Script **generated by TTT**

Title: Simon: Compilerbau (07.04.2014)

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TECHNISCHE UNIVERSITÄT MÜNCHEN
FAKULTÄT FÜR INFORMATIK

Compiler Construction I

Dr. Michael Petter, Dr. Axel Simon

SoSe 2014

Organizing

- Master or Bachelor in the 6th Semester with 5 ECTS
- Prerequisites
  - Informatik 1 & 2
  - Theoretische Informatik
  - Technische Informatik
  - Grundlegende Algorithmen
- Delve deeper with
  - Virtual Machines
  - Programmoptimization
  - Programming Languages
  - Praktikum Compilerbau
  - Hauptseminars

Materials:

- TTT-based lecture recordings
- the slides
- Related literature list online
- Tools for visualization of virtual machines
- Tools for generating components of Compilers

Organizing

Dates:
Lecture: Mo. 14:15-15:45
Tutorial: You can vote on two dates via moodle

Exam:

- One Exam in the summer, none in the winter
- Exam managed via TUM-online
- Successful (50% credits) tutorial exercises earns 0.3 bonus

Preliminary content

- Basics in regular expressions and automata
- Specification and implementation of scanners
- Reduced context free grammars and pushdown automata
- Bottom-Up Syntaxanalysis
- Attribute systems
- Typechecking
- Codegeneration for stack machines
- Register assignment
- Basic Optimization

Topic:

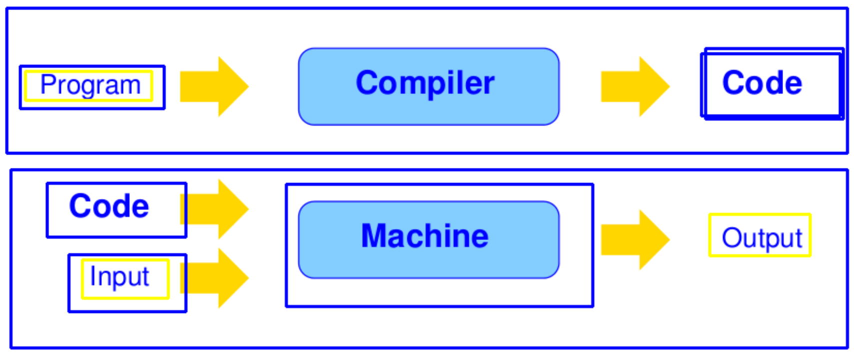
Introduction

Interpreter

Pro:
No precomputation on program text necessary
⇒ no/small Startup-time

Con:
Program components are analyzed multiple times during the execution
⇒ longer runtime

Concept of a Compiler:



Two Phases:

1. Translating the program text into a machine code
2. Executing the machine code on the input

Compiler

A precomputation on the program allows

- a more sophisticated variable management
- discovery and implementation of global optimizations

Disadvantage

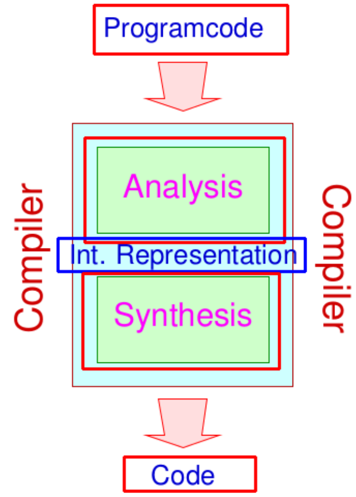
The Translation costs time

Advantage

The execution of the program becomes more efficient
⇒ payoff for more sophisticated or multiply running programs.

Compiler

general Compiler setup:



Compiler

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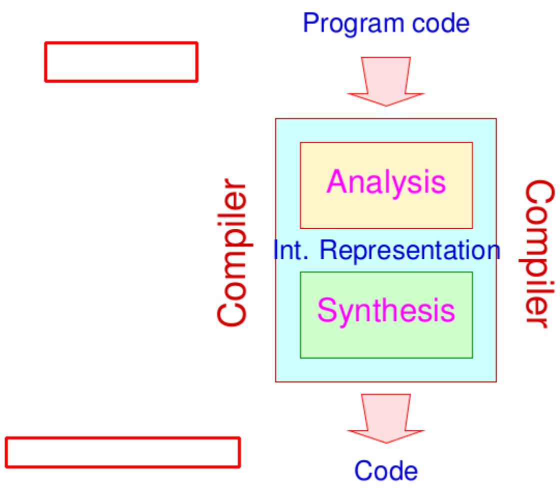
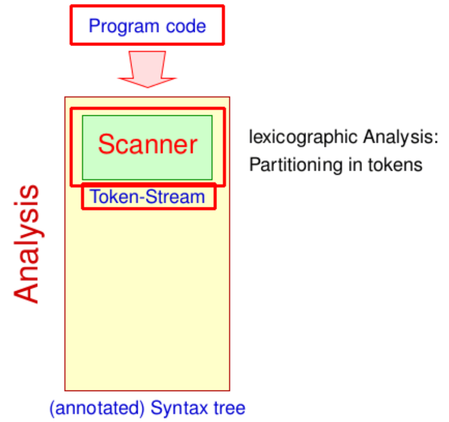


Compiler

The Analysis-Phase is divided in several parts:



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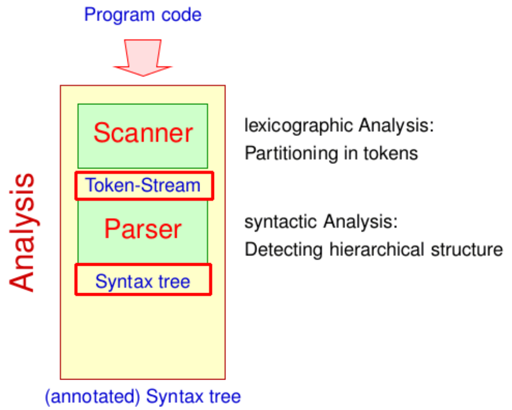

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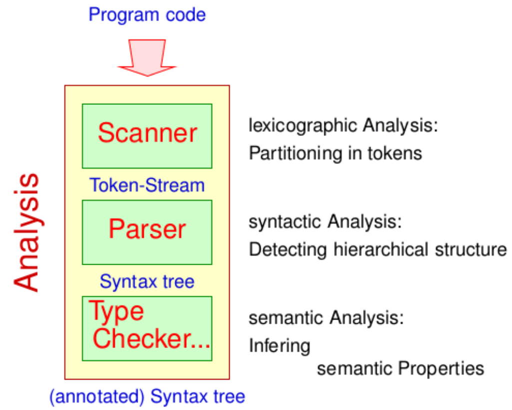
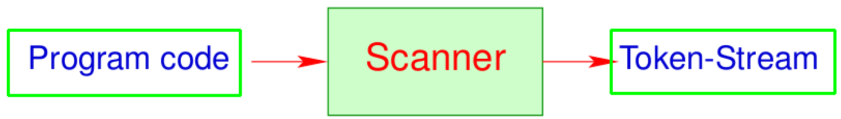


Topic:

Lexical Analysis

The lexical Analysis



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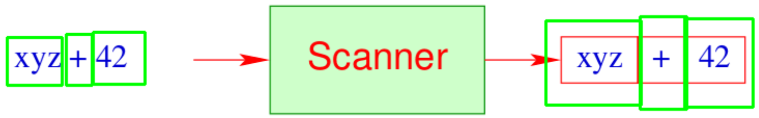

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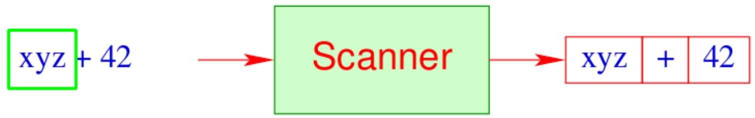

- A Token is a sequence of characters, which together form a unit.
- Tokens are subsumed in classes. For example:
  - → Names (Identifiers) e.g. `xyz`, `pi`, ...
  - → Constants e.g. `42`, `3.14`, `"abc"`, ...
  - → Operators e.g. `+`, ...
  - → reserved terms e.g. `if`, `int`, ...

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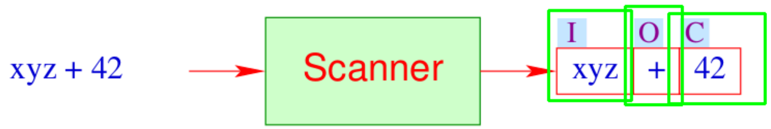

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The lexical Analysis

Classified tokens allow for further pre-processing:

- Dropping irrelevant fragments e.g. Spacing, Comments,...
- Separating Pragmas, i.e. directives vor the compiler, which are not directly part of the program, like include-Statements;
- Replacing of Tokens of particular classes with their meaning / internal representation, e.g.
  - → Constants;
  - → Names: typically managed centrally in a Symbol-table, evt. compared to reserved terms (if not already done by the scanner) and possibly replaced with an index.

⇒ Siever

The lexical Analysis

Discussion:

- Scanner and Siever are often combined into a single component, mostly by providing appropriate callback actions in the event that the scanner detects a token.
- Scanners are mostly not written manually, but generated from a specification.

The lexical Analysis - Generating:

Advantages

Productivity The component can be produced more rapidly

Correctness The component implements (provably) the specification.

Efficiency The generator can provide the produced component with very efficient algorithms.

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Disadvantages

- Specification is just another form of programming — admittedly possibly simpler
- Generation instead of implementatation pays off for Routine-tasks only
  ... and is only good for problems, that are well understood

The lexical Analysis - Generating:

... in our case:

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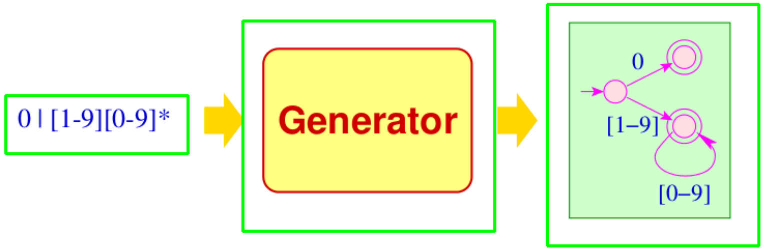

Specification of Token-classes: Regular expressions;
Generated Implementation: Finite automata + X

Chapter 1:
Basics: Regular Expressions

Regular expressions

Basics

- Program code is composed from a finite alphabet Σ of input characters, e.g. Unicode
- The sets of textfragments of a token class is in general regular.
- Regular languages can be specified by regular expressions.

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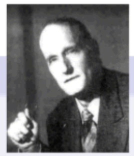
Stephen Kleene

Definition Regular expressions

The set $\mathcal{E}_\Sigma$ of (non-empty) regular expressions is the smallest set $\mathcal{E}$ with:

- $\epsilon \in \mathcal{E}$ (ϵ a new symbol not from Σ);
- $a \in \mathcal{E}$ for all $a \in \Sigma$;
- $(e_1 \mid e_2), (e_1 \cdot e_2), e_1{}^* \in \mathcal{E}$ if $e_1, e_2 \in \mathcal{E}$.

Regular expressions

... Example:

$((a \cdot b^*) \cdot a)$
$(a \mid b)$
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Attention:

- We distinguish between characters $a, 0, \$$,... and Meta-symbols $(, |,)$,...
- To avoid (ugly) parantheses, we make use of Operator-Precedences:

$$^* > \cdot > |$$

  and omit "$\cdot$"
- Real Specification-languages offer additional constructs:

$$e? \equiv (\epsilon \mid e)$$
$$e^+ \equiv (e \cdot e^*)$$

  and omit "ϵ"

Regular expressions

Specifications need Semantics
...Example:

Specification	Semantics
$abab$	$\{abab\}$
$a \mid b$	$\{a, b\}$
ab^*a	$\{ab^n a \mid n \geq 0\}$

For $e \in \mathcal{E}_\Sigma$ we define the specified language $[\![e]\!] \subseteq \Sigma^*$ inductively by:

$$\begin{aligned}
[\![\epsilon]\!] &= \{\epsilon\} \\
[\![a]\!] &= \{a\} \\
[\![e^*]\!] &= ([\![e]\!])^* \\
[\![e_1|e_2]\!] &= [\![e_1]\!] \cup [\![e_2]\!] \\
[\![e_1 \cdot e_2]\!] &= [\![e_1]\!] \cdot [\![e_2]\!]
\end{aligned}$$

Keep in mind:

- The operators $(\_)^*, \cup, \cdot$ are interpreted in the context of sets of words:

$$\begin{aligned}
(L)^* &= \{w_1 \ldots w_k \mid k \geq 0, w_i \in L\} \\
L_1 \cdot L_2 &= \{w_1 w_2 \mid w_1 \in L_1, w_2 \in L_2\}
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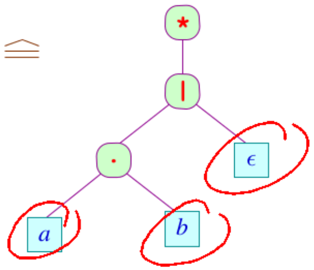
- Regular expressions are internally represented as annotated ranked trees:

$(ab|\epsilon)^* \quad \widehat{=}$



Inner nodes: Operator-applications;
Leaves: particular symbols or ϵ.

Regular expressions

Example: Identifiers in Java:

```
le = [a-zA-Z_\$]
di = [0-9]
Id = {le} ({le} | {di})*
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Regular expressions

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Remarks:

- "le" and "di" are token classes.
- Defined Names are enclosed in "{", "}".
- Symbols are distinguished from Meta-symbols via "\".

Finite automata

Michael Rabin

Dana Scott

Definition

A non-deterministic finite automaton (NFA) is a tuple $A = (Q, \Sigma, \delta, I, F)$ with:

Q	a finite set of states;
Σ	a finite alphabet of inputs;
$I \subseteq Q$	the set of start states;
$F \subseteq Q$	the set of final states and
δ	the set of transitions (-relation)

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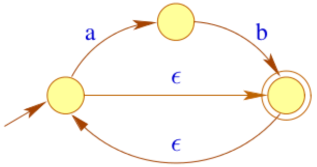
For an NFA, we reckon:

Definition

Given $\delta : Q \times \Sigma \to Q$ a function and $|I| = 1$, then we call A deterministic (DFA).

Finite automata

- Computations are paths in the graph.
- Accepting computations lead from I to F.
- An accepted word is the sequence of lables along an accepting computation ...



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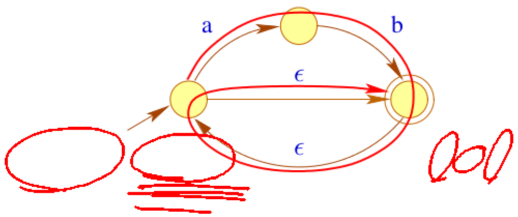
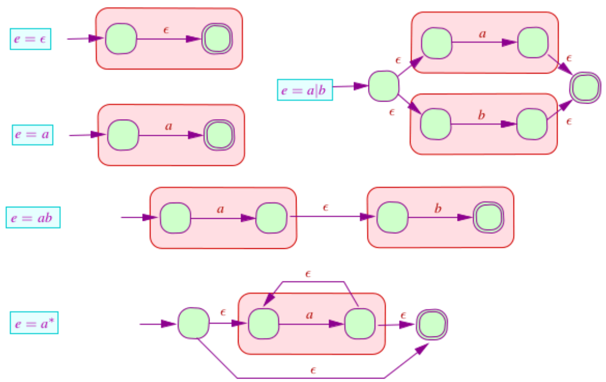


Chapter 3:

Converting Regular Expressions to NFAs

In linear time from Regular Expressions to NFAs




Ken Thompson

Thompson's Algorithm

Produces $\mathcal{O}(n)$ states for regular expressions of length n.