What is a Compiler?

Compiler $\equiv$ A program that translates code in one language (source code) to code in another language (target code).

Usually, target code is semantically equivalent to source code, but not always!

Examples

- C++ to Sparc assembly
- C++ to C (some C++ compilers work this way)
- Java to JVM bytecode
- High Performance Fortran (HPF: a parallel Fortran language)
  to Fortran: a parallelizing compiler
- C to C (or any language to itself):
  Why? Make code faster, or smaller, or instrument for performance . . .

Uses of Compiler Technology

- **Code generation:** To translate a program in a high-level language to machine code for a particular processor
- **Optimization:** Improve program performance for a given target machine
- **Text formatters:** translate TeX to dvi, dvi to postscript, etc.
- **Interpreters:** "on-the-fly" translation of code, e.g., Java, Perl, csh, Postscript
- **Automatic parallelization or vectorization**
- **Debugging aids:** e.g., purify for debugging memory access errors
- **Performance instrumentation:** e.g., -pg option of cc or gcc for profiling
- **Security:** JavaVM uses compiler analysis to prove safety of Java code
- **Many more cool uses!** Hardware design / synthesis, power management, code compression, fast simulation of architectures, transparent fault-tolerance, . . .

Key: *Ability to extract properties of a program (analysis), and optionally transform it (synthesis)*

A Code Optimization Example

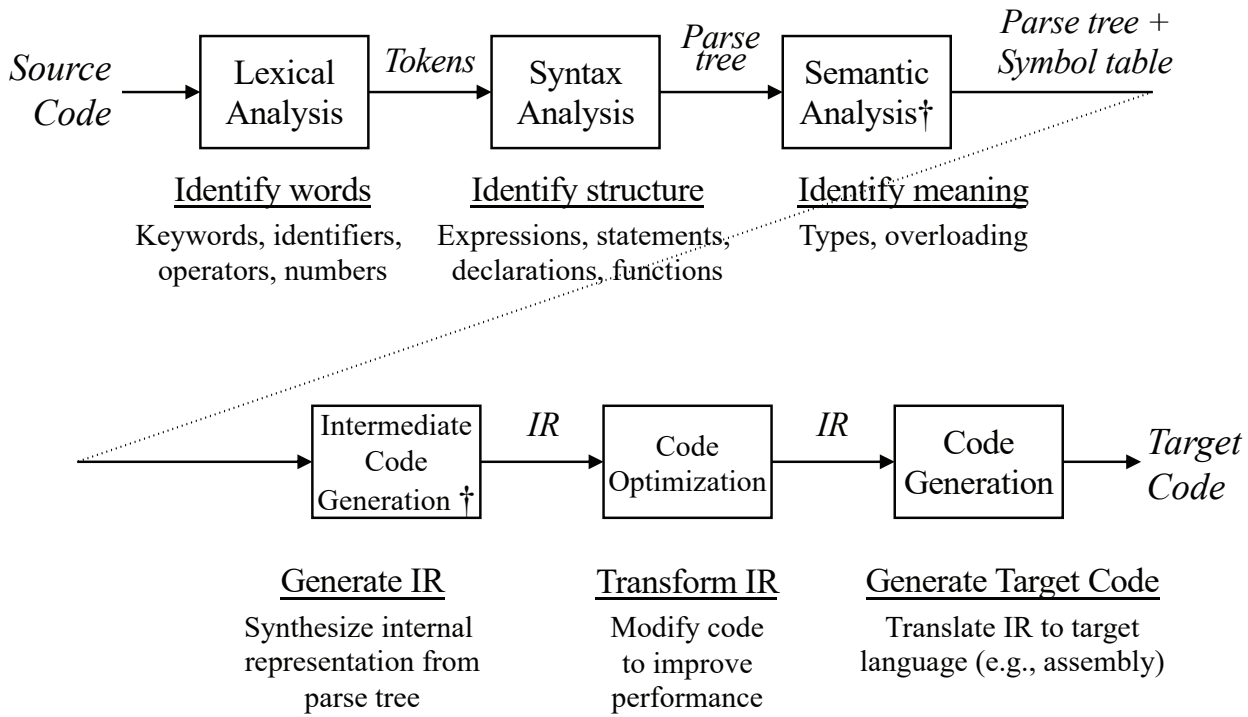
What machine-independent optimizations are applicable to the following C example? When are they safe?

```
1  /* A, B, C are double arrays; X, Y are double scalars; rest are int scalars.
2      int main(int argc, char** argv) {
3              ...     /* Declare and initialize variables. */
4              X = ...;
5              N = 1; i = 1;
6              while (i <= 100) {
7                  j = i * 4;
8                  N = j * N;
9                  Y = X * 2.0;
10                 A[i] = X * 4.0;
11                 B[j] = Y * N;
12                 C[j] = N * Y * C[j];
13                 i = i + 1;
14             }
15             printArray(B, 400);
16             printArray(C, 400);
17     }
```

A Code Optimization Example: Result

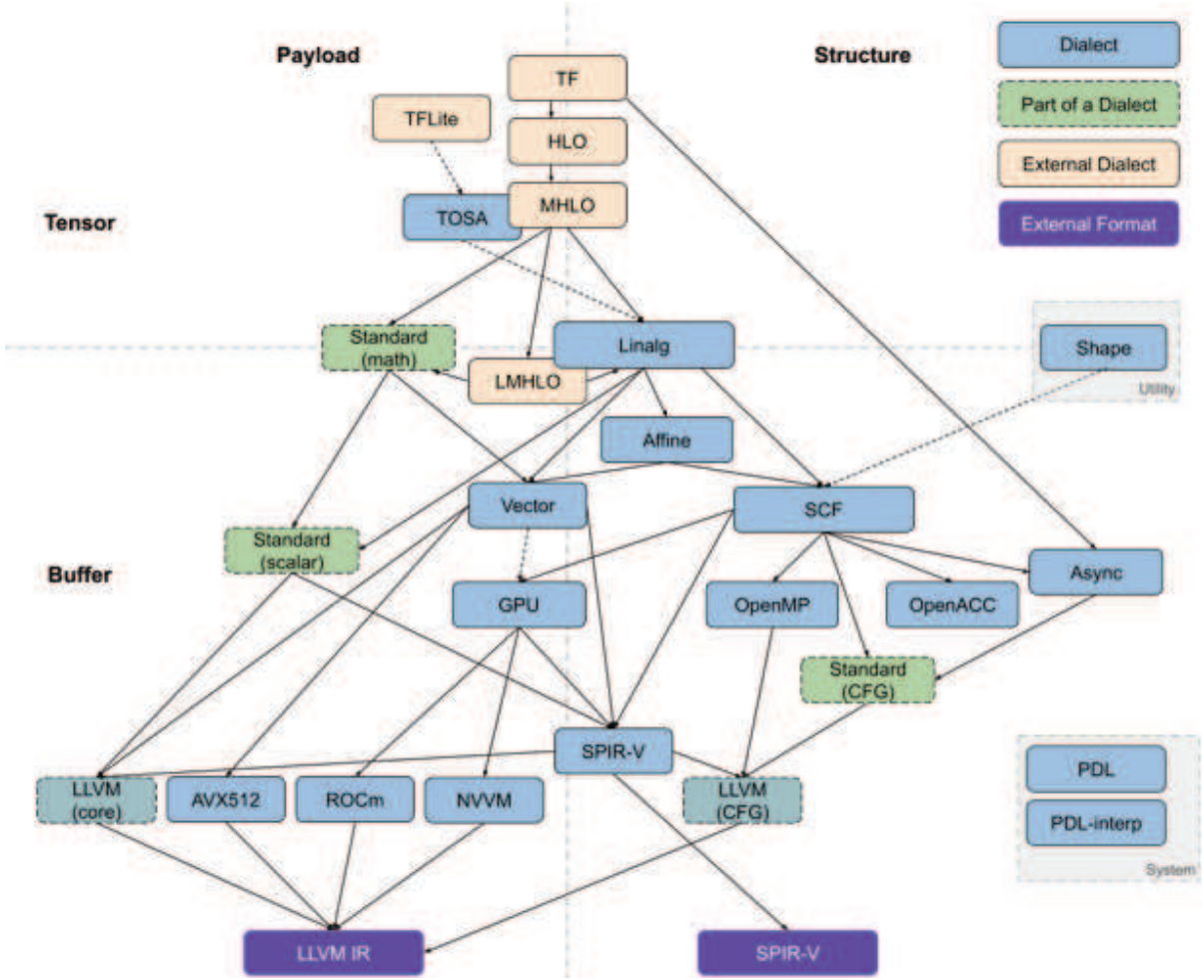
```
1  X = ...
2  N = 1;
3  j = 4;                          //  Induction Variable Substitution (SUBST),
4                                  //          Strength Reduction
5  Y = X * 2.0;                    //  Loop-Invariant Code Motion (LICM)
6  while (j <= 400) {              //  Linear Function Test Replacement (LFTR)
7                                  //  Dead Code Elimination (DCE) for i * 4
8      N = j * N;
9                                  //  DCE of A, since A not aliased to B or C
10     tmp = Y * N;
11     B[j] = tmp;
12     C[j] = tmp * C[j];          //  Common Subexpression Elimination (CSE)
13     j = j + 4;                  //  Induction Variable Substitution,
14                                 //          Strength Reduction
15 }
16 printArray(B, 400);
17 printArray(C, 400);
```

Classical Structure of a Compiler



† ***Order varies***

An Emerging Exception: MLIR



Topical Outline

1. The structure of a compiler
2. Intermediate representations
3. Runtime storage management (excluding garbage collection)
4. Intermediate code generation
5. Machine code generation
   - Overview: Instruction selection, register allocation, instruction scheduling
   - Global register allocation by graph coloring
6. Code Optimization
   - Peephole optimizations
   - Control flow graphs and analysis
   - Static Single Assignment (SSA) form
   - Introduction to iterative dataflow analysis
   - SSA and iterative dataflow optimizations

Programming Projects

An Optimizing Compiler for COOL using C++

Source Language: COOL

- Object-oriented language similar to Java
- But small and very well-defined: syntax *and* semantics

Target Language: LLVM Virtual Instruction Set

- *Both* intermediate representation *and* assembly language
- Designed for effective language-independent optimization

Project phases

MP1: *Scanning and Parsing*: COOL to Abstract Syntax Tree (AST)

MP2: *Intermediate code gen., Part 1*: AST to LLVM, local expressions only

MP3: *Intermediate code gen., Part 2*: AST to LLVM, all of COOL

MP4: *Native code gen*: Basic graph-coloring regalloc for LLVM to X86-64

Unit Project: *A mid-level dataflow optimization pipeline using SSA: ADCE, ConstProp, LICM, DomTreeCSE, plus optional passes (e.g., store hoisting, SROA, devirtualization+inlining)*.

Getting Started on the Programming Projects

1. Login and set up your account on the EWS machines.
2. Read the COOL Reference manual (CoolAid), Chapters 1-11 (through syntax) at least. The manual is on the class web site under the Resources/ link.
3. Download and read the COOL examples from the file cool-examples.tar.gz. These are also on the Resources/ page. Write a COOL program to get familiar with the syntax.
4. *Optional:* download and install LLVM on a **nix* platform!
   Not *necessary*: We will release a shared version for everyone's use in this class.
5. **4-credit students:** *DON'T* read source code for scalar transforms.
   All students: *DON'T* read source code for any LLVM register allocators.

Getting The Most Out Of Any Class

"Education is what survives when what has been learned has been forgotten."

–B. F. Skinner, *New Scientist*, May 21, 1964.

Get the big picture:

Why are we doing this? Why is it important?

Understand the basic principles:

If you know how to apply them, you can work out the details

Learn why things work a certain way:

Automatic vs. manual, elegant vs. ad hoc,
solved problem vs. open

Think about the cost-benefit trade-offs:

Performance vs. correctness, compile-time vs. payoff

Getting The Most Out Of This Class

"Sir, I can give you an explanation but not an understanding!"

–British parliamentarian

- Do the exercises in class; read the text and notes
- Start the assignment the day it's handed out, not the day it's due
- Pay attention to the discussions
- Ask questions, and participate

Getting Started: Summary

- Read the CS 426 Web site — all pages
- Check that you are set up on Piazza
- Log in and set up your EWS account
- Download and read the COOL manual and examples
- Write a few simple COOL programs
- (Optional) Download and install LLVM on a **nix* platform
  (*Do not read specified source code*!)