Agenda

- Top-Down Parsing
- Predictive Parsers
- LL(k) Grammars
- Recursive Descent
- Grammar Hacking
  - Left recursion removal
  - Factoring
Basic Parsing Strategies (1)

- Bottom-up
  - Build up tree from leaves
    - Shift next input or reduce using a production
    - Accept when all input read and reduced to start symbol of the grammar
  - LR(k) and subsets (SLR(k), LALR(k), …)
Basic Parsing Strategies (2)

• Top-Down
  – Begin at root with start symbol of grammar
  – Repeatedly pick a non-terminal and expand
  – Success when expanded tree matches input
  – LL(k)
Top-Down Parsing

- Situation: have completed part of a leftmost derivation
  \[ S \Rightarrow^* wA\alpha \Rightarrow^* wxy \]
- Basic Step: Pick some production
  \[ A ::= \beta_1 \beta_2 \ldots \beta_n \]
  that will properly expand \( A \) to match the input
  - Want this to be deterministic
Predictive Parsing

- If we are located at some non-terminal $A$, and there are two or more possible productions
  
  $A ::= \alpha$
  
  $A ::= \beta$
  
  we want to make the correct choice by looking at just the next input symbol

- If we can do this, we can build a *predictive parser* that can perform a top-down parse without backtracking
Sounds hard, but …

- Programming language grammars are often suitable for predictive parsing
- Typical example

\[
stmt ::= \text{id} = \text{exp} \; | \; \text{return} \; \text{exp} \; | \\
\text{if} ( \text{exp} ) \; stmt \; | \; \text{while} ( \text{exp} ) \; stmt
\]

If the remaining unparsed input begins with the tokens

\[
\text{IF} \; \text{LPAREN} \; \text{ID}(x) \; \text{…}
\]

we should expand \text{stmt} to an if-statement
LL(k) Property

- A grammar has the LL(1) property if, for all non-terminals $A$, when both
  
  $A ::= \alpha$
  
  $A ::= \beta$
  
  appear in the grammar, then:

  $$\text{FIRST}(\alpha) \cap \text{FIRST}(\beta) = \emptyset$$

  ($\text{FIRST}(\alpha) =$ set of terminals that begin any possible string derived from $\alpha$)

- If a grammar has the LL(1) property, we can build a predictive parser for it that uses 1-symbol lookahead
LL(k) Parsers

• An LL(k) parser
  – Scans the input Left to right
  – Constructs a Leftmost derivation
  – Looking ahead at most $k$ symbols
• 1-symbol lookahead is enough for many realistic programming language grammars
  – LL(k) for $k>1$ is very rare in practice
LL vs LR (1)

- Table-driven parsers for both LL and LR can be automatically generated by tools
- LL(1) has to make a decision based on a single non-terminal and the next input symbol
- LR(1) can base the decision on the entire left context as well as the next input symbol
LL vs LR (2)

∴ LR(1) is more powerful than LL(1)
  – Includes a larger set of grammars
But
  – It is easier to write a LL(1) parser by hand
  – There are some very good LL parser tools out there (ANTLR, JavaCC, …)
Recursive-Descent Parsers

• An advantage of top-down parsing is that it is easy to implement by hand
• **Key idea:** write a function (procedure, method) corresponding to each non-terminal in the grammar
  – Each of these functions is responsible for matching the next part of the input with the non-terminal it recognizes
Example: Statements

Grammar

\[ stmt ::= id = exp ; \]
\[ | \text{return } exp ; \]
\[ | \text{if ( } exp \text{ ) stmt} \]
\[ | \text{while ( } exp \text{ ) stmt} \]

Method for this grammar rule

// parse stmt ::= id=exp; | ...  
void stmt( ) {
    switch(nextToken) {
        RETURN: returnStmt(); break;
        IF: ifStmt(); break;
        WHILE: whileStmt(); break;
        ID: assignStmt(); break;
    }
}
Example (cont)

// parse while (exp) stmt
void whileStmt() {
    // skip “while (”
    getNextToken();
    getNextToken();

    // parse condition
    exp();

    // skip “)”
    getNextToken();

    // parse stmt
    stmt();
}

// parse return exp ;
void returnStmt() {
    // skip “return”
    getNextToken();

    // parse expression
    exp();

    // skip “;”
    getNextToken();
}

Invariant for Parser Functions

• The parser functions need to agree on where they are in the input
• Useful (and typical) invariant: When a parser function is called, the current token (next unprocessed piece of the input) is the token that begins the expanded non-terminal being parsed
  – Corollary: when a parser function terminates, it must have completely consumed input corresponding to that non-terminal
Possible Problems

• Two common problems for recursive-descent (and LL(1)) parsers:
  
  – Left recursion (e.g., $E ::= E + T | ...$)

  – Common prefixes on the right hand side of productions
Left Recursion Problem

• Grammar rule

\[ expr ::= expr + term \]

| term

• Code

// parse expr ::= …
void expr() {
    expr();
    if (current token is PLUS) {
        getNextToken();
        term();
    }
}

• And the bug is????
Left Recursion Problem

• If we code up a left-recursive rule as-is, we get an infinite recursion

• Non-solution: replace with a right-recursive rule

\[
expr ::= term + expr \mid term
\]

– Why isn’t this the right thing to do?
One Left Recursion Solution

• Rewrite using right recursion and a new non-terminal
• Original: $expr ::= expr + term | term$
• New:
  
  $expr ::= term exprtail$
  
  $exprtail ::= + term exprtail | \epsilon$

• Properties
  – No infinite recursion if coded up directly
  – Maintains left associatively (required)
Another Way to Look at This

• Observe that
  
  \[ expr ::= expr + term | term \]
  
  generates the sequence
  
  \[ term + term + term + \ldots + term \]
  
• We can sugar the original rule to match
  
  \[ expr ::= term \{ + term \}^* \]
  
• This leads directly to parser code
  
  – But need to fudge things to respect the original precedence/associativity
Code for Expressions (1)

```c
// parse
//    expr ::=  term { + term }*
void expr() {
    term();
    while (next symbol is PLUS) {
        // consume PLUS
        getNextToken();
        term();
    }
}

// parse
//    term ::= factor { * factor }*
void term() {
    factor();
    while (next symbol is TIMES) {
        // consume TIMES
        getNextToken();
        factor();
    }
}
```
Code for Expressions (2)

```java
// parse
// factor ::= int | id | ( expr )
void factor() {
    switch(nextToken) {
        case INT:
            process int constant;
            // consume INT
            getNextToken();
            break;
        case ID:
            process identifier;
            // consume ID
            getNextToken();
            break;
        case LPAREN:
            // consume LPAREN
            getNextToken();
            expr();
            // consume RPAREN
            getNextToken();
        ...
    }
}
```
Left Factoring

- If two rules for a non-terminal have right-hand sides that begin with the same symbol, we can’t predict which one to use
- “Official” solution: Factor the common prefix into a separate production
Left Factoring Example

• Original grammar:

\[
ifStmt ::= \text{if } ( \text{expr} ) \text{ stmt} \\
| \text{if } ( \text{expr} ) \text{ stmt else stmt}
\]

• Factored grammar:

\[
ifStmt ::= \text{if } ( \text{expr} ) \text{ stmt } \text{ ifTail} \\
ifTail ::= \text{else stmt} | \varepsilon
\]
But it’s easiest to just code up the “else matches closest if” rule directly

```c
// parse
//     if (expr) stmt [ else stmt ]

void ifStmt() {
    getNextToken();
    getNextToken();
    expr();
    getNextToken();
    stmt();
    if (next symbol is ELSE) {
        getNextToken();
        stmt();
    }
}
```
Top-Down Parsing Concluded

• Works with a somewhat smaller set of grammars than bottom-up, but can be done for most sensible programming language constructs
• If you need to write a quick-n-dirty parser, recursive descent is often the method of choice