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

What can be programmed?

- **What class of problems can be solved?**
  - G4, 1000Mhz Pentium III, Cray, pencil?
  - Alan Turing proved some things, hypothesized others
    - Halting problem, Church-Turing thesis

- **What class of problems can be solved efficiently?**
  - Problems with no practical solution
    - What does practical mean?
  - Problems for which we can’t find a practical solution
    - Solving one solves them all
    - Would you rather be rich or famous?

Schedule students, minimize conflicts

- Given student requests, available teachers
  - write a program that schedules classes
  - Minimize conflicts

- Add a GUI too
  - Web interface
  - ...

I can’t write this program because I’m too dumb

One better scenario

I can’t write this program because it’s provably impossible
Another possible scenario

I can’t write this program but neither can all these famous people.

Graph coloring (see colorable.cpp)

- Can vertices of a graph be colored so that no two adjacent vertices share the same color?
  - What is minimum # colors
  - Can graph be k-colored?

- Two problems, second is called a decision problem, first is an optimization problem

- Can a graph be 2-colored?
  - Depth first search, mark vertex with a color and ...

- Can a graph be k-colored?
  - Backtrack search

Graph coloring continued

- Two-color problem solving using depth-first search, see code in colorable.cpp that uses stack
  - Every reachable vertex put on stack,
  - Every edge processed once
  - Complexity is O(.....)

- K-colorable problem tries each of k-colors
  - For each color, use it on a vertex and then visit all adjacent vertices that aren’t colored yet
  - Backtrack to undo colorings if they don’t work out before trying next color
  - Recurrence is at best: \( T(n) = kT(n-1) + O(1) \)
  - What is solution to Towers of Hanoi problem?

Towers of Hanoi

- Move disks from “from” peg to “to” peg
- What is the recurrence: \( T(n) = 2T(n-1) + O(1) \) Solution?

```
#define T(n) \( 2T(n-1) + O(1) \)

void Move(int from, int to, int aux, int numDisks)
// pre: numDisks on peg from,
// post: numDisks moved to peg to
{
    if (numDisks == 1) {
        cout << from << " to " << to << endl;
    } else {
        Move(from, aux, to, numDisks-1);
        Move(from, to, aux, 1);
        Move(aux, to, from, numDisks-1);
    }
}
```
The halting problem: writing DoesHalt

```cpp
bool DoesHalt(const string& progname,
               const string& s)
// post: returns true if progname halts given s
//       as input, false otherwise

int main()
{
    string f = PromptString("enter filename ");
    string s = PromptString("input for "+filename);
    if (DoesHalt(f,s)) cout << "does halt" << endl;
    else cout << "does not halt" << endl;
}
```

A compiler is a program that reads other programs as input
- Can a word counting program count its own words?
- The DoesHalt function might simulate, analyze, ...
  - One program/function that works for any program/input

Consider the program `confuse.cpp`

```cpp
#include "halt.h"

int main()
{
    string f = PromptString("enter filename ");
    if (DoesHalt(f,f))
    {
        while (true)
        {
            // do nothing forever
        }
    }
    return 0;
}
```

We want to show writing DoesHalt is impossible
- Proof by contradiction:
  - Assume possible, show impossible situation results

Not impossible, but impractical

- Towers of Hanoi
  - How long to move n disks?
- What combination of switches turns the light on?
  - Try all combinations, how many are there?
  - Is there a better way?

More lights + backtracking

- Turn all lights on
  - Random configuration
  - All off
- Solvable?
  - Try all combinations?
  - Try all in first row?
- From CPS 108, project
Travelling Salesperson

- Visit every city exactly once
- Minimize cost of travel or distance
- Is there a tour for under $2,000? less than 6,000 miles?
- Is close good enough?
  - Consider spanning tree

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

- 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

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

Are hard problems easy?

- P = easy problems, NP = “hard” problems
  - P means solvable in polynomial time
  - Difference between N, N^2, N^10 ?
  - NP means non-deterministic, polynomial time
  - guess a solution and verify it efficiently

- Question: P = NP ?
  - if yes, a whole class of difficult problems can be solved efficiently—one problem is reducible to another
  - if no, none of the hard problems can be solved efficiently
  - showing the first problem was NP complete was an exercise in intellectual bootstrapping, satisfiability/Cook/(1971)
  - An NP complete problem is in NP (guessable/verify) and is the same “difficulty” as every other problem in NP

Theory and Practice

- Number theory: pure mathematics
  - How many prime numbers are there?
  - How do we factor?
  - How do we determine primeness?

- Computer Science
  - Primality is “easy”
  - Factoring is “hard”
  - Encryption is possible

public-key cryptography
randomized primality testing
Shafi Goldwasser

- RCS professor of computer science at MIT
  - Co-inventor of zero-knowledge proof protocols
  - How do you convince someone that you know something without revealing “something”
- Consider card readers for dorms
  - Access without tracking

Work on what you like, what feels right, I now of no other way to end up doing creative work

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

... on computing pioneer Howard Aiken “the problem was not to keep people from stealing your ideas, but to make them steal them.”
- Duke valedictorian 1953, started UNC Computer Science Dept in 1964, won Turing Award in 1999
- Mythical-Man Month, “Adding man-power to a late project makes it later”, ... “There is no silver-bullet for Software Engineering... [because of essential complexity]”
- Chaired Executive Committee of the Central-Carolina Billy Graham Crusade in 1973

What is computer science?

- What is a computation?
  - Can formulate this precisely using mathematics
  - Can say “anything a computer can compute”
  - Study both theoretical and empirical formulations, build machines as well as theoretical models
- How do we build machines and the software that runs them?
  - Hardware: gates, circuits, chips, cache, memory, disk, ...
  - Software: operating systems, applications, programs
- Art, Science, Engineering
  - How do we get better at programming and dealing with abstractions
  - What is hard about programming?