trouble to reach some obscure corner of London'' in order to hear a rock group called ''The Citations.''

Some critics feel that this intense preoccupation with the stuff of citations belies a drive for the corporate dollar, of which Garfield has quite a few at stake. As one reviewer of his *Essays* put it, ''Garfield promotes his products; Garfield announces his plans for editorial change; Garfield evaluates his products for the information community; Garfield introduces his associates and vouches for their character and integrity; Garfield acknowledges the adulation his publications have received among users. Garfield's gross is his intense preoccupation with his corporate welfare. It is never so labeled, but no label is needed.''

But it is, after all, Garfield's corporate self-interest, coupled with his subtle insights into the information needs of the scientific community, that has put such revolutionary tools into the hands of scientists around the globe. And, as *Science* found in Philadelphia, the craving for corporate growth has not been at the expense of a certain style. The company's fleet of chauffeur-driven cars, for example, includes a Cadillac, a Lincoln, a Jaguar, and, until 2 years ago, at which point Garfield gave it to his son, a Checker.

—WILLIAM J. BROAD

Erratum: In the report ''Children absorb tris-BP flame retardant from sleepwear: urine contains the mutagenic metabolite, 2-3-dibromopropanol'' by A. Blum *et al.* (15 September 1978, p. 1020), the unit of measure for dibromopropanol in Table 1, column 3, should have been nanograms, rather than milligrams, per milliliter. In reference 28, sentence 2, the word ''sells'' should have been ''formerly sold.'' We apologize for this error to Apex Chemical Company, Inc., which discontinued sale of Fyrol flame retardant, for use in children's sleepwear.

RESEARCH NEWS

Computer Science: Surprisingly Fast Algorithms

Mathematicians have traditionally been more concerned with showing that solutions to problems exist than with determining what the solutions are. The advent of the computer changed this situation by making it possible to at least think about computing solutions to complex problems. But it has become increasingly clear that there is a big difference between a solution that can be computed in theory and one that can be computed in practice. Often the straightforward way of solving a problem involves so many operations that, even for moderately sized problems, the solution is effectively noncomputable.

From this concern with finding computable solutions to problems came the idea of developing ''fast'' algorithms that require fewer steps than those currently in use. The payoffs from fast algorithms can be enormous. For example, the development of the fast Fourier transform (FFT) completely changed whole areas of science, such as crystallography, by making possible computations that were previously infeasible. Similarly, entire issues of engineering journals have been devoted to applications of the FFT.

Recently, computer scientists have discovered new fast algorithms for manipulating polynomials and power series. (A polynomial is an expression of the form $a_0 + a_1x + a_2x^2 + a_3x^3 + \ldots + a_nx^n$, where the a's are constants. The integer n is the ''degree'' of the polynomial. A power series is a polynomial extended to include an infinite number of terms.) Since operations on power series are so common, the new algorithms could be of great practical importance.

The new algorithms are also interesting from a mathematical point of view. According to Alan Borodin of the University of Toronto, they are completely nonintuitive and so are ''very, very surprising.'' For example, one result is that any power of a polynomial can be computed as quickly as squaring the polynomial.

Discoveries of these fast algorithms began in 1972, when M. Sieveking of the University of Zurich found a new, rapid way to compute the first N terms of the reciprocal of a power series. Then H. T. Kung of Carnegie-Mellon University noticed that Sieveking's method is actually a well-known procedure called Newton iteration. Shortly after Kung made this observation, John Lipson of the University of Toronto and, independently, Kung and Joseph Traub of Carnegie-Mellon determined that Newton iteration can be applied to solve power series equations, thus leading to a number of fast algorithms.

The idea behind Newton iteration is to approximate the power series solution to a particular equation with a polynomial consisting of the initial terms of the power series that is the actual solution. At each step of the Newton iteration, more terms are added to the polynomial approximation. Traub explains that when Newton iteration is applied to power series equations, the iteration always converges and the number of correct terms at least doubles at each step.

Using Newton iteration, Kung showed that the first N terms of the reciprocal of a power series can be computed as quickly as multiplying two Nth degree polynomials. The fastest known method for polynomial multiplication is the FFT, which requires $N \log N$ operations.

Dividing a power series by a power series can be thought of as a multiplication problem in which one power series is multiplied by the reciprocal of another. When division is represented in this way, Kung's result about reciprocals leads to the conclusion that the first N terms of the quotient of two power series can be computed in no more than $N \log N$ steps. Thus division is no harder than multiplication.

Kung and Traub recently generalized the result about power series to apply to all algebraic functions, including such complicated functions as the reciprocal of a power series. These algebraic functions, which arise in many areas of mathematics, are the solutions of polynomial equations in which the coefficients of the variables are themselves polynomials. The textbook method of computing algebraic functions is by comparison of coefficients—a method that can be extremely slow. For example, if the algebraic function satisfies a polynomial of degree n, computation of the first N terms of the polynomial by comparison of coefficients requires as many as N^n operations. With new algorithms, the first N terms of any algebraic function can be computed with the same number of operations that are needed to multiply two Nth degree polynomials, or $N \log N$. They established this result by showing that the first N terms of any ''regular'' algebraic function can be computed rapidly by iteration. (A regular function is of a certain form that makes the calculation of its coefficients straightforward.) Then they showed that any algebraic function can easily be converted to a regular function.

Still another application of this new approach to manipulating power series is

0036-8075/78/1124-0857$00.50/0 Copyright © 1978 AAAS

the discovery, by Richard Brent of the Australian National University, that the computation of the first N terms of any power of a power series is no harder than squaring the power series. To obtain this result, Brent changed the representation of the power series by taking its logarithm. He then solved the problem in its new form and changed back to the original representation by taking the exponential. Brent showed that these changes of representation can be computed with relatively few operations. The first N terms of both the logarithms and the exponential can be computed with no more steps than are needed to multiply two Nth degree polynomials.

The most recent, and to some mathematicians the most surprising, result on manipulating power series involves the speed of self-composition. Composition is a complicated operation that involves taking the power series of a power series—that is, letting one power series serve as the variable, x, that is raised to powers in the other power series. Self-composition is composing a power series with itself. Repeated self-composition is of considerable practical importance, occurring in applications that include difference equations, numerical analysis, and the study of dynamical systems. By changing the representation of self-composition problems, Brent and Traub were able to show that any number of self-compositions can be done as quickly as a single composition.

It is too soon to tell how great an impact these new algorithms will have on day-to-day computer calculations. But the intellectual impact of these algorithms is already apparent. As Borodin explains, previously no one even considered looking for fast algorithms to manipulate power series. It was generally assumed that the naïve way to do these calculations was the only way. The recent results, then, provide encouraging evidence that slow manipulations need not always be accepted.

—Gina Bari Kolata

The 1978 Nobel Prize in Economics

For his contributions to our understanding of decision-making, particularly in organizations, and for numerous other contributions to social science, Herbert A. Simon has been awarded the Nobel Prize in Economics for 1978. It is an appropriate tribute to an exceptional figure in contemporary science. Since I have known Simon as a colleague, collaborator, and friend for 25 years, it is natural for me to be asked to describe his work and its place in social science. But I do it with some hesitation. The canvas is too large for the brush, and not reliably passive. I recall telling a friend once that the only commentary it would be safe to write about Herb Simon would be an epitaph, because that would be the one comment on his work to which Herb would not reply. For once, however, the pleasure of honoring him overcomes a recognition that I do it inadequately.

Herb Simon is an economist, psychologist, political scientist, sociologist, philosopher, computer scientist, and a not-bad tetherball player. The number of disciplines with which he has been associated and the creativeness of even his minor efforts sometimes obscure the intellectual coherence of his major work. Although he has written many things and almost everything has stimulated important work, Simon's major professional life divides into two periods. The first is the period from 1947 to 1958, when he focused on decisions, particularly in organizations, but also wrote extensively on a variety of problems in the modeling of behavior. This is the work that is best known in economics, political science, and sociology. The second period is from 1958 to 1978, when his concerns shifted to human problem-solving and artificial intelligence. This is the work, much of it done in collaboration with Allen Newell, that is best known in psychology and computer science. Although the two audiences tend to be different, the two periods show a common enthusiasm for trying to connect the behavioral study of intentional action and the engineering design of intelligent systems.

Simon's deep concern for the engineering of intelligence is not always explicit, but it is persistent. His interest in organizational decision-making was tied to an interest in improving decision-making through information technology. His interest in understanding human problem-solving was tied to an interest in artificial intelligence. He has sometimes been seen as overly rationalistic by behavioral students of human choice, and as overly behavioral by economists and other enthusiasts for rational models of human action; but both sets of comments are misleading. He studies reason's limitations in the name of reason. Implicit in much of the research is a belief that improvement in the design of intelligence requires an understanding of human behavior. He is an insightful theorist of thinking, deciding, problem-solving, and choosing. But he studies human behavior not simply because of curiosity about how people behave, although he has that, but more because of an interest in, and affinity for, the perfection of intelligence. Like B. F. Skinner, with whom he shares almost nothing else, he is an unrepentant knight of the enlightenment. Not Freud, but Descartes.

It is a sweet fate and a tribute to the power of Simon's intellect that this man, whose most unwavering characteristic is commitment to the intelligence of rational discourse and to the technology of reason, should receive the Nobel Prize for his provocative explications of some of the ways in which human beings and human institutions are often intelligent without being, in the usual sense, rational. Simon's major contributions to the economics of decisions are found in a small number of works published between 1947 and 1958: *Administrative Behavior* (1947), *Models of Man* (1957), and *Organizations* (1958). In those works, and the articles from which they were drawn, he outlined some ways in which economic theories of the firm and other theories of rational choice might be revised. The specifics were important, but the impact of the work was less through the details than through the basic reformulations they reflected.

In company with most economists, Simon began with the assumption that human choice behavior was intendedly rational. That is, he assumed that decision-makers had a set of criteria known to them in advance of their actions, and that they made choices by measuring estimates of the consequences of alternative actions against the criteria. What Simon added was an awareness of the informational and computational limits on rationality within human institutions. Where most theories of rational choice assumed that all relevant alternatives were known, Simon suggested that alternatives had to be discovered through search and that typically only a relatively few alternatives were considered. Where most theories assumed that information on the consequences of alternatives was

0036-8075/78/1124-0858$00.50/0 Copyright © 1978 AAAS