Compiler Construction

Lecture 1: Introduction

Summer Semester 2016

Thomas Noll
Software Modeling and Verification Group
RWTH Aachen University

https://moves.rwth-aachen.de/teaching/ss-16/cc/

Outline of Lecture 1

People

- Lectures:
  - Thomas Noll (noll@cs.rwth-aachen.de)
- Exercise classes:
  - Christoph Matheja (matheja@cs.rwth-aachen.de)
  - Matthias Volk (matthias.volk@cs.rwth-aachen.de)
- Student assistant: Wanted!!!
  - Evaluation of exercises
  - Organisational support
  - 12 hrs/week contract
  - Previous CC experience not a prerequisite (but of course helpful)

Target Audience

- BSc Informatik:
  - Wahlpflicht Theoretische Informatik
- MSc Informatik:
  - Theoretische Informatik
- MSc Software Systems Engineering:
  - Theoretical Foundations of SSE

Expectations

- What you can expect:
  - how to implement (imperative) programming languages
  - application of theoretical concepts (scanning, parsing, static analysis, ...)
  - compiler = example of a complex software architecture
  - gaining experience with tool support

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- What you can expect:
  - how to implement (imperative) programming languages
  - application of theoretical concepts (scanning, parsing, static analysis, ...)
  - compiler = example of a complex software architecture
  - gaining experience with tool support
- What we expect: basic knowledge in
  - (imperative) programming languages
  - algorithms and data structures (queues, trees, ...)
  - formal languages and automata theory (regular and context-free languages, finite and pushdown automata, ...)

Organisation

- Schedule:
  - Lecture Tue 14:15–15:45 AH 6 (starting 19 April)
  - Lecture Thu 14:15–15:45 AH 6 (starting 14 April)
  - Exercise class Tue 12:15–13:45 AH 2 (starting 26 April)
  - Special: 16/21 June (itestra)
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- Written material in English (including exam), lecture and exercise classes in German, rest up to you

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What Is It All About?

Compiler = Program: Source code $\rightarrow$ Target code

Source code: in high-level programming language, tailored to problem

- imperative vs. declarative (functional, logic) vs. object-oriented
- sequential vs. concurrent

Target code: low-level code, tailored to machine

- platform-independent byte code (for virtual machine such as JVM)
- platform-dependent assembly/machine code (RISC/CISC/parallel/...)

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Compiler vs. interpreter

Compiler: translates an executable program in one language into an executable program in another language (possibly applying “improvements”)

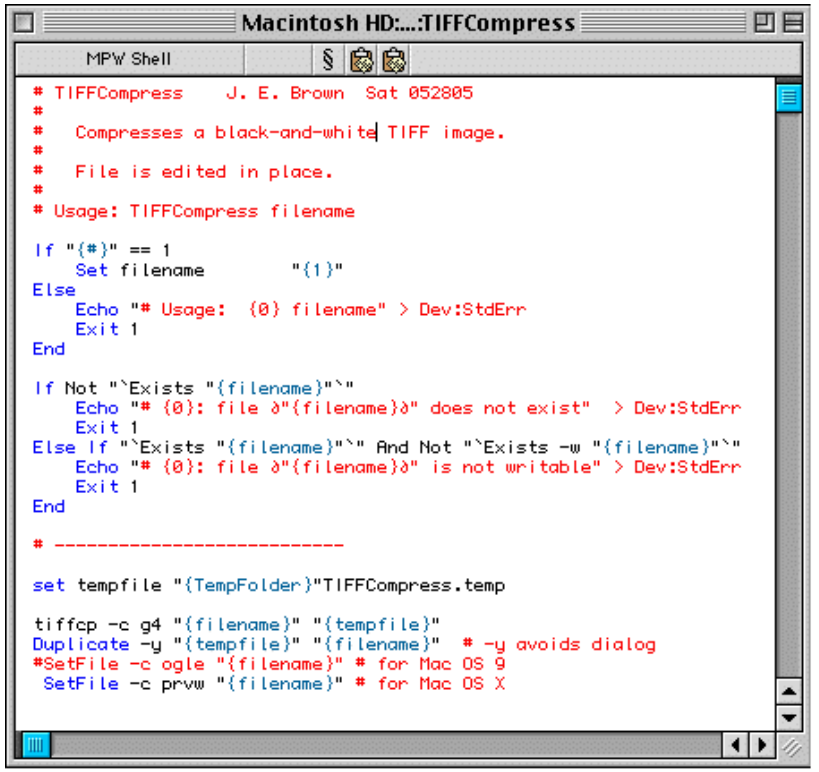
Interpreter: directly executes an executable program, producing the corresponding results

What Is a Compiler?

Usage of Compiler Technology I

Programming language interpreters

- Ad-hoc implementation of small programs in scripting languages (perl, bash, ...)
- Programs usually interpreted, i.e., executed stepwise
- Moreover: many non-scripting languages also involve interpreters (e.g., JVM as byte code interpreter)



Usage of Compiler Technology II

Web browsers

- Receive HTML (XML) pages from web server
- Analyse (parse) data and translate it to graphical representation

```
1  <!DOCTYPE html PUBLIC "-//W3C//DTD HTML
2  <html>
3      <head>
4          <title>Example</title>
5          <link href="screen.css" rel="sty
6      </head>
7      <body>
8          <h1>
9              <a href="/">Header</a>
10         </h1>
11         <ul id="nav">
12             <li>
13                 <a href="one/">One</a>
14             </li>
15             <li>
16                 <a href="two/">Two</a>
17             </li>
```

Usage of Compiler Technology III

Text processors

- LaTeX = “programming language” for texts of various kinds
- Translated to DVI, PDF, ...

```
\documentclass[12pt]{article}
%options include 12pt or 11pt or 10pt
%classes include article, report, book, letter, thesis
\title{This is the title}
\author{Author One \\ Author Two}
\date{\today}
\begin{document}
\maketitle
This is the content of this document.
This is the 2nd paragraph.
Here is an inline formula:
$V=\frac{4 \pi r^3}{3}$
And appearing immediately below
is a displayed formula:
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\end{document}
```

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Properties of a Good Compiler I

Efficiency of generated code

Goal: target code as fast and/or memory efficient as possible

- program analysis and optimisation
- cf. course on *Static Program Analysis* (WS 2014/15, WS 2016/17)

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Remark: mutual tradeoffs!

Properties of a Good Compiler II

Correctness

Goals: conformance to source and target language specifications; “equivalence” of source and target code

- compiler validation and verification
- proof-carrying code, ...
- cf. course on *Semantics and Verification of Software* (SS 2015, SS 2017)

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Syntax: “How does a program look like?”

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- “Operational semantics”: execution evokes state transformations of an (abstract) machine

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Pragmatics

- length and understandability of programs
- learnability of programming language
- appropriateness for specific applications
- ...

Motivation for Rigorous Formal Treatment

Example 1.1

1. From NASA's Mercury Project: FORTRAN `DO` loop
   - `DO 5 K = 1,3`: DO loop with index variable `K`
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for i := 2 to 1 do ...
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   FORTRAN IV: once
   PASCAL: never

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3. What if `p = nil` in the following program?

   ```
   while p <> nil and p^.key < val do ...
   ```

   Pascal: strict Boolean operations ↯
   Modula: non-strict Boolean operations ✓

Historical Development

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Automatic compiler generation: since 1980s
- `[f]lex`, `yacc`, ANTLR, action semantics, ...
- cf. `http://catalog.compilertools.net/` (somewhat outdated ...)

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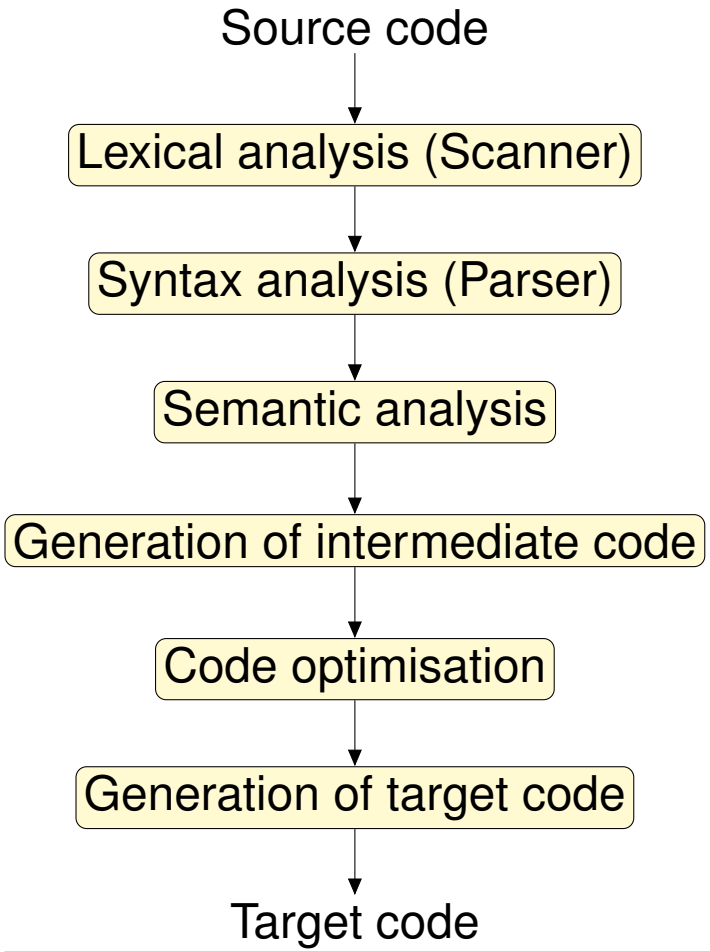
Generation of target code: tailored to target system

Additionally: optimisation of target code, symbol table, error handling

Conceptual Structure of a Compiler



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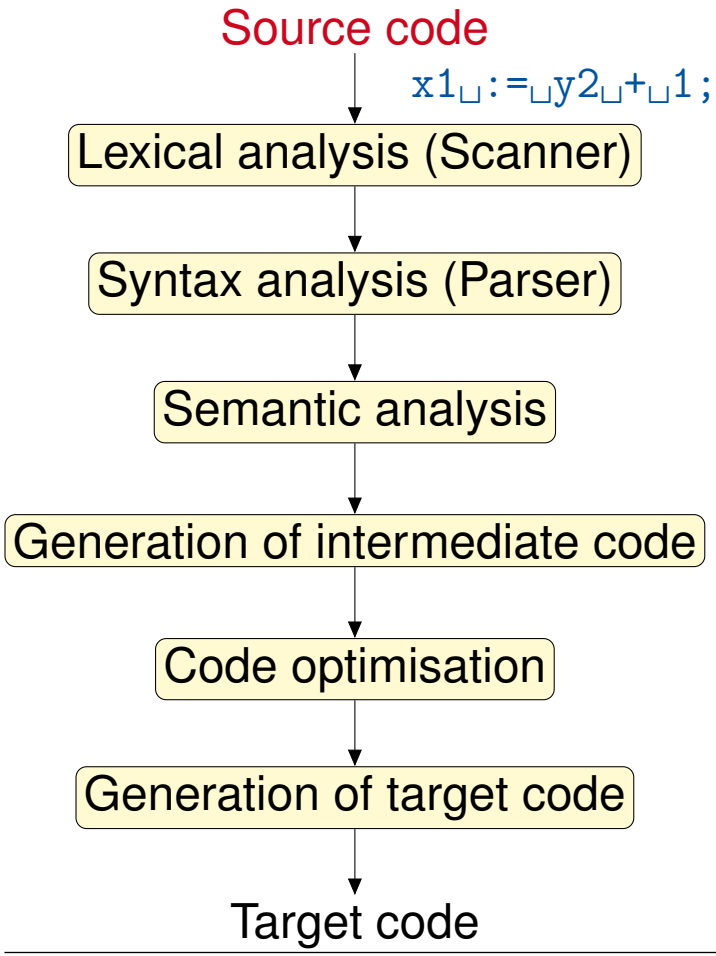

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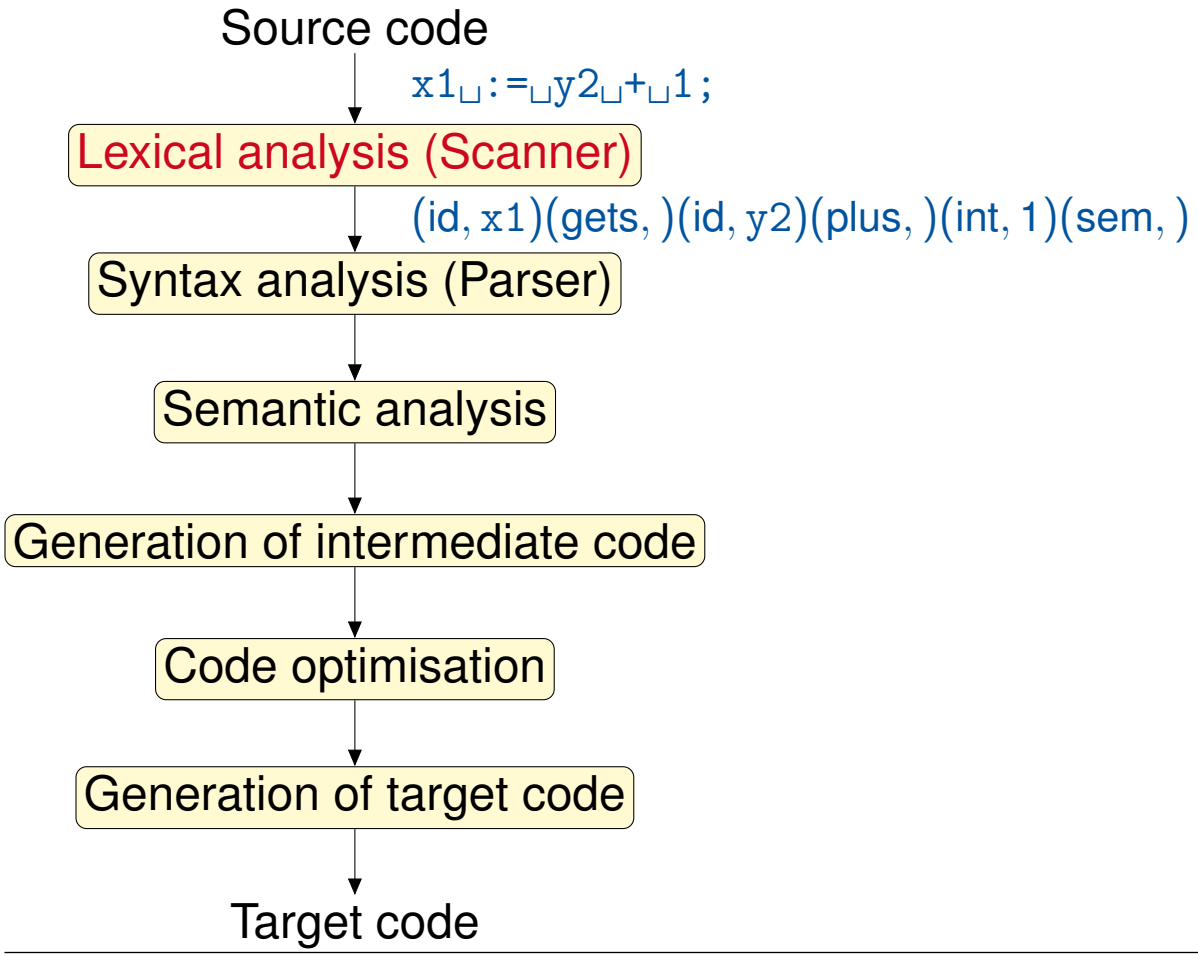

regular expressions/
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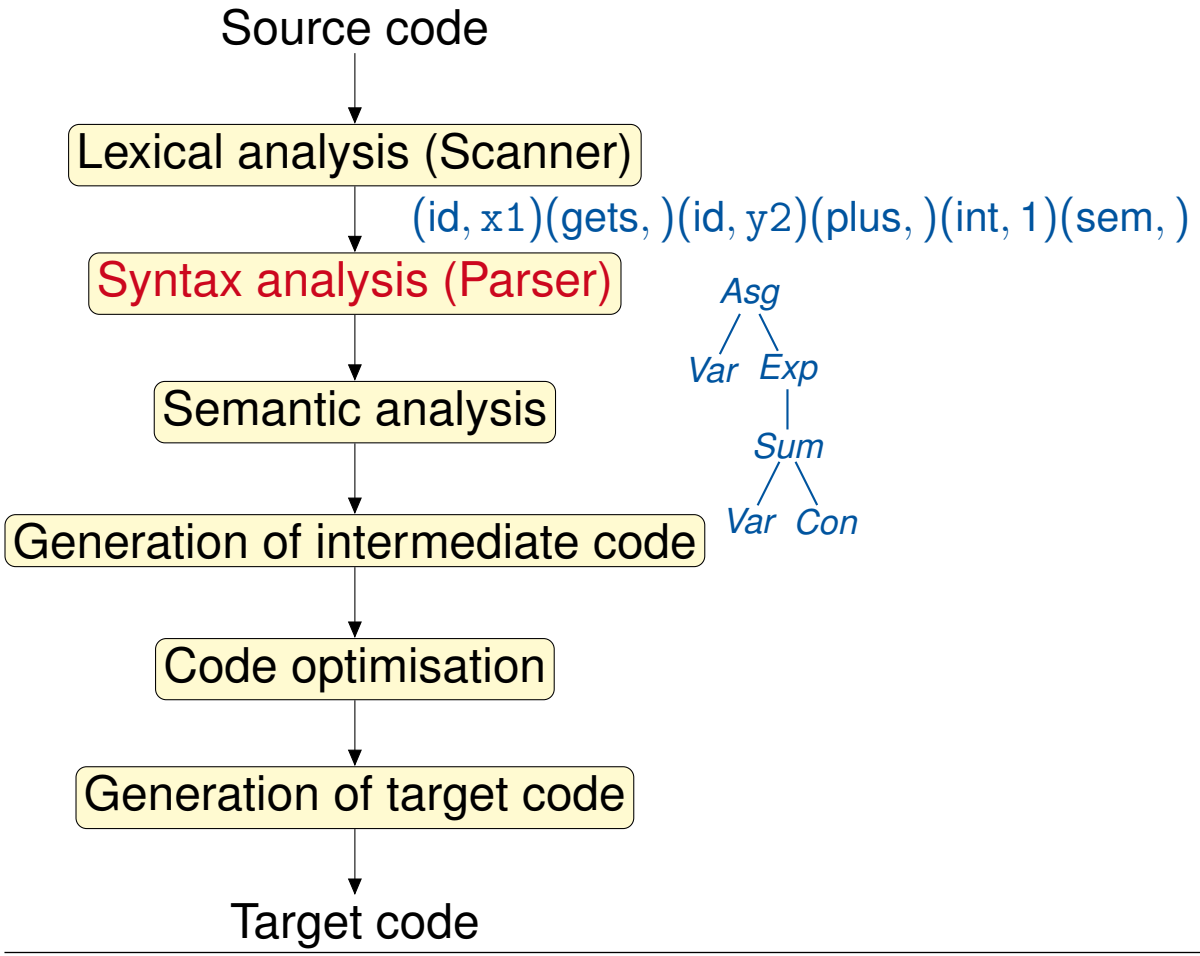

context-free grammars/
pushdown automata

The High-Level View

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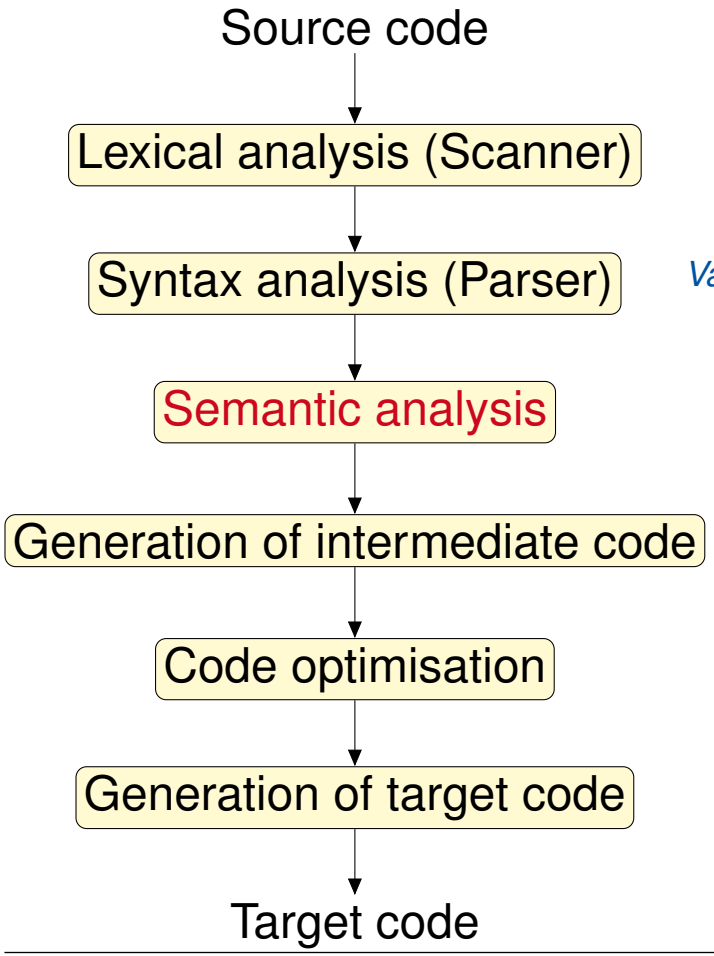

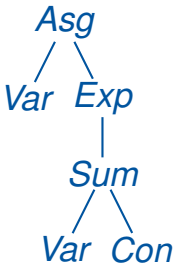

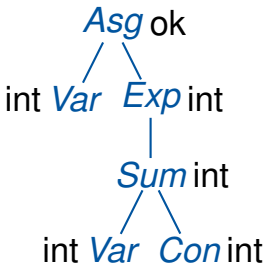

attribute grammars

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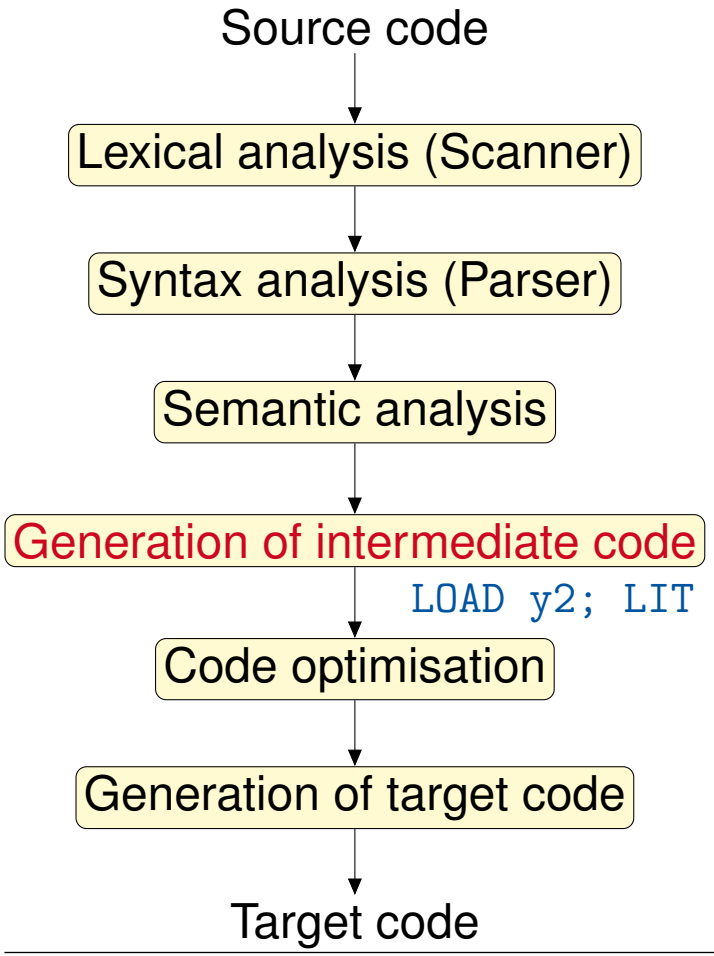

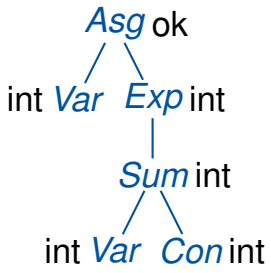

tree translations

```
LOAD y2; LIT 1; ADD; STO x1
```

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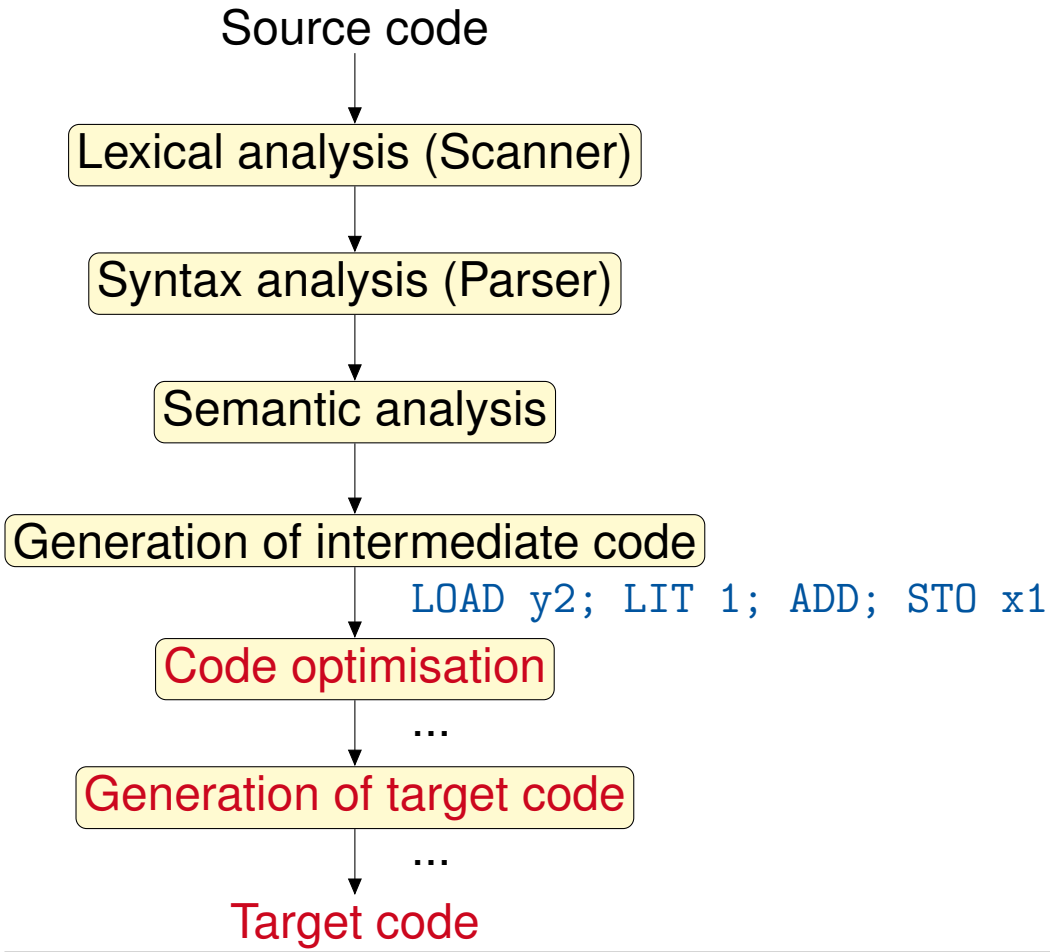

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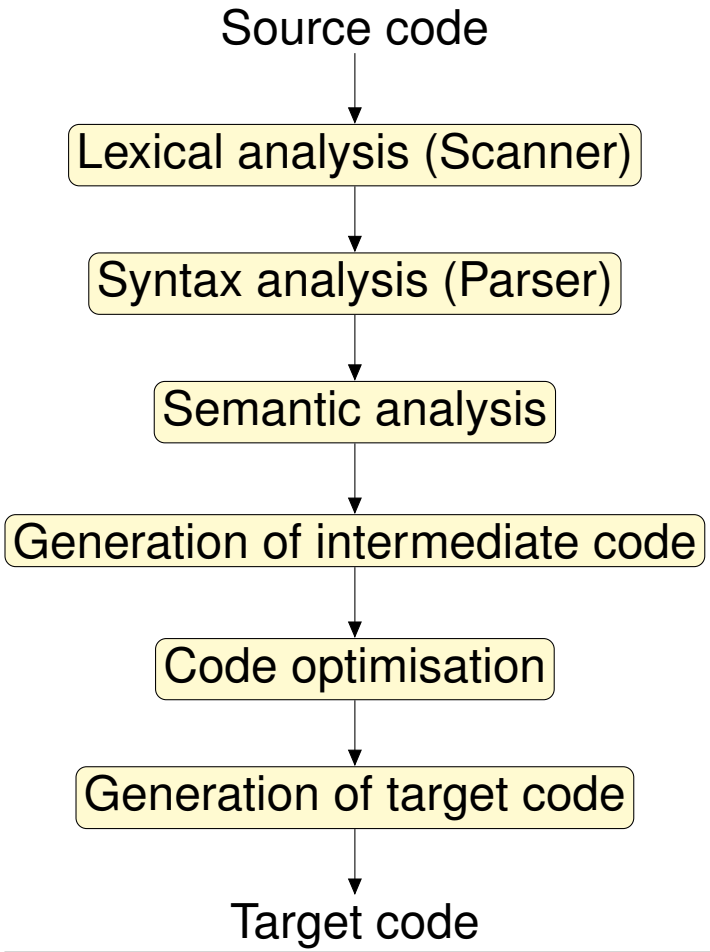

[omitted: symbol table, error handling]

Classification of Compiler Phases

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Synthesis: generation of (intermediate/target) code + optimisation

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Front-end vs. back-end

Front-end: machine-independent parts
(analysis + intermediate code + machine-independent optimisations)

Back-end: machine-dependent parts (generation + optimisation of target code)

- instruction selection
- register allocation
- instruction scheduling

Role of the Runtime System

- Memory management services
  - allocation (on heap/stack)
  - deallocation
  - garbage collection
- Run-time type checking (for non-“strongly typed” languages)
- Error processing, exception handling
- Interface to the operating system (input and output, ...)
- Support for parallelism (communication and synchronisation)

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General

- A.V. Aho, M.S. Lam, R. Sethi, J.D. Ullman: *Compilers – Principles, Techniques, and Tools; 2nd ed.*, Addison-Wesley, 2007
- A.W. Appel, J. Palsberg: *Modern Compiler Implementation in Java*, Cambridge University Press, 2002
- D. Grune, H.E. Bal, C.J.H. Jacobs, K.G. Langendoen: *Modern Compiler Design*, Wiley & Sons, 2000
- R. Wilhelm, D. Maurer: *Übersetzerbau, 2. Auflage*, Springer, 1997

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Specific

- O. Mayer: *Syntaxanalyse*, BI-Wissenschafts-Verlag, 1978
- D. Brown, R. Levine T. Mason: *lex & yacc*, O'Reilly, 1995
- T. Parr: *The Definite ANTLR Reference*, Pragmatic Bookshelf, 2007