COMPUTER RECREATIONS

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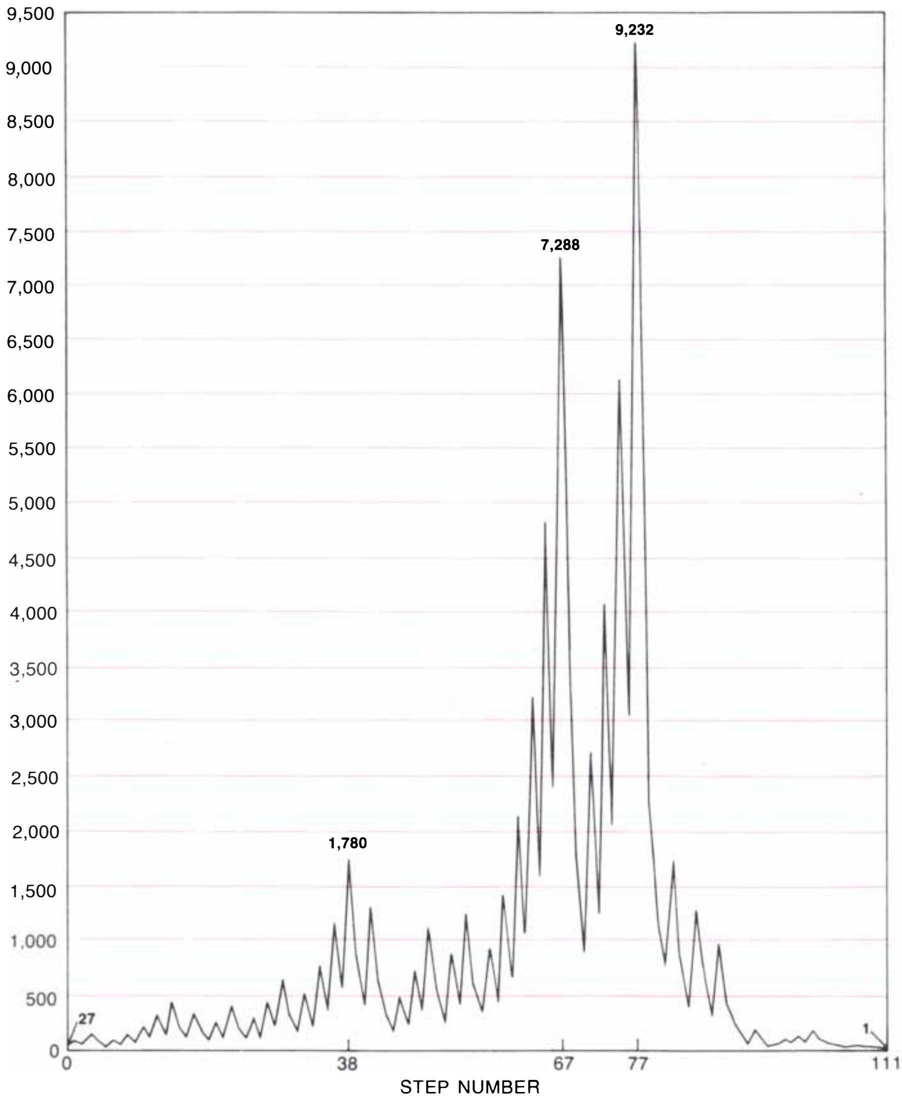
COMPUTER RECREATIONS

On the ups and downs of hailstone numbers

by Brian Hayes

Three steps forward and two steps back: it is not the most efficient way to travel, but it seems certain to get you there in the end. A curious unsolved problem in the theory of numbers puts that conclusion in doubt. The problem can be stated as follows. Choose any positive integer (any whole number greater than zero) and call it N. If the number is odd, triple it and add 1, or in other words replace N by $3N + 1$. If the number is even, divide it by 2, replacing N by $N/2$. In either case the result is the new value of N and the procedure is repeated. After many iterations do the numbers tend to grow larger or smaller? Do they converge on some particular value or diverge toward infinity? How long does it take to settle the "fate" of a number?



The sequence of hailstone numbers beginning with 27

For any given value of N, answering these questions calls for nothing more than simple arithmetic. For example, if N is 27, an odd number, the next value is $(3 \times 27) + 1$, or 82; it is followed by 41 and then by 124. Evidently there will be many ups and downs in this series of numbers; the value goes up whenever N is odd and down whenever it is even. The reader is invited to extend the series to see where it leads.

The difficult task is not evaluating the series for a given N but finding a general solution, one that applies to all possible values of N. As yet no general solution has been devised. A great many numbers have been tested explicitly, and they all follow the same pattern, but no one has been able to prove that every number conforms to the pattern. It is hardly the most important unsolved problem in number theory, but it is one of the most irksome. The procedure is easy to describe and to carry out, but it is remarkably difficult to understand what is going on.

The problem illustrates well both the utility and the limitations of the digital computer as a mathematical instrument. To explore beyond the smallest integers some mechanical aid to computation is needed, but almost any computer will do, even a programmable calculator. On the other hand, extending the calculation to a significantly larger range of numbers is practical only with the most powerful computing machinery. When it comes to the very deepest questions, it is not certain any computer can be of help. For the most part the computer is a tool of "experimental" mathematics: it generates examples and counterexamples. Discovering a principle in the peregrinations of N seems to call for theorem proving rather than number crunching.

When the transformation rule is applied repeatedly to an arbitrary number, what outcome can be expected? Here are three naive hypotheses:

The first argument runs thus: There are equal numbers of odd and even integers, and so in any long series of calculations odd and even values of N should come up equally often. When N is odd, it is increased by a factor of 3 (and a little more), but when N is even, it is decreased by only a factor of 2. Hence the value of N after many iterations should increase without limit. On the average the value should increase by $(3N + 1)/2$ per iteration. For large values of N that is essentially $3/2\ N$.

The second hypothesis relies on the notion that what goes up must come down. This line of reasoning begins with the observation that whenever the calculation happens to yield an exact power of 2, the series of numbers immediately cascades back down to a value of 1. (When any power of 2 except 2 itself is divided by 2, the result is necessarily an even number, so that the descending branch of the calculation is invariably selected.) There are infinitely many exact powers of 2 among the infinite counting numbers, and a calculation that is continued long enough is certain to alight on one of them. Very large values of N might well be reached in the course of a calculation, but eventually there must be a crash.

The third argument is similar in form to the second but leads to a different conclusion. Note that whenever the calculation changes direction, such as when an odd number is encountered after a series of even ones, it reenters territory it has been in before. Indeed, in wandering up and down the number line it can return to a finite domain of numbers arbitrarily often. Eventually it can be expected to stumble onto a value it has visited before, and once that happens the entire future of the calculation is fixed. Because the procedure for choosing a next step is fully deterministic, any duplicated value of N must lead into a loop that will thereafter be repeated endlessly.

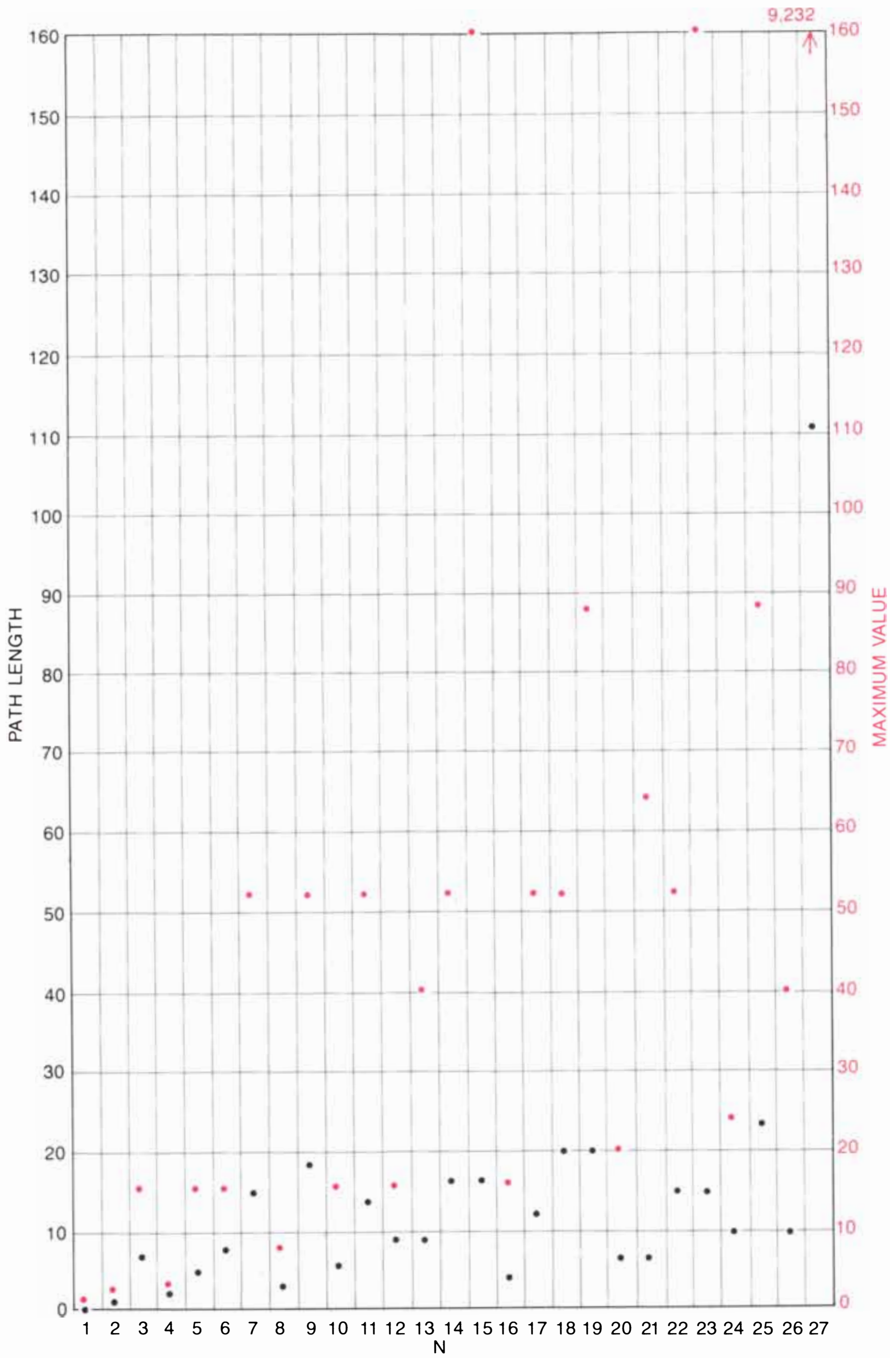
The three hypotheses presented here should not be taken too seriously. They cannot all be right. Some of their premises are definitely open to question. In particular, all three theories rely on a probabilistic analysis, but the series of numbers generated by applying the rule is not a random one. What does mathematical experiment have to say about the matter?

The place to begin the calculation is at the beginning, with 1. It is an odd number, and so the instructions call for multiplying it by 3 and adding 1. The result, 4, is even and is therefore divided by 2, yielding another even number; dividing by 2 again brings the calculation back to 1. Hence with the first computation two of the speculative theories cited above are given handsome support. As the crash hypothesis predicts, the calculation stumbles on a power of 2; it does so after just one iteration. As the cyclical theory predicts, the calculation becomes trapped in an endless loop; the values 4, 2 and 1 will be repeated indefinitely.

Among all the counting numbers 1 is very special: it is the first and the smallest. The results obtained when N is equal to 1 may therefore be atypical; before reaching any conclusions one ought to check further. Since the fate of 2 and 4 are known already from the calculation for $N = 1$, the obvious candidate is 3. It is odd, and so the next value is $(3 \times 3) + 1$, or 10. Dividing by 2 yields 5, and then multiplying by 3 and adding 1 gives a result of 16. Again a power of 2 has turned up, and the series cascades through $N = 8$ into the 4–2–1 loop.

After examining the first four natural numbers the trend seems clear, and yet there is still reason for doubt. In the calculations made so far two quantities of interest stand out: the highest value of N reached during a calculation and the path length, which I shall define as the total number of iterations needed to reach a value of 1. For 1 itself the maximum value is 1 and the path length is zero. For 2 the peak is 2 and the length is 1. For 3 the maximum is 16 and the length is 7. The example of 3 suggests that the maximum value reached and the length of the series can be much larger than the initial value of N, and so perhaps the function will turn out to be unbounded for some values of N.

Consider again the series generated when the initial value is 27. As noted above, the first three numbers are 82, 41 and 124, but two successive divisions bring the series back down to 31. Hence after five steps almost no progress has been made. As the calculation continues, however, the three-steps-forward, two-steps-back mechanism gives rise to a series of oscillations of ever larger amplitude. New peaks are reached at 142, 214, 322 and 484. There are further setbacks (at step 19 the value has dropped to 91), but the trend continues to be upward. The calculation passes through 700, through 1,186 and through 2,158



The path length **(black)** *and the maximum value reached* **(color)** *for the first 27 integers* and by the 77th iteration has reached the substantial value of 9,232. It seems we are on our way. As it turns out, however, the path ends at 1 after a total of 111 steps, never having risen higher than 9,232. (The complete path is shown in the illustration on page 10.)

Calculations of the kind I have just traced have been made for all the integers in an extremely wide range. Nabuo Yoneda of the University of Tokyo has tested all values up to 2^{40}, or 1.2×10^{12}. In every case the result has been the same: after a finite number of steps the series subsides into the 4–2–1 loop, where it must stay forever. Among the first 50 integers 27 has the longest path back to 1 (although 41 and 31 are not much shorter and reach the same peak value, for reasons that should be apparent from the information given above). No positive integer has been found to generate a series that goes off toward infinity, and no loops other than the 4–2–1 loop have been found. Nevertheless, the conjecture that all positive numbers conform to the same pattern remains without a secure theoretical basis.

N	PATH LENGTH	MAXIMUM VALUE
1	0	1
2	1	2
3	7	16
6	8	16
7	16	52
9	19	52
18	20	52
25	23	88
27	111	9,232
54	112	9,232
73	115	9,232
97	118	9,232
129	121	9,232
171	124	9,232
231	127	9,232
313	130	9,232
327	143	9,232
649	144	9,232
703	170	250,504
871	178	190,996
1,161	181	190,996
2,223	182	250,504
2,463	208	250,504
2,919	216	250,504
3,711	237	481,624
6,171	261	975,400
10,971	267	975,400
13,255	275	497,176
17,647	278	11,003,416
23,529	281	11,003,416
26,623	307	106,358,020
34,239	310	18,976,192
35,655	323	41,163,712
52,527	339	106,358,020
77,031	350	21,933,016

Sequence of longest paths up to N = *100,000*

N	PATH LENGTH	MAXIMUM VALUE
1	0	1
2	1	2
3	7	16
7	16	52
15	17	160
27	111	9,232
255	47	13,120
447	97	39,364
639	131	41,524
703	170	250,504
1,819	161	1,276,936
4,255	201	6,810,136
4,591	170	8,153,620
9,663	184	27,114,424
20,895	255	50,143,264
26,623	307	106,358,020
31,911	160	121,012,864
60,975	334	593,279,152
77,671	231	1,570,824,736

Sequence of peak values up to N = *100,000*

The $3N + 1$ problem, as it is generally called, has a murky history, but it does not seem to be of great antiquity. Over the past 30 years or so it has turned up repeatedly in various university departments of mathematics and computer science, its comings and goings seeming to be as capricious as the advances and recessions of the numbers themselves. Jeffrey C. Lagarias of Bell Laboratories, who has recently looked into the origins of the problem and the prospects for solving it, notes that it may have been invented several times. In the 1930's Lothar Collatz, who was then a student at the University of Hamburg, investigated a class of problems that includes the $3N + 1$ problem, although the work was not published until many years later. In 1952 the British mathematician B. Thwaites independently discovered the problem, and a few years later it was invented yet again by Richard Vernon Andree of the University of Oklahoma at Norman.

Lagarias cites some 20 research articles on the $3N + 1$ problem and its generalizations, most of them published within the past 10 years, but the problem had circulated by word of mouth long before. Collatz' colleague Helmut Hasse introduced it at Syracuse University in the 1950's, and Stanislaw Ulam took it to Los Alamos and elsewhere. Shizuo Kakutani, who first heard of the problem in about 1960, reported to Lagarias: "For a month everybody at Yale worked on it, with no result. A similar phenomenon happened when I mentioned it at the University of Chicago. A joke was made that the problem was part of a conspiracy to slow down mathematical research in the U.S."

Another sustained attack on the problem, with an emphasis on computer-aided numerical calculations, was made in the early 1970's by a group in the Artificial Intelligence Laboratory at M.I.T. The problem is recorded as Item 133 in the group's informal (and unpublished) transactions, called HAKMEM, or "hackers' memorandum."

In its wanderings the problem has been known by many names. Calling it the $3N + 1$ problem does not seem entirely satisfactory, in that it gives undue attention to one half of the procedure and slights the other half. Of the various alternatives the one I find most congenial identifies the numbers generated from a given starting value as "hailstone numbers." The path the series follows is rather like the trajectory of a hailstone through a storm cloud, rising in updrafts and then falling under its own weight.

A computer program for calculating hailstone numbers can be written in a few lines of a higher-level programming language such as BASIC. Indeed, the central algorithm can be expressed in a single statement. In BASIC it might be

```
IF N MOD 2 = 0 THEN N = N/2
ELSE N = 3*N + 1 .
```

Here the first operation is one that people (but not computers) are capable of doing without explicit calculation: determining whether N is odd or even. N MOD 2 is a modulus operation, which computes the remainder when N is divided by 2. If the remainder is 0, the THEN part of the statement is executed and N is set equal to $N/2$; otherwise the ELSE part is executed, setting N equal to $3N + 1$.

A program in BASIC serves well enough for generating hailstone numbers from the first few hundred integers, but if more extensive calculations are undertaken, it becomes intolerably slow. The BASIC statement calls for a division (as part of the modulus operation), a comparison and then either a second division or a multiplication and an addition. Division and multiplication are time-consuming operations, particularly in a small computer system. There is much to be gained here by speaking directly to the central processing unit in its own language. All the division and multiplication operations can thereby be eliminated.

The illustration on the opposite page gives a schematic account of such a machine-language program. It is assumed that the value of N is initially in a register designated AX, which also serves as an "accumulator" where arithmetic operations are done. The value at the start of the procedure is the binary representation of the decimal number 27.

The first step is to save a copy of the initial value in another register, here labeled BX. The division operation is avoided by exploiting a property of the binary number system: shifting a binary number to the right one position is equivalent to dividing it by 2, just as shifting a decimal number to the right divides it by 10. In the course of the shift the rightmost digit (the units digit) is preserved in a one-bit storage location called the carry flag. Testing the carry flag determines whether the original number was odd or even, since in binary notation every odd number ends in a 1 and every even number ends in a 0.

If N is even, the calculation is now finished. The value remaining in register AX after shifting to the right one place is the quotient $N/2$. In this case, however, N is odd and further computations are needed. First the original value of N is recovered from register BX. Then, instead of multiplying by 3, the value is added to itself twice; even though this requires two machine instructions instead of one, it is done appreciably faster. The final step is to increment the number in AX by 1. In the instruction set of one microprocessor the entire procedure takes 20 cycles of the computer's clock when N is even and 18 cycles when N is odd. At a clock frequency of roughly five megahertz the program fragment could in principle be executed some 250,000 times per second. (A few more clock cycles could be saved, at some cost in program clarity.) The equivalent algorithm employing division and multiplication instructions takes 175 cycles for even N and 286 cycles for odd N.

In the illustration registers are shown as being eight bits wide and can therefore accommodate numbers no larger than 2^8, or 256. In most microprocessors the registers are actually 16 bits wide and can hold numbers up to 65,536. Even that limit is a severe constraint; a program employing 16-bit arithmetic could not calculate hailstone numbers beyond $N = 702$. Achieving a higher capacity requires multiple-precision arithmetic, in which a single number is split between two or more registers or memory locations. With 32 bits of precision numbers up to about four billion can be represented; 64 bits extend the limit to 10^{19}. Each increase in precision, however, exacts a penalty in speed.

The algorithm for calculating one value of N is only a fragment of a working program. In addition there must be some facilities for getting input values into the machine and for displaying results. A practical set of programs for exploring the hailstone numbers ought to do a good deal more. For example, it should be possible to print out the entire series of numbers generated by a given starting value, or to list the path length and maximum value associated with all the integers in a given range. Another program could be set up to search for integers yielding progressively longer paths or larger peak values. There are many other possibilities.

Variations on the $3N + 1$ formula employing different coefficients and constants are also worth exploring. R. William Gosper and Richard Schroeppel, when they were members of the HAKMEM group, investigated the $3N - 1$ problem and showed that it is equivalent to the $3N + 1$ problem with negative values of N. Every number they checked terminates in one of three loops; the longest loop begins at $N = 17$ and has a period of 18 steps.

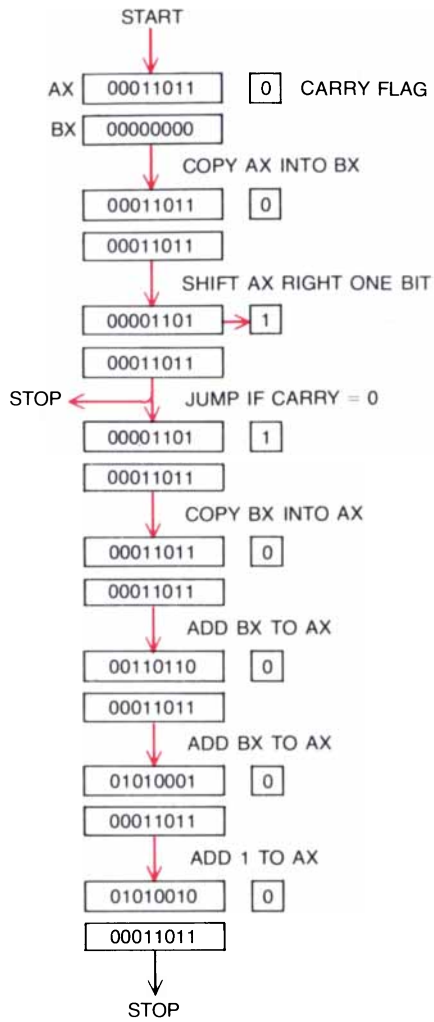
A program whose only aim is to search for numbers that do not fall into the 4–2–1 loop can be greatly streamlined. If numbers are checked in succession beginning with 1, only odd numbers need to be examined. Any even number is immediately reduced by half, and so the path it generates would already have been detected. For similar reasons there is no need to follow the path of a number all the way to 1; once the value of N falls below the initial value the candidate can be dismissed. Still more effective rules for narrowing the search have been developed by William H. Henneman, a student in the HAKMEM group who is now at Boston University.

Although no proof has yet been discovered, a hint of an explanation may lie in a heuristic argument more refined than the three naive hypotheses given above. There it was noted that in any stage of the calculation N has an equal probability of being multiplied by 3 or divided by 2, leading to the suggestion that the value should tend to increase by a factor of 3/2 per iteration. Lagarias points out, however, that one-fourth of all the integers are divisible not only by 2 but also by 4; one-eighth of them are divisible by 8, one-sixteenth by 16 and so on. Taking into account divisions by all possible powers of 2 yields a prediction that N should decrease by a factor of 3/4 per iteration. The empirical evidence supports the prediction.

Even if it turns out that all positive integers fall into the 4–2–1 loop, the hailstone numbers offer an abundance of curiosities. Perhaps the most intriguing properties of the numbers are conspicuous patterns in the distribution of path lengths and peak values. If a number as small as 27 can keep the ball in the air for 111 steps and reach a height of 9,232, one might well expect that the path length and the peak value would grow rapidly as N increased. Actually the path length grows very slowly; the increase in the maximum value is faster, but it is also quite erratic.

Among the first 100 integers the longest path is 118 steps (at $N = 97$); among the first 100,000 integers the longest path is just 350 steps (at $N = 77{,}031$). Thus increasing N by a factor of 1,000 increases the path length by a factor of only 3; the relation appears to be a logarithmic one. The record maximum of 9,232 set at $N = 27$ is not exceeded until $N = 255$, which reaches a peak of 13,120. New maximums are recorded at quite irregular intervals. The hailstone sequence for $N = 77{,}671$ reaches the extraordinary height of 1,570,824,736.

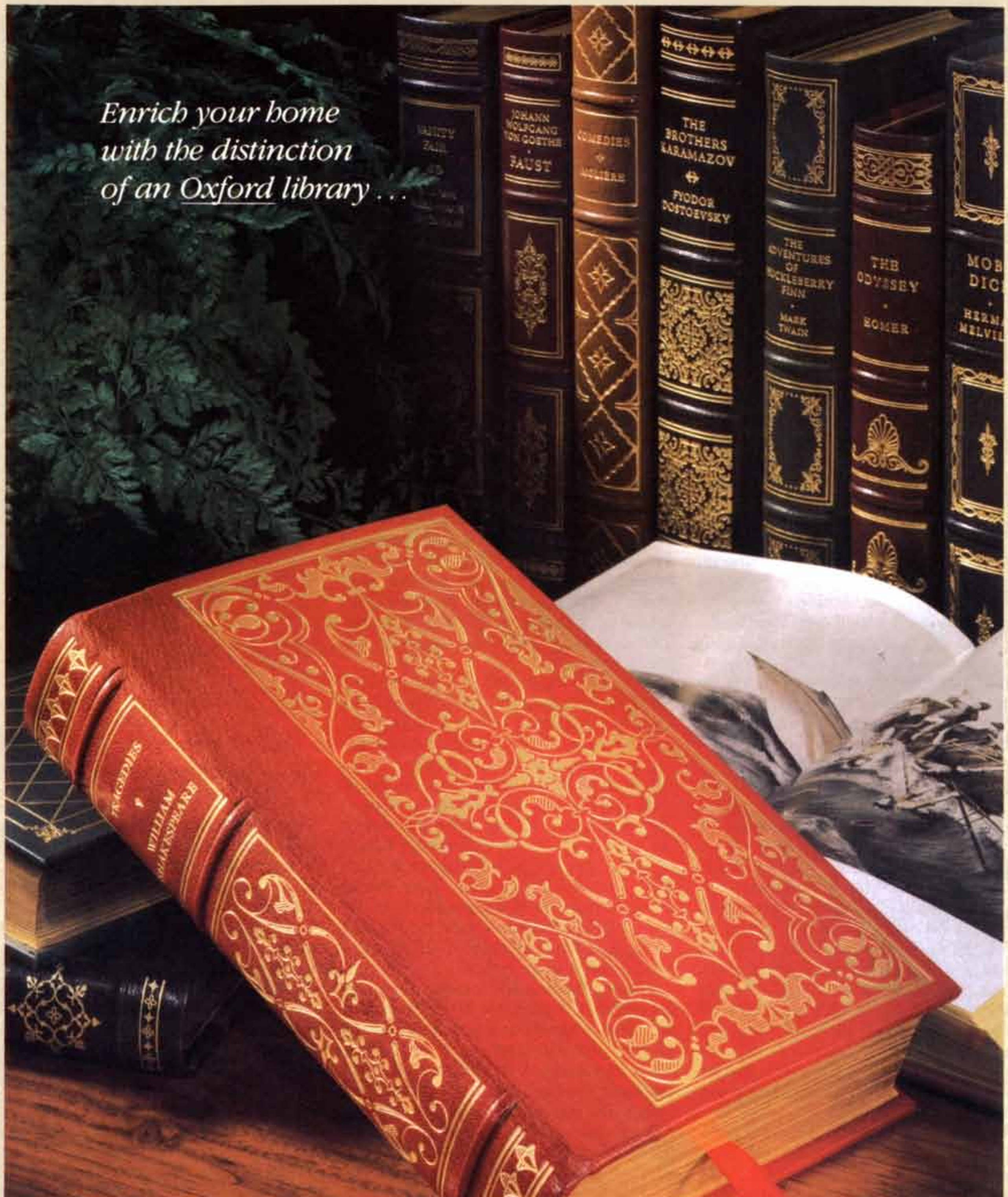
It is easy to see that the peak value reached in a hailstone calculation must invariably be an even number. It can also be proved that only an odd value of N can set a new record for maximum height (with the possible exception of $N = 2$). In the case of numbers that set new records for path length there is no theoretical argument I know of that requires them to be either odd or even. Nevertheless, among the first 100,000 integers path-length records are set almost exclusively by odd values of N.



The hailstone algorithm

A listing of the path length and maximum value for a range of numbers has a frustrating mixture of regularity and disorder: it is definitely not random, but the pattern resists interpretation. For instance, certain maximum values are much commoner than others and far too common to be explained by any statistical process. The outstanding example is 9,232, the number first reached at $N = 27$. Of the first 1,000 integers more than 350 have their maximum at 9,232.

The distribution of path lengths is equally peculiar. Every possible length can be produced (by the successive exact powers of 2), but again some numbers appear far more often than others. Moreover, both the path lengths and the maximum values show a strong tendency to form clusters. In 1976 Fred Gruenberger of California State University in Northridge published a list of such clusters; the largest was a string of 52 consecutive numbers that all have the same path length. Can two consecutive val-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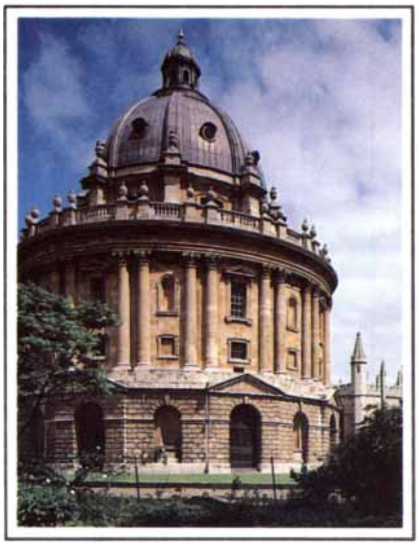

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ues of N have the same path length and the same maximum? The question can be settled algebraically, but readers who prefer a numerical demonstration might want to examine the hailstone sequences for $N = 386$ through $N = 391$.

One illuminating way to look at the hailstone problem is to turn it upside down. Suppose it is true that all positive numbers ultimately fall into the 4–2–1 loop. They must then form an unbroken chain through which any number in the infinite counting sequence is connected to the bottom of the loop. Accordingly it should be possible to invert the hailstone function: to begin with 1 and apply the transformation "backward" in order to generate every larger number. If some number cannot be reached in this way, by following the river upstream, the number cannot yield 1 as its final value.

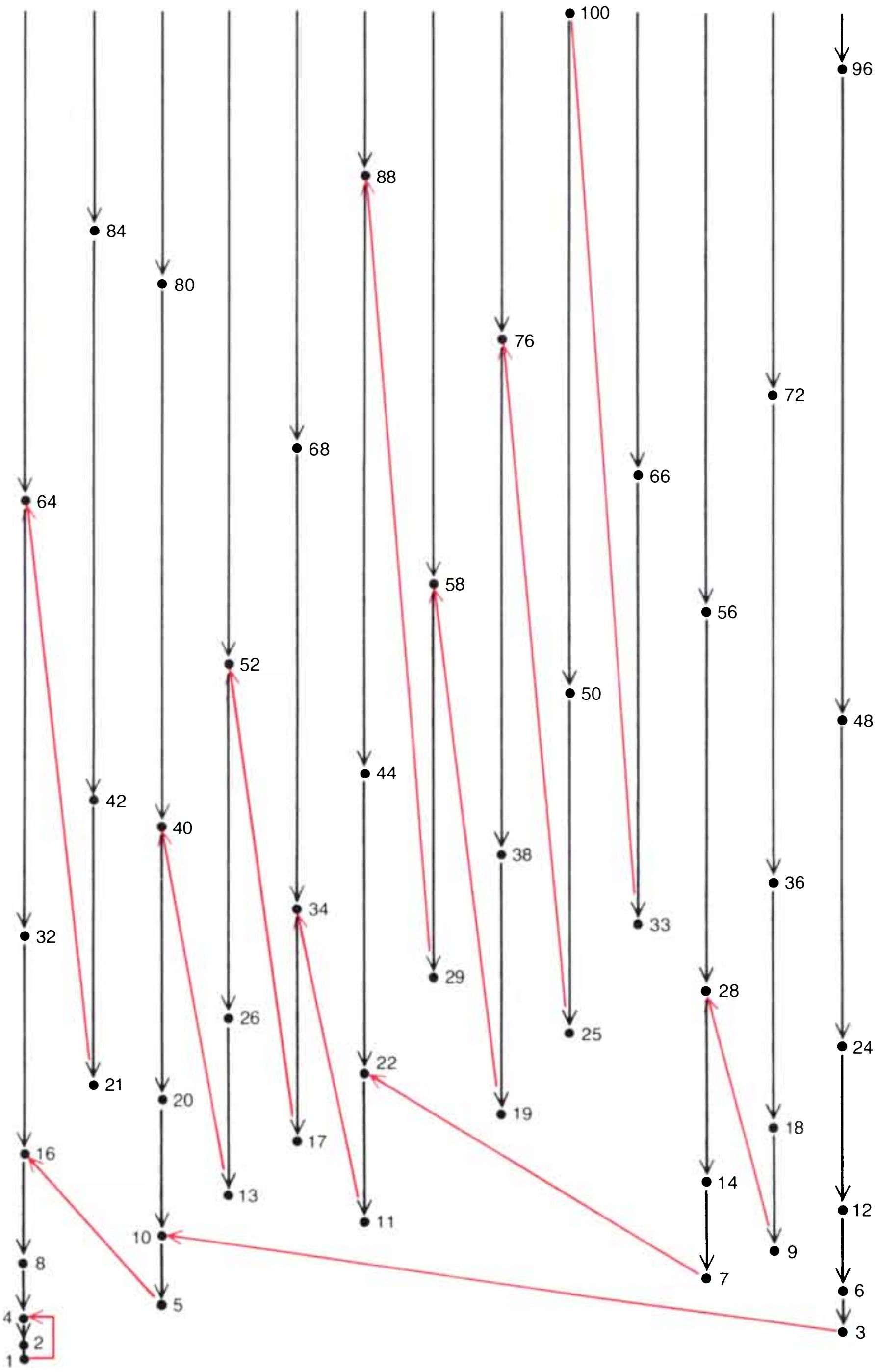
The method might well yield a general solution of the hailstone problem, if only it could be carried to completion. As it turns out, the procedure is not as straightforward as it seems. The normal hailstone function is deterministic: a value of N at any point in the calculation can have only one possible successor. If N is 40, for example, the next number can only be 20. When the path is traced in reverse, there are ambiguities. When the value $N = 20$ is encountered, it is known it could only have been generated from 40, which must therefore be the next value. At 40, however, the next value could be either 80 or 13; the stream splits, and both tributaries must be explored. There is a bifurcation at every number of the form $6K + 4$, where K can be zero or any positive integer.

A branching system of this kind can be traced only to a finite depth. A single branch must be followed until some predetermined limit is reached and then attention must be diverted to another branch. When the limit is set at 100, 13 branches are explored and 49 numbers are confirmed to be connected to the system of numerical rills and rivulets. With the limit at 1,000 there are 84 branches, but only 340 numbers are counted. A limit of 10,000 yields 1,065 branches, which pass through 4,235 numbers. Note that more than half of the numbers seem to lie in the interstices between the branches of the stream. As the limit is increased more numbers are included, but even more are missed. If the ramifications of the system could be explored to infinite depth, would all positive integers ultimately find a place in it? That is the big question yet to be answered.

In October two combinatorial problems were mentioned as being unlikely candidates for solution by "nonalgorithmic" methods with an electronic spreadsheet. A number of readers were quick to show that it can be done.

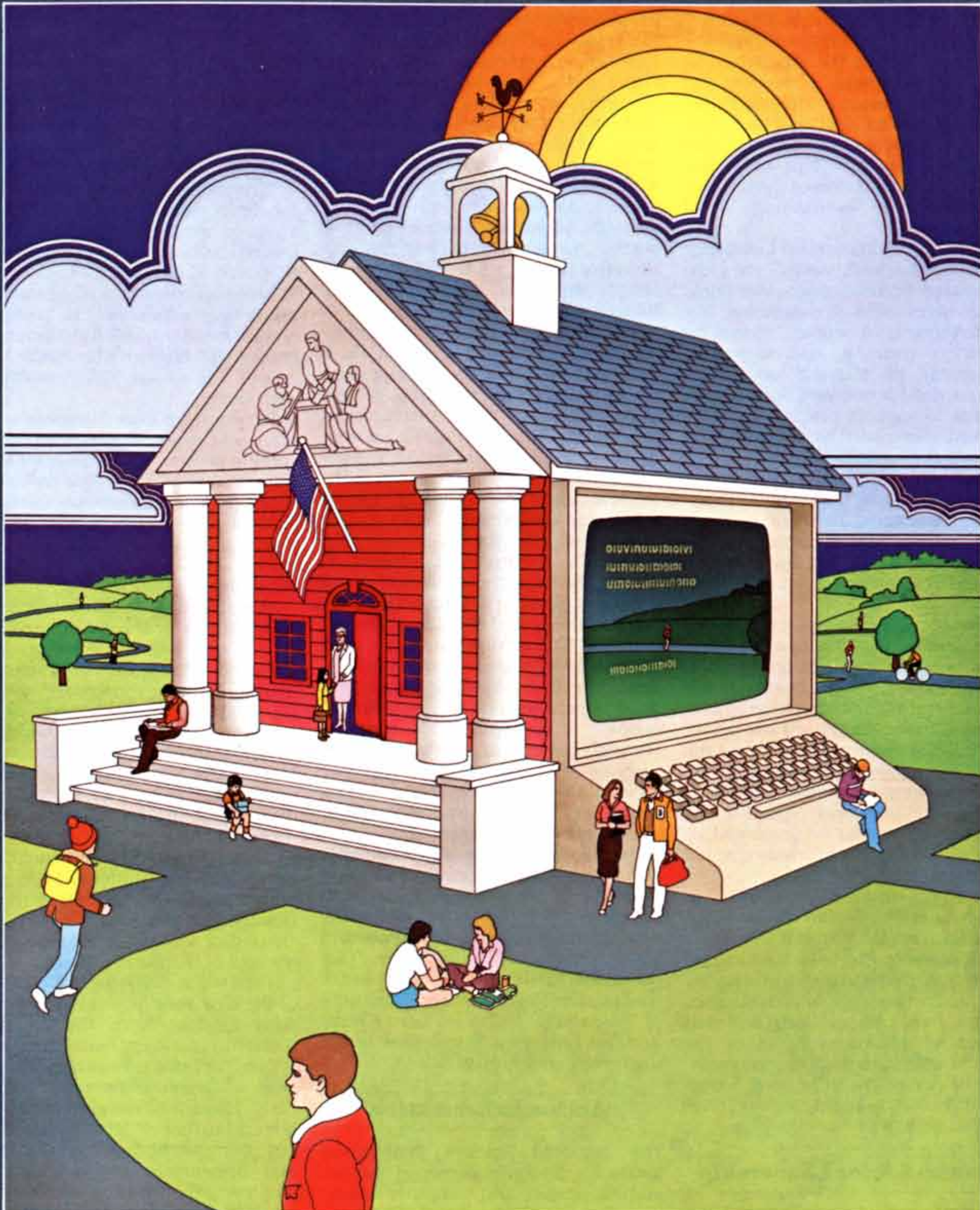
Spreadsheet solutions to the Tower of Hanoi problem were sent by David Behar, John B. Jones, Jr., George Arthur Miller, J. B. Sladen, Alun Wyn-jones and others. The techniques employed were similar. An algorithm in which odd-numbered disks circulate clockwise and even-numbered ones counterclockwise was disassembled so that a temporal sequence of instructions became a spatial array of them.

Behar, Miller and Sladen also solved the eight-queens problem. Here the main difficulty is the need to backtrack when a developing solution fails. I had supposed some record of previous unsuccessful attempts would have to be kept, but that is not the case. D. H. Fremlin, in a commentary on the spreadsheet approach to the problems, pointed out "a method that will generate all the moves in turn without any memory other than what is displayed.... The formulas are complicated and involve sequential algorithms if they are done in their natural forms, but all these 'look for' subroutines can be represented on the spreadsheet by local calculations."



Tree generated by inverting the hailstone function

The Computer in Education



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More than ten years ago Daniel Bell, in *The Post Industrial Society*, wrote "In the post-industrial society technical skill becomes the base of power and education the avenue to power...." Ten years later Bell's conclusions have been reinforced by the experiences of leaders in business, education and government. Last year three such men published *Global Stakes: The Future of High Technology in America*. They are Ray Stata, president of Analog Devices, Inc., and James Botkin and Dan Dimanescu, consultants, all of Massachusetts.

"As society shifts toward knowledge intensity," the book states, "the critical resource becomes not conventional capital investment in machinery, but the investment in people... money for education, training, and research... investment in physical equipment such as word processors or computer systems to support people's activities or, even more so, the software that operates the equipment."

Scholastic Aptitude Test (SAT) scores "reveal a 22% drop in the number of top-scoring mathematics students," *Global Stakes* documents. "In 1972, a total of 93,868 students had scores of 650 or above versus 73,386 in 1980...."

Congress has taken note. In March 1983, Senator Paul Tsongas of Massachusetts introduced the High Technology Morrill Act, "a bill to establish a national technology education grants program." Tsongas named the bill after the 1862 law that established the Land Grant colleges. Funding for the 1862 law came from assessments on railroad rights-of-way; funding for Tsongas's bill would be generated by assessments against oil leases granted on Federal lands.

Thus both industrialists and academics have sounded an alarm: American education isn't what it should be. Simultaneously the "information age" has arrived, partly in the form of highly capable, increasingly affordable microcomputers and similarly any discussion of education turns to the point of computers—and vice versa. How the two ought to be used is now the subject of a highly constructive national debate.

Private-Sector Leadership

Analog Devices, Inc. is one of the advanced-technology companies clustered about Boston's Route 128.

In a January 1983 speech before a Massachusetts High-Technology Council audience, which included President Reagan, Analog's president, Ray Stata, said, "One-third of our work force needs college degrees, more than half in science and technology.

"The simple fact is that our educational system today does not have the capacity to educate and train enough people, with the right qualifications, to sustain our industry's growth."

Analog is a manufacturer of components and systems for precision measurement and control, which is to say real world signal-processing. Over the three years of 1980-82, Analog and its employees contributed more than $1.25 million to 45 educational institutions. As Analog vice president for strategic planning, Graham Sterling states, "We've made it clear that our industry *cannot* do the whole job.. it simply won't get done without enhanced state and federal support."

The sense of "newness" of microcomputers, in or out of education, is well-founded, since few leading firms are as many as ten years old. Yet one major company, Texas Instruments, was founded back in 1930; at that time its main business was oil and gas exploration. Today the company is the world's largest manufacturer of semiconductor components, with a clear focus in education.

From a corporate standpoint TI shares the urgency of the authors of *Global Stakes*. In a 1982 address before the Council of Chief State School Officers, TI executive vice president William Sick pointed out that the firm, according to its own growth plans, will need large numbers of new technical people. "If current trends continue through the end of the decade," Sick demonstrated, "TI will have to hire 12% of all electrical engineering and computer science graduates. That clearly will be a problem...."

Bernie List is Texas Instruments vice president/corporate staff and manager of corporate education and training. "Our commitment to the educational market is an intense and highly personal one," List states. "Our president, Fred Busy, has been head of the Board of Regents at Texas Institute of Technology. That job's been a pipeline, for Fred, to a 'microcosm' of the university community.

Action in Education

The National Science Foundation funded a 50-state survey of mathematics, science and computer education initiatives. Over half the states reported they had established task forces or commissions on computer education. Thirty-two states reported state-level computer education programs. Marc S. Tucker is Director of the Project on Information Technology and Education in Washington. Tucker's two-year-old Project, funded by the Carnegie Corporation of New York, is intended to examine the role of technology, specifically computers, in education.

"No parent of the fifties ever felt that his or her children would badly damage career opportunities if they failed to master the 8mm film loop projector. They did not send their children to TV camp or buy them home-language laboratories. Something else is happening here," Tucker states.

"Scarcely any area of human activity has been more resistant to scientific analysis and technological change than education," wrote B.F. Skinner in SCIENTIFIC AMERICAN back in 1961. "There is no dearth of suggestions for improving education. In assigning certain mechanizable functions to machines, the teacher will emerge in his proper role as an indispensable human being."

Twenty years after Skinner's article, more and more "suggestions" are becoming actions. The Center for Children and Technology at New York's Bank Street College of Education was founded three years ago "to bring thoughtful research to bear on burgeoning electronic technology and its role in children's lives."

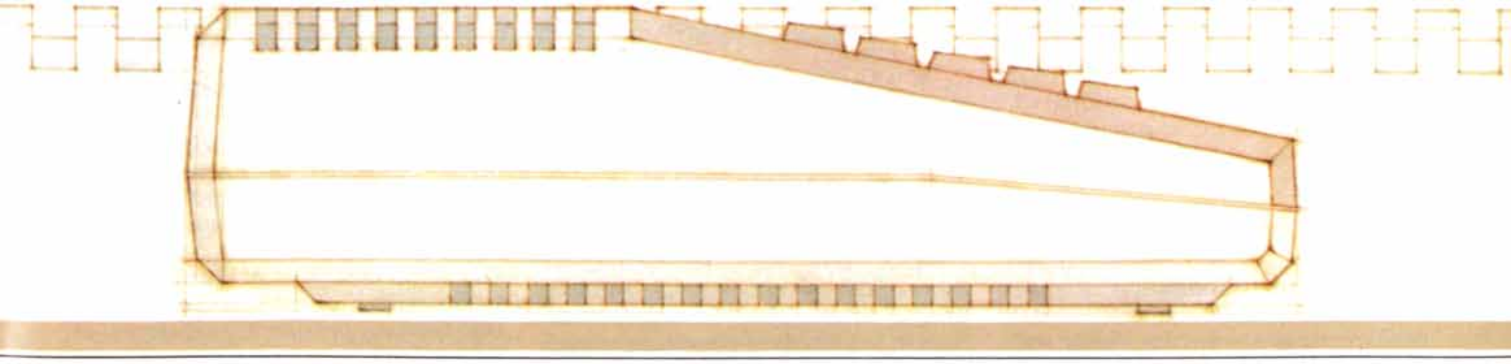
At the Bank Street Children's School, children cluster around three computers. At one, a pretty third-grade girl draws complex figures on a screen. At another, three youngsters use the school-devised, and now commercial, word processing program "Bank Street Writer" to develop a story about a train.

"There is a great deal of chaos and confusion," says Karen Sheingold, director of the Bank Street Center. "Some of the reasons why we exist are to sort it all out. Funders include the Xerox and International Paper Company Foundations as well as the U.S. Department of Education.

Another active program is New York's "School of the Future" project, originally started in 1980 under the auspices of the New York Academy of Sciences, with funding from the Atari and Richard Lounsbery Foundations.

Director Bonnie Brownstein is a disciple of Seymour Papert of MIT, an early advocate of computers for children and author of "Mindstorms, Children, Computers and Powerful Ideas." Ms. Brownstein points out that—whatever the desired end-result of computers-in-education may be—children are very much part of the process.

The computer responds at once to the actions of a child. Interaction at any level is educational in some manner. Ms. Brownstein observes, "To place a point on a monitor screen, you must have two number elements: the



Prints with built-in format or lets you create your own: center, underline. Boldface, elongated, proportional and condensed print.

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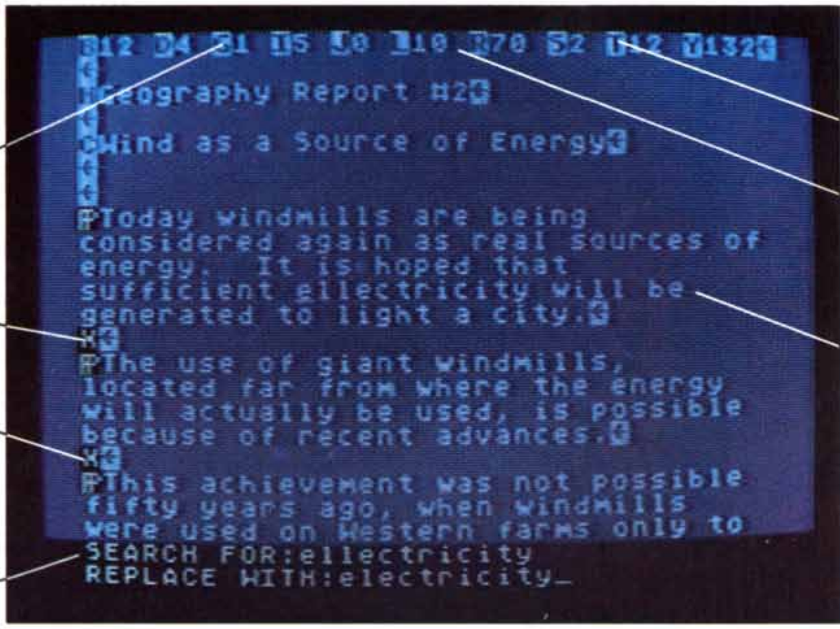
Duplicates and moves blocks of text.

Searches for and/or replaces words or phrases, one at a time or all at once.



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Corrects spelling (with extra software).

Chains and merges files.

Has "print preview": you can check your copy before it's printed.

You can't find a friendlier, more powerful word processor at twice the price. New AtariWriter.™ Under $100.

Now you can do multi-featured word processing at home, simply. At a family budget price.

Our ROM-based cartridge technology means you can use new AtariWriter on any ATARI® Home Computer (even 16K) for personal and business correspondence, term papers, committee reports, mailings, etc.

It also lets you choose between cassette and disk storage systems.

One very special AtariWriter feature: you can correct as you write, without switching back and forth between Create and Edit modes.

And our memory buffer offers an "undo" command to let you change your mind, and restore text you've just deleted.

Check into our remarkable AtariWriter, and our choice of letter quality and dot matrix printers, also reasonably priced, at Atari dealers. Call 800-538-8543 for dealer nearest you. In California, call 800-672-1404.

You'll do more with Atari Home Computers.

X and *Y* coordinates. Five-year-olds understand that. It's revolutionary."

Much of the national debate on the computer's role in education centers on the extent of the "revolution."

The American Federation of Teachers (AFT) in Washington produced a resolution at its 1982 annual convention dealing with computers in education. "Schools have an obligation to prepare students for the highly technological age in which they will live," reads the resolution's preamble.

The National Education Association has contracted with a private company, Cordatum, Inc., to help evaluate and certify microcomputer educational software. "We will set standards and guidelines for what educational software should look like," says Dr. Larry J. Fedewa, executive director for the project, introduced in May 1983."

In Dr. Fedewa's assessment, it is teachers themselves, who most strongly influence purchase decisions regarding course materials. Where standards are lacking, teachers have learned to consult each other. One result: the Minnesota Educational Computing Consortium (MECC).

"MECC arose in 1973 to try to put some order in the 'pockets' of computing all over Minnesota," spokesperson Shirley Griffing relates. "Our State is fortunate in having highly concerned private-sector influences like Honeywell and Control Data and 3M.

MECC now evaluates and offers thousands of educational software program packages. "We supply materials to hundreds of educators outside Minnesota. It's all word of mouth," says Ms. Griffing.

"Orders come in from all over the U.S., plus Germany, Japan, New Zealand, Belgium, even Botswana," she concludes. "Botswana! I had to look it up."

Sarah F. Klein, past president of the National Science Teachers Association, considers the computer's role in society as "a way of life." She points out that "A young person's first exposure to the working world is often a job employing computers—cashiering in a supermarket, or waiting on tables, or pumping gasoline. It would be an injustice to future generations if we didn't recognize the value of computers in the learning process."

Computers in the Grades

McGrath, Alaska is approximately 300 miles northwest of Anchorage; its nearest villages are Crooked Creek and Red Devil. In part because of its remoteness, McGrath has four to five times the computer-to-student ratio as the nation as a whole, according to Dan Shanis, president (and owner) of Educational Services of Alaska. The main reason for the large volume of microcomputers in Alaska's schools, he adds, is money: oil money, distributed by the Alaska Department of Education, which funds local school budgets.

McGrath and other remote Alaskan areas are a sort of prototype for the possible effects, nationwide, of a massive infusion of government-administered money into education. "We've no hard data, but I can tell you the program has been a real success," says Shanis. "First of all, computers are intrinsically interesting, and most kids respond to them. Secondly, we've pushed for programs which really improve thinking skills—not just programs which regurgitate textbooks in question-and-answer format. Finally, we've revolutionized our approach to 'special' education: gifted students have more to work with than they can handle, and remedial students have simple, rewarding tools to help them keep up."

The Apple Education Foundation, established in 1979, is perhaps the major positive private-sector influence on enhancement of learning via microcomputers. The Foundation's grants have exceeded $1.5 million in support of its Charter, which states "The primary goal of the Foundation is to improve the results of the educational process."

Steve Jobs, chairman of Apple Computer, has committed his company and the Foundation to leadership in educational enhancement. This commitment is largely market-driven, as estimates of increased microcomputer installations in schools range from 150,000 to 500,000 per year in just the next three years. The Foundation's objectives and activities treat the existence of microcomputers as a platform on which to build improved basic learning skills and methods, to enhance "learning how to learn."

In 1974, when Cupertino's economy was based largely on grain storage, Allan B. Ellis wrote in *The Use and Misuse of Computers in Education*, "... thinking about the computer's role in education does not mean thinking about computers; it means thinking about education." Thinking about education—and acting on it—is the Foundation's business.

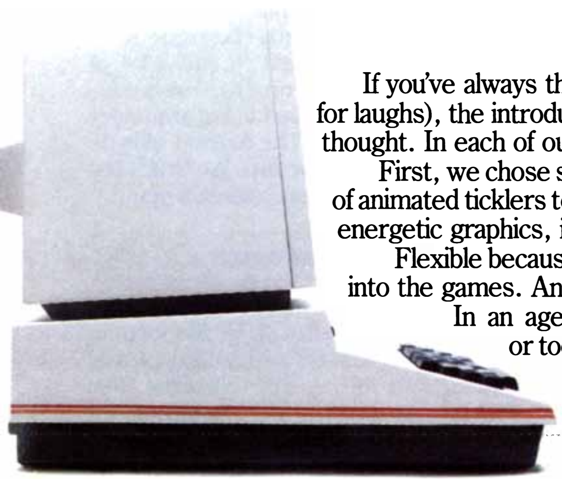
Few companies have evolved as rapidly within the educational-applications market as WICAT Systems, Inc., of Orem, Utah. WICAT was formed by educators, in 1977, as a non-profit research group; its name is an acronym for World Institute for Computer-Assisted Teaching. Founders predicted the impact of microcomputers in education; WICAT was to develop high-quality educational software for the forthcoming technology.

WICAT's efforts were hampered by the quality of its products. In its early years, hardware with capacity to run WICAT software was too expensive. In response, WICAT engineers and managers designed, built, and marketed their *own* hardware, based on the then-new high-capacity Motorola 68000 microprocessor. WICAT, Inc., the non-profit corporation, smoothly became profit-making WICAT Systems, Inc. Its products are designed to complement the technology of 1985 and beyond.

WICAT founder and current board chairman D.H. Heuston states, "Our objective is simply defined: literacy, for every child in the world."

The Jefferson County, Colorado school district is representative of hundreds of communities which have undertaken large-scale microcomputer programs. It is representative as well in that its area, adjacent to Denver, has a high concentration both of university people and advanced technology industry. As the culmination of a 1981 plan, the District spent $2.3 million for 1,695 microcomputers for its 114 schools. Each school will have 15 machines in a computer laboratory of not more than 30 students. 25 manufacturers were evaluated on 41 price and performance criteria. Apple computer was selected.

Among computer hardware manufacturers only Tandy Corporation, of Fort Worth, maintains its own retailing network—the national "Radio Shack" chain, familiar as a source of



high-technology equipment long before the advent of personal computers.

"Tandy has a special and useful knowledge of the educational market," says education division director Bill Gattis. "Our National School Bid Department processes requisitions and requests for bids from all schools who approach us, often through our local Radio Shack stores. Thus we know what they buy. And it's interesting to read educators' public comments that simple 'drill-and-practice' programs are inferior to more interactive literacy and needs-application software, because 'drill-and-practice' material is overwhelmingly what they're buying."

Diane LeBold is editor of "Commodore—The Microcomputer Magazine," a bi-monthly published by Commodore Business Machines, the big Pennsylvania microcomputer manufacturer. Commodore claims to have more of its machines in schools worldwide than any other hardware maker. In the magazine's May 1983 special education issue, LeBold describes a central aspect of Commodore's marketing philosophy: "When we talk about computer education there's one important thing we have to remember—there are real live kids at the other end of our talk."

Commodore approaches those "real live kids" in a businesslike fashion, indeed. As Commodore's 1982 sales climbed 63% to over $300 million, its profitability remained at over 13%. The firm's entrepreneurial president, Jack Tramiel, describes its education marketing approach as "unlocking the Ivory Tower." One of its newest and already successful products, the Commodore 64™, sells for less than $250 and is compatible with peripherals and software designed for earlier Commodore models. Commodore's latest software/"courseware" catalog weighs nearly 8 1/2 pounds and runs to over 800 pages.

David Rosenwald, director of education sales, says Commodore is anticipating an education market where overall planning, teacher training, and softwear availability have reached high levels. "To provide computer literacy, two kids per machine is the maximum practical ratio. A school is a business; it can't afford to pay more than it has to, to produce its product. In literacy applications, kids need to learn how the microcomputer works and how to use it."

Commodore has constructed a national network through which educators can communicate with the Company and each other. Hundreds of schools have been established as Commodore Education Resource Centers; they share information among themselves and with their schools, and are aware of materials published by Commodore, including names of clubs or "users' groups" which specialize in Commodore equipment and software. Commodore's dealer organization complements its approach to the education market. Parents and others seeking a single Commodore microcomputer have a range of retailers to choose from. Educators, who require added values like training and system-design advice, may access with specialized dealers such as Fisher Scientific, who are trained and equipped to provide solutions to computer-related learning needs. Such dealers can deliver any configuration of Commodore products, and can provide training for teachers and administrators as well as for the staff responsible for repairing school-owned equipment.

"Computers can, if used correctly and with the right software, enhance the learning of any subject. A good (software) program will offer variety... the computer should teach the student in the same way a teacher would." These might be the words of an academic professional; they are in fact those of Tracey Cullinan, a 15-year-old Los Altos student, one of 20 young people who comprise a Youth Advisory Board commissioned by Atari, Inc. of Sunnyvale, California.

Atari is totally committed to learning enhancement via computer—preferably with its own four models ranging (in price and feature content) from the 600 XL to the recently-unveiled 1450XLD, all with full color and sound built in. The new 1450XLD includes a telecommunications connection and a synthesizer permitting the computer to translate text into its own speech: it can literally talk to its operator.

"As an educational medium—in the classroom or in the home—the computer's potential is like a great dream," says Linda Gordon, senior vice president of the Atari Educational Division. "Our job is turn the dream into reality."

Atari has a two-level strategy to achieve this objective: the first level, focusing on communication, experiment and training, involves The Atari Institute for Educational Action Research; the second level, concerned with product and courseware supply and service, is the responsibility of Gordon's marketing group. Both build on a specific Atari benefit—wide acceptance, among young people, that Atari leads in developing challenging, exciting products and programs.

The Atari Institute was founded in 1981. It promotes the concept of "lifelong learning" as a matter of Atari corporate policy. Institute program manager Sandra Williams says, "Literacy as a concept is tied, to an extent, to what teachers learned in school. The traditional definition of literacy is out-of-date. Even geography no longer constrains the spread of the 'new' literacy."

Williams explains, "We have a program called 'Sister School Project,' for example. The project links bigger schools which are technologically experienced with smaller schools just starting up. Teachers—and students—can get help or exchange ideas via telecommunications facilities built-in to Atari equipment." Between "Sister Schools," traditional roles and limits are minimized; a student at one school can help a teacher at another. Teachers are able to reach easily beyond their own classroom walls—even beyond their school districts. The Atari Institute provides partial funding and initial instruction. It then stands back and observes.

Some of the Institute's observations are discussed with youth advisors, corporate managers, and—ultimately—with Atari Educational Group personnel. Ideas are given project status and professionally "followed up." Bob Hall, director of educational division sales, demonstrated a videodisc-based software catalog for teachers. "The disc contains actual excerpts from hundreds of Atari software programs," Hall explained at a demonstration. "Teachers can select titles from an accompanying list, and then personally 'call up' a one-minute preview, just as it would appear on an Atari monitor." The videodisc facility may well aid teachers in helping parents and other community members understand Atari's role in their children's classrooms.

"We're not ashamed to call a lot of what we do 'Edu-tainment,'" says educational division marketing manager Mark McCrackin. "The market tells us that learning can be fun. We think listening to the market makes sense."

Courseware

Educational software, or "courseware," is most tangible in the form of individual cassette tapes and plastic discs, and accessible material like PLATO, containing the thoughts, information and graphics implanted by authors, artists and educators. The talents and skills of these people, packaged and produced and marketed by software "publishers," defines the influence of courseware. Of course students can, and are frequently anxious to, create and "run" courseware or other software programs they have designed themselves.

The Children's Computer Workshop, according to director of research

Leona Schauble, "creates educational media that are irresistibly fun." Programs available from CCW include: "Growbots" for pre-teens. This creates an agricultural environment which a child tries to cultivate (factors such as climate and pests are built-in). "Timebound," which involves science and chronology in a quest to "trap" a mad inventor and "Bagasaurus" simulating word-choice to improve dictionary/thesaurus skills.

"Programs are created by a team of professionals," explains Ms. Schauble. "On the team are programmers, for the technical side; artists and designers; and education specialists and psychologists. Our producers, all from education, mediate among the team. Finished products are evaluated by our eleven full-time researchers, and by about 150 children."

Few companies have the tradition and experience in understanding "family values" as The Reader's Digest Association does. Family values are subjective and difficult to quantify. By any definition they include high quality education, and Reader's Digest products (the famous monthly magazine, plus books and records) are generally perceived as constructive and useful.

Reader's Digest—through its new Microcomputer Software Division in Pleasantville, New York—has already developed programs for school and home markets. Some, like "The Chambers of Vocab™", use traditional game devices like mazes to reinforce children's interests while encouraging them to build language skills.

"There's always been a sense that tedium and learning go hand-in-hand—that young people who enjoy the education process are a bit strange," says Reader's Digest division director Richard Scott. "That's a dangerous thing to say. But our experience has *proved* that people like the occasional logic puzzles and 'vocabulary-builder' features in our magazine. And if any sort of computer-oriented education practice is to extend into the home, it will have to compete for the student's leisure time—with what the child considers as fun."

Program development manager Ellen Smith agrees. "As a parent, I've learned to deal with the real world," she says. "My 20 years of experience have convinced me that you have to sell the benefits of education—not to yourself or other adults, but to the children.

"We have a new product called 'Micro Habitats™' in our Video Construction Set Series. You can see where we're going just from the title: high-resolution color-background environments, including underwater, jungle, and outer space. Pre-animated shapes—sharks, lobsters, even a submarine—may be moved and placed by the child. Each has a sound effect, and as environments are created, the sounds build and mix.

"'Habitats' won't influence SAT scores the way our four disk, 30-workbook 'Problem Solving Strategies™' courseware will. But critical thinking is the central theme of both products, and it can happen anywhere."

Sunburst Communications, a software publisher also located in Pleasantville, markets "The Factory," a program noted as exemplary in several education trade publications. This ingenious program requires the user (grade levels, like many truly interactive programs, are from 4 to Adult) to correctly place, rotate and perform various operations in order: test a machine, build a factory, then make a product. Educational objectives are to develop inductive thinking, visual discrimination, and spatial perception, and to understand sequence, logic, and efficiency.

No one knows the number of independent publishers/producers of educational courseware microcomputer programs. Neither Atari nor Apple executives in education marketing know the number of programs available for the products they manufacture. These facts *are* known: there are a great many publishers and a great many programs; there soon will be a great many more; finally, a few highly-motivated publishers of high-quality programs have been identified, and are achieving rapid and substantial acclaim.

"Pinball Construction Set" is published by Electronic Arts of San Mateo. It permits players to create their own pinball games, and to control scores, sounds, colors, and weight and speed of the "ball," on either Apple or Atari computers. Beyond its entertainment value, the program permits practice in operations common to many microcomputer activities.

Two other Electronic Arts products, "M.U.L.E." and "Seven Cities of Gold," combine the features of games and simulations. Both programs were authored by an Ozark Mountain-based team comprised of brothers Dan and Bill Bunten, Alan Watson, and Jim Rushing. "M.U.L.E." alone represents 3500 man-hours of writing and experimentation. It is a game, whose object is to amass money, land, and goods by various means. Within the games format are clear, practical examples of such economics/mathematics basics as supply and demand, economies of scale, the learning curve theory of production, the law of diminishing returns, and the classic prisoner's

Readings

The Computer Primer is a 481-page *handwritten* book by Ann Cavanaugh, a Connecticut teacher, and published by Trillium Press of New York. Ms. Cavanaugh's handwriting is excellent: "The first aids to calculation were fingers.... A caveman might have used three fingers to describe the three deer that got away on his hunting trip. The word 'digits' is derived from the Latin word 'digitis' which means fingers." The book ($12.50) is used with students eight years old and up. "It's a kids' book," says Trillium editor Tom Kemnitz, "but..."

The Apple Guide To Personal Computers in Education compresses much information into 48 pages (including over seven pages of color artwork by Don Weller). $1.95.

I Speak Basic To My Apple (or Atari or TRS-80 or Commodore PET or other microcomputer; book is "system-specific") comes from Hayden Book Company of Hasbrouck Heights, N.J.

Cost of a classroom course, with materials for teacher and 20 students: about $160.

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3M computer media products remember everything, every time. Their reputation for reliability is backed up by something very rare in the magnetic media industry: over thirty years of manufacturing experience. That experience, plus the fact that 3M controls the entire manufacturing process, assures that the same high quality is built into every computer media product we make. So you can have complete confidence in every 3M data cartridge, diskette, and roll of computer tape you buy.

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dilemma.

Electronic Art's president Trip Hawkins, a former Apple executive, says his products are designed to provide "a new category of experiences. We have new artists at work in a new medium. The hardware, with its elaborate hidden machinery, is the scaffold on which we work. The products we create must be simple (to operate), 'hot' (in the McLuhan context), and 'deep' (highly interactive). Whether we fit into a classroom environment is moot; the learners will find us."

Ann Piestrup is chairman of The Learning Company, an independent courseware publisher in Portola Valley, California. Even though Piestrup's firm is just four years old (like many of the children who derive benefit from its products), it has established a national reputation for high quality. One of The Learning Company's programs, "Rocky's Boots," permits children to begin understanding both the engineering basis of computers and the manner in which they are operated. Briefly, the program displays simplified circuit-components which children learn to move and connect. Using color, sound, and gamelike scoring features, operable "systems" may be designed. Success and achievement are rewarded by an animated "Rocky Raccoon" character who appears and dances on the computer monitor screen. The *New York Times* wrote last summer, "... if you have an Apple and kids, not getting 'Rocky's Boots' is like having a toaster and not buying bread."

One phenomenon of computer-assisted education is the privacy of the relationship between a child and a truly interactive, success-directed courseware program like "Rocky's Boots." Even the most caring and sensitive parent can barely gauge the involvement, fascination, and delight obtained by a child, as high-quality courseware operates. As more high quality courseware develops, and children become "literate" in a way never before experienced, parents often will find themselves distanced from their children's learning experiences. It will cause a new and constructive "coming of age" for both generations.

College and Beyond

Most schools employing microcomputers at the K-12 grade levels use them in tutorial projects, in gifted-child programs, and for organized classes in which the computer is primarily the object, rather than the medium, of instruction. At the college/university level microcomputers and/or computer terminals are much more integrated into the learning curriculum. Technical and engineering colleges/universities have wide-ranging computer facilities and extensive student demand for their use; several colleges, including Stevens Institute of Technology, Drexel University and Carnegie-Mellon University require microcomputer ownership of all entering freshmen.

Digital Equipment Corporation of Maynard, Massachusetts is the largest maker of minicomputers. DEC education systems are well-suited to central networking. "I think the school districts will eventually make it through host computers," says Bob Trocchi, product group manager for education, "with a number of computers tied into a central unit, such as a DEC PDP-11. It's just not possible to manage more than two or three micros in a classroom," he says. "You would have to deal with dozens of floppy disks and exuberant youngsters."

DEC has started an interesting innovation at Indiana University. For a small fee, students in some dormitories may use DEC-supplied standalone computers for word processing. "It has been most successful," says Trocchi. "Dorms without the machines are complaining."

Data General Corporation of Westboro, Massachusetts, was founded in 1968. Its 1982 sales of over $800 million ranked it 339th on last year's *Fortune* 500. Along with Data General's sales growth has come a growing involvement with education on three main levels: first, the company's need for more qualified people to augment its own staff; second, its development of the new Desktop Generation™ computer line for broad-reach school-system administrative use and interconnection to its own and IBM compatible systems; third, its entry into the professional-level small computer market with products designed in part for student use.

Planning Data General's approach to the education marketplace is the responsibility of Peter Jessel (Ph.D., MIT; M.B.A., Wharton). "We respond to what we see," he says. "For years our products have had strong application in university-level situations. But now we see the same kind of work being done by freshmen—even by high-schoolers—that was once put only before upperclassmen. The computer learning process is migrating downward, in terms of student age."

Data General has, for two years, been developing a distributed data processing system potentially serving school districts in New York State, under the auspices of the Southern Tier Regional Computer Center. The Center is located at the Broome-Delaware-Tioga BOCES (Board of Cooperative Educational Services) in Binghamton. The system permits wide use of the IBM 4300 mainframe computer shared by all the schools for administrative, instructional, and research services. Students' access to scores of installed computers and terminals brings them high-quality programming software, plus the databases and other resources created over the past several years and restricted hitherto to the mainframe system.

The Center has proposed to Data General that an expanded system be created as a controlled model, for possible application among similar large Centers across the country.

"When we first examined the potential of the elementary/high school market for Data General products, back in the seventies, we found confusion," says manager of industry marketing Bob Orr.

"Now we are beginning to see sophistication: realistic, consistent objectives coming from education professionals who are planning-wise and product-wise. We can employ consultative selling and be productive as long term business partners."

Future Quality

Dorothy W. Blake, coordinator of planning for Media Resources and Utilization for the Atlanta Public Schools, spoke before the House Committee on Education and Labor in January of last year. Here are selections from her remarks:

"... I speak from the experience of a mother, a grandmother, the wife of a school principal, the wife of a former science teacher, and, after three decades in the school business, I consider everybody who works as a part of the instructional team as those who have answered a very high calling...

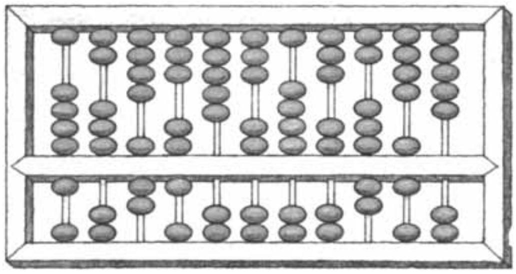
"Elementary and secondary school students as well as their teachers must learn to use newer technologies, such as microcomputers and/or computer terminals, not only to solve mathematics and science problems, but also to gain further access to information needed for their education and for their work and for daily living.

"The machines, and the young people, are here to stay. They match each other in their high quality and great potential."

This special report on "The Computers In Education" was written by Peter J. Brennan and produced by Development Counsellors International Ltd. of New York. Original artwork/graphics: Sherin & Matejka, Inc.

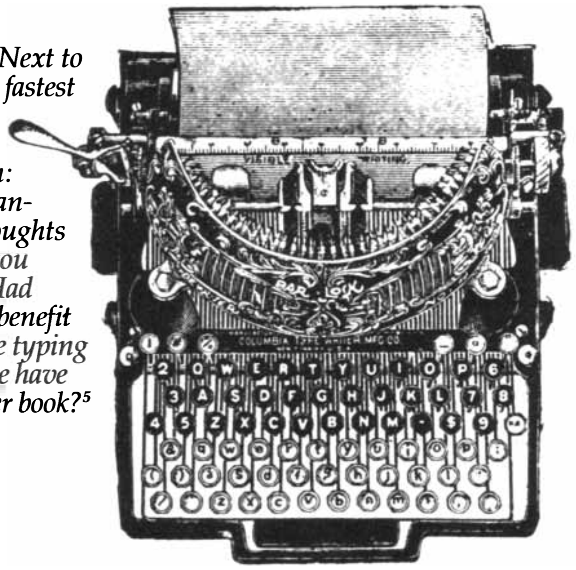
NOTES ON THE ORIGINS AND CAUSES

Paper. First century AD, China. Information becomes a more abundant resource. But now has paper itself become too abundant? The plague of the 20th century office: Clutter.[1]

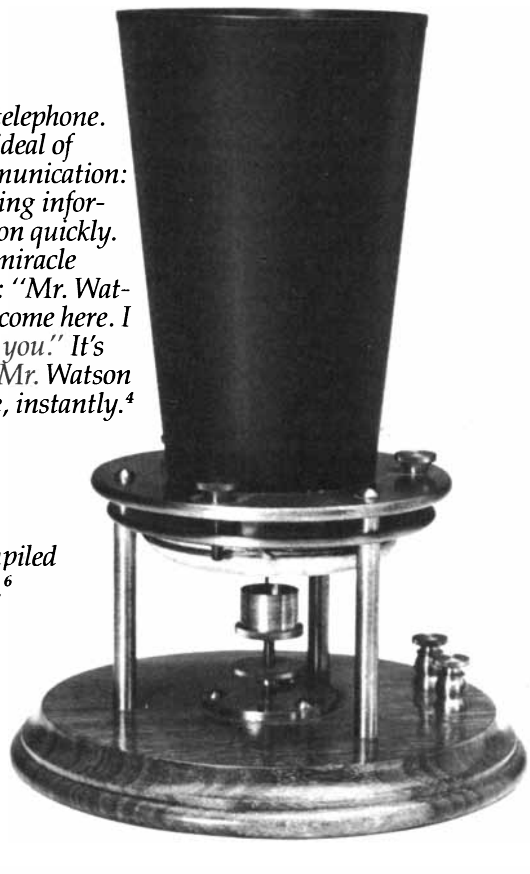


The abacus. Early hardware. Until recently it was, in the hands of a skilled operator, actually faster than a computer. Note: "Skilled operator."[2]

The keyboard. Next to shorthand, the fastest writing system known to man. Question: If you could transcribe your thoughts faster, would you think faster? Had Cervantes the benefit of even average typing skills, would he have written another book?[5]



The telephone. The ideal of communication: Sharing information quickly. The miracle isn't: "Mr. Watson, come here. I need you." It's that Mr. Watson came, instantly.[4]



The encyclopaedia. By definition, all current and essential information compiled and made accessible to the non-specialist. A fourteen-volume learning tool.[6]

[1]It is to be noted, in general, that Digital Equipment Corporation's computer systems place particular stress on the elimination of many routine administrative chores involving paper, such as student registration, class scheduling, budget accounting.

[2]As recently as ten years ago it was the consensus that there would gradually come into being a sort of "computer priest class," who alone would consult these electronic oracles. Today, thanks to accessible systems–Digital's VAX, in particular–computer literacy is fast becoming accepted as a basic skill, like reading.

[3]An alternative to the postal system is developing between computer-connected parties: Electronic mail on the VAX system. VAX computers at different branch-campuses routinely exchange and transmit even lengthy written communications. Finding a stamp, a chronically irritating chore, becomes a thing of the past.

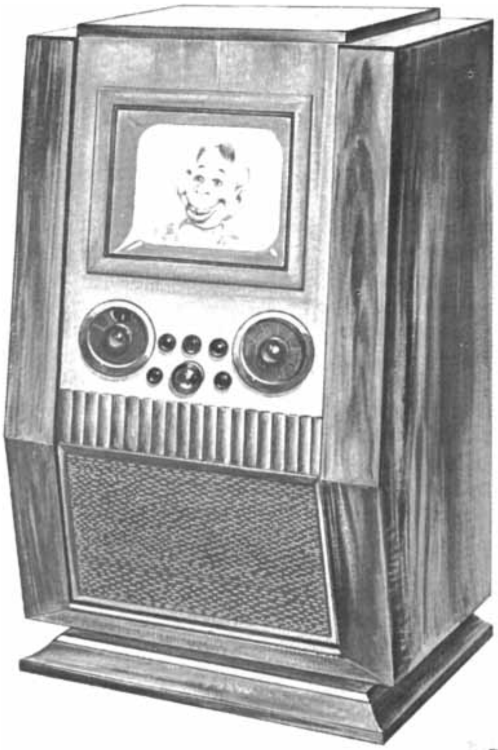
[4]Imagine a twist: What if Watson had been out? (Or his phone had been busy!) What if you wanted to ask a colleague in London a question. Would you call him at 1 A.M. his time? Or would you use a terminal to relay your question (via DECmail) to his terminal–guaranteed it would get to him?

[5]Cervantes was sometimes an inattentive writer. Had he the benefit of what any freshman can have today–a computer to "converse with"–his terminal might have flashed him "...Hold it! Two pages ago you said that person's name was spelled..."On the vast potential of student time-sharing, consider that with current VAX technology it is perfectly possible for a motivated student to sit down at a terminal for a minute between classes and simulate the moon's gravitational system.

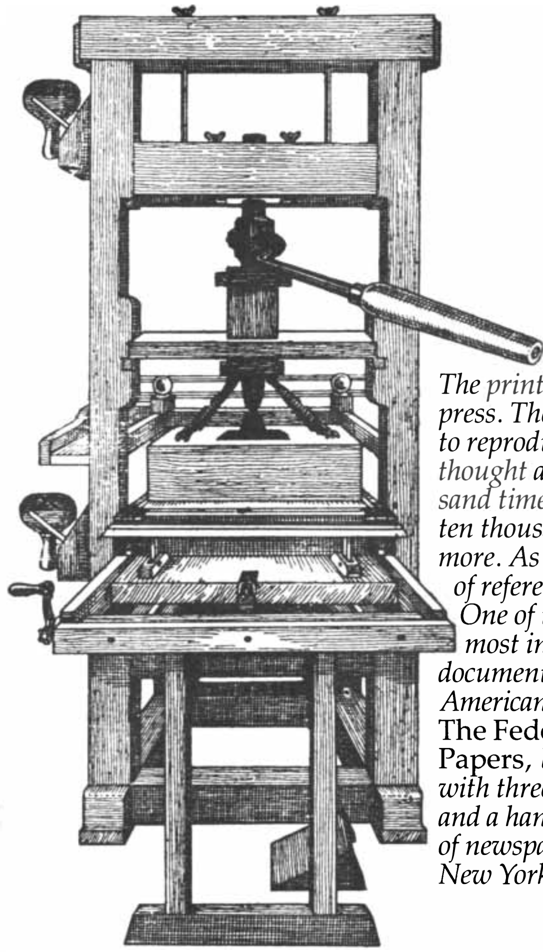
[6]The encyclopaedia, if taken one more step, becomes computer-based education: An infinitely patient computer conducting a student through a simulated chemistry experiment step by step. Let him *see* the consequences of, say, adding water to sulphuric acid. Obviously, this requires a computer terminal screen with exceptional graphics capability, like Digital's GIGI terminal, and Courseware Authoring System.

[7]A telling comparison: To get out an *annual* col-

OF THE COMPUTER REVOLUTION.

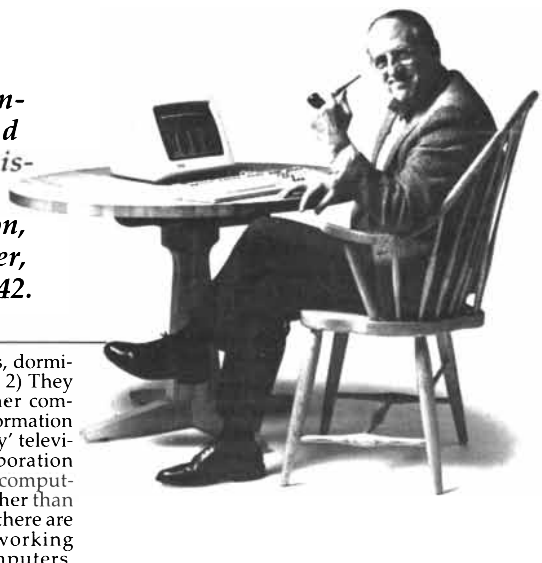


TV. Significant because many forms of information simply need pictures. Imagine you had to describe a Rubik's cube in writing. Or discuss the operation of the law of supply and demand on Australian wheat consumption in twenty-five words or less.[8]



The printing press. The ability to reproduce a thought a thousand times. Then ten thousand more. As a point of reference: One of the most influential documents in American history, The Federalist Papers, *began with three men and a handful of newspapers in New York state.*[7]

The mail. The most ambitious system for the distribution of information in the world. Awesome in conception, but less than foolproof.[3]



Digital Equipment Corporation. Suppliers of educational computer systems, office information systems, word processors and personal computers, and software for students, faculty, administrators, office managers, and anybody who works with ideas.

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lege catalogue, it takes on the average a staff of 25, working 40 hours a week for 20 weeks. There now exists a text management system, DECset, which would accept data coming from the many various sources, fit it all together, adjust it all to sudden revisions, produce galleys ready for paste-up, and finally, put them onto film. There are implications here for the academic press, in that DECset may make the publishing of specialized works economically feasible.

[8]Significant also as a *personal and portable* source of information. A $60 window on the world that can be set up on anybody's kitchen table, television is a very close ancestor of the modern personal computer. This comparison may be developed: 1) Like TV, personal computers are to be found in student unions, dining halls, dormitories, sororities – no longer just in labs; 2) They can be linked to each other and to other computer systems on campus to share information among them, forming a kind of 'two way' television network. Digital Equipment Corporation has, incidentally, carried this ability of computers to communicate with each other farther than has any other company. At this writing, there are no serious rivals to its DECnet networking approach which allows personal computers, word processors, terminals, VAXs, and DECsystems to share information.

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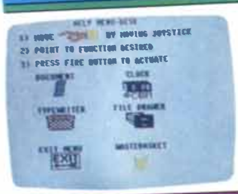

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