Compiler Construction

Lecture 1: Introduction

Winter Semester 2022/23

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https://moves.rwth-aachen.de/teaching/ws-22-23/cc/

Software Modeling and Verification Chair
RWTH AACHEN UNIVERSITY

Outline of Lecture 1

Staff

- Lectures:
  - Thomas Noll
- Exercise classes:
  - Kevin Batz
  - Ira Fesefeldt
- Student assistant:
  - Jonas Seidel

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
  - formal languages and automata theory (regular and context-free languages, finite and pushdown automata, ...)
  - algorithms and data structures (queues, stacks, trees, ...)

Organisation

- All material made available via RWTHmoodle Classroom
  - slides
  - videos from Winter 2020/21
  - exercise sheets
- Schedule:
  - Lecture ~~Mon 12:30–14:00 AH 2~~ Mon 14:30–16:00 Aula 1 (starting Oct 17)
  - Lecture ~~Tue 12:30–14:00 AH 2 (starting Oct 18)~~ Fri 12:30–14:00 Ro (starting Oct 21)
  - Exercise class Wed 14:30–16:00 AH 2 (starting Oct 26)

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- Assignment sheets in weekly intervals, starting Oct 19
- Work on assignments in groups of four
- Submission deadline: one week after publication
  - on paper or via RWTHmoodle
- Corrections provided as annotations to submissions

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- Written exams (2 h, 6 credits)
  - Thu, Feb 23, 2023
  - Wed, Mar 22, 2023
- Exercises are optional (no admission requirements for exam)

Outline of Lecture 1

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

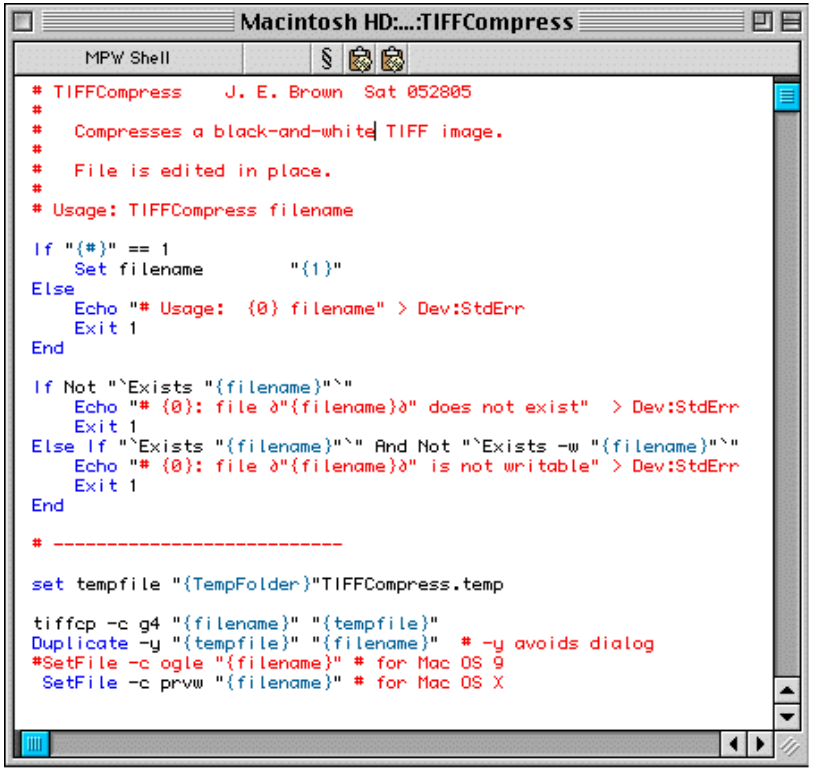
Compiler: translates an executable program in one language into an executable program in another language (possibly applying "improvements")

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

Usage of Compiler Technology I

Programming language interpreters

- Ad-hoc implementation of little 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, ...

```latex
\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 valid 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 (based on formal semantics of source/target language)
- proof-carrying code, ...
- cf. course on *Semantics and Verification of Software* (Summer 2023)

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Efficiency of generated code

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

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Caveat: mutual tradeoffs!

Aspects of a Programming Language

Syntax: “How does a program look like?”

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Semantics: “What does this program mean?”

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

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Pragmatics

- Length and understandability of programs (C vs. COBOL)
- Learnability of programming language (e.g., higher-order functions)
- Appropriateness for specific applications (imperative/object-oriented/functional/logic/...)
- ...

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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(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 ✓

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Code generation: since 1940s

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Automatic compiler generation: since 1980s

- `[f]lex`, `yacc/bison`, `ANTLR`, ...
- *Free Compiler Construction Tools*

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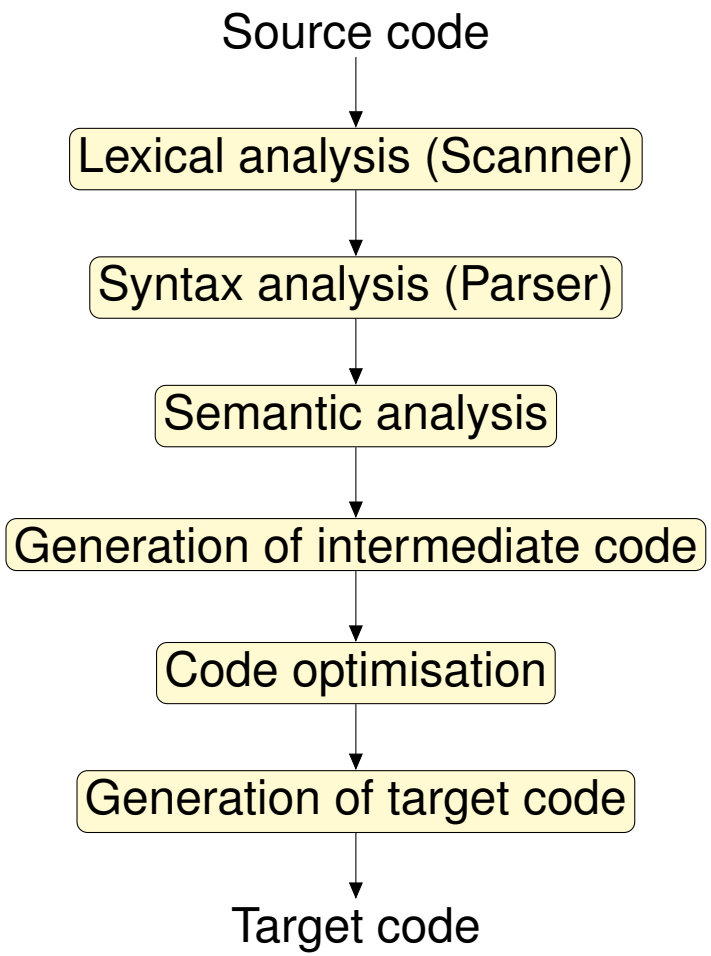
Generation of target code: tailored to target system

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

Conceptual Structure of a Compiler



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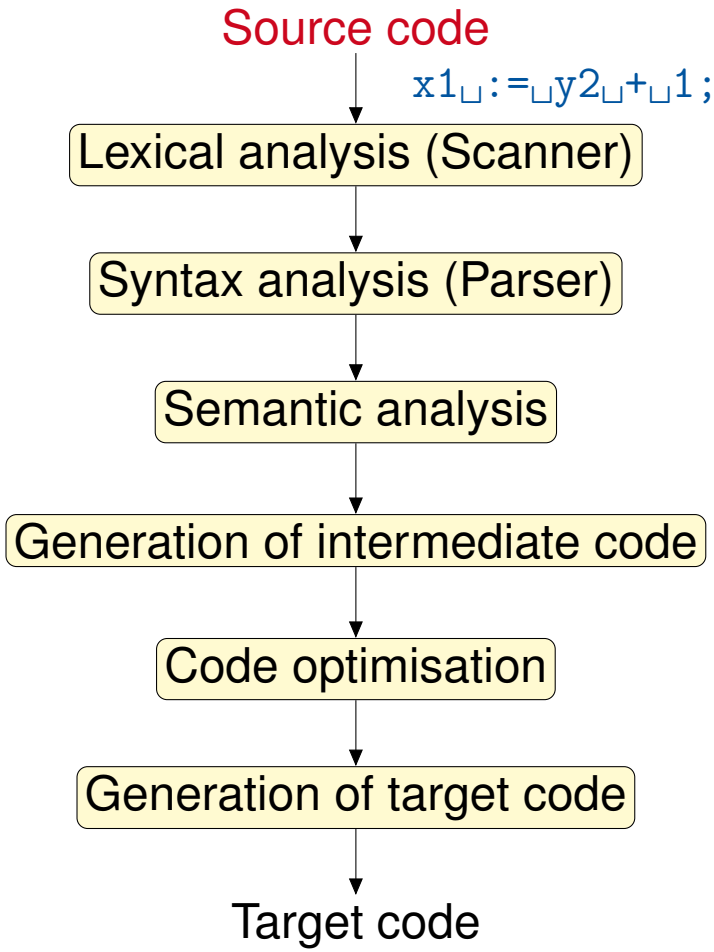

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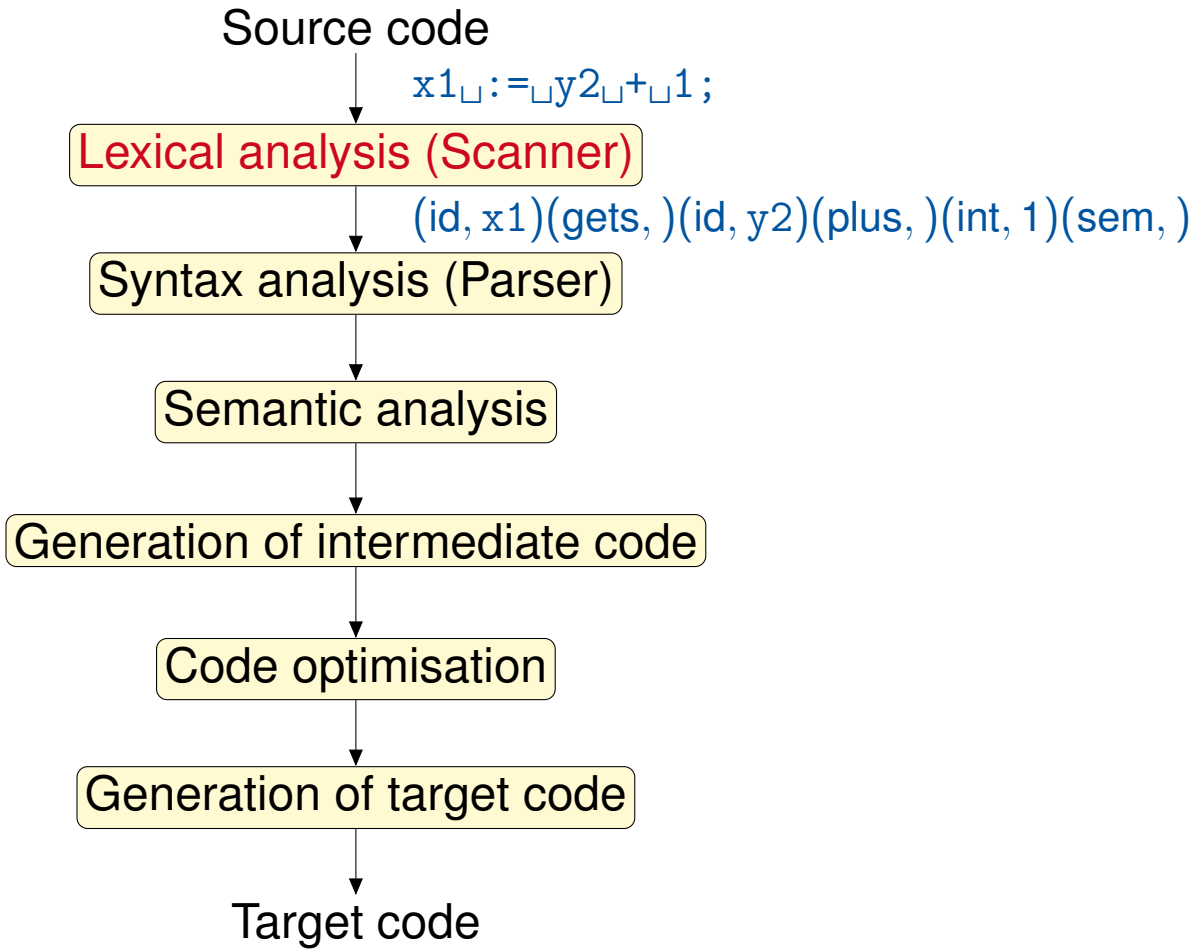

regular expressions/
finite automata

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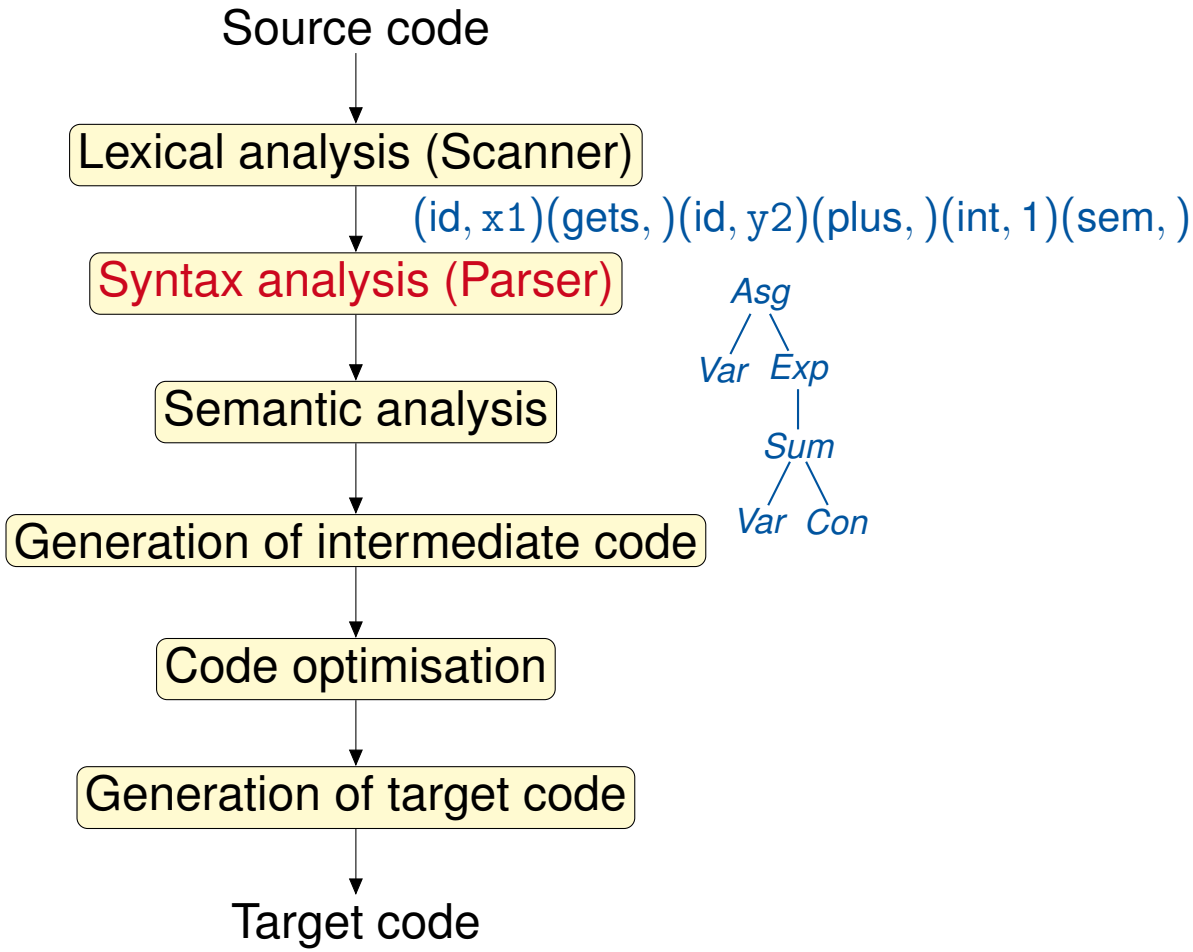

context-free grammars/
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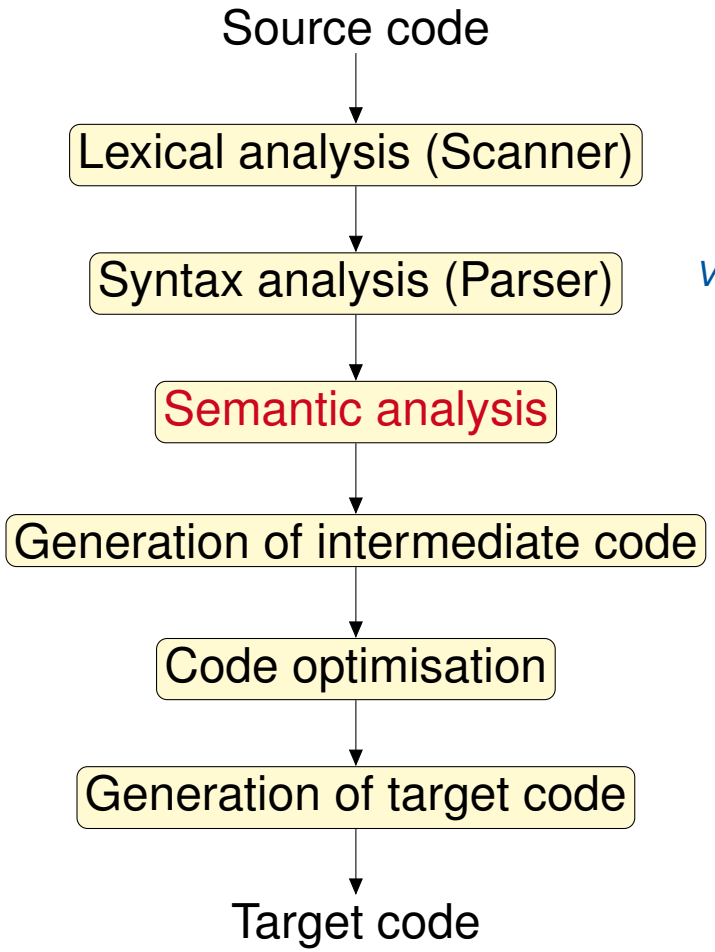

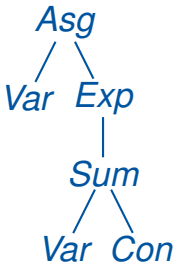

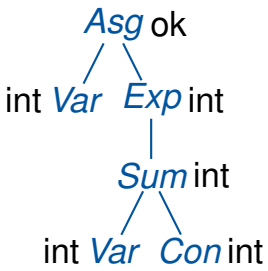

attribute grammars

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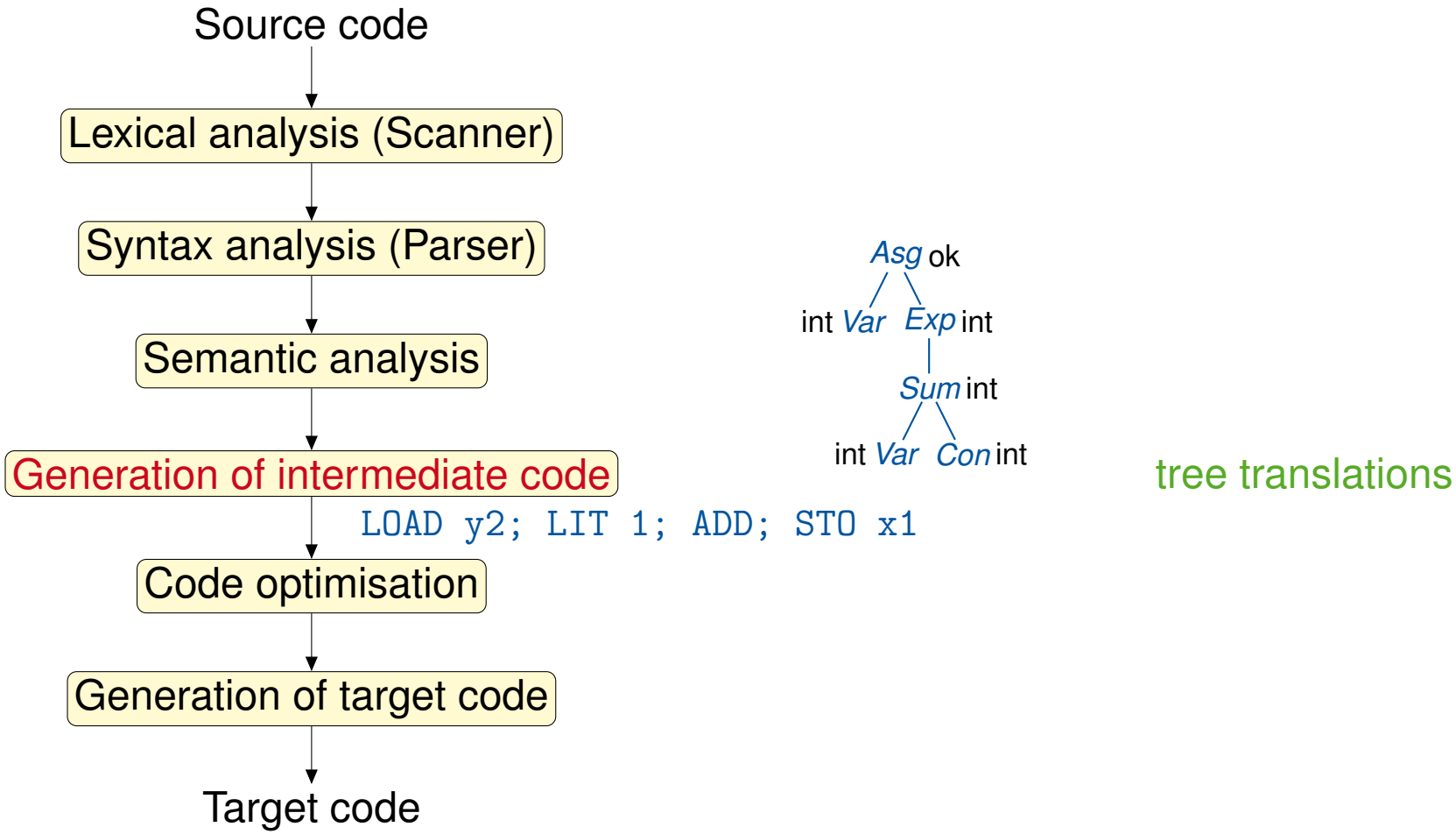

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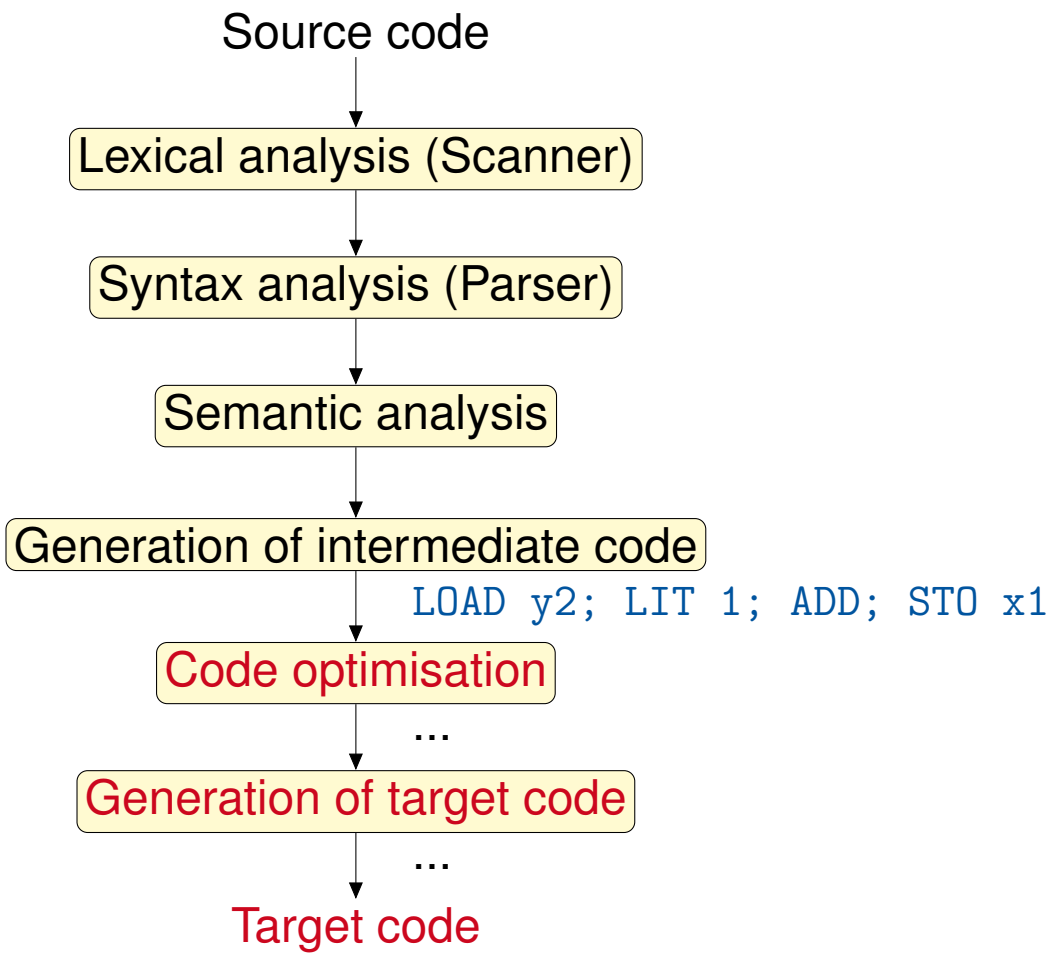

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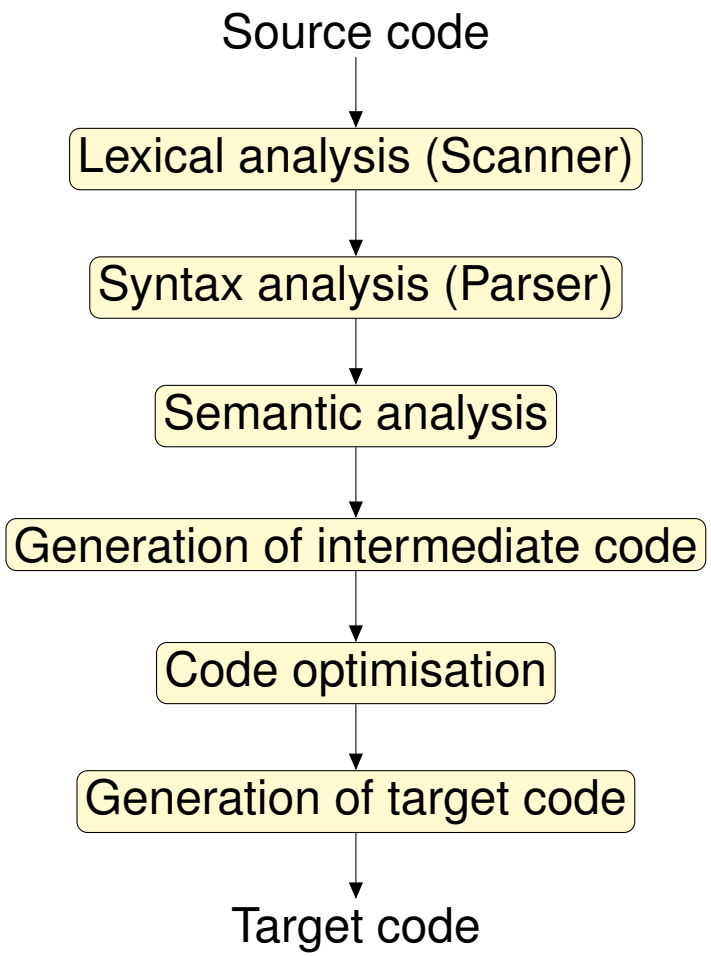

[omitted: symbol table, error handling]

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Analysis vs. synthesis

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

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Frontend vs. backend

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

Backend: 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 (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