

New Directions for Tying Physics and Biologic Systems

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Abstract

The author considers the current situation with *Quantum mechanics*, *Biological systems*, and the wide use of *multilevel analysis* at all levels. Several trends are considered, suggesting that new directions are needed to connect all levels of physical space. In particular is a need to include scale in locating objects and processes at different levels, providing for a single model of reality that connects all levels. This direction presents other concerns, such as the need to measure distance across scale and potentially for a new numeric system that can represent a single value for a complex measurement that could measure across scale. These would be directions that could significantly expand both science and mathematics, connecting all levels of scale.

1. Introduction

The question of how to connect quantum mechanics with biological systems has been slowly building over many decades. Generally, the connection seems to presume a bottom-up approach, where reality is defined at the lowest levels. Physics has benefited greatly from this approach and continues to look for the defining aspects of nature in the smallest phenomena underpinning all other objects. Biology, on the other hand, has found integral phenomena at many levels of scale, calling for multilevel modeling approaches. Can we find ways to connect these two disciplines with different approaches? This paper suggests there is a way, however, some changes in approach will be needed for this to work.

Of particular concern for tying these two disciplines together is the reductionist approach of physics against the multilevel modeling approach of systems biology. A strict reductionist approach requires all action to start at the lower level and move upward. This conflicts with multilevel modeling approaches of biological systems: “One of the major theoretical outcomes of multilevel modelling is that causation in biological systems runs in both directions: upwards from the genome and downwards from all other levels. There are feedforward and feedback loops between the different levels [1]”.

Evidence of this situation is apparent from a number of systems biologists who explicitly state that biological systems require multilevel analysis and cannot be reduced to actions and processes strictly at the quantum mechanical level [1-4]. Nartallo-Kaluarachchi et al reject the reductionist approach “in order

to build a holistic approach that develop models consolidating different spatial and temporal scales, using multimodal data, and considering complex representational structures [4]. The complexity of biological systems involves, as Green & Batterman calls it, After the quote should be “[5]”, where modeling a biologic process requires multiple models at different scales.

Multilevel models can address the connections between scales, however: “examples from multi- scale modeling in both physics and biology show that modelers in both domains must confront the tyranny of scales problem. There is no single approach that can account for all relevant aspects of multi-scale systems [5]”. So, Green and Batterman indicate the tyranny of scales exists for both physics and biology, a bit at odds with a strict reductionist approach. The author suggests resolving the tyranny of scales might be a means to tie physics and biology.

As evidence against the strict reductionist approach, Batterman gives the example of a square peg and a round hole at our level where quantum mechanics plays either a minor role or even can be dismissed entirely when modeling a specific large-scale situation. The materials of the peg and the board with the hole can be of many different materials with the large-scale situation being the same. Quantum mechanics matters little, if at all, in such a situation. As well, there are many situations where quantum mechanics impacts the lower levels of biological systems, including large molecules, DNA, and proteins. Allowing for phenomena at multiple levels of scale and making connections between these levels of scale could connect the very small with our level with the very large.

Some observed phenomena need to be modeled at the level of the phenomena, even if there is an underlying explanation of how the phenomena emerges. As an example, the concept of heat emerges from the movement of molecules, however, heat cannot be modeled at the level of molecules. Understanding how these phenomena emerge will involve modeling the processes at the level they are observed. Any explanation only at the level of quantum mechanics will be insufficient to describe the emergent phenomena.

The interconnected aspects of biological systems with their environments present additional issues, as the surrounding context of a biological system is crucial to an understanding of it. Such concerns have led some scientists to call for new methods, processes, and potentially mathematics to handle the multilevel complexity of biological systems:

“Developing the mathematical and computational tools to deal with these multiple causation loops is itself a major challenge. The mathematics that naturally suits one level may be very different from that for another level. Connecting levels is not therefore trivial. Nor are the problems simply mathematical and computational [1]”.

“The problem refers to the scale-dependency of physical behaviors that presents a hard challenge for modeling and explaining multi-scale systems. No single mathematical model can account for behaviors at all spatial and temporal scales, and the modeler must therefore combine different mathematical models relying on different boundary conditions [5]”.

“We need at least a comparable change of paradigms or conceptual enrichment of Mathematics in order to deal with the biological phenomena: by their peculiar autonomy and contextual dependence, we cannot easily draw their mathematics on the phenomenal view by “cutting them off” from their contexts and by giving them constructed contours. This, I believe, is the underlying methodological challenge for Mathematics in Biology, as Mathematics usually organizes the physical world, sets norms for it [3]”.

“Clearly, developing a holistic framework for modelling complex biological systems that explains empirical data and yields useful predictions, remains one of the most daunting yet pressing challenges in interdisciplinary science... The unique challenges of biological complexity call for innovative tools that move beyond the prevalent reductionist approaches in current mathematical modelling [4]”.

This essay will present directions for solutions to both the tyranny of scales and the call for new mathematical tools, with new mathematical tools required to manage the many levels of scale. Resolving the tyranny of scales will also connect physics with biological systems.

2. The Argument for Scale

The use of multi-scale modeling and dimensional analysis both can be seen as indications that science is converging upon the need to explicitly include scale. Some authors tack scale onto our existing theory of space-time [6,7]. And there are signs that a fourth physical dimension exists [8,9]. Some scientists even suggest such a fourth physical dimension could answer some unexplained phenomena today [10-13]. A number of these indications come under the discipline of physics. On the systems biology side, Come close to the scientific hypothesis of this paper when they state: “We highlight three particularly promising avenues that have the potential to significantly enhance mathematical biology, by adopting a holistic viewpoint integrating multiple biophysical processes and scales within a single [4].” While they advocate for a single model across biologic systems, they do not propose adding scale as a physical continuum of space that crosses many disciplines. The author suggests these are implicit, even explicit, signs of a convergence toward including scale as a physical aspect of space.

Consider the observation that if we touch our finger to a pane of glass, the direct evidence is of our finger touching the glass. If we perceive the action with a magnifying glass, we will see specific ridges of our skin touching the less-than-smooth surface of the glass. If we perceive the action with a microscope, we will see cells touching the crystalline surface of the glass. We can continue indirect observations using different magnifying tools down to the protein and molecular scale levels. We could set up multiple observational tools to observe different scale levels during the same action, and we would gather the observational evidence that the action occurs at all these levels together, not one or the other. If science is about observations, then we should agree that nature operates as a cohesive whole, not at only one or another level.

A potential implication is that scientific and mathematical tools will need to deal with multiple levels of scale concurrently and not resort to any single level. Longo presents the difficulty for biological systems: “... concerning the challenges for Mathematics in Biology, are not just meant as informal/technical considerations, but they are an attempt to analyze the peculiar interface by which life presents itself to us. The mathematical analysis of the difficulties should stimulate a foundational investigation on the tools used and stress this constitutive role that Mathematics has w. r. to reality: these difficulties are due to the different “autonomy”, criticality and multi-scalar phenomenality of life, if compared to the physical one[3].”

Looking over the many areas of multi-scale modeling, the insistence of interconnections between levels of scale, and the observation that the world indeed has many levels of scale, would seem almost a corollary that we should be including all these levels of scale in a cohesive model of the universe. By this the author means that the continuum of scale should be an explicit aspect of our models. We have identified scale as a continuum along which many areas of

science have evolved with differing objects and processes at each level. Integrating these many levels would involve crossing levels of scale. We should, therefore, include scale as a continuum, as a dimension, in our models. Note that adding such a dimension does not suddenly change the reality we live in, nor does it suddenly change all the work science has accomplished to date. It would, however, map the many scale levels of science onto a single cohesive model of reality.

To address the tyranny of scales we should add the continuum of scale as a physical dimension to our models, working toward a single holistic model. The author believes this is the next direction that scientists should look to as we expand our knowledge and understanding of our world, including connecting quantum mechanics and biological systems. The separation of scientific disciplines might present a challenge for this holistic approach, even if it could bring many disciplines together using a single model of reality.

Scale should be explicitly identified in our models as a dimension of space. However, it is not like our traditional three dimensions, since a unit of length in scale would not match a unit of length in our traditional dimensions. A unit of length in scale, relative to our traditional units of length, would be an exponential unit, possibly using a logarithmic scale. This should not be a reason to exclude it as a continuum, a dimension, of physical space in our models. It does provide some interesting challenges.

A particular issue with including scale as a physical dimension derives from this difference in measuring distances: How do we manage a physical space where not all dimensions are the same? We have mathematics to handle such a geometric situation. Do we have the appropriate mathematical tools to handle units of length in scale? Connecting models at different scale positions would require some form of distance measure for the scale dimension. We may not have units of measure that equate to lengths in scale, especially those that are relatively different than our other length units. This situation, the author believes, is the real issue to be resolved. Without appropriate units of measure for scale lengths, we will not be able to manage models involving a scale dimension and likely is a key reason scale has not already been included in our model of reality.

3. New Mathematical Tools

An important concern in adding scale as a dimension is our ability to measure across it. We should note that traditional measurements involve a level of accuracy with an error term. The accuracy, or more appropriately the error term, of a measurement at one level of scale might not be comparable to a measurement at a different level of scale. The error term of the larger measurement can be much greater than the entire quantity of the smaller measurement. For example, we might have a measurement of 2.15 meters, which might be better stated as $2.15 \pm .005$ meters and another measurement of $3.41 * 10^{-9} \pm .01$ ($* 10^{-9}$ meters). The potential

error in the first measurement ($\pm .005$ meters) dwarfs any accuracy of the second measurement at 0.0000000341 meters.

In our current paradigm, measurement accuracy is considered an inherent issue of any measurements which cross scale. If this is the case, we will be unable to properly deal with measurements across scale, since we assume we will always be lacking considerable accuracy at the extremes of scale. At first glance this might seem to be an inherent limitation of our abilities to measure. However, the author suggests the problem resides with our implicit assumption that scale is simply an aspect of being ‘more accurate’ and not, therefore, a real or measurable property of space. This implicit assumption essentially results in a confusion of accuracy with scale, hiding the idea that scale could possibly be a measurable property of space.

This confusion can be overcome. We can consider scale to be a dimensional aspect of space that is measurable with such measurements including their own accuracy of measurement along scale. This means accuracy and scale are not synonymous and should not be confused. Note that this conclusion is a result of simply allowing scale to be in any way measurable.

An additional implicit assumption is that we already have all the mathematical tools necessary to make any measurement in the universe. The author suggests this is a false assumption and that what is lacking are our mathematical tools. Our means of measuring and calculating quantities – our numeric representational systems – are inadequate to the task of measuring across scale. We require new mathematical tools for measuring and calculating, which the author suggests is a new numeric representational system.

Looking at the many areas of science that are utilizing multi-scale modeling, the author has indicated there appears to be a convergence towards the need to incorporate scale into our models. In a similar vein, looking at the increasing use of complex numbers in science, the author suggests that complex numbers are more foundational as well. There is an issue with complex numbers, however, as we represent them as two separate values – as in $x + iy$. A true unit of measure, such as a distance measurement, should involve a single value. From a pure mathematical perspective, a complex number should be a single value. Then why are we limited to representing such numbers as a pair of values? Because we do not have a value for $\sqrt{-1} = 'i'$. Identifying a value for ‘i’ would resolve this situation. It would provide a means of having a single value for a complex number – that could also be a measurement. If such a single complex value could provide a measure for the unit of scale length, then we have a program for significantly advancing both science and mathematics.

As a consideration for the need to identify complex values as single values, there is the intuition that how we represent number values has a direct impact upon the capabilities of our science using those numeric values. Consider attempting to develop our

current science using Roman numerals or just fractions. The author submits that current science requires our positional numeric system (typically the decimal numeric system) to represent number values as measurements. Extrapolating here, we might find that a new complex numeric system capable of representing complex numbers as single values might prove able to extend what science can handle. This could mean we are able to handle calculations and equations beyond what our current positional numeric system can.

In addition, consider that Roman numerals generally represent Integers, fractions represent Rational numbers, and positional (decimal) numerals represent Real numbers. This would be another indication that a new numeric system is needed that represents Complex numbers as single values and would constitute a new direction for mathematics and science.

To drill into how we might identify such a new complex numeric system, consider the progression of Number systems with numeric systems. Integers only need addition and subtraction to reach every Integer. So, a numeric system that only incorporates addition and subtraction would be sufficient (e.g. Roman numerals). Rational numbers require multiplication and division to reach every Rational. Fractions can, theoretically, represent any Rational number and incorporate division into the definition of a fraction. Note that addition/subtraction and multiplication/division are reversing (or complimentary) operations. Real numbers need exponents to reach every Real number. Decimals incorporate exponents into the definition of a single value and can handle powers and roots (e.g., square root, cube root). These are also reversing operations. Again, extrapolating, Complex numbers would need a pair of reversing operations to define single values for complex values. The author suggests the reversing operations are integration and differentiation. A numeric system using natural logarithms and, say, Laurent series might be a direction to look into.

Consider that integration and differentiation are inherent in connecting models at different scales, integrating from a smaller scale level to a larger scale. A new numeric system that had integration and differentiation built into it could prove a powerful tool for integrating levels of scale, to say nothing of the many areas of science using complex numbers today. The author suggests this is an expansive direction for mathematics that would provide many advantages for science.

It is very possible that such a numeral system may not be representable using traditional paper and pencil methods, requiring the use of computers. It is also possible that we would need to shift to this new numeric system en masse across all areas of scientific fields that involve scale – moving away from strictly Real values represented by decimals.

4. Conclusion

In conclusion, as we move toward digitally modeling objects at the many levels of reality, from the quantum world to biological

systems to comic levels, we find the need for locating objects in scale. This will require a four-dimensional scientific model of space that spans and connects multiple scientific disciplines. This, in turn, will require some distance measure and units that cross non-linear scales. The ability to measure across non-linear scale leads to the need to advance the underlying means of taking measurements and of representing numbers, so that such exponential distance measurements can be adequately quantified. This measurement requirement leads to the need for a new more powerful numeric representational system that can represent a complex number as a single value. Both directions, adding scale to our models and defining a new numeric system, have the potential to significantly advance both science and mathematics.

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