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ALLOMETRY IN BIOLOGY: ALLOMETRY IN SYSTEMS SCIENCE GENERALIZED SYSTEMS FORMS: WILL THEY ALWAYS REMAIN A MYSTERY?

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ABSTRACT

This paper gives the background for several hypothetical correlations that are invariant across many hierarchical levels of natural systems. These correlations would be similar to those found in biological systems and called allometry. First, the paper defines allometry in the biological and engineering sciences providing some simple examples of each. Second, it cites several similarities between these examples of scalar relationships in biology and those that might be profitably explored in systems science using a more sweeping set of parameters than those used in biology. Third, the paper points out how the study of allometry in biology is already a systems-level study. Fourth, several proposed general systems scaling relationships are suggested. Fifth, the potential importance of systems allometry to basic general systems research and systems design and applications is discussed.

INTRODUCTION

Recently there has been a sudden profusion of articles, books, and fascinating results demonstrating many cases of allometry and scaling relationships in the biological sciences (McMahon and Bonner, 1983; Calder, 1984; Schmidt-Nielsen, 1984). As a result of the increased activity, allometry in the biological sciences is now seen as a more pervasive phenomenon, involving more characteristics, than previously suspected. Actually the field of allometry is well over 50 years old if one regards Huxley's exposition of the original equation as the begining (Huxley, 1932). Historians of science might extend the general awareness of the basis for allometry still further to the better aspects of the "correlation of parts" doctrine elucidated by Baron Georges Cuvier in the early 1800's. When compared with the allometries or scaling relationships in engineering as illustrated in McMahon and Bonner's text (1983), it is clear that the phenomenon of scalar relationships may be even more productive in helping us understand generalized systems form if applied to other natural and man-made systems. Setting the rational basis for this exploration is the purpose of this paper. It is not its purpose to provide the data just yet, although some suggestive results will be shown in the keynote address which this paper represents.

DEFINITIONS AND EXAMPLES OF ALLOMETRIC RELATIONSHIPS IN BIOLOGY

Allometry is a statistical methodology which reveals regularities in patterns of change in organisms and displays them in graphic form. Even non-biologists are impressed with the immensely varied forms typical of the biosphere across a range of sizes covering 21 orders of magnitude (10^{21}). The diverse topologies of these organisms prepares us to accept an assumption of variety with little regularity across this span of sizes. Imagine our surprise then, when a simple equation and graphing method reveals startling regularities that hint we have just begun to perceive, much less understand a complex set of regularities which may point to a unifying theory as yet unsuspected. The close association of allometric investigations and measurement provides a dimension of quantitative authority and reliability to pursuit of this unifying theory. In this short paper, I will try to apply to explore the characteristics of allometry in order that it might serve as a model for systems science which is also in pursuit of a unifying theory and also is much in need of a quantitative dimension to aid it in that pursuit.

The manipulation of measurements typical of allometry is a very productive way to compare size-based or size-invariant characteristics of widely different organisms, biological processes, or evolutionary lineages. Huxley derived the formula in his first book on the subject (1932).

$$y = a\ x^b$$

or in log form......

$$\log y = \log a + b \log x$$

Most often, the variables x and y are represented by the total body mass of an organism and one of the parts of the organism. The equation correlates the changes in mass with proportional changes in the parts of the total. For example, in both horse ontogeny (development of the fetus), and also in horse phylogeny (evolution of a lineage of species), the increase in size of face and skull bones maintain a regular and reproducible proportionality described by the equation

$$Y = 0.25\ X^{1.23}$$

(provided data is taken from fossils representing the distant horse ancestor Merychippus of 28 million years ago to present horse development) This is a remarkable regularity. It is even more dramatic, and therefore suspect, when displayed graphically. If y is plotted against x on log axes (log-log paper) a straight line or linear plot results with slope b and intercept log a. This line of regular change is somewhat overemphasized by the mechanics of making it (regression), but gives a fair indication of proportionality and invariance in changes of proportionality across a wide range of organisms and properties of organisms.

The literature is replete with examples. A childrens' book of organisms have been studied in this manner.....ants, clams, humans, Irish elk (deer), insectivores, birds, beetles, baboons, and butterflies. Even past species long departed from the face of the earth like fossil bears, titanotheres, and horses have been mapped allometrically across millions of years of change. All manner of organs and body parts have been studied.....brains, forelegs, mouthparts, horns, facial bones, digits, clam shells, carapaces, and teeth. What is even more impressive to me is that studies are now being conducted of the processes of living systems like reproduction, growth, physiology, population dynamics, ecological energetics, life spans and life history strategies, paleontology, and evolution. Calder (1984) states that allometry is "becom(ing) an interdisciplinary undertaking." This movement from the original emphasis on morphology to more dynamic processes involving a wealth of disciplines is what attracts me to make the suggestion that allometry may be made to work for systems science and systems science for allometry.

To return for a moment to the original, simple equation, note that numerical quantity "a" and exponent "b" are empirically derived. Although they are consistently the same for a given part:whole comparison or correlation, they may be quite different for other parts: whole sets within the same organism. "a" is a scale factor or an "initial growth index." It expresses the size of y when $x = 1$. Changes in "a" can have dramatic effects on the history of an evolutionary lineage. To pick an example personally interesting to you consider the following. In humans there was a significant change in "a" from 0.34 in Australopithecus to 1.73 in Homo (us) when brain size is plotted as a function of body weight (Pilbeam and Gould, 1974). The difference in the two straight lines in a log-log plot of this human allometry is a partial measure of the difference between an ape lifestyle and a civilization capable of supporting intellectuals who like to write papers reflecting on abstract topics such as this. If I understand him correctly, Salthe (1985) feels that changes in "a" can be highly significant discontinuities in the evolution of an organism (as the above certainly was in man) and may be the cause of the distance between, or lack of interacttion between hierarchical levels. It is this kind of proposition and the debate or measurement and falsification it stimulates that moves the science of allometry to systems levels. The quantitative aspect of exploring these possibilities is of crucial importance. Many midwives and doctors have long recognized that the human head is outrageously large at birth, but after birth the head grows more slowly than it apparently did as a fetus in utero while the legs grow much more rapidly until the typical adult proportions are attained. But a quantitiative version of this simple observation can be so much more useful especially when compared with many other such observations. Changes in "a" indicate changes in growth patterns. This draws our attention to the causes of the change, which leads to more satisfying unifying theories. In the case of human head:leg growth, the quantitative difference between the placement of the straight lines on log-log graph is an indication of change in growth genes, perhaps. Huxley noted this and introduced the concept of heterogonic growth- differences in growth rates. Goldschmidt reduced this to the idea of "rate genes" responsible for the observed differences. If a gene is responsible for the rate of growth of a particular structure, then different alleles for that locus are possible in a population, and they will supply different controls of the size of that structure relative to the rest of the body. Thus, different "a" for different speciations. These rate genes could also be responsible for the timing of the absolute point of appearance of the rudiment for a structure. If we focus on the point at which "a" = 1 in our quantitative studies, we perceive the basis for Gould's suggestion that later, larger versions of part:whole proportions are scaled-up versions of earlier forms, and can make more of the observation. Or if it is "b" that changes, then "a" is retained but the whole process starts from a larger rudiment (or its point of appearance changes). This lets us connect the molecular levels of an organism with its distant morphological levels. And this connection is very important. There is growing evidence in an entirely different field (molecular biology of differential gene activation) that rate genes, indeed, do exist, and can be studied with the armamentarium of tools of that discipline. When morphology and molecular biology, or ecology and molecular biology unite or connect through allometry, much more explanation could result. And in following this analogy, systems science can unite its extremely disparate pursuits more effectively if it attempts systems-level allometry. It is important to note that these "connections" are not yet realized, even for allometry, but positive indications exist for their possibility.

If similar connections across widely separated levels of organization were discovered from attempts at finding allometries between systems characteristics, then systems science would have the "rules for deabstraction" or correspondence principles (Troncale, 1985) it so desparately needs.

BIO-ALLOMETRY IS ALREADY A SYSTEMS-LEVEL STUDY

In a very real sense allometry in biology and engineering directly measures the consequences of wholeness. It provides quantitative evidence that there are underlying mechanisms, as yet unknown in many cases, that manifest themselves as regular patterns of proportional change despite the separations between individuals in a population, species in a lineage, or populations in a community. This gives the rather empty sound and repetitive claims concerning the importance of holism a new respectability, and a potential for generating much more useful guiding information for the design of systems. Each allometric equation measures the holistic context of particular features of living organisms. Presumably, the values of 0.25 for "a" in the Equus lineage, and the value of 0.34 or 1.73 for "a" in the human lineage are the consequence of the various influences on those body parts relative to total mass of organisms in each case. The regularity indicated by the linear log-log plot across the many cases examined suggests that the net of causes for which this number represents an effect remain a consistent influence despite changes in particulars across the cases. The net of causes is the wholeness of the organism, or evolutionary lineage studied. This wholeness is highly interconnected, imposes a "constraint field" on the possibilities for change, and is a very real, potentially measureable phenomenon. Since systems science has made an -ism out of holism with all that this implies, it is very helpful that bio-allometry provides a quantitative tool to approach wholeness more practically.

This is not to imply that biologists would agree on this perception. For they do not believe that allometry has revealed the underlying causes that make Huxley's simple equation work. Raff and Kaufman (1983) state that "a genetic or molecular appreciation of the alterations on bodily proportions that accompany growth remains elusive and is assuredly more complex than the simple allometric equation implies." But this only reinforces the point that here biology is touching its interface with systems studies. Oriented as they are to reductionism, biologists feel immediately uncomfortable when they perceive their empirical discoveries pointing to a phenomenon that cannot be enclosed or grasped by their empirical techniques. Allometric relationships are clearly pointing at complex interactions and their consequences that cannot be tested by the separate-and-control experimental method. Calder (1984) notes that "perhaps this perceived deficiency of (finding a unifying) theory of comparative physiology exists because we have not completed our empirical homework, the homework that reveals the basic patterns."

I would like to suggest that although biology when considering allometry is already at the systems-level, it might find the techniques and concepts of systems science useful in unraveling the net of interactions it detects. For example, until recently bio-allometry was virtually fixated on comparing everything to mass or other Newtonian parameters. Perhaps the type of systems science which also attempts to approach its phenomenon quantitatively by scalar level (Troncale, 1981 and 1982) could suggest additional parameter sets, especially non-Newtonian parameters that also might be significant to scalar relationships. In this way systems science could help biology formulate a unifying theory for the regularities found by allometry which biologists feel strongly is implied by the data, but for which they have no contributing concepts at-the-ready. And systems science would help itself by providing a first example of robust application of general theory back to a parent discipline in a manner which also contributes directly to improving general theory. Indeed, quantitative studies of bio-allometry at systems levels by systems theorists could then be used as a model for similar attempts in other natural sciences.

SIMILARITIES: BIO-ALLOMETRY AND SYSTEMS SCIENCE

Both bio-allometry and systems science involve comparison across disciplines. Even though all of the disciplines involved in bio-allometry are clustered under the heading of biology, it should be obvious that biology is a mega-discipline with numerous specialties with rather distinct results and techniques. Cell biology versus zoology, molecular biology versus ecology; it would be difficult to find a better example of a general discipline so diverse, with its sub-disciplines more separated in terms of communications than biology.

Furthermore, biology covers a multitude of scalar levels like systems science. While chemistry is restricted to phenomena of just a couple of orders of magnitude, biology covers more than 21 orders of magnitude. It is true that systems science ranges across an even wider range of magnitude, and in fact contains biology within that range. But few single disciplines capture the flavor of interdisciplinary inquiry in systems science as much as biology.

In this paper I am merely suggesting that bio-allometry now move from interdisciplinary inquiry to transdisciplinary inquiry with the partnership of systems science. This suggestion is backed up by a suggested set of quantitative studies to serve as an exploratory model.

Another significant parallel between bio-allometry and systems science would be that both are concerned with some form of isomorphy. Bio-allometry is concerned with the constancy of a pattern of a proportional rate of change or relative growth across different groups. Isomorphies are constancies or patterns maintained across variety. Clearly, the isomorphies studied in systems science range across more scalar levels and a more broad conception of variety. I am not saying the two are identical as much as related and capable of helping each other. In bio-allometry, if $b = 1$, as it sometimes is, the relative sizes of x and y are constant regardless of size. Growth, in these cases, is isometric which is closer to a strict isomorphy. The growth of the part experiences the same rate as the growth of the whole. But, in most cases, $b \neq 1$ and so growth is not isometric, but still remains proportional. Does it lose its flavor of isomorphism in these cases? I argue that it does not. The proportionality is still constant. And here lies a possible lesson that has bedeviled the debate between systems investigators and disciplinary-based investigators for decades. Unlike the strict interpretation of isomorphy in mathematics, systems isomorphies (homeomorphies in some worker's terminology) may be constancies of "processes" not just absolute identity of variables in equations or structures. And in bio-allometry the process behind the growth and development of structures remains constant, thus their proportionality, even though changes in absolute structure may be observed. Further, the constancies of rate of change are maintained across differences. Kaufman and Raff (1983) cite three kinds of allometry including: (i) function of growth in ontogeny of a species, (ii) relationships among related species of different sizes, and (iii) allometry related patterns in evolutionary lineages. Calder (1984) has a different taxonomy of allometries across species or organs of an individual involving physiological (functional), developmental, or ecological variables. Note that all of these involve maintainance of constancy whithin a set, and between sets at the same time-- as one observes in isomorphies on the process level. There is in bio-allometry an element of intra-something......that is intra-individual (when organs are compared to total organism), intra-specific (when species are compared in an ecology), or intra-evolutionary lineage (when species in a time sequence across millions of years) are compared. But to detect the allometry, it is required that the comparison move from intra-levels of organization to inter-levels of organization. It is on the inter-level that the allometry is manifest. And this is precisely the case for revealing isomorphies in systems science except that systems science includes more levels. So the tendency of bio-allometry to search across higher levels of taxons, to move steadily from intra- to inter-levels of comparison is similar heuristically to systems science.

Both systems science and bio-allometry are also similar in a tendency to emphasize cross-connectivity or interconnections in a phenomona on a level. In the words of Schmidt-Nielson, "allometric equations are useful because they may reveal principles and connections that otherwise remain obscure" (Schmidt-Nielson, 1984). Systems science stands to gain in association with allometric studies because it will inherit a tool to quantify the results of intensive holistic interconnections. Systems science might also gain a tool to quantify isomorphies, at least across a very limited range of scales. Still, this would be a definite improvement.

Finally, just as bio-allometry struggles with the elusive problems of explaining highly diverse forms across 21 orders of magnitude, systems science struggles to understand and explain general systems form. Both also attempt to link the phenomenon of form to the phenomena of function.

KEY SYSTEMS-RELATED QUESTIONS ARISING FROM ALLOMETRIC STUDIES

Allometric investigations have an uncanny way of exposing some very central questions of interest to systems scientists to quantitative exploration and perhaps, resolution. One important question involves the mystery of linkages across separations or discontinuities. Much of the history of science involves the discovery of a linkage or correspondence principle that joined once separated phenomena. Examples include the unification of once-separated heavenly bodies by Newtonian mechanics and gravitation, or the unification of electrical forces with others in the theory of electromagneticism, or of strong and weak nuclear forces in quantum thermodynamics. Both biology and systems science are beginning to focus on a similar revolution in meta-sciences involving linkages across formerly completely separated phenomena. Just how do effects influence what appear to be entities across a vacuum? It would be hopeless to attempt to answer this question without empirical measurements (from allometry) guiding our formulation of theory. Both theory and measurement must inform each other for progress to be realized.

Another important question possibly amenable to allometric analysis involves the demands of functionality and how these dictate systems form. In the case of bio-allometry the relationships are quite specific to the subject domain, but in cases of systems allometry not only the parameters, but also the systems forms will be necessarily more general but still hopefully accessible to quantitative analysis. For example, in bio-allometry one finds quantitative evidence for the differences in the squat and massive legs of the elephant versus the delicate, thin legs of the mouse. It is the faster rise of body mass (3 as an exponent) which indicates that the mass of something large like an elephant will be logarithmically larger than the mass of a mouse so that the legs will have to be much more structurally massive in the former case relative to the body than in the latter case. Similarly, respiration is a function of surface which rises as the square of body mass, but respiration must satisfy body volume (mass) which rises as the cube of body linear dimensions, so that to keep up with the need the alveoli of the lungs (which is to say the functional respiratory surface) must itself rise faster than the linear body dimensions or it will not be able to supply the mass with oxygen. In general, it is thought that sensory organs show negative allometry, while sexual features show positive allometry, again in response to their general functions relative to body mass. So, in all of these cases a rationale develops which explains the changes in body form.

In his 1917 book On Growth and Form, D'Arcy Thompson introduced the notion of Cartesian transformation in two dimensions to explain the transitions in body form and body shapes as unlike as different species of crab carapaces, or the transition from a fusiform, teleost fish to a related giant marine sunfish. The Cartesian graph that he used to accomplish the transitions has the same constraints and opportunities as the underlying biochemical growth genes which were responsible for the change but were largely unknown at that time. Today, with modern computers capable of three-and-more dimensional coordinate systems we can extend his useful model multidimensionally. If these multidimensional models were attempted it may provide a way of accessing changes in generalized systems form as represented in multidimensional space. Here I am not talking about systems form as in morphology as much as form in the sense of relationship among systems characteristics.

A third important question associated with the possibilities in bio- and systems allometry concerns the matter of causation. Correlations are not cause-and-effects. They may point the way to cause-and-effects, but they most often are not proof of a cause-and-effect. Thus, even in the more specified case of bio-allometry, Calder (1984) stresses that the causes of the regularities involved in many allometries are still a mystery. Does the proportionality result from inheritance of a gene complex, or a control gene, or does it result from some minimization constraint of the environment not yet observable? If it is the former it may be analyzed in reductionist terms; if it is the latter it may require a mergence of techniques of systems theory and biology to trace the influences.

SOME PROPOSED GENERAL SYSTEMS SCALING RELATIONSHIPS

The guiding principle in suggesting that allometric-like relationships exist across the phenomena studied in systems science involves a significant shift in perception. I would suggest that we treat a "level of organization" as if it were an entity. The parameters used to characterize a level of organization would then be plotted against each other form. In the case of bio-allometry the relationships are quite specific to the subject domain, but in cases of systems allometry not only the parameters, but also the systems forms will be necessarily more general but still hopefully accessible to quantitative analysis. For example, in bio-allometry one finds quantitative evidence for the differences in the squat and massive legs of the elephant versus the delicate, thin legs of the mouse. It is the faster rise of body mass (3 as an exponent) which indicates that the mass of something large like an elephant will be logarithmically larger than the mass of a mouse so that the legs will have to be much more structurally massive in the former case relative to the body than in the latter case. Similarly, respiration is a function of surface which rises as the square of body mass, but respiration must satisfy body volume (mass) which rises as the cube of body linear dimensions, so that to keep up with the need the alveoli of the lungs (which is to say the functional respiratory surface) must itself rise faster than the linear body dimensions or it will not be able to supply the mass with oxygen. In general, it is thought that sensory organs show negative allometry, while sexual features show positive allometry, again in response to their general functions relative to body mass. So, in all of these cases a rationale develops which explains the changes in body form.

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A distinctive regularity of change, or trend could be detected in parameter values for linear measurements, mass, area, and volume for the several bio-levels presented in the aforementioned papers (although the latter two parameters suffered from an insufficient number of data points in the sample at that time). More interestingly, the data for lifespans, interaction distances, and generation times also showed definite regularities across limited ranges of the several levels studied. Interaction distance measures the distance across which two entities on a level of organization can effectively interact; at greater distances communication ceases. Interaction energies measures the energy necessary for effective communication between two entities on a level of organization; at lesser energies communication ceases. Generation time measures the amount of time required for the ontogeny of an entity at a particular level of organizations (gestation or maturation time). Just as interestingly for these last parameters, some showed a discontinuity in the trend at a certain level implying an important shift in dynamics between the operational parameter relationships.

What is suggested here is applying this data in the ways that bio-allometricians apply their data.....first to the data on biological systems then to physical and sociological systems. There are two possibilities; trends would continue across non-living and living systems hierarchical levels, or they would not and discontinuities would be observed. Either outcome would be intriguing to study in this quantitative manner. Pursuing the allometric analogy, lifespans would be plotted against mass or linear values to detect consistent patterns of proportional change. Then interaction energies and interaction distances would be separately plotted against mass or linear values. Finally, lifespans would be plotted against parameters like interaction energies, or against interaction distances. When I am satisfied that enough data is contained in the data base on information-based parameters, this data will be plotted against the newtonian parameters. Permutations of each data set will be plotted against every other data set in much the way that bio-allometricians conduct their studies, except that in these cases levels of organization will be compared for regular patterns of proportional change rather than individuals.

At this writing, these suggestions have not been carried out to the extent needed to report the data and conclusions, so this paper has focused on the rationale behind the hypothesized study. But it appears that in some cases the change in pattern or discontinuities observed across levels may be likened to a change in "b" (the scalar variable) in the allometric equation. If this proves to be true then systems allometry will not only be born, it will have its first significant result. It is not my impression that changes in "b" will be associated with changes in level, but rather with changes in domains of levels. So this study will examine transdisciplinary isomorphies across levels while also indicating the extent of, or range of validity or application of those isomorphies. General systems science needs information on this latter question as much as it needs quantitative demonstration of isomorphies themselves.

Bonner (1984) notes that Calder (1984) and Schmidt-Nielson (1984) make the point that "it may not always be the examples that come close to the allometric mean that are interesting, but the exceptions." He then goes on to describe examples biologists find interesting because they indicate how an organism may have evolved special adaptations to overcome the constraints which probably drive the allometric relationship for most organisms in the first place. Disciplinary-based workers would, indeed, find these exceptions interesting because of their reductionist approach. In the study suggested here, I do not believe the exceptions will perform as much as the means (which is why I suggest using the data of Table 1 described above and in Troncale, 1981 and 1982) because in systems studies holistic or comparative trends are emphasized over special cases.

Finally, I am aware of an historical metaphor that will guide this study. Kepler, using Brahe's data, made important discoveries. But he did not discover what he thought he would discover in the data. He set out to prove with the data that the motions of the planets (their orbits) followed a pattern dictated by the perfect solids because he felt the Creator would have selected such an ideal way to determine their motion to show His hand in creation. But the data eventually drove Kepler to quite a different conclusion. Despite the expectations expressed above, the data in this case may drive workers to entirely different conclusions, and I hope to use Kepler as a role model in "listening" to the data. Calder (1984) praises the use of raw allometries, those not yet clearly explained or demonstrated, for the exploration of new hypotheses. Certainly, systems allometry as suggested here will be an exploration of "raw" allometries or scalar relationships.

THE SIGNIFICANCE OF SYSTEM-ALLOMETRY TO SYSTEMS BASIC RESEARCH AND SYSTEMS APPLICATIONS

In a past section, the significance of allometry to central questions in systems science was mentioned. In addition several more desirable impacts could be forseen. Systems theory needs to be more quantitative for its own productivity to increase. In biology, allometry is so interconnected that the latest work is beginning to show that allometries can be derived from one another. Bio-allometry is more than fifty years old, but down the line systems allometry may secure this very desirable outcome. McMahon and Bonner (1983) indicate that partly because of its empirical base, bio-allometry and allometry in conventional engineering have led to predictions. Prediction is the sign of a more mature science and would be a desirable advance in systems theory. Although bio-allometry has not led to the fundamental causes which are responsible for the proportional change patterns as yet, it does clearly demarcate the existence of those causes, and provides direct clues and "trails" for the eventual discovery of underlying causes. Systems theory definitely needs clues and "trails" to fundamental causes of systems functions. Finally, bio-allometry also suggests to systems theory that isomorphies need not be perfectly "iso" to be interesting. In bio-allometry, perfectly isometric growth is the exception and not the rule. Still, the consistency in rate of change of proportionality of growth is very important. Perhaps this will gradually change systems science's impression of the character of its most important product-- isomorphies.

Systems allometry is equally useful in the area of systems design and application, at least potentially. Consider the cases of allometry in conventional engineering which have not been cited here but are well covered in McMahon and Bonner (1983). Allometry in these physically-based systems can be used to predict directly the constraints on design and to choose among alternative designs on a rational basis. Schmidt-Nielson (1984) indicates this in his discussion of the three parameters of dimension, materials, and design alternatives which could be used to solve engineering problems using the predictions and trends of allometric-based considerations. Would it not be wonderful, in some future time, after considerable empirical homework is completed, to be able to approach some systems-level design problems using systems allometry to aid in selecting rationally among alternatives? Systems allometry could also be used effectively in diagnosing system problems. Systems theory has not, to date, provided specialists in systems design/application adequate tools for diagnosis of systems problems. Bonner (1984) cites the many parallels between bio-allometry and allometry in conventional engineering. Perhaps both of these areas will have instructive parallels with the proposed systems-allometry.

CAUTIONS

It is customary for serious allometricians to end their papers with caveats because there is some real danger of believing too much in techniques like regression analysis (since it uses real data) without emphasizing the limits of the technique. Systems allometry will have to be even more cautiously utilized than its predecessors. For example, Calder (1984) notes that there is a requirement for dimensional consistency in use of the allometric equations for results to be significant. Dimensional consistency will be harder to attain in systems allometric studies due to the breadth of disciplines covered. It is also known that as the range of log scales (orders of magnitudes) increase, the impact of graphic portrayals increase obscuring real differences. The slope of the log-log plot used to identify allometry is little changed given addition of data compared to the changes observed with the same data changes in a log-linear (arithmetic) plot. So the technique of plotting becomes an artifact if not used carefully. The size range of the data begins to have a greater impact on the graphic form than the sample size. In systems allometry, as suggested above, the size range of the data will be greater than any application yet encountered. Its log-log plots must protect from the inherent deception of minimizing dispersion. Schmidt-Nielson (1984) warns that "allometric equations cannot be used for extrapolations beyond the range of data on which they are based." Systems allometry may have the opposite problem. Its range of data will be so broad that it is possible that more local patterns will be obscured by global patterns; both must be sought. Finally, in my own preliminary attempts it seems that the incredibly broad span of values in the systems data (virtually 80 orders of magnitude) rapidly becomes impossible to deal with using most contemporary computer systems. Many statistical equations require squaring values at one point or another and in the case of systems parameters the result sometimes exceeds allowed maxima and minima for number storage. Further, the number of cases and values for each case which can be processed in a reasonable amount of time by computers for such statistical testing as "clustering theory" algorithms is exceeded by the types of tests suggested by Troncale (1981, 1982). Yet this type of clustering is essential to the later success of systems allometry. Systems allometricians will also have to be hyperaware of the caution that statistical correlations are not evidence of cause-and-effect and the two should never be confused.

Despite all of these cautions (which may be regarded as interesting problems to be solved, not barriers) and given all of the significant questions addressed and potential contributions, systems allometry appears to be a promising and utilitarian new tool for systems science.

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