The Architecture of Complexity
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Introduction: There are some properties common to many complex systems. Complex Systems are those that are made up of a large number of parts that interact in a non-simple way. Given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. Empirically, a large proportion of the complex systems we observe in nature exhibit hierarchic structure. On theoretical grounds we could expect complex systems to be hierarchies in a world in which complexity had to evolve from simplicity. In their dynamics, hierarchies have a property, near-decomposability, that greatly simplifies their behavior. Near-decomposability also simplifies the description of a complex system, and makes it easier to understand how the information needed for the development or reproduction of the system can be stored in reasonable compass.

HIERARCHIC SYSTEMS. By a *hierarchic system,* or hierarchy, I mean a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem. Etymologically, the word "hierarchy" has had a narrower meaning than I am giving it here. We shall want to consider systems in which the relations among subsystems are more complex than in the formal organizational hierarchy. The mathematical term "partitioning" will not do for what I call here a hierarchy; for the set of subsystems, partitioning, independently of any systems of relations among the subsets. By hierarchy I mean the partitioning in conjunction with the relations that hold among its parts. Consider social systems (families), biological and physical systems (nucleus-cell-organism, atom-molecules-galaxy). A crystal and molecule can be considered very flat hierarchy. Some hierarchies have a large span (number of components). A hierarchy be be described in terms of intensity of interaction whether it be spacial for physical systems or communication for social systems. Electronic and nervous systems reduce the physical limitations.

THE EVOLUTION OF COMPLEX SYSTEMS. The time required for the evolution of a complex form from simple elements depends critically on the numbers and distribution of potential intermediate stable forms. In particular, if there exists a hierarchy of potential stable "sub-assemblies," with about the same span, s, at each level of the hierarchy, then the time required for a subassembly can be expected to be about the same at each level-that is proportional to l/(l-p)s. The time required for the assembly of a system of n elements will be proportional to logs n, that is, to the number of levels in the system. This only assumes survival of the stable. Not all complexity is hierarchical but long chain polymers can be considered to have span=1. There is no implication for entropy – the equilibrium of the intermediate states need have only local and not global stability, and they may be stable only in the steady state - that is, as long as there is an external source of free energy that may be drawn upon. Problem solving requires selective trial and error of sub-assemblies that make progress towards the goal. In problem solving, there are two basic kinds of selectivity: Firstly, various complexes come into being, at least effervescently, and those that are stable provide new building blocks for further construction. Secondly, by using previous experience or their analogues, trial-and-error search is greatly reduced or altogether eliminated.

NEARLY DECOMPOSABLE SYSTEMS. We can distinguish between the interactions *among* subsystems, on the one hand, and the interactions ***within*** subsystems. The interactions at the different levels may be, and often will be, of different orders of magnitude. We can describe such a system as *decomposable* into the subsystems comprised of the individual particles as a first approximation. As a second approximation, we may move to a theory of *nearly decomposable* systems, in which the interactions among the subsystems are weak, but not negligible. In a nearly decomposable system, the short-run behavior of each of the component subsystems is approximately independent of the short-run behavior of the other components. In the long run, the behavior of any one of the components depends in only an aggregate way on the behavior of the other components. To understand why the span of hierarchies is sometimes very broad and sometimes narrow we need to examine more detail of the interactions. In general, the critical consideration is the extent to which interaction between two (or a few) subsystems excludes interaction of these subsystems with the others. (consider water molecules)

THE DESCRIPTION OF COMPLEXITY. The fact, then, that many complex systems have a nearly decomposable, hierarchic structure is a major facilitating factor enabling us to understand, to describe, and even to "see" such systems and their parts. Or perhaps the proposition should be put the other way round. If there are important systems in the world that are complex without being hierarchic, they may to a considerable extent escape our observation and our understanding. There is redundancy in complexity which takes a number of forms: Hierarchic systems are usually composed of only a few different kinds of subsystems, in various combinations and arrangements. Hierarchic systems are, as we have seen, often nearly decomposable. Hence only aggregative properties of their parts enter into the description of the interactions of those parts. By appropriate "recoding," the redundancy that is present but unobvious in the structure of a complex system can often be made patent. State descriptions consider a point in time while Process descriptions consider paths between two states. The organism must develop correlations between goals in the sensed world and actions in the world of process. If the existence of a particular complex form increases the probability of the creation of another form just like it, the equilibrium between complexes and components could be greatly altered in favor of the former. DNA serves as a template both for itself and for RNA while RNA is a blueprint for protein, protein is a recipe for metabolism. Does the DNA contain a hierarchical description of development?