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Chapter III

Modularity and Complex Adaptive Systems

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Abstract

Modularity is ubiquitous in complex adaptive systems. Modules are clusters of components that interact with their environment as a single unit. They provide the most widespread means of coping with complexity, in both natural and artificial systems. When modules occur at several different levels, they form a hierarchy. The effects of modules and hierarchies can be understood using network theory, which makes predictions about certain properties of systems such as the effects of critical phase changes in connectivity. Modular and hierarchic structures simplify complex systems by reducing long-range connections, thus constraining groups of components to act as a single component. In both plants and animals, the organisation of development includes modules, such as branches and organs. In artificial systems, modularity is

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used to simplify design, provide fault tolerance, and solve difficult problems by decomposition.

Introduction

What is Modularity?

A train consists of an engine and carriages. A tree consists of branches and leaves. Trains and trees, like innumerable other systems, are built from modules. Modularity is a structural property of systems that arises when a system is composed of self-contained groups of elements that behave as a single unit. Complex systems often contain modules, which increase predictability and simplify control. Modules can usually be identified by the pattern of connections which are stronger and more numerous within modules than between modules. Modularity has the effect of isolating elements and processes from one another, and constraining their interactions. Modules isolate functionality into units that are both reliable and reusable. Complicated problems can be approached by dividing into smaller problems to reduce the combinatorial complexity. The formation of modular structures is a crucial mechanism in the emergence of order in many complex systems. Therefore, modularity is fundamentally related to the *adaptive* nature of many complex systems.

The human body provides an example of a natural complex system that contains a hierarchy of modules. Each cell in the body is a module; the cell's internal component parts and processes are isolated from those of other cells. The cells themselves are not a homogenous collection. Instead, groups of cells are specialised and clustered together to form modules. These modules are recognisable as organs, such as the liver, the heart, and the lungs, as well as muscles, nerves, and so on. Each organ, or module, can be identified with a particular function. The interaction between these modules is well defined. For example, the heart and kidneys do not interact directly. They perform specialized functions connected with another entity—the blood. One organ is responsible for movement of blood around the body. The other is involved in maintenance of the chemical composition of the blood. The use of modules in a complex biological system allows cells to operate in an efficient way, by concentrating on one group of activities.

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