~~CS406~~

CS323: Compilers

Spring 2023

Week1: Overview, Structure of a compiler

Why Study Compilers?

Job Postings: 2022 LLVM Developers' Meeting (swoogo.com)

Modular

Company Contact: Mike Edwards - llvmjobs2022@modul

Job Title: AI Compiler Engineer

Very Very Exciting Jobs!

Job Title: Senior Apple GPU Compiler Backer

Job Description: As a member of the AGX compiler for current and future Apple GPUs room for growth that works on every Apple

arm

Company Description: Arm's processors are shipped in billions of produ with unique code generation challenges. LLVM is a foundational code ge Learning accelerators. For example, in the past year, 75 Arm engineer performance optimization, security hardening, support for new instruction

Company Contact: Kristof Beyls - kristof.beyls@arm.com

Job Title: Many LLVM-related jobs at Arm

Job Description: Your skills and knowledge of compiler fundamenta contribute to the LLVM community will help us develop innovative techn security of the entire field of computing.

Arm always has lots of LLVM-related job vacancies open.

MathWorks

Company Description: MATLAB® and Simulink® are the pro languages using state-of-the-art compiler technologies such as stringent demands—for speed, memory, area, standards com customers to implement their ideas and enable them to deplo customers and products span domains including Deep Lear Generation.

Company Contact: Akshatha Bhat - akshathb@mathworks.com

Job Title: Compiler Engineer LLVM, Senior Software Engineer - JI

ink® are the programming enable our customers to in

HUAWEI

Company Description: Founded in 1987, Huawei is a leading global pro technology infrastructure and smart devices. We invest heavily in f technological breakthroughs that drive the world forward. We have more t more than 170 countries and regions. Huawei's Heterogeneous Compiler L fastest growing teams in the field of compilation technology.

Company Contact: Shivani Bhardwaj - shivani.bhardwaj@huawei.com

Job Title: Junior Compiler Software Engineer

Job Description: Be a team player in a fast-paced R&D environment, wher - LLVM-based compilers targeting next-generation mobile, network, or serv

MEDIATEK

everyday genius

- Few disciplines with **deep theory + practice**

"..Theory and practice are two sides of the same coin.." - Jeff Ullman, ACM Turing Award lecture.

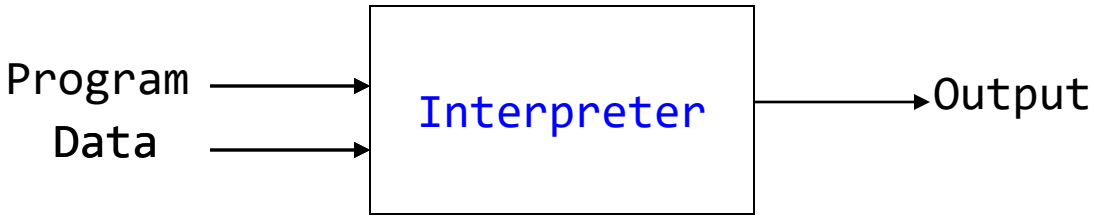
Intro to Compilers

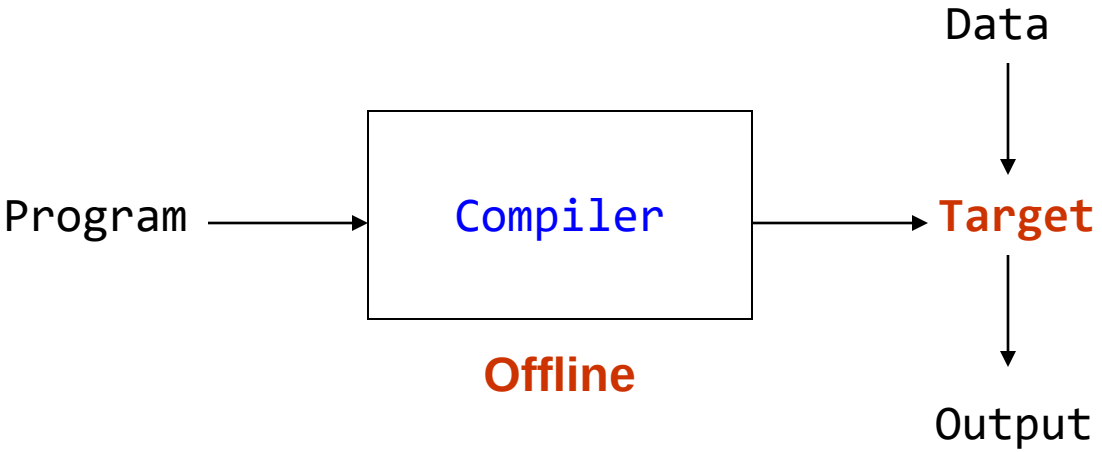
- One way to implement *programming languages*
  - Programming languages are notations for specifying computations to machines

  - *Target* can be an assembly code, executable, another source program etc.

Intro to Compilers

- Alternate way to implement programming languages



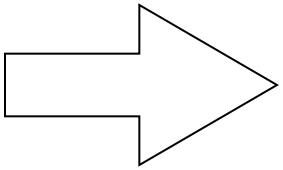


these are the two types of language processing systems

What is a Compiler?

Traditionally: Program that analyzes and **translates** from a high-level language (e.g. C++) to low-level assembly language that can be executed by the hardware

```
int a, b;
a = 3;
if (a < 4) {
    b = 2;
} else {
    b = 3;
}
```



```
    var a
    var b
    mov 3 a
    mov 4 r1
    cmpi a r1
    jge l_e
    mov 2 b
    jmp l_d
l_e:mov 3 b
l_d:;done
```


slide courtesy: Milind Kulkarni

Compilers are *translators*

- Fortran
- C
- C++
- Java
- Text processing language
- HTML/XML
- Command & Scripting Languages
- Natural Language
- Domain Specific Language

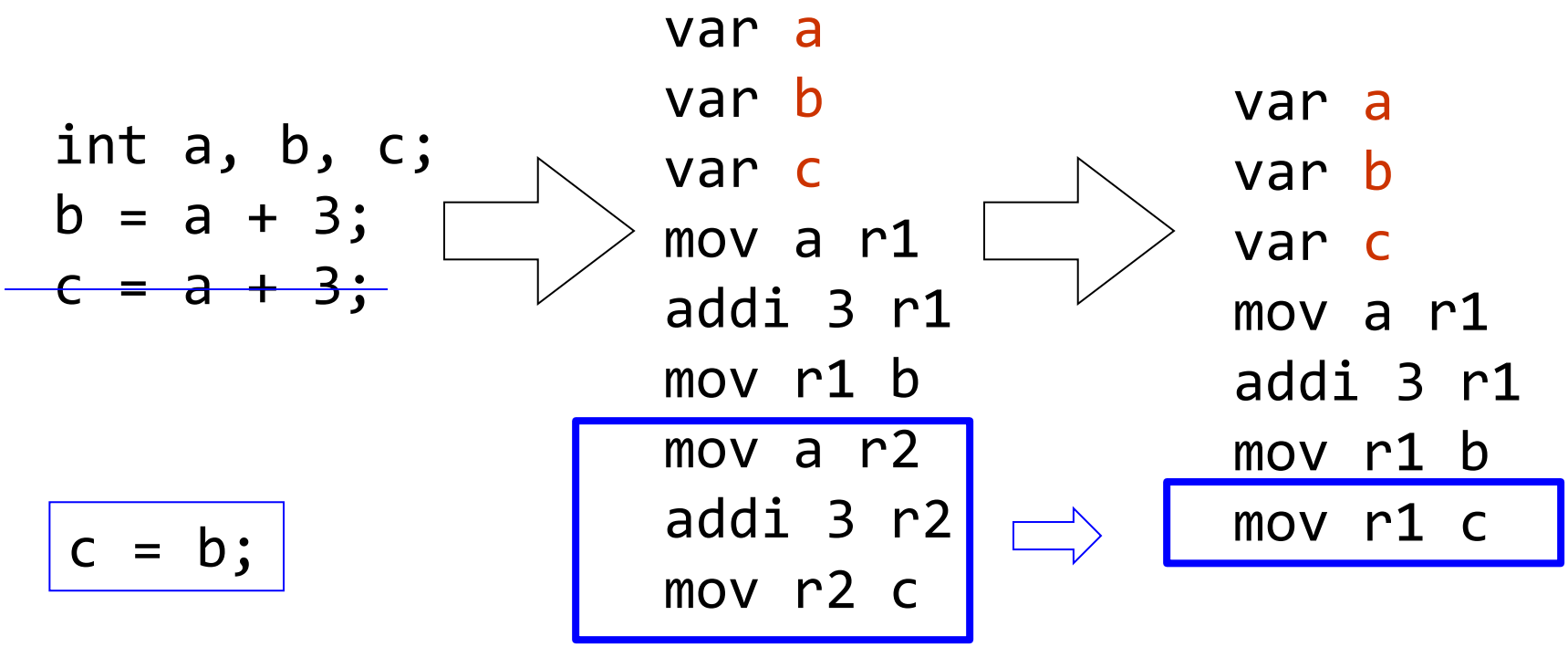
translate

- Machine code
- Virtual machine code
- Transformed source code
- Augmented source code
- Low-level commands
- Semantic components
- Another language

slide courtesy: Milind Kulkarni

Compilers are *optimizers*

- Can perform optimizations to make a program more efficient



slide courtesy: Milind Kulkarni

Why do we need compilers?

- Compilers provide *portability*
- Old days: whenever a new machine was built, programs had to be rewritten to support new instruction sets
- IBM System/360 (1964): Common Instruction Set Architecture (ISA) --- programs could be run on any machine which supported ISA
  - Common ISA is a huge deal (note continued existence of x86)
- But still a problem: when new ISA is introduced (EPIC) or new extensions added (x86-64), programs would have to be rewritten
- Compilers bridge this gap: write new compiler for an ISA, and then simply recompile programs!

slide courtesy: Milind Kulkarni

Why do we need compilers?

- Compilers enable high-performance and productivity
- Old: programmers wrote in assembly language, architectures were simple (no pipelines, caches, etc.)
  - Close match between programs and machines --- easier to achieve performance
- New: programmers write in high level languages (Ruby, Python), architectures are complex (superscalar, out-of-order execution, multicore)
- Compilers are needed to bridge this *semantic gap*
  - Compilers let programmers write in high level languages and still get good performance on complex architectures

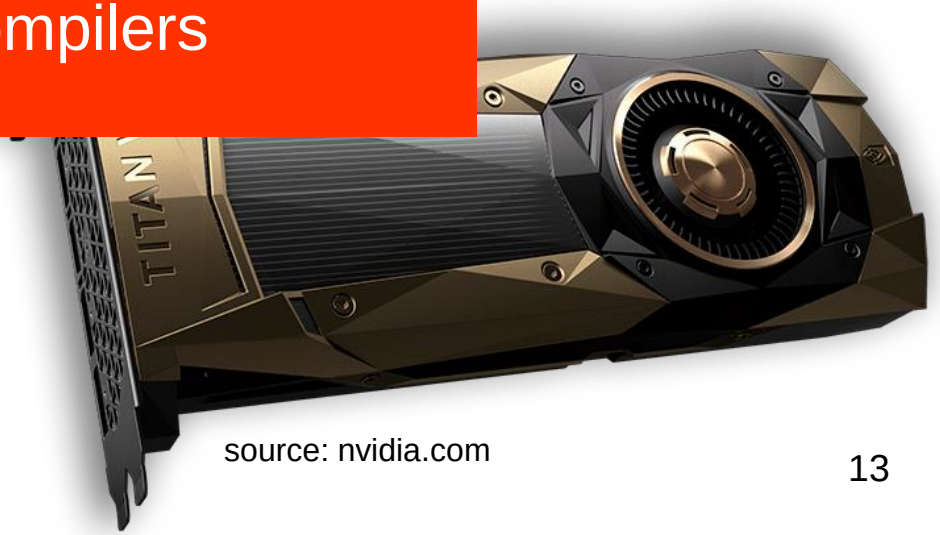
slide courtesy: Milind Kulkarni

Semantic Gap

- Python code that actually runs on GPU

```
import pycuda
import pycuda.autoinit from pycuda.tools import
make_default_context
c = make_default_context()
d = c.get_device()
……
```

Impossible without Compilers



source: nvidia.com

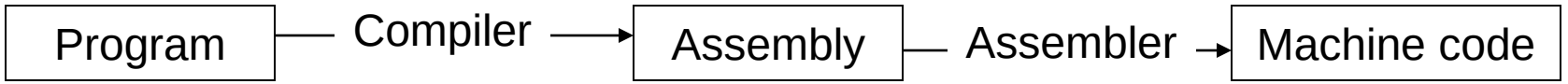
Example: Compilers as Translators

1. High level language $\Longrightarrow$ assembly language **(e.g. gcc)**
2. High level language $\Longrightarrow$ machine independent bytecode **(e.g. javac)**
3. Bytecode $\Longrightarrow$ native machine code **(e.g. java's JIT compiler)**
4. High level language $\Longrightarrow$ High level language

   (e.g. domain-specific languages, many research languages)

How would you categorize a compiler that handles SQL queries?

HLL to Assembly



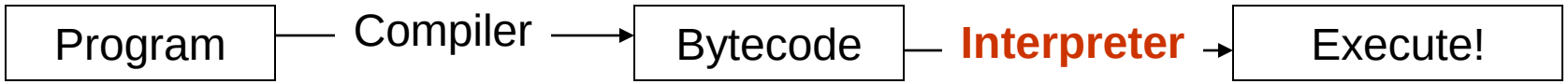
- Compiler converts program to assembly
- Assembler is machine-specific translator which converts assembly to machine code

```
add $7 $8 $9 ($7 = $8 + $9 ) => 000000 00111 01000 01001 00000 100000
```

- Conversion is usually one-to-one with some exceptions
  - Program locations
  - Variable names

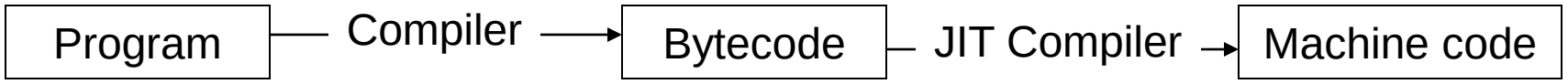
slide courtesy: Milind Kulkarni

HLL to Bytecode



- Compiler converts program into machine independent bytecode
  - e.g. javac generates Java bytecode, C# compiler generates CIL
- Interpreter then executes bytecode “on-the-fly”
- Bytecode instructions are “executed” by invoking methods of the interpreter, rather than directly executing on the machine
- Aside: what are the pros and cons of this approach?

HLL to Bytecode to Assembly



- Compiler converts program into machine independent bytecode
  - e.g. javac generates Java bytecode, C# compiler generates CIL
- Just-in-time compiler compiles code *while program executes* to produce machine code
  - Is this better or worse than a compiler which generates machine code directly from the program?

slide courtesy: Milind Kulkarni

History

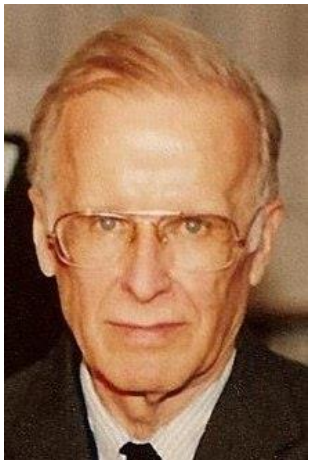
- 1954: IBM 704
  - Huge success
  - Could do complex math
  - Software cost > Hardware cost

Source: IBM Italy, https://commons.wikimedia.org/w/index.php?curid=48929471

How can we improve the efficiency of creating software?

History

- 1953: Speedcoding
  - *High-level programming language* by John Backus
  - Early form of *interpreters*
  - Greatly reduced programming effort



  - About 10x-20x slower
  - Consumed lot of memory (~300 bytes = about 30% RAM)

Fortran I

- 1957: Fortran released
  - Building the compiler took 3 years
  - Very successful: by 1958, 50% of all software created was written in Fortran
- Influenced the design of:
  - high-level programming languages e.g. BASIC
  - practical compilers

Today's compilers still preserve the structure of Fortran I