HIERARCHY THEORY VII. SYSTEMS ALLOMETRY II. FURTHER TESTS OF QUANTITATIVE CORRELATIONS ACROSS LEVELS OF SYSTEMS ORGANIZATION

Dr. Len Troncale
Department of Biological Sciences
Institute for Advanced Systems Studies
California State University
Pomona, California, USA, 91768

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ABSTRACT

This paper is the second in a series presenting evidence for the new specialization in systems theory called systems allometry. It presents data in support of the systems allometric equation which states that the mass of hierarchical levels of organization vary directly as the square of their linear dimensions across all bio-systems levels studied at the 95 % confidence limit. It presents three other allometric equations that fail such a test, but whose interim allometric equations may deserve additional study. It discusses the novel concept of regarding a "level of organization" as if it was an indivisible natural entity. The paper uses the proven systems allometric equation to obtain two other equations as predictions that may then be tested, using these to suggest that some aspects of the theoretical aspects of systems science may someday be empirically refinable. Finally, it discusses how such quantified and quantifiable results in systems science may be used in systems design and application.

STATEMENT OF THE PROBLEM: THE RELATION BETWEEN ABSTRACT HIERARCHY THEORY AND EMPIRICAL REFINEMENT

It has been almost twenty years since the appearance of the first conferences and books on abstract hierarchy theory. It is time to assess their product. Can theory that is not conscientiously followed by either empirical testing or attempts at practical application lead to anything of lasting value? Or do hypotheses, insights, and postulates proliferate without becoming part of mainstream praxis because they are not proven or provable? In the most recent face-to-face symposium of a multi-year conference on hierarchy theory, participants noted that although contributions had been regular and substantial, no consensus statements had emerged. This null result occurred even though the thru-the-mail portion of the international conference had been completely focused on integration and comparison across the many disciplines represented by the participants.

This reviewer feels that the main reason for such a lack of consensus and steady, incremental progress over so many years is the lack of even a shred of empirical testing or application on the part of the theorists. Without such stimulus, theorists can maintain their favorite concepts unchallenged. Without the force of testing or praxis, there is no pressure for real comparison, for relinquishing one idea relative to another, for conforming our internal mental ideas to the guidance of external nature, for compromising on ideas by their synthesis. Theory is sterile without testing and/or application, as has been recently pointed out by several workers (Miller, 1986; Ackoff, 1986; Checkland, 1986; and Troncale, 1985).

In this paper a new field of systems specialization is proposed: systems allometry. It is based on almost one hundred years of work in biological and engineering-based allometric studies as described in the first article in this series (Troncale, 1986). This paper presents some of the first analyses of empirical data. These analyses indicate that testable, quantifiable correlations exist across hierarchically-based levels of real systems. If the correlations tested here are verified, expanded, and accepted by other systems researchers, an exemplar may emerge that will stimulate the search for consensus statements in hierarchy theory in particular, and for incremental progress in systems theory in general. The existence of quantifiable regularities in natural hierarchies may also be used as guidelines in systems design and application moving ideas in systems theory more quickly into systems praxis. So, this paper suggests a new specialization that has the potential for testing ideas in systems theory and requiring their synthesis into a consensus.

INTERIM USE OF THE META-HIERARCHY DATA BASE TO DEMONSTRATE ALLOMETRIC REGULARITIES ACROSS "LEVELS OF ORGANIZATION"

A series of past papers (Troncale, 1981, 1982) presented the description of a data base which consisted of empirical measurements collected from the referreed journals of various scientific specialties for the purpose of testing for the non-anthropomorphic (natural) levels of hierarchies in nature. For completeness, data continues to be added to the data base on all natural levels from sub-sub-atomic particles through atoms and elements, through the numerous levels of biological and geological organization up to societal levels. Data has been entered on newtonian parameters such as linear measurements, mass, interaction distance, interaction energy, interaction time, numbers per level, generation time, generation energy, lifespan, and fecundity. Additional data is being sought on informational parameters such as total information content, minimum generational information, information flow rate, and information complexity. Clustering analysis applied to the data presents researchers with the opportunity of assigning objects to hierarchical levels on a basis other than pure intuition. The existence of this data base also allows the search for correlations among and between various pairwise comparisons of parameters across levels (as was suggested in an earlier paper, Troncale, 1982). Systems allometry is made possible by the existence of this data base and many more pairwise comparisons can now be attempted, with much larger data sets, than the initial tests described in the next sections. The data base is resident on Kaypro, IBM, and Cyber computers at the Institute for Advanced Systems Studies, California State University, Pomona.

EVIDENCE FOR CROSS-LEVEL CORRELATIONS
A CASE STUDY ANNOUNCING THE BIRTH OF
A NEW SYSTEMS SPECIALTY – SYSTEMS ALLOMETRY

How could one represent a "level of organization?" Whatever the method used, it must synthesize the particulars for all entities within the level into one quanta, equally, without ignoring any of the entities. The simplest method might be using the mean of all the measurements representing a parameter (for example, mass).

To characterize the "group" of entities at that level. If the same method is used for all levels compared, then the integration of the particulars into one quanta per level per parameter will not introduce its own variation; the synthetic treatment of each level will be the same. If the log of the mean is used, then the many "levels" of organization we intend to compare in this attempt can be placed on the same graph. Logs are necessary because the absolute numbers range across too many log scales to fit on one graph paper. In Figure One, for example, the linear dimensions range across 14 magnitudes, while the mass dimensions range across 35 log scales! And this graph represents a test of correlation of two parameters across only biological levels. Finally, the standard tests must be run to insure that the sample data represents the total population of data sufficiently to validate the correlation.

The meta-hierarchy data base at the Institute currently yields the following mean values for mass to characterize the biological entities cited below (by level of biological organization):

Level	*Mean Value* *(in kgs)*	*Number of Measurements*
Molecules	2.44 x 10 (-22)	73
Organelles	7.89 x 10 (-21)	10
Cells	3.98 x 10 (-14)	6
Tissues	4.31 x 10 (-1)	29
Communities	1.48 x 10 (0)	4
Organisms	3.86 x 10 (0)	11
Ecosystems	9.81 x 10 (12)	14

Therefore, a total of seven levels and 147 measurements taken from the refereed literature are included in a characterization of the levels of biological organization from molecules to ecosystems by the parameter mass. It will be interesting to see if these values are altered much as many new items of data are included in the data base. The meta-hierarchical data base also contains the following mean values for linear dimensions for biological levels of organization:

Level	*Mean Value* *(in meters)*	*Number of Measurements*
Molecules	1.10 x 10 (-8)	18
Organelles	2.73 x 10 (-7)	266
Cells	1.77 x 10 (-5)	272
Tissues	6.08 x 10 (-3)	94
Organisms	3.79 x 10 (-1)	126
Communities	1.21 x 10 (5)	7

Therefore, a total of six levels and 783 measurements taken from the refereed literature are included in this characterization of levels of biological hierarchical organization using the parameter of linear dimensions. The standard deviations are not listed here (see Troncale, 1982), but it is interesting to note that the increase of numbers of measurements for linear dimensions resulted in a significant decrease in standard error scores.

Having these two sets of synthetic data, we may now ask the important question: "Is there a regular or constant relationship between the MASSES characteristic of a level and its LINEAR DIMENSIONS?" This question has already been asked for easily recognisable individual entities like species or organisms or mechanical objects. But no one has thought to ask the question of an entire set of individuals as they are represented in the unitary concept of a "scalar level of organization" which is usually considered an artificial construct of the human mind. A more dramatic question would be: "Does this relationship remain the same ACROSS MANY LEVELS OF ORGANIZATION?" We may ask this question only for six levels in the comparison of mass to linear dimensions since these are the only levels for which we currently have the appropriate data in the meta-hierarchical data base.

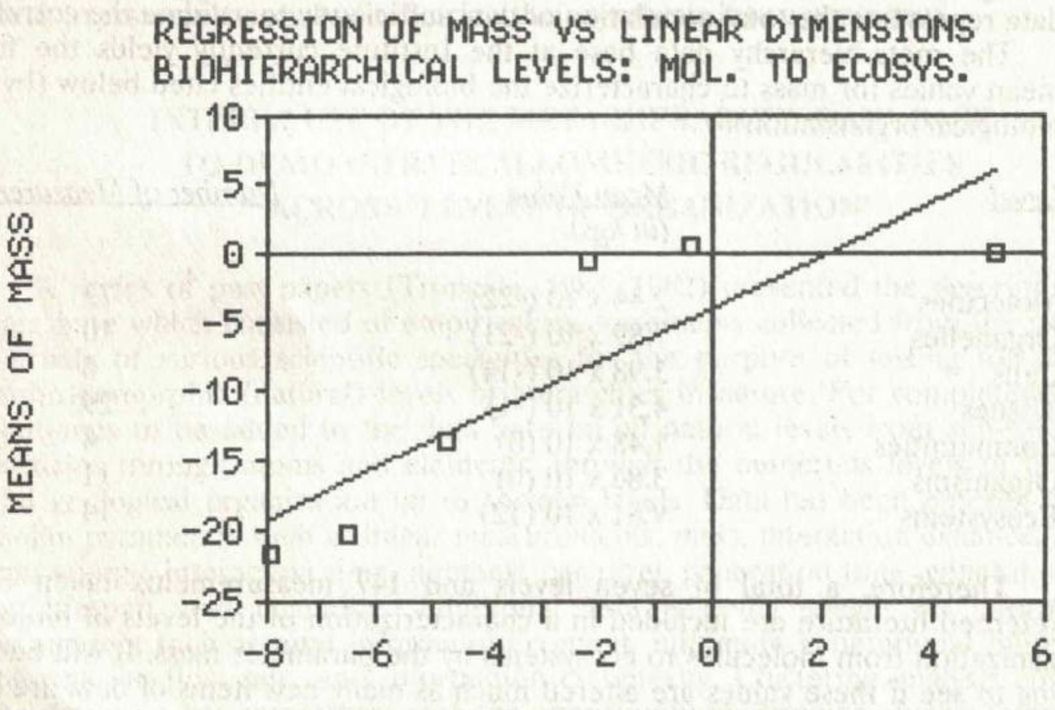


Figure One shows the Regression of Mass versus Linear Dimensions for the Biohierarchical Levels- Molecules to Eco-Communities (M = molecular level; O = organellar level; CL = cellular level; T = tissue/organ level; G = organism level; and CM = eco-community level of organization). The graph represents the comparison of the logs of 12 means constructed from 930 empirical measurements taken from the specialty journals representing the best of science for the levels of biology cited. The "best fit" line drawn through the points exhibits the following regression characteristics (given the 6 observation points and the 4 degrees of freedom):

Constant (y intercept)	-3.75683
Standard Error of Y	5.914579
R Squared	0.746586
Correlation Coefficient	0.864052
X Coefficient	1.912356
Standard Error of Coef.	0.557074

The correlation coefficient is greater than the 0.811 required for significance at the 95 % confidence level. About 75 % of the data is explained by the regression line. The regression line itself indicates that there is a significant correlation between the masses characteristic of a hierarchical level in biological systems and their linear dimensions, NO MATTER WHAT LEVEL ONE EXAMINES, ACROSS ALL LEVELS, AND DESPITE THE OBVIOUS DIFFERENCES OF MOLECULES, ORGANISMS, AND ECOSYSTEMS. Further, this correlation maintains itself across the entire spectrum of biological organization thus far examined.

This condition can be expressed in an allometric equation (described in Troncale, 1986) using the anti-log of the Y intercept as the constant (or scale factor) of the allometric equation, and the calculated X coefficient as the slope, thus

$$Y = .000175\ X^{1.912}$$

but since the scale factor is so small a number (one part in over ten thousand in influence) it may be ignored, and since 1.912 is as close an empirical reading to "2" as one could hope to obtain, this allometric equation can be rewritten as

$$Y = X^2$$

or, the mass of a hierarchical level of organization in biological systems varies directly as the square of its linear dimensions.

This is an unexpected empirical finding that generalizes a great deal of data on a broad spectrum of natural objects. Because it is a correlation on the level of "level of organization", it is an empirically-based relationship in the domain of systems science. The new specialty of systems allometry may usher in an era of testable systems science theory. In later sections, we will show how it can be used to predict other relationships in systems level of organization that can be tested empirically. Since it is an empirically-based finding regarding hierarchical organization, it may impact the search for consensus and advances in hierarchy theory.

ADDITIONAL CORRELATIONS UNDER STUDY

Given the 15 newtonian and 5 information-based parameter sets currently being assembled for the meta-hierarchical data base (Troncale, 1981, 1982) many more pairwise correlations like the above could be tested in the near future. Here I include three additional pairwise comparisons that failed the 95 % confidence limit tests when treated exactly as the above, showing: 1) this system can discriminate between real and false correlations (all tests are not passed), and/or 2) the correlation coefficient is very sensitive to the number of levels included in the test, in addition to the amount of data included for each level. I do not include the regression data on each for the sake of brevity.

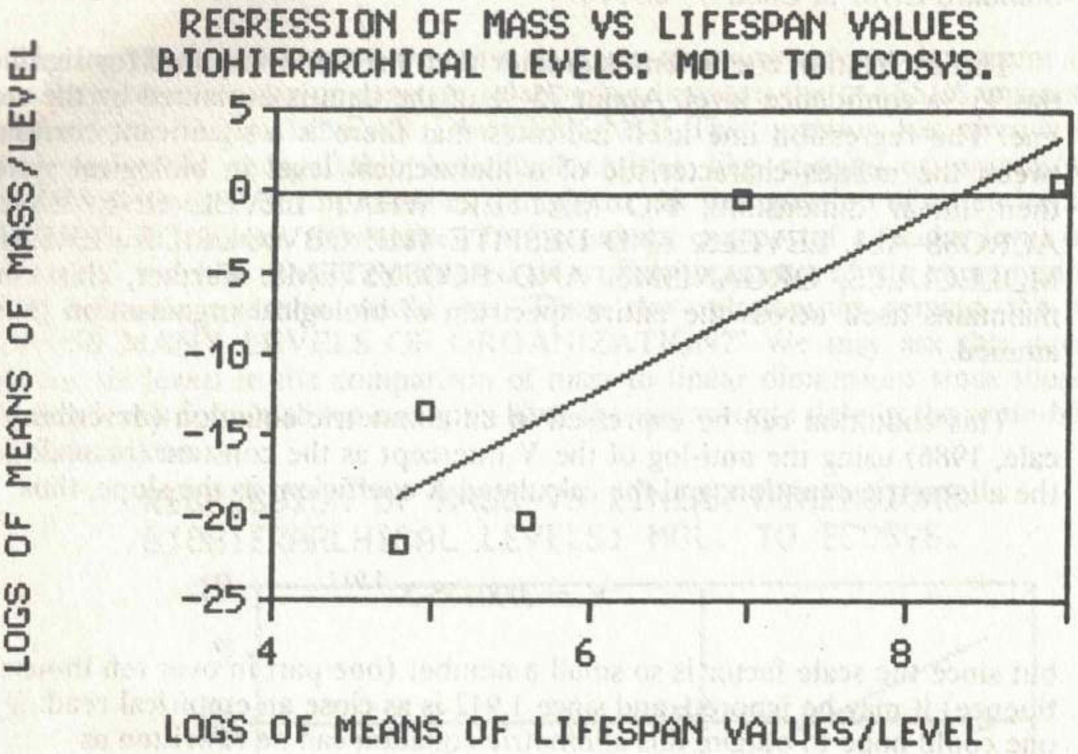


Figure Two shows the "best fit" regression line between logs of means of values for MASS versus logs of means of values for LIFESPAN values across the biohierarchical levels from molecules to organisms. Lifespan is self-explanatory...how long a typical entity at that level continues to exist. Five levels and 502 empirical measurements are currently included in this test. About 75 % of the data are explained by the regression line shown. However, the correlation coefficient of 0.862 is below the 0.878 required, and so this test fails the 95 % confidence level test. This is unfortunate since the allometric equation for the regression line shown is very interesting. The scale factor constant is so small (1.27 x 10(-44)), that it can be ignored, so that the resulting equation reads

$$Y = X^5$$

We can and will add data to this test on the community and ecosystem levels which will raise the degrees of freedom to five at which this correlation coefficient passes the 95 % confidence limit test. It will be interesting to see if this addition will change the statistics to improve or destroy the correlation coefficient and the above allometric equation.

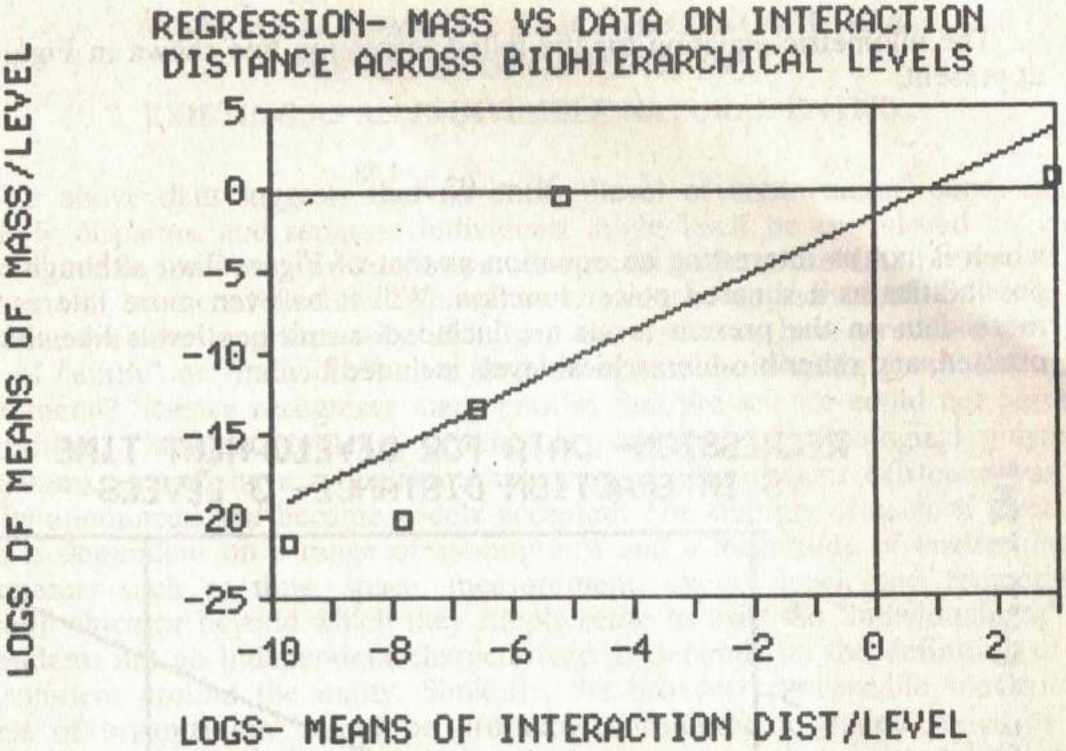


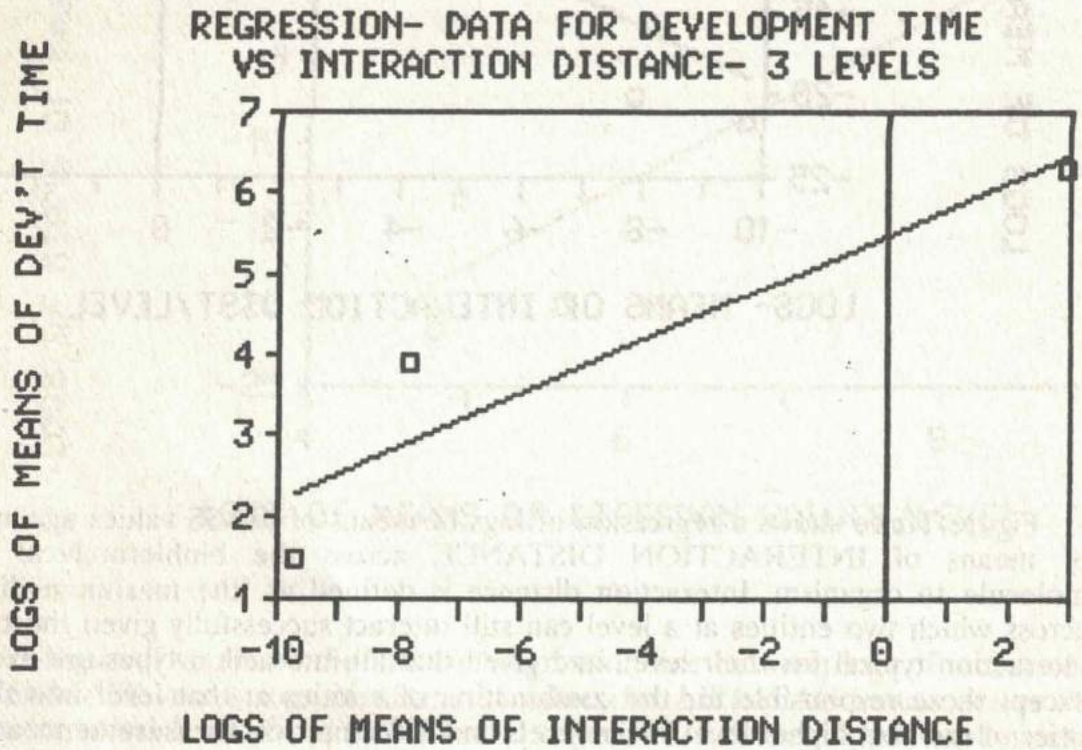
Figure Three shows a regression of logs of means of MASS values against logs of means of INTERACTION DISTANCE across the biohierarchical levels molecule to organism. Interaction distance is defined as "the maximum distance across which two entities at a level can still interact successfully given the type of interaction typical for their level, and given that all interaction types are excluded except those responsible for the combination of entities at that level into the entities of the next higher level." Five levels and 356 empirical measurements are represented in this test. Although 67 % of the data is explained by the "best fit" regression line, the correlation coefficient is about 0.82 and fails the required 0.88 necessary to meet the conventional 95 % confidence level.

However, this failure illustrates two important possibilities. First, when all of the seven putative biohierarchical levels are included after further collection of data, the degrees of freedom will be six, not three, and the above data already passes the 95 % confidence test with only four degrees of freedom. Second, note that the data point for tissue/organ (T) shows the greatest dispersion from the regression line. In past work on the meta-hierarchical data base using clustering theory, it was shown in preliminary data that tissue/organ level appeared to fail the test for identification as a non-anthropomorphic, hierarchical level (Troncale, 1981). If this continues to prove true with more rigorous testing, then some of the parameters describing the tissue/organ level would be expected to have characteristics that would disguise or disrupt tests for true correlations across bio-levels. This indicates that the tests using clustering theory to validate in some way our intuitions about what are truly levels in natural hierarchies are closely related to tests on correlations between levels as predicted (Troncale, 1984), and that both must be optimized simultaneously.

The allometric equation for the failed regression line shown in Figure Two is, at present,

$$Y = .03\, X^{1.78}$$

which is not as interesting an equation as that of Figure Two although it still has possibilities as a squared power function. Will it be even more interesting when more data on the present levels are included, suspicious levels like tissue\organ omitted, and other bio-hierarchical levels included?



In Figure Four, I try to get away from the use of MASS in every comparison by regressing the log of means for DEVELOPMENT TIME against the log of means for INTERACTION DISTANCE across three bio-hierarchical levels using ony 161 available measurements. The lesser number of levels represented, and depleted data for each results in a pleasing "best fit" line which still fails the 95 % confidence limit test. Still, 85 % of the data is "explained" by the regression line shown, and if the data follows the same pattern after adding three more levels, and the correlation coefficient remains the same, this category of line would pass the 99 % confidence level test.

In summary, these last three correlation tests fail, but should be recognized as tests on clearly incomplete data sets. The glimpses of possible allometries they provide suggest it worthwhile to complete the data sets and retry the correlations.

SYSTEMS ALLOMETRY AND THE CONCEPT OF A "LEVEL OF ORGANIZATION" EXISTING AS AN INDIVISIBLE NATURAL ENTITY

The above data suggests that an entire "level of organization" consisting of formerly disparate and separate individuals might itself be considered an indissoluble unit in some way we cannot perceive at all without the data presented. To some it will be incredible that a "level" be considered an individual. But is it not true that over the long time span of human awareness we have stretched the concept of "entity" or "individual" time and time again to contain more and more phenomena? Science recognizes many entities that pre-science could not perceive as entitites. Galaxies, elements, sub-atomic particles, cells, biological polymers, ecosystems, etc. all have a birth time when the reality of their existence was belatedly announced and became widely accepted. The stability of each of these entities is dependent on a range of assumptions and a magnitude of environmental parameters such as time, space, measurement, energy level, and temperature without which or beyond which they simply cease to exist. So "individualness" is a dependent, not an independent characteristic. It depends on the definition of the environment around the entity. Similarly, the broadest conceivable spectrum of "levels of organization" might be profitably considered a graded series of "individuals" or "entities" given a broad enough parameter set and its analysis in the above correlation tests.

Discrimination is an act of human awareness. According to Jaynes (1976), the evolution of human consciousness moves from blurred distinctions and obligate holism in pre-humans, step-by-step, to the increased discriminations made possible by language, to the much increased discrimination made possible by the scientific method, especially its reductionist strain. Systems science attempts to reconnect the many discriminant parts into obligate interacting wholes. Even the most successful examples of scientific reductionism illustrate that the presence of dynamic interactions between individuals renders formerly separate parts into new entities of wholeness. This same history amply illustrates that it is often the dynamic characteristics of a phenomena that are the last to be discovered. Our minds seem to be overly oriented to discrimination (perhaps due to our dependence on language) and overly reluctant to perceive super system organization until the evidence is overwhelming. Thus, our universe is populated with an immense number of discriminant parts, and a paucity of wholes. If many examples such as the data shown above prove to exist, future civilizations might profitably look for synthetic wholes even to the extent of "levels of systems organization" which have empirically demonstrable, regular, and predictable patterns across them.

ON THE POSSIBILITY OF MAKING AND TESTING PREDICTIONS IN SYSTEMS SCIENCE

The new systems specialization of "systems allometry" would be able to generate its own testable predictions on systems organization. This would be a welcome and needed new development in systems science, specifically in its systems theory strains. For example, one result of this study (Figure One) is the relationship, mass is directly proportional to the square of linear dimensions for all studied bio-hierarchical levels. But we know that volume is directly proportional to the cube of linear dimensions, and that density is equal to mass divided by volume. Substituting the result of this paper for M and the previously known equation for volume into D M/V, we get

$$D\ L^2 / L^3 \text{ or } D\ L^{-1}$$

With the existence of the meta-hierarchical data base, we can now test this prediction to see if it proves true, providing tests of the theoretical statements that might emerge from the previous studies.

POTENTIAL USE OF THE NEW FIELD OF SYSTEMS ALLOMETRY IN SYSTEMS DESIGN AND APPLICATION

It is very popular in many fields, but especially in systems fields, to have the applications-oriented workers criticise the theoreticians as impractical and unproductive. Yet one good piece of theory might completely alter the way practical people solve an entire class of problems. When an applications person solves an application problem, one specific case of the problem is solved. When a theoretician solves a key theoretical problem, all cases of that type of problem are potentially solved.

If the new field of systems allometry is able to provide evidence for a series of consistent correlations across all known hierarchical levels, then these may be used in practical systems design. That all natural organizational levels of a certain type possess quantifiable allometric regularities would argue that these regularities are required for optimal or sufficing systems function. Such regularities might best be respected and emulated by those responsible for advising organizations or engineers in various domains of systems application. Hierarchy theory of this genre would be armed by both descriptive and prescriptive power. A systems design agent could predict with some confidence the range of values within which a certain hierarchical design would operate best. Sizes, lifespans, densities, information loads, etc. would not be independently determined, but rather would be interdependently decided using verified and verifiable quantities. This presumes much work beyond the simple beginnings reported here, but perhaps the data reported here is sufficiently tantalizing a glimpse of the possibilities that increased interest and resource allocation may be attracted to the new field of systems allometry.

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