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.

Necessary materials:

- Calculator

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

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:

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

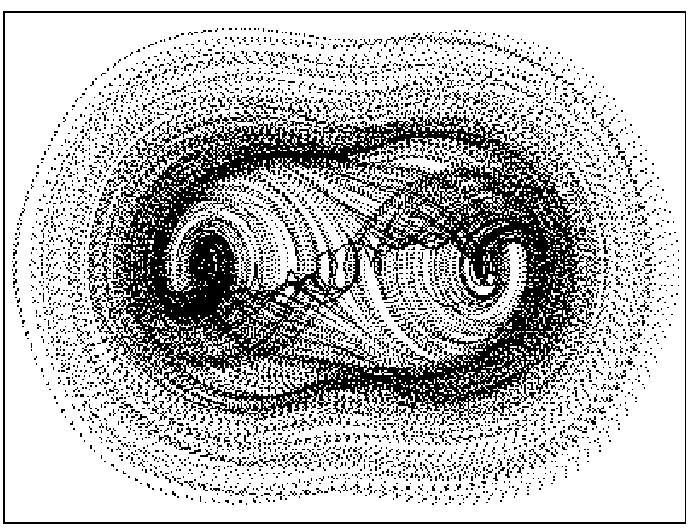
1) Take your starting value. We'll call this x_1. Press STO on the calculator to put it into memory.

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

- 1-RCL= (compute 1-x_n)
- ×RCL= (multiply by x_n)
- ×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.



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

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://cmmap.colostate.edu

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

Reducing Your Carbon Footprint

Each year, every person in the United States adds about 40,000 pounds of carbon dioxide to the atmosphere.

Suppose you wish to reduce your carbon footprint by 10%—you need to make changes to eliminate 4,000 pounds of carbon dioxide.

What changes do you make?

The following activities or products each contribute about 1 pound of carbon dioxide to the atmosphere. So, think: What changes would you make?

One pound of carbon dioxide corresponds to:

Electricity: One pound of carbon dioxide corresponds to approximately 1 kW-hr of electricity, enough for:

- 100 hours of laptop use (low power MacBook air)
- 10 hours of TV use (HDTV)
- 15 minutes of electric clothes dryer use

Travel: One pound of carbon dioxide will get you:

- 1 mile on an airplane
- 2 miles in a car

Heating and cooling: One pound of carbon dioxide buys you:

- 15 minutes of air conditioning
- 6 minutes of heating with a gas forced air furnace
- 2 minutes of a hot shower

Food and beverages: It takes one pound of carbon dioxide to produce and deliver to you:

- 1/2 oz. of beef
- 1 pound of dry beans
- 1 pint of milk
- 1 bottle of Fat Tire

Consumer goods: Producing and delivering clothing and other goods costs energy, which means carbon in the atmosphere. One pound of carbon dioxide gets you:

- 1/100 of a pair of boots
- 1/50 of a lightweight jacket or shirt
- 1/25 of a pair of flip-flops

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- 100 local apples or 10 domestic apples or 1 imported apple

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