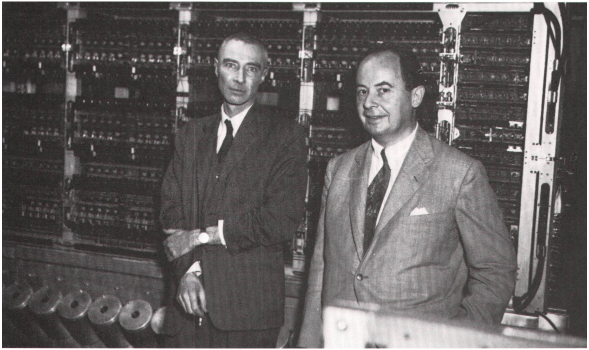
Computational thinking

Victor Eijkhout, Susan Lindsey

Fall 2019

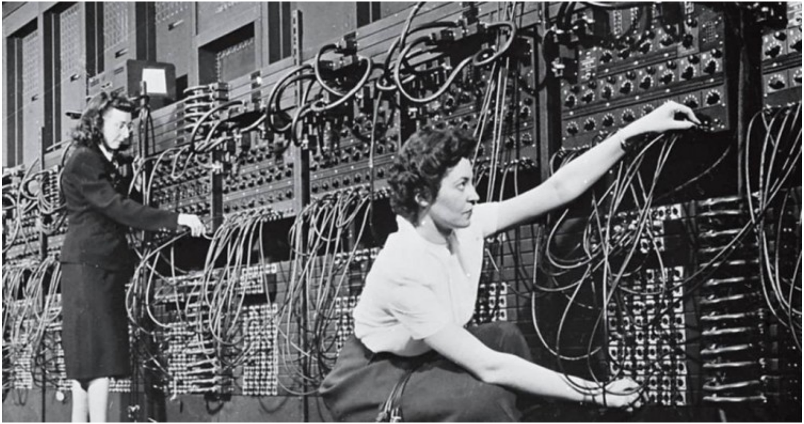
Earliest computers

Historically, computers were used for big physics calculations, for instance, atom bomb calculations



Hands-on programming

Very early computers such as ENIAC were hardwired



later became 'stored program' computer.

see `http://eniacprogrammers.org/`

Program entry

Later programs were written on punchcards

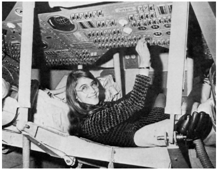
The first programming language

Initial programming was about translating the math formulas; after a while they made a language for that: FORmula TRANslation

Programming is not simple

Programs can get pretty big:

Margaret Hamilton, director of the Software Engineering Division, the MIT Instrumentation Laboratory, which developed on-board software for the Apollo program.



It's not just translating formulas anymore.

Translating ideas to computer code: computational thinking.

Programming is everywhere

Programming is used in many different ways these days.

- You can make your own commands in *Microsoft Word*.
- You can make apps for your *smartphone*.
- You can solve the riddles of the universe using big computers.

This course is aimed at people in the last category.

Is programming a craft or a science?

How about a ‘discipline’?

Computational thinking: elevator scheduling

Mathematical thinking:

- Number of people per day, speed of elevator $\Rightarrow$ yes, it is possible to get everyone to the right floor.
- Distribution of people arriving *etc.* $\Rightarrow$ average wait time.

Sufficient condition $\neq$ existence proof.

Computational thinking: actual design of a solution

- Elevator scheduling: someone at ground level presses the button, there are cars on floors 5 and 10; which one do you send down?

Coming up with a strategy takes creativity!

Exercise 1

Algorithms are usually not uniquely determined. There can be cleverness involved.

Four self-driving cars arrive simultaenously at an all-way-stop intersection. Come up with an algorithm that a car can follow to safely cross the intersection. If you can come up with more than one algorithm, what happens two cars using different algorithms meet each other?

Computation and complexity

Looking up a name in the phone book

- start on page 1, then try page 2, et cetera
- or start in the middle, continue with one of the halves.

What is the average search time in the two cases?

Having a correct solution is not enough!

Abstraction

- The elevator programmer probably thinks: ‘if the button is pressed’, not ‘if the voltage on that wire is 5 Volt’.
- The Google car programmer probably writes: ‘if the car before me slows down’, not ‘if I see the image of the car growing’.
- . . . but probably another programmer had to write that translation.

A program has layers of abstractions.

Data abstraction

What is the structure of the data in your program?

Stack: you can only get at the top item

Queue: items get added in the back, processed at the front

A program contains structures that support the algorithm. You may have to design them yourself.

Do you have to know much about hardware?

Yes, it's there, but we don't think too much about it in this course.

`https://youtu.be/JEpsKnWZrJ8`

Advanced programmers know that hardware influences the speed of execution (see TACC's ISTC course).

What is an algorithm?

An algorithm is a sequence of unambiguous instructions for solving a problem, i.e., for obtaining a required output for any legitimate input in a finite amount of time

[A. Levitin, Introduction to The Design and Analysis of Algorithms, Addison-Wesley, 2003]

The instructions are in some language:

- We will teach you C++ and Fortran;
- the compiler translates those languages to machine language

Program steps

- Simple instructions: arithmetic.
- Compicated instructions: control structures
  - conditionals
  - loops

Program data

- Input and output data: to/from file, user input, screen output, graphics.
- Data during the program run:
  - Simple variables: character, integer, floating point
  - Arrays: indexed set of characters and such
  - Data structures: trees, queues
    - Defined by the user, specific for the application
    - Found in a library (big difference between C/C++!)

Comparing two languages

Python vs C++ on bubblesort:

```python
for i in range(n-1):
  for j in range(n-i-1):
    if numbers[j+1]<numbers[j]:
      swaptmp = numbers[j+1]
      numbers[j+1] = numbers[j]
      numbers[j] = swaptmp
```

```cpp
for (int i=0; i<n-1; i++)
  for (int j=0; j<n-1-i; j++)
    if (numbers[j+1]<numbers[j]) {
      int swaptmp = numbers[j+1];
      numbers[j+1] = numbers[j];
      numbers[j] = swaptmp;
    }
```

```
[] python bubblesort.py 5000
Elapsed time: 12.1030311584
[] ./bubblesort 5000
Elapsed time: 0.24121
```

The right language is not all

Python with quicksort algorithm:

```
numpy.sort(numbers,kind='quicksort')
```

```
[] python arraysort.py 5000
Elapsed time: 0.00210881233215
```

Don't reinvent the wheel

- Can you choose a language that has the right tools?
  Python is way better than C++/Fortran for text processing and file manipulation.
- Is your algorithm part of a standard library or a library you can download/buy?
  Millions of programmers, just like you, have needed linear algebra algorithms. Most of what you could need already exists!