CSE 413
Programming Languages & Implementation

Hal Perkins

Spring 2021

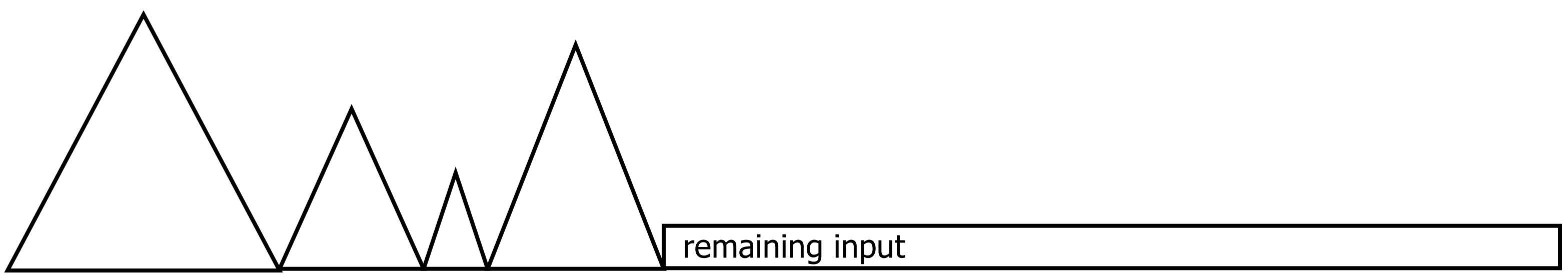
Top-Down and Recursive-Descent Parsing

Agenda

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

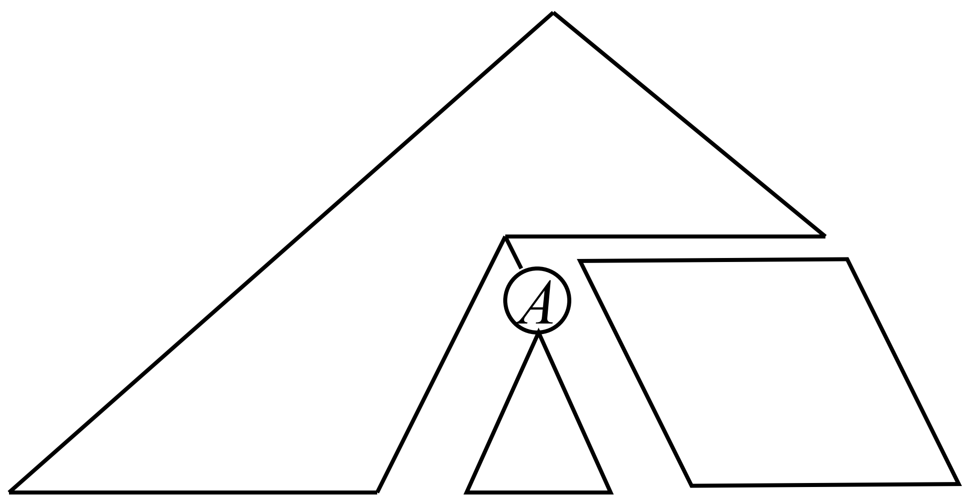
Basic Parsing Strategies (1)

- 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

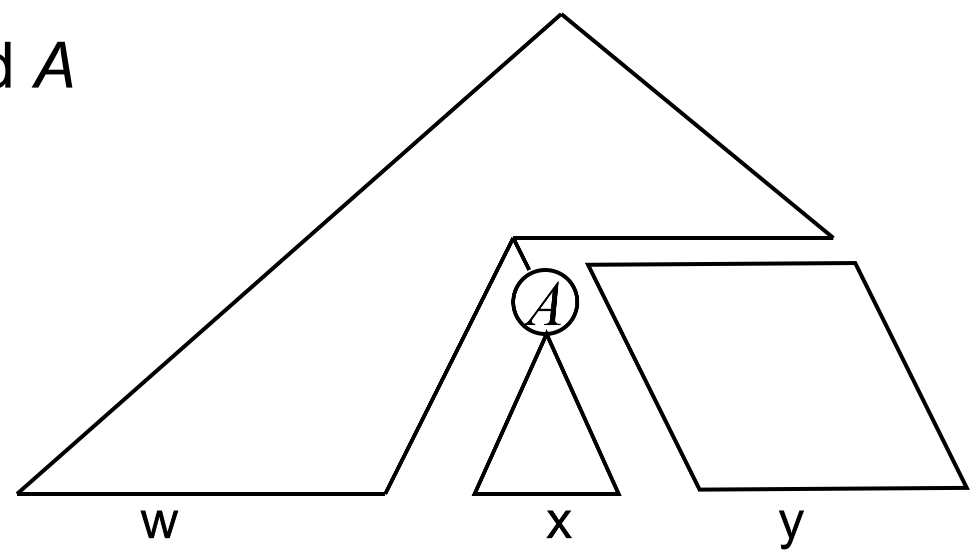
  S =>* w$A\alpha$ =>* wxy

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

  If the remaining unparsed input begins with the tokens

  IF LPAREN ID(x) …

  we should expand *stmt* to an if-statement

LL(k) Property

- A grammar has the LL(1) property if, for all non-terminals *A*, when there are two productions

  $A ::= \alpha$

  $A ::= \beta$

  in the grammar, then:

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

  FIRST(α) = set of terminals that begin any possible string derived from α)
    - Assumption, neither α nor β can expand to ε. There are ways to handle this if it happens, but we will avoid the issue

- 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 important 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* ;
    | 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;
  }
}
```

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* | *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* | ε
- Properties
  - No infinite recursion if coded up directly
  - Maintains left associatively (required)
    - Need to be a bit careful in coding up semantic actions to get this right, but not hard to do

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 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)

```
// 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)

```
// 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 ::= 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

- (If you squint properly this is really just left factoring where the two productions are parsed by a single routine)

```
// 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