CPS 06
Program Design and Methodology I

Owen Astrachan

Susan Rodger

http://www.cs.duke.edu/courses/cps006/current

http://www.cs.duke.edu/csed/tapestry

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)

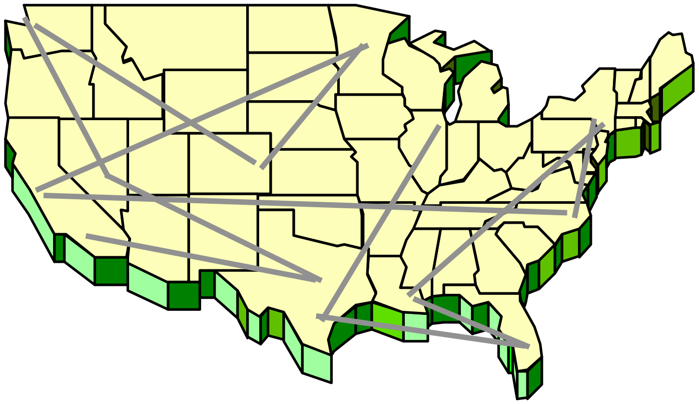
- Instrumental in breaking codes during WW II
- Developed mathematical model of a computer called a Turing Machine (before computers)
  - solves same problems as a Pentium III (more slowly)
- Church-Turing thesis
  - All "computers" can solve the same problems
- Showed there are problems that cannot 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?

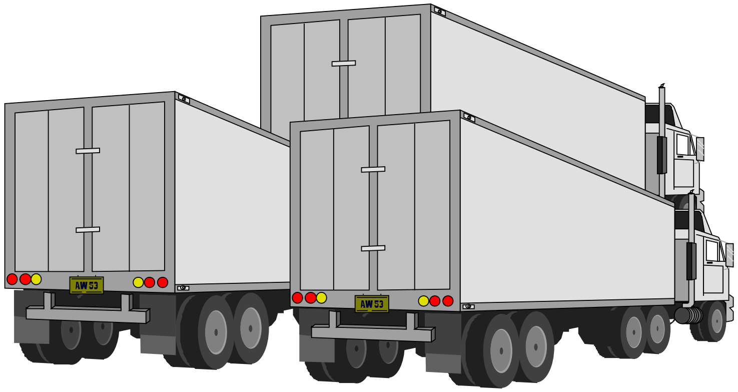


Try all paths, from every starting point -- how long does this take?

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

Complexity Classifications

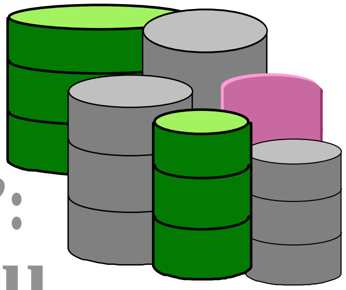
- Given a route and a claim: This route hits all cities for less than $2,000
  - *verify* properties of route efficiently.
  - Hard to *find* optimal solution



Pack trucks with barrels, use minimal # trucks

- Verification simple, finding optimal solution is hard

Ideas?



- Other problems are similar

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

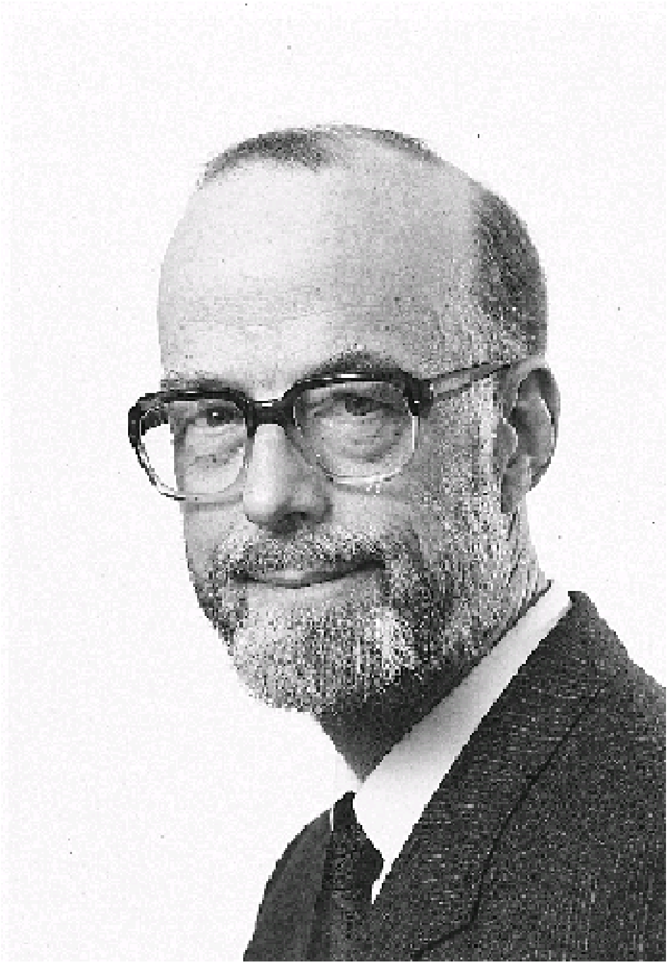
- **Problem posed in 1971, central to the field**

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**

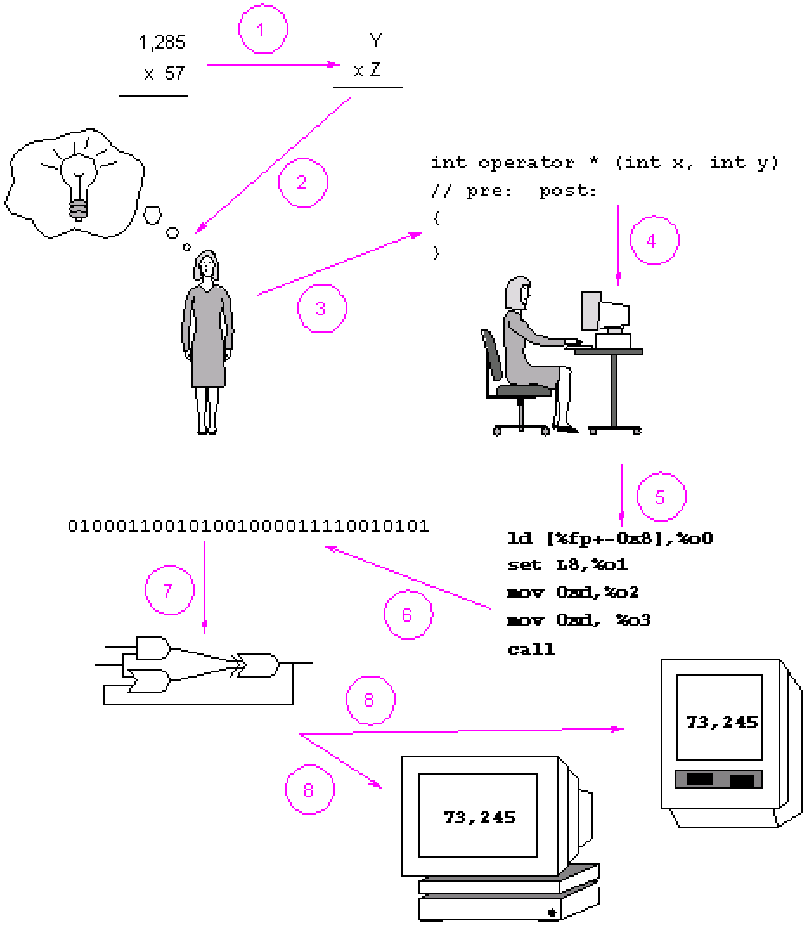
"Beginning students don't know how to do top-down design because they don't know which end is up"



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**



```
int operator * (int x, int y)
// pre:  post:
{
}
```

```
ld [%fp+-0x8],%o0
set L8,%o1
mov 0xd,%o2
mov 0xd, %o3
call
```

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
```

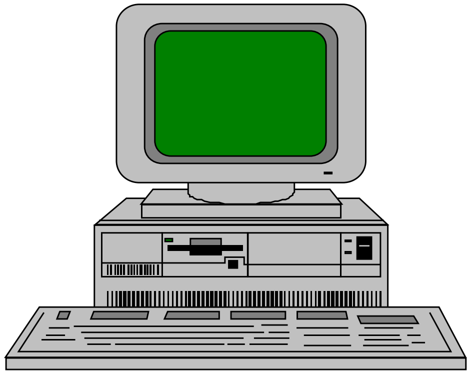
Alternatives to compilation

- 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, ...

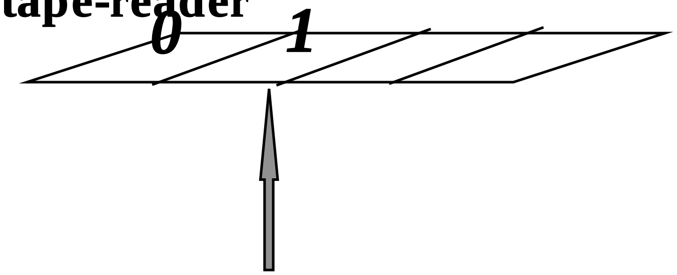
What is a computer?

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

Mainframe, PC,laptop, supercomputer



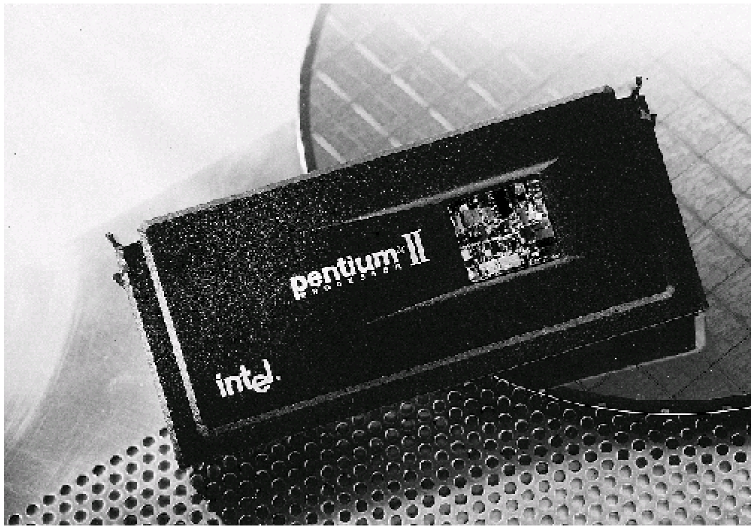
infinite tape, moving tape-reader

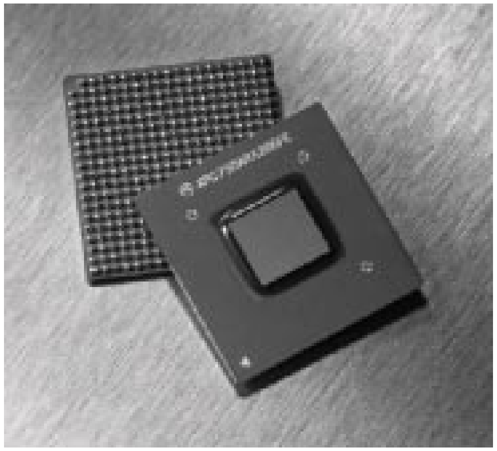


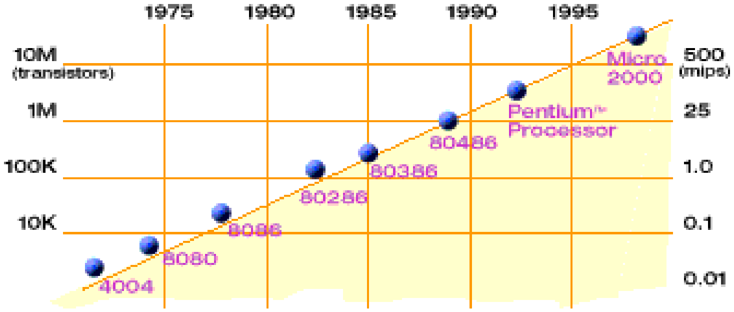
A computer is a computer, is a computer, Church-Turing Thesis, all have same "power"

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