinking

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1. Systems Thinking: Overview and Some Core Concepts

Overview

Systems thinking is a powerful tool for understanding and addressing complex, interconnected problems and issues. It provides methodologies and techniques that can be used to help deepen understanding of an issue or problem, develop more considered decision-making, create more sustainable solutions, and improve and amplify the positive impact of actions. This makes it an appropriate approach for making a significant difference in complex systems, such as the marine environment as such an approach can help develop more effective policy and management strategies to address marine environmental issues and promote sustainable development.

It was in the 1940s and 1950s that systems thinking emerged as a transdiscipline in its own right i.e. separate from any particular discipline but applicable to them all. The founding fathers of systems thinking as a transdiscipline were von Bertalanffy (a biologist), who established 'general system theory', and Wiener (a control engineer), who established cybernetics. Von Bertalanffy (1968) was concerned with the complexity of entire organisms. In an attempt to deal with this complexity, he believed that organisms must be studied as 'complex wholes'. The name 'cybernetics' was first applied to a field of study by Wiener (1948) which he defined as the "science of control and communication in the animal and the machine". Cybernetics, Wiener argued, had application to many different disciplines because it dealt with general laws which governed control processes whatever the nature of the system under governance.

Some Core Concepts

In this briefing paper, the aim is to develop a conception of a system, informed by the ideas of von Bertalanffy, Wiener and other systems theorists, which will have general applicability. The central concepts of such a system are shown in Figure 1.

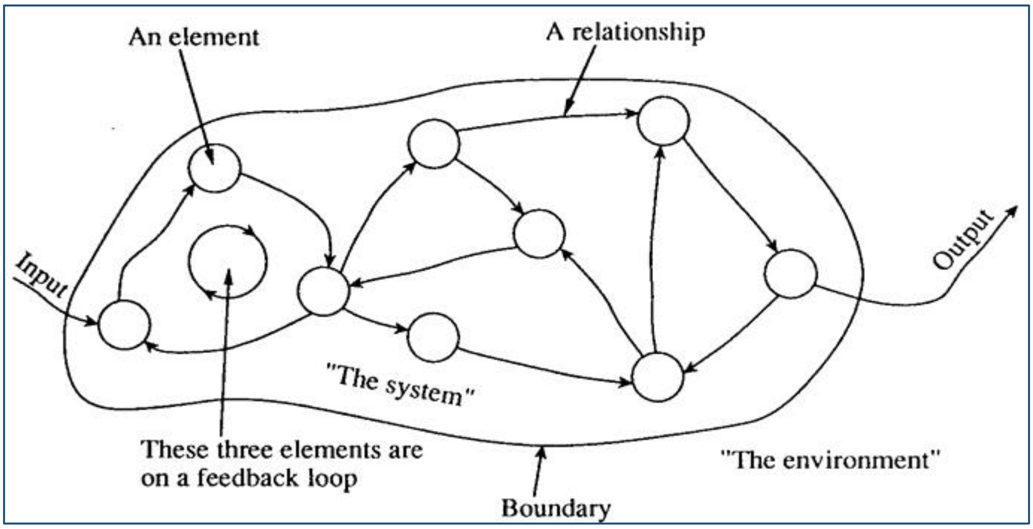

Figure 1. A general conception of a system (from Flood and Jackson, 1991a)

The terms used in this Figure 1 are: element, relationship, boundary, input and output, environment and feedback. However, we need some further notions to describe the complete concept, these are: attributes, transformation, purpose, open system, homeostasis, emergence, communication, control, identity and hierarchy. Let us expand on these ideas.

A system consists of a number of elements and the relationships between the elements. A richly interactive group of elements can be separated from those in which few and/or weak interactions occur. This can be achieved by drawing a boundary around the richly interactive group. The system identified by a boundary will have inputs and outputs, which may be physical or abstract. The system does the work of transforming inputs into outputs. The processes in the system are characterised by feedback, whereby the behaviour of one element may feed back, either directly from another element by way of their relationship, or indirectly via a series of connected elements, to influence the element that initiated the behaviour. We give attributes to elements and relationships according to how we measure them (e.g., for an element we might use size, weight, colour, number, volume; and, for relationships, measurements might be in terms of intensity, flow, strength).

A system so described is separated by its designated boundary from its environment. It is termed an open system if the boundary is permeable and allows inputs from and outputs to the environment. A system is able to sustain an identity by maintaining itself in a dynamic steady state in the face of and using its changeable environment (we label this homeostasis). That does not mean that nothing is happening in the system; all the constituent parts may themselves have to adapt and/or change in the process of continuing essential transformation processes. A system that maintains an identity and stable transformation processes over time, in changing circumstances, is said to be exhibiting some form of control. Essential to this is the communication of information between the elements. A system can be said to be purposive if it is carrying out a transformation, and is termed purposeful if its purpose is internally generated.

A system stabilised by its control mechanisms, and possessing an identity, can be further understood through its emergent properties. These are properties relating to the whole system but not necessarily present in any of the parts. The term "synergy" refers to the increased value of parts working together as a whole. Emergent properties arise where a complex interconnected network exhibits synergy such that "the whole is greater than the sum of the parts".

Systems are generally understood to occur in hierarchies, so that a system we are considering may also be considered as a sub-system of a wider system. And, if we "blow up" any of the parts of the system of concern, we may usefully conceive of them as sub-systems which exhibit all the characteristics of a system as set out above. We say that these sub-systems are identifiable at a higher level of resolution than the system of which they are part. Sub-systems may themselves be considered in terms of parts, or sub-subsystems, at an even higher resolution level.

2. Systems Approaches and Example Modelling Tools

Here we consider how different thinkers started to use systems these concepts, in different ways.

Systems Approaches

Some of the early approaches in the systems discipline, often referred to as hard systems thinking, regarded systems as real-world entities. As such the focus was on capturing and understanding these systems through expert modellers creating, often large-scale, representations of all the parts and interrelationships to understand given the behaviour of the system and its emergent properties. The fundamental assumption of such an approach is of a hard external reality that can be captured by an expert modeller who can manipulate the model to derive some kind of optimal solution to whatever problem or issues is faced and then (re)engineering the system, based on the learning from the modelling effort, for optimal achievement. Approaches based on this kind of logic include Systems Analysis (see for example, Miser and Quade, 1985, 1988). Adopting a similar line of realist thought were approaches that looked to understand the structures that underlie complex situations such as System Dynamics (see for example, Forrester, 1961).

In such hard or realist approaches, people were often regarded as rule-following, deterministic parts of the system being modelled rather than self-conscious actors who can change their purposes (Ackoff, 1979). Recognition of the negative effects of the dehumanising of the human parts of a system by hard systems approaches (Checkland, 1985) led to the creation of new systems approaches, which recognised that systems are always seen from the perspective of an observer/participant (Churchman, 1979). These approaches looked to promote stakeholder participation, surface different perspectives through facilitated qualitative modelling, and dialogue for collaborative learning. Such approaches were based on the assumption that different stakeholder positions offered partial perspectives on the complex whole and hence it is necessary to bring stakeholders together to bring about the kind of mutual understanding that can provide the basis for some kind of accommodation and agreement of a way forwards.

Often referred to as soft systems thinking, these approaches include soft systems methodology (Checkland, 1981), strategic assumption surfacing and testing (Mason and Mitroff, 1981), interactive planning (Ackoff, 1981) and interactive management (Warfield, 1994). In addition, some of the earlier hard or structuralist approaches were reinterpreted to address the challenges revealed from a soft perspective, such as to become more participatory, such as system dynamics (e.g. Vennix and Vennix, 1996; Lane and Oliva, 1998) and organisational cybernetics (e.g. Espejo and Harnden, 1989).

The fundamental assumption of the soft approaches is of an ideal speech situation in which everyone is able and willing to contribute and the force of the best argument will out but the naivity of such an assumption with respect to the use of power led to the emergence of approaches associated with a more critical perspective (see for example, Ulrich, 1983, 1987, 1994). Ulrich's key idea is that, as everyone's view of a system is partial, boundaries are inevitably set with reference to the purposes and values of decision makers. However, boundary judgements are often presented as definitive and imposed without being subject to question about whose purposes are being served. From a critical perspective, boundary judgements regarded as subjective and value-laden reflecting decisions about whose voices should and should not be heard. Ulrich encourages dialogue about implicit boundary decisions on the key assumptions upon which that project should be based. However, when dialogue is avoided by decision makers, those affected by their ideas have the right to make a 'polemical' case to compel decision makers to engage in dialogue. The key principle is preventing powerful stakeholders (decision makers and experts) from simply taking their boundaries and values for granted and imposing them on others.

Around about the same time as the emergence of critical approaches focussed on the use of power, systems thinking took a critical term in another way. This other critical turn was based on methodological pluralism: drawing creatively from hard, soft and critical methodologies, and reinterpreting methods through new frameworks or guidelines for choice (e.g., Jackson and Keys, 1984; Jackson, 1991; Mingers and Gill, 1997). Much of the work on methodological pluralism was developed under the banner of 'critical systems thinking' (Flood and Jackson, 1991b; Flood and Romm, 1996; Jackson, 2000, 2003, 2019).

Methodological pluralism makes good sense in the context of marine and coastal management, as some approaches are particularly useful for evolving stakeholder perspectives (e.g., Checkland, 1981), others support intervention in organisational and institutional structures (e.g., Beer, 1966, 1981) and other ask important questions about which stakeholder voices are being considered (e.g., Ulrich, 1987, 1995). Please refer to the BP on Stakeholders and Stakeholder Communication for further information.

Work from a pluralist position on cultural theory may also be considered relevant (e.g., Thompson et al., 1990; Thompson, 1997).

Having provided a summary overview of the development of systems thinking, let us now, for the sake of illustration, describe a couple of modelling methods offered by this discipline.

Example Modelling Methods

Mind Maps

Mind maps (Buzan, 1974) are a simple fast form of individual brainstorming. Although relatively unstructured whether you are creating them by hand or using a software package such as xmind[1], there are some guidelines that can help in their construction (Open University, n.d.):

- Express the focal idea you wish to explore as a keyword or phrase and put it in a circle near the centre of the page to allow the diagram to grow in any direction necessary.
- Capture related ideas, expressed in one or a few words, and write them down around the central idea. Link related ideas to the focal idea with a straight line (note, the lines do not show directional links). Keep going by considering each line or branch to see if further branches (ideas) link to it.
- Start by working fairly freely and then look at the map to see whether any of the strands are effectively the same idea and also to check whether you are creating a single-layer map with ideas attached to the focal idea or issue, or a multiple-layered map with secondary circles creating fans.
- Different colours can be used to group or highlight particular fans or clusters of ideas.
- If you get stuck or lose the thread, start with a new focal keyword or phrase and create a subsidiary map rather than clutter up the original. Alternatively, leave your mind map for a while to allow fresh thinking before adding to it or redrawing it, combining or grouping similar ideas.

See Figure 2 for an example of a mind map.

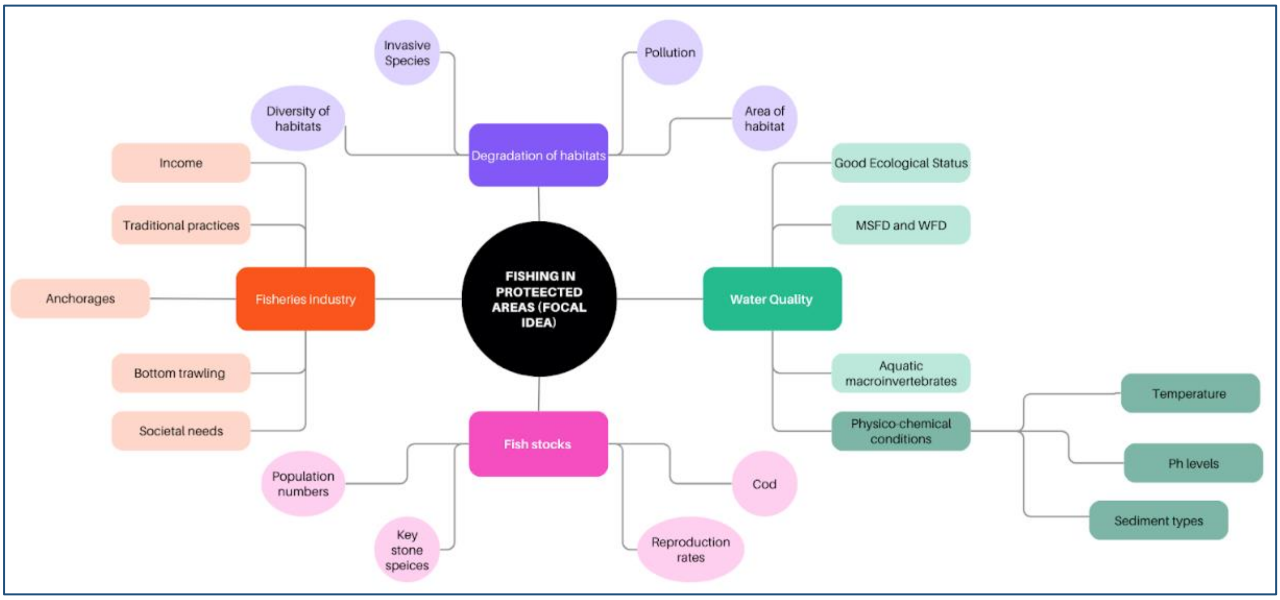

Figure 2. Mind Map on Fishing in Protected Areas

For collaborative idea mapping, the whiteboard tool in Canva[2] allows multiple people to add and link ideas.

[1] https://xmind.app/
[2] https://www.canva.com/

Causal Loop Diagrams

A causal loop diagram (CLD) is a qualitative systems-based model that shows the relationships between a set of elements that are variables (factors liable to change e.g., indicators) operating in a system (Barbrook-Johnson & Penn, 2022) . The basic premise of causal loop diagramming is that the structure of a system ought to fully explain its behaviour and the process of developing CLDs can help stakeholders converge on a shared understanding of system behaviour and also how to intervene in a system, through the identification of root causes and manipulation of leverage points, to bring it closer to a desired state (Meadows, n.d.). This type of systems approach was discussed in the 1960s (Forrester, 1961) and has been widely used and further since (e.g., Senge, 1990 and Sterman, 2000). Causal Loop Diagramming with stakeholders has already been used extensively in marine management (e.g., Videira, 2012).

A CLD can also provide the basis for quantitative modelling techniques e.g. system dynamics, which can provide a more robust exploration of system behaviours and testing of policy and practice options before final decision making and implementation. See Figure 3 for a diagram portraying the process of CLD based investigation and modelling.

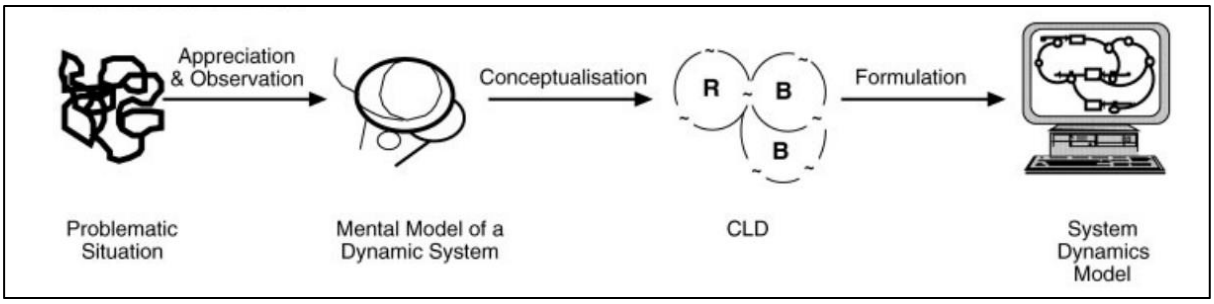

Figure 3. A Causal Loop Diagram (CLD) based process for issue conceptualisation and formulation[3] (Lane, 2008)

The creation of a CLD focusses on the identification of key of elements and the relationships between them and it is important to be clear about exactly what we are referring to here.

<u>On Elements</u>

An element is a variable that has two attributes: a name and a level which can be expressed quantitatively, e.g. size of a population, or qualitatively, e.g. population well-being. In addition, we can distinguish between endogenous variables, both influencing and influenced by other variables within the CLD, and exogenous variables, influencing but not being influenced. In a complex system there are many variables, and we can (in principle) describe the state of the whole system by reporting the levels of all of these variables but this might not be possible due to lack of data or even desirable given the amount of resource that assessing the state of all variables would absorb. It is important to be pragmatic and focus attention on just those elements that are relevant to the issue of concern.

Elements should be named using nouns or noun phrases. It is important that the name given to an element makes it clear that the thing or characteristic referred to is capable of change:

- Use clear language to describe elements in a neutral way that does not have any positive or negative connotations.

[3] R=Reinforcing Loop; B=Balancing Loop

- Use a name that allows for variation and does not tie the level of the variable to an end point of its range.

On The Level of Detail or Abstraction

Sometimes, to ensure a consistent level of abstraction in a CLD, elements need to be aggregated or disaggregated. Aggregation involves identifying related elements and expressing them as a single element that captures their overall effect (see Figure 4). Aggregation is sometimes necessary when excessive detail and too many elements detracts from the understanding of the system's behaviour.

Set of Related Variables Needing Aggregation	Example of Aggregated Variable
Rainfall, Humidity, Temperature, Wind speed	Suitability of Climate
Level of pollution, Area of public green space, Air quality, Extent of tree canopy	Healthiness of urban environment

Figure 4. Examples of Element (Variable) Aggregation (Proust and Newell, 2020)

In some instances, an element needs to be disaggregated because it expresses a concept that is too high-level or too abstract to be meaningful (see Figure 5).

Original Variable	Possible Components of Disaggregated Form
Water quality	Concentration of pathogens Concentration of suspended sediments pH
Worldviews	Level of concern for environment Level of belief in anthropogenic climate change

Figure 5. Examples of Element (Variable) Dis-aggregation (Proust and Newell, 2020)

The process of aggregation and disaggregation is essential to achieve a level of abstraction and detail appropriate to the issue being addressed. In looking to portray complex systems in simple ways, detailed knowledge of the underlying sub-systems and elements may not just be unnecessary but counter-productive in inhibiting our ability to 'see' the structures that are driving the behavior of the system. With this and keeping it simple in mind, it is recommended that the number of elements in a CLD should be limited to about 15 to 20 in order to maintain overview and coherence (Haraldsson, 2004). It is likely that the process of creating an issue based composite CLD will lead you to exceed this recommendation but it is good to keep it in mind so that you simplify and aggregate to improve clarity and simplicity where possible.

On Connections in CLDs

Causal relationships onnections between linked elements are shown as connecions in CLDS (uni-directional arrows). Connections are either:

- reinforcing—denoted by a '+' or an 's' as the elements (variables) move in the same direction, an increase or reduction in one element causes an increase or reduction in the element it influences
- opposing—denoted by a '–' or an 'o' as the elements move in opposite directions, an increase one element causes a decrease in the element it influences.

See Figure 6 for further description of the connections between elements. When working with others on the construction of a CLD then it is important to agree the labelling convention that will be used consistently and this is especially important if multiple CLDs are to be constructed by multiple teams.

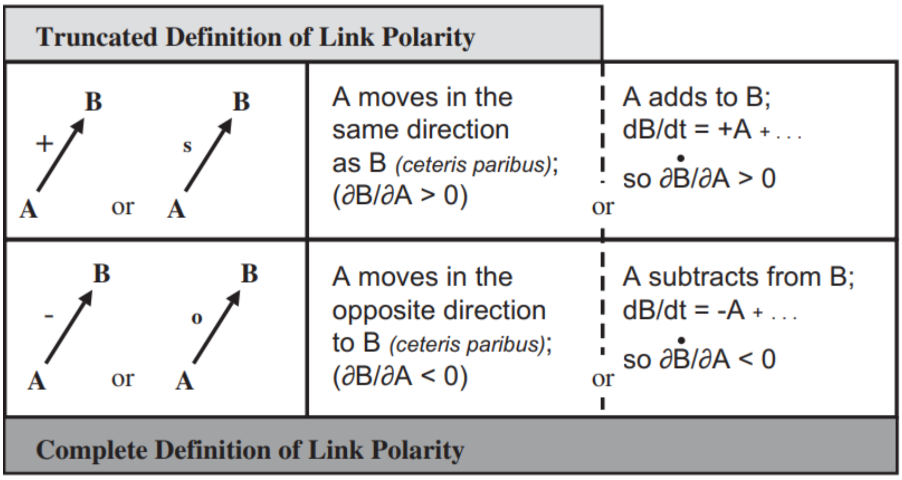

Figure 6. Polarity signs in Causal Loop Diagrams (Lane, 2008)

When there are multiple connections between elements, they can form causal loops, also known as feedback loops. A feedback loop is a closed sequence of causes and effects, that are either reinforcing (vicious or virtuous circles that act as the engine for the growth or decline of a system) or balancing, where self-correction occurs which enables the system to maintain a steady state. See Figure 7 for an example of a simple CLD.

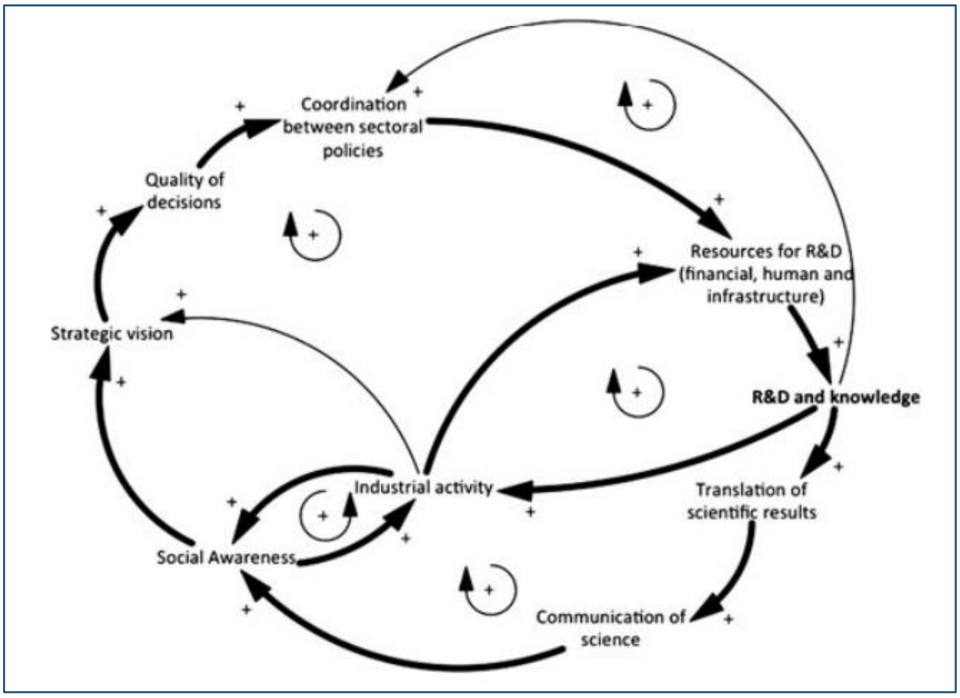

Figure 7. Causal Loop Diagram for issue of 'R&D awareness and dissemination of ocean-related activities (Videira, 2012)

On System Levels and Scales

It has already been mentioned that, when constructing CLDs, it is essential to achieve a level of abstraction and detail appropriate to the issue being addressed but it is also important to recognise that an issue can manifest at different system levels so it is important to identify the level at which the impacts of concern are being realized. The process of unfolding complexity, involving the definition of distinct system levels and interactions between levels, is important as it helps clarify the system-in-focus, the sub-systems that constitute it and the meta-system of which it is a part (see Figure 8). The process of identifying different system levels is essentially a process of defining boundaries and whilst we often defer to familiar definitions (e.g., city, state, country) these can and should be made problematic so that systems levels are defined that are meaningful to stakeholders and appropriate for supporting understanding given the issue being addressed (Jackson, 2019). For example, stakeholders may determine that it is more meaningful to define a particular system level based on common geographical features rather than institutional arrangements. It is important, though, to give a meaningful label to each systems level, should one not already exists, and at each system level there should be a consistent level of abstraction and detail.

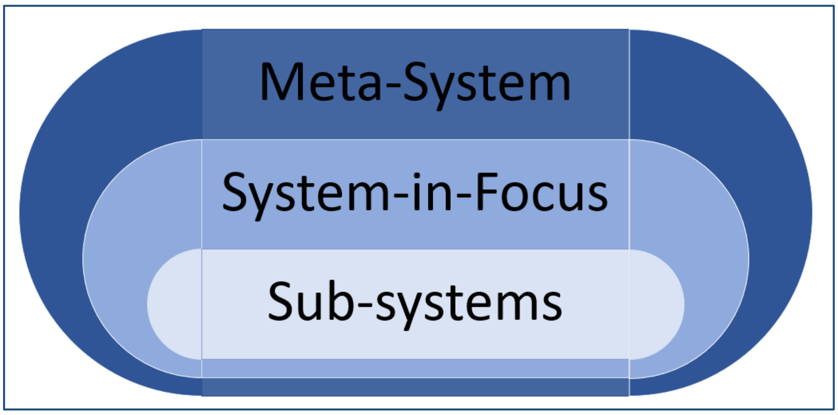

Figure 8. Unfolding Complexity across System Levels

As well as system levels it is also relevant to consider the relevant scale of each level and there are different ways of thinking about scale:

- Temporal scale - This is defined by the time feedback mechanisms in the system take (this might also be thought of as a 'delay' or 'lag' in the effect of one variable on another). If we are focussed on an issue that has a short time-frame then we might not include feedback loops with very long delays as the impacts of these will not be realized over the period we are concerned with. That said, this requires careful consideration to ensure that important slow changes are not disregarded and that the potential for the speed of change to change is recognized.
- Physical scale - This is the physical size of the system. The pace of change in smaller systems tends to be quicker than in larger ones.

Simple CLDs are often drawn by hand but sometimes the number of elements and connections get difficult to present on a hand-drawn model, as it is often necessary to move them about so that connecting arrows do not cross, and there are a range of data visualisation software packages that are available to support the building of CLDs.

Kumu and Gephi are data visualization and analysis packages and templates (e.g. causal loop modelling and social network analysis) to support a range of modelling processes. Kumu[4] is free to join and public projects can be created for free (an overview of Kumu can be found here[5]).

CLDs are useful for capturing and sharing basic insights on the causal relationships that are driving the behaviour of a system. These basic models can be further developed and software packages (e.g. Vensim, iThink) provide enhanced analysis and simulation capability (see for example, Maani and Cavana, 2007).

3. Summary

This briefing paper provides a summary overview of systems thinking. As a transdiscipline, the approaches and core concepts of systems thinking have been applied usefully across a diverse range of disciplines. In summary, key principles include:

- Respecting the complementary nature of different paradigmatic approaches within systems thinking as each offers something valuable when dealing with complex problem situations.
- Identifying the different parts of a system (e.g., elements, relationships, boundaries, inputs, outputs, feedback loops) and understanding how different parts of a system interact to create structures that drive system behaviour.
- Considering systems to be adaptive, with the ability to maintain dynamic stability through feedback and control mechanisms. Systems are also seen as purposive, meaning they have a function or goal, often defined by their structure and the interactions between their parts.
- Making the definition of boundaries problematic as they determine which elements, relationships, and interactions to include within the system under study, thereby shaping the scope of analysis and ensuring that key components relevant to the issue are considered without overcomplicating the model.

[4] https://kumu.io
[5] https://kumu.io/tour

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