Astronomical Simulation

Imagine trying to build a bomb by analyzing only the shrapnel. Cosmologists (who study the history, structure, and dynamics of the universe) are attempting this – but on a much larger scale. Recent advances in computer science are making this possible.

The History of Supercomputing

In the early 1960's, a research group led by Seymour Cray built a new type of computer: a supercomputer. Their pride, the CDC6600, was almost 400 times faster than the fastest computer at the time. It was able to perform 4.6 million multiplications and divisions (floating point operations, or *flops*) each second.

Seymour Cray

In the late 1980's, researchers built the first supercomputers that harnessed the power of hundreds of smaller specialized computers, called nodes. By processing a problem *in parallel* (breaking a problem up and splitting it between the nodes,) researchers coaxed 10 billion flops (10 gigaflops) out of their machines.

In December of 1996, Intel installed the world's fastest supercomputer at the United States Department of Energy. Networking 9,216 nodes (each an Intel Pentium Pro processor,) the *ASCI Option Red Supercomputer* peaks at a computation rate of 1.8 trillion flops (teraflops.) As a comparison, it would take over 40,000 years for a human to calculate a trillion floating point operations on a manual calculator.

Simulation and Modeling

There are two approaches to fully understand the workings of a system. The first approach alters the system and analyzes the effects of change. The second approach experiments with a model of the system. In Cosmology, we cannot physically reproduce the beginning of the universe – we must work on a model.

When we decide to work on a model of the system, we have another choice: to make a physical model of the system or to work on a mathematical model.

An engineer examines one of the many nodes in the *Option Red Supercomputer*

Since we can't create a physical model of the beginning of the universe, we must create a mathematical model.

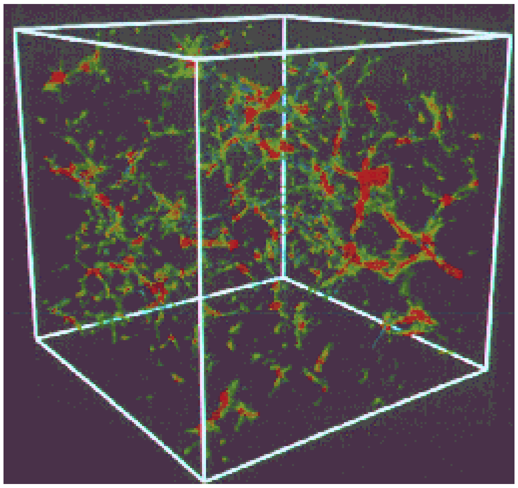
Once we decide on a mathematical model, we have two more choices: either an analytical model or a simulation. An analytical solution works when the model is simple enough to be represented by a set of equations and relationships: for example, the distance traveled by a projectile. In this analytical model, we can precisely calculate the outcome using a few of Newton's laws and equations.

More commonly, though, systems are much too complex to be described by a few simple equations and must be simulated. In a simulation, researchers create a simplified computer model of the system to be analyzed and watch its response to changing conditions.

The Cosmologist's Delight

Cosmologists – the interstellar equivalent of evolutionary scientists – study the history, structure, and dynamics of the universe. Although the "Big Bang" theory is becoming accepted as the most probable explanation of today's universe, each answer seems to raise a dozen more questions.

One question, for example, is the composition of the universe. What mix of stellar gas, ordinary matter, and dark matter makes up our universe?



Computer simulation of the Universe

What is Dark Matter?

In the late 1930's, Jan Oort suggested the presence of "Dark Matter" to explain the seemingly anomalous speed of objects in our galaxy. Although Dark Matter cannot be directly detected, its presence can be inferred – but scientists couldn't prove its existence until almost 40 years later.

In the 1970s, astronomers measured the speed of stars orbiting our galaxy (among others). Kepler's law states that that the speed of an orbiting body depends only on two things: the distance to the center of the orbit and the total mass contained inside the orbit. Using these laws, astronomers realized that the mass of the universe must be much higher than the mass we detect.

The Simulation

With the increasing power of today's supercomputers, scientists can finally simulate the massively complex mathematical model of the beginning of the universe. In their most recent simulation, scientists have created a model unique not only in size but in scale.

Partly funded by the National Science Foundation's "Computational Grand Challenge," Cosmologists simulated a mammoth model of the universe that spans 500 million light years on each side. In perspective, a light year is the distance that light travels in a year: 9,461,000,000,000 km.

The simulation begins approximately 300,000 years after the big bang (when the universe expanded and cooled enough to start forming atoms) and lasts 15 billion imaginary years. To model the universe, they use a technique called "N-Body Simulation."

Using Newton's law of gravity and plenty of raw computing power, scientists predict the interaction of hundreds of millions of individual stars each second. Given the right mix of matter, dark matter, and other variables, the simulated universe should condense to structures similar to the universe as it stands today.

Because the simulation contains hundreds of millions (compared to the trillions of stars in the real universe), it is fairly accurate on a large scale.

Unfortunately, scientists have yet to discover the right mix. In current models, the universe condenses either much too quickly, or much too slowly.

Scientists affectionately call this search for the right parameters "tinkering with the universe." When they finally simulate the proper mix of matter, black matter, and elementary particles, though, astrologists will be quite a bit closer to understanding the birth of the universe.