Chaos: Making a New Science Study Guide

Chaos: Making a New Science by James Gleick

Contents

Plot Summary

"Chaos: Making a New Science" by James Gleick begins with the most basic knowledge of chaos as it is presented in weather. The book frequently returns to the information in Chapter 1, particularly the work of Edward Lorenz.

Gleick begins by discussing the weather simulator created by Edward Lorenz. The weather changed slowly yet it never rained, seasons never changed, and nightfall never arrived. Instead, the weather was always a permanent, dry condition as if it was the middle of the day in some midseason. Lorenz had created a type of weather Camelot. The year was 1960. Lorenz, a research meteorologist, was a fixture at the Massachusetts Institute of Technology. Although his machine broke down about once a week, Lorenz managed to mesmerize his colleagues. Gleick explains Lorenz's processes and numerical methods and applications that would make him the weather god in his own artificial universe.

In the 1960s, not only did meteorologists dislike forecasting, they also mistrusted computers. Computers seemed to these scientists like large calculators that were not competent enough to do the necessary computations. Edward Lorenz would change the way many people would think. Lorenz's experiments would prompt the development of the National Meteorological Center in the 1980s.

The book also introduces the works of many prominent scientists at length. This includes the work of John Yorke, the man credited with creating the term "chaos" in reference to science. Although Yorke was a brilliant mathematician, he often referred to himself as a philosopher. He was a dedicated admirer of Steve Smale, another famed scientist. Smale was a difficult but brilliant mathematician at the time that worked at and eventually directed the Institute for Physical Science and Technology.

Benoit Mandelbrot's work iss also discussed and recognized for its vital contribution to the science of chaos. Chaos is examined in many different lights and atmospheres from outer space to nature to the human body. Gleick also talks about modern day experiments.

Gleick is a gifted science writer in his own right. Gleick presents material in a straightforward manner. It is chronological in nature with historical referenced to Edward Lorenz and Benoit Mandelbrot as they are revisited and used by scientists that are involved in developing new theories. The book attempts to share these complex theories accessible for the lay person as well as the fledgling scientist.

Chapters 1-2

Chapters 1-2 Summary and Analysis

Chapter 1: The Butterfly Effect: Edward Lorenz and his toy weather. The computer misbehaves. Long-range forecasting is doomed. Order masquerading as randomness. A world of nonlinearity. "We completely missed the point."

Chapter 1, "The Butterfly Effect" begins with a quote from Richard Feynman: "Physicists like to think that all you have to do is say, these are the conditions, now what happens next?" (Chap. 1, p. 9).

Gleick begins by discussing the weather simulator created by Edward Lorenz. The weather changed slowly but surely, yet it never rained, seasons never changed, and nightfall never arrived. Instead, the weather was always a permanent, dry condition as if it was the middle of the day in some mid-season. Lorenz had created a type of weather Camelot. The year was 1960. Lorenz, a research meteorologist, was a fixture at the Massachusetts Institute of Technology. Although his machine broke down about once a week, Lorenz managed to mesmerize his colleagues. Gleick explains Lorenz's processes, numerical methods, and applications that would make him the weather god in his own artificial universe.

"To most serious meteorologists, forecasting was less than science. It was a seat-of-the-pants business performed by technicians who needed some intuitive ability to read the next day's weather in the instruments and the clouds. It was guesswork." (Chap. 1, p. 13).

In the 1960s, not only did meteorologists dislike forecasting, they also mistrusted computers. Computers seemed to these scientists like large calculators that were not competent enough to do the necessary computations. However, Lorenz was able to boil down weather to the bare bones. In order to be able to read the print outs, Lorenz created a simplified set of graphics. However, Lorenz noticed that his graphs changed dramatically when he rounded off the numbers he entered into the Royal McBee. Lorenz thought that perhaps long term forecasting was doomed to failure.

In the 1950s and 1960s two technologies were maturing together. The space satellite and the digital computer were making new things possible. As a result, an international program was being designed - The Global Atmosphere Research Program.

In the 1980s, the National Meteorological Center was born in Maryland. It was the second best forecasting site in the world. The European Center for Medium Range Forecasts, the best in the world, was located in Reading, England.

"The Europeans attributed their success to their young, rotating staff and their Cray supercomputer, which always seemed to be one model ahead of the American counterpart." (Chap. 1, p. 19).

Both sites learned to make realignments that could drastically change the outcome of the tests performed. Computer modeling made weather into a bona fide science.

One of the biggest issues with forecasting was that predicting anything beyond 2-3 days was speculative; anything beyond 6-7 days was useless. Lorenz believed that this was due to the Butterfly Effect. The Butterfly Effect showed that the smallest change in the initial input of data would radically change the outcome.

"The Butterfly Effect acquired a technical name: sensitive dependence on initial conditions." (Chap. 1, p. 23).

Lorenz went looking for simpler ways to reproduce this complex behavior. He discovered a way by using three equations. Gleick explains Lorenz's approach and the concept of linear versus nonlinear relationships. The principles developed by Lorenz are shown in a diagram and lengthy description of the Lorenzian Waterwheel.

Chapter 2: Revolution: A Revolution in seeing; Pendulum clocks, space balls, and playground swings; The invention of the horseshoe; A mystery solved: Jupiter's Great Red Spot.

"Of course, the entire effort is to put oneself outside the ordinary range of what are called statistics." (Stephen Spender, Chap. 2, p. 33).

Gleick talks about Thomas S. Kuhn, a historian of science. Kuhn discusses an experiment conducted by two psychologists in the 1940s. Subjects were allowed to glance at playing cards one at a time. Then they were asked to name them. The trick was that some of the cards were freakish: there might be a black queen of diamonds or a red six of spades. At first the subjects had no problem calling out what they saw, ignoring the alterations. When they were permitted to have a longer look, they began to hesitate. When given even more time, they caught on to the alterations. Some actually experienced complete disorientation.

"Professional scientists, given brief, uncertain glimpses of nature's workings, are no less vulnerable to anguish and confusion when they come face to face with incongruity." (Chap. 2, p. 35).

Kuhn's work, when it was published in 1962, opened up a can of worms that has never been closed. Kuhn asserted that while some scientists spent their days mopping up problems and operations. They were straight problem solvers. Experimentalists, on the other hand, carried out modified versions of previously performed experiments.

Revolutions are created out of things that have come to an end. New sciences are formed when one previously accepted science has reached its limit and has nowhere else to go. The only problem with studying and experimenting with a new science is that, for the most part, no one else will understand it. This produces a particularly large problem for graduate students because their professors do not know how to work with or grade the experimentation and work..

Gleick refers to the pendulum as being the laboratory mouse of chaos, the new science. Yet how could something that swings free at the end of a rod represent turbulence? Gleick outlines the work of several great scientists and their tools:

Archimedes used a bathtub; Newton was inspired by an apple; Galileo used a church lamp that swayed back and forth; Christian Huygens used a pendulum for timekeeping; Foucault used a twenty-story high pendulum as a way to demonstrate the earth's rotation.

There were still discoveries to be made with the pendulum even though its usage went back to Aristotle and beyond. While some saw the pendulum as trying to return to its most stable state, others saw it as being a way to measure inertia, motion, and gravity. Gleick goes on to discuss how Galileo's discoveries were different from Aristotle's and what was learned through his extensive experimentation.

Another form of pendulum can be seen in a toy known as "space balls" or a "space trapeze." Playground swings also fall under the same category.

Traditionally, a dynamicist will write out a system's equations in order to better understand the system. Gleick explains that when discussing a playground swing one must take into account the velocity, angle, friction, and driving force. It is simple for a computer to determine and solve these equations. However, it goes back to what Lorenz discovered with the Butterfly Effect - if the equations and data are not precise enough, one minute change can drastically change the outcome.

In the 1960s, scientists began to make other discoveries that paralleled Lorenz's earlier discoveries. One of those scientists was Stephen Smale from the University of California at Berkeley. Smale was young but already famous for solving esoteric problems. Smale made several mistakes in his presentation of his theories. When in Moscow, instead of focusing on his work, Smale condemned American involvement in Vietnam as well as the Soviet invasion of Hungary. Smale also criticized the lack of personal freedom in the Soviet Union. After his speech, Smale was escorted away and questioned by Soviet officials. When Smale returned to Berkeley, he learned that his grant had been withdrawn.

Gleick discusses the theories of Henri Poincare, considered to be the last great mathematician working at the turn of the century. Poincare was the first scientist to understand the possibility of chaos.

Physicists began to assert that chaos was present with instability. In 1959, Smale received a letter from a colleague explaining that this theory was false.

"Chaos and instability, concepts only beginning to acquire formal definitions, were not the same at all. A chaotic system could be stable if its particular brand of irregularity persisted in the face of small disturbances." (Chap. 2, p. 48).

Gleick explains the invention of the horseshoe. It proved to be a basis of understanding chaotic properties of dynamical systems. The basics are explained.

Jupiter's Great Red Spot had been a massive, swirling oval. It was clear to many that the Red Spot was caused by turbulence.

Several theories are explained and discussed such as the Lava Flow Theory, the New Moon Theory, the Egg Theory, and the Column-of-Gas Theory.

Pictures from the Voyager helped to explain much of what was happening on Jupiter. It had been assumed that Jupiter was a solid mass surrounded by a paper-thin atmosphere. It was soon discovered that Jupiter was actually fluid in motion.

In the 1980s, Philip Marcus, an applied mathematician and astronomer, was one of the few scientists in the US and Britain that attempted to model the Red Spot. Marcus used Lorenz's theory and built upon it. In doing so, he reinvented himself as a specialist in chaos.

Chapters 3-4

Chapters 3-4 Summary and Analysis

Chapter 3: Life's Ups and Downs: Modeling wildlife populations. Nonlinear science, "the study of elephant animals." Pitchfork bifurcations and a ride on the Spree. A movie of chaos and a messianic appeal.

"The result of a mathematical development should be continuously checked against one's own intuition about what constitutes reasonable biological behavior." (Harvey J. Gold, Chap. 3, p. 57).

Ecologist and biologists use mathematical equations to create, see and interpret the world's ecosystems through computer modeling. They use a four year period to watch animals in the seas and the rainforests thrive, grow, and reproduce. However, no one is sure how many species exist - is it five million or fifty million? Biologists and ecologists study different aspects of the natural world using elementary tools.

"In the emergence of chaos as a new science in the 1970s, ecologists were destined to play a special role. They used mathematical models, but they always knew that the models were thin approximations of the seething real world. In a perverse way, their awareness of the limitations allowed them to see the importance of some ideas that mathematicians had considered interesting oddities." (Chap. 3, p. 59).

One of the biggest questions came to be how different parameters affected the ultimate destiny of a changing population. The answer was that a lower parameter will cause the idealized population to end up at the lower level while higher parameter will lead to an increased, steady state. This did not mean that the issue was solved. The numbers refused to behave and often remained erratic.

John Yorke is introduced. Yorke is credited with creating the term "chaos" in reference to science. Although Yorke was a brilliant mathematician, he often referred to himself as a philosopher. He was a dedicated admirer of Steve Smale, a difficult but brilliant mathematician that worked at and eventually directed the Institute for Physical Science and Technology.

Because of Yorke's work and brilliance, he was permitted to work on things that were outside traditional constraints. Everything changed for Yorke when he was given a copy of Lorenz's "Deterministic Nonperiodic Flow." Yorke realized that one of the largest problems with his work was that mathematicians and physicists were often worlds apart because they did not always speak the same language. There needed to be a hybrid.

"When Yorke saw Lorenz's paper, even though it was buried in a meteorology journal, he knew it was an example that physicists would understand." (Chap. 2, p. 67).

Yorke was determined to find a way for physicists to "see" chaos in a way that it was seen by mathematicians. There needed to be a revolution.

Nonlinear problems continued to be an issue as many mathematicians and physicists are not used to dealing with those types of problems. Gleick quotes Enrico Fermi: "It does not say in the Bible that all laws of nature are expressible linearily!" Stanislaw Ulam said that calling the study of chaos a nonlinear science was akin to calling zoology "the study of nonelephant animals." (Chap. 3, p. 68).

Yorke consulted his friend and biologist Robert May. May's background is discussed. May's work was similar to Smale's work - he was trying to understand one simple all at once - on a global level rather than a local level.

Included are diagrams of period-doublings and chaos.

May, like many before him, was confused by the changes when a parameter was increased.

Illustrations of the Windows of Order Inside Chaos and the outline of the bifurcation diagram are included.

"And yet relation appears, a small relation expanding like the shade of a cloud on sand, a shape on the side of the hill." (Wallace Stevens, Chap. 4, p. 81).

In 1960 Benoit Mandelbrot, a mathematical jack of all trades, recognized the ghost of an idea when he spotted a diagram charted out on the blackboard in Hendrik Houthakker's office at Harvard. Mandelbrot had been working at International Business Machines Corporation where he had been working in economics, studying distribution of various incomes in the economy. Mandelbrot was invited by Houthakker to speak at Harvard. When Mandelbrot saw the diagram in Houthakker's office, he was baffled at how his diagram could appear before he had given his lecture. Houthakker was confused and explained that the diagram represented eight years of cotton prices. The men did agree, however, that there was something peculiar about the chart. There were both predictable and random changes in the prices. The way to plot variation was the use of the bell shaped curve.

Mandelbrot saw the diagram of cotton prices as being an ideal data source. The data was ideal for two reasons - it was old and centralized. The old data removed some of the aspects of a fluctuating system. The fact that the data was centralized made it easier to track. Mandelbrot sifted the information through the computers at IBM and found astonishing results.

Because of the nature of Mandelbrot's work, he was always an outsider in various fields as he seemed to choose the most unorthodox approaches.

"To the physicists expanding on the work of people like Lorenz, Smale, Yorke, and May, this prickly mathematician remained a sideshow - but his techniques and his language became an inseparable part of their new science." (Chap. 4, p. 87).

Although it would be a shocking revelation to his colleagues, Mandelbrot is best described as being a refugee.

Mandelbrot was born in Warsaw, Poland in 1924. His parents were Lithuanian Jews. His father was a clothing wholesaler and his mother was a dentist. The family was forced to move to Paris in 1936 due to geopolitical circumstances. The family chose Paris because of the present of Mandelbrot's uncle, a mathematician named Szolem Mandelbrojt. The family barely escaped capture by the Nazis and fled to Tulle.

Young Benoit Mandelbrot became an apprentice to a toolmaker. He was often singled out by his height and lack of education. Although the world was filled with fear and uncertainty for many, Mandelbrot recalls little personal difficulties. He was befriended by schoolteachers who were also scholars. They were all refugees which may have prompted a strong bond. Mandelbrot claimed that he never learned the alphabet or multiplication tables past the fives. However, when Mandelbrot returned to Paris after the liberation, he was admitted into the Ecole Normale and Ecole Polytechnic despite his lack of preparation. Mandelbrot called upon his variety of skills to cover for his lack of knowledge in certain areas. Mandelbrot began at the Ecole Normale but quickly moved on to the Ecole Polytechnic. Both were highly prestigious and exclusive schools.

Gleick discusses the issues engineers had with understanding Mandelbrot's work.

Gleick describes the Cantor Set as being an abstract construction named for Georg Cantor, a 19th century mathematician. In a Cantor Set, one must begin with the interval of numbers from 0-1 and then represent those with a line segment. Remove the middle third, leaving two line segments. Remove the middle third of each of those line segments, leaving four line segments. Repeat the process, which goes to infinity. What is left is referred as Cantor Dust as the line segments become minute.

The Noah and Joseph Effects are discussed. The Noah Effect represents discontinuity while the Joseph Effect represents persistence.

Gleick discusses classical geometry, using a coastline as an example.

"Since Euclidean measurements - length, depth, thickness, failed to capture the essence of irregular shapes, Mandelbrot turned to a different idea, the idea of dimension. Dimension is a quality with a much richer life for scientists than for non-scientists." (Chap. 4, p. 96).

Mandelbrot decided that if he was going to proceed with this work, it would need a name. Mandelbrot finally decided on "fractal." The definition of fractal is the ability to see infinity.

The Koch Curve is discussed as is fractal dimension. Diagrams in this section include constructing with holes as well as peano curves, Sierpinski carpets and Sierpinski gaskets.

Mandelbrot had an advantage over many other scientists in that he had the entire computer system of IBM behind him. These computers allowed Mandelbrot to do what others could not in terms of computations and calculations.

Gleick discusses the study of earthquakes. The best place in the US to study earthquakes is the Lamont-Doherty Geophysical Observatory, located in the southern part of New York State. One of the most prominent scientists to come out of the Observatory was Christopher Scholz.

"Scholz became known in his field as one of a few people taking up fractal techniques. He knew that some of his colleagues viewed this small group as freaks. If he used the word fractal in the title of a paper, he felt that he was regarded either as being admirably current or not-so-admirably on a bandwagon." (Chap. 4, p. 106).

Physics of earthquakes are discussed. Although scientists began to embrace the term fractal, they continued to shun Mandelbrot. It seems that the scientists did not have as much as issue with fractal as they did with Mandelbrot. Mandelbrot continued to investigate things that were thought obsolete or useless and continued to draw new conclusions. This, too, made Mandelbrot unpopular.

"Mathematics differs from physics and other applied sciences in this respect. A branch of physics, once it becomes obsolete or unproductive, tends to be forever part of the past. It may be a historical curiosity, perhaps the source of some inspiration to a modern scientist, but dead physics is usually dead for a good reason." (Chap. 4, p. 113).

Geometry is compared to emerging art and architecture.

Many people believe that physicists are ones to make a science of chaos as they are more curious than mathematicians.

Graphic pictures are included in this section to illustrate Gleick's points. They include: The Lorenz Attractor; The Koch Curve; 6 images of The Mandelbrot Set; The Complex Boundaries of Newton's Method; Fractal Clusters; and The Great Red Spot Real and Simulated.

Chapters 5-6

Chapters 5-6 Summary and Analysis

Chapter 5: Strange Attractors: A problem for God; Transitions in the laboratory; Rotating cylinders and a turning point; David Ruelle's idea for turbulence; Loops in phase space; Mille-feuilles and sausage; An astronomer's mapping; "Fireworks or galaxies."

"Big whorls have little whorls which feed on their velocity, and little whorls have lesser whorls and so on to viscosity." (Lewis F. Richardson, Chap. 5, p. 119).

Turbulence caused a problem with pedigree. The great physicists had to consider the issue whether formally or informally. Wild patterns disrupt the boundary between solid and fluid. Energy will drain rapidly from large-scale motions to small-scale motions. The scientists had to ask themselves why.

Theoretical physics had come to a standoff with the phenomenon of turbulence. By modern times, this issue was no longer on the front lines.

How is turbulence defined? Turbulence is defined as a mess of disorder on all scales. It is not stable.

Gleick describes the rules of a smooth flow and how eddies can be used to demonstrate turbulence.

"Theorists conduct experiments with their brains. Experimenters have to use their hands, too. Theorists are thinkers, experimenters are craftsmen. The theorist needs no accomplice. The experimenter has to muster graduate students, cajole machinists, flatter lab assistants." (Chap. 5, p. 125).

Gleick discusses the work performed by Swinney and Gollub and also explains the importance of strange attractors as they apply to physics.

Chapter 6: Universality: A new start at Los Alamos; The renormalization group; Decoding color; The rise of numerical experimentation; Mitchel Feigenbaum's breakthrough; A universal theory; The rejection letters; Meeting in Como; Clouds and paintings.

"The iterating of these lines brings gold; the framing of this circle on the ground brings whirlwinds, tempests, thunder and lightning." (Dr. Faustus, Chap. 6, p. 155).

Mitchell Feigenbaum arrived at the Los Alamos National Laboratory in 1974 when he was 29 years old. Feigenbaum determined that in order for physicists to make something out of the cliché that there was order in chaos, they would need a positive frame work. Gleick reviews Feigenbaum's history and education from age 4.

In addition to his graduate studies at M.I.T., Feigenbaum was immersed in the culture and art of the Romantic period. His favorites seemed to be Mahler and Goethe. Goethe was much more than a writer, he was also a scientist. Feigenbaum embraced Goethe's assertions and formed his own opinions and experiments.

While Feigenbaum accomplished a great deal, he was shunned by prestigious journals. Still, Feigenbaum was not to be discouraged or dissuaded. His thirst for knowledge was too great.

chapters 7-8

chapters 7-8 Summary and Analysis

Chapter 7: The Experimenter: Helium in a Small Box; "Insolid billowing of the solid"; Flow and form in nature; Albert Libchaber's delicate triumph; Experiment joins theory; From one dimension to many.

"It's an experience like no other experience I can describe, the best thing that can happen to a scientist, realizing that something that's happened in his or her mind exactly corresponds to something that happens in nature." (Leo Kadanoff, Chap. 7, p. 189).

The life and work of Albert Libchaber is examined. Libchaber had a similar background to Mandelbrot, living as a refugee during World War II. Libchaber was recognized at the Ecole Normale Superieure as becoming a mature scientist. Libchaber had become a relatively well known low temperature physicist, focusing on the study of quantum behavior of superfluid helium. Through this work, Libchaber invented what he referred to as Helium in a Box. The work with helium was a delicate project for which Libchaber received much acclaim.

Although Libchaber was unaware of it at the time, he reverted back to some of the same experiments and ideas that had been questioned by Lorenz. Libchaber's results also paralleled the Navier-Stokes equation, an equation that relates the pressure, viscosity, velocity, density of a fluid.

Chapter 8: Images of Chaos: The complex plane; Surprise in Newton's method; The Mandelbrot set: Sprouts and tendrils; Art and commerce meet science; Fractal basin boundaries; The chaos game.

"What else, when chaos draws all forced inward to shape a single leaf." (Conrad Aiken, Chap. 8, p. 213).

Mitchell Feigenbaum met Michael Barnsley in 1979 at a conference in Corsica. Barnsley was an Oxford educated mathematician who had studied period-doubling, universality, and the infinite cascades of bifurcations. Like many scientists, Barnsley believed that he a new idea. The idea referred to a numerical territory known as a complex plane. Gleick offers a scientific explanation of Barnsley's numerical theory.

The Boundaries of Infinite Complexity are shown in a diagram. Gleick also compares the Mandlebrot Set to the Julia Set.

Fractal basin boundaries were used to address deep issues in theoretical physics. Richter and Peitgen studied phase transitions, nonmagnetization and magnetization in materials. Their picture of those boundaries showed the complex beauty that began to seem to natural.

Barnsley decided to take a different route. He considered nature's images as well as patterns that were generated by living organisms. Finally, Barnsley turned to randomness. Barnsley began to call the global construction of fractals "the chaos game."

"To play the chaos game quickly, you need a computer with a graphics screen and a random number generator, but in principle a sheet of paper and a coin will work just as well." (Chap. 8, p. 236).

Richter and Peitgen began to turn it into an art form even before Douady and Hubbard began to understand its mathematical essence. This was even before Mandelbrot discovered it. It may have existed earlier yet there was more to be unveiled.

chapters 9-11

chapters 9-11 Summary and Analysis

Chapter 9:

The Dynamical Systems Collective: Santa Cruz and the sixties; The analog computer; Was this science?; "A long-range vision"; Measuring unpredictability; Information theory; From microscale to macroscale; The dripping faucet; Audiovisual aids; An era ends.

"Communication across the revolutionary divide is inevitably partial." (Chap. 9, p. 241).

Gleick begins this chapter by introducing The University of California at Santa Cruz. The school was the newest part of The University of California system and it quickly drew a number of eclectic and brilliant people to its doors. Among those people was Robert Stenson Shaw, a 31-year-old Harvard graduate. The year was 1977 when Shaw arrived.

William Burke was a Santa Cruz cosmologist and relativist. One day while he was in Boston, Burke ran into his friend Edward Spiegel, an astrophysicist. Spiegel and Burke got into a conversation about Lorenz, whom Spiegel knew on a personal level. The discussion also led to "cosmic arrhythmias" which was Spiegel's specialty. When Burke returned to Santa Cruz, he handed Robert Shaw a piece of paper to run through the analog computer. The paper contained only three equations.

Shaw would eventually take his enthusiasm for his studies and form The Dynamical Systems Collective, a group that also included James Crutchfield, Norman Packard, and J. Doyne Farmer. The group was often jokingly referred to as the Santa Cruz Chaos Cabal. The group's main focus was information theory.

Although the group managed to make some astounding discoveries, it soon fell apart as it was difficult to sort out who was doing what in the collective. The result of the work, however, led to having the first major paper published in the prestigious American journal, "Physical Review Letters."

Chapter 10: Inner Rhythms: A misunderstanding about models; The complex body; The dynamical heart; Resetting the biological clock; Fatal arrhythmia; Chick embryos and abnormal beats; Chaos as health.

"The sciences do not try to explain, they hardly even try to interpret, they mainly make models." (John Von Neumann, Chap. 10, p. 273).

"The justification of such a mathematical construct is solely and precisely that it is expected to work." (John Von Neumann, Chap. 10, p. 273).

Chapter 10 moves into another area in which chaos had never been clearly defined - the human body.

Bernardo Huberman was an Argentinian transplant in California. Huberman, a research fellow at Xerox's Palo Alto Research Center, had been part of the Santa Cruz group. He had kept up with his interest in chaos but now he saw other issues that needed to be addressed. While Huberman was giving a lecture at the National Institutes of Health, he began to notice that there was a communication gap among the people in his audience. One of Huberman's most recent studies focused on the erratic eye movements of schizophrenics.

"Psychiatrists have struggled for generations to define schizophrenia and classify schizophrenics, but the disease has been almost as difficult to describe as to cure. Most of its symptoms appear in mind and behavior." (Chap. 10, p. 276).

Schizophrenics cannot track the motion of a pendulum with their eyes. The person's eyes will tend to jump around in small increments. There are no explanations. Huberman began to study the mechanics of the eye.In the 1980s, chaos entered into a new realm - physiology. Scientists began to recognize that the body was a place of oscillation and motion and began to develop methods to listen to its drumbeat.

Gleick details the work of chaos as it relates to the heart. David Ruelle began to speculate about the heart. Ruelle was fascinated with the fact that while there is a steadiness about the heart there are also irregularities:

"The normal cardiac regime is periodic, but there are many nonperiodic pathologies (like ventricular fibrillation) which lead to the steady state of death. It seems that great medical benefit might be derived from computer studies of a realistic mathematical model which would reproduce the various cardiac dynamical regimes." Chap. 10, pp. 280-281

The experiments and results have shown the scientists a great deal but there is still a mystery as to how the body can work while it seems to have chaos present.

Chapter 11: Chaos and Beyond: New beliefs, new definitions; The Second Law, the snowflake puzzle, and loaded dice; Opportunity and necessity.

Chapter 11 is the summary of the history of chaos. It covers the last two decades and the similarities between the works of Edward Lorenz, Michel Henon, Robert May, Benoit Mandelbrot, Doyne Farmer, and more.

Gleick makes several points that summarize the book:

Systems behave in simple ways. As long as the systems could be reduced to a few perfectly determined, perfectly understood laws, the long term behavior of the systems would be predictable and stable.

Complex behavior implies complex causes; Different systems behave differently.

Included in this section are also illustrations of branching and clumping, the study of pattern formation; and balancing stability and instability in the form of crystallized liquid.

Gleick reiterates that it is possible to have both chaos and disorder. The key is to realize that internal chaos is affected by outside forces and vice versa. It is imperative for the scientist to look at the entire picture in order to understand the system.

Characters

James Gleick

James Gleick (1954 -) is a native of New York City. Gleick graduated from Harvard College, one of two major schools located within Harvard University, in 1976. After founding Metropolis, an alternative weekly newspaper based in Minneapolis, Gleick returned to New York where he worked as a reporter and editor for The New York Times. Gleick has also served as the McGraw Distinguished Lecturer at Princeton University from 1989-90. He collaborated with eminent nature photographer Eliot Porter on the Nature's Chaos, which discussed the presence of chaos as it appears in the natural world. Gleick also worked on Chaos: The Software by Autodesk. In 1993, Gleick founded an early internet service called The Pipeline based in New York. Gleick also served as the first editor of the Best American Science Writing series.

Gleick has several best selling books to his credit, including his first, "Chaos: Making a New Science." "Chaos" was a national bestseller and was a finalist for the Pulitzer Prize as well as the National Book Award. Gleick's other best selling books include "Isaac Newton" and "Genius: The Life and Science of Richard Feynman." Both books qualified as finalists for the Pulitzer Prize. Gleick also published two other books, "Faster" and "What Just Happened?"

Benoit Mandelbrot

Benoit Mandelbrot was born in Warsaw, Poland in 1924. His parents were Lithuanian Jews. His father was a clothing wholesaler and his mother was a dentist. The family was forced to move to Paris in 1936 due to geopolitical circumstances. The family chose Paris because of the present of Mandelbrot's uncle, a mathematician named Szolem Mandelbrojt. The family barely escaped capture by the Nazis and fled to Tulle.

Young Benoit Mandelbrot became an apprentice to a toolmaker. He was often singled out by his height and lack of education. Although the world was filled with fear and uncertainty for many, Mandelbrot recalls little personal difficulties. He was befriended by schoolteachers who were also scholars. They were all refugees that may have prompted a strong bond. Mandelbrot claimed that he never learned the alphabet or multiplication tables past the fives. However, when Mandelbrot returned to Paris after the liberation, he was admitted into the Ecole Normale and Ecole Polytechnic despite his lack of preparation. Mandelbrot called upon his variety of skills to cover for his lack of knowledge in certain areas. Mandelbrot began at the Ecole Normale but quickly moved on to the Ecole Polytechnic. Both were highly prestigious and exclusive schools.

In 1960 Benoit Mandelbrot, a mathematical jack of all trades, became involved in analyzing the cotton prices as an ideal data source. The data was ideal for two reasons - it was old and centralized. The old data removed some of the aspects of a fluctuating system. The fact that the data was centralized made it easier to track. Mandelbrot sifted the information through the computers at IBM and found astonishing results.

Because of the nature of Mandelbrot's work, he was always an outsider in various fields as he seemed to choose the most unorthodox approaches.

Edward Lorenz

Edward Lorenz was the first to build a true weather simulator and calculated the data that would make weather forecasting possible. He coined the term and concept "The Butterfly Effect."

Stephen Smale

Stephen Smale was a scientist from the University of California at Berkeley. Smale was young but famous for solving esoteric problems when he began to cause controversy. Still, Smale's experiments had value and inspired others to follow in his footsteps.

Robert May

Robert May was a biologist and friend to Yorke. May's work was similar to Smale's work on a global level rather than a local level.

John Yorke

John Yorke is credited with creating the term "chaos" in reference to science. Although Yorke was a brilliant mathematician, he often referred to himself as a philosopher.

Bernardo Huberman

Bernardo Huberman was an Argentinian transplant in California. Huberman, a research fellow at Xerox's Palo Alto Research Center, had been part of the Santa Cruz group. He had kept up with his interest in chaos but now he saw other issues that needed to be addressed. While Huberman was giving a lecture at the National Institutes of Health, he began to notice that there was a communication gap among the people in his audience. One of Huberman's most recent studies focused on the erratic eye movements of schizophrenics.

Robert Stenson Shaw

Robert Stenson Shaw, was a 31-year-old Harvard graduate when he arrived in Santa Cruz.. The year was 1977 when Shaw arrived. Under the advisement of William Burke, Shaw would eventually take his enthusiasm for his studies and form The Dynamical

Systems Collective, a group that also included James Crutchfield, Norman Packard, and J. Doyne Farmer.

Mitchell Feigenbaum

Mitchell Feigenbaum, a graduate student at M.I.T., arrived at the Los Alamos National Laboratory in 1974 when he was 29 years old. Feigenbaum determined that in order for physicists to make something out of the cliché that there was order in chaos, they would need a positive framework.

Albert Libchaber

Albert Libchaber had a similar background to Mandelbrot, living as a refugee during World War II. Libchaber was recognized at the Ecole Normale Superieure as becoming a mature scientist. Libchaber had become a relatively well known low temperature physicist, focusing on the study of quantum behavior of superfluid helium. Through this work, Libchaber invented what he referred to as Helium in a Box.

Objects/Places

Chaos

Chaos is defined as an unstable action in the presence of a stable environment.

"Chaos and instability, concepts only beginning to acquire formal definitions, were not the same at all. A chaotic system could be stable if its particular brand of irregularity persisted in the face of small disturbances." (Chap. 2, p. 48).

Gleick discusses the theories of Henri Poincare, considered to be the last great mathematician working at the turn of the century. Poincare was the first scientist to understand the possibility of chaos.

Physicists began to assert that chaos was present with instability. In 1959, Smale received a letter from a colleague explaining that this theory was false.

"In the emergence of chaos as a new science in the 1970s, ecologists were destined to play a special role. They used mathematical models, but they always knew that the models were thin approximations of the seething real world. In a perverse way, their awareness of the limitations allowed them to see the importance of some ideas that mathematicians had considered interesting oddities." (Chap. 3, p. 59).

John Yorke is introduced in the text as being credited with creating the term "chaos" in reference to science. Although Yorke was a brilliant mathematician, he often referred to himself as a philosopher.

Later studies would show that chaos is able to be present at the same time as order, despite previous theories.

The Butterfly Effect

Edward Lorenz is responsible for coining the term "The Butterfly Effect." Lorenz learned that the outcome of his experiments depended solely on the accuracy of the data input into the equations. Lorenz applied this theory to his weather experiments.

Lorenz was able to boil down weather to the bare bones. In order to be able to read the print outs, Lorenz created a simplified set of graphics. However, Lorenz noticed that his graphs changed dramatically when he rounded off the numbers he entered into the Royal McBee.

One of the biggest issues with forecasting was that predicting anything beyond 2-3 days was speculative and that anything beyond 6-7 days was useless. Lorenz believed that this was due to the Butterfly Effect. The Butterfly Effect showed that the smallest change in the initial input of data would radically change the outcome.

"The Butterfly Effect acquired a technical name: sensitive dependence on initial conditions." (Chap. 1, p. 23).

Lorenz went looking for simpler ways to reproduce this complex behavior. He discovered a way by using three equations. Gleick explains Lorenz's approach and the concept of linear versus nonlinear relationships. The principles developed by Lorenz are shown in a diagram and lengthy description of the Lorenzian Waterwheel.

Royal McBee

The Royal McBee is the computer used by Edward Lorenz in the 1960s. It is the tool that helped Lorenz discover the Butterfly Effect.

Dynamic Systems Collective

Dynamic Systems Collective was founded by Robert Shaw, James Crutchfield, Norman Packard, and J. Doyne Farmer. They were jokingly refereed to as the Santa Cruz Chaos Cabal.

Weather Forecasting

Weather forecasting was once considered an art form until Lorenz introduced the Butterfly Effect. Soon it became a science and mid to long-range forecasting became a possibility.

Los Alamos National Laboratory

Los Alamos National Laboratory is the place where Feigenbaum went to work in 1974.

Massachusetts Institute of Technology

The Massachusetts Institute of Technology M.I.T. is one of the most prestigious schools in the world for physics and mathematics. Several of the scientists mentioned in the book attended M.I.T.

International Business Machine Products

International Business Machine Products (IBM) was the place where Benoit Mandelbrot had been working when he began to study economics and the distribution of various incomes in the economy. The computers at IBM would prove to be of great benefit to Mandelbrot's work.

Harvard University

Harvard University is one of the most prestigious schools in the world for physics and mathematics. Several of the scientists mentioned in the book attended M.I.T.

The National Meteorological Center

In the 1980s, the National Meteorological Center was born in Maryland. It was the second best forecasting site in the world.

Themes

Chaos

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Experimentalists

One of the main themes in "Chaos: Making a New Science" by James Gleick is experimentation, including the experiments as well as the Experimentalists. Gleick states that the difference between scientists and experimentalists is that scientists tend to spend their days mopping up problems and operations. Experimentalists, on the other hand, carried out modified versions of previously performed experiments. Likewise, theorists and experimentalists are quite different in the way they approach the work:

"Theorists conduct experiments with their brains. Experimenters have to use their hands, too. Theorists are thinkers, experimenters are craftsmen. The theorist needs no accomplice. The experimenter has to muster graduate students, cajole machinists, flatter lab assistants." (Chap. 5, p. 125).

The book is filled with experimentalists that think outside the box. While this technique and mindset will eventually make them legends, it is extremely difficult to be taken seriously as a scientist, particularly when colleagues do not understand the concept or the experiment. Gleick states that the only problem with studying and experimenting with a new science is that, for the most part, no one else will understand it. This produces a particularly large problem for graduate students because their professors do not know how to work with or grade the experimentation and work.

Some of the most famous Experimentalists included in the book include Lorenz, Mandelbrot, Feigenbaum, Shaw, Smale, May, Yorke, and Huberman. Historical Experimentalists include Goethe, Newton, and Galileo.

The Butterfly Effect

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Style

Perspective

James Gleick (1954 -) is a native of New York City. Gleick graduated from Harvard College, one of two major schools located within Harvard University, in 1976. After founding Metropolis, an alternative weekly newspaper based in Minneapolis, Gleick returned to New York where he worked as a reporter and editor for The New York Times. Gleick has also served as the McGraw Distinguished Lecturer at Princeton University from 1989-90. He collaborated with eminent nature photographer Eliot Porter on the Nature's Chaos, which discussed the presence of chaos as it appears in the natural world. Gleick also worked on Chaos: The Software by Autodesk. In 1993, Gleick founded an early internet service called The Pipeline based in New York. Gleick also served as the first editor of the Best American Science Writing series.

Gleick has several best selling books to his credit, including his first, "Chaos: Making a New Science." "Chaos" was a national bestseller and was a finalist for the Pulitzer Prize as well as the National Book Award. Gleick's other best selling books include "Isaac Newton" and "Genius: The Life and Science of Richard Feynman." Both books qualified as finalists for the Pulitzer Prize. Gleick also published two other books, "Faster" and "What Just Happened?"

Tone

James Gleick is the author of "Chaos: Making a New Science." This is a work of non-fiction. The tone of the book is typically non-partisan. This is a particularly difficult tone to achieve considering the personal experiences and controversial material in the text. The material was painstakingly researched and compiled by science writer James Gleick.

James Gleick (1954 -) is a native of New York City. Gleick graduated from Harvard College, one of two major schools located within Harvard University, in 1976. Gleick has also served as the McGraw Distinguished Lecturer at Princeton University from 1989-90. He collaborated with eminent nature photographer Eliot Porter on the Nature's Chaos, which discussed the presence of chaos as it appears in the natural world. Gleick also worked on Chaos: The Software by Autodesk.

Gleick presents material in a straightforward manner. The book is chronological in nature with historical referenced to Edward Lorenz and Benoit Mandelbrot as they are revisited and used by scientists that are involved in developing new theories. The book attempts to create a relatable story for the lay person as well as the fledgling scientist and to make complex theories accessible.

Structure

"Chaos: Making a New Science" by James Gleick is a work of non-fiction. It contains a prologue, 11 chapters, notes, acknowledgments, and an index.

The shortest chapter is 17 pages in length; the longest chapter is 34 pages in length. The average length of the chapters is pages. The prologue is pages in length; the epilogue is pages in length.

Each chapter is described in the table of contents with specific topics addressed although there are no specific subheads in the text. The work is generally chronological in nature.

Chapter 1: The Butterfly Effect: Edward Lorenz and his toy weather. The computer misbehaves. Long-range forecasting is doomed. Order masquerading as randomness. A world of nonlinearity. "We completely missed the point."

Chapter 2: Revolution: A Revolution in seeing; Pendulum clocks, space balls, and playground swings; The invention of the horseshoe; A mystery solved: Jupiter's Great Red Spot.

Chapter 3: Life's Ups and Downs: Modeling wildlife populations. Nonlinear science, "the study of elephant animals." Pitchfork bifurcations and a ride on the Spree. A movie of chaos and a messianic appeal.

Chapter 4: A Geometry of Nature: A discovery about cotton prices; a refugee from Bourbaki; Transmission errors and jagged shores; New dimensions; The monsters of fractal geometry; Quakes in the schizosphere. From clouds to blood vessels; The trash cans of science; "To see the world in a grain of sand."

Chapter 5: Strange Attractors: A problem for God; Transitions in the laboratory; Rotating cylinders and a turning point; David Ruelle's idea for turbulence; Loops in phase space; Mille-feuilles and sausage; An astronomer's mapping; "Fireworks or galaxies."

Chapter 6: Universality: A new start at Loa Alamos; The renormalization group; Decoding color; The rise of numerical experimentation; Mitchel Felgenbaum's breakthrough; A universal theory; The rejection letters; Meeting in Como; Clouds and paintings.

Chapter 7: The Experimenter: Helium in a Small Box. "Insolid billowing of the solid"; Plow and form in nature; Albert Libchaber's delicate triumph; Experiment joins theory; From one dimension to many.

Chapter 8: Images of Chaos: The complex plane; Surprise in Newton's method; The Mandelbrot set: sprouts and tendrils; Art and commerce meet science; Fractal basin boundaries; The chaos game.

Chapter 9: The Dynamical Systems Collective: Santa Cruz and the sixties; The analog computer; Was this science?; "A long-range vision"; Measuring unpredictability; Information theory; From microscale to macroscale; The dripping faucet; Audiovisual aids; An era ends.

Chapter 10: Inner Rhythms: A misunderstanding about models; The complex body; The dynamical heart; Resetting the biological clock; Fatal arrhythmia; Chick embryos and abnormal beats; Chaos as health.

Chapter 11: Chaos and Beyond: New beliefs, new definitions; The Second Law, the snowflake puzzle, and loaded dice; Opportunity and necessity.

Quotes

"Physicists like to think that all you have to do is say, these are the conditions, now what happens next?" (Richard Feynman, Chap. 1, p. 9).

"Of course, the entire effort is to put oneself outside the ordinary range of what are called statistics." (Stephen Spender, Chap. 2, p. 33).

"The result of a mathematical development should be continuously checked against one's own intuition about what constitutes reasonable biological behavior." (Harvey J. Gold, Chap. 3, p. 57).

"And yet relation appears, a small relation expanding like the shade of a cloud on sand, a shape on the side of the hill." (Wallace Stevens, Chap. 4, p. 81).

"Big whorls have little whorls which feed on their velocity, and little whorls have lesser whorls and so on to viscosity." (Lewis F. Richardson, Chap. 5, p. 119).

"The iterating of these lines brings gold; the framing of this circle on the ground brings whirlwinds, tempests, thunder and lightning." (Dr. Faustus, Chap. 6, p. 155).

"It's an experience like no other experience I can describe, the best thing that can happen to a scientist, realizing that something that's happened in his or her mind exactly corresponds to something that happens in nature." (Leo Kadanoff, Chap. 7, p. 189).

"What else, when chaos draws all forced inward to shape a single leaf." (Conrad Aiken, Chap. 8, p. 213).

"Communication across the revolutionary divide is inevitably partial." (Chap. 9, p. 241).

"The sciences do not try to explain, they hardly even try to interpret, they mainly make models." (John Von Neumann, Chap. 10, p. 273).

"The justification of such a mathematical construct is solely and precisely that it is expected to work." (John Von Neumann, Chap. 10, p. 273).

"People have made these weird numerology observations, but the mechanisms are not very easy to understand." (Chap. 11, p. 291).

Topics for Discussion

Explain the history of the Butterfly Effect. How was it discovered by Edward Lorenz? What is the Butterfly Effect? Why was its discovery important to the up and coming science of weather forecasting? How is weather forecasting different today than it was in the 1960s.

Gleick often refers to the work of Galileo and Newton. How were the theories of these two famous scientists used in the search for chaos? What contributions did each make that helped modern day scientists?

Why do you think Mandelbrot was shunned by his colleagues as well as the science community in general? Why were mathematicians and scientists ready to accept Mandelbrot's fractal concept while still denying him the credit due?

Discuss the basic concept of chaos and how it was recorded in the natural world. Why was it important to understand its presence?

Explain how the use of the computer revolutionized the scientific world and its quest to define chaos.

Explain the presence of chaos in the body. How does it affect the heart? Why was chaos considered when reviewing the psychological instabilities of schizophrenics? What else can be learned about the human body by applying the principles outlined by Gleick?

Discuss the formation and work of the Dynamic Systems Collective. Where, how, and why was it formed? Who was a part of it? What work was performed? What discoveries were made by its members? Why did it fall apart?