CSE 390B, Autumn 2022

Building Academic Success Through Bottom-Up Computing

Final Project Overview & Operating Systems

Final Project Overview, The Software Stack, Overview of Operating Systems, Project 8 Overview

Lecture Outline

- **Final Project Overview**
  - **E-Portfolio Details and Topics Brainstorming**
- The Software Stack
  - Roadmap of Hardware and Software Components
- Overview of Operating Systems
  - Abstraction, Protection, Processes, Virtual Memory
- Project 8 Overview
  - Micro Jack Details, Tips for Getting Started

Final Project E-Portfolio Overview

- You will create an E-Portfolio that is geared toward a new Allen School student
- Your E-Portfolio is a culminating project in having you reflect on the **metacognitive skills** you've learned and **providing advice** for entering the program
- During our final class, you will give a 6–8-minute presentation on your E-Portfolio

Final Project Due Dates

- Part I: E-Portfolio Outline
  - Due next Thursday (12/8) at 11:59pm
- Part II: Final E-Portfolio
  - Due Tuesday of finals week (12/13) at 4:00pm
- Part III: E-Portfolio Presentations
  - During the scheduled CSE 390B final
  - CSE 390B Final Time: Tuesday, 12/13 from 4:30-6:30pm
  - CSE 390B Final Location: CSE2 G04 (same as usual classroom)

Reflection on Metacognitive Skills

Individually first, take some time to reflect on the following questions, and then discuss in groups:

- Which two metacognitive topics would you consider including in your E-Portfolio and why?
  - Reflect on which ones you've grown the most in, have impacted you the most, were most challenging to grow in, etc.
- What are some examples of yourself demonstrating those two metacognitive skills?
  - Please be specific here! Aim to share these skills as if you are telling a story and showing concrete applications of these skills

Reflection on a Technical Skill

Individually first, take some time to reflect on the following questions, and then discuss in groups:

- What technical topic from CSE 390B would you consider including in your E-Portfolio and why?
  - Reflect on technical skills that helped connect the dots, were most interesting to you, most challenging for you to grasp, etc.
- What is the impact of having knowledge of that technical skill? In other words, why is that technical skill useful?
  - Please be specific here as well — think about how this technical skill would be useful in an academic or personal setting

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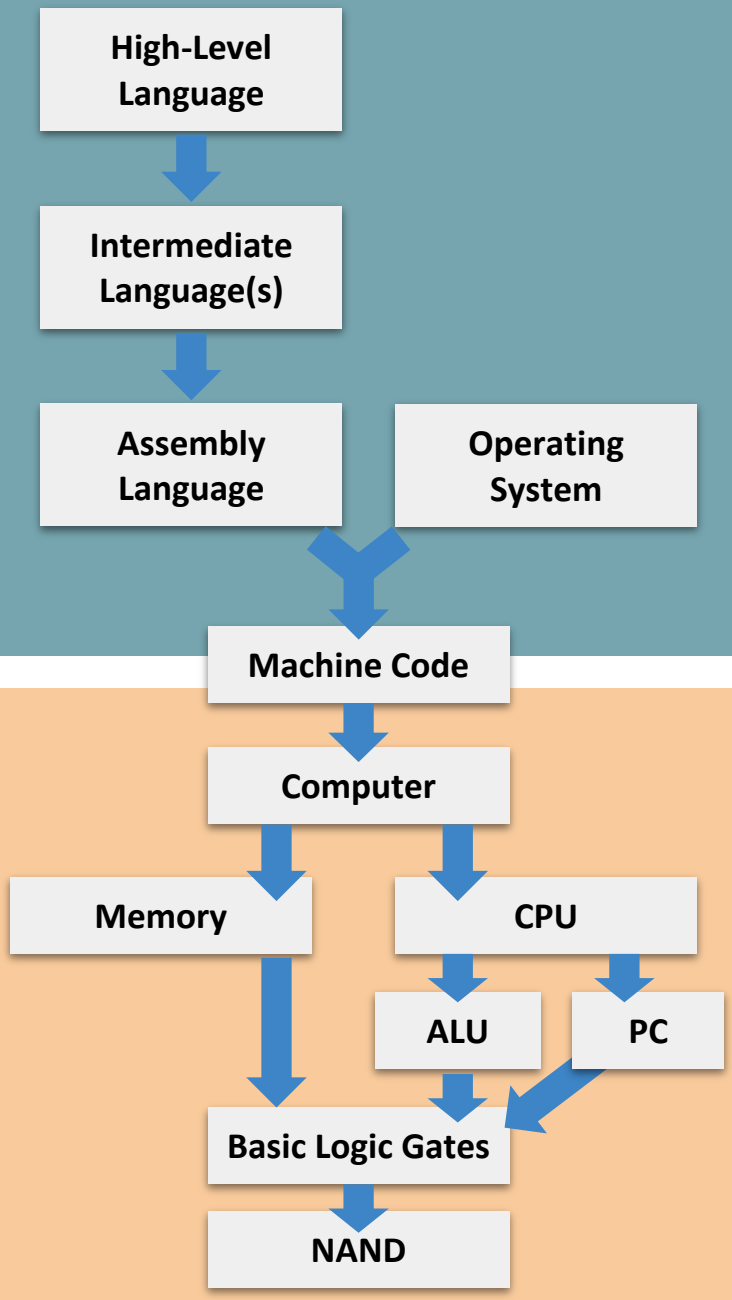
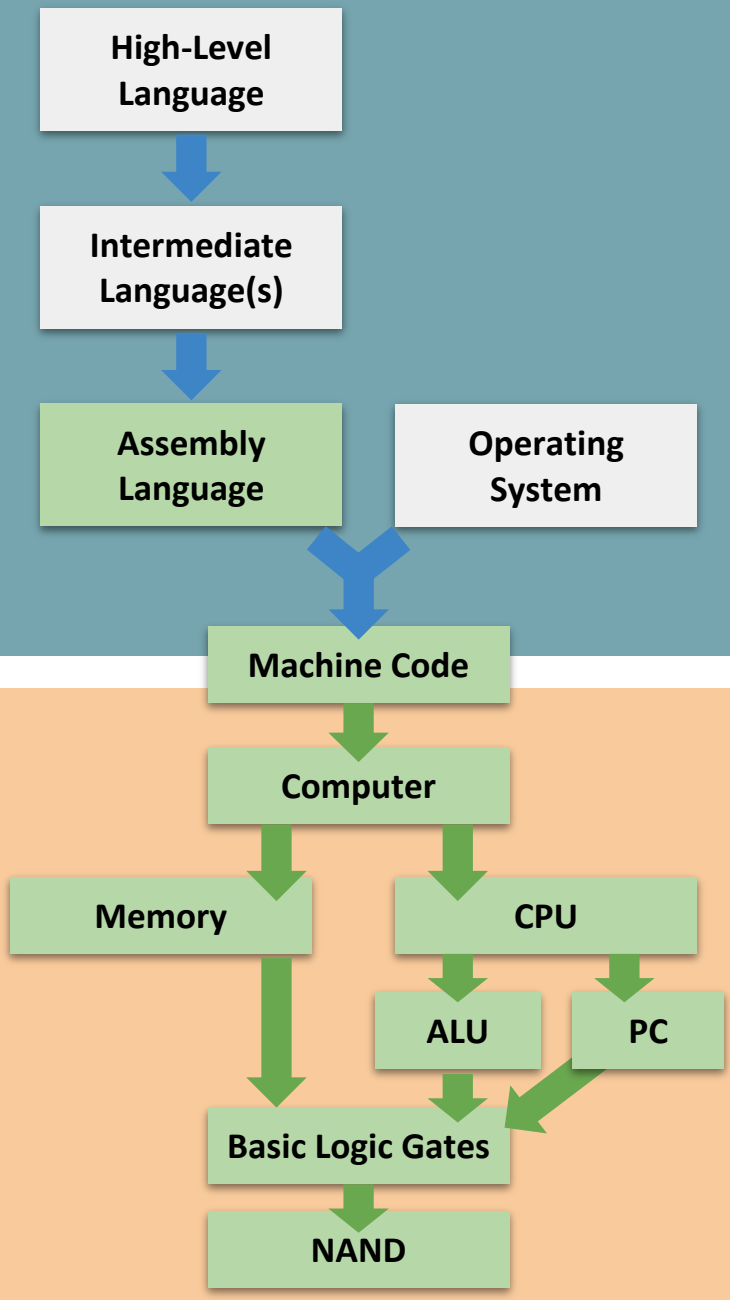
Roadmap


High-Level Language
Intermediate Language(s)
Assembly Language
Operating System
SOFTWARE
Machine Code
HARDWARE
Computer
Memory
CPU
ALU
PC
Basic Logic Gates
NAND

Roadmap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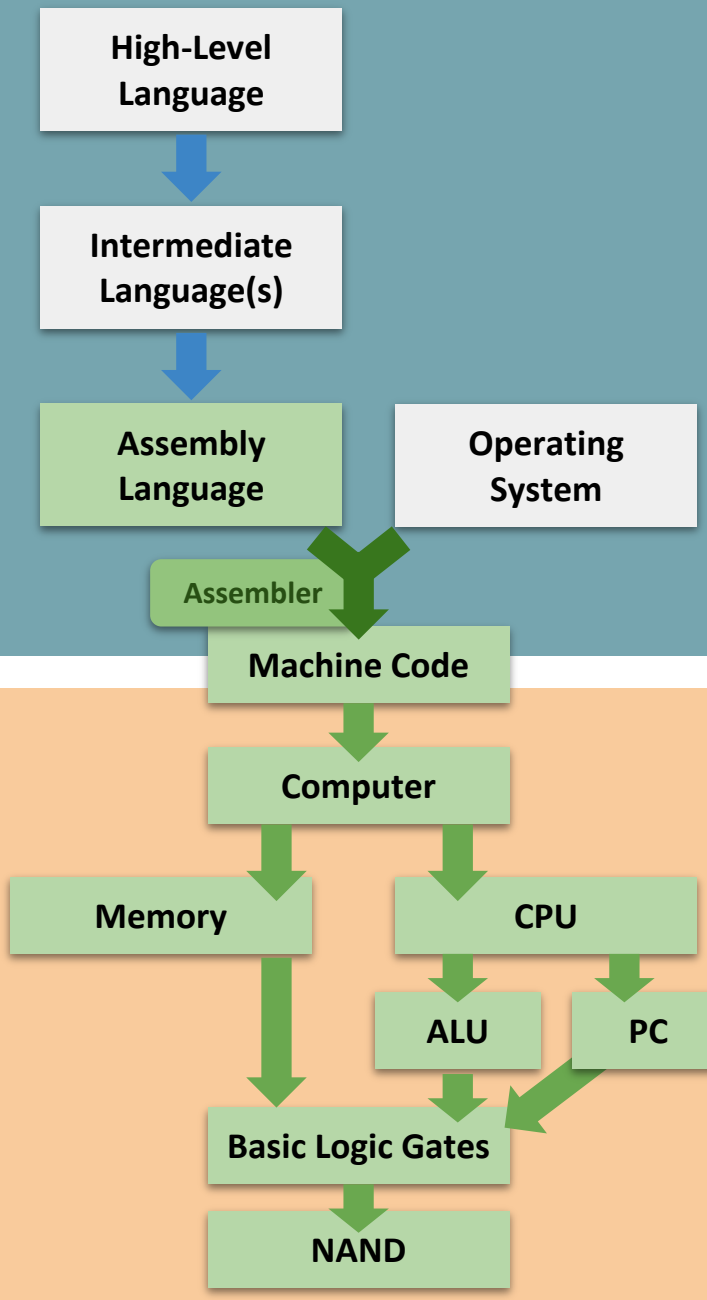
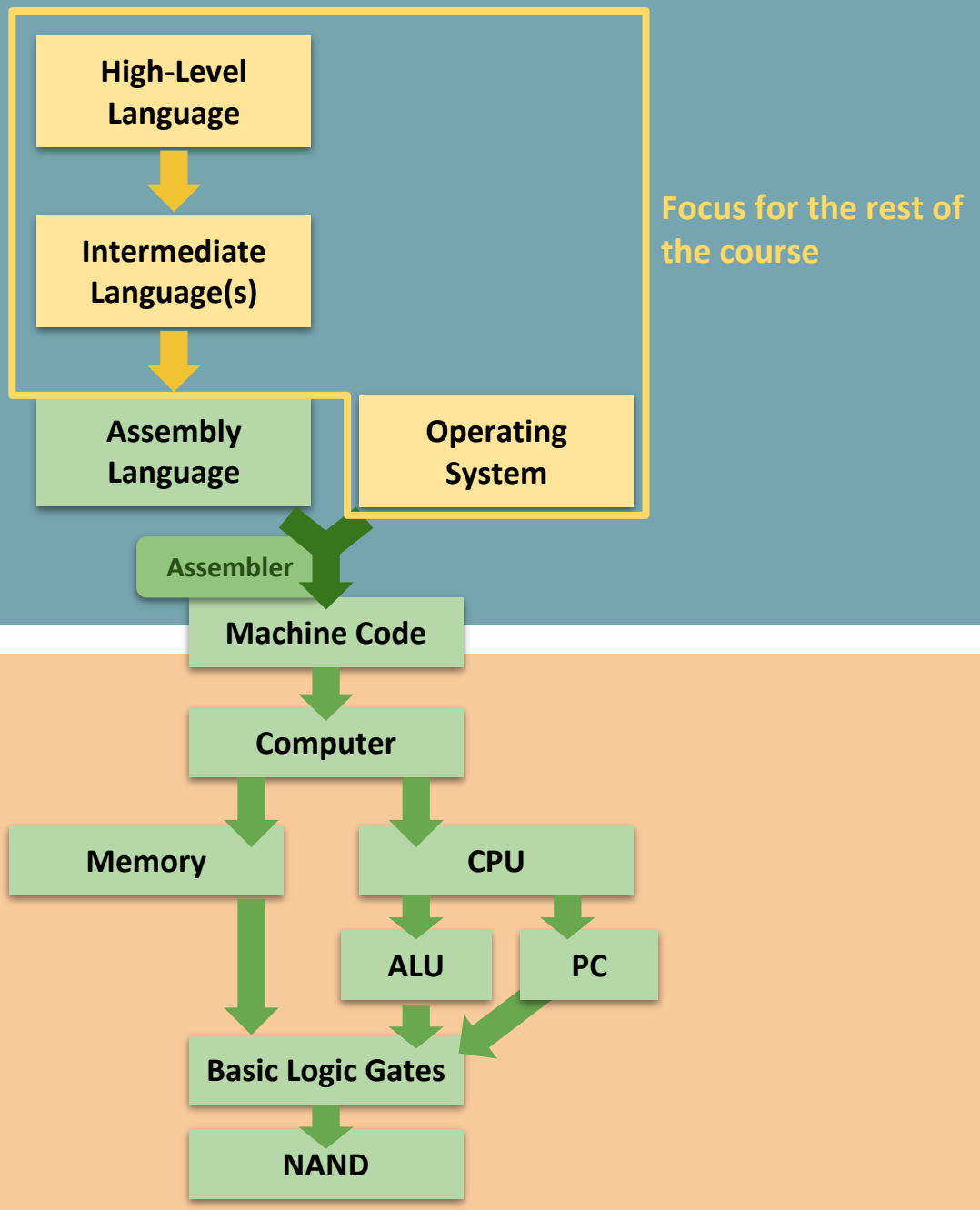


SOFTWARE

HARDWARE

Roadmap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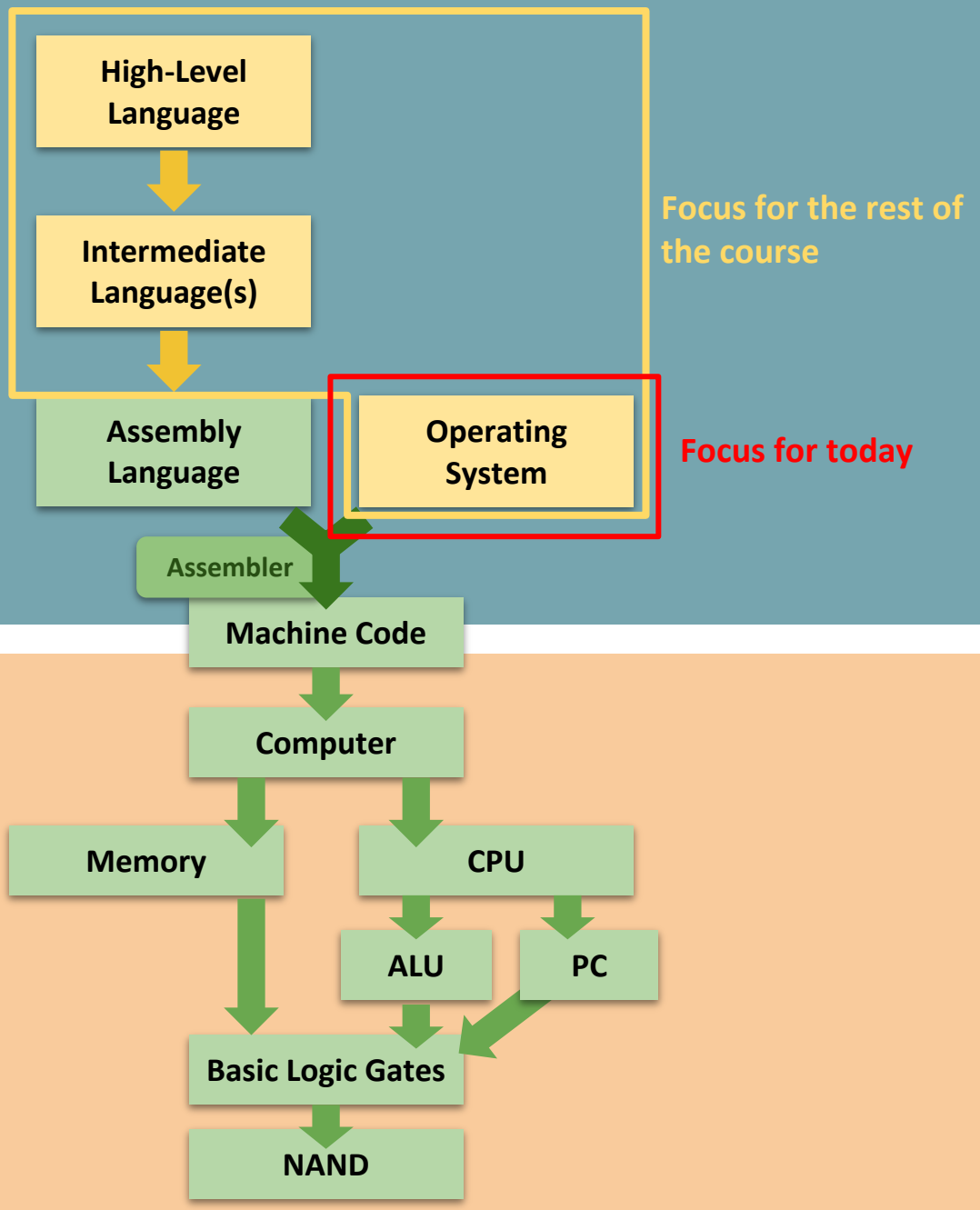
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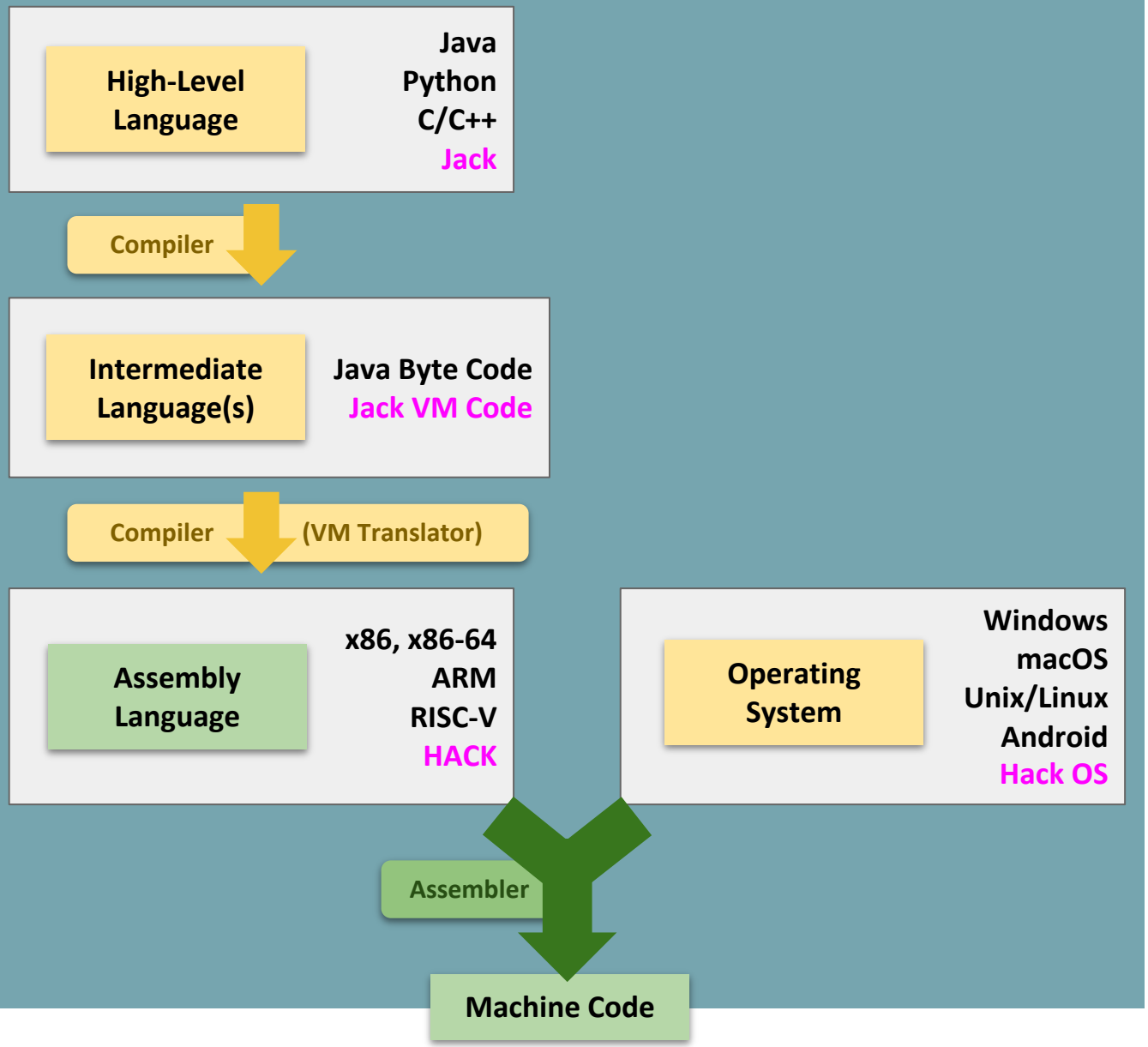
Software Overview



SOFTWARE

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The Operating System

- The operating system (OS) is just another piece of software
  - A massive, complex piece of software
  - In the end, uses the same machine language your code does
- OS is more trusted than the rest of the software that runs on your computer
- User programs and applications invoke (ask) the OS to perform operations they are not trusted or allowed to
  - Means the OS needs to be secure

Why an Operating System?

- Directly interacts with the hardware

- Benefit: **Abstraction**
  - Provides high-level functionality for messy hardware devices
  - OS must be ported to new hardware, but user-level programs can then be portable

- Benefit: **Protection**
  - OS is trusted to touch hardware; user-level programs are not
  - Prevents user-level programs from causing errors in the hardware
  - Maintains security between programs and user accounts

Operating Systems: Abstraction

- Many abstractions provided by real-world operating systems

- File System
  - File contents = just bits in the "giant array" that is the hard drive ("permanent" storage, as opposed to temporary storage in RAM that disappears when computer is turned off)
  - OS keeps a record of which ones fall into which "files"

Operating Systems: Abstraction

- Many abstractions provided by real-world operating systems

- Network Stack
  - Communicating with network devices ≈ communicating with screen/keyboard memory map
  - OS handles messy, time-sensitive protocols

- Processes
  - Only one process can run at once on a CPU
  - Operating systems can manage resource sharing
  - OS switches very quickly, illusion of running both “at once”

Operating Systems: Protection

- The CPU has different "privilege" levels when it is executing (controlled by a register on the CPU)

- OS code and memory can only be executed by an OS privilege level
  - Your applications run at a lower level and cannot access OS code and memory

- This prevents applications from crashing entire system
  - For example, if your web browser crashes, usually it doesn't crash your entire computer
  - Also helpful for security purposes

Operating Systems: Protection

- Example: Suppose we want only the OS to be allowed to run instruction **`SET_ON_FIRE`**
  - But if the OS is just a machine code program like any other… what's the security hole?

Operating Systems: Protection

- Example: Suppose we want only the OS to be allowed to run instruction **`SET_ON_FIRE`**
  - But if the OS is just a machine code program like any other… what's the security hole?

Your Code

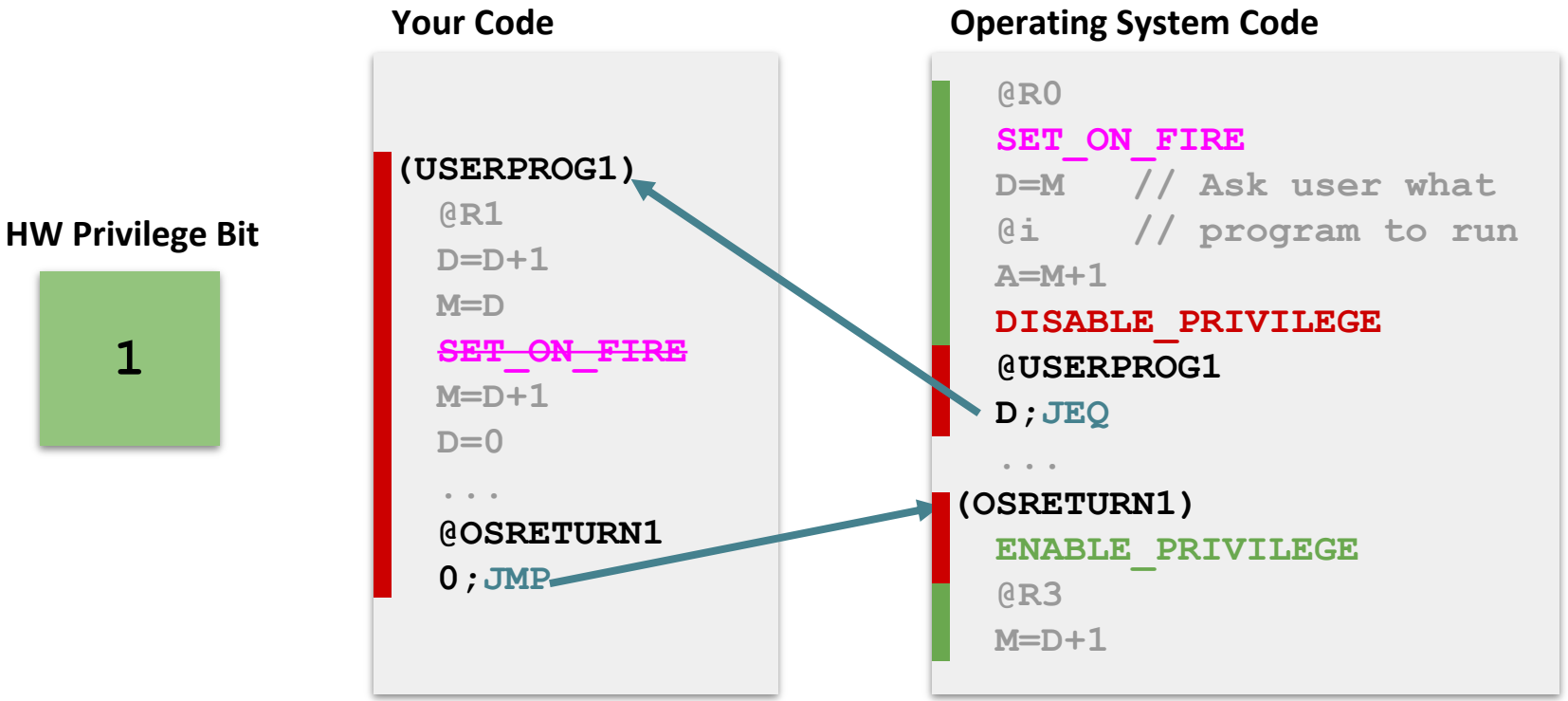
```
(USERPROG1)
  @R1
  D=D+1
  M=D
  SET_ON_FIRE
  M=D+1
  D=0
  ...
  @OSRETURN1
  0;JMP
```

Operating System Code

```
  @R0
  D=M    // Ask user what
  @i     // program to
run
  A=M+1
  M=-D
  @USERPROG1
  D;JEQ
  ...
(OSRETURN1)
  @R3
  M=D+1
```

Operating Systems: Protection

- The fix: hardware bit for "privileged mode"
  - Processor checks before running SET_ON_FIRE
  - OS disables before jumping to user code, re-enables on return
    - (Processor also must check that user code can't enable privilege)



Operating System: Processes

- A "process" is an application running on your computer
  - E.g., your web browser, terminal, Microsoft Word, etc.
- Each app instance contained in one or more processes
  - The OS manages these processes
- Multiple processes are "running" at the same time, but it's just the OS quickly switching between them
- A process only has access to its memory, and cannot access the memory of other processes
  - This is helpful because if one process crashes or is malicious, it makes it more difficult to crash or corrupt other processes too

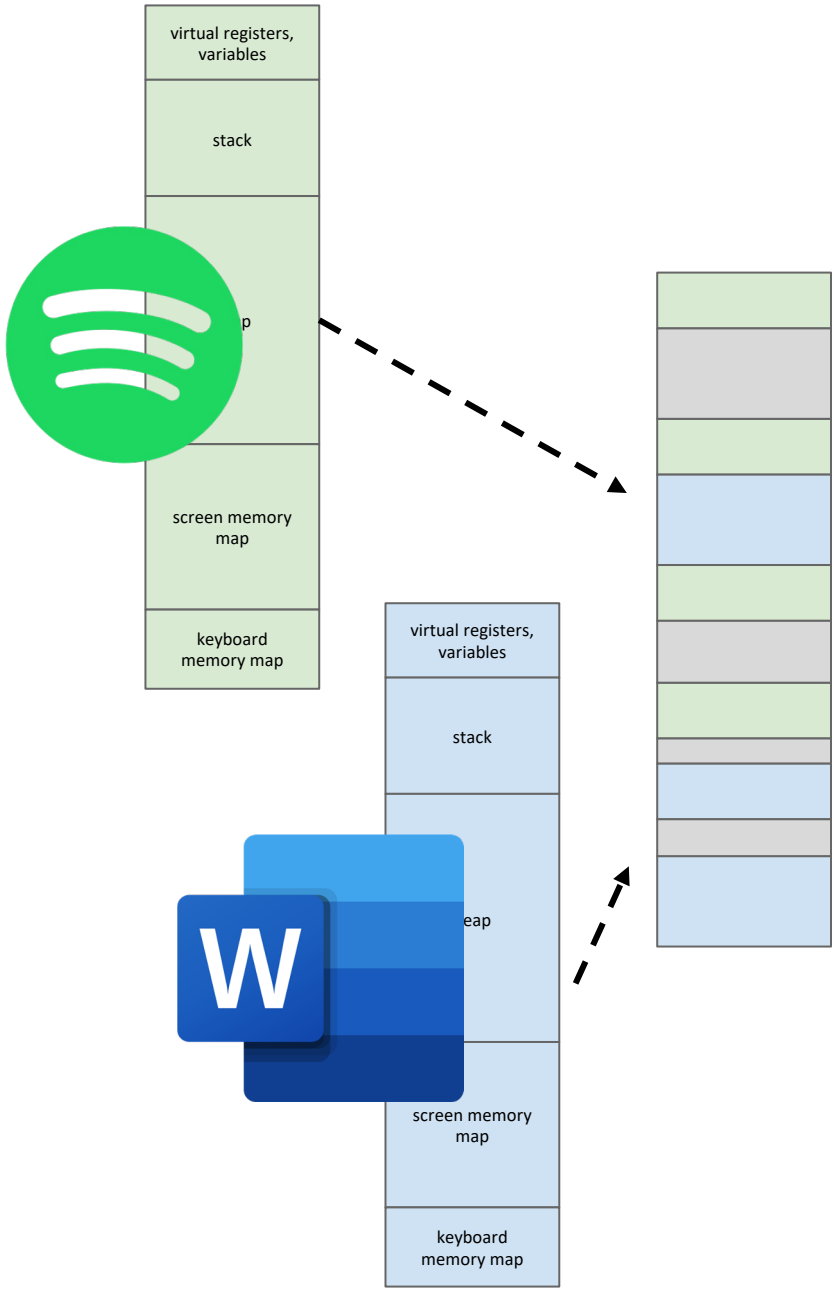
Why *Not* an Operating System?

- The Hack computer we've built is… small
  - Uses the same principles as your laptop CPU
  - But in terms of scale, closer to a microprocessor or small embedded chip

- For embedded systems, often an OS is overkill—instead, designed to be programmed with/run a single program at a time
  - Pro: developer gets complete control over the device
  - Con: re-implement OS features, no protection

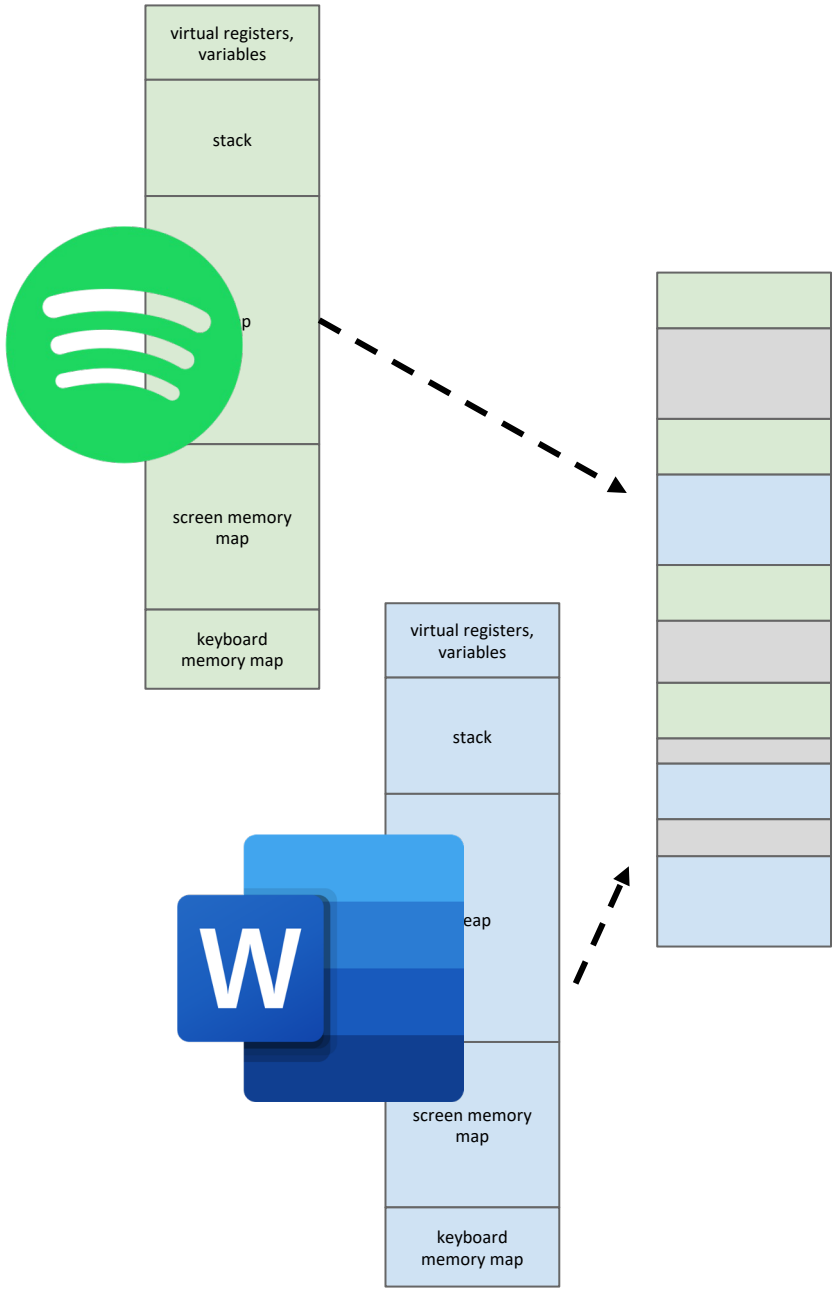
Virtual Memory

- Most OS's allow multiple processes, but shouldn't be able to modify values in another's address space
- OS provides illusion of separate address spaces via virtual memory
  - Really all one physical memory
  - OS & hardware map pieces of virtual memory to pieces of physical memory



Virtual Memory

- **Benefit of security**: Programs only know about their own address space
  - Don't even have a way to describe address of other application's data
- **Drawback is efficiency**
  - Virtual address translation is fast nowadays, but still slower than directly accessing memory



Comparison of Operating Systems

- Three different ways to do essentially the same thing
  - Everyone has their own preference
- Each has their own benefits and tradeoffs
  - Work on varying types of hardware, provide different levels of customization, different features, work better with different software, open source vs. proprietary, etc.
- You could choose to do some research next time you are deciding on a laptop, computer, or OS

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- **Project 8 Overview**
  - **Micro Jack Details, Tips for Getting Started**

Project 8 Overview

- You will be given starter code for a compiler that reads a micro version of Jack and spits out Hack

- The Scanner & Parser are working
  - Task A: read through comments to understand what's going on

- The Code Generation is buggy and half-finished
  - Task B: find the bugs by practicing deliberate debugging strategies (e.g., step through generated Hack code using CPUEmulator)
  - Task C: Complete the implementation of the compiler

Project 8: Micro Jack

- Stripped-down version of Jack language
  - More manageable but enough features to be interesting
- Available features:
  - Types: **`int`** and **`int[]`**, **`var`**
  - Structures: **`if`**, **`while`**, **`+`**, **`-`**, **`==`**, **`!=`**
- Missing features:
  - Functions, function calls, classes, objects, strings, for loops, array bounds checking, etc.

Any number of variable declarations

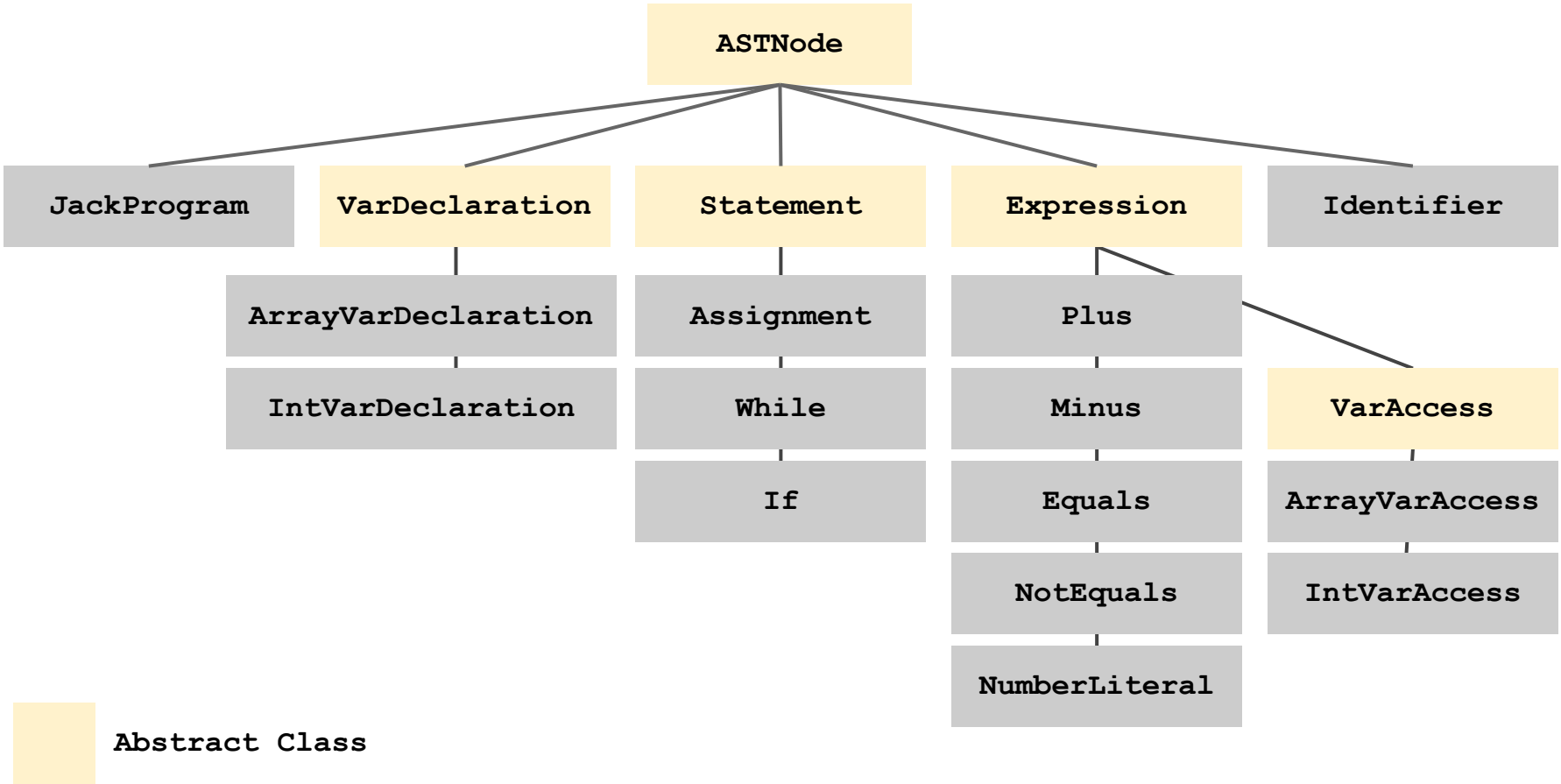
`Basic.jack`

```
var int a, b[1], c;
var int d[10], e;

let a = 1;
let b[0] = 1;
let n = 9;
while (n != 0) {
  let d[n] = a;
  let n = n - 1;
}
let screen[100] = d[0];
```

Then any number of statements

Project 8: The AST Nodes

- You are provided with all AST Node classes needed
  - All your code will be implemented within these classes



Project 8: Generating Code

- Each AST node has a printASM method that should print out Hack instructions to System.out (and recursively call printASM on children)
  - You're provided with **`instr("@R0")`** and **`label("LOOP")`** convenience functions
  - Each can take a comment as a second argument — highly recommended!

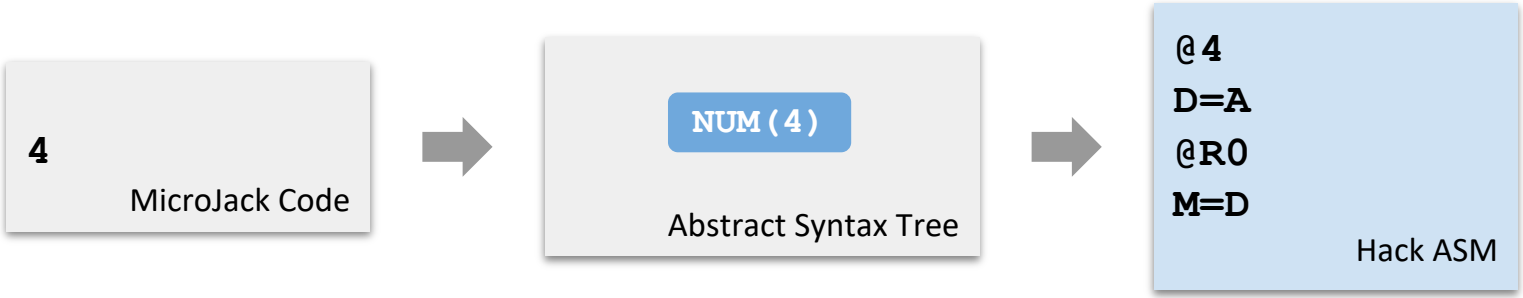
```
public class If extends Statement {
    public Expression condition;
    public List<Statement> statements;

    @Override
    public void printASM(symbolTable) {
        condition.printASM(symbolTable);
        instr("@R0", "Get cond result");
        instr("D=M");

        ...
    }
}
```

Project 8 Overview

- Step 1: Read comments provided in the starter code
- Step 2: Implement **`NumberLiteral.java`** (~4 lines)
- Step 3: Debug **`Plus.java`** (2 bugs)
- Step 4: Implement **`Minus.java`** (~13 lines, similar to **`Plus.java`**)
- Step 5: Implement **`NotEquals.java`** (~21 lines, similar to **`Equals.java`**)
- Step 6: Implement **`ArrayVarAccess.java`** (~3 lines)
- Step 7: Debug **`If.java`** (2 bugs)
- Step 8: Implement **`While.java`** (~14 lines)

Example: Number Literal (Step 1)

- Called a "literal" because it's a literal value embedded in the Micro Jack code
  - Generated Hack Assembly should simply put that value in R0



Example: Number Literal (Step 1)

```
public class NumberLiteral extends Expression {
    public int value;

    public NumberLiteral(String value) {
        this.value = Integer.parseInt(value);
    }

    @Override
    public void printASM() {
        comment("Start Number Literal");
        instr( ? );
        instr("D=A");
        instr("@R0");
        instr("M=D");
        comment("End Number Literal");
    }

    @Override
    public String toString() {
        return Integer.toString(value);
    }
}
```

4

```
// Start Number Literal
@4
D=A
@R0
M=D
// End Number Literal
```

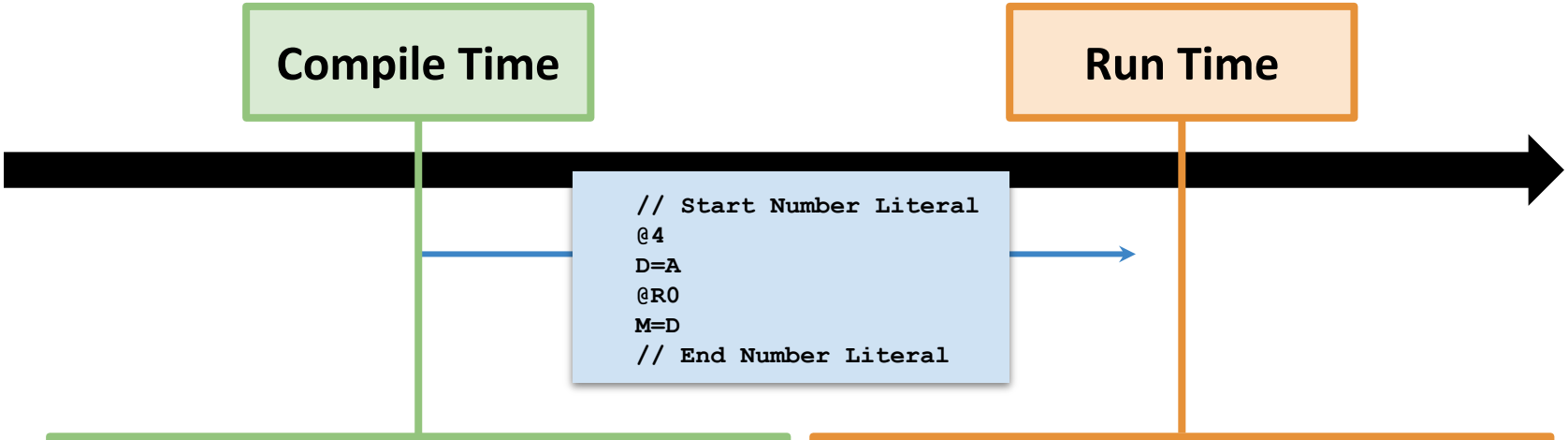
Example: Number Literal (Step 1)

```
public class NumberLiteral extends Expression {
    public int value;

    public NumberLiteral(String value) {
        this.value = Integer.parseInt(value);
    }

    @Override
    public void printASM() {
        comment("Start Number Literal");
        instr("@" + toString());
        instr("D=A");
        instr("@R0");
        instr("M=D");
        comment("End Number Literal");
    }

    @Override
    public String toString() {
        return Integer.toString(value);
    }
}
```

4

```
// Start Number Literal
@4
D=A
@R0
M=D
// End Number Literal
```

Example: Number Literal (Step 1)



- Java (the compiler) is running
- 4 is stored as value field inside an NumberLiteral ASTNode
- When executed, **prints code that stores it another way**!

```
public class NumberLiteral extends Expression {
    public int value;

    public NumberLiteral(String value) {
        this.value = Integer.parseInt(value);
    }

    @Override
    public void printASM() {
        comment("Start Number Literal");
        instr("@" + toString());
        instr("D=A");
        instr("@R0");
        instr("M=D");
        comment("End Number Literal");
    }

    @Override
    public String toString() {
        return Integer.toString(value);
    }
}
```

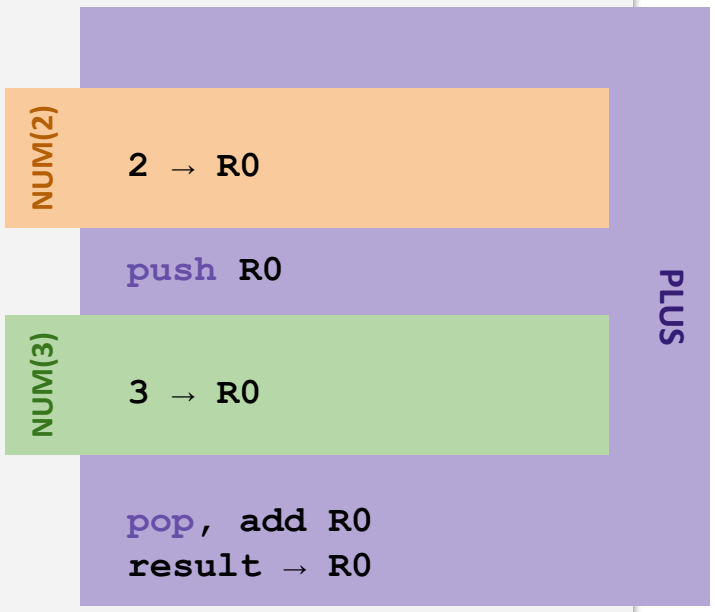
- Hack ASM (the output) is running
- 4 is stored as constant inside an assembly instruction
- When executed, loads 4 from instruction into A register

Example: Plus (Step 2)

```
public class Plus extends Expression {
    public Expression left;
    public Expression right;

    @Override
    public void printASM() {
        comment("Start Plus");

        left.printASM();

        instr("@R0");
        instr("D=M");

        right.printASM();

        push();

        instr("@R1");
        instr("A=M");

        instr("D=D+A", "perform the addition");

        ...
```

Example: Plus (Step 2)

1 Structural Bug: Map to abstract diagram for Plus:




```
public class Plus extends Expression {
    public Expression left;
    public Expression right;

    @Override
    public void printASM() {
        comment("Start Plus");

        left.printASM();

        instr("@R0");
        instr("D=M");

        right.printASM();

        push();

        instr("@R1");
        instr("A=M");

        instr("D=D+A", "perform the addition");

        ...
```

1 Detail Bug: Step through generated code, Check state at each step

Micro Jack Technical Details

- Can't write a negative integer literal
  - Instead, use subtraction from zero: `0 - 1`
- All variable declarations must come before all regular statements
  - Why? Simplifies concept of a "defined" variable
- No defined operator precedence
  - If order matters for an operation, use parentheses

Micro Jack Technical Details

- Arrays are just as you would expect
  - **`arr[index]`** just calculating an address: take address of **`arr`** variable and add index to it as an offset
  - No array bounds checking — you can run off the end of an array

- Booleans are just 0 (false) and non-zero (true)

Project 8: Debugging Tips

- Try walking through the general **`printASM`** code to understand why each line is there
  - Add comments to the assembly as you go! Much easier to understand resulting file
- Find the smallest example you can
  - Provided tests get progressively more complex, but you may want to write your own tiny test case to isolate
  - **`printASM`** methods can get long fast—we've added comments so you can isolate to the section you're working on
- "Play Computer": as you step through the code, write down the state you expect after each instruction, then advance and see if the CPUEmulator agrees

Additional Project 8 Tips

- When debugging assembly, a good first step is to try understanding the code and adding comments to the assembly as you go
  - Much easier to understand resulting file

- A **`printDebug`** method has been implemented for you on all AST nodes
  - Use it to visualize exactly what the parser is giving you, but also as a basis for **`printASM`**
  - Both need to do processing on the current node and strategically recurse on its children

Additional Project 8 Tips

- Pushing and popping from the stack can be intimidating, but formulaic
  - Understand it once, copy and paste afterward
  - **`push()`** and **`pop()`** are already implemented for you

- We provide only a few Micro Jack test files
  - We encourage you to write more of your own (think back to the debugging lecture)
  - Can use **`Sandbox.*`** to write more tests or create your own files

Project 8 Tools Practice

- Practice using the Project 8 tools — try the following:
  - Run **`git pull`** to pull the Project 8 starter code
  - Navigate to the **`src`** directory: **`cd src`**
  - Compile the Java source code of the compiler by running: **`javac $(find . -name "*.java")`**
  - Use your compiler to compile the Jack file for the **`OnlyVars.jack`** program: **`java compiler/Compiler compile ../test/OnlyVars.jack`**
  - Load and run **`OnlyVars.tst`** in the CPUEmulator

- The above steps were taken from the "How to Run Tests" portion of the specification
  - Can refer to this when needed as you work through the project

Post-Lecture 17 Reminders

- This Thursday's Lecture: Final Project E-Portfolio Workshop & Computer Networks

- Project Reminders
  - **Project 7, Part II (Professor Meeting Report) due this Thursday (12/1) at 11:59pm**
  - Project 8 (Debugging & Implementing a Compiler) due next Tuesday (12/6) at 11:59pm
  - Final Project, Part I (E-Portfolio Outline) due next Thursday (12/8) at 11:59pm

- Check Canvas for late updated late days through Project 6