Gottfried Wilhelm Leibniz

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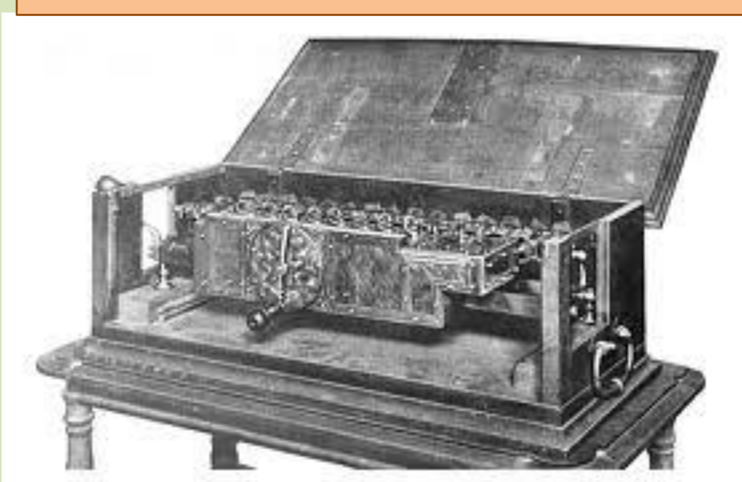


The *Stepped Reckoner* of Gottfried Leibniz

- The great polymath Gottfried Leibniz was one of the first men (after **Raymundus Lullus** and **Athanasius Kircher**), who dreamed for a logical (thinking) device.
- Even more—Leibniz tried to combine principles of arithmetic with the principles of logic and imagined the computer as something more of a calculator—as a *logical* or *thinking* machine.
- In his treatises ***De progressione Dyadica***, March1679, and ***Explication de l'Arithmetique Binaire***, 1703.

He discovered also that computing processes can be done much easier with a binary number coding .

Calculating machine - the binary system

- In the *De progressione Dyadica* Leibniz even describes a calculating machine which works via the binary system: a machine without wheels or cylinders—just using balls, holes, sticks and canals for the transport of the balls:

- *This [binary] calculus could be implemented by a machine (without wheels)... provided with holes in such a way that they can be opened and closed.*
- *They are to be open at those places that correspond to a 1 and remain closed at those that correspond to a 0.*
- *Through the opened gates small cubes or marbles are to fall into tracks, through the others nothing.*
- *It [the gate array] is to be shifted from column to column as required...*!

Dream of the general problem-solver

- Leibniz dreamed of inventing the general problem-solver, as well as a universal language:
- *I thought again about my early plan of a new language or writing-system of reason, which could serve as a communication tool for all different nations...*
- *If we had such an universal tool, we could discuss the problems of the metaphysical or the questions of ethics in the same way as the problems and questions of mathematics or geometry.*
- *That was my aim: Every misunderstanding should be nothing more than a miscalculation (...), easily corrected by the grammatical laws of that new language. Thus, in the case of a controversial discussion, two philosophers could sit down at a table and just calculating, like two mathematicians, they could say,*
  'Let us check it up ...'

Leibniz, the Predecessor of Cybernetics

- Certainly the impressive ideas and projects of Leibniz had to wait some centuries, to be fulfilled.
- The ideas of Leibniz will be used two and half centuries later by Norbert Wiener, the founder of Cybernetics.
- So, let's ground and examine his famous *Stepped Reckoner*.

Similar a pedometer device

- Leibniz got the idea of a calculating machine most probably in 1670 or 1671, seeing a pedometer device.
- The breakthrough happened however in 1672, when he moved for several years to Paris, where he got access to the unpublished writings of the two greatest philosophers—Pascal and Descartes.
- Most probably in this year he became acquainted (reading Pascal's *Pensees*) with the calculating machine of Pascal (Pascaline), which he decided to improve in order to be possible to make not only addition and subtraction, but also multiplication and division.

Famous stepped-drum machine

- At the beginning, Leibniz tried to use a mechanism, similar to Pascal's, but soon realized, that for multiplication and division it is necessary to create a completely new mechanism, which will make possible the multiplicand (dividend) to be entered once and then by a repeating action (rotating of a handle) to get the result.
- Trying to find a proper mechanical resolution of this task Leibniz made several projects, before to invent his famous *stepped-drum* mechanism.
- One of his projects (see the nearby sketch) describes something very similar to the pin-wheel mechanism, which will be reinvented in 1709 by **Giovanni Poleni**.
- The undated sketch is insribed *"Dens mobile d'une roue de Multiplication"* (the moving teeth of a multiplier wheel).
- Some historians even assume, that the pin-wheel was used in one version of the Leibniz's calculating machine, which didn't survive to the present (the machine was under continuous development more than 40 years and several copies were manufactured).

First Obstacles – Possibilities of Fine Mechanics

- Starting to create the first prototype, Leibniz soon faced the same obstacles that Pascal had experienced: poor workmanship, unable to create the fine mechanics, required for the machine.

- He complained:

"If only a craftsman could execute the instrument as I had thought the model."

The first wooden prototype

- The first wooden prototype of the *Stepped Reckoner* (this is a later name, actually Leibniz called his machine ***Instrumentum Arithmeticum***) was ready soon and **in the end of 1672** and beginning of 1673 it was demonstrated to some of his colleagues at French Academy of Sciences, as well as to the Minister of Finances Jean-Baptiste Colbert.

- Then Leibniz was sent to London with a diplomatic mission, where he succeeded not only to met some English scientists and to present his treatise called *The Theory of Concrete Motion*, but also **to demonstrate the prototype of his calculating machine to the Royal Society on 1st of February, 1673.**

- The demonstration was probably not very successful, because the inventor admitted that the instrument wasn't good enough and promised to improve it after returning to Paris.

- Nevertheless, the impression of Leibniz must had been very positive, because **he was elected as a member of Royal Society in April, 1673.**

Arithmetic machine – easy, fast, reliable

- In a letter of 26th of March 1673 to one of his correspondents—Johann Friedrich, mentioning the presentation in London

  Leibniz described the purpose of the *arithmetic machine* as making calculations

  ***easy, fast, and reliable*.**
- Leibniz also added that theoretically the numbers calculated might be as large as desired, if the size of the machine was adjusted: *a number consisting of a series of figures, as long as it may be (in proportion to the size of the machine)*.

First metal prototype

- Back in Paris, Leibniz hired a skilful mechanician—the local clockmaker Olivier, who was a fine craftsman, and he made the first metal (brass) prototype of the machine.
- It seems the first working properly device was ready as late as in 1685 and didn't manage to survive to the present day, as well as the second device, made 1686-1694.
- **Olivier used to work for Leibniz up to 1694.**
- Later on professor Rudolf Wagner and the mechanic Levin from Helmstedt worked on the machine, and after 1715, the mathematician Gottfried Teuber and the mechanic Haas in Leipzig did the same.

Appreciation by Arnauld and Huygens

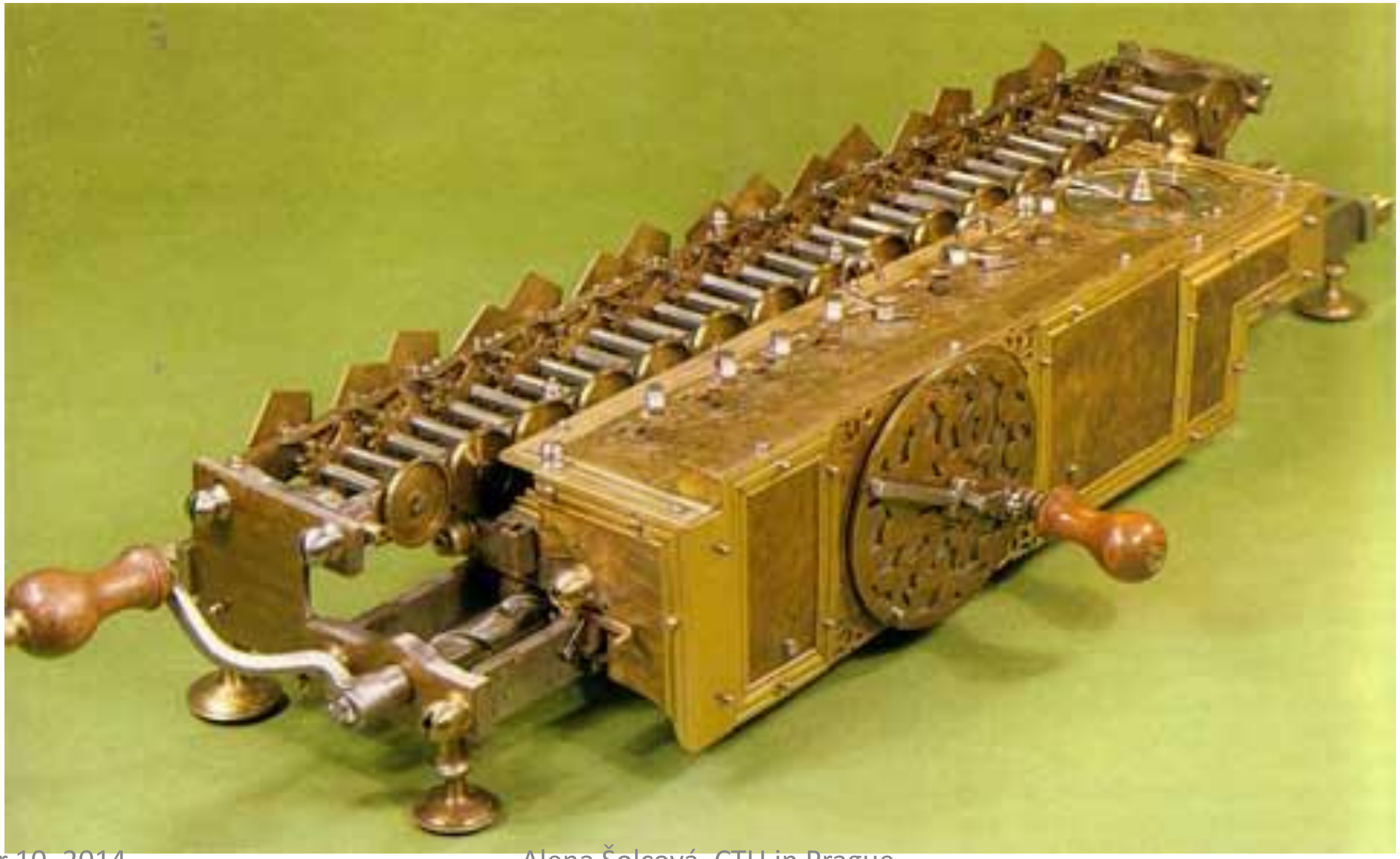
- In 1675 the machine was presented to the French Academy of Sciences and was highly appreciated by the most prominent members of the Academy—**Antoine Arnauld** and **Christian Huygens**.
- Leibniz was so pleased by his invention, that he immediately informed some of his correspondents: e.g. Thomas Burnett, 1st Laird of Kemnay:
- *I managed to build such arithmetic machine, which is completely different of the machine of Pascal, as it allows multiplication and division of huge numbers to be done momentarily, without using of consecutive adding or subtraction,* and to other correspondent, the philosopher Gabriel Wagner—*I managed to finish my arithmetical device. Nobody had seen such a device, because it is extremely original*.

Today – two old machines

- **It is unknown how many machines were manufactured by order of Leibniz.**
- It is known however, that the great scientist was interested in this invention all his life.
- **He spent on his machine a very large sum at the time—some 24000 talers according to some historians, so it is supposed the number of the machines to be at least 10.**
- One of the machines (probably third manufactured device), produced 1690-1720, was stored in an attic of a building of the University of Göttingen sometime late in the 1770s, where it was completely forgotten. It remained there, unknown, until 1879, when a work crew happened across it in a corner while attempting to fix a leak in the roof.
- In 1894-1896 Arthur Burkhardt restored it, and it has been kept at the Niedersächsische Landesbibliothek for some time.
- At the present time exist two old machines, which probably are manufactured during Leibniz's lifetime (in the Hanover State Library and in the Deutsches Museum in München), and several replicas (see one of them in the photo below).

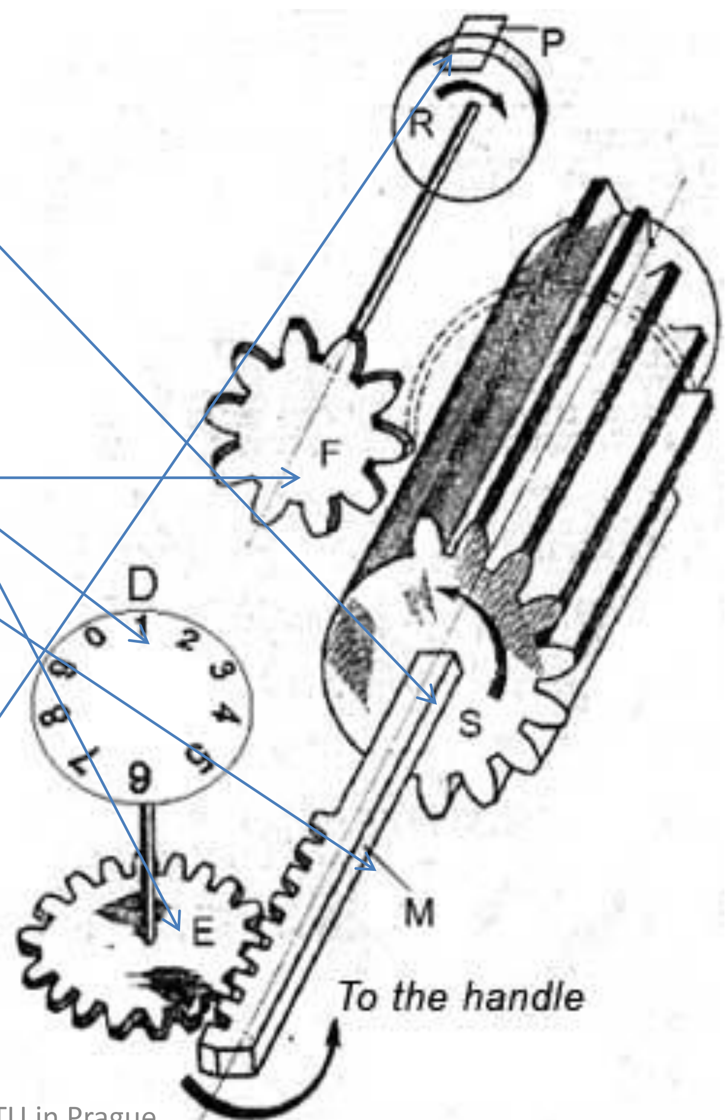
Replica

The mechanism of the machine is
67 cm long, 27 cm wide and 17 cm high
and is housed in a big oak case with dimensions 97/30/25 cm.



The stepped-drum mechanism

- The stepped-drum (marked with *S* in the sketch) is attached to a four-sided axis (M), which is a teeth-strip. This strip can be engaged with a gear-wheel (*E*), linked with the input disk (*D*), on which surface are inscribed digits from 0 to 9.
- When the operator rotates the input wheel and the digits are shown in the openings of the lid, then the stepped drum will be moved parallel with the axis of the 10-teeth wheel (*F*) of the main counter.
- When the drum rotated to a full revolution, with the wheel (*F*) will be engaged different number of teeth, according to the value of the movement, which is defined by the input disk and the wheel (*F*) will be rotated to the appropriate angle.
- Together with the wheel (*F*) will be rotated linked to it digital disk (*R*), whose digits can be seen in the window (*P*) of the lid. During the next revolution of the drum to the counter will be transferred again the same number.

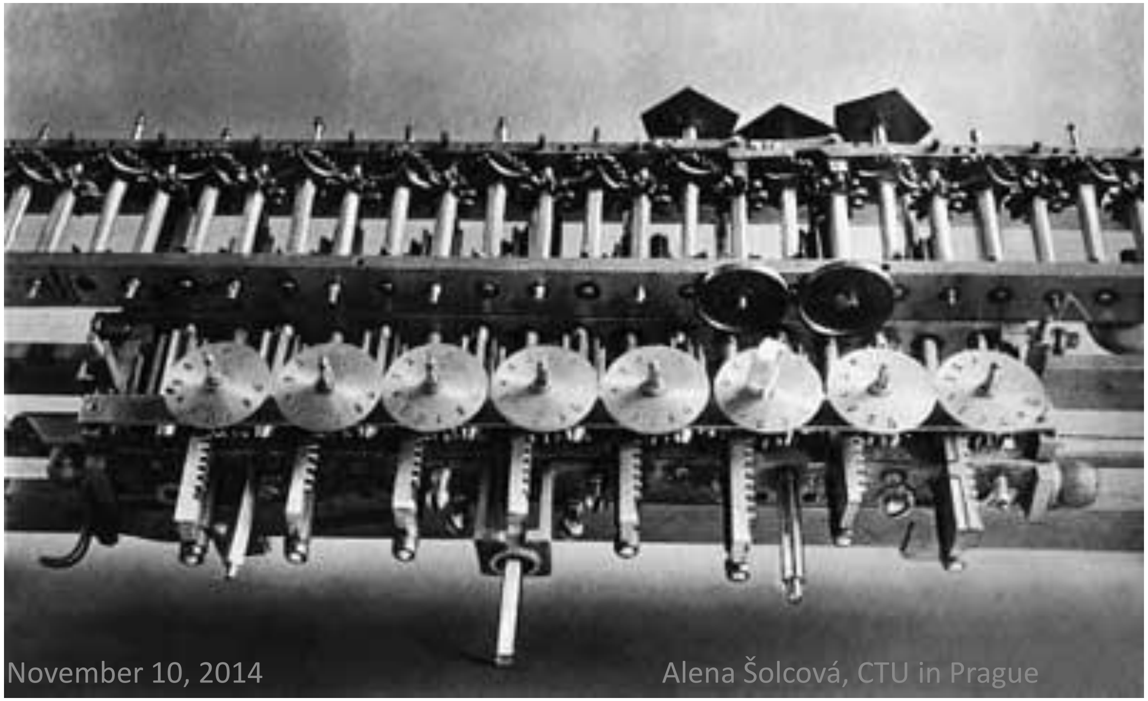


The Mechanismus without Cover

The input mechanism of the machine is 8-positional, i.e. it has 8 stepped drums, so after the input of the number by means of input wheels, rotating the front handle (which is connected to the main wheel (called by Leibniz *Magna Rota*)

All digital drums will make 1 revolution each, adding the digits to the appropriate counters of the digital positions.

The output (result) mechanism is 12-positional.



The result (digits inscribed on the digital drums) can be seen in the 12 small windows in the upper unmovable part of the machine.

The Tens Carry Mechanism

When a carry must be done, the rod (7) will be engaged with the star-wheel (8) and will rotate the axis in a way, that the bigger star-wheel (11) will rotate the pinion (10).

On the axis of this pinion is attached a rod (12), which will be rotated and will transfer the motion to the star-wheel (10) of the next digital position, and will increase his value with 1. So the carry was done.

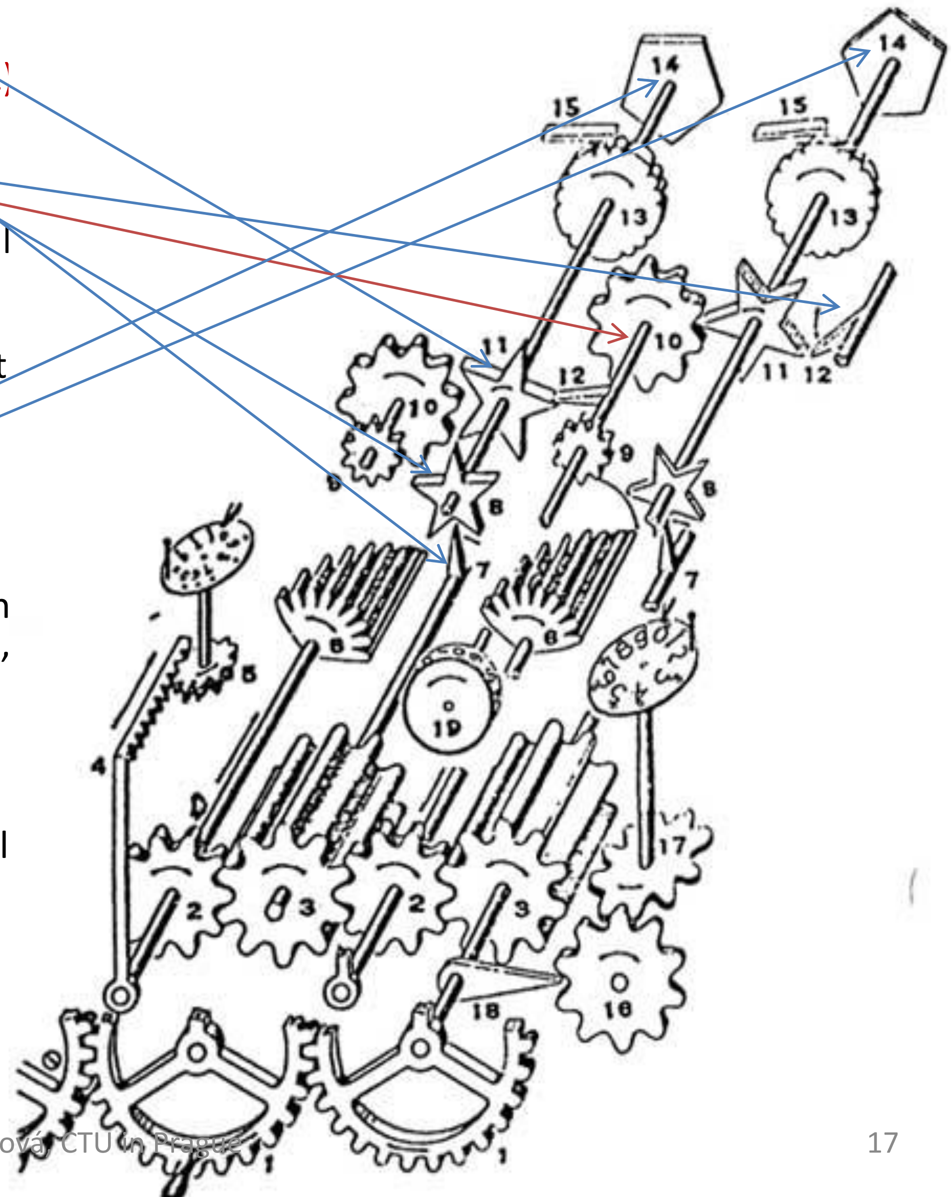
The transfer of the carry however will be stopped at this point, i.e. if the receiving wheel was at the 9 position, and during the carry it have gone to 0 and another carry must be done, this will not happen.

There is a workaround however, because the pentagonal disks (14) are attached to the axis in such way, that theirs upper sides are horizontal, when the carry has been done, and with the edge upwards, when the carry has not been done (which is the case with the right disk in the sketch).

If the upper side of the pentagonal disk is horizontal it cannot be seen over the surface of the lid, and cannot be noticed by the operator, so manual carry is not needed.

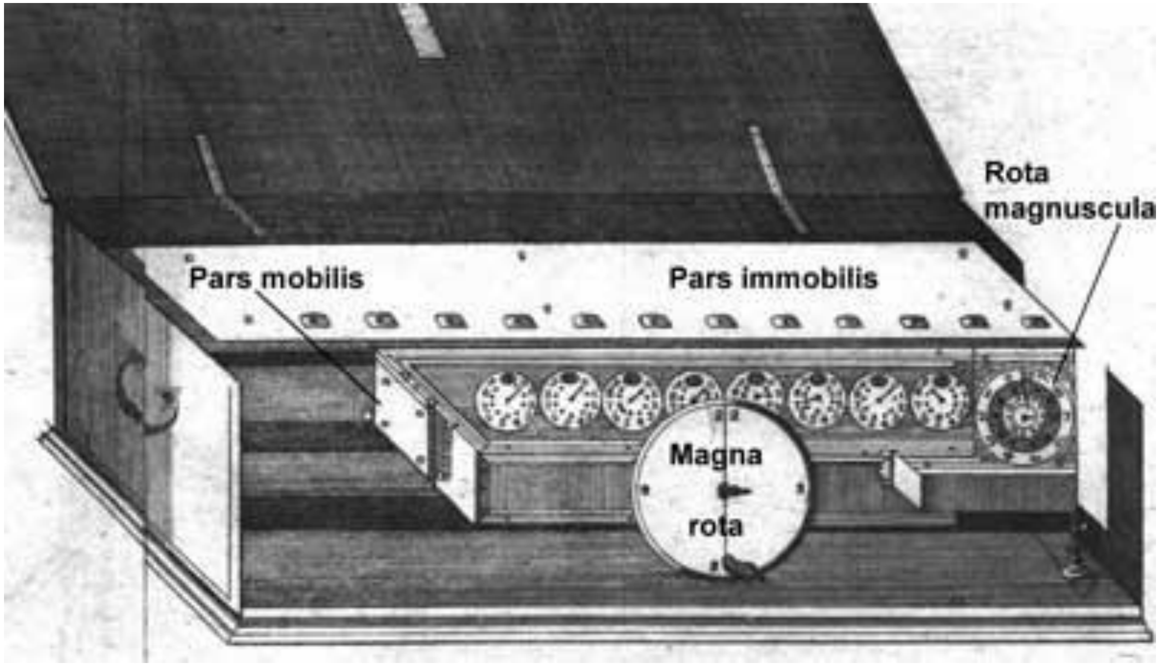
I however the edge can be seen over the surface of the lid, this will mean that the operator must rotate manually this disk, performing a manual carry.

The tens carry mechanism (© Aspray, W., Computing Before Computers)



An outside sketch

Based on the drawing from *Theatrum arithmetico-geometricum* of Leupold



The mechanism of the machine can be divide to 2 parts.

The upper part is unmovable and was called by Leibniz *Pars immobilis*.

The lower part is movable and is called *Pars mobilis* .

In the *Pars mobilis* is placed the 8-positional setting mechanism with stepped drums, which can be moved leftwards and rightwards,
so to be engaged with different positions
of the 12-positional unmovable calculating mechanism.

Adding, Substraction, and Other Operation

- Adding with the machine is simple
  - first addend is entered directly in the result wheels (windows) (there is a mechanism for zero setting and entering numbers in the result wheels),
  - second addend is entered with the input wheels in the *Pars mobilis*, and then the forward handle (*Magna rota*) is rotated once.
- Subtraction can be made in a similar way,

  but all readings must be taken from the red subtractive digits of the result wheels,

  rather than the normal black additive digits.
- On multiplication,

  the multiplicand is entered by means of the input wheels in the *Pars mobilis*,

  then *Magna Rota* must be rotated to so many revolutions, which number depends on the appropriate digit of the multiplier.

  If the multiplier is multidigital, then *Pars mobilis* must shifted leftwards with the aid of a crank and this action to be repeated,

  until all digits of the multiplier will be entered.
- Division is done by setting the dividend in the result windows and the divisor on the setup dials, then a turn of *Magna rota* is performed and the quotient may be read from the central plate of the large dial.

To multiply 358

- There is also a counter for number of revolutions, placed in the lower part of the machine, which is necessary on multiplication and division—the large dial to the right of the small setting dials.
- This large dial consists of two wide rings and a central plate—the central plate and outer ring arc inscribed with digits, while the inner ring is colored black and perforated with ten holes.
- If for example we want to multiply a number on the setting mechanism to 358, a pin is inserted into hole 8 of the black ring and the crank is turned, this turns the black ring, until the pin strikes against a fixed stop between 0 and 9 positions.
- The result of the multiplication by 8 may then be seen in the windows. The next step requires that the setting mechanism to be shifted by one place by means of the crank (marked with *K* in the upper figure), the pin inserted into hole 5, and the crank turned, where upon the multiplication by 58 is completed and may be read from the windows.
- Again the setting mechanism must be shifted by one place, the multiplication by 3 is carried out in the same manner, and now the result of the multiplication by 358 appears in the windows.

Better than Pascal

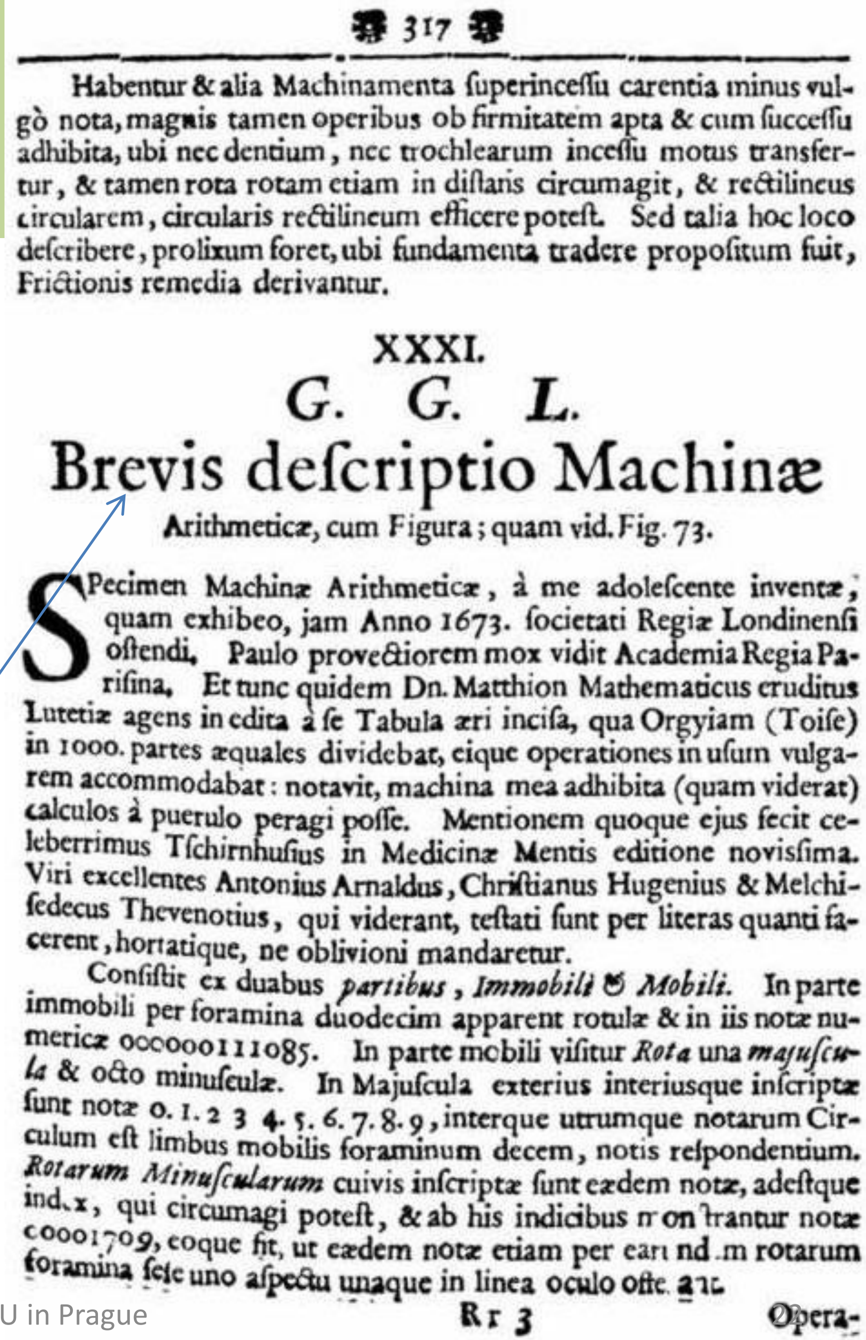
- Leibniz did manage to create a machine, much better than the machine of Pascal.
- The *Stepped Reckoner* was not only suitable for multiplication and division, but also much easier to operate.
- In 1675 during the demonstration of the machine to the French Academy of Sciences, one of the scientists noticed that

  "...using the machine of Leibniz even a boy can perform the most complicate calculations!"

First description

The first description of Leibniz's stepped-drum calculator appeared in 1710, made by Leibniz himself, in *Miscellanea Berolinensia*, the journal of the Berlin Academy of Sciences.

It was a 3-pages short description, entitled *"Brevis descriptio Machinae Arithmeticae, cum Figura"*, and the internal mechanism of the machine is not described.



317

Habentur & alia Machinamenta superincessu carentia minus vulgò nota, magnis tamen operibus ob firmitatem apta & cum successu adhibita, ubi nec dentium, nec trochlearum incessu motus transfertur, & tamen rota rotam etiam in distans circumagit, & rectilineus circularem, circularis rectilineum efficere potest. Sed talia hoc loco describere, prolixum foret, ubi fundamenta tradere propositum fuit, Frictionis remedia derivantur.

XXXI.

G. G. L.

Brevis descriptio Machinæ

Arithmeticæ, cum Figura; quam vid. Fig. 73.

Specimen Machinæ Arithmeticæ, à me adolescente inventæ, quam exhibeo, jam Anno 1673. societati Regiæ Londinensi ostendi, Paulo provectiorem mox vidit Academia Regia Parisina, Et tunc quidem Dn. Matthion Mathematicus eruditus Lutetiæ agens in edita à se Tabula æri incisa, qua Orgyiam (Toise) in 1000. partes æquales dividebat, eique operationes in usum vulgarem accommodabat: notavit, machina mea adhibita (quam viderat) calculos à puerulo peragi posse. Mentionem quoque ejus fecit celeberrimus Tschirnhusius in Medicinæ Mentis editione novissima. Viri excellentes Antonius Arnaldus, Christianus Hugenius & Melchisedecus Thevenotius, qui viderant, testati sunt per literas quanti facerent, hortatique, ne oblivioni mandaretur.

Consistit ex duabus *partibus*, *Immobili & Mobili*. In parte immobili per foramina duodecim apparent rotulæ & in iis notæ numericæ 000000111085. In parte mobili visitur *Rota* una *majuscula* & octo minusculæ. In Majuscula exterius interiusque inscriptæ sunt notæ 0. 1. 2 3 4. 5. 6. 7. 8. 9, interque utrumque notarum Circulum est limbus mobilis foraminum decem, notis respondentium. *Rotarum Minuscularum* cuivis inscriptæ sunt eædem notæ, adestque ind. x, qui circumagi potest, & ab his indicibus m on trantur notæ 00001709, eoque fit, ut eædem notæ etiam per ea nd m rotarum foramina sese uno aspectu unaque in linea oculo offe a c.

Rr 3 Opera-

2nd Page

318

Operatio hæc eſt: Sit datus numerus Multiplicandus per datum Numerum Multiplicantem, modo Productum non excedat duodecim notas, Ex. gr. 1709. numerus anni currentis multiplicari debeat per 365. numerum dierum; itaque, poſito priùs per foramina octo rotarum apparuiſſe non niſi o, indiculi in rotis quatuor minuſculis dexterrimis admoveantur notis 1709: partis autem mobilis (à ſitu, qui in figura apparet dextrorſum promotæ) hic ſit initio ſitus: ut nota prima octo Rotarum partis mobilis reſpondeat notæ primæ duodecim rotarum partis immobilis; uti nunc in figura reſpondet tertiæ. Porro notæ partis immobilis initio ſint itidem non niſi o. Quia jam 1709. debet multiplicari per 365, multiplicetur primum per 5, quod ita fiet: brevis ſtylus infigatur foramini, quod reſpondet Numero 5, in rota majuſcula exteriùs notato. Deinde *Magna Rota* (nondum hactenus memorata) in medio ferè partis mobilis conſpicua, arrepto dextra capulo ejus circumagatur; quo facto ſimul movebitur limbus mobilis rotæ majuſculæ. Is motus continuetur, donec, (quod mox fiet) ſtylus foramini limbi infixus, & cum limbo circumactus in obſtaculum incurrat, quod in Rota Majuſcula comparet inter o. & 9, Quo facto ex reſiſtenta admonebimur, abſolutam eſſe hanc operationem, & per foramina partis immobilis dexteriora apparebit productum ex 1709 per 5, nempe 8545. Sed quia plures ſunt notæ in multiplicante, & proxima à prima eſt 6; promovebimus partem mobilem ſiniſtrorſum, ita ut prima nota Rotarum octo, reſpondeat, ſecundæ notæ Rotarum duodecim. Hoc facto ſtylum infixum hactenus foramini exteriùs notato, 5, infigemus foramini etiam exteriùs notato, 6, jamque iterum capulo arrepto rotam illam Magnam in Medio partis mobilis poſitam circumagemus, donec ſtylus in obſtaculum impingat: eaque ratione non tantùm numerus multiplicandus 1709 multiplicatus erit per 6, ſed etiam productum erit additum producto priori, & notæ partis immobilis dexteriores per foramina comparentes erunt 111085. Supereſt in multiplicatore nota 3. Itaque iterum uno gradu promoveatur pars mobilis ſiniſtrorſum & ſtylus infigatur foramini in limbo, quod reſpondet notæ exteriori 3, atque ita Machina in eo erit ſtatu, quem *Figura* exhibet. Ac tunc demum, circumacta tertium Rota magna, donec obſtaculum ſentiatur, numerus multiplicandus 1709 non tantùm multiplicatus erit per 3, ſed etiam productum ſimul

1 709 . 365 =

8 545

1 02 54

<u>5 12 7</u>

6 23 785

3rd Page

mul prioribus erit additum, prodibitque productum integrum ex 1709 multiplicato per 365, nempe 623785.

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  1709
   365
  ----
  8545
 10254
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111085
 5127
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623785
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Id maximi commodi habet hæc operatio, in *Multiplicatione* vel *Diviſione*, quod nihil refert, quantus ſit numerus multiplicandus, modo machinæ magnitudinem (hoc loco octo notas) non excedat; eodem enim tempore res peragitur, ſive multarum ſive paucarum ſit notarum. Mentis nullam fere attentionem requiri manifeſtum eſt, ut hoc, quicquid eſt, meritò dici poſſit, *opus infantum*. *Diviſio* eadem facilitate reciproco opere peragitur, nec quæritur nota quotientis, ſed ipſa ſe offert. *Dividendus* collocatur in rotis partis immobilis, ubi demum & *Reſiduus* conſpicuus manet. *Diviſor* exhibetur in rotis minuſculis partis mobilis, *Quotiens* per notas ſingulas circuli interioris, quarum ex adverſo ſtylus poſt operationem quieſcit, deſignatur; cùm multiplicatio circulo exteriore ſit uſa pars mobilis in machinæ, durante diviſione, quoties opus promovetur dextrorſum; cum in multiplicatione promota fuerit ſiniſtrorſum. *Additio* concipi poteſt ut multiplicatio per unitatem, *ſubtractio*, ut diviſio, cujus quotiens unitas. Ita quatuor, quas vocant, ſpecies habemus, quibus omnia alia peraguntur. Quanquam Additio & Subtractio etiam ſine Multiplicationis aut Diviſionis imitatione perfacile in Machina per ſe efficiantur, & ita quidem, ut parte mobili opus non ſit.

XXXII.