Computers and programming languages
introduction

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The College of William & Mary

Lecture 01
Class goals and structure

Primary purpose

- learn to specify a problem
- break it up into algorithmic pieces
- implement a program to execute these pieces
  - learn Matlab
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- then learn numerical analysis basics while keep mastering Matlab
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Weekly schedule

- Monday, Wednesday: normal lecture hours
- Friday: short lecture, lab, hands on
Building blocks

To learn a language we need to practice and use this language a lot of weight on homeworks and projects. No final exam. Final project defense instead December 14 at 14:00 in Small Hall 233.

Grades contribution:
Homeworks: 15%
Midterm projects: 60%
Final project: 25%

Assignments and lecture notes will be posted on my homepage:
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Homeworks and midterm project deadlines

- **due date**: corresponding Monday at 1:00pm for email submission
- report to be submitted via email as well as a carbon copy to be collected at the beginning of the Monday class

if there is no listings and no algorithms/data files you will get zero points.

**Late submission penalties**
For each consequent day after due date there will be a penalty (10% out of maximum possible score). Even if submission happens 1 minute after due date, it holds 1 day penalty.

**Projects homework preparation recommendation**
Do not wait till the last day to finish your exercise. Programs almost never work at the first try and require quite a lot of time to debug.
Collaboration and grading scale

- Collaborations are not permitted for homeworks.
- Projects to be done in group of 2 or 3 persons. This is the time to actively discuss and cooperate. Only one report per such group is needed.
  - But everyone expected to have a full understanding of the project.
  - Be ready to answer questions related to the project without your group support.

Grading scale

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Everything required during this class will be provided during lecture times.

Two **optional** books for your own references.

A short Matlab reference book: "Getting Started with MATLAB: A Quick Introduction for Scientists and Engineers" by Rudra Pratap

- ISBN-10: 0199731241

A more extended treatment of numerical algorithm with Matlab: "Numerical Methods in Engineering with MATLAB" by Jaan Kiusalaas

- ISBN-10: 0521191335
Early history of computing

Computers used to be human.

Computing aids - no programming possible.

- Abacus
- Sliding ruler
- Pre-calculated tables of functions (logarithm, trigonometry...)
- Mechanical calculators

Modern computers appeared at 1946 - ENIAC (Electronic Numerical Integrator and Computer):
- Weight: 30 tons
- Cost: $500,000 ($6,000,000 adjusted)
- Power consumption: 150 kW

Eugeniy Mikhailov (W&M)
Practical Computing
Lecture 01
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ENIAC vs modern PC

Speed operations per second

ENIAC
- 5000 additions
- 357 multiplications
- 38 divisions

Athlon 3000+ (2GHz)
- 70,000,000 additions
- 70,000,000 multiplications
- 50,000,000 divisions
- 15,000,000 sin operations
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Common features of modern computer

- Central Processing Unit (CPU)
- memory
  - holds data and executable code
- data input and output
- same hardware can do different calculation sequences
- usually use binary system
- programmable for any general task

Speed measured in FLOPS (the number of floating point operations per second) which usually proportional to the clock frequency.

Different computer architectures (AMD, Mac, Intel, ARM . . . ) have different proportionality coefficient.

My 2 GHz AMD PC can do about 50 MegaFLOPS
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Computers are incredibly fast,
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Computers are incredibly fast, accurate, and *stupid*. Humans beings are incredibly slow,
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Leo Cherne (1969)
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Thus

Computer is not a substitute for a brain
Programming languages overview

There are hundreds programming languages.
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- **Super low-level language**
  - binary code
    - the only thing which computers understand
    - each instruction looks like a number
    - usually it is not human readable
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- Unfortunately none of them serves all needs.
Compiled

- generate computers binary code
  - it takes time
- faster execution time
- a bit harder to debug
- if you find and fixed an error (bug) you need to recompile

Examples:
Assembler, C, C++, Fortran

Examples:
Java, Python

Interpreted

No compilation interpretation to machine code per instruction slow (since you have to interpret same instruction over and over)
cross-platform code
Examples: Perl, JavaScript, Lua, Php, Tcl, Shells, Matlab
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Programming languages implementations

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just-in-time compilation
- middle ground
- compile once to bytecode
- cross-platform
- Examples: Java, Python

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Matlab as a language of choice

Matlab (matrix laboratory)
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Pro
- interpreted
  - easy to use and debug
- quite fast if done right, since main functions are compiled
- large selection of scientific related functions
- built in graphics/plotting
- Turing complete (you can do with it everything which computer is capable)
- designed to do numerical calculations

Contra
- interpreted could be slow if programmed inefficiently
- Not free to modify internals
- quite fast since for main functions it calls a compiled code
- rudimentary symbolic calculations
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Matlab: where to get

- Free for W&M students
- available for Mac and Windows
- visit http://www.wm.edu/offices/it/a-z/software/index.php
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Discretization - The main weakness of computers

- coming from resources limitation

For example:

\[ \frac{1}{6} = 0.1666666666666666 \cdots \]

But computer has limited amount of memory. Thus it cannot hold infinite amount of digits and has to truncate somewhere.

Let’s say it can hold only 4 significant digits.

\[ \frac{1}{6} = 0.6667_c \]

This called **round off error** due to truncation/rounding. Then for computer

\[ \frac{1}{6} = \frac{1}{5.9999} \]

or

\[ 0.1667123 = 0.1667321 = 0.1667222 = 0.1667111 \]

or even more interesting

\[ 20 \times \left( \frac{1}{6} \right) - \frac{20}{6} = 20 \times 0.1667 - 3.333 = 3.334 - 3.333 = 10^{-4} \]
Modern general purpose computers use binary representation

- bit is the smallest unit of information
- bit value is either 0 or 1

Bit is too small so we use byte

- byte = 8 bits stitched together
- byte can represent values in the range $-128 \cdots 0 \cdots 127$
- the major (the leftmost) but usually holds the sign ($s$) of the number
  - 0: means positive
  - 1: means negative

01001010

Decimal representation $01001010_2 = (-1)^0 \times (0 \times 2^0 + 1 \times 2^1 + 0 \times 2^2 + 1 \times 2^3 + 0 \times 2^4 + 0 \times 2^5 + 1 \times 2^6) = 2 + 8 + 64 = 74$
Byte is clearly too small to be used for real-life computation. Matlab uses 8 bytes or 64 bits for number representation:

- available range $-2,147,483,648 \cdots 0 \cdots 2,147,483,647$
- you can find this range by executing `intmin` and `intmax`
- notice that you cannot use numbers outside of this range
  - $2,147,483,647 + 10 = 2,147,483,647$
  - this is called **overflow error**
Float numbers representation

What to do if you need to store a float number?

For example, $-123.765 \times 10^{12}$.

First convert it to scientific notation:

$-1.23765 \times 10^{14}$

truncate it to certain number of significant digits (let's use 4 for example, actually 17 decimals for 64 bits float number):

$-1.237 \times 10^{14}$

resulting number should have a form $(s) \times c \times b^q$ where:

- $s$ is a sign bit (1 in our case)
- $c$ is the coefficient (1.237)
- $b$ is the base (10)
- $q$ is the exponent (14)

Computers internally use binary base $b = 2$:

- 64 bits for full representation
- 52+1 bits for mantissa (about 17 decimal digits)
- 11 bits for exponent ($\pm 307$)
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Computers internally use binary base

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Limits of the float representation

- **maximum** $\pm 1.797693134862316 \times 10^{308}$
  - (use `realmax` in Matlab)
  - $(1.797693134862316 \times 10^{308}) \times 10 = \text{Inf}$
  - overflow error

- **minimum** $\pm 2.225073858507201 \times 10^{-308}$
  - (use `realmin` in Matlab)
  - $(2.225073858507201 \times 10^{-308})/10 = 0$
  - underflow problem

- **truncation error**
  - $1.797693134862316 + 20 = 21.797693134862318$
  - $1.797693134862316 + 100 = 101.79769313486232$

- **how to mitigate**
  - try to use numbers of the similar magnitude
  - do not rely on the least significant digits