Introduction

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CS3300 Compiler Design
IIT Madras
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Languages

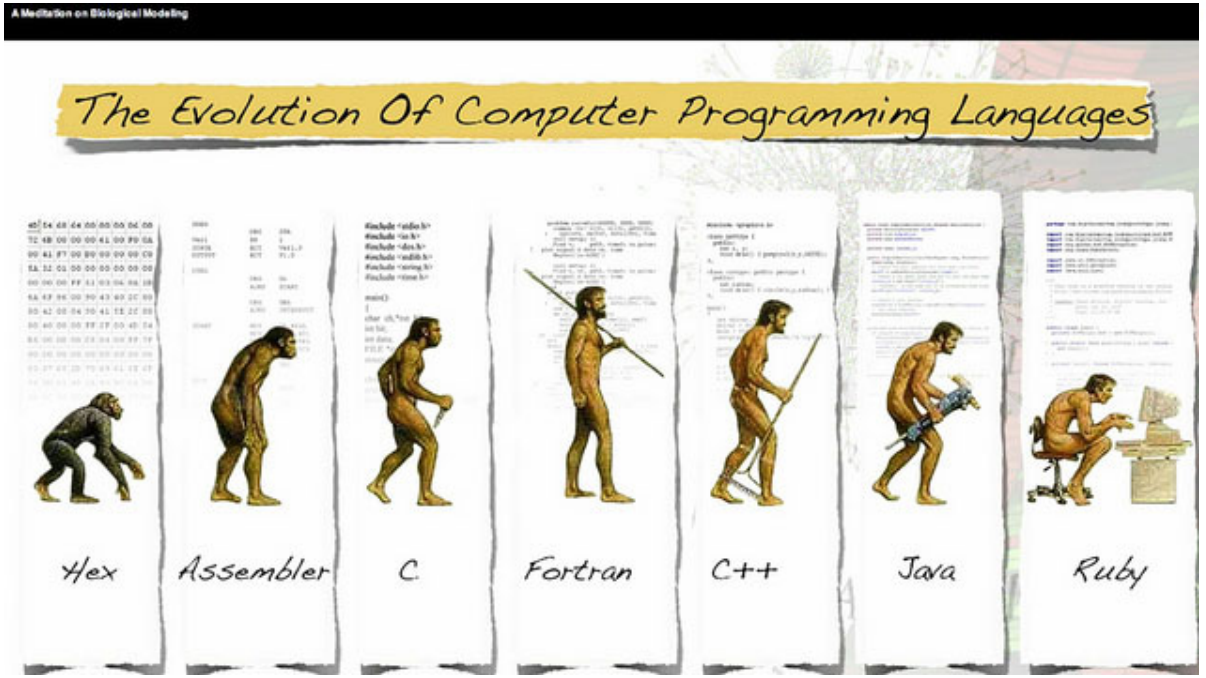
Wall of Love, Paris
Source: google images

Languages

- Why do we need languages?
  - Humans communicate
    - sign language, body language, braille
  - Birds communicate
    - mark territories, attract for mating, warn danger
  - Animals communicate
    - mark territories, convey need, preparation for attack
  - Aliens?

Programming Languages

- Why do we need programming languages?
- And why so many?
  - What is your first language?
  - Tamil. Yours?
  - C.



Source: google images

Programming Languages

- There are some special purpose languages
  - HTML for webpages
  - LaTeX for document formatting
  - ps for postscript files; sql, VHDL
  - Shell scripts, awk, grep, sed
  - Makefile has a language; smtp
  - How about google search?
    - filetype:pdf, link:www.cse.iitm.ac.in
  - Gmail: in:unread, in:starred
  - vi: :se ai, :wq, :se ft=c
  - What about ls -l, ls -Ri, ls --color, ls -1 dir1 dir2 ?

Language is for Communication

- Using mobile buttons
- Using ipad touch
- Using a calculator
- Using a fan switch
- Using a remote for projector / laser

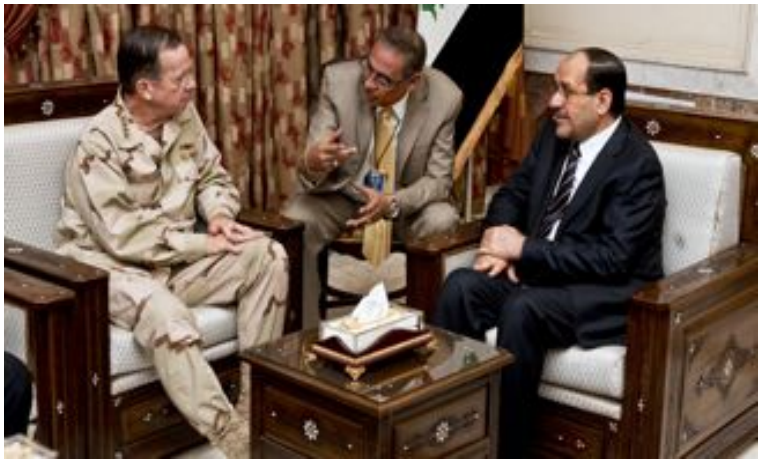
... some of these are not programmable today.

They have a limited abstraction.

We will work with programming languages.

Compiler

- When do we need a compiler?
  - நான் தமிழ் தெரியுமா
  - मुझे हिंदी आता है
  - Ich kenne Deutsch
  - I know English



Source: google images

Jobs of a Compiler

- Translate: input language, output language
- Maintain correctness
  - पिताजी अजमेर गए।
  - Father died today.
- Be efficient
  - Why are you laughing?
  - I understood yesterday's joke.
- Generate a good language
  - I got books but more than that I got your letter.
  - मैं किताबें, लेकिन मैं अपने पत्र मिला है कि अधिक से अधिक मिला

Good Language (2015)

I got books but more than that I got your letter.

मैं किताबें, लेकिन मैं अपने पत्र मिला है कि अधिक से अधिक मिला है।

I have books, but I got your letter got more than that.

मैं किताबें हैं, लेकिन मैं अपने पत्र है कि अधिक से अधिक मिला।

I have books, but that's more than I got your letter.

मैं किताबें हैं, लेकिन लगता है कि मैं अपने पत्र मिला है की तुलना में अधिक है।

I have books, but I have received your letter is more than.

मैं किताबें हैं, लेकिन मैं अपने पत्र की तुलना में अधिक है प्राप्त हुआ है।

Good Language (2018)

I got books but more than that I got your letter.

मुझे किताबें मिलीं लेकिन उससे ज्यादा मुझे आपका पत्र मिला।

I got the books but I received your letter more than that.

मुझे किताबें मिलीं लेकिन मुझे उससे अधिक पत्र मिला।

I got books but I received more letters from him.

मुझे किताबें मिलीं लेकिन मुझे उससे ज्यादा पत्र मिले।

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मुझे किताबें मिलीं लेकिन मुझे उससे अधिक पत्र प्राप्त हुए।

Good Language (2020)

I got books but more than that I got your letter.

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Compilers work with Strings

- Characters, words / tokens, sentences, programs
- Fun with strings
  - quick brown fox jumps over the lazy dog
  - stewardesses
  - typewriter
  - skepticisms
  - quine

Programs as Data

```
char*f="char*f=%c%s%c;main(){printf(f,34,f,34,10);}%c";main(){printf(f,34,f,34,10);}
```

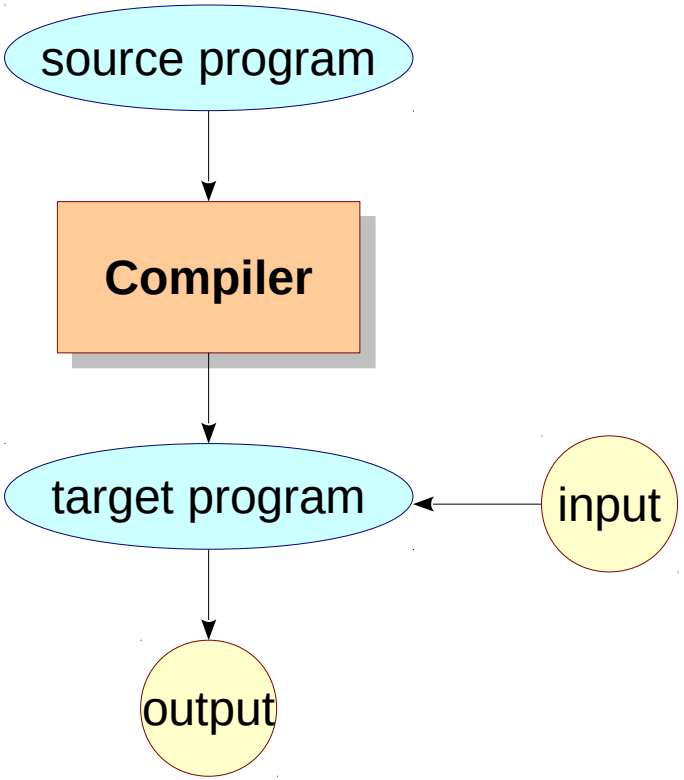
Why should we Design a language?

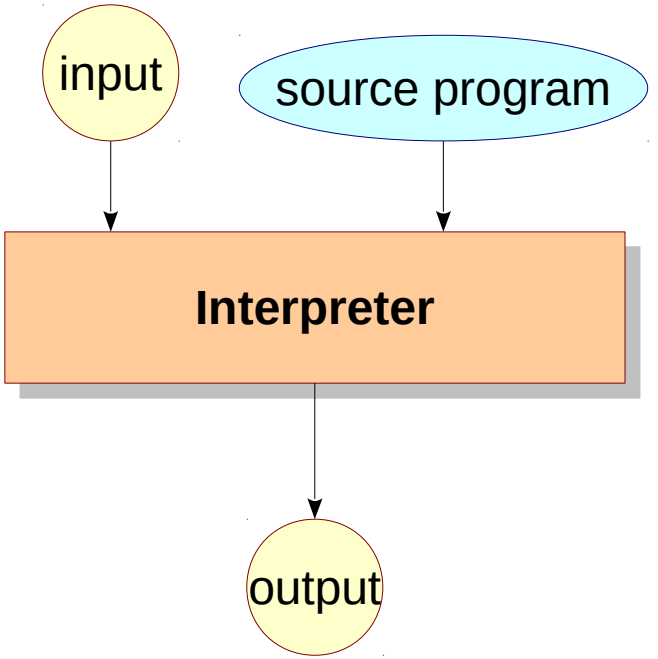
- Language matters!
  - A: Would you accept a gamble that offers a 10% chance to win $95 and a 90% chance to lose $5?
  - B: Would you pay $5 to participate in a lottery that offers a 10% chance to win $100 and a 90% chance to win nothing.
- Outcomes of a treatment for lung cancer. Two descriptions were:
  - C: The one-month survival rate is 90%.
  - D: There are 10% deaths in the first month.
- B fetched many more positives. 84% physicians chose option C.

Source: Thinking Fast and Slow, Daniel Kahneman

Classwork

- Write a program that takes a function name as input and calls that function.





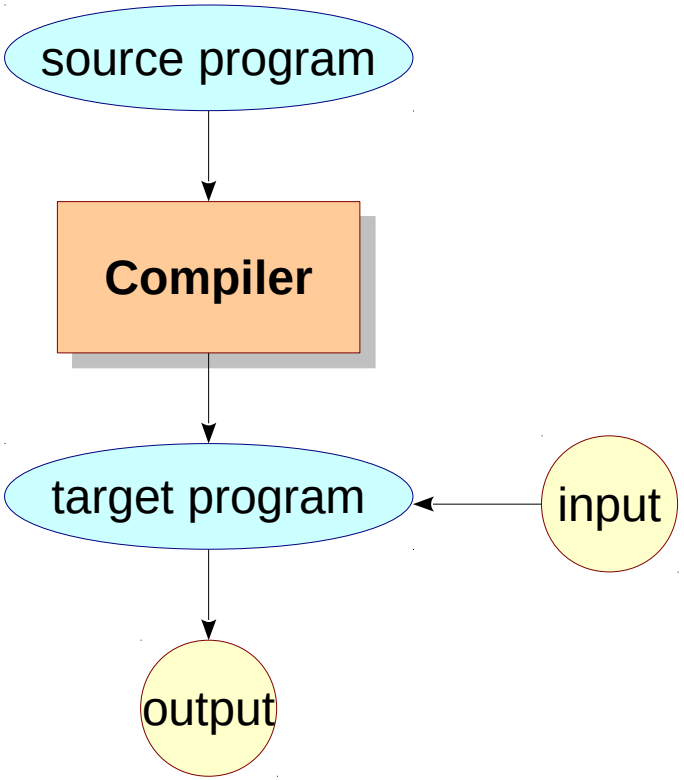
- What does this mean?
  - You may be able to do the following with interpreters.

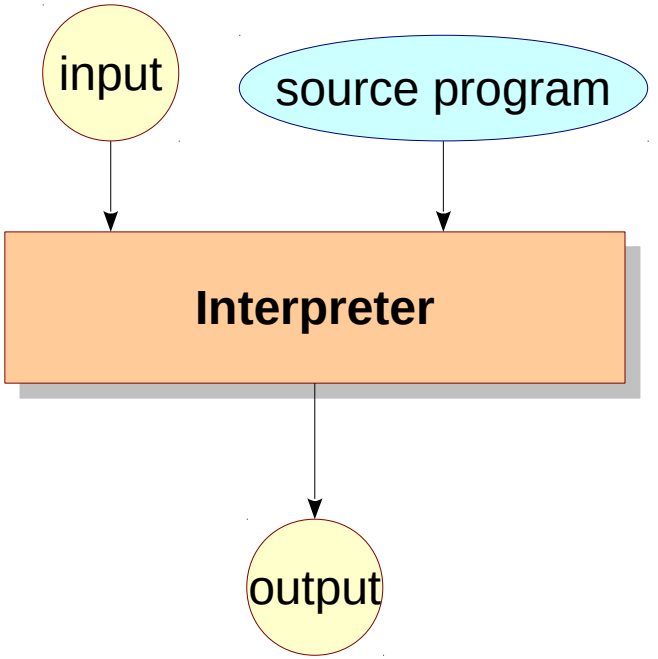
```
$x = 0; $y = 0;
echo "Enter a variable name: ";
$line = fgets(STDIN);
$line = trim($line);
${$line} = 20;
echo "x=$x, y=$y\n";
```

How about C?

```
void main() {
        int x = 0, y = 0;
#include "/dev/stdin"
        = 10;
        printf("x = %d, y = %d\n", x, y);
}
```


Everything is fair in love, war and C.



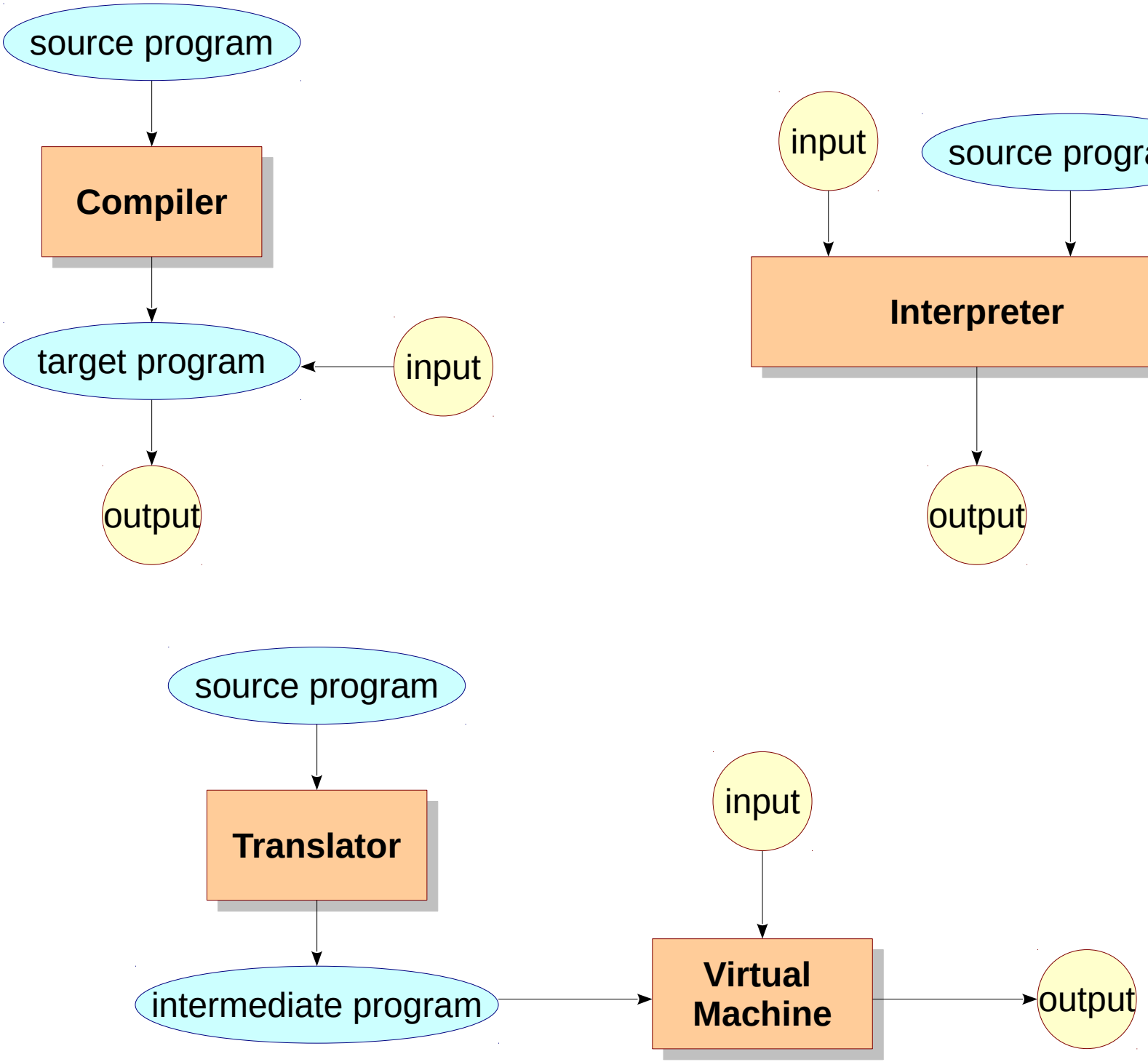


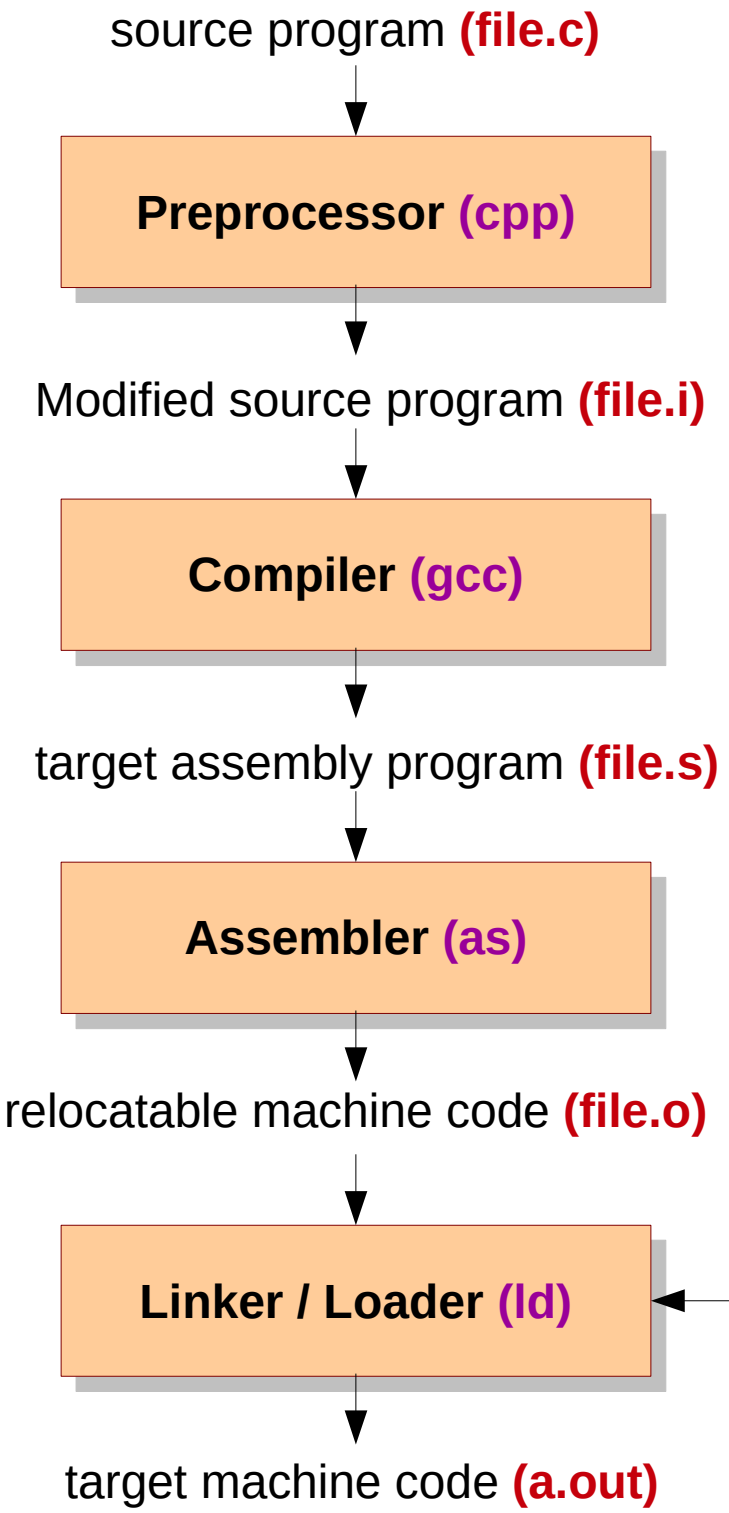
- What does this mean?
  - You may be able to do the following with compilers.

```
x += 2;
x += 2;
--x;
x += 5;
++x;
x += 9
```

is equivalent to

```
x += 18;
```


source program
Compiler
target program
input
output
input
source program
Interpreter
output
source program
Translator
intermediate program
input
Virtual Machine
output



- cpp file.c >file.i
- gcc -S file.i
- as file.s -o file.o
- ld -o a.out file.o ...*libraries*...

Try the following:

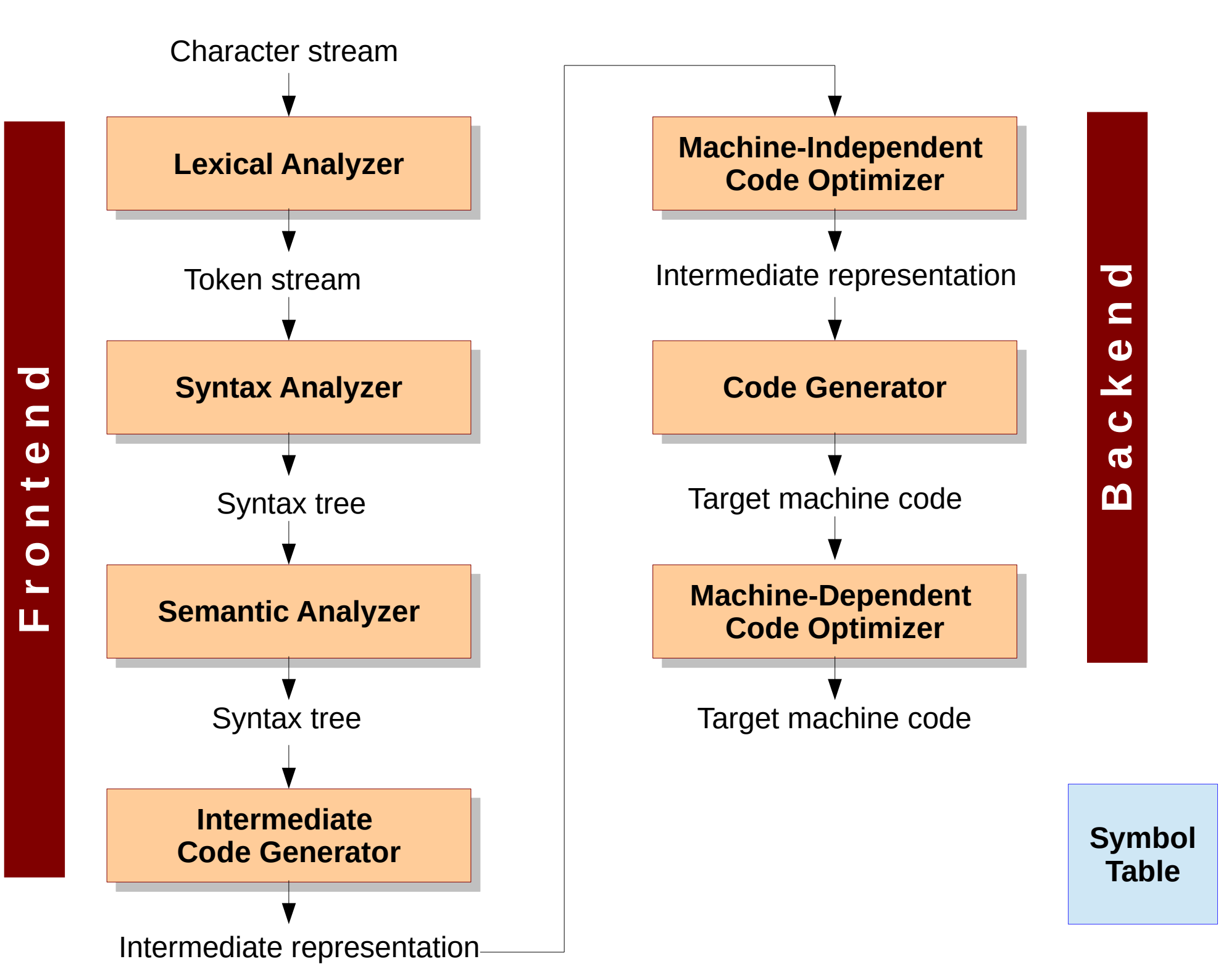
- gcc **-v** file.c
- gcc **-save-temps** file.c

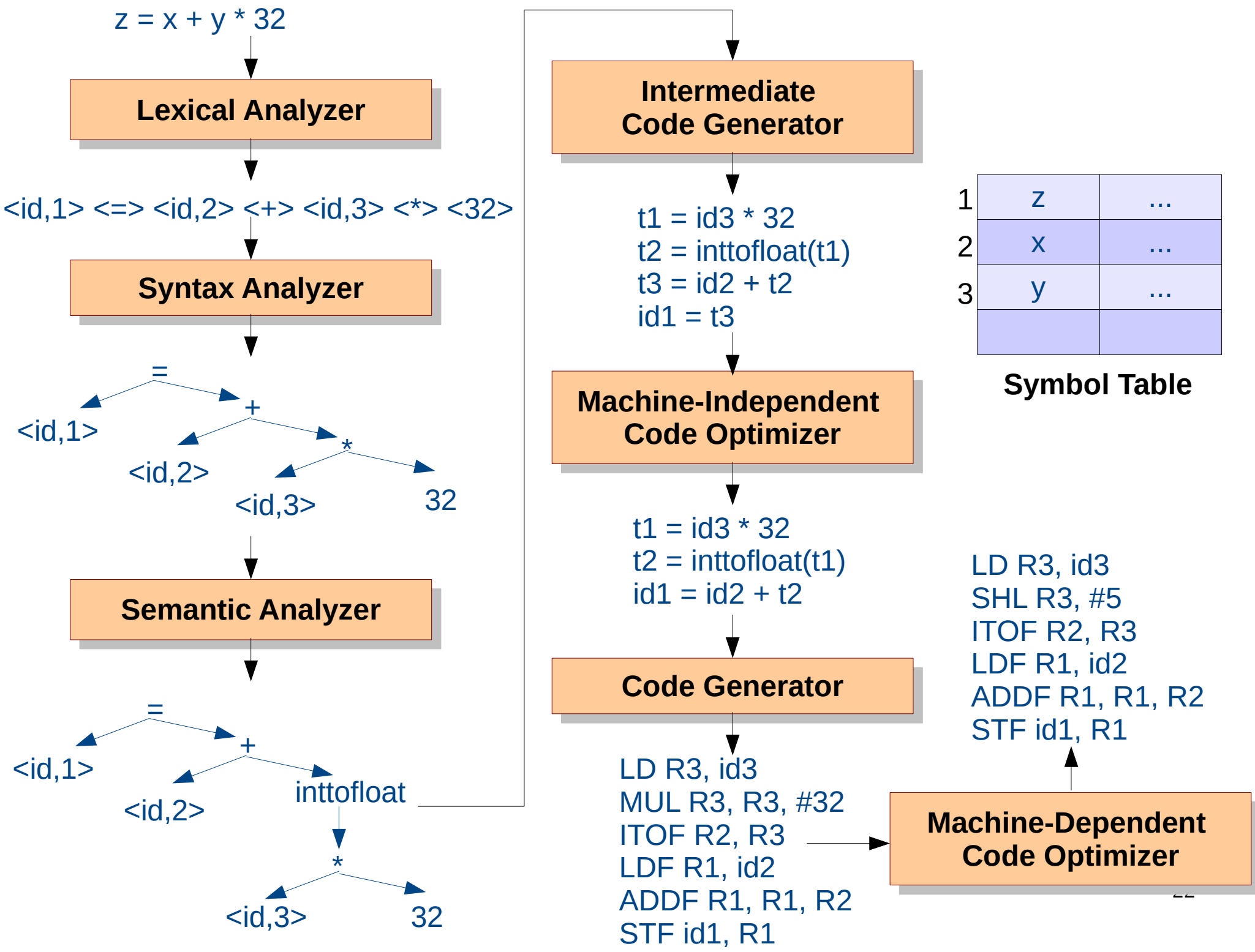
Language Translators

- **Preprocessor**: collects source programs, expands macros.
- **Compiler**: Translates source program into a low-level assembly.
- **Assembler**: Produces (relocatable) machine code.
- **Linker**: Resolves external references **statically**, combines multiple machine codes.
- **Loader**: Loads executable codes into memory, resolves external references **dynamically**.

Homework

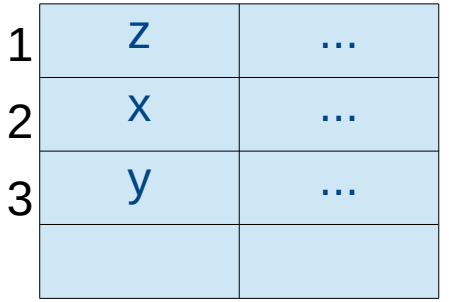
- Exercises 1.1.1-5 from ALSU.


Character stream
Lexical Analyzer
Token stream
Syntax Analyzer
Syntax tree
Semantic Analyzer
Syntax tree
Intermediate Code Generator
Intermediate representation
Frontend
Machine-Independent Code Optimizer
Intermediate representation
Code Generator
Target machine code
Machine-Dependent Code Optimizer
Target machine code
Backend
Symbol Table


z = x + y * 32
Lexical Analyzer
<id,1> <=> <id,2> <+> <id,3> <*> <32>
Syntax Analyzer
=
<id,1>
+
<id,2>
*
<id,3>
32
Semantic Analyzer
=
<id,1>
+
<id,2>
inttofloat
*
<id,3>
32
Intermediate Code Generator
t1 = id3 * 32
t2 = inttofloat(t1)
t3 = id2 + t2
id1 = t3
Machine-Independent Code Optimizer
t1 = id3 * 32
t2 = inttofloat(t1)
id1 = id2 + t2
Code Generator
LD R3, id3
MUL R3, R3, #32
ITOF R2, R3
LDF R1, id2
ADDF R1, R1, R2
STF id1, R1
Machine-Dependent Code Optimizer
LD R3, id3
SHL R3, #5
ITOF R2, R3
LDF R1, id2
ADDF R1, R1, R2
STF id1, R1
1 z ...
2 x ...
3 y ...
Symbol Table

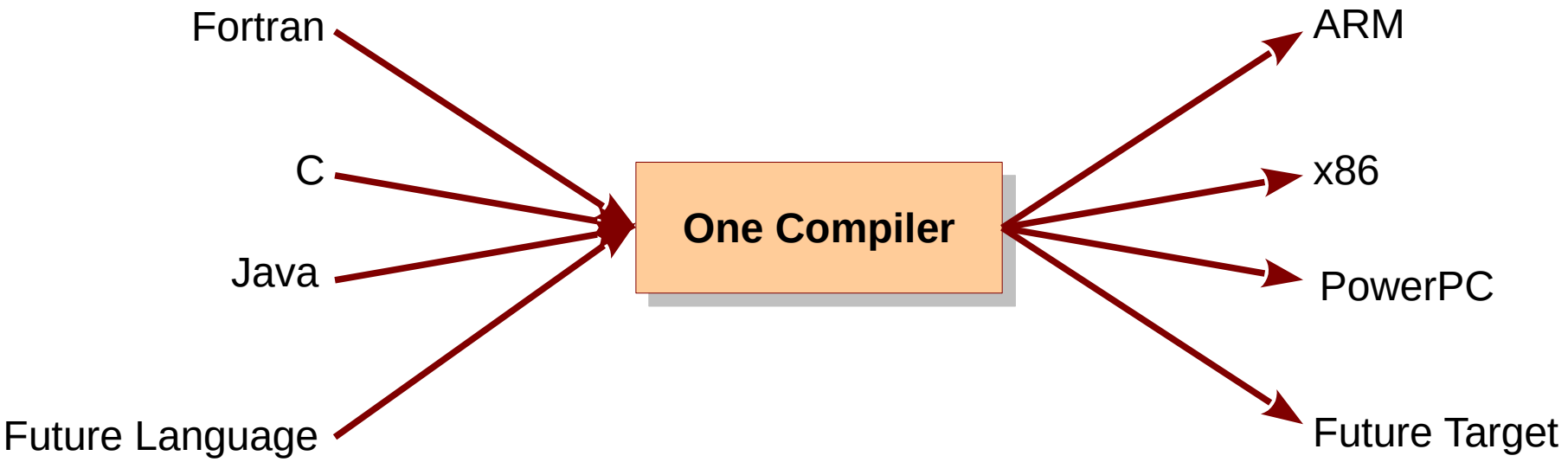
Symbol Table

- Records variable names
- Collects their attributes
  - Type (int, char)
  - Storage requirement ([30], 1)
  - Type modifiers (const, static)
  - Scope (global, static)
  - Information about arguments (for functions)
- Efficient insertion, search (sometimes deletion)
  - C: **int** x, y, z;
  - Pascal: **var** x, y, z: **integer**;

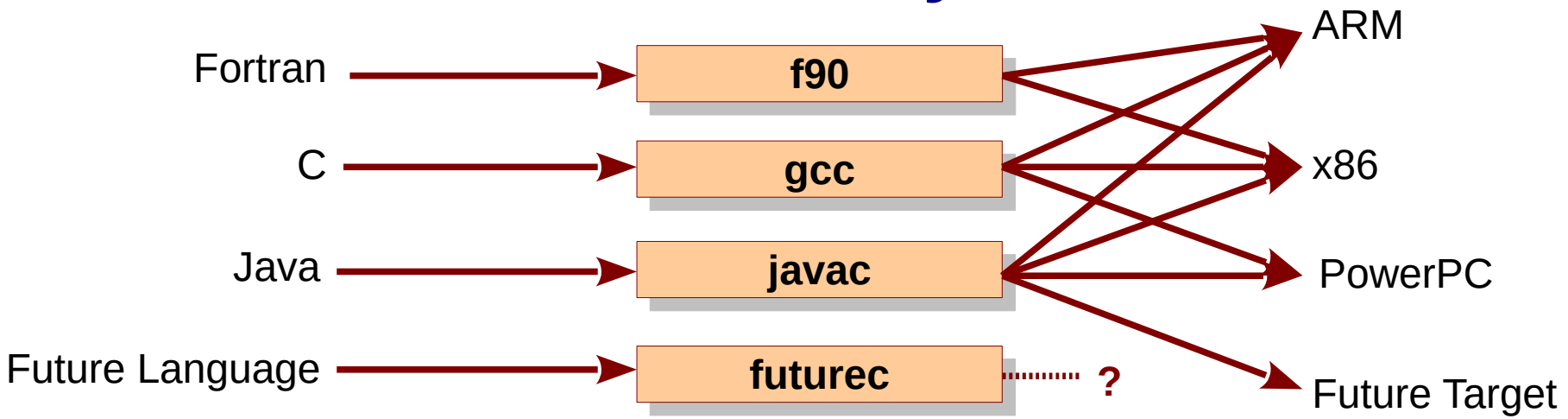


Symbol Table

Ideal World



Reality



Reality getting worse

- I don't have a compiler for this platform.
- My program compiles with an older version of gcc.
- My program compiles with the new version, but does not run on this new platform.
- My program compiles with an older gcc if you disable optimizations.
- My program compiles if you have llvm 5.4, clang 5.5, gcc 5.0.1 on x86_64 with lonestar 1.2 or above on Ubuntu 16 or below.

Evolution of Programming Languages

- First electronic computers in 1940s.
- Programmed in machine language (0 and 1).
  - Move data from one location to another.
  - Add the content of two registers.
  - Compare two values
  - ...
- S l o w, T e D i u s, and ErorrP run.

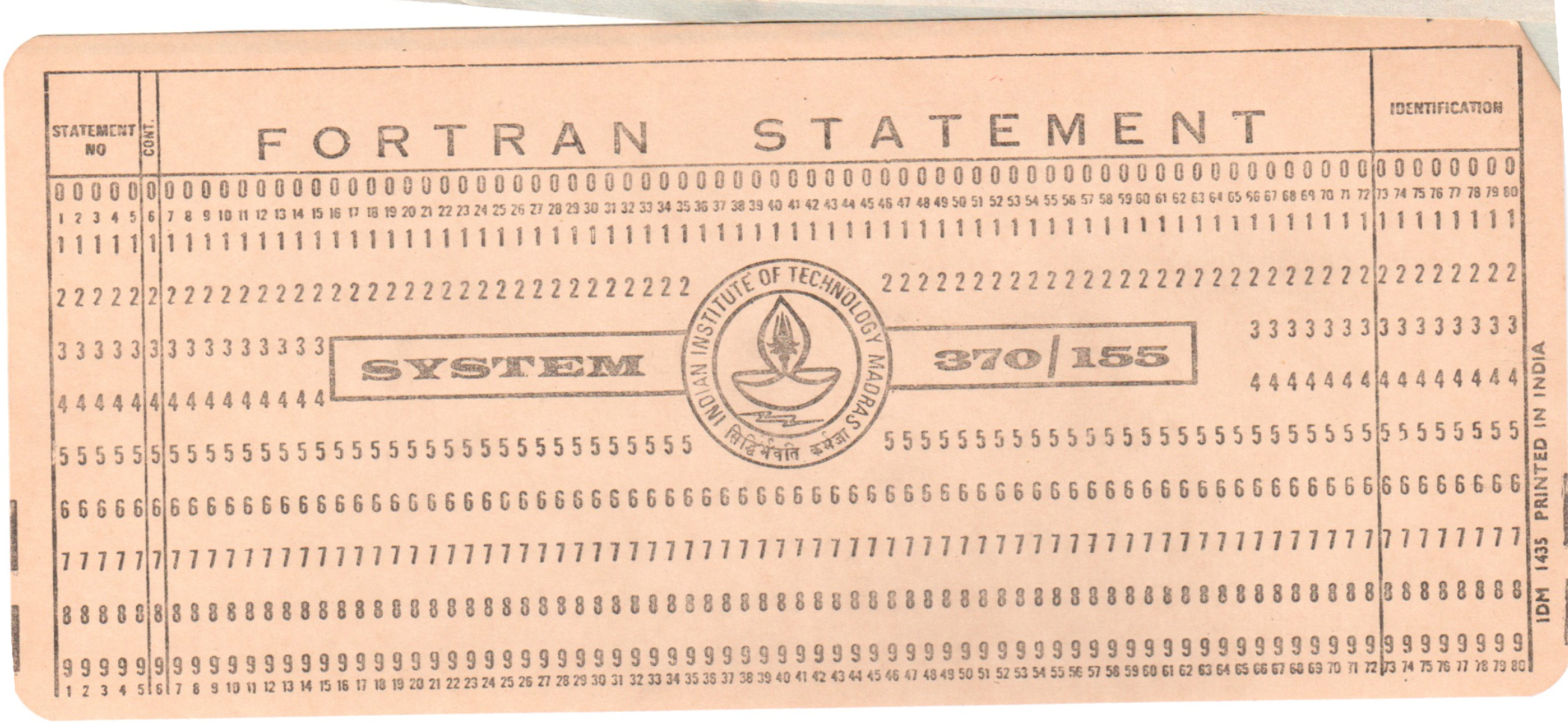
Maggie and Buildings

Punched Tape

Punched Card

Image source: wikipedia

Punched Tape



Punched Card

Courtesy: Deepak Khemani

Evolution of Programming Languages

- Assembly languages in early 1950s.
  - Initially, only mnemonics for machine instructions
  - Later, support for macros
- High-level languages in late 1950s.
  - **Fortran** for scientific computing
  - **Cobol** for data processing
  - **Lisp** for symbolic computation
  - These were so successful that they are still in use.

PL Classification

- Thousands of languages
  - Need to be categorized
- Based on paradigm
  - Imperative (c, c++, java), declarative (lisp, prolog)
- Based on generation *(think of generation gap)*
  - First (machine), second (assembly), third (fortran, cobol, lisp, c), fourth (sql, ps), fifth (prolog)
- Others
  - OO (c++, c#, Ruby), scripting (awk, js, php, python, ruby)

Compiler Writing

- is challenging.
- A compiler is a large program.
- A compiler must translate correctly potentially infinite set of programs that could be written in the source language.
- The problem of generating the optimal target code from a source program is undecidable.
  - Heuristics and Trade-offs.
- **Compilers is an area where Theory meets Practice.**

Static versus Dynamic

- Time
- Compilation
- Optimization
- Analysis
- Type
- Linking
- Scoping

Static versus Dynamic

- Time: compilation versus execution, preprocessor versus compilation
- Compilation: gcc versus jit
- Optimization: without and with input
- Analysis: without and with environment
- Type:
  - strongly typed versus scripting languages
  - inheritance and virtual functions
- Linking: .a versus .so
- Scoping

Static versus Dynamic

- Time
- Compilation
- Optimization
- Analysis
- Type
- Linking
- Scoping

```
int i = 1;
void f() {
    printf("%d", i);
}
void main() {
    int i = 2;
    f();
}
```

Static	Dynamic
1	2

Where do we use dynamic scoping?

Classwork

- Find the output of the program under static and dynamic scoping.

```
int a = 1, b = 2, y = 3;
void gun(int x, int b) {
	printf("%d %d\n", x, b);
}
void fun(int x, int y) {
	printf("%d %d\n", x, y);
	gun(a, y);
}
void main() {
	int a = 3;
	{
		int b = 4;
		fun(a, b);
	}
	gun(a, b);
	fun(a, b);
}
```

Parameter Passing

- Call by value
  - This happens in C
- Call by reference
  - Supported in C++, aliasing
- Call by name
  - Macros
- Call by value-result
  - Supported in ADA

```
int i = 1;
int *ip = &i;
void f(int x) {
      int y;
      x = 3;
      ip = &y;
      x = i+x+2;
}
void main() {
      f(*ip);
      printf("%d", i);
}
```

Call by value: 1
Call by reference: 8
Call by name: 3
Call by value-result: 6

Classwork

- Create an example that does not use pointers which produces different output under the four parameter passing schemes.