CS/ENGRD 2110
Object-Oriented Programming and Data Structures

Spring 2012

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Lecture 6: Grammars & Parsing

Java Tips

- Declare fields and methods **`public`** if they are to be visible outside the class; helper methods and private data should be declared **`private`**
- Constants that will never be changed should be declared **`final`**
- Public classes should appear in a file of the same name
- Two kinds of boolean operators:
  - **`e1 & e2`**: evaluate both and compute their conjunction
  - **`e1 && e2`**: evaluate **`e1`**; don't evaluate **`e2`** unless necessary

- instead of

```
if (s.equals("")) {
    f = true;
} else {
    f = false;
}
```

write

```
f = s.equals("");
```

- instead of

```
if (s.equals("")) {
    f = a;
} else {
    f = b;
}
```

write

```
f = s.equals("")? a : b;
```

Application of Recursion

- So far, we have discussed recursion on integers
  - Factorial, fibonacci, combinations, a^n
- Let us now consider a new application that shows off the full power of recursion: *parsing*
- Parsing has numerous applications: compilers, data retrieval, data mining,…

Motivation

- Some legal english sentences:
  - The cat ate the rat.
  - The cat ate the rat slowly.
  - The small cat ate the big rat slowly.
  - The small cat ate the big rat on the mat slowly.
  - The small cat that sat in the hat ate the big rat on the mat slowly.
  - The small cat that sat in the hat ate the big rat on the mat slowly, then got sick.
- …

- Not all sequences of words are legal sentences
  - The ate cat rat the
- How many legal sentences are there?
- How many legal programs are there?
- Are all Java programs that compile legal programs?
- How do we know what programs are legal?

http://java.sun.com/docs/books/jls/third_edition/html/syntax.html

A Grammar

- Grammar:
  - set of rules for generating sentences in a language
- Example grammar:
  - Sentence $\rightarrow$ Noun Verb Noun
  - Noun $\rightarrow$ boys
  - Noun $\rightarrow$ girls
  - Noun $\rightarrow$ bunnies
  - Verb $\rightarrow$ like
  - Verb $\rightarrow$ see
- Our sample grammar has these rules:
  - A Sentence can be a Noun followed by a Verb followed by a Noun
  - A Noun can be 'boys' or 'girls' or 'bunnies'
  - A Verb can be 'like' or 'see'
- Examples of Sentence:
  - boys see bunnies
  - bunnies like girls
  - …
- White space between words does not matter
- The words boys, girls, bunnies, like, see are called tokens or terminals.
- The words Sentence, Noun, Verb are called nonterminals.
- This is a very boring grammar because the set of Sentences is finite (exactly 18 sentences)

A Recursive Grammar

- Example recursive grammar:
  - Sentence → Sentence and Sentence
  - Sentence → Sentence or Sentence
  - Sentence → Noun Verb Noun
  - Noun → boys
  - Noun → girls
  - Noun → bunnies
  - Verb → like
  - Verb → see

- This grammar is more interesting than the last one because the set of Sentences is infinite

- Examples of Sentences in this language:
  - boys like girls
  - boys like girls and girls like bunnies
  - boys like girls and girls like bunnies and girls like bunnies
  - boys like girls and girls like bunnies and girls like bunnies and girls like bunnies
  - ....

- What makes this set infinite? Answer:
  - Recursive definition of Sentence

Detour

- What if we want to add a period at the end of every sentence?
  - Sentence → Sentence and Sentence .
  - Sentence → Sentence or Sentence .
  - Sentence → Noun Verb Noun .
  - Noun → …
- Does this work?
- No! This produces sentences like:
  - girls like boys . and boys like bunnies . .

Sentences with Periods

- Grammar
  - PunctuatedSentence → Sentence .
  - Sentence → Sentence and Sentence
  - Sentence → Sentence or Sentence
  - Sentence → Noun Verb Noun
  - Noun → boys
  - Noun → girls
  - Noun → bunnies
  - Verb → like
  - Verb → see

- Add a new rule that adds a period only at the end of the sentence.
- The terminal tokens here are the 7 words plus the period (.)

Grammar for Simple Expressions

- Grammar
  - E $\rightarrow$ integer
  - E $\rightarrow$ (E + E)

- Simple expressions:
  - An E can be an integer.
  - An E can be '(' followed by an E followed by '+' followed by an E followed by ')'

- Set of expressions defined by this grammar is a recursively-defined set.

- Here are some legal expressions:
  - 2
  - (3 + 34)
  - ((4+23) + 89)
  - ((89 + 23) + (23 + (34+12)))

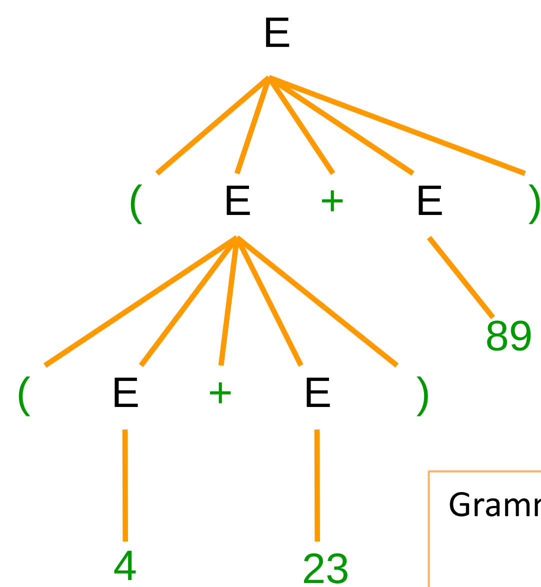
- Here are some illegal expressions:
  - (3
  - 3 + 4

- The terminal tokens in this grammar are (, +,), and any integer.

Parsing

- Grammars can be used in two ways
  - A grammar defines how to generate 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)
- To parse a sentence is to build a parse tree
  - This is much like diagramming a sentence

- Example: Show that ((4+23) + 89) is a valid expression E by building a parse tree



Grammar

E → integer

E → (E + E)

Recursive Descent Parsing

- Idea: Use the grammar to design a recursive program to check if a sentence is in the language
- To parse an expression E, for instance
  - We look for each terminal (i.e., each token)
  - Each nonterminal (e.g., E) can handle itself by using a recursive call
- The grammar tells how to write the program!

```
boolean parseE() {
  if (first token is an integer) return true;
  if (first token is '(' ) {
       parseE();
       Make sure there is a '+' token;
       parseE( );
       Make sure there is a ')' token;
       return true;
  }
  return false;
}
```

Grammar

$E \rightarrow$ integer

$E \rightarrow (E + E)$

Java Code for Parsing E

```
public static Node parseE(Scanner scanner) {
  if (scanner.hasNextInt()) {
   int data = scanner.nextInt();
   return new Node(data);
  }
  check(scanner, '(');
  left = parseE(scanner);
  check(scanner, '+');
  right = parseE(scanner);
  check(scanner, ')');
  return new Node(left, right);
}
```

Grammar

E → integer

E → (E + E)

Detour: Error Handling with Exceptions

- Parsing does two things:
  - It returns useful data (a parse tree)
  - It checks for validity (i.e., is the input a valid *sentence*?)

- How should we respond to invalid input?

- *Exceptions* allow us to do this without complicating our code unnecessarily

Exceptions

- Exceptions are usually thrown to indicate that something bad has happened
  - `IOException` on failure to open or read a file
  - `ClassCastException` if attempted to cast an object to a type that is not a supertype of the dynamic type of the object
  - `NullPointerException` if tried to dereference null
  - `ArrayIndexOutOfBoundsException` if tried to access an array element at index i < 0 or ε the length of the array

- In our case (parsing), we should throw an exception when the input cannot be parsed

Handling Exceptions

- Exceptions can be caught by the program using a **`try-catch`** block
- **`catch`** clauses are called *exception handlers*

```
Integer x = null;
try {
   x = (Integer)y;
   System.out.println(x.intValue());
} catch (ClassCastException e) {
   System.out.println("y was not an Integer");
} catch (NullPointerException e) {
   System.out.println("y was null");
}
```

Defining Your Own Exceptions

- An exception is an object (like everything else in Java)
- You can define your own exceptions and throw them

```
class MyOwnException extends Exception {}

...

if (input == null) {
   throw new MyOwnException();
}
```

Declaring Exceptions

- In general, any exception that could be thrown must be either *declared* in the method header or *caught*

```
void foo(int input) throws MyOwnException {
  if (input == null) {
    throw new MyOwnException();
  }
  ...
}
```

- Note: `throws` means "can throw", not "does throw"
- Exception (haha):
  - Subtypes of `RuntimeException` do not have to be declared (e.g., `NullPointerException`, `ClassCastException`)
  - These represent exceptions that cannot be recovered from anyway. They indicate a bug.
  - Do not make your exceptions subtypes of `RuntimeException`

How Exceptions are Handled

- If the exception is thrown from inside the **`try`** clause of a **`try-catch`** block with a handler for that exception (or a superclass of the exception), then that handler is executed
  - Otherwise, the method terminates abruptly and control is passed back to the calling method
- If the calling method can handle the exception (i.e., if the call occurred within a try-catch block with a handler for that exception) then that handler is executed
  - Otherwise, the calling method terminates abruptly, etc.
- If none of the calling methods handle the exception, the entire program terminates with an error message

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):
    - $S \rightarrow b$
    - $S \rightarrow Sa$
- Can rewrite grammar
    - $S \rightarrow b$
    - $S \rightarrow bA$
    - $A \rightarrow a$
    - $A \rightarrow aA$
- 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
    - $S \rightarrow A$
    - $S \rightarrow aaxB$
    - $A \rightarrow x$
    - $A \rightarrow aAb$
    - $B \rightarrow b$
    - $B \rightarrow bB$
  - The string aaxbb 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
  - Which then does the else go with?

- 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 language (e.g., an if-statement must end with a 'fi')
  - Operator precedence (e.g. 1 + 2 * 3 should always be parsed as 1 + (2 * 3), not (1 + 2) * 3
  - Other methods (e.g., Python uses amount of indentation)

Exercises

- Think about recursive calls made to parse and generate code for simple expressions
    - 2
    - (2 + 3)
    - ((2 + 45) + (34 + -9))
- Derive an expression for the total number of calls made to parseE for parsing an expression
    - Hint: think inductively
- Derive an expression for the maximum number of recursive calls that are active at any time during the parsing of an expression (i.e. max depth of call stack)

Exercises

- Write a grammar and recursive program for palindromes
  - mom
  - dad
  - i prefer pi
  - race car
  - murder for a jar of red rum
  - sex at noon taxes
- Write a grammar and recursive program for strings A^nB^n
  - AB
  - AABB
  - AAAAAAABBBBBBB
- Write a grammar and recursive program for Java identifiers
  - <letter> [<letter> or <digit>]$^{0 \ldots N}$
  - j27, but not 2j7