



[Course](#) > [Compu...](#) > [Turing...](#) > Turing ...

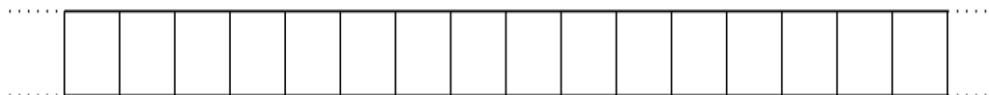
## Turing Machines

Let me start by introducing you to **Turing Machines**, which are computers of a particularly simple sort. They are named after their creator, the great British mathematician and hero of the Second World War, Alan Turing.

A Turing Machine's **hardware** consists of two components, a memory tape and a tape-reader:

### The Memory tape

You can think of the tape as a long strip of paper, divided into cells:



The tape is assumed to be infinite in both directions. (Alternatively, one might assume a finite tape, and an assistant who is ready to add paper to either end, as needed.)

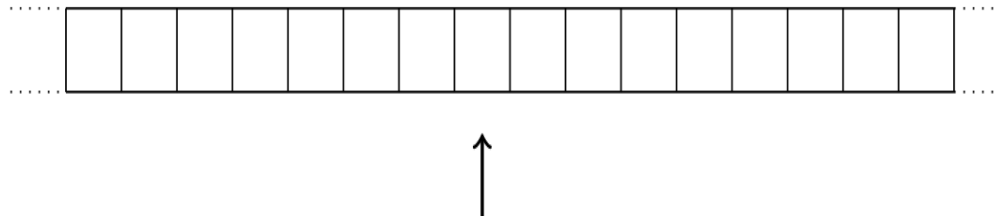
### The Tape-reader

At any given time, the machine's "reader" sits on a particular cell of the memory tape, and is able to perform the following functions:

- Read the symbol written on the cell
- Write a new symbol on the cell
- Move one cell to the left

- Move one cell to the right

We will indicate the position of the reader in our diagrams by placing arrow beneath the cell at which the reader is positioned:



A Turing Machine's **software** (i.e. the computer program it implements) consists of a finite list of **command lines**. Each command line is a sequence of five symbols, corresponding to the following parameters:

$\langle \text{current state} \rangle \langle \text{current symbol} \rangle \langle \text{new symbol} \rangle \langle \text{direction} \rangle \langle \text{new state} \rangle$

Think of a command line as encoding the following instruction:

If you are in  $\langle \text{current state} \rangle$  and your reader sees  $\langle \text{current symbol} \rangle$  written on the memory tape, replace  $\langle \text{current symbol} \rangle$  with  $\langle \text{new symbol} \rangle$ . Then move one step in direction  $\langle \text{direction} \rangle$ , and go to  $\langle \text{new state} \rangle$ .

The parameters of a command line are to be filled in as follows:

- $\langle \text{current state} \rangle$  and  $\langle \text{new state} \rangle$  are filled with numerals ("0", "1", "2", etc.).
- $\langle \text{current symbol} \rangle$  and  $\langle \text{new symbol} \rangle$  can be filled with letters or numerals (e.g. "a", "0"), or with the special symbol "\_", which is used to indicate a blank.
- $\langle \text{direction} \rangle$  are filled with "l" (for "left"), "r" (for "right"), or "\*" (for "don't move").

For instance, the command line "7 0 1 r 2" is interpreted as the following instruction:

If you are in state 7 and your reader sees "0" written on the memory tape, replace the "0" with a "1". Then move one step to the right, and go to state 2.

And the command line “0 \_  $a$  \* 10” is interpreted as:

If you are in state 0 and your reader sees a blank, replace the blank with an “ $a$ ”. Then stay put, but go to state 10.

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