Parsing

CSE 413, Autumn 2002

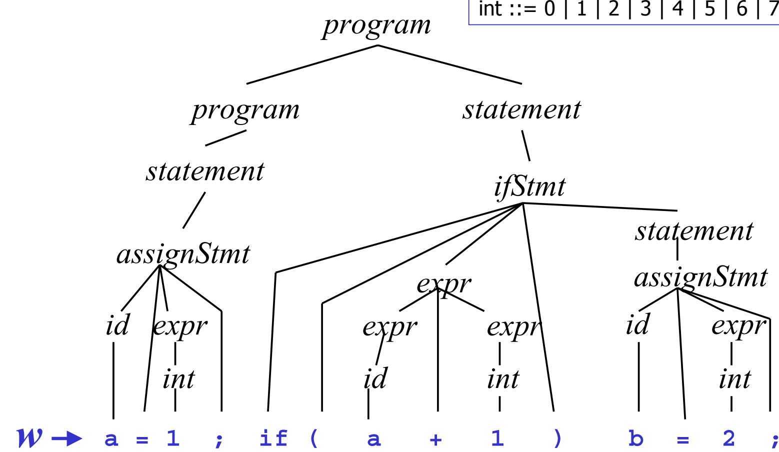
Programming Languages

http://www.cs.washington.edu/education/courses/413/02au/

Parse Tree Example

G

program ::= *statement* | *program statement*
statement ::= *assignStmt* | *ifStmt*
assignStmt ::= *id* = *expr* ;
ifStmt ::= if (*expr*) *stmt*
expr ::= *id* | *int* | *expr* + *expr*
Id ::= a | b | c | i | j | k | n | x | y | z
int ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9



Common Orderings

- Top-down
  - » Start with the root
  - » Traverse the parse tree depth-first, left-to-right (leftmost derivation)
  - » LL(k)
- Bottom-up
  - » Start at leaves and build up to the root
    Effectively a rightmost derivation in reverse
  - » LR(k) and subsets (LALR(k), SLR(k), etc.)

Bottom-Up Parsing

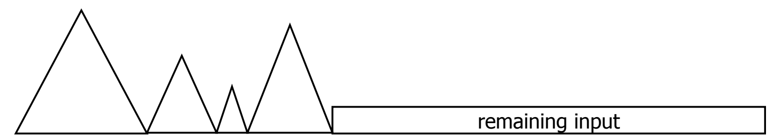
- Idea: Read the input left to right
- Whenever we've matched the right hand side of a production, reduce it to the appropriate non-terminal and add that non-terminal to the parse tree
- The upper edge of this partial parse tree is known as the *frontier*

LR(1) Parsing

- Left to right scan
- Rightmost derivation
- 1 symbol lookahead
- Most practical programming languages have an LR(1) grammar
- LALR(1), SLR(1), etc. – subsets of LR(1)

Basic Parsing Strategies

- 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), …)



Example

- Grammar

S ::= aABe

A ::= Abc | b

B ::= d

- Bottom-up Parse

a b b c d e

Details

- The bottom-up parser reconstructs a reverse rightmost derivation
- Given the rightmost derivation

  $S \Rightarrow \beta_1 \Rightarrow \beta_2 \Rightarrow \ldots \Rightarrow \beta_{n-2} \Rightarrow \beta_{n-1} \Rightarrow \beta_n = w$

  parser will discover $\beta_{n-1} \Rightarrow \beta_n$, then $\beta_{n-2} \Rightarrow \beta_{n-1}$, etc.
- Parsing terminates when
  - » β_1 reduced to S (success), or
  - » No match can be found (syntax error)

How Do We Automate This?

- Key: given what we've already seen and the next input symbol, decide what to do.
- Choices:
  - » Perform a reduction (ie, reduce)
  - » Look ahead further (ie, shift)
- Can reduce A=>β if both of these hold:
  - » A=>β is a valid production
  - » A=>β is a step in this rightmost derivation
- This is known as a *shift-reduce* parser

Implementing Shift-Reduce Parsers

- Key Data structures
  - » A stack holding the frontier of the tree
  - » A string with the remaining input

Shift-Reduce Parser Operations

- *Shift* – push the next input symbol onto the stack
- *Reduce* – if the top of the stack is the right side of a handle A::=β, pop the right side β and push the left side A.
- *Accept* – announce success
- *Error* – syntax error discovered

Shift-Reduce Example

S ::= aABe
A ::= Abc | b
B ::= d

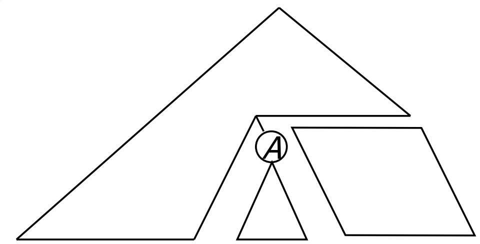
Stack	Input	Action
$	abbcde$	*shift*

How Do We Automate This?

- Definition
  - » *Viable prefix* – a prefix of a form that can appear on the stack of the shift-reduce parser
- Construct a DFA to recognize viable prefixes given the stack and remaining input
  - » Perform reductions when we recognize them
- Most compiler building tools are based on this design and implement LR parsing using a DFA constructed from a set of grammar productions

Basic Parsing Strategies

- 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)



LL(k) Parsers

- An LL(k) parser
  - » Scans the input <u>L</u>eft to right
  - » Constructs a <u>L</u>eftmost derivation
  - » Looking ahead at most <u>k</u> symbols
- 1-symbol look ahead is enough for many practical programming language grammars

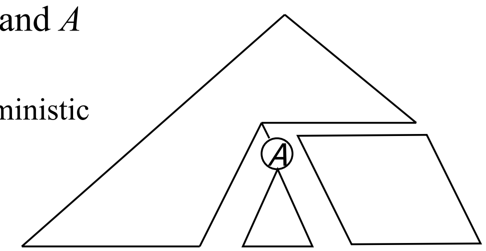
Top-Down Parsing

- 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
- Common situation

  stmt ::= *id* = *expr* ; | return *expr* ;
  | if (*expr*) *stmt* | while (*expr*) *stmt*

  If the first part of the unparsed input begins with the tokens

  IF LPAREN ID(x) …

  we know we can expand *stmt* to an if-statement

LL(1) Property

- FIRST(α)
  - » the set of tokens that appear as the first symbols of one or more strings generated from α
  - » for example, from preceding slide: FIRST(*stmt*) = {Token.ID, Token.KW_RETURN, Token.KW_IF, Token.KW_WHILE}
- 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 $\text{FIRST}(\alpha) \cap \text{FIRST}(\beta) = \emptyset$
- If a grammar has the LL(1) property, we can build a predictive parser for it

Table-Driven LL(k) Parsers

- A table-driven parser can be constructed from the grammar (also true for LR(k))
- Example
  1. *S* ::= (*S*) *S*
  2. *S* ::= [*S*] *S*
  3. *S* ::= ε
- Table

	(	)	[	]	$
S	1	3	2	3	3

w: `(([ ]))$`

LL vs LR

- 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
- ∴ LR(1) is more powerful than LL(1)
  » Includes a larger set of grammars
  » but LL(1) is sufficient for many languages

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* = *expr* ;
| return *expr* ;
| if (*expr*) *stmt*
| while (*expr*) *stmt*

```
// parse stmt ::= id=exp; | …

void parseStmt( ) {
  switch(nextToken.getType()) {
   case Token.ID:
       parseAssignStmt(); break;
   case Token.KW_RETURN:
       parseReturnStmt(); break;
   case Token.KW_IF:
       parseIfStmt(); break;
   case Token.KW_WHILE:
       parseWhileStmt(); break;
   default:
       error(); break;
  }
}
```


Example (cont)

```
// parse while (exp) stmt

void parseWhileStmt() {

   matchToken(Token.KW_WHILE);
   matchToken(Token.LPAREN);

   parseExpr();

   matchToken(Token.RPAREN);

   parseStmt();
}
```

```
// parse return exp ;

void parseReturnStmt() {

   matchToken(Token.KW_RETURN);

   parseExpr();

   matchToken(Token.SEMICOLON);
}
```

Note: your code needs to handle the case when matchToken fails.

Invariant for 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
  - » 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 hand side of productions

Left Recursion Problem

- Grammar rule

expr ::= *expr* + *term*
| *term*

- Code

```
// parse expr ::= …

void parseExpr() {
  parseExpr();
  if (current token is ADD) {
     matchToken(ADD);
     parseTerm();
  }
}
```

- 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* | *term*
  - » Why isn't this the right thing to do?

Left Recursion Solution

- Rewrite using right recursion and a new non-terminal
- Original: *expr* ::= *expr* + *term* | *term*
- New

  expr ::= *term exprTail*

  exprTail ::= + *term exprTail* | ε
- Properties
  - » No infinite recursion if coded up directly
  - » Maintains left associativity (required)

Another Way to Look at This

- Observe that

  expr ::= *expr* + *term* | *term*

  generates the sequence

  term + *term* + *term* + … + *term*
- We can sugar the original rule to show this
  - » *expr* ::= *term* (+ *term*)*
  - » or *expr* ::= *term* { + *term* }
- This can simplify the parser code

Code for Expressions

```
// parse
// expr ::=  term { + term }

void parseExpr() {
   parseTerm();
   while (next symbol is ADD) {
        matchToken(ADD);
        parseTerm();
   }
}
```

```
// parse
// term ::= factor { * factor }

void term() {
   parseFactor();
   while (next symbol is MUL) {
        matchToken(MUL);
        parseFactor();
   }
}
```


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
  - » But we won't need them in our grammar
  - » refer to a compiler text for more info

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* | ε

Parsing if Statements

- But it's easiest to just code up the "else matches closest if" rule directly

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

void parseIfStmt() {
   matchToken(IF);
   matchToken(LPAREN);
   parseExpr();
   matchToken(RPAREN);
   parseStmt();
   if (next symbol is ELSE) {
        matchToken(ELSE);
        parseStmt();
   }
}
```


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 between an array element reference and a function call?

Handling *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*) | …

  and fix later when more information is available
- Semantic analysis after parsing can resolve details that are difficult to express directly in the grammar

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