Compilation A

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Content

1. Compiler Overview
2. Lexical Analysis
3. Syntactic Analysis
4. Abstract Syntax
5. Semantic Analysis
6. Code generation
7. Interpretation

Schedule

- Fridays 08-09 CO2 – Lecture.
- Fridays 11-12 INF1 – Practical work.
- Sometimes, like today, both time slots will be used for lectures in CO2. The exact schedule is available on the web.

Course Material

- Course page:
  http://lampwww.epfl.ch/teaching/CompilationA/2003/html/
- Book:
  - **Modern Compiler Implementation in Java (second edition)**
    by Andrew W. Appel and Jens Palsberg

The Course

- Lectures.
- Exercises – not obligatory.
- Assignment – not obligatory.
- Exam – very hard without doing exercises and the assignment.

The assignment

- Implement a small programming language.
  - Including a compiler and an interpreter for the language.
  - A framework will be given and each week you will have to do one small step towards the full implementation.
- You may work in groups of 2 to 3 persons.
- More information will be given next Friday and on the Web.

Part I

Part I: Compilation

- What is a compiler?
- Why is this interesting to study?
- What is a language and how do we describe languages?

Part I

The Task of a Compiler

- The main task is to map programs written in a *source* language into a *target* language.
- Often the source language is a programming language and the target language is a machine language.
- The same techniques can also be used for source-to-source translators, machine-code translation, data manipulation e.g. in XML.
- Part of the task of a compiler is also to detect whether a given program conforms to the rules of a language.

Part I

The Task of an Interpreter

- The task of an interpreter is to map programs written in a given *source* language into an *internal representation* and then to *execute* the internal representation.
- Some languages (LISP, BASIC) are mostly interpreted.
- Some languages (Java, Erlang, Prolog) are compiled into *abstract machine code*, which is then interpreted by a *virtual machine*.

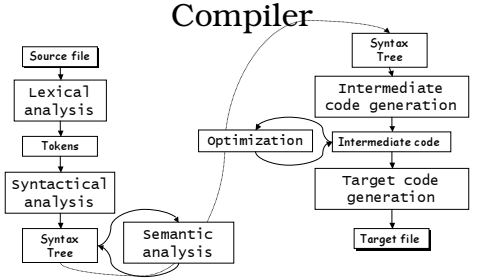
Part I

Native code vs. Interpretation

	Execution speed	Compile time	Portability
Native code	Fast	Long	Hard
Virtual machines	Medium	Medium	Medium
Interpretation	Slow	Short	Easy

Part I

The Structure of a Compiler



Part I

The Structure of a Compiler

- Phases are not necessarily executed after each other.
- Intermediate data structures does not always exist in their entirety.
- In the case of an interpreter, the interpretation can take place on the syntax tree or on the intermediate code. For simple languages sometimes even during parsing.

Why Study Compiler Construction?

Part I

- Many programs have to read and analyze input:
  - Configuration files.
  - User commands.
  - XML, HTML
- Techniques used in a compiler can be used when analyzing other types of data – it teaches you how to organize, manipulate and output information from an analysis.

Why Study Compiler Construction?

Part I

- Understanding of compilers gives better understanding of languages:
  - You will be able to design languages.
  - You will understand how programs are executed and hence will be able to write more efficient programs.
- Compilers connect software and hardware.

What is a language?

Part I

- The first task of a compiler is to understand the meaning of a program written in a programming language.
- Before we can solve this problem we need to have a clear and concise understanding of what a *language* is.

Languages

Part I

- Formally a language is a set of flat *strings* (sentences).
- In practice, each string in a language has a *structure* which can be described in a tree.
- The Structural rules for sentences are defined by a *grammar*.

Grammars

Part I

- A grammar describes all possible sentences in a language by describing the parts of a legal sentence.
- Example: In a simple version of the English language all sentences consists of a subject, followed by a verb.
- This can be described by the grammar:

```
Sentence ::= Subject " " Verb.
```

Grammars

Part I

- To make the grammar

```
Sentence ::= Subject " " Verb.
```

complete we need to add two more *productions:*

```
Subject ::= "Erik" | "Nikolay"
Verb ::= "runs" | "stops"
```

This defines a language with 4 sentences:

Erik runs | Erik stops |

Nikolay runs | Nikolay stops

Grammars

Part I

- An infinite number of sentences can be expressed by a finite number of productions by using recursion.
- Example:

```
Number ::= Digit | Digit Number
Digit ::= “0” | “1” | “2” | “3”
        | “4” | “5” | “6”
        | “7” | “8” | “9”
```

Context-free Grammars

Part I

- A context-free grammar is formally defined by:
  - A set of *terminal symbols* (`“0”, “Erik”`). (The set of all terminal symbols makes up the alphabet of the language.)
  - A set of *non-terminal symbols* (`Subject, Sentence`).
  - A set of syntactic rules, or *productions* (`Subject ::= “Erik” | “Nikolay”`).
  - A *start* symbol (`Sentence`).

The language of a grammar

Part I

- A grammar defines as its language the set of those sequences of terminal symbols which can be derived from the start symbol by successive application of productions.
- A grammar is one description of a language.
- There are in general many grammars for a language.

BNF

Part I

- Backus-Naur Form was developed by J. Backus and P. Naur for Algol 60.
- A production (*rule*) consists of a left-hand-side (lhs) and a right-hand-side (rhs).
- The rhs contains terminals and non-terminals.
  - We use | for alternatives.
  - We use juxtaposition for concatenation.
  - Concatenation binds stronger than |
  - We often quote or capitalize terminals.

EBNF (Extended BNF)

Part I

- EBNF allows us to use:
- ( ) – for grouping.
- ε – for the empty word.
- [E] – for (ε | E).
- { E } – for (ε | E | EE | EEE | …)

EBNF

Part I

We can now write:

```
Number ::= Digit {Digit}
Digit ::= “0” | “1” | “2” | “3”
| “4” | “5” | “6” | “7” | “8” | “9”
```

And:

```
Sentence ::=
(“Erik”|“Nikolay”) “ ” (“runs”|“stops”)
```

EBNF

- Can I replace all recursion by {}?
- No, e.g.:

```
Par ::= "(" Par ")" | "3"
```

- Can I replace all {} by recursion?
- Yes, every grammar in EBNF can be translated to a grammar in BNF.

Regular Languages

- A language is *regular* of it can be expressed by a single EBNF rule without recursion.
- Since there is only one, non-recursive rule all symbols on the rhs must be terminal symbols.
- The rhs is called a *regular expression (reg-exp)*.
- Regular languages are interesting because they can be recognized by *finite state machines.*

Regular Expressions

- A regular language can also be described by a number of EBNF rules without recursion.
- There are alternative ways of writing regular expressions. The most common is:

`E*` for `{E}`.	`[ac]` for ("a"|"c").
`E?` for `[E]`.	`[a-d]` for ("a"|"b"|"c"|"d").
`E+` for `E{E}`.	`[^0-9]` for anything but a digit.

Two level descriptions

- The description of a language is often divided into two levels: a lexical (words or *tokens*) and a syntactical (sentences).
- Similarly a compiler recognizes sentences in the language in two steps, with a lexical analysis and syntactic analysis.
- The lexical analysis recognizes words in the language and the syntactical analysis recognizes sentences in the language.

Two level descriptions

- This division is natural to do, since we also think in words and sentences.
- The rules for words are usually a lot simpler than the rules for sentences. Most words can be described by one regular expression, but the description of sentences often requires recursion (to be concise).
- By splitting the recognition we can deal with white space and comments easily and in one place.

A Small Language

- Syntax of arithmetic expressions

```
Expr ::= Expr (MINUS | PLUS) Term
       | Term
Term ::= Term (TIMES | DIV) Factor
       | Factor
Factor ::= NUMBER | LPAR Expr RPAR
```

Part I

A Small Language

- Lexical description of *tokens*:

```
TIMES   ::= "*"
DIV     ::= "/"
PLUS    ::= "+"
MINUS   ::= "-"
LPAR    ::= "("
RPAR    ::= ")"
NUMBER  ::= DIGIT {DIGIT}
DIGIT   ::= "0" | … | "9"
```

Part I

A Small Language

- Notice that the syntactical description uses recursion, but that the lexical description does not.
- Notice that NUMBER is a terminal in the syntactical description but a non-terminal in the lexical description.

Part I

White space

- Usually you want to allow white spaces (" ", "\n", "\t") and comments between tokens.
- These are not tokens, and not members of the alphabet of the syntactic description.
- But they are members of the alphabet of the lexical description, and has to be handled by the compiler.

Next part...