

If you can't predict the weather, how can you predict the climate?

A laboratory experiment from the Little Shop of Physics at Colorado State University



Overview

This is a very good question. Here's the one word answer: Chaos.

Theory

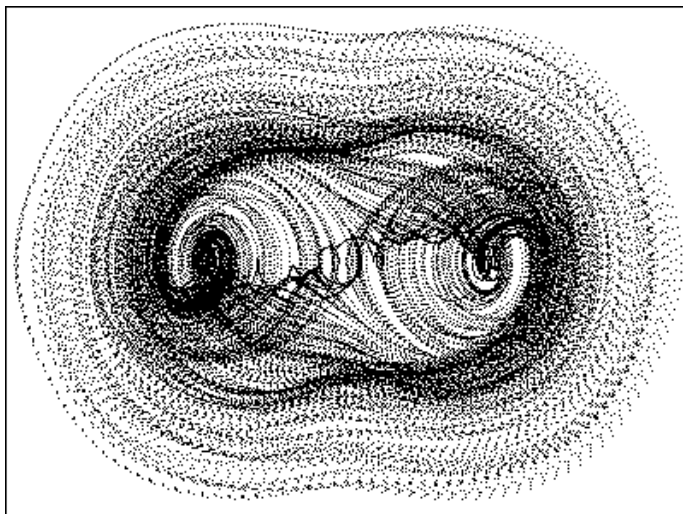
Contrary to popular usage, “chaos” doesn't mean randomness. Systems—like the atmosphere—that are chaotic are unpredictable in some ways but follow certain well-defined patterns. This is the essence of chaos, and rather than trying to explain this seeming contradiction, it's easier to just explore a system that seems like it should be quite regular but is actually chaotic.

Doing the Experiment

We are going to compute successive values of an iterative equation—one in which you use one value to compute the next value. Here's the equation we use:

$$x_{n+1} = (1 - x_n)(x_n)\lambda$$

λ is a parameter that can be varied. We are going to use 3.87 here. We are going to compute successive values with a calculator. To simplify, we have a recipe that tells how to compute these values:



This is a graph of the velocity (vertical axis) vs. the position (horizontal axis) of a pendulum undergoing chaotic motion.

Necessary materials:

- Calculator

You can also do this exercise with a computer running a spreadsheet.

1) Pick a value for the parameter for the equation.

1) Take your starting value. We'll call this x_1 . Press STO on the calculator to put it into memory.

2) Now, we need to compute the next value, x_2 . Press the following keys:

- 1-RCL= (compute $1-x_n$)
- \times RCL= (multiply by x_n)
- $\times 3.87$ = (multiply by 3.87)
- STO (put the result in memory for the next round)

3) Record the value and do Step 2 again.

And just keep doing Steps 2 and 3.

The big question is this: What do the results mean? Here are two trends to notice:

- Each value seems random, but there are trends. In particular, notice the “high, low, medium” sets of values. You’ll often—but not always—see this type of trend.
- Small changes in this initial value don’t make much difference in the initial rounds, but make a big difference later. That’s “sensitivity to initial conditions,” one of the hallmarks of chaos.

The values are quite unpredictable on a short scale, but there are some very clear trends that are quite stable. Weather and climate!

Summing Up

This simple experiment does have a lot to tell us about chaos and, ultimately, the difference between weather and climate.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: <http://cmmmap.colostate.edu>

Little Shop of Physics: <http://littleshop.physics.colostate.edu>