Human Beings as Chaotic Systems

By Crystal Ives

One of the most commonly used metaphors in our society is the human body as a machine. At lunch we “fill our tanks” to “keep our motors running.” Our hearts beat like “clockwork.” A complex problem sets our “gears turning.” Is the body simply a machine, as our reductionist tradition and modern language implies? Can we view ourselves as a conglomeration of replaceable “parts”? Discoveries in chaos theory are leading scientists to believe that this is not the case.

The intricacies of the human body have amazed scientists for generations. Innumerable, entwined feedback loops regulate our internal processes, keeping us within the narrow bounds needed for survival. Despite this regulation, our systems are aperiodic and unpredictable in the long term. We are incredibly ordered on several scales of magnitude, but irregularly so. Our bodies conform to a set of non-linear, dynamic rules. The human body is not a simple machine, but an amazingly complex chaotic system.

I. What is a Chaotic System?

From the moment the founders of chaos theory first began their studies, the discipline has grown in science and is, as some researchers argue, the direction of the future. The contributions of Poincaré, Lorenz, and Mandlebrot have led to our understanding of what chaos is and its importance in the natural world. Though the study of predictable, linear systems makes up the bulk of a classical education, those systems are by far the exception, not the rule. Most natural systems play by the rules of chaos.

A butterfly in a meadow flaps its wings and a storm is born on the Pacific Ocean. This classic example of a key aspect of chaotic systems is known as the “butterfly effect.” Chaotic systems have extraordinary sensitivity to internal conditions which makes them inherently unpredictable in the long term. In order to make an accurate prediction of weather patterns, one would have to know the precise details of everything that would have an effect on the system. Weather is such a sensitive system that the contributing factors are essentially infinite. Also, these infinite, tiny initial conditions are magnified in the system so that two nearly identical starting points will end up unrecognizably different. Thus, chaotic systems like the weather are unpredictable and the flapping of a butterfly’s wings gives rise to a storm.

Another characteristic of chaotic systems is order without periodicity. A chaotic system operates according to set rules, but constant feedback, time delays, and tiny changes make the system behave randomly without repetition. When chaotic data is plotted in three dimensions, patterns called “strange attractors” emerge. The line representing the data always stays within set bounds, but loops endlessly toward a center point, never repeating itself. Such graphs look like mad spider’s webs, tangled string, or, like Lorenz’s first attractor, a pair of butterfly wings.

A third key aspect of chaotic systems is the beautiful order that emerges from them. A system can wear order and chaos like different masks, depending on the situation. A chaotic system can gyrate from order to chaos and back again. When the system becomes increasingly unstable, an attractor draws the stress and the system splits and returns to order. This process is called bifurcation. Bifurcation results in new possibilities that keep the system alive and random.

A final aspect of chaos is fractal geometry. Fractals were first created using computers to iterate a nonlinear equation, letting the internal sensitivity of the equation create shapes and figures on the screen (Brigs 25). Polish mathematician Benoit Mandlebrot coined the name fractal to describe the fragmented, irregular nature of these images.

A fractal has several characteristics, one of which is fractal scaling. The same level of detail occurs at all scales within the fractal so that as one delves deeper into the fractal, it never simplifies. Another key characteristic is self-similarity. The shapes seen at one scale of a fractal closely resemble the shapes seen at all other levels of detail. No matter how many times a certain area of the fractal is magnified, self-similarity will be maintained. A final characteristic is known as geometry between dimensions, which means that a fractal exists in any one of an infinite number of dimensions (Brigs 20). Imagine a string, twisted in a self-similar pattern into the shape of a square. Does the string exist as a one-dimensional line, or did it develop into a two-dimensional plane? (Brigs 65). Mandlebrot's fractal dimension for this figure is somewhere around 1.26, neither one dimensional nor two (Brigs 70). Fractals are important in chaos because they dramatically illustrate complex systems with definite properties.

II. The Heart of Chaos

A prime example of chaos in the human body is found in the beating of the heart. To our ears, the heart beats with a periodic, "clock-like" regularity. However, more sensitive instruments reveal that normal heart rhythm shows small variability in the interval between beats (Brigs 126). Our hearts rarely beat the same way twice.

Normal heart rate rhythm is governed by the sinoatrial node. Electrical excitation spreads from the node through the atria, the atrioventricular node, the purkinje fibers and then to the ventricles (Kim and Stringer 299). The signals given by the sinoatrial node vary in strength and urgency so that almost every command is different, creating an erratic rhythm. This signal variance results from competition between the sympathetic and parasympathetic nervous system. The sympathetic nervous system urges the heart to beat faster with more intensity, while the parasympathetic system strives to relax it. The interplay between these systems creates signal diversity and a complex and unpredictable heart rhythm (Ward 140).

Another cause of chaotic heart rhythms is dynamic interplay between the respiratory and cardiovascular systems. The respiratory rhythm affects the timing of cardiac impulses so that heart rate increases with increased inspiration. This coupling is called respiratory sinus arrhythmia and increases heart rate variability (Kim and Stringer 311). Logically it makes sense: interdependency and feedback between two chaotic systems adds even more variation to the system as a whole.

In addition to random aperiodicity, the heart also displays two additional characteristics of chaotic systems: the emergence of order and the existence of strange attractors. Kim and Stringer write, "there exists a wide spectrum of dynamics in the cardiac rhythm, ranging from….regularity to extreme fluctuation and complexity" (317). The heart exists in a delicate balance between order and chaos. Also, a strange, aperiodic spider's web emerges from phase-space (three-dimensional) plotting of electrocardiograph data. The beating heart has a strange attractor (Brigs 126). If we accept these proofs, the heart is rightly classified as a chaotic system. But why would it be beneficial to have a chaotic heart?

There are several good reasons for variation in heart rhythm. As any weight-lifter knows, constant repetition of an exact movement creates fatigue. Through variation, the heart limits its fatigue. Also, a chaotic heart is better equipped to adapt to changing demands. The variance in beat intensity and rate makes the heart effectively beat at all speeds and intensities all of the time. When the body's demand increases, the heart is able to pick up the slack without the shock of a quick tempo change (Ward 141). Therefore, the heart beats in a chaotic fashion for good reason. However, the cardiovascular system is not the most dynamic and varied system in the body. The best example of chaos is found in the human brain.

III. Our Chaotic Mind

The classic model of brain function as it relates to behavior is known as the neuron doctrine. The doctrine states that the physiological basis for behavior can be found at the level of individual neurons whose activity is triggered by a stimulus (Freeman 1). This explanation assumes that the brain can be explained by the properties of its parts and takes no active role in the thinking process, but only reacts to environmental stimuli. Furthermore, it is possible to describe this passive, mechanistic brain with linear mathematics.

Chaos theory, however, strongly opposes the neuron doctrine. Psychiatrist and dynamicist Arnold Mandell voices his frustration with the stubborn doctrine: "More than fifty transmitters, thousands of cell types, complex electromagnetic phenomenology, and continuous instability based on autonomous activity on all levels…and still the brain is thought of as a chemical point-to-point switchboard" (Gleick 299). A new theory of brain function is being uncovered in chaos.

Scientists researching brain activity are unsatisfied with anything less than a chaotic theory of the mind. Freeman concludes, "We have found that brain function cannot be explained in terms of features of neurons taken individually or as part of a local network, nor is it adequately characterized as a passive reaction to stimuli" (3). The brain is a chaotic system, intricately related by internal feedback that must be analyzed as a whole. Small internal uncertainties are amplified over time, making long term predictions of brain activity impossible (Skarda and Freeman 8). Furthermore, its chaotic activity creates new solutions; an internal process critical to learning. Finally, the peculiar behavior in the brain has only been logically explained by non linear mathematics (Brigs 298).

Electroencephalographic (EEG) images of the brain's electrical activity are similar to the electrocardiograph data of the heart. Brain activity is chaotic and unpredictable yet has a hidden order that, when plotted as a phase-space diagram, is attracted to a certain region. There are numerous fractal strange attractors in the brain that change as thinking processes vary. Paul Rapp, a neuroscientist for the Medical College of Pennsylvania comments on the discovery: "For the first time we are able to see changes in the geometry of EEG activity that occur as the result of human cognitive activity….I expected to see something very boring that did not significantly change as the subject began to think. The moment these structures flooded onto the screen and began to rotate, I knew I was seeing something very extraordinary" (Brigs 32). These attractors in the brain are thought to play a key role that distinguishes the brain from all other computing machines: the ability to actively create.

A theory exists that learning takes place when a new stimulus leads to the emergence of an unpatterned, increasingly chaotic state in the brain. This activity causes a bifurcation that provides the substrate for a new nerve cell assembly and a new strange attractor (Freeman 4). While more research needs to be done, it is clear that the brain's ability to generate new information internally is critical to our creative processes. It is likely that chaos is essential to that ability.

Creative processes aside, the benefits of chaotic activity in the brain are similar to those of the heart. Neurons must be exercised consistently to assure their proper function. If neurons are not used for long periods of time, they die. Random firing of inactive neurons provides a suitable mechanism for maintaining neuron health. Thus, chaos is essential to normal brain functioning. What was previously dismissed as random noise is biologically relevant. Background noise in the brain is steady, stable, and controllable--but not absolutely so. Like the erratic beating of the heart, electromagnetic impulses in the brain are still chaotically random. Chaotic activity in the brain enables for rapid state transitions. Such transitions are essential for processing information. Without them, cognition and perception would be agonizingly slow (Skarda and Freeman 7).

Two of the critical dynamic organs in our body demonstrate chaotic patterns of behavior. Chaos doesn't stop there, however. Our entire bodies are a complex, dynamic system. Our physiology, like so much in nature, takes on fractal dimensions. We are creatures of chaos.

IV. Fractal Physiology

The intricate beauty of fractals cannot be denied. Theories exist that suggest that fractal qualities may even be intrinsic to our aesthetic sense. Says computer engineer Homer Smith, "If you like fractals, it is because you are made of them. It you can't stand fractals, it's because you can't stand yourself. It happens" (Brigs 129). His statement is true: many of the systems in our body demonstrate fractal characteristics.

The typical human lung has a surface area bigger than a tennis court (Glieck 110). The human intestine has 300 square meters of surface area. Obviously, an incredibly efficient packing system is needed for such feats, and fractal geometry is such a system. Just as Mandlebrot's famous coastline can have nearly infinite length, self-similarity on every scale greatly increases surface area without increasing volume (Brigs 124). Recall Mandlebrot's fractal dimensions as a way of measuring the efficiency of the packing structure of a system. The human vascular system is bent and packed so extensively that is has an effective fractal dimension of three. The system of arteries has a dimension of 2.7 (Brigs 71). This means that the vascular system is as compact as a single line entwining itself into a perfect sphere yet retaining the surface area of the entire line.

Fractals are also very efficient ways of distribution. A whale is ten million times heavier than a mouse yet needs only seventy percent more branches in its circulatory system (Ward 156). The distributive systems of the body--cardiovascular, respiratory, lymphatic, digestive, and excretory-- all display fractal characteristics. For example, the branching of arteries, veins, and capillaries in the cardiovascular system is random, self-similar, and detailed at every scale.

Not just effective, fractal geometry is also simple. Exponential explanations of the body's branching structure require more detailed equations than non-linear descriptions. The fractal branching for all the systems of the body, from the bile ducts in the liver to the perkenje fibers in the heart, can be described by the body with a few simple bits of information (Gleick 110). It is easy for DNA to specify a single repeating process of bifurcation and development for all of the various systems that display such structure. Our bodies are fractals simply because it is the simplest, most efficient choice possible.

V. The Disease of Order and Applied Chaos

From the beginnings of the field of pathology, it has been thought that disorder caused disease in the body. Now physicians and scientists have begun to see chaos as health (Gleick 292). Arnold Mandell wonders, "Is it possible that mathematical pathology, chaos, is health? And that mathematical health, which is…predictability and differentiability…is disease?" (Glieck 298). It is not only possible, but likely.

A linear process, given a slight nudge, tends to remain off track. A nonlinear process, given the same nudge, returns to its starting point. For this reason, nonlinear systems can withstand small jolts and operate over a broad range of environmental conditions. Systems disordered in the right way are highly adaptable and poised at a critical point, ready to react swiftly to any change (Ward 146). From seizures to leukemia, disease is finally being recognized for what it is: an acute attack of order.

Physicians have begun to classify a new order of "dynamical diseases" caused by abnormally periodic order. Epileptic seizures, leukemia, heart attack, and sudden infant death syndrome are just a few such dynamic disorders. Even aging itself has been called a loss of deterministic chaos or complexity (Kim and Stringer 322).

Take for example an epileptic seizure. The amount of chaos in the epileptic's brain actually decreases as neurons at the seizure's focus begin to entice other neurons to fire in sync with them. This condition, called dynamical entrainment, can start days before the attack. Chris Sackallares, neurologist at the University of Florida, compares the phenomenon to a computer that can suddenly only play the same game of solitaire over and over (Svitil 2). Sackallares, along with bioengineer Leonidas Lesemidis, have developed a technique that can identify seizures in the making ninety percent of the time with an average of seventy-five minutes notice. They do this by using dense mathematics to calculate a Lyapunov exponent- a measure of chaos in the brain.

Such reliable advance warning of seizures could lead to the development of an implanted chip that would identify when seizure were about to occur and deliver an electrical impulse to return the brain to its normal chaotic state. This is not the only application of chaos in medicine. The opportunities are as infinite as the dynamic systems themselves.

While many potential applications of chaos theory to medicine have yet to be dreamed of, many are currently being researched. Some possible applications are: early warning of heart attack by monitoring chaos level in heart beat; respirators that operate on chaotic patterns like healthy working lungs (so alveoli sacs don't collapse); diagnostic tools developed to distinguish between healthy and abnormal tissue based on fractal dimensions; prediction of epidemics by the identification of the chaotic attractor in the spread of disease; and artificial intelligence based on the chaotic model of the mind. This is by no means an all-inclusive list. The applications of chaos theory to medicine are, appropriately, unpredictable.

The human body is a complex dynamic system that plays by the rules of chaos. From the strange attractors in a heart beat to the fractal dimensions in the lungs, we are beings composed of chaos. Once physicians and scientists gain more understanding of our chaotic state and the diseases caused by abnormal order, the potential for practical application is vast. Where will a more complete understanding of chaos lead us? No one can say. One thing is certain, chaos in us and our surroundings will not be ignored. What little understanding we have now could be just the flapping of a butterfly's wings before the storm.

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