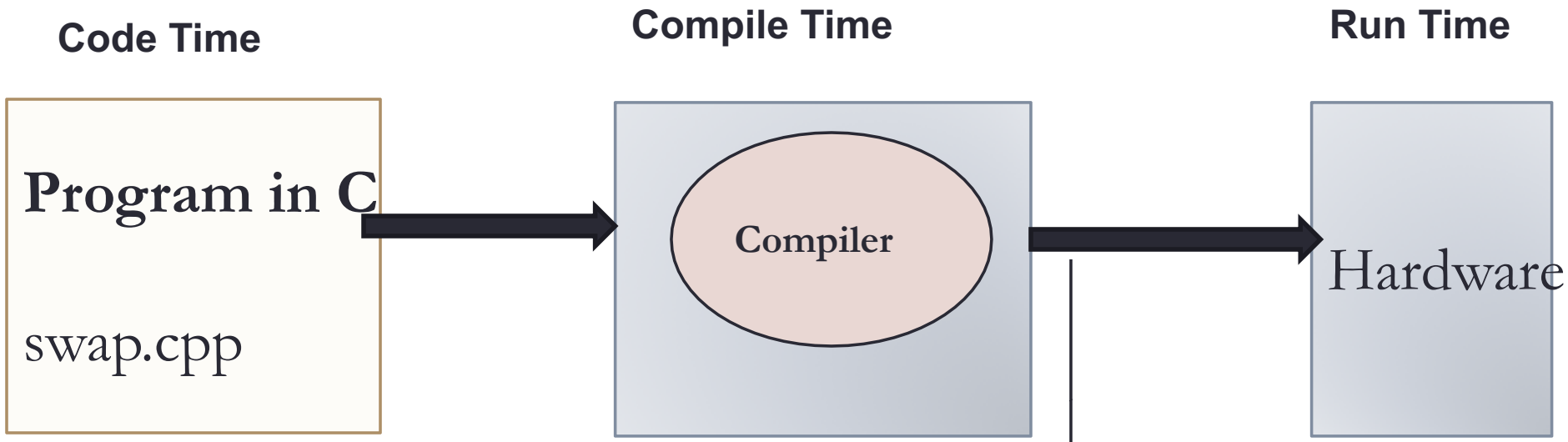
# COMPILATION REVISITED
# DATA REPRESENTATION

Problem Solving with Computers-I


# Demo

- Basics of code compilation in C++ (review)
- Makefiles (used to automate compilation of medium to large projects) consisting of many files
- We will start by using a makefile to compile just a single program
- Extend to the case where your program is split between multiple files
- By the end of this you should know what each of the following are and how they are used in program compilation
  - Header file (.h)
  - Source file (.cpp)
  - Object file (.o)
  - Executable
  - Makefile
  - Compile-time errors
  - Link-time errors

# Steps in program translation



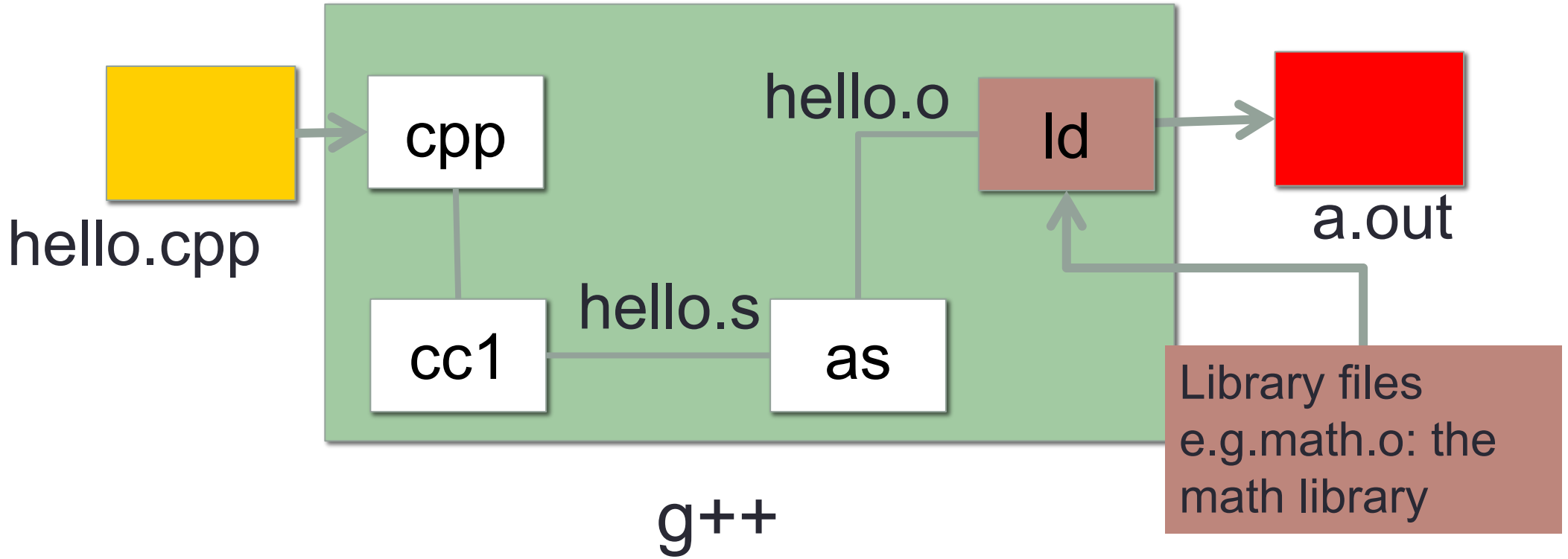

**Program:**
Text file stored on computers hard disk or some secondary storage

**Executable:**
Program in machine code
+Data in binary

```
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
```

# g++ is composed of a number of smaller programs

- Code written by others (libraries) can be included
- ld (linkage editor) merges one or more object files with the relevant libraries to produce a single executable



# Steps in gcc

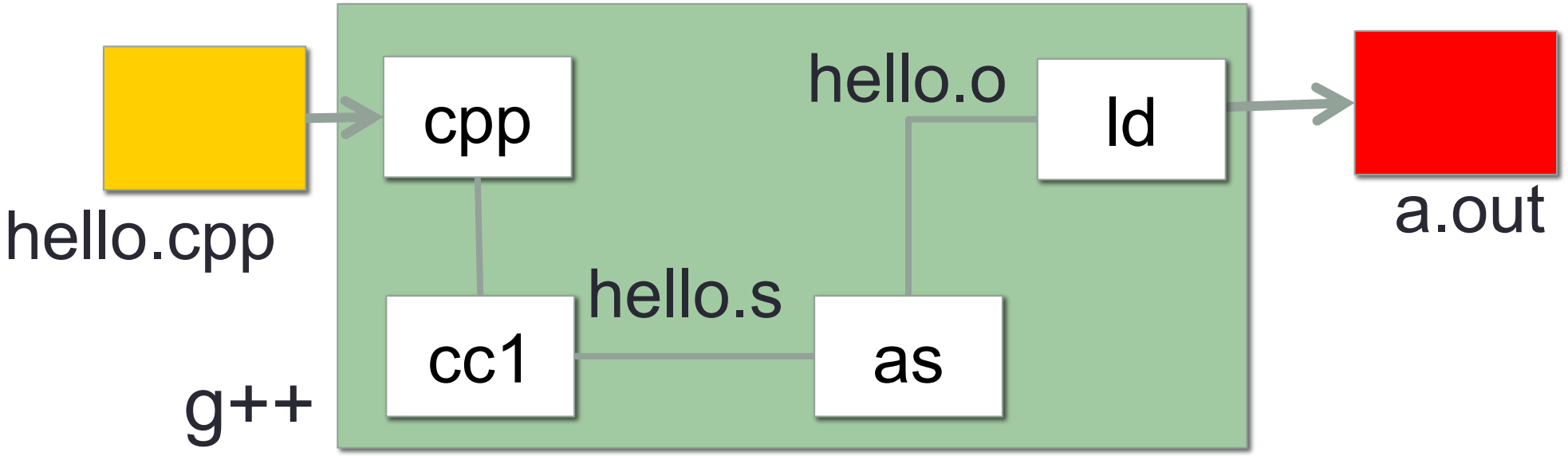
- Ask compiler to show temporary files:

$ g++ –S hello.cpp

$ g++ –c hello.o

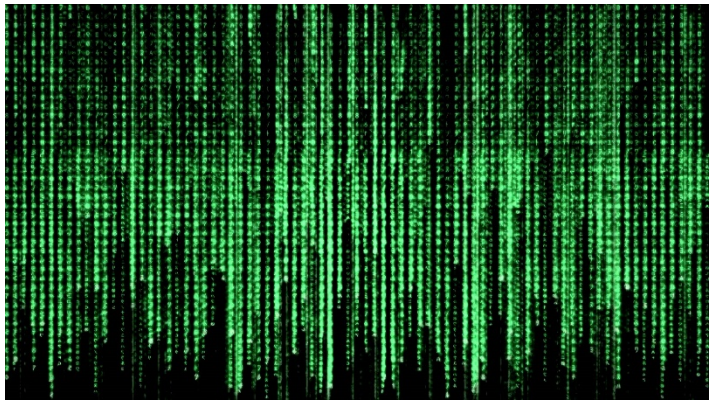
$ g++ –o hello hello.cpp

$ g++ functions.o main.o –o myhello



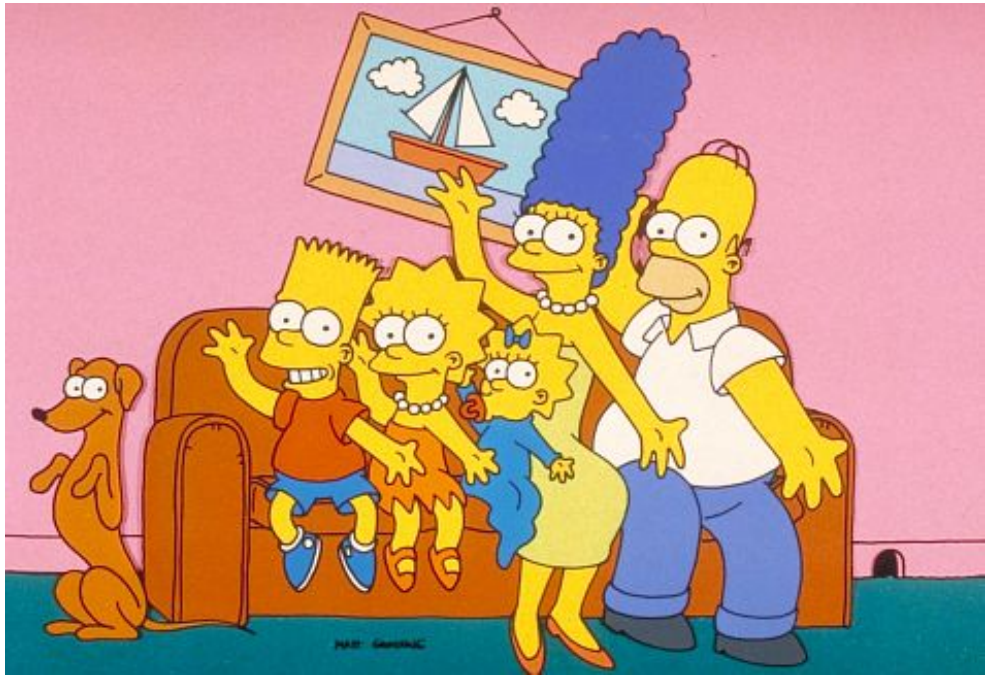
# What does ‘data’ on a computer look like?

- Imagine diving deep into a computer
- Expect to see all your data as high and low voltages
- In CS we use the abstraction:
  - High voltage: 1 (true)
  - Low voltage: 0 (false)



# Decimal (base ten)

- Why do we count in base ten?
- Which base would the Simpson's use?



# External vs. Internal Representation

- External representation:
  - Convenient for programmer

- Internal representation:
  - Actual representation of data in the computer's memory and registers: Always binary (1's and 0's)

# Positional encoding for non-negative numbers

- Each position represents some power of the base

Why is each base important??

# $101_5$ = ? In decimal

A. 26

B. 51

C. 126

D. 130

# Binary representation (base 2)

- On a computer all data is stored in binary
- Only two symbols: 0 and 1
- Each position is called a *bit*
- *Bits take up space*
- 8 bits make a *byte*
- *Example of a 4-bit number*

# Converting between binary and decimal

Binary to decimal: $1\ 0\ 1\ 1\ 0_2 = ?_{10}$

Decimal to binary: $34_{10} = ?_2$

# Hex to binary

- Each hex digit corresponds directly to four binary digits
- Programmers love hex, why?

$25B_{16}$ = ? In binary

| | | |
|---|---|---|
| 00 | 0 | 0000 |
| 01 | 1 | 0001 |
| 02 | 2 | 0010 |
| 03 | 3 | 0011 |
| 04 | 4 | 0100 |
| 05 | 5 | 0101 |
| 06 | 6 | 0110 |
| 07 | 7 | 0111 |
| 08 | 8 | 1000 |
| 09 | 9 | 1001 |
| 10 | A | 1010 |
| 11 | B | 1011 |
| 12 | C | 1100 |
| 13 | D | 1101 |
| 14 | E | 1110 |
| 15 | F | 1111 |

# Hexadecimal to decimal

$25B_{16}$ = ? Decimal

# Hexadecimal to decimal

- Use polynomial expansion

- $25B_{16} = 2*256 + 5*16 + 11*1 = 512 + 80 + 11$
  $= 603$

- Decimal to hex: $36_{10}=?_{16}$

# Binary to hex: 1000111100

A. 8F0

B. 23C

C. None of the above

# BIG IDEA: Bits can represent anything!!

| Numbers | Binary Code |
| --- | --- |
| 0 | |
| 1 | |
| 2 | |
| 3 | |

How many (minimum) bits are required to represent the numbers 0 to 3?

# BIG IDEA: Bits can represent anything!!

| Colors | Binary code |
| --- | --- |
| Red | |
| Green | |
| Blue | |

How many (minimum) bits are required to represent the three colors?

# BIG IDEA: Bits can represent anything!!

**Characters**

‘a’

‘b’

‘c’

‘d’

‘e’

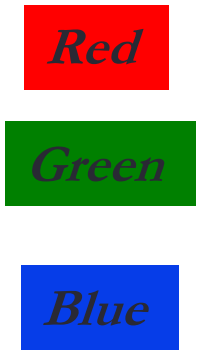
N bits can represent at most $2^N$ things

# What is the minimum number of bits required to represent all the letters in the English alphabet in lower case?

A. 3
B. 4
C. 5
D. 6
E. 26

# BIG IDEA: Bits can represent anything!!

- Logical values?
  - 0 ⇒ False, 1 ⇒ True
- colors ?




- Characters?
  - 26 letters ⇒ 5 bits ($2^5 = 32$)
  - upper/lower case + punctuation
    ⇒ 7 bits (in 8) (“ASCII”)
  - standard code to cover all the world’s languages ⇒ 8,16,32 bits (“Unicode”)
    www.unicode.com
- locations / addresses? commands?

- MEMORIZE: N bits ⇔ at most $2^N$ things

# What is the maximum positive value that can be stored in a byte?

A. 127

B. 128

C. 255

D. 256

# Data types

Binary numbers in memory are stored using a finite, fixed number of bits typically:

- 8 bits (byte)
- 16 bits (half word)
- 32 bits (word)
- 64 bits (double word or quad)

Data type of a variable determines the:

- exact representation of variable in memory
- number of bits used (fixed and finite)
  - range of values that can be correctly represented

# Next time

- Arrays