Compiler Construction

Lecture 1: Introduction

Winter Semester 2018/19

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RWTH Aachen University

https://moves.rwth-aachen.de/teaching/ws-1819/cc/

Software Modeling and Verification Chair
RWTH AACHEN UNIVERSITY

Outline of Lecture 1

People

- Lectures:
  - Thomas Noll (noll@cs.rwth-aachen.de)
- Exercise classes:
  - Philipp Berger (berger@cs.rwth-aachen.de)
  - Matthias Volk (matthias.volk@cs.rwth-aachen.de)
- Student assistant:
  - Justus Fesefeldt

Target Audience

- BSc Informatik:
  - Wahlpflicht Theoretische Informatik
- MSc Informatik:
  - Wahlpflicht 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, stacks, trees, ...)
  - formal languages and automata theory (regular and context-free languages, finite and pushdown automata, ...)

Organisation

- Schedule:
  - Lecture Mon 12:30–14:00 AH 6 (starting 8 Oct)
  - Lecture Thu 12:30–14:00 AH 5 (starting 11 Oct)
  - Exercise class Mon 15:15–16:45 AH 5 (starting 15 Oct)
  - Two special lectures in mid-December (itestra)
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- Written material in English (including exam), lecture and exercise classes in German, rest up to you

Outline of Lecture 1

What Is a Compiler?

What Is It All About?

https://en.wikipedia.org/wiki/Compiler

"A compiler is computer software that transforms computer code written in one programming language (the source language) into another programming language (the target language)... The name compiler is primarily used for programs that translate source code from a high-level programming language to a lower level language (e.g., assembly language, object code, or machine code) to create an executable program."

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Compiler vs. interpreter

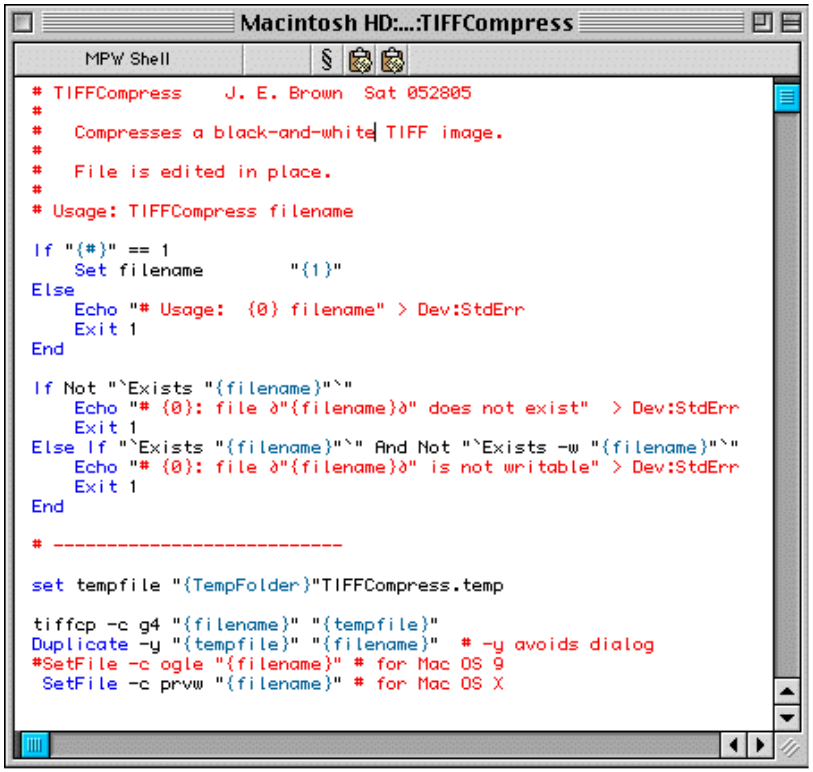
Compiler: translates an executable program in one language into an executable program in another language (possibly applying "improvements")

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

Usage of Compiler Technology I

Programming language interpreters

- Ad-hoc implementation of small programs in scripting languages (JavaScript, Perl, Ruby, 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:
$$V=\frac{4 \pi r^3}{3}$$
\end{document}
```

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Expected Properties of a Compiler I

Correctness of translation

Goals:

syntactic correctness: conformance to source and target language specifications

- accept all (and only) syntactically valid input programs
- produce correct target code

semantic correctness: “equivalence” of source and target code

- behaviour of target code “corresponds to” (expected) behaviour of source code

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Techniques:

- compiler validation and verification
- proof-carrying code, ...
- cf. course on *Semantics and Verification of Software* (WS 2017/18, SS 2019)

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Efficiency of generated code

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

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Remark: mutual tradeoffs!

Aspects of a Programming Language

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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   (cf. Dirk W. Hoffmann: *Software-Qualität*, 2nd ed., Springer 2013)

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3. What if value of `p` is `nil` in the following program?

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

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

Historical Development

Code generation: since 1940s

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Automatic compiler generation: since 1980s
- `[f]lex`, `yacc/bison`, `ANTLR`, ...
- cf. `https://www.thefreecountry.com/programming/compilerconstruction.shtml`

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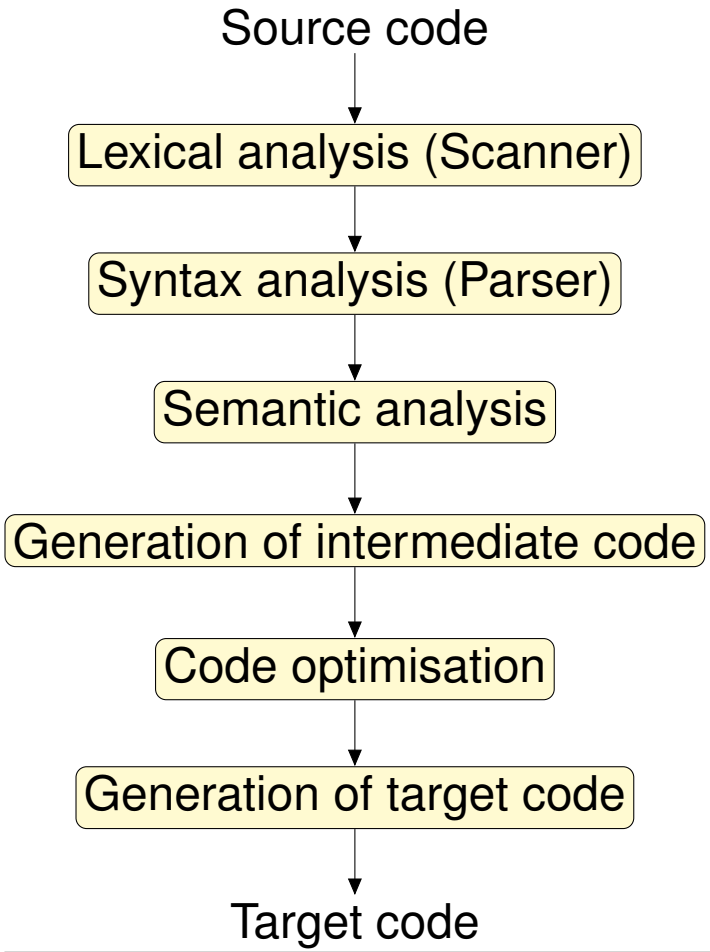
Additionally: optimisation of target code, symbol table, error handling

Conceptual Structure of a Compiler



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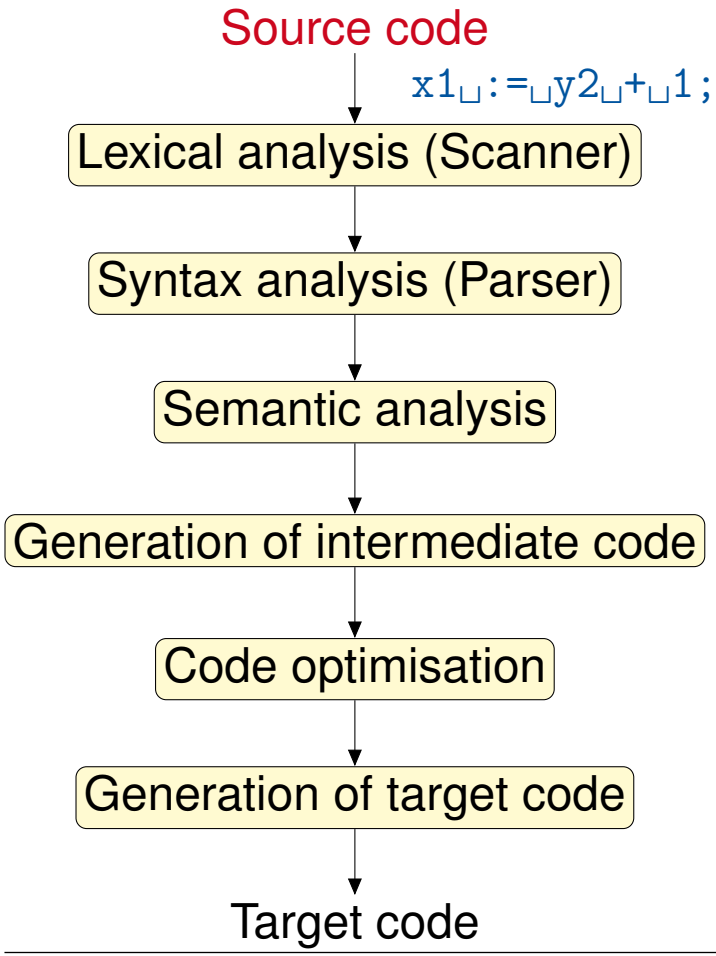

The High-Level View

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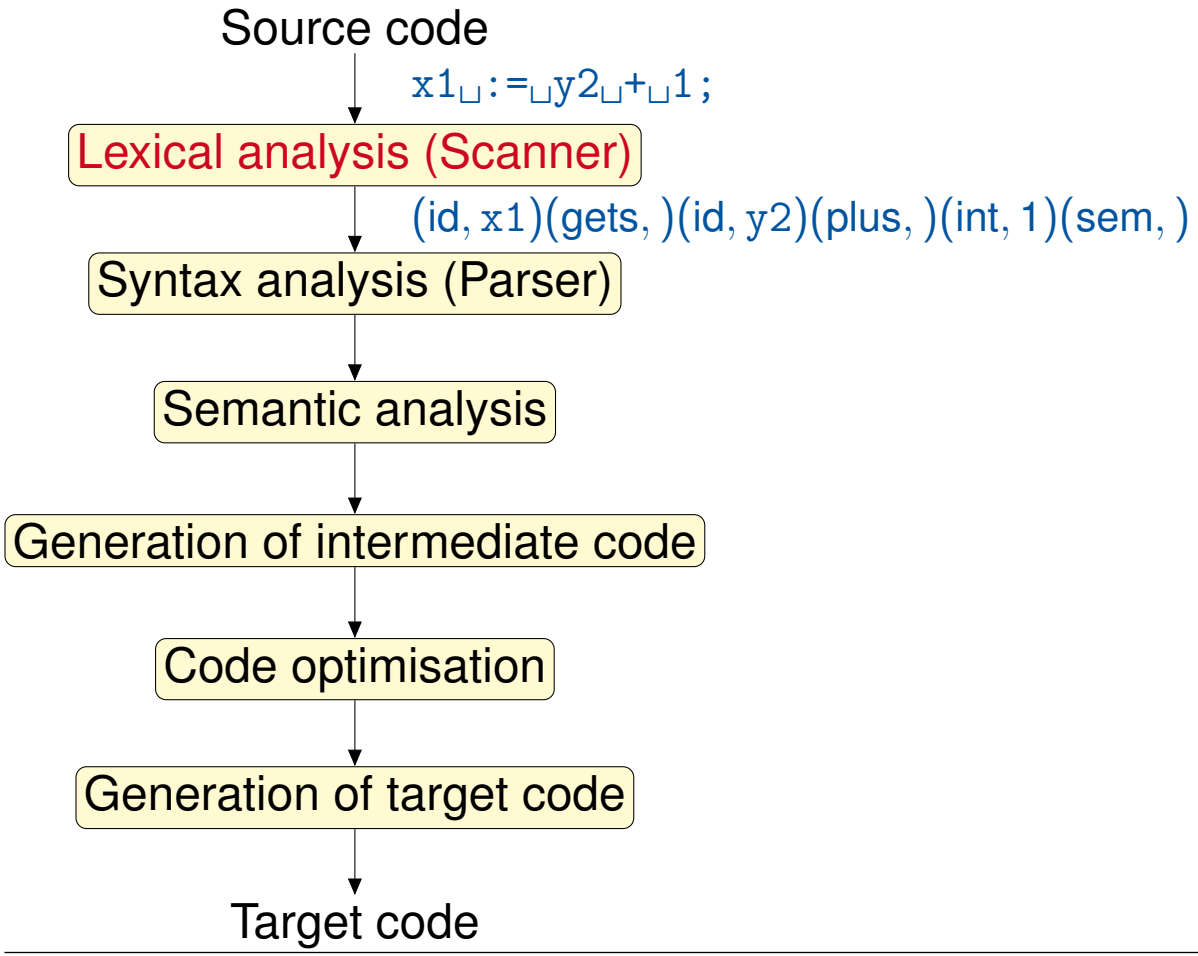

regular expressions/
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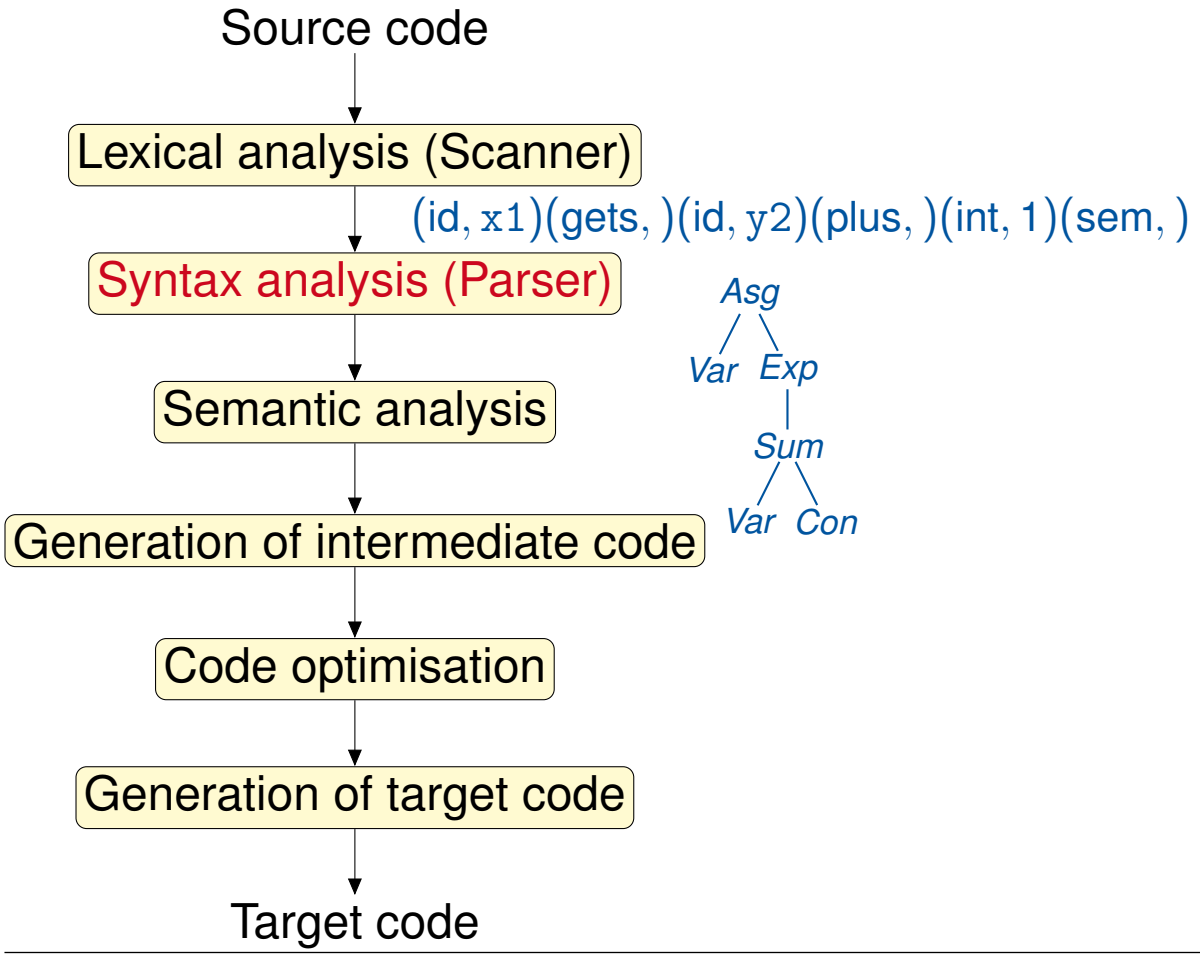

context-free grammars/
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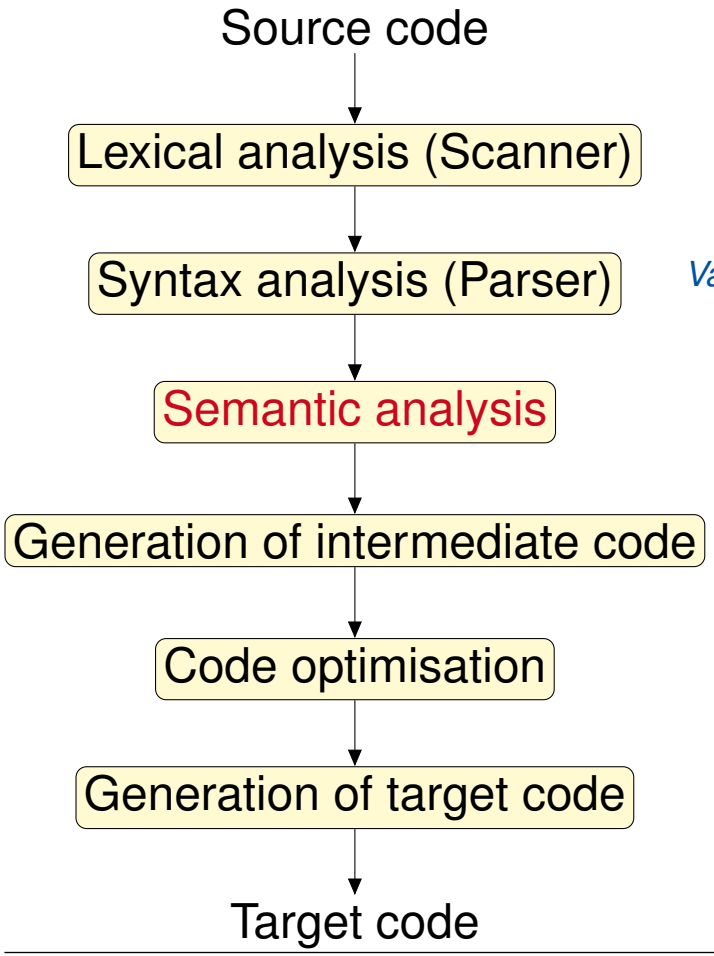

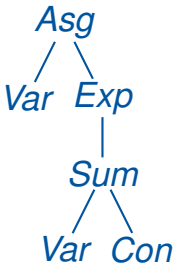

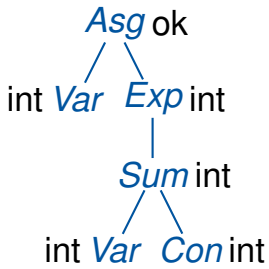

attribute grammars

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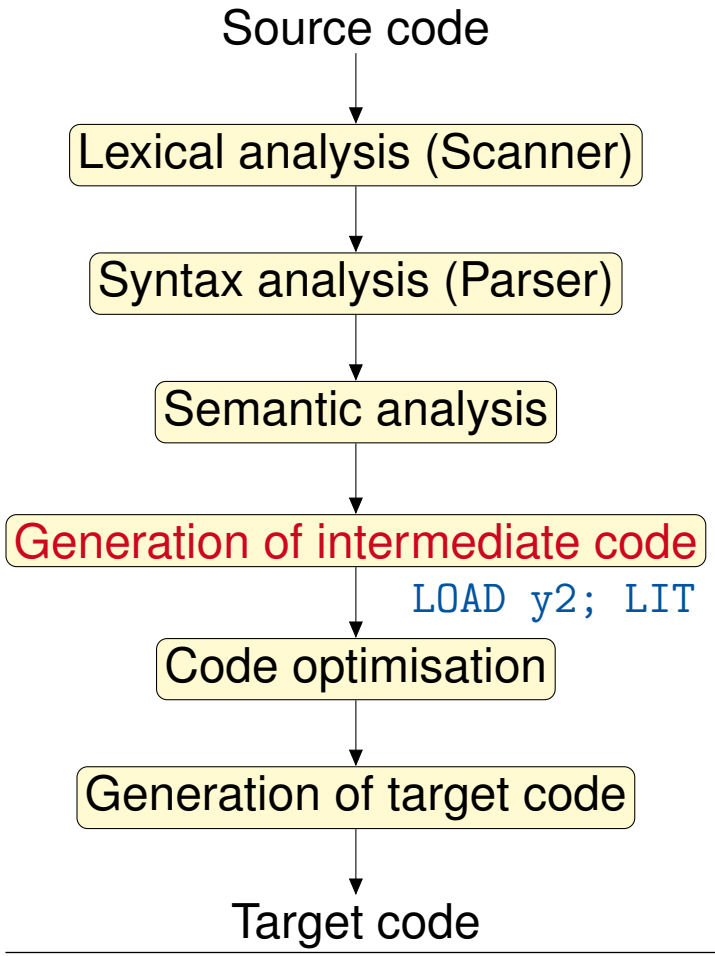

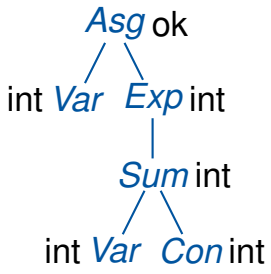

tree translations

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

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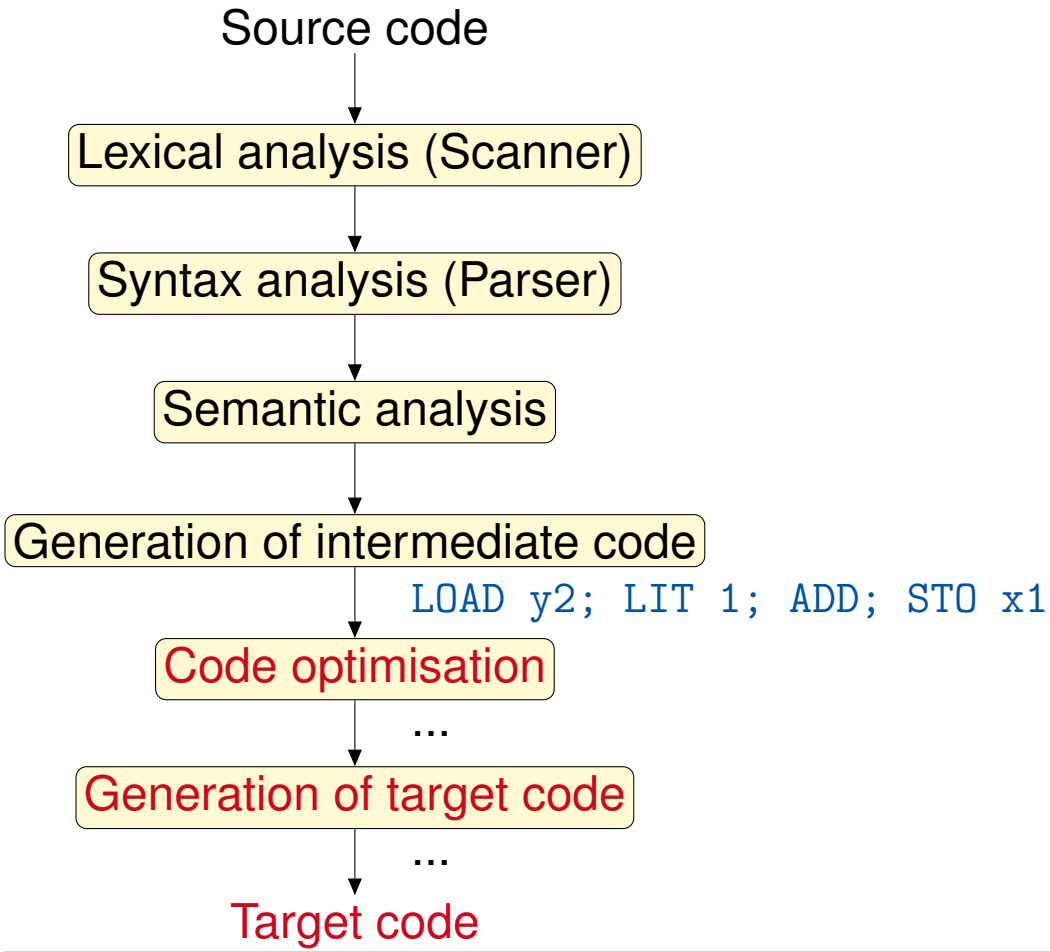

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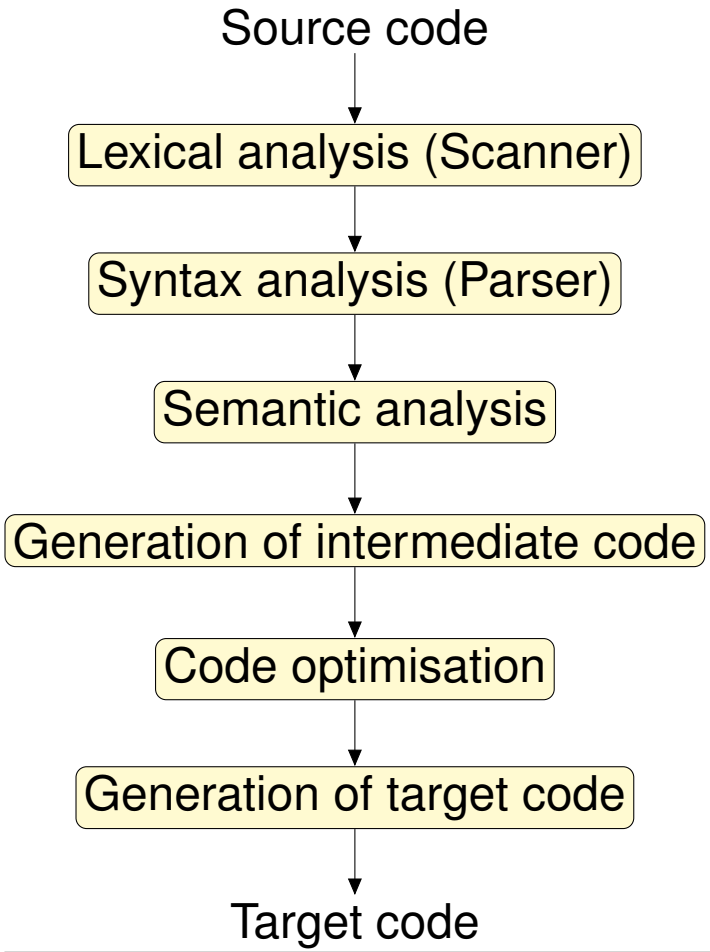

[omitted: symbol table, error handling]

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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Literature

Literature (CS Library: “Handapparat *Softwaremodellierung und Verifikation*”)

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