A Computer Science Tapestry

Exploring Programming and Computer Science with C++
Second Edition

Owen Astrachan
Duke University

McGraw-Hill

Computer Science and Programming

- **Computer Science is more than programming**
  - **The discipline is called *informatics* in many countries**
  - **Elements of both science and engineering**
    - **Scientists build to learn, engineers learn to build**

      – Fred Brooks
  - **Elements of mathematics, physics, cognitive science, music, art, and many other fields**
- **Computer Science is a young discipline**
  - **Fiftieth anniversary in 1997, but closer to forty years of research and development**
  - **First graduate program at CMU (then Carnegie Tech) in 1965**
- **To some programming is an art, to others a science**

What is Computer Science?

What is it that distinguishes it from the separate subjects with which it is related? What is the linking thread which gathers these disparate branches into a single discipline? My answer to these questions is simple --- *it is the art of programming a computer*. It is the art of designing efficient and elegant methods of getting a computer to solve problems, theoretical or practical, small or large, simple or complex.

C.A.R. (Tony)Hoare

Computer Science

- **Artificial Intelligence** thinking machines
- **Scientific Computing** weather, hearts
- **Theoretical CS** analyze algorithms, models
- **Computational Geometry** theory of animation, 3-D models
- **Architecture** hardware-software interface
- **Software Engineering** peopleware
- **Operating Systems** run the machine
- **Graphics** from Windows to Hollywood
- **Many other subdisciplines**

Algorithms as Cornerstone of CS

- **Step-by-step process that solves a problem**
  - **more precise than a recipe**
  - **eventually stops with an answer**
  - **general process rather than specific to a computer or to a programming language**
- **Searching: for phone number of G. Samsa, whose number is 929-9338, or for the person whose number is 489-6569**
- **Sorting: zip codes, hand of cards, exams**
  - **Why do we sort? What are good algorithms for sorting?**
    - **It depends**
      - Number of items sorted, kind of items, number of processors, ??
  - **Do we need a detailed sorting algorithm to play cards?**

Sorting Experiment

- Groups of four people are given a bag containing strips of paper
  - on each piece of paper is an 8-15 letter English word
  - create a sorted list of all the words in the bag
  - there are 100 words in a bag

- What issues arise in developing an algorithm for this sort?
  -
  -
- Can you write a description of an algorithm for others to follow?
  - Do you need a 1-800 support line for your algorithm?
  - Are you confident your algorithm works?

Themes and Concepts of CS

- Theory
  - properties of algorithms, how fast, how much memory
  - average case, worst case: sorting cards, words, exams
  - *provable* properties, in a mathematical sense
- Language
  - programming languages: C++, Java, C, Perl, Fortran, Lisp, Scheme, Visual BASIC, ...
  - Assembly language, machine language,
  - Natural language such as English
- Architecture
  - Main memory, cache memory, disk, USB, SCSI, ...
  - pipeline, multi-processor

Theory, Language, Architecture

- We can prove that in the worst case quicksort is bad
  - doesn't matter what machine it's executed on
  - doesn't matter what language it's coded in
  - unlikely in practice, but worst case always possible
- Solutions? Develop an algorithm that works as fast as quicksort in the average case, but has good worst case performance
  - quicksort invented in 1960
  - introsort (for introspective sort) invented in 1996
- Sometimes live with worst case being bad
  - bad for sorting isn't bad for other algorithms, needs to be quantified using notation studied as part of the theory of algorithms

Abstraction, Complexity, Models

- What is an integer?
  - In mathematics we can define integers easily, infinite set of numbers and operations on the numbers (e.g.,+, -, *, /)

    {…-3, -2, -1, 0, 1, 2, 3, …}
  - In programming, finite memory of computer imposes a limit on the magnitude of integers.
    - Possible to program with effectively infinite integers (as large as computation and memory permit) at the expense of efficiency
    - At some point addition is implemented with hardware, but that's not a concern to those writing software (or is it?)
    - C++ doesn't require specific size for integers, Java does
- Floating-point numbers have an IEEE standard, required because it's more expensive to do arithmetic with 3.14159 than with 2

Alan Turing (1912--1954)

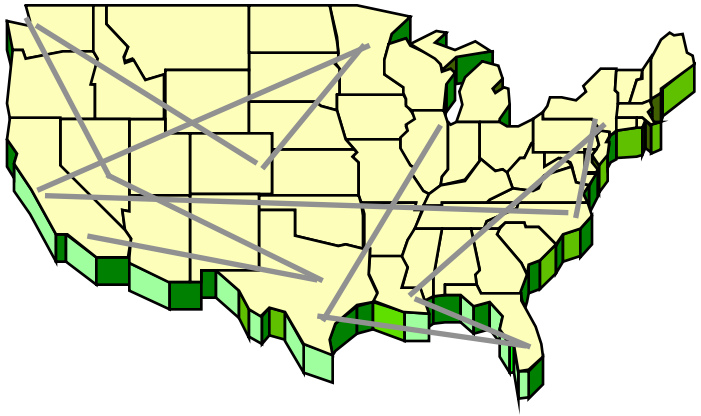
- Instrumental in breaking codes during WW II
- Developed mathematical model of a computer called a Turing Machine (before computers)
  - solves same problems as a Pentium III (more slowly)
- Church-Turing thesis
  - All "computers" can solve the same problems
- Showed there are problems that cannot be solved by a computer
- Both a hero and a scientist/ mathematician, but lived in an era hard for gay people

Search, Efficiency, Complexity

- Think of a number between 1 and 1,000
  - respond high, low, correct, how many guesses needed?
- Look up a word in a dictionary
  - Finding the page, the word, how many words do you look at?
- Looking up a phone number in the Manhattan, NY directory
  - How many names are examined?
- How many times can 1,024 be cut in half?
  - $2^{10} = 1{,}024$, $2^{20} = 1{,}048{,}576$

Complexity: Travelling Salesperson

- Some problems are hard to solve, others seem hard to solve but we can't prove that they're hard (hard means computationally expensive)
- Visit every city exactly once
  - Minimize cost of travel or distance
  - Is there a tour for under $2,000 ? less than 6,000 miles?
- Must phrase question as yes/no, but we can minimize with binary search.
- Is close good enough?

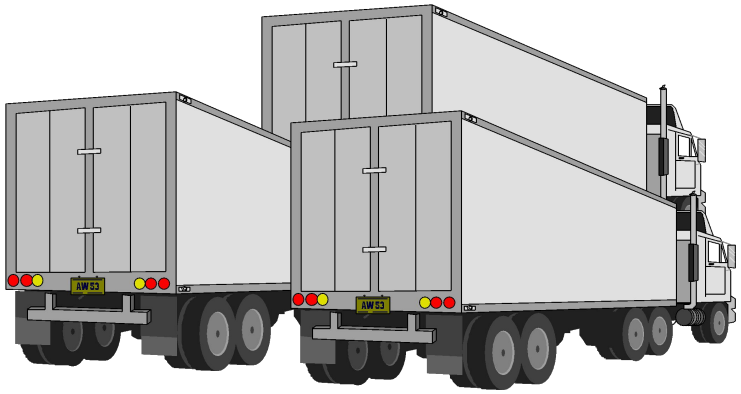


Try all paths, from every starting point -- how long does this take?

a, b, c, d, e, f, g
b, a, c, d, e, f, g ...

Complexity Classifications

- Given a route and a claim: This route hits all cities for less than $2,000
  - *verify* properties of route efficiently.
  - Hard to *find* optimal solution

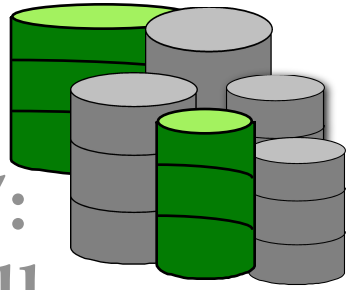


- Verification simple, finding optimal solution is hard

Pack trucks with barrels, use minimal # trucks

- Other problems are similar

Ideas?



Problems are the "same hardness": solve one efficiently, solve them all

Are hard problems easy?

- **P = easy problems, NP = "hard" problems**
  - **P stands for polynomial, like x^2 or x^3**
  - **NP stands for non-deterministic, polynomial**
    - **guess a good solution**

- **Question: P = NP ?**
  - if yes, a whole suite of difficult problems can be solved efficiently
  - if no, none of the hard problems can be solved efficiently

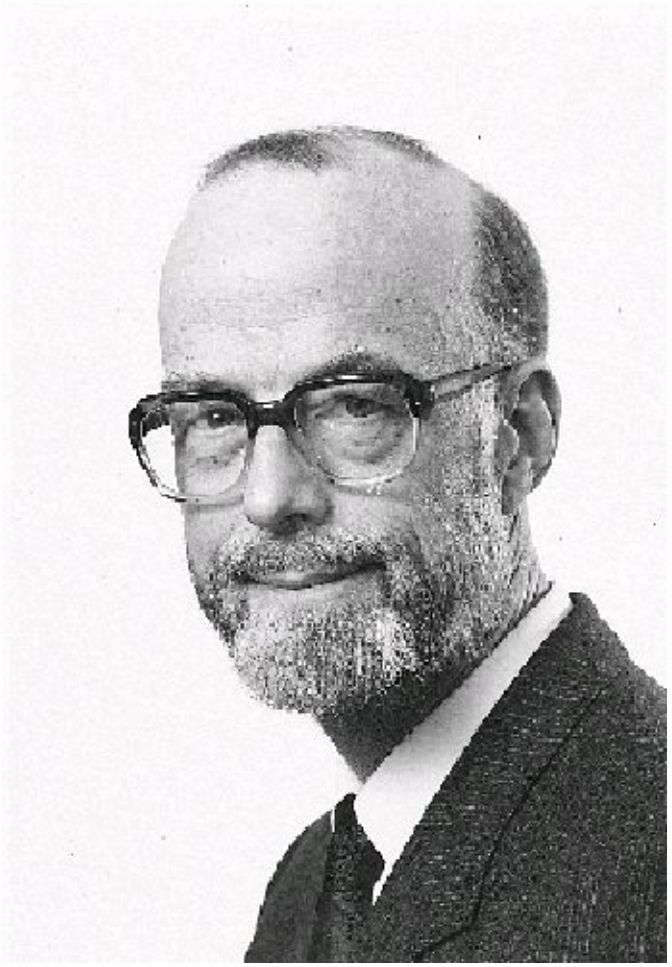
- **Problem posed in 1971, central to the field**

Most computer scientists believe P ≠NP, this is arguably the most important unsolved problem in computer science

C.A.R. (Tony) Hoare (b. 1934)

- Won Turing award in 1980
- Invented quicksort, but didn't see how simple it was to program recursively
- Developed mechanism and theory for concurrent processing
- In Turing Award speech used "Emporer's New Clothes" as metaphor for current fads in programming

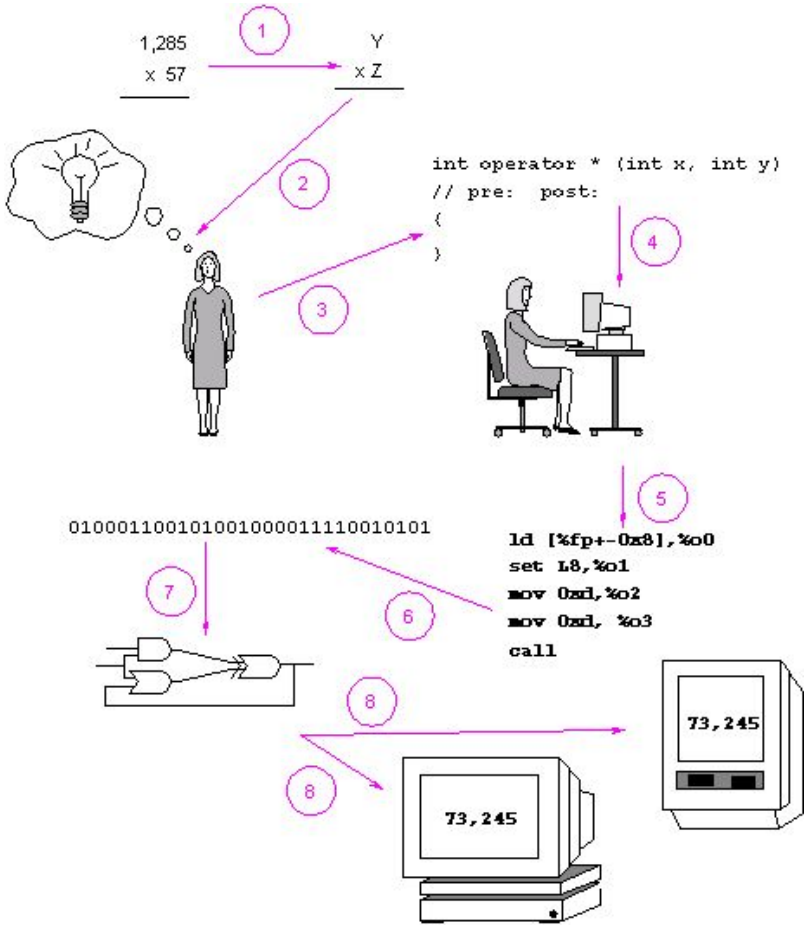
"Beginning students don't know how to do top-down design because they don't know which end is up"



Creating a Program

- Specify the problem
  - remove ambiguities
  - identify constraints
- Develop algorithms, design classes, design software architecture
- Implement program
  - revisit design
  - test, code, debug
  - revisit design
- Documentation, testing, maintenance of program

- From ideas to electrons



From High- to Low-level languages

- C++ is a multi-purpose language, we'll use it largely as an object-oriented language, but not exclusively
  - Contrast, for example, with Java in which everything is a class
  - Contrast with Fortran in which nothing is a class
- Compilers translate C++ to a machine-specific executable program
  - The compiler is a program, input is C++, output is an executable
  - What language is the compiler written in?
  - In theory C++ source code works on any machine given a compiler for the machine
- C++ and other *programming* language are more syntactically rigid than English and other *natural* languages

Levels of Programming Language

- Machine specific assembly language, Sparc on left, Pentium on right, both generated from the same C++

```
main:
        save %sp,-128,%sp
        mov 7,%o0
        st %o0,[%fp-20]
        mov 12,%o0
        st %o0,[%fp-24]
        ld [%fp-20],%o0
        ld [%fp-24],%o1
        call .umul,0
        nop
        st %o0,[%fp-28]
        mov 0,%i0
        b .LL1
        nop
```

```
main:
        pushl %ebp
        movl %esp,%ebp
        subl $12,%esp
        movl $7,-4(%ebp)
        movl $12,-8(%ebp)
        movl -4(%ebp),%eax
        imull -8(%ebp),%eax
        movl %eax,-12(%ebp)
        xorl %eax,%eax
        jmp .L1
        .align 4
        xorl %eax,%eax
        jmp .L1
```

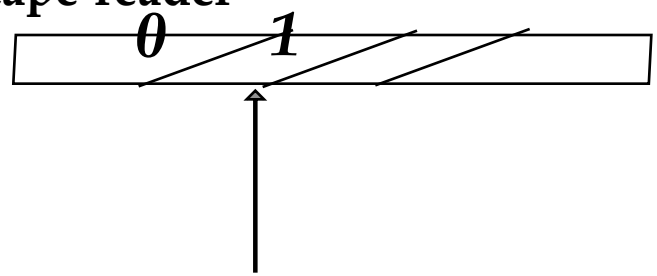
Alternatives to compilation

- Some languages are *interpreted,* Scheme and Java are examples
  - like simultaneous translation instead of translation of written document. The same word may be translated many times
  - The interpreter is a program that translates one part of a source code at a time
    - The interpreter is machine specific, written in some programming language
- JVM, the Java Virtual Machine
  - Like a PC or Mac but machine is virtual, written in software
  - Executes Java byte codes which are created from Java source
    - Like assembly language: between source code and executable
  - JVM must be written for each architecture, e.g., Linux, Windows, Mac, BeOS, ...

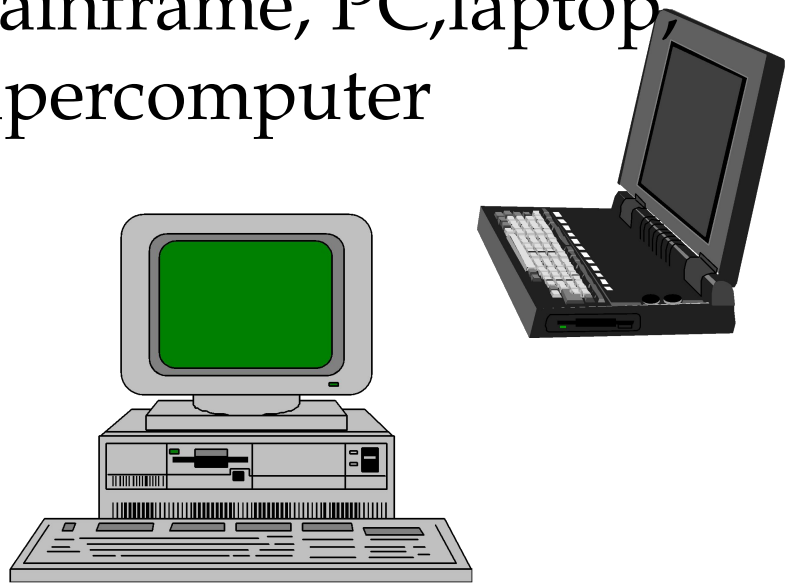
What is a computer?

- **Turing machine: invented by Alan Turing in 1936 as a theoretical model**

infinite tape, moving tape-reader



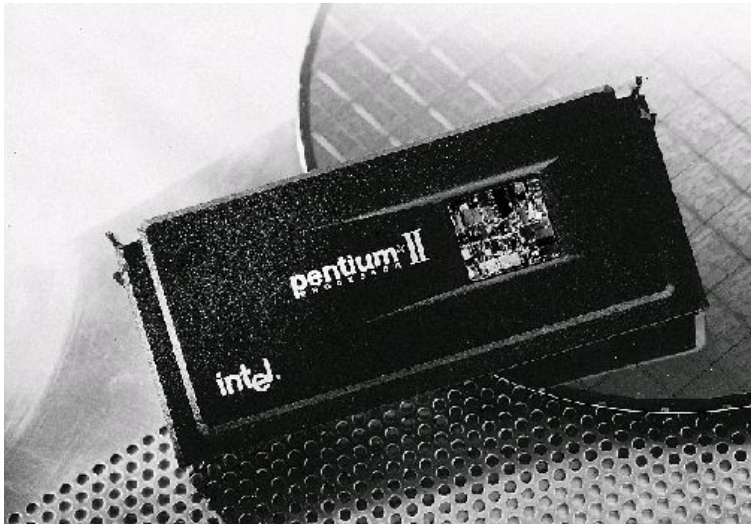
Mainframe, PC,laptop, supercomputer

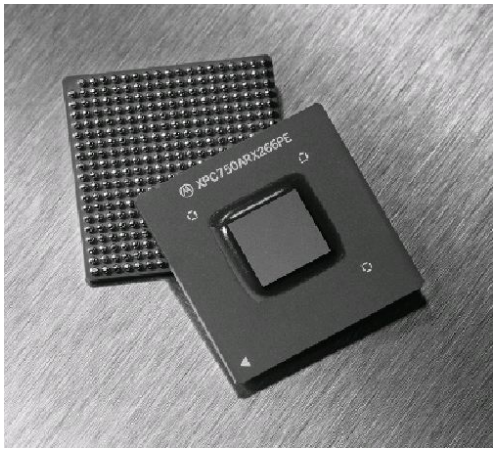


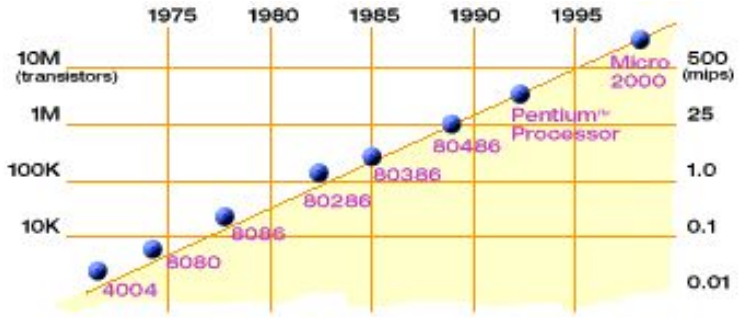
A computer is a computer, is a computer, Church-Turing Thesis, all have same "power"

Chips, Central Processing Unit (CPU)

- CPU chips
  - Pentium (top)
  - G3 (bottom)
  - Sound, video, …
- Moore's Law
  - chip "size" (# transistors) doubles every 12--18 months (formulated in 1965)
  - 2,300 transistors Intel 4004, 7.5 million Intel Pentium II







Why is programming fun?

What delights may its practitioner expect as a reward?

First is the sheer joy of making things

Second is the pleasure of making things that are useful

Third is the fascination of fashioning complex puzzle-like objects of interlocking moving parts

Fourth is the joy of always learning

Finally, there is the delight of working in such a tractable medium. The programmer, like the poet, works only slightly removed from pure thought-stuff.

Fred Brooks