Chaos and Butterflies

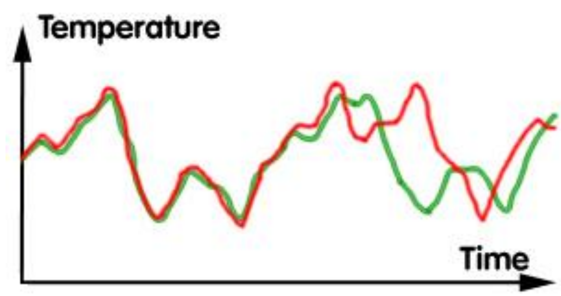
I'm going by quoting James Gleick who inspired me to overcome my laziness and write something. *In Chaos: Making of a New Science*, he writes:

> "Theoretical physics has strayed far from human intuition about the world. Whether this will prove to be fruitful heresy or just plain heresy, no one knows."

Today, theoretical physics has reached a point approaching exhaustion. We have discovered the great laws governing nature like Newtonian mechanics, Quantum Mechanics, Special Relativity, General Relativity and so on. We now can predict the outcome of experiments with extreme accuracy because we know all the basic particles - quarks, gluons etc. – and how they interact. So with the experimental data available till now, we have sufficient theories to explain the laws of nature.

One may assume that with the knowledge of all the laws and how everything interacts, we can then model the laws into equations and start to predict. All we require, thus, is infinite computational power to predict how any natural system would work or evolve in time. We can, for instance, with this knowledge predict how the weather would change for months. We just need brute force to make enormous calculations.

So we gather up some supercomputers and start simulating a very simplified and idealized weather. We program all the equations of pressure change, wind flow, Eddie currents etc. This then begins to provide us with simulations. But when we try to simulate it again with the same initial conditions it gives us a totally different output:



HOW TWO WEATHER PATTERNS DIVERGE

From nearly the same starting point, rounded to fewer significant figures, Edward Lorenz saw his computer produce patterns that grew further and further apart until all resemblence disappeared. (From Lorenz's 1961 printouts).

Aha! I know what you are thinking - there must be some sort of glitch in the program. However, this is in fact popularly known as the **'Butterfly Effect'**: A small flutter from a butterfly here could cause a tornado in another part of the world**.** The idea of the butterfly's flutter is ascribed to Lorentz who, in a December 1972 meeting of the American Association for the Advancement of Science in Washington D.C., asked: *Does the Flap of a Butterfly's Wings in Brazil set off a Tornado in Texas?*

So now I try to explain this whole phenomenon. The way this is carried out is by taking approximate measurements: if, for instance, an astronomer has to predict the trajectory of the meteor, he would tend to neglect the gravitational pull of a far off star because it introduces only a very small error - the error would stay small for millions of year and with this assumption the astronomer would essentially calculate the right answer. Thus, a tiny error in fixing the positions will cause a tiny error in predicting the trajectory. The philosophy of science, according to Gleick, as we study it is:

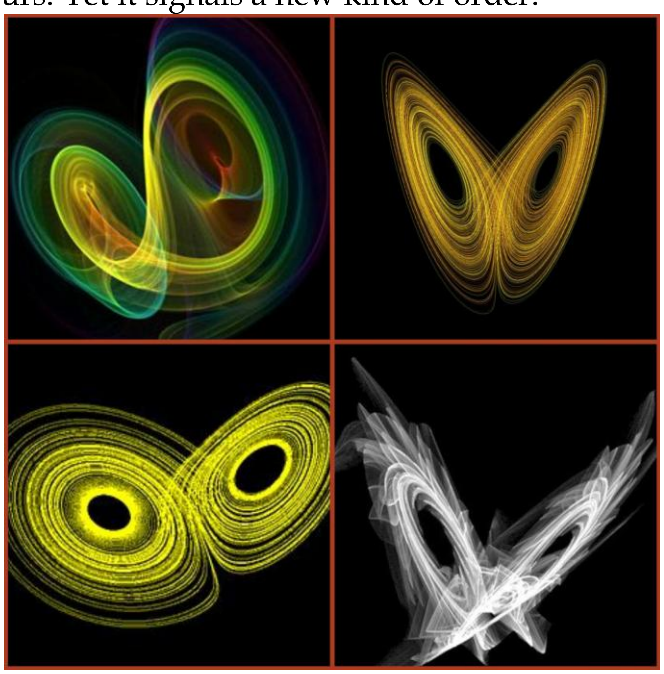
> "Very small influences can be neglected. There's a convergence in the way things work, and arbitrarily small influences don't blow up to have arbitrarily large effects"

Simply put, approximately accurate input gives approximately accurate output. But here's the catch: in non linear-dynamical systems like the weather and most other things a very small change completely changes the output. A simple example of such a system is friction: without friction, we have a simple linear equation. The more force I exert the more acceleration the object will obtain. But in actuality, friction depends on speed. Speed, in turn, depends on the friction. This twisted changeability makes nonlinearity hard to calculate. Most of the systems around us, which look really simple, are non linear and this is in essence the issue. I like to think of this as the act of playing the game changing the rules itself.

Hence, what happens in such systems is that a small error cascades up towards the system and changes the outcome leading to complete disorder, noise and chaos much like the butterfly. This is known as “Chaos Theory” and it blows the concepts of Newtonian determinism. Simple systems like a convection current in water, the flow of a liquid, the cooling of a tea cup, the movement of a water wheel, even cloud patterns - all are totally unpredictable and chaotic thanks to Chaos theory. One can further make sense if one considers that as the universe expands, entropy increases leading to greater disorder. The question however is: how then is there so much order in the world around us?

What you have read till now is just bad news. I’ve been trying to tell you that there is too much disorder, everything just goes into randomness and becomes noise. Now, here you may think I am going crazy but aha! - There is order in this disorder. This is where Lorentz comes in. Lorentz saw patterns in random noise and provided us with Lorenz’s systems – essentially, a plot of non linear or chaotic systems. In other words, Lorentz saw order masquerading as randomness.

Normally, a simple system would have a path that leads to one place and stops (the system is settling to a steady state) or it may form a loop (the system is settling into a pattern of behavior that repeats itself periodically). But Lorentz’ system does neither. Instead, it displays a kind of infinite complexity. It always stays within certain bound but never repeats and traces a strange distinctive shape like a butterfly. The shape signals pure disorder, since no point or pattern of points ever recurs. Yet it signals a new kind of order.



Chaos Theory lies at the heart of everything from fluid dynamics to population growths, from noise in circuits to weather forecasts. Using current laws we can predict exactly what particles, dark matter, will result if we collide two particles in a particle accelerator but not what the temperature of my teacup in the next minute because of the complexity and disorder involved. However, with Chaos Theory, we can find patterns in the randomness and noise and solve what seem like the simplest of problems but are exceedingly complicated. Chaos Theory could be the way out, the intuition which has gone missing from theoretical physics of late. In other words, it could bring Theoretical Physics back from particle accelerators to simple toys.

To know more, refer to James Gleick's *In Chaos: Making of a New Science*. If, however, you wish to see the bungled applications of Chaos Theory, you could instead watch "The Butterfly Effect": a fictitious take of how this effect plays a role in time travel.

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