Software Tools
Compilers

Part II - Lecture 7

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Today's Outline

- Introduction to Compilers
- Syntax
- LL(k) Parsers

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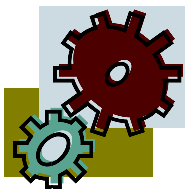
Introduction to Compilers



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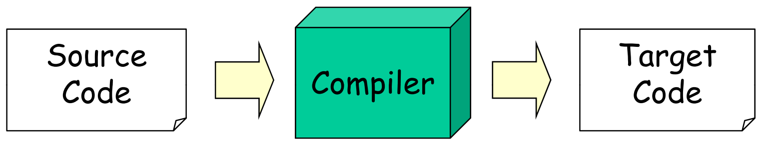
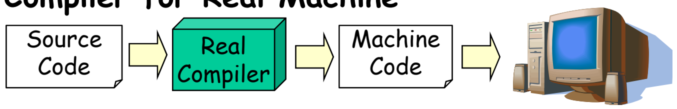
Compiler Overview

- Compilers are programs that generate target code from source code
  - Source code is typically higher-level, e.g. textual
  - Target code is typically lower-level, e.g. binary machine code (the target is a machine architecture)
- Compilation involves translation between two computer languages
- Compilation may involve other steps such as error checking and optimization

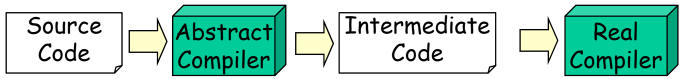


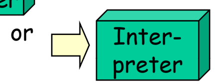
Types of Compilers

Compiler for Real Machine

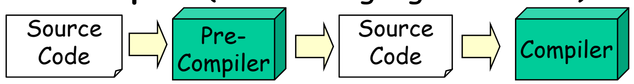


Compiler for Abstract Machine (→ platform independence)

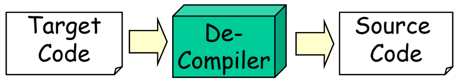




Pre-Compiler (→ new language features)



De-Compiler (→ reverse engineering)



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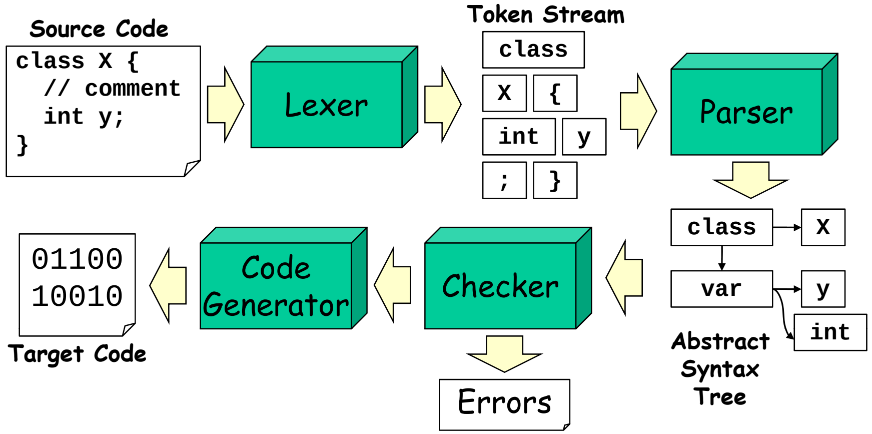
Stages of a Compiler



- Lexer chops the source code into tokens
- Parser constructs the syntactic relations between the tokens (abstract syntax tree, AST)

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Syntax

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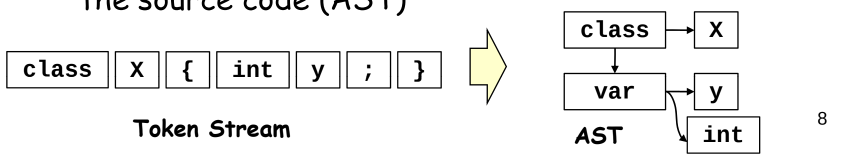
Syntax of a Language

- Syntax means structure (within and between words)
  - How do the words ("tokens", "lexemes") look like? → specified by regular expressions
  - How can the words be combined into sentences? → specified by a context-free grammar
- Analyzing source code in two steps:
  - Lexer groups characters into tokens (token stream) and removes whitespace (e.g. space, tab, return)
  - Parser groups tokens into a tree-representation of the source code (AST)



Regular Expressions

- Regular expressions are used to describe the tokens of a language: **EXPR_NAME:** *expr* ;
- *expr* can consist of the following parts:
  - Literals: '*string*' (e.g. **CLASS:'class';**)
  - Character range: '*char*$_1$'..'*char*$_2$'
    E.g. **DIGIT:'0'..'9';**
  - Alternatives: *expr*$_1$ **|** *expr*$_2$ **|** … **|** *expr*$_n$
  - Optional occurrence: **(***expr***)?**
  - Multiple occurrence (0..*): **(***expr***)***
  - At least one occurrence (1..*): **(***expr***)+**
  - Brackets **( )** around expressions if necessary

Regular Expression Examples

```
// keywords
CLASS: 'class';
IF: 'if';
LPAREN: '(';
PLUSPLUS: '++';
```

```
class Example {
   boolean x = true;
   int y = -99;
   float z = 0.99999;
}
```

```
// literals (i.e. values for types)
BOOL_LITERAL: 'true'|'false';
INT_LITERAL: ('+'|'-')? ('0'..'9')+ ;
FLOAT_LITERAL:
  ('+'|'-')? ('0'..'9')+ '.' ('0'..'9')* ;

// identifier with letter and alphanumeric postfix
// e.g. for variable names, method names, ...
IDENTIFIER: ('a'..'z' | 'A'..'Z')
             ('a'..'z' | 'A'..'Z' | '0'..'9')* ;
```


Context-free Grammars

- Grammar rules are used to describe the relations between tokens: **ruleName:** *expr* ;
- Grammar rules are similar to regular expressions, but can also use other grammar rules (recursion possible!)
- *expr* can consist of the following parts:
  - Token ("terminal" symbol): **TOKEN_NAME**
  - Rule reference ("non-terminal" symbol): **ruleName**
  - Alternatives: *expr*$_1$ **|** *expr*$_2$ **|** … **|** *expr*$_n$
  - Optional occurrence: **(***expr***)?**
  - Multiple occurrence (0..*): **(***expr***)***
  - At least one occurrence (1..*): **(***expr***)+**
  - Brackets **( )** around expressions if necessary

Example: Java Grammar

```
compilationUnit:
  (packageDeclaration)?
  (importDeclaration)*
  (typeDeclaration)* ;
```

```
package my.package;
import java.util.*;
import javax.swing.JButton;
class HelloWorld extends Hello
implements MyInterface { … }
```

```
packageDeclaration:
  PACKAGE IDENTIFIER (DOT IDENTIFIER)* SEMI;

importDeclaration:
  IMPORT IDENTIFIER (DOT IDENTIFIER)* (DOT STAR)? SEMI;

typeDeclaration: classDeclaration | interfaceDeclaration;

classDeclaration: modifiers CLASS IDENTIFIER
  (EXTENDS type)? (IMPLEMENTS typeList)? classBody;
```

More Java Grammar

```
// Java expressions (parts that can be evaluated)
expr: INT_LITERAL | BOOL_LITERAL | …
   |    IDENTIFIER
   |    PLUSPLUS expr            // e.g. ++x
   |    expr PLUS expr           // e.g. x+1
   |    expr STAR expr           // e.g. x*y
   |    LPAREN expr RPAREN       // e.g. (2+y)*x
   |    LPAREN expr RPAREN QUESTION
        expr COLON expr ;        // e.g. (x)? 1 : 2

// Java statements (parts that can be executed)
statement: if | for | while | assign | …
   | expr SEMI                   // e.g. m();
   | LCURLY (statement)* RCURLY ; // e.g. { a(); b(); }

// if statement with optional else
if: IF LPAR expr RPAR statement
   (ELSE statement)?  ;   // e.g. if (true) a(); else b();
```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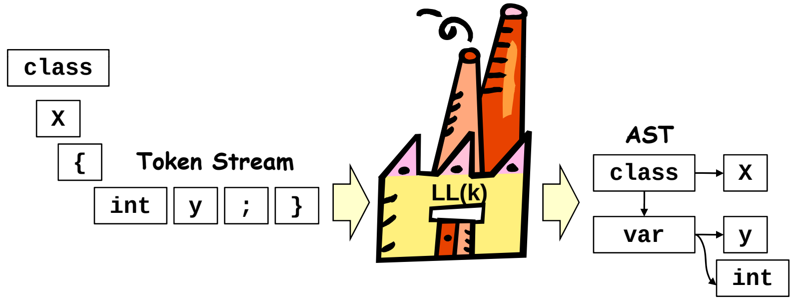
LL(k) Parsers



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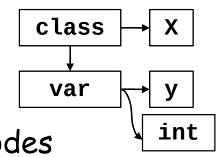
LL(k) and LR(k) Parsers

- There are different parser algorithms; popular ones are LL(k) and LR(k)
- The first **L** means the token stream is processed from **L**eft to right
- **LL** means top-down parsing:
  - First create root of AST
  - Decompose parent nodes into child nodes
- **LR** means bottom-up parsing:
  - First look at the tokens and group them using the grammar rules (starting at lowest level of AST)
  - Group child nodes into parent nodes
- Lookahead (**k**): the parser looks at the next k tokens in the stream to decide how to proceed



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How LL(k) Works

1. Begin with the start rule (usually first grammar rule)
2. Look at the alternatives on the right side; try to figure out which alternative to choose by looking at the next k tokens
3. Go through the symbols of the chosen alternative:
   - If terminal: try to match it with the next token
   - If non-terminal: consider the rule of the non-terminal and recurse to step 2.

```
type: CLASS IDENTIFIER classBody
    | INTERFACE IDENTIFIER intfBody;
classBody: LCURLY (member)* RCURLY;
member: IDENTIFIER IDENTIFIER SEMI
    | IDENTIFIER IDENTIFIER
      LPAREN params RPAREN methodBody;
```

Input to parse

```
class Foo {
   int x;
   String y;
   void m() { }
}
```

Parsing Example

1. Start rule `type`, which alternative?
   Next token is `CLASS` therefore choose first alternative
   Go through symbols: `CLASS IDENTIFIER classBody`
   - `CLASS` is matched with input
   - `IDENTIFIER` (`Foo`) is matched with input
2. Apply rule `classBody`, only one alternative
   - `LCURLY` is matched with input
3. Apply rule `member`, which alternative? Look ahead 3 tokens.
   - Match `IDENTIFIER` (`int`), `IDENTIFIER` (`x`) and `SEMI`
   - Jump back where we left in rule `classBody`

```
type: CLASS IDENTIFIER classBody
    | INTERFACE IDENTIFIER intfBody;
classBody: LCURLY (member)* RCURLY;
member: IDENTIFIER IDENTIFIER SEMI
    | IDENTIFIER IDENTIFIER
      LPAREN params RPAREN methodBody;
```

Input to parse

```
class Foo {
   int x;
   String y;
   void m() { }
}
```

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Parsing Example Cont.

4. Back in rule `classBody` we see another member (no `LCURLY` yet)
   So we apply rule `member` again. Lookahead 3 tokens.
   - Match `IDENTIFIER` (`String`), `IDENTIFIER` (`y`) and `SEMI`
   - Jump back where we left in rule `classBody`
5. Back in rule `classBody` we see another member (no `LCURLY` yet)
   So we apply rule `member` again. Lookahead 3 tokens.
   - Match `IDENTIFIER` (`void`), `IDENTIFIER` (`m`), `LPAREN`
   - Process parameters in `params` and body in `methodBody`
   - Jump back where we left in rule `classBody`
6. Found `RCURLY`, so no more members. Done!

```
type: CLASS IDENTIFIER classBody
    | INTERFACE IDENTIFIER intfBody;
classBody: LCURLY (member)* RCURLY;
member: IDENTIFIER IDENTIFIER SEMI
    | IDENTIFIER IDENTIFIER
      LPAREN params RPAREN methodBody;
```

Input to parse

```
class Foo {
   int x;
   String y;
   void m() { }
}
```

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Parser Implementation

1. Write a method for every rule
2. Check for alternatives with lookahead (`if`s / `while`s)
3. Match tokens (removes tokens from token stream)
4. Call methods of rules to apply the rules

```
type:
   CLASS
   IDENTIFIER
   classBody
 | INTERFACE
   IDENTIFIER
   intfBody;


classBody:
  LCURLY
  (member)*
  RCURLY;
```

```
void type() {
  if(tokens[0] == CLASS) {
    match(CLASS); match(IDENTIFIER);
    classBody();
  } else if(tokens[0] == INTERFACE) {
    match(INTERFACE); match(IDENTIFIER);
    intfBody();
  } else System.out.printf("Error!"); }

void classBody() {
  match(LCURLY);
  while (tokens[0] != RCURLY) member();
  match(RCURLY); }
```

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Summary

Today's Summary

- Compilers generate target code from source code
  - Lexer groups characters into tokens
  - Parser groups tokens into AST
- Regular expressions are used to describe tokens
- Context-free grammars are used to describe relations between tokens (as captured in the AST)
- LL(k) parsers can be implemented by making a method out of every grammar rule

References:

- Hursh Jain. Grammars and Parsers. http://www.mollypages.org/page/grammar/
- Dick Grune, Ceriel J.H. Jacobs. Parsing Techniques. http://www.cs.vu.nl/~dick/PTAPG.html

Quiz

1. Explain the stages of a typical compiler.
2. Create regular expressions and a grammar for simple arithmetic expressions (numbers, +, *, brackets)
   (Tip: start each rule with a token so you can use it for lookahead in question 3)
3. Give pseudo code for a LL(k) parser for 2.