Seeking the Soul of an Old Machine

Charles Babbage's difference engine is ready to run—built for the first time 150 years after it was designed

IT'S A LITTLE LATE BY TODAY'S HIGH-SPEED standards for computer development, but Charles Babbage's Difference Engine No. 2 will at least be complete in time for his 200th birthday later this year. On 27 June Britain's Science Museum will have the 3-ton machine—with its 4000 gears, levers, and wheels built of bronze—ready to produce its first computations at the turn of a crank. In the process, the museum believes Babbage's reputation as the grandfather of computing will be restored.

Babbage was an irascible Victorian genius who wrote on chess, property tax, philosophy, geology, optics, ballet, armaments, light houses, archeology, postal services, and lock-picking. But he is celebrated today chiefly for the machines he designed to automate mathematical calculations, an obsession that sprang from a deep dissatisfaction with the mathematical tables of the time. Navigational tables, for example, were heavily relied upon by shipping but were full of errors, which almost certainly caused several shipwrecks. The tables were created by mathematical scribes using a technique that relies on simple repetitive calculations. It is tedious and error-prone, and the errors offended Babbage: "I wish to God these calculations had been executed by steam," he wrote. His machines were designed to do essentially that, automating the method of finite differences that the scribes used (see box). But Babbage was never to complete a single machine. The government paid him more than £17,000 (worth \$1.3 million today) in the hope that the machine would generate more accurate navigation tables.

"The big thing is... were his designs bonkers or not?"

—Doron Swade

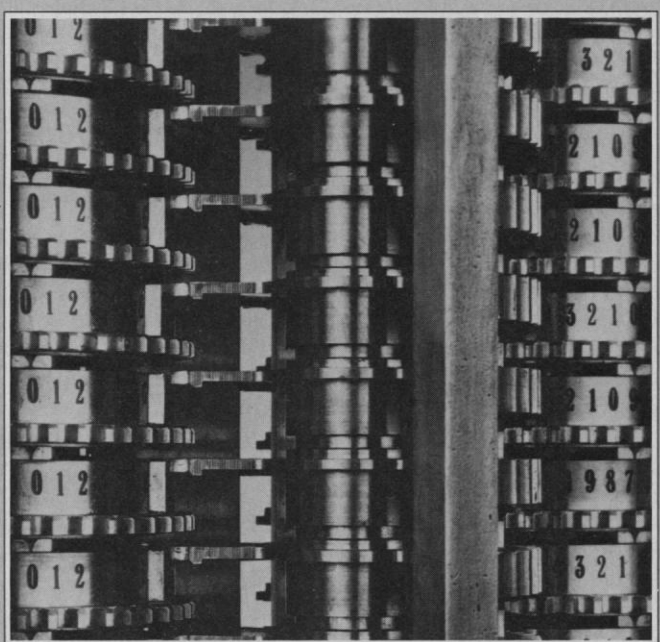
Eleven years later the machine was still under construction and Babbage was quarreling with his engineer over money. When the government refused to come up with more funds, Babbage used his own, constantly moving on to ever more grandiose projects. By the time he died he was disillusioned and bitter, blaming the British government for a lack of appreciation of his ideas.

"Babbage's genius and his failures are always mentioned in the same breath," says Doron Swade, curator of computing at the Science Museum. "The big thing is, was he right? Were his designs bonkers or not?" Swade decided to find out the direct way—by building the engine using parts manufactured no more precisely than in Babbage's day and seeing if it worked.

"Every history book says Babbage failed because of the limitations of technology," Swade explains, but "the circumstances surrounding the collapse of all his projects had nothing explicitly to do with the limitations of technology." The opportunity to assess Babbage's genius empirically came in 1985, shortly after Swade, an electronics design engineer and historian of science, became curator of computing at the Science Museum. The museum holds all Babbage's design drawings and notebooks, and Swade found himself wondering why nobody had tried to build a machine before. "Within two weeks of having that thought, a man appeared at my doorstep called Allan G. Bromley, a computer scientist from Australia,

How the machine works

All photos: Photo Researchers



When Babbage was asked how his machine worked, he began with a simple example: the price of meat. In Babbage's day there were printed tables that made it easy to look up the cost, in pounds, shillings, and pence, of any quantity of meat at any price per pound. Babbage pointed out that if the price of meat were, say, 5 pence per pound, you could calculate the entry for 20 pounds of meat in two ways: Either add 5 pence to itself 20 times, or multiply 5 pence by 20.

For the person drawing up the table, multiplication has the great advantage that every answer in the table is independent. If you make an error in calculating the value of 20 lbs, it will not affect your answer for 21 lbs. Adding 5 at each step is a much easier way to build the table, but has the grave disadvantage that a single error will permeate every subsequent entry. Babbage sought to automate the method of addition, retaining its simplicity while eliminating error.

In the hands of Victorian scribes, methods involving no more than addition could be used to do far more than make multiplication tables. Babbage's explanation (contained in his 1864 autobiography *Passages from the Life of a Philosopher*) moves on to a table of what he calls triangular numbers, that is, 1, 1+2, 1+2+3, 1+2+3+4, and so on, as made by arranging rows of marbles in the form shown below.

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(1)   (2)    (3)     (4)
 0     0      0       0
      0 0    0 0     0 0
            0 0 0   0 0 0
                   0 0 0 0
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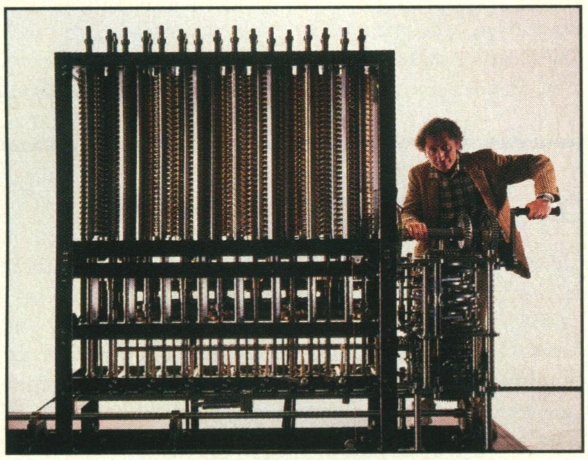
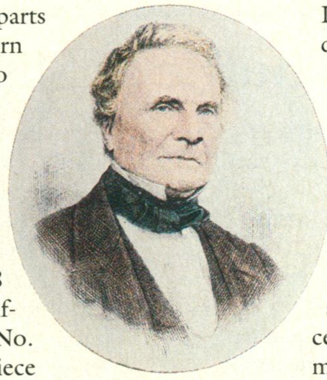
with a three-page document, suggesting that we build Difference Engine Number 2 for the bicentenary of Babbage's birth."

Bromley had studied the drawings on and off since 1979. His proposal had credibility, and Swade made it his business "to do whatever it took to get the machine built." Along the way, he encountered several of the forces that dogged Babbage: eminent people who said it couldn't be done; lack of finance; indifference from his peers. Eventually a consortium of British computer companies guaranteed the £250,000 ($450,000) the museum needed.



Cranking out polynomials: *Doron Swade, curator of computing at Britain's Science Museum.*

Babbage's working drawings were redrafted so that modern engineers could use them. The engine's 4000 parts were machined using modern tools, but to an accuracy no greater than Babbage himself achieved in some of his trial engines. And the whole contraption has been assembled into a gleaming burnished monument 10 feet long, 6 feet high, and 18 inches deep. Difference Engine No. 2 is the centerpiece of an exhibition celebrating Babbage and his works.



Charles Babbage

Swade and his colleagues are currently in the final throes of commissioning the machine before the official inaugural run on 27 June. "You lever things with a screwdriver, turn the crank, and look for movement," says Swade. The technology may be different, but the logic of debugging remains the same. If all goes well, the machine will crank out seventh order polynomials to 30 decimal places. But as Swade readily admits, the Difference Engine is not what many people think it is. "It isn't a computer. It is a dedicated, 'hardwired' calculator. It crunches numbers the only way it knows how—by the method of differences" (see box below).

It was Babbage's other great design, the so-called Analytical Engine, that might deserve the title of First Computer. The Analytical Engine was a general-purpose machine, programmable with punch cards for data and instructions. It had a separate store for information and a mill for acting on it. It embodied concepts such as microprogramming, that is, having a single complex function performed by several subsidiary functions. It would loop round a calculation a fixed number of times and was capable of conditional branching. It had output to a printer and curve plotter. It had almost everything a modern computer has, lacking only a way of storing the program within the machine. But all this existed only on paper. Babbage started to make two simplified assemblies that incorporated the working principles of the analytical engine, one of which was completed by his son. But the engine was never built.

Had Babbage built it, the Analytical Engine would have been the size of a locomotive. Hardly the thing to start with, but if the Difference Engine is a success, who knows? "We'd love to do it," says Swade, "and judging by the crazed look in the eyes of the team building the Difference Engine, we may not have heard the last of it."

■ JEREMY CHERFAS

He draws up a table of the following kind:

Number of the group (see above)	Number of marbles in each group	Difference between the number of marbles in each group and that in the next: First difference	Second difference
1	1		
2	3	2	
3	6	3	1
4	10	4	1
5	?		

In Babbage's table, the first "difference" is simply the difference between the number of marbles in one group and that in the next; the second "difference" is the difference between successive first differences.

The number of marbles in the fifth group can be calculated directly by multiplication, as being $(5\times6)/2=15$, that is, $y=x+[x-1]+[x-2]\ldots$, expressed by the general equation $y=[x]\times[x+1]/2)$. But it can also be calculated by addition—through the method of "finite differences"—as the sum of the number in the previous group, plus the two preceding differences: $10+4+1=15$. Continuing in the same way, succesive solutions of the equation, for increasing values of x, can be churned out one after the other by repeatedly adding the differences to the previous value.

Exactly the same principle applies to a table of the square of numbers:

Number	Square	First difference	Second difference
1	1		
2	4	3	
3	9	5	2
4	16	7	2
5	?		

Again, the number in the fifth group by direct calculation is $5\times5=25$, while by the method of differences it is $16+7+2=25$.

These are simple examples. The beauty of the method of differences, as Babbage put it, is that "mathematicians have discovered that all the Tables most important for practical purposes, such as those relating to Astronomy and Navigation can…be calculated…by that method." Indeed, in Babbage's day, that was precisely how humans did calculate trigonometric tables. The point was that the scribes would err, while Babbage's engine would not.

Inside the engine, the wheels are programmed with the differences, out to 30 decimal places if necessary, and with the starting value. Babbage's elegant engineering then allows each crank of the handle to turn the wheels, via a series of cams and levers. The result: The differences are automatically added to obtain the next entry in the table. ■ J.C.