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The Quantum Nature of Species

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Abstract. In this note, we provide a starting point for an explanation of a strange phenomenon in the set of all species: indeed, it turns out that species are very far apart, although one would expect a continuum since DNA changes are very small. We point out here the role of societies of animals, suggesting that ethology should be a major component of genetic studies.

Résumé. Dans cette note, nous présentons le point de départ pour une explication d'un phénomène étrange dans l'ensemble des espèces: en effet, il se trouve que les espèces sont très éloignées les unes des autres, bien qu'on s'attendrait à un continuum puisque les changements de l'ADN sont très petits. Nous identifions le rôle des sociétés, en suggérant que l'éthologie soit une composante majeure des études génétiques.

If we were launched from outside, on our planet, as intelligent people, what would we expect to see in the spectrum of life? Suppose that we know already that evolution works by tiny changes over millions of years, each one being a small modification of the DNA. Then what we would expect to see is a continuum of species. We would see a full continuous spectrum of animals from the chimpanzee to the homo sapiens, as well as between any other species. And we could speak with other monkeys, those who are closest to us. While this verbal exchange would not be perfect, it would be possible to raise a monkey, close to us, since his/her birth, and talk between us quite like human beings do.

But this is not the reality. Species are very far apart. This is a paradox, and it is quite hard to figure out why the quantum differentiation of species is predominant everywhere on the planet.

For instance, a British scientist spent years in Africa and raised young monkeys. While there was an emotional relation between her and them, no precise language ever appeared.

A cat raised entirely by human beings will naturally speak the language of cats. It is as if everything was in the mind of a given species, no matter how we raise it. The barrier between species is immense.

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So the question arises: why is life on our planet so quantized? There are several experimental facts that explain this situation, but there is no meta theory.

For instance, it is known that the distance between two closely related species, measured in DNA distance, is most apparent in sexual chromosomes. Actually, the sexual chromosomes are 50% more apart than others, so that reproduction between two closely related species is impossible.

Here is a citation from Presgraves [1], a specialist in chromosomes (see especially the last sentence):

> "Chromosomes are divided into two types: sex chromosomes and autosomes. Sex chromosomes are the XY chromosomes that denote a male in both fruit flies and humans and the XX that denote a female. When the researchers mapped the factors that cause hybrid males to become sterile, they found that there were many more incompatibility factors on the X sex chromosome compared to on the autosomes. This means that sex chromosomes become functionally different between species much faster than non-sex chromosomes."

This quantization of life is therefore a fascinating subject.

Actually, we do not know very well why this quantization occurs. There are several explanations, but they are so diverse, and related to specific species and their exact environment, that no explanation is really satisfactory. Let us be clear: biologists make a scientific endeavour of the utmost importance, and as we know, nothing is more difficult than studying life, the most complex organization in the large field of sciences.

We propose here a theory, which is certainly understood by many evolutionary biologists, at least implicitly, that could be of some utility.

We will define two Planck constants.

Definition 1. The "DNA Planck constant" is the elementary modification in DNA when it occurs once.

Definition 2. The "Species Planck constant" is the modification in the DNA that separates species, that is to say when the coupling between a male and a female does not lead to a pregnancy.

Of course, the second constant is much larger that the first one, for a ratio of several thousands or millions.

But the question still remains: why species are quantized and not a continuum?

For mathematicians and physicists, the answer is clear: there is a critical value somewhere between the first and the second constants. Then when does this critical value arise?

[1] Daven C. Presgraves is the Shirley Cox Kearns professor of biology at the Departement of Biology at the University of Rochester.

It has been a major trend in biology (up to 2000) trying to explain biology in terms of agents, be they hormones, enzymes, or RNA messengers. But genetics has recently uncovered the role of geometry in the fabric of DNA and of life in general. This discovery was anticipated half a century before by René Thom (Fields Medallist, IHES). It is not his controversial theory of morphogenesis that is important, but rather his theory of singularities that led him to the Fields medal (as well as his theory of cobordism). This led him later to his "catastrophe theory", that embodies much of the singularities that we experience. Here we must imagine a dynamical system in motion that we may control by a few parameters. A catastrophe appears when, whatever the controlling parameters that we choose, a singularity occurs. By elementary Morse theory, a singularity is when the topological body changes its own shape, for instance when a point is a disc, and when this disc becomes attached with a handle, and then when a second handle appears, to form at the endpoint a torus. From a point to a full torus, the evolution of the shape is entirely due to four singularities. However, in this topological process, entirely governed by a finite number of singularities (where elementary topological changes occur, like elementary changes in the DNA), one must study how the ends resulting from each elementary step are identified. This leads to a rich and fascinating theory in mathematics known as differential topology (or differential geometry). Fortunately, mathematicians know that these problems of differential identification of ends occur only in dimension 4 and over. Therefore, one could expect that the changes in biology, which is a 3-dimensional theory, does not contain the subtle problems of complexity that we discover in higher dimensions.

So although life is the most complex subject of study, the fact that it can be realized, as a model, in three dimensions, makes it much easier to understand. One could argue that physics is also 3-dimensional, but actually there are lots of hidden dimensions in physics, so that for instance String Theory has more than twenty dimensions. Here is our first conjecture:

Conjecture 1. *There are no hidden dimensions in biology.*

This means that any scientific (say mathematical) study of biology will always remain within three dimensions. Of course one may include time as a fourth parameter, but nothing more. Therefore this excludes that the most fascinating new discoveries of mathematics in higher dimension will ever apply to biology. This is perhaps why most great mathematicians are not immediately attracted to biology. However, this attitude could change. Let us sum up: differential geometry, in its finest form, will not impact biology, but topology will. Moreover the quantum aspect of DNA changes points to a reunion of both combinatorial and quantum sciences as the main tools in our understanding of life. Here "quantum" should be understood, not in some allegory with quantum physics, but rather as a rigorous manifestation of a fundamental principle of discretization. I just mean that the word "quantum" should not be reserved to quantum mechanics, but also to any appearance of a lack of continuum, as soon as we see a phenomenon that is made by elementary indecomposable steps. In this sense, we use the word "quantum" as an indecomposable unit, exactly as the Ancient Greeks defined that notion (actually the Greeks used more the word "atom", but it is the same).

For the sake of this discussion, I would like to recall the extraordinary endeavour of the Ancient Greeks that led them to ask that fundamental question: is the world in space and in time discrete (atomized in structures that cannot be decomposed indefinitely) or is it a perfect continuum? Half a century before Socrates, there were two schools, one maintingning that the world is a continuum and the other claiming that it is discrete (quantized). And twenty years before Socrates (whose impact on sciences is negligible), Zeno of Elea produced two extraordinary paradoxes, one that destroyed the continuum theory and the other that destroyed the quantum theory. We all know his first paradox that destroys the continuum theory, with Achilles and the tortoise, which was solved by the infinitesimal calculus that the subsequent Greeks (especially Eudoxus and Archimedes) mastered quite well. But it seems that nobody knows, even among scientists, the second paradox. Here it is. Suppose that you have three line segments, each one divided into three equal parts, one over the other. Call them A_1, A_2, A_3 for the upper segment, and the same for the B and C segments. Then suppose that each of the three parts of these segments has length equal to the smallest quantum non-decomposable length possible. Now displace the segment A to the right by one unit of length. At the same time, displace the segment B to the left. Assume that the time needed for this displacement is one indecomposable unit of time. Then, viewed from C, that remained still, there is no problem. But seen from B, A was displaced by two units in one unit of time, that is to say by one unit by half a unit of atomic time. This is a contradiction.

One sees immediately that this paradox embodies not only Galileo's relativity, two thousands years before Galileo, but also a study of quantization. Actually, in my courses in mathematical physics, I often ask my students to see where is the error in this paradox.

Let us come back to biology and the quantum nature of species.

Before expressing our main conjectures, we suggest examples from physics and mathematics. When a film of water is placed on a cold piece of glass, after a certain moment, the water accumulates into single drops. This is a phenomenon of classical quantization. The surface tension at the surface of each drop of water preserves the structure of drops. Note here that a large part of quantum physics can be understood by a process, known as geometric quantization, that assigns to each classical system its quantization, although here the formation of drops is purely classical.

Another physical example is the condensation of water in the clouds into small particles.

But here is a more interesting thought. Suppose for a moment that the species were distributed continuously, as suggests the first Planck constant (indeed the first Planck constant is so small that it should lead to a continuous spectrum of species). Then take an interval from 0 to 1, that would reflect that continuous spectrum, say from the chimpanzee to the homo sapiens. We would then have a continuous variety of animals, each one coupling or speaking to their neighbours on that interval. This would lead to a covering of the interval made of an infinity of sub-intervals. But compactness in mathematics tells us that from that infinity of sub-intervals, there is always a finite collection of intervals. And actually, these sub-intervals define the finite number of species. In some sense, each of these intervals, in finite number, concentrates to a single point which could be considered as the "central point" of that interval.

So this would explain why, from a continuum, we get a discrete set of species. Of course, we must explain why neighbourhoods accumulate to points.

This is a very interesting question in evolutionary biology. Here we suggest a general answer made of two conjectures.

Conjecture 2. *The socialisation of life organisms, in various groups and tribes, explains the quantum distinction between species. Socialisation enables one to ignore a large number of elementary DNA modifications and leads to an atomisation, by sexual reproduction, into a quantum state of life beings that preserves its social response to reproduction and predator attacks.*

Conjecture 3. *This socialisation is so strong that the only way to see another close species emerge is when the first species disappears or becomes inoffensive.*

We would like to emphasize here that our analogies with the physics of drops of water were only pedagogical - they have no scientific value as to how biology works. They were meant to show that other forms of atomisation exist, even in pure classical physics. However, our mathematical argument on the interval from 0 to 1, where 0 would be a chimpanzee and 1 a homo sapiens, is fundamental. It is not solely an analogy, but a scientific reality. We beleive that life obeys that mathematical description.

In reality, the evolution from say the chimpanzee to the homo sapiens is not an interval. It is actually part of a tree. But this tree is compact at any moment t of the evolution. It has several vertices, each one representing a species. Some vertices are interior while others are part of the endpoints of the tree. All interior vertices correspond to species that have disappeared, while the vertices at the endpoints of the tree are either species that will disappear (endangered) or species that are dominant. In any case, our mathematical argument on neighbourhoods, compactness and atomisation of species, applies as well to trees. Our argument made no distinction between intervals or trees as long as they are compact.

Our Conjectures 2 and 3 imply the following statement:

Corollary. *Ethology* [2] *is a fundamental part of genetics. One cannot understand genetics without ethology.*

[2]Ethology is the scientific study of animal behavior, with a focus on understanding behavior from an evolutionary and biological perspective, often involving naturalistic observation in the animal's environment. The field was pioneered by Konrad Lorenz and Nikolaas Tinbergen, and it explores the causes, functions, and adaptive significance of animal actions, with potential applications in conservation, welfare, and of course human behaviour since human beings are animals.

It is actually a surprising statement. In other words, it means that ethology must be studied from a genetic point of view. They are the *same* science, and they should be reunited. This means that courses given to students in genetics should be joint with courses on ethology, and vice versa. This junction between branches of sciences occurs regularly in the evolution of mathematics across centuries. Let us give examples that show that mathematics, today, is the unification of several branches of apparently different disciplines.

Viète, in the XVIth century, unified trigonometry and mathematics. Actually, while trigonometry was only a pseudo-science, entirely dedicated to calculations of areas and positions of planets or stars, he designed a proof of the rational solution of algebraic equations of the third degree by using trigonometry. Later on, mathematicians, by computing the Taylor development of trigonometric functions, included all of trigonometry as an obvious branch of mathematics.

Fifty years after Viète, Descartes unified classical physics (mechanics), geometry and algebra as one single theory. Later on, Leibniz, Newton and Lagrange unified analysis with the rest of mathematics, as well as making theoretical physics a branch of mathematics.

In the XIXth and XXth centuries, logic and computer science were also absorbed into mathematics.This is why, nowadays, mathematics is the only science that has only one congress, held every four years. What a contrast with biology, where no biologist can understand the works of another biologist. Most articles in Science or Nature are related to biology, but the specialisation is so excessive that these articles are beyond a reasonable understanding. This contrast is mainly due to the fact that biology is a recent science, while mathematics is the oldest. There is a need for a formal, mathematical, unified theory of biology.

The only two great mathematicians who tried to develop a mathematical theory of biology were René Thom and Mikhail Gromov, both from the Institut des Hautes Etudes Scientifiques (IHES). None of their contributions has never impacted the science of biology, even marginally.

In order to develop a genuine mathematical theory of biology, one must first identify categories and functors, in the mathematical sense. Here "categories" are not what biologists think. They must be completely different from their way of thinking life. A category must be understood, abstractly, as a common action of agents. These agents could be very diverse, as long as they share a common goal or action, or common characteristics. Then a fonctor from one category to another is a morphism that describes, abstractly, the interaction.

The confusion, or ultra-specialisation, in the works of biologists comes from the absence of categories and functors. We must understand life on just a few principles, like the least action principle in mathematics and physics. It is a fact that most great mathematicians nowadays can understand any new discovery in any field of mathematics. Of course, they do not understand the fine details, but they have an idea of the results and the methods of proof. But it is not the same in biology. No biologist today can have the slightest idea of a work of another biologist who would not be in his/her precise field of study. Each branch (and there are many) or any article of biology is completetely out of reach for a large majority of the other biologists. There is no common language. There is nothing that unifies biology, even though biology is a much simpler science than mathematics.

As Mikhail Gromov said in one of his lectures, the helix shape of DNA is not a surprise. If it were planar, it would not interact as actively with neighbours. Its geometry is made to deploy itself in full dimension 3. Actually, this is our Conjecture 4:

Conjecture 4. *Any live organism deploys itself in its environment in such a way that it occupies the largest possible 3-dimensional space.*

This conjecture is not at all obvious, because many life organisms seem to be planar, especially uni-cellular organisms. So this conjecure is probably false. The question then arises: when, and under which circumstances does a living organism deploy itself in three dimensions?

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