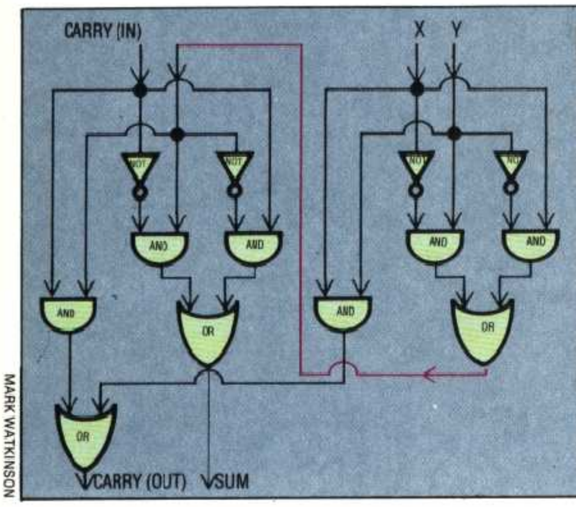

Full Adder

The full adder is the circuit that adds the digits in a binary sum. It is made up of two half adders and an OR gate. The full adder can deal with three inputs – the two digits and a possible carried digit. The arithmetic is done in two steps. In the first step the two digits are added and in the second the 'carry' is added to this answer. These two steps occur within the arrangement of gates where the two half adders are joined through an OR gate

This circuit is almost there. The only thing lacking is that an input of two 1s, although giving a 'sum' of 0, correctly, fails to produce a carry signal. However, an additional AND gate, wired in parallel to the two inputs, produces a carry signal when, and only when, both inputs are true. The truth table for the circuit in the illustration, called a half adder, is as follows:

X (input one)	Y (input two)	C ('carry' output)	S ('sum' output)
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

It is called a 'half adder' because, in a sense, it is only half adequate. If all we wanted to do was to add a single column of two binary digits, it would be fine. Usually, however, we will want to add two bytes of data together, and each byte contains eight bits. The adder looking after the rightmost column of binary digits would indeed need to be nothing more than a half adder. However, all the adders to the left of that need to be able to accept three inputs — the two digits from 'their' column and any carry from the next column to the right. Consider this addition:

```
 011
+111
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1010
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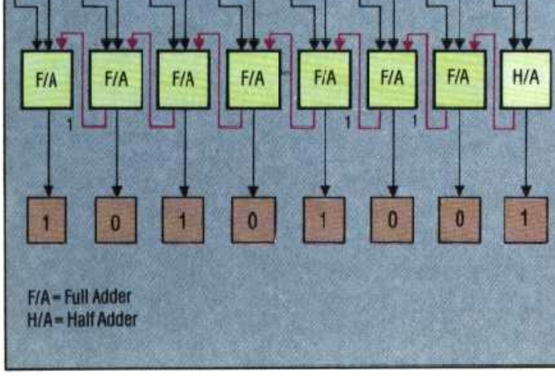
When adding the 'ones' column, we say 1 and 1 is 0, carry 1' and write a 0 under the 'ones' column. When we add the 'twos' column, we say 1 and 1 is 0, carry 1, plus the carry from the 'ones', is 1, carry 1. We write a 1 under the 'twos' column and carry 1 to the 'fours' column. Here we say 0 and 1 is 1, plus the carry from the 'twos' column, is 0, carry 1. We write the 0 in the 'fours' column and carry 1, which we write under the 'eights' column. In other words, the truth table for a 'full adder' able to handle carries as well as two binary digits, would look like:

X	Y	C(in)	C(out)	S
0	0	0	0	0
1	0	0	0	1
0	1	0	0	1
0	0	1	0	1
0	1	1	1	0
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

A full adder can be made using two half adders and an additional OR gate. The 'carry out' of each full adder is connected directly to the 'carry in' of the adder on its left and as many full adders can be chained together in this way as required.

In modern microcomputers, most additions and other arithmetical operations are carried out in large numbers of adder circuits conceptually identical to the ones we have described above. For the most part, though, these adder circuits are included in, and form just a part of, the circuitry of the CPU (the Central Processing Unit). Before the days of large scale integration that culminated in the microprocessor, simpler integrated circuits containing just a few gates were in common use. These circuits are usually called TTL chips (TTL stands for transistor-transistor logic because of the way most of the logic switching is performed by transistors directly coupled together). The inside of a typical CPU consists of a single silicon chip incorporating small areas of RAM and ROM memory, very large numbers of switching circuits and a part known as the ALU or Arithmetic and Logic Unit. The ALU is the part of the CPU containing all the logic gates and adders needed for the computer to perform computations and make logical decisions.



8-Bit Adder

When you add large numbers carefully together the addition is done digit by digit. The computer does the same. In the illustration, two 8-digit binary numbers are being added. The top row contains the first number and the second row the other. Working from the right-hand side, there can be no 'carry' to add to the sum of the first two digits, so a half adder is sufficient. But for the second and subsequent pairs of digits, full adders must be used (any 'carry' is indicated by a 1 below the adder). Try working through the process as the computer does and check your answer in the bottom row