

# 1DL321: Kompilorteknik I (Compiler Design 1)

Introduction to Programming  
Language Design and to Compilation

# Administrivia

---

- Lecturer:
  - Kostis Sagonas ([kostis@it.uu.se](mailto:kostis@it.uu.se))
- Course home page:  
<http://user.it.uu.se/~kostis/Teaching/KT1-12/>
- Assistants:
  - Stavros Aronis ([stavros.aronis@it.uu.se](mailto:stavros.aronis@it.uu.se))
  - Andreas Löscher ([andreas.loscher@it.uu.se](mailto:andreas.loscher@it.uu.se))
  - responsible for the lessons and the assignments

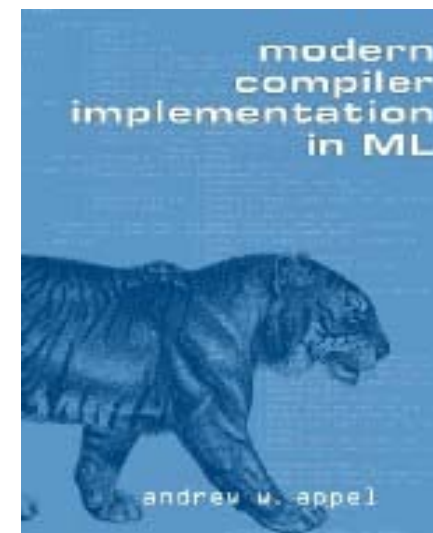
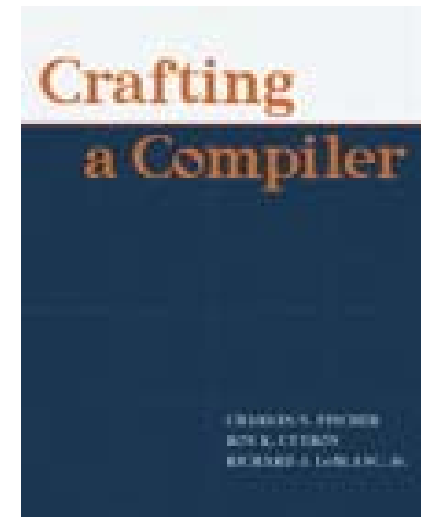
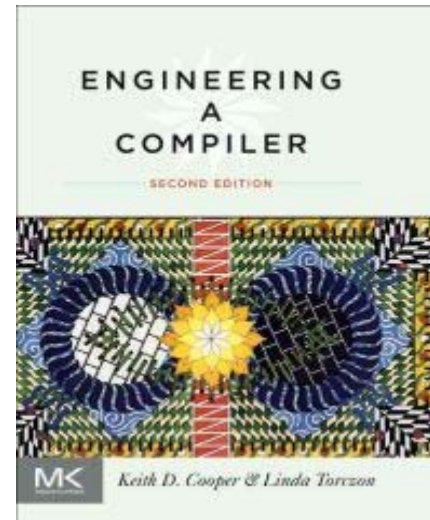
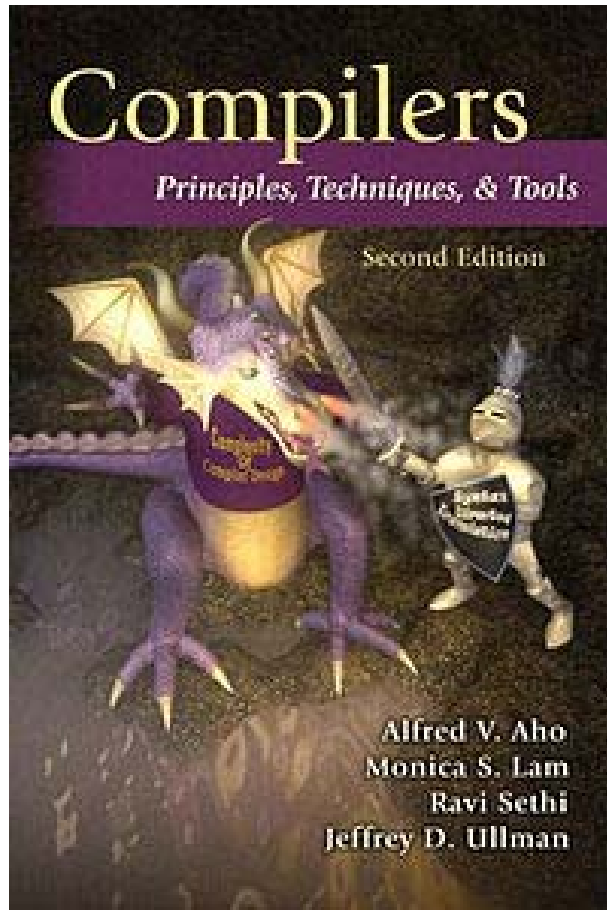
## Course Structure

---

- Course has theoretical and practical aspects
- Need both in programming languages!
- Written examination = theory (4 points)
  - first exam scheduled for 11th January 2013
- Three assignments = practice (1 point)
  - Electronic hand-in to the assistants before the corresponding deadline
  - You can submit **one** late assignment if you need to but it cannot be later than the deadline of the next assignment (for 1 and 2) or the exam (for 3)

# Course Literature

---



## Academic Honesty

---

- For assignments you are allowed to work in pairs (but no threesomes/foursomes/...)
- Don't use work from uncited sources
  - Including old assignments



# The Compiler Project

---

- A follow-up course
- that will be taught in period 3
- and will allow you to see the material you have learned in KT1 in practice
- by building a complete compiler
- for a small (toy?) language

# How are Languages Implemented?

---

- Two major strategies:
  - Interpreters (older, less studied)
  - Compilers (newer, much more studied)
- Interpreters run programs "as is"
  - Little or no preprocessing
- Compilers do extensive preprocessing

# Language Implementations

---

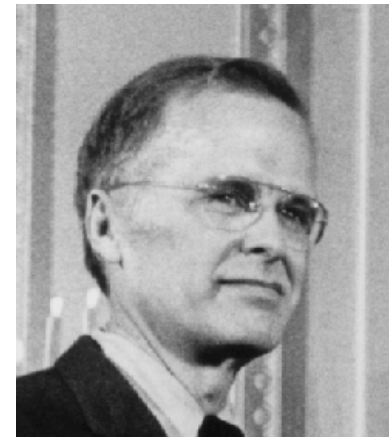
- Batch compilation systems dominate
  - gcc
- Some languages are primarily interpreted
  - Java bytecode
  - Postscript
- Some environments (e.g. Lisp) provide both
  - Interpreter for development
  - Compiler for production



## (Short) History of High-Level Languages

---

- 1953 IBM develops the 701
- Till then, all programming done in assembly
- Problem: Software costs exceeded hardware costs!
- John Backus: "Speedcoding"
  - An interpreter
  - Ran 10-20 times slower than hand-written assembly



# FORTRAN I

---

- 1954 IBM develops the 704
- John Backus
  - Idea: translate high-level code to assembly
  - Many thought this impossible
    - Had already failed in other projects
- 1954-7 FORTRAN I project
- By 1958, >50% of all software is in FORTRAN
- Cut development time dramatically
  - (2 weeks → 2 hours)

# FORTRAN I

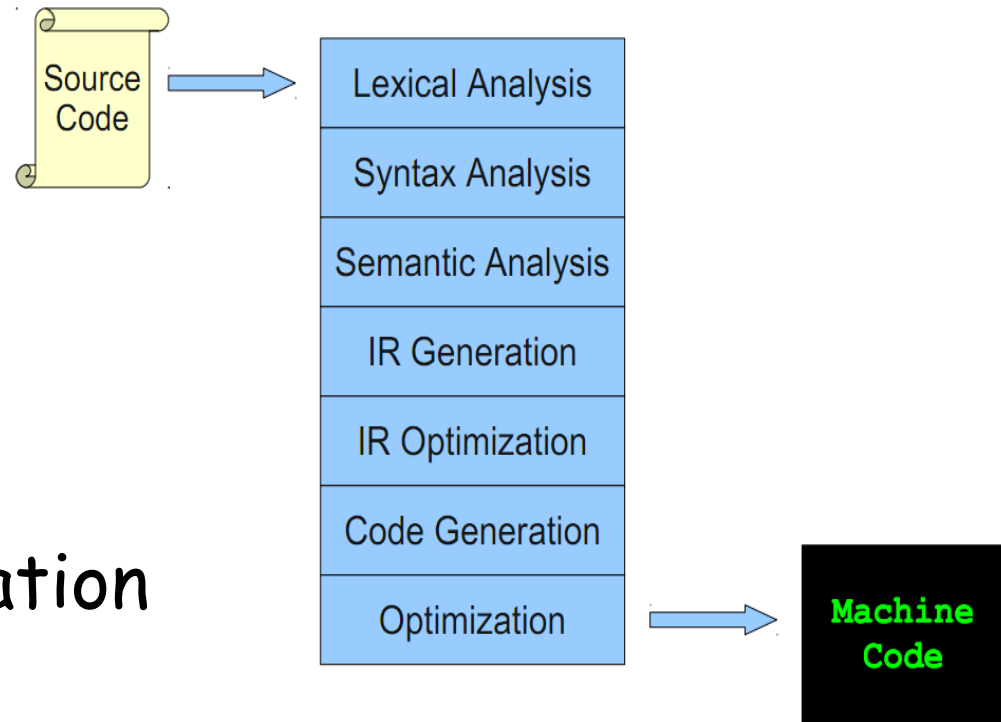
---

- The first compiler
  - Produced code almost as good as hand-written
  - Huge impact on computer science
- Led to an enormous body of theoretical work
- Modern compilers preserve the outlines of the FORTRAN I compiler

# The Structure of a Compiler

---

1. Lexical Analysis
2. Syntax Analysis
3. Semantic Analysis
4. IR Optimization
5. Code Generation
6. Low-level Optimization



The first 3 phases can be understood by analogy to how humans comprehend natural languages (e.g. Swedish or English).

# Lexical Analysis

---

- First step: recognize words.
  - Smallest unit above letters

This is a sentence.

- Note the
  - Capital "T" (start of sentence symbol)
  - Blank " " (word separator)
  - Period "." (end of sentence symbol)

## More Lexical Analysis

---

- Lexical analysis is not trivial. Consider:

ist his ase nte nce

- Plus, programming languages are typically more cryptic than English:

\*p->f ++ = -.12345e-5

## And More Lexical Analysis

---

- Lexical analyzer divides program text into "words" or "tokens"

if (x == y) then z = 1; else z = 2;

- Units:

if ( , x , == , y , ) , then , z , = , 1 , ; , else , z , = , 2 , ;

# Parsing

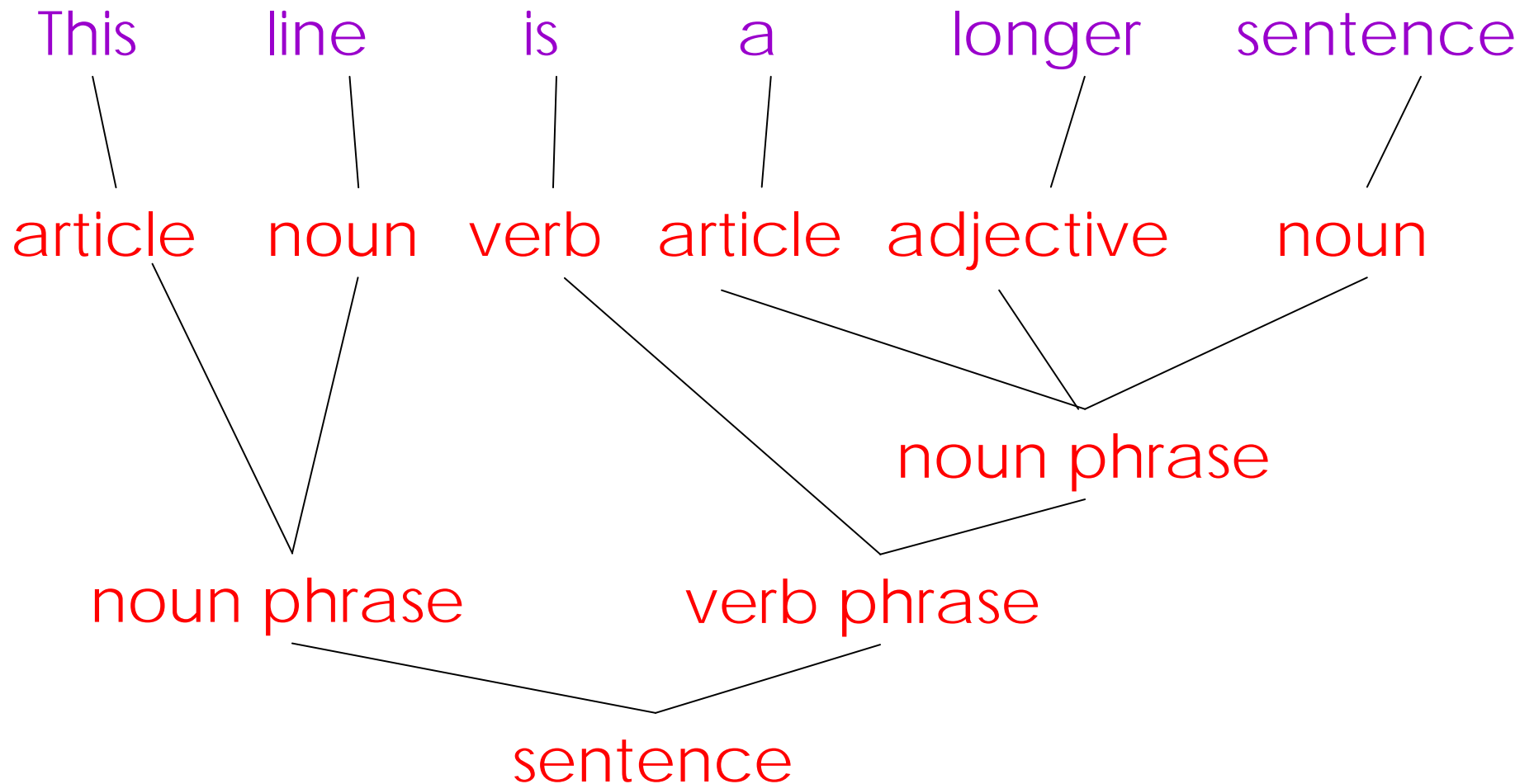
---

- Once words are understood, the next step is to understand the sentence structure
- Parsing = Diagramming Sentences
  - The diagram is a tree



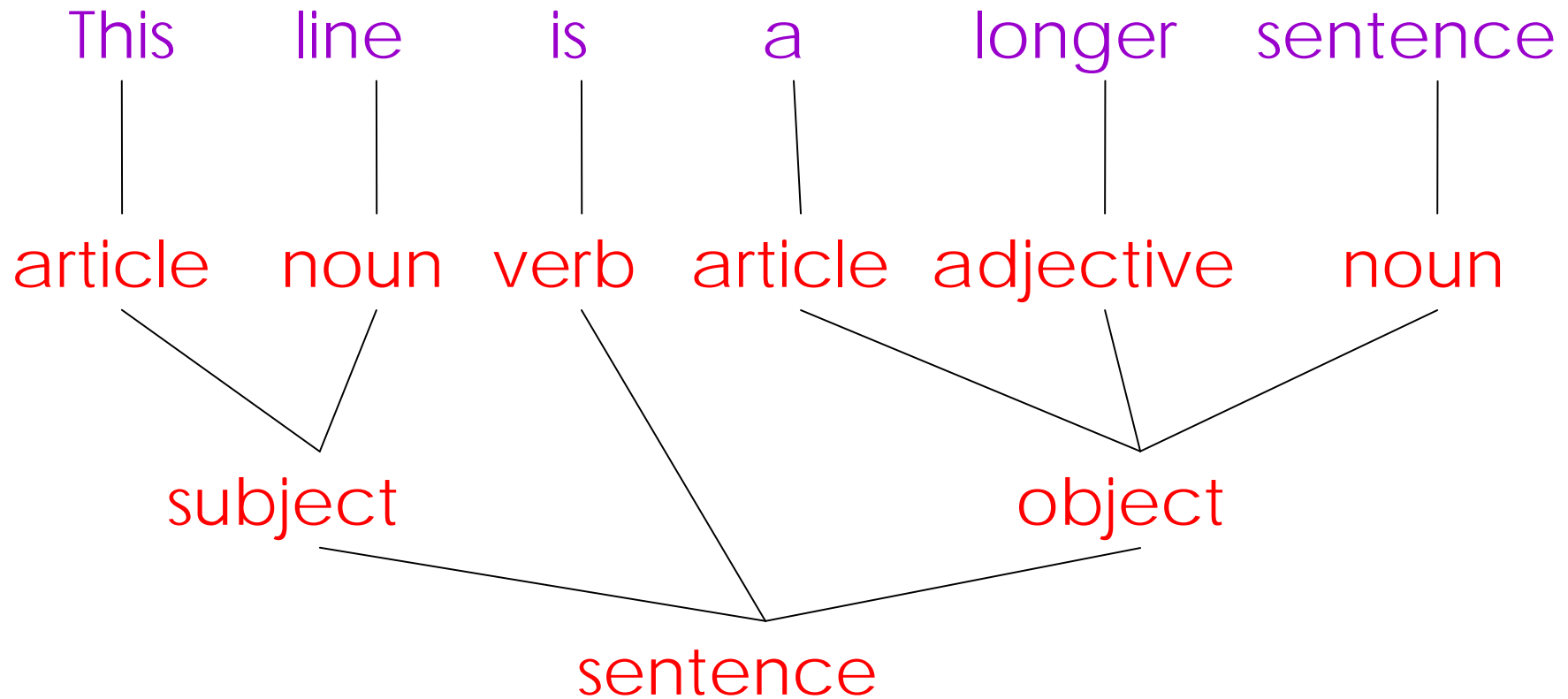
# Diagramming a Sentence (1)

---



# Diagramming a Sentence (2)

---



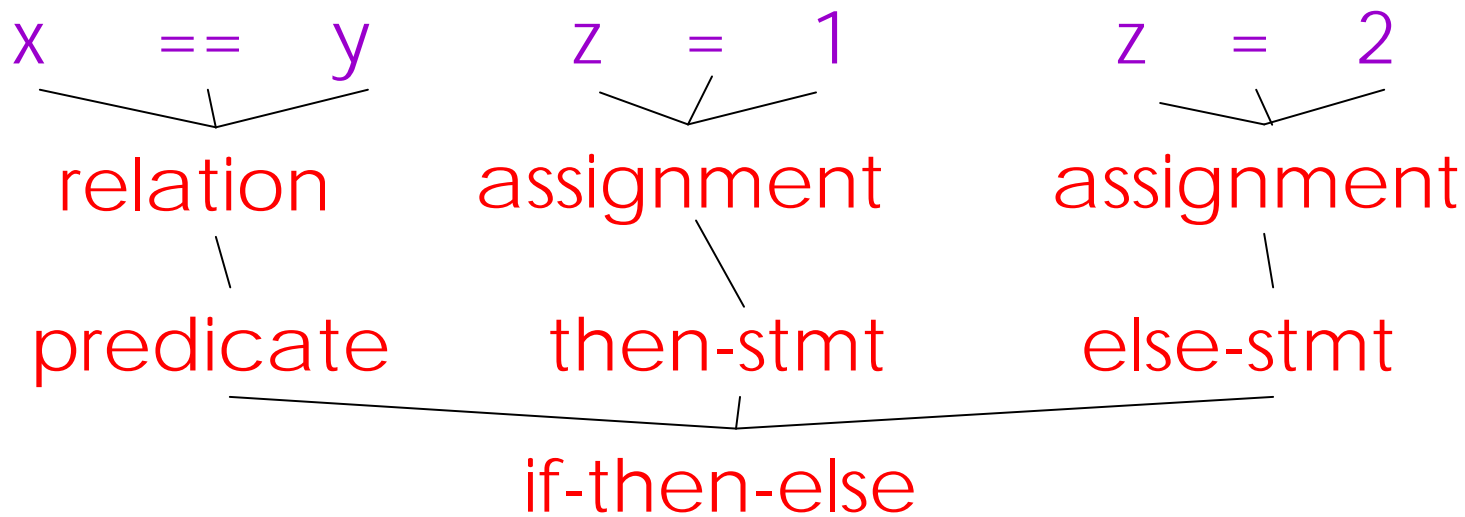
# Parsing Programs

---

- Parsing program expressions is the same
- Consider:

If (x == y) then z = 1; else z = 2;

- Diagrammed:



## Semantic Analysis

---

- Once the sentence structure is understood, we can try to understand its "meaning"
  - But meaning is too hard for compilers
- Most compilers perform limited analysis to catch inconsistencies
- Some optimizing compilers do more analysis to improve the performance of the program

## Semantic Analysis in English

---

- Example:

Jack said Jerry left his assignment at home.

What does "his" refer to? Jack or Jerry?

- Even worse:

Jack said Jack left his assignment at home?

How many Jacks are there?

Which one left the assignment?

# Semantic Analysis in Programming Languages

---

- Programming languages define strict rules to avoid such ambiguities
- This C++ code prints "4"; the inner definition is used

```
{  
    int Jack = 3;  
    {  
        int Jack = 4;  
        cout << Jack;  
    }  
}
```

## More Semantic Analysis

---

- Compilers perform many semantic checks besides variable bindings
- Example:

Arnold left her homework at home.
- A “type mismatch” between *her* and *Arnold*;  
we know they are different people
  - Presumably Arnold is male

# Optimization

---

- No strong counterpart in English, but akin to editing
- Automatically modify programs so that they
  - Run faster
  - Use less memory/cache/power
  - In general, conserve some resource more economically
- The compilers project has no optimization component
  - for those interested, there is also the "Advanced Compiler Design (KT2)" course !



# Optimization Example

---

$X = Y * 0$  is the same as  $X = 0$

**NO!**

Valid for integers, but not for floating point numbers

## Code Generation

---

- Produces assembly code (usually)
- A translation into another language
  - Analogous to human translation

# Intermediate Languages

---

- Many compilers perform translations between successive intermediate forms
  - All but first and last are *intermediate languages* internal to the compiler
  - Typically there is one IL
- IL's generally ordered in descending level of abstraction
  - Highest is source
  - Lowest is assembly

## Intermediate Languages (Cont.)

---

- IL's are useful because lower levels expose features hidden by higher levels
  - registers
  - memory/frame layout
  - etc.
- But lower levels obscure high-level meaning

# Issues

---

- Compiling is almost this simple, but there are many pitfalls
- Example: How are erroneous programs handled?
- Language design has big impact on compiler
  - Determines what is easy and hard to compile
  - Course theme: many trade-offs in language design

# Compilers Today

---

- The overall structure of almost every compiler adheres to our outline
- The proportions have changed since FORTRAN
  - Early:
    - lexical analysis, parsing most complex, expensive
  - Today:
    - semantic analysis and optimization dominate all other phases; lexing and parsing are well-understood and cheap

# Current Trends in Compilation

---

- Compilation for speed is less interesting. However, there are exceptions:
  - scientific programs
  - advanced processors (Digital Signal Processors, advanced speculative architectures, GPUs)
- Ideas from compilation used for improving code reliability:
  - memory safety
  - detecting data races
  - security properties
  - ...

# Programming Language Economics

---

- Programming languages are designed to fill a void
  - enable a previously difficult/impossible application
  - orthogonal to language design quality (almost)
- Programming training is the dominant cost
  - Languages with a big user base are replaced rarely
  - Popular languages become ossified
  - but it is easy to start in a new niche...



# Why so many Programming Languages?

---

- Application domains have distinctive (and sometimes conflicting) needs
- Examples:
  - *Scientific computing*: High performance
  - *Business*: report generation
  - *Artificial intelligence*: symbolic computation
  - *Systems programming*: efficient low-level access
  - Other special purpose languages...

## Topic: Language Design

---

- No universally accepted metrics for design
- "A good language is one people use"
- NO!
  - Is COBOL the best language?
- Good language design is hard

# Language Evaluation Criteria

---

Characteristic	Criteria		
	Readability	Writeability	Reliability
Simplicity	YES	YES	YES
Data types	YES	YES	YES
Syntax design	YES	YES	YES
Abstraction		YES	YES
Expressivity		YES	YES
Type checking			YES
Exceptions			YES

## History of Ideas: Abstraction

---

- Abstraction = detached from concrete details
- Necessary for building software systems
- Modes of abstraction:
  - Via languages/compiler
    - higher-level code; few machine dependencies
  - Via subroutines
    - abstract interface to behavior
  - Via modules
    - export interfaces which hide implementation
  - Via abstract data types
    - bundle data with its operations

# History of Ideas: Types

---

- Originally, languages had only few types
  - FORTRAN: scalars, arrays
  - LISP: no static type distinctions
- Realization: types help
  - provide code documentation
  - allow the programmer to express abstraction
  - allow the compiler to check among many frequent errors and sometimes guarantee various forms of safety
- More recently:
  - experiments with various forms of parameterization
  - best developed in functional languages

## History of Ideas: Reuse

---

- Exploits common patterns in software development
- Goal: mass produced software components
- Reuse is difficult
- Two popular approaches (combined in C++)
  - Type parameterization (`List(Int)` & `List(Double)`)
  - Class and inheritance: C++ derived classes
- Inheritance allows:
  - specialization of existing abstractions
  - extension, modification and information hiding

# Current Trends

---

- **Language design**
  - Many new special-purpose languages
  - Popular languages to stay
- **Compilers**
  - More needed and more complex
  - Driven by increasing gap between
    - new languages
    - new architectures
  - Venerable and healthy area

## Why study Compiler Design?

---

- Increase your knowledge of common programming constructs and their properties
- Improve your understanding of program execution
- Increase your ability to learn new languages
  
- Learn how to build a large and reliable system
- Learn new (programming) techniques
- See many basic CS concepts at work