CS 101
Computer Programming and Utilization

Basics

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Computer

- "A machine that can be *programmed* to carry out sequences of arithmetic or logical operations (computation) automatically."
  - en.wikipedia.org/wiki/Computer

PROGRAM = योजना [pr. {yojana}] (Verb)

Usage : The computer is **programm**ed to receive instructions from the user.
उदाहरण : योजना अपवाद उत्पन्न हुआ

+23

PROGRAM = कार्यक्रम [pr. {karyakram}] (Noun)

Usage : he proposed an elaborate **program** of public works
उदाहरण : क्या कर्ता कार्यक्रम के प्रति प्रतिक्रिया दे रहा है

program

verb [T]

UK /ˈprəʊ.græm/ US /ˈproʊ.
-mm-

to write a series of instructions that make a computer perform a particular operation:

- [+ to infinitive] *She programmed the computer **to** calculate the rate of exchange in twelve currencies.*

Cambridge Dictionary

program

noun [C]

US /ˈproʊ·græm, -grəm/

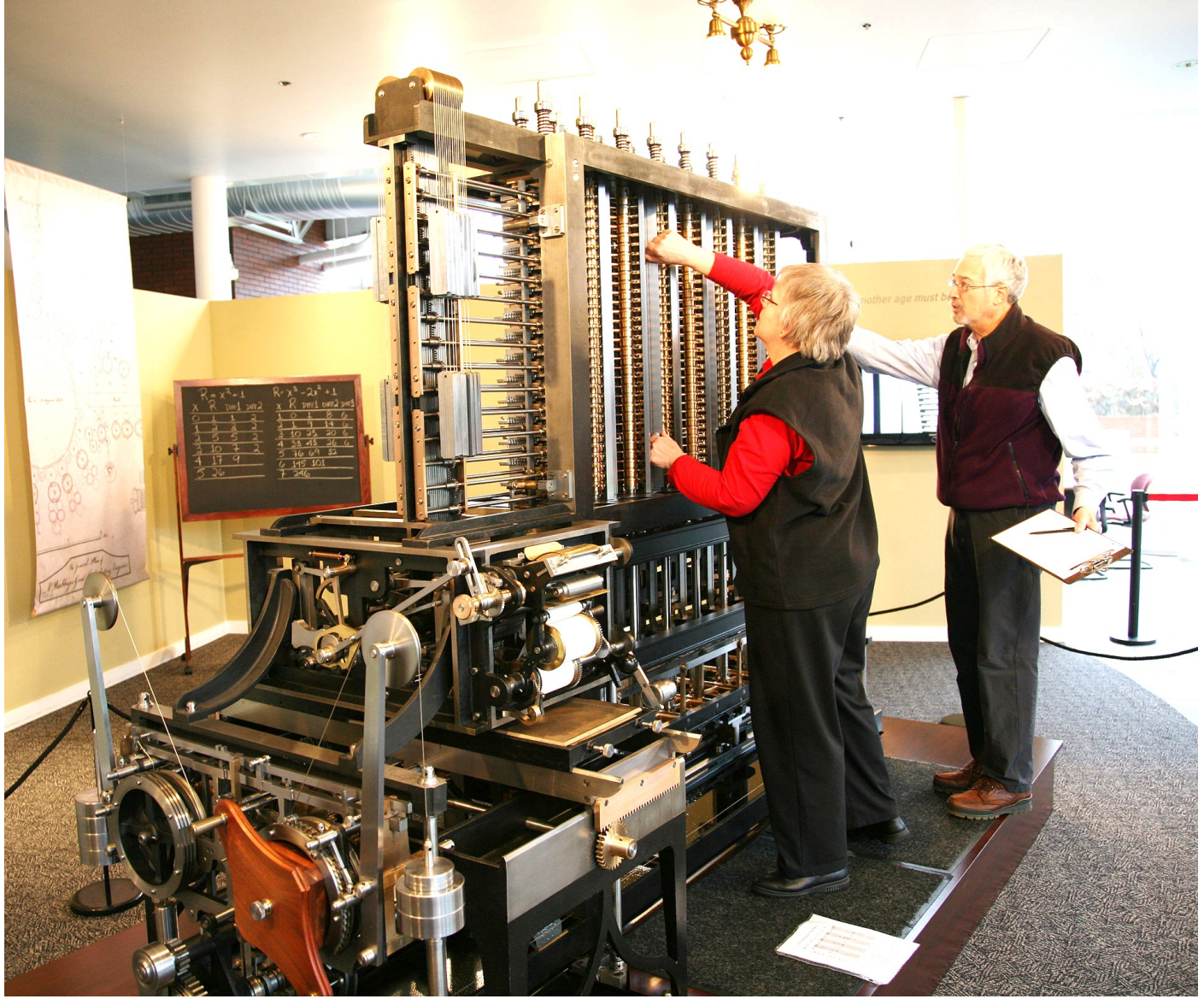
program *noun* [C] (ACTIVITIES)

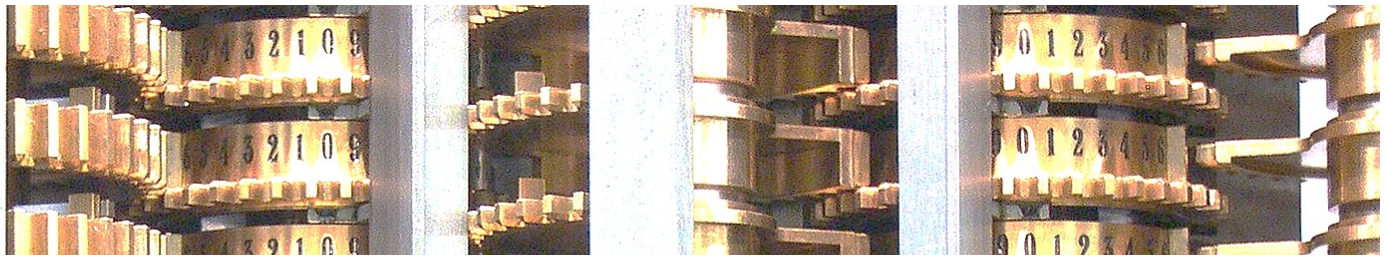
a group of activities or things to be achieved:

- *a training program*
- *the university basketball program*
- *a pilot recycling program*

Computer

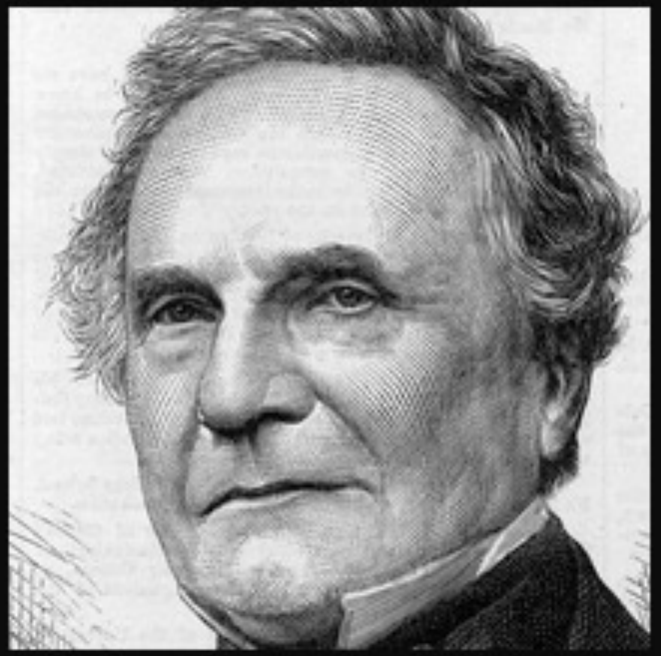
- **Mechanical** calculator
  - Processing numbers
  - Charles Babbage's "difference engine"
    - British mathematician, philosopher, inventor, mechanical engineer
    - Math professor at Cambridge University
  - Designed to tabulate/interpolate polynomial functions in 1820s
  - en.wikipedia.org/wiki/Difference_engine
  - en.wikipedia.org/wiki/File:Babbage_Engine_Demonstra





Computer

- On the importance of processing data (numerical, or in other forms)



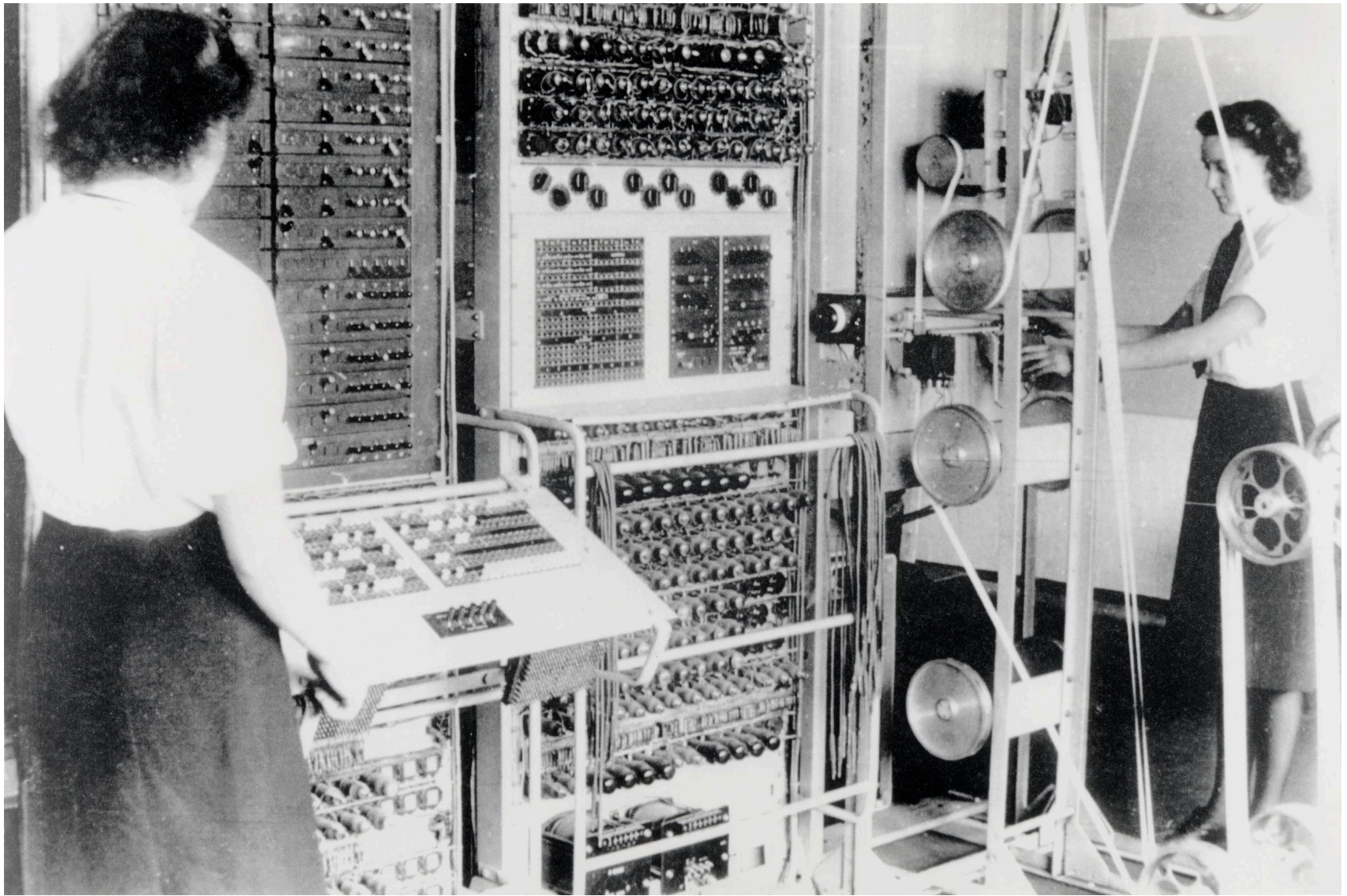
Errors using inadequate data are much less than those using no data at all.

~ Charles Babbage

AZ QUOTES

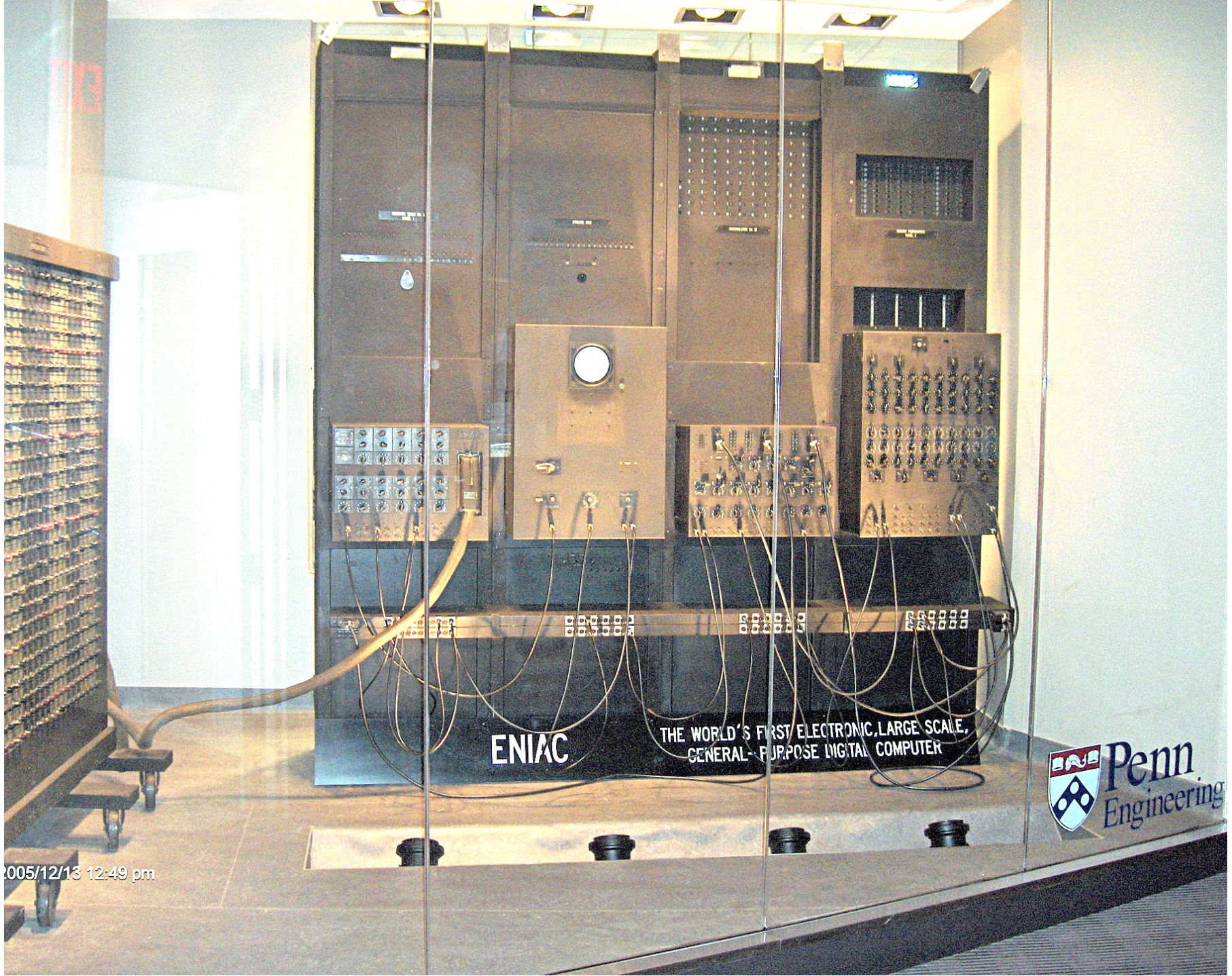
Computer

- **Electronic** digital computer
  - Cryptanalysis during second world war
  - Used thermionic valves (vacuum tubes) to perform logical and counting operations
  - en.wikipedia.org/wiki/Colossus_computer



Computer

- ENIAC (Electronic Numerical Integrator and Computer)
  - First programmable, electronic, **general-purpose** digital computer, completed in 1945
  - en.wikipedia.org/wiki/ENIAC



Computer

- Supercomputer
  - Modern
  - General-purpose computer with a high level of performance
    - en.wikipedia.org/wiki/Supercomputer

Computer

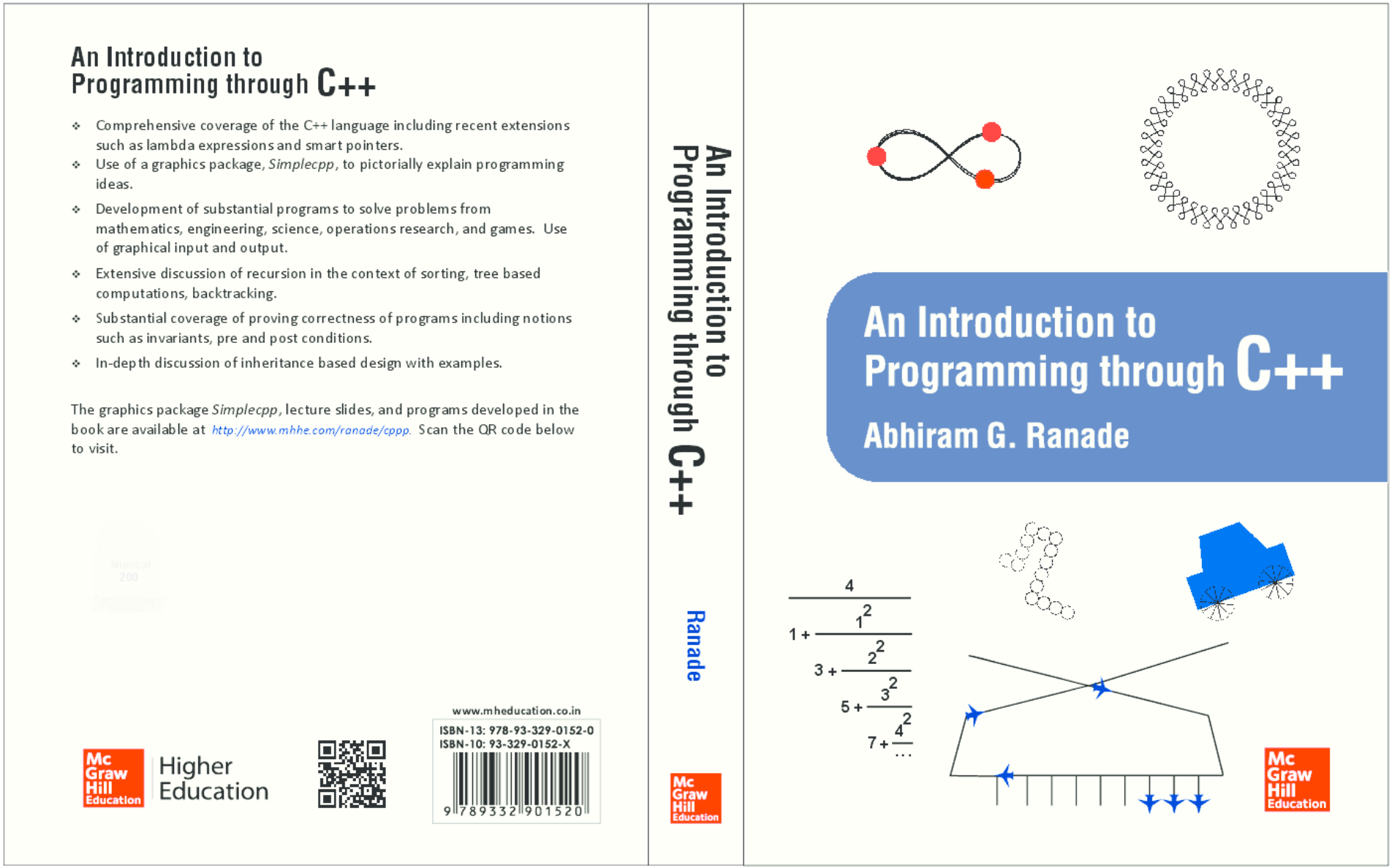
- Smartphone
  - “Portable computer device that combines mobile telephone functions and computing functions into one unit”
    - en.wikipedia.org/wiki/Smartphone

Programming

- "Computer program"
  - A sequence or set of instructions that the computer performs/executes/runs
  - A computer program in its human-readable form is called "source code", or simply "code"
- "Programming" (in the CS-101 context)
  - Process of performing particular computations (or more generally, accomplishing specific computing results), usually by designing and building executable computer programs
- "Programming language"
  - A system of notation for writing computer programs
  - Involves communication of a human with a computer
  - Aspects of "syntax" of language: form (how words are put together)
  - Aspects of "semantics" of language: meaning (of phrases and sentences)

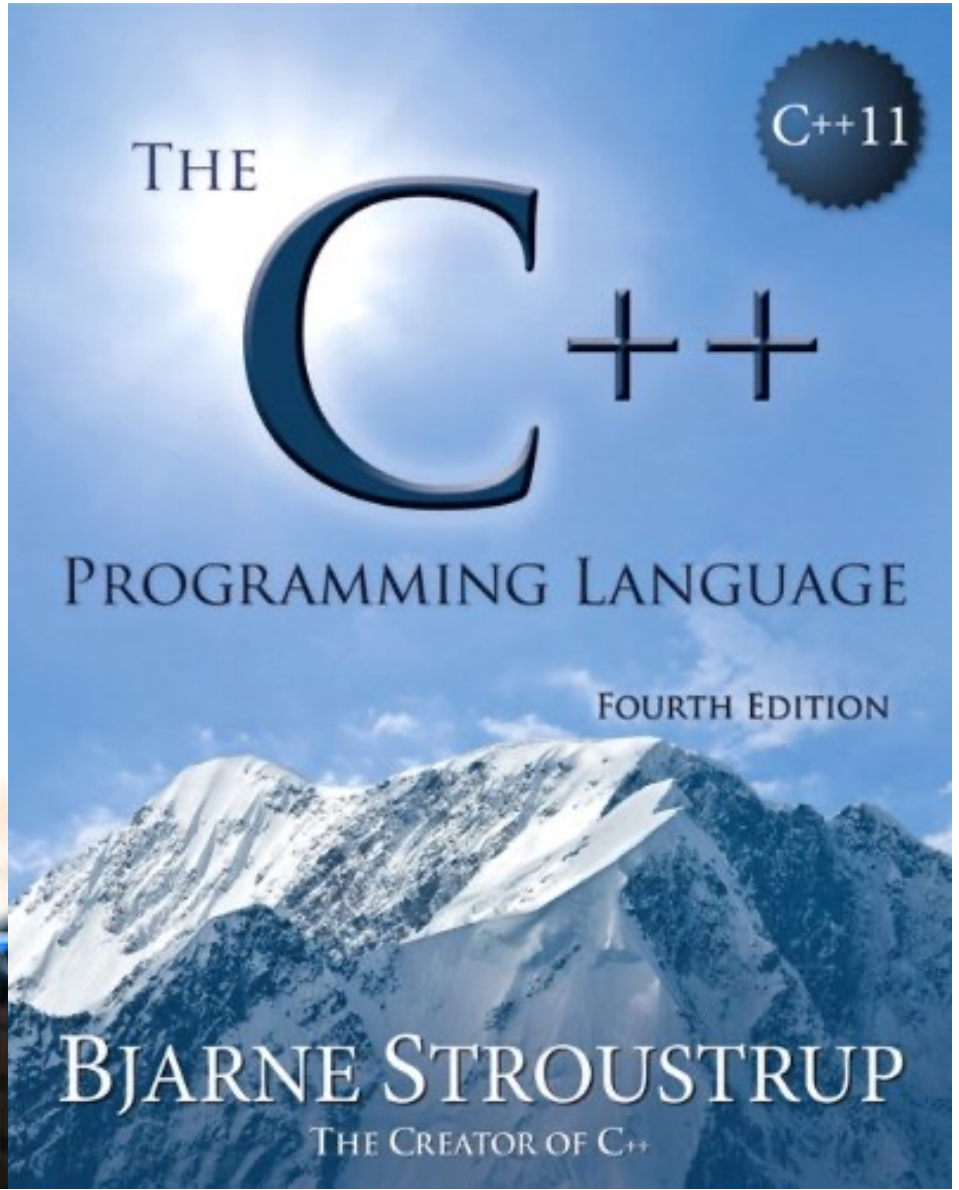
Main Text Book for CS-101

- www.cse.iitb.ac.in/~ranade/book.html
- Designed essentially for CS-101 students at IITB



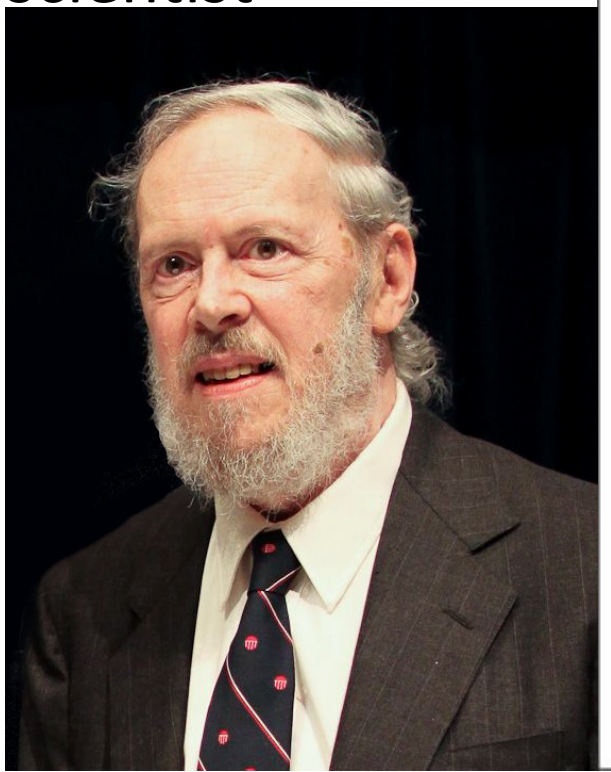
C++

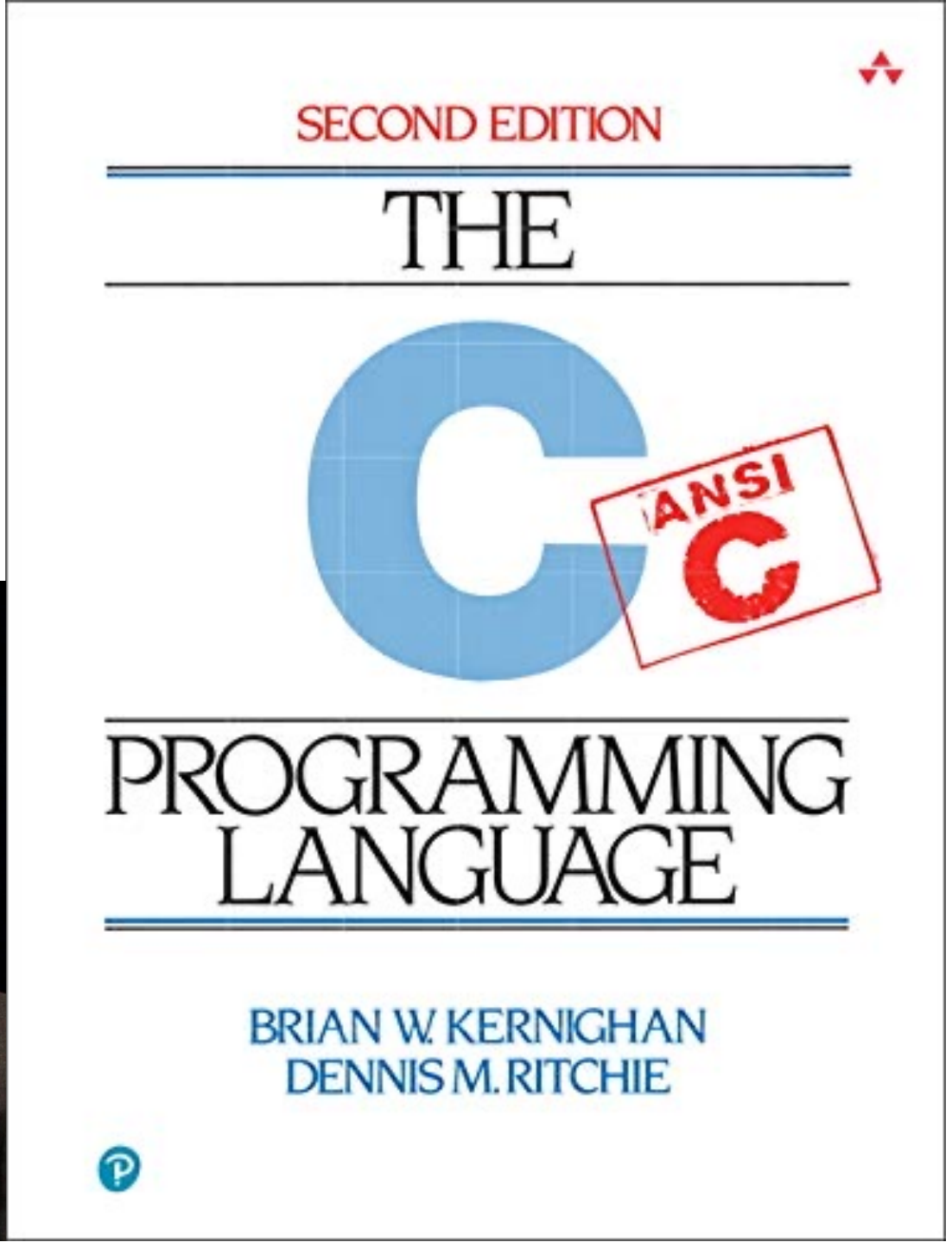
- High-level, general-purpose programming language
  - Created by Danish computer scientist Bjarne Stroustrup
    - PhD from University of Cambridge
    - Currently professor of computer science at Columbia University
  - Created in 1980s at AT&T Bell Labs
  - en.wikipedia.org/wiki/C++



C

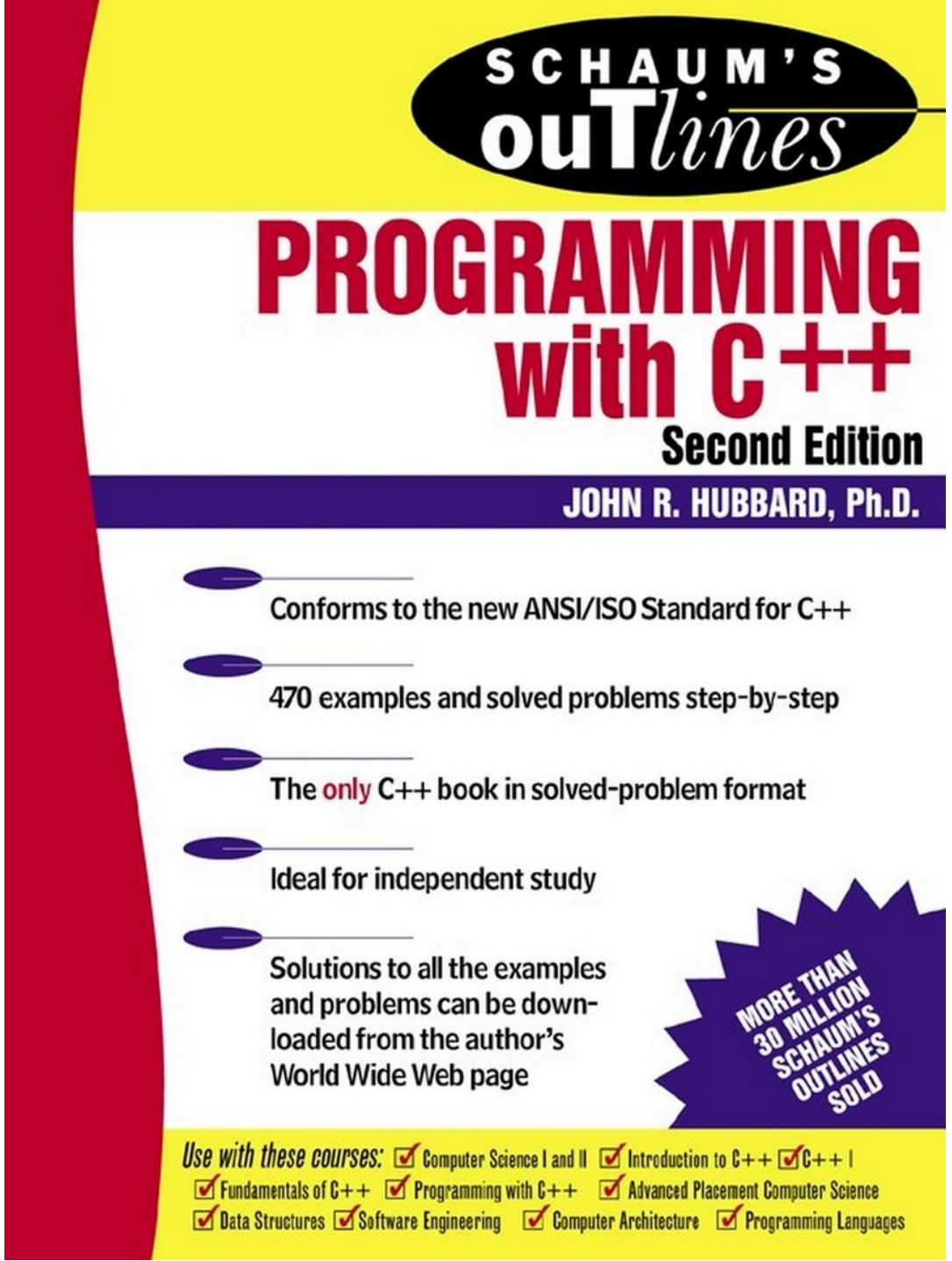
- Precursor was "C" programming language
  - Also a general-purpose programming language
  - Created in the 1970s by Dennis Ritchie, an American computer scientist (Turing Awardee)
    - PhD from Harvard Univ
  - C was successor to B
  - Among most widely used programming languages
  - Wikipedia links to books and more





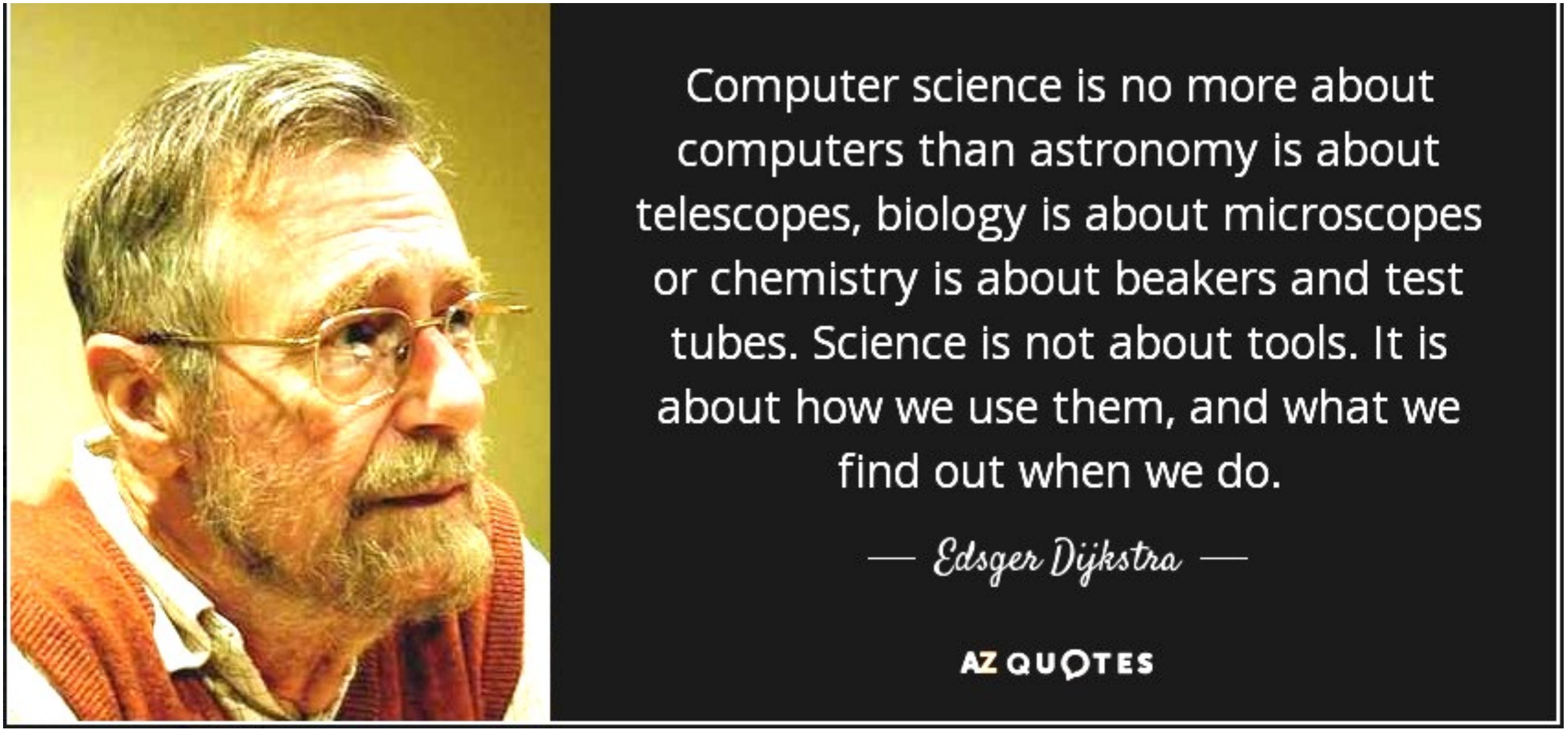
Reference Book for CS-101

- Remember: CS-101 isn't a course about any specific programming language, e.g., C++ or C
  - Our goal isn't to master all subtleties in any specific programming language
- This course is about fundamental concepts in programming, which are common to many languages



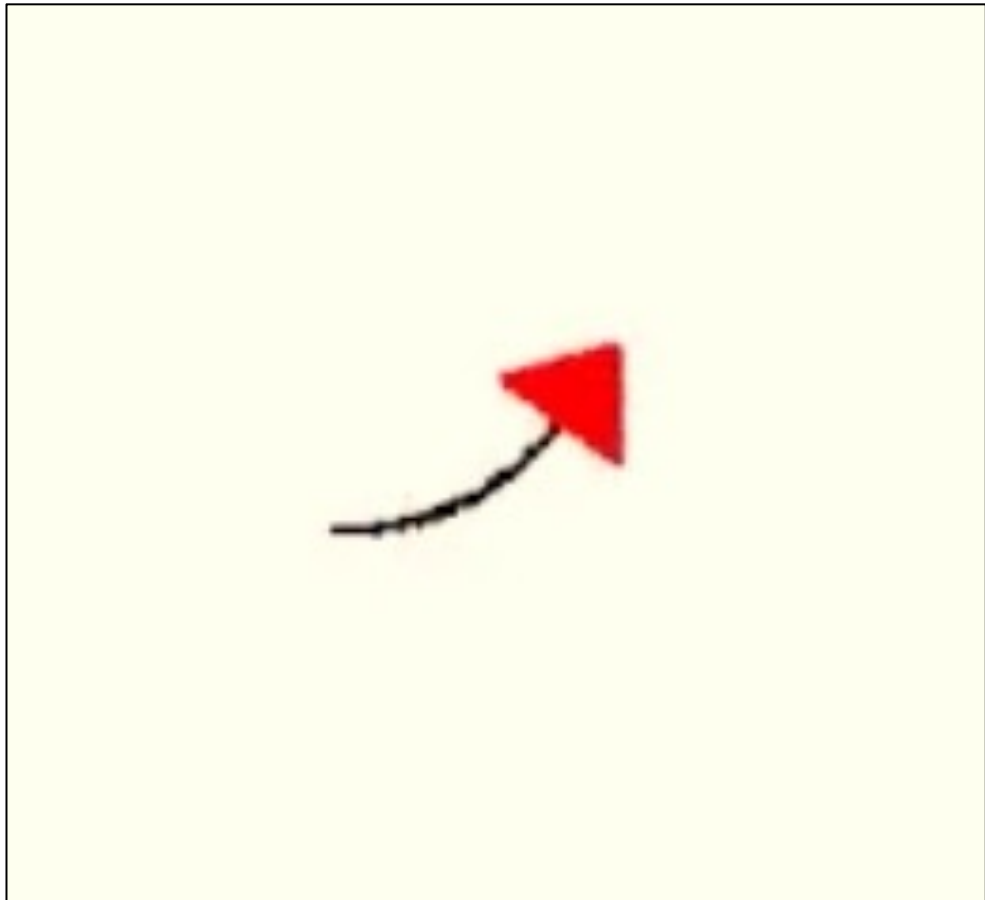
Computer Programming and CSE

- CS isn't only about computers or programming or languages. In fact, …



SimpleCPP

- SimpleCPP package is a gentler interface to C++
  - https://www.cse.iitb.ac.in/~ranade/simplecpp/
  - It has been designed specifically for the book
- Unlike C++, SimpleCPP has a built-in graphics interface
  - Called “turtleSim”,
    short form for “turtle simulator”
  - Allows you to move a “turtle”/cursor/pen-tip
  - “Turtle” can optionally draw as it moves
- We will start with SimpleCPP
  and then proceed to C++

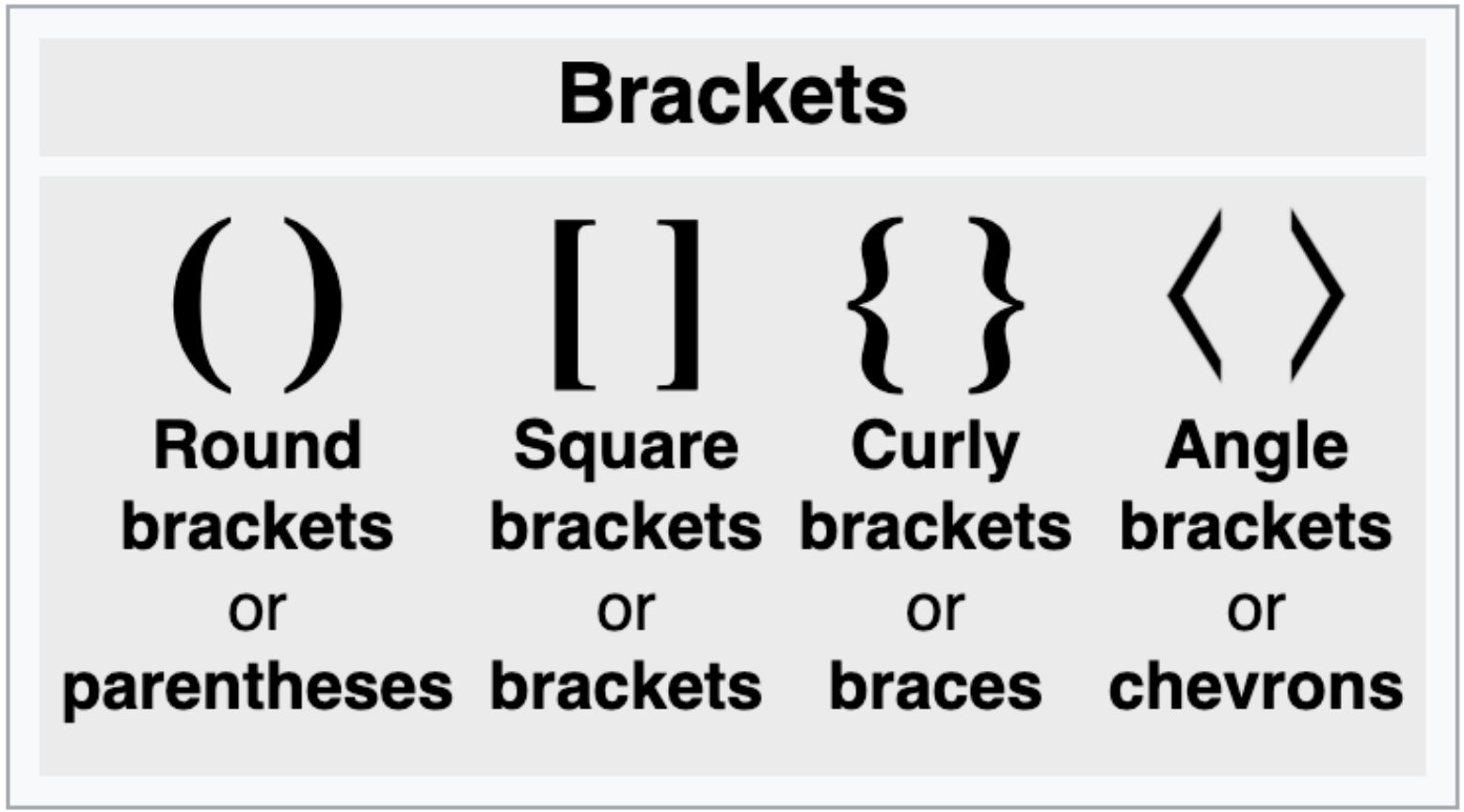


SimpleCPP

- History of the turtle
  - techcommunity.microsoft.com/t5/small-basic-bl
    small-basic-the-history-of-the-logo-turtle/ba-p/3
  - Turtle robots invented by William Grey Walter, a robotician, in 1948
  - No screens. So write.
  - en.wikipedia.org/wiki/Logo_(programming_language), 1967

First Program

- Lots of things going on; lets study one by one
- Some aspects of syntax
  - Brackets are of many kinds: ⟨ ⟩, { }, [ ], ( )
  - en.wikipedia.org/wiki/Bracket




```
#include <simplecpp>
main_program{
   turtleSim();

   forward(100);
   left(90);
   forward(100);
   left(90);
   forward(100);
   left(90);
   forward(100);

   wait(5);
}
```

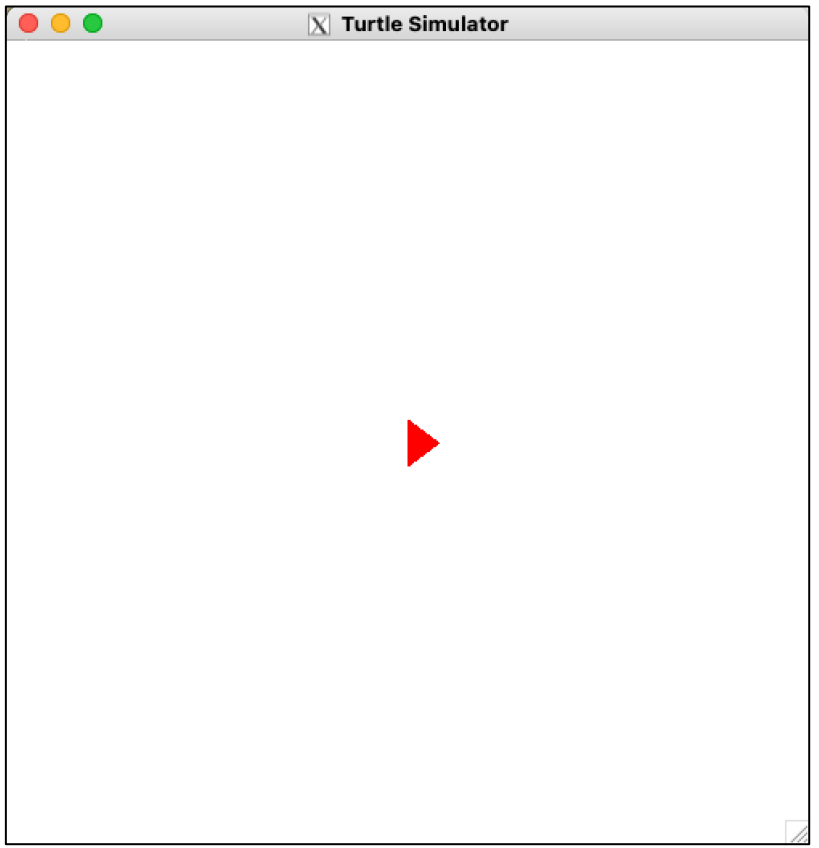
First Program

- #include …
  - Declares that program uses some facilities called “simplecpp” outside default facilities provided by C++
  - The program uses these facilities
    - Without this line, program won’t work
- main_program{ … }
  - A container of instructions/commands/statements
  - Inside the braces are the set of instructions the computer should start executing
  - There can be other containers too

```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

First Program

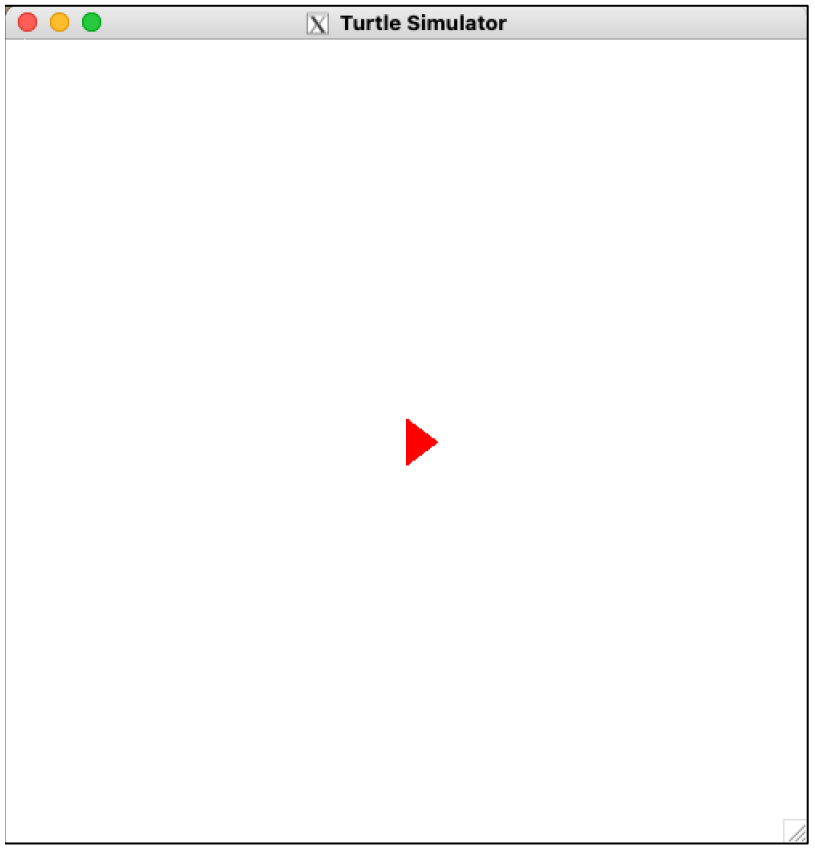
- turtleSim() command
  - Opens a window with a triangular cursor
  - Triangle = “turtle” with a pen that can be used to draw
  - Initially, turtle it directed towards east

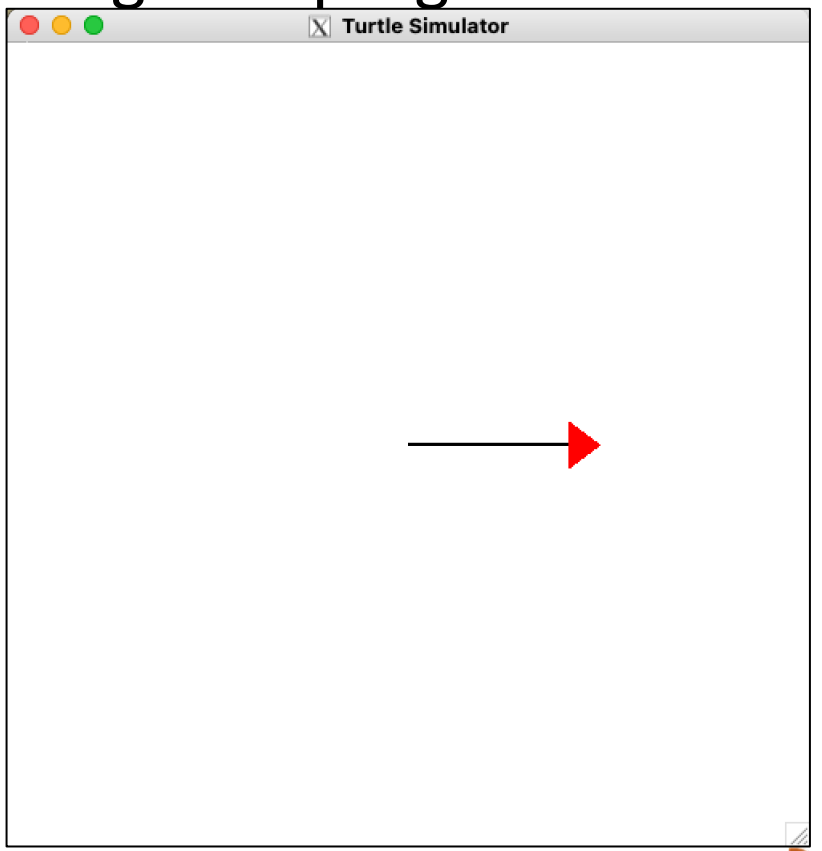



```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

First Program

- forward(100) command
  - Makes turtle move ahead (in current direction)
  - If pen state is “down”, turtle draws as it moves
  - Amount “100” can be changed in program

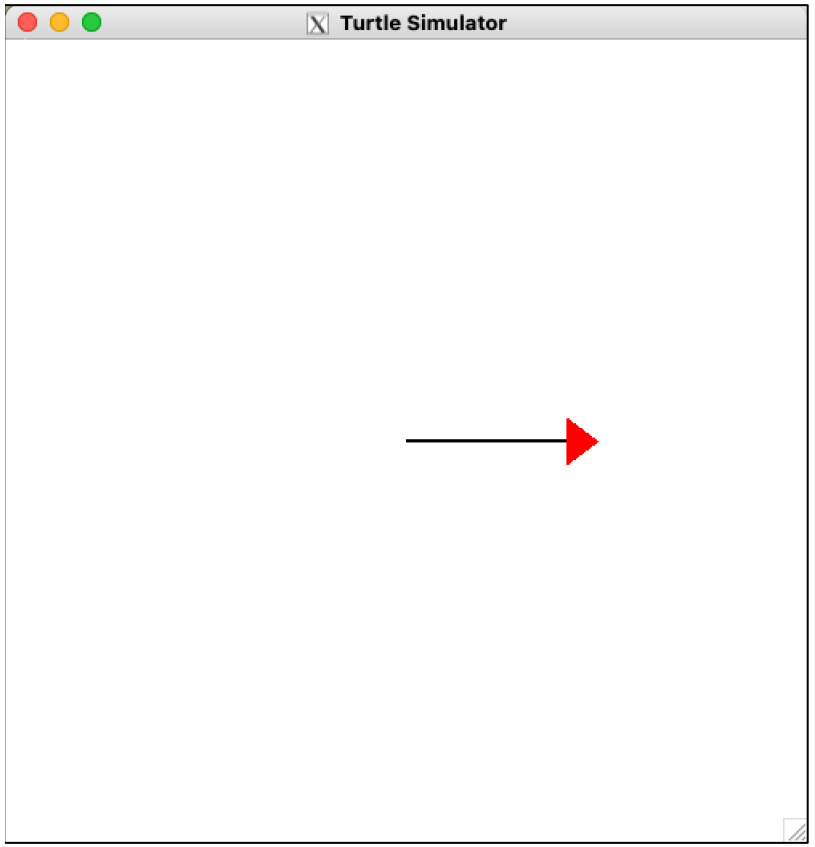


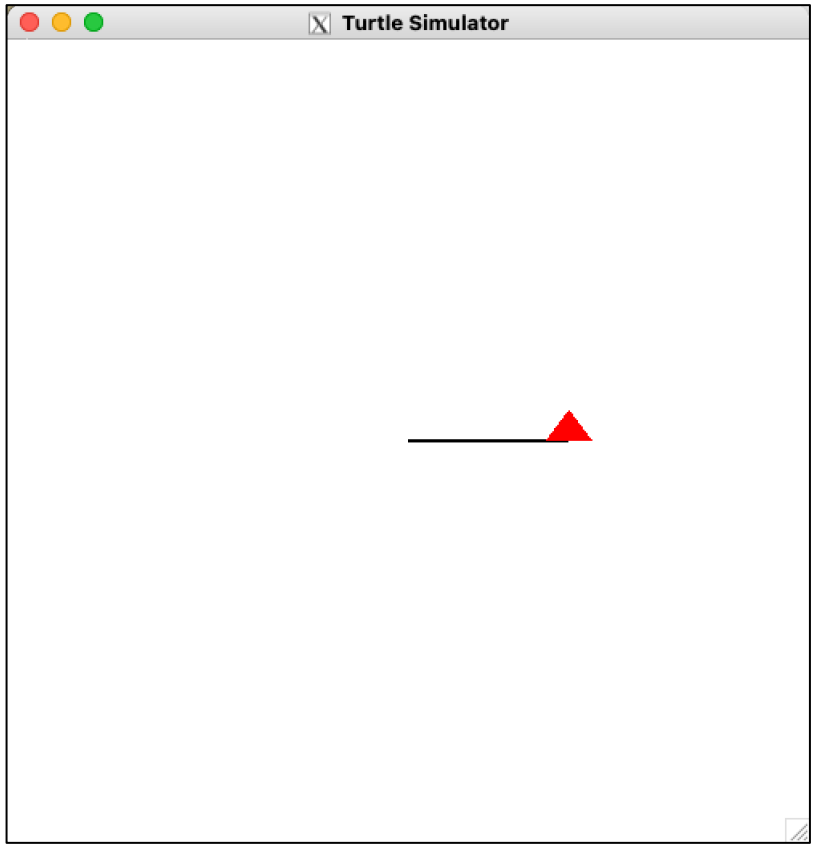



```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

First Program

- left(90) command
  - Changes direction by 90 degrees counter-clockwise
  - Amount “90” can be changed in program

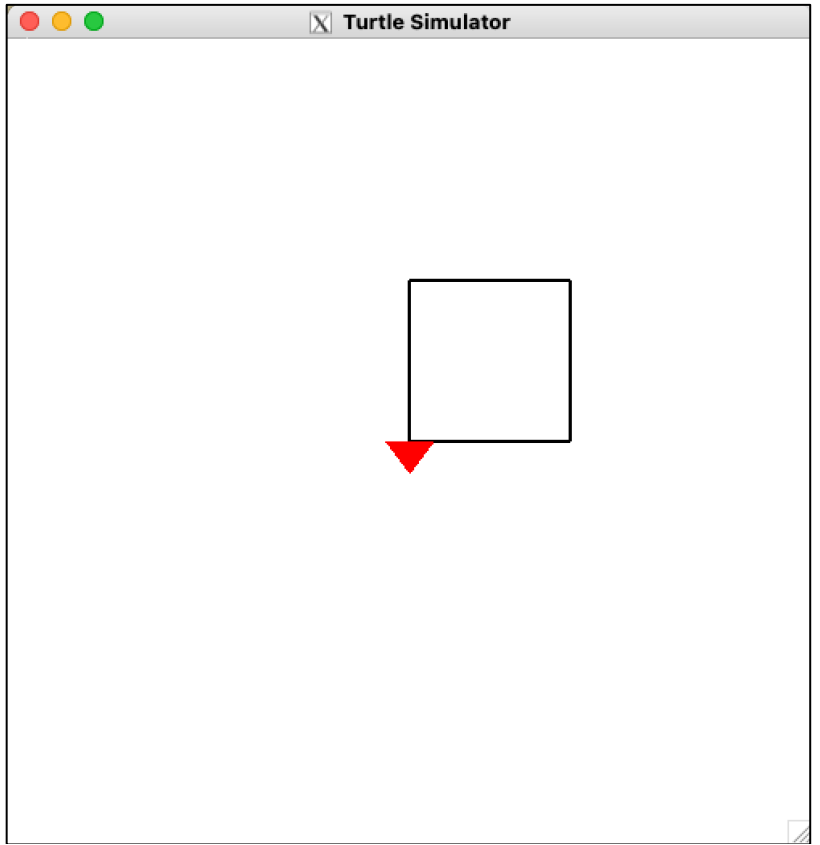





```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

First Program

- wait(5) command
  - Makes program execution wait for 5 seconds
- After the last line is executed, program ends
- "turtleSim" command doesn't need additional information, unlike forward() and left() commands. Hence, empty parentheses




```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

First Program

- Syntax
  - Each command must be followed by a semi colon
  - Programming languages usually allows spaces and linebreaks at many places
    - E.g., the following is valid, but not recommended

```
turtleSim();forward(100)    ;
left  (90
);
```

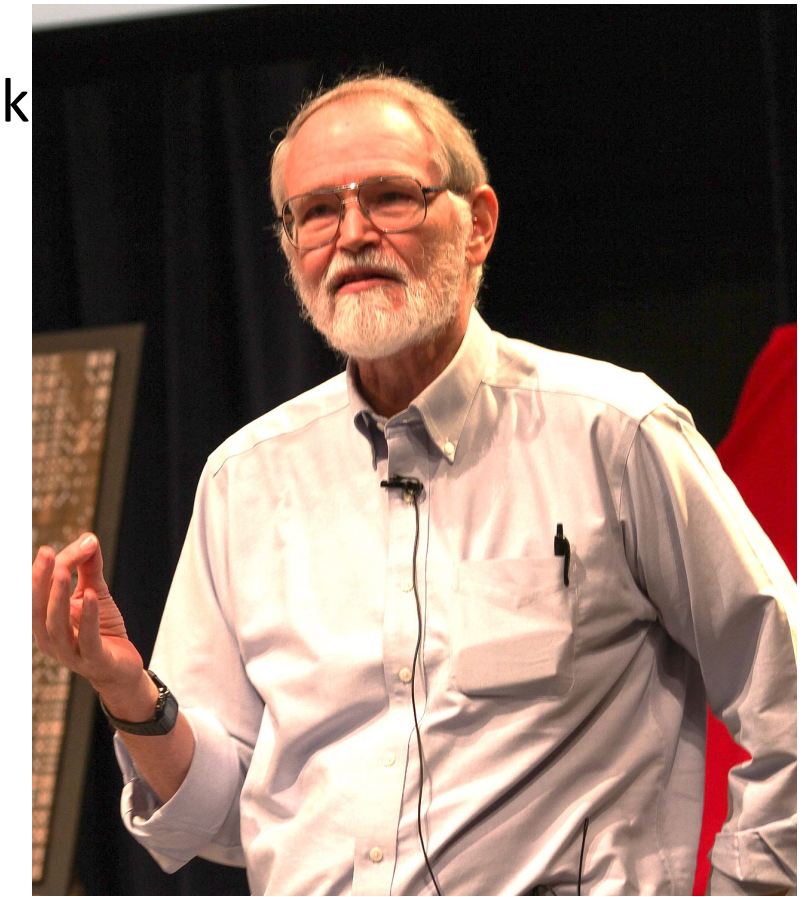
  - Indentation
    - e.g., putting leading spaces before lines for ease of readability
    - Designates “paragraphs” or logical blocks of commands within a program, to convey the structure within a program
    - Editors often help automate this process as we type

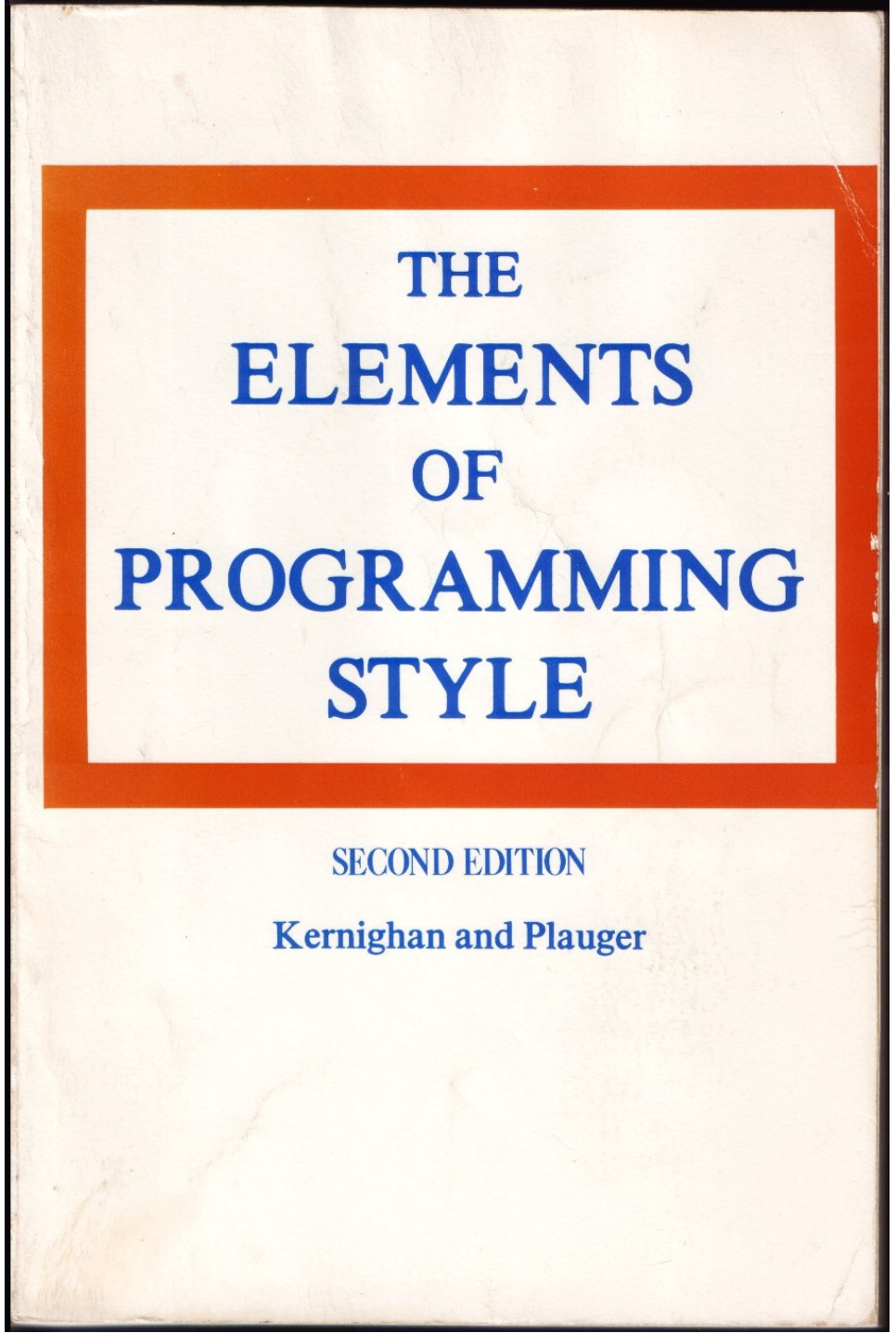
```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

Programming Style

Programming Style

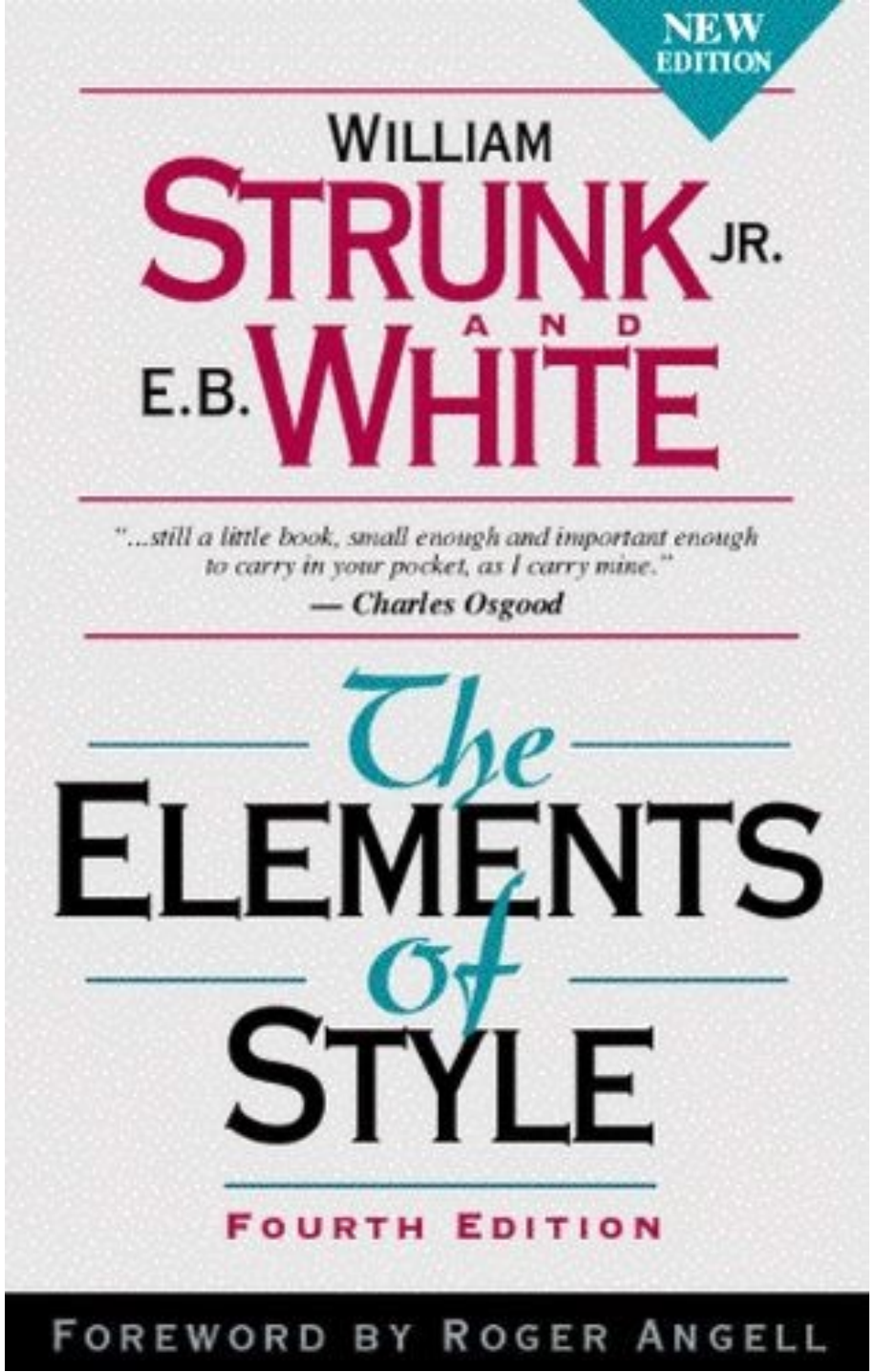
- The Elements of Programming Style
  - Brian W. Kernighan and P. J. Plauger
  - en.wikipedia.org/wiki/The_Elements_of_Programming_Style
    - Brian Kernighan
    - Co-wrote classic book on C programming with Dennis Ritchie (inventor of C) at Bell Labs



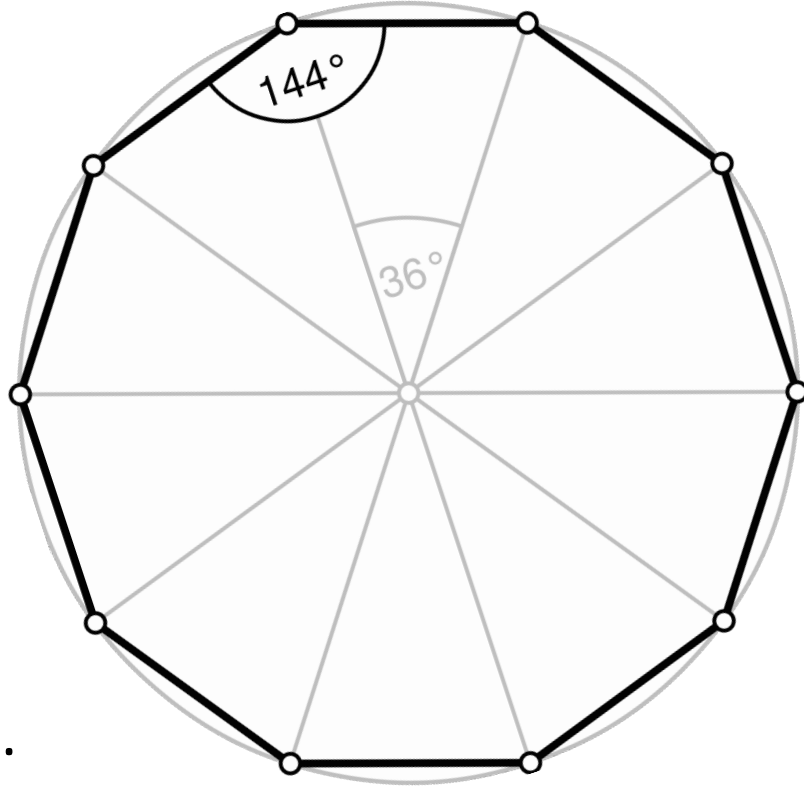


Technical-Writing Style

- The Elements of Style
  - William Strunk Jr. and E. B. White
  - First written by Strunk, professor of English at Cornell, in 1918
  - Then enlarged by his former student, White in 1959
  - Time magazine recognized this book, in 2011, as one of the 100 best and most influential books written in English since 1923



Programming Process

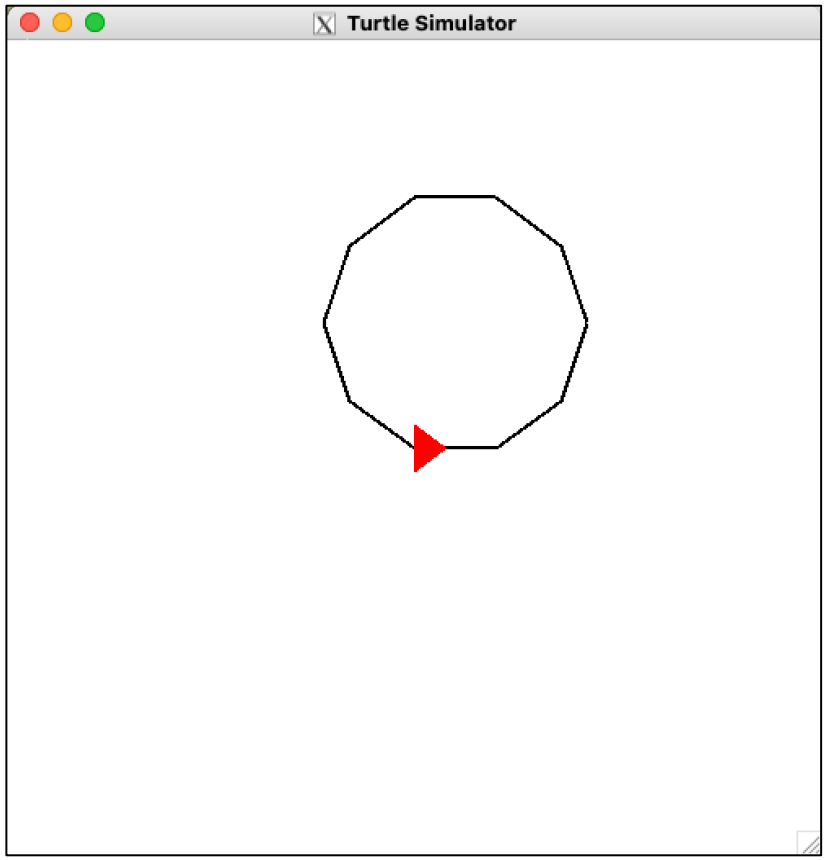


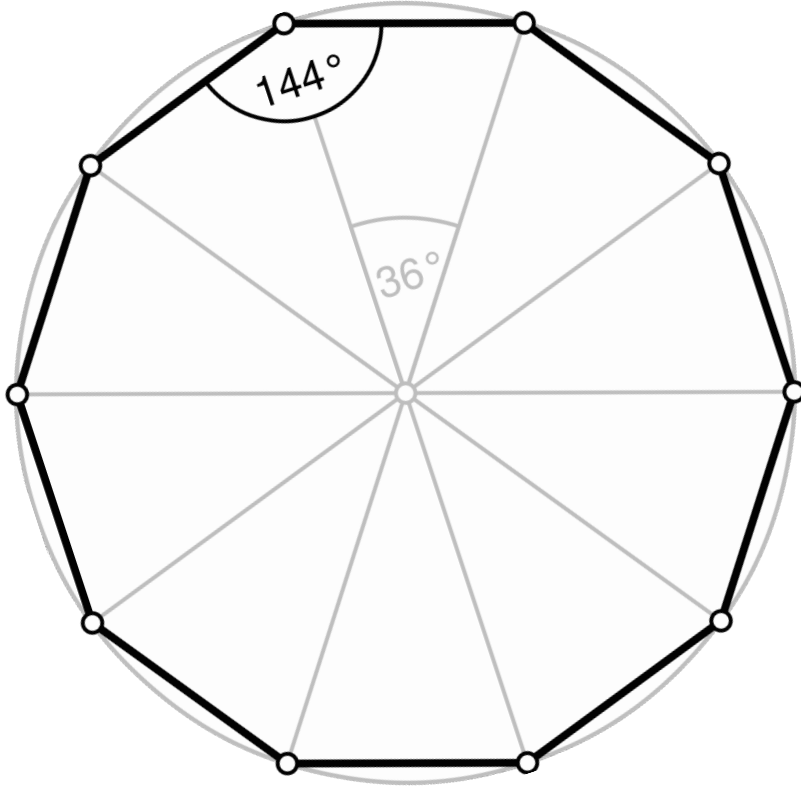
- Writing a program to draw a regular decagon
  - First thing to do is the math and logic **on paper**
    - Don't rush to start typing the program
  - After figuring out math and logic
    you may want to write a (rough) program **on paper**
  - Then run program **in your head**
    - Find problems with (rough) program and fix them. Repeat.
  - Then start typing to input program into computer
  - As you've typed a part of program, you may want to run that part
    to ensure that it works as expected
    - Otherwise there is some error in your math or logic (or typing/syntax). If so, fix it.
  - Finish writing your program and run it
    - Check output
    - If there is some error in your math or logic, revisit typed program to fix error

Repeating a Block of Commands

- Writing a program to draw a regular decagon

```
#include <simplecpp>
main_program{
   turtleSim();
   repeat(10){
         forward(100);
         left(36);
   }
   wait(5);
}
```



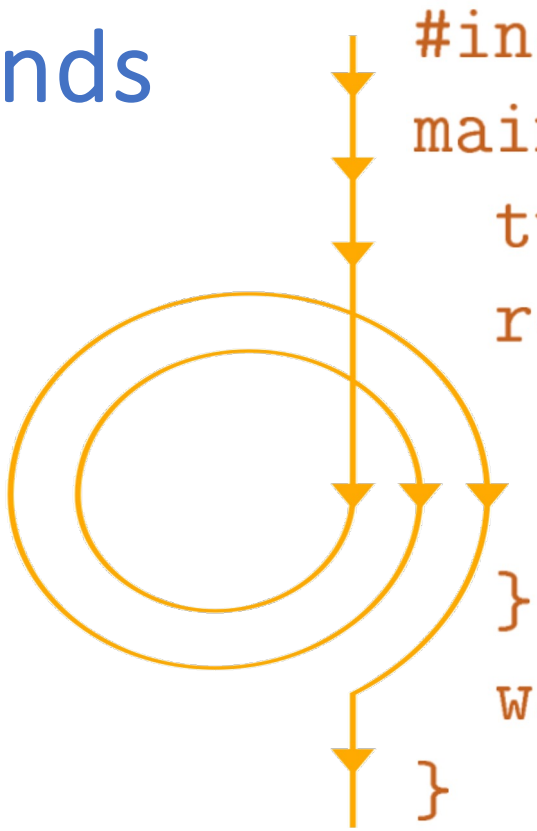


- Repeat statement's general form
  - Statements = "body" of repeat statement/command
  - Each execution of body is called an "iteration"

```
repeat(count){
   statements
}
```

Repeating a Block of Commands

- What we have is a “repeat loop”
- “Loop” = control-flow statement for specifying “iteration”



```
#include <simplecpp>
main_program{
   turtleSim();
   repeat(10){
        forward(100);
        left(36);
   }
   wait(5);
}
```

iteration

noun [C or U]

UK /ˌɪt.ᵊrˈeɪ.ʃᵊn/ US /ˌɪt̬.əˈreɪ.ʃᵊn/

Add to word list

formal

the process of doing something again and again, usually to improve it, or one of the times you do it:

- *the repetition and iteration that goes on in designing something*

Repeating a Block of Commands

- Writing a program to allow user to draw **any** regular polygon

1. Need to ask user
   how many sides does the polygon have
2. Need to get input from the user
   into the program
3. Need to use
   that information
   into our
   drawing procedure

```
#include <simplecpp>
main_program{
  turtleSim();
  repeat(10){
        forward(100);
        left(36);
  }
  wait(5);
}
```

```
#include <simplecpp>
main_program{
  turtleSim();

  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);
  left(90);
  forward(100);

  wait(5);
}
```

Repeating a Block of Commands

- Writing a program to allow user to draw any regular polygon
  - "int" indicates integer
  - "int nsides" makes computer reserve a region in its memory named 'nsides' which will store an integer value
    - Future references by program to 'nsides' will refer to content stored (= value) in this memory region
  - 'nsides' is called a "variable"
  - "int nsides" defines/creates variable 'nsides'

```
#include <simplecpp>
main_program{
   int nsides;
   cout << "Type in the number of sides: ";
   cin >> nsides;
   turtleSim();
   repeat(nsides){
         forward(50);
         left(360.0/nsides);
   }
   wait(5);
}
```

Repeating a Block of Commands

- Writing a program to allow user to draw any regular polygon
  - 'cout' is a name that refers to computer display/screen
  - 'cout <<' indicates something being passed on to cout, which is denoted within "…"
  - 'cin' refers to keyboard
  - 'cin >>' indicates getting something from keyboard and storing it in memory region indicated by variable following it

```
#include <simplecpp>
main_program{
   int nsides;
   cout << "Type in the number of sides: ";
   cin >> nsides;
   turtleSim();
   repeat(nsides){
         forward(50);
         left(360.0/nsides);
   }
   wait(5);
}
```

Repeat Within a Repeat

- What does this do ?
  - What if nsides = 2 ?
  - What if nsides = 1 ?
  - What if nsides = 0 ?
  - What if nsides < 0 ?
  - Duty of the program to verify correctness of input

```
#include <simplecpp>
main_program{
  int nsides;

  turtleSim();

  repeat(10){
    cout << "Type in the number of sides: ";
    cin >> nsides;
    repeat(nsides){
        forward(50);
        left(360.0/nsides);
    }
  }
  wait(5);
}
```

Garbage In Garbage Out

- en.wikipedia.org/wiki/Garbage_in,_garbage_out

On two occasions I have been asked, "Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?" ... I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question.

—Charles Babbage, *Passages from the Life of a Philosopher*[5]

More Commands in SimpleCpp

- penUp(), penDown()
- What will the following code do ?
  - repeat (10)
    { forward (10); penUp(); forward (5); penDown(); }
- Numerical functions
  - sqrt(x)
  - sine(x), cosine(x), tangent(x) – where ‘x’ is in degrees
  - sin(x), cos(x), tan(x) – where ‘x’ is in radians
  - arcsine(y), arccosine(y), arctangent(y)
  - exp(x), log(x), log10(x)
  - pow(x,y)
  - Name ‘PI’ refers to π

Practice Examples for Lab: Set 1

- 1

Modify the program given in the text so that it asks for the side length of the polygon to be drawn in addition to asking for the number of sides.

- 2

A pentagram is a five pointed star, drawn without lifting the pen. Specifically, let A,B,C,D,E be 5 equidistant points on a circle, then this is the figure A–C–E–B–D–A. Draw this.

- 3

If you draw a polygon with a large number of sides, say 100, then it will look essentially like a circle. In fact this is how circles are drawn: as a many sided polygon. Use this idea to draw the numeral 8 – two circles placed tangentially one above the other.

- 4

Read in the lengths of the sides of a triangle and draw the triangle. You will need to know and use trigonometry for solving this.

Practice Examples for Lab: Set 1

- 5

We wrote "360.0" in our program rather than just "360". There is a reason for this which we will discuss later. But you could have some fun figuring it out. Rewrite the program using just "360" and see what happens. A more direct way is to put in statements `cout << 360/11; cout << 360.0/11;` and see what is printed on the screen. This is an important idea: if you are curious about "what would happen if I wrote ... instead of ...?" – you should simply try it out!

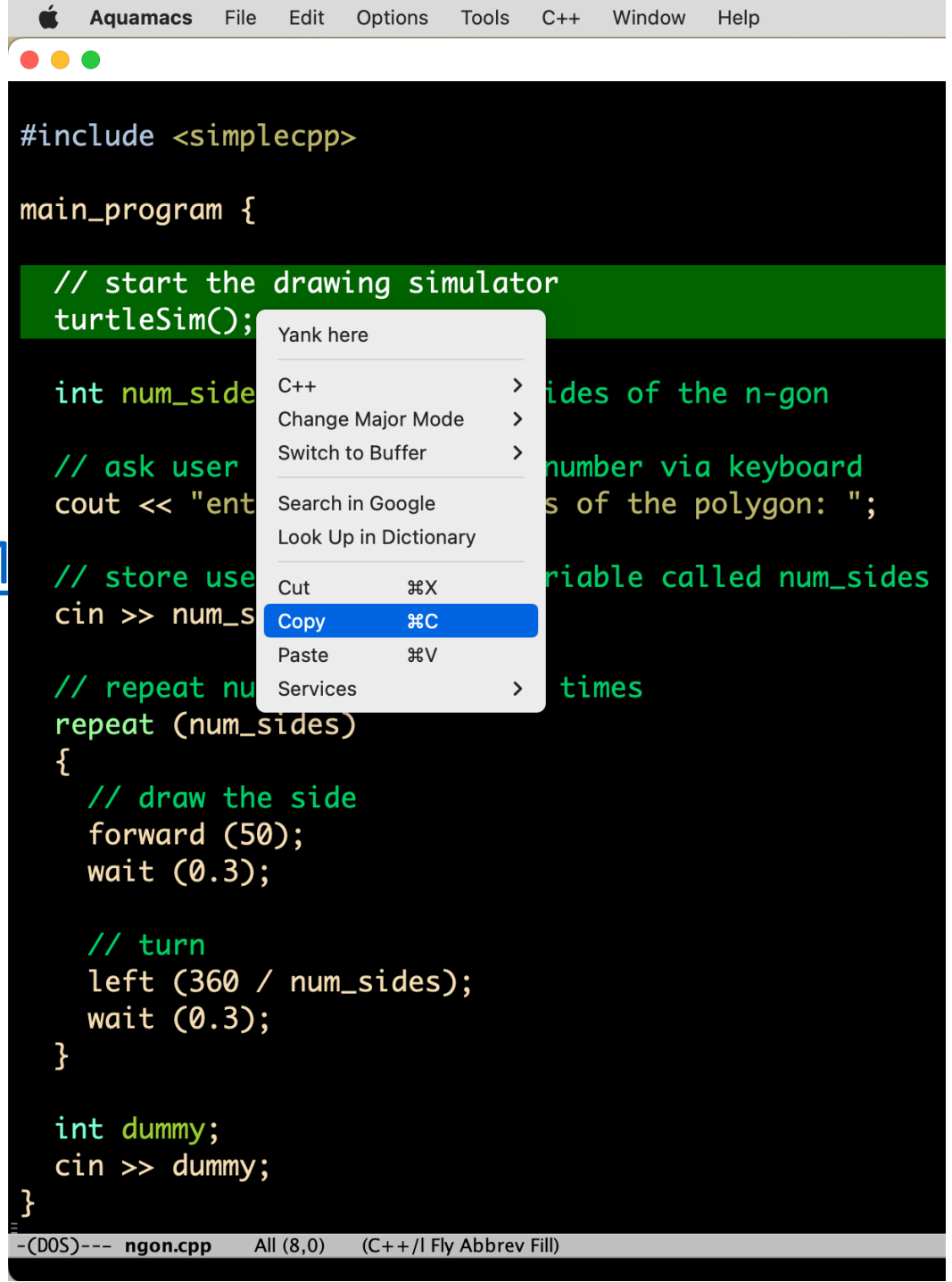
- 6

- https://en.wikipedia.org/wiki/Heptagram

Draw a seven pointed star in the same spirit as above. Note however that there are more than one possible stars. An easy way to figure out the turning angle: how many times does the turtle turn around itself as it draws?

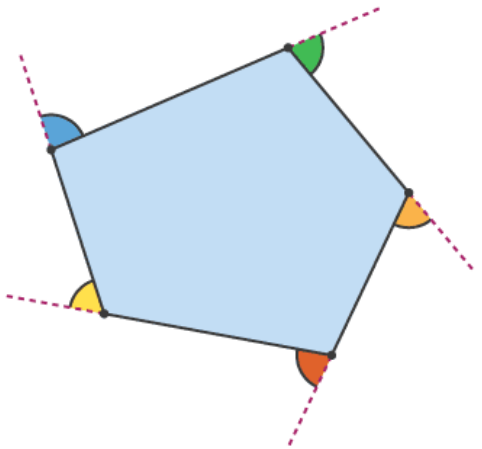
Emacs

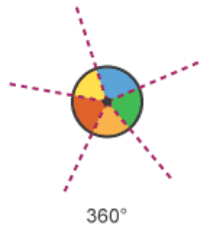
- Emacs on Ubuntu
  - 3 ways to install Emacs on Ubuntu linux.how2shout.com/3-ways-to-install-emacs-text-editor-on-ubuntu-22-04-lts/
  - How to Install EMACS on Ubuntu www.youtube.com/watch?v=aNpexBTEQBM
- Emacs on Windows
  - www.gnu.org/software/emacs/download.html
  - gnu.mirror.net.in/gnu/emacs/windows
    get the most-recent dated version
- Emacs on MacOS
  - aquamacs.org

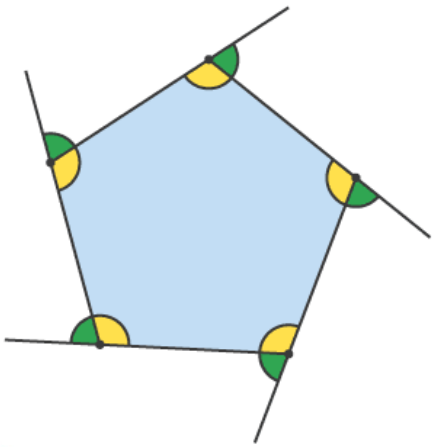


Comments

```
#include <simplecpp>
/* Program to draw a regular polygon with as many sides as the user wants.
   Author: Abhiram Ranade
   Date:   18 Feb 2013.
*/
main_program{
  int nsides;
  cout << "Type in the number of sides: ";
  cin >> nsides;

  turtleSim();

  repeat(nsides){
     forward(50);          // Each side will have length 50 pixels.
     left(360.0/nsides); // Because sum(exterior angles of a polygon) = 360.
  }
  wait(5);
}
```

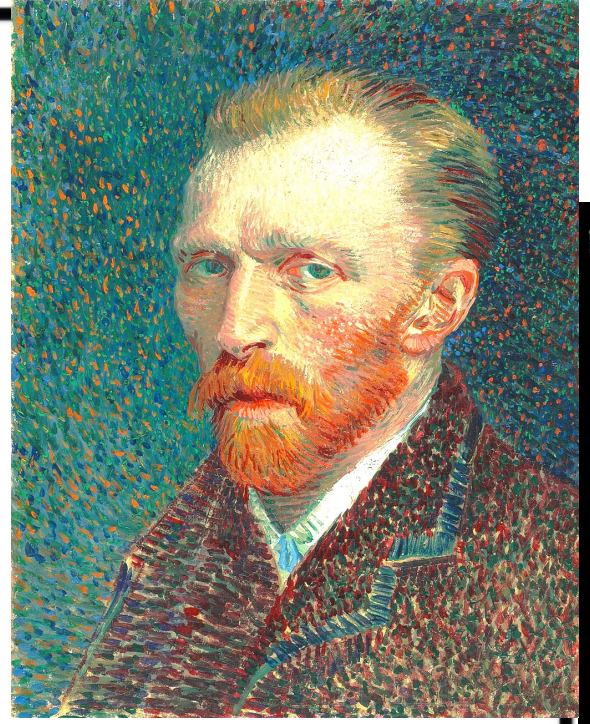






Comments

- Don’t state the obvious
  - Examples to avoid
    - cin >> nsides; // read in nsides
    - Above comment only states what is being done, but that is clear from syntax itself
- Give **insights** into the logic used
  - Describe **why** are you doing what you are doing
- Aim to write **self-documenting code**
  - Make the code read as close to English as possible
  - Chose names of variables wisely to make is obvious what their use is
  - Write down the logic
  - Minimize amount of "external" documentation that is necessary



geek & poke
DID VAN GOGH COMMENT HIS WORK?
PROGRAMMING IS AN ART

Comments

- www.youtube.com/watch?v=OlacUh

Comments

Funny Source Code Comments

```
//
// Dear maintainer:
//
// When I wrote this code, only I and God
// knew what it was.
// Now, only God knows!
//
// So if you are done trying to 'optimize'
// this routine (and failed),
// please increment the following counter
// as a warning
// to the next guy:
//
// total_hours_wasted_here = 67
//
```

Comments


fb.com/programmingjokes/
NERD LIFE studio
what makes code bad?
No comment.

Commen

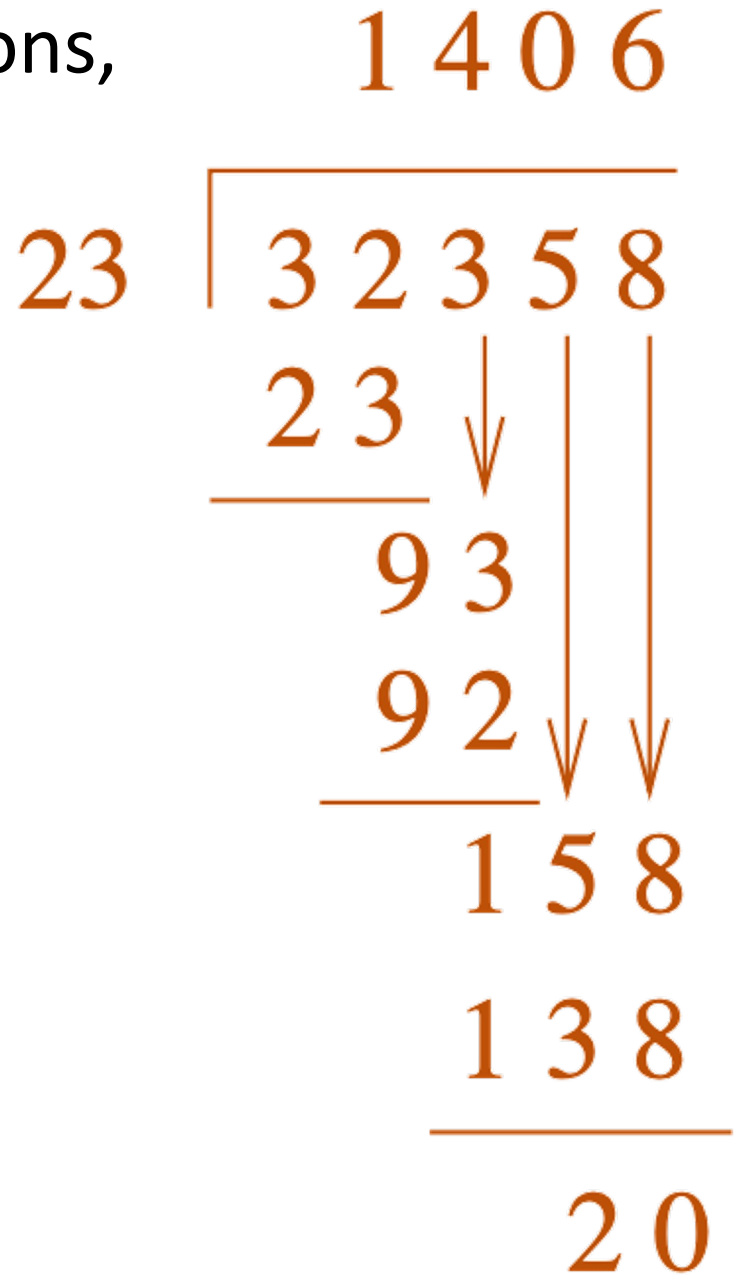

YEAR 0
YEAR X
LET ME WRITE THIS CODE IN ONE LINE WITH COMPLEX ABSTRACTIONS. I AM SO CLEVER!
LET ME WRITE THIS CODE SUCH THAT FUTURE-ME CAN EASILY UNDERSTAND IT.
workchronicles.com

Computation Without Graphics

```
main_program{
   int n;
   cout <<"Type the number you want cubed: ";
   cin >> n;
   cout << n*n*n << endl;
}
```

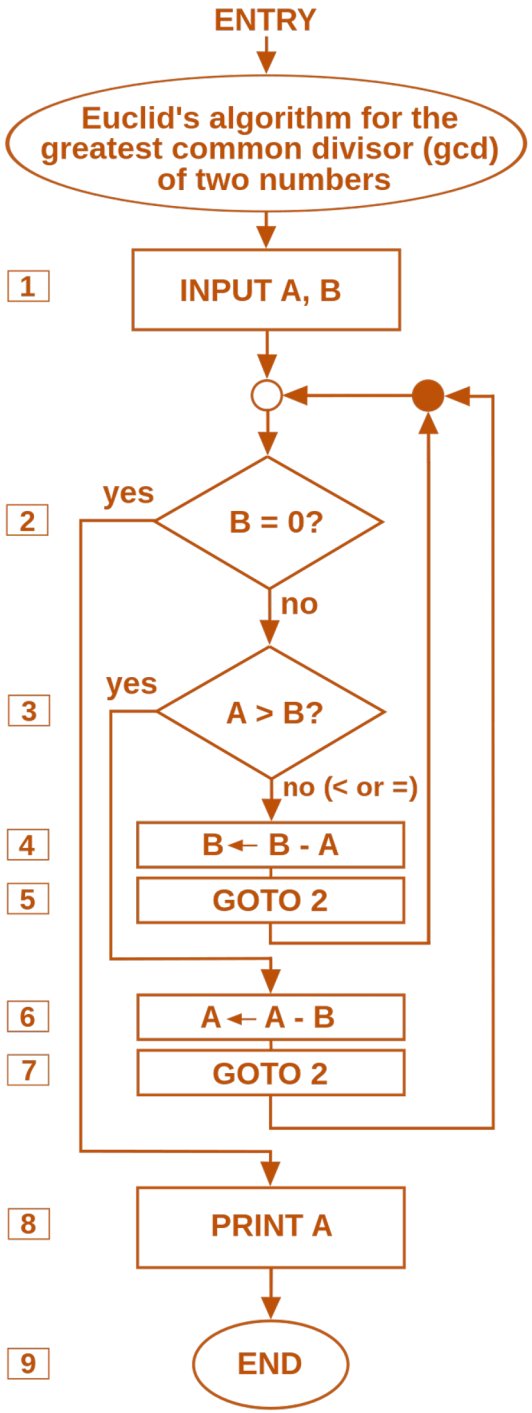
Algorithm

- Algorithm = a finite sequence of rigorous instructions, typically used to solve a class of specific problems or to perform a computation
  - en.wikipedia.org/wiki/Algorithm
- Example: Algorithm for long division
- Origin of the word
  - Around 825,
    Muhammad ibn Musa al-Khwarizmi
    wrote kitāb al-ḥisāb al-hindī
    (“Book of Indian computation”) and
    kitab al-jam' wa'l-tafriq al-ḥisāb al-hindī
    (“Addition and subtraction in Indian arithmetic”)

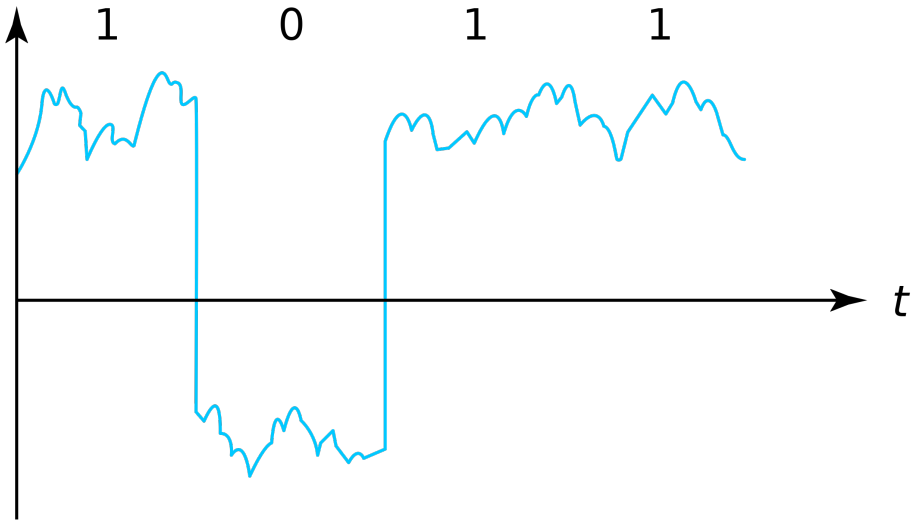


Algorithm

- Example:
  Euclid’s algorithm for finding greatest common divisor (GCD)



Digital Electronics



- "bit" denotes a number that is either 0 or 1
  - Like a "digit"
    that represents a number within 0,1,2,…,9
  - Number in binary number system
    (binary number) is represented using bits
  - Mapping voltages, in electric circuits, to highs and lows, or ones and zeros
    - Use this to represent a binary (base-2) number system
- Binary system in ancient India
  - Weights excavated from Indus Valley Civilization corresponded to ratios 1, 2, 4, 8, 16, …; basis of binary numbers, because ratios double
    - en.wikipedia.org/wiki/History_of_measurement_systems_in_India#Early_history
  - Pinagala created it in 3rd century BC to study poetic meters
    - https://en.wikipedia.org/wiki/Pingala#Combinatorics
    - www.jstor.org/stable/23445644 [Binary Numbers in Indian Antiquity]

Number Representation Formats

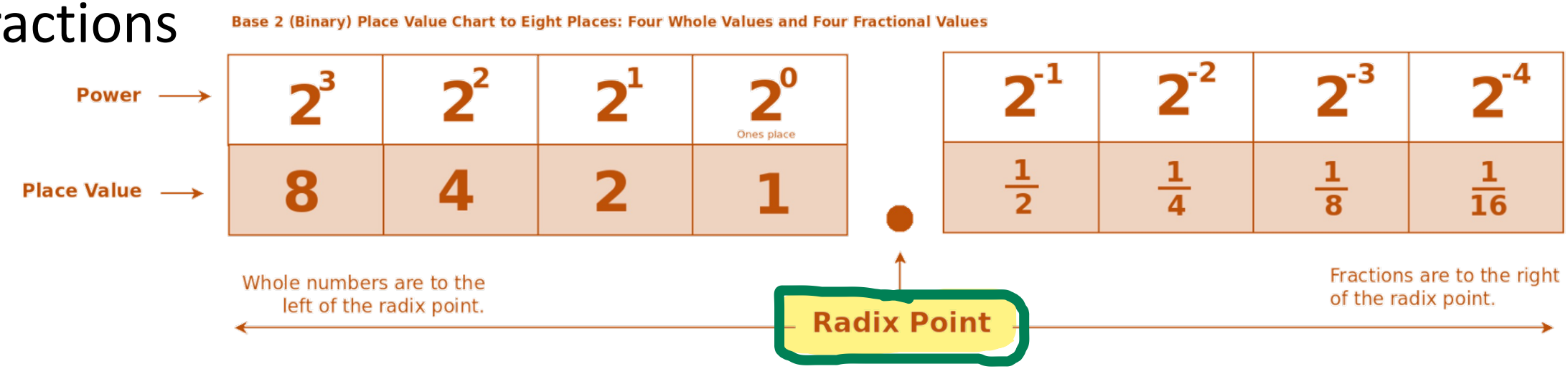
- Signed integer ("int")
  - One bit stores/represents sign (positive or negative)
  - Remaining bits store magnitude
  - Using 'n' bits can represent numbers from $-2^{n-1}+1,\ldots, 2^{n-1}-1$
- Unsigned integer ("unsigned int")
  - A non-negative integer
  - Using 'n' bits can represent numbers from $0,1,\ldots,2^{n}-1$

Number Representation Formats

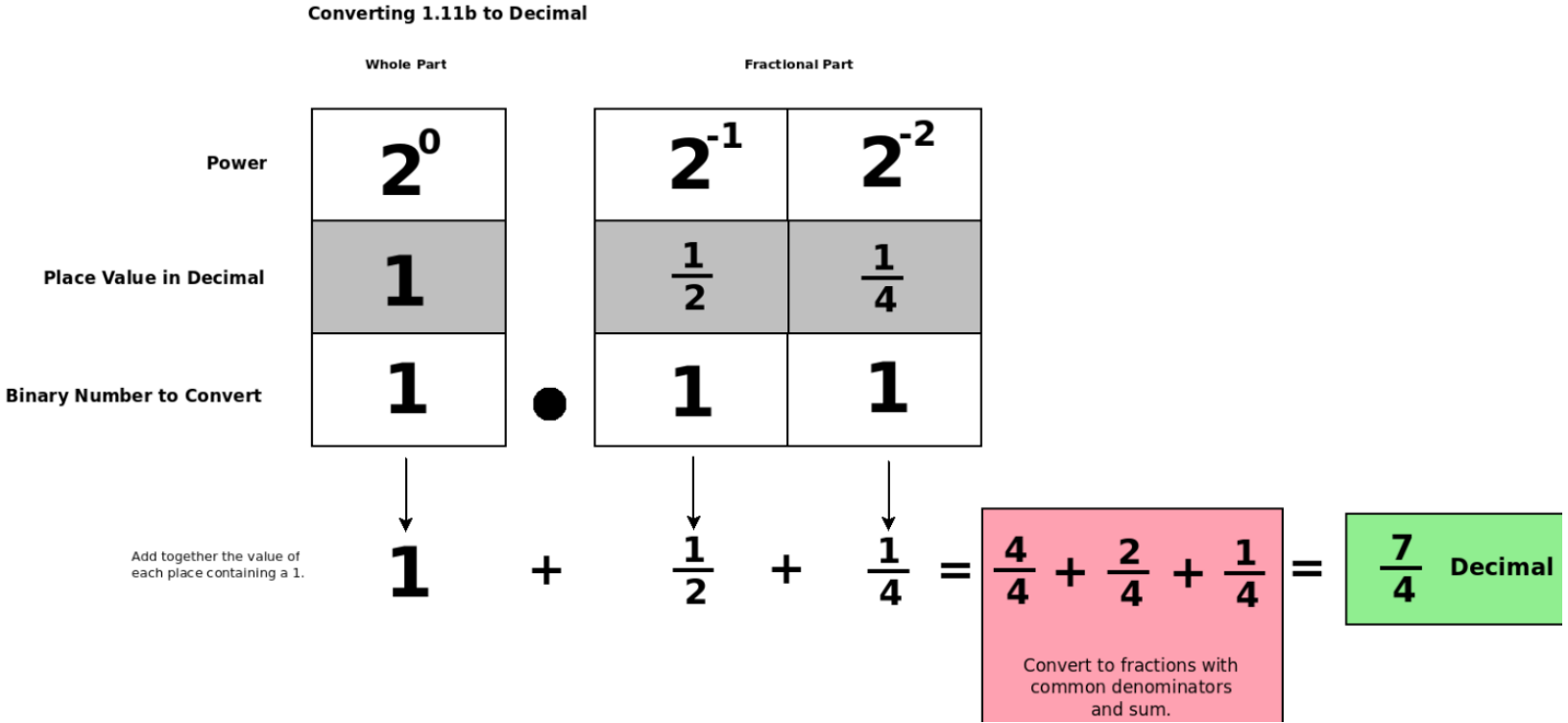
- "Floating-point" ("float")
  - Modeling real numbers approximately, up to finite precision
  - Uses 3 types of components (inspired from scientific notation)
    - Sign `-5.68434e-14` means $-5.68434 \times 10^{-14} = -0.0000000000000568434$
    - "Significand" = real number, usually having magnitude between 1 and 10
    - "Exponent" = integer
    - Example
      - Avogadro number in base 10: $6.02214076 \times 10^{23}\ \text{mol}^{-1}$
      - Avogadro number in base 2: $1.11111110001010101111111 \times 2^{1001110}$
      - Store sign and magnitude of significand
        - Decimal point can always be assumed after the first bit of the significand
      - Store sign and magnitude of exponent
    - Special representations
      - Infinity (+ and -)
      - NaN = Not-a-Number, resulting from operations like 0/0 or sqrt(-1) or $0 \times \infty$
    - Details in "IEEE 754" floating-point format

Number Representation Formats

- Binary fractions
  - Place values

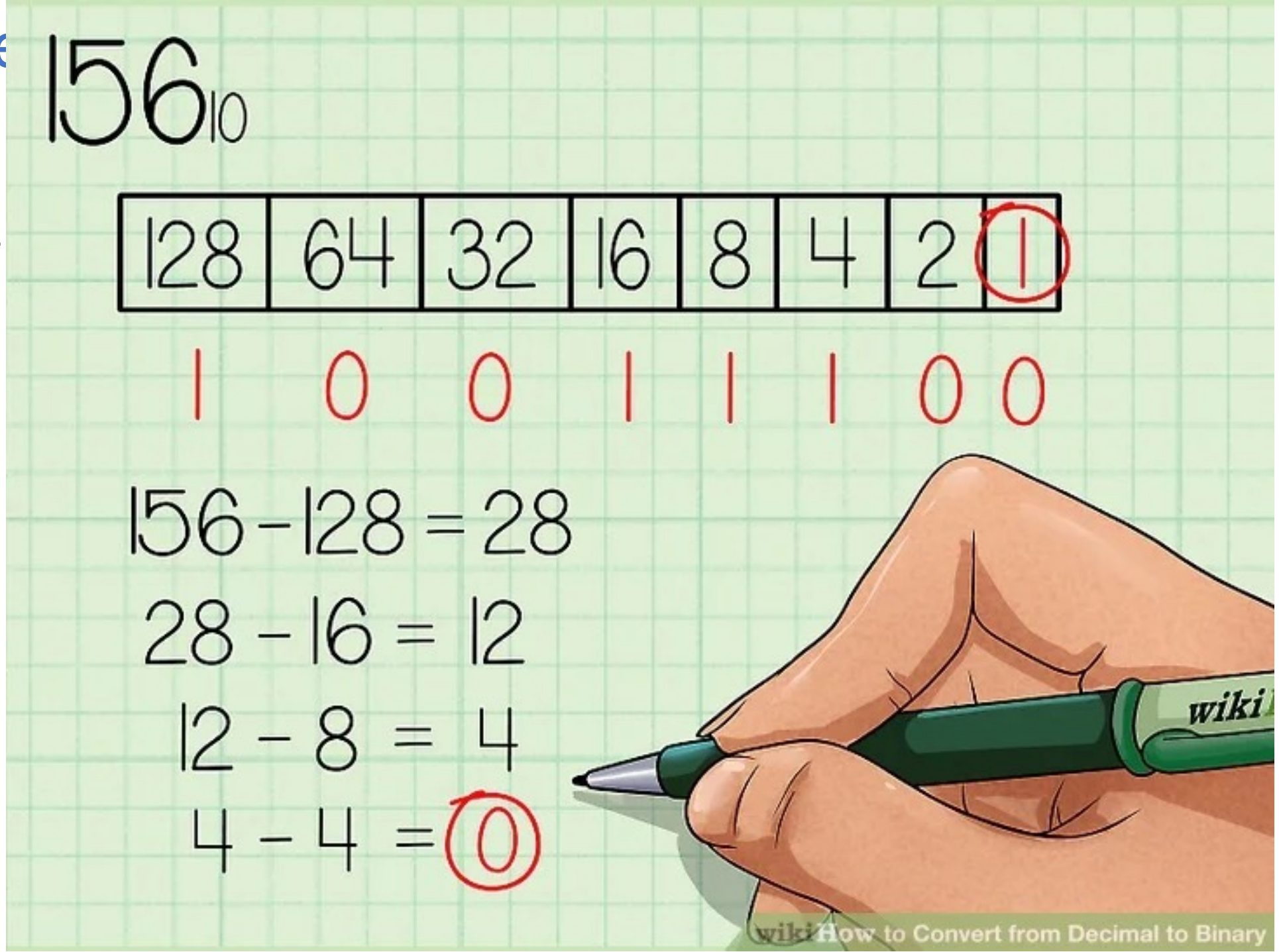


  - Convert 1.11 binary to decimal



Number Repre

- Binary fractions
  - Convert decimal integer to binary: **Method 1**
  - www.wikihow.com/Convert-from-Decimal-to-Binary



Number Represe

- Binary fractions
  - Convert decimal integer to binary: **Method 2**
  - www.wikihow.com/Convert-from-Decimal-to-Binary
  - e.g., 9_{10}

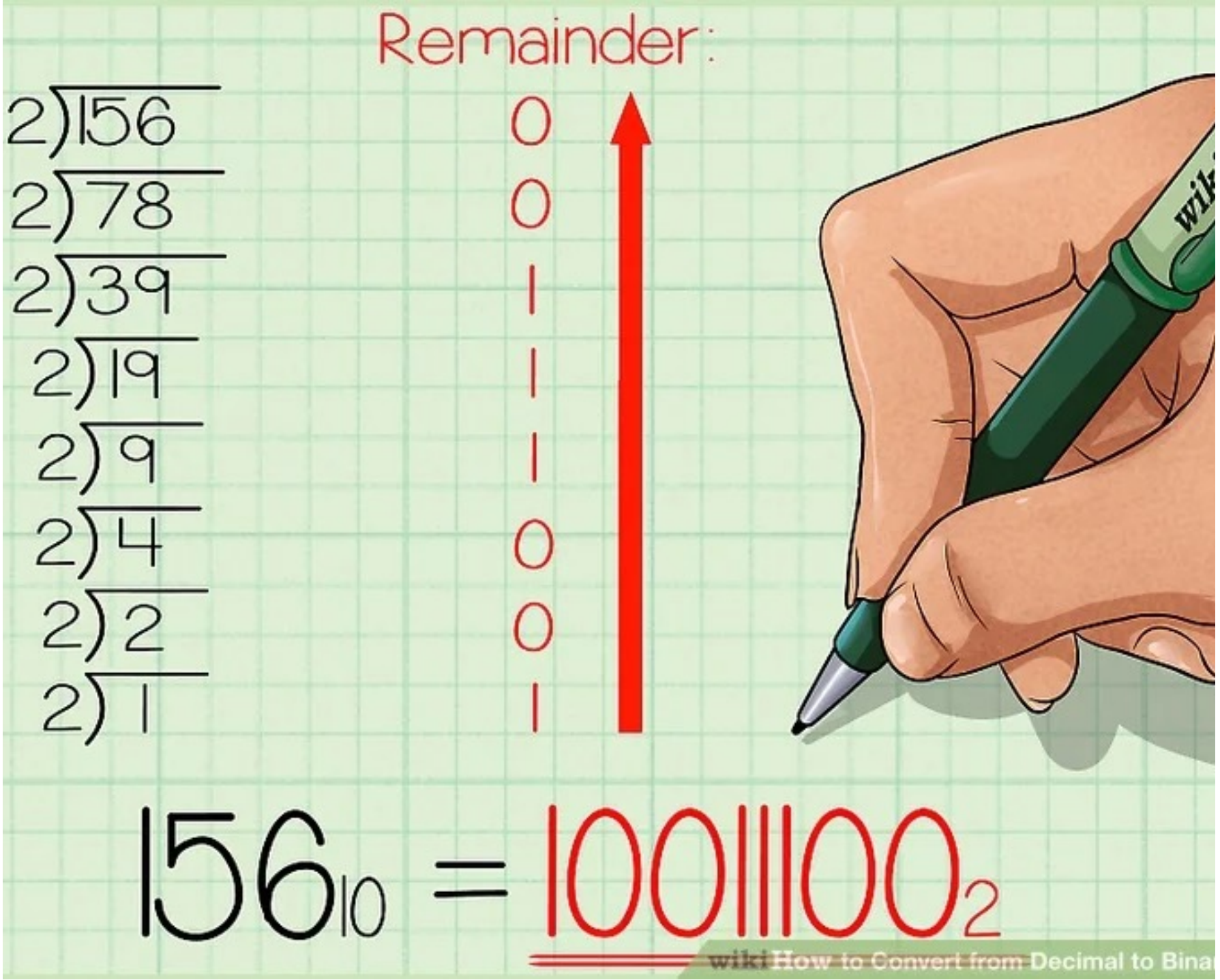
$= 2(4) + 1$

$= 2(2[2] + 0) + 1$

$= 2(2[2(1)+0] + 0) + 1$

$= 8*1 + 4*0 + 2*0 + 1$

$= 1001_2$



Number Representation Formats

- Binary fractions
  - Convert decimal to binary: **Method 3**
  - www.wikihow.com/Convert-from-Decimal-to-Binary
  - Convery 1.22 decimal to binary
  - If you want to compute upto 8 places after radix point, then start with round(1.22 * 2^8) = round(312.32) = 312
  - www.rapidtables.com/convert/number/decimal-to-binary.html?x=1.22

(312)/2	156	0	0
(156)/2	78	0	1
(78)/2	39	0	2
(39)/2	19	1	3
(19)/2	9	1	4
(9)/2	4	1	5
(4)/2	2	0	6
(2)/2	1	0	7
(1)/2	0	1	8

$= (100111000)_2 / 2^8$

$= (1.00111000)_2$

Number Representation Formats

- Floating-point
  - How is 123.45 stored in memory ?
  1. First converted to binary form: $123.45 = 1111011.01110011_2$
  2. The point is "floated" so that all non-zero bits are to the right

     $$123.45 = 0.11110110111001 1_2 \times 2^7$$

  3. For 32-bit float
     - Store sign (1 bit)
     - Store significand (23 bits) = `11110110111001 1`
     - Store exponent (8 bits) = 00000111

IEEE

- Institute of Electrical and Electronics Engineers
- Pronounced: I-triple-E
- Professional association for electronics engineering, electrical engineering, and other related disciplines
- Formed in 1963
- “Claims to produce over 30% of the world's literature in the electrical, electronics, and computer engineering fields”
  - 200 peer-reviewed journals and magazines
  - 1200 conference proceedings every year
- en.wikipedia.org/wiki/Institute_of_Electrical_and_Electronics_Engineers

IEEE

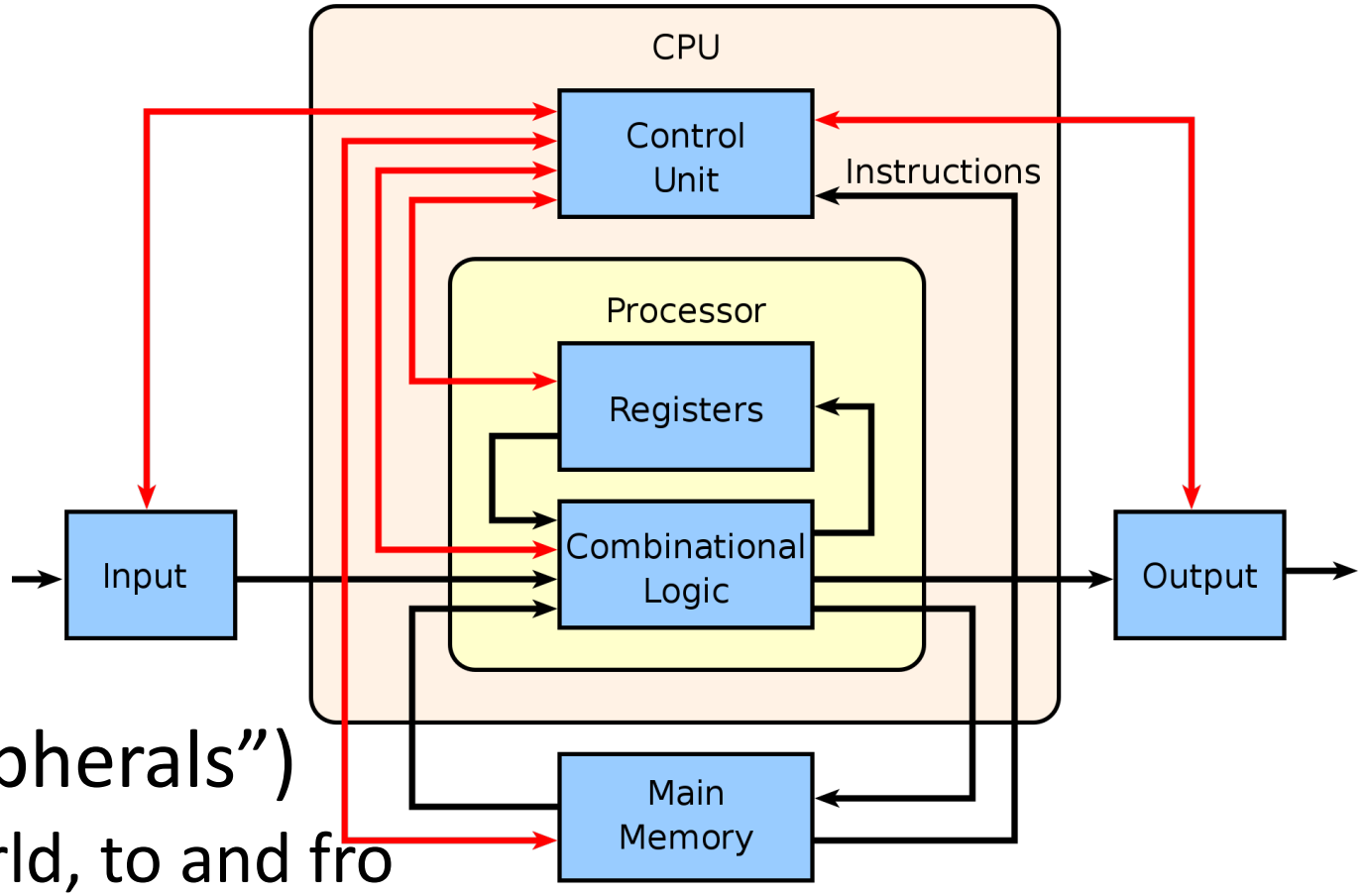
- Fields
  - IEEE Aerospace and Electronic Systems Society
  - IEEE Antennas & Propagation Society
  - IEEE Broadcast Technology Society
  - IEEE Circuits and Systems Society
  - IEEE Communications Society
  - IEEE Electronics Packaging Society
  - IEEE Computational Intelligence Society
  - IEEE Computer Society
  - IEEE Consumer Technology Society
  - IEEE Control Systems Society
  - IEEE Dielectrics & Electrical Insulation Society
  - IEEE Education Society
  - IEEE Electromagnetic Compatibility Society
  - IEEE Electron Devices Society
  - IEEE Engineering in Medicine and Biology Society
  - IEEE Geoscience and Remote Sensing Society
  - IEEE Industrial Electronics Society
  - IEEE Industry Applications Society
  - IEEE Information Theory Society
  - IEEE Instrumentation & Measurement Society
  - IEEE Intelligent Transportation Systems Society
  - IEEE Magnetics Society
  - IEEE Microwave Theory and Techniques Society
  - IEEE Nuclear and Plasma Sciences Society
  - IEEE Oceanic Engineering Society
  - IEEE Photonics Society
  - IEEE Power Electronics Society
  - IEEE Power & Energy Society
  - IEEE Product Safety Engineering Society
  - IEEE Professional Communication Society
  - IEEE Reliability Society
  - IEEE Robotics and Automation Society
  - IEEE Signal Processing Society
  - IEEE Society on Social Implications of Technology
  - IEEE Solid-State Circuits Society
  - IEEE Systems, Man, and Cybernetics Society
  - IEEE Technology and Engineering Management Society
  - IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society
  - IEEE Vehicular Technology Society

Number Representation Formats

- NaN = Not-a-Number
- What is NaaN ?

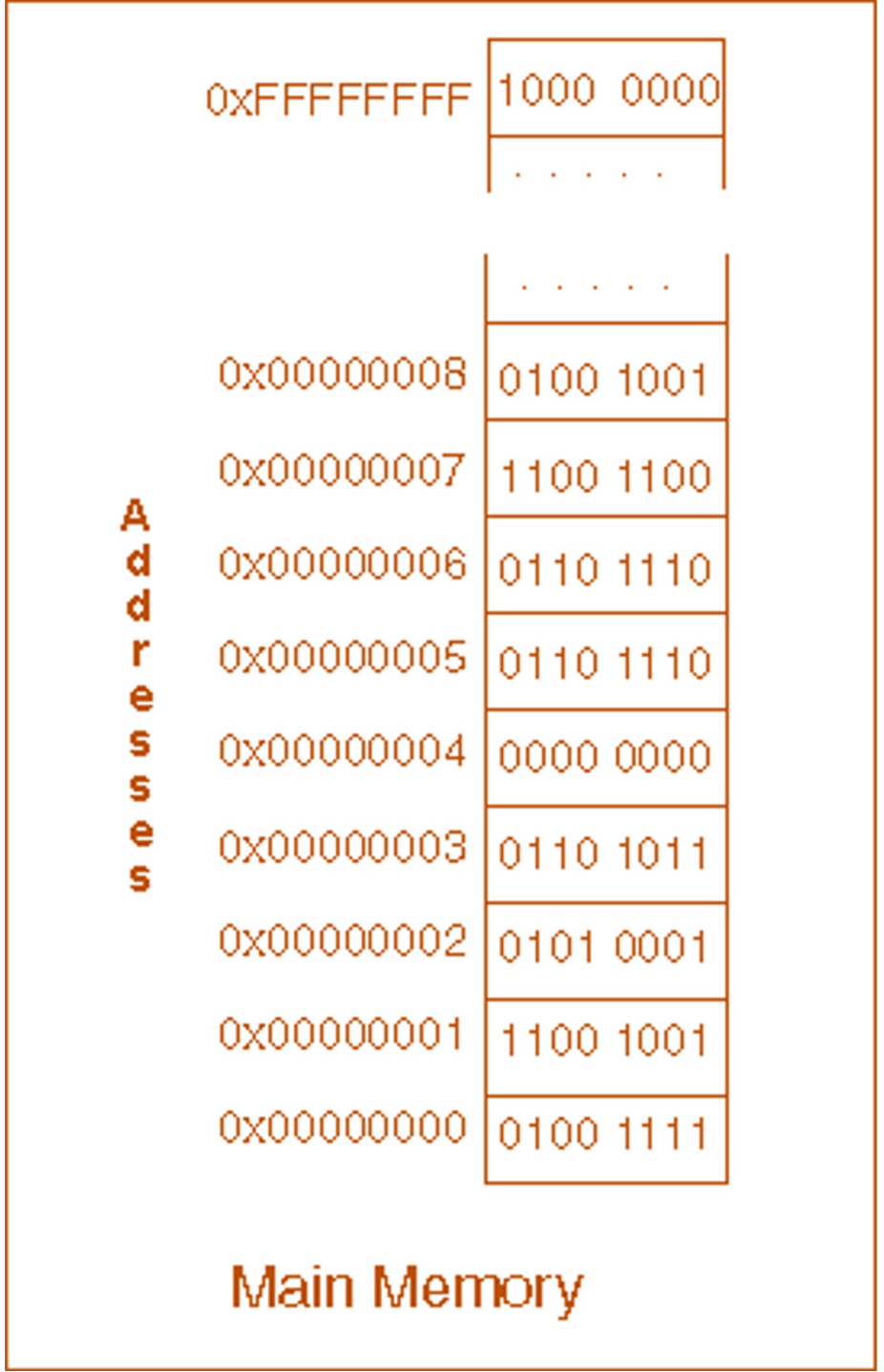
Parts of a Computer

- Main memory
  - Stores numbers/data, program/instructions
- Arithmetic (and logic) unit (ALU)
  - Performs arithmetic and logical operations on data
- Input-Output (IO) devices (“peripherals”)
  - To communicate with outside world, to and fro
    - e.g., keyboard, mouse, display screen, printer, disk
- Control unit: controls all units
- Central Processing Unit (CPU) = ALU + control unit
- Network: medium of transferring data between units



Main Memory

- Each byte of storage has an "address" / "location"
  - Byte = group of 8 bits
  - Memory with N bytes of storage has addresses going from 0 to 2^N-1
  - Addresses are also represented in binary (or hexadecimal = base-16)
- Example
  - CPU can execute instruction to store/"write" number N at address A
  - CPU can execute instruction to "read" number stored at address B



Control Unit

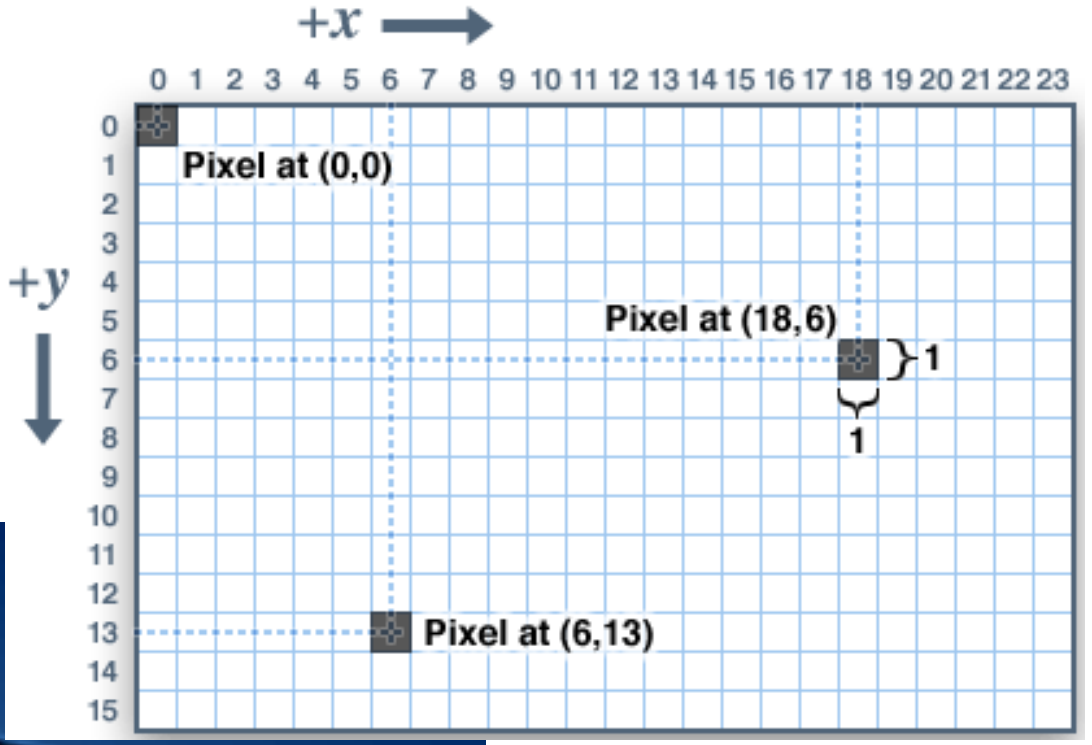
- Executes a sequence of operations (also represented as numbers)
  - "Machine language" used to communicate/specify sequence of instructions
  - e.g., a sequence of instructions (or a program) could be:
    53 100 57 100 100 104 57 100 104 104 63 104 99
    - 53, 100. This would read in a real number from the keyboard.
    - 57, 100, 100, 104. This would multiply the number in memory locations 100 with itself and put the result in location 104. Thus the square of the number will get placed in location 104. Note that after this instruction executes we will have the original number and its square in locations 100 and 104 respectively.
    - 57, 100, 104, 104. This would multiply the number in memory locations 100 and 104 and put the result in location 104. Thus the number and its square would get multiplied, and the result, the cube, would get placed in location 104.
    - 63,104. This would print out the cube on the screen.
    - 99. The program would stop.

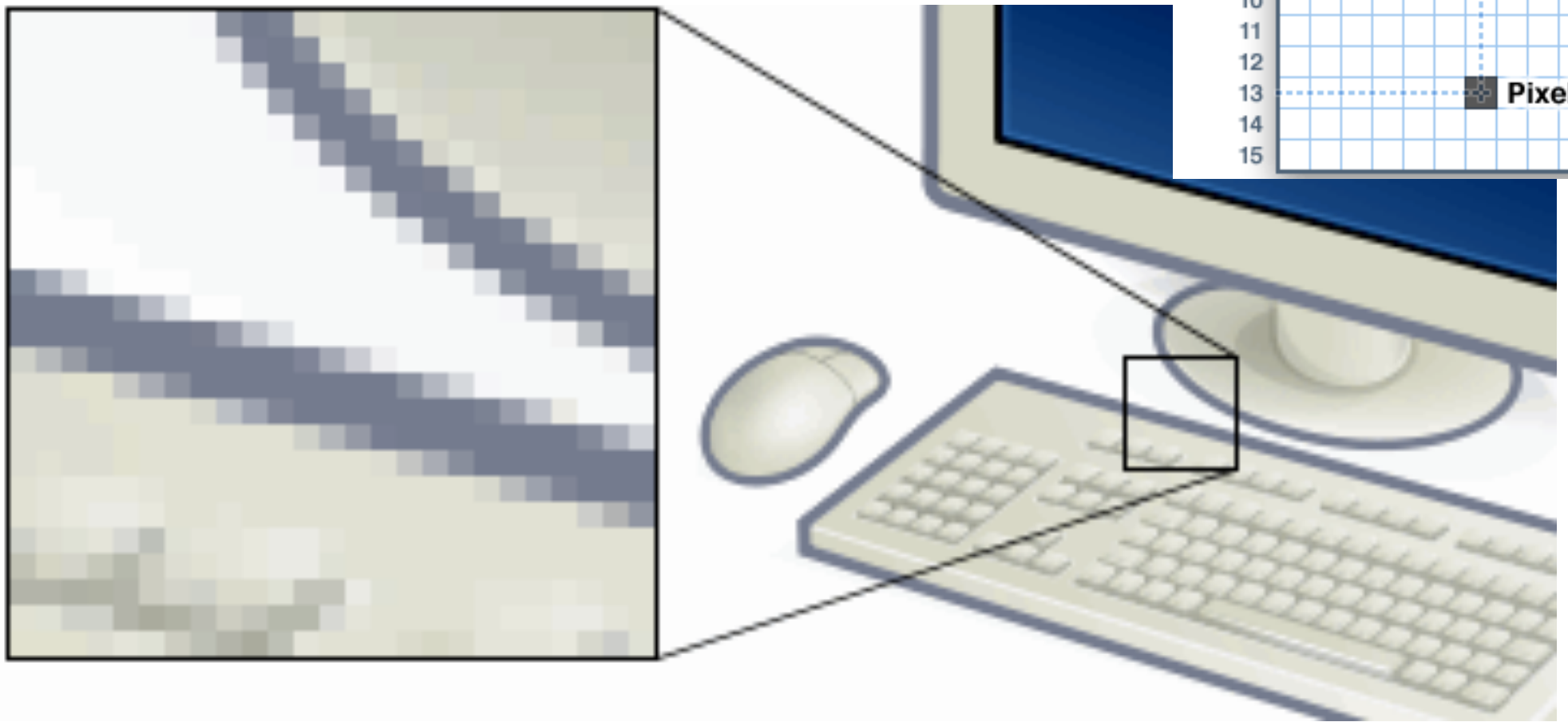
IO device: Keyboard

- Pressing each key (e.g., alphabetic character, numeral) sends a code to the computer

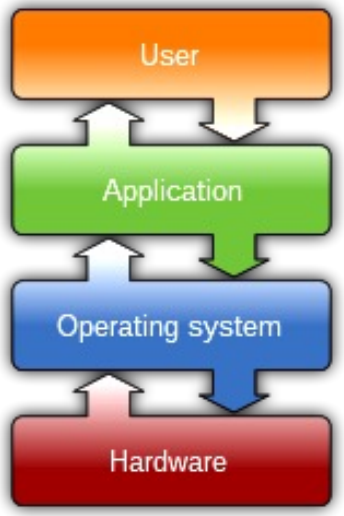
IO device: Display

- Pixels (picture elements) arranged in a grid
  - Pixel has a location
  - Pixel has a color





Operating System



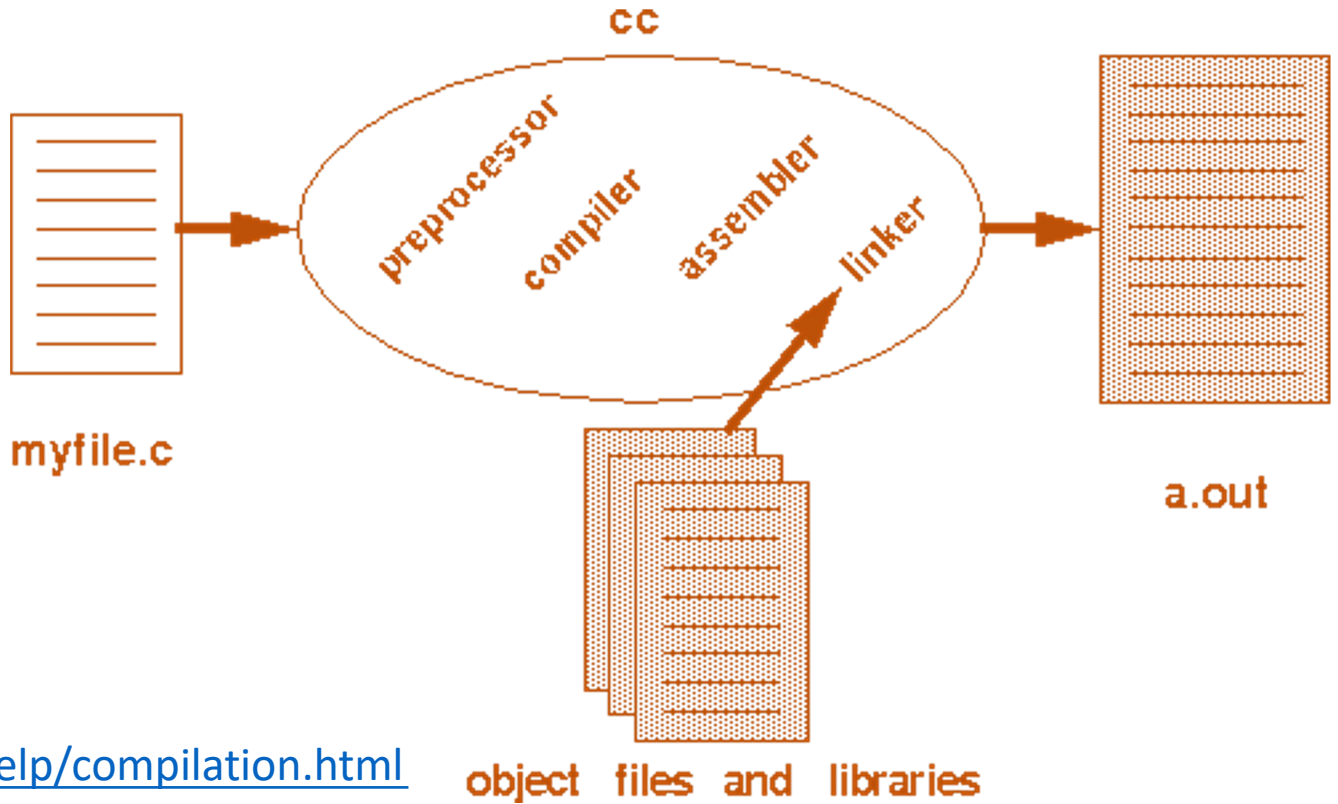
- Operating system (OS)
  - "Software that manages computer hardware and software resources, and provides common services for computer programs."
    - en.wikipedia.org/wiki/Operating_system
  - UNIX: "a family of multitasking, multiuser computer operating systems that derive from the original AT&T Unix, whose development started in 1969 at Bell Labs research center by Ken Thompson, Dennis Ritchie, and others"
    - en.wikipedia.org/wiki/Unix
    - Unix was written in C and lower-level languages
  - Linux: "a family of open-source Unix-like operating systems based on Linux kernel, an operating system kernel first released in 1991, by Linus Torvalds"
    - en.wikipedia.org/wiki/Linux
    - Often packaged with other software provided by GNU project
    - GNU is a collection of free software; can be used as/with an OS
    - GNU is a recursive acronym: "GNU's Not Unix!"

Operating System

- Gnu: antelope found in African plains; Wildebeest

Programming Languages

- **Machine language** communicates directly with ALU
- We'd like higher-level abstractions for communication
  - Higher-level languages, e.g., simpleCPP
  - Program s++ contains softwares including a "compiler" that translates our instructions in simpleCPP language to a lower-level language and stores that in "a.out"
    - a.out = "assembler output"
- Translation software
  - cc: C Compiler
  - gcc: GNU C compiler
  - c++: C++ compiler
  - g++: GNU C++ compiler
  - s++: built using g++



courses.cs.washington.edu/courses/cse378/97au/help/compilation.html

Variables and Data Types

- "Variable" = region of memory, associated with a name, that is allocated for holding a data entity of a certain type/kind
  - A variable has a **name.** A variable has a memory **address.** A variable has a **type**
  - Variable's name can be used to refer to (or access) information/data at memory address
    - We refer to this information as the value of the variable
- Examples
  - General syntax to create/define a variable:

    ```
    data-type variable-name;
    ```

  - Example: `int nsides;`
  - Can create/define several variables in a single statement in a program

    ```
    data-type variable-name1, variable-name2, ... variable-namek;
    ```

Variables and Data Types

- Fundamental data types of C++

1 Byte = 8 Bits

Data type	Possible values (Indicative)	# Bytes Allocated (Indicative)	Use for storing
`signed char`	-128 to 127	1	Characters or small integers.
`unsigned char`	0 to 255		
`short int`	-32768 to 32767	2	Medium size integers.
`unsigned short int`	0 to 65535		
`int`	-2147483648 to 2147483647	4	Standard size integers.
`unsigned int`	0 to 4294967295		
`long int`	-2147483648 to 2147483647	4	Storing longer integers.
`unsigned long int`	0 to 4294967295		
`long long int`	−9223372036854775808 to 9223372036854775807	8	Even longer integers.
`unsigned long long int`	0 to 18446744073709551615		
`bool`	`false` (0) or `true` (1)	1	Logical values.

Variables and Data Types

- How does signed char store numbers from **-128** to 127 ?
  - Table shows an example for a 3-bit storage system
    - Leftmost bit is indicative of sign
    - When sign is negative,
      get magnitude by
      flipping other bits and then adding 1
  - Twos-complement notation:
    en.wikipedia.org/wiki/
    two%27s_complement
    - Details are beyond scope of CS-101

Three-bit integers

Bits	Unsigned value	Signed value (Two's complement)
000	0	0
001	1	1
010	2	2
011	3	3
100	4	–4
101	5	–3
110	6	–2
111	7	–1

Variables and Data Types

- Fundamental data types of C++

`float`	Positive or negative. About 7 digits of precision. Magnitude in the range 1.17549×10^{-38} to 3.4028×10^{38}	4	Real numbers.
`double`	Positive or negative. About 15 digits of precision. Magnitude in the range 2.22507×10^{-308} to 1.7977×10^{308}	8	High precision and high range real numbers.
`long double`	Positive or negative. About 18 digits of precision. Magnitude in the range 3.3621×10^{-4932} to 1.18973×10^{4932}	12	High precision and very high range real numbers.

Variables and Data Types

- Fundamental data types of C++
  - Storage allocated for different data types might vary across machines
  - Use sizeof() operator to find out exactly how many bytes would be allocated

```
cout << "\t          char: " <<          sizeof(char) << endl;
cout << "\t         short: " <<         sizeof(short) << endl;
cout << "\t           int: " <<           sizeof(int) << endl;
cout << "\t          long: " <<          sizeof(long) << endl;
cout << "\t unsigned char: " <<  sizeof(unsigned char) << endl;
cout << "\tunsigned short: " << sizeof(unsigned short) << endl;
cout << "\t  unsigned int: " <<   sizeof(unsigned int) << endl;
cout << "\t unsigned long: " <<  sizeof(unsigned long) << endl;
cout << "\t   signed char: " <<    sizeof(signed char) << endl;
cout << "\t         float: " <<          sizeof(float) << endl;
cout << "\t        double: " <<         sizeof(double) << endl;
cout << "\t   long double: " <<    sizeof(long double) << endl;
```

```
          char: 1
         short: 2
           int: 4
          long: 4
 unsigned char: 1
unsigned short: 2
  unsigned int: 4
 unsigned long: 4
   signed char: 1
         float: 4
        double: 8
   long double: 8
```

Variable Naming

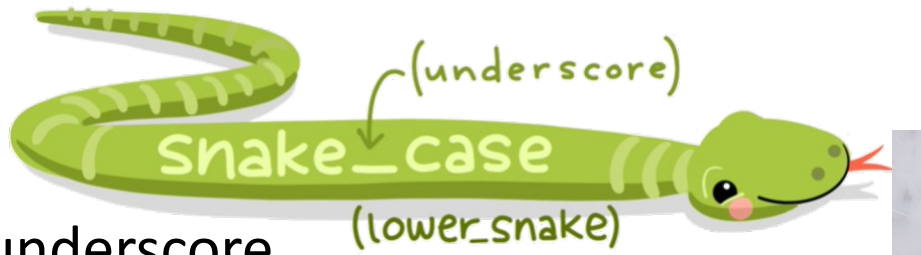
- Design name to indicate the intended purpose of variable in program
  - E.g., “int mm” creates/defines a variable called “mm”, but where the name “mm” seems too cryptic
  - E.g., “int mathMarks” is a better statement
- Design data-type according to intended values of variable
  - E.g., “unsigned int numSides”, or “unsigned char numSides”, or “unsigned int mathMarks”
- Variable names are case sensitive
  - E.g., mathMarks, MathMarks, mathmarks, are all different variables
- Create/define variable when and where you need it in the program
  - Creating variable in line 10 and using it first on line 500 isn’t helpful to reader

Variable Naming

- Variable naming convention
  - en.wikipedia.org/wiki/Naming_convention_(programming)
  - “To reduce the effort needed to read and understand source code”
  - “To enable code reviews to focus on issues more important than syntax”
  - Example
    - Compare `a = b * c;` vs. `weekly_pay = hours_worked * hourly_pay_rate;`
      - Note: spaces aren’t allowed in variable names; underscores are allowed
  - Length of name; tradeoffs
    - Shorter names can be easier to type (but some editing software allow text completion), but can be too cryptic
    - Longer names can give more insight into purpose and use of variable, but very long names lead to visual clutter

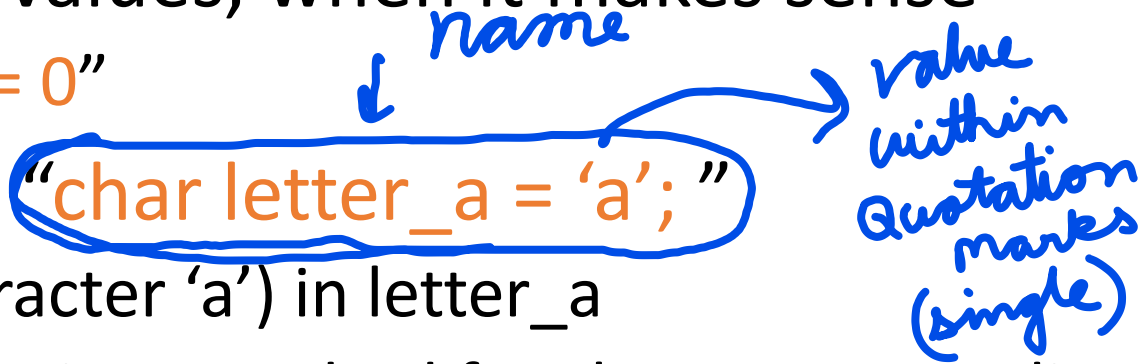
Variable Naming

- Character "case"
  - Uppercase: e.g., PI
  - Lowercase: e.g., count
  - Camel case
    - Without spaces. With capitalized words.
    - e.g., wordCount, iPhone, eBay
    - e.g., YouTube
  - Snake case
    - Replace space by underscore
    - e.g., word_count
  - Kebab case (doesn't work with C++)
    - Replace space by underscore
    - e.g., the-quick-brown-fox-jumps-over-the-lazy-dog



Variable Initialization

- Creating/defining a variable "int numSides"
  - Allocates memory region of size 4 bytes
  - Associated name 'numSides" with that memory location
  - Doesn't specify any value of variable, or content in memory region
    - By default, this memory can contain any junk information
- ✓Good idea to initialize variable values, when it makes sense
  - E.g., "unsigned int numOfSides = 0"
- What does this statement do ? "char letter_a = 'a'; "
  - Stores number 97 (code for character 'a') in letter_a
  - ASCII en.wikipedia.org/wiki/ASCII is a standard for character encoding in electronic communication
    - American Standard Code for Information Interchange



ASCII

- codes

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(	72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29	)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[END OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	[	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	|
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D	]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	_	127	7F	[DEL]

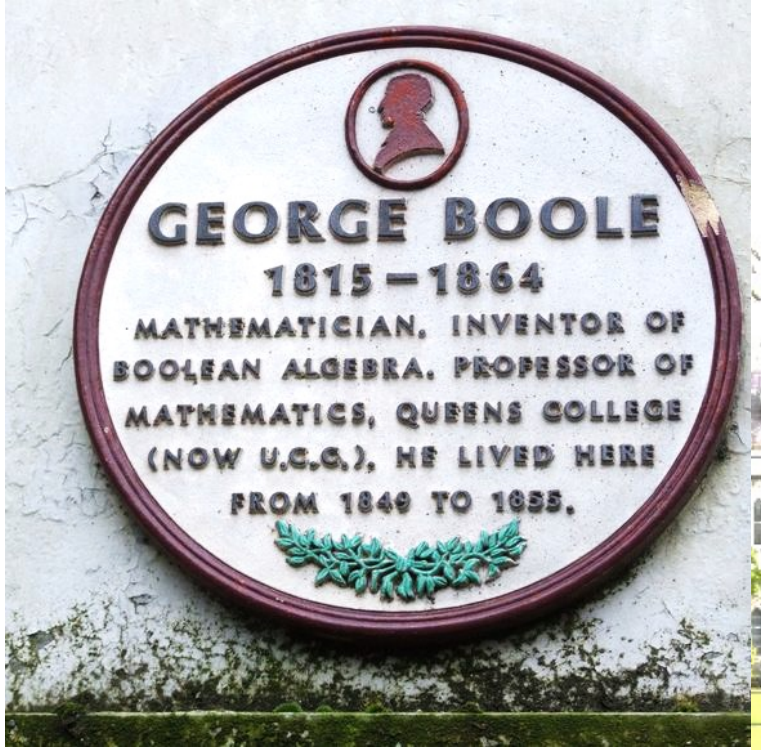
ASCII codes

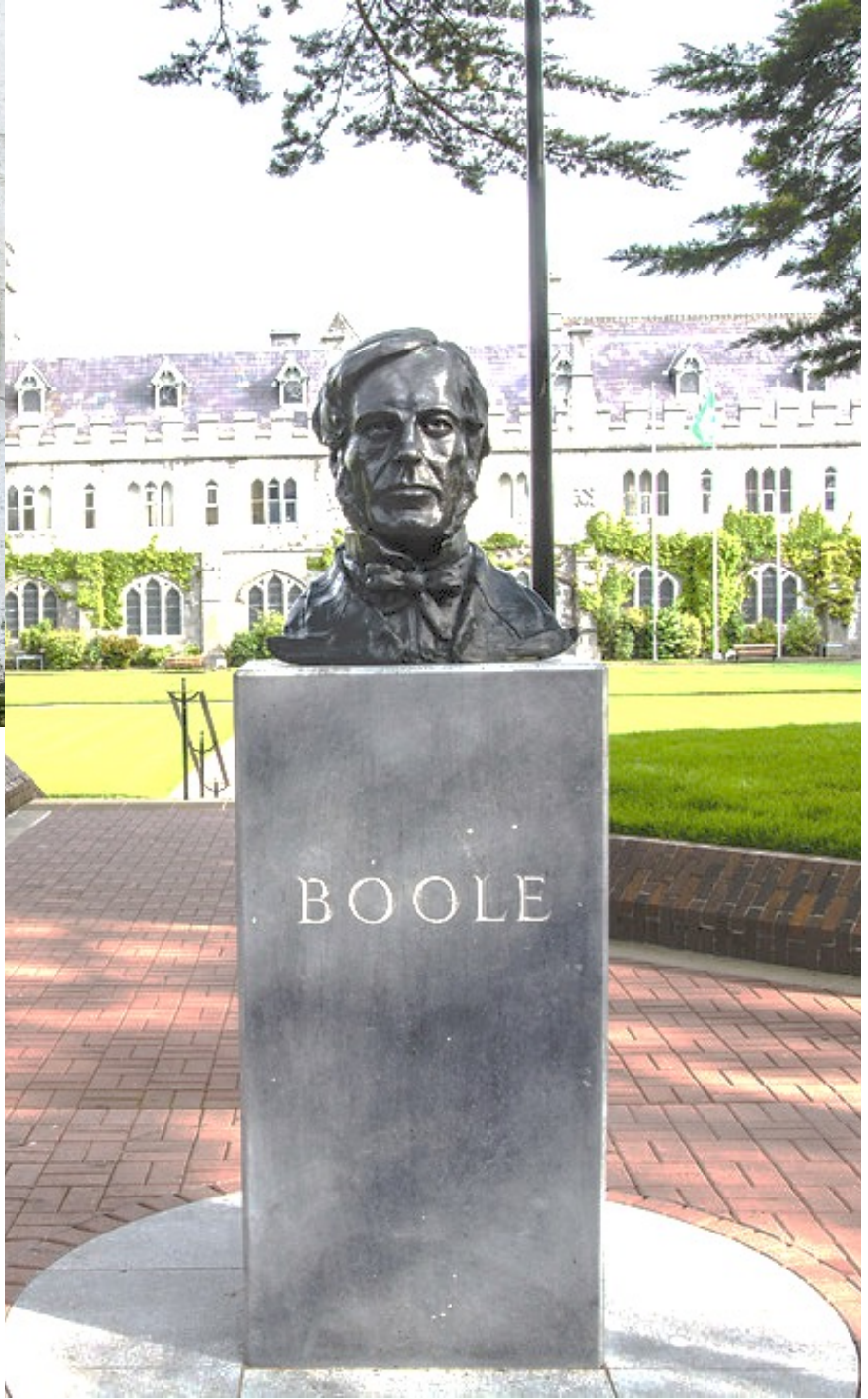
- What will this type ?

```
main_program{
  char small, capital;

  cout << "Type in any lower case letter: ";
  cin >> small;

  capital = small + 'A' - 'a';

  cout << capital << endl;
}
```

Boolean

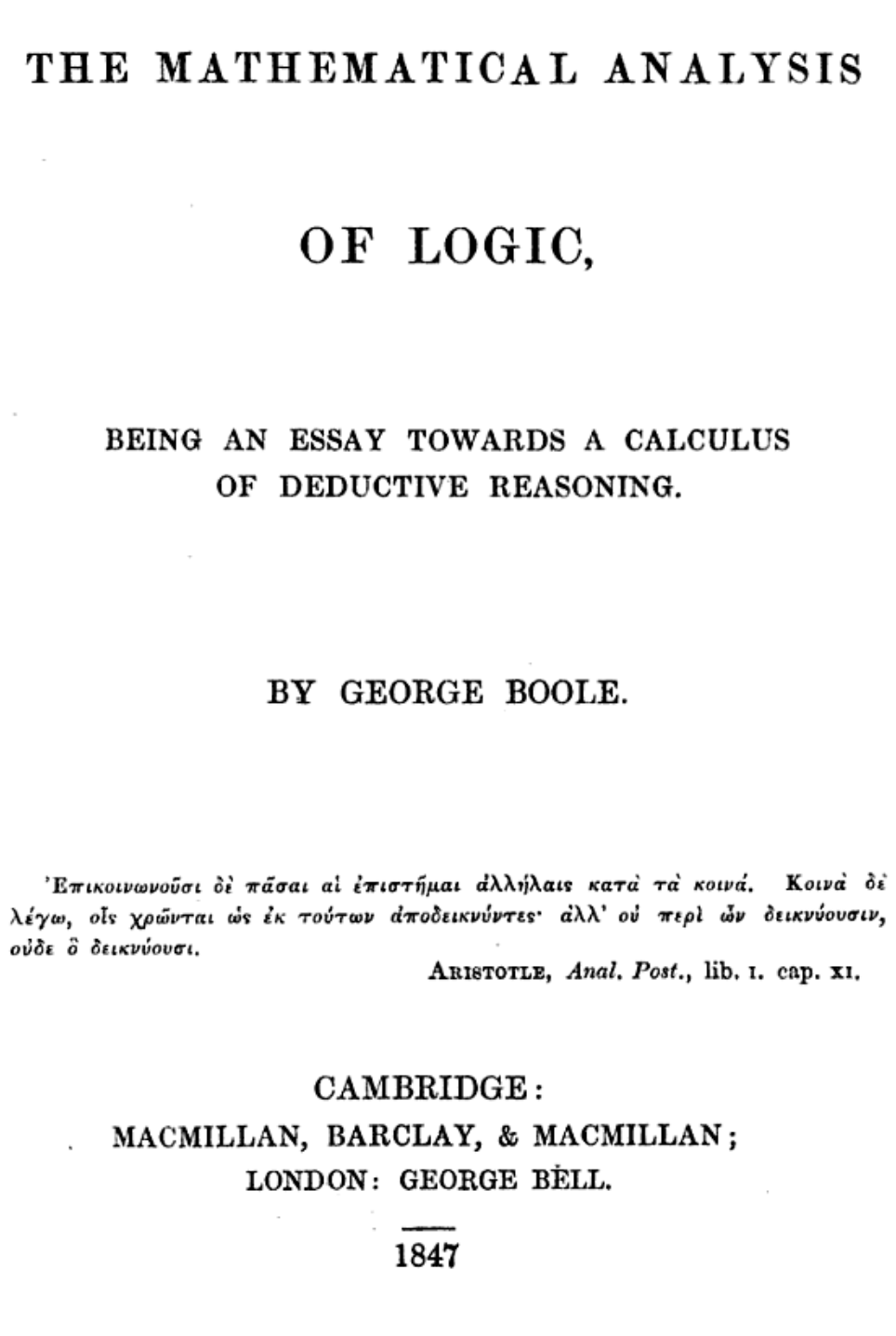
- Boolean data type,
  e.g.,
  "bool penDown = true"
- George Boole
  - Self-taught
    English mathematician,
    philosopher, and logician
  - Son of a shoemaker
  - At 16, he began teaching to support his family
  - At 19, he established his own school
  - First professor of mathematics
    at University College Cork





Boolean

- George Boole
  - In 1847 (age 32), Boole developed Boolean algebra, a fundamental concept in binary logic



THE MATHEMATICAL ANALYSIS

OF LOGIC,

BEING AN ESSAY TOWARDS A CALCULUS
OF DEDUCTIVE REASONING.

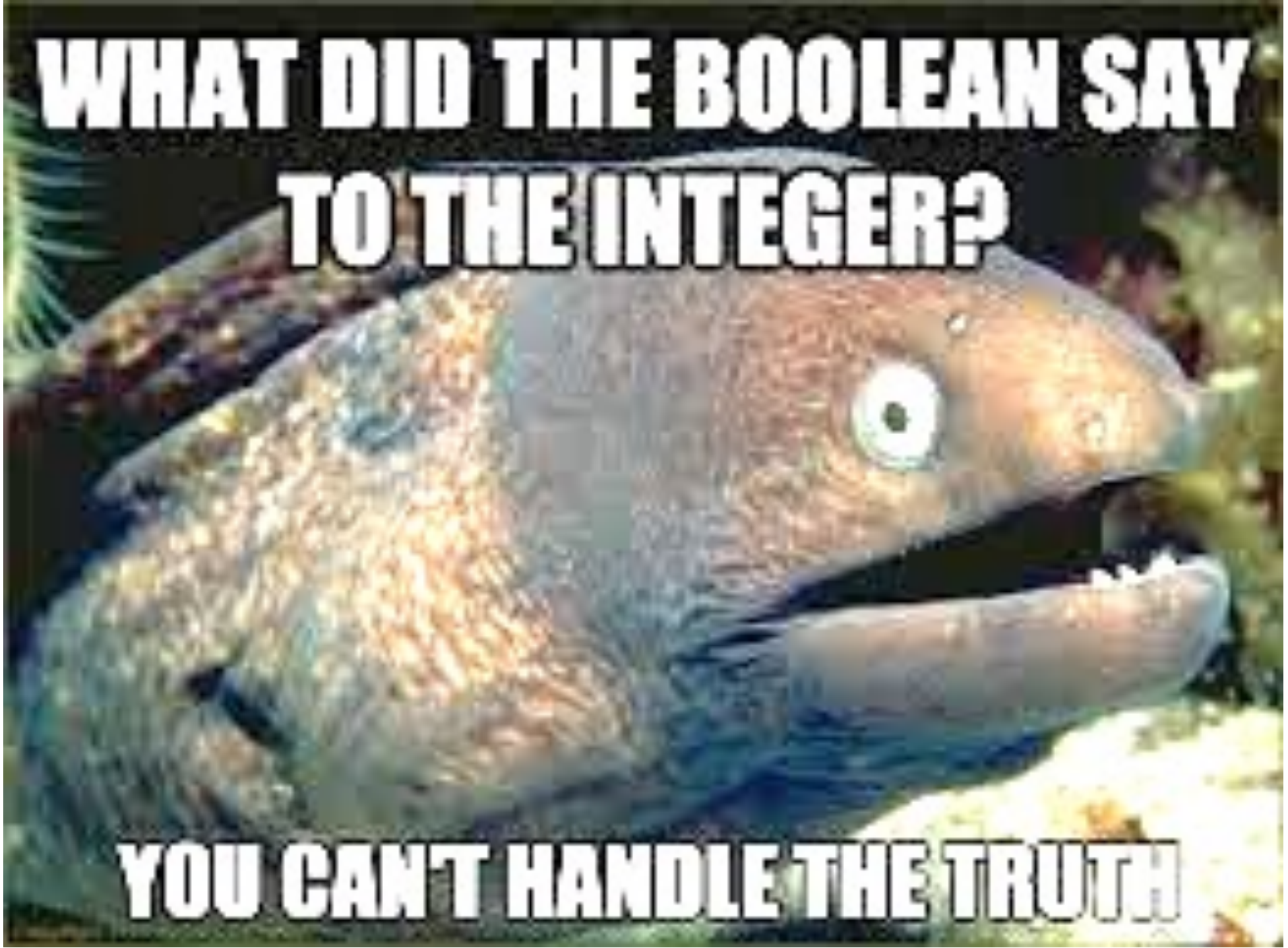
BY GEORGE BOOLE.

Ἐπικοινωνοῦσι δὲ πᾶσαι αἱ ἐπιστῆμαι ἀλλήλαις κατὰ τὰ κοινά. Κοινὰ δὲ λέγω, οἷς χρῶνται ὡς ἐκ τούτων ἀποδεικνύντες· ἀλλ' οὐ περὶ ὧν δεικνύουσιν, οὐδὲ ὃ δεικνύουσι.

ARISTOTLE, *Anal. Post.*, lib. I. cap. XI.

CAMBRIDGE:
MACMILLAN, BARCLAY, & MACMILLAN;
LONDON: GEORGE BELL.

1847


WHAT DID THE BOOLEAN SAY TO THE INTEGER?
YOU CAN'T HANDLE THE TRUTH

In Lighter Vein: https://bhailang.js.org

General

`hi bhai` is the entrypoint for the program and all program must end with `bye bhai`. Anything outside of it will be ignored.

```
This will be ignored

hi bhai
  // Write code here
bye bhai

This too
```

Variables

Variables can be declared using `bhai ye hai`.

```
hi bhai
    bhai ye hai a = 10;
    bhai ye hai b = "two";
    bhai ye hai c = 15;
    a = a + 1;
    b = 21;
    c *= 2;
bye bhai
```

Built-ins

Use `bol bhai` to print anything to console.

```
hi bhai
    bol bhai "Hello World";
    bhai ye hai a = 10;
    {
       bhai ye hai b = 20;
       bol bhai a + b;
    }
    bol bhai 5, 'ok', nalla , sahi , galat;
bye bhai
```

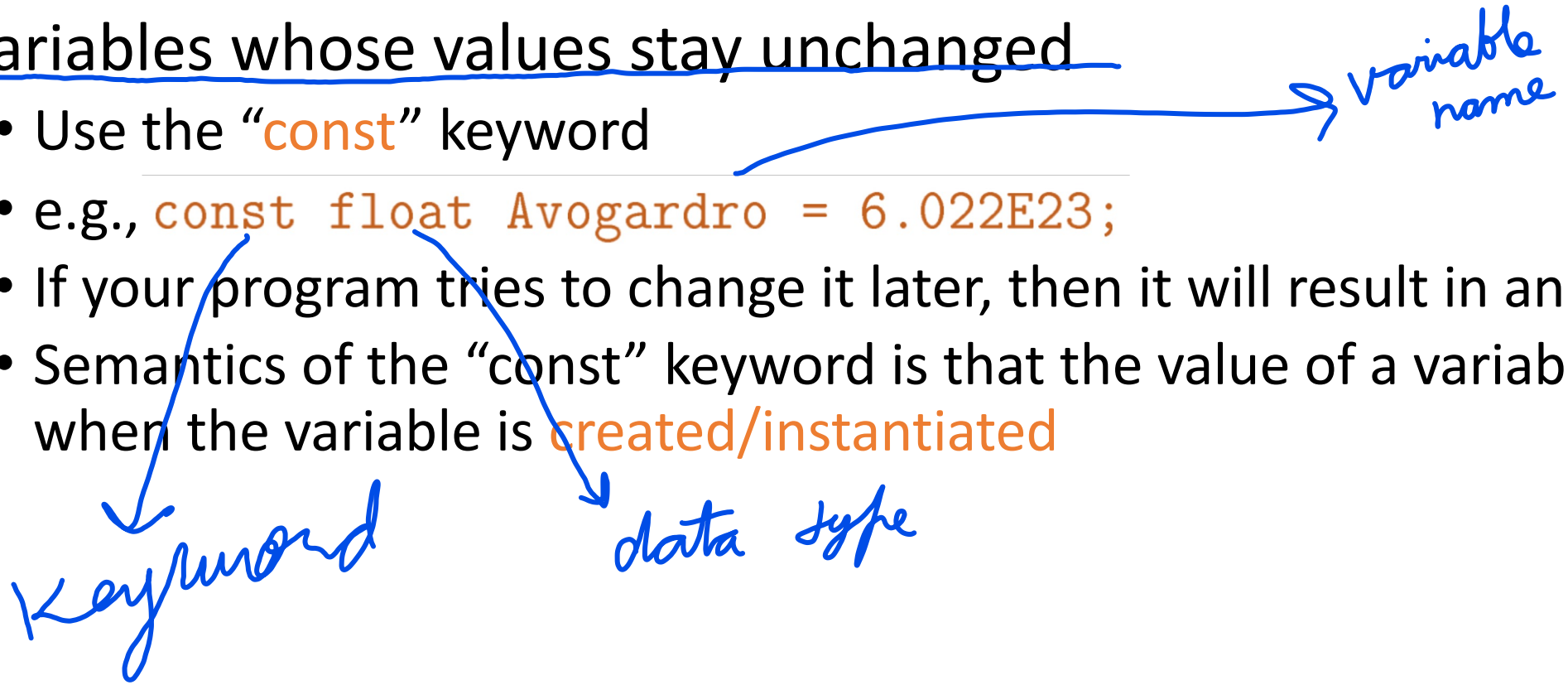
Types

Numbers and strings are like other languages. Null values can be denoted using `nalla`. `sahi` and `galat` are the boolean values.

```
hi bhai
    bhai ye hai a = 10;
    bhai ye hai b = 10 + (15*20);
    bhai ye hai c = "two";
    bhai ye hai d = 'ok';
    bhai ye hai e = nalla;
    bhai ye hai f = sahi;
    bhai ye hai g = galat;
bye bhai
```

Variable Initialization

- Variables whose values stay unchanged
  - Use the “const” keyword
  - e.g., `const float Avogardro = 6.022E23;`
  - If your program tries to change it later, then it will result in an error
  - Semantics of the “const” keyword is that the value of a variable is to be fixed when the variable is created/instantiated



Reading Data into a Variable

- Statement: cin >> varName;
  - When statement is executed, program waits to receive input from keyboard
    - End of input typically indicated by keying “enter”/newline
  - Initial “whitespace” characters will be ignored before we type in a value consistent with the data type of varName
    - Whitespace characters = those representing horizontal or vertical space in typography
    - These are invisible, but occupy space on a page, e.g., space (‘ ’), tab (‘\t’), newline (‘\n’)
    - Case 1: varName is of numeric type
      - Initial whitespaces ignored
    - Case 2: varName is of char type
      - Initial whitespaces ignored
      - ASCII value of first non-whitespace character is assigned to varName
- Reading many values: cin >> varName1 >> varName2;

Printing Variable Values on Display

- Statement: cout << varName;
- If you want a end-of-line to be printed,
  use:
  cout << varName << endl;
  or use:
  cout << varName << "\n";
- Consider: char c = 97; cout << c << endl;
  - This will print the character whose ASCII value is 97
- Printing several values
  - e.g., cout << varName1 << endl << varName2 << endl;
  - e.g., cout << "varName1: " << varName1 << ", "
    << "varName2: " << varName2 << endl;

Assignment

- Syntax: variable = expression;
- Example

```
int x=2,y=3,p=4,q=5,r;
r = x*y + p*q;
cout << x*y+p*q << endl;
```

- Example
  - Valid statement: p = p + 1;
  - First evaluate expression on right-hand-side;
    Then assign expression value to variable on left
- Example
  - Invalid statement: p+1 = p;
  - Left hand side isn't a variable

Evaluating Expressions

- Precedence of operators
  - In mathematics and computer programming, the order of operations (or operator precedence) is a collection of rules that reflect conventions about which procedures to perform first in order to evaluate a given mathematical expression
    - e.g., 1 + 2 × 3 is interpreted to have the value 1 + (2 × 3) = 7, and not (1 + 2) × 3 = 9
  - Order
    1. Parenthetic subexpressions
    2. Exponentiation
    3. Multiplication and Division
    4. Addition and Subtraction
  - More details:
    - naipc.uchicago.edu/2014/ref/cppreference/en/cpp/language/operator_precedence.html

Assignment

- The assignment statement is itself also an expression !
- Example

```
int x,y,z;
x = y = z = 1;
```

- Associativity of operator “=” is right-to-left
  - Rightmost “=” assignment is evaluated/executed first
  - Its expression value is 1, which is then used to assign “y”

```
x = (y = (z = 1));
```

Integer Division

- Consider

```
int m=100, n=7, p, q;
p = m/n;
q = 35/200;
```

  - Value of p will be 14. Value of q will be 0.
  - Integer division produces the integer part (floor) of the decimal quotient

- Example:

```
cout <<"Give the duration in seconds: ";
int duration; cin >> duration;
int hours, minutes, seconds;
hours = duration/3600;
minutes = (duration - hours*3600)/60;
seconds = duration % 60;
cout <<"Hours: "<< hours <<", Minutes: "
     << minutes <<", Seconds: "<< seconds << endl;
```

  - When input is 5000, output is: `Hours: 1, Minutes: 23, Seconds: 20`

Integer Division

- Example

```
int x=100, w;
float y,z;
y = 360/x;
z = 360.0/x;
w = 360.0/x;
```

  - Value of y will be ? 3
  - Value of z will be ? 3.6
  - Value of w will be ? 3

- Syntax for explicit type conversion:
  "type (expression)" or "(type) expression"
  - e.g., "y = float(360) / x" will lead to value of y being 3.6

Example

- Be careful about precedence rules, order of evaluation, integer division
- Example

```
main_program{
    double centigrade, fahrenheit;

    cout << "Give temperature in Centigrade: ";
    cin >> centigrade;

    fahrenheit = 32.0 + centigrade * 9.0/5.0;
    cout << "Temperature in Fahrenheit: " << fahrenheit << endl;
}
```

  - What if we wrote 9/5 instead of 9.0/5.0 ?
    - Will division happen first or will multiplication happen first ?
      - When multiplication happens, it will be done in double precision
    - Mixing floating-point and integer variables in this way leaves room for ambiguity. Avoid such code.

Assignment with Repeat

- What will this do ?

```
main_program{
  turtleSim();
  int i = 1;
  repeat(10){
    forward(i*10); right(90);
    forward(i*10); right(90);
    i = i + 1;
  }
  wait(5);
}
```

Increment and Decrement Operators

- Post-increment operator: ++ as a suffix
  - int a = 1, b;
    b = a++;
  - Use variable ‘a’ in evaluating expression, and increment variable after use
  - So, after execution: value of b is 1, value of a is 2
- Pre-increment operator: ++ as a prefix
  - int a = 1, b;
    b = ++a;
  - Increment variable, and then use incremented variable to evaluate expression
  - So, after execution: value of b is 2, value of a is 2
- Less-confusing and preferred way
  - Write b = a; a++; OR
  - Write a++; b = a;

Compound Assignment Operators

- Instead of writing
  varName = varName + expression;
  one could write
  varName += expression;
- Similar usage for -=, *=, /=
- Usually we avoid such usage,
  to prefer clarity and easy of understanding
  - Because we are usually more familiar with standard assignment operator “=”
  - Because these may be prone to misreading (e.g., as “=”)

Assignment with Repeat

- What will this do ?

```
main_program{
   int count;
   cout << "How many numbers: ";
   cin >> count;

   float num,sum=0;
   repeat(count){
      cout << "Give the next number: ";
      cin >> num;
      sum = sum + num;
   }

   cout << "Average is: ";
   cout << sum/count;
   cout << endl;
}
```

Block, Scope

- Block = region of program starting from "{" to the corresponding "}"
  - If we consider two blocks within a program, then
    they must be entirely disjoint OR
    one block must be entirely contained (nested) within the other
- Parent block of a variable definition =
  innermost block in which variable is defined
- "Scope" of a variable = region of program where the variable can be referenced/used, i.e., where the variable is "visible"
  - A variable is created when its definition is encountered during execution;
    variable is destroyed when its parent block is exited
  - Notion of scope helps prevent name collisions by allowing the same name to refer to different objects – as long as the names have separate scopes
    - Shadowing: Variable defined within a scope shadows variable defined in outer scope

Assignment with Repeat

- What will this do ?
  - A different way
  - Need to create and destroy variable num within each iteration of repeat loop, leading to extra overhead for bookkeeping
  - Prevent inadvertent access of variable num outside loop
    - So this is the preferred way because it is safer and more readable

```
main_program{
   int count;
   cout << "How many numbers: ";
   cin >> count;

   float sum=0;
   repeat(count){
      cout << "Give the next number: ";
      float num;
      cin >> num;
      sum = sum + num;
   }

   cout << "Average is: ";
   cout << sum/count;
   cout << endl;
}
```

Practice Examples for Lab: Set 2

- 1 Write a program that prints the arithmetic sequence $a, a+d, a+2d, \ldots, a+nd$. Take a, d, n as input.

  Write a program that prints out the geometric sequence $a, ar, ar^2, \ldots, ar^n$, taking a, r, n as input.

- 2 Write a program that reads in distance d in inches and prints it out as v miles, w furlongs, x yards, y feet, z inches. Remember that a mile equals 8 furlongs, a furlong equals 220 yards, a yard is 3 feet, and a foot is 12 inches. So your answer should satisfy $d = (((8v + w) \cdot 220 + x) \cdot 3 + y) \cdot 12 + z$, and further $w < 8, x < 220, y < 3, z < 12$.

- 3 What is the value of `x` after the following statements are executed? (a) `x=22/7;` (b) `x=22.0/7;` (c) `x=6.022E23 + 1 - 6.022E23` (d) `x=6.022E23 - 6.022E23 + 1` (e) `x=6.022E23 * 6.022E23`. Answer for three cases, when `x` is defined to be of type `int`, `float`, `double`. Put these statements in a program, execute and check your conclusions.

Practice Examples for Lab: Set 2

- 4 What will be the effect of executing the following code fragment?

```
float f1, f2,centigrade=100;
f1 = centigrade*9/5 + 32;
f2 = 32 + 9/5*centigrade;
cout << f1 << ' ' << f2 << endl;

char x = 'a', y;
y = x + 1;
cout << y << ' ' << x + 1 << endl;
```

- 5 For what values of `a,b,c` will the expressions `a+(b+c)` and `(a+b)+c` evaluate to different values?

- 6 Draw a smooth spiral. The spiral should wind around itself in a parallel manner, i.e. there should be a certain point called "center" such that if you draw a line going out from it, the spiral should intersect it at equal distances as it winds around.

Numeric Overflow

- Integer “overflow”
  - Occurs when manipulating integers beyond their maximum allowed value

```
{ // prints n until it overflows:
  int n=1000;
  cout << "n = " << n << endl;
  n *= 1000;  // multiplies n by 1000
  cout << "n = " << n << endl;
  n *= 1000;  // multiplies n by 1000
  cout << "n = " << n << endl;
  n *= 1000;  // multiplies n by 1000
  cout << "n = " << n << endl;
}
```

```
n = 1000
n = 1000000
n = 1000000000
n = -727379968
```

Numeric Overflow

- Floating-point overflow
  - Occurs when manipulating floating-point numbers beyond their maximum allowed value

```
{ // prints x until it overflows:
  float x=1000.0;
  cout << "x = " << x << endl;
  x *= x;  // multiplies n by itself; i.e., it squares x
  cout << "x = " << x << endl;
  x *= x;  // multiplies n by itself; i.e., it squares x
  cout << "x = " << x << endl;
  x *= x;  // multiplies n by itself; i.e., it squares x
  cout << "x = " << x << endl;
  x *= x;  // multiplies n by itself; i.e., it squares x
  cout << "x = " << x << endl;
}
```

```
x = 1000
x = 1e+06
x = 1e+12
x = 1e+24
x = inf
```

Numeric Round-Off Error

- Floating-point round-off error

```
double x = 1000/3.0;cout << "x = " << x << endl;  // x = 1000/3
double y = x - 333.0;cout << "y = " << y << endl; // y = 1/3
double z = 3*y - 1.0;cout << "z = " << z << endl; // z = 3(1/3) - 1
```

```
x = 333.333
y = 0.333333
z = -5.68434e-14
```

What to do now?

E-Format for Floating-Point Values

- Floating-point
  - “cin” can also read in scientific format

```
{ // prints double values in scientific e-format:
  double x;
  cout << "Enter float: ";  cin >> x;
  cout << "Its reciprocal is: " << 1/x << endl;
}
Enter float: 234.567e89
Its reciprocal is: 4.26317e-92
```

Block, Scope

- Example
  - What will the output be ?

```
main_program{
   int sum=0;
   repeat(5){
      int num;                    // statement 1
      cin >> num;
      sum += num;
   }
   cout << sum << endl;
   int prod=1;
   repeat(5){
      int num;                    // statement 2
      cin >> num;
      prod *= num;
   }
   cout << prod << endl;
}
```

Block, Scope

- Example
  - What will the output be ?

10
5
10
5
10
5
10

```
main_program{
   int p=10;                    // statement 3
   repeat(3){
      cout << p << endl;        // statement 4
      int p=5;                  // statement 5
      cout << p << endl;        // statement 6
   }
   cout << p << endl;           // statement 7
}
```

  - Variable ‘p’ defined/created in statement 5 shadows variable ‘p’ defined/created in statement 3

Block, Scope

- Example
  - What will the output be ?
    - Trick question: compilation error

```
#include<simplecpp>

main_program {

  int p = 10;
  repeat (3)
    {
      cout << p << a << endl;
      int a = 5;
      cout << p << a << endl;
    }
  cout << p << endl;
}
```

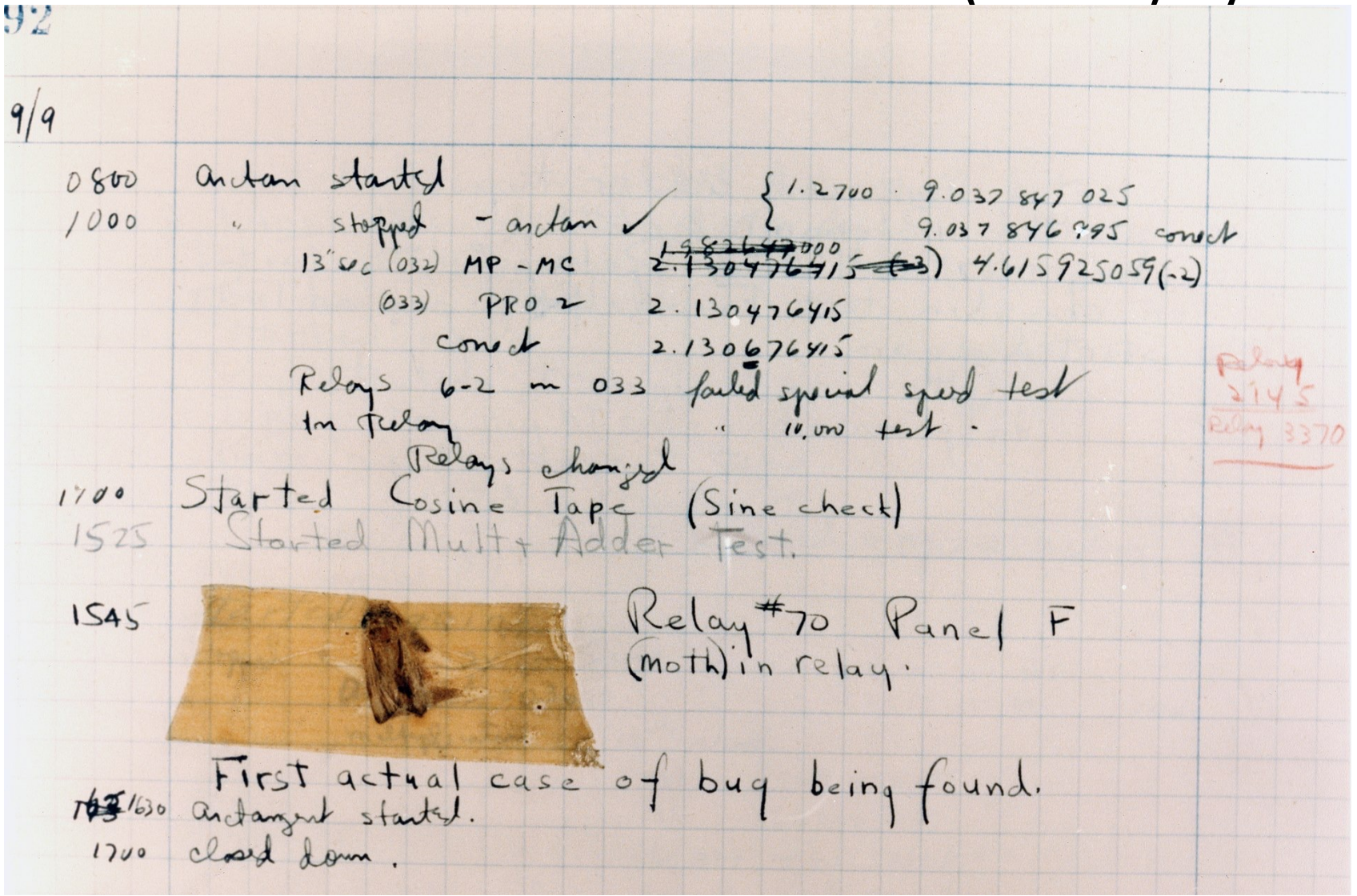
```
prog1.cpp:9:20: error: ‘a’ was not declared in this scope
    9 |         cout << p << a << endl;
      |                    ^
      |
```

Programming Mistakes

- Software "bug"
  - "An error, flaw or fault in the design, development, or operation of computer software that causes it to produce an incorrect or unexpected result, or to behave in unintended ways."
    - en.wikipedia.org/wiki/Software_bug
- "Debugging" = process of finding and correcting bugs
  - Compile-time errors; s++ will usually give line number where it thinks there is an error
  - Run-time errors
- History
  - Middle-English word bugge is the basis for the terms "bugbear" and "bugaboo" as terms used for a monster
  - Term 'bug' used by Thomas Edison (1878), Isaac Asimov (1944)
  - Term 'debug' reported in Oxford Dictionary in context of aircraft engines

Bug

- A page from Harvard Mark II electromechanical computer's log, featuring a dead moth that was removed from the device (1940s) by Admiral Grace Hopper



Bug

- Admiral Grace Hopper
  - American computer scientist, mathematician, US Navy rear admiral
  - Prior to joining the Navy, Hopper earned PhD in mathematics from Yale University
  - Computer programming pioneer
  - Presidential Medal of Freedom

Program Design

- Writing a program to compute: $e = \lim_{n \to \infty} \frac{1}{0!} + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \cdots + \frac{1}{n!}$

- Program specification

Input to e computation program: Integer n, where $n \geq 0$.
Output from e computation program: $1/0! + 1/1! + \ldots + 1/n!$

  - Evaluate ‘e’ up to the first (n+1) terms in its expansion
- Observation and planning
  - Sum
    - Need a variable to store sum
    - Summation can be written in a loop; i-th iteration computes i-th term
  - Terms
    - Each term involves a factorial, e.g., i!
    - Need a variable to store each term
    - Computing t! reuses work done to compute (i-1)!, i.e., i! = (i-1)! * i

Program Design

- Plan program structure

```
main_program{
  int n; cin >> n;
  int i = ...;                          // we fill in the blanks later.
  double result = ..., term = ...;

  repeat(n){
    // Need code to calculate 1/0!+1/1!+...+1/t! in the tth iteration.
    // At the beginning of the tth iteration
    // i = t, term = 1/(t-1)!, result = 1/0!+1/1!+...+1/(t-1)!
  }
  cout << result << endl;
}
```

Program Design

- Write the program

```
main_program{
  int n; cin >> n;      // the last term to be added is 1/n!

  int i=1;              // counts iterations of the loop
  double term = 1.0;    // for holding terms of the series
  double result = 1.0; // Will contain the final answer

  repeat(n){ // Plan: When entering for the tth time, t = 1,2,..,n
             // i = t, term = 1/(t-1)!, result = 1/0!+...+1/(t-1)!
    result = result + term/i;
    term = term/i;
    i = i + 1;
  }
  cout << result << endl;
}
```

Program Design

- Test the program
  - Does it compile ? Are there compilation errors ?
    - Syntax errors
  - Does it run without crashing ? Are there run-time errors ?
    - Usually semantic errors
  - Does it run and give the correct output ?
    - Test for various values of n
    - n=0 doesn't run the loop at all
    - n=1 runs the loop once
    - n=2 runs the loop twice (is term in second run reusing term from first run correctly ?)
    - …
  - Use cout statements profusely during testing; even put them inside loop
  - Comparing against "ground truth"
    - See if we get close to actual value of e for large n

Practice Examples for Lab: Set 3

- 1 Write a program to approximately compute e^x by adding first 15 terms of the series

$$e^x = \frac{x^0}{0!} + \frac{x^1}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

Whenever getting a wrong result, use Variable Initialisation.

- 2 Write a program that computes the value of an nth degree polynomial $A(x) = a_0 + a_1x + a_2x^2 + \dots + a_nx^n$. Assume that you are given n then the value x, and then the coefficients $a_0, a_1, \dots, a_n$.
- 3 Evaluate the polynomial, but this time assume that you are given the coefficients in the order $a_n, a_{n-1}, \dots, a_0$.
- 4 Write a program to compute the value of

$$D(r) = \sum_{k=0}^{r} (-1)^k \frac{r!}{k!}$$

Practice Examples for Lab: Set 3

- 5) Which of the following programs correctly approximates value of ‘e’?

```
main_program{
  int n, fac=1, i=2;
  double e=1.0;
  cin >> n;

  repeat(n){
    e = e + 1.0/fac;
    fac = fac * i;
    i = i + 1;
  }
  cout << e << endl;
}
```

```
main_program{
  int n, fac=1, i=1;
  double e=1.0;
  cin >> n;

  repeat(n){
    e = e + 1.0/fac;
    fac = fac * i;
    i = i + 1;
  }
  cout << e <<
}
```

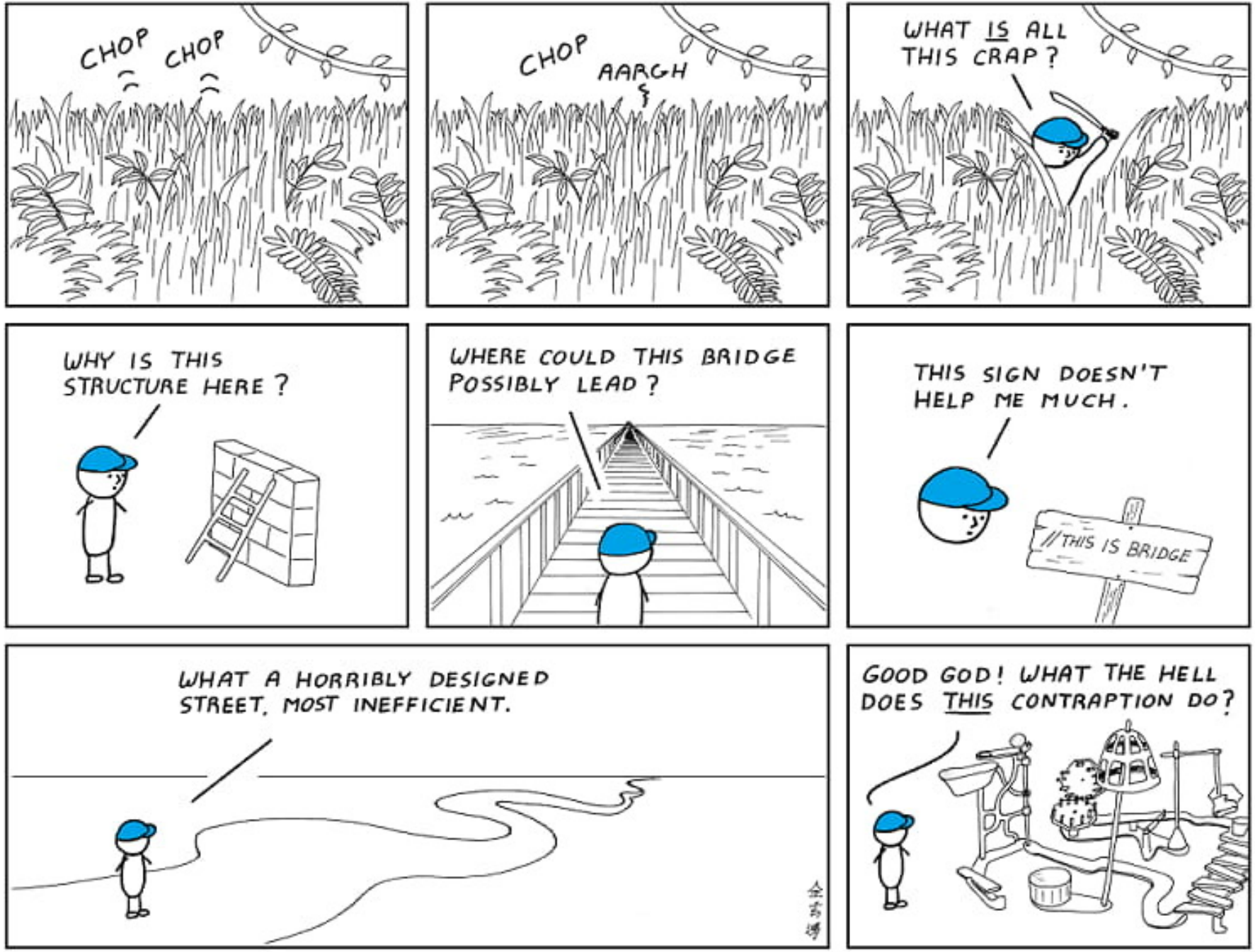
- 6) Write a program to approximately compute sin(x) using its series:

$$\sin x = \sum_{n=0}^{\infty} (-1)^n \frac{x^{2n+1}}{(2n+1)!}$$

$$= x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots$$

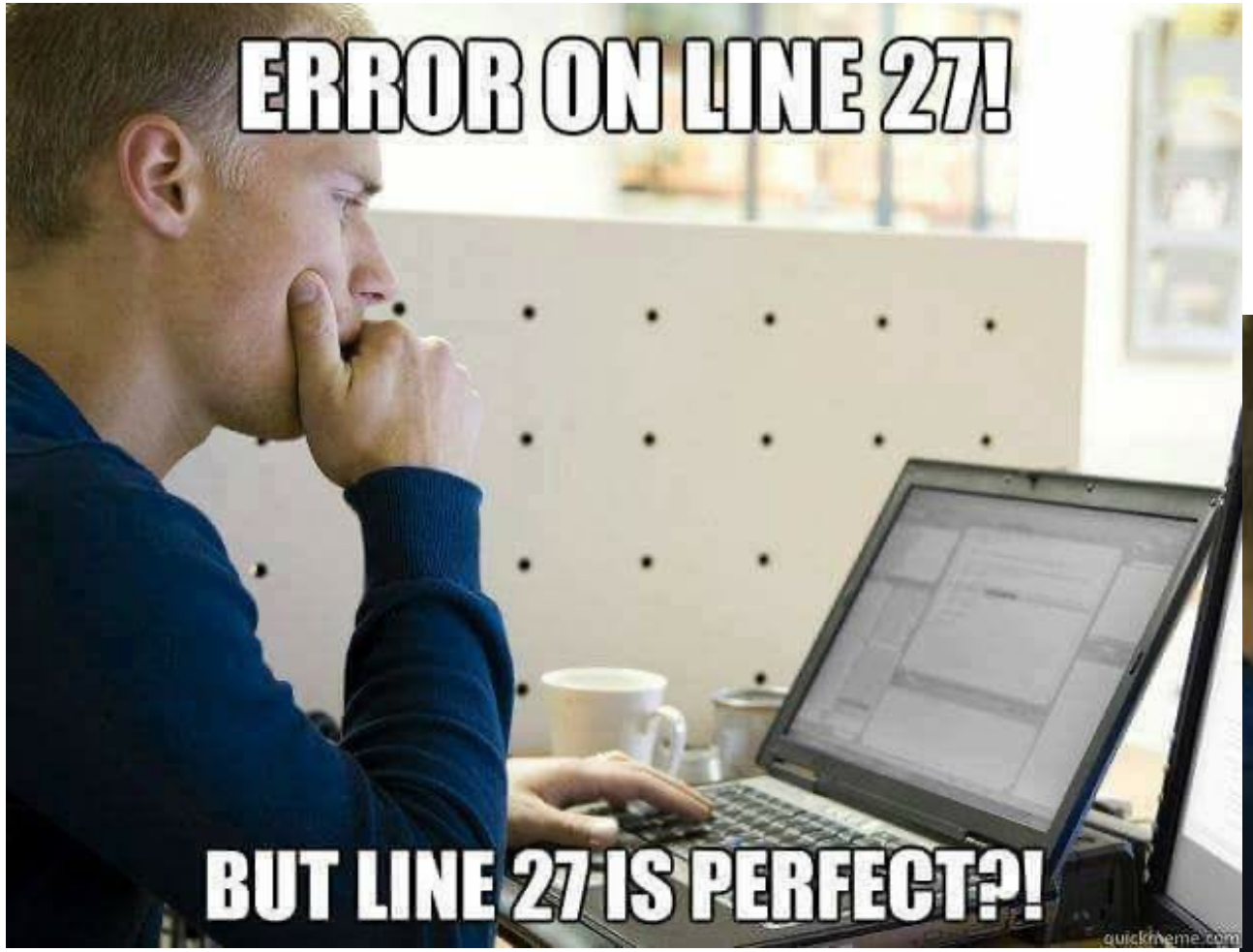
valid for all $x \in \mathbb{R}$.

Program Design



I hate reading other people's code.

Debugging

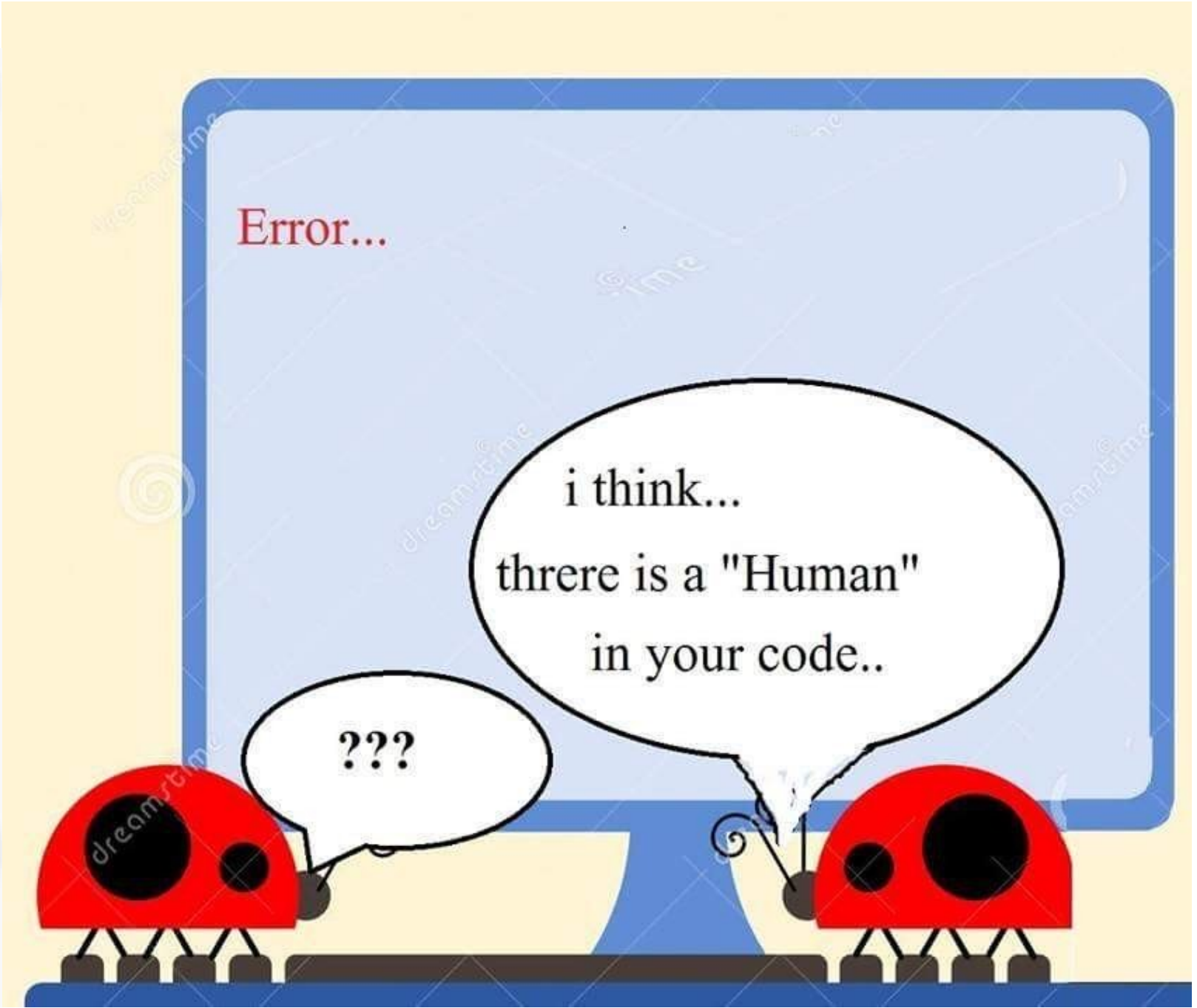

ERROR ON LINE 27!
BUT LINE 27 IS PERFECT?!


Hit Compile. 1 Error. Fix it.
Hit compile again. 927234 errors.

Debugging

6 STAGES OF DEBUGGING

1. That can't happen.
2. That doesn't happen on my machine.
3. That shouldn't happen.
4. Why does that happen?
5. Oh, I see.
6. How did that ever work?

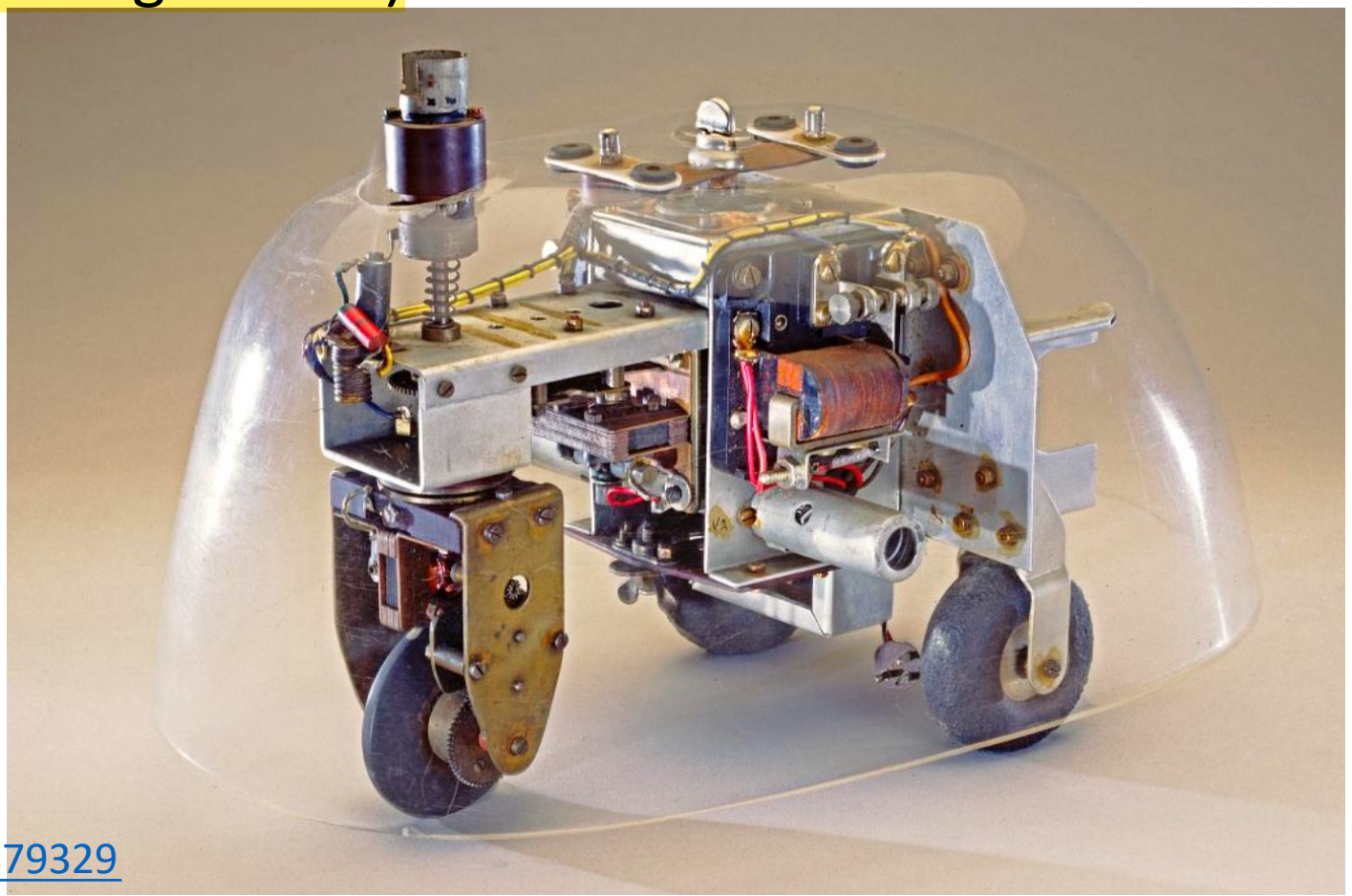


SimpleCPP Graphics

- Let the art begin
- initCanvas()
  - Opens a window, without a turtle
    - Can create a turtle later, if we want
  - Getting the size of canvas: canvas_width(), canvas_height()
  - initCanvas (windowNameString, width, height)
- Canvas coordinates
  - Origin at top left
  - X coordinates increase towards right
  - Y coordinates increase towards bottom
- closeCanvas()
  - removes the window

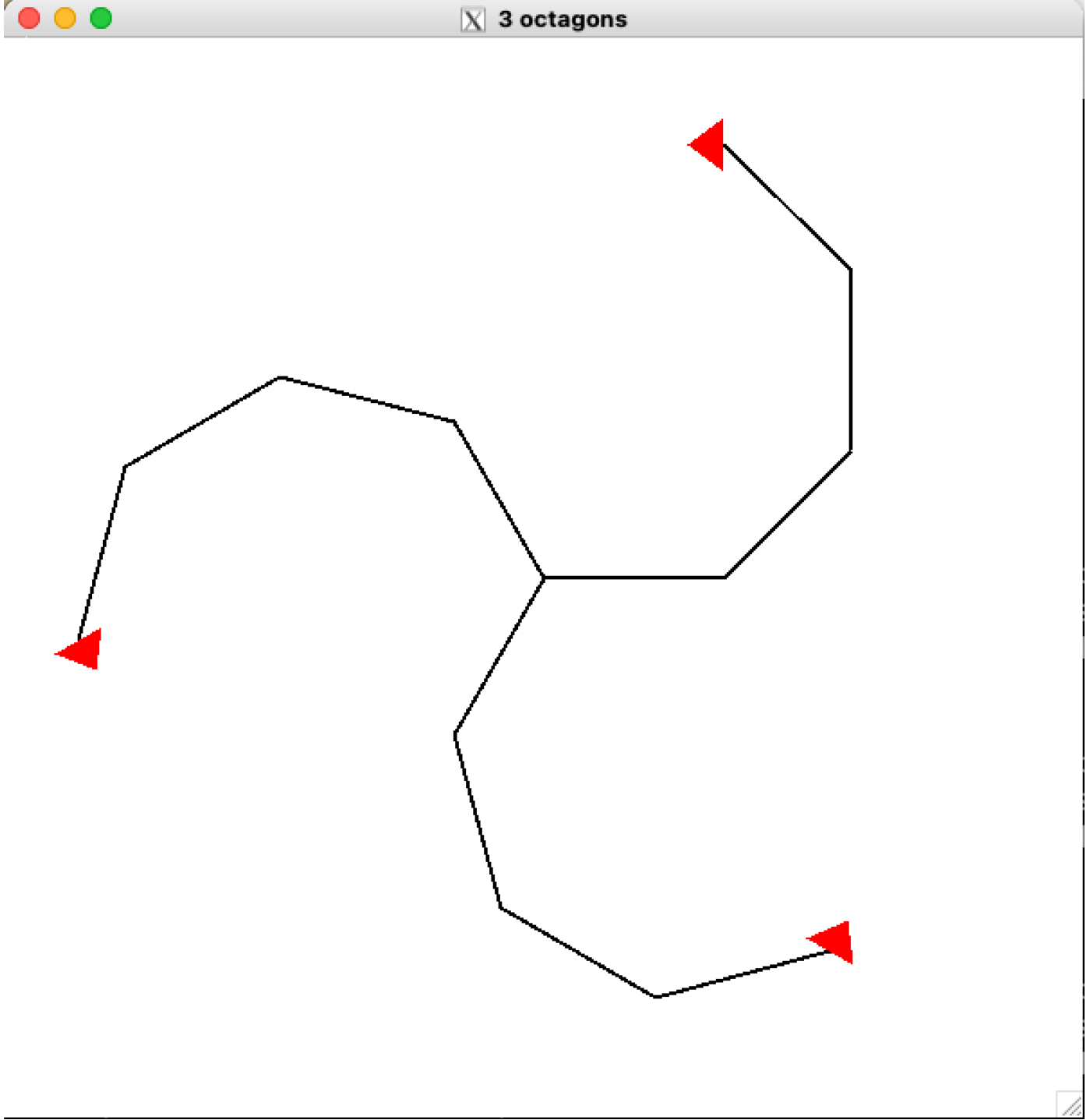
SimpleCPP Graphics

- Multiple turtles !
  - Turtle turtle1, turtle2, turtle3;
  - To command a specific turtle (say, turtle1) use: turtle1.commandName (commandArguments)
    - e.g., turtle1.forward (100);
    - e.g., turtle1.right (90);



americanhistory.si.edu/collections/search/object/nmah_879329

```cpp
#include <simplecpp>

main_program
{
  initCanvas ("3 octagons", 600, 600);

  // create 3 turtles to draw 3 octagons
  Turtle t1, t2, t3;
  // orient each turtle/octagon differently
  t1.left (0);
  t2.left (120);
  t3.left (240);

  repeat (8) // draw octagons
    {
      // draw a side of each of the 3 octagons
      t1.forward (100);
      t2.forward (100);
      t3.forward (100);

      // turn
      t1.left (360 / 8);
      t2.left (360 / 8);
      t3.left (360 / 8);

      // wait for click
      getClick();
    }
}
```



```cpp
#include <simplecpp>

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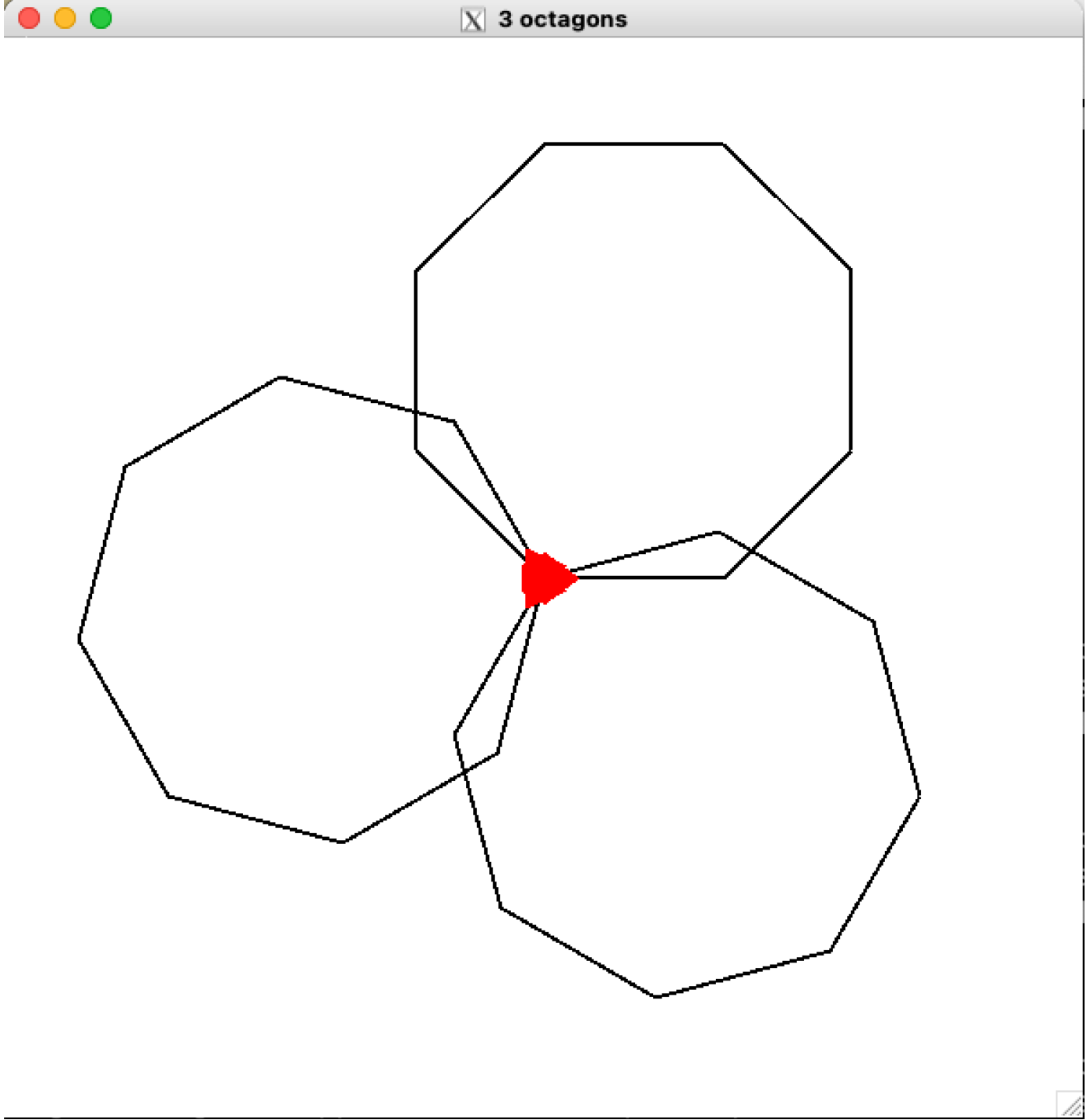
  initCanvas ("3 octagons", 600, 600);

  // create 3 turtles to draw 3 octagons
  Turtle t1, t2, t3;
  // orient each turtle/octagon differently
  t1.left (0);
  t2.left (120);
  t3.left (240);

  repeat (8) // draw octagons
    {
      // draw a side of each of the 3 octagons
      t1.forward (100);
      t2.forward (100);
      t3.forward (100);

      // turn
      t1.left (360 / 8);
      t2.left (360 / 8);
      t3.left (360 / 8);

      // wait for click
      getClick();
    }
}
```



SimpleCPP Graphics

- Other shapes
  - Circle circleName (centerCoordinateX, centerCoordinateY, radius);
    - e.g., Circle c1 (10, 10, 100);
    - All arguments of type double
  - Rectangle rectangleName (centerX, centerY, width, height);
    - e.g., Rectangle r1 (0, 0, 100, 200);
  - Line lineName (lineStartX, lineStartY, lineEndX, lineEndY);
    - e.g., Line l1 (0, 0, 100, 200);
  - Text textName (centerX, centerY, messageString);
    - e.g., Text t1 (10, 20, “Hello C++”)
    - textWidth (“Hello C++”), textHeight (“Hello C++”) gets width and height of text
    - ```
      Text t(100,100,"C++ g++");
      Rectangle R(100,100,textWidth("C++ g++"),textHeight());
      ```
      ```

SimpleCPP Graphics

- Commands allowed on a shape (say, s)

```
s.moveTo(x,y);
s.move(dx,dy);
```

where the former moves the shape to coordinates `(x,y)` on the screen, and the latter displaces the shapes by `(dx,dy)` from its current position.

```
s.scale(relfactor);
s.setScale(factor);
```

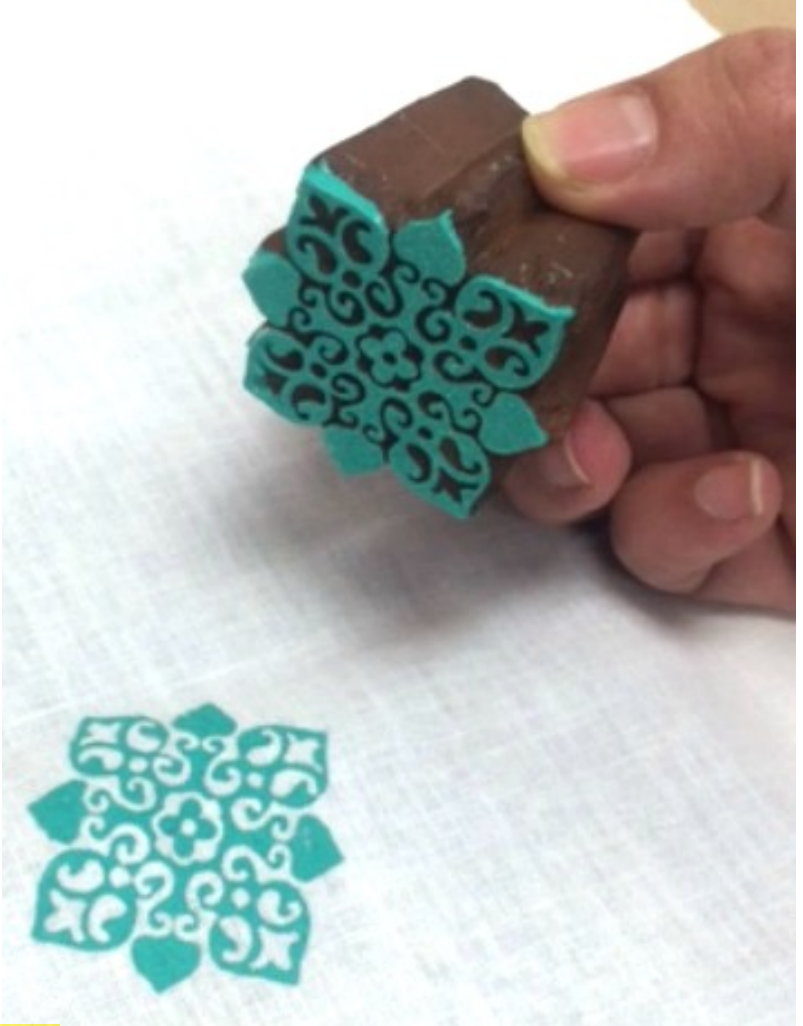
Here `relfactor, factor` are expected to be `double`. The first version multiplies the current scale factor by the specified `relfactor`, the second version sets the scale factor to `factor`.

SimpleCPP Graphics

- Commands allowed on a shape (say, s)
  - s.setFill (booleanVar)
    - Does not apply to line shapes
  - s.setColor (color)
    - Color argument can be “red” or COLOR(redVal, greenValue, blueValue)
  - s.hide()
  - s.show()
  - s.rotate(angle)
    - Angle should be in radians, measured clockwise
- Getting information about a shape
  - s.getX(), s.getY()
  - s.getScale() – returns scale factor
  - s.getOrientation() – returns angle

SimpleCPP Graphics

- Imprinting shapes on to canvas
  - s.imprint()
- Drawling lines without creating a line shape
  - imprintLine (lineStartX, lineStartY, lineEndX, lineEndY, color);
  - imprintLine (lineStartX, lineStartY, lineEndX, lineEndY);
    - Default color is black
- Resetting a shape
  - s.reset(arguments same as those used during creation)



SimpleCPP Graphics

- Clicks from the canvas
  - getClick() waits for the user to click at some coordinate on the canvas;
  - When user clicks at location (x,y), then getClick() returns integer v=65536*x+y
  - (x,y) can be recovered from v as: $x = \lfloor v/65536 \rfloor, \qquad y = v \bmod 65536$
  - Note:
    v is a 32-bit integer.
    2^{16} = 65536.
    Assuming coordinates x,y << 65536; so 16-bits is enough to store them.
    So, 65536*x is a number that has all zeros in least-significant 16 bits.
    So, x gets stored in most-significant 16 bits
    and y gets stored in least-significant 16 bits.

SimpleCPP Graphic

- Shooting a projectile on canvas using shapes and getClick()

```
#include <simplecpp>

main_program{
  initCanvas("Projectile motion", 500,500);

  int start = getClick();

  Circle projectile(start /65536, start % 65536, 5);
  projectile.penDown();

  double vx=1,vy=-5, gravity=0.1;

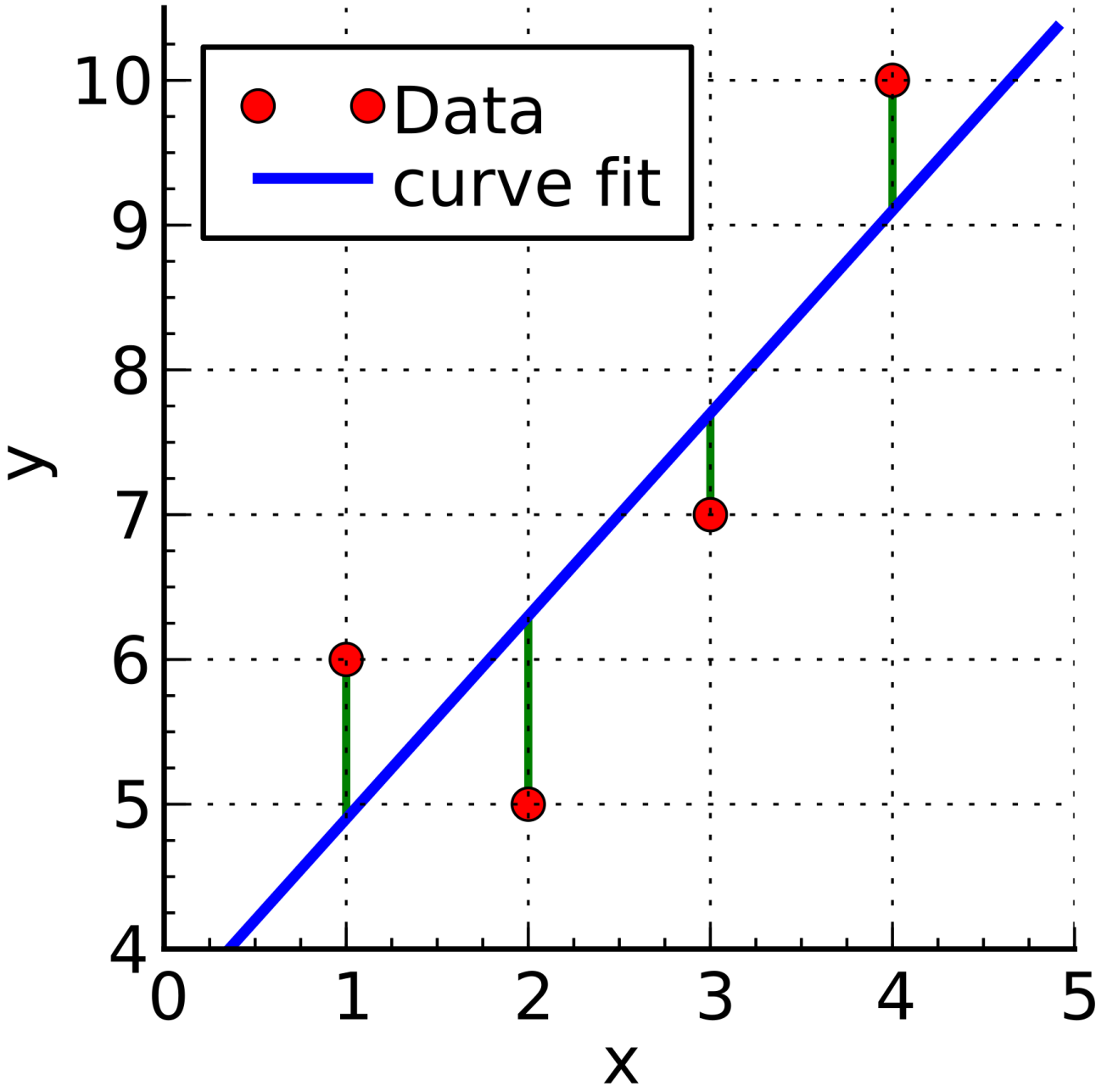
  repeat(100){
    projectile.move(vx,vy);
    vy += gravity;
    wait(0.1);
  }
  wait(10);
}
```

Line Fitting (Linear Regression)

- Data: $(x_1,y_1), (x_2,y_2), \ldots, (x_n,y_n)$
- Find line: $y = mx + c$
- Define quality of fit as negative sum of squared vertical distances
- Find line maximizing quality of fit

$$\min \sum_{i=1}^{n} (y_i - mx_i - c)^2$$

  - Minimize over variables m and c
- Differentiate w.r.t. m and c, assign derivatives to zero, solve 2 equations in 2 unknowns



Line Fitting (Linear Regression)

- Differentiate w.r.t. m and c, assign derivatives to zero, solve 2 equations in 2 unknowns

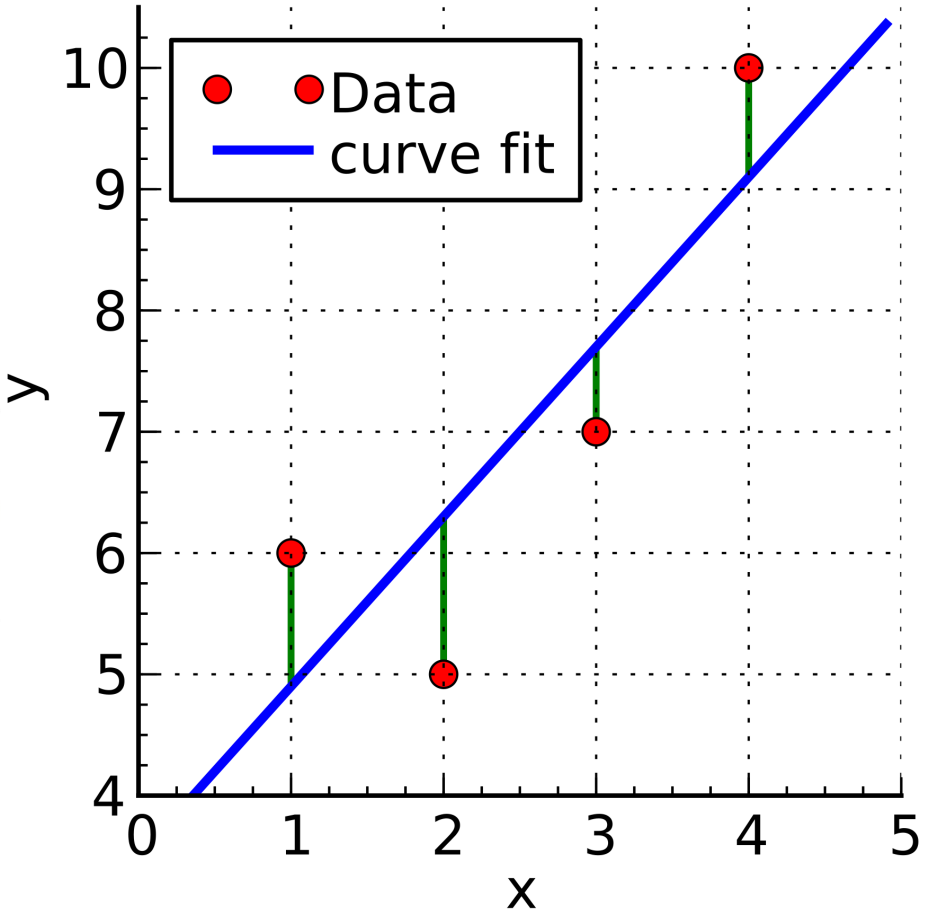
$$0 = \frac{\partial}{\partial m}\sum_{i=1}^{n}(y_i - mx_i - c)^2 = -2\sum_{i=1}^{n} x_i(y_i - mx_i - c)$$

$$m\sum_i x_i^2 + c\sum_i x_i = \sum_i x_i y_i$$

$$0 = \frac{\partial}{\partial c}\sum_{i=1}^{n}(y_i - mx_i - c)^2 = -2\sum_{i=1}^{n}(y_i - mx_i - c)$$

$$m\sum_i x_i + nc = \sum_i y_i$$

$p = \sum_i x_i^2,\ q = \sum_i x_i,\ r = \sum_i x_i y_i,$ and $s = \sum_i y_i$



$$m = \frac{nr - qs}{np - q^2} \qquad c = \frac{ps - qr}{np - q^2}$$

```
#include <simplecpp>

main_program
{
  cout << "Number of data points: ";
  unsigned int n; cin >> n;

  initCanvas ("Line Fitting", 600, 600);

  Circle shapeCircle(0,0,0); // to show the data on the canvas

  double p = 0, q = 0, r = 0, s = 0; // internal variables

  repeat (n) // get data, computer internal variables
  {
    // get the datum coordinates
    const int codedLocation = getClick();
    const double x = codedLocation / 65536;
    const double y = codedLocation % 65536;

    // plot the datum
    shapeCircle.reset (x, y, 5);
    shapeCircle.imprint ();

    p += x*x;
    q += x;
    r += x*y;
    s += y;
  }

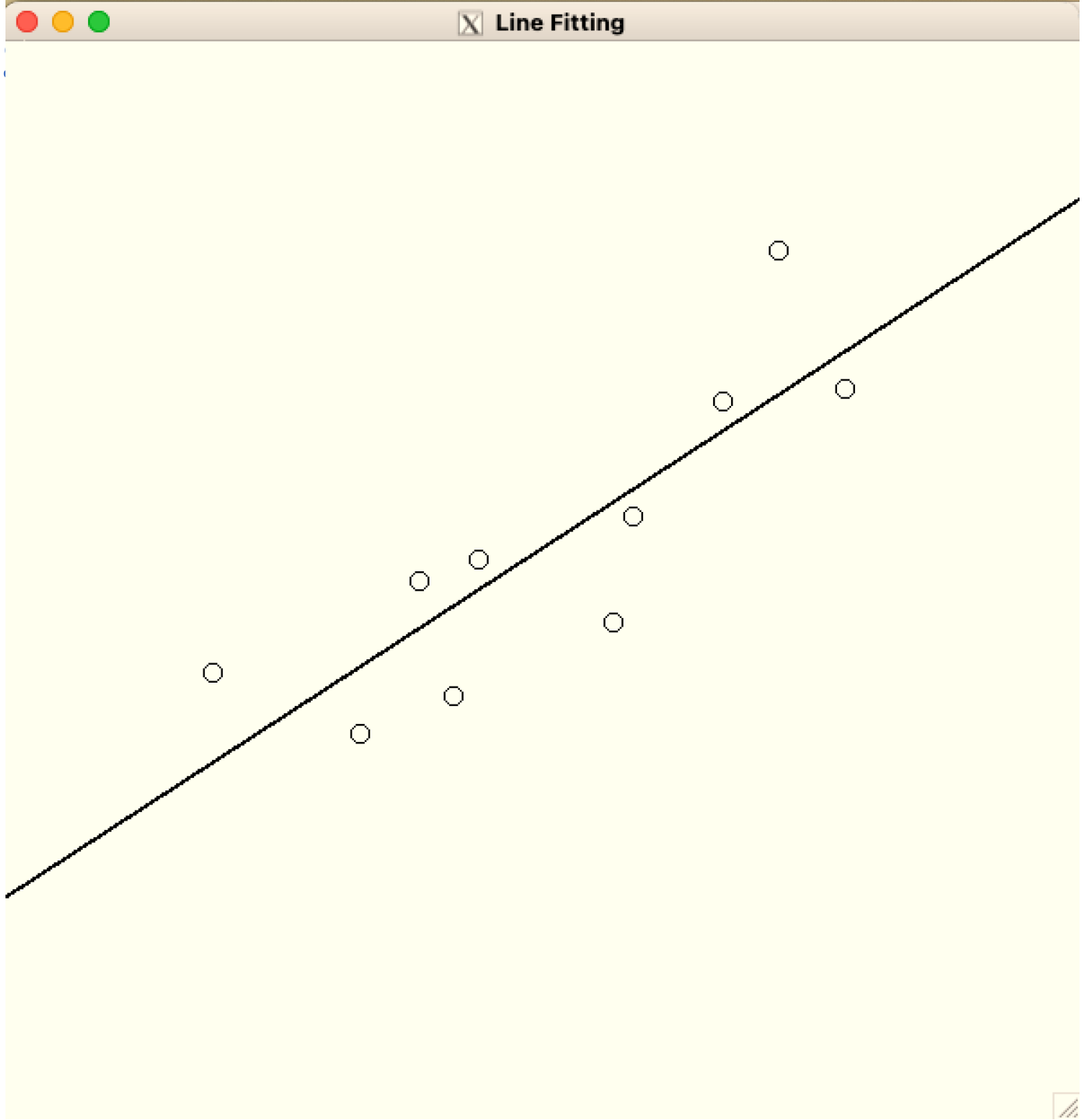
  // find the best-fit line
  const double lineSlope     = (n*r - q*s) / (n*p - q*q);
  const double lineIntercept = (p*s - q*r) / (n*p - q*q);

  // plot the best-fit line
  Line fittedLine (0, lineIntercept, 600, 600 * lineSlope + lineIntercept);

  getClick();
}
```

Line Fitting (Linear Regres

- Program run with input as 10 datapoints



Pseudocode

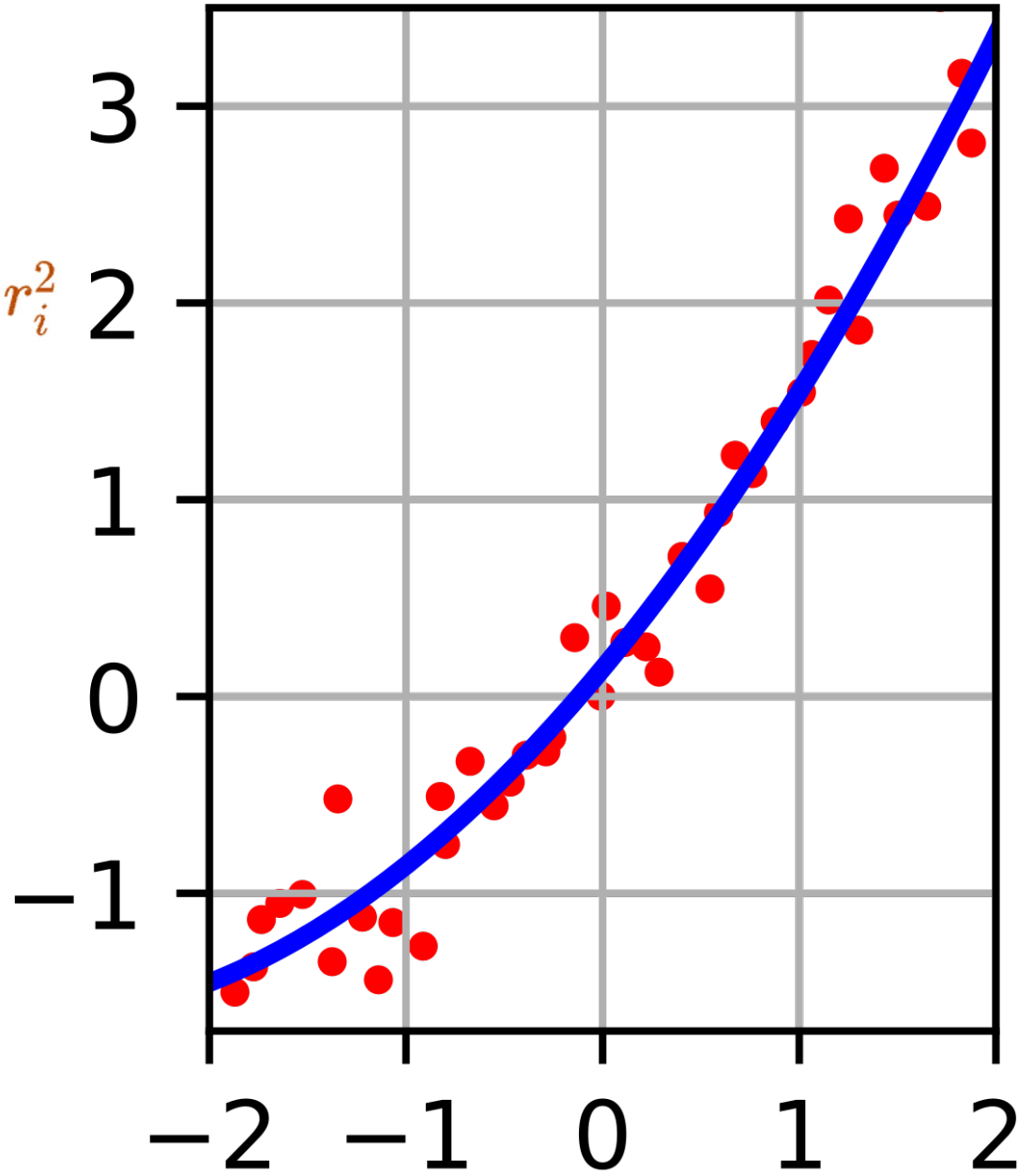
- Definition: Plain-language description of the steps in an algorithm
- Often uses structural conventions of a normal programming language, but is intended for human reading rather than machine reading
  - Uses natural language; uses compact mathematical notation
  - Omits details essential for machine understanding of algorithm, e.g., variable definitions and language-specific code
- Pseudocode is subjective; a standard doesn't exist
- Example
  - Set sum = 0
    Repeat 5 times
      Get number
      sum = sum + number^2
    Print sum

Regression

- Statistical analysis
- Method of Least Squares
  - Minimize sum of squared errors $S = \sum_{i=1}^{n} r_i^2$
    - Error between value predicted by model and datum

$$r_i = y_i - f(x_i, \boldsymbol{\beta})$$

  - Described by Legendre in 1805
  - Described by Gauss in 1809 (or 1795)
    - Used in astronomy



Practice Examples for Lab: Set 4

- 1

Plot the graph of $y = \sin(x)$ for x ranging in the interval 0 to 4π. Draw the axes and mark the axes at appropriate points, e.g. multiples of $\pi/2$ for the x axis, and multiples of 0.25 for the y axis.

- 2

Draw an 8×8 chessboard having red and blue squares. Hint: Use the `imprint` command. Use the repeat statement properly so that your program is compact.

- 3

Modify the projectile motion program so that the velocity is given by a second click. The projectile should start from the first click, and its initial velocity should be in the direction of the second click (relative to the first). Also the velocity should be taken to be proportional to the distance between the two clicks.

- 4

Write a program that accepts 3 points on the canvas (given by clicking) and then draws a circle through those 3 points.

Practice Examples for Lab: Set 4

- 5

In this problem you are to determine how light reflects off a perfectly reflecting spherical surface. Suppose the sphere has radius r and is centered at some point (x, y). Suppose there is a light source at a point (x', y). Rays will emerge from the source and bounce off the sphere. As you may know, the reflected ray will make an angle to the radius at the point of contact equal to that made by the incident ray. Write a program which traces many such rays. It should take r, x, y, x' as input. Of course, in the plane the sphere will appear as a circle.

- 6

This is an extension to the previous problem. Extend the reflected rays backward till they meet the line joining the circle center and light source. The points where the rays meet this line can be said to be the image of the light source in the mirror; as you will see this will not be a single point, but the image will be diffused. This is the so called spherical aberration in a circular mirror.