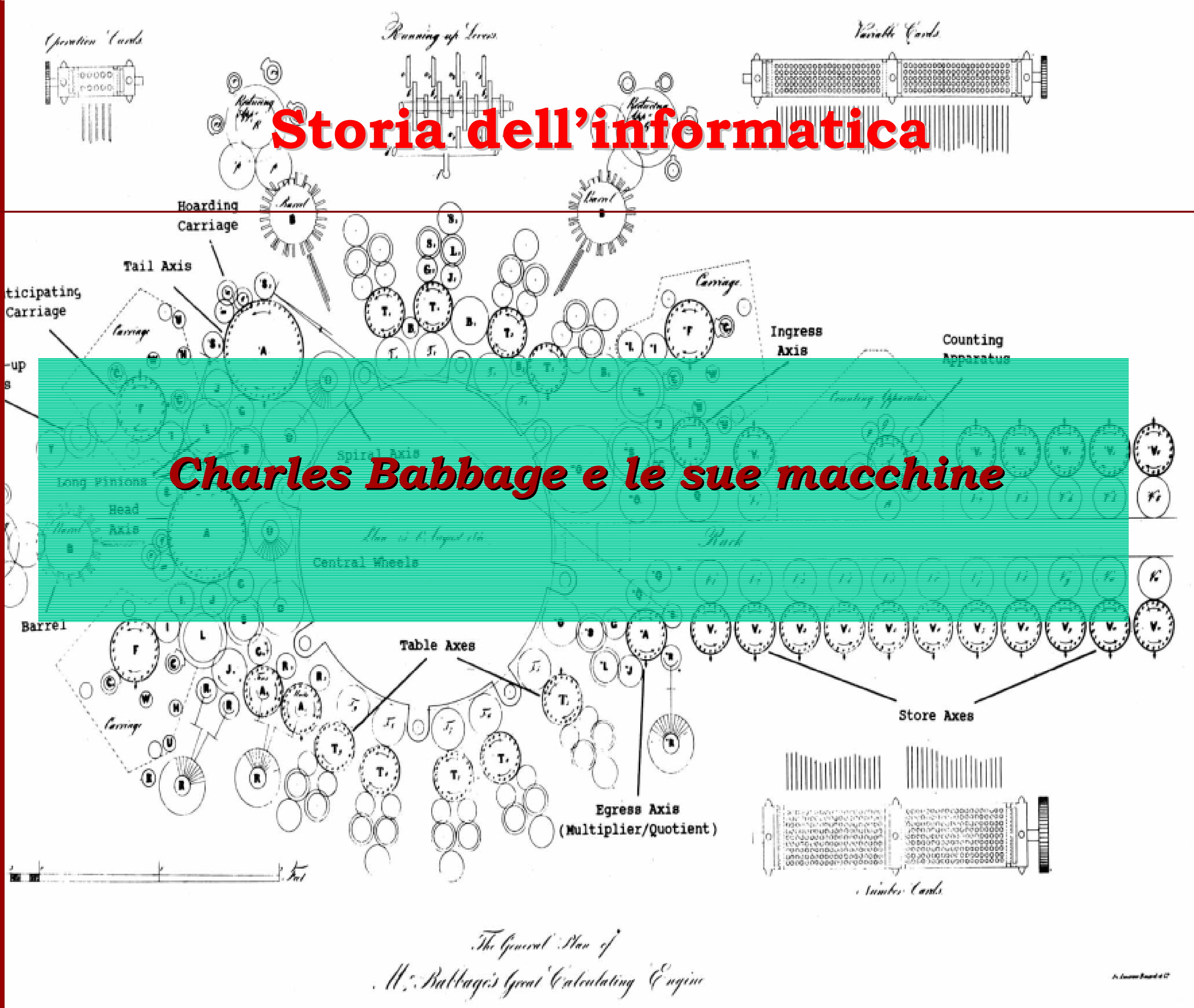
Storia dell'informatica

Charles Babbage e le sue macchine

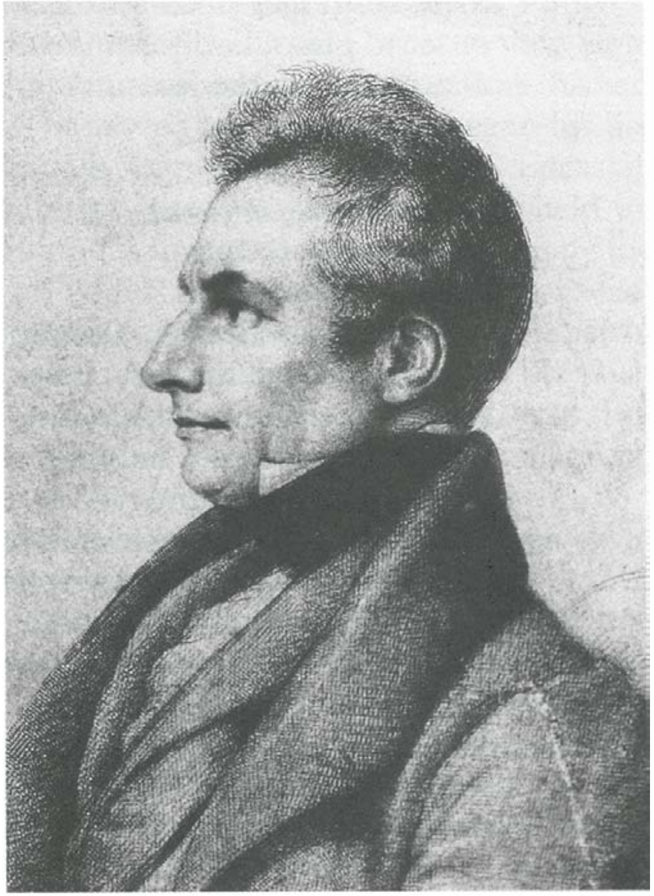


Charles Babbage (1791-1871)

Charles Babbage, perhaps more than any other person, can be considered to be the grandfather of the computer age.

He invented the *Difference Machine* for the purpose of calculating mathematical tables, and later designed more general machine known as the *Analytical Engine*.

From this, a general concept of programming was considered for the very first time.



«Babbage non rappresenta un capitolo nella “storia del calcolatore”. Ne completa uno, e ne inizia un altro.»

V. Pratt, *Macchine pensanti* (1990).

Babbage's Achievements

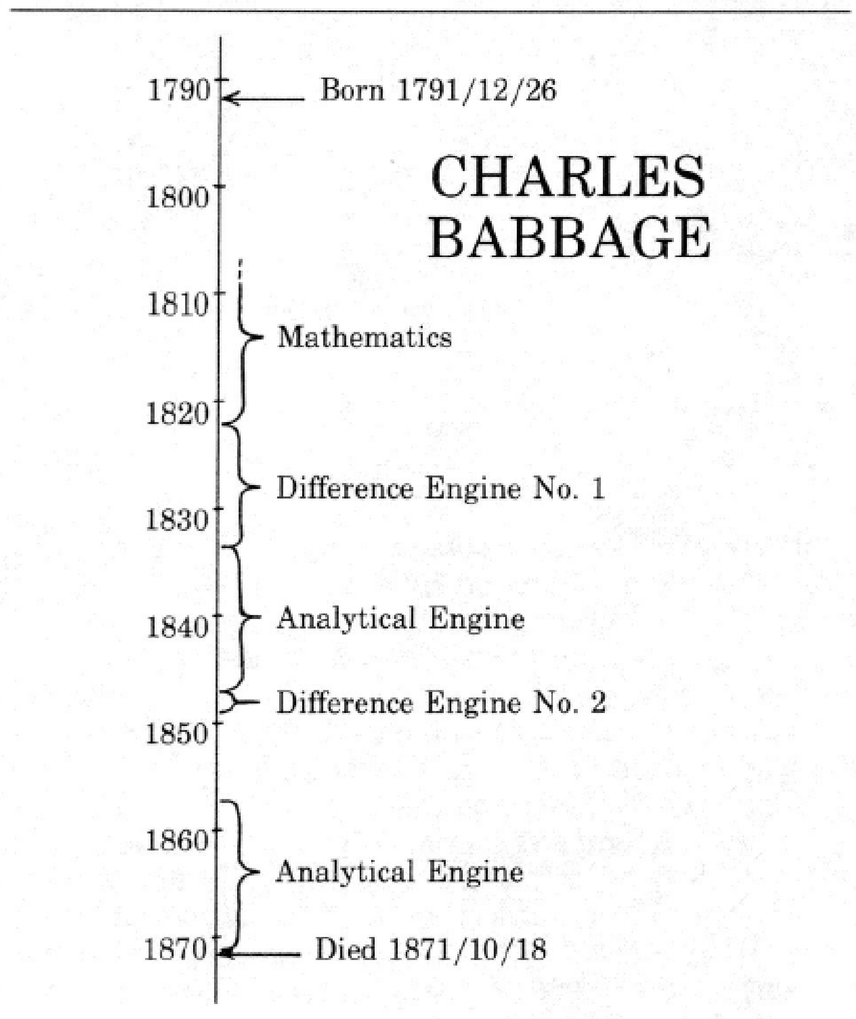
Charles Babbage gave contributions to mathematics, social sciences, philosophy, and mechanical engineering.

His published works include:

- *A Comparative View of the Various Institutions for the Assurance of Lives* (1826)
- *Table of Logarithms of the Natural Numbers from 1 to 108,000* (1827)
- *Reflections on the Decline of Science in England* (1830)
- *On the Economy of Machinery and Manufactures* (1832)
- *Ninth Bridgewater Treatise* (1837)
- *Passages from the Life of a Philosopher* (1864)

Charles Babbage (1791-1871): Some principal career details

		Age
1812-14	Founder member of Analytical Society (including also J. Herschel and G. Peacock); author in *Memoirs* (1813)	21
1814-27	Main researches in functional equations, in close collaboration with Herschel	
1816	Translation (with Herschel and Peacock) of S.F. Lacroix, *Calculus*	
1816-19	Possibility of publishing de Prony's tables	
1820	First ideas and models for calculating engine	
1822	Letter to Humphry Davy, on the possibilities of an engine	29
1825	Studies magnetism by rotation with Herschel	
1826	*A Comparative View of the Various Institutions for the Assurance of Lives*	35
1827	*Tables of Logarithms of the Natural Numbers* (corrected version, 1831)	
1829	Government backing for First Difference Engine secured	
1832	*On the Economy of Machinery and Manufactures* (new editions 1832, 1833, 1835)	
1832	Part of First Difference Engine completed	
1834	D. Lardner publishes article on this engine	41
1834-37	Main development of ideas for Analytical Engine	
1837	Meets A. Lovelace; she assists him in his work on engines	
1837	*The Ninth Bridgewater Treatise: A Fragment* (2nd edition 1838)	44
1840	Visits Italy; arouses interest in his engines, especially L. Menabrea	
1841-43	Lovelace and Menabrea publish articles on his engines	
1847	Sketches out Second Difference Engine	56
1850-53	Develops system of flashing signals for lighthouses	
1850s	Works on cryptography	
1862	Meets G. Boole	
1864	*Passages from the Life of a Philosopher* (autobiography of sorts)	71


1790
Born 1791/12/26
CHARLES
BABBAGE
1800
1810
Mathematics
1820
Difference Engine No. 1
1830
Analytical Engine
1840
Difference Engine No. 2
1850
1860
Analytical Engine
1870
Died 1871/10/18

The Need for Accuracy

Mathematical and astronomical tables were essential aids to navigation and the prerequisite of much scientific work, but the production of such tables without significant mechanical aids was an enormous undertaking.

Moreover, even the best tables contained many errors, partly due to arithmetical mistakes and partly because of the difficulty of typesetting and proofreading long numerical tables.

Cambridge, UK, 1812/13

«I was sitting in the rooms of the Analytical Society, at Cambridge, my head leaning forward on the table in a kind of dreamy mood, with a table of logarithms lying open before me. Another member, coming into the room, and seeing me half asleep, called out: "Well, Babbage, what are you dreaming about?", to which I replied: "I am thinking that all these tables" (*pointing to the logarithms*) *"might be calculated by machinery."»*

C. Babbage, *Passages from the Life of a Philosopher* (1864).

Gaspard de Prony (1755-1839)

The immediate inspiration for Babbage's inventions was a French commission set up under Baron Gasper de Prony, a French mathematician and engineer, to produce a highly accurate series of logarithmic and trigonometric tables.

The Computer as a Child of the Industrial Revolution

Prony sought to apply the industrial method of division of labour to the production of tables.

The workforce was divided into three groups:

- The first consisted of half a dozen eminent mathmeticians, who identified the formulae most suitable for calculating the tables.
- The second group contained analysts who assigned numerical values to the algebraic expressions in the formulae.
- These were then handed over to a third group of nearly a hundred people who undertook the routine arithmetical calculations.

Babbage’s Inspiration

Prony's method was for Babbage a revolutionary backthrough, since it showed, in Babbage's words:

"that the division of labour can be applied with equal success to mental as to mechanical operations, and...it ensures in both the same economy of time."

Babbage realised that a logical extension of this intellectual industrialisation was that the work of the third group should be undertaken by machine.

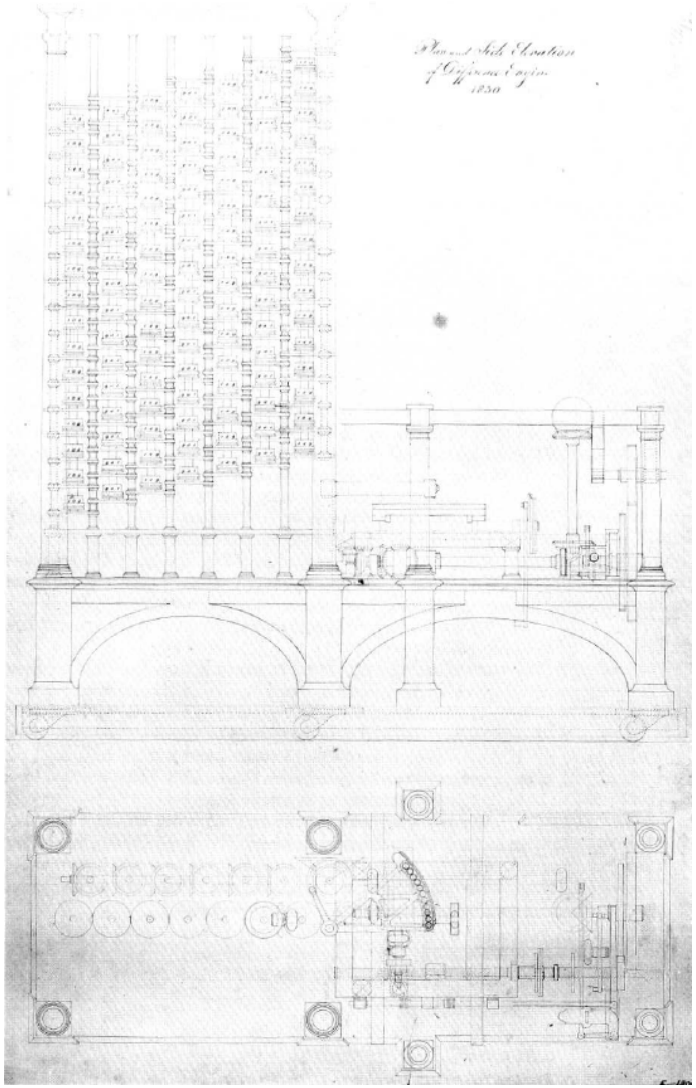
Moreover, if the machine directly produced the printed version, the main causes of error in the production of tables would be eliminated.

This was the origin of the *Difference Engine*, which was really just a calculating machine.

Whilst designing this machine, Babbage realised that the work of the analysts in coverting formulae to numbers could also be automated.

This was the aim of the *Analytical Engine*, which would receive the formulae through punch cards.

The flexibility of the punch card system permitted the combination of different operations, leading to a form of programming.



The Difference Engine consisted of two major parts-the calculating mechanism and the printing and control mechanism.

Elevation and plan drawings of Babbage's Difference Engine as planned about 1830.

The calculating mechanism is on the left; the axes of figure wheels for the tabular value (far right) and six differences are clearly visible.

The printing mechanism is on the right, and the moving table carrying the stereotype printing plate and the sector carrying the digit-type punches are visible in the center of both drawings.

Idea of the Difference Engine

Given a polynomial of degree *N*

$$f(x) = a_0 + a_1 x + a_2 x^2 + \cdots + a_{N-1} x^{N-1} + a_N x^N$$

its value at equally spaced points 0, *h*, 2*h*, 3*h*, etc can be evaluated in the following way: The *N*-th difference is a constant, adding this difference to get *N*-1 th difference, adding *N*-1 th difference to get *N*-2 th difference, and so on until adding first difference to get the function value. The difference is defined to be:

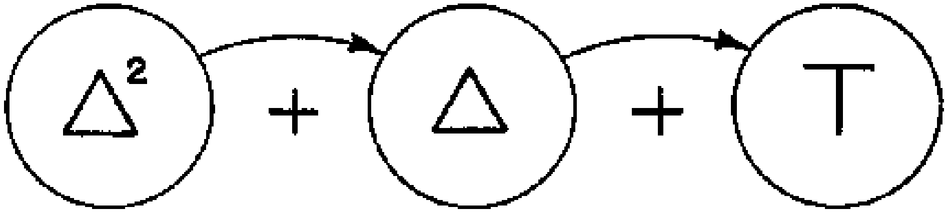
$$\Delta f(x) = f(x+h) - f(x), \qquad \text{1st difference}$$

$$\Delta^2 f(x) = \Delta f(x+h) - \Delta f(x), \qquad \text{2nd difference}$$

$$\Delta^3 f(x) = \Delta^2 f(x+h) - \Delta^2 f(x), \qquad \text{3rd difference}$$

$$\ldots$$

Δ^2	Δ	T (X^2+X+41)	x
		41	0
	2		
2		43	1
	4		
2		47	2
	6		
2		53	3
	8		
2		61	4
	10		
		71	5



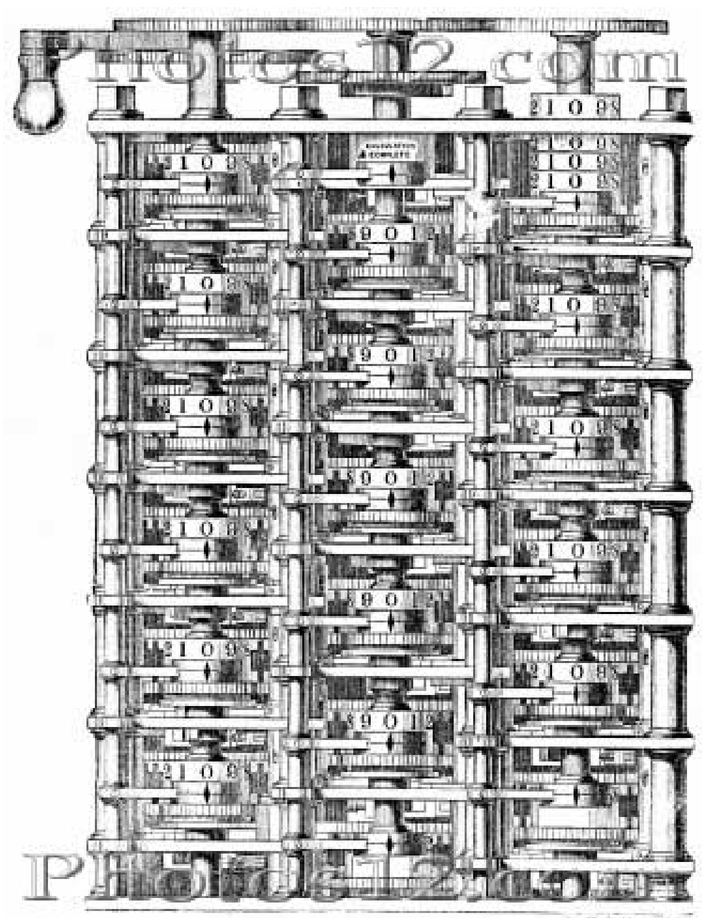
Finite Difference Example

- Given function $F(x)=x^2+2x+3$, let $h = 1$
- $F(0)=3$, $\Delta F(0)=F(1)-F(0)=3$, $\Delta^2 F(0)=\Delta F(1)-\Delta F(0)=F(2)-2F(1)+F(0)=2$
- Thus to get function values at 0, 1, 2, 3, etc, we form:

x	0	1	2	3	4	5	6	7 ...
$\Delta^2 F$	2	2	2	2	2	2	2	2 ...
ΔF	3	5	7	9	11	13	15	17 ...
F	3	6	11	18	27	38	51	66 ...

Known initial values

The Difference Machine



2nd difference   1st difference   F : function value

Each column of wheels stores the *n*-th difference.

A major operation in the computation is to add the higher order difference to the next lower order difference.

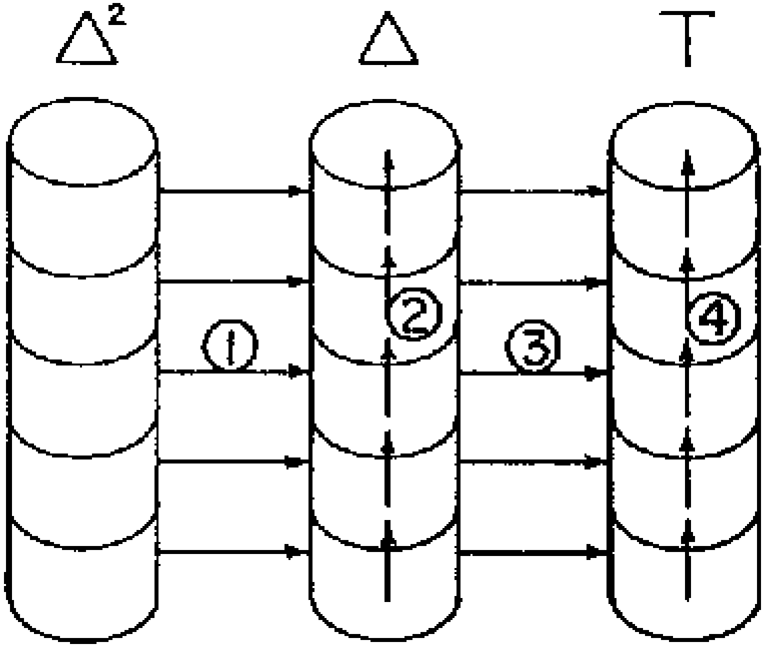
Each addition consists of two distinct steps-the simultaneous addition of all figures of the first difference to the corresponding figures of the tabular value, and the consecutive propagation of carries from the units up to the most significant digits as required.

Tabulation of a function involves the repetition of this basic addition process for each of the orders of difference involved.

As each axis is also an adding mechanism the tabulation of a cubic function from third differences, for example, requires six steps for each tabular value produced:

1. Addition of third difference digits to second difference digits
2. Carry propagation among second difference digits
3. Addition of second difference digits to first difference digits
4. Carry propagation among firstt difference digits
5. Addition of first difference digits to tabular value digits
6. Carry propagation among tabular value digits.

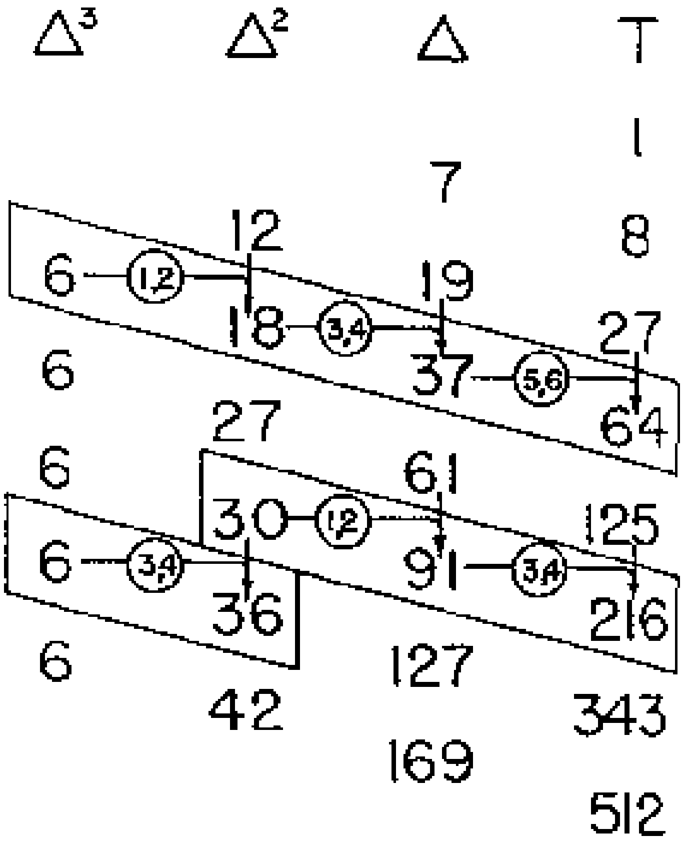
Negative numbers may be handled with no additional mechanism by representing them as their ten's complements.

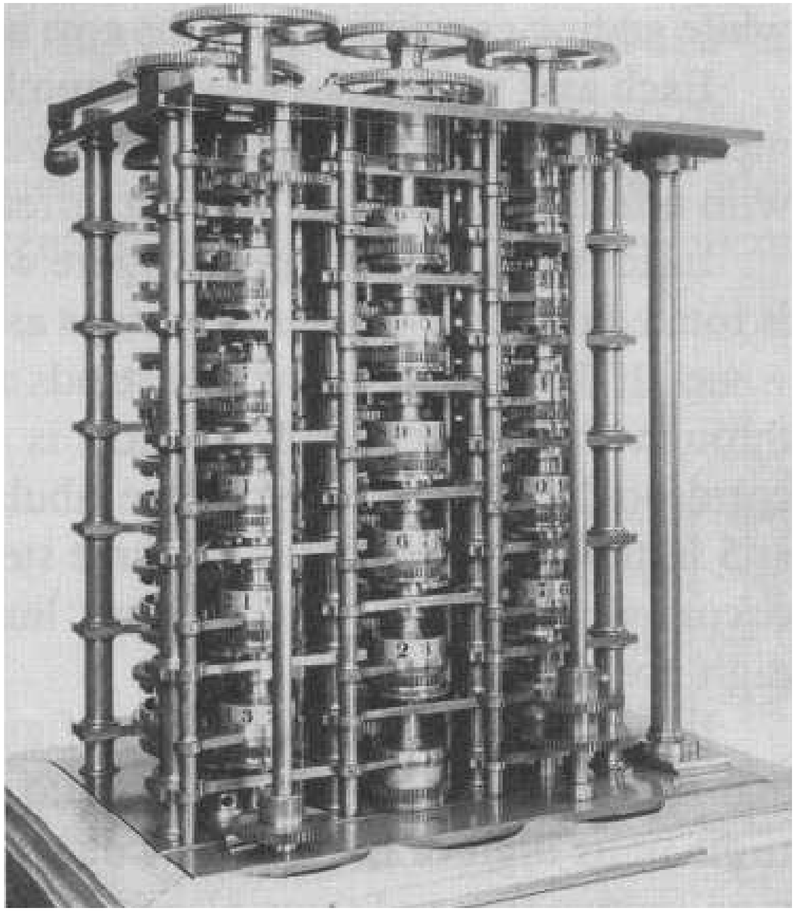


Tabulation of a quadratic, showing sequential updating of the differences.

Pipelining

Tabulation of a cubic, showing the overlapping of updating used in the Difference Engine so that the calculating time is independent of the number of differences used.



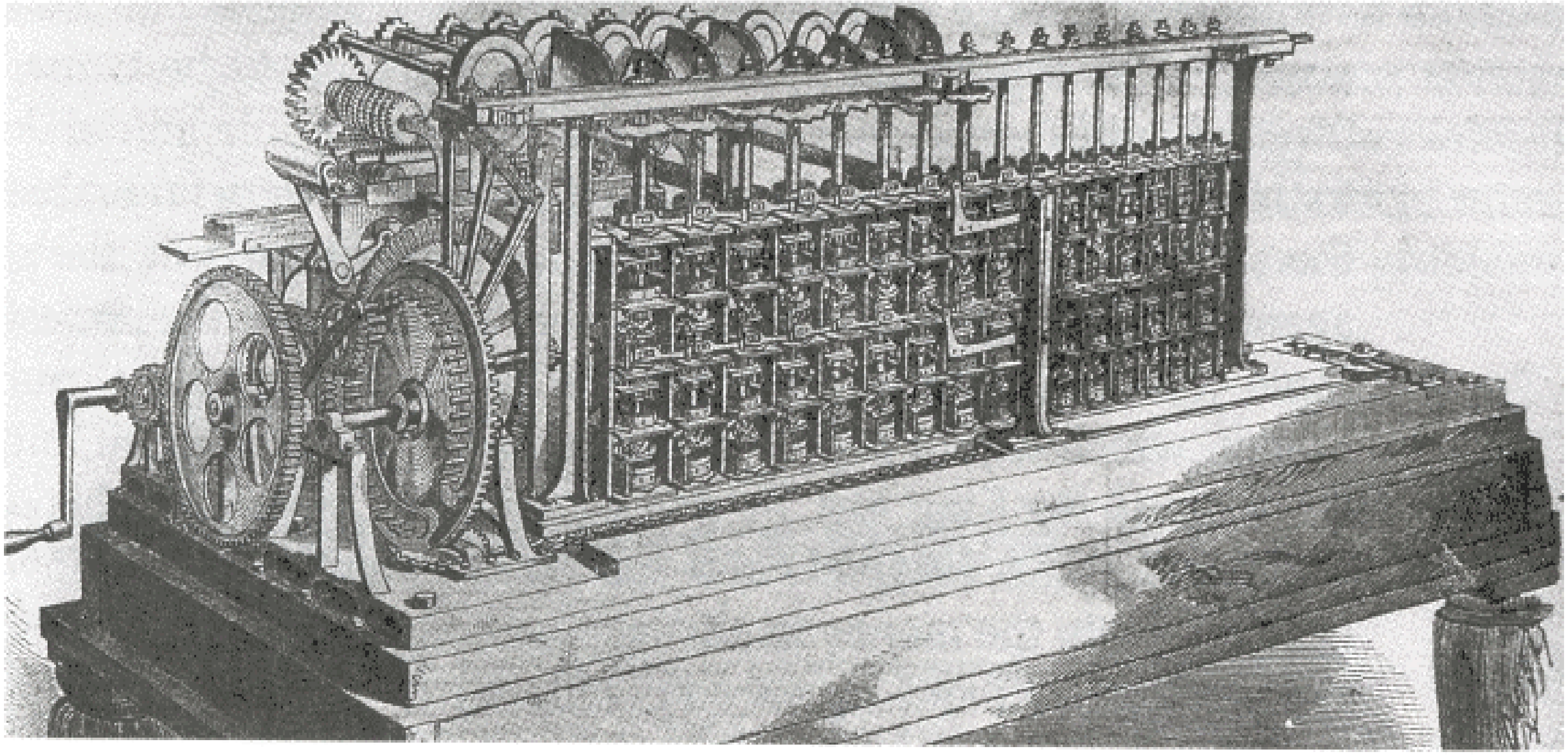


The portion of the calculating mechanism of the Babbage's Difference Engine assembled in 1832.

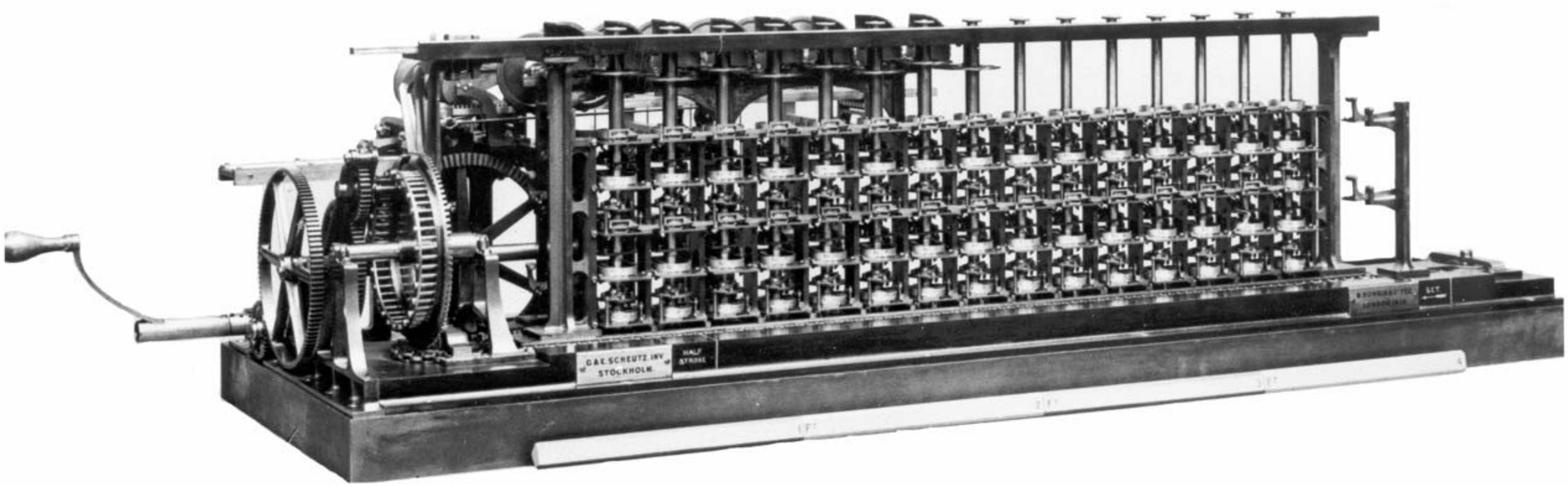
Records of nearly a hundred functions tabulated by Babbage with this portion have survived.

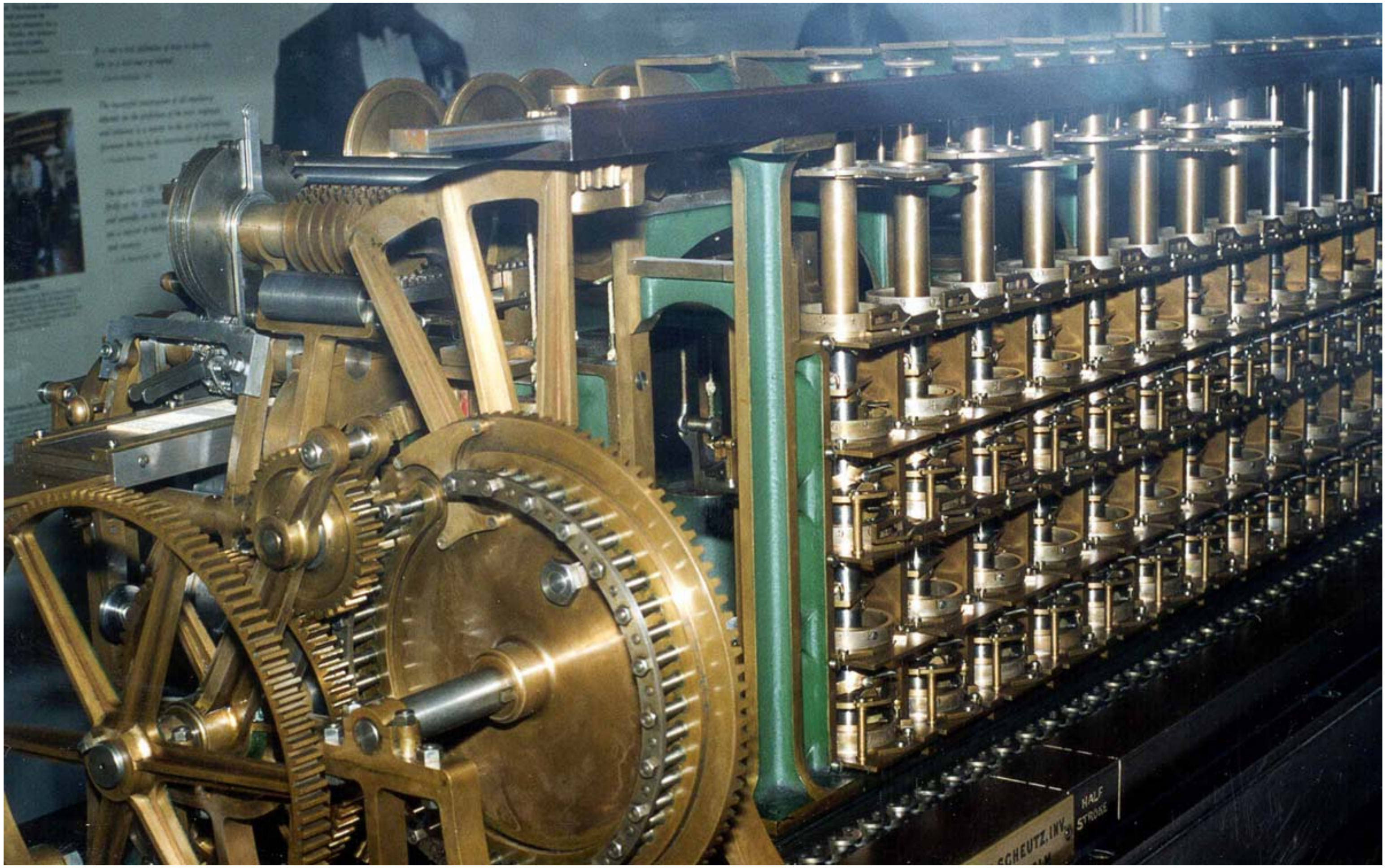
Due to various reasons, the machine was never finished after spending £17,000 from the Government and £20,000 from his own pocket.

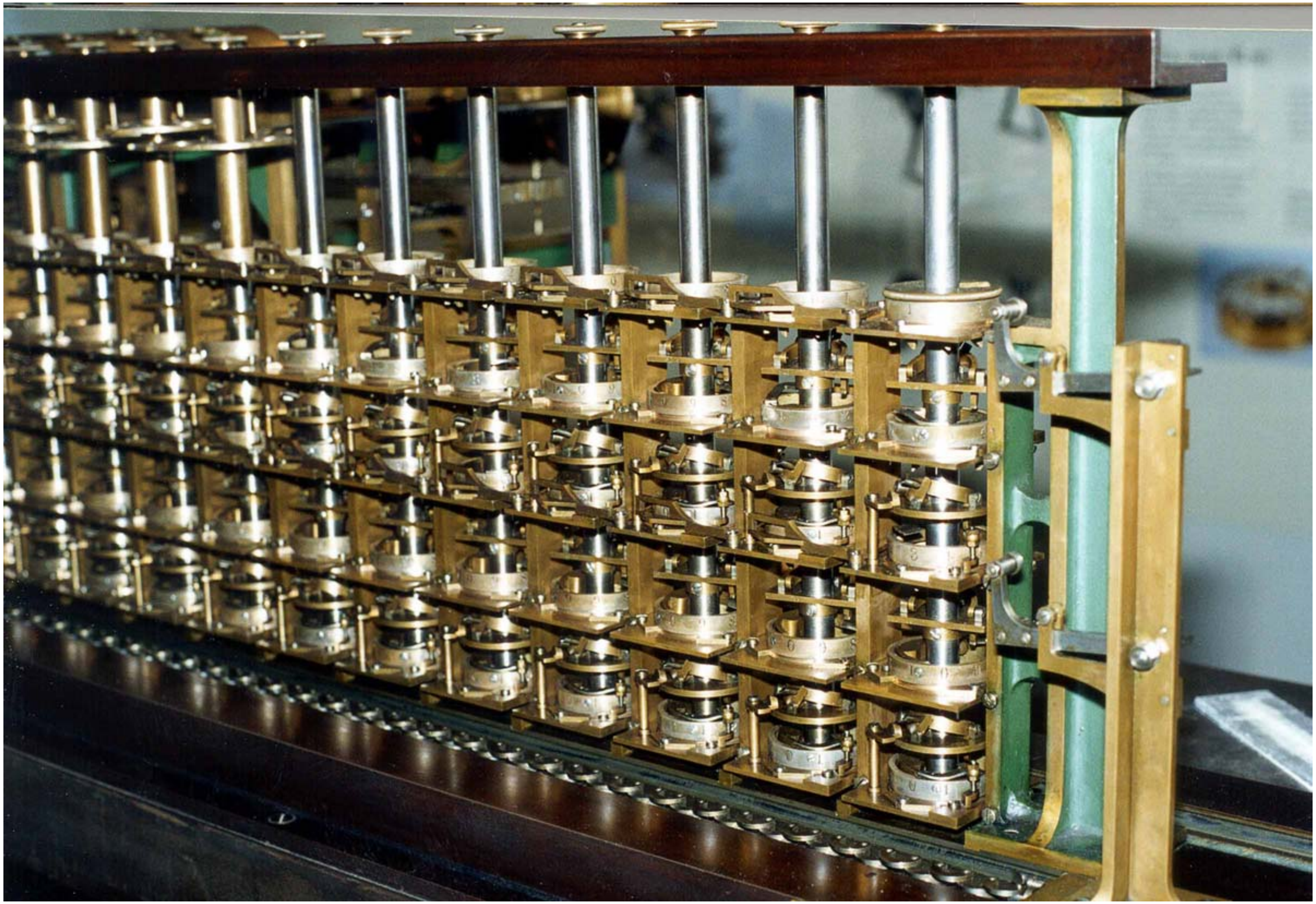
The Scheutz Difference Engine



Around early 1850, Sheutz father-and-son team built the first functional difference machine.


G & E. SCHEUTZ. INV.
STOCKHOLM.
HALF
STROKE


HALF
STROKE



The Difference Engine No. 2

Work on the design of the Analytical Engine ended in 1847. At that time Babbage turned to the design of a Difference Engine No. 2, exploiting the improved and simplified arithmetic mechanisms developed for the Analytical Engine.

The logical design was the same as for the earlier Difference Engine, but he employed simpler mechanisms for storing and adding numbers and carry propagation,

The printing mechanism was simplified so that a whole number was impressed on a printing plate as a single action rather than in a digit-by-digit manner.

A conventional print copy, using inked rollers, was made simultaneously.

The control was arranged by a single barrel in a very straightforward manner.

The design and a complete set of drawings was prepared by mid-1848. These Babbage offered to the British government, apparently to satisfy a commitment he felt existed in consequence of the failure of the project to build the first Difference Engine.

The government showed no interest in the new design.

The Construction of DE No. 2 at the Science Museum, London

The proposal to construct Difference Engine No. 2 was made by Bromley in May 1985 during one of his sabbatical visits from Sydney.

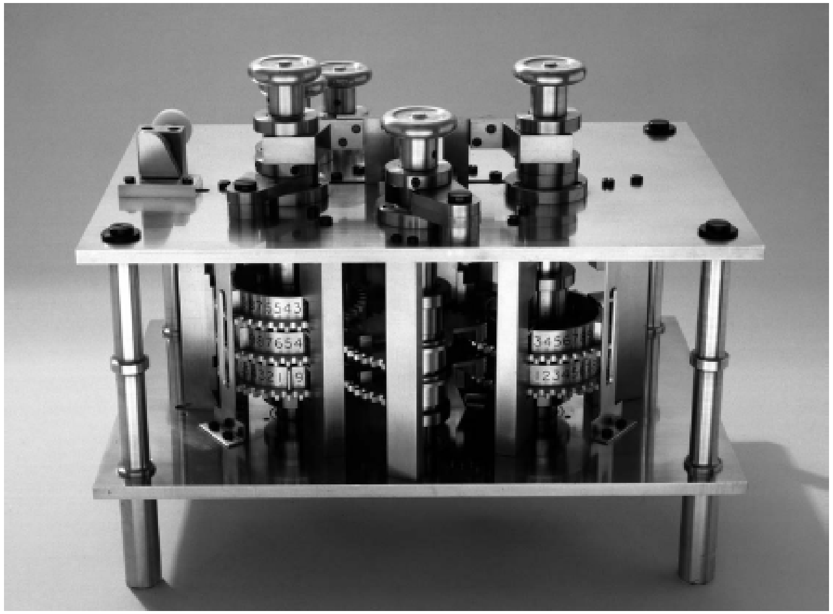
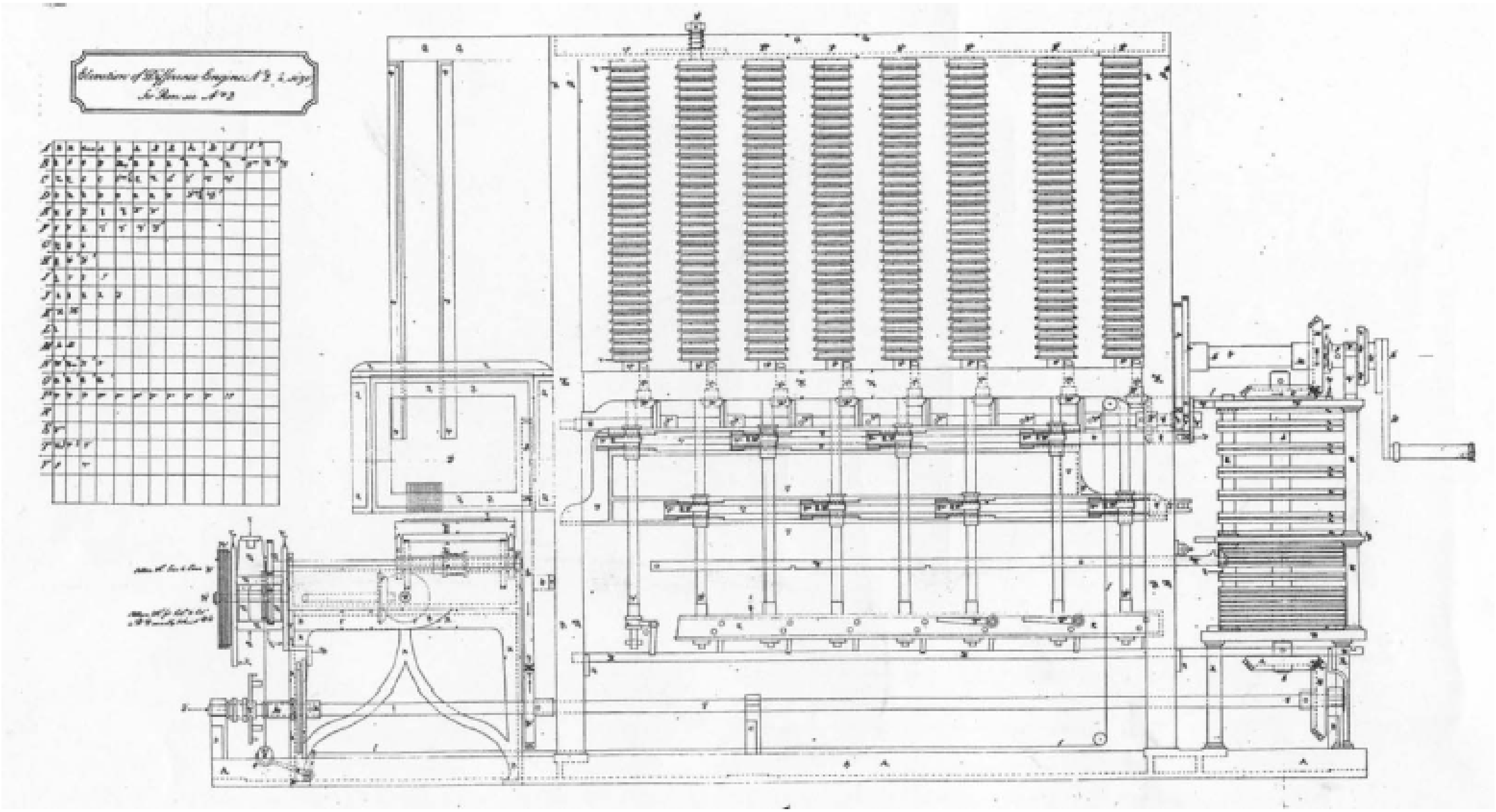


Figure 1. Trial piece, 1989. Adds a two-digit decimal number to a three-digit number and takes account of the tens carriage. (Photo courtesy of the Science Museum, London.)

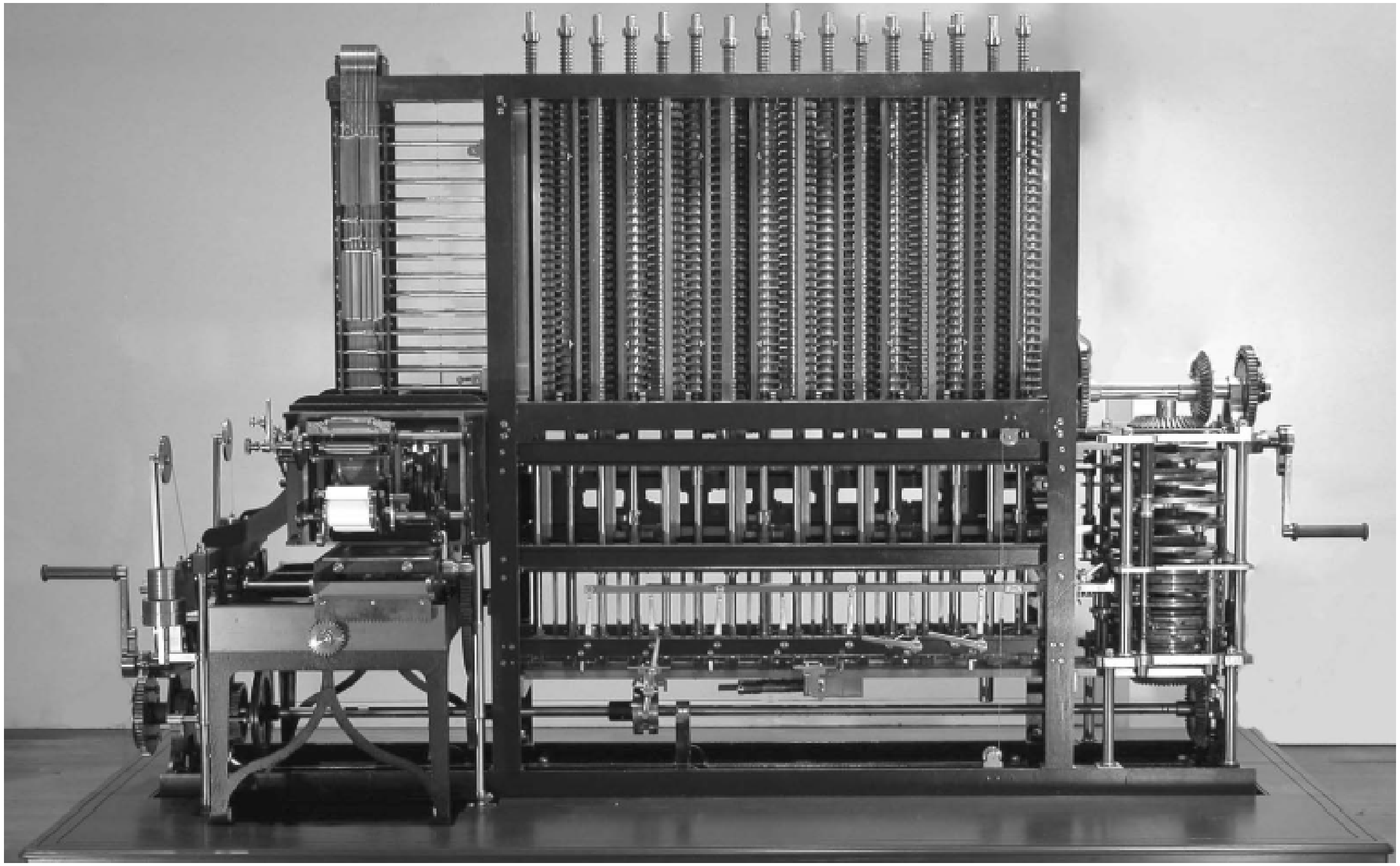
Fitting and assembly started in September 1990, and the calculating section was fully assembled by late June 1991.

The engine performed its first full automatic error-free tabulation of the function $y = x^7$ on 29 November 1991, 27 days before Babbage's 200th birthday.



Design drawing. Main elevation showing crank handle (right), calculating section (center), and output apparatus (left).

Science Museum Library Babbage Papers, drawing BAB [A] 163, “Elevation for Difference Engine No. 2.” (Drawing courtesy of the Science Museum, London.)



Difference Engine No. 2, on display at the Science Museum, 2005. Eleven feet long and 7 feet high, the engine weighs 5 metric tons and has 8,000 parts. Main crank handle is at the right; the calculating section is in the center; and the output apparatus (printer and stereotype mechanisms) are at the left.

The Analytic Engine

«During the last six months I have invented a new machine, of a much greater power: I have abandoned all other research and at present I am making rapid progress, but probably will not have it built at this point. I am myself astonished at the power which I have been enabled to give it, and which I would not have believed possible a year ago.»

C. Babbage, in a letter to L. A. J. Quetelet, May 1835.

The Structure of the AE

«The Analytical Engine consists of two parts:

- *1st. The store in which all the variables to be operated upon, as well as all those quantities which have arisen from the result of other operations, are placed.*

- *2nd. The mill into which the quantities about to be operated upon are always brought.*

Every formula which the Analytical Engine can be required to compute consists of certain algebraical operations to be performed upon given letters, and of certain other modifications depending on the numerical value assigned to those letters.»

C. Babbage, *Passages from the Life of a Philosopher* (1864).

Representing Numbers

- The Analytical Engine was a decimal machine that used a sign-and-magnitude representation for numbers.
- In both the store and the mill the digits of numbers are represented by the positions of wheels (figure wheels) rotating about vertical axes.
- A collection of figure wheels on an “axis” corresponds to a register in a modern computer.
- The Analytical Engine is built from a series of horizontal plates separating the figure wheels on the various axes.
- The space between two plates is called a cage.
- The bottom cage holds the units figure wheels on each axis, the next above the tens, then hundreds, and so on. In general, digit transfers take place simultaneously in all cages, so the Analytical Engine is a digitwise parallel machine.

- All numbers in the Analytical Engine are of 40 digits, and there are 40 cages and 40 figure wheels on each axis.

- This large number was possibly chosen to simplify scaling problems in the absence of a floating-point number system.

- Since the plates dividing the cages were about 3 inches apart, a figure axis would be about 10 feet high. Allowing for the control mechanism underneath, the Analytical Engine would have stood about 15 feet high. The mill would have been about 6 feet in diameter, and the store would have run 10-20 feet to one side.

- The Analytical Engine would therefore have been about the size and weight of a small railway locomotive.

Figure Wheels

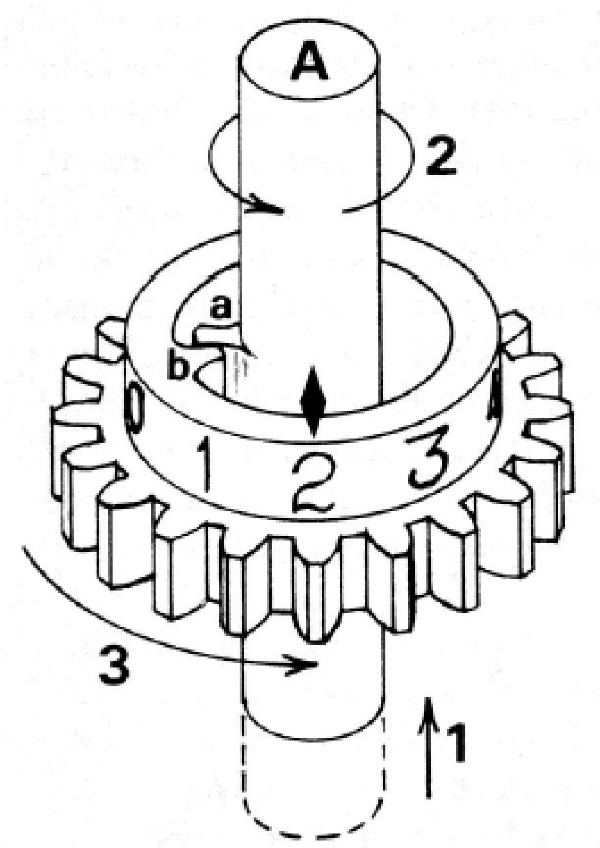


Figure wheel typical of the store and the mill figure axes.

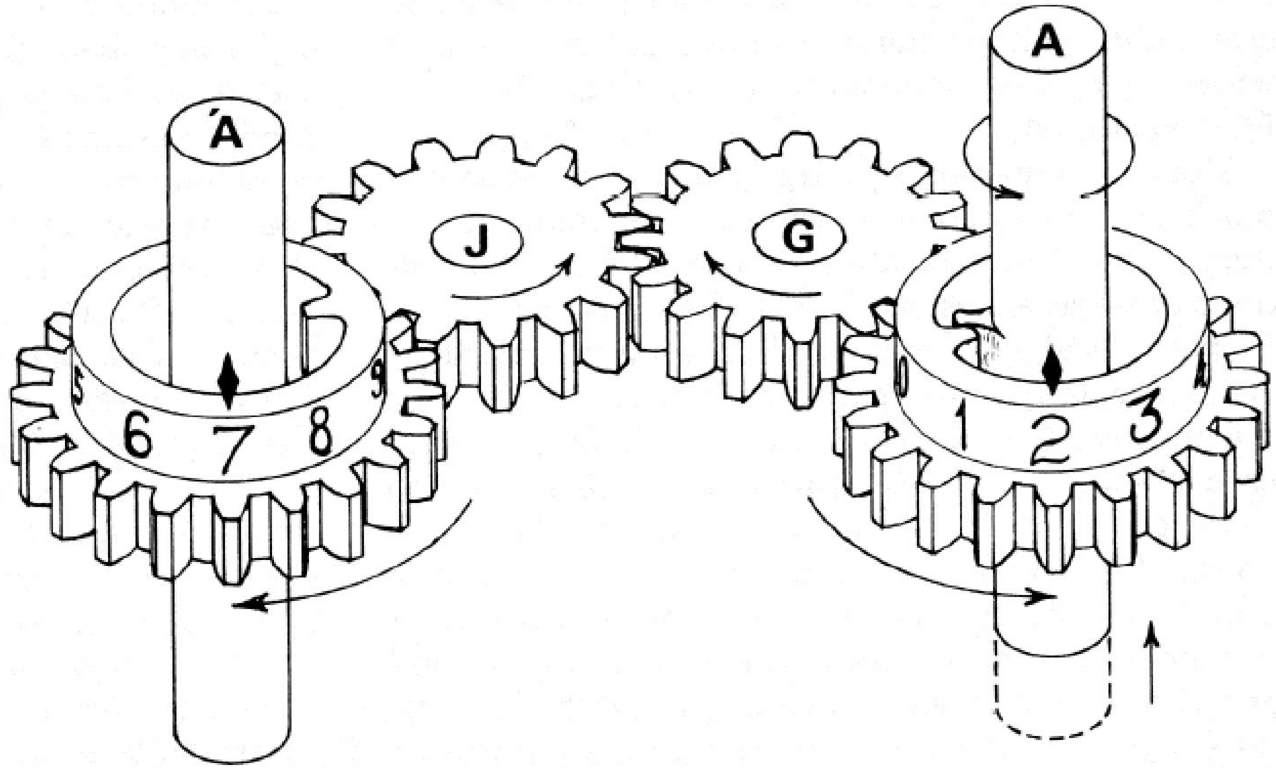
The wheel may stand in one of 10 positions to store the digit shown by the index mark.

The number may be read by raising the axis until its finger is level with that on the inside of the figure wheel and rotating it through nine digit positions.

The figure wheel will come to stand at the 0 position, and a movement proportional to the digit originally stored will be given to the remainder of the mechanism by the gear teeth.

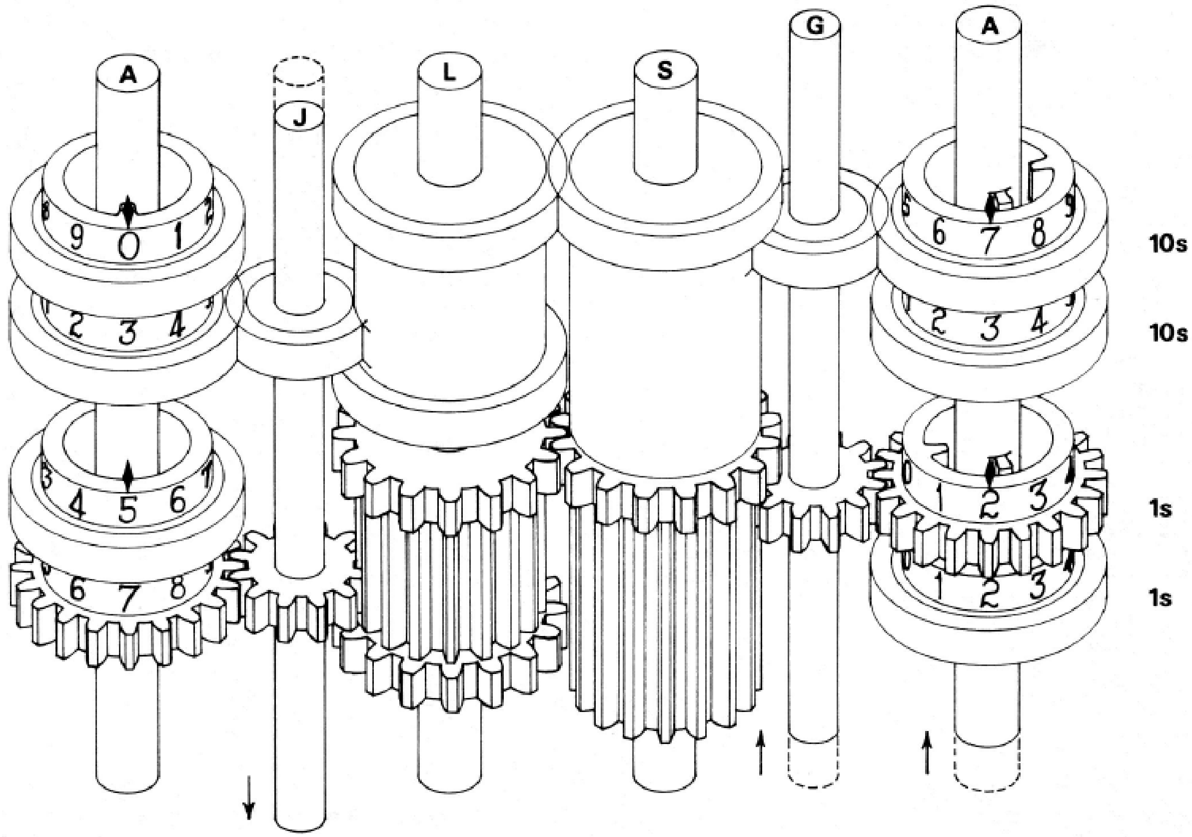
The process is termed Giving Off.

Basic Process of Addition



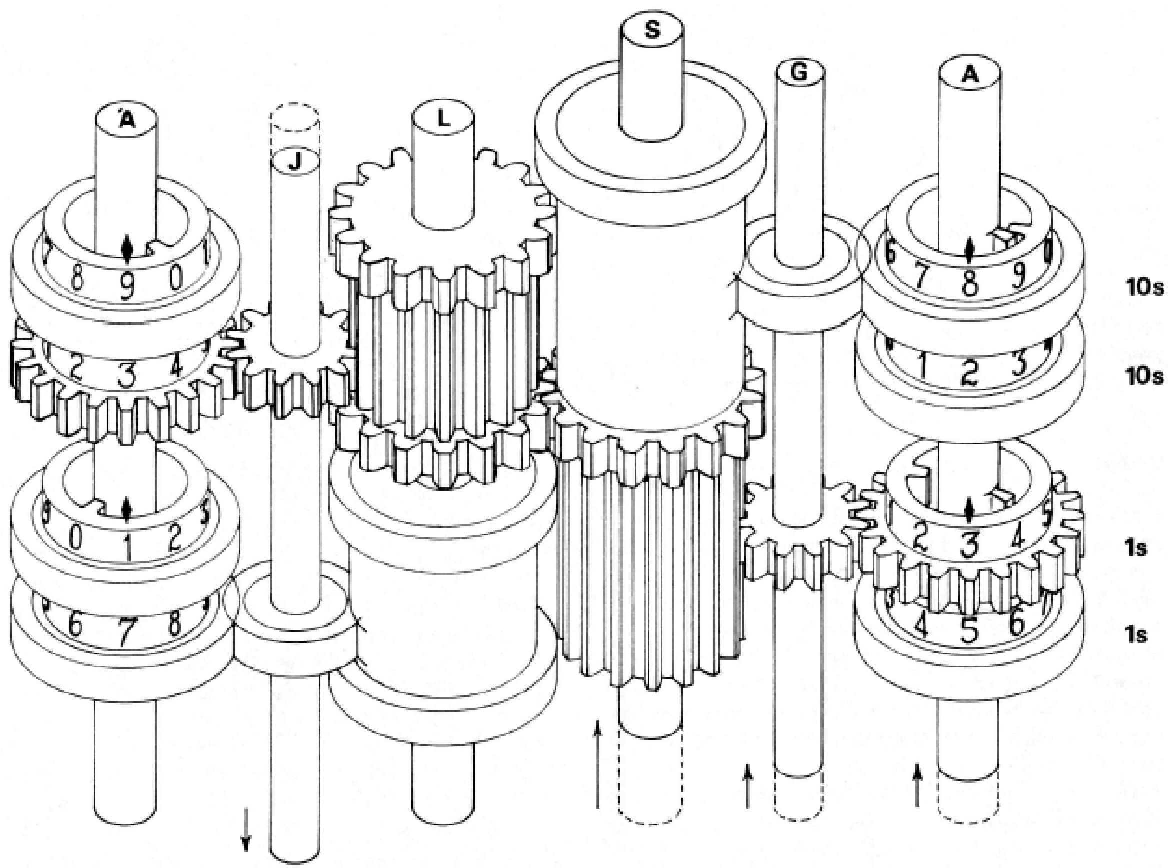
A digit is given off by the figure wheel on the right and received by the figure wheel on the left. If the receiving figure wheel is not originally at 0, it will finally come to stand at the sum of its original value and the digit received. This process occurs simultaneously for all digits of numbers.

Digitwise Parallel Addition



Two figure wheels are shown in each cage, so two numbers may be stored on each figure axis. In practice the mechanism is arranged in a circle so that the axes A and ‘A coincide. A number given off may therefore be received on the alternate set of figure wheels of the same axis.

Process of stepping (or multiplication and division by 10)



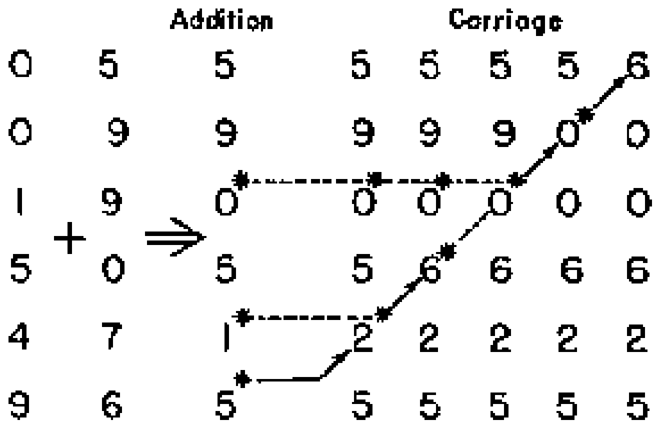
The “long pinions” S are raised with their axis to engage the long pinions L in the cage above. A number given off will therefore be stepped up a cage, or multiplied by 10. A transfer in the reverse direction will divide by 10.

Anticipating Carry

«The most important part of the Analytical Engine was undoubtedly the mechanical method of carrying the tens. On this I laboured incessantly, each succeeding improvement advancing me a step or two. The difficulty did not consist so much in the more or less complexity of the contrivance as in the reduction of the time required to effect the carriage.»

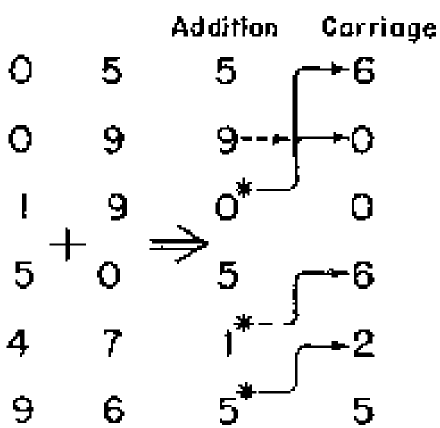
C. Babbage, *Passages from the Life of a Philosopher* (1864).

Babbage's Two Methods of Carry Propagation



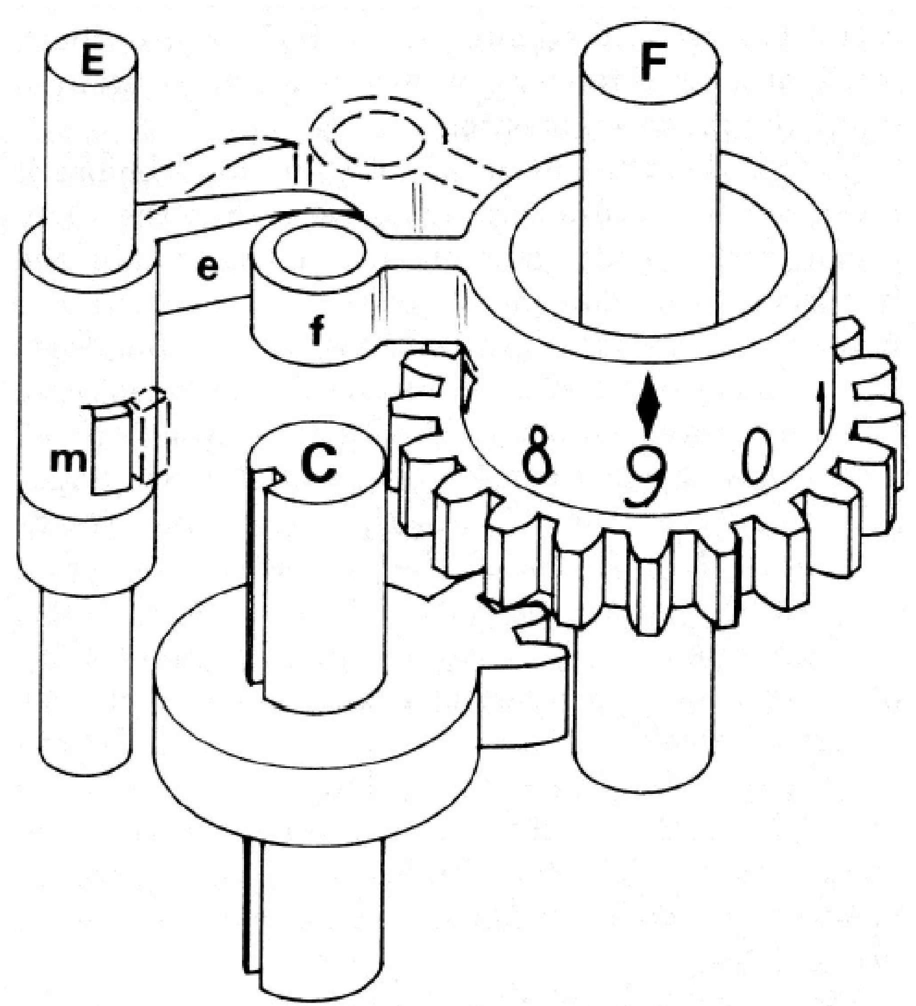
The upper example shows the sequential carry mechanism used in the Difference Engine.

Corresponding digits are first added simultaneously (units to units, tens to tens, and *so* on) and carriages warned, as shown by a star. The carriage propagation then proceeds sequentially from the units digit upward.



The lower example shows the anticipating carriage used in the Analytical Engine. The addition process is unchanged, but all of the carriages are propagated simultaneously.

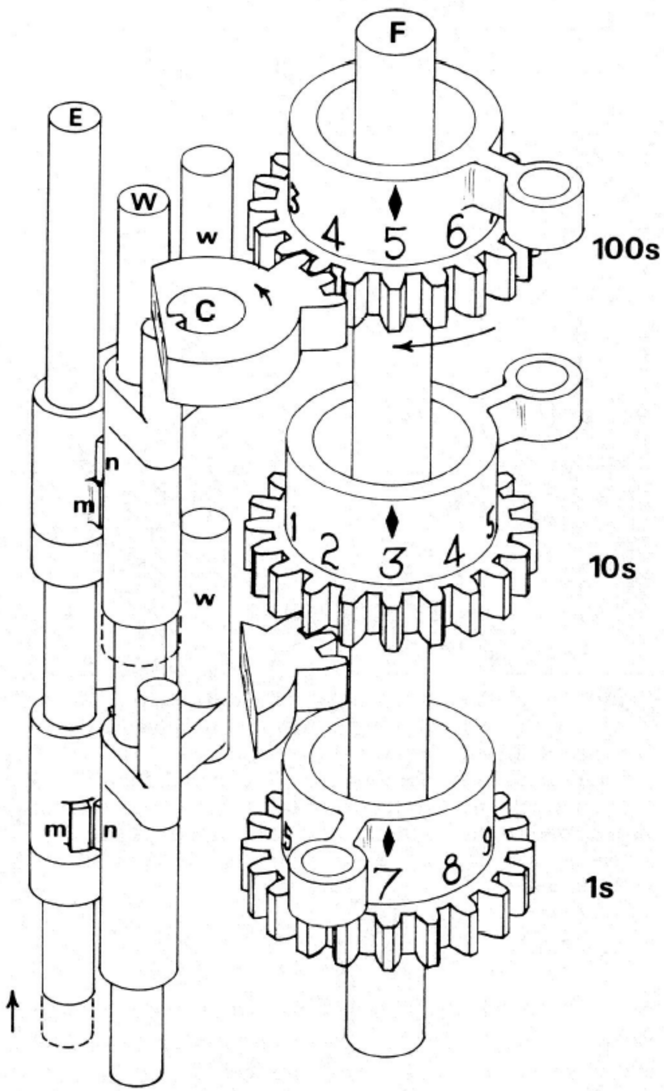
The Carry Mechanism



When the carry figure wheel moves past 9 to 0 arm f acts on arm e to rotate the “carry warning” indicating that a carry is necessary into the cage above.

A carry from the cage below will raise the “carry sector” on axis C into gear with the figure wheel and advance it by one digit position.

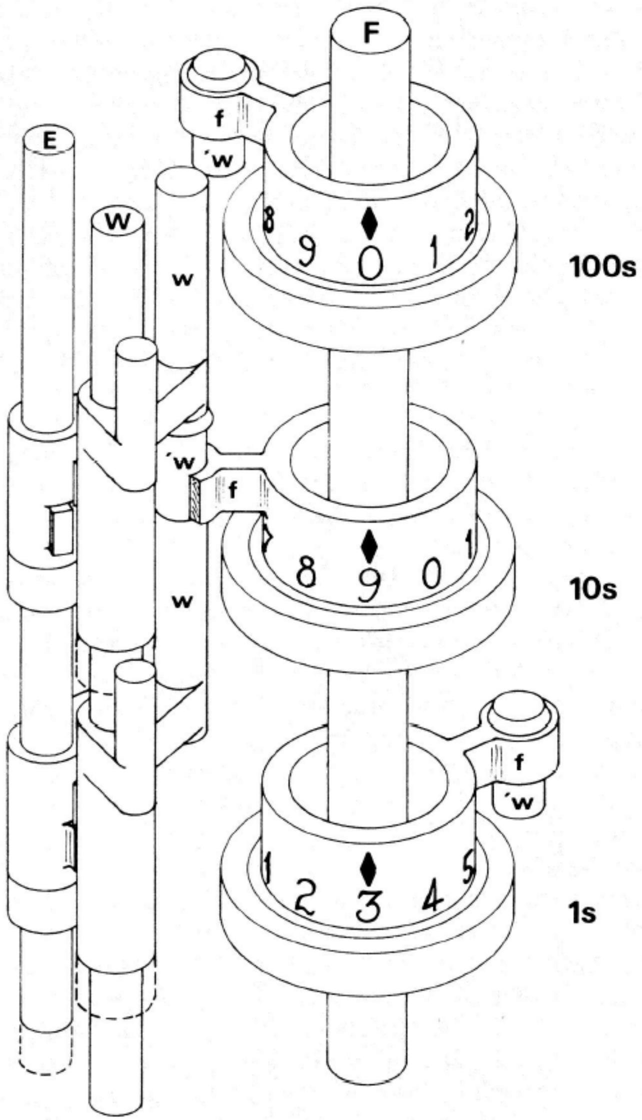
The Carry Mechanism



The carry warning is raised with its axis E and lifts the carry sector in the cage above into gear with its figure wheel.

In the figure there is a carry from the tens into the hundreds cage, but none from the units to the tens.

Anticipating Carry



The movable wire ‘W carried in the arm of the figure wheel may interpose between the fixed wires w to propagate a carry through several cages.

In the figure a carry is generated in the units cage.

Because the tens figure wheel stands at 9, a carry is propagated to the hundreds cage.

The hundreds figure wheel does not stand at 9 and therefore breaks the chain of carry propagation.

The Logic of Anticipating Carry

Now, of course, we see the anticipating carriage as a simple example of logical manipulation. Each cage of the mechanism implements the logical equation

$$C_i = G_{i-1} + P_{i-1}C_{i-1}$$

where C indicates a carriage to be made, G indicates a carriage generated by a figure wheel passing from 9 to 0, and P indicates a carriage propagated by a figure wheel standing at 9 (and + is the OR operator).

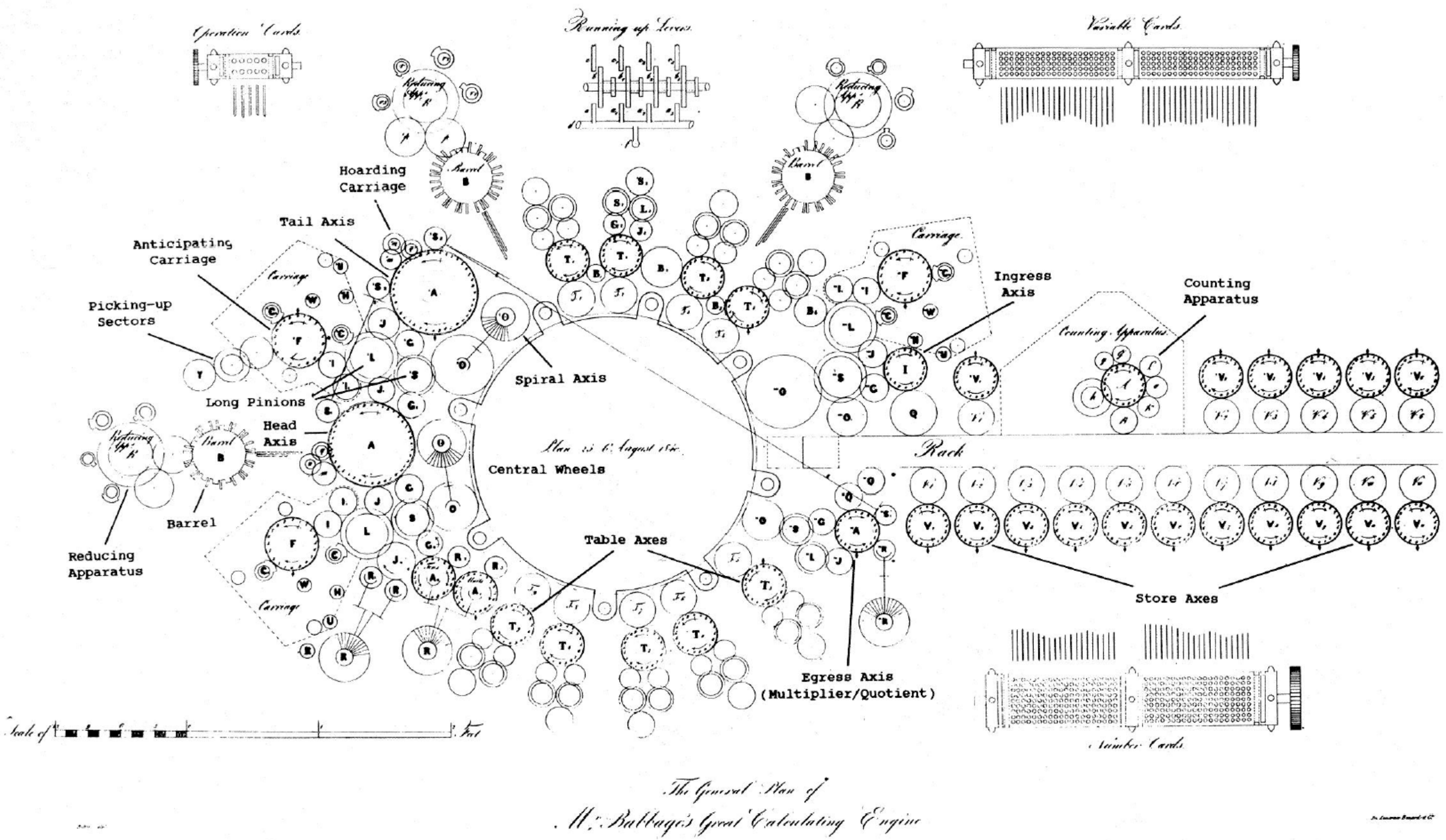
By substitution, a carriage mechanism in one cage acting on that in the cage above, we find

$$C_i = G_{i-1} + P_{i-1}G_{i-2} + P_{i-1}P_{i-2}C_{i-2}$$

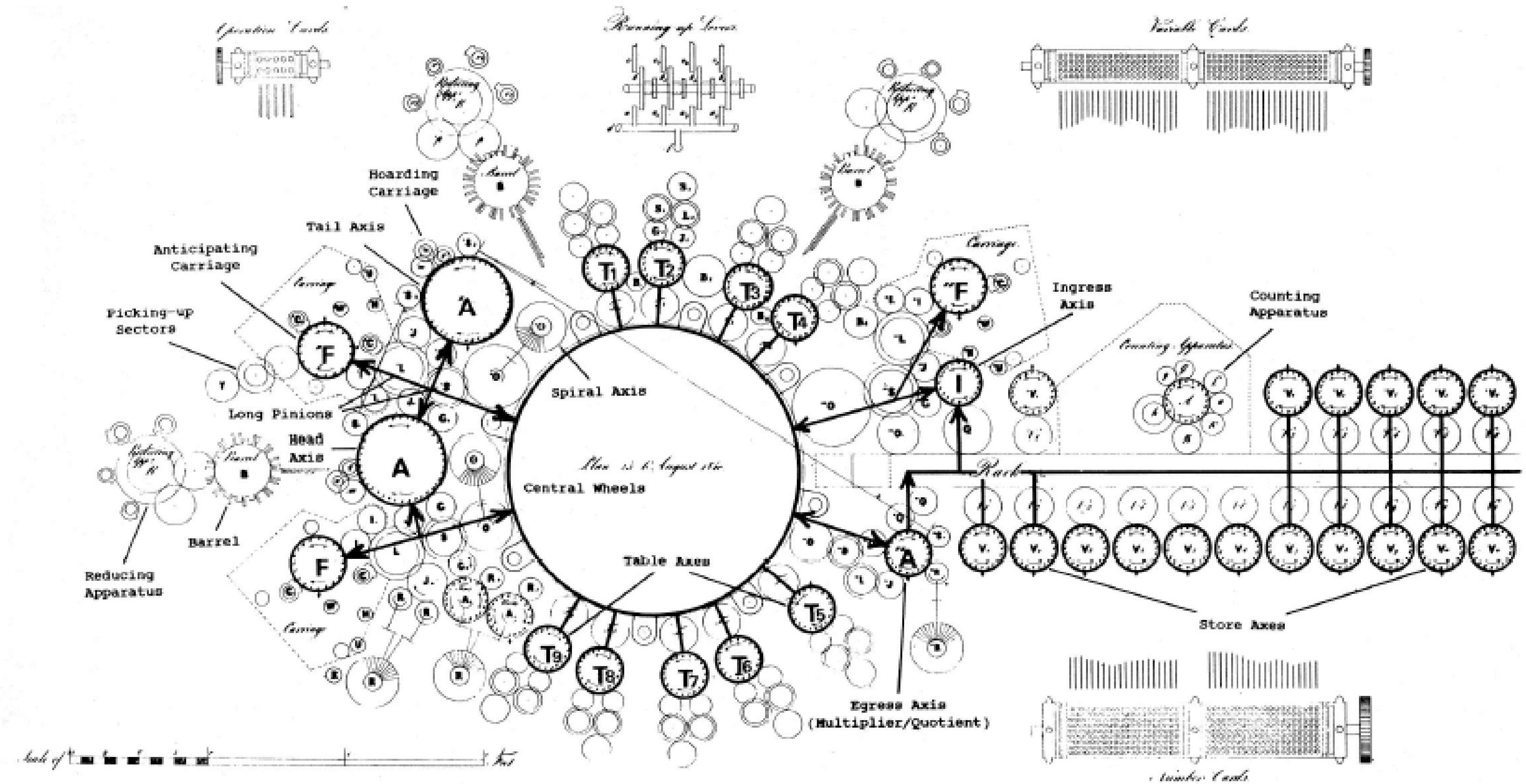
and so on.

But Babbage did not have at his disposal the modern forms of logic that arose from the work of George Boole in the late 1840s.

The Architecture of the AE

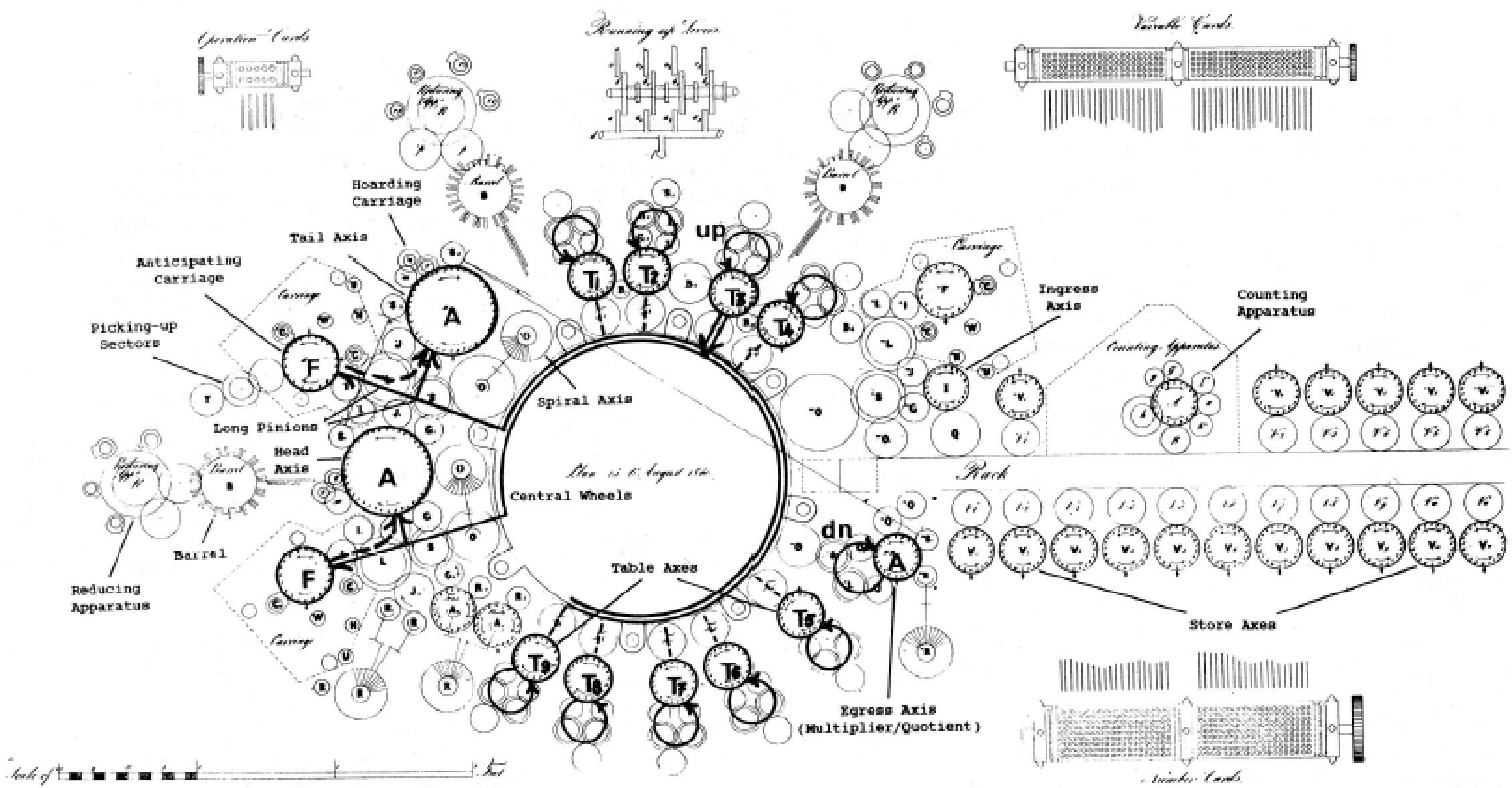


Major Registers and Data Paths of the AE



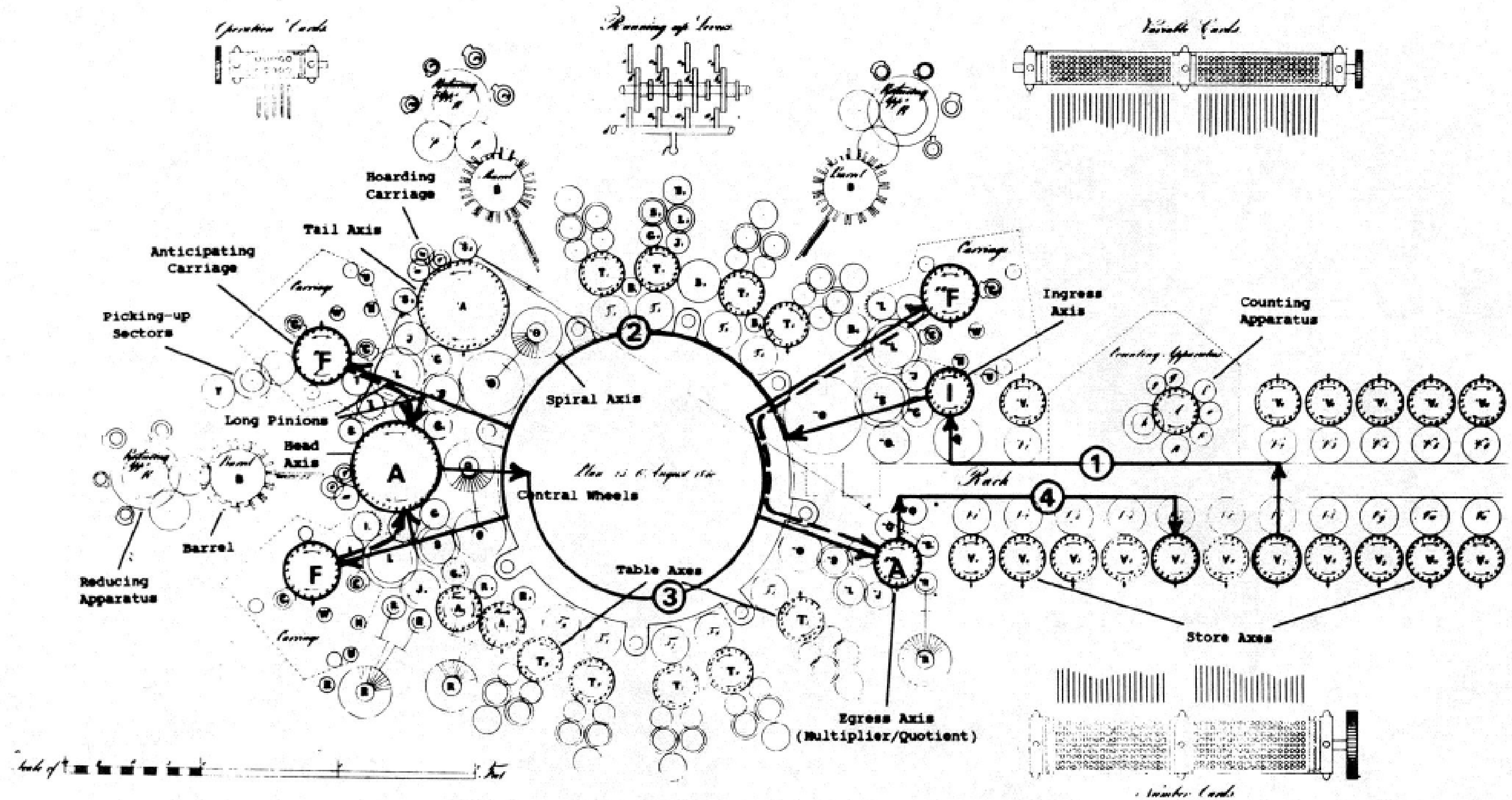
The store axes are arranged along the racks to the right, and communicate with the mill via the “ingress” and “egress” axes, which act as buffer registers. The mill is arranged around the “central wheels,” which act as an internal data bus servicing accumulators A and ‘A and table axes T1, to T9 used in multiplication and division. F, ‘F, and “F are the figure axes of the three sets of anticipating carry apparatus.

The Main Loop of Multiplication



A partial product, selected by a digit of the multiplier, is given off by a table axis (in this case T3) and added to the product on the head and tail axes A and ‘A. Simultaneously, the multiplier is stepped down on “A to select the next partial product, and the table axes are all stepped up to maintain the correct alignment with the product.

Addition



Stages in the pipeline of signed addition. An operand is fetched from the store to the ingress axis I, added to or subtracted from the total on A, the result converted into sign-and-magnitude representation on egress axis "A, and returned to store, in four separate steps that may be overlapped with one another for different operands.

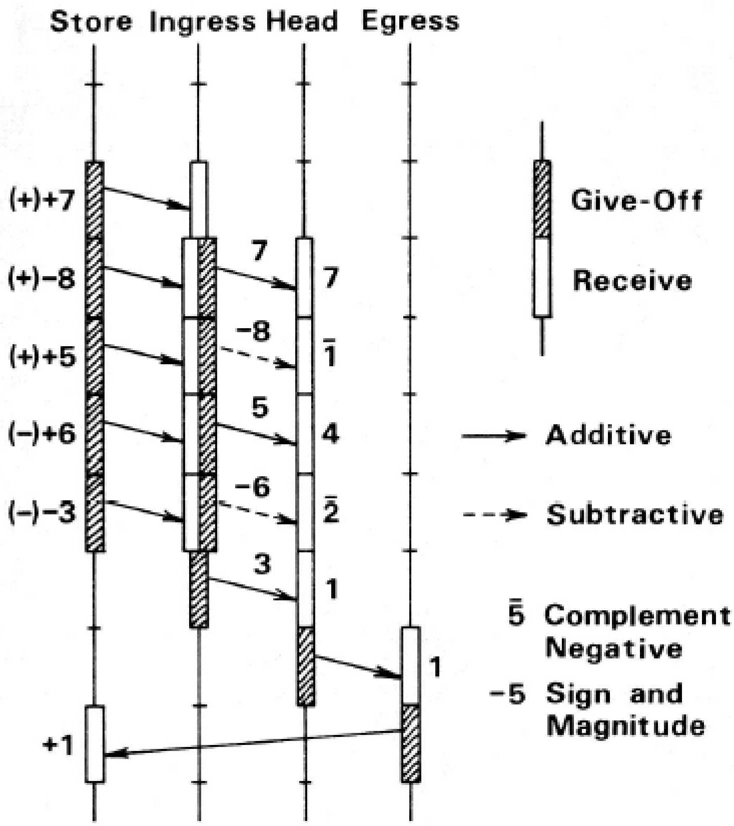


Figure 14. *Overlapping of functions in the pipeline for signed addition.* Five operands are accumulated, and only the result is returned to the store.

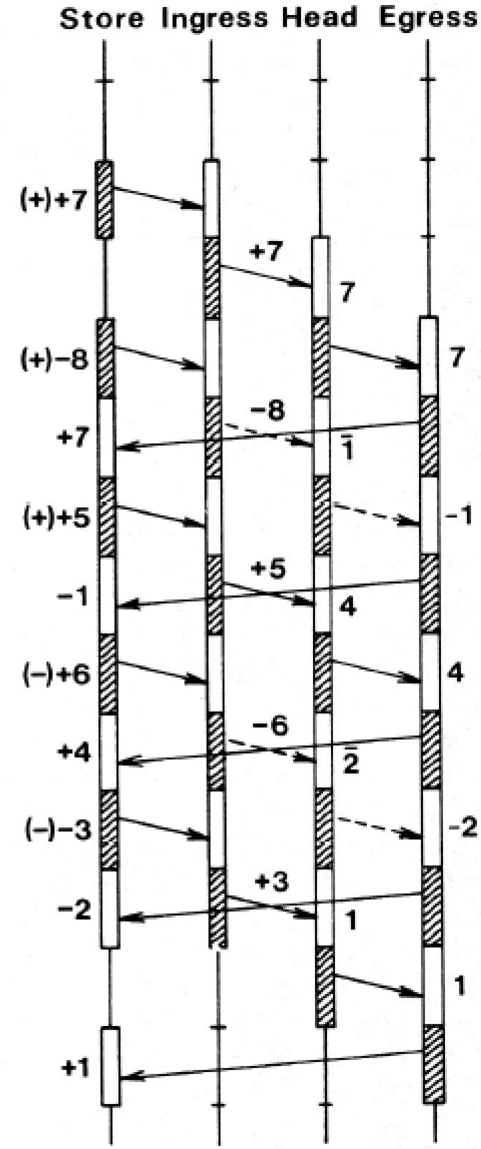
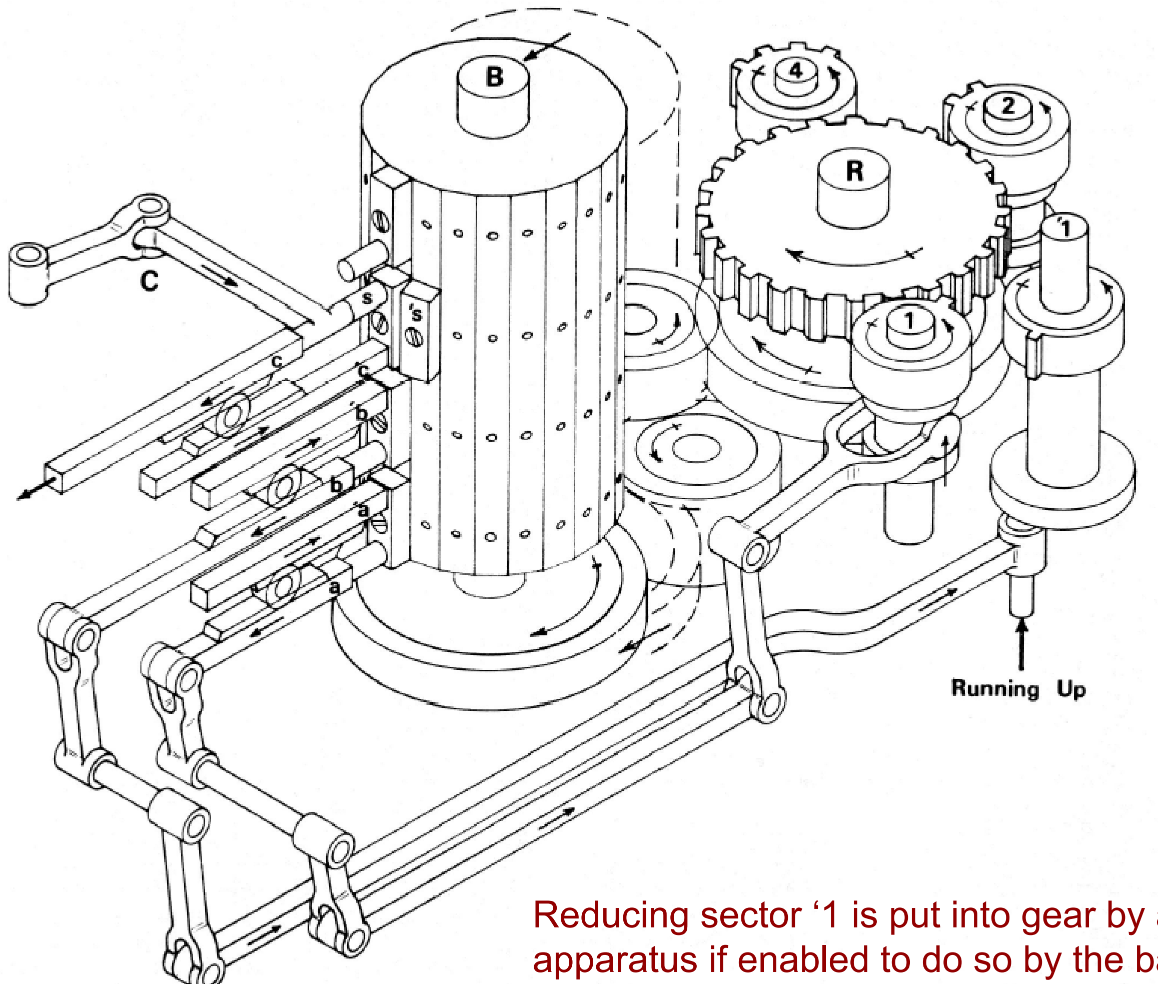


Figure 15. *Overlapping of functions in the pipeline for signed addition.* The same five operands are accumulated as in Figure 14, but each of the five partial sums is returned to store.

Control Mechanism



A microprogram word is represented by a vertical row of studs screwed to the barrel. These act on the ends of the control levers when the barrel moves sideways. The “reducing sectors” of one, two, and four teeth advance the barrel over the corresponding number of verticals, and several may act in combination at one time. In the figure, reducing sector 1 is put into gear directly by order of the barrel via control lever a.

Reducing sector ‘1 is put into gear by a “running up” from the carry apparatus if enabled to do so by the barrel and lever b, The effect is a conditional transfer. A “conditional arm” is sensed by control lever c to provide an action conditional on a previous event.

The Control Mechanism

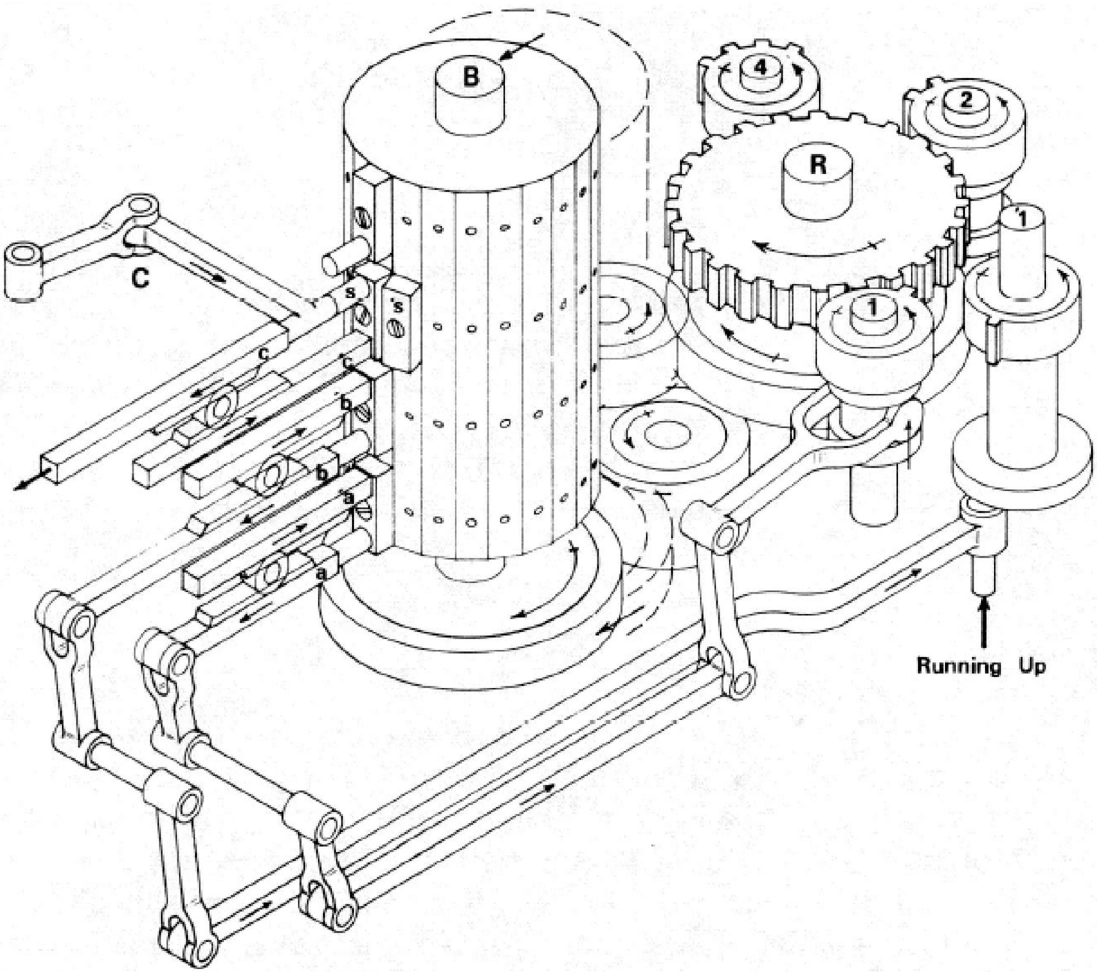
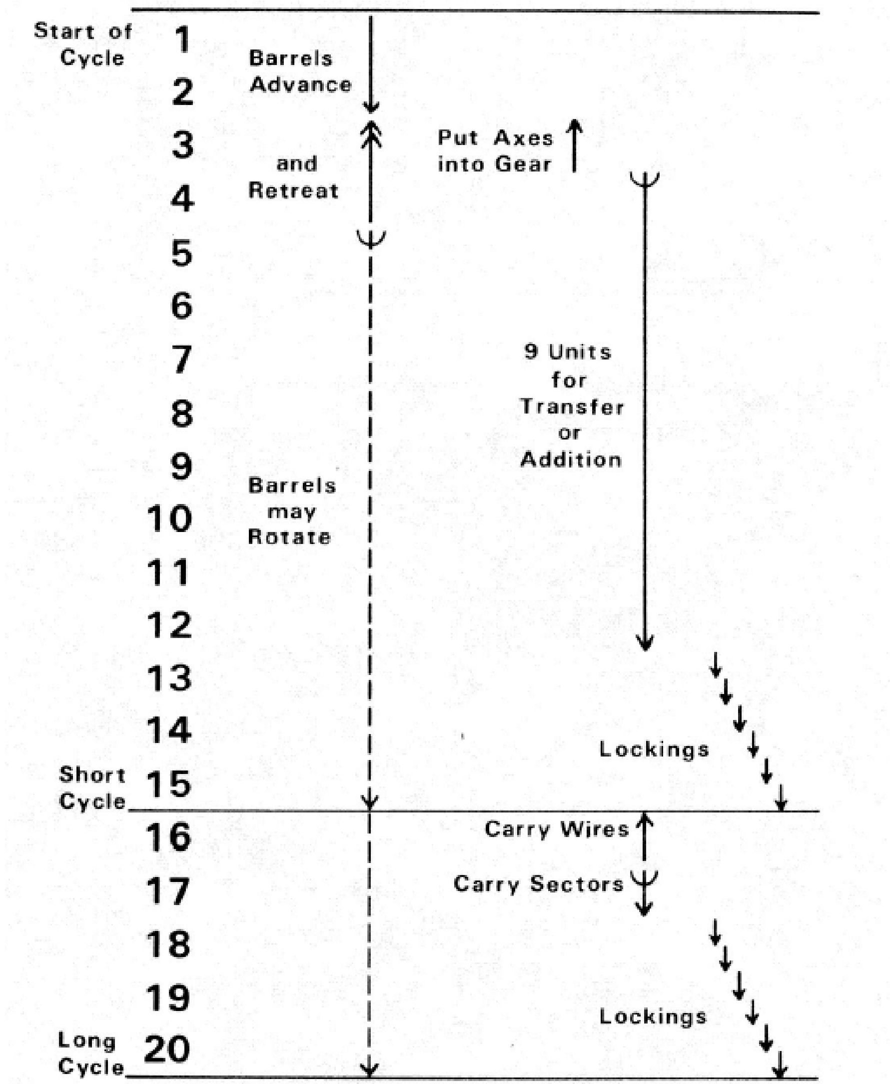


Figure 11. The microprogram barrel with the reducing mechanism that advances the barrel from one vertical to another. Pins in row *a* on the barrel control one of the sectors of the reducing apparatus to advance the barrel one vertical. Pins in row *b* enable another sector to be placed in gear in the event of a running up in the calculating mechanism and thus conditionally advance the barrel to another vertical. Pins in row *c* sense a conditional arm and thus respond to a conditional event in an earlier cycle of operation.

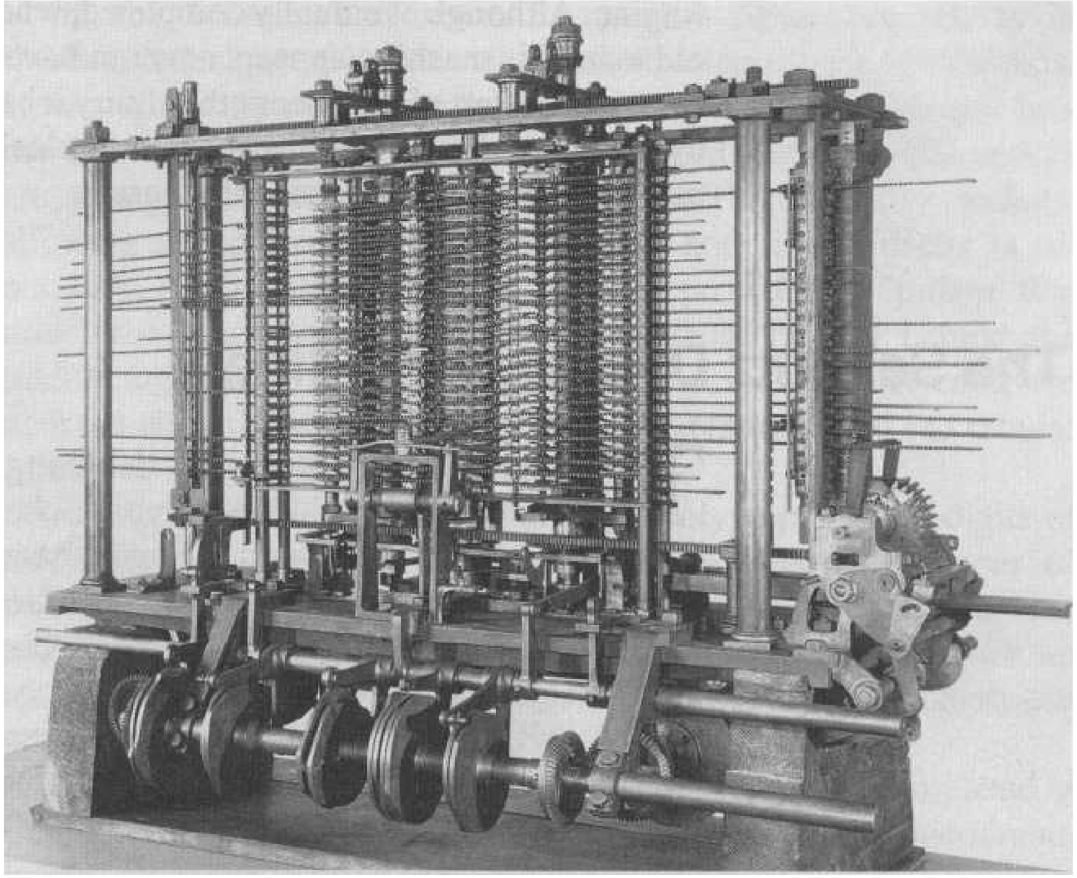
Timing Cycles of Operations



Timing diagram to illustrate the major events in the basic cycle of operation of the Analytical Engine.

Every cycle includes the transfer or addition phase, but the carry phase is only required in cycles that perform an addition.

The style of this figure is similar to Babbage's own notations.



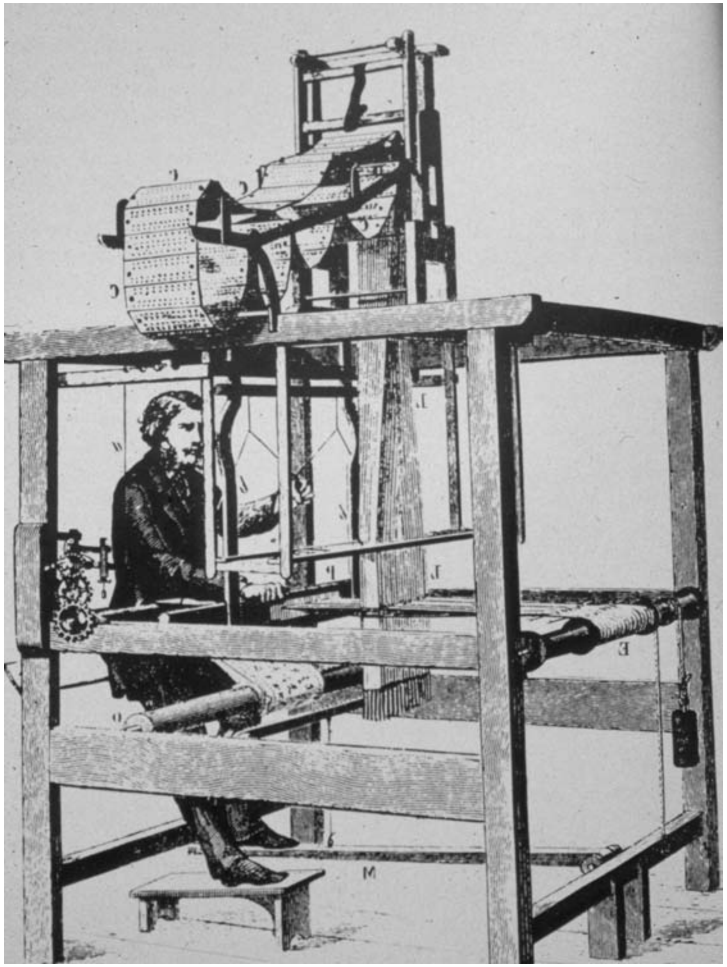
A model of the mill of the Analytical Engine that was under construction at the time of Babbage's death.

The horizontal racks communicate numbers between the two number axes in the center and to the printing mechanism at the right.

An anticipating carriage mechanism is located between the number axes.

Jacquard’s Loom

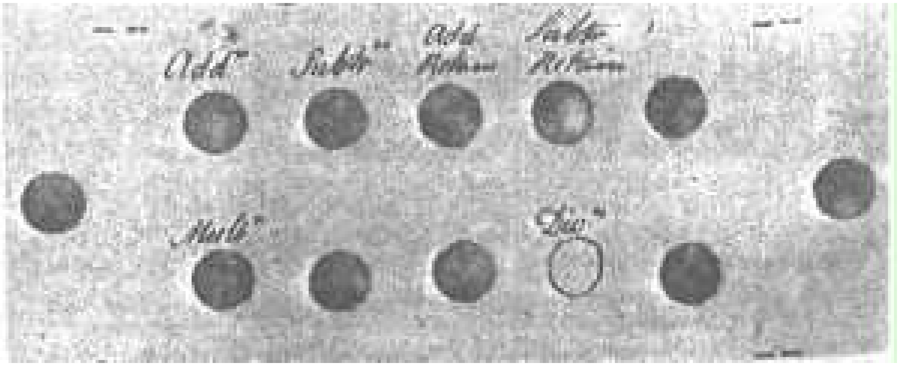
[Jacquard-card Making.]



The Punched Cards

«There are therefore two sets of cards, the first to direct the nature of the operations to be performed--these are called operation cards: the other to direct the particular variables on which those cards are required to operate--these latter are called variable cards.»

C. Babbage, *Passages from the Life of a Philosopher* (1864).

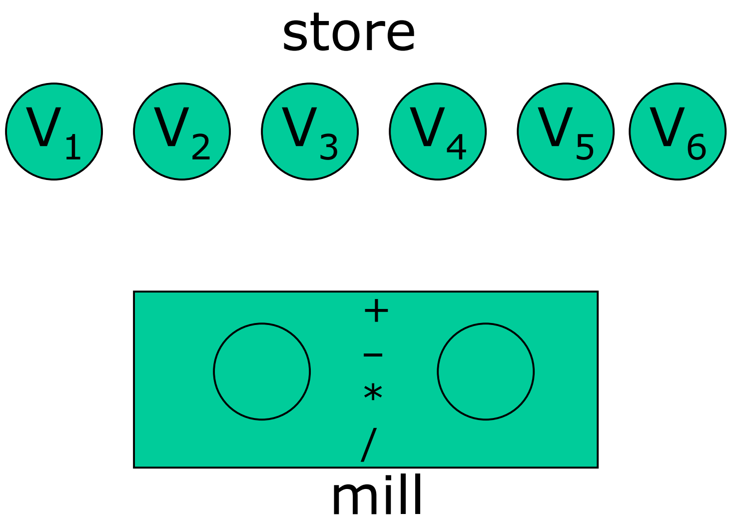


Programming the Analytical Engine

The analytical engine can do calculations with arbitrarily complex expressions, like $a(b+c)/(d-e)$.

It was controlled by a series of punched cards. Let V_n denote the n-th register in the store, let:

a was stored in V_1
b was stored in V_2
c was stored in V_3
d was stored in V_4
e was stored in V_5



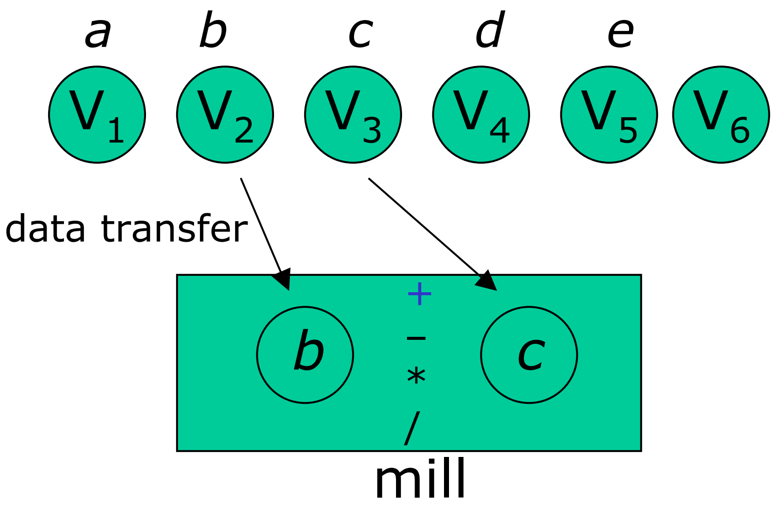
Programming

Then instruction on the cards would have something like:

transfer value in V_2 to mill

transfer value in V_3 to mill

add



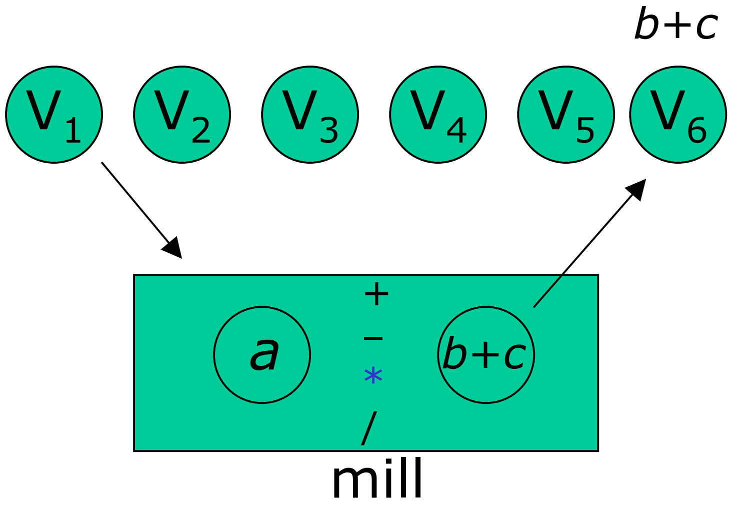
Programming

transfer the sum in mill to V_6

transfer value in V_1 to mill

multiply the mill

transfer the product in mill to V_7



Programming - continued

Transfer value in V_4 to mill

transfer value in V_5 to mill

subtract

transfer the difference to V_8

transfer value in V_7 to mill

transfer value in V_8 to mill

divide

transfer the result in mill to V_9

$$V_2 + V_3 = V_6$$

$$V_6 * V_1 = V_7$$

$$V_4 - V_5 = V_8$$

$$V_7 / V_8 = V_9$$

The final result is in V_9

In Babbage's Words…

Passages from the Life of a Philosopher

BY

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1864

To those who are acquainted with the principles of the Jacquard loom, and who are also familiar with analytical formulæ, a general idea of the means by which the Engine executes its operations may be obtained without much difficulty.

It is known as a fact that the Jacquard loom is capable of weaving any design which the imagination of man may conceive. It is also the constant practice for skilled artists to be employed by manufacturers in designing patterns. These patterns are then sent to a peculiar artist, who, by means of a certain machine, punches holes in a set of pasteboard cards in such a manner that when those cards are placed in a Jacquard loom, it will then weave upon its produce the exact pattern designed by the artist.

Now the manufacturer may use, for the warp and weft of his work, threads which are all of the same colour; let us suppose them to be unbleached or white threads. In this case the cloth will be woven all of one colour; but there will be a damask pattern upon it such as the artist designed.

But the manufacturer might use the same cards, and put into the warp threads of any other colour. Every thread might even be of a different colour, or of a different shade of colour; but in all these cases the form of the pattern will be precisely the same--the colours only will differ.

<u>The analogy of the Analytical Engine with this well-known process is nearly perfect</u>.

The Analytical Engine is therefore a machine of the most general nature. Whatever formula it is required to develop, the law of its development must be communicated to it by two sets of cards. When these have been placed, the engine is special for that particular formula. The numerical value of its constants must then be put on the columns of wheels below them, and on setting the Engine in motion it will calculate and print the numerical results of that formula.

Every set of cards made for any formula will at any future time recalculate that formula with whatever constants may be required.

Thus the Analytical Engine will possess a library of its own. Every set of cards once made will at any future time reproduce the calculations for which it was first arranged. The numerical value of its constants may then be inserted.

Babbage in Turin

In 1840 I received from my friend M. Plana a letter pressing me strongly to visit Turin at the then approaching meeting of Italian philosophers. In that letter M. Plana stated that he had inquired anxiously of many of my countrymen about the power and mechanism of the Analytical Engine.

…

It was during these meetings that my highly valued friend, M. Menabrea, collected the materials for that lucid and admirable description which he subsequently published in the Bibli. Univ. de Genève, t. xli. Oct. 1842.

The elementary principles on which the Analytical Engine rests were thus in the first instance brought before the public by General Menabrea.

Ada Lovelace, the First Programmer

Some time after the appearance of his memoir on the subject in the "Bibliothèque Universelle de Genève," the late Countess of Lovelace informed me that she had translated the memoir of Menabrea. I asked why she had not herself written an original paper on a subject with which she was so intimately acquainted? To this Lady Lovelace replied that the thought had not occurred to her. I then suggested that she should add some notes to Menabrea's memoir; an idea which was immediately adopted.

We discussed together the various illustrations that might be introduced: I suggested several, but the selection was entirely her own. So also was the algebraic working out of the different problems, except, indeed, that relating to the numbers of Bernoulli, which I had offered to do to save Lady Lovelace the trouble. This she sent back to me for an amendment, having detected a grave mistake which I had made in the process.

The notes of the Countess of Lovelace extend to about three times the length of the original memoir. Their author has entered fully into almost all the very difficult and abstract questions connected with the subject.

These two memoirs taken together furnish, to those who are capable of understanding the reasoning, a complete demonstration--That the whole of the developments and operations of analysis are now capable of being executed by machinery.

The 1878 Report

The Analytical Engine

Report of the Committee, consisting of Professor CAYLEY, Dr. FARR, Mr. J. W. L. GLAISHER, Dr. POLE, Professor FULLER, Professor A. B. W. KENNEDY, Professor CLIFFORD, and Mr. C. W. MERRIFIELD, *appointed to consider the advisability and to estimate the expense of constructing* Mr. BABBAGE'S *Analytical Machine, and of printing Tables by its means. Drawn up by* Mr. MERRIFIELD.

1878

IX. *General Conclusions, and Recommendation.*

1. We are of opinion that the labours of Mr. Babbage, firstly on his Difference Engine, and secondly on his Analytical Engine, are a marvel of mechanical ingenuity and resource.
2. We entertain no doubt as to the utility of such an engine as was in his contemplation when he undertook the invention of his analytical engine, supposing it to be successfully constructed and maintained in efficiency.
3. We do not consider that the possibilities of its misuse are any serious drawback to its use or value.
4. Apart from the question of its saving labour in operations now possible, we think the existence of such an instrument would place within reach much which, if not actually impossible, has been too close to the limits of human skill and endurance to be practically available.
5. We have come to the conclusion that in the present state of the design of the engine it is not possible for us to form any reasonable estimate of its cost, or of its strength and durability.
6. We are also of opinion that, in the present state of the design, it is not more than a theoretical possibility; that is to say, we do not consider it a certainty that it could be constructed and put together so as to run smoothly and correctly, and to do the work expected of it.
7. We think that there remains much detail to be worked out, and possibly some further invention needed, before the design can be brought into a state in which it would be possible to judge whether it would really so work.
8. We think that a further cost would have to be incurred in order to bring the design to this stage, and that it is just possible that a mechanical failure might cause this expenditure to be lost.
9. While we are unable to frame any exact estimates, we have reason to think that the cost of the engine, after the drawings are completed, would be expressed in tens of thousands of pounds at least.
10. We think there is even less possibility of forming an opinion as to its strength and durability than as to its feasibility or cost.
11. Having regard to all these considerations, we have come, not without reluctance, to the conclusion, that we cannot advise the British Association to take any steps, either by way of recommendation or other wise, to procure the construction of Mr. Babbage's Analytical Engine and the printing tables by its means.
12. We think it, however, a question for further consideration whether some specialized modification of the engine might not be worth construction, to serve as a simple multiplying machine, and another modification of it arranged for the calculation of determinants, so as to serve for the solution of simultaneous equations. This, however, inasmuch as it involves a departure from the general idea of the inventor, we regard as lying outside the terms of reference, and therefore perhaps rather for the consideration of Mr. Babbage's representatives than ours. We accordingly confine ourselves to the mere mention of it by way of suggestion.

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Readings

- C. Babbage, *Passages from the Life of a Philosopher*, Ch. VIII (1864).
- L. Menabrea. *Sketch of the Analytical Engine, with notes of A. A. Lovelace* (1842).
- *The 1878 Report* by Cayley et al (1878).

Together with supplementary material on the AE, in:

http://www.fourmilab.ch/babbage/contents.html

Idee per approfondimenti

- Babbage e le sue macchine
- Il calcolo meccanico dopo Babbage
- L’influenza di Babbage sulla “Computer science” (Ludgate, Torres, Bush, Aiken, etc.)