SOME ANALOGIES OF HIERARCHICAL ORDER IN BIOLOGY AND LINGUISTICS

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I. INTRODUCTION

The ubiquity of hierarchical order is obvious, and the obvious is hard to explain, but a number of workers [1] have suggested the possibility of constructing a theory (or cluster of theories), rooted in such disciplines as thermodynamics, information theory, topology, and logic, which might reveal the underlying unity of a wide variety of branching and multi-level systems. It is the purpose of this paper to contribute to both the empirical and theoretical aspects of this discussion, by examining levels of structure and function in molecular biology and linguistics, and by developing, from parallelisms between these two areas, a hierarchical model of possibly greater generality.

We consider first the hierarchy of spoken language [2]: phoneme, morpheme, word, sentence, utterance, discourse; or of written language: letter, syllable, word, sentence, paragraph, section, chapter, book. These lists are straightforward up to and including the "sentence," beyond which they are somewhat arbitrary. The items, "utterance," "paragraph," etc., are meant only to illustrate more complex units and to suggest that linguistic hierarchies consist typically of a small number of levels. This is characteristic of the organizational and/or operational structure of many "concrete" [3] systems; more "abstract" hierarchies, e.g. those which specify gradations of some attribute, often consist of a greater number of elements. For example, the system of cosmological entities, ordered by gravitational forces, ranges from aggregates of galaxies to planetary satellites, meteors, etc., but the hierarchy of the structure of matter extends through

G. J. Klir (ed.), *Applied General Systems Research*

additional levels down to elementary particles and the like. Similarly, the organizational or "line" structure of command in the military has fewer levels than might be suggested by existing gradations of rank.

Thus, the following hypothesis: Concrete systems are typically limited to a small number of levels, say five to ten, after which the hierarchy often becomes consolidated in a stable and coherent whole (which may become a base unit for still higher levels). We shall refer to the range between base and terminal levels as a "period." For example, a library consists of two periods: letter to book and book to library. The hierarchy of structures from atom to cell is, in our opinion, also such an interval, the intermediary levels of which include small molecules, polymers, macromolecular aggregates, and the like. We could continue on to tissues, organs, organ systems, organisms, populations, etc., but suggest that the intervals from atom to cell and cell to organism represent natural divisions. In general, there may be some uncertainty about which level should begin and/or end a period, but the range of uncertainty is usually not great, and the principle of this distinction, i.e. the idea of periods, is not purely subjective. For example, it would be inappropriate to start the cellular hierarchy at the level of protons and neutrons or quarks, because the domain of influence of the cell as a system does not penetrate down to these levels. Or we might extend the biological hierarchy to include tissues, organs, and so on up to the level of the individual organism, but at this point, biological structure most typically passes into social organization, as in families, populations, and communities.

The biological hierarchy we shall actually discuss is the following: atom (or atomic ion); chemical group (or small molecule or molecular ion); amino acid; (monomeric) protein; (multimeric) enzyme; multienzyme complex; organelle (or membrane system); cell. That is, we trace out only one "path" (of many) in the set of structures between single atoms and whole cells, focusing mainly on proteins, the principal dynamic agents in the cell, and especially on those entities of the protein hierarchy most general in function [4]. Thus, for example, above the level of polypeptide chain or monomeric protein, we choose the "spherical" multimer rather than the helical polymer, as the latter typically has a more specialized function. Much of the discussion which follows will pertain also to the nucleic acids and to some deeper and more general properties of the cellular period.

II. PARALLELISMS BETWEEN THE BIOLOGICAL AND LINGUISTIC PERIODS

A number of investigators [5] have considered analogies between linguistic entities and the nucleic acid levels of nucleotide,