Final Project: Exploring the Galaxy

The Fermi Paradox and Von Neumann machines

Background

Do advanced civilizations exist elsewhere in our Galaxy? Enrico Fermi, better known for his work on nuclear physics, didn't think so. He reasoned that, given the age of the galaxy, any civilization whose technology is sufficiently advanced to be capable of building and launching space probes could explore the entire galaxy within only a few million years. This is a very short timescale compared to the age of the Galaxy (~10 billion years), which prompted Fermi to ask the question: if there are advanced civilizations out there, why haven't they dropped by yet? (Of course, there are some who believe they did, sometime in the past, and far too many others who think they are here now!)

Our Galaxy is about 100,000 light years across, so a probe traveling at an easily achievable 5% of the speed of light could cross the entire galaxy in only 2 million years. It would take a lot longer for a single probe to visit all 2 hundred billion stars, however. And the time required for interstellar travel is still discouragingly long for species like us, with relatively short lifespans (we'll stick to hard reality and forget about warp drives, hyperspace jumps and the like). To get around such problems, the mathematician and computer pioneer John von Neumann invented the idea of intelligent self-replicating robot probes. A mother probe would be sent out and, upon reaching its destination, would use local resources to construct several copies of itself. The daughter probes would then be sent out and repeat the process. The number of probes grows exponentially and it can be calculated that every star in the galaxy could be visited in just a few million years.

The aim of this project is to simulate the exploration of the galaxy by robotic space probes. However, to make things easier we'll assume to start with that our hypothetical advanced civilization doesn't have the technology to build intelligent, self-replicating probes and has to make do with dumb non-replicating probes.

The program

Design, write and test a PYTHON function to compute and plot the paths taken by a series of robotic space probes sent out by a hypothetical advanced civilization located at the centre of the Galaxy. The number of probes in the series, N_{probes}, and the number of steps taken by each probe (N_{steps}) should be given as input parameters. To make the simulation manageable, you can represent the Galaxy as a two-dimensional grid of equally-spaced stars. Each 'star' represents a solar system to be visited. The advanced civilization is located at the origin of the grid ($x = 0$, $y = 0$). To begin with, restrict the grid size to 101 × 101 units. (Using an odd number of grid points in each dimension allows you to locate your civilization at the exact center.)

The space probes leave the home planet and visits adjacent stars by means of a 2-dimensional random walk in *x* and *y*. That is, when a probe leaves a given star its next target is selected randomly from the 4 possible directions, with equal probabilities.

Your program should

- Compute the absolute total distance traveled by each probe (i.e., the distance *r* it ends up from the origin)
- Compute the average absolute distance and the root mean square distance traveled by a series of probes (N_{probes}).
- Include an option for plotting the actual path of a selected probe (for example, every 10^{th} probe)
- Keep a record of how many 'visits' each star has received and create a contour map or wire-grid plot of the number of visits when the probe series is complete.
- Each probe should send a 'signal' back to the home planet if it reaches the edge of the galaxy (i.e., print out a message with the current co-ordinates and total number of steps taken when it reaches the edge of the grid).

Programming issue: You will need to record the *x* and *y* co-ordinates of the probe in order to plot its path. To record the number of visits, you will need to represent the galaxy as a 2-D array, each array element representing a star. Also, consider what happens if a probe reaches the edge of the grid. Will you allow it to leave the galaxy or turn it back?

Investigation

There are many different experiments you can try. Here are some suggestions.

First, just try running the simulation for a single probe but adjusting N_{steps}. Next, run the simulation for say a series of 100 probes and determine how many steps are needed on average, for the probe to reach the edge of the galaxy. Try different combinations of N_{steps} and N_{probes}. What is the most effective strategy for exploring the galaxy?

Exploration would be more efficient if the probes were smarter about choosing their next target. Modify the program to prevent any probe returning to the last star it visited. Does this significantly reduce the resources (i.e. N_{probes} and N_{steps}) needed to explore the Galaxy?

Space exploration is a risky business, particularly when it comes to landing on planets, as the fate of some recent spacecraft sent to Mars has shown. Suppose that there is a finite chance that any given probe will fail at any particular step. Modify the program to include a failure probability (try different values around 1%). What affect does this have on your Galaxy exploration endeavor?

Can you model the Galaxy in a more realistic way? Here are some ideas.

- The civilization is not located at the center but at some arbitrary point (e.g., about 1/3 of the distance from the center to the edge, like us).
- "Stars" do not occupy every point in the grid, but are distributed at random.

- The Galaxy is not, of course, square. Model it instead as a disk (you may, however, want to retain the rectangular grid and impose the Galaxy "disk" on that).

Optional and very challenging. Modify your program to include self-replicating probes. Instead of sending out a series of 'dumb' probes, our advanced civilization dispatches a single self-replicating probe. Whenever the probe arrives at a star, there is a small probability (this should be an adjustable parameter) that circumstances (i.e., environment and local resources) are right for replication. If conditions are favorable, the probe makes two copies of itself, also self-replicating, which then continue the exploration (the original probe dismantles itself in the replication process). If conditions are not favorable, the probe continues to the next star. This is a complex programming problem because you will have to keep track of an ever-increasing fleet of probes. However, a successful attempt will earn extra credit.

Resources

http://www.seds.org/messier/more/mw.html (some background on the Galaxy)

http://casswww.ucsd.edu/archive/public/tutorial/MW.html (…and another page with some useful illustrations)

http://mathworld.wolfram.com/topics/RandomWalks.html (all about random walks)

http://abyss.uoregon.edu/~js/cosmo/lectures/lec28.html (a concise overview of the issues surrounding the Fermi paradox)

http://www.geoffreylandis.com/percolation.htp (the Fermi Paradox as a problem in percolation theory)

http://mkaku.org/home/?page_id=246 (thoughts on the Physics of extraterrestrial civilizations by a well-known "TV Physicist")

http://www.seti.org/ (web site of the SETI program.)