1DL321: Kompilatorteknik I (Compiler Design 1)

Introduction to Programming Language Design and to Compilation

Administrivia

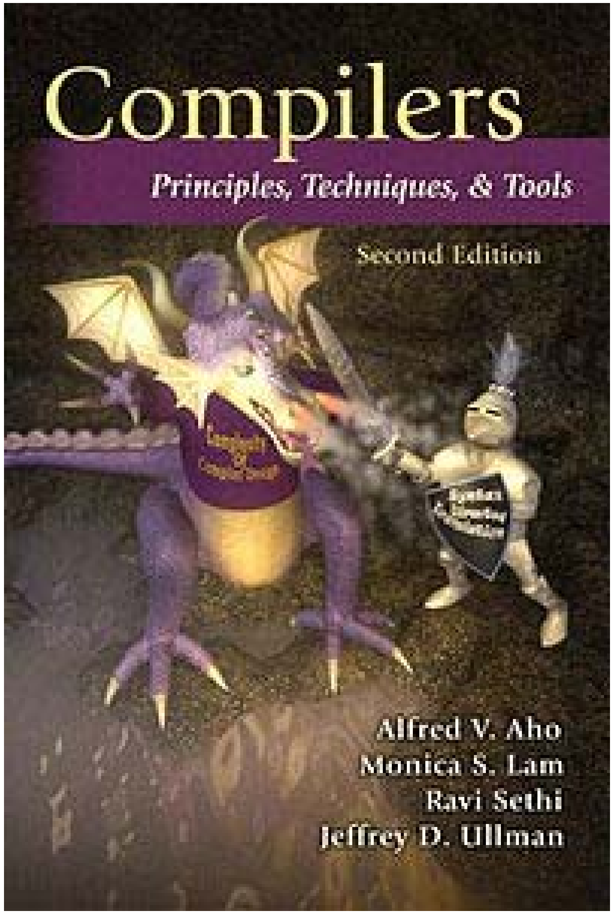
- Lecturer:
  - Kostis Sagonas (kostis@it.uu.se)
- Course home page:

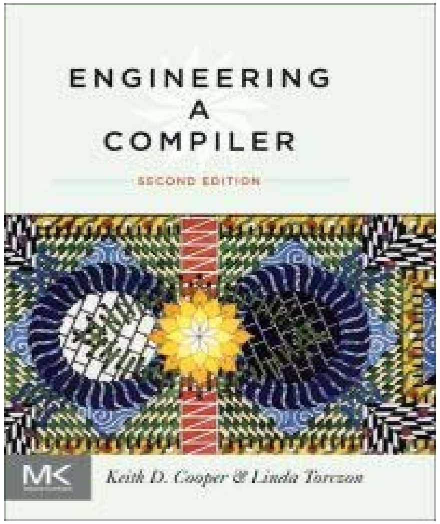
  http://www.it.uu.se/edu/course/homepage/komp/ht15
- Assistant:
  - Stavros Aronis (stavros.aronis@it.uu.se)
  - responsible for the lessons and the assignments

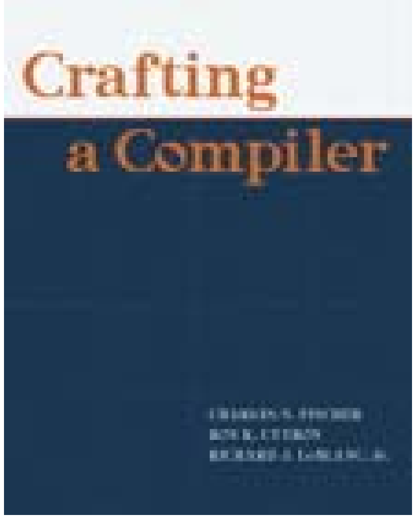
Course Structure

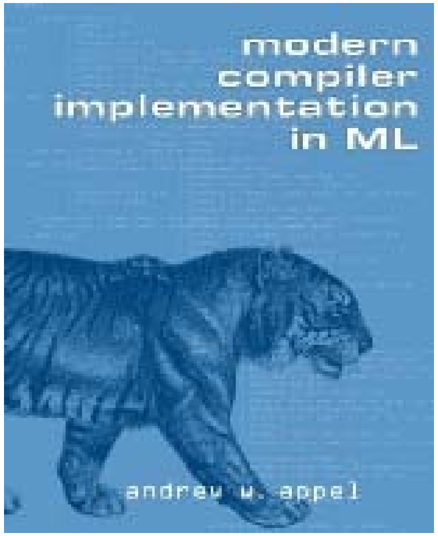
- Course has theoretical and practical aspects
- Need both in programming languages!
- Written examination = theory (4 credits)
  - first exam scheduled for 14th December 2015
- Four assignments = practice (1 credit)
  - Electronic hand-in to the assistant before the corresponding deadline
  - You can submit **one** late assignment, if you need to, but it cannot be later than the deadline of the next assignment (for 1-3) or Dec. 20th (for 4th)

Course Literature









Academic Honesty

- For assignments you are allowed to work in pairs (but no threesomes/foursomes/...)
- Don't share your work with others
  - e.g. post on public repositories
- Don't use work from non-cited sources
  - including old assignments

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

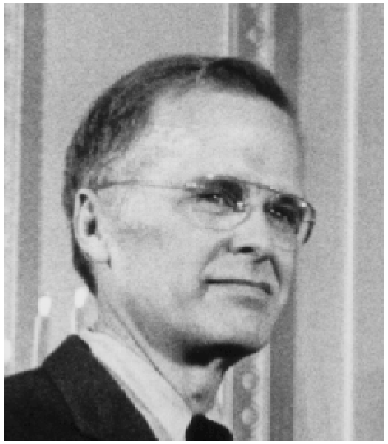
- Compilers do extensive preprocessing

Language Implementations

- Today, batch compilation systems dominate
  - gcc, clang, ...
- Some languages are primarily interpreted
  - Java bytecode compiler (javac)
  - Scripting languages (perl, python, javascript, ruby)
- Some languages (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 is 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

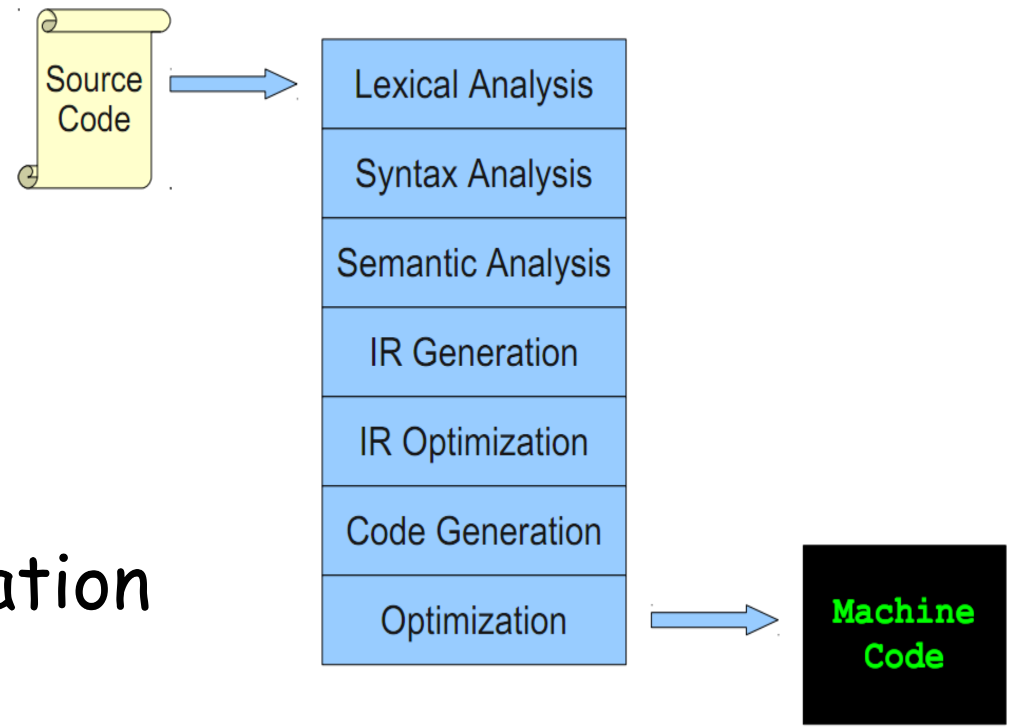
- The first compiler
  - Produced code almost as good as hand-written
  - Huge impact on computer science

- 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).

First Step: Lexical Analysis

- 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;
```

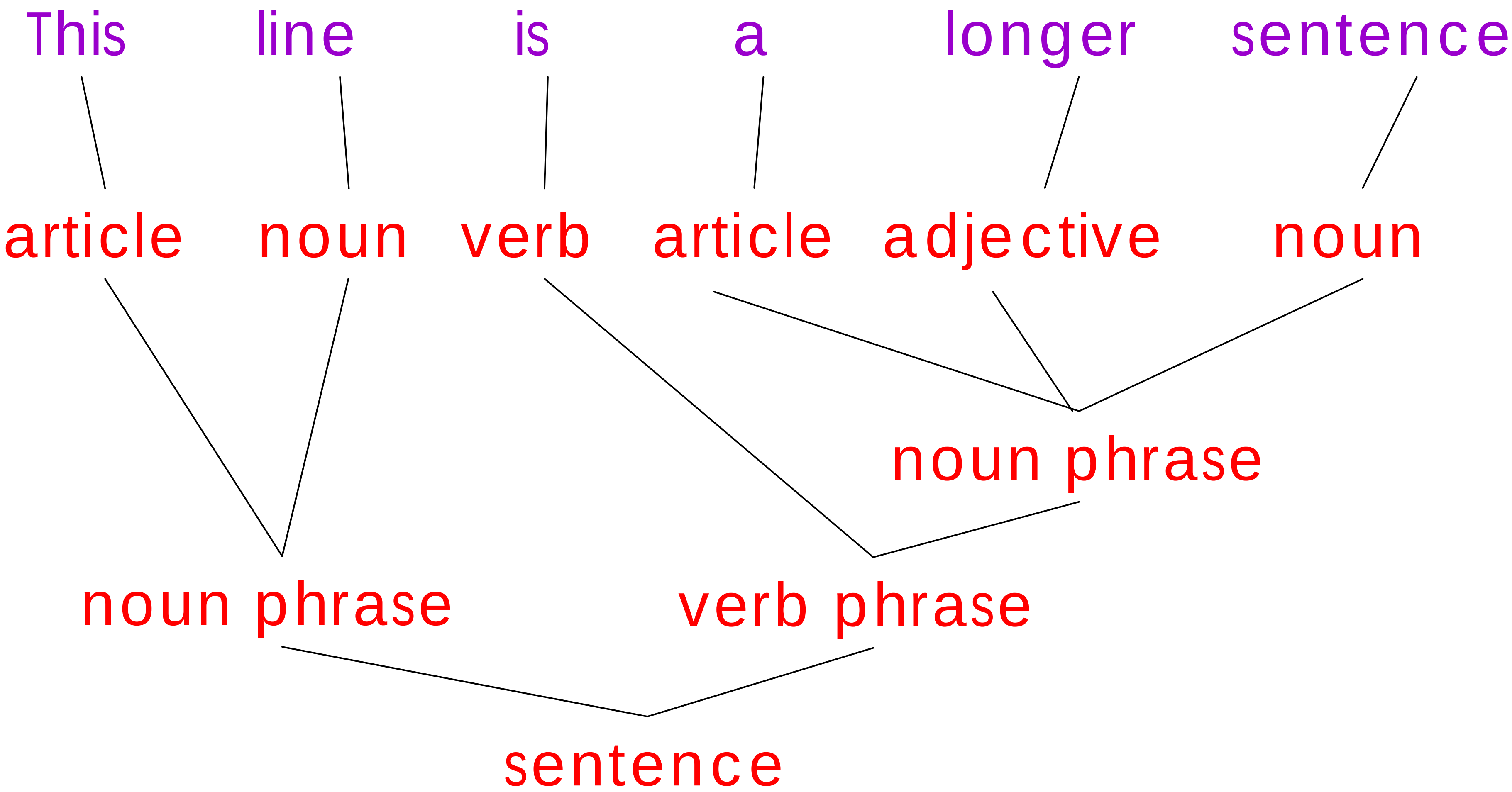
- Units:

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

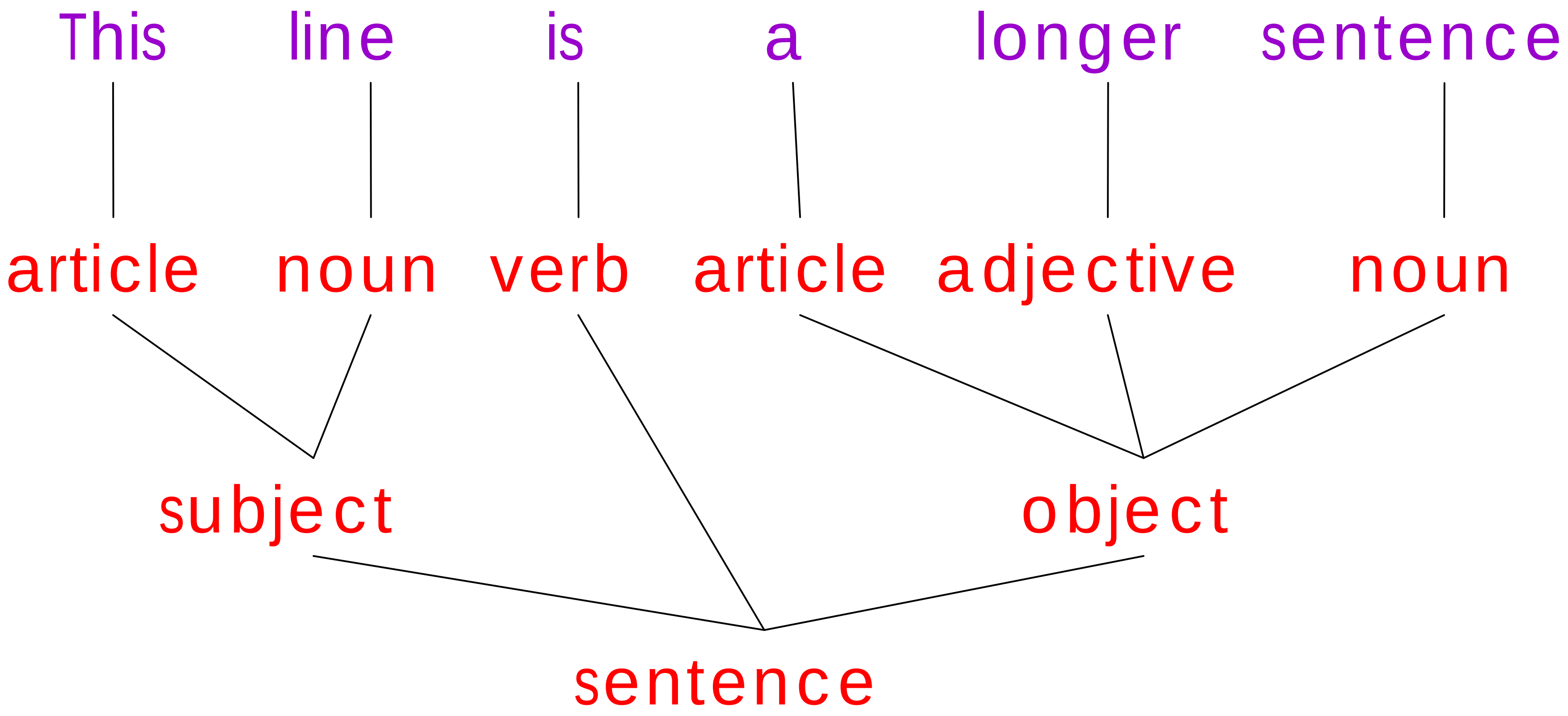
Second Step: Syntax Analysis (Parsing)

- Once words are identified, 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)

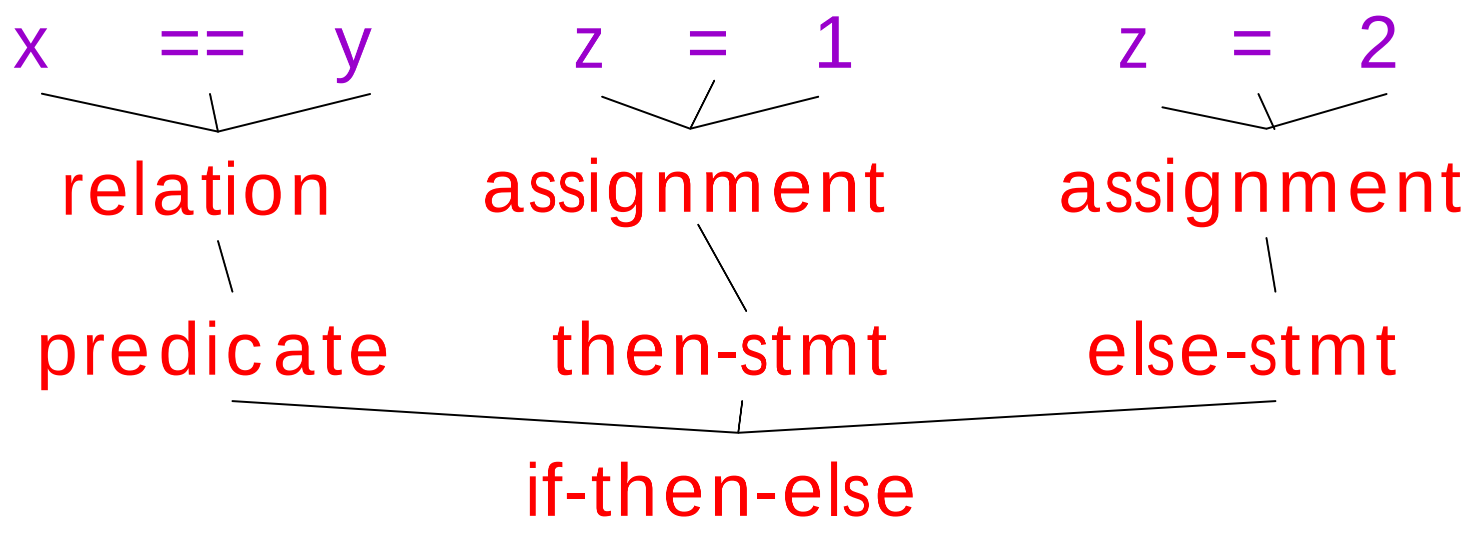


Parsing Programs

- Parsing program expressions is the same
- Consider:

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

- Diagrammed:



Third Step: 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 42; the inner definition is used

```
{
  int Jack = 17;
  {
    int Jack = 42;
    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
    - avoid some source code redundancy
    - exploit the underlying hardware more effectively
  - Use less memory/cache/power
  - In general, conserve some resource more economically

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
- Intermediate languages 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:
    - lexical analysis and parsing are well-understood and cheap
    - semantic analysis and optimization dominate
    - focus on concurrency/parallelism and interactions with the memory model of the underlying platform
    - optimization for code size and energy consumption

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
  - ***Web programming***: scripts that run everywhere
  - ***Multicores***: concurrency and parallelism
  - 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/compilers
    - 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 languages are implemented
- Learn new (programming) techniques
- See many basic CS concepts at work