Compiler Design

Lecture 5: Top-Down Parsing

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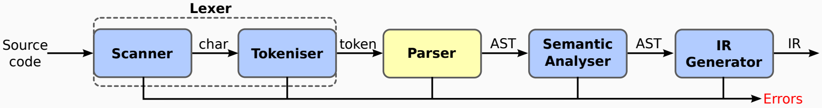
The Parser



- Checks grammatical correctness of the stream of words/tokens produced by the lexer
- Outputs the AST (Abstract Syntax Tree) which represents the input program

Table of contents

Context-Free Grammar (CFG)

Context-Free Grammar (CFG)

Definition

Specifying syntax with a grammar

A Context-Free Grammar (CFG) is used to specify the syntax

Definition

A Context-Free Grammar G is a quadruple (S, N, T, P) where:

- S is a start symbol
- N is a set of non-terminal symbols
- T is a set of terminal symbols or words
- P is a set of production or rewrite rules where only a single non-terminal appears on the left-hand side $P : N \rightarrow (N \cup T)^*$

Context-Free Grammar (CFG)

RE to CFG

From Regular Expression to Context-Free Grammar

- **Kleene closure** A^*:
  replace A^* to A_{rep} in all production rules and add
  $A_{rep} = A \; A_{rep} \mid \epsilon$
  as a new production rule.

- **Positive closure** A^+:
  replace A^+ to A_{rep} in all production rules and add
  $A_{rep} = A \; A_{rep} | A$
  as a new production rule.

- **Option** $[A]$:
  replace $[A]$ to A_{opt} in all production rules and add
  $A_{opt} = A \mid \epsilon$
  as a new production rule.

Example: function call

```
funcall ::= IDENT "(" [ IDENT ("," IDENT)* ] ")"
```

after removing the option:

```
funcall ::= IDENT "(" arglist ")"
arglist ::= IDENT ("," IDENT)*
          | ϵ
```

after removing the closure:

```
funcall ::= IDENT "(" arglist ")"
arglist ::= IDENT argrep
          | ϵ
argrep  ::= "," IDENT argrep
          | ϵ
```

Recursive-Descent Parsing

Main idea

Steps to derive a syntactic analyser (*i.e.* half a parser) for a context free grammar expressed in an EBNF style:

- Convert all the regular expressions as seen;
- Implement a function for each non-terminal symbol A.
  This function recognises sentences derived from A;
- Recursion in the grammar corresponds to recursive calls of the created functions.

This technique is called recursive-descent parsing or predictive parsing.

Recursive-Descent Parsing

Writing a Parser

Parser class (pseudo-code)

```
Token currentToken;

void error(Category... expected) {/* ... */}

boolean accept(Category... expected) {
  return (currentToken ∈ expected);
}

void expect(Category... expected) {
  if (accept(expected))
     nextToken(); // modifies currentToken
  else
    error(expected);
}
```

CFG for function call

```
funcall ::= IDENT "(" arglist ")"
arglist ::= IDENT argrep
          | ϵ
argrep  ::= "," IDENT argrep
          | ϵ
```

Recursive-Descent Parser

```
void parseFunCall() {
  expect(IDENT);
  expect(LPAR);
  parseArgList();
  expect(RPAR);
}

void parseArgList() {
  if (accept(IDENT)) {
    nextToken();
    parseArgRep();
  }
  // else nothing to do
}

void parseArgRep() {
  if (accept(COMMA)) {
    nextToken();
    expect(IDENT);
    parseArgRep();
  }
  // else nothing to do
}
```

Recursive vs Iterative approaches

Project hint: you can keep the EBNF syntax and use an iterative (rather than recursive) approach as this might simplify your code.

Example: function call

```
funcall ::= IDENT "(" [ IDENT ("," IDENT)* ] ")"
```

Recursive-Descent Parser with iterations

```
void parseFunCall() {
  expect(IDENT);
  expect(LPAR);
  if (accept(IDENT)) {
    nextToken();
    while (accept(COMMA)) {
      nextToken();
      expect(IDENT);
    }
  }
  expect(RPAR);
}
```

LL(K) grammars

LL(K) grammars

Need for lookahead

Consider the following bit of grammar

```
stmt    ::= assign ";"
          | funcall ";"
funcall ::= IDENT "(" arglist ")"
assign  ::= IDENT "=" exp
```

```
void parseAssign() {
  expect(IDENT);
  expect(EQ);
  parseExp();
}

void parseStmt() {
  ???
}
```

```
void parseFunCall() {
  expect(IDENT);
  expect(LPAR);
  parseArgList();
  expect(RPAR);
}
```

If the parser picks the wrong production, it may have to backtrack.
Alternative is to look ahead to pick the correct production.

LL(K) grammars

LL(1) property

How much lookahead is needed?

- In general, an arbitrarily large amount

Fortunately:

- Large subclasses of CFGs can be parsed with limited lookahead
- Most programming language constructs fall in those subclasses

Among the interesting subclasses are LL(1) grammars.

LL(1)

Left-to-Right parsing;
Leftmost derivation; (i.e. apply production for leftmost non-terminal first)
only 1 current symbol required for making a decision.

Basic idea: given $A \to \alpha|\beta$, the parser should be able to choose between α and β.

First sets

For some symbol $\alpha \in N \cup T$, define First(α) as the set of symbols that appear first in some string that derives from α:

$$x \in \mathit{First}(\alpha) \text{ iif } \alpha \to \cdots \to x\gamma, \text{ for some } \gamma$$

The *LL(1)* property: if $A \to \alpha$ and $A \to \beta$ both appear in the grammar, we would like:

$$\mathit{First}(\alpha) \cap \mathit{First}(\beta) = \emptyset$$

This would allow the parser to make the correct choice with a lookahead of exactly one symbol! (almost, see next slide!)

What about ϵ-productions (the ones that consume no symbols)?

```
G ::= C b
C ::= A
    | B
A ::= a
    | ε
B ::= b
```

input1: ab
input2: b

Both inputs are correct.

However, when seeing the b in the second example, the parser does not know whether to go down the A derivation or B derivation:

- In the case of A, we could choose the ϵ and consume nothing, and the b will be consumed in G (which is the only valid derivation);
- In the case of B, we could directly consume the b, but then we will have a problem later on and would need to backtrack.

Therefore, the parser may have to backtrack since it needs to try out different paths.

If $A \rightarrow \alpha$ and $A \rightarrow \beta$ and $\epsilon \in First(\alpha)$, then we need to ensure that $First(\beta)$ is disjoint from $Follow(\alpha)$.

$Follow(\alpha)$ is the set of all terminal symbols in the grammar that can legally appear immediately after α.
(See EaC§3.3 for details on how to build the *First* and *Follow* sets.)

Let's define $First^+(\alpha)$ as:

- $First(\alpha) \cup Follow(\alpha)$, if $\epsilon \in First(\alpha)$
- $First(\alpha)$ otherwise

_LL(1)_ grammar

A grammar is *LL(1)* iff $A \rightarrow \alpha$ and $A \rightarrow \beta$ implies:

$$First^+(\alpha) \cap First^+(\beta) = \emptyset$$

Given a grammar that has the *LL(1)* property:

- each non-terminal symbols appearing on the left hand side is recognised by a simple routine;
- the code is both simple and fast.

Predictive Parsing

Grammar with the *LL(1)* property are called *predictive grammars* because the parser can "predict" the correct expansion at each point. Parsers that capitalise on the *LL(1)* property are called predictive parsers. One kind of predictive parser is the *recursive descent* parser.

LL(K) grammars

LL(K)

Sometimes, we might need to lookahead one or more tokens.

LL(2) Grammar Example

```
stmt    ::= assign ";"
          | funcall ";"
funcall ::= IDENT "(" arglist ")"
assign  ::= IDENT "=" exp
```

```
void parseStmt() {
  if (accept(IDENT)) {
    if (lookAhead(1) == LPAR)
      parseFunCall();
    else if (lookAhead(1) == EQ)
      parseAssign();
    else
      error();
  }
  else
    error();
}
```

Problems with LL(k) parsers

Non-distinct first set in the grammar

Example

```
Stmt    ::= Assign
          | Exp ";"
Assign  ::= Exp "=" Exp ";"
```

How do you choose between assignment or expression?

```
void parseStmt() {

  if (accept(first(Exp) ??))
    parseAssign();

  else if (accept(first(Exp) ??))
    parseExp();
}
```

What about using a lookahead?

⇒ not possible since Exp can be of any length.

Left factorization

Rewrite : $A \to \alpha\beta|\alpha\gamma|\ldots$

Into:

$A \to \alpha A'$

$A' \to (\beta|\gamma)$

May need to apply this indirectly.

```
Stmt    ::= Assign
          | Exp ";"
Assign  ::= Exp "=" Exp ";"
```

becomes:

```
Stmt    ::= Exp Stmt'
Stmt'   ::= Assign | ";"
Assign  ::= "=" Exp ";"
```

```
void parseStmt() {
  parseExp();
  parseStmtPrime();
}

void parseStmtPrime() {
  if (accept(EQUAL))
    parseAssign();
  else
    expect(SC);
}

void parseAssign() {
  expect(EQUAL);
  parseExp();
  expect(SC);
}
```

Beware of left recursion!

Left Recursion

```
Expr ::= Expr Op Expr
       | "(" Expr ")"
       | Number
Op   ::= '+' | '*'
```

```
void parseExpr() {
  if (accept(LPAR,DIGIT))
    parseExpr();
    parseOp();
    parseExpr();
  else if (accept(LPAR)) {
    expect(LPAR);
    parseExpr();
    expect(RPAR);
  }
  else if (accept(DIGIT))
    parseNumber();
}
```

Example input: 1+1

Infinite recursion!

Removing Left Recursion

You can use the following rule to remove direct left recursion:

$A \to A\alpha_1 | A\alpha_2 | \ldots | A\alpha_m | \beta_1 | \beta_2 | \ldots | \beta_n$
where β_i does not start with an A and $\alpha_i \neq \varepsilon$

can be rewritten into:

$A \to \beta_1 A' | \beta_2 A' | \ldots | \beta_n A'$

$A' \to \alpha_1 A' | \alpha_2 A' | \ldots | \alpha_m A' | \varepsilon$

Hint

Use this to deal with binary operators, `arrayaccess` and `fieldaccess` in the project

Left recursive grammar

```
Expr ::= Expr Op Expr
       | "(" Expr ")"
       | Number
Op   ::= '+' | '*'
```

Equivalent non-left recursive grammar

```
Expr   ::= "(" Expr ")" Expr'
         | Number Expr'
Expr'  ::= Op Expr Expr'
         | ϵ
Op     ::= "+" | "*"
```

```
void parseExpr() {
  if (accept(LPAR)) {
    expect(LPAR);
    parseExpr();
    expect(RPAR);
    parseExprPrime();
  }
  else if (accept(DIGIT)) {
    parseNumber();
    parseExprPrime();
  }
  else
    expect(LPAR,DIGIT);
}

void parseExprPrime() {
  if (accept(PLUS,TIMES) {
    parseOp();
    parseExpr();
    parseExprPrime();
  }
}
```

All is good now!

Recap

To write a recursive descent parser, follow these steps:

1. Express the language syntax as an LL(k) CFG;
2. Left factorize the grammar if necessary;
3. Remove left recursion from the grammar if present;
4. Write the recursive parser using at most k lookaheads.

Your parser will never have to backtrack!
$\Rightarrow$ $O(N)$ time complexity, hurray!

Next lecture

- Bottom-up parsing