How computers work

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Sep. 2015

Automaton

Definitions from the Merriam-Webster dictionary:

- A mechanism that is relatively self-operating
- A machine or control mechanism designed to follow automatically a predetermined sequence of operations

. . .

Examples:

- drinks vending machine

- clocks

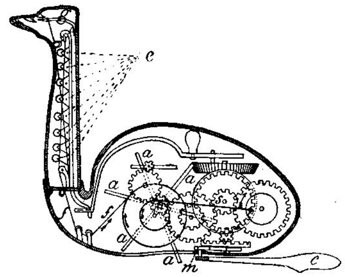
- "Canard" et "Joueur de flûte" by Jacques de Vaucanson (1733)

"L'Encyclopédie fit de Vaucanson un demi-dieu et le célébra pour ses automates extraordinaires : pour la première fois des êtres artificiels étaient capables, par le génie du cerveau humain, de jouer parfaitement d'un instrument de musique ou de se comporter comme de véritables êtres vivants."

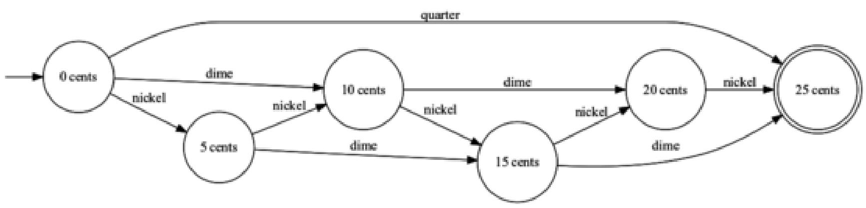
Formal description of automata

At a abstract level, an automaton can be formally described by: - a set of internal **states** - a **transition** table that describes the **events** that lead to changes from state to state

Figure 1: Automate du Quartier de l'horloge à Paris

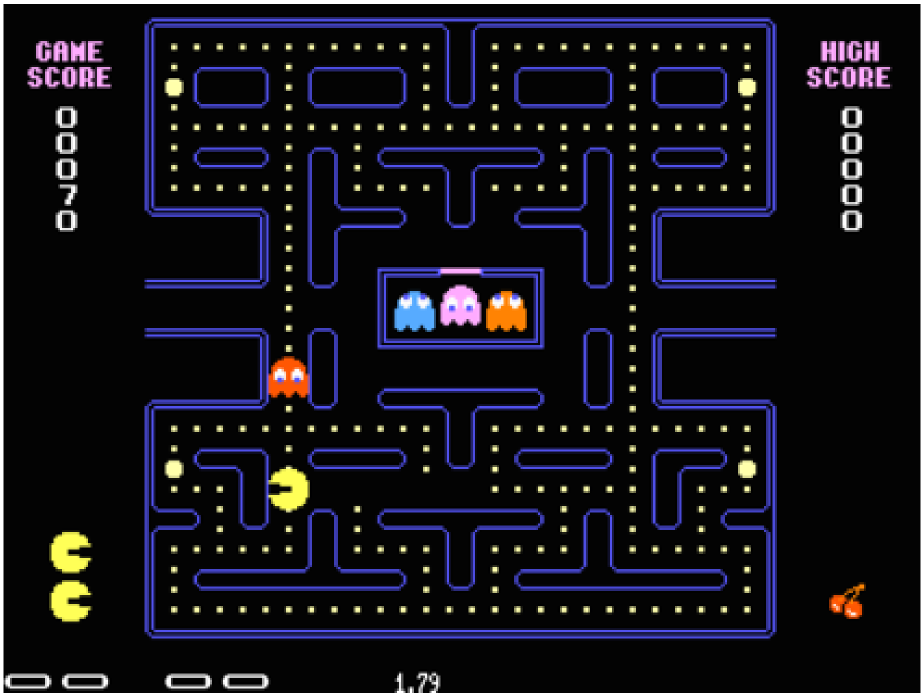


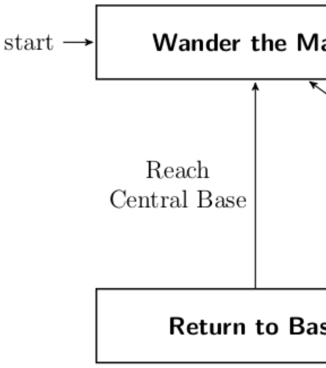
Le canard : *a*, roues à palette ; *c*, patte palmée ; *e*, châssis, *f*, corde à boyau ; *g*, ressort ; *m*, levier horizontal ; *s*, pignon.



Change counter in a vending machine

Pacman's ghost





Birdsong

Finite state automaton description of Bengalese Finch songs

From Berwick et al., 2011 *Trends in Cognitive Sciences* 15, 3: 113–21

(see also Descartes. *Les animaux Machines* Lettre au Marquis de Newcastle

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Pattern recognition

(a very useful tool in Computer Science are *regular expressions*, a way to describe patterns and find them in data)

Capturing the Grammar of English language

See David Temperley's Visual representation of the English language for more.

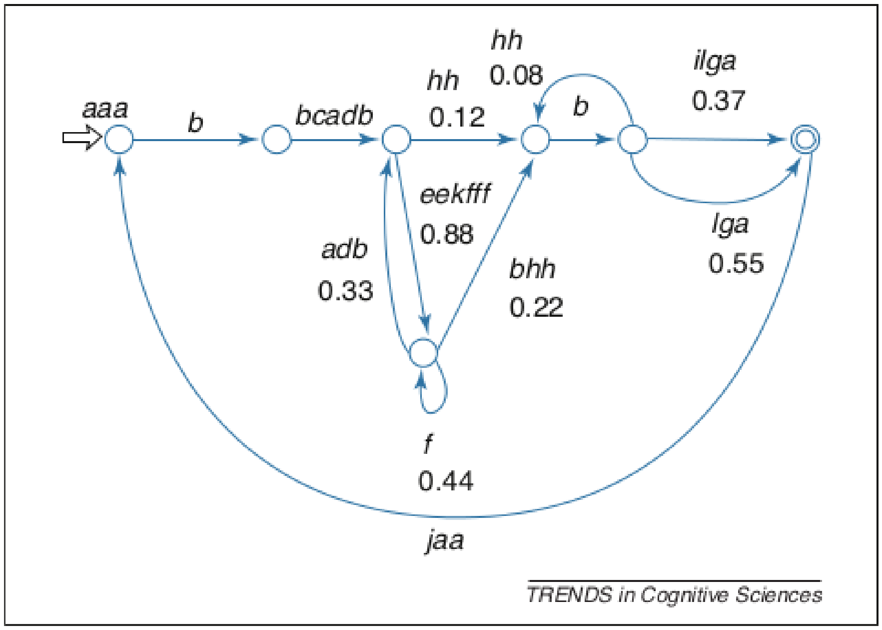


Figure 3. Probabilistic finite-state transition diagram of the song repertoire of a Bengalese finch. Directed transition links between states are labelled with note sequences along with the probability of moving along that particular link and producing the associated note sequence. The possibility of loops on either side of fixed note sequences such as *hh* or *lga* mean that this song is not strictly locally testable (see Box 3 and main text). However, it is still *k*-reversible, and so easily learned from example songs [35]. Adapted, with permission, from [75].

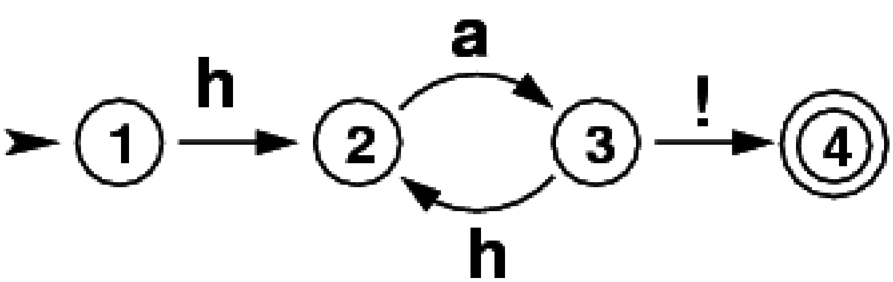


Figure 2: Haha!

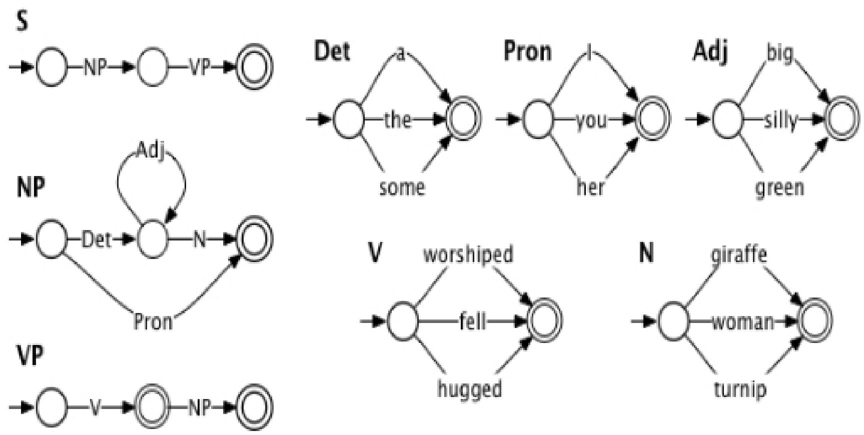


Figure 3: simple fragment of English

Remarks

- Events associated to transition can be input and/or output
- Automata can react to external events in a context-sensitive manner because the current states depends on the history of states.

Computer science terminology: *finite state machines* (FSM), or _finite state automaton___ (FSA)

Exercice: draw the transition diagram for a simple coffee machine with three states (off/on/brewing) and two buttons (switch on/off and brew)

Computers

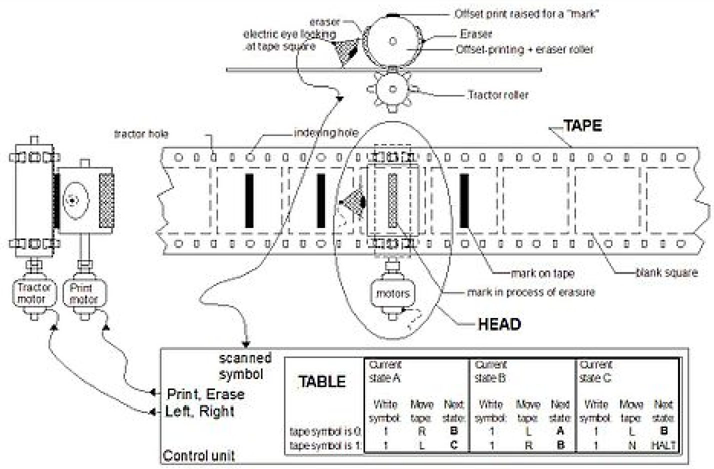
Computer = automaton with an additional memory store.

Turing Machines

Alan Turing (1936).

Intended as a mathematical model of computation, it is a finite state machine augmented with a tape and a mechanism to read/write on it.

. . .



A fanciful mechanical Turing machine's TAPE and HEAD. The TABLE instructions might be on another "read only" tape, or perhaps on punch-cards. Usually a "finite state machine" is the model for the TABLE.

In the 1930s, there were several independent attempts to formalize the notion of computability, and it was discovers that all of them were equivalent in power!

Church–Turing thesis : a function on the natural numbers is computable in an informal sense (i.e., computable by a human being using a pencil-and-paper method, ignoring resource limitations) if and only if it is computable by a Turing machine.

For more information about Turing machines, see https://en.wikipedia.org/wiki/Turing_machine

Register machines

A register machine is another computing model that is closer to actual computers.

The seven secrets of computer power revealed (Chapter 24 from Daniel Dennett (1023) *Intuition Pumps and other tools for thinking*)

(an older version is available at http://sites.tufts.edu/rodrego/files/2011/03/Secrets-of-Computer-Power-Revealed-2008.pdf)

(Online Demo at http://proto.atech.tufts.edu/RodRego/

Registers = memory locations, each with a unique *address* (1, 2, 3, . . .), and each able to have , as *contents*, a singel integer (0, 1, 2, . . .)

Processing unit that can execute instructions in a stepwise, one-at-a-time fashion. The processor knows just 3 instructions:

- *End*
- *Increment register* with 2 arguments: a register #, an step number
- *Decrement register and Branch* with 3 arguments, a register number and two step numbers.

Program 1 (ADD[0,1])

```
1 DEB 0 2 3
2 INC 1 1
3 END
```

Exercice; Simlulate this program on a machine wheret Reg0 contains 4 and Reg1 contains 7, and explain what it is doing.

. . .

This program adds the content of register 0 to register 1 (destroying the content of 0)

Program 2 (MOVE[4,5])

Exercice: write a program that moves the content of reg4 intro reg5

. . .

```
1 DEB 5 1 2
2 DEB 4 3 4
3 INC 5 2
4 END
```

. . .

Program 3 (COPY[1,3])

The following program copies the content of reg1 into reg3, leaving reg1 unchanged.

```
1 DEB 3 1 2
2 DEB 4 2 3
3 DEB 1 4 6
4 INC 3 5
5 INC 4 3
6 DEB 4 7 8
7 INC 1 6
8 END
```

Program 4 (NON DESTRUCTIVE AD[1,2,3])

```
 1 DEB 3 1 2
 2 DEB 4 2 3
 3 DEB 1 4 6
 4 INC 3 5
 5 INC 4 3
 6 DEB 4 7 8
 7 INC 1 6
 8 DEB 2 9 11
 9 INC 3 10
10 INC 4 11
11 DEB 4 12 13
12 INC 2 11
13 END
```

. . .

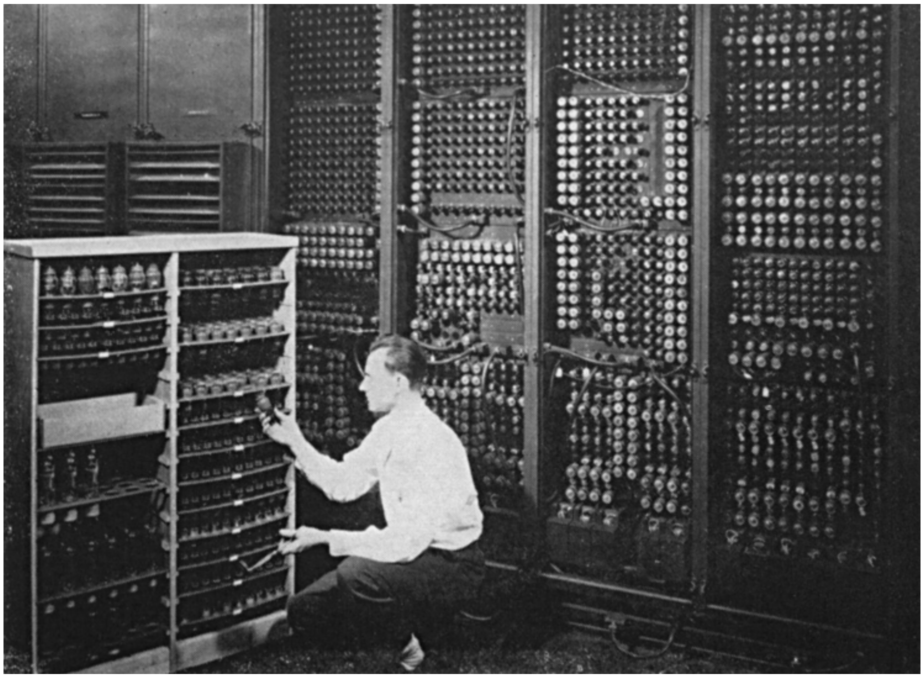
Note that *conditional branching* is the key instruction that gives the power to the machine. Depending on the content of memory, the machine can do either (a) or (b).

The 7 secrets of computers revealed

1. Competence without comprehension. A machine can do perfect arithmetic without having to comprehend what it is doing.
2. What a number in a register stands for depends on the program
3. The register machine can be designed to discriminate any pattern that can be encoded with numbers (e.g. images, text, sensory inputs,. . .)
4. Programs can be encoded by numbers.
5. All programs can be given a unique number which can be treated as a list of instructions by a Universal Machine.
6. all improvements in computers over Turing machine (or Register machine), are simply ways of making them faster
7. There is no secret #7

Programs

- The first computers were not programmable. They were hardwired!



- Programmable computer:
  - a program is a set of instructions stored in memory.
  - Loaded and executed by a processor.
  - Such programs are written in machine langage (the language of the processor)

Programs in higher-level languages (rather than Machine language) can be either * **compiled**, or * **interpreted**

In both cases, you write the program as textual files.

A **compiler** translates the program into an executable file in machine language. The exectutable file is standalone.

An **interpreter** reads the file and execute the commands one by one. It is slower, but easier to interact with. Disatvange: you need the interpreter at all time.

Operating systems

In the first computers, there was only **one** program running. Yo would load the program into memory, then run it until the end. Programs were ran in BATCH mode, in a sequence.

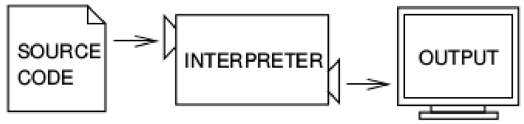


Figure 1.1: An interpreter processes the program a little at a time, alternately reading lines and performing computations.

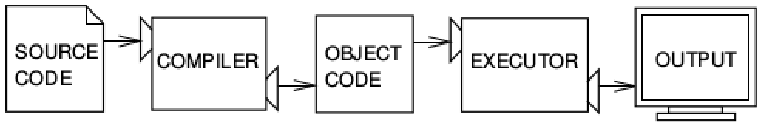


Figure 1.2: A compiler translates source code into object code, which is run by a hardware executor.

Then, it was realized that computers could 'time-share' between programs, allowing several users (or programs) to share the computer.

This requires an operating systems (O.S.). The O.S. is the first program that loads into the computer during the boot. When running:

- it controls the hardware (screen/printer/disk/keybord/mouse,. . .) (drivers)
- it manages all the other programs (processes/tasks/applications).
  - sharing memory
  - allocating processors and cores
  - allocating time

  Check out *Task Manager* (Windows)/*System Monitor* (Linux)/ *Activity Monitor* (Mac)

Different OS offer different “views” of the computer (e.g. 1 button mouse in Mac, 2 in Windows, 3 in Linux), so often programs are designed to work on one OS (bad!). Prefer multiplatform software (like Python).

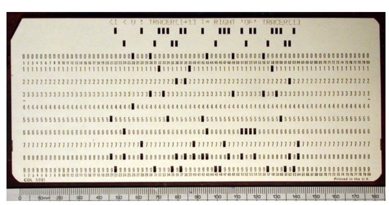
Several OS can be installed in a given machine: - choice at boot (multiboot) - an OS can run inside a **virtual machine**, that is a program running in another (or the same) OS, and emulating a full computer.

What is a Terminal?

Terminal (or **console**): originaly, a device comprising a keyboard and screen, allowing a human to *interact* with a computer.

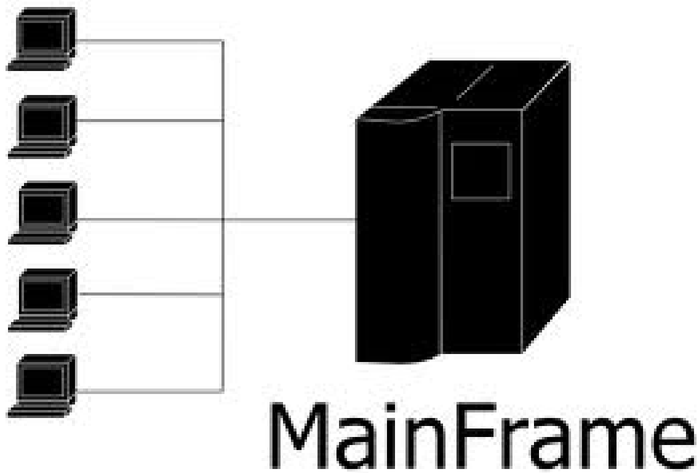
Notes:

- Early computers had no keyboard, no screen. The input was done through punched cards and output would be printed out).



- In the mainframe era, many terminals were connected to a single, powerful, computer. Everybody was sharing the same computer.

- With the advent of *Personal Computers*, the terminal and the computer became a single apparatus.



However, terminals can be *virtual*. A terminal is a program that let you run text programs. You interact by typing and displaying text. No graphical interface/no mouse.

When you open a terminal, a program called a **shell** is started that displays a prompt, and waits for you to enter commands with the keyboard.

How to open a Terminal

- Ubuntu-Linux: Ctrl-Alt-T (see https://help.ubuntu.com/community/UsingTheTerminal)
- MacOSX: Open Finder/Applications/Utilities/Terminal (see http://www.wikihow.com/Get-to-the-Command-Line-on-a-Mac)
- Windows: Win+X+Command-Prompt (see http://pcsupport.about.com/od/commandlinereference/f/open-command-prompt.htm)

The shell

Inside the terminal, you are interacting with a program called a **Shell**.

Various *Shells* exists: under Windows: cmd/powershell; under, Mac/linux: bash/tsch… they speak slighlty different languages.

The shell displays a prompt and waits for you to type commands that it will execute. For example, if you type ipython, it will start the ipython program.

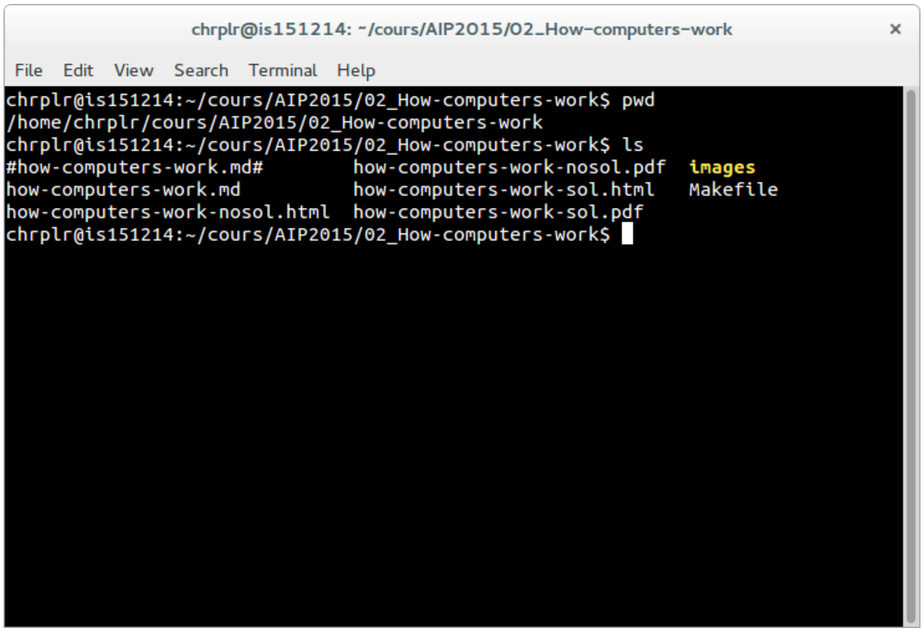


Figure 4: Picture of a 'virtual' terminal in Linux

One issue is that you have to know the available commands and the language. By contrast with a Graphical User Interface shell with Windows/Icons/Menus, **Textual shells** have a very poor ergonomy. Yet, there are more powerful. They provides variables, loops,… to facilitate automation of tasks.

For example, to create 20 directories in a single bash command under linux:

```
for f in 01 02 03 04 05 06 07 08 09 10; do mkdir -p subject_$f/data subject_$f/results; done
```

To learn more, see Wikipedia's article on *Shell_(Computing)*: http://en.wikipedia.org/wiki/Shell_%28computing%29

Good news: you will not need to learn a *shell* language, only a few commands (pwd/cd/ls/dir) to allow you to navigate the filesystem and run a program.

Disks, Directories and files

Most computers (not all) have two kinds of memories: - volatile, fast, memory, which is cleared when the computer is switched off (processor's caches, RAM) -

‘permanent’, slow, memory, which is not erased when the computer is switched off (DISKS, Flashdrives (=solid-state drives))

The unit of storage is the **file**.

Files are nothing but blobs of bits stored “sequentially” on disks.

A first file could be stored between location 234 and 256, a second file could be stored at location 456.

filenames, directory structure

To access a file, one would need to know its location on the disk. To simplify human users’ life, the OS provide a system of “pointers”, that is **filenames** , organised in directories.

To help users further, the directories are organised in a hierarchical structure: a directory can contain filenames and other (sub)directories. The top-level directory is called the **root**.

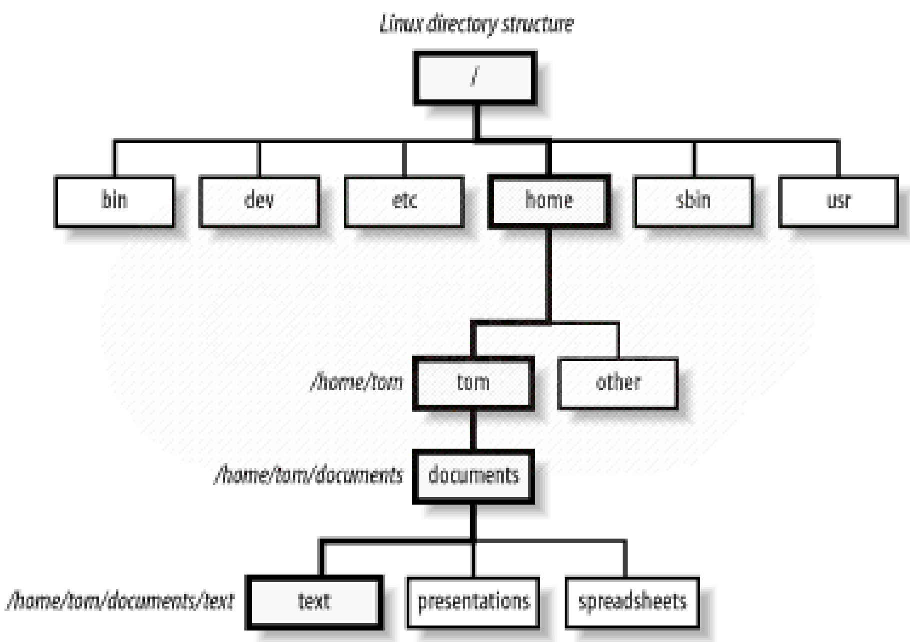


Figure 5: Linux directory structure

To locate a file, you must know: - its location in the directory structure - its basename

Remark: a given file can have several names in the same or various directories (remember: a filename is nothing but a link between a human readable charachter string to a location on the disk)

Working directory. Absolute pathnames vs. relative pathnames (..)

It would be tedious to always have to specify the full path of a files (that is, the list of all subdirs from the root)

Here comes the notion of **working directory**: A running program has a working directory and filenames can specified **relative** to this directory.

Suppose you want to access the file pointed to by `/users/pallier/documents/thesis.pdf`. If the current working directory is `/users/pallier`, you can just use `documents/thesis.pdf` (notice the absence of '/' at the beginning).

To determine the current working directory, list its content, and change it:

- under bash

  ```
  pwd
  ls
  cd Documents
  ```

- under Windows/cmd

  ```
  echo %cd%
  dir
  cd Documents
  ```

- under python (or ipython):

```
import os
os.getcwd()
os.listdir('.')
os.chdir('documents')
os.getcwd()
```

PATH

A command can simply be a program's name. Typing it and pressing Enter will start the program.

The shell knows where to look for programs thanks to a special environment variable called the **PATH**.

Under bash

```
echo $PATH
which ls
which python
```

Under Windows/DOS:

```
echo %PATH%
```

The PATH variable lists all the directories that contains programs.

It is possible to add new directories to the PATH variable, to access new programs.

bash

```
export PATH=newdirectory:$PATH
```

DOS

```
PATH=newdirectory;%PATH%
```

What is a library (or module/package)?

A set of new functions that extend a language (.DLL (Windows);.a or .so (Linux); framework bundles (MacOs))

Dynamic libraries can be used simultaneously by several processes.

Eg. the function @@sqrt@@ can be defined once, and called by several programs, saving memory.

In Python, use @@import library

```
import math
math.srqt(2)
```