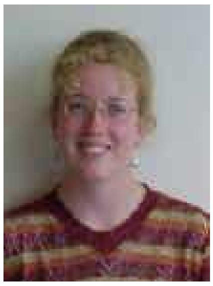

Pascal's Calculator

by Nicole Ketelaars

In this article, we discuss the '*pascaline*', a calculator that was designed by Blaise Pascal between 1642 and 1645. This machine was an inspiration for the later calculators, which were developed by Leibniz. We describe both the exterior and the mechanical interior of the machine. Furthermore, we explain how to add numbers on this machine.

The History of the Pascaline

Pascal developed the pascaline between 1642 and 1645. In 1645, the king of France awarded Pascal with a royal privilege that gave Pascal the exclusive right to manufacture and sell the pascaline. Despite this privilege, the machine never was a commercial success. The costs were simply too high. This was caused by the fact that the techniques for producing the interior parts were not yet fully developed. For example, the manufacturing of cogwheel-transmissions was considered to be difficult. Approximately 50 of these machines were built, of which 8 are still preserved nowadays. Most of them are kept in the Musée du Conservatoire National des Arts et Métiers in Paris.

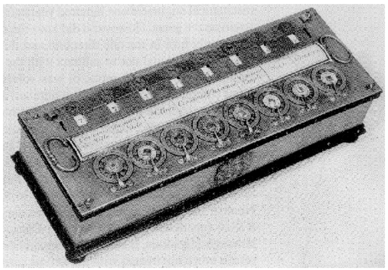

Figure 1: The pascaline

The Exterior of the Pascaline

A pascaline (see Figure 1) is a rectangular box of approximately 30 cm long, 7 cm high and 15 cm deep. On the top of the pascaline, we see eight discs with a diameter of approximately 5 cm. These discs are divided into a number of units[1]. Each of these discs is build up of two wheels. The outer wheel of these two is attached to the top of the pascaline, and the inner wheel is a wheel of spokes that can be turned. Above each disc, we see a number.

To use the pascaline, numbers have to be entered in the machine. This can be done on the top of the calculator.

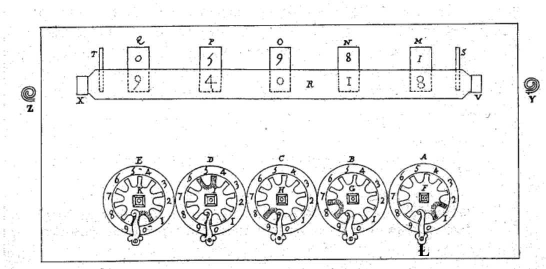

Figure 2: Schematical representation of the top of the pascaline

In Figure 2, we see a schematical representation of the top. We have noted already that each wheel consists of an outer wheel that is attached to the top and an inner wheel of spokes that can be turned. The spaces that are between the spokes are numbered anti-clockwise in an increasing order. These digits are denoted on the outer wheels. Above each disc, we can see a small metal stopbar (indicated with an *L* at the rightmost disc) that is attached to the top of the machine. We can enter numbers in the machine by using an additional small stick. We put this stick in the space formed by two spokes that corresponds with the digit that has to be entered. Then, we turn the inner wheel clockwise until the stick touches the metal stopbar. The rightmost disc represents the units, the disc next to it the tens et cetera. Above each disc, a small window is made, through which we can see which digit has been entered on the disc[2].

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[1] The precise division of the discs depends on the use of the machine. Some pascalines have discs that are all divided into 10 units, others are founded on the old French monatary system and have discs with 10, 12 or 20 units.

[2] In Figure 2, we see two of such windows and a bar that covers one of these windows. This bar has to be shifted to the other set of windows if we subtract two digits instead of adding them. For more details, we refer to [Mehmke]. The function of these two rows lies outside the scope of this article. We only note that for adding, the covering bar should be up.

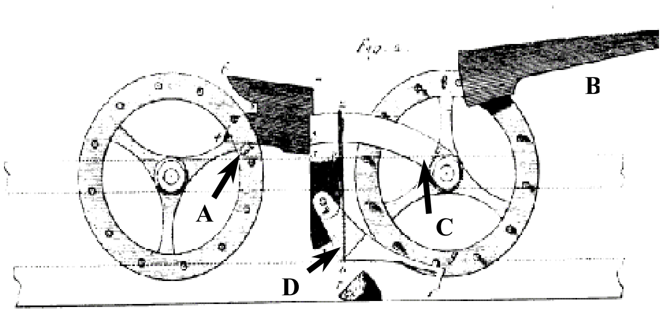

Figure 3: The carry-mechanism of the pascaline, seen from the side

The Interior of the Pascaline

The pascaline works by counting the number of rotations of the wheel of spokes. The most important problem of adding two numbers is the fact that once a wheel has made a complete turn, it has to register this on the wheel to its left. This event is called a “carry”. A problem arises if a carry of 1 of one wheel causes the neighbouring wheel to complete its turn and therefore causes a carry to the next wheel. In the extremest case, a carry on the first wheel causes all wheels to perform a carry to their neighbours (when we add 1 to 9999, the units become 0, with a carry to the tens. The tens become 0, with a carry to the hundreds. The hundreds become 0, with a carry to the thousands, and the thousands become 0 with a carry to the tenthousands). To perform such a successive carry, large mechanical forces have to be applied on the first wheel. Pascal designed a mechanism to ease such a carry. He used a lever mechanism that made use of gravity. The mechanism that performs the carry between two wheels is graphically displayed in Figures 3 and 4.

In Figure 3 we see two spoke wheels (with the spokes perpendicular to the plane of the wheel) each containing ten pins. The pins are “sticking out of the paper”. The left wheel can be thought of as the wheel of the units, the right wheel as that of the tens (the tens are on the right of the units, because we look at the back of the mechanism). The wheels turn anti-clockwise. One complete rotation of the left wheel corresponds to one tenth of a rotation of the right wheel. On the circumference of the left wheel, we have an additional pin, pointing into the paper. This pin is positioned on position *A* of Figure 3. We refer to this pin as the carry-pin. There are two more parts in the drawing that need explanation. On the top side of the right wheel, we see a so-called stop-arm, that can turn around axis *B*, that is positioned on the right side of the right wheel. When the right wheel is turned anti-clockwise, this arm is lifted by the passing pin. When the pin passed the arm, the arm falls down again. In this way, Pascal assured that the wheel can only stop on fixed positions. Without this arm, the roll on which the digits are written might stop too early, such that there are two half digits visible in the window on the top of the pascaline. The second part that needs explanation is the lever *C* that is positioned on the axis of the rightwheel. We refer to this lever as the carrylever. This lever consists of several parts. It can be turned independent of the wheel. The lever has a fixed end that can be lifted by the carry-pin on the left wheel. Attached to this lever is a pole downwards, to which a turnable part is attached (indicated by a *D* in Figure 3). This part will be referred to as pusher. The pusher can turn around an axis that is connected to the carry-pin. Moreover, the pusher is lifted by a spring that is also connected to the carrylever. The end of the pusher is in the reach of the pins of the right wheel. When the right wheel is turned anti-clockwise, the pins push the pusher down. Thus, the pusher does not impeed the turning of the right wheel.

When the left wheel is turned anti-clockwise, the carrylever is on a certain moment lifted by the carry-pin. This causes the lever to turn clockwise. Therefore, the pusher is moved away of the right wheel (to the left in the Figure). As soon as the end of the pusher moves beyond the pin that kept it down, the pusher is lifted by the spring. The left wheel still rotates in the meantime. When the left wheel is rotated so much that the carry-pin is no longer below the carrylever, the carrylever will fall back. Therefore, the end of the pusher moves to the right and pushes the lower pin, which causes the right wheel to turn over one pin. The stoparm prevents the wheel from stopping too early or moving too far.

We see that this process gives the desired result: when the left wheel has completed a turn, the right wheel is moved one pin. In the pascaline this construction can be found for each wheel, as shown in Figure 4.

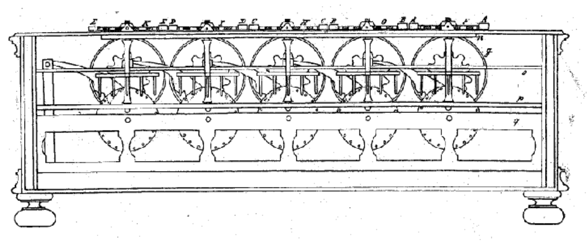

Figure 4: A sideview of the pascaline. We see the carry mechanism repeated at each wheel

The last step in describing the interior of the pascaline deals with the connection of the carry mechanism with the discs and windows on the top of the machine. This connection can be seen in Figure 5. We see that the number that is set by turning the disc on top is transferred to the carry mechanism via a perpendicular cogwheel connection. The carry mechanism transfers its rotation to the number-wheel. In this way, the appropriate digit is shown in the window.

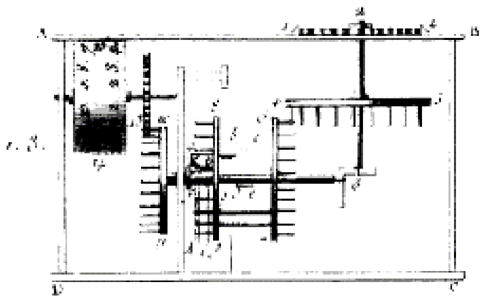

Figure 5: The connection between the carry mechanism and the discs at the top of the pascaline

Adding with the Pascaline

The pascaline can be used to add and subtract two numbers. Multiplications and divisions were not possible. In this section we discuss the way two numbers can be added. Before starting the calculation, the numbers that can be seen through the windows have to be set to zero. Since the pascaline does not have a reset button, this has to be done manually. One by one, the wheels have to be turned using the small stick that was descirbed before. To add two numbers, the first number has to be entered, digit by digit. It is not necessary to work from left to right or from right to left, as long as the units are entered on the position of the units, the tens on the position of the tens et cetera. The second number is added to the first number by setting the digits of the second number on the same way as before, but without resetting the pascaline. The result of the addition is shown in the windows on top. The user does not have to perform a carry himself. This is done by the carry mechanism in the machine. Suppose for example that we add 6 to 6. At the first setting of the unit wheel, the wheel turns 216 degrees. At the second setting, the unit wheel turns another 216 degrees. This is more than 360 degrees. Therefore, the carry lever has been lifted once, causing the wheel of the tens to turn 36 degrees. The windows will show a 2 at the unit wheel (corresponding to 72 degrees) and a 1 at the wheel of the tens (corresponding to 36 degrees).

Subtracting two numbers is significantly more complicated than adding two numbers. I would like to refer the interested reader to the book of [Kistermann], who discusses the difficulties that arise when two numbers are subtracted.

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