Computers Are Not That Great!

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It Matters How Fast Programs Run

- Computers are amazingly fast … but that's because we usually ask them to do really easy stuff; they can do billions of instructions per second (gips?) …

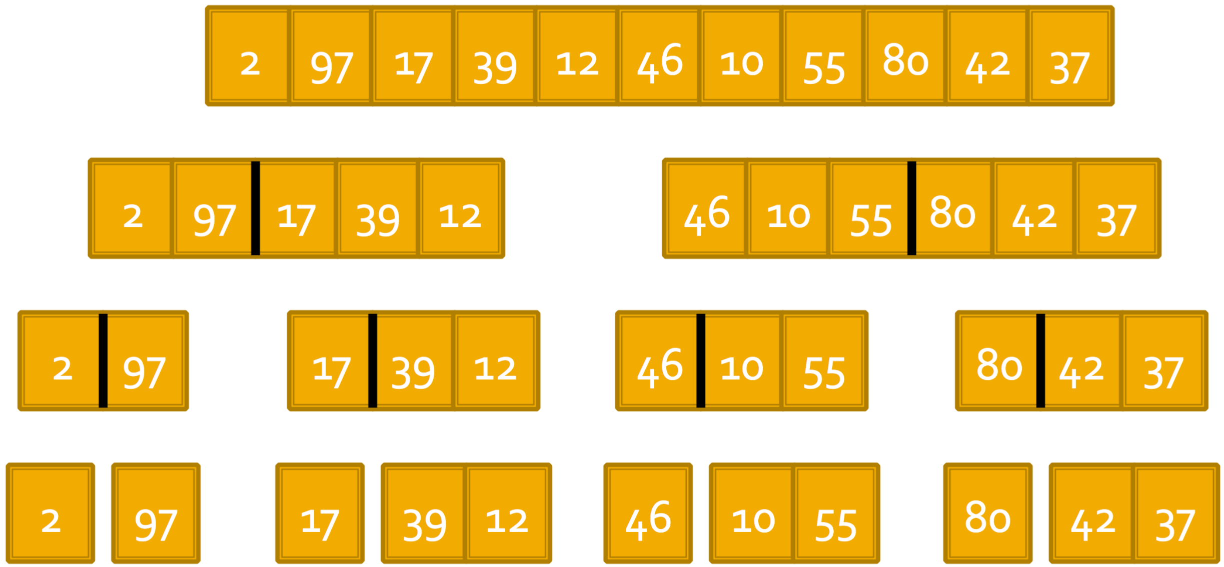
- So, what's a "really easy" computation? *cn*
  - Looking up in a dictionary or address book how the letters you've typed might be completed
  - Recovering a losslessly compressed file
  - Looking in a file for a specific letter string
  - …

A Little More Work To Do

- How long would it take the Census Bureau to alphabetize the US population by first name?
  - Recall Exchange Sort & Bubble Sort – both are "n^2 algorithms," meaning they take cn^2 seconds for some amount of time c – usually the overhead to process one item; lets estimate $c \sim 0.5\ \mu s$
  - If the US population is $n = 310{,}000{,}000 = 3.1 \times 10^8$
  - $n^2 = 3.1 \times 10^8 \times 3.1 \times 10^8 = 9.6 \times 10^{16}$
  - $0.5\ \mu s = .000\ 000\ 5s = 5.0 \times 10^{-7} s$
  - $cn^2 = 5.0 \times 10^{-7} s \times 9.6 \times 10^{16} = 48 \times 10^9 s = 1521$ *years*

One Other Approach

- Recall there was also the Merge Sort



Merge Sort requires $cn\ log_2\ n$

$cn\ log_2\ n = 5.0 \times 10^{-7}s \times 3.1 \times 10^8 \times 29$

$= 15.5 \times 10s \times 29 = 4495s = 1.24$ hr

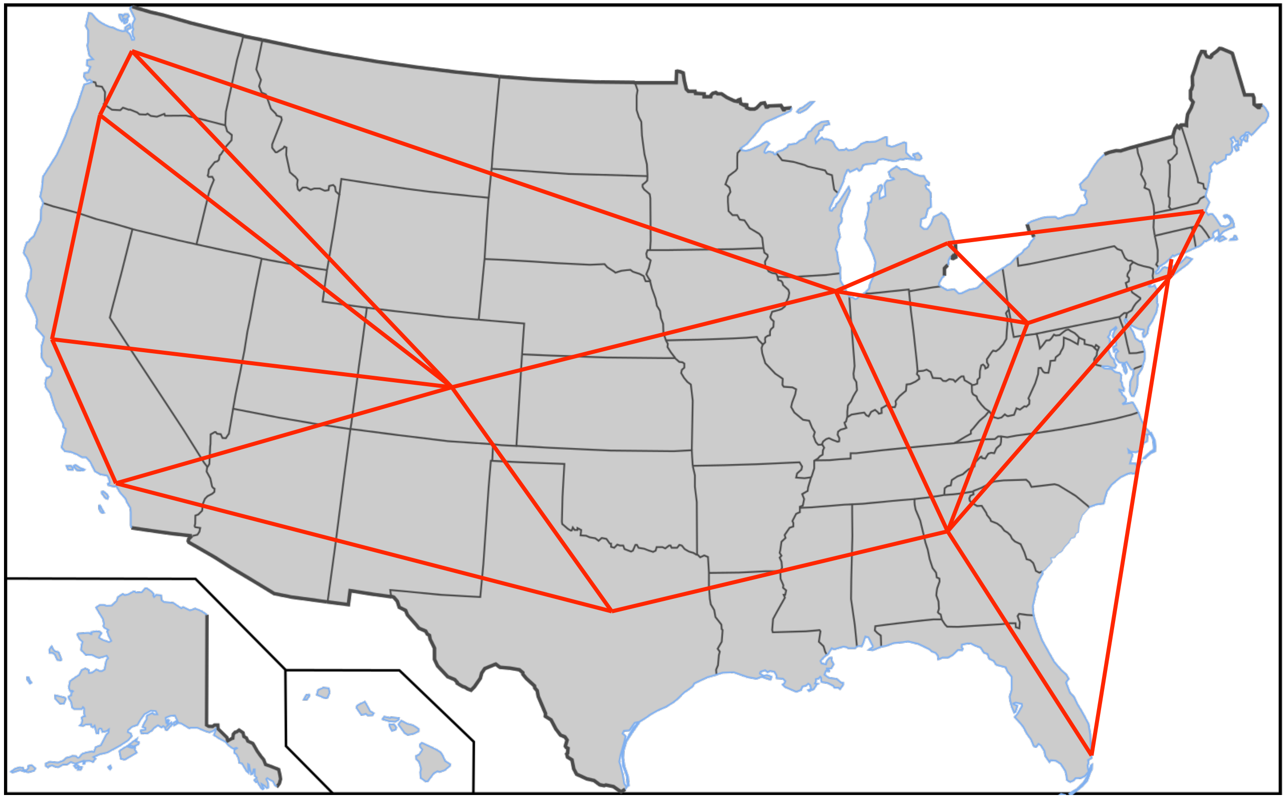
Summarizing Alphabetize Task

- The input size n = 310,000,000 = 3.1 x 10^8
- Exchange sort & Bubble sort require cn^2 time
- For c=1/2 microsecond, cn^2 = 1521 years
- Merge sort requires $cn \log_2 n$ time
- Because $\log_2 n = 29$, $cn \log2\ n$ = 1.24 hours

- Algorithms matter … and smarter algorithms are better

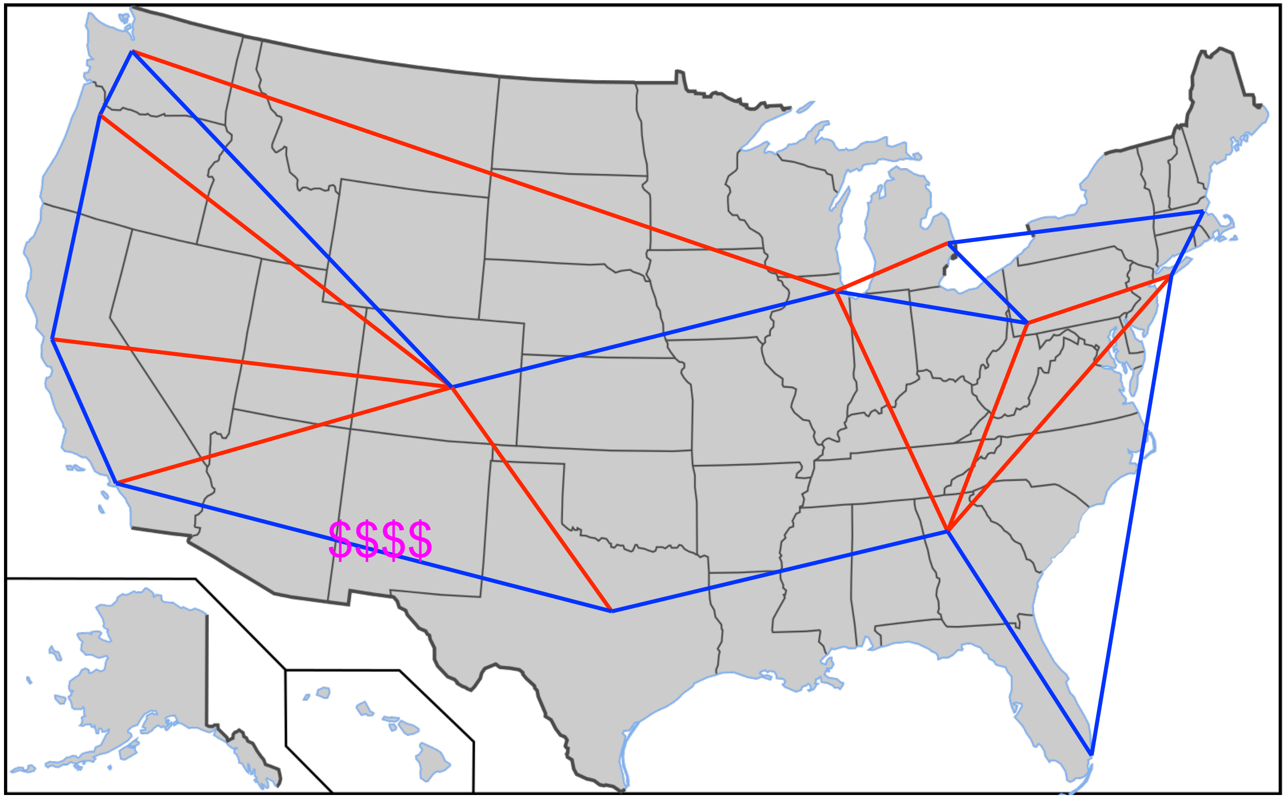
Computations That Are Harder Still

- More data means more work, but sometimes it means a lot more work
- Traveling salesman problem:



TSP – Visit Each City Once

- Minimize the cost of the plane tickets
  - Finding a tour is reasonably easy
  - Finding the cheapest tour is NP-hard



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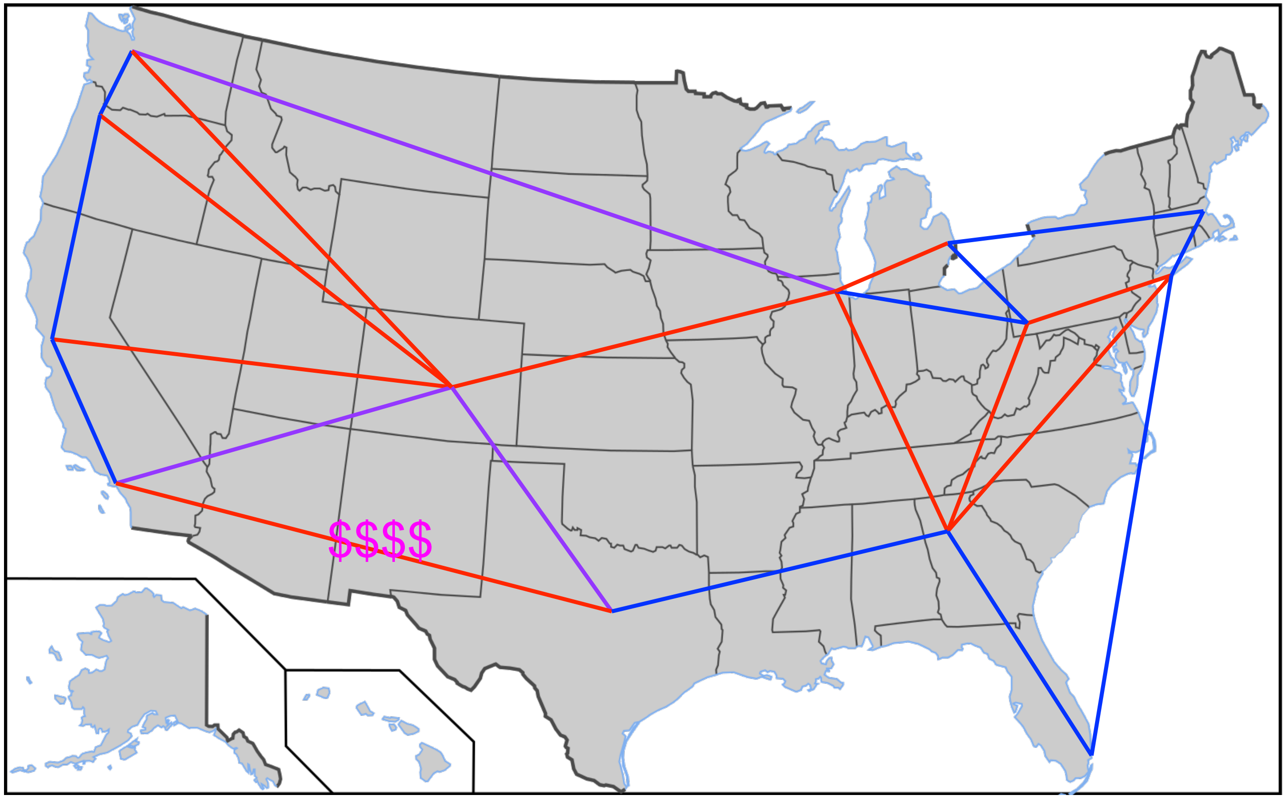


NP-Hard & NP-Complete Problems

- NP, which stands for "nondeterministic polynomial time" (don't learn that), is a class of problems with these features:
  - They are easy (like cn^2, perhaps) ways to solve if the computer can guess and is always right
  - They have no known easy (like cn^5, say) solutions, it seems, if the computer can't guess, which it can't
  - All known solutions effectively check all possible alternatives and pick the best
  - These are "normal" computations, like TSP
  - "Complete" means solve one and you've solved all

In Computer Science Programs …

- … Are Data
- For Example: Processing is a program that accepts YOUR program as data and runs it … so it "computes on" (processes) your program
- Except for really trivial languages (e.g. HTML) all programming languages are universal – CS people can write a program in that one language, say Processing, which can run programs in any other language – all programs
- This is the "Universality Principle"

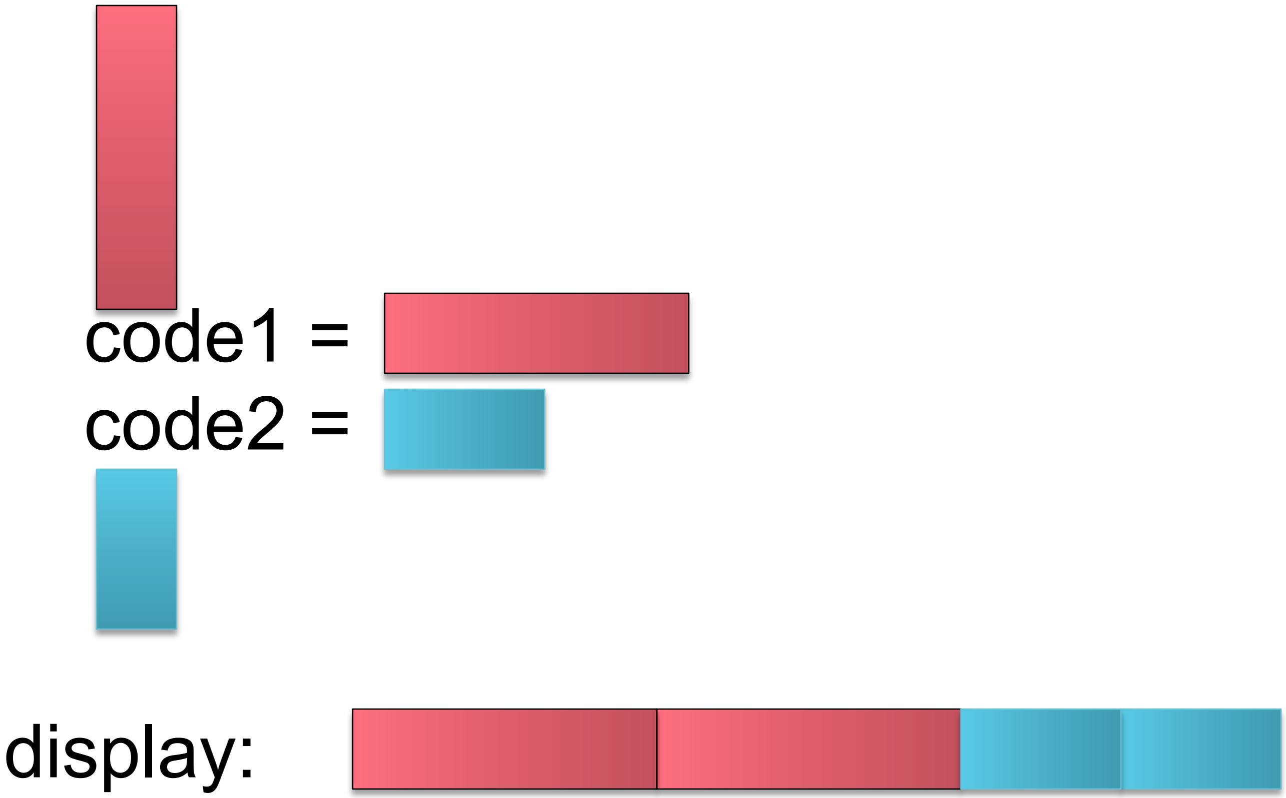
A Program To Print Itself Out

```
String code1, code2;
void setup( ) {
  size(500, 400);
  background(255);
  noLoop( );
  fill(0);
}
void draw( ) {
  code1 = "\"String code1, code2; " +
         "void setup( ) { " +
         "size(500,400); " +
         "background(255); " +
         "noLoop( ); fill(0); } " +
         "void draw( ) { " +
         "code1 =  ;\"";
  code2 = "code1 = code1 + code1 + \"code2 = \" + code2 + code2; " +
         "text(code1, 50, 50, 200, 400); }\"  ";
  code1 = code1 + code1 + "code2 = " + code2 + code2;
  text(code1, 50, 50, 200, 400);
}
```

Fixing the tiny syntactic differences is easy

Schematic of Self-Printing Pgm

- Divide the program into two halves --



Running the Program …

- Output

"String code1, code2; void setup( ) { size(500,400); background(255); noLoop( ); fill(0); } void draw( ) { code1 = ;""String code1, code2; void setup( ) { size(500,400); background(255); noLoop( ); fill(0); } void draw( ) { code1 = ;"code2 = code1 = code1 + code1 + "code2 = " + code2 + code2; text(code1, 50, 50, 200, 400); }" code1 = code1 + code1 + "code2 = " + code2 + code2; text(code1, 50, 50, 200, 400); }"

Helpfully Formatted Output

"String code1, code2; void setup( ) { size(500,400); background(255); noLoop( ); fill(0); } void draw( ) { code1 = ;"

> "String code1, code2; void setup( ) { size(500,400); background(255); noLoop( ); fill(0); } void draw( ) { code1 = ;"
>
> code2 = " code1 = code1 + code1 + "code2 = " + code2 + code2; text(code1, 50, 50, 200, 400); }"

code1 = code1 + code1 + "code2 = " + code2 + code2; text(code1, 50, 50, 200, 400); }"

Adding Additional Code

- Notice that new code can be added, and the program can still print itself out

Put the new code here and here

```
void draw( ) {
  code1 = "\"String code1, code2; " +
          "void setup( ) { " +
          "size(500,400); " +
          "background(255); " +
          "noLoop( ); fill(0); } " +
          "void draw( ) { " +
          "code1 =  ;\"";
  code2 = "code1 = code1 + code1 + \"code2 = \" + code2 + code2; " +
          "text(code1, 50, 50, 200, 400); }\"  ";
  code1 = code1 + code1 + "code2 = " + code2 + code2;
  text(code1, 50, 50, 200, 400);
}
```

Summarizing

- A self-printing program shows that programs can manipulate program text …
- Examples of programs manipulating programs
  - The highlighter that "colors" your programs
  - The translator that converts Processing code into machine code so a computer can run it
  - The code that figures out what you did wrong when you forget a semicolon
  - A debugger can help you find errors in your pgm

A Problem That Can't Be Solved

- Suppose we want to determine if a Processing program draws a red circle or not
- It seems possible, perhaps …
  - Analyze the code to see if it displays any circles
  - Check if any of the circles it draws are red
  - Etc.
- Suppose Boolean check-pde(String code) is a Processing function that determines if a Processing program draws a red circle (return true) or does not draw a red circle (return false)

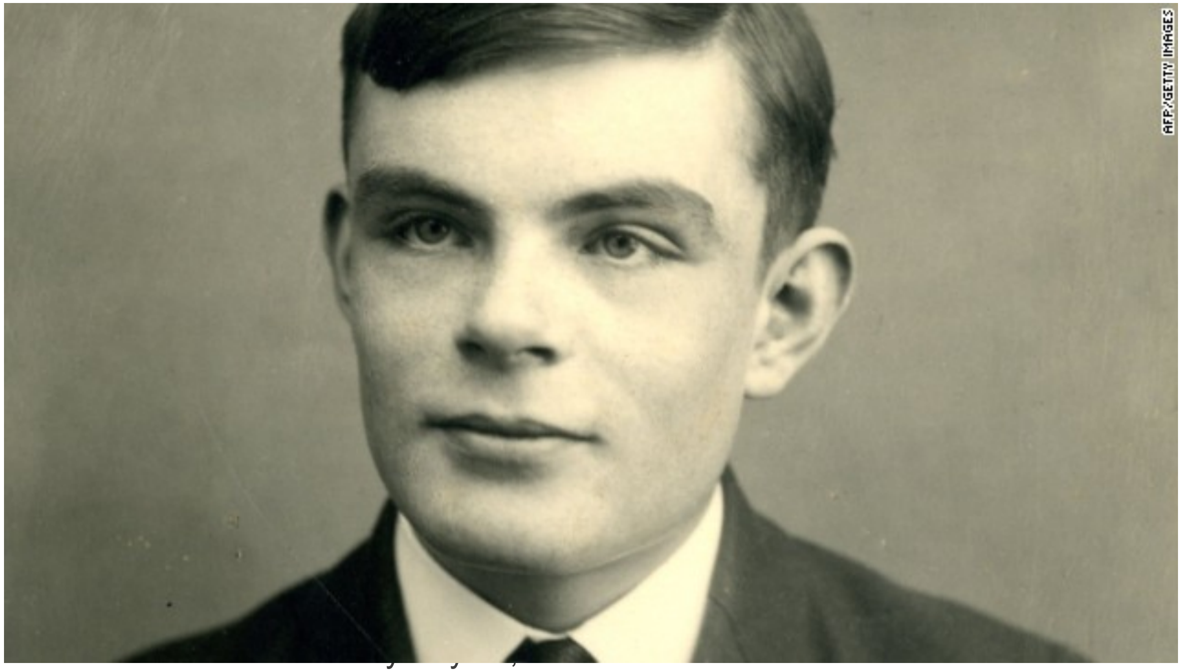
Assuming check-pde( ) works …

```
String code = "void trick( )... " ;
void setup( ) {
  size(200,200); background(255); noLoop( );
}
void draw( ) {
  trick( ); //Guaranteed to get it wrong!
}
void trick( ) {
  if (check-pde(code)){ //does code draw red circle?
    fill(0,0,255);  //check-pde says yes
  } else {
    fill(255,0,0);  //check-pde says no
  }
  ellipse(100,100,10,10);
}
```

Analyze What Happens

The Impact

- There are simple problems that computers cannot solve, b/c probs are not algorithmic … no deterministic sequence of operations can find the answer; debugging is an example
- Alan Turing's insight in 1936



Summary

- We considered how "hard" computations can be, where "hard" is measured as running time
- Linear time – thinking about how long the code runs
- Quadratic; NlogN – thinking about sorting
- NP Hard and the TSP
- Universal machine – yeah Turing!
- Undecidibility