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 a handle
    - Accept when all input read and reduced to start symbol of the grammar
  - LR(k) and subsets (SLR(k), LALR(k), ...)

remaining input
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 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
Example

- Programming language grammars are often suitable for predictive parsing
- Typical example
  
  \[ stmt ::= id = exp ; | return exp ; \\
  \hspace{1cm} | \text{if} ( exp ) stmt | \text{while} ( exp ) stmt \]

  If the next part of the input begins with the tokens

  \texttt{IF LPAREN ID(x) ...}

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

- A grammar has the LL(1) property if, for all non-terminals $A$, if productions $A ::= \alpha$ and $A ::= \beta$ both appear in the grammar, then it is the case that $\text{FIRST}(\alpha) \cap \text{FIRST}(\beta) = \emptyset$

- 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 practical programming language grammars
  - LL(k) for k>1 is very rare in practice
Table-Driven LL(k) Parsers

- As with LR(k), a table-driven parser can be constructed from the grammar.

Example

1. \( S ::= ( \ S \ ) \ S \)
2. \( S ::= [ \ S \ ] \ S \)
3. \( S ::= \varepsilon \)

Table

<table>
<thead>
<tr>
<th></th>
<th>(</th>
<th>)</th>
<th>[</th>
<th>]</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S</strong></td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
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 (i.e., contents of the stack) 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
- ∴ (editorial opinion) If you’re going to use a tool-generated parser, might as well use LR
  - But there are some very good LL parser tools out there (ANTLR, JavaCC, ...) that might win for other reasons
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 its non-terminal with the next part of the input.
Example: Statements

- Grammar
  
  \[ stmt ::= id = exp; \]
  
  | return exp ;
  
  | if ( exp ) stmt
  
  | while ( exp ) 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;
    }
  }
// 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 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 is done, it must have completely consumed input correspond to that non-terminal
Possible Problems

- Two common problems for recursive-descent (and LL(1)) parsers
  - Left recursion (e.g., \( E ::= E + T \mid \ldots \) )
  - Common prefixes on the right side of productions
Left Recursion Problem

- Grammar rule

  \[ expr ::= expr + term \]  
  \[ \text{or} \quad term \]  

- Code

  ```c
  // 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

\[
expr ::= \text{term} + expr \mid \text{term}
\]

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

- Rewrite using right recursion and a new non-terminal
- Original: \( expr ::= expr + term \mid term \)
- New
  \[
  expr ::= term \text{ exprtail} \\
  \text{exprtail} ::= + term \text{ exprtail} \mid \varepsilon
  \]
- Properties
  - No infinite recursion if coded up directly
  - Maintains left associatively (required)
Another Way to Look at This

- Observe that
  \[ expr ::= expr + term \mid term \]
generates the sequence
  \[ \ldots(((term + term) + term) + \ldots) + term \]
- We can sugar the original rule to reflect this
  \[ expr ::= term \{ + term \}^* \]
- This leads directly to parser code
Code for Expressions (1)

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

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

// parse
// factor ::= int | id | ( expr )
void factor() {

    switch(nextToken) {

        case INT:
            process int constant;
            getNextToken();
            break;

        case ID:
            process identifier;
            getNextToken();
            break;

        case LPAREN:
            getNextToken();
            expr();
            getNextToken();
            break;

        ...

    }
}
What About Indirect Left Recursion?

- A grammar might have a derivation that leads to a left recursion
  \[ A \Rightarrow \beta_1 \Rightarrow^* \beta_n \Rightarrow A \gamma \]
- There are systematic ways to factor such grammars
  - See any good compiler book
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.
- Solution: Factor the common prefix into a separate production.
Left Factoring Example

- **Original grammar**
  
  \[ ifStmt ::= if ( expr ) stmt \]
  
  \[ | if ( expr ) stmt else stmt \]

- **Factored grammar**
  
  \[ ifStmt ::= if ( expr ) stmt ifTail \]
  
  \[ ifTail ::= else stmt | \epsilon \]
Parsing if Statements

- 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();
    }
}
```
Another Lookahead Problem

- In languages like FORTRAN, parentheses are used for array subscripts.
- A FORTRAN grammar includes something like:

```
factor ::= id ( subscripts ) | id ( arguments ) | ...
```

- When the parser sees “id (“, how can it decide whether this begins an array element reference or a function call?
Two Ways to Handle $id(\ ?\ )$

- Use the type of $id$ to decide
  - Requires declare-before-use restriction if we want to parse in 1 pass
- Use a covering grammar
  
  \[
  factor ::= id(\ commaSeparatedList ) | \ldots
  \]

  and fix/check later when more information is available (e.g., types)
Top-Down Parsing Concluded

- Works with a 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.
Parsing Concluded

- That’s it!
- On to the rest of the compiler
- Coming attractions
  - Intermediate representations (ASTs etc.)
  - Semantic analysis (including type checking)
  - Symbol tables
  - & more...