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CHAPTER SEVEN

Systems Theory

Having arbitrarily introduced the notion of systems in the previous chapter and alluded to various systemic notions on many occasions thus far in the book, it is now appropriate that we step back and consider where this type of thinking leads. This necessitates us first describing some core concepts from Systems Theory, and in particular the notion of self-reference. Then we will be in a position to consider the structural coupling of observation and cognition, before moving on to uncover the paradoxical nature of scientific method that culminates in *Science's First Mistake*.

Systems Theory has developed over many decades and describes different types of systems: physical, biological, economic, political, legal, scientific, technological, social (Arbib and Cornelis, 1981; Bausch, 2002; Germana, 2001; Geyer, 2001; Lin, 1988; Saviotti, 1986; Trist and Emery, 1965). Such broad-ranging usage demonstrates that the Theory has reached a level of abstraction suitable enough for it to be applicable in a large number of areas (Avgerou, 2000; Kallinikos, 2006a,b), and abstract enough to facilitate the emergence of this diversity of applicability (Xu, 2000). Granted there are specific concepts that are used contextually within different individual problem areas, however, the underlying structure of the theoretical framework is common to all, and exhibits a rather remarkable simplicity.

Systems Theory, then, is suitable for communicating a number of ideas across different disciplines, and so lends itself as the natural candidate for the theoretical framework of this book. In this chapter we introduce some key aspects in order to provide a description of the evolutionary processes of science, and to reflect on key scientific ideas, as well as on their interplay with technology. In particular we focus on self-reference, a unique concept within the tradition of second-order cybernetics that has influenced the latest steps in the evolution of Systems Theory. We will then use this concept to describe the processes that orchestrate the development of scientific theories, as well as to highlight the inevitable emergence of paradoxes whatever the system identified by an observer.

System/Environment

We should start by asking: just what is a system? A simple way to proceed when considering relevant notions is initially to compare a system with a

biological cell. A cell contains ribosomes, cytoplasm, mitochondria etc. Each of these could have been chosen to be a system in itself, or alternatively they could be viewed as sub-systems within the system of the cell. The cell itself and its components are seen to be coherent by an observer, and their properties and mutual behaviours factor into the choices that turn this complex thing into a perceived unity: a system.

No matter how we choose to define our system, the choice implies the designation of a specific perspective for a particular purpose. Each perspective can change, depending on the purpose of the observer designating the system and operating within his own particular choices. The metaphor of choosing our system to be similar to a cell shouldn't be imposed too rigidly, and it should be jettisoned as soon as possible, as we will need to generalize our ideas beyond the specifics of that simple organism, and move beyond the analogy of biological systems. But it is a useful springboard to more complex ideas.

For a system can be a human body, a financial institution, an organizational structure, a celestial body, a legal framework, a societal structure, or indeed, a scientific theory. In principle, a system can be anything an observer defines it to be, and as such any particular system will be observer-relative. The very act of defining a system involves an unavoidable restriction that essentially highlights the issue that a system is an artificial construction, which reduces the complexity of 'everything' being observed so that 'something', some particular thing, can be separated out from the *chaos* and complexity, made coherent, and thus identified for further exploration and study. Hence, the act of choosing a system is the first and fundamental step taken by an observer to reduce the complexity that surrounds him. A consequence of any such choice by the observer implies that no matter what system is actually chosen, it is isolated from the complexity of other systems and is artificially singled out for study by the very operation of observation. Such simplification of the complexity of the 'whole' means that the choice itself must be partial: the system can never capture the whole. This is a necessary compromise without which observation would have been impossible.

For this reason, no system can be fully described; the issue is always whether the description chosen is appropriate for the task at hand. Indeed every individual system is brought into existence with such a choice and for some purpose.

Definitions of the concept of system abound, but as far as this book is concerned a system can be decomposed in two distinct ways, although it

must be noted that both views are somewhat restrictive. One is to consider a system as an assembly of sub-systems, and then to consider these sub-systems as assemblies of sub-sub-systems, *ad infinitum*. The other is to consider a system as an assembly of elements, together with the relationships between these elements. The first option gives a basic function for dissecting systems hierarchically, but it is a rather structural perspective of the decomposition of the concept of system. The second is to some extent better in pinpointing that there are important interrelationships between the elements of a system. However, it does not account for the role of communication between those elements, a role that is crucial for conceptualizing the complexity of the system and its individual elements. Thinking about our metaphor of a cell and its components from these two perspectives is a good starting point for grasping these subtleties.

If we consider communication between systems then an important aspect surfaces. As Luhmann remarks:

This concept of communication can be built into a theory of complex systems only if one gives up the long-established idea that systems exist as elements *and* relations among these elements. It is replaced by the thesis that, because of complexity, carrying out the process of relating elements requires selections, and thus relationship cannot be simply added onto the elements. With those selections, the process of relating qualifies elements by cutting off some of their possibilities. In other words, the system contains, as complexity, a surplus of possibilities, which it self-selectively reduces. This reduction is carried out through communicative processes, and therefore the system needs a 'mutualistic' basic organization – that is, attribution of its elements to complexes that are capable of communication (Luhmann, 1995).

No matter which of the two viewpoints is chosen for the decomposition of a system, both views presuppose that the system has been identified by a *human observer* as being of special interest. Later on we shall see that broadly speaking *observation* of another type is possible, that of observation by computer albeit with severe restrictions. The designation of any particular system is therefore an observer-relative act. Thus any system can be designated otherwise by a different observer, even by the same observer but in a different frame of mind or with a different purpose. The behaviour of each element of an identified system has an effect on the behaviour of the

system as a whole. The elements may form sub-systems, each a system in itself. Each element and sub-system will affect the behaviour of the whole, and all are interdependent. They are affected by being in the system, and are changed if they leave it¹; as the system itself is changed with the loss of a sub-system.

A system is perceived to have a *boundary*, which separates the system from its *environment*. This differentiation between system/environment has repeatedly been remarked upon previously in this book. We note that the environment should not be considered as some type of residual category, but as constitutive of the system's existence. By examining the relationship between a system and its environment, that system is often classified by others as either closed or open, depending on how the system regulates its boundary for receiving information from its environment. However, the classification of closed or open is problematic, being made on the basis of the environmental influences (quite possibly unknown elements from the environment) that affect the system. How this degree of openness or closedness is orchestrated by the system itself is even more vague, since that too is dependent upon the definition of a system: an act that is observer-relative.

This notion of open versus closed systems is now considered outmoded, and has been replaced by the concept of *self-referential systems*, something that will be described later. However, even with something as simple as a cell, it is never totally clear and unambiguous as to where the *inside* ends and the *outside* (namely the environment) begins, all exacerbated by the structural coupling between the two; not to mention the issue of residual category: 'relationship to the environment is *constitutive* in system formation' (Luhmann, 1995).

With more complex systems the ambiguity is yet more apparent: is the air in the lungs, or gastro-intestinal bacteria, inside or outside the system of the human body? The boundary is chosen according to the human observer's particular purpose and priorities, since it is the observer that identifies the system to begin with, and hence who designates how the boundary is to be perceived for any particular chosen system. However, when the system is artificially separated from its environment, and subsequently the environment is considered to be a mere residual category, all the ensuing paradoxes and the severed structural couplings will be conveniently swept up into this mythical boundary, where they are ignored to simplify further consideration. For example, even with the million and one questions we

humans could ask about where the body ends and the environment begins, we still believe we know what a human body is.

Whatever the purpose or priority, the choice of boundary will encompass some concept of a dynamic yet coherent *reference state*, which in turn will identify a generalized version of the system itself to the observer.

Feedback

The interaction between a system and its environment is what is known as *feedback*. Evidently, the environment must not be considered as some sort of inert background, rather as a complex system in itself: a bubbling soup of interacting systems, both similar and different, all continuously changing and affecting one another. Furthermore, the exchange of feedback between a system and its environment should not be viewed as a mere set of input/output processes. As the environment is constitutive to the system's existence, it becomes structurally coupled to the system; hence all interactions between system/environment do not simply originate in one or the other. These interactions coexist in both system and environment. In this sense the concept of feedback is artificial. Feedback is what occurs between system and environment when we isolate a system for study, selectively cutting it off from the complex and multiple interactions of its natural habitat. Not that we would ever know what that original habitat was; by observing, we lose that information by necessity. In this respect, a system's environment is also the result of identifying the system. It is a result of observing.

This constant negotiation between the system and its environment, which we capture in the concept of feedback, is mediated by the elusive concept of the boundary that separates the system from its environment. The system affects its environment, and is affected by it. Through a series of actions, to which the system's elements and relations are subjected, the system triggers changes in its environment, and vice versa.

Such feedback is termed *negative feedback* when it counteracts any disruptive processes, and reinforces the relative stability of the system. For example, breathing in and out causes the outline (the boundary?) of a living body to change, but it is still recognizable as a body. Stop breathing altogether, and the body displays less variation from the reference state (at least in the short term), although it soon enters *positive feedback* in that it is dead, and will begin to decompose into other systemic components. Positive feedback amplifies the processes that carry the actual state of the system away from what the observer recognizes as the reference state, in this case a living body.

It is important to realize that no system is passive. Even the simple cell is no solid inert lump, rather it is in a state of constant flux about what the observer perceives to be an idealized reference state, albeit fictitious, that represents cell-ness to him. That state of flux is also relative, since even when a system is apparently doing nothing (according to the observer), the structural coupling means the system's relationship to the environment is constantly changing and this outside world is itself in a constant state of flux. Structural coupling then refers to the relationships that exist between system and environment, relationships that are prone to further differentiations by other observers and relationships that are ultimately constitutive of the system's existence and that cannot be fully described because of the complexity present in any system's environment.

The observer, whose choices initiate a particular system, will view it as doing something (even if that something is nothing), which will involve the system sampling its environment as part of a feedback process. That is to say, each system is itself a first-order observer, in that it will include some means for such sampling, although this observation does not necessarily involve cognition (a fairly obvious conclusion if the chosen system is a tree). Thus the choosing of a system by the original observer must necessarily involve a second-order observation (the chooser observing the system observing/interacting with its environment), and in doing so that system tends to be perceived by him as being autonomous in its actions. This is why the idea that a system is the result of an observer's choice, rather than a specific and self-evident thing in the world, may seem so odd to those uninitiated in Systems Theory. We are back with Bishop Berkeley, and his tree.

The apparently now-autonomous system must be adaptive to the continual changes in the environment, both predictable changes to the extent that the system can anticipate environmental feedback and the unpredictable. It must survive, reproduce, possibly be purposeful and teleological (where developments both in itself and in the environment are due to the purpose and design of the system), grow, colonize and cooperate. The system must achieve the same results in different ways and from different initial conditions (so-called *equifinality*), and do any of the things that physical, biological or social systems do.

However, positive feedback will tend to distort the system, possibly to a point where it is no longer recognizable when compared with the original reference state; not necessarily to the point of death, but transformed into a different system, such as from a caterpillar into a butterfly. Therefore, if

the chosen system is to be recognized (the caterpillar, and not the butterfly) that system must for the time being somehow maintain the relatively stable form of its reference state. However, we must accept, in a deliberately vague way, that a system will not remain in an unchanging initial state, and that the very concept of state is problematic since it freezes a system in time, and time itself constitutes the most mysterious and mind-boggling of all entities, even for physicists. A system is therefore what it has become, what it will become through feedback, which is why no description of the system will ever capture totally the whole that it is. By implication, no system can accurately describe itself.

By the very nature of a consensus demarcation that is its boundary, any system will have an identity, which must be maintained in a dynamic yet stable and recognizable reference state: a self-organizing property named *homeostasis*. In order to be homeostatic, a system must receive energy/material/information from outside its boundary. At least in the short term it must be *negentropic*; negative entropy (negentropy) is perceived as contrary to entropy. Entropy is the thermodynamic principle that systems run down to ultimate disorder or to death, which is the state of maximum entropy.

Emergence

Any system exhibits an internal complexity; such a complexity (as ‘a surplus of possibilities’) is partly required to deal with the changes in the system’s environment, and is partly the result of the system’s co-evolution with its environment. An important side-effect of this process is that there is no causal control over the qualities that a system’s elements tend to exhibit. Elements at each macro-level are identified by *emergent properties* that do not exist at lower micro-levels; this systemic property is characteristic of any chosen system.

On their own the complexity of components at micro-levels cannot ‘explain’ the emergent properties of macro-levels. For example, the micro-level behaviour of individual brain cells cannot explain the emergent macro-laws of the cognitive functions of the brain. Even more profoundly, the laws of physics and chemistry, considered at the micro-level, cannot explain biology at the macro-level, let alone the emergence of life. In turn, biology at the micro-level cannot explain the macro-level behaviour of individual animals, including humans. Similarly, the aggregation of individual behaviour does not explain emergent societal behaviour or differing cultures.

This issue, that unexpected structures/functions emerge within systems, is crucial. Consider the question 'can a single cell think?' The answer is obviously (probably) no! But the approximately 100 billion cells in the human brain certainly can. Cognition surfaces as an emergent quality from the entire functioning system, although this cannot be attributed to the single elements that are perceived to constitute the system.

There comes a point in a complex coming together of 'things' that a change occurs, which is not solely quantitative, but one involving a considerable qualitative shift. 'The whole is more than the sum of its parts' (Aristotle).² This renders reductionism (i.e. the process of breaking up an identified problem into its parts and examining the parts instead) irrelevant when describing higher-level systemic formation in any complex system (like the brain). Decomposition of a system into its parts will fail to describe the new laws that are a property of the system itself. These new laws cannot be attributed to the parts of the system alone; they govern the new macro-levels and result from the complex interactions of the systems' parts; such new levels experience what are utterly emergent phenomena and are dependent upon connections that are created amongst different elements within the system (such as synapses in the brain, or memories).

An ever more crucial question, and one that merits considerable pondering (even though we can hardly provide any conclusive comments), concerns the threshold at which this change from quantitative to qualitative occurs. How many brain cells does it take for the collection to start thinking? Is there any property within the evolving system of the brain that could potentially determine this? Or is thought simply an unknowable emergent property?

Standing in direct contrast to reductionism is the notion of holism,³ namely that parts cannot exist independently of the whole; the emergent properties exhibited by complex systems cannot be reduced to individual parts. Holism stresses that parts cannot be 'understood' without reference to the whole. Of course, this book claims that reference to/understanding of the whole is also impossible; both reductionism and holism may have a utility but at the cost of introducing paradoxes.

Pondering such difficult questions should be left aside as what determines the emergent behaviour in any system is heavily dependent on the system itself, and by implication on the observer who chooses the system, thereby observing some particular emergent properties while at the same time ignoring others. By its very definition, emergence cannot be reduced to something else. However, far more important to the thrust of this book is the

recognition that there are indeed emergent phenomena: a set of properties that are based on, and at the same time emerging from, the system's components and their interrelations. Such emergent phenomena cannot be fully accounted for in advance; they are heavily dependent on the internal complexity of the system, on the processes that guide the interaction between system and environment, and their state at the moment of formation.

Communication

As previously remarked, communication between elements of a system leads to a compromise in the elements' connective capacity. There needs to be a reduction in the complexity of individual elements so that they can interconnect with other elements. The internal complexity of a system, perceived to be a surplus of possibilities for the system's own restructuring, is needed in order for the system to regulate itself, and to control its actions and reactions, to maintain its identity, and to renew or repair itself while interacting with its environment. Control here is not to be taken as a causal mechanism within the system. Because of the complexity, intrinsic both in the system itself and in the environment to which the system is structurally coupled, the system can anticipate environmental and internal influences, but cannot manipulate them with any degree of certainty.

The environment itself is a thriving bubbling mass of systems. As the environment of any system is perceived to be substantially more complex than the system itself, the system becomes dependent on the constant restructuring of the complexity of its environment. As a response, the system restructures itself according to its own internal complexity, namely its surplus of possibilities for re-interconnecting its elements. The system moderates the exchange of feedback with its environment in a process of continuous adaptation. This adaptation does not always serve the system well. Systems may become extinct, and do so frequently, depending on their capacity (rather incapacity) to survive the changes in their environment.

Hence, from the development of new systems and the breakdown of old systems that result from interactions within the environment, we can infer that there can be no permanent control over a system that is continuously evolving. There is only a limited form of control in the sense of purposefully directing a system's procedures as they exist in their present states. These control procedures will have evolved along with the system, but they are as much a consequence of relative stability of the environment, namely the order sensed by the observer in the environment, as of the system itself.

Self-reference

All of the processes described above are very important in how any system functions and how an observer perceives it. A system is differentiated by its environment; in doing so, it is established as a unique entity that is co-dependent with its environment, and at the same time must survive the positive feedback that may destabilize it. In order for the system to survive the changing environment and processes of positive feedback, it attempts to regulate the exchange of feedback through its boundary. To be effective in sustaining itself it has to utilize the surplus of possibilities of its re-constitution that exist in the form of an *internal complexity*: the mechanism for dealing with environmental complexity. That having been said, the authors must comment on the phrasing of these latter sentences. The reader must still remember that every system is brought into existence by the act of choice of an observer. And yet somehow, as is quite normal when discussing systems, we are suddenly talking about that system as if it is blessed with self-action and the originating observer has been abstracted away. We are back in the territory of orders of observation, just like with the prisoner brainteaser in the previous chapter; and this is why much of the remainder of this book will be considering the implications of such orders of observation.

Reading the above paragraph carefully we will notice that with every single systemic function described, the apparently self-active system has to refer to itself in order either to carry out a particular function or to deal with the complexity of its environment. Broadly speaking, this is the basic idea behind the concept of *self-reference*. As Luhmann notes:

Our thesis, namely, that there are systems, can now be narrowed down to: there are self-referential systems ... there are systems that have the ability to establish relations with themselves and to differentiate these relations from relations with their environment ... one can call a system self-referential if it itself constitutes the elements that compose it as functional unities and runs reference to this self-constitution through all the relations among these elements, continuously reproducing its self-constitution in this way (Luhmann, 1995).

The primary distinction used in this regard is that between system and environment. All of the foundations of Systems Theory are based essentially on this distinction. To be capable of identification by an observer, the system must be differentiable from its environment, but the same distinctions

between system/environment can apply reflexively within the system itself (i.e. internally). This is rather characteristic of a system's self-referential nature.

That self-reference has a key role to play in theoretical descriptions becomes evident in the use of the concept in major philosophical and scientific works. In an insightful comparison of the works of Michel Foucault, Friedrich Nietzsche and Niklas Luhmann, Stephen Rossbach describes how Foucault came close to the concept, Nietzsche even closer, but it was Luhmann who, many years later, made self-reference the centrepiece of his work by providing a theory for social systems, and at the same time consolidating Systems Theory (Rossbach, 1993).

Luhmann himself was greatly influenced by cybernetics, and in particular second-order cybernetics, which already included concepts of control and communication, learning and adaptation, (co-)evolution, and most relevant, self-organization. With the theory's use in biology, and in particular via the concept of *autopoiesis* by Maturana and Varela, systems were seen to have another very important property (Maturana and Varela, 1998). The word *autopoiesis* comes from the combination of two Greek words, namely those of *αυτο* (auto: meaning 'self') and *ποιώ* (poiesis: meaning 'to make'). *Autopoiesis* refers to systems that have the capacity to 'make themselves', insofar as this refers to the systems' capacity to refer to themselves and thereby to re-constitute their functioning parts.

One of the first accounts of the concept of self-reference comes from Korzybski in describing language as a 'uniquely circular structure, where an "effect" becomes a causative factor for future effects, influencing them in a manner particularly subtle, variable, flexible, and of an endless number of possibilities' (Korzybski, 1948). This idea of a structure, a bizarre form of re-entry, a form that enters itself and hence can be characterized as self-referential, has intrigued many researchers over the years.

The relationship between complexity and self-reference is also crucial. For if any type of system confronts an increase in environmental complexity, such an increase can only be 'controlled' (this is not really control, merely an attempt to cope) via a series of systemic self-referential processes that have the potential of increasing both the system's internal complexity and hence the pattern of selections within the system. These in their turn can allow for a greater degree of flexibility in the responses from the system; but such a process cannot be characterized by mere causalities. In this manner, self-reference can also be recognized as the crucial mechanism

with which the system uses its own internal information system in attempts to reduce the complexity of the information that is its interpretation of its environment, so that it can survive both that complexity and the changes of its environment.

There are three predominant meanings that can be distinguished when referring to the concept of self-reference. According to Felix Geyer these are: a *neutral meaning*, whereby any changes that occur in the system's state are dependent upon the state of that system at a previous moment; a *biological meaning* whereby the system contains information and knowledge about itself; and the stronger *second-order cybernetics meaning*, whereby a system collects information about its own functioning, which in turn can further contribute to a change of its functioning (Geyer, 2002).

Clearly, self-reference means much more than merely what the two words alone imply, namely a reference of the system to itself. For that would simply end in a tautological form that would be of little or no use, and one completely de-contextualized from the broader systems-theoretical context. Self-reference must instead be seen as a concept central to systems. In order to resolve the issue of de-contextualization, the following key aspects need to be considered:

- i) Self-reference is fundamental to the formation and survival of a system. The system not only refers to itself and its constitutive elements, but also maintains that (self)-reference for sustaining its functions. In this way, the system is autopoietic, for otherwise, if self-reference is not maintained, the system collapses.
- ii) Self-reference is fundamental to reducing environmental complexity: the system refers to itself and to the relations that support it, so that it can exploit its pattern of selections. By exploiting this pattern through self-reference, the system is better able to increase its internal complexity and contingency in order to cope with environmental changes.
- iii) Self-reference is fundamental for information processing, whereby the system refers to itself by interrogating those elements that are supported by its information system, which is a necessary sub-system of every system.

However, in all this talk about systems we must make it quite clear that systems do not exist as 'things' in themselves operating in what is the unknowable non-linear complexity of the 'real world' around us. Systems

are products of the mind of an observer who decides what to observe, what distinctions to create, thereby designating those systems. The hypothesis of this book is that systems emerge from the structural coupling of observers' cognition and observation. They are the means through which we develop the concept of *structure* in social, economic, political, scientific and other contexts, as well as the means through which we impose ourselves on the *Chaos* all around, and thereby pull usable and useful information out of it. In effect, the identification of systems is dependent on observation.

The creation of any particular system can be portrayed as a bottom-to-top process by an individual, which functionally differentiates that system. However, as Luhmann remarks, that creation occurs within a society; for example the invention of coinage leading to the differentiation of an economic system (Luhmann, 1995). Nevertheless it is still the structural coupling between cognition and observation in the minds of various individual observers that allows the system to develop. By interfering with each system's processes, each observer is both participating and guiding the system in its development. However, a surplus of observers, leading to a surplus of differentiations, implies that the system experiences an imposed complexity, far beyond its intrinsic complexity. Hence, the self-referential development of a system can never be causally determined.

To the authors, the ability to create systems is the self-referential stuff, the way and the means, of both observation and cognition. What this thinking implies for the human condition in general and for the scientific approach in particular is now analysed in the chapters that follow.

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