Emergence; Can Matter Be Creative?

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Reductionism

We live on a planet that is five billion years old in a universe that is fourteen billion years old. We are also part of a stream of life that is about 3.8 billion years old. Since we are very well adapted to this world, most of what we can see, hear or touch seems very natural and obvious. It is only when we start asking questions and using sophisticated instruments that the complexity of our world comes to light.

One of the most important methods that scientists have used to understand complex structures or phenomena is called reductionism. Basically, it consists of three steps: breaking the whole into pieces, analyzing the pieces and then reassembling them back into the whole. For example, we can understand the nature of an automobile by breaking it down into its functional pieces: engine, transmission, wheels, etc., and then in turn break these pieces into their components.

Despite its usefulness, however, reductionism implies that the whole is nothing but the sum of the parts, and thus may either end up trivializing it or suggesting that there must be additional unidentified components.

For example, a live animal is dramatically different from a dead one, even though their structures are nearly identical. This apparent conflict between what we observe and what reductionist analysis would lead us to expect has given rise to the belief in something called a life force. Likewise, despite the relatively minor anatomical and genetic differences between humans and animals, especially other primates, human behavior is infinitely more complex than animal behavior. Many, if not most people, attribute the difference to our having a soul.

Both the life force and the soul are supernatural in that they are assumed not obey the ordinary laws of physics and chemistry, and so can not be studied or analyzed by ordinary scientific methods. If this perspective is correct, then current methods of science must be inadequate and a complete description our universe must incorporate supernatural elements.

A second difficulty with reductionism arises when you take it to its logical conclusion. Everything in the Universe is composed of atoms and these atoms obey the laws of physics. Before the days of quantum mechanics, it was argued that given a large enough computer and complete knowledge of the locations and velocities of all the atoms, one could absolutely forecast the future. The uncertainty principle saved us from that specter, but still one is left with the queasy feeling that our tangible world is just a statistical shadow of the real atomic world, what is termed an epiphenomenon. An example of an epiphenomenon is a movie or a television image. What appears to be a real person or a car moving about turns out to be just a well timed sequence of pictures. And, with modern graphics technology, the person or car may never have existed, except as an algorithm in a computer.

Emergence

In the past couple of decades, there has arisen a school of thought that associates the above philosophical problems with an over reliance on reductionism. It is asserted that all levels of observable phenomena that are described by a science (physics, chemistry, biology, psychology and so on) are all equally real. For example, chemistry provides a systematic description of phenomena that would at the atomic level be mere coincidental events.

Furthermore, ordinary mater appears to have the capability to take on novel forms when conditions are appropriate, forms that are not "nothing but" combinations of what preceded them. This behavior has been termed "Emergence." Ordinary matter appears to be creative at all levels of complexity, and becomes more so as its complexity increases.

I'd like to illustrate these ideas with a few examples. The science behind all of the examples is well known and so I will present no new phenomena. What is new is how we interpret them and the realization there is a common thread. The first example is about how nuclear physics gave birth to chemistry and then sat back to watch the show.

Origin of chemistry

Let's start at the beginning. As I'm sure you are aware, our current understanding is that the entire universe was created in an incomprehensively large and hot explosion known as the "Big Bang." The only things that existed shortly after the Big Bang were radiation (light, gamma rays, etc.) and elementary particles (mesons, electrons, protons, neutrons, etc.) All of the four forces, nuclear, electrical, weak and gravitational played a role, but the nuclear forces were the dominant actors. ,

After the resulting cloud of particles had cooled and expanded, gravitation caused large groups of them to cluster and contract, releasing their gravitational energy and thus heating up the particles to the point where they began to collide with each other. This enabled the nuclear forces, which are very short range, to cause them to react and combine with each other. The resulting bonding of the particles released enormous amounts of additional energy converting the cluster into a star. All the nuclei of the known elements were created in this manner. (Although a large number of very complex processes are at work in a star, they are well understood because physicists have been able to study the reactions with cyclotrons and other accelerators.)

So a star ends up being a soup comprised of a variety of nuclei of various electrical charges and masses. The star also contains enough electrons flying about to make it roughly electrically neutral. It does not contain any significant numbers of atoms because they are immediately broken up by the high temperatures as soon as they are formed. Ultimately, however, many of the stars exploded, scattering their remains throughout space. As their remains cooled, atoms became the dominate form of matter through positively charged nuclei acquiring negatively charged electrons. In atoms, each nucleus finds itself at the center of a cloud of electrons and thus isolated from other nuclei. The formerly dominant, but very short range, nuclear forces no longer had any effect. The primary forces between atoms were now electrical. Even though atoms are electrically neutral, forces and bonds could occur by the nuclei sharing electrons. Thus there emerged the potential for a vast new set of interactions and properties that we have termed chemistry .The potential was realized when there was a condensation of a second generation of stars, in which some of the matter was left as planets that provided a variety of different environments.

Liquids and solids

Next, let's put ourselves in the shoes of a physicist who has only studied gases given off from an exploding star. He tries the simplest possible experiment; just putting an atom in a jar. Unless it sticks to the jar, it bounces around forever. He then puts a million similar atoms in it. Nothing novel happens, but he can start to observe some average quantities due to the impacts of the atoms on the walls. Let's call them temperature and pressure. These increase as he adds more and more atoms, but nothing much else happens. That is, until we reach a critical density, and then something incredible happens; most of the atoms stick together and fall down to the bottom of the jar. The atoms have organized themselves into a new form of matter; we say that the gas has converted itself into something we call a liquid. What's more, he finds that almost all his various samples of gas will do the same thing, just at different temperatures and pressures.

He is amazed by the properties; whereas gases can be easily be compressed, liquids can not. They have surfaces which can support waves and also resemble a tight membrane; we call this surface tension. If heated, the liquids can go into violent motion, that is: boiling.

Many of you are probably saying, "What's the big deal? Liquids are everywhere. Neither any of us or your imaginary physicist would exist if liquids didn't have their properties." But, that's just the point. Liquids comprise less than a tiny fraction, .000000. ..percent of all matter; they don't exist either in stars or in outer space. We only exist because of a combination this unique property of matter and the special extra-stellar environment we call planets.

Two physicists, Ludwig Boltzmann and Willard Gibbs were able to develop a theory that relates this behavior, called a phase change, to Newton's laws of motion, but only after its properties were known. In general, an emergent phenomenon is characterized by requiring new science to fully understand it. In this way, chemistry emerged from physics, organic chemistry from general chemistry, biology from organic chemistry, and so on. At each step, the emergent properties require different ways of describing them. But it should be remembered that the lower level description/laws are not violated, they just don't say much.

Origin of order

If our scientist had cooled his sample further, he would have gotten another shock; he would have found that he would have had to push his samples very hard to even get them to change their shapes. The liquid would have become a solid.

Matter often exhibits a strong tendency to self-organize as it freezes, that is changes from a liquid to a solid. I'm talking, of course, about crystallization, a process in which a reasonably pure substance will further purify itself by driving out impurities and then order its atoms into a large, uniform structure whose shape is related to the shape of the molecules making up the crystal.

Crystals require time to grow and that changes the nature of the emergence. The environment that a crystal sees as it grows usually changes in various ways, and the details of the shape of a crystal will reflect the history of its creation. Snowflakes are probably the most dramatic example of this. Although they all are hexagonal and symmetric, it its reputed that no two are identical. Their hexagonal structure is inherited from the symmetry of the water molecule, while the crystal's symmetry results from a variety of factors such as radial heat flow and vibrational modes. The elaborate radial patterns are due to variations in the temperature and humidity as the growing crystal falls through the atmosphere.

Life

Emergence becomes really interesting when we start thinking about life and intelligence. It is widely believed that life emerged when the early Earth had a reducing atmosphere. Stanley Miller and Harold Urey, and then many others have shown that many amino acids and other building blocks of life are copiously produced when there are energy discharges in such an atmosphere. Such molecules do tend to organize themselves into long chains. One might argue that life arises from a process similar to crystal formation but this doesn't hold up to examination; although a crystal is self-organizing, its structure is too simple and repetitive to encode the design of an organism.

Erwin Schrodinger, one of the principal founders of quantum mechanics, reasoned that an essential step toward life would be the creation of a non-periodic molecule that is stable and self-replicating. He was proven right 20 years later when Watson and Crick decoded the structure of DNA.

The self-creation of a complex entity capable of replicating itself will inevitably be a very low probability event. But, because the molecule is self-replicating, it need only happen once. Then all the available building blocks in the early sea would be rapidly organized into copies of the original molecule. We can expect that the copying process would not be very precise and so the sea would be filled with a variety of molecules, each of which would be attempting to add building blocks. Some would be better than others at this process and with time would increase their numbers at the expense of the others. Thus, evolution started at the molecular level.

There are an enormous number of steps between the creation of a simple reproducing molecule and life as we know it today, but then they have had 3.8 billion years in which for them to occur. In this process, emergence takes the form of Darwinian evolution which preserves and amplifies any positive step. During the first three billion years, life created a wide variety of organisms, each consisting of a single-cell that provided all the functions needed to keep the organism alive an allow it to reproduce. (They came in two varieties, prokaryotes and eukaryotes. The former include the bacteria, while the latter contain protozoa such ameba and paramecia. The primary differences are that the eukaryotes are about 1000 times larger and contain specialized organs such as flagella for swimming.)

About 500-600 million years ago, some cells learned how to cooperate and specialize so that a colony of them could have capabilities that no single cell could duplicate on its own. This resulted in what is known as the Cambrian explosion, the rapid generation of an enormous variety of species of both plants and creatures. Most did not survive and evolution has continued to produce new species at a rapid clip. The average lifetime of a species is about 10 million years and the lifetime doesn't appear to be increasing with time. The Intelligent Design people believe all this is orchestrated by a supreme "designer," but almost all biologists believe living matter is doing it on its own via random mutations and natural selection.

Slime mold, a rather revolting red-orange mass called a that lives on forest floors, gives us an instructive example of cell cooperation. If you watch it for a few days, you will find that moves slowly over the floor devouring leaves and rotting wood. But if the weather becomes cooler and wetter, it may just vanish, only to reappear when it warms up again. What is happening? The slime mold acts as a single organism when it is to its advantage to have mobility, but breaks up into thousands single-celled mold particles when it is not. So, who decides which strategy is best? There isn't any leader; it's a bottoms-up collective decision.

This bottoms-up approach appears to be a common theme in biology. Somehow, cells seem to know how to organize themselves. For example, the human body contains 200 different types of cells organized into incredibly complexity of structures. A common assumption is that genes form something like a blueprint for constructing the body. But we now know that humans have only about 100,000 genes, a number that is grossly inadequate to describe anything so complex. To add insult to injury, it has been found that nearly as many genes are involved in the construction of a mouse brain as are involved in the construction of a human brain.

Intelligence

Francis Crick, co-discoverer of the structure of DNA, calls the realization that thoughts, feelings, passions, and so forth, are the results of chemical processes in the brain an" Astonishing Hypothesis." Again, it can best be understood as the result of a bottoms-up process of organizing the elemental components, in this case: neurons. For example, a newborn's brain contains on the order often times the number of synapses as an adult. As it ages, there is something of a Darwinian process in which the ones that are utilized remain and the others whither away.

It is instructive to consider social insects, such as ants, termites and bees. Your average ant does not display much intelligence and can not have much of a world view since she can not exchange any news as we know it with her nest mates. Communication is via chemical signals that express things such as: "I've found food" or "this other ant smells dead." Indeed, researchers have painted live ants with squeezings from dead ants, and found that their nest mates invariably haul them to the dump despite their vigorous objections.

A colony of ants, however, shows great sophistication in the construction of its nest, its day to day operation and defense. No one has ever been able to find a leadership hierarchy in an ant, bee or termite colony; the term "queen" is a misnomer, she does not rule, but is merely an egg laying machine. Therefore we must conclude that the skills displayed by the colony emerge from a bottom-up process resulting from one-on-one interactions between individual ants. Therefore, it should not come as a surprise that our own intelligence might emerge from similar one-on-one or one-on-several interactions between our billions of neurons.

Summary

Although humans generally expect creativity to come from a leader or designer - a top-down perspective - there is increasing evidence that creativity is inherent in matter and will emerge when conditions are appropriate.

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