Towards a Metaphorical Biology

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ABSTRACT: The metaphorical nature of biological language is examined and the use of metaphors for providing the linguistic context in which similarities and differences are made is described. Certain pervasive metaphors which are characterised by systemic properties are noted, and in order to provide some focus to the study, systemic metaphors associated with machine, text and organism are discussed. Other systemic metaphors such as society and circuit are also reported. Some details concerning interrelations between automaton and organism are presented in the light of the previous discussion.

An approach towards the analysis of biosystem metaphors is outlined which relates part-whole, organisational level and systemic metaphors in a single model. Examples are provided throughout the discussion and mainly come from computing. The potential for metaphorical transfers between these domains is considered.

KEY WORDS: Computing, metaphor, models, systemic metaphors.

1. INTRODUCTION

> Metaphor and simile are the characteristic tropes of scientific thought, not formal validity of argument...
>
> (Harré 1986, p. 7)

The purpose of this article is to look at biological thinking in relation to some highly pervasive metaphors which affect the kinds of models that are produced to describe and explain biological systems. In so doing, an attempt will be made to consider certain ways of categorising metaphors. A selective examination of some aspects of the creative nature of metaphor and how it can be applied to and shared with certain developments in computing will also be considered.

There are many examples from the history of science of how new discoveries and insights have been made by scientists thinking metaphorically. Some metaphors have a strong image-producing quality. Kekulé's dream of snakes chasing their tails that 'seeded' his model of the benzene molecule is a very good example. We may also note the importance of the didactic value of certain visual metaphors, for example, the lock-and-key hypothesis of enzyme-substrate action attributed to Emil Fischer. Some metaphors are based on an ideal mathematical form. For example, the circle has been an important inspiration to the evolution of the biosciences. William Harvey's proposal for the existence of

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'invisible anastomoses' (later to be called capillaries) was based on the belief that blood flowed in a circle (also discussed in Rothbart 1984). Thus we read:

> I began to think within myself whether it (the blood) might have a sort of motion, as it were, in a circle. (cited White 1982, p. 198).

There can be little doubt that Harvey's mechanistic approach, together with subsequent investigations of Stephen Hales on vascular systems, had an important influence on the development of physiology. In more recent times we may hypothesise that the discoveries of various biochemical cycles have conceptual associations with the mathematical notion of a circle (e.g., the closed loop in a thermodynamic circuit). Circles are not only found in physiological systems but also ecosystems (e.g., biogeochemical cycles) and more generally in what may be described as feedback systems. Circle and cycle are two examples of a range of concepts which have a mathematical and aesthetic quality and include: symmetry, order, unity, coherence and harmony (based on Engler 1990). Indeed, these and other notions (such as transformation) underpin a structuralist position (Piaget 1971).

Some developments in the biosciences have a close relationship to certain pervasive ways of thinking in our language and thought. For example, the evolution of physiology in the nineteenth century has a strong basis in the idea that an organism is a kind of machine. Thus, Friedrich Wöhler's discovery that the organic compound urea could be made from inorganic components and the definition of Claude Bernard's doctrines of determinism and the constancy of the *milieu intérieur* contributed to the machine view: that vital phenomena are determined by physicochemical conditions (in the same way as the parts of a machine or the workings of a chemical plant). The idea of treating living things like machines can be traced back in modern times at least to Descartes and his mechanical machine analogy of man (Traite de l'Homme 1664). As reductionistic science progressed up to the present century, the machine metaphor continued to be exploited for example, the clock analogy of van Helmont, the heat engine of Lavoisier or the chemical plant of Pasteur. Twentieth century developments in machine theories of life have imported ideas from cybernetics and automata theory such that generalised machines are conceptualised as information processing devices in which energy and matter are kinds of information.

Another example of a pervasive way of thinking in biology which has recently received analysis regarding its metaphorical nature, is the selection metaphor (Ho and Fox 1988). In this case the notion of Darwinian selection (and its subsequent neo-Darwinian elaboration) is examined in terms of the nineteenth century mechanical and materialistic intellectual environment in which it developed (Chapter 1). The rhetoric associated with ideas like competition and fitness is questioned in the light of contemporary experimental findings which suggest the importance of co-operation, the fluidity of the genome and the permeability of Weismann's germ/soma barrier (Chapter 7). Such ideas would not easily fit into the neo-Darwinian scheme. Ho demonstrates how Weismann's barrier, the central dogma of molecular biology and the fixity of a genome within a single life cycle are related to a machine view of life (Chapter 7). It is not the purpose of this article to debate the issues raised by Ho, Fox and others but rather to identify the presence of metaphorical thinking in the biosciences.

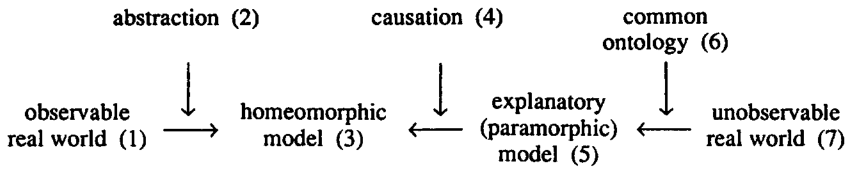
2. AN APPROACH TO METAPHORS IN SCIENCE

The approach developed in this article is based on the belief that people structure their knowledge to help them deal with the complex world in which they live (see Paton and Nwana 1990). The key feature is that knowledge is organised into integrative frameworks. Human understanding of real world complexities is partly achieved by relating what there is to a set of metaphors which are deeply embedded in our thought and language (Lakoff and Johnson 1980) and for this reason we often describe what is unknown in terms of what is familiar.

There are several theories that attempt to explain the nature of metaphor. A good overview of this field and the role of metaphor in scientific thinking can be found in Soskice (1986). In the present article metaphor is understood to be the trope which provides the context for making comparisons and describing differences between objects, and by which analogies and similes can be made. If it is going to work, the referent or tenor of the metaphor (i.e., that which is being described) and the vehicle (i.e., the modifying term which 'carries' it) must share common properties. It is the identification of these properties which is important to an understanding of the usage of metaphors.

The approach to the role of metaphor developed here is based on a realist understanding of science as described by Harré (1970, 1986, 1990) and elaborated in Paton *et al.* (1990b). The real world, that is, that which is referenced, has observable and non-observable features. Humans construct models in order to deal with the complexities of the real world and these are formed by abstraction; by simplifying complexity. In the simplest case a model is produced by abstracting from what is observable alone. This kind of model lacks explanatory power because it cannot account for the causal relations between its parts. Most scientific models have explanatory power. This is because the descriptive or homeomorphic model (see Figure 1) is not only formed by abstraction from observables but is dependent on models of what cannot be observed. These explanatory (paramorphic) models provide the causal framework necessary for explanation. Their basis is in interpretations of the unobservable real world which share common kinds of entities. It is metaphors which provide the context for such common ontologies (see Aronson 1984). For example, Harvey's "invisible anastomoses" (see Section 1 of this article) could only be described within the context of a circuit. The observable was incomplete and it was only with the developments in light microscopy that Malpighi was able to reveal what was until then unseen.

Ricoeur (1973) argued that metaphor is able to redescribe reality through the tension existing between sameness and difference; the old remains but is seen in



Note:
(1) and (7) are the real world domain.
(3) and (5) are cognitive constructions, the products of cognitive processes.
(2), (4) and (6) are cognitive processes involved in model construction.

Fig. 1. Summary scheme of Harré's approach to models (due to Harré 1990).

a new light. Metaphors have a creative function in science and we may note three ways metaphorical thinking can be involved in the production of paramorphic models:

- Catachretic: human experience is bigger than the human literal vocabulary which is used to describe, discover and communicate it (Ortony 1975). We use metaphors to fill this vocabulary gap; for example, to introduce theoretical terminology where none previously existed (Boyd 1979).
- Ontological: metaphors help make up how we see the world, how we set about studying it and can be understood in terms of ways of perceiving relationships and situations from different perspectives (Genter and Grudin 1985).
- Didactic: much of what we assume has been learned "literally" is actually learned metaphorically. Most metaphors (whether good or bad) are intentionally manufactured by a teacher in order to promote understanding by the student (Lewis 1939).

These three categories are not easily isolated from each other, for example, a didactic metaphor in one context such as genome-as-text, could be re-applied creatively in another, for example by transferring ideas concerned with society-as-text such as the need for interpretation and non-mechanistic (contextual) explanations (see Ricoeur 1971). This would specify ontological details related to a different perspective on a domain. The transfer of new metaphors to a domain can change the ways problems are perceived and the kinds of questions that can be asked.

3. SOME GLOBAL METAPHORS IN THE BIOSCIENCES

Two basic kinds of metaphor are particularly important in any analysis of biosystems: SYSTEMIC metaphors and SPATIAL metaphors. The former provides information about the parts, inter-relations and organisation of a biological system and the latter helps us understand its functionality. For example, a natural or artificial neural network (in the computing sense) may be thought of as an automaton which transforms inputs into outputs through some mechanism. The behaviour may be described in terms of changes to an adaptive landscape. These two basic kinds of metaphor are abstract in nature and we identify further metaphors associated with each. A network showing some of the top-level features of our categorisation of global metaphors is shown in Figure 2. A concept in upper case is a global metaphor, and the associated concepts which are listed are properties of the metaphor (called M-properties).

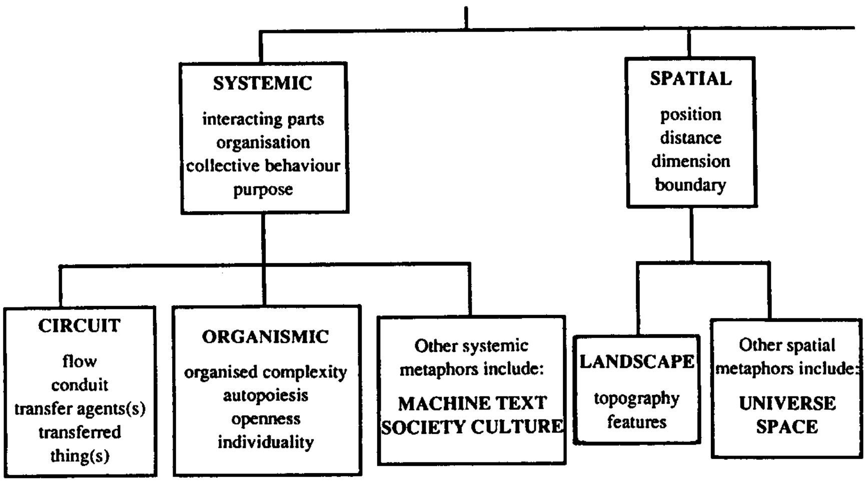


Fig. 2. Some global metaphors.

For example, the circuit metaphor possesses systemic M-properties as well as a its own specific set which includes:

Flow
Conduit
Transfer agent(s)
Transferred things

Each of these properties can be associated with further details of the cognitive domain and its referents in the real world. For example, "flow" takes certain verbs concerned with transfer which will indicate temporal information (in terms of 'from...to...'), causality (associated with the temporal relations) and mechanism (associated with the temporal and causal details). Furthermore, transfer verbs take certain cases and we may expect agent, object, source, goal. The metaphor reveals the richness of the context from which more precise analogies can then be made. For example, electricity is analogous to water within the circuit metaphor in that they flow through a conduit due to differences in pressure or potential. When someone uses the circuit metaphor it is possible to anticipate metatheoretical issues concerned with its use. The circuit M-property "conduit" may be a simple cycle or a complex network – all are included within this broad generic type.

Global metaphors provide common ontologies for the models we construct. Often more than one metaphor is used to talk about a biosystem – mainly because they are described in terms of multiple levels. However, one metaphor will tend to dominate. For example, the notion of "level" is related to the "organised complexity" M-property of the organismic metaphor. For the purposes of this paper, we concentrate on applications of the systemic metaphor (for further details see Paton *et al.* 1991).

4. MACHINES, TEXTS AND ORGANISMS

It has been noted that certain metaphors are pervasive in our thinking. Sometimes they are so pervasive that we may not realise we are thinking metaphorically. In this section three systemic metaphors are examined more fully, namely machine, text and organism.

These three notions share common properties, such as: interacting parts, organisation, collective behaviour and purpose. The presence of common properties at the systemic level of description can lead to category mistakes or certainly to confusion between sortal types. Keil (1989) comments on this when discussing the problems of differentiating between natural kinds and complex artifacts. Part of the problem is because the language used to talk about one systemic metaphor can be transferred to the language used to talk about another. Examples of the overlap between sortal types are given in Table I which shows the source metaphor for some concepts which can be associated with the other two sources. For example, language which denotes more than one source metaphor would include: "programs in the brain", "the language of life", "optimal design for organisms", "photosynthetic efficiency" and "adaptable automata". This reinforces the multidimensionality or polytypicality of the biosystem concept in that a particular biosystem can be described using a plurality of sources.

An example of the interrelationships between machine, text and organism comes from the well-known argument of Polanyi (1968). In his article he attempts to demonstrate the non-reducibility of living systems at all levels of organisation by using analogues from machines and text. He investigates certain common properties between the three in order to demonstrate non-reducibility:

- machines, texts and organisms are under dual control – that is, control that

applies to component interactions and control that applies to the emergent behaviour of the whole;
- machines, texts and organisms have irreducible boundary conditions – in the case of machines and text this is related to design and in the case of organisms to structure.

Source	Examples
MACHINE	Goal, Design, Purpose, Mechanism, Input, Output, Equilibrium, Control, Efficiency, Optima.
TEXT	Code, Program, Interpretation, Language, Grammar, Translation, Meaning, Context.
ORGANISM	Growth, Order, Organisation, Adaptibility, Complexity, Openness, Individuality.

Table I
Some transferable concepts (M-properties) between three systemic metaphors.

Biological machines have mechanical, chemical, electrical, thermodynamic and cybernetic modes of thinking associated with them although there may be one dominant form. The machine metaphor will now be examined with a few examples.

Some biologists may wish to describe a brain as a kind of machine. In this case "machine" is being used metaphorically and we could anticipate certain implications of its use (based on Morgan's (1980) metaphorical analysis of human administrative systems):

- Brains are designed for performing work in pursuit of pre-specified ends and goals and the means-end relationship have a purposive rationality. This will involve teleological or teleonomic justifications. Both of these ideas have a machine basis.
- Model details are drawn from mechanical concepts. Here ideas related to equilibrium, stability, mechanism, control, regulation and balance are likely to be used. The operation of the whole is judged in terms of efficiency.
- The brain is viewed as a somewhat closed, static structure. Emphasis is placed on the input-output nature of the brain-CNS and the normative functions of the system.

The mechanism by which the machine (brain) operates involves the transfer and transformation of information in a circuit. At this level of abstraction isomorphic biological machines (automata – see below) can be described at a variety of levels of organisation such as: DNA (e.g., Burks and Farmer 1984), immune system (e.g., Bruni *et al.* 1975) and brain (Arbib 1972).

If a biosystem's behaviour can be modelled by a computer then a useful analogy can be developed. The abstract system representation in a program together with the mode of operation of the computer can be used to model the biosystem's functionality. One attempt to exploit this idea using physiological models has been made (Yamamoto and Wolff 1984). Concepts describing the compartments of the system digraph, called 'nouns', are represented by memory locations within the computer. The functional dependencies of the 'nouns', the arcs of the system digraph, are called 'verbs', but are only realised when the program is executed. It is possible to integrate program and computer operation and describe it as an automaton. An automaton can be thought of as an idealised machine that performs computations and whose inputs and outputs are symbols (also called information). The living system – automaton metaphor holds when notions such as symbol and transformation are incorporated into the common ontology for both systems. Further analysis reveals the development and transfer of concepts such as learning, memory, program, non-linear behaviour and adaptation (see Farmer and Packard 1986). In more general terms we may note that the current machine metaphor for biosystems need not be trapped in the determinism of the nineteenth century. The tools of thought from non-linear dynamics and automata theory continue to provide concepts for theoretical biology. As Langton puts it:

> ...living systems are nothing more than complex biochemical machines...(though)...different from the machines of everyday experience.
> (Langton 1989, pp. 4–5).

In this case biological automata are the machinery of living organisms.

Will the machine metaphor, in any of its variant forms, always dominate biological thought? There are several reasons to think that it could. Firstly, organisms and machines share a lot of common properties and computers, a major analogue, provide the source for many paramorphic models. Indeed, the scope of metaphorical transfers from biology to computing is also substantial (e.g., Langton 1989; Paton *et al.* 1990a). This is especially true of the life-like behaviours exhibited by software such as artificial neural networks and cellular automata. In this case "life" is artificial; restricted to (living in) a machine. From a metaphorical point of view it will be necessary to ask in what way the virtual world in a computer is a paramorphic model for the real world of an organism. A second, maybe more practical reason for the prevalence of the machine metaphor is that machines and the physics, chemistry, and mathematics used to describe them – whether in holistic or reductionistic terms – has often been the best language available even when particular disciplines may disagree on their overall approaches. For example, the functionalism of physiology and the applied teleology of ethology both utilise the machine metaphor although one tends to be reductionistic and the other holistic.

The scope for machine description has been extended almost to the inclusion of autopoietic systems (see Klir 1985) and the machine concept, with all its associated abstract description languages, continues to evolve. Biology has also provided concepts to the engineering sciences and the interplay of M-properties has blurred the conceptual boundaries between the machine metaphor and the organism metaphor. Machine thinking not only pervades functionalist biology (as could be expected), it also pervades structuralism. For example, many of the functionalist and structuralist concepts distinguished by Lambert and Hughes (1988) appear in the language of neural networks – both natural and artificial. This kind of argument could be used to suggest that the two systemic metaphors will become fused into a single abstract category, a hybrid of machine and organism. However, there are more kinds of systems than generalised machines. Pattee (1977) attempts to provide a criterion for describing a complex system which requires the complementarity of a dynamic (machine) mode and a linguistic, self-descriptive mode. He seeks to utilise two sources – machine and text and although the language he uses remains very much that of a machine, an automaton, he points to requirements beyond current machine thinking. The issue that must be faced is whether describing complementarity using machine language merely extends the metaphor.

A clear example of the elaboration of the computational metaphor for the study of brains by a biologist is that of Young (1978). In the context of the present discussion, we may note that there is a distinctive attempt to shift the emphasis from the machine language of structure-function to the text language of coded information. Young comments:

> The whole organism can be considered as a coded representation of its environment. We can say the wings of a bird 'represent' the air... Thom has put it information equals form. (Young 1978, p. 43).

This shift would be non-trivial. The relationship between structure and function and the argument for treating them as two types of the same thing has been proposed by many writers (e.g., Frank 1935; Gerard 1957). As Young (1978) points out, they express the language of the machine metaphor. Clearly, equating "coded representation" with the symbolic level of description might permit the production of an algorithm that could execute a grammar. At this stage we would still be talking in terms of a machine, albeit an automaton. However, the question of the application of such an approach would depend on the computability of a solution. This may not be possible. Furthermore, emphasis on symbolic computation restricts the discussion to syntactic details. If "information equals form", an appreciation of the meaning and context, that is the semantics, will be necessary. Indeed, consideration of M-properties of text, such as style, structure, interpretation (not the same as translation) and context, have a validity in biosystem desriptions.

Machines and texts are both human artifacts. The referents of scientific models may not be. However, the language of the machine metaphor or the text metaphor play a key part in such models. The natural world is often talked about as a machine that runs or a text to be read. A challenge to biophilosophy would be to provide a means of extending or changing systemic metaphors in meaningful ways.

5. TOWARDS A METAPHORICAL BIOLOGY

Metaphors provide insights into the ways problems are conceived as well as how they can be solved. Four properties of biological systems are now described:

- Architecture – the physical form of the system, its parts and how they are arranged.
- Functionality – the behaviour of the system as a whole.
- Mechanism – the different workings together of the parts that bring about activities.
- Organisation – the ways these activities are expressed in the dynamics of the whole.

These four properties provide a valuable way of managing an analysis of biological concepts and of dealing with metaphorical transfers. One application of this has been a proposal to use the liver as the metaphorical context in which ideas concerned with parallel problem solving in computers could be applied (Paton *et al.* 1990a). A simplified model of the liver was developed (based on Jungerman 1987 and Jungerman and Katz 1989). From this, certain similarities between the liver and the requirements of Multiple Instruction, Multiple Data (MIMD) computers were noted (for an overview of MIMD machines, see Haynes *et al.* 1982). Using the four properties listed above, it was possible to begin to characterize a model liver/MIMD machine:

- architecture (tree-like arrangement of the major communication conduit breaking down into networks of individual vessels, fractal space filling by hepatocytes arranged as radial plates within hexagonal cylinders);
- mechanism (genomic switching of individual hepatocytes, reaction-diffusion catalysis);
- organisation (local communication between parallel components, metabolic integration, zonal heterogeneity);
- functionality (multiple input, multiple data, multi-functional).

In this example, which seeks to apply hepatic architecture, mechanisms, organisation and functionality to MIMD computers, we deal with an abstract biological machine that can process data. Specifically, this data (biochemicals) is in large quantities and of great diversity.

This example seeks to apply models of an organ to models of MIMD computers. The direction of application can also be reversed. This is pertinent to liver research as there are many gaps in knowledge. The caveat, which hopefully is becoming clearer to the reader, is that the liver requires more than the machine metaphor to describe it. For example, hepatocytes within a particular radial plate may be better served by the society metaphor at the organisational level of description.

Biosystems can be investigated from a variety of perspectives and certain aspects of this are relevant to the present discussion. Firstly, as Gerard (1957) pointed out, we must take account of their 'being' (instantaneous state), 'behaving' (contiguous state transitions) and 'becoming' (history). These temporal details are very important because of the ways they can affect our thinking in relation to architecture, mechanism, organisation and functionality. For example, biological architectures are dynamic in their 'behaving' and 'becoming' (i.e. they are not fixed or static – compare with Morgan's M-properties of machine in Section 4 above).

Secondly, a biosystem can be described as either a part or a whole depending on the level of organisation being addressed (see Figure 3).

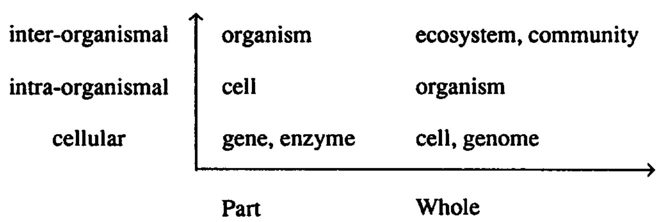


Fig. 3. Some parts and wholes at different levels of organisation.

A cell is a whole at the cellular level but a part at the organismal level and whereas biological thinking about parts tend to be mechanistic, thinking about wholes is not (see Sattler 1986; Lambert and Hughes 1988). This distinction is important for systemic metaphors. As Rapoport (1972) noted, certain dichotomies exist in our thinking which have related meanings: analytic – synthetic, atomistic – holistic, local – global, differential – integral. Part – whole is a further example.

Not only can we investigate the same unit in mechanistic or holistic terms (depending on level), we can also describe one unit metaphorically, in terms of another. For example, in some investigatory situations it may be pertinent to represent an organism as an ecosystem or a cell as an organism. The multiplicity of potential metaphorical transfers further increases when we apply the systemic metaphors (see Figure 2). For example, the "societies" of some ant species far exceed human "societies" in their persistence, division of labour and integration and because of these and other features some argue that an ant colony is better described as an organism. Shifting from one systemic metaphor to another will change the language used to describe a system.

It is now possible to begin to explore the metaphorical relations between parts and wholes at different levels of organisation. The purpose of this is not to create a kind of metaphorical fudge but to identify pertinent common ontologies among possible paramorphic models.

(i) Units as Systems

Figure 4 shows meaningful relations that can be made between part-whole units and some systemic metaphors. The semantics of the relation read from left to right is "AS_A", for example, "organism AS_A text" or "ecosystem AS_A machine". (Note that AS_A is the preferred relation because a homeomorphic model is decribed within the context of the metaphor).

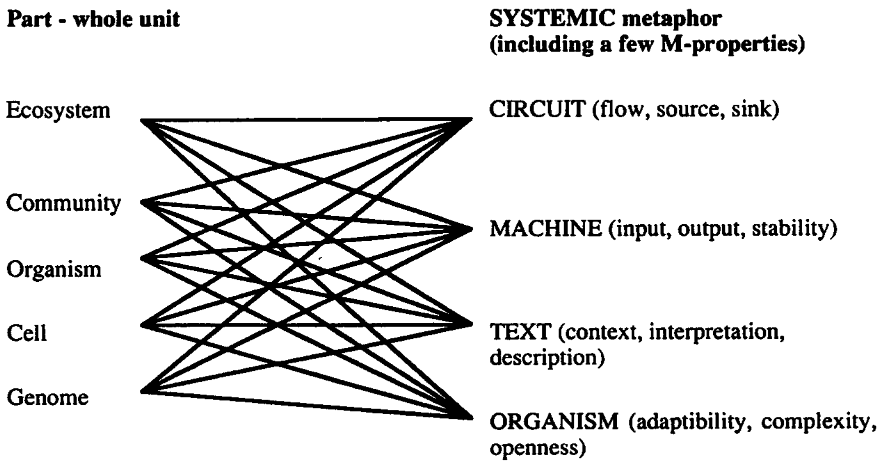


Fig. 4. Relations between biological units and some systemic metaphors.

The implication for the development of biological knowledge is that some systemic metaphors have been exploited more fully with certain organisational units than others (e.g., genome-as-text, cell-as-machine, community-as-society). Investigating the metaphorical links may make it possible to extend their application either catachtretically, ontologically or didactically. The constraining factor is that they all share the same systemic context.

(ii) Units as Units

Any given unit will share M-properties with any other unit. For example, we may construct a model of a cell as a kind of ecosystem. The usual language of cell biology does not include the idea of a niche but, in making such a metaphorical transfer, the part-part emphasis of cellular compartmental models could be changed to the whole-part emphasis of a niche model.

Currently poorly understood organs such as the brain or the liver could be subject to an ecological analysis with an emphasis on: zonation of cells, niche structure, environmental factors, population and community. The idea of zonation should not be treated in the same way as that of spatial location due to a particular functional anatomy; the latter often identifies machine thinking. Zonation occurs because of interactions between parts and between the parts and their environment. A study of the niche structure could de-emphasise ideas about part-part and focus on whole-part interrelations. Niche and zone will complement each other, especially when the collective behaviour of the system is under consideration. The choice of an ecological approach also provides an emphasis for the openness of the system and its interaction with and changing of the environment. Population and community concepts can provide distinctive paramorphic models for dealing with the system as a whole, its origins and development together with that which is shared and changing.

(iii) Metaphors in Metaphors

It has been pointed out elsewhere that circuit is often the key mechanism nested within machine. Another example of the nesting of systemic metaphors is shown in Figure 5 and is one of many ways of describing the relationships between non-reducible organismic levels. It demonstrates that in addition to the semantic relation "AS_A", systemic metaphors also can be interrelated by "IN_A".

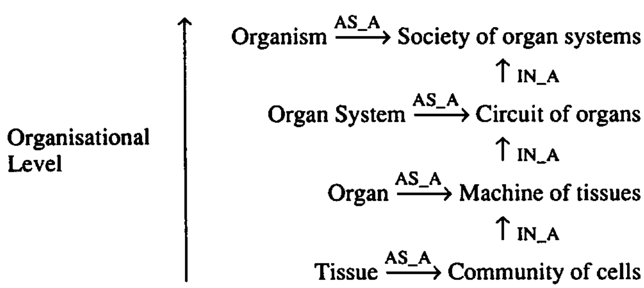


Fig. 5. One example of a hierarchy of systemic metaphors.

The discussion so far has been programmatic. In order to give an application, consider some of the developments in ideas associated with artificial neural networks through metaphorical transfer. Firstly, the processing units in the networks are architecturally and mechanistically very different from biological neurons. The common feature is non-linear behaviour. Crick (1989) noted they did not (then) include any analogous mechanisms to the role of NMDA receptors in long-term potentiation and many mechanistic details of natural networks listed by, for example, Getting (1989) are not found. These artificial systems are not only described in terms of natural nervous systems (see Anderson and

Rosenfeld 1988) but ideas from the immune system have also been transferred (e.g., Farmer *et al.* 1986; Bersini and Varela 1990). Some workers have also transferred concepts in the other direction, that is from neural networks to the immune system (e.g., Vertosick and Kelly 1989; Weisbuch and Atlan 1989). Indeed the paramorphic model used to describe the functionality of the two is the selection metaphor (see Darden and Cain 1989). It is also pertinent to note that concepts associated with other organisational levels have also been used such as, populations (Barnard and Bergman 1990) and colonies (Collins and Jefferson 1990).

6. CONCLUDING COMMENT

Many biological models have a systemic component in their description. They are related to certain pervasive metaphors found in our language and thinking. An appreciation of the nature of these metaphors can help us appreciate the scope and limitations of particular models and the possible contexts in which novel metaphorical transfers can be made. Systemic metaphors occur in biology because different structures and processes exhibit common properties; here called systemic M-properties. Any particular model will exhibit qualitative differences in these properties and this is manifested in the polytypic nature of biosystems and in the restriction that, because it is an abstraction, no single model can simultaneously optimise generality, precision and relevance to all details of the real world domain (Levins 1970). A biosystem considered as a machine may appear to have more in common with another machine than with a biosystem described as a text or as a society. There are more shared properties between the former two. The caveat is that there are limitations to machine thinking in biology. However, alternatives (rather than replacements) are available. The issue of the polytypicality of the biosystem concept and the more general understanding of systemic metaphors is an area of ongoing research. Potential metaphorical transfers need to be managed, not to stifle creativity, but rather to appreciate the language that will be shared. In this respect further investigation of the language associated with each metaphor and its usage in biology will be needed.

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