An extremely brief and simple history of science: the 'neuroperspective'

Science, as a product of society, naturally conforms to the mindset of the constituents of those societies. But people's outlooks depend on what they have learnt in their times and, fundamentally, on how they perceive the world around, that is, their senses determine their perspective. Therefore, it is not remarkable that science, at least a good part of it, relies on mathematics.

Math, after all, is the art of counting, and early in human (pre)history our ancestors found necessary to count items: animals in the neighbourhood, food morsels, water reservoirs, moons/days before a new crop… Although, apparently and perhaps as an exception to the rule, there are some peoples who do not seem to care too much about numbers, specifically one isolated hunter-gatherer tribe from the Amazon only count three "numbers" —one, two and many—, this being an oddity and is thought to be due to lack of words to name more numbers [1]. But counting is not only a human feature. There are animals which have some notion of magnitude and have been shown to, effectively, count; here (https://www.quantamagazine.org/animals-can-count-and-use-zero-how-far-does-their-number-sense-go-20210809/) you can learn that not only smart animals like corvids have a sense of numbers, but also spiders, lions, ants and frogs. Therefore there is something in the nervous system that prompts creatures to either count or pay attention to magnitude. Those interested to know what parts of the brain may be responsible for this talent about numerosity can find some literature in the web; here we will only mention that there is evidence for dedicated neural networks in the parietal, frontal and temporal lobes of our brains which encode the number of elements in a set —in fact the term "number network" has been used in the neuroscientific literature to describe these interconnected brain regions.

Hence, we can appreciate that math, as in counting items, appeared in primordial history and further developed due principally to a couple of things, our large brains (all those interconnected neural nets aforementioned) and one prominent human characteristic: greed. For sure all animals are greedy, as those who have pets can attest, but in humans this has gone to an extreme and therefore rulers wanted to quantify how many subjects were under their command, landowners coveted to know what surface area they owned, monarchs needed to quantify how much they will obtain taxing their citizens, etc. Thus the need to quantify appeared early in history. From this compulsion, so to speak, to quantify (which, by the way, has only been magnified as history advanced such that today we are swamped with all possible sorts of quantifications of all imaginable events and phenomena) and thanks to our ability to represent numerical values with symbols, mathematics flourished. Ancient societies like Mesopotamians (who are credited with the invention of mathematics about 5000 years ago) and Egyptians developed enough algebra and geometry to quantify areas for crops or to look at the stars in the sky.

If the original sources of mathematics were forced on us by certain imperatives, many of which of economical nature, afterwards it continued to develop by a mixture of necessity and pleasure —another prominent behavioural trait to such an extent that the pursuit of reward (and averting pain) is what determines almost the entire repertoire of animal behaviours—, as mathematicians derive gratification from the abstract character and purity of math, or so they claim. Consequently, mathematics has been constantly changing and pervaded science, not only the quantitative sciences like physics and chemistry but also others like taxonomy —the art of classification of organisms— to evaluate differences among taxonomic groups.

But much of today's use of mathematics in science consists in differential calculus, that invention of Leibniz and Newton (arguments about pre-eminence aside) which aims to study the continuous change of whatever variable. And perchance this emphasis on calculus should not be surprising, because it is based on yet another illusion that our great illusionist —the brain— creates: the illusion of continuity; one may spend substantial moneys to go to a magician's performance but we have an everyday performance from the ultimate illusionist that rests above your eyes and ears. Brains create our realities [2], and particularly our minds like to interpolate/extrapolate perceptions. To wit, when you suddenly change your sight from left to right your eyes perform a saccade —a ballistic movement of the eyes that abruptly changes the point of fixation— but you do not notice any discontinuity in your visual field; neither do you see an empty space where your retinal blind spot is located, the place where the optic nerve connects to the retina such that there are no light-sensitive cells so this part of your retina can't see, but the mind insists on making the scene continuous and we are not aware of our blind spot. This impression of continuity occurs during our movements too: you will see your finger moving continuously although finger movements are not smooth but discontinuous recurring at intervals of ~100 ms. In fact, there exists the "Law of Continuity", a Gestalt concept thought to govern perception stipulating that our mind tends to interpolate/extrapolate perceptual objects or spaces between objects. Interested readers can perform a cursory search using keywords such as "brain illusion continuity" and experience the powers of your mind hallucinating at this continuity illusion. The fact is that we know that sensory processing is determined by sampling routines in that much of the sensory input that enters the brain does so because we actively acquire it using a motor sampling routine; yet, we are not aware of those intermittent sensory sampling routines and perceive, through all our senses, a continuous world. It is hard not to speculate that this illusion of continuity creates our personal identity, the self: the sensation of continuity in cognition and behaviour generates the sense (perception) of self. But now we digress…

Let it be clear that we are not considering here the common debate among physicists about whether nature is discrete (digital) or continuous (analogue), rather this is about our representation of aspects of reality due to our perception. Perchance then when scholars debate the question of whether the universe is continuous or digital, this mind's tendency to perceive continuity could be taken into consideration to understand why we cling to continuity (for other reasons, see [3]). Having said all this, it is true that not everything scientific utilizes the "continuum"; although classical physics uses mostly the continuous, computer science uses the discrete.

A convenient perspective to characterise an inconvenient reality? Introducing the interaction state space

Be that as it may, we have come to a point where science is based on math, and specially the approach of calculus with the typical continuous time evolution of observables. But, is science (based on mathematics) just a convenient approximation to comprehending nature? Thinkers like H. Poincaré or D. Hilbert already noted that much of math and scientific methods developed because of their convenience, for instance the latter said, in 1928, that "mathematical existence is merely freedom from contradiction"; this is not place to discuss it, but readers are invited to go over more brainy texts like Wigner's about the unreasonable effectiveness of mathematics in the natural sciences, where you will learn the "appropriateness and accuracy of the mathematical formulation of the laws of nature in terms of concepts chosen for their manipulability" [4].

I guess it could be said that —always endeavouring to simplify— how we study nature is determined by two main features: the view that variables can be represented by points in a certain Cartesian state space and the idea of a deterministic continuous time evolution of those variables represented by trajectories in that state space. This is the standard manner in great part of the experimental quantitative sciences, for sure in physics and chemistry, and also in some biology and geology. In short, Cartesian coordinates and *dt* rule a good deal of science (*dt* is the ever-present denominator in any derivative of a property with respect to time). Let us start inspecting that state space.

M. Merleau-Ponty said in his *Phenomenology of Perception*: "Space is not the setting in which things are arranged, but the means whereby the position of things becomes possible". I find this an appealing definition of space as it is a dynamic one. And, since the position determines a possibility for elements living in that whatever state space to interact, then this sentence could be rephrased as space being the means whereby the interaction of things becomes possible. By interaction is meant everything from just collisions to, say, gravitation, electromagnetic or chemical interactions; and naturally, some types of interactions are possible only if the units —or elements of that space— have the right physical properties that allow them to interact with others, interactions which normally entail an exchange of energy or matter (although considering the famous Einstein's equivalence $E=mc^2$ we could consider these two as equivalent, two sides of the same coin). Along the same lines, we could think of time as the means whereby the interactions (or relations) proceed. Indeed, time and space are so interconnected that it may make more sense to forget about their differences; for instance, the definition of the metre (a measure of space) is in terms of the speed of light, in terms of time basically: the distance that light travels in a vacuum in the fraction 1/299,792 of a second. So if defining space uses time, and time represents interactions/relations among things, then space too represents interactions, exchange of energy/matter. In any event, the purpose now is not to delve into the concepts of space and time discussed by scholars, but rather to explore an alternative perspective of our description of natural phenomena that is more realistic, though more cumbersome as we shall soon see.

To put it very simply and pictorially, imagine that some elements that are able to interact exist in a classical three dimensional sate space with coordinates (*x*, *y*, *z*) which then disappear, leaving us with the relative positions of the (possibly) interacting units. So one can even say we have sort of substituted topology for geometry, as the specific coordinates for each element do not matter now, only their relative position. Similar ideas have appeared in the literature, e.g. [5] indicating that there could be "an alternative interpretation of classical physics in which physical states are not mathematical points characterized by (n-tuples of) real numbers"; others have questioned whether the description of points by a list of three real numbers —or four, if time is included in the description, that is, the typical (*x, y, z, t*)—, though successful and simple, is just an approximation breaking down at the microscopic scale, perhaps the Planck scale [6].

In essence then we are left with *properties in an interaction state space* (or manifold), so to speak. In other words, we have elements with properties that are able to interact if the topology allows, as this geometry/topology provides the possibility for interactions to occur. Unsurprisingly, this is the frame of some fundamental laws of nature, or at least fundamental equations. To wit, Newton's law for the force of gravity or Coulomb's law for attraction and repulsion of charges share a similar scheme: properties (mass in one case or charges in the other) divided by the topology (the square of the distance between those properties), so what determines the interaction (force) basically are the properties (which are able to interact) depending on their relative position. Some other models widely used have similar framework, for instance the Ising model for the analysis of magnetic interactions or the Hopfield model for neural networks have the general structure "coupling factors multiplied by properties", the coupling depending on the relative positions that will make or not possible the interaction and the properties can be magnetic dipoles or neural activity respectively.

So we have gotten rid of the spatial coordinates, and now we should tackle time, the aforementioned *dt*, the other fundamental component of calculus and our models of nature that satisfies our experience of a continuous reality as mentioned in the previous section. Should we eliminate as well the time axis in our plots representing the evolution of variables? What does time represent? Basically, time is our concept to represent the change in things. And things change due to interactions. Therefore, the constituents of our universe, be they particles, molecules or living creatures, live and evolve in a state space of interactions. So the time axis in our typical graphs may be replaced with an, admittedly much less convenient, "interaction axis", which of course would not be just one axis; rather, what we would have is a multidimensional manifold where the evolution of, say, the velocity of a molecule, considers all interactions of that molecule with the rest surrounding it. In short, the 2 or 3 dimensional space would be changed for a multidimensional one taking into account all movements of other molecules that will impact/influence (through collisions or interactions of several types) our molecule of interest.

If you have problems visualising this, you are not the only one, it requires an exercise of imagination just like those multidimensional manifolds which cannot be visualised that mathematicians and physicists create in their works. Here we are shifting the focus of attention to the *fundamental role of interactions*; it requires us to change our time concept for an interaction concept, so to speak. Hence, instead of considering the velocity of a molecule as the derivative (change) of space with time (the famous equation we learn in high school, $v=ds/dt$), it can be thought of as the changing relations with other elements in the molecule's neighbourhood. If all this sounds bizarre, perhaps we should take into account that, in fact, the fundamental significance of interactions is present throughout our models of natural phenomena. A well-known example: the Boltzmann equation where the time evolution of the velocities of particles in a gas is determined by interactions —in this case the collisions— between those particles.

Now, the advantage of the classical representation of a particle's velocity or position using the customary graph where time is one axis, disappears when we consider what really is going on, what that time axis represents: multiple collisions with many particles around. This great multidimensionality renders that state space impossible to plot. Nonetheless, our purpose here was to examine what genuinely is taking place in natural phenomena, and it was warned before that this was not going to be a convenient manner to visualise phenomena. Moreover, current technologies do not allow for a complete measurement of the position and momenta of the many particles surrounding our particle of interest, therefore it is impossible to generate that interaction space. Nevertheless, we are talking about what can be done in principle, not in practice. Besides, the situation is different in other fields, for instance in neuroscience it is feasible to record the activity simultaneously in many neurons in an area, so here one can construct an activity space where the activity of one neuron can be related to others in the neighbourhood. The same can be done in other disciplines like sociodynamics or the study of animal behaviour in ecosystems where the actions/behaviours of many individuals can be known and related to one in particular. We are thinking here out of the box, something scientists in current times can hardly do lest their funding agency cuts their financing.

Of course nobody is saying the likes of Leibniz or Newton talked nonsense with their calculus, or that the classical paradigm should be abandoned. Rather, the point here is that perhaps some more deep thought should be devoted to this perspective of focusing *on properties of points in an interaction —or relational— state space*. I wonder what new developments in science could be achieved by this approach. Although perhaps the shift is not that substantial as it sounds, after all our classical state spaces are relational structures —meaning structures where relations among constituents occur— which represent the behaviour of a system. Therefore my suggestions in this text may not constitute a tremendous paradigm shift, I am just trying to focus on the essence, the fundamentals, and we have to consider that some of science's paradigm shifts have been tied to alterations in our understanding of the "fundamental" (for discussions about what "fundamental" may be, see [7]). Next section explores a possible extension of current scientific endeavours that may improve our understanding of nature unifying levels of description, by focusing on an elemental fact everybody understands: interactions.

Searching for universal laws — the scrutiny of relations among systems

The words properties of elements and relations (or interactions) among them have appeared numerous times in the preceding paragraphs. It is therefore not a big stretch of the imagination to suggest that a possible framework to help with this more abstract perspective proposed above on the foundations of the progression of natural phenomena would be afforded by category theory, if only because, in simple terms, it is the study of functional relations. As well, and in a more philosophical tone, to some people versed in philosophy this scheme of relations among properties as a fundamental concept to characterise nature may sound like ontic structural realism, in that structures and not "things" are fundamental and the focus on studying relations among those structures/properties. Variants of structural realism propose that relations and not intrinsic properties are the fundamental aspect of natural phenomena, although one should acknowledge that properties determine the possible relations that may occur. Nevertheless, discussing philosophical approaches is beyond our purpose now, rather the intention is to explore an alternative view of natural phenomena that may be more accurate than the standard one, albeit it may be more cumbersome as we have seen.

Whether philosophising or not, to all intents and purposes what we do in scientific research is basically studying relations; correlations among variables is a major aspect of our science, be that in clinical trials or in biochemistry. The cause-effect perspective rules science, and this is nothing more than a relation between a cause and a possible effect. But this is fine, we could just note that scholars like Poincaré or Bohr pointed out the crucial importance of studying relations, as the former scientist said: "The aim of science is not things themselves […] but the relations among things; outside these relations, there is no reality knowable"; and the latter proposed that "In our description of nature the purpose is not to disclose the real essence of phenomena, but only to track down as far as possible relations between the multifold aspects of our experience".

Following the advice of two celebrated scientists, I am trying to "find the point of view from which the subject appears in its greatest simplicity" (this recommendation due to J. W. Gibbs), and to comprehend nature "by the use of a minimum of primary concepts and relations" (this one due to A. Einstein in his essay *Physics and Reality*), in order to uncover general principles for the progression of natural phenomena that transcend levels of description —that is, general laws through which we can understand the behaviour of disparate systems, from the atomic level to the astronomical. It seems to me that one of the "simplest viewpoints" is the consideration of the relations/interactions among constituents of our state spaces. And the "primary concepts" underlying the dynamics of those relations/interactions can be found out by a high-level perspective about how those interactions proceed, how energy/matter is exchanged among the constituents, without becoming lost in very specific mechanisms. Naturally, investigating specific mechanisms is necessary, but this is mostly what we do in current science, at least in most of the sciences except perhaps in some parts of theoretical physics where abstract thinking is foremost. But these abstractions are hard to grasp by people outside the field; I am thinking about string theory or quantum mechanics, worthy efforts but hard to understand even for the specialists. It is my opinion that investigating something more tangible, as it were, like the structure and dynamics of relations/interactions among the elements of our universe, can lead to notions that are understandable and within the reach of scientists in many fields, who may want to apply —why not, doesn't need to be only basic science— that knowledge to control unwanted phenomena as I will mention two paragraphs below.

So let's briefly get back to category theory. For those unfamiliar with it, we can just note that category theory is the study of mathematical structure, the study of things and the mappings between those things, mappings that can be conceived essentially as relations. Since I have been proposing to use more abstract frameworks that eliminate artificial concepts like time or Cartesian coordinates, I would suggest that category theory has great promise in achieving a unification, as J. Ireson-Paine puts it: "category theory is a great source of unifying concepts and organising principles […] If these could be taught in the right way, they could help many researchers unify existing concepts". (http://www.j-paine.org/make_category_theory_intuitive.html). This is the benefit of abstraction, by throwing away all the details an object's structure reveals itself. While being an abstract framework, category theory has practical use too, as one can explore in https://rs.io/why-category-theory-matters/; it is found in biology too, the forefather of biological category theory is Robert Rosen with his relational biology.

But it doesn't have to be only category theory. The study of relations at a high level perspective could be done using any framework that allows for the understanding of features of these relations that do not depend on the specific constituents of the systems under study. After all, the laws of nature are concerned with regularities in natural phenomena. What is advocated here is that we should pay more attention to holistic frameworks rather than focusing so much in the typical reductionist approach. An in-depth study of the relations (or interactions, as discussed in the previous section interactions are here considered a form of relations) and the dynamics of those relations, performed at a sufficiently high-level viewpoint such that the specific features of the constituents are not considered, may contribute to the finding of those regularities that make natural phenomena possible. This knowledge could have practical applications too. As a brief example, we already have indications that characterising dynamic relations among systems' constituents lead us to some, let's say, "universal" features, and these are used to control or alter phenomena we do not like, namely pathological conditions. So for example, synchronization is a fundamental aspect to characterise relations between activities, and specially the study of fluctuations in that synchrony —that is, the variability in the correlations of activity— has indicated the primordial role of these fluctuations in pattern formation in a diversity of natural phenomena; and it has been put to good use: the knowledge of the variability in the dynamics of these relations among nerve cells has been used to control epileptic seizures, or the evaluation of the level of irregularity and correlations of geoelectric time series has been used to try to predict earthquakes [8], or the study of heart rate variability (which after all is a way of studying the correlated activity among heart cells) has resulted in a prognostic marker for ventricular arrhythmias [9].

As a final note, in this proposed perspective of interaction state spaces where the interactions/relations depend on the relative position of the elements, the interactions become probabilities because these relations will depend on whether the relative positions of the possibly interacting constituents of the space allow for the interaction to occur. But again this is not news, quantum mechanical laws already dictate that predictions are limited to probabilities. Nonetheless, the examination of the regularities in the dynamics of the interactions at different levels of description may advance finding an answer to the long-standing argument about whether probabilities are fundamental [10].

Money matters: needed changes to make science and academia much, much better

The previous musings about changing our perspectives may or may not improve science although I suspect it is a vision closer to reality. But this proposed alternative view where the perfect knowledge about, say, the position where a molecule ends up at the end of the day is replaced by something more abstract, requires some thought about the foundations of our science. And this leads us to another aspect, this one for sure will improve science. As we all know, funding agencies are not too keen to fund foundational research, not even (truly) exploratory research. The utilitarian approach to science is absolute [11]. Thus to really improve science and academia in general, a balance should exist between money awarded to big groups or others researching practical approaches and money given to a scientist who, alone in a remote corner of an institute, investigates whatever entices him. There should be much more funds towards this type of fundamental research, investigating abstract, holistic ideas. And this is normally done by individuals, not by big consortia; funding bodies should be reminded that a major factor in the progress of science is the individual scientist, individual curiosity is the main driving force of science, although individual creativity and the lone scientist are species close to extinction [12]. The term "fundamental" in this paragraph is not meant as discovering the true essence of nature or fundamental entities which do not need to be explained, rather it means the foundations of our representation of that nature. Anyhow, it is somewhat surprising that fundamental research is infinitesimally funded in spite of the fact that some paradigm shifts in science were brought about by changing what was considered to be fundamental, something funding agencies and politicians seem to have forgotten. Establishing this monetary balance in research funding for sure will improve science and will be a factor bringing academia back to what once was: a place to think about natural phenomena, and not, as it is today, a corporate place to gather grants and squeeze researchers to publish as many papers as they can possibly publish.

Conclusions

To wrap up, we have seen how our current science is to some extent contingent on some particular aspects of human mentality and that it is ruled, to a large degree, by calculus, the continuous change of observables with time, mostly because of its convenience. I have suggested an alternative perspective of focusing *on properties of points in an interaction —or relational— state space*. We have seen that important laws of nature share the same structure —properties that interact if the distance allows— and govern interactions between microscopic units (Coulomb's law) or huge bodies (Newton's gravitation law). Therefore, I have wondered whether some regularities (laws of nature) can be discovered that rule the interactions/relations among constituents of systems at very different levels of description, in such a manner that general principles for the progression of natural phenomena that transcend levels of description can be uncovered. In the same way as the strength of thermodynamics is its ability to discover correlations among observables in the absence of detailed knowledge of the features of the system constituents, it is my opinion that a high-level study of the structure of relations/interactions using the schemes abovementioned may advance science to more holistic views of natural phenomena. This may not constitute a new science, although the initiation of a new science of systems and processes based on the interrelation between topology, logic and physics has been suggested [13]. In any event, scientists do not dispense eternal truths —even truth is not finitely definable, for an instructive argument on this matter see chapter 3 in [14]—, our endeavours being just a crude approximation to "reality". And a more balanced funding arrangement so that fundamental research stops being less favoured over utilitarian research will bring us closer to whatever that reality is.