Computing in the Language of Science

Computer programs are too difficult to read and to modify, says physicist Kenneth Wilson, who is devising a better way

A group of physicists, computer scientists, and computer services personnel at Cornell University has initiated an ambitious project aimed at allowing researchers to use the language of science when they write computer programs. Their ultimate goal, says Cornell computer scientist Alan Demers, is to design a system so facile that users should never have to look at FORTRAN at all. Although they are only in the early stages of designing this system, the Cornell investigators find that already they have examples of a way to make FORTRAN programs far more understandable than they are now.

The project, called GIBBS, was conceived by Kenneth Wilson, an elementary particle physicist who does extensive computer calculations in the course of his research. For years, Wilson has been increasingly concerned by the standard computer programming language for scientists, FORTRAN. "What's wrong with FORTRAN is that you can't read it. It's not a language of communication between people. The logical ideas are totally scrambled and to read a program you typically have to leaf back and forth among 60 pages," he says. For example, a programmer might write statements that tell the computer to add a string of numbers. If that were all the program were to do, the instructions would be to read in the numbers to be summed, add them up, and print the result. But, says Wilson, as the program gets more and more complex, that sequence no longer appears all in one place. The programmer will tell the computer to read in data for a whole series of calculations. Elsewhere in the program, the computer will be told various initial values. In still other places, it will do the calculations. "You are always dealing with that organization—not what you want to *explain* next but what the computer should *do* next," Wilson remarks.

Because FORTRAN programs are hard, if not impossible, to follow, they also are difficult to modify and scientists frequently question their validity. Says Demers, "Scientists will write a large simulation program and assert that it performs certain computations. Nobody is going to read the program because it is very complicated and difficult to read such a program, much less check it for errors. It leads you to be skeptical of its results."

Computer scientists have developed other ways of programming, called "structured" or "top-down" programming, that, they claim, alleviate some of these difficulties with FORTRAN. But, says Wilson, he and others have resisted. "Scientists have already learned to express themselves in two very different languages. The first is scientific language, which is a combination of English, or whatever their native language may be, and technical jargon. The second language is FORTRAN. Now the computer scientists say, 'You've got to learn a third language.' That's not so easy. It's like saying that suddenly you have to learn French." Moreover, he asserts, the newer computer languages still do not really solve the problem of making scientific programs readable and modifiable. "What scientists and engineers want deep down is to do everything in their natural language. Their reaction against learning the newer computer languages is much more negative than it would be if it were just a reaction against adapting existing codes. Their reaction is driven by an unconscious need to go back to the language of science.'

Chapter 1: Mathematics Overview

Perform:

Linear: $\sum_n x_n$

Quadratic: $\sum_n x_n^2$

Cubic: $\sum_n x_n^3$

Index to subsidiary chapters:

2. Formulae for variables
3. Range of subscripts
5. Presentation

Chapter 2: Formulae for variables

Define:

$x_n = n^2 + 3n + 4$

Index to subsidiary chapters:

3. Range of subscripts
4. Optimization

Chapter 3: Range of subscripts

Convention:

n runs from 1 to 23

Chapter 4: Optimization

Replace:

$n^2 + 3n + 4$ by $4 + n(3+n)$

Chapter 5: Presentation

Print:

'Linear' result to 5 decimal places
'Quadratic' result to 5 significant figures
'Cubic' result to 5 significant figures

A simple GIBBS program

When Kenneth Wilson showed the computer scientists this example, they suddenly understood the power of GIBBS programs.

About 1 year ago, Wilson decided to do something about this programming problem and got together with Cornell computer scientists Demers and David Gries. He found, however, that it was not so easy to bring these computer scientists to share his view of the difficulties with FORTRAN. "It took us several months before we could *really* talk to each other about what the problem was," he remarks. "At first we were mostly talking at cross-purposes. The breakthrough came when we agreed to write a research proposal and I had to write an example."

After seeing the possibilities of this new way of writing programs, the computer scientists were won over—and astonished by the way the rewritten programs would look. "The computer scientists never recognized how profound the difference is between the way you present science and the way you present computer programs," Wilson says.

In the initial stage of the GIBBS project, the scientists were encouraged to rewrite programs the way a scientist would write a textbook. Their instructions were to start with a few key concepts or equations, then refine or transform these equations by adding successive levels of computations and record each change in a separate "chapter."

Demers describes the process of developing GIBBS programs as akin to what goes on when a physicist tries to describe an algorithm to his colleague. "A lot of dialogue goes on with remarks like, 'Oh, you're going to sum over this index, then iterate over these dimensions.' " Eventually, says Demers, the Cornell group wants the computer to interact with the scientist in the same way as the physicist colleague interacts. But for now, they are going through this interactive process on paper, leaving a record of the dialogue with the imagined computer system. What they end up with, says Demers, is a document that is a far better description of the computations than ever existed before.

Demers says he was skeptical when Wilson first proposed writing and documenting a FORTRAN program in this way. But now, he realizes, Wilson "is clearly right." Others agree. R. Miles Waugh, the manager of computer applications at Philip Morris plans to send a group to Cornell to learn to write programs in this new way. The GIBBS method, Waugh remarks, provides, "a rapid translation of scientific knowledge into computerese. It interprets the scientist's need the first time through." The project itself, he says, "is a fifth-generation kind of thing."

Wilson himself is anxious for others to try similar projects. "One of the things that is needed is more GIBBS-type collaborations" he says. "This is as hard as building an operating system. I make no promises that the GIBBS project by itself will solve the computer language problem, but to have more chance of success we need more projects in competition with it."—GINA KOLATA

Ice Cap of 30 Million Years Ago Detected

The oxygen isotopes of marine sediments are providing strong indirect evidence of an Antarctic ice cap twice as ancient as the present one

Paleoceanographers are finding strong indications of a major ice sheet that covered Antarctica 30 million years ago, 15 million years earlier than an ice cap had been generally supposed to exist. If it later melted away before the present ice cap formed, as now seems likely, then the icing over of the entire Antarctic continent was not a one-time, irreversible step toward the present global ice age. Significant amounts of early glacial ice would also mean that sea level changes due to the waxing and waning of an ice cap extended farther into the past, affecting such processes as biological evolution, climate, and the accumulation of marine sediments. Some researchers are now unwilling to rule out even older ice caps at times when the globe was much warmer than it is today.

Researchers have been endeavoring to decipher the geologic history of Antarctic ice under some severe limitations. The present ice has not left geologists working on the continent much to look at. What little rock that is left exposed does contain hints of ice older than 15 million years. This early ice seems to have been massive enough to cover volcanoes now standing well above the present ice and to override the Transantarctic Mountains and shape the presently ice-free Dry Valleys (*Science*, 28 May 1982, p. 973). That convinced some geologists, but not many paleoceanographers, that substantial ice existed sometime before the traditional date for ice-cap formation. The latter had already set 15 million years as the earliest time of significant ice during the past 250 million years.

Paleoceanographers have worked under their own limitations, ones that are beginning to be circumvented. Their main tool has been the oxygen isotope composition of the carbonate skeletons of microorganisms, called forams, preserved in deep-sea sediments. The lighter of the two stable isotopes, oxygen-16, tends to accumulate preferentially in glacial ice. When ice enriched with oxygen-16 forms on Antarctica, the heavier isotope, oxygen-18, tends to be left behind in the ocean where it increases in abundance relative to the lighter isotope. Forams record the relative proportions of each isotope in seawater when they form their carbonate skeletons. The more ice on the land, the heavier the carbonate isotopes of their skeletons. The problem has been that this effect of ice volume on the oxygen isotope composition of forams adds to the effect of seawater temperature. The chilling of seawater mimics the growth of ice.

> Old and new data are being more assertively interpreted in terms of ice volume changes

On the basis of scanty observations, most paleoceanographers had until now assumed that the variations in oxygen isotope composition before 15 million years ago could be ascribed solely to ocean temperature variations. Three groups of researchers studying foram microfossils at three different sites now have isotopic evidence that temperature changes alone probably could not have caused the observed variations. Kenneth Miller and Richard Fairbanks of Lamont-Doherty Geological Observatory studied foram microfossils at two Deep-Sea Drilling Project sites in the western North Atlantic (*1*). Lloyd Keigwin of Woods Hole Oceanographic Institution and Gerta Keller of the U.S. Geological Survey (USGS) in Menlo Park (*2*) and Miller and Ellen Thomas of Scripps Institution of Oceanography (*3*) studied separate sites in the equatorial Pacific.

All of these researchers agree that about 29 million years ago the isotopic composition of seawater was so heavy that, if the traditional assumption of an ice-free world were made, deep ocean water would have to have been as cold or colder than it is today. That is just a couple of degrees above 0°C. One calculation would make deep seawater as cold as −0.2°C. The reasonable alternative to ice-cold seawater in a supposedly ice-free world, everyone seems to agree, is seawater that was slightly less frigid and a significant volume of ice, presumably in Antarctica. Estimates of the actual ice volume run from one-third to one-half the present volume of the Antarctic ice cap. That much water removed from the ocean and stored as ice would have lowered sea level about 40 meters. Eighteen thousand years ago, when both Antarctic and Northern Hemisphere ice sheets had reached their maximum size, mean sea level fell to at least 100 meters lower than today.

Now that early ice has a certain measure of respectability, old and new data are being more assertively interpreted in terms of ice volume changes. In 1980, Keigwin pointed out that about 36 million years ago oxygen isotopes in both bottom- and surface-dwelling forams became slightly heavier. They were not so heavy as to require unreasonable bottom