GRAMMARS & PARSING

Lecture 7
CS2110 – Fall 2009

Java Tips

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- 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

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- 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

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- 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

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Sentence	→	Noun Verb Noun
Noun	→	boys
Noun	→	girls
Noun	→	bunnies
Verb	→	like
Verb	→	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'

- Grammar: set of rules for generating sentences in a language
- 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

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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 $\rightarrow$ Sentence and Sentence .
- Sentence $\rightarrow$ Sentence or Sentence .
- Sentence $\rightarrow$ Noun Verb Noun .
- Noun $\rightarrow$ …

- Does this work?
- No! This produces sentences like:
  - $\underbrace{\underbrace{\text{girls like boys .}}_{\text{Sentence}}\ \text{and}\ \underbrace{\text{boys like bunnies .}}_{\text{Sentence}}\ .}_{\text{Sentence}}$

Sentences with Periods

- PunctuatedSentence $\rightarrow$ Sentence .
- Sentence $\rightarrow$ Sentence and Sentence
- Sentence $\rightarrow$ Sentence or Sentence
- Sentence $\rightarrow$ Noun Verb Noun
- Noun $\rightarrow$ boys
- Noun $\rightarrow$ girls
- Noun $\rightarrow$ bunnies
- Verb $\rightarrow$ like
- Verb $\rightarrow$ see

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

boys like girls
and girls like boys
or girls like bunnies

Grammar for Simple Expressions

- 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
  - Is language finite or infinite?
  - Do recursive grammars always yield infinite languages?

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

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

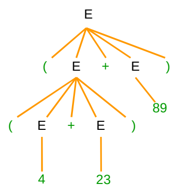
- The *tokens* in this grammar are (, +,), and any integer

Parsing

- 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*)

- 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*



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;
}
```

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);
}
```

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 ≥ 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

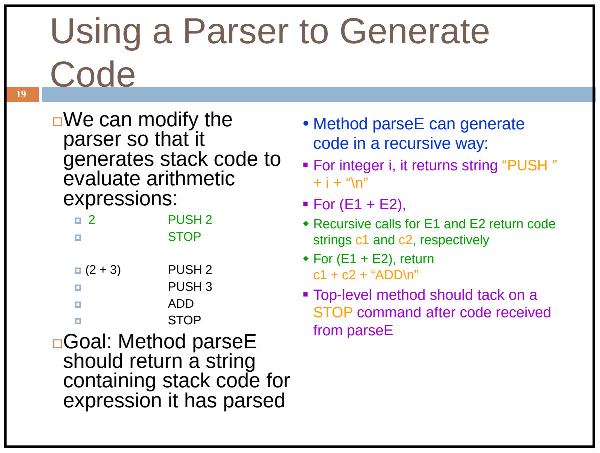
- In general, any exception that could be thrown must be either *declared* in the method header or *caught*

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

- Note: **`throws`** means "can throw", not "does throw"
- Subtypes of **`RuntimeException`** do not have to be declared (e.g., **`NullPointerException`**, **`ClassCastException`**)
  - These represent exceptions that can occur during "normal operation of the Java Virtual Machine"

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



Using a Parser to Generate Code

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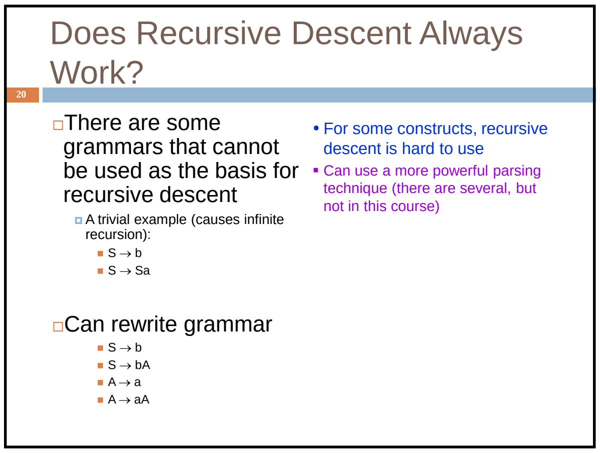
- We can modify the parser so that it generates stack code to evaluate arithmetic expressions:

```
2          PUSH 2
           STOP

(2 + 3)    PUSH 2
           PUSH 3
           ADD
           STOP
```

- Goal: Method parseE should return a string containing stack code for expression it has parsed

- Method parseE can generate code in a recursive way:
  - For integer i, it returns string "PUSH " + i + "\n"
  - For (E1 + E2),
    - Recursive calls for E1 and E2 return code strings c1 and c2, respectively
    - For (E1 + E2), return c1 + c2 + "ADD\n"
  - Top-level method should tack on a STOP command after code received from parseE



Does Recursive Descent Always Work?

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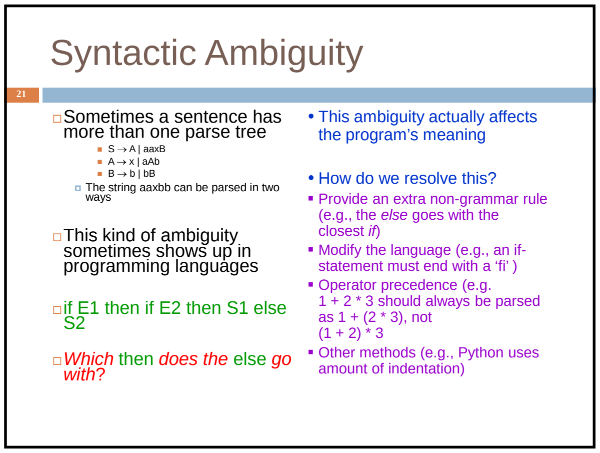
- There are some grammars that cannot be used as the basis for recursive descent
  - A trivial example (causes infinite recursion):
    - $S \rightarrow b$
    - $S \rightarrow Sa$
- Can rewrite grammar
    - $S \rightarrow b$
    - $S \rightarrow bA$
    - $A \rightarrow a$
    - $A \rightarrow aA$

- 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

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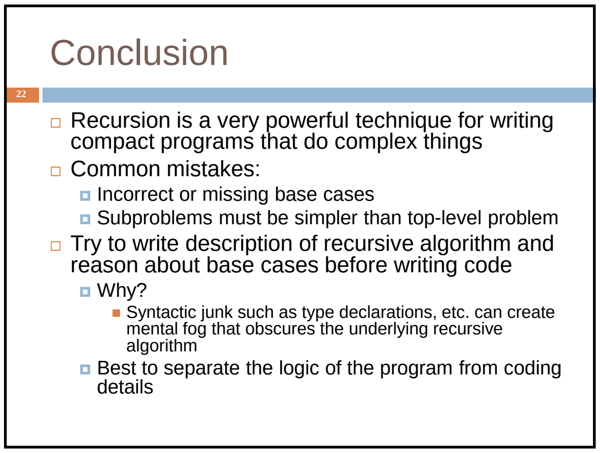
- Sometimes a sentence has more than one parse tree
    - $S \rightarrow A \mid aaxB$
    - $A \rightarrow x \mid aAb$
    - $B \rightarrow b \mid bB$
  - The string aaxbb can be parsed in two ways
- This kind of ambiguity sometimes shows up in programming languages
- if E1 then if E2 then S1 else S2
- *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)



Conclusion

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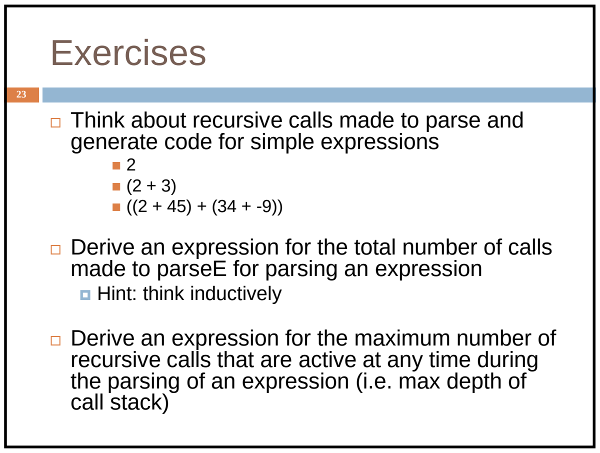
- Recursion is a very powerful technique for writing compact programs that do complex things
- Common mistakes:
  - Incorrect or missing base cases
  - Subproblems must be simpler than top-level problem
- Try to write description of recursive algorithm and reason about base cases before writing code
  - Why?
    - Syntactic junk such as type declarations, etc. can create mental fog that obscures the underlying recursive algorithm
  - Best to separate the logic of the program from coding details



Exercises

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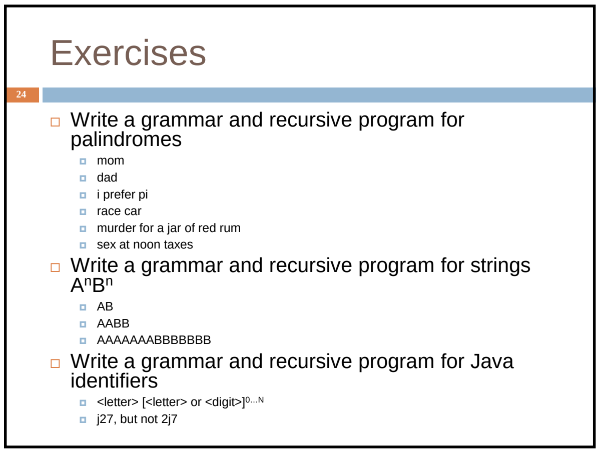
- Think about recursive calls made to parse and generate code for simple expressions
    - 2
    - (2 + 3)
    - ((2 + 45) + (34 + -9))
- Derive an expression for the total number of calls made to parseE for parsing an expression
  - Hint: think inductively
- Derive an expression for the maximum number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



Exercises

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- 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