Understanding how nature works: Last piece of the puzzle?

by
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While we keep fitting pieces into the puzzle of nature, we should be aware that we are only working on a small corner and that the hope of dropping in the last piece is beyond our grasp.

Scientists attempt to find patterns in the things human beings see and experience. The most desirable and useful patterns are those that can summarize many observations into a compact principle. For example, Newton's laws of motion, compact enough to be written on a postcard, provide a simple and elegant picture of planetary orbits around the sun and at the same time describe the motion of a baseball in flight, or a car on a highway, as well as all other kinds of motion we see every day.

The striking successes of Newton's laws of motion have led scientists to hope for other powerful laws to explain and simplify other kinds of phenomena. Each time someone discovers one of these organizing principles, the experience brings elation to scientists—something like the satisfaction in matching up pieces of a jigsaw puzzle. As each new law is discovered, the universe seems a little more understandable. Each new success also invites speculation about the overall size of the puzzle. Are we about to close the borders and complete the pattern? Are we close to finding the last set of laws needed to describe the universe, giving us unlimited understanding and capability for prediction?

In recent decades, we have discovered some patterns that don't seem to help complete the puzzle, but rather appear to extend it. These difficult ideas are now accepted as accurate descriptions of natural phenomena. The following is a brief introduction and illustration of three of these concepts: dynamic systems, complexity, and chaos.

Dynamic systems

Early researchers in almost every field of science have regarded natural things as static and unchanging. The stars, for example, were seen as steady points of light fixed on a rotating, hemispherical "ceiling." Now we understand them to be large, complex, and dynamic bodies, moving at blinding speeds in different directions, heating up or cooling down, exploding or contracting, colliding or flying apart. Stars only appear static because their changes are slow when compared to the time scale of human experience.

Bone is another example where a static appearance is deceiving. Bones are sometimes compared with the steel girders buried inside the walls of a building. Their function is to provide the rigidity necessary to keep the body upright, but otherwise they are supposed to keep out of sight and not break. This they usually do, but the similarity to steel girders ends there.

Bone is a composite material, the inspiration for numerous high-technology manmade materials. Strong crystals of a calcium salt are embedded in a matrix of elastic collagen to make up a material that is both light and strong. Fiberglass—combining the strength of glass fibers with the flexibility of plastic—is a well known manmade composite. Others continue to appear, such as the graphite composites used in making tennis racquets.

Even more important than its structural form, bone is a living structure made up of a community of cells interspersed with small blood vessels. One type of bone cell secretes the elastic collagen and helps form the crystals from calcium and phosphate in the surrounding solution. Another type of bone cell breaks down the collagen and dissolves the crystals back into solution. These two types of cells work in different regions in a manner something like urban renewal. Older parts of bone are dismantled in some areas while construction of new bone proceeds in other areas. The two processes are carefully balanced so we always have the right amount of bone necessary for support. Hormones from other parts of the body help with the regulation of this dynamic process, and even external forces on the bone influence the breakdown and renewal processes.

Steel beams are static and are thus unable to adapt to different needs or to repair themselves when damaged. Bone characteristics, on the other hand, can be changed by subtle alterations of the growth or destruction processes. The growth rate is normally in exact balance with the rate of destruction, but if the growth rate is increased slightly, the balance will tip in favor of growth, and the size of the bone will increase. The balance could, of course, tip just as easily in the direction of destruction, as has been observed in extended space flights. Because bone construction is guided by cell internal instructions, bones can repair and restore themselves by shifting the balance toward growth in selected areas. New bone is deposited to repair breaks, crooked bones can gradually become more straight, and bones with more stress can grow stronger to handle the load. As dynamic systems, bones are thus much more versatile and adaptable than static girders.

The methods used to study dynamic systems are also quite different from those used to study static objects. For the latter, the main tasks are naming, classification, and measurements of physical characteristics such as size, shape, color, etc. Dynamic systems require many more measurements and observations. It is necessary to know how such systems behave under different conditions and in response to different stimuli. Furthermore, it is difficult (if not impossible) to summarize all the behavior variations of a dynamic system in a few words or mathematical equations. The usual approach is to write equations describing the way each component of the system relates to the others, but it may be very difficult to solve the equations to predict how the system will behave as a whole.

Dynamic systems are thus combinations of interacting components, and their interesting characteristics come from the changing relationships between components. One force is balanced against others, and the changing balance means changing behavior. Once we recognize the nature of the dynamic systems, it becomes apparent that we are surrounded by such systems. From microscopic cells to the global environment, we see complex forces and processes grouped together and interacting with one another. Instead of a fixed universe, we see one characterized by interaction, change, variation, and response.

Complexity

Someone has said that the "hard" or mathematical sciences have succeeded because they looked for and found simple things to study—sufficiently simple to be described by the mathematical tools available, such as Newton's laws of motion. Physics textbooks, for example, have been filled with exercises assuming "frictionless" motion. Textbook writers know that we have to live with friction in real life, but the mathematical tools to make predictions are limited. Hence, the actual situations have not been given extensive treatment. In recent decades, computer technology has greatly expanded available mathematical tools, permitting scientists to work on and think about systems of much greater complexity. Scientists in all fields are now including more realism in their studies, instead of being limited to idealizations known to be greatly oversimplified. In fact, a new branch of science now focuses on complexity itself.[1]

Consider, for example, the muscle cells that form the heart and that cause the heart to pump blood. Functionally, these cells are small "motors" that use energy derived from food to make the heart contract and pump the blood through arteries, capillaries, and veins. The technology of mechanical motors is well developed, but it is of little help in understanding heart cells because the principles on which they work are quite different.

In the heart cell, the contractile force is generated by large molecules with electrical attractions. How these molecules generate force and motion is interesting and complex enough, but that only begins to describe how the muscle works. The contractile molecules are held in place by an elastic matrix and by the thin membrane walls of the cells. The membrane wall separates the fluid inside the cell from the outside fluid and serves several functions, including regulating the fluid environment around the contractile molecules and coordinating the contraction of the large number of cells making up the heart. The number of molecules of all kinds inside the cell has to be kept constant so that the forces of osmosis do not shrink the cell or cause it to swell and tear apart. The energy necessary to power the contraction has to be obtained from glucose circulating in the outside fluid and converted into a form usable by the contractile molecules. Oxygen necessary to release the energy has to be taken in, and carbon dioxide and other waste products removed from the cell. The calcium ions that initiate the contraction have to be moved around inside the cell and their amount closely regulated. Finally, each cell has to communicate with its neighbors to know when to contract, so that the entire heart muscle works together as an efficient pump.

Large molecules span the cell membrane wall of the muscle cell to move molecules in and out, making all these processes work. At least a dozen types of such transport molecules are known to exist in heart cell membranes, and more may yet be discovered. Each is like a miniature factory with numerous steps in the process that moves molecules in and out. The transport molecules do not work independently, but are affected by the results of all the other transport molecules and by other factors in their environment. As a result, they are effectively linked together into one large, complex system.

Thus the microscopic heart cell—too small to be seen by the unaided eye—is a system of incredible complexity with numerous interacting parts, each highly complex in itself. We cannot predict the behavior of the heart cell by simply adding together what we know about its individual components (complex molecules). It is necessary to know both the behavior of its components *and* how they interact with each other as a "community." Only with powerful computers has it been possible to even begin to understand how such a system functions,[2] and the most powerful computers available today fall far short of the capacity necessary to process all that we know about heart cells.

The heart is, of course, only part of the circulatory system, the circulatory system is only one of the organ systems in the body, and one person is only a small part of a society. The task of understanding a single complex system is difficult enough, but nature seems to be made up of an endless hierarchy of linked and interacting systems. Our mathematical tools (including computers) struggle to cope with one or two levels of this hierarchy at a time, but for the whole they are completely inadequate.

Chaos

Scientists have made a living studying regular behavior. It isn't that everything we see is regular and repeatable. There just didn't seem to be any point in studying irregular behavior, since the whole point of science is to find regularities. This approach made it impossible to discover "chaos" as a principle in science until about 25 years ago when Robert May started thinking about systems that produce unpredictable results.

May was studying the laws of populations and how their sizes change from one generation to another. If each individual in one generation produces two offspring in the next (a relationship represented by a very simple mathematical equation), the result is an explosion of growth, given the name Malthusian from the person who first studied the mathematics of such growth. A slight modification of the basic growth equation gives the Logistic equation, with limited growth. May programmed the Logistic equation into his computer and studied how it behaved as he changed the growth ratio (average number of children per parent). For some smaller values of the ratio, the equation predicted a population of steady size. A little larger value of the ratio, and the population oscillated back and forth—regularly—between high and low values. A little larger ratio and the oscillation suddenly went twice as fast. Still a little larger value of the ratio and... *chaos*: the population changed values irregularly with no visible pattern.

Mathematicians had seen chaotic behavior in mathematical equations before the 1970s, but May was the first to connect mathematical chaos with the real world. The result was startling because it weakened one of the fundamental dogmas of science: mathematical equations were considered to be the highest form for expressing principles of nature, and the solutions to mathematical equations describing natural systems were believed to be repeatable—no matter who did the calculation or how often it was repeated. That, after all, is the basic use of mathematics in science—to make predictions precise and repeatable. May showed that equations written to describe natural processes may under some circumstances give unpredictable results. Since May's discovery, chaotic behavior has been found in numerous areas such as epidemics, heartbeat patterns, business cycles, and fluid flow.[3]

May's discovery had two important results. First, scientists saw that they could no longer ignore phenomena that show irregular and non-repeating patterns. Second, there was a realization that even when correct mathematical equations are written to describe a natural system, and there is a way to solve the equations, we may not be able to use those solutions for the practical purpose of prediction because the outcome may be chaotic or random behavior. An example is the frustrating problem of trying to make long-term weather predictions.

Conclusion

The understanding of the three concepts described above—the ubiquity of dynamic and complex systems and chaos—has helped mathematicians recognize the limitations of the scientific process and the wider scope of mathematics. No longer do scientists anticipate being able to describe all phenomena by applying a few laws expressed in mathematical form. Even if a unified formulation of natural forces and substance could be achieved, practical considerations such as limited mathematical tools and computer power and the possibility of chaos limit the predictions that could be made. While we do keep fitting pieces into the puzzle of nature, we recognize that we are only working on a small corner and that the hope of dropping in the last piece is beyond our grasp.

The three concepts described above also offer some new opportunities for the believer in a Creator God to enlarge his or her understanding. If the principles do apply to nature, then they are—in some sense—characteristics of God Himself that we might expect to find in His relationship with human beings. Learning from experience with dynamic systems, for example, we might expect to find a God who can adapt and adjust His responses to interact with human beings in a wide variety of conditions. He could well be described as unchanging in principle of relationships, yet adaptable to changing times as human needs change.

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Notes and references

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