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Multilevel Systems and Policy

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1. Introduction

Making multilevel systems well defined is essential for the implementation of computer models to investigate the multilevel consequences of policy. This chapter shows that systems thinking can provide practical guidance to those building models of complex multilevel social systems in order to inform policy making. Part-whole aggregation and taxonomic aggregation are described as methods of representing multilevel structure, and it is shown how they are interleaved in the construction of vocabulary to describe multilevel systems. This enables complex nested structures to be represented as a kind of backcloth that supports patterns of aggregate and disaggregate numbers that describe the day-to-day traffic of people, resources and responsibility that are essential for systems to function.

Decision making in policy involves examining complex systems and evaluating the possible outcomes of interventions. This can be done in an open way so that different stakeholders can agree on what might happen, even if they disagree on what should happen.

Almost all social and economic systems have many levels. At the highest levels, every ministry in every country is responsible for a multilevel system, *e.g.* health, agriculture, transport, justice, defence, education, and so on. Similarly, all but the smallest companies and enterprises in the private sector have many levels of organisation. To illustrate this, consider the National Health Service (NHS) in the UK. For England this has organisational structure: 1. Secretary of State > 2. Department of Health > 3. NHS England > 4. Clinical Commissioning Groups > 5. planned hospital care, rehabilitative care, urgent and emergency care, community health services, mental health services (NHS, 2016). This five-level organisational scheme would have even more levels if it went down to the level where individual patients receive treatment. As an example from the private sector, the mining company RioTinto divides its operations into twenty countries with varying numbers of companies (RioTinto, 2016). Each of the companies has its own internal organisational structure. In both these examples, the vocabulary and the organisational structure it is expressing are essential to represent and manage the company at the different levels of aggregation.

The science of complex systems has developed new computational methods to investigate possible system behaviours and policy outcomes. These include building computational models that give replicable and sometimes unanticipated insights into system behaviours. The great advantage of computer modelling is that the representation of the system and its dynamics are explicit and open to question.

This chapter analyses the properties of multilevel systems and presents a method of building the multilevel vocabulary necessary to represent their different levels of organisation. It introduces a way of representing multilevel systems at *all* levels in a well-defined way. The presentation will be qualitative through examples and diagrams. A more comprehensive technical account can be found in Johnson (2006, 2014).

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2. Systems thinking, modelling and policy

In the natural sciences it is assumed that there is an external reality that can be studied objectively to discover immutable scientific truths. The phenomena observed seem to be indifferent to being studied and who studies them. The study of social systems is not so straightforward. It is a commonplace that people see the same situation differently. When people act together to achieve a shared goal their views need to be coordinated. One way to do this is construct formal *models* of systems as the basis for consensus. Model construction is a social process with the model evolving through social interaction. *Systems thinking* provides methodologies for building models of social systems. The starting point here will be the four part definition of a system given in Bignell and Fortune (1984) which states that a system is:

1. an assembly of components, connected together in an organised way
2. the components are affected by being in the system and the behaviour of the systems is changed if they leave it
3. the organised assembly of components does something
4. the assembly has been identified as being of particular interest.

The first problem that any investigator has to answer is *where is the boundary of the system?* In the physical sciences it has been very easy to put boundaries around the system studied. The physicist can shut the door of the laboratory and ignore everything that happens outside. Even inside the laboratory much can be ignored. When looking at social systems everything can seem to affect everything else and there are no clear boundaries. However, it is impracticable to include everything in a description of a social system so some things must be ignored or left out but it is really important to know what can be omitted and what it is important to include. When things are left out that do impact on the behaviour of a system it may act in unpredictable ways, and policies may have unintended consequences. The fourth part of the definition of system provides guidance on this when building policy-oriented models of multilevel systems. The system does something that is of particular interest (to the analyst) and will be analysed in this light. Anything that impacts on what is of particular interest will be included in the representation of the system and its environment. Thus:

1. anything the system can control directly is *inside* the system
2. anything else that affects the system or its elements but cannot be controlled by the system is in the *system environment*.
3. everything else is *outside* the representation of the system.

The four part definition is explicitly tied to a particular stakeholder or stakeholder group and allows that different stakeholders may have different views of the same system. For example, Figure 1(a) shows an individual or group's view of a system that may differ from another individual or group's view of the 'real' situation. Figure 1(b) shows the boundary to the formal representation and those things not explicitly included in the system or its environment.

Figure 1. Situations and individual systems representations of them

Models are used to explore the behaviour of systems. All policy is based on models, whether or not they are formalized and based on evidence. Although all models are imperfect representations of the 'real' situation, an advantage of using formal models is making explicit what is under consideration and what is not, and what is known and what is not. A *model* of a system is an explicit list of its components and the components of its environment and an explicit description of how they are connected in an organised way. The model will state explicitly what the system does and the transformations it makes to itself and its environment through time, and how it responds to the environment and changes in the environment through time.

3. Representing multilevel part-whole social structures

Any system has at least two levels - the whole system at the highest level and the component parts at the lowest level. For example, Figure 2 illustrates a UK General Practitioner (GP) system. A patient with a health problem wanting to see a doctor contacts the receptionist to request an appointment, which either results in an appointment being made, or the patient being left with their problem unresolved. In the former case the patient has a clinical consultation with the doctor resulting in a diagnosis with or without a prescription for medicinal treatment, or it may result in a referral to a specialist physician.

Figure 2. An action-flow description of the General Practitioner system in the UK

Figure 3 shows the GP system drawn as a *part-whole cone*. At the lowest level are all the parts, and at the highest level the apex represents the whole system. These are called the *Top Level*, and the *Bottom Level*. The ellipse at the bottom of the cone is called its *base*. We write $base(GP\ System) = \{ patient, problem, receptionist, doctor, diagnosis, advice, prescription, referral, pharmacist, \dots \}$ to show the set of parts. The symbol R_{GP} signifies the relational structure between the parts. Thus R_{GP} maps the base of the cone at one level to its apex at a higher level, as shown by the arrow between the base and apex of the cone.

Figure 3. The GP system as a part-whole cone.

However, the GP system is just one subsystem of the whole NHS. There are other subsystems such as the Hospital and Ambulance Systems. These all have to fit together to make the whole, and there will be legal and administrative documents defining this. Let the symbol R_{NHS} represent all the relational information that says how these subsystems work together.

For example, in Figure 4 the Ambulance subsystem is connected to the Emergency Phone Line System (not shown) used by members of the public for emergency access the Police, Fire and Ambulance systems. Given the necessary information, an ambulance is dispatched in the Ambulance system and either treats the patient where they are or transports them to a hospital, where the Ambulance subsystem hands over responsibility for the patient to the Hospital System. This is part of the R_{NHS} relationship.

Now, as shown in Figure 4, the representation has three levels: the whole system at the *top level*, the subsystems of the system at an *intermediate level* and the parts of the subsystems at the *bottom level*.

Figure 4. Intermediate levels between the top and bottom levels

The part-whole relationship by assembly is particularly important in multilevel systems because constructed wholes are never parts of their parts, *e.g.* a car is not part of its engine and the NHS is not part of a hospital. This means that *the parts are always at a lower level to the whole*, and there is an immutable upwards arrow that establishes a difference in levels.

It is common to call the highest level of a system its macrolevel, the lowest level its microlevel and the intermediate level its mesolevel. The problem with this is that many systems have more than one intermediate level, as illustrated in Figure 5. One way to discriminate the intermediate levels is to number them with Level 1 at the microlevel, Level 2 the first mesolevel, Level 3 the next intermediate level, Level 4 the next intermediate level, and Level 5 the macrolevel of the whole system, as shown at the right of Figure 5.

Figure 5. There may be many intermediate levels between the top and bottom levels

Since building a multilevel vocabulary often involves adding or removing levels between existing levels, there is no absolute interpretation for the number representing a level. This relatively can be emphasized by the '*Level N+k*' notation, where *N* is an arbitrary level, *Level N+1* is the level above it and *Level N-1* is the level below.

Defining part-whole structures has to be done with care, as illustrated by the following example taken from Winston *et al.* (1987):

Simpson's finger is part of Simpson,
Simpson is part of the Philosophy Department,
Simpson's finger is part of the Philosophy Department.

The university's rules and statutes determine the assembly of Simpson and other academics into the Philosophy Department. The statutes establish which people are members (the parts) and the part-whole relationship of interaction between those people to form the higher-level structure, *e.g.* hold weekly meetings with minutes. By itself, Simpson's finger is not eligible to be a member of the Philosophy Department and the apparent conundrum is artificial.

More generally, when describing the structures of multilevel systems it is necessary to know explicitly the relationships that makes the parts into the whole.

To summarize this section, the key features of part-whole systems are that:

- the components of a part-whole structure exist at a lower level than the whole
- it is necessary to make explicit how the parts fit together to make the whole
- a structure at one level may become a component in a higher level structure
- there can be any number of levels between the lowest and highest levels

4. Multilevel Taxonomic Aggregation

Taxonomic aggregation plays an important role in policy and management. For example, the *Statistical Classification of Economic Activities in the European Community*, known as NACE (*Nomenclature statistique des Activités économiques dans la Communauté Européenne*), has twenty highest-level classes:

A - Agriculture, forestry and fishing
B - Mining and quarrying
C - Manufacturing
D - Electricity, gas, steam and air conditioning supply
E - Water supply; sewerage; waste management and remediation activities
F - Construction
G - Wholesale and retail trade; repair of motor vehicles and motorcycles
H - Transporting and storage
I - Accommodation and food service activities
J - Information and communication
K - Financial and insurance activities
L - Real estate activities
M - Professional, scientific and technical activities
N - Administrative and support service activities
O - Public administration and defence; compulsory social security
P - Education
Q - Human health and social work activities
R - Arts, entertainment and recreation
S - Other services activities
T - Activities of households as employers; undifferentiated goods - and services - producing activities of households for own use
U - Activities of extraterritorial organisations and bodies

Each of the classes has a variety of subclasses, as illustrated for Construction in Table 1. The taxonomic aggregations can be drawn in the form of trees, as illustrated in Figure 6.

Division	Group	Class	ISIC Rev. 4
SECTION F — CONSTRUCTION			
41		Construction of buildings	
	41.1	Development of building projects	
	41.10	Development of building projects	4100*
41.2		Construction of residential and non-residential buildings	
	41.20	Construction of residential and non-residential buildings	4100*
42		Civil engineering	
	42.1	Construction of roads and railways	
	42.11	Construction of roads and motorways	4210*
	42.12	Construction of railways and underground railways	4210*
	42.13	Construction of bridges and tunnels	4210*
	42.2	Construction of utility projects	
	42.21	Construction of utility projects for fluids	4220*
	42.22	Construction of utility projects for electricity and telecommunications	4220*
	42.9	Construction of other civil engineering projects	
	42.91	Construction of water projects	4290*
	42.99	Construction of other civil engineering projects n.e.c.	4290*
43		Specialised construction activities	
	43.1	Demolition and site preparation	
	43.11	Demolition	4311
	43.12	Site preparation	4312*
	43.13	Test drilling and boring	4312*
	43.2	Electrical, plumbing and other construction installation activities	
	43.21	Electrical installation	4321
	43.22	Plumbing, heat and air conditioning installation	4322
	43.29	Other construction installation	4329
	43.3	Building completion and finishing	
	43.31	Plastering	4330*
	43.32	Joinery installation	4330*
	43.33	Floor and wall covering	4330*
	43.34	Painting and glazing	4330*
	43.39	Other building completion and finishing	4330*
	43.9	Other specialised construction activities	
	43.91	Roofing activities	4390*
	43.99	Other specialised construction activities n.e.c.	4390*

Table 1. The NACE classification for construction

(From: <http://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF>, Page 72)

Figure 6. Part of the NACE taxonomic aggregation drawn as a tree.

Usually taxonomies are created for a purpose, such as the collection of statistics. For example, Table 2 shows the added value of a company's activities classified as Construction (C), Wholesale and retail trade; repair of motor vehicles and motorcycles (G), and Professional, scientific and technical activities (M). In principle firms can assign the added value of their activities to the different classes, and this can be summed over all firms to give national statistics of the activities at the various levels of aggregation. Typically such figures are used for economic planning by national government and the European Commission.

Section	Division	Group	Class	Description of the class	Share
C	25	25.9	25.91	Manufacture of steel drums and similar containers	10%
	28	28.1	28.11	Manufacture of engines and turbines, except aircraft, vehicle & cycle engines	6%
		28.2	28.24	Manufacture of power-driven hand tools	5%
		28.9	28.93	Manufacture of machinery for food, beverages and tobacco processing	23%
			28.95	Manufacture of machinery for paper and paperboard production	8%
G	46	46.1	46.14	Agents involved in the sale of machinery, industrial equipment, ships & aircraft	7%
		46.6	46.61	Wholesale of agricultural machinery, equipment and supplies	28%
M	71	71.1	71.12	Engineering activities and related technical consultancy	13%

Table 2. An example of using the NACE classification to record a company's added value
<http://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF>

5. Naming elements and classes by intension and extension

There are two ways of defining classes. One way involves listing all the things referred to by a word or phrase. For example, at the time of writing the class of 'twenty-first century British Prime Ministers' has members Blair, Brown, Cameron and May. This listing is called a definition of 'twenty-first century British Prime Ministers' by *extension*.

In contrast to defining terms by extension, they can be defined by *intension*, which usually means establishing a rule defining class membership. For example, according to the Oxford Dictionary, a car is "a road vehicle, typically with four wheels, powered by an internal-combustion engine and able to carry a small number of people". Thus my desk is not a car, but the machine I drove to work this morning is a car. Intensional definitions can be difficult to apply in practice because they require interpretation. For example, some 'cars' can carry nine people, so may not qualify as cars. Also as shown in Figure 7(b), the definition of car may need updating to include things excluded by the intensional definition but desired in the extension such as being powered by electricity, as with the BMW i3 electric car.

When building structured vocabularies inconsistencies can arise between intension and extension. For example, a vocabulary to classify television programmes had a class 'Sports Not Requiring Equipment' illustrated extensionally with the examples wrestling and boxing (Figure 7(c) (Gould *et al.*, 1984). However boxing requires equipment such as gloves, gum shields, and a ring and is not a 'sport not requiring equipment'. The problem here is that the *name* of the class itself has meaning, and in this case the intension contained in the name does not match the desired extension.

Figure 7. Care is needed when naming classes and defining them by extension and intension

Note that taxonomic cones are different to part-whole cones. An element in the base of a cone defined by extension means ‘belongs to this list’, while intension means ‘the element obeys this rule’. In contrast, part-whole aggregation requires an assembly relation saying ‘the elements are put together this way’. Part-whole assemblies create new things.

A definition by extension corresponds to using a computer lookup table with all the elements listed as data. A definition by intension corresponds to formulating a computer function that accepts data and decides if the required pattern holds between them or not.

5. Grounding and transitivity in taxonomic aggregation

Figure 8. The words Einstein, Curie and Lavoisier are *grounded* elements, not classes.

Taxonomic aggregation does not create new entities, it simply provides a way of defining subsets of entities. For example, Figure 8 (a) shows a taxonomy of scientists with a subclass of physicists. It also shows the chemist Lavoisier. All of these scientists existed irrespective of taxonomic definitions such as ‘physicist’ and ‘chemist’ which give just one of many ways these they could be grouped, *e.g.* they could be grouped as women and men (Fig. 8(b)). Figure 8 also illustrates how words can be *grounded* in real things. Here Einstein, Curie and Lavoisier are *grounded elements*, *e.g.* the name ‘Curie’ here uniquely identifies the real person Marie Curie. In contrast the word ‘physicist’ does not uniquely name any individual, but names a group of individuals. The extension of the word ‘physicist’ uncontroversially includes Einstein and Curie. Whether or not it should include Lavoisier is a matter of debate and agreement between those defining and using the taxonomy.

Taxonomies are usually *transitive*. If a grounded element belongs to a lower level class, and that lower level class aggregates into a higher-level class, then the grounded element also aggregates into the higher-level class. This is because the classes of the taxonomy define *sets* of grounded elements, and a subset of a subset of a set is also a subset of that set.

Taxonomic aggregations are usually tree-like partitions with disjoint classes for any level. This can cause distortion and is not essential. For example, in a taxonomy to classify sports, water polo belongs to both the classes ‘ball games’ and ‘water sports’. When counting the number of ‘ball game’ and ‘water sports’ teams, a water polo team counts for both classes. However, there is no need to double count the water polo team when counting the number of SPORTS teams at a more aggregate level.

Figure 9. A lattice taxonomy allows elements to belong to more than one class

7. Interleaved Multilevel Part-Whole and Taxonomic Aggregation

Words and phrases are used to denote objects, relationships between objects to form systems, the systems formed, and classes of objects and subsystems. This vocabulary has a structure of levels reflecting the things identified. This can be signified by drawing an upward arrow between them. Figure 10(a) shows a three level taxonomic aggregation while Figure 10(b) shows a three level part-whole aggregation.

Figure 10. Taxonomic versus structural aggregation

Although they are different, part-whole aggregations and taxonomic aggregations work together in multilevel systems. To illustrate this consider the arch construction in Figure 7.

Figure 11. Interleaved taxonomic and part-whole aggregations

In this multilevel system blocks are assembled to form three types of arches. Each individual arch is assembled into a class of arches of that type. At the lowest level, the individual blocks are assembled into sets of their type. Thus the part-whole aggregation is sandwiched between

two taxonomic aggregations. At the top level the different classes of arches are brought together under a single taxonomic class of arches, denoted A . In this example there are three taxonomic aggregations and one part-whole aggregation.

Figure 12 illustrates how such a scheme might be used and the subtle distinction between an organisational description of the objects in a multilevel system, the objects themselves, and the part-whole structure of the objects. On the left is a multilevel description of the arch in terms of the types of blocks that are assembled to make it. This is different to an actual instance of the block, as shown on the right. The multilevel description of the arch means that one can work top-down on the left to find out the components are necessary to build an instance of the arch. This information enables the set of parts to be assembled, as with a furniture flat pack. The relation R then says how those parts should be assembled, as with the instructions in a flat pack.

Bottom-up, the assembly of the actual parts into sets of parts of the same kind is called a *homogeneous grounded taxonomic aggregation* at the bottom left of Figure 12. This aggregation is like putting components of the same kind into a bin container.

The bottom-up assembly of the set of components needed to make the arch is called a *heterogeneous grounded taxonomic aggregation* at the bottom right of Figure 12. This is like taking the parts from bins of homogeneous components to make the set of heterogeneous components, ready for the bottom up part-whole arch assembly. This process creates a real object, *grounded* in the real components at the lowest level.

Figure 12. The interleaved taxonomic and part-whole aggregation in action

Although this illustrative example involves physical objects, these ideas can equally well be applied to social systems. For example when building a team of people, the types of people will be specified and so will the way they must work together to achieve the team objective. Then individual people will be appointed as part of a heterogeneous grounded taxonomic aggregation. Following this, part-whole aggregation will be needed to meld the individuals into a well-working team. This might involve training for individuals and the whole group.

8. Traffic on the multilevel backcloth

In an early attempt to formulate a mathematical theory of multilevel systems, R. H. Atkin (1975, 1977) made a distinction between relational structure and patterns of numbers distributed over relational objects called *simplices*. The distinction is clear to see in network theory. Networks are formed from *vertices* and *edges*, also called *nodes* and *links* in social analysis. Whereas a network such as a road system may not change over a given period of time, the speed and number of vehicles may change considerably during that time. Atkin

called the relatively static relational structure the *backcloth* and he called the relatively dynamic patterns of numbers the *traffic*.

Backcloth structure at the microlevel could include the relational structure of a family. The traffic on this structure could include the number of family holidays taken and the money spent on them. At higher levels, institutions such as businesses form relatively fixed relational structures supporting patterns of numbers such as their costs and incomes. Another example is the relational structure of a hospital supporting a traffic of patients treated and money spent.

For decision-making purposes, the patterns of numbers over the multilevel structure are of great importance. In particular it is important to understand how numbers at the lower level aggregate into number at the higher level, and how higher level quantities can be distributed top-down. Figures 13 and 14 illustrate the bottom up aggregation of backcloth and traffic.

Figure 13. Aggregation of numbers over the multilevel backcloth.

Figure 14 shows disaggregate parts mapped to disaggregate numbers at the lower level mapped to aggregate numbers at the higher level. An important feature for these mappings is that they are coherent as the multilevel traffic aggregates over the multilevel backcloth.

Figure 14. Aggregating backcloth and traffic from Level N to Level N+1

The general question is whether or not the *Level N+1* numbers can be reconstructed from the *Level N* number? The answer is that it can if the mappings have appropriate aggregation properties.

Figure 15. A city assembled from four zones

As an example of aggregation of lower level statistics consider a city denoted by the symbol z^{N+1} at *Level N+1*. Suppose it is made up of four *Level N* zones, z_1^N , z_2^N , z_3^N , and z_4^N . The population of the city at *Level N+1* is simply the sum of the populations of the zones at *Level N*. It will be called a *linear* aggregation. The widespread use of spreadsheets for managing social systems shows that linear aggregation is very common. However, complex multilevel systems have many non-linear structures and, by themselves, spreadsheets by are not powerful enough to represent their dynamics.

9. Information closure and the lowest level of representation

What is the lowest level necessary to understand the dynamics of multilevel systems? For example, when trying to understand the behaviour of the people in a social system is it necessary to know their genetic makeup? The answer is that it depends on the purpose of the analysis. Genetic makeup is central in personalized medicine (Royal Society, 2005), but currently it is not considered relevant to the majority of social systems in the public and private sectors.

In a different context and using a different notation, Pfantte *et al.* (2014) suggest the following properties for multilevel systems:

“I. Information closure: The higher level process is informational closed, *i.e.*, there is no information flow from the lower to the higher level. Knowledge of the microstate will not improve predictions of the macrostate.”

“II. Observational commutativity: It makes no difference, whether we perform the aggregation first, and then observe the upper process, or we observe the process on the microstate level, and then lump together the states.”

These properties are illustrated in Figure 16. The first says that the upper process is information closed if knowledge from the lower process adds nothing new to knowledge of the higher process. For example, Hook’s law states that the extension of a spring is proportion to the mass attached to it. This could be modelled at a lower level using Finite Element methods but for most purposes this would add nothing useful to Hook’s Law. Observational commutativity means that going the round diagram either way makes no difference.

Figure 16. Observational commutativity

10. Lowest level traffic disaggregation – synthetic micropopulations.

In complex systems science and its applications to decision-making, computer simulation is a major tool for investigating the possible consequences of policy actions. Moeckel *et al.* (2003) write “Microsimulation models require micro data. However, the collection of individual micro data, *i.e.* data that can be associated with single buildings, or the retrieval of individual micro data from administrative registers is neither allowed in most countries nor desirable for privacy reasons. Therefore these models work with synthetic micro data that can be retrieved from general accessible aggregate data. A synthetic population has to be generated that represents individual actors in the form of households and household members. A synthetic population is statistically equivalent to a real population. For each household characteristic such as household size, income, number of cars and address are generated. Each person is described by characteristics such as age, sex, religion, and work location. For creating addresses for the synthetic population, land-use data are disaggregated to raster data by GIS techniques.” The first large-scale applications of synthetic micropopulations for micro simulation was the TRANSIMS systems developed at Los Alamos National Laboratory for road traffic modelling in the nineteen nineties (Barrett *et al.*, 1999).

Figure 17 shows the generality of creating synthetic micropopulations. On the left, at *Level N* each sampled individual has some characteristic. These values are aggregated to give the population statistics for the real population. Implicitly there is a population to which these statistics can be extrapolated. For example, if data were collected on the incomes of people in various British cities, the *extrapolation population* could be Britain, but would not include Spain or Germany, and certainly not India, China or Brazil.

Figure 17. Synthetic micropopulations

Higher-level statistical values can be distributed across a new 100% synthetic population at *Level N*, *i.e.* every member of the new population is assigned a value. This is done by a process of *disaggregation* (the down arrow on the right) which typically uses Monte Carlo methods to assign values to the members of the new population.

Synthetic micropopulations are very important for modelling multilevel systems in a policy context. Many social systems are information complete at the lowest level of individual people. To explore their multilevel dynamics it is essential to be able to run computer models at the lowest level of individual people. Synthetic micropopulations enable this.

11. The Formal Model of Multilevel Systems

Figure 11 shows the *Formal System Model* (FSM) (Fortune, 1993). It is adapted from Checkland (1981) who in turn drew on the work of Churchman (1971) and Jenkins (1969). It has been widely used to identify system risk and causes of system failure. In the context of multilevel systems, this model explicitly considers three levels: the system, its subsystems, and the wider system in which it is embedded. Of course, a subsystem one FSM could itself be modelled as a system with its own subsystems and wider system in a different FSM, and similarly, the wider system could be represented as a system in a different FSM with its own wider system but in this section it will be shown how a single model can be extended to any number of levels of representation.

Figure 18. The Formal System Model (adapted from Fortune, 1993)

This multilevel model suggests a number of important questions for those analyzing systems for policy purposes. The questions, adapted from Fortune and Peters (1995), are:

- What is the continuous purpose or mission of the system and its subsystems?
 - What are the system and subsystems supposed to do? Who set the purpose/mission? Does everyone agree at every level? Have the expectations been made known within the system? Are they consistent between levels?
- What is the structure of the system?
 - What are the components of the system and its subsystems? What are the interactions between the parts? At each level, how do the system and subsystems bring about the transformations to convert inputs into outputs?
- What is the nature of the decision-making sub-system at each level?
 - How is the system managed? Who is responsible for deciding how the purposes of the system are achieved at each level? Who is responsible for providing the resources to enable this to happen?
- What is the nature of the performance-monitoring sub-systems?
 - Are the transformation processes being monitored at each level? Are deviations from the expectations being reported to the decision-making subsystem so that corrective actions can be initiated where necessary?

- What is the degree of connectivity between the multilevel components?
 - At each level, what are the essential interactions for the system to perform without failure? Where is there feedback between the components of the system? What types of influences link the components within and between levels?
- What is the environment that interacts with the system?
 - What are the components of the multilevel environment? Where are the boundaries between the system, its subsystems, and their environments?
- How are resources distributed across the system?
 - At each level, does the decision-making subsystem control the resources? Have sufficient resources (in terms of quality and quantity) been allocated to carry out the transformations that are required within and between levels?
- How does the system maintain continuity and adapt to change?
 - At each level, how does the system monitor its changing environment? What is the capability of the system and its subsystems to adapt to change? How effective are the system and its subsystem's attempts to influence the environment? Are they well coordinated between levels?

In network science, a repeated or noteworthy configuration of nodes and arrows is called a *motif* (Johnson et al. 2017). Inspection of the Formal System Model shows the motif illustrated in Figure 19 at both the system and wider system levels:

Key to meaning of the arrows

P – Performance: reports performance information to
 R – Resources: - provides resources and legitimates operations
 I – Information: provides information on
 M – Mission – decides on transformations implements by designed set of subsystems and components
 E – Expectation: makes known expectations

Figure 19. The systems – decision making – monitoring motif of multilevel systems

This kind of ‘fractal’ structure is exactly what is required for modelling multilevel systems for policy applications. In principle *every* managed social system has subsystems and components, and the managers’ responsibilities include making clear the mission and the expectations at each level and allocating the resources necessary to enable the desired transformations to be made. The managers’ responsibilities also include monitoring the performance of the system, which in turn requires that the necessary information be made available. The configuration of components and arrows in Figure 19 will be called the *multilevel systems motif*.

This motif structure gives a general architecture for the multilevel management of multilevel systems, as illustrated in Figure 20.

(a) the combined system– and wider system– decision making – monitoring motifs

(b) the system – decision making – monitoring structures at micro-, meso- and macro-levels

Figure 20. Nested system– decision making – monitoring motifs

As an example, consider the so-called bed-blocking problem which the National Audit Office (2016) summarizes thus.

Unnecessary delay in discharging older patients ... from hospital is a known and long-standing issue. For older people [this] can lead to worse health outcomes and can increase their long-term care needs [and] is an additional and avoidable pressure on the financial sustainability of the NHS and local government. ... Older people are cared for in hospital by the NHS, but once discharged some may need short- or long-term support from their local authority or community health services. This may involve living at home with some support or living in a care home. NHS community healthcare and short-term care to increase people's independence provided by local authorities are free. Local authorities have to apply a financial means test and an eligibility test based on levels of need for other types of care.

Figure 21. The health and social care accountability and funding structure (NAO 2016)

... The number of recorded delayed transfers of care has increased substantially over the past two years [a 31% increase between 2013 and 2015]. The main drivers for this increase are the number of days spent waiting for a package of home care (which more than doubled between 2013 and 2015, from 89,000 to 182,000) and waiting for a nursing home placement or availability (which increased by 63%) ... The delayed transfers of care data substantially underestimate the range of delays that patients experience. ... we estimate that the number of older patients in hospital who are no longer benefiting from acute care to be ... about 2.7 million bed days a year.

(National Audit Office, 2016, Pages 5-7, Sections 1, 2, 9 and 10)

The analysis of this problem by the National Audit Office includes a representation of the health and social care accountability and funding structure reproduced here as Figure 21. The left and right of the diagram can be separated to give the formal multilevel system model sketched in Figure 22.

Figure 22. An abbreviated formal multilevel system model of the bed-blocking system

A complete version of the abbreviated model shown in Figure 22 would require the multilevel structure of the Hospital Services system and Social Care Services system to be made explicit. But even without this the model illustrates that the problem of a hospital administrator not being able to discharge a patient is due to a local authority administrator being unable to put together a suitable care package at the microlevel.

The NAO analysis includes the possibility of the Local Electorate monitoring and improving the performance of local authorities in providing the social care packages required to alleviate the bed-blocking problem. However, the range of services provided by local authorities is much wider than those provided by the NHS. The resources allocated by local authorities to social care compete with those allocated to education, transport, planning, parks, leisure, food standards, waste disposal, and much else. Voters may be dissatisfied with local politicians for their performance in any of these areas. Furthermore in the UK, local elections are often influenced by national issues as much as they are by local performance. This suggests that electoral pressure on local councils is not an effective performance monitoring tool.

There are major problems underlying the UK's bed blocking crisis. The broad political consensus is that this care should be provided by the State, and all the major parties are committed to this principle but the level of social care required for a growing aging population would be very expensive and thus require significant tax increases. However, there is no consensus on how the extra money should be raised, and what would be the best way to spend it. There are many suggestions reflecting individual and collective norms and values, but no practical way to choose between them.

On 6 January 2016 Norma Lamb MP proposed setting up a cross party commission to address the problem, requesting that "leave be given to bring in a Bill to establish an independent commission to examine the future of the National Health Service and the social care system; to take evidence; to report its conclusions to Parliament; and for connected purposes." He said "The Government face a choice—either the system will drift into a state of crisis or we confront the existential challenge now. This transcends narrow party politics. We have to decide as a country how much we want to spend on our NHS and care system. What can we do differently to make better use of the resources available? Should we consider, as I have proposed, a dedicated NHS and care tax, and give local areas the ability to vary it? Should we end the artificial divide between the NHS and social care?" (Lamb, 2016a,b).

If the request for an independent commission is granted how might the science of complex system be useful? The question of how much a country wants to spend on its health and welfare system is political. The question of what can be done differently to make better use of the resources available is technical, and this is where science can help. Generating and evaluating different ways of doing things means *designing* and testing new structures and procedures. This involves making explicit the requirements of the system and the constraints that must be satisfied. The health and welfare system for an aging population is a complex multilevel system and the methods of complex systems science can be used to investigate the possible outcomes of any suggested policy attempting to solve this long standing problem. A more precise prescription for combining policy questions, complexity science, policy informatics and citizen engagement as *Global Systems Science* is given in Dum *et al.* (2017).

The purpose of the multilevel system model presented here is to support computer analysis of the possible outcomes of policy. There are many actors and agents in this system, from national politicians to those delivering services at the local microlevel, including individual nurses, doctors, administrators, porters, and so on. The multilevel structures sketched here can support computer models of these agents and their interactions at all system levels, allowing any policy options to be tested and different policies to be compared. Without computational assistance analysts may get lost or miss something important at one of the levels.

Computer simulations cannot say definitively that a policy will work but they can investigate the range of likely outcomes as an input to the policy process. Simulations can sometimes give strong evidence that a policy will not work, *e.g.* by showing that the policy never gives outcome expected, no matter how the assumptions and associated parameters are varied.

Multilevel social systems are often information-complete at the lowest level of the individual agent. What people do at the microlevel can impact on all higher levels and cause a system to fail. The theory of synthetic micropopulations provides the data necessary for simulation at all levels including the lowest.

12. Conclusions

This chapter has outlined a method of representing multilevel systems for policy purposes. Making clear the multilevel structure is particularly important when the impact of policy is to be investigated by computer simulation. However, even for less formal analyses of policy awareness of the subtleties of multilevel systems can add greater precision and make successful policy more likely. The main ideas covered include:

- Socio-economic systems have two kinds of multilevel structure.
 - Part-whole systems play a major role in multilevel systems, where intermediate level wholes may become parts in higher-level structure.
 - Taxonomic aggregation plays another major role in multilevel systems but, taxonomic aggregation is very different to part-whole aggregation.
- Part-whole and taxonomic aggregations are interleaved in multilevel systems.
- Multilevel classes can be defined by extension (listing the members) or intension (giving a rule for membership). Care is required to ensure that class names with intensional meaning are consistent with the intended extensions.
- Systems thinking provides fundamental ideas and motivation for analyzing systems, including providing a multilevel representation by generalizing the Formal Systems Model to include all levels of decisionmaking.
- A theory of multilevel systems must be grounded in real things. This includes part-whole aggregations where the part-of relation may or may not be transitive.
- Taxonomic aggregations need not force observers to assign things to just one class.
- Confusing anomalies can appear in multilevel systems, *e.g.* part-whole aggregation is not transitive.
- Objects in multilevel systems can be grounded and information-closed at intermediate levels so that analyzing them at lower levels gives no extra information.
- Patterns of numbers are distributed over the multilevel structure which acts as a kind of backcloth for the system traffic.
- data can be disaggregated top-down to form synthetic micropopulations to enable massive multilevel computer simulations to support policy.

In an increasingly complex multilevel world the risks inherent in ignoring or not knowing the dependencies between subsystems are increasing. An operational theory of multilevel systems will not prevent the willful implementation of bad policies, but can support the design and implementation of policies that achieve their objectives without unintended consequences.

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