Week 3
More Parsing

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Recall

- A language (computer or human) has
  - An alphabet
  - Tokens (i.e., words)
  - Syntax (i.e., structure)
  - Semantics
- We know the alphabet
- The tokens are simple
- Syntax??
  - Syntax can be described by a *Context Free Grammar*
  - A grammar uses *productions* of the form V → w
  - V is a single *nonterminal* (i.e., it's not a token)
  - w is word made from both *terminals* (i.e., tokens) and nonterminals

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Compiling Overview

- Compiling a program
  - Lexical analysis
    - Break program into tokens
  - Parsing
    - Analyze token arrangement
    - Discover structure
  - Code generation
    - Create code
- What you'll be doing
  - Lexical analysis
    - This will be given to you
  - Parsing
    - Recursive Descent Parsing
    - Build an Abstract Syntax Tree (AST)
  - Code generation
    - Use the AST to create code

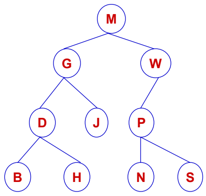
Building a Parse Tree

- Grammars can be used in two ways
  - A grammar defines a language (i.e., the set of properly structured sentences)
  - A grammar can be used to parse a *sentence* (thus, checking if the sentence is *in* the language)
- For us,
  - We will give you the grammar for Bali
  - The *sentence* is a Bali program
- You can show a sentence is in a language by building a *parse tree* (much like diagramming a sentence)
- Example: Show that 8+x/5 is a valid Expression (E) by building a parse tree
  - E → T { ('+' | '-') E }
  - T → F { ('*' | '/') T }
  - F → (n | w | '(' E ')')

{ } indicates 0 or more occurrences
(| |) indicates choice
n is a number
w is a word

Tree Terminology

- M is the *root* of this *tree*
- G is the *root* of the left *subtree* of M
- B, H, J, N, and S are *leaves*
- P is the *parent* of N
- M and G are *ancestors* of D
- P, N, and S are *descendents* of W
- A collection of trees is called a *??*



An Extended Example

- A simple computer language
- Just 3 variables: x, y, z
- Just two statement types: assignment and do

```
x = 1; y = 1;
do 5:
  x = x * y;
  y = y + 1;
  end;
end.
```

- We can invent a grammar to describe legal programs
  - We need rules for building *expressions*, *statements*, and *programs*
  - Context Free Grammars are just what's needed to describe these rules

The Grammar

program → { statement } **end .**

statement → name **=** expression **;**

statement → **do** expression **:**
{ statement } **end ;**

expression → part [(**+** | **-** | ***** | **/**) part]

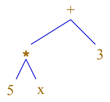
part → (name | number | **(** expression **)**)

name → (**x** | **y** | **z**)

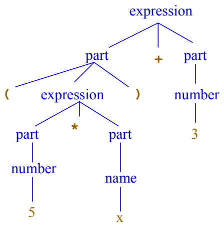
- Notation:
  - { } indicates zero or more occurrences
  - [ ] indicates zero or one occurrence
  - (| |) indicates choice
- What is the parse tree for the expression (5 * x) + 3?

Abstract Syntax Tree

- We can build a parse tree, but an AST (*Abstract Syntax Tree*) is more useful
  - Idea is to show less grammar and more meaning



Abstract Syntax Tree

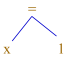


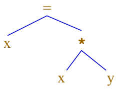
Parse Tree

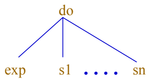
Designing the AST

- We can decide how the AST should look for each of our language constructs

```
x = 1; y = 1;
do 5:
  x = x * y;
  y = y + 1;
  end;
end.
```







Recursive Descent Parsing

- Idea: Use the grammar to design a recursive program that builds the AST
- To parse a do-statement, for instance
  - We look for each terminal (i.e., token)
  - Each nonterminal (e.g., expression, statement) can handle itself
- The grammar tells how to write the program

```
public DoNode parseDo {
   Make sure there is a “do” token;
   exp = parseExpression();
   Make sure there is an “:” token;
   while (not “end” token) {
         s = parseStatement();
         stList.add(s);
         }
   Make sure there is an “end” token;
   Make sure there is a “;” token;
   return DoNode(exp, stList);
```

In Practice

- We define a parent class ASTNode
- DoStatement can be a subclass
  - The parseDo program can be used as the outline for the *constructor*
- Each possible node in the AST will have its own subclass of ASTNode
- Some of the grammar’s nonterminals don’t correspond to nodes in the AST
  - E.g., statement, expression, part
  - For these we *don’t* want to create classes
  - But we do need recursive methods for these nonterminals
  - One place to put such methods:
    - In the parent class (ASTNode)

Does Recursive Descent Always Work?

- There are some grammars that cannot be used as the basis for recursive descent
  - A trivial example (causes infinite recursion):
    - S -> b
    - S -> Sa
- Can rewrite grammar
  - S -> b
  - S -> bA
  - A -> aA
- For some constructs Recursive Descent is hard to use
  - Can use a more powerful parsing technique (there are several, but not in this course)

Syntactic Ambiguity

- Sometimes a sentence has more than one parse tree

  S → A | aaB
  A → ε | aAb
  B → ε | aB | bB

  - The string aabb can be parsed in two ways
- This kind of ambiguity sometimes shows up in programming languages

if E1 then if E2 then S1 else S2

- This ambiguity actually affects the program's meaning
- How do we resolve this?
  - Provide an extra non-grammar rule (e.g., the *else* goes with the closest *if*)
  - Modify the grammar (e.g., an if-statement must end with a '*fi*')
  - Other methods (e.g., Python uses amount of indentation)
- We try to avoid syntactic ambiguity in Bali

Code Generation

- The same kind of recursive viewpoint can drive our code generation
  - This time we recurse on the AST instead of the grammar
  - Write the code for the root node; the subtrees (e.g., exp) can take care of themselves

```
class AssignmentStatement extends
    ASTNode {

    String var; ASTNode exp;

    public AssignmentStatement {
          var = variable on left;
          exp = expression on right;
          }
    public void generate ( ) {
          exp.generate( );
          // Exp result is left on stack
          Generate code to move top
                    of stack into mem
                    location of var;
          } }
```