CSE302: Compiler Design

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January 18, 2007

Today's Outline

- Recap
- A simple syntax-directed translator (Chapter 2)
  - Introduction (Section 2.1)
  - Syntax definition (Section 2.2)
  - Parsing (Section 2.4)
- Summary and homework

Six Compilation Phases

- Lexical analysis
- Syntax analysis
- Semantic analysis
- Intermediate code generation
- Code optimization
- Code generation

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Contents in Chapter 2

- Illustrate some compiler techniques via developing a simple language translator coded in Java (Appendix A)
  - Source language
  - Target language: three-address code
- The front-end of a compiler

Six Compilation Phases

- Lexical analysis
- Syntax analysis
- Semantic analysis
- Intermediate code generation
- Code optimization
- Code generation

A Simplified Model of A Compiler Front End

- do i=i+1; while (a[i]>v);

- 1: i = i + 1

  t1 = a[i]

  if t1>v goto 1

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A Formal Method of Describing Syntax

- Backus-Naur Form (1959)
  - For Algol 58 (John Backus, the Peter Naur)
  - BNF is equivalent to context-free grammars
    - Context-free grammars were developed by Noam Chomsky in mid-1950s to define a class of languages called context-free languages
      - A BNF grammar defines a language
        - Recognizer vs. generators
    - A BNF grammar or description is a production-rule collection

BNF Rules

- A BNF rule defines an abstraction for syntactic structure

  <while_stmt> → **`while`** (<logic_expr>) <stmt>

- Abstractions are used to represent classes of syntactic structures: they act like syntactic variables (also called nonterminal symbols)
- Terminal symbols: lexemes and tokens

LHS & RHS of BNF Rules

- A rule has a left-hand side (LHS) and a right-hand side (RHS), and consists of terminal and/or nonterminal symbols
- An abstraction (or nonterminal symbol) can have more than one RHS

<stmt> → <single_stmt>

| **begin** <stmt_list> **end**

BNF Functionality

- Describe grammars and derivations
  - Describe lists of similar constructs
  - Parse trees
- Powerful enough to avoid grammar ambiguity
  - Operator precedence and associativity

Describing Lists

- Syntactic lists are described using recursion

  <ident_list> → **ident**

  | **ident**, <ident_list>

- A rule is recursive if its LHS appears in its RHS

A BNF Grammar

- A BNF grammar defines a language
- Sentences of a language are generated through applications of rules, beginning with a start symbol
- A grammar for a small language

<program> → <stmts>
<stmts> → <stmt> | <stmt> ; <stmts>
<stmt> → <var> = <expr>
<var> → **a** | **b** | **c** | **d**
<expr> → <term> + <term> | <term> - <term>
<term> → <var> | **const**

Derivation

- A sentence generation is called a derivation
- An example derivation:

<program> => <stmts>
=> <stmt>
=> <var> = <expr>
=> **a** = <expr>
=> **a** = <term> **+** <term>
=> **a** = <var> **+** <term>
=> **a = b +** <term>
=> **a = b +** const

<program> → <stmts>
<stmts> → <stmt> | <stmt> ; <stmts>
<stmt> → <var> = <expr>
<var> → **a | b | c | d**
<expr> → <term> + <term> | <term> - <term>
<term> → <var> | **const**

Terms in Derivation

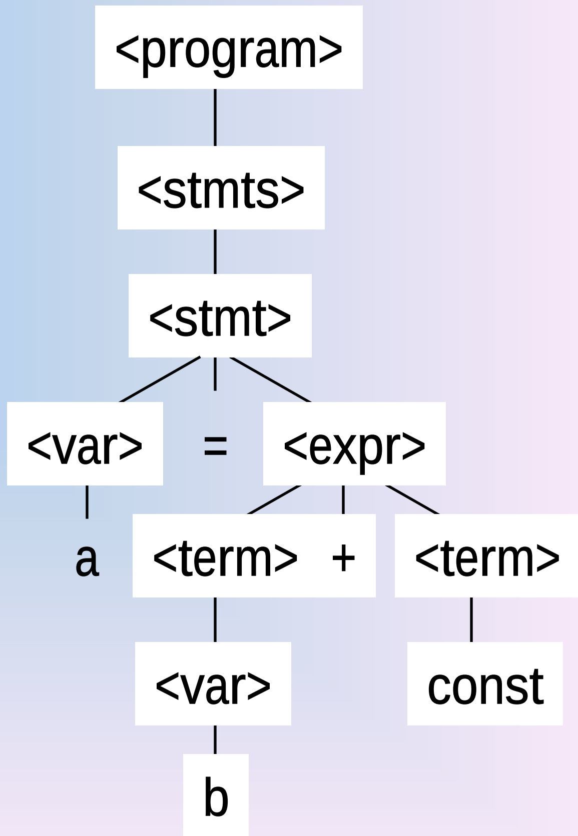
- Every string of symbols in the derivation is a sentential form
- A sentence is a sentential form that has only terminal symbols
- A leftmost derivation is one in which the leftmost nonterminal in each sentential form is the one that is expanded
- A derivation may be neither leftmost nor rightmost

<program> => <stmts>
=> <stmt>
=> <var> = <expr>
=> **a** = <expr>
=> **a** = <term> **+** <term>
=> **a** = <var> **+** <term>
=> **a = b +** <term>
=> **a = b +** const

Parse Tree

- A hierarchical representation of a derivation

<program> => <stmts>
=> <stmt>
=> <var> = <expr>
=> **a** = <expr>
=> **a** = <term> **+** <term>
=> **a** = <var> **+** <term>
=> **a = b +** <term>
=> **a = b +** const



Lists, Grammar, and Parse Trees

BNF Functionality
- Describing Lists
- Grammar & Derivation
- Parse Trees
- Avoiding Ambiguity

<program> → <stmts>

<stmts> → <stmt> | <stmt> ; <stmts>

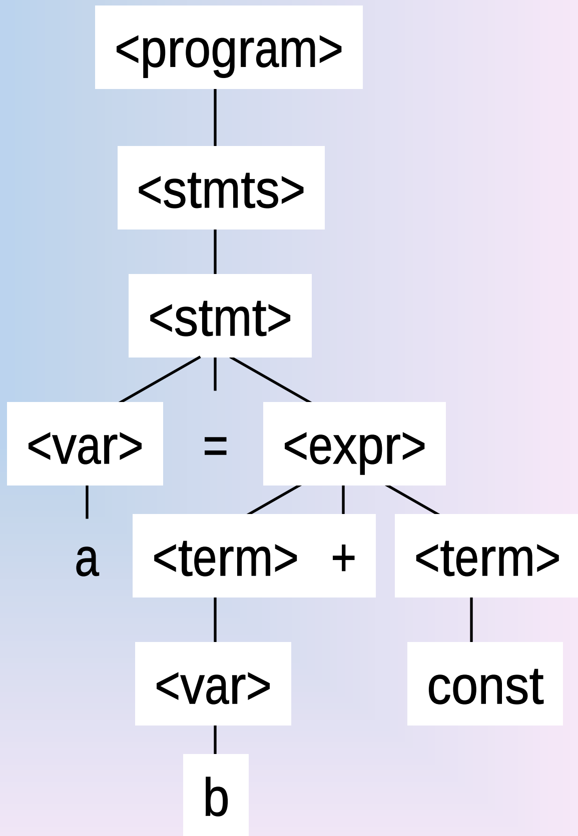
<stmt> → <var> = <expr>

<var> → a | b | c | d

<expr> → <term> + <term> | <term> - <term>

<term> → <var> | const

<program>
=> <stmts>
=> <stmt>
=> <var> = <expr>
=> **a** = <expr>
=> **a** = <term> **+** <term>
=> **a** = <var> **+** <term>
=> **a = b +** <term>
=> **a = b +** const



Avoiding Ambiguity

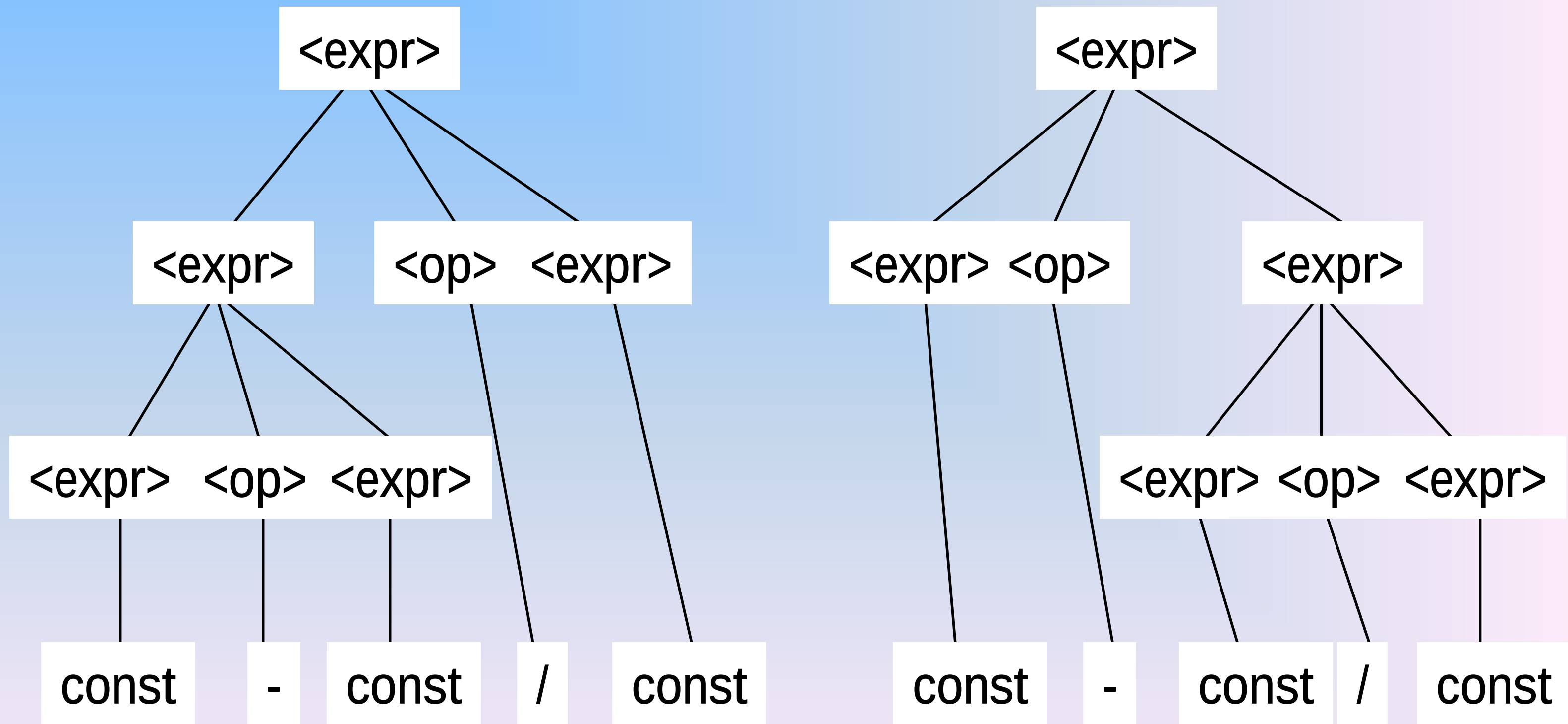
- A grammar is ambiguous iff it generates a sentential form that has two or more distinct parse trees
  - Operator precedence ambiguity
  - Operator associativity ambiguity
  - ...

An Ambiguous Expression Grammar

BNF Functionality
- Describing Lists
- Grammar & Derivation
- Parse Trees
- Avoiding Ambiguity

<expr> → <expr> <op> <expr> | const

<op> → / | -



An Unambiguous Expression Grammar

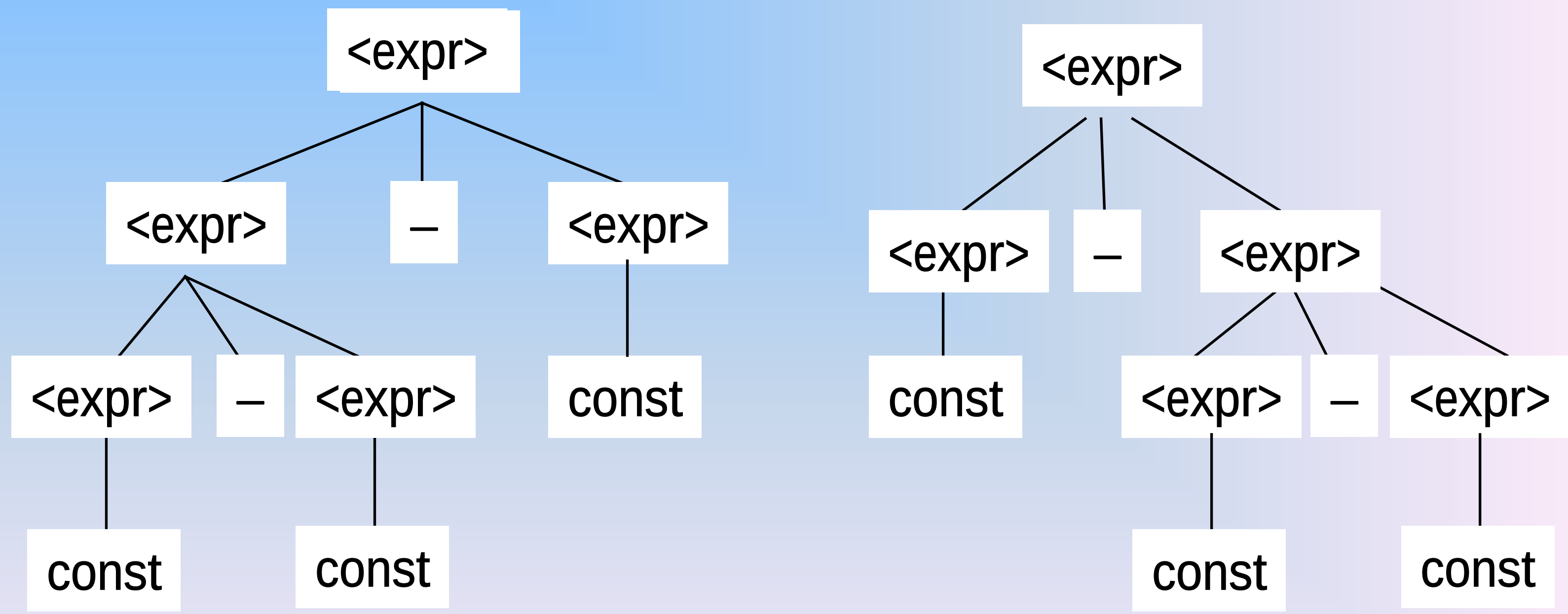
- If we use an additional nonterminal to indicate precedence levels of the operators, we will not have such ambiguity

<expr> → <expr> - <term> | <term>
<term> → <term> / **const** | **const**

Another Ambiguity

- Operator associativity ambiguity

<expr> -> <expr> - <expr> | const (ambiguous)

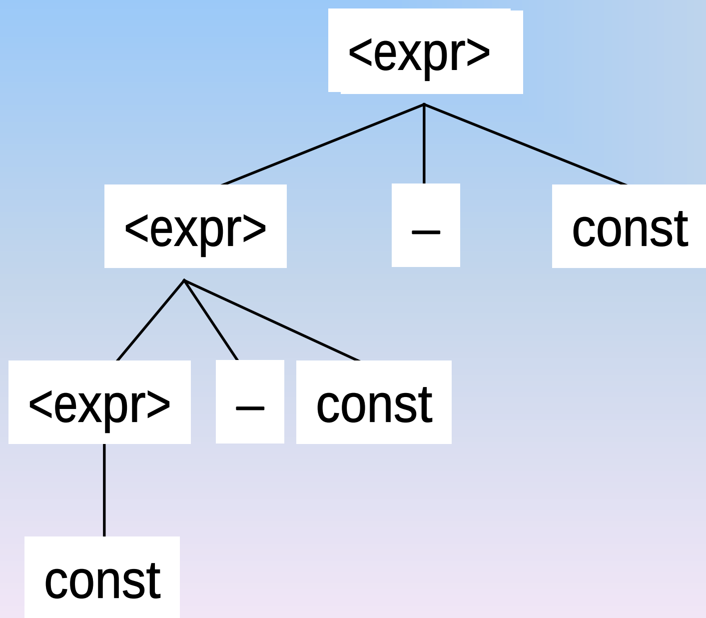


Avoid Ambiguity

- Operator associativity can also be indicated by a BNF description

<expr> -> <expr> - <expr> | const (ambiguous)

<expr> -> <expr> - const | const (unambiguous)



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Parsing

- Parsing is the process of determining how a string of terminals can be generated by a grammar
  - Parse tree generation
  - Parsers make a single left-to-right scan over the input tokens, look ahead of one terminal at a time, and construct the parse tree.
- Top-down parsing vs. bottom-up parsing

Predictive Parsing (1)

- A Recursive-Descent Parser
  - Directly following the BNF grammar
  - <expr> → <term> + <term> | <term> - <term> | <term>
  - <term> → 0 | 1 | 2 | ... | 9
- Pseudo code

```
void expr() {
      term();
      if( token==plus_op
       or token==minus_op) {
          match(token);
          term();
      }
      else error();
}
```

```
void term() {
    match(int_literal);
}

void match(expectedToken) {
    if(token==expectedToken)
            getNextToken();
    else error();
}
```

- Demo
  - A homework question

Predictive Parsing (2)

- A BNF grammar
  - stmt → **expr**; | **for**(optexpr; optexpr; optexpr) stmt | **other**
  - optexpr → ε | **expr**
- Pseudo code

```
void stmt() {
    switch ( lookahead )  {
      case expr:
        match(expr); match(';'); break;
      case for:
        match(for); match('('); optexpr(); match(';'); optexpr(); match(';');
                    optexpr(); match(')'); stmt(); break;
      case other;
        match(other); break;
      default: report("Syntax error");
    }
}
void optexpr() { if ( lookahead == expr ) match(expr); }
void match(terminal t) {
    if ( lookahead == t ) lookahead = nextToken; else report("Syntax error"); }
```

Predictive Parsing (3)

- A BNF grammar
  - stmt $\rightarrow$ **expr**; | **if**(**expr**) stmt | **for**(optexpr; optexpr; optexpr) stmt | **other**
  - optexpr $\rightarrow$ ε | **expr**
- A statement
  - for (; expr ; expr) other

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You should now be able to ...

- Evaluate whether a grammar is ambiguous;
- Use BNF to specify operator precedence;
- Write a simple recursive-descent parser.

Grammar Ambiguity

- A grammar is ambiguous iff it generates a sentential form that has two or more distinct parse trees
- Every derivation with an unambiguous grammar has a unique parse tree, although that tree can be represented by different derivations

You should now be able to ...

- Evaluate whether a grammar is ambiguous;
- Use BNF to specify operator precedence and associativity;
- Write a simple recursive-descent parser.

Operator Precedence by BNF

- Guidelines
  - Use terminal operator lexemes
  - Use additional nonterminals as operands

<expr> → <expr> <op> <expr> | const
<op> → / | -

An ambiguous grammar

<expr> → <expr> - <term> | <term>
<term> → <term> / **`const`** | **`const`**

An unambiguous grammar

Operator Associativity by BNF

- Operator associativity can also be indicated by a BNF description

<expr> -> <expr> + <expr> | const (ambiguous)

<expr> -> <expr> + const | const (unambiguous)

- Guidelines
  - **A rule's LHS appears at the beginning of its RHS, which is a left-recursive rule. Then it indicates left associativity.**
  - **Right associativity (LHS is the operand at the right-hand side, not at the left)**
    - **Exponentiation operator**

      <expr> -> <base> ** <expr> | <base>

      <base> -> id | const

You should now be able to ...

- Evaluate whether a grammar is ambiguous;
- Use BNF to specify operator precedence and associativity;
- Write a simple recursive-descent parser.

Homework (Due on 01/22 at 11:55 PM)

- 1.1. (10 points) Just as shown in Figure 1.7 in the textbook (page 7), detail the six steps of compilation for the statement: A=B*5+C/3 where A, B, C are variables of floating-point type.
- 1.2. (10 points) Consider the context-free grammar:

  $S \rightarrow + S S \mid - S S \mid a$

  a) Show how the string +a-aa can be generated by this grammar.

  b) Construct a parse tree for this same string.
- 1.3. (10 points) Implement an executable and correct recursive-descent parser based on the pseudo code for the BNF grammar illustrated in this lecture:
  - <expr> → <term> + <term> | <term> - <term> | <term>
  - <term> → 0 | 1 | 2 | ... | 9

Reading Assignment

- Chapter 18 in The Java Language Specification, Third Edition
  - The Grammar of the Java Programming Language
  - http://java.sun.com/docs/books/jls/