

# Emergence: The whole is greater than the sum of the parts. Do you see the forest or only the trees?

## Reducing a system to its component parts and interactions

How does your car work? To understand it you might pull the engine apart and figure out what the component parts are and how they interact with one another. Over the last century a similar strategy and practice, known as reductionism, has been extremely successful in providing both a quantitative description and conceptual understanding of a wide range of phenomena in science. For example, biologists break organisms down to cells then to membranes, proteins, and DNA. Physicists consider atoms as composed of nuclei and electrons, nuclei as composed of protons and neutrons, which in turn are composed of quarks.

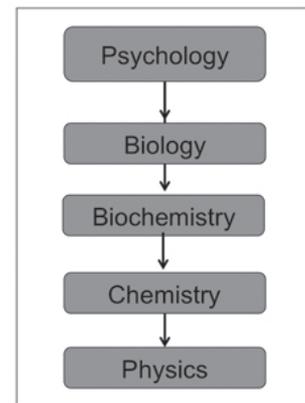
The advances made through scientific reductionism are many. Some of the best known include the discoveries of genetic information encoded in DNA and the molecular basis of disease. We can now understand the “zoo” of elementary particles produced in atom smashers in terms of just a few elementary particles called quarks. The structure of molecules and chemical bonding can be explained in terms of the laws of quantum mechanics.

The famous theoretical physicist Richard Feynman once said, “If, in some cataclysm, all scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis ... that all things are made of atoms.”

## The hierarchical structure of nature and scientific disciplines

This process of reducing complex systems to their component parts and interactions leads naturally to a hierarchical (i.e., layered or stratified) view of reality and the relationship between scientific disciplines. At each level of the hierarchy the units or objects are composed of units from the lower level. For example, the molecules that chemists study are composed of the atoms that physicists study. At lower levels, the degree of complexity (or number of variables) in the systems decreases. In addition, the time and length scales of interest mostly get smaller as one goes to lower levels.

Increasing  
•Complexity  
•Length scales  
•Time scales



But viewing the various disciplines as a hierarchy does raise several important questions. First, what is the exact relationship between the disciplines? Second, does the fact that physics is on the bottom mean it is the most fundamental discipline? Third, if I fully understand things on one level can I actually explain everything on the next higher level? For example, can all of biology really be explained solely in terms of chemistry?

## Reductionism as a philosophy

Because the scientific practice of reductionism has been so successful, some scientists make grander claims, which are really philosophical rather than scientific. These claims range from “this is always the

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best way to do science” to “this shows humans are nothing but DNA or quarks and electrons.” Prominent advocates of such a worldview or philosophical perspective include Richard Dawkins, Stephen Hawking, and Steven Weinberg. But there are other distinguished scientists who have a different perspective on the practice of science and its philosophical implications. Many of the popular advocates of reductionism attempt to use it to justify an atheistic perspective. But there are important philosophical questions that reductionism cannot answer in an objective fashion. Such questions include: “what is fundamental?”; “what is an explanation?”; and “what is the purpose of things?”

## Reductionism in theology

Given the scientific successes of reductionism, perhaps it is not surprising that, since the eighteenth century, reductionism has had a significant influence on theology. Influential approaches to the study of the Bible and the content of Christian belief have used reductionist methods. Many have claimed this to be a scientific approach to theology. Attempts have been made to reduce Christianity to philosophy, anthropology, psychology, or history. Some have claimed that the Bible is merely literature, or an edited collection of source documents. These approaches may have some merit to help us understand aspects of the Bible and its context but they also have significant limitations, as we will see.

## What is emergence? More is different

Pulling your car engine apart may be fascinating and can give insight into how it works. However, that is not the end of the story. Putting it back together is usually a lot more difficult! Identifying the individual parts and understanding how they interact with one another does not mean that you understand or are able to predict properties that car enthusiasts love such as torque, fuel efficiency, or acceleration. Such properties are collective properties of the whole system. Then there are more complex questions, such as, "Why does it feel so much better to drive a new BMW than a 20-year-old Vauxhall?" After all, the engine components in the two cars are pretty much the same. Then there are the philosophical questions: "What is the purpose of the car?" Is it to transport people, to drive my family on holidays, or to give me social status?

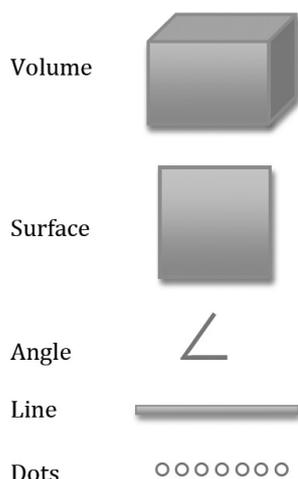
These sorts of observations and questions help us to understand emergence, which is arguably one of the most important scientific concepts developed in the second half of the twentieth century. Emergence refers to the observation that the whole is greater than the sum of the parts; furthermore, the whole is qualitatively different. A system composed of many constituent interacting parts has properties that we often cannot anticipate from knowledge of the properties of the individual parts. This concept is evident in many phenomena at the heart of physics, chemistry, and biology.

### Examples of emergence

Mass is an additive property of matter. The mass of a material is the sum of the masses of the constituent atoms. In contrast, the rigidity, hardness, and colour of a material are emergent properties. Assembling different collections of atoms (and sometimes changing that assembly only slightly) produces diverse phases of matter. These can have very different properties, ranging from metals to superconductors to insulators to magnets to liquid crystals. Consider, for example, the differences between graphite and diamond. Graphite is black and soft. Diamond is transparent and hard. Yet they are both composed of carbon atoms. The atoms in graphite and diamond are just in a different geometrical relationship. Colour and hardness are not properties associated with individual atoms but are, rather, emergent properties that can only be defined for collections of atoms.

### Signatures of emergent properties

Geometry provides a simple way to illustrate some key aspects of emergence<sup>1</sup>. Consider the figure below, which shows increasing simplicity.



1. At each strata, or level, there are unique properties and concepts that are not present at the level below. For example, the concept of volume has no meaning below the top level.

2. Although emergent properties can sometimes be understood after they have been observed, they are difficult to predict solely from knowledge of properties of lower strata. For example, if we lived in a "flatland" consisting of only lines and flat shapes it would be difficult to conceive of the concept of volume without having encountered it before.

3. Emergent properties at one level are associated with a modification of the properties of and the relationships between the constituent components at lower levels. For example, the concept of a square can be discussed in terms of line segments that are placed at right angles to each other.

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4. Emergent properties are universal. That is, they are independent of the finer details of the constituents. For example, the

concept of the symmetry of a cube (i.e., the way it looks identical after it has been rotated by 90 degrees about certain axes) is independent of what the cube is made of or of its dimensions. Some properties of a car are independent of the specific chemical composition of the fuel (e.g., diesel, ethanol, liquid propane gas) that its engine uses.

## The scientific challenge of emergence

Knowing the constituents of a system of scientific interest and the laws that describe their interactions, therefore, does not mean we can understand or predict the collective properties of the system. Indeed, this is one of the biggest challenges in science today. For example:

i. Even if we know the exact geometrical arrangement of the atoms in a solid, it is difficult to predict whether the material will be magnetic or not, and whether it will be a metal, an insulator, or a superconductor.

ii. For more than a decade we have known the complete DNA sequence of the human genome. In principle, this contains all the information necessary to understand all diseases. However, understanding how different DNA sequences (i.e., different genes) lead to different biological properties remains a grand scientific challenge.

iii. Knowing the identity of the atoms that make up a specific biological molecule does not mean we can necessarily predict the biological function of that molecule.

## Emergence raises philosophical questions

### What is an explanation? What is understanding?

Reductionists tend to claim that the ultimate explanation for a phenomenon is the one that operates at the lowest possible level. The question, "Why does a car travel between two cities?" has several different answers, ranging from "because the owner wanted to visit his mother" to "because the driver chose that

1. P.L. Luisi, "Emergence in Chemistry: Chemistry as the Embodiment of Emergence," Foundations of Chemistry 4, 183 (2002).

route” to “because combustion of the fuel produces expansion of gas which drives a piston in the engine.” Determining which answer is “correct” depends on the context of the original question. Furthermore, different individuals, social groups, and contexts will all dictate different standards and values that will determine what constitutes a “satisfactory” explanation.

### What is fundamental?

Reductionists claim that the constituent particles of a system and the interactions between them are fundamental (i.e., the microscopic is more fundamental than the macroscopic). Genetics is more fundamental than cell biology, which is more fundamental than physiology. Physics is claimed to be more fundamental than chemistry. However, not all prominent scientists agree with such a perspective. The following have written popular books arguing that emergent properties and laws are just as fundamental: Ilya Prigogine (Nobel Prize, Chemistry, 1977), Bob Laughlin (Nobel Prize, Physics, 1998), and Roald Hoffmann (Nobel Prize, Chemistry, 1982).

### What is real?

Reductionists also tend to claim that the fundamental constituent particles are what is real. Water may appear to be a continuous static fluid of uniform density. On the other hand, it can be viewed as a rapidly fluctuating collection of molecules which are separated by empty space. Is the fluid real or are the molecules real?

### Ontological versus epistemological emergence

In philosophy, ontology concerns the discussion of the nature of objects and what makes them “real”. Epistemology concerns the process whereby we establish what is “true”. There are two distinctly different perspectives on emergence. These have been referred to as ontological emergence and epistemological emergence. These are also known as “strong” emergence and “weak” emergence, respectively. The former is a more radical and less widely held view. Ontological emergence claims that the actual nature of entities at one level is distinctly different from that at lower levels. For example, consciousness is asserted to be distinctly different from the brain and it will be impossible to understand consciousness solely in terms of physical and chemical processes. In contrast, epistemological emergence asserts that although in principle it may be possible to describe objects and phenomena in terms of lower-level objects and phenomena, in practice it is impossible, or at least extremely difficult, to do this.

### Can emergence help us better understand Christian beliefs?

The argument, then, is that science shows us the limited role of reductionism, both as a method of gaining knowledge about the world and as a philosophical perspective on truth and the nature of reality. Are there any parallels in theology, which is concerned with the knowledge of God?

Karl Barth (1886–1968) was arguably the most influential theologian of the twentieth century. He even appeared on the cover of Time magazine! As a student he was taught by many of the leading academic German theologians. They espoused a reductionist approach to theology and the study of the Bible, attempting to reduce it to history, philosophy, or anthropology. Later Barth

became very critical of these approaches because he considered that they did not embody a truly “scientific” approach. He wrote:

*Theology is one among those human undertakings traditionally described as “sciences.” Not only the natural sciences are “sciences.” Humanistic sciences also seek to apprehend a specific object and its environment in the manner directed by the phenomenon itself; they seek to understand it on its own terms and to speak of it along with all the implications of its existence.*

To Barth, the object of theology was the God who revealed himself through his Son Jesus Christ and now to us through his Holy Spirit (i.e., the God of the Trinity). The object of theology is not us or our thoughts about God or the biblical text or Israel or the early church. Although Barth acknowledged that other disciplines could be helpful to theology, he continually and passionately proclaimed that theology was an autonomous discipline. Furthermore, we cannot choose the methods and concepts we use to understand this God who chooses to reveal himself on his own terms. Although Barth had no formal education or specific interest in the natural sciences, we can see in his work a significant parallel with an epistemological emergent perspective in science. The latter acknowledges that at all the levels shown in Figure 1, unique concepts and methods relevant only to that level arise.

### Can emergence help us better understand the relationship between science and the Bible?

The claims of some atheist scientists that Christian beliefs are not valid stem from a commitment to philosophical reductionism, rather than from actual scientific evidence. In particular, perceived conflicts between science and the Bible result from a rigid reductionism, which asserts that there is a universal method and approach to both finding and defining what is true. Instead, we need to acknowledge emergence illustrates that the objects we are investigating, and that we are attempting to understand and make true statements about, are distinctly different in science and theology. Consequently, the questions we are asking, the types of answers we are seeking, and our criteria for truth will be different. These differences make relating science and theology a particularly subtle, challenging, and fascinating exercise.

### Further reading

Michael Poole, Reductionism: Help or Hindrance in Science and Religion, Faraday paper no. 6.

Steven Johnson, Emergence: The Connected Lives of Ants, Brains, Cities, and Software (Penguin, 2002).

Robert B. Laughlin, A Different Universe: Reinventing Physics from the Bottom Down (Basic Books, 2005).

Denis Noble, The Music of Life: Biology beyond Genes (Oxford, 2006).

Karl Barth, Evangelical Theology: An Introduction (Eerdmans, 1963).

Ross McKenzie, Emergence, reductionism and the stratification of reality in science and theology, Scottish Journal of Theology 64, 211 (2011).



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