Review Article

Science in Light of the Analogy of Being

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Scientific progress advances not only through the exploration of new domains but also by engaging with increasingly complex forms of reality. *Complexity* refers to situations in which a whole or system consists of many interacting parts whose combined activity generates emergent properties. Classical philosophy addresses this subtle relationship between whole and parts through the concept of the analogy of being (*analogia entis*), which affirms the ontological priority of the whole while still allowing meaningful forms of reductionist analysis.

To illuminate this philosophical perspective, we compare it with experimental findings involving de Broglie-type matter waves, which exhibit holistic behavior and thus suggest that nature itself often operates with priority given to the whole. Finally, a hierarchical table—from elementary particles to biological organisms and human beings—illustrates how the analogy of being provides a useful conceptual framework for understanding the increasing levels of complexity encountered in the natural world.

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1. Introduction

From ancient Greek philosophy to modern science, there is considerable interest in the relationship between the whole and its parts. One finds, on the one hand, reductionism, which assumes that by analyzing the parts one can understand the properties of the whole. On the other hand, holism holds that the general properties cannot be reduced to those of their parts. Aristotle's common-sense approach yields a way of thinking about the whole and its parts that offers sufficient flexibility to capture the best of the two opposing concepts. In his philosophy, he gives ontological priority to the whole, but he allows for parts that can be dealt with. He states that besides being on its own and not being at all, there is another alternative: the potential being.

This subtlety opens a new way for addressing the relationship between the whole and its parts. The latter have only a potential being as long as the whole is not yet divided. But they are beings and can be studied. Aristotle states that *being is said in many ways* (Metaphysics IV, 2, 1003a33). Later, Aquinas would speak of the analogy of being[1][2].

These introductory considerations are relevant to a correct understanding of complexity and the emergence of properties observed in many fields of science. Aristotle already introduced a hierarchy of beings, as Anderson did in his seminal essay, *More Is Different*[3]. In the following, we will employ the Aristotelian way of thinking, as we did in our study, *Aristotle and the Foundation of Quantum Mechanics*[4]. Aristotle used everyday experience to illustrate his philosophical conclusions. In the present study, we will use De Broglie matter waves[5] and Young's double slit experiments[6] with particles ranging from photons and electrons to complex molecules. In this way, we intend to demonstrate nature's priority for the whole convincingly.

In the following section, we aim to identify, based on a few examples, some characteristics of complexity in science and technology. In previous studies, issues of complexity were analyzed using a comparable philosophical approach[7] and more specifically in biological systems[8].

2. Complexity in Science and Technology

The first striking sensation one experiences in a high-tech environment is its multidisciplinary setting. For example, one could consider a microprocessor chip in a computer. It is grounded in physical phenomena that can be understood only by solid-state physics, which is based on quantum mechanics. The design of microprocessors lies at the intersection of electrical engineering, information science, and applied mathematics. The production is based on advanced optical lithography, with primarily chemical deposition and etching. Advances in the field are the result of detailed studies that systematize numerous empirical findings. As a consequence, no single scientist or engineer can possess complete knowledge of the state of the art in the relevant fields.

Each discipline must contribute to a complex whole or system that a single human mind cannot understand completely. The specialization and extension of the knowledge base are sufficiently advanced that, even within a single discipline, hundreds or thousands of scientists simultaneously work to develop the desired technological product or system.

The above example can be extended to even more dizzying proportions by considering that billions of microprocessors are connected globally. They interact in what is probably the most complex human-made technological system, the World Wide Web. This can, in fact, be considered a single distributed computer system. The number of disciplines, and not to say the number of scientists contributing to its development, is exceeding any extrapolation made only a few decades ago.

Considering now complex systems in general, one can distinguish several characteristic properties[9], see also [10]:

- One does not encounter a single preferential level of detail that allows the adequate description of the system. Instead, one must work with multiple levels of description.
- On the micro level, the system consists of a very large number of separate elements that interact with each other.
- There is emergent behavior, a spontaneously arising activity at the higher level. This activity at the macro level, with new structures and interaction, is not the result of external control and is not directly reducible to the properties of the micro-elements.

To analyze this new situation, which stems from the increasing complexity of science and technology, one must move to a meta-level that transcends the realm of science. Philosophy is a convenient candidate, as it can assess the roles of different disciplines and, in particular, provides an ontological basis for complex systems. The observation of Strumia[11] supports this view:

> ***Complexity, whole*** **and** ***parts, dynamics, attractors, chaos, order, information, self-organization, teleonomy, finality, project, intelligence, mind, concept, self-similarity, analogy,*** etc., are the new words arising today, practically, inside ***any science***. They sound similar, even if not identical, to some (Latin) terms of ancient (Greek and Mediaeval) philosophy of nature, metaphysics and logic: ***complexio, totum et partes, motus, quies, ordo, forma, finis, intellectus, anima, intentio, similitudo, analogia (entis),*** etc.

It is clear that one must select an appropriate philosophical approach. Ancient Greek atomism, for example, would not be sufficient as it focuses mainly on the constituent parts, the atoms. As in the reductionist approach, the ontological basis of the higher-level properties is then only weakly provided. To find a suitable coherent philosophy, or more specifically, a coherent metaphysics, is a great challenge. But it is crucial to arrive at a view on reality that makes complexity intelligible. The complex artificial or natural being is not just more of the same. Its phenomenological richness cannot be reduced to the multiplied simplicity of the building blocks.

3. Hierarchy in the material world and the analogy of being

In this section, we will examine in detail the ontological basis for complexity. The central question is whether the whole exceeds its constituent parts. In other words, is there something new in the complex being, or is complexity something related to our way of thinking? Does it mean that we call it complex because the whole exceeds our restricted intellectual power or the capacity of our computers? To arrive at an answer, we conduct an analysis grounded in the metaphysics of Aristotle and Aquinas, employing the analogy of being. In addition, we use the distinction of material and formal principles (hylomorphism) to clarify the ontological structure of material beings[12].

For Aristotle, in each material being or thing, one can distinguish two principles, matter (*hyle*) and form (*morphe*). A modern picture could illustrate these two concepts. Imagine a LEGO world with all things made out of the famous LEGO bricks. In a LEGO object, e.g., a racing car, one could distinguish the bricks (matter) from the design and arrangement of those bricks (form). Bricks are always arranged, even if it is only a random heap left after the child's play. Moreover, an arrangement without bricks would not be a real thing. The transition from the LEGO world to the real world could be achieved by adopting an atomist view: LEGO bricks are indivisible atoms. The arrangement is only geometric ordering. Aristotle transforms the LEGO paradigm in a metaphysical analysis: matter is not a being in itself but a metaphysical principle, whereas the geometric arrangement is replaced by another metaphysical principle, form, which contains all the information that constitutes the being. However, the form is not yet a being as it must be implemented in matter.

Examining the word *to be* reveals a complex range of meanings. It can refer to the existence of a human, an idea, a dog, an atom, a water droplet, a specific color, or even the First Cause. The kind of being varies among these; for instance, the being of a droplet or atom is much weaker and less definite than that of a dog or a human. An idea's existence is even more subtle, as it must reside within something else—whether in someone's mind or in material form on paper or another medium. In this way, an idea participates in the being of something or someone else.

One can therefore say that *to be* indicates different relations, but all seem to belong to a certain class. Aristotle expresses this by stating: *being can be said in many ways*. In other words, being is not univocal; it does not always express unambiguously the same relation, but also not equivocal like the word *mint*, a name of a plant or the name of a place where coins are produced.

In the Aristotelian-Thomistic tradition, terms like *"to be"* are denominated as analogous because they exhibit proportionality. The being of a human person relates to a human person as the being of an atom to an atom. They are predicated as more or less and allow certain levels within a hierarchy. This hierarchy is grounded in the observation that the lower beings can participate in the being (esse) of the higher beings.

Other related terms have a similar analogue character. The *substance* is one of these. With this expression, one denominates things (or persons in the case of intelligent beings) that have their own being (esse), unlike an idea that exists in an intelligent being. In the case of a human being, one readily accepts that one is dealing with a substance. For an atom, the answer depends on the specific context under consideration. If one considers them as a unity with their own being, one can speak about a substance, it is part of a substance (in the case of an atom in a human being) or an agglomeration of substances (if one considers elementary particles). It is worthwhile to quote in some extension A.G.M. van Melsen[13]:

> We do not hesitate to use this concept (***substantia***) with respect to human beings and animals, but we encounter increasing difficulties when we are applying it to plants, minerals, liquids, gases, beams of light, etc. In the latter cases the concept ***substantia*** seems to be devoid of any meaning. It does not amaze us, therefore, that science dropped this concept from its vocabulary. Yet with respect to human beings and animals the concept ***substantia*** cannot be missed whereas, difficult as it may be to indicate other concrete substances, there can be no doubt that material entities do exist. This implies that the analogy of the concept ***substantia*** should be fully taken into account.

Based on the analogy of being, one can establish a hierarchy of beings by increasing complexity (Table I). Simultaneously, an ordering of the different scientific disciplines is obtained. This table is inspired in part by Anderson[3], who discusses in detail the layers related to physics without directly addressing metaphysical issues. The hierarchy in the table is established non-uniquely, as different perspectives are possible.

being (ens)	*material principles*	*formal principles*	*discipline(s) involved*
nation	'matter' involved: human beings	laws of nature, moral laws, leading to concepts of politics, e.g. democracy	politology, humanities, sociology
human being	matter involved (i.a. cells, organs) similar to other mammals	laws of nature, moral laws, leading to concepts related to human beings, e.g., ethics	medicine, biology, humanities
animal	matter involved (i.a. cells)	laws of nature, leading to concepts related to animals, e.g., growth, reproduction	biology, physiology
biological cell	matter involved, i.a. molecules	laws of nature, leading to concepts related to cells, e.g., cell division	biology, chemistry
artifact (e.g. airplane)	matter involved (i.a. atoms, molecules)	laws of nature, leading to concepts related to airplanes, i.a., travel comfort	physics, engineering, ergonomics
molecule	matter involved (i.a. atoms)	laws of nature, leading to concepts related to molecules, i.a., heat of formation	physics, chemistry
atom	matter involved (i.a. protons)	laws of nature, leading to concepts related to atoms, i.a., radioactivity	physics
proton	matter involved (i.a. quarks)	laws of nature, leading to concepts related to protons	Physics
electron	matter involved; it is an elementary particle	laws of nature, leading to concepts related to electrons	physics, electro-dynamics

Table I. Hierarchy of beings with increasing complexity

The first column in Table I indicates the beings or substances under consideration. In the following two columns, the material and formal principles (causes) that determine these beings are specified within the terms of Aristotelian hylomorphism. Each higher level is based on the foregoing levels (not necessarily all of them) and adds something new, primarily due to the greater richness of the formal principles. Also, the

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material principles gain in complexity, as they are, in many cases, the beings of the level below. The new total being is more than the sum of the parts. This is explicitly indicated by adding, in the column of formal principles, some of the new concepts that arise at each level.

Because intuition is needed to grasp the full richness of these terms, a purely formal, quantitative approach grounded in lower-level concepts is insufficient to capture their higher-level aspects. It often happened that the ordering and deeper understanding of concepts at a higher level led to new disciplines. Sometimes, however, the new discipline does not draw on the disciplines of the lower levels. For example, knowledge of nuclear physics does not help develop a sound human ethic. It will, however, be strictly necessary in nuclear medicine.

According to the scheme in Table I, reductionism cannot be a scientific solution to higher-level objects. At the level of a human being or an animal, all will agree that, after a sufficiently long process of decomposition, one will end up with atoms or nuclear particles. This relates, however, only to the material principle of the substance in question. The formal principle that determines the arrangement of atoms and provides strong unity, however, completely exceeds the formal principles of the underlying layers. In Anderson[3], it is argued that even in physics, systems composed of simple physical objects, such as a collection of atoms, exhibit phenomena that cannot be described without new concepts.

The role of the disciplines and the relation to the different levels in Table I is indicated in the last column. One should bear in mind that the list of disciplines at every level is not exhaustive. At higher levels, complexity increases, and only a multidisciplinary approach will yield meaningful progress. Consider, for example, the case of a human artifact, the airplane. For the design and realization of a new generation of transatlantic jets, a large group of specialists must collaborate: materials scientists, physicists, various engineers, safety specialists knowledgeable about the legal rules of different countries, economists, and artists for the design of the cabin, among others. All these specialists apply their own scientific knowledge and concepts. Their intuition is needed to arrive at a "good" airplane. The quality "good" cannot be formalized, as the optimizations proposed by different disciplines are, in a sense, contradictory. Safety requirements, for example, mostly entail adaptations that increase load during flight and therefore yield less cost-effective solutions.

4. Physics and how nature is dealing with the whole and its parts

Does nature respect the analogy of being? Is there an experiment that confirms nature's preference for the whole? A simple experiment would be to place a specific molecule on a balance, or, alternatively, to

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determine the weight of the individual constituent atoms. One obtains the same weight for the molecule as the sum of the weights of its atoms. The same result is obtained for any row of Table I. The weight of the whole is not different from the sum of the weights of all constituents.

When one leaves the realm of classical physics, the situation changes. Quantum mechanics invites us to rethink the relation between the whole and its parts, see Driessen[4]. For our discussion, the famous quantum-mechanical Young double-slit experiment provides valuable insight into the primacy of the whole. In Young's original experiment, a plane wave of light is incident on a double slit and produces an interference pattern on a screen, as shown in Fig. 1. This pattern is one that one would expect from any wave.

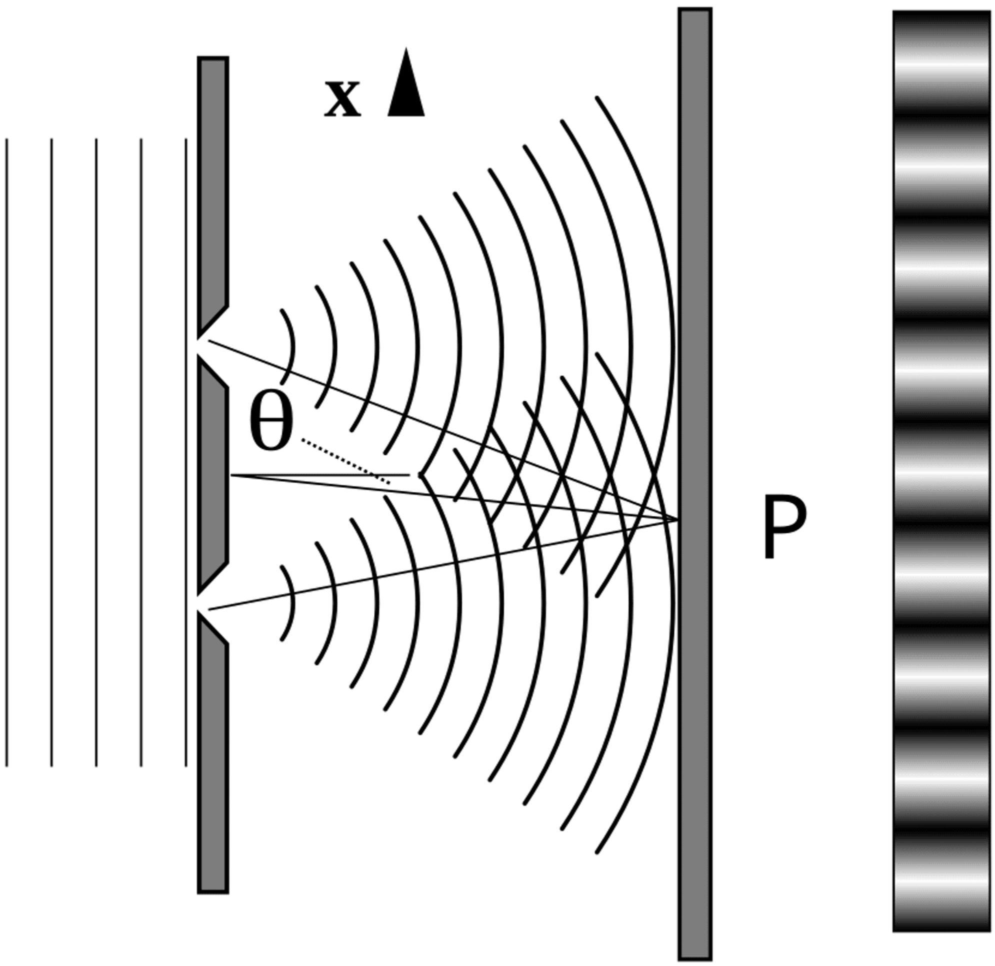

Figure 1. Schematic picture of Young’s double-slit experiment, including an interference pattern detected by a detector array. The figure is taken from Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Doubleslit.svg

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If one reduces the intensity so that only a single photon is in the setup at a given time, classically, no interference would be expected, as the trajectory of a single photon is expected to either lead through the upper or the lower slit. Quantum mechanics, however, predicts that an interference pattern will still be observed. Alternatively, better said, the probability to detect a photon at point P can be calculated by representing the single photon by a wave with wavelength λ that can be obtained by:

$$\lambda = h/p \tag{1}$$

Where h is Planck's constant and p is the momentum of the photon. De Broglie made a bold statement: any material object with mass *m* and speed v can be related to a matter wave with a specific wavelength related to the mass and the speed by:

$$\lambda = \frac{h}{p} = \frac{h}{mv} \tag{2}$$

One could illustrate this relation by considering a particle composed of two identical parts, for example, an H_2 molecule with two H atoms. Eq. 2 tells us that with identical speed v, one gets:

$$\lambda_H = 2\lambda_{H_2} \tag{3}$$

If the H_2 molecule were the same as just two H atoms, its De Broglie wavelength would be λ_H , but only the amplitude of the wave would be different. According to De Broglie, a hydrogen molecule is treated as a whole rather than as a compound of two parts.

What about the experiment? In the Young double-slit experiment, the incoming plane wave of light can be exchanged by a beam of identical particles with the same speed, which, according to De Broglie, act as matter waves. After passing through the double slit, the particles are detected on the screen with a movable particle detector or a detector array. In a classical approach with a particle source, one would expect, after some time, two spots on the screen: a blurred image of the two slits. QM reveals the wave properties by displaying a fringe pattern on the screen. In the example above involving hydrogen atoms or hydrogen molecules, one obtains a periodic local maximum for the molecules exactly at two sets of positions: one where the atomic pattern has a maximum and, surprisingly, another where it has a minimum. One may therefore conclude that, in the H_2 experiment, no hydrogen atoms are involved. The double slit experiment distinguishes between the whole, H_2, and the constituent parts H.

Meanwhile, experiments have been conducted to verify Eq. 2 with electrons, protons, atoms, molecules, and biological molecules up to 25,000 Dalton[14]. In all cases, Eq. 2 is valid where *m* is the total mass of the particle involved. Nature invites us to follow the Aristotelian approach. The whole determines the experimental outcome, and not the potential parts. Returning to Anderson, who assumes that the reductionist approach is always open, one expects that the constituent parts can be made visible by other types of experiments. Only the energy scale should then be extended to compensate for the binding energy of the hydrogen molecule in our example.

One could generalize the two situations mentioned about the weight and the De Broglie wavelength. A useful term is nonlinear ontology, recalling nonlinear functions in mathematics. A function f(x) is linear if, for all a and b,

$$f(a+b) = f(a) + f(b) \tag{4}$$

Linear ontology would mean

$$\text{property (of the whole: a+b)} = \text{property of part a} + \text{property of part b} \tag{5}$$

In our example of measuring the weight of the H_2 molecule and the sum of the weights of its constituent atoms, Eq. (5) is valid. In the experiment with the De Broglie wavelength, there is evidently a nonlinear ontology.

The examples could be extended to other situations: X-ray absorption, for example, is determined by the individual atoms in a human or animal body. At the same time, visible-light absorption by a molecule is fundamentally different from the absorption of its constituent atoms.

The interesting conclusion follows: one could go up and down the levels of Table I and observe either complete reductionism and the simple aggregation of particles, or, in other circumstances, a nonlinear ontology: something new emerges at the higher or lower layer. There is analogy of being as *being is said in many ways*.

Another comment addresses the disciplines involved in studying the whole in a given row of Table I. Often, disciplines listed in the Table below the row of interest can be used within the scheme of linear ontology. The new disciplines, which treat the whole, primarily refer to nonlinear ontology.

As in the example of the De Broglie wavelength, quantum mechanics plays a fundamental role in necessitating the recognition of a fundamentally new behavior at higher levels. In the example of going from electrons, protons, and atoms to molecules, Young's double slit experiments confirm De Broglie's hypothesis. A challenging question is whether quantum mechanics, and specifically quantum biology[15], provides a means to understand the transition from molecules to living organisms. All that is known is that the living organism acts as a whole. In addition, the transition from a living organism to a dead one cannot be detected at the scale of individual parts, such as molecules or atoms. The decomposition process is not detectable in the initial phase.

5. Conclusion

It has been shown that concepts from quantum mechanics are compatible with Aristotelian philosophy. In a previous paper[4], we showed that the natural minima of movement correspond to the quantum jumps observed in quantum mechanics. Here, we discussed the analogy of being, based on Aristotle's insight into the priority of the whole over the parts. The parts are potential beings, yet they can nevertheless be studied conveniently. Reductionism is not excluded, as one ultimately arrives at atoms or elementary particles, as shown in the lower rows of Table I. The formation of the system or whole demands more as new realities emerge, introducing concepts that often are meaningless to the parts.

In Table I, a distinction is made between the material and formal principles. It leads to a hierarchy of both matter and form. The matter at a higher row refers to the potential parts that are beings at the lower rows.

The beings on a lower row become the material principles at a higher row. Additionally, within the formal principles, a hierarchy of disciplines emerges. P.W. Anderson[3] published a similar hierarchy of disciplines as given in Table I and states:

> The elementary entities of science X obey the laws of science Y. But this hierarchy does not imply that science X is " just applied Y". At each stage entirely new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one.

Nature sometimes explicitly confirms the priority of the whole over the parts. Experiments with matter waves demonstrate this, e.g., in a Young double-slit setup. For this behavior, the term nonlinear ontology is introduced. It means that the characteristic properties of the whole can not be derived from the parts. Something new arises when going to a higher row in Table I. Probably the largest nonlinear ontology is found when going from lifeless matter to living organisms.

Finally, one could remark that Table I not only presents the ontological hierarchy from elementary particles to complex systems, including life. It also shows the historical development of the universe. At each new row, new information plays an important role in the new complex reality. In the case of an artifact, as shown in Table I, an airplane required the intellectual effort of generations of engineers and scientists to reach its current level of aviation technology. It remains one of the big questions how nature provides natural beings with the information needed to reach ever-increasing complexity. In the origin of life, its evolution[16], and the arrival of human beings[17], these questions remain especially challenging. Science cannot provide a direct answer but invites us to address these fundamental questions. In his posthumous book, Stephen Hawking devotes the first chapter to answering the question *"Why we must ask the big questions."*[18].

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