Lecture 9: Low-Level Programming

http://www.cs.virginia.edu/cs216

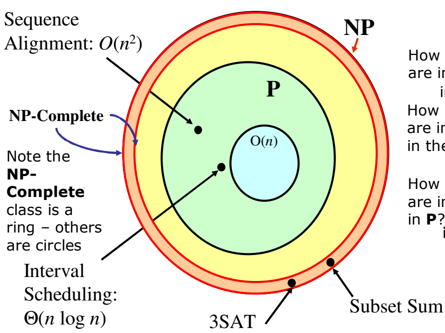
Menu

- Complexity Question
- Low-Level Programming

Exam 1

Out Wednesday, Due Monday, 11:01AM
Covers everything through Lecture 8
Expect questions on:
order notation, algorithm analysis, lists, trees, recursive programming, dynamic programming, greedy algorithms
Not on complexity classes (Lecture 8)

Problem Classes if P ≠ NP:



How many problems are in the $\Theta(n)$ class?
infinite
How many problems are in **P** but not in the $\Theta(n)$ class?
infinite
How many problems are in **NP** but not in **P**?
infinite

Is it ever *useful* to be confident that a problem is hard?

Knapsack Cipher [Merkle & Hellman, 1978]

- Public Key: $A = \{a_1, a_2, \ldots, a_n\}$
  - Set of integers
- Plain Text: $x_1, \ldots x_n$
  x_i = 0 or 1
- Cipher Text: $$s = \sum_{i=1}^{n} x_i a_i$$

Subset Sum is Hard

- Given s and A it is NP-Complete to find a subset of A that sums to s
- Need to make decrypting each (for recipient with the "private key")

Superincreasing Set

- Pick $\{a_1, a_2, \ldots, a_n\}$ is a *superincreasing sequence*

$$a_i > \sum_{j=1}^{i-1} a_j$$

How hard is subset sum if A is superincreasing?

Knapsack Ciphers

- Private Key = $\{p_1, p_2, \ldots, p_n\}$
  - A superincreasing sequence
  - Values M and W:

$$M > \sum_{i=1}^{n} b_i$$

$$GCD(M, W) = 1$$

- Public Key = $\{a_1, a_2, \ldots, a_n\}$

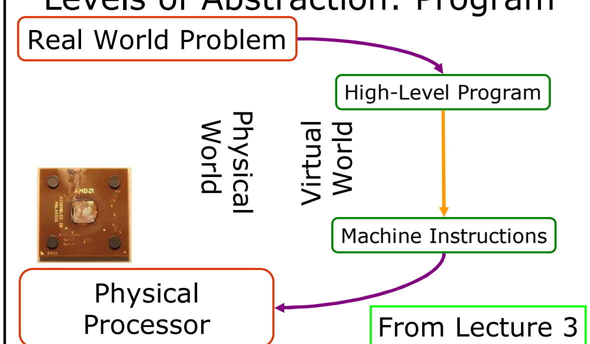
$$a_i \equiv (b_i W) \bmod M$$

Flawed Security Argument

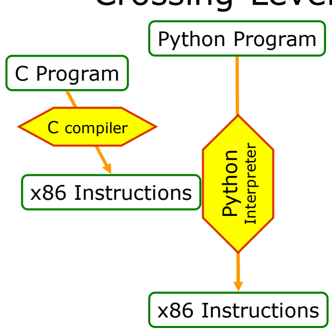
- Subset Sum is NP-Complete
- Breaking knapsack cipher involves solving a subset sum problem
- Therefore, knapsack cipher is secure

Flaw: NP-Complete means there is **no fast general solution**. Some instances may be solved quickly.
(Note: Adi Shamir found a way of breaking knapsack cipher [1982])

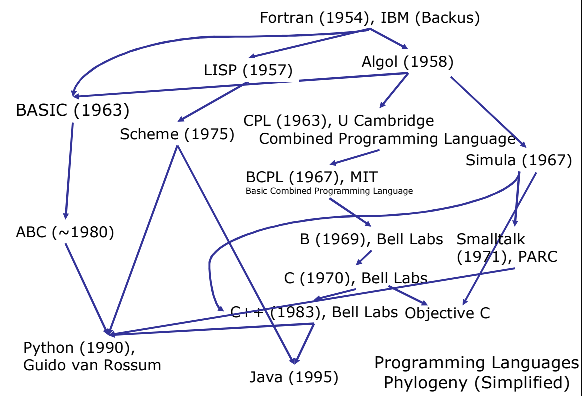
Levels of Abstraction: Program



Crossing-Levels

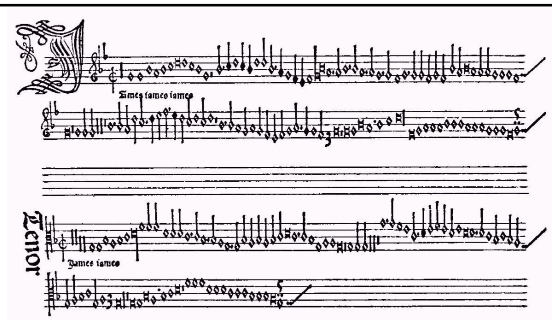


Programming Languages

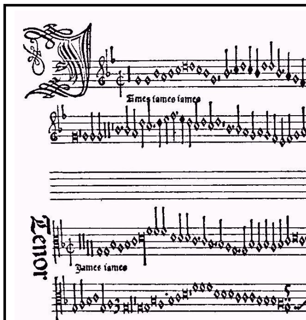


Programming Languages
Phylogeny (Simplified)

Why so many Programming Languages?



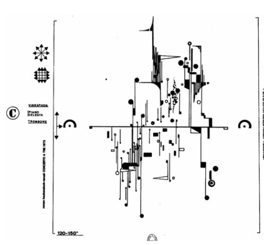
"Jamais Jamais Jamais" from *Harmonice Musices Odhecaton A*. Printed by Ottaviano Dei Petrucci in 1501 (first music with movable type)



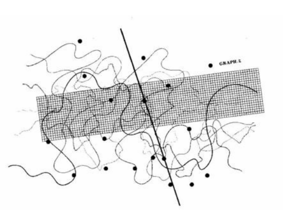
"Jamais Jamais Jamais" from *Harmonice Musices Odhecaton A*. (1501)

J S Bach, "Coffee Cantata", BWV 211 (1732)
www.npj.com/homepage/teritowe/jsbhand.html

Modern Music Notation

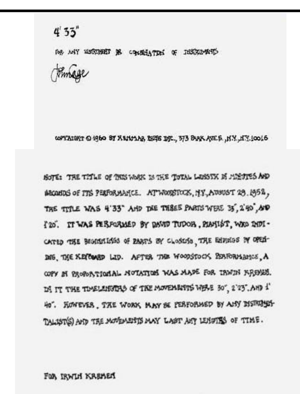


Roman Haubenstock-Ramati, *Concerto a Tre*



John Cage, *Fontana Mix*

http://www.medienkunstnetz.de/works/fontana-mix/audio/1/



Thought and Action

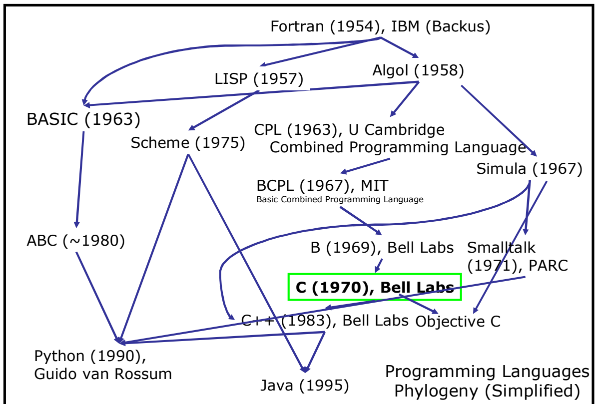
- Languages change the way we **think**
  - Scheme: think about procedures
  - BASIC: think about GOTO
  - Algol, Pascal: think about assignments, control blocks
  - Java: think about types, squiggles, exceptions
  - Python?
- Languages provide **abstractions** of machine resources
  - Hide dangerous/confusing details: memory locations, instruction opcodes, number representations, calling conventions, etc.

Abstractions

- Higher level abstractions
  - Python, Java, BASIC, …
  - Easier to describe abstract algorithms
  - But, cannot manipulate low-level machine state
    - How are things stored in memory?
    - Opportunities for optimization lost
- Lower level abstractions
  - C, C++, JVML, MSIL, Assembly, …
  - Harder to describe abstraction algorithms
  - Provides programmer with control over low-level machine state

Biggest Single Difference: Memory Management

- High-level languages (Python, Java) provide automatic memory management
  - Programmer has no control over how memory is allocated and reclaimed
  - Garbage collector reclaims storage
- Low-level languages (C, Assembly) leave it up to the programmer to manage memory



Programming Languages Phylogeny (Simplified)

C Programming Language

- Developed to build Unix OS
- Main design considerations:
  - Compiler size: needed to run on PDP-11 with 24KB of memory (Algol60 was too big to fit)
  - Code size: needed to implement the whole OS and applications with little memory
  - Performance, Portability
- Little (if any consideration):
  - Security, robustness, maintainability

C Language

- No support for:
  - Array bounds checking
  - Null dereferences checking
  - Data abstraction, subtyping, inheritance
  - Exceptions
  - Automatic memory management
- Program crashes (or worse) when something bad happens
- Lots of syntactically legal programs have undefined behavior

Example C Program

```
void test (int x) {
   while (x = 1) {
      printf ("I'm an imbecile!");
      x = x + 1;
   }
}
```

Weak type checking:
In C, there is no boolean type.
Any value can be the test expression.

x = 1 assigns 1 to x, and has the value 1.

```
I'm an imbecile!
I'm an imbecile!
I'm an imbecile!
I'm an imbecile!
I'm an imbecile!
I'm an imbecile!
```

In Java:

```
void test (int x) {
   while (x = 1) {
      printf ("I'm an imbecile!");
      x = x + 1;
   }
}
```

```
> javac Test.java
Test.java:21: incompatible typ
found   : int
required: boolean
        while (x = 1) {
               ^
1 error
```


Fortran (1954) LET

Algol (1958) :=

CPL (1963), U Cambridge :=
Combined Programming Language

BCPL (1967), MIT :=
Basic Combined Programming Language

B (1969), Bell Labs =

C (1970), Bell Labs =

C++ (1983), Bell Labs =

Java (1995), Sun =

= vs. :=

Why does Python use = for assignment?

- Algol (designed for elegance for presenting algorithms) used :=
- CPL and BCPL based on Algol, used :=
- Thompson and Ritchie had a small computer to implement B, saved space by using = instead
- C was successor to B (also on small computer)
- C++'s main design goal was backwards compatibility with C
- Python was designed to be easy for C and C++ programmers to learn

C Bounds Non-Checking

```
int main (void) {
  int x = 9;
  char s[4];

  gets(s);
  printf ("s is: %s\n", s);
  printf ("x is: %d\n", x);
}
```

Note: your results may vary (depending on machine, compiler, what else is running, time of day, etc.). This is what makes C fun!

```
> gcc -o bounds bounds.c
> bounds
abcdefghijkl          (User input)
s is: abcdefghijkl
x is: 9
> bounds
abcdefghijklm
s is: abcdefghijklmn
x is: 1828716553      = 0x6d000009
> bounds
abcdefghijkln
s is: abcdefghijkln
x is: 1845493769      = 0x6e000009
> bounds
aaa... [a few thousand characters]
crashes shell
```


Charge

- Wednesday: Exam 1 is out, due Monday
- No regularly scheduled Small Hall and office hours while Exam 1 is out