Lecture 3: The mechanical calculating machines of the 17th century, Charles Babbage's Analytical Engine

Every now and then, an individual is born with an unusual ability to memorize and retain large numbers (40, 59 and more digit long) for a long period of time. They could recall these numbers even after weeks. Because of this ability, they could also perform arithmetic operations on large numbers mentally, without any external aids. They can achieve this by memorizing intermediate results and using them when needed.

For instance, to multiply 397 by 173 some of these people use the following method. First, represent 397×173 as the sum of simple products:

$397 \times 173 = 397 \times (100 + 70 + 3) =$
$(100 \times 397) + (70 \times 397) + (3 \times 397) =$
$(100 \times 397) + (70 \times (300 + 90 + 7)) + (3 \times (300 + 90 + 7)) =$
$(100 \times 397) + (70 \times 300) + (70 \times 90) + (70 \times 7) + (3 \times 300) + (3 \times 90) + (3 \times 7).$

Then perform 100×397, and get the partial sum of 39,700
then add $70 \times 300 = 21,000$, and get the partial sum of 60,700,
then add $70 \times 90 = 6,300$, and get the partial sum of 67,000,
then add $70 \times 7 = 490$, and get the partial sum of 67,490,
then add $3 \times 300 = 900$, and get the partial sum of 68,390,
then add $3 \times 90 = 270$, and get the partial sum of 68,660,
then add $3 \times 7 = 21$, and get the final number 68,681.

The above calculation requires memorization of a sequence of partial sums:

$$39,700, \quad 60,700, \quad 67,000, \quad 67,490, \quad 68,390, \quad 68,660, \quad 68,700.$$

At the beginning there was abacus

Performing arithmetic operations on large numbers mentally, say by the method of multiplication discussed above, is beyond the capabilities of most of us. We can typically memorize single numbers about 5 to 8 digit long and only for a short period of time. To do every-day arithmetic on large numbers we need external aids, such as modern calculators, or follow algorithms for performing such operations using pen and paper. Some calculating aids were devised almost concurrently with the first uses of counting.

One of the most ancient and most prevailing counting aids consisted of vertical lines drawn on sand or ground, and pebbles that were placed on these lines (as shown in Figure 1). Such "counters" could be drawn on sand with a stick. They could be made of a flat surface made of a slab of stone or a wooden board with etched grooves, or even of a piece of cloth with painted lines. These early counters are classifies (for rather obvious reasons) as the dust abacus, the line abacus, and the grooved abacus. Regardless of the material used, historians classify all of these devices as *abacus*.

```
----ooooo   hundreds of thousands
---------   tens of thousands
-------oo   thousands
-----oooo   hundreds
--------o   tens
------ooo   units
```

Fig. 1. A depiction of a counting board consisting of 6 horizontal lines with several pebbles on them showing the number 502,413. The bottom line represented units, the lines above it: tens, hundreds, and so on. Romans placed small marbles along the lines called *calculi* which is the plural of *calculus* or pebble – hence the origin of the modern word *calculate*.

Arithmetic operations such as addition and subtraction could be performed on counting boards with ease and without much prior training as demonstrated by the following example of adding 928 to 502,413.

Example 1: To add 928 to 502,413 on a counting board such as the one depicted above, one first started with the counter configuration set to 502,413.

```
----ooooo          ----ooooo        ----ooooo         ---ooooo
---------   + 8    ---------  + 2   ---------  + 9    --------
-------oo   units  -------oo  10s   -------oo  100s   -----ooo
-----oooo   =====> -----oooo  ===>  -----oooo  ====>  -----ooo
--------o          -------oo        -----oooo         ----oooo
------ooo          --------o        --------o         -------o
```

The last configuration of the counter shows 503,341.

The exact point of origin of counting boards is difficult to establish. Historical references to early use of abacus-like devices in various regions of the world have been found. Counting-boards were known in Mesopotamia more than 4,000 years ago (Mesopotamia spanned the area corresponding to the present-day territories of Iraq, northeastern Syria, southeastern Turkey and southwestern Iran). These counters were adopted by Greeks and Romans. Some forms of abacus were known in ancient China before 1000 B.C.

One of the most famous early artifacts depicting counting practices using counting boards is the Darius Vase made by Darius Painter between 340 and 320 BC. The vase depicts, among other scenes, a tax collector occupied with calculations on a counting board.

Fig. 2. Darius Vase on display in the National Museum of Archaeology in Naples. Source: National Museum of Archaeology, Naples.

Fig. 3. A close-up of the tax collector on the Darius Vase. Source: National Museum of Archaeology, Naples.

The following two illustrations depict the use of counting boards in trade.

Fig. 4. This drawing depicting a counting board appeared in one of Adam Riese's books on arithmetic (1492-1559).

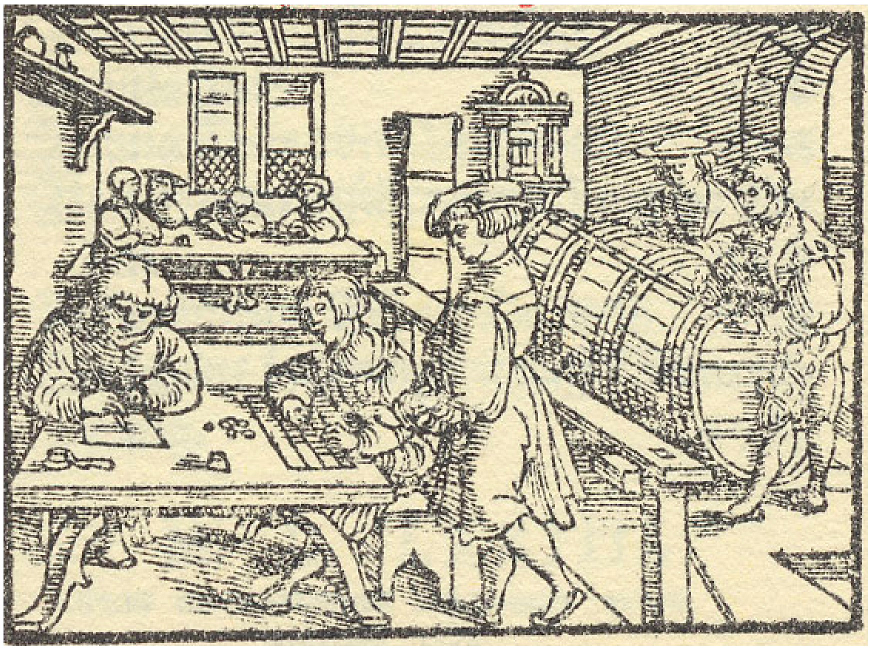

Fig. 5. This drawing depicting the use of a counting board in trade and commerce appeared in one of Adam Riese's books on arithmetic.

Portable and hand-held abacus

Some of the counters assumed a portable, and even hand-held form. One of such early gadgets is the so-called Roman hand abacus, possibly introduced around 300-200 B.C.

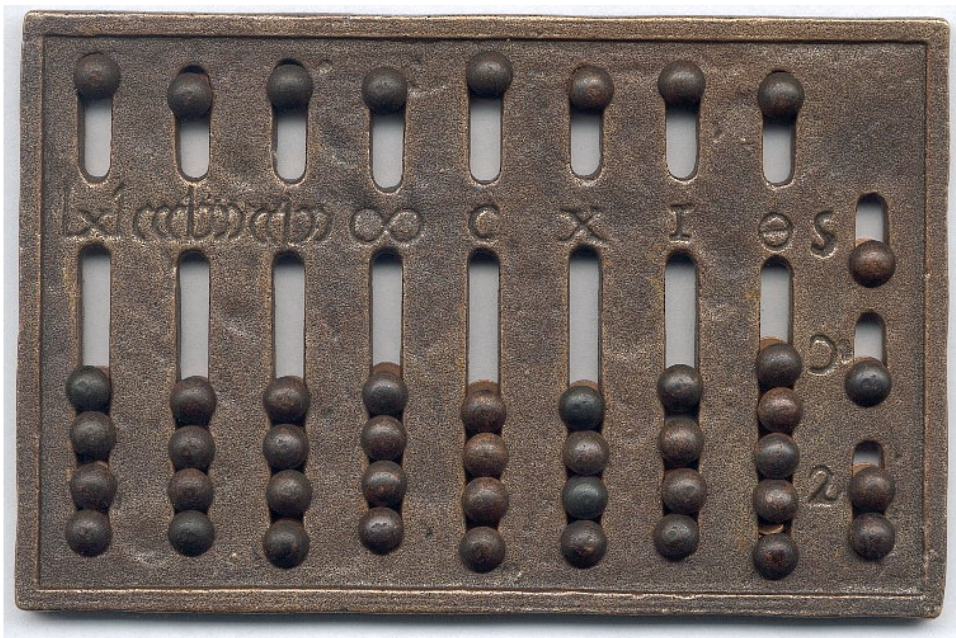

Fig. 6. Modern replica of Roman hand-held abacus.
From http://www.ieeeghn.org/wiki/index.php/Ancient_Computers.
Photographer/source unknown.

Figure 6 depicts a pocket-sized metal plate with vertical slots on which beads were placed and moved. Each column (with the exception of the two right-most) was marked with a symbol representing a decimal value: ”I” (units), ”X” (tens), ”C” (hundreds), ”∞” (thousands), and so on. The upper slots of each column contained a single bead (denoting 5 of column value) while the lower slots contained 4 beads (representing a single unit of the column value). To finish up the description, the units in the 0 position were 1/12 of the I position, and the units in the 3 position were 1/3 of the 0 position.

How did the Roman hand-held abacus work?

Another portable abacus was developed in Middle Ages and, possibly, had its roots in the Roman hand-held abacus. It was made of a wooden frame with beads sliding on rods fixed in the frame (see Figure 7). This "modern" abacus was adopted and refined in China (*suanpan*) around 12th century (?) and, later, in Korea (*jupan*, 13th/14th century), and Japan (*soroban*, 16th century). Other refinements of this abacus include Russian abacus (*schoty*), Polish abacus (*liczydlo* or *Slavonic abacus*), and many others.

Fig. 7. Soroban abacus. Source: eBay.

One can easily notice a similar arrangement of beads on the wires of the soroban to that of the Roman hand-held abacus.

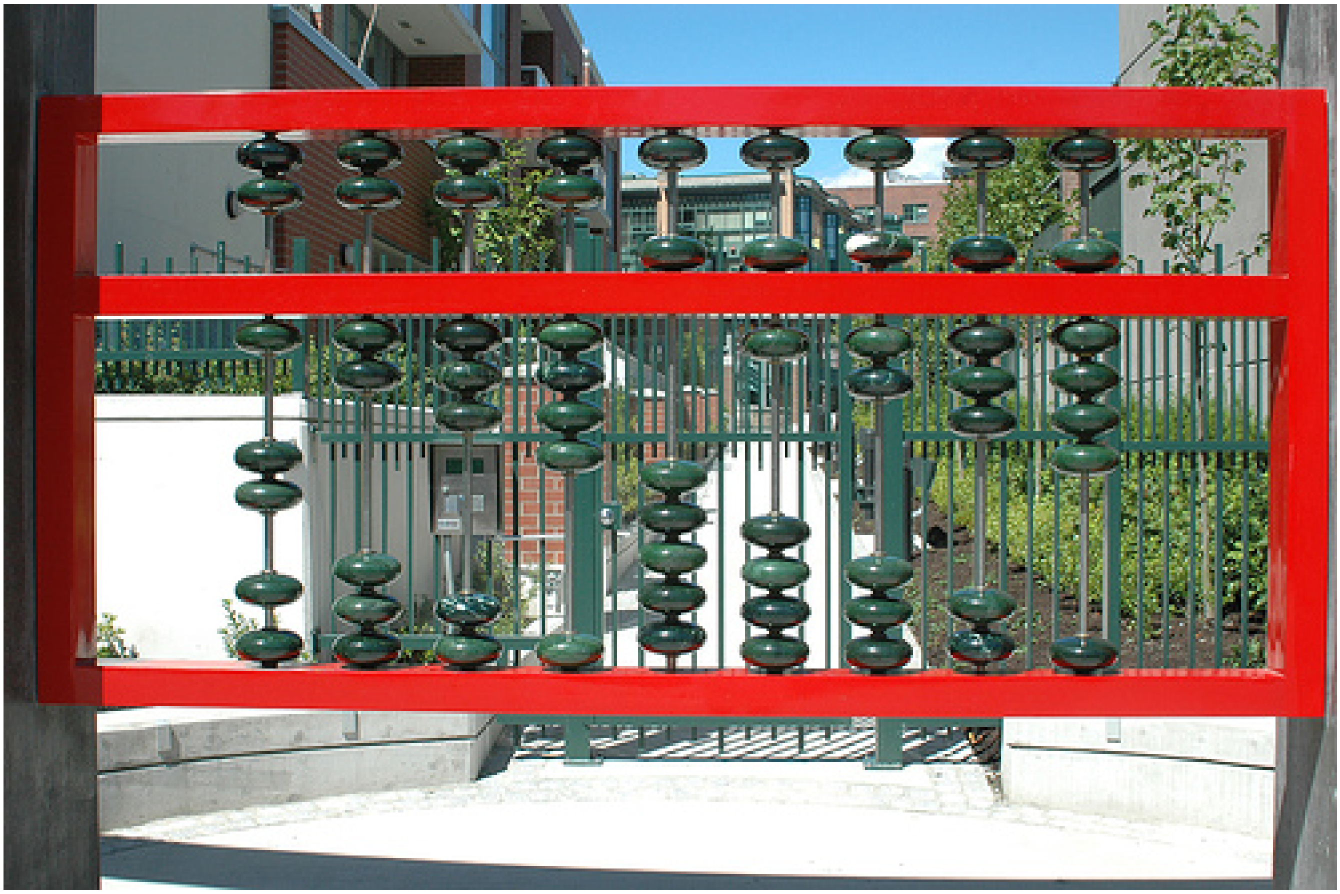

Fig. 8. Chinese abacus in Vancouver's China Town.

Using soroban or suanpan one could not only preform the ordinary arithmetic operations (of addition, subtraction, multiplication, and division) at high speed but also more complex operations such as square root and cube root.

Mechanical Calculators

The first mechanical devices designed to ease the labour of doing mathematics by automatically performing ordinary day-to-day arithmetic such as addition, appeared in the 17th century. An operator of these early mechanical calculators could, at least in principle, erroneously carry arithmetic calculations on numbers without much understanding of the device's design.

In practice, some technical problems faced by the early calculator designers were too difficult to overcome and resulted in either simplified machines that performed operations in semi-automatic mode, or were operating only with small numbers (say up to 6 digits).

Typically, only one or just a few copies of each such calculator were built generating some attention and excitement within scientific circles. However, the impact of these early calculators on society at large was minimal.

How to design a mechanical adder with display?

In principle, the design of a calculating machine could follow that of a portable rod-and-bead abacus. Let us design one using sticks with consecutive digits written on them: with 9 on top and 0 on the bottom, as shown in Figure 9.

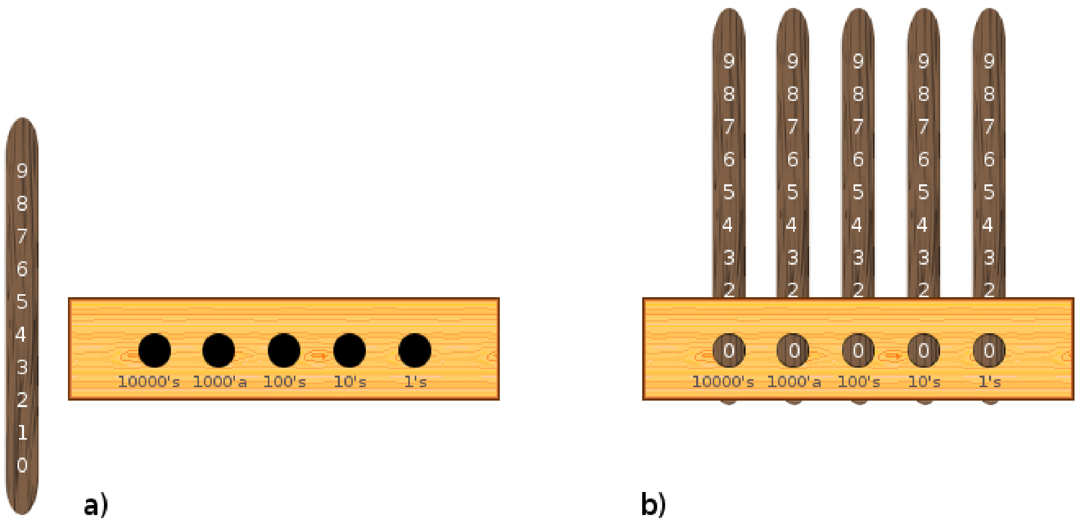

Fig. 9. Stick calculator (a); ready to use (b).

In this stick calculator, the sticks are inserted in a wooden board with little holes through which one can see one digit at a time. The sticks correspond to rods in an abacus or grooves in a counting board. When viewed from right to left, they record the number of units, tens, hundreds, thousands, and tens of thousands.

The calculator's display eliminates the need of counting to derive the result of calculation and, from this point of view, it is an improvement over counting boards. But is this device fully automatic?

The use of the stick calculator is simple. For instance, to add 23 to 123, we do the following:

1. set the stick calculator to 123 by pressing the rightmost stick down until the digit 3 appears in the window, then pressing the preceding stick until the digit 2 appears in the window, and finally, pressing the 100's stick one digit down (Fig. 10(a));

2. press the rightmost stick down 3 times to indicate the addition of 3 units (Fig. 10(b));

3. press the 10s stick down 2 times to indicate the addition of 2 tens (Fig. 10(c));

4. read the result of the addition from the window.

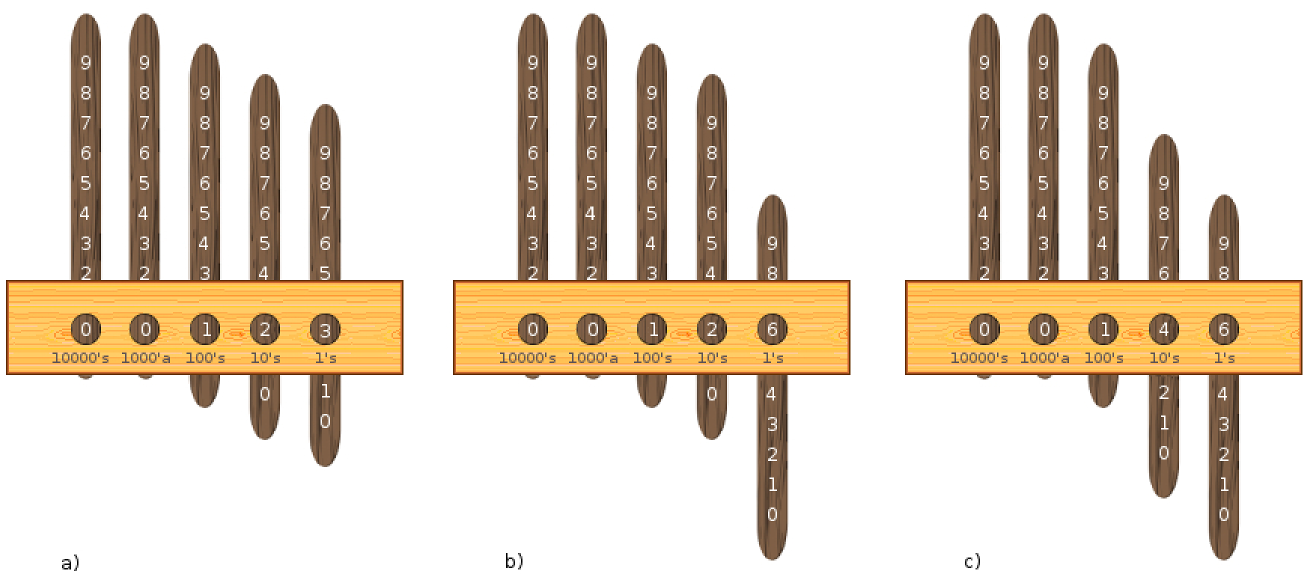

Fig. 10. Using stick calculator to add 23 to 123. Record 123 on stick calculator (a); push the units stick 3 times (b); push the 10s stick two times (c).

There are two problems with our stick calculator which can be best explained with an example.

Example 2: Let us use the stick calculator to perform the addition 9+1. This addition, which should result in 10, cannot be correctly performed using the method described above for the following reasons.

(A) the unit stick shows 9 and cannot be further pushed;

(B) even if we removed the unit stick and inserted it anew (showing 0 units), the 10s stick still shows 0.

To solve the first problem (of pushing the stick while it shows "9") we can indeed adopt a rule that such a push forces the user to reinsert the stick to indicate "0" (i.e. to "resets the stick").

To solve the second problem, let us recall the way we perform addition using the pen-and-paper method. Let us add 2 to 99:

```
                  1            11    <----- carry values
   099          099           099
+    2        +   2        +    2
-----   ===>  -----  ====> -----
   ??1          ?01           101
```

Fig. 11: Generating "carry" values during addition.

The method relies on recording "carry" value and adding it to an appropriate position: first to 10s and, then, to 100s.

To solve problem B, we can adapt the carry method for addition to our stick calculator as well. The rule that we need is this:

> *if a stick shows 9 and it has to be pressed, then we reset it to 0 and, then, press the preceding stick once.*

The following figure shows the process of adding 8 to 123.

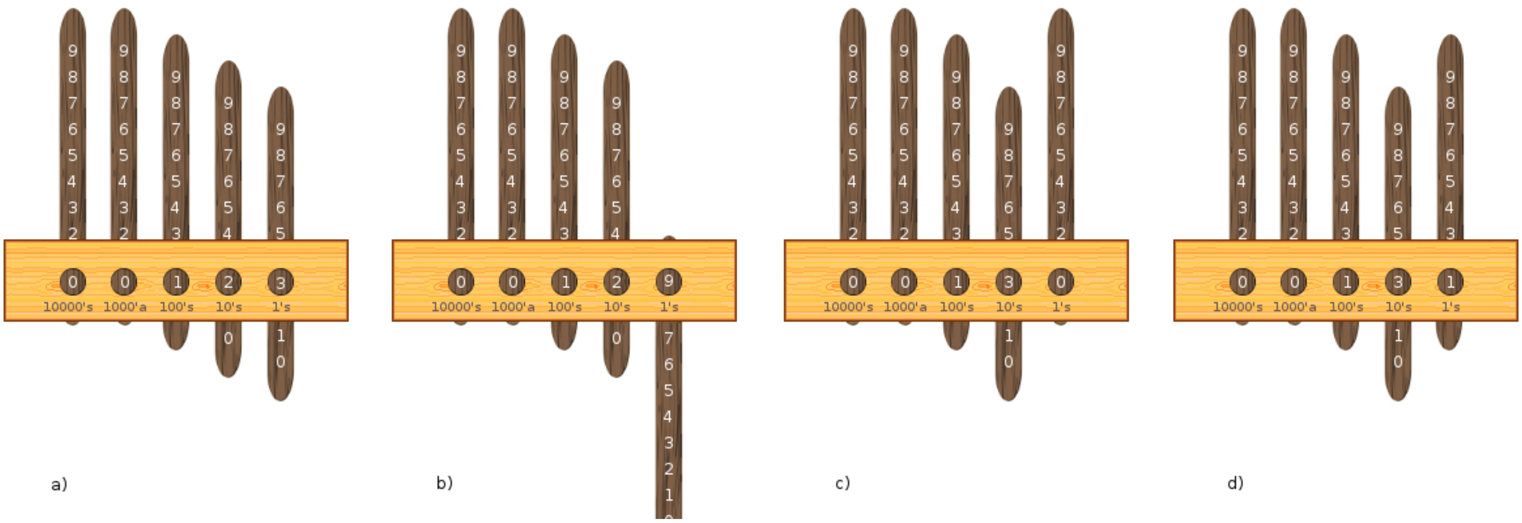

Fig. 12. Using stick calculator to add 8 to 123. Record 123 on stick calculator (a); push the units stick until the very end (6 times) (b); push the 10s stick once to perform the carry operation and reset the unit stick to 0 (this counts as one unit push) (c); push the unit stick once.

How to implement the carry mechanism in a calculator?

The designers of early mechanical calculators had the following objectives:

- the calculator should perform at least the operations of addition, subtraction, and multiplication;
- the result of a calculation should be directly readable from a calculator without any need of counting;
- the calculator should perform the carry operation automatically, without any intervention from the user.

Our stick calculator satisfies the first two requirements. It can support addition and subtraction. It can also do multiplication by repeated addition. So, to multiply 23 by 4, perform 4 additions of 24 on the stick calculator. However, our calculator has no "carry mechanism". This operation has to be performed by the calculator's operator as demonstrated in the last example.

The most persistent difficulty faced by the 17th century designers of mechanical calculators was the proper and reliable implementation of the carry mechanism. As we shall see shortly, early calculators had unreliable carry mechanisms that restricted the size of numbers that these calculators could operate on (up to 6 to 7 digits).

Some early calculators did not have any carry mechanism at all; as in the case of our stick calculator, it was the responsibility of an operator to keep track of carry values. In fact, the manufacturing of inexpensive mechanical calculators without carry mechanisms would continue until the advent of the digital electronic calculator.

First mechanical calculators, why so late?

In the 17th century, scientists were, generally speaking, not interested in mechanization of calculation; they found early attempts at constructing devices for carrying basic arithmetic operations curious at best.

The first mechanical calculators were technically unreliable and unequal to the demands of routine use of arithmetic by actuaries and bankers, scientists, surveyors, navigators, engineers, merchants, and others as the calculators could operate reliably only with a few digit-long numbers. There weren't very many of such calculators either.

In the 17th century practice, one relied on pen-and-paper methods for performing basic arithmetic operations and on mathematical "look-up" tables. The invention of movable type mechanical printing (printing press) allowed the production of such tables in multiple copies. However, the creation of mathematical tables was a long and laborious process. In general, every entry, such as the value of $1,254 \times 2,456$ had to be computed separately and recorded in the table (see Figure 13). But once there, to determine what's $1,254 \times 2,456$, one had only to consult an appropriate page and extract the result.

×	2,450	2,451	2,452	2,453	2,454	2,455	2,456	2,457	2,458	2,459
1,250	3,062,500	3,603,750	3,065,000	3,066,250	3,067,500	3,068,750	3,070,000	3,071,250	3,072,500	3,073,750
1,251	3,064,950	3,066,201	3,067,452	3,068,703	3,069,954	3,071,205	3,072,456	3,073,707	3,074,958	3,076,209
1,252	3,067,400	3,068,652	3,068,652	3,069,904	3,071,156	3,072,408	3,073,660	3,074,912	3,076,164	3,077,416
1,253	3,069,850	3,070,103	3,071,356	3,072,609	3,073,862	3,075,115	3,076,368	3,077,621	3,078,874	3,080,123
1,254	3,072,300	3,073,554	3,074,808	3,076,062	3,077,316	3,078,570	3,079,834	3,082,078	3,083,332	3,083,586
1,255	3,074,750	3,076,005	3,077,260	3,078,515	3,079,770	3,081,025	3,082,280	3,083,535	3,084,790	3,086,045
.	.	.	.	.	.	.	.	.	.	.

Fig. 13. A Fragment of a multiplication table.

It was not until the beginning of the 3rd decade of the 19th century when the "automated carry" problem was 'solved' and the commercial manufacturing of calculators commenced in Europe. Why so late?

It is possible that some sophisticated craftsmen of the Renaissance could have solved the "carry problem" if they wanted to, if there was some scientific urgency in designing calculators as opposed to just curiosity. In fact, Leonardo da Vinci (1452 1519) himself designed a device that resembled a calculator or could have been turned into a mechanical calculator. A drawing of such a device was discovered in February 1965, in the National Library of Spain in Madrid. Would he be able to solve the "carry problem" with the technology available in the 16th century if there were social pressure to build mechanical calculators? We will never know.

However, the 16th and 17th centuries produced men of astonishing mechanical cleverness and sophistication. The clock-makers and goldsmiths were considered the most technically advanced tradesman existing. These skillful craftsmen were often designing and building scientific instruments, precision mechanical apparatus, from clockwork automata that simulated animals and people, to other ingenious mechanical toys and wondrous figures such as mechanical devils and clockwork monks.

Do these facts at least suggest that useful mechanical calculators could have been built before the 19th century, if there was any need for them? Let us take a look at the Clockwork Prayer.

In her excellent series of articles on a 16th century mechanical monk–the so-called Clockwork Prayer–Elizabeth King wrote:

> In the Smithsonian Institution is a sixteenth-century automaton of a monk, made of wood and iron, 15 inches in height. Driven by a key-wound spring, the monk walks in a square, striking his chest with his right arm, raising and lowering a small wooden cross and rosary in his left hand, turning and nodding his head, rolling his eyes, and mouthing silent obsequies. From time to time, he brings the cross to his lips and kisses it. ...
>
> Looking at this object in the museum today, one wonders: what did a person see and believe who witnessed it in motion in 1560?[2]

Fig. 14. The Clockwork Prayer: Mechanical Monk, Circa 1560. Photographer unknown. Source:
http://www.blackbird.vcu.edu/v1n1/nonfiction/king_e/prayer_introduction.htm.

17th century calculators

It was possibly the excitement about the clockwork automata that gave the impetus to the early work on the mechanization of arithmetic, that is on building mechanical devices for performing basic arithmetic operations. As mentioned earlier, the first such devices started to appear in early 17th century and were not very useful. The list of early calculator designers begins with Wilhelm Schickard and Blaise Pascal.

Wilhelm Schickard (1592-1635), professor of many disciplines in Tubingen, Germany: in approximately 1623 he designed a six position adder, subtracter, and multiplier with a simple carry mechanism that, however, could not handle extensive use of concurrent carry operations (as when performing 899,999+1) without damaging the machine.

Fig. 15. A replica of a Schickard Calculator. Source: http://archive.computerhistory.org.

Some early 20th century designs of calculators were also using carry mechanisms similar to that employed in the Schickard Calculator and suffered from similar problems. For instance, performing the addition 1+ 899,999 on the Lightning Adding Machine manufactured by Lightning Adding Machine Company of Los Angeles, Ca. (one of these calculators resides at York University Computer Museum) is almost impossible without breaking the instrument.

Blaise Pascal (1623-1662), French mathematician and philosopher: designed and constructed approximately 50 different machines for addition and subtraction (8 position); it had a complex "gravity-based" carry mechanism which was very sensitive and not always reliable in operation; Pascal machines were discussed widely in Europe.

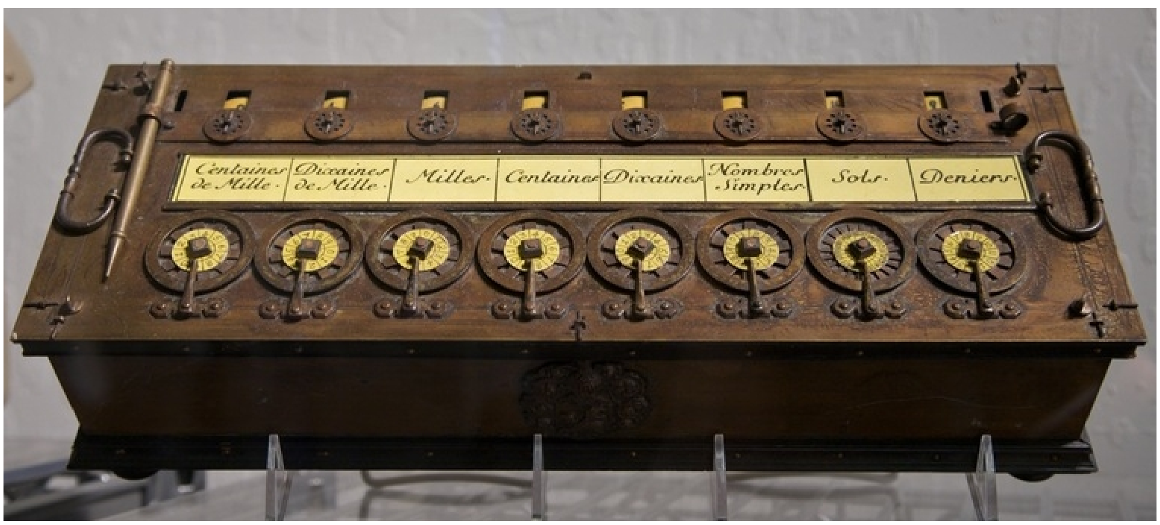

Fig. 16. One of the Pascal's calculators. Source unknown.

Gottfried Wilhelm Leibniz, German mathematician: sometime before 1670, he designed his calculating machine; his design greatly influenced the next generation of calculators that would start to appear in the 19th century.

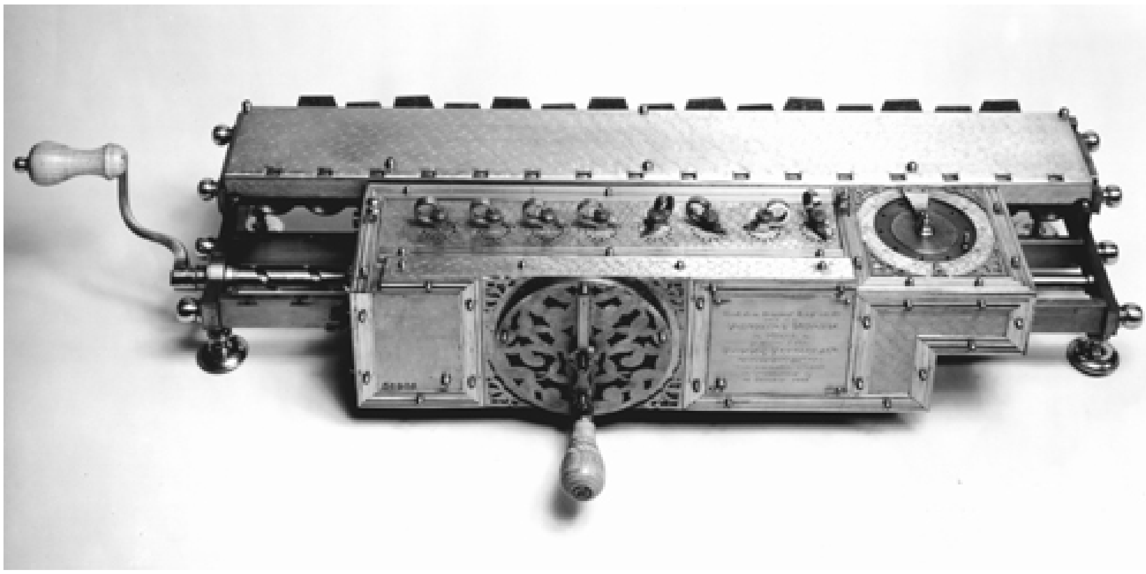

Fig. 17. A replica of Leibniz calculator. Source: http://archive.computerhistory.org.

Samuel Morland (1625-1695), English career diplomat: invented three kinds of simple calculating instruments including an adder. The adder was offered commercially but was not successful; it had no proper carry mechanism but only a carry indicator; the instruments had a number of wheels that could be rotated clockwise using a stylus (see Figure 18). The result of a rotation could be observed in a one-digit wide window located over the top of the wheel. Carry bit was indicated by an additional wheel rotated when the main wheel was turned from 9 through 0.

Fig. 18. Morland's 1660 calculator. Source: Nico Baaijens
http://www.calculi.nl/pages/sub/23305/Antiquities_2_.html

The tables crisis

Tables with look-up data have been in use for more than two thousand years. Their success lay in their scope and simplicity of use. There were printed tables for calculating values of a large variety of mathematical functions, astronomical tables, navigation tables, tables for administrative records, tables for financial applications (such as compound interest tables), and even tables for actuarial applications such the ones containing mortality data (for calculation of life insurance).

Table making was a successful industry until the mid 1900s. Printed tables as calculation aids had a significant impact on scientific and economic advancement.

Pre 20th-century production of tables relied mostly on manual labour and that was not only tedious but prone to errors that could be introduced in large numbers during the calculation, recording, and typesetting of data. Typically, published tables had a long errata, listing all known errors.

The errors in mathematical tables were not only the cause for embarrassment for a publisher but they could also create serious problems: they could cause the loss of revenues for banks and governments, and even loss of lives, if, for instance, such errors were made in ship navigation tables.

Charles Babbage, the designer of some of the most interesting machines for automated production of mathematical tables claimed that, at some point the British government had lost between two and three million pounds due to errors in tables used for annuities (and that was in the early 19th century!).

x	$\frac{2}{\sqrt{\pi}} e^{-x^2}$	$\frac{2}{\sqrt{\pi}} \int_0^x e^{-\alpha^2} d\alpha$
1.000	0.41510 74974 20595	0.84270 07929 49715
01	.41427 76978 09643	.84311 54854 78076
02	.41344 87300 69275	.84352 93486 22624
03	.41262 05958 47470	.84394 23832 16054
04	.41179 32967 83914	.84435 45900 92706
1.005	0.41096 68345 10002	0.84476 59700 88552
06	.41014 12106 48838	.84517 65240 41197
07	.40931 64268 15244	.84558 62527 89859
08	.40849 24846 15760	.84599 51571 75372
09	.40766 93856 48649	.84640 32380 40168
1.010	0.40684 71315 03900	0.84681 04962 28277
11	.40602 57237 63236	.84721 69325 85311
12	.40520 51640 00110	.84762 25479 58462
13	.40438 54537 79718	.84802 73431 96492
14	.40356 65946 58998	.84843 13191 49722
1.015	0.40274 85881 86635	0.84883 44766 70026
16	.40193 14359 03065	.84923 68166 10825
17	.40111 51393 40482	.84963 83398 27073
18	.40029 97000 22840	.85003 90471 75254
19	.39948 51194 65857	.85043 89395 13372

TABLES OF

PROBABILITY FUNCTIONS

VOLUME I

$$H'(x) = \frac{2}{\sqrt{\pi}} e^{-x^2} \text{ and } H(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-\alpha^2} d\alpha$$

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for the City of New York

1941

Fig. 19. The cover of *Tables of Probability Functions* (bottom image), published by A.N. Lowan in 1941, and a sample page from the book (top image).

Table making machines

The first designs of machines for automated preparation and printing of data for mathematical tables appeared in the late 18th century (Müller's machine, cf. [3], pp. 124-125).

However, the person most famous for attacking the problem of automated manufacturing of mathematical tables was not Müller but a British inventor, mathematician, political economist, scientist, and a prolific writer Charles Babbage (1791-1871).

Babbage was a person that left a heritage that is both astonishing in its scope and still difficult to assess. His knowledge of table making was unrivaled and he possessed one of the most extensive and comprehensive collections of such publications in existence.

Babbage objective was to mechanize the entire process of table production (from calculation of data to typesetting), in an effort of freeing the process from human errors. During his life time he conceived three machines to do just that:

- Difference Engine No. 1: started in 1822, demonstrated a partial machine in 1823, started the development in 1824, and finally, abandoned the work without completion in 1833 (1/7 was done); if constructed, the machine would have approximately 25,000 parts and weighted several tones;

- Difference Engine No. 2: designed between 1847-49; it was to consist of approximately 4,000 parts (excluding the printing mechanism);

- Analytical Engine: conceived in 1834 – most interesting among the Babbage's designs.

Unlike the first mechanical calculators of Schickard, Pascal, Leibniz, and Morland, Babbage's Difference Engines were not designed to perform ordinary arithmetic operations but to compute a variety of values using the so-called "difference" method and to print the results in a table form. In addition, Babbage's machines were neither small, primitive, nor "personal". They were all mechanically complex, very large, and, if constructed, affordable to only very rich institutions.

Babbage's Difference Engines were not general-purpose machines but rather special purpose devices designed to execute the difference method exclusively.

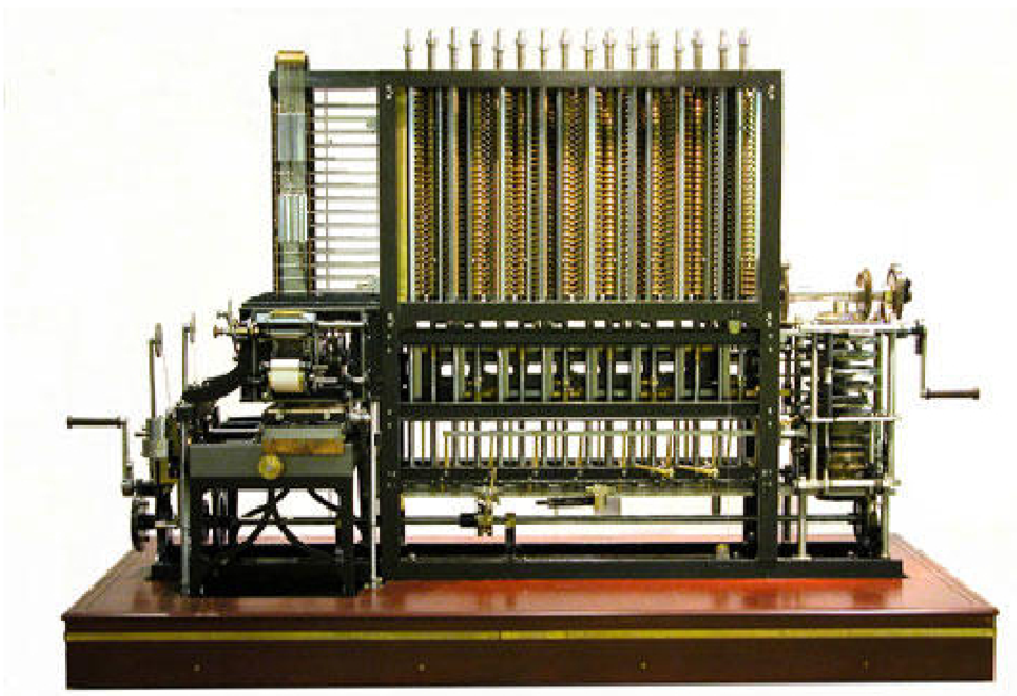

Fig. 20. Charles Babbage's Difference Engine No. 2 reconstructed at the Science Museum in London in 2002 after 17-years-long project. The machine: 11-feet-long by 7-feet-high, five-ton, 4,000 parts. Source unknown.

The Analytical Engine was a different kind of a device all together. The mathematical tasks that it could perform were not permanently predetermined by its construction but they depended on a user. In short, the Analytical Engine was to be a general-purpose device to compute the so-called algebraic functions.

Many features of the Analytical Engine could be found in the 20th century designs of electronic computers. Without going into a long list of technical details, we shall mention only most significant few. The Analytical Engine:

- was programmable with programs stored on *punched cards*; some of the programs were written and "punched" onto the cards by Ada Lovelace, daughter of Lord Byron (more on Ada Lovelace below); some of the programming statements used to program the Analytical Engine have their counterparts in modern programming languages;
- had a module called "store" where numbers and intermediate results were held; modern computers also use the concept of a store in the form of RAM and cash memories;
- had a module called "mill" where the arithmetic operations were performed; modern computers also use the concept of a "mill" – it is the arithmetic unit within a microprocessor or a dedicated integrated circuit.

Our knowledge of the Analytical Engine's principles of operation comes not from Babbage himself but from an Italian engineer Luigi Menabrea who published a paper on the subject after listening to Babbage's lecture in Turin in 1840. Another source is Ada Lovelace who not only expanded Menabrea's paper with lengthy additional notes on the significance of the machine but also wrote a number of programs for the (non-existing) Analytical Engine. She is rightly recognized as the first computer programmer and honoured by, among other distinctions, naming one of the programming languages–ADA–after her.

Some historians call Babbage a 'computer pioneer', a 'father' or 'grandfather of computing' because of his work on the Analytical Engine. The Engine's architecture (which we will not discuss in any detail in this lecture), resembled, to some degree, those of early general-purpose, stored-program electronic computers.

But to be a "father" or a "grandfather" one has to have children. Unfortunately for Babbage, his Analytical Engine was neither built nor had any impact on other generations of calculating and computing devices. In short, his Engine had never existed (apart from a design) and had no "technological children".

Whether Babbage deserves the name of the grandfather of computing or not, his work demonstrates that certain key architectural ideas in designing of modern programmable computing devices were already budding in the 19th century, long before the society would offer technologies to manufacture such devices.

Some concluding remarks on Babbage

It is important to stress that Babbage's failures were not due to errors in his designs but to the limitations of Victorian-era manufacturing technologies, the inability to produce large quantities of the same part with high precision.

In fact, The Science Museum, London, reconstructed Babbage's Difference Engine No. 2 to the Babbage's original designs and specifications. The reconstructed machine is composed of approximately 4000 parts, it measures 7 feet high, 11 feet long, and 18 inches deep. It generates and prints data as envisioned by Babbage, proving the correctness of his designs, indicating that, perhaps, his Analytical Engine was also feasible.

In the end it was not Babbage but George and Edvard Scheutz, Swedish father and son, who inspired by Babbage's efforts designed, built, and practically used the first difference engine to automatically calculate and print tables (around 1843).

Their machine was much smaller and was made using rather rudimentary tools proving that Babbage's obsession with precision mechanics was unnecessary. One of the two "commercial" machines manufactured by Scheutz family was sold to the Dudley Observatory in Albany, New York, and the second to the General Register Office in London.

There is also some evidence that at least some of the design ideas for Babbage's difference engines came from others (e.g. Johann Müller, 1746-1830, an engineer and master builder). This reinforces our earlier observation about inventions depending critically on a chain of technological progress (see week 2).

To learn more about Babbage, consult the required readings as well as [4].

Conclusions

In the end, the mechanical table calculation machines were not very successful. It would not be until the advent of an electronic computer when the table-for-everything industry would benefit from automated calculation and typesetting. It was the need for accurate table making that contributed to the modern era of computing. One of the first electronic, digital computers–Eniac–was designed solely to compute tables accurately.

In the period spanning the 17th, 18th, and 19th centuries many people tried to build calculating aids to support a variety of tasks from scientific to business. Most of these efforts failed. For instance, the difference engines were difficult to build, limited in their scopes, and not in high demand. Only mechanical calculators made progress responding to social needs for affordable calculating needs (the subject of our next lecture).

References

1. M.R. Williams, *A History of Computing Technology*, 2nd ed.,

2. E. King, *Clockwork Prayer*
http://www.blackbird.vcu.edu/v1n1/nonfiction/king_e/prayer_introduction.htm
(follow the links on the bottom).

3. M. Campbell-Kelly, M. Croarken, R. Flood, and E. Robson (eds), *The History of Mathematical Tables: From Sumer to Spreadsheets*, Oxford University Press, 2003.

4. F.G. Ashurst, *Pioneers of Computing*, 1983.