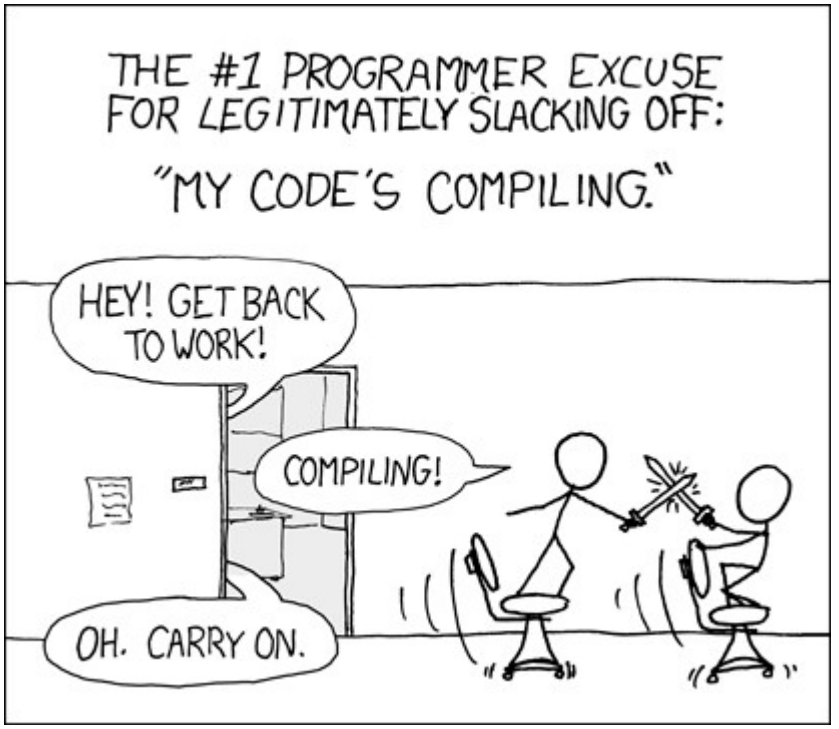
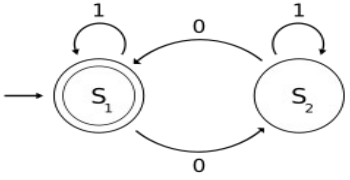
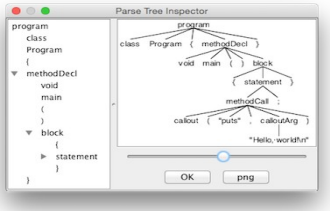
CS 432
Fall 2018

Mike Lam, Professor





Compilers



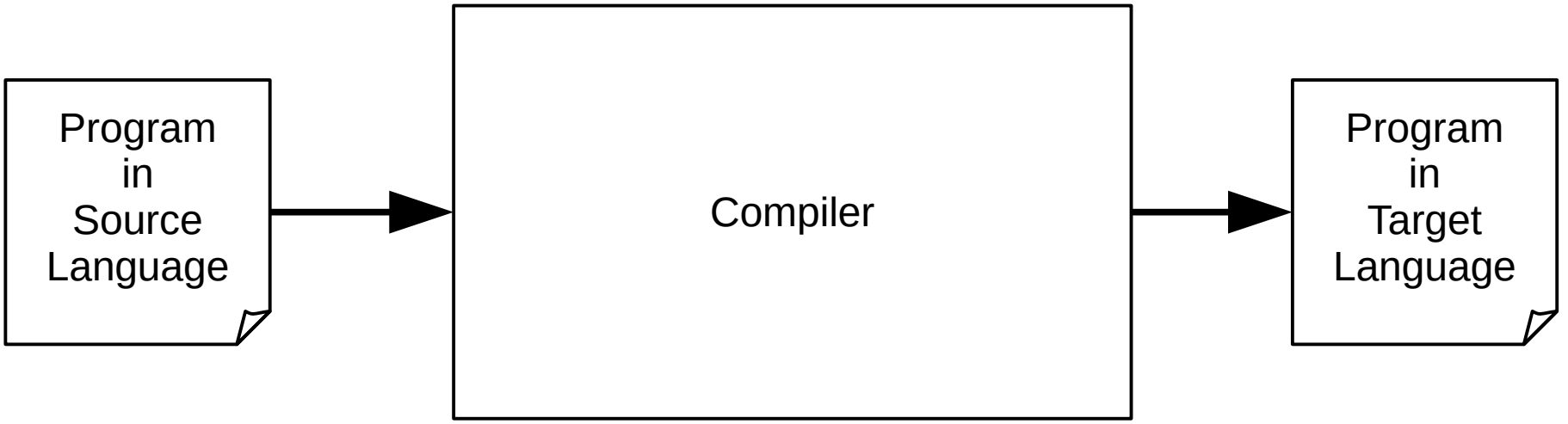
Advanced Systems Elective

Discussion question

- What is a compiler?

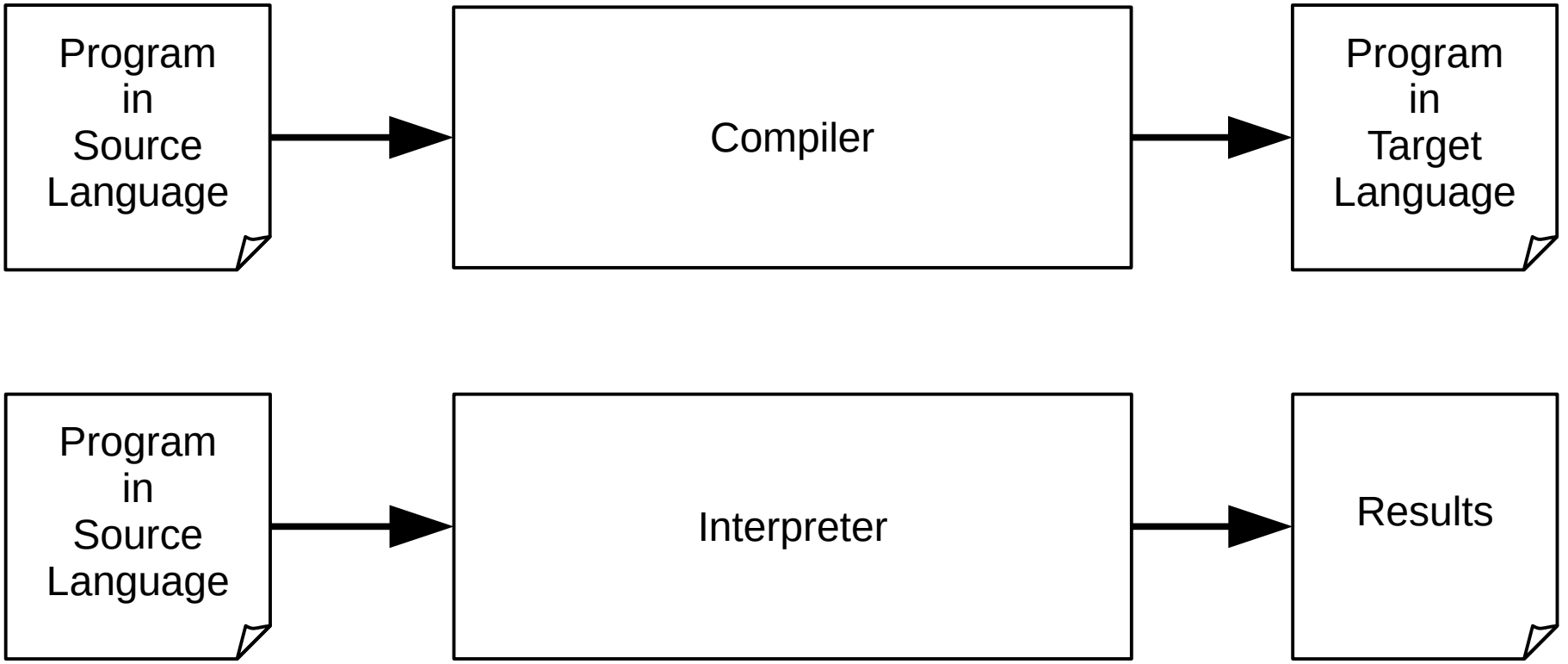
Automated translation

- A compiler is a computer program that **automatically translates** other programs from one language to another
  - (usually from a *human-readable* language to a *machine-executable* language, but not necessarily)



Automated translation

- Compilation vs. interpretation:



Discussion question

- Why should we study compilers?
  - *(besides getting systems elective credit...)*

Compilers: a convergent topic

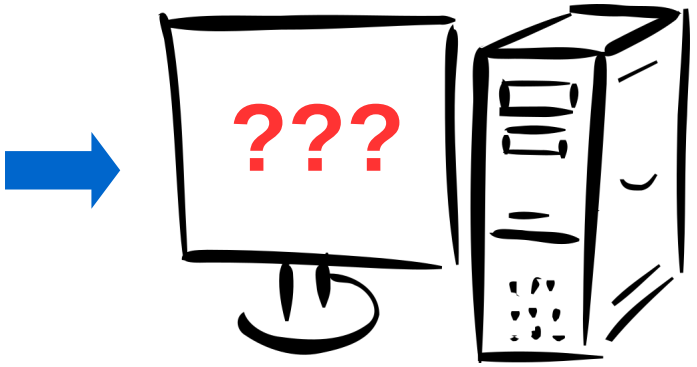
- Data structures
  - CS 240
- Architectures, machine languages, and operating systems
  - CS 261, CS 450
- Automata and language theory
  - CS 327, CS 430
- Graph algorithms
  - CS 327
- Software and systems engineering
  - CS 345, CS 361
- Greedy, heuristic, and fixed-point algorithms
  - CS 452

Reasons to study compilers

- Shows how many areas of CS can be combined to solve a truly "hard" problem (automated language translation)
- Bridges theory vs. implementation gap
  - Theory informs implementation
  - Applicable in many other domains
- Practical experience with large(er) software systems
  - My master copy is nearly 7K LOC
  - Of this, you will re-write over 1K LOC this semester
- Exposure to open problems in CS
  - Many optimization issues are subject to ongoing research

Course goal

- Fundamental question
  - "How do compilers translate from a human-readable language to a machine-executable language?"
- After this course, your response should be:
  - "It's really cool! Let me tell you..."



Course design theory

- First, a bit of background ...

Course design theory

- Big ideas
  - E.g., "A compiler is a large software system consisting of a sequence of phases"
- "Enduring understandings" (stuff you should remember in five years)
  - E.g, "Large problems can sometimes be solved by composing existing solutions to smaller problems."
- Learning objectives (stuff you should remember at the end of the course)
  - E.g., "Identify the technical challenges of building a large software system such as a compiler."

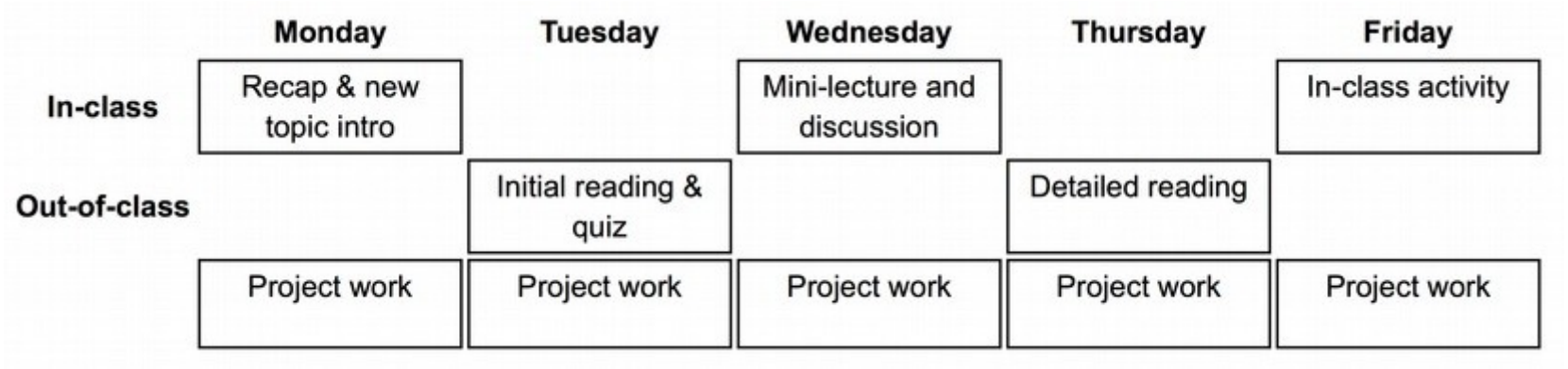
- Activities and assignments flow from learning objectives
  - E.g., "Draw a diagram illustrating the major phases of a modern compiler."
- Exams reflect activities and assignments
- Goal: “engaged” and *effective* learning

Learning objectives

- Identify and discuss the technical and social challenges of building a large software system such as a compiler.
- Develop and analyze formal descriptions of computer languages.
- Apply finite automata theory to build recognizers (lexers) for regular languages.
- Apply pushdown automata theory to build recognizers (parsers) for context-free languages.
- Evaluate the role of static analysis in automated program translation.
- Apply tree traversals to convert a syntax tree to low-level code.
- Discuss the limitations that an architecture or execution environment places on the generation of machine code.
- Describe common optimizations and evaluate the tradeoffs associated with good optimization.

Course format

- Website: `https://w3.cs.jmu.edu/lam2mo/cs432/`
  - Make sure you're using the right year's website!
- Weekly schedule (roughly)

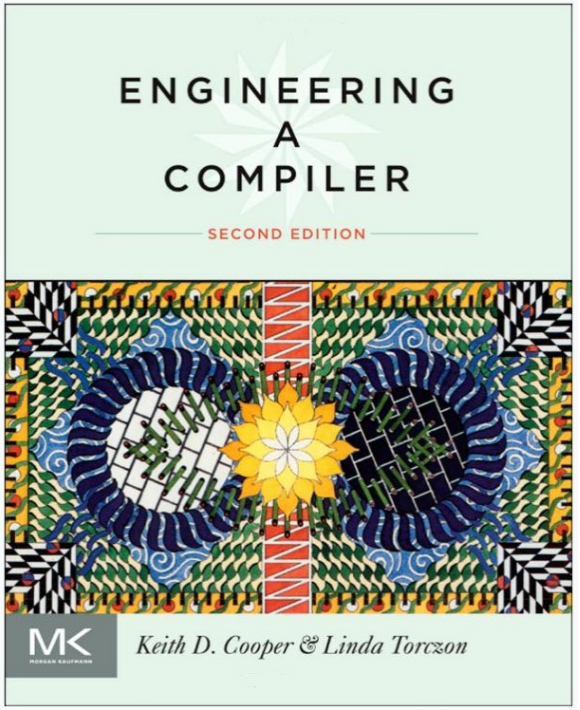


	Monday	Tuesday	Wednesday	Thursday	Friday
In-class	Recap & new topic intro		Mini-lecture and discussion		In-class activity
Out-of-class		Initial reading & quiz		Detailed reading	
	Project work	Project work	Project work	Project work	Project work

- *Formative* vs. *summative* assessment
  - Formative: quizzes and activities (20% of final grade)
  - Summative: projects and exams (80% of final grade)

Course textbook

- Engineering a Compiler, 2nd Edition
  - Keith Cooper and Linda Torczon
  - 1st chapter scanned; posted under “Files” on Canvas
  - Reserve copy at Rose library



- Decaf/ILOC references
  - PDFs on website

Semester-long project

- Compiler for "Decaf" language
  - Implementation in Java
  - Maven build system w/ fully-integrated test suite
  - Five major projects: "pieces" of the full system
  - Compiles to ILOC (new machine language from textbook)
- Submission: code + reflection + review + response
  - Code can be written in teams of two
    - Benefits vs. costs of working in a team
  - Reflection must be submitted individually
  - Individual graded code reviews due a week later
  - Review responses (how did your reviewer do?)

Course policies

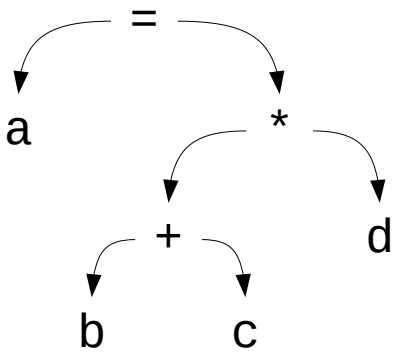
- Questions?

Compiler rule #1

- "The compiler must preserve the *meaning* of the program being compiled."
  - What is a program's *meaning*?

Intermediate representation

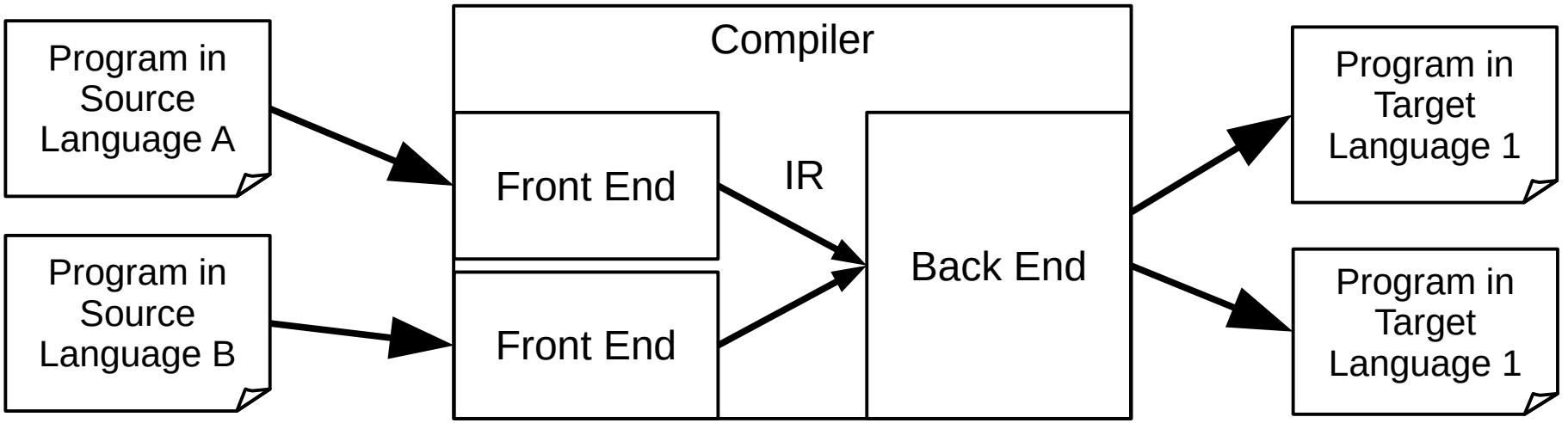
- Compilers encode a program's meaning using an intermediate representation (IR)
  - Tree- or graph-based: abstract syntax tree (AST), control flow graph (CFG)
  - Linear: register transfer language (RTL), Java bytecode, intermediate language for an optimizing compiler (ILOC)




```
load b → r1
load c → r2
add  r1, r2 → r3
load d → r4
mult r3, r4 → r5
store r5 → a
```

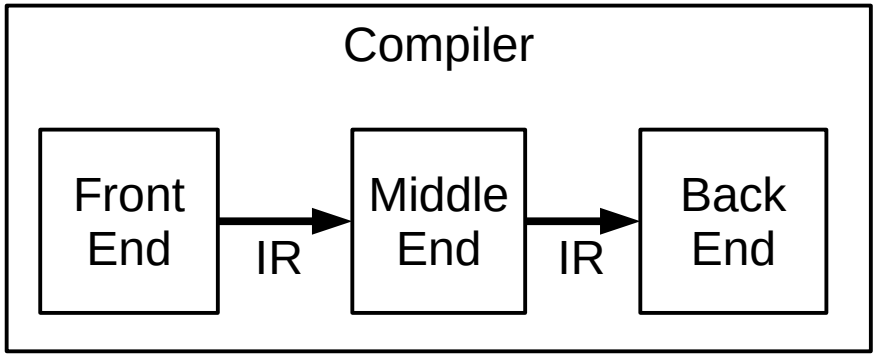
Standard compiler framework

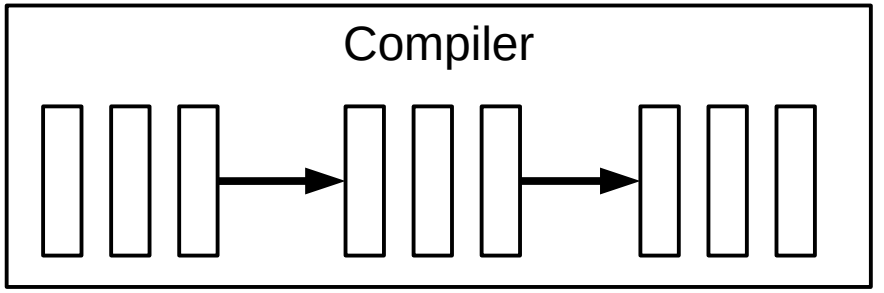
- Front end: understand the program (src → IR)
- Back end: encode in target language (IR → targ)
- Primary benefit: easier *re-targeting* to different languages or architectures



Modern compiler framework

- Multiple front-end passes
  - Lexing/scanning and parsing
  - Tree analysis processing
- Multiple middle-end passes
  - Local optimizations
  - Global optimizations
- Multiple back-end passes
  - Instruction selection/scheduling
  - Register allocation
  - Linking





Compiler rule #2

- The compiler should *help* the programmer in some way
  - What does *help* mean?

Discussion question

- What would be your design goals for a compiler?
  - E.g., what functionality or properties would you like it to have?

Compiler design goals

- Translate to target language/architecture
- Optimize for fast execution
- Minimize memory/energy use
- Catch software defects early
- Provide helpful error messages
- Run quickly
- Be easily extendable

Differing design goals

- What differences might you expect in compilers designed for the following applications?
  - A just-in-time compiler for running server-side user scripts
  - A compiler used in an introductory programming course
  - A compiler used to build scientific computing codes to run on a massively-parallel supercomputer
  - A compiler that targets a number of diverse systems
  - A compiler that targets an embedded sensor network platform

Decaf language

- Simple imperative language similar to C or Java
- Example:

```
// add.decaf - simple addition example

def int add(int x, int y)
{
    return x + y;
}

def int main()
{
    int a;
    a = 3;
    return add(a, 2);
}
```


```
$ java -jar decaf-1.0.jar -i add.decaf
5
```

Before Wednesday

- Readings
  - "Engineering a Compiler" (EAC) Ch. 1 (23 pages)
  - Decaf reference ("Resources" page on website)
- Tasks
  - **Complete first reading quiz on Canvas**
  - **Complete course intro survey on Canvas**
  - **Download the reference compiler from Canvas ("Files")**
  - Write some code in Decaf
  - Install the JDK and Maven on your system

Upcoming events

- CS senior night
  - **Wednesday, Sept. 5, 5:00-6:30pm**
  - Graduation info, job fairs, photos, etc.
  - Senior students only
- CISE career fair
  - **Wednesday, Sept. 19, time/location TBD**
  - Over 20 companies looking for technology majors
  - Internships and full-time positions

See you Wednesday

- Have a great semester!