CS 541 — Fall 2018

Programming Assignment 3
CSX_go Parser

Write a Java CUP parser specification to implement a CSX_go parser. A grammar that defines CSX_go syntax appears below. You should examine the grammar carefully to learn the structure of CSX_go constructs. In most cases, structures are very similar to those of Java and C++. At this stage, you need not understand exactly what each construct does, but rather just how each construct appears. Labeled for statements and the break and continue statements are optional; you get extra credit if you implement them.

The CSX_go grammar listed below encodes the fact that the unary ! Operator has the highest precedence. The * and / operators have the next-highest precedence. The + and − operators have the third-highest precedence. The relational operators (==, !=, <, <=, >= and >) have the fourth-highest precedence. The boolean operators (&& and | |) have the lowest precedence. Thus !A+B*C==3 | | D!=F is equivalent to the following fully-parenthesized expression: ((((!A)+(B*C))==3) | | (D!=F)). All binary operators are left-associative, except the relational operators, which do not associate at all (for instance, A==B==C is invalid). The unary operators are (of course) right-associative. Be sure that your parser for CSX_go properly reflects these precedence and associativity rules.

program → package identifier varDecls funcDecls

varDecls → varDecl varDecls
| λ

varDecl → var   identifier type ;
| var   identifier type = expr ;
| var   identifier type [ intlit ] ;
| const identifier = expr ;

funcDecls → funcDecl funcDecls
| λ

funcDecl → func identifier ( formals ) optType block

formals → someFormals
| λ
someFormals → formalDecl
| formalDecl , someFormals

formalDecl → identifier type
| identifier [ ] type

optType → type
| λ

stmts → stmt stmts
| λ

stmt → if expr block
| if expr block else block
| for expr block
| identifier : for expr block
| name = expr ;
| read readlist ;
| print printlist ;
| identifier ( actuals ) ;
| return ;
| return expr ;
| break identifier ;
| continue identifier ;
| block

block → { vardecls stmts } optionalSemi

optionalSemi → ;
| λ

type → int
| char
| bool

actuals → someActuals
| λ

someActuals → expr
| expr , someActuals

readlist → name , readlist
| name

printlist → expr , printlist
| expr

eexpr → expr || term
| expr && term
| term
Using JavaCUP to Build a Parser

You will use JavaCUP, a Java-based parser generator, to build your CSX_go parser. You’ll have to rewrite the CSX_go grammar into the format required by JavaCUP. This format is defined in the “CUP User’s Manual,” available in the “Useful Programming Tools” section of the class homepage. A sample CUP specification corresponding to CSX_lite (a small subset of CSX_go) may be found in ~raphael/courses/cs541/public/proj3/startup/csx_lite.cup.

Once you’ve rewritten the CSX_go grammar we’ve provided and entered it into a file (say CSX_go.cup), you can test whether the grammar can be parsed by a CUP-generated parser. Run

java java_cup.Main < CSX_go.cup

Java CUP might generate a message

*** Shift/Reduce conflict found in state #XX

where XX is a number that depends on the exact structure of the grammar you enter. This
message indicates that the grammar we’ve provided is almost, but not quite, in a form acceptable to CUP. This problem is a common occurrence. Most context-free grammars used to define programming languages can be handled by JavaCUP, sometimes after minor modification.

You may rewrite the CSX_go grammar in any way you wish, adding or changing productions and nonterminals. You must not change the CSX_go language itself (the sequences of tokens considered valid).

Once your grammar is in the right format and generates no error messages, JavaCUP creates a file parser.java that contains the parser it has generated. It also creates a file sym.java, which contains the token codes the parser is expecting. Use sym.java with JLex in generating your scanner to guarantee that both the scanner and parser use the same token codes.

The generated parser tables are in parser.java. Compiling this file generates some warnings that you may ignore. It calls Scanner.next_token() to get tokens. Class Scanner (provided by us) creates a Yylex object (a JLex scanner) and calls yylex() as necessary to provide tokens. Be sure to call Scanner.init(in) prior to parsing with in, the FileInputStream you wish to scan from.

If there is a syntax error during parsing, parse() throws a SyntaxErrorException; be sure to catch it. It also calls syntax_error(token) to print an error message. We provide a simple implementation of syntax_error in lite.cup (the parser specification for CSX_lite). You may improve it if you wish (perhaps to print the offending token). You should test your parser on a variety of simple inputs, both valid and invalid, to verify that your parser is operating correctly.

Generating Abstract Syntax Trees

You should consider the material in this section a hint, not a requirement.

So far, your parser reads input tokens and determines whether they form a syntactically correct program. You now must extend your parser so that it builds an abstract syntax tree (AST). The AST will be used in the next projects by the type checker and code generator to complete compiling a CSX_go program.

Abstract syntax tree nodes are defined as Java classes, with each particular kind of AST node corresponding to a particular class. The AST node for an assignment statement corresponds to the class AsgNode. The classes comprising AST nodes are not independent. All of them are direct or indirect subclasses of the following:

```java
abstract class ASTNode {
    int lineNum;
    int colNum;

    static void genIndent(int indent){ ... }

    ASTNode(){lineNum=-1; colNum=-1;}
    ASTNode(int l, int c){lineNum=l; colNum=c;}
    boolean isNull(){return false;} // Is this node null?
    void unparse(int indent){};
};
```

ASTNode is the base class from which all other classes for AST nodes descend. ASTNode is an abstract superclass; objects of this class are never created. Its definition serves to define the fields and methods shared by all subclasses.

ASTNode contains two instance variables: lineNum and colNum. They represent the line and column numbers of the tokens from which the AST node was built. Thus for AsgNode, the
AST node for assignment statements, lineNum and colNum record the position of the assignment’s target variable, since that’s where the assignment statement begins.

ASTNode also has two constructors that set lineNum and colNum. These constructors are called by constructors of subclasses to set these two fields (to either explicit or default values).

The method isNull is used to determine if a particular AST node is “null”; that is, if it corresponds to \( \lambda \). Only special “null nodes” define their isNull function to return true; other AST nodes inherit the definition in ASTNode.

The method unparse() is used to “unparse” an AST node — that is, to print it out in a clear human-readable form. Unparsing is discussed below. Each subclass provides its own definition of unparse(); the default — to print nothing — is usually inappropriate. Thus the AsgNode's unparse() defines how assignment statements are to be printed. Each kind of AST node should have its own unparsing rules. Member genIndent() is a utility routine used by unparse().

An example of an AST node we might build while parsing a CSX_go program is:

```java
class ProgramNode extends ASTNode {
    ProgramNode(IdentNode id, MemberDeclsNode m,
             int line, int col){ ... }
    void unparse(int indent) { ... }
    private IdentNode packageName;
    private MemberDeclsNode members;
};
```

ProgramNode corresponds to the start symbol of all CSX_go programs, program. ProgramNode is a subclass of ASTNode, so it inherits all of ASTNode’s fields and members. It contains a constructor, as do all AST nodes. This constructor sets the private members of the class. It also calls ASTNode’s constructor to set lineNum and colNum. Its unparse() provides a definition of unparsing appropriate to the program structure the class represents. Since ProgramNode corresponds to a non-\( \lambda \) construct, it is content to inherit and use ASTNode’s definition of isNull.

ProgramNode also contains two private fields, which correspond to the two subtrees a ProgramNode contains: the name of the project (an identifier), and the declarations (variables and functions) within the program. The type declarations tell us precisely the kind of subtrees that are permitted. If we try to assign a subtree corresponding to an integer literal to className, we get a Java type error, because the AST node corresponding to integer literals (IntLitNode) is different from the type that packageName expects (which is IdentNode).

This precaution explains why we’ve created so many different classes for AST nodes. Each different kind of node has its own class, and it is wrong to assign a class corresponding to one kind of AST node to a field expecting a different kind of AST node.

We list below (in Table 1) all the AST classes you might use. For each class, we list the field names in that class and the type of each field. This type is usually a reference to a particular AST class object.

In some cases, a field may reference a special kind of AST node, a “null node,” that corresponds to \( \lambda \). That is, if a subtree is empty, we use a null node to represent that fact. For example, in a function, declarations are optional. As you might expect, null nodes have no internal fields. They simply serve as placeholders so that all subtrees that are expected are always present. Null nodes represent null subtrees. Java’s strict type rules make it necessary to create several different classes for null nodes. However, it is easy to reference a null node of the correct type. If you want a null node that can be assigned to a field of class XXX, then XXX.NULL is the null node you want. For example, if you want to assign a null node to a field expecting a StmtNode, then StmtNode.NULL is the value you should use. It is better to reference a
null node than to store a null value. If all object references in AST nodes point to something then we never have to check a reference before we use it.

Some AST nodes are always leaves (e.g., IdentNode); others have one or more subtrees. Thus the AsgNode has two subtrees, one for the name being assigned to (target) and the other for the expression being assigned (source).

The AST nodes IdentNode, IntLitNode, CharLitNode and StrLitNode do not have subtrees, but do contain the string value, integer value, character value, or string value returned by the scanner (in token objects). Leaf nodes like TrueNode and BoolTypeNode have no fields (other than lineNum and colNum inherited from their superclass). For such nodes, we need no information beyond their class.

Besides astNode, we use a number of other abstract superclasses to build our AST. One of these is StmtNode. We never actually create a node of type StmtNode. But then why do we bother to define it?

Sometimes we want to be able to reference one of a number of kinds of AST nodes, but not just any node. Thus in a StmtNode we want to reference any kind of AST node corresponding to a statement, but not AST nodes corresponding to non-statements. We solve this problem by declaring a reference to have type StmtNode. We make all classes corresponding to statements (like AsgNode or ReadNode) subclasses of StmtNode. The rules of Java say that a reference to a class S may be assigned an object of any subclass of S. A subclass of S contains everything S does (and perhaps more). Thus an AsgNode may be assigned to a variable expecting a StmtNode without error. However, an AST node that is not a subclass of StmtNode (e.g., BoolTypeNode) may not be assigned to a variable expecting a StmtNode.

Although the set of suggested class definitions in ast.java looks complex, the main benefit of using them is that it becomes very difficult to insert AST nodes in the wrong place. If you try, you’ll get an error message complaining that the type of node you are trying to assign to an AST node’s field is invalid. In Table 2, below, we list all the AST nodes that might appear in ast.java and their superclass.

Table 1. Suggested classes for AST Nodes in CSX_go

<table>
<thead>
<tr>
<th>Java class</th>
<th>Fields Used</th>
<th>Type of Fields</th>
<th>Null node allowed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProgramNode</td>
<td>packageName, varList, funcList</td>
<td>IdentNode, List&lt;VarDeclNode&gt;, List&lt;FuncDeclNode&gt;</td>
<td>No, No</td>
</tr>
<tr>
<td>VarDeclNode</td>
<td>varName, varType, initValue</td>
<td>IdentNode, TypeNode, ExprNode</td>
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</tr>
<tr>
<td>ConstDeclNode</td>
<td>constName, constValue</td>
<td>IdentNode, ExprNode</td>
<td>No, No</td>
</tr>
<tr>
<td>ArrayDeclNode</td>
<td>arrayName, elementType, arraySize</td>
<td>IdentNode, TypeNode, IntLitNode</td>
<td>No, No, No</td>
</tr>
<tr>
<td>IntTypeNode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BoolTypeNode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CharTypeNode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VoidTypeNode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node Type</td>
<td>Field 1</td>
<td>Field 2</td>
<td>Field 3</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>FuncDeclNode</td>
<td>name</td>
<td>IdentNode</td>
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</tr>
<tr>
<td></td>
<td>args</td>
<td>List&lt;ArgDeclNode&gt;</td>
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</tr>
<tr>
<td></td>
<td>returnType</td>
<td>TypeNode</td>
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</tr>
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<td></td>
<td>body</td>
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<td>ArrayArgDeclNode</td>
<td>argName</td>
<td>IdentNode</td>
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</tr>
<tr>
<td></td>
<td>elementType</td>
<td>TypeNode</td>
<td>No</td>
</tr>
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<td>ValArgDeclNode</td>
<td>argName</td>
<td>IdentNode</td>
<td>No</td>
</tr>
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<td></td>
<td>argType</td>
<td>TypeNode</td>
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<td>AsgNode</td>
<td>target</td>
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</tr>
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<td>source</td>
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<td>thenPart</td>
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</tr>
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<td></td>
<td>elsePart</td>
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<td>ForNode</td>
<td>label</td>
<td>ExprNode</td>
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</tr>
<tr>
<td></td>
<td>condition</td>
<td>ExprNode</td>
<td>No</td>
</tr>
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<td></td>
<td>loopBody</td>
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<td>targetVar</td>
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<td>moreReads</td>
<td>ReadNode</td>
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<td>DisplayNode</td>
<td>outputValue</td>
<td>ExprNode</td>
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<td>moreDisplays</td>
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<td>CallNode</td>
<td>methodName</td>
<td>IdentNode</td>
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</tr>
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<td></td>
<td>args</td>
<td>ArgsNode</td>
<td>Yes</td>
</tr>
<tr>
<td>ReturnNode</td>
<td>returnVal</td>
<td>ExprNode</td>
<td>Yes</td>
</tr>
<tr>
<td>BreakNode</td>
<td>label</td>
<td>IdentNode</td>
<td>No</td>
</tr>
<tr>
<td>ContinueNode</td>
<td>label</td>
<td>IdentNode</td>
<td>No</td>
</tr>
<tr>
<td>BlockNode</td>
<td>decls</td>
<td>List&lt;VarDeclNode&gt;</td>
<td>Yes</td>
</tr>
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<td></td>
<td>stmts</td>
<td>List&lt;StatementNode&gt;</td>
<td>No</td>
</tr>
<tr>
<td>ArgsNode</td>
<td>argVal</td>
<td>ExprNode</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>moreArgs</td>
<td>ArgsNode</td>
<td>Yes</td>
</tr>
<tr>
<td>StrLitNode</td>
<td>strval</td>
<td>String</td>
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</tr>
<tr>
<td>BinaryOpNode</td>
<td>leftOperand</td>
<td>ExprNode</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>rightOperand</td>
<td>ExprNode</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>operatorCode</td>
<td>int</td>
<td>No</td>
</tr>
<tr>
<td>UnaryOpNode</td>
<td>operand</td>
<td>ExprNode</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>operatorCode</td>
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<td>No</td>
</tr>
<tr>
<td>CastNode</td>
<td>resultType</td>
<td>TypeNode</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>operand</td>
<td>ExprNode</td>
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</tr>
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<td>FuncCallNode</td>
<td>funcName</td>
<td>IdentNode</td>
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<tr>
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<td>funcArgs</td>
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<td>Yes</td>
</tr>
<tr>
<td>IdentNode</td>
<td>idname</td>
<td>String</td>
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</table>
Table 2  Classes Used in AST Nodes and Their Superclasses

<table>
<thead>
<tr>
<th>AST Node</th>
<th>Superclass</th>
<th>AST Node</th>
<th>Superclass</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArgDeclNode</td>
<td>ASTNode</td>
<td>VoidTypeNode</td>
<td>TypeNode</td>
</tr>
<tr>
<td>ArgsNode</td>
<td>ASTNode</td>
<td>ArrayArgDeclNode</td>
<td>ArgDeclNode</td>
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<td>ArrayDeclNode</td>
<td>DeclNode</td>
<td>AsgNode</td>
<td>StmtNode</td>
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<td>BinaryOpNode</td>
<td>ExprNode</td>
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<td>StmtNode</td>
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<td>TypeNode</td>
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<td>ExprNode</td>
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<td>ExprNode</td>
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<td>ExprNode</td>
<td>TrueNode</td>
<td>ExprNode</td>
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<tr>
<td>TypeNode</td>
<td>ASTNode</td>
<td>UnaryOpNode</td>
<td>ExprNode</td>
</tr>
</tbody>
</table>

Getting Started

We’ve placed skeleton files for the project in ~raphael/~courses/cs541/public/proj3/startup. Look at file ast.java. This file compiles to a large number of .class files (one for each kind of AST node, as well as others). To keep your project directory manageable, the Makefile places all .class files in a subdirectory, classes/. Be sure your CLASSPATH environment variable includes this directory. The Java code in the skeleton files is not up to standard; you should use a style checker.
to improve the code.

Building ASTs in JavaCUP

We’ll need to build ASTs for CSX_go programs we have parsed. One of the reasons we’re using JavaCUP to build our parser is that it’s easy to build ASTs. JavaCUP allows us to embed actions, in the form of Java code, in the productions JavaCup parses. When parse() matches a production containing an action it automatically executes that action. For example the following rule (drawn from lite.cup)

```java
stmt ::= ident:id ASG exp:e SEMI
{: RESULT =
    new AsgNode(id, e, id.lineNum, id.colNum);
:}
```

specifies the production stmt → ident = expr ;. Whenever parse() matches this production, it calls the constructor AsgNode (since AsgNode corresponds to assignment statements). The constructor for AsgNode takes four parameters: ASTs nodes corresponding to the source and target of the assignment, and a line and column number to associate with the assignment. The special suffixes :id and :e represent references (automatically maintained by the parser) to the ASTs for the ident and expr that it has already parsed. These ASTs have already been built by the time this production is matched. We define the line and column of the assignment to be the line and column of the leftmost symbol in the assignment, which is the ident. Since id references the AST node built for ident, id.lineNum represents the line number already stored for the identifier.

After astNode builds a new AST node for the assignment and links in its subtrees, the parser assigns its result to RESULT, which is a special symbol that represents the left-hand side non-terminal (stmt). As it matches productions, the parser builds and merges AST subtrees into progressively larger trees. Finally, when it matches the first production (corresponding to an entire program), the parser returns the root of the complete AST. The bookkeeping required to maintain AST pointers as the parser matches productions is automatic.

Information placed in tokens returned by the scanner can also be easily accessed. A suffix placed after a terminal symbol allows the token object corresponding to the terminal symbol to be accessed. Thus the rule

```java
exp ::= exp:l PLUS:op ident:r
{: RESULT = new BinaryOpNode(l, sym.PLUS, r,
    op.lineNum, op.colNum); :}
```

uses the lineNum and colNum values of the PLUS token (extracted as op.lineNum and op.colNum) in constructing a BinaryOpNode that represents the AST for the addition operation.

The objects referenced for each terminal and non-terminal symbol in the grammar are defined by terminal and non terminal directives. The lines

```java
terminal CSXIdentifierToken IDENTIFIER;
terminal CSXToken SEMI, LPAREN, RPAREN, ASG, LBRACE, RBRACE;
```

tell Java CUP that the tokens for ';', '('(', ')', etc. are all instances of class CSXToken, whereas the IDENTIFIER token is an instance of class CSXIdentifierToken. The lines
say that the nonterminal prog references class csxLiteNode, whereas the nonterminal stmts references StmtsNode.

The function parse() returns an object of type Symbol. For successful parses, it is the start symbol (program) of the derivation. The value field of the returned Symbol contains the AST corresponding to program.

Unparsing

For grading, testing and debugging purposes, it is necessary to display the abstract syntax tree your parser creates. A convenient way to do so is to create a member function unparse(int indent) that prints out the node’s structure in conventional (text-oriented) form. (indent is the number of tabs to indent prior to printing the node’s structure.) unparse “pretty prints” the construct, adding new lines and tabs as appropriate to create a pleasing and easily-readable listing. For constructs that are forced to begin on a new line (like statements and declarations) you should print a line number at the beginning of the construct’s unparsing, using the lineNum value stored in the AST node. The line numbers printed might not be consecutive, since they correspond to the original input text. Moreover, some parts of a construct that appear on a new line (like the ‘}’ at the end of the class definition) get a line number that appears “out of order” because the line number stored with an AST node corresponds to where the construct begins.

Each abstract syntax tree node is associated with a production that can be viewed as a pattern that specifies how a node is to be displayed. For example given an AsgNode, which we always print on a new line, we first print out the line number (using the node’s lineNum value) and indent using unparse()’s indent parameter. We then call target.unparse(0) (to print the target variable, without indenting), print ‘=’, call source.unparse(0) (to print the source expression, without indenting), and finally print ‘;’.

For IntLitNodes, we print intval. For StrLitNodes, we print strval (the full string representation, with quotes and escapes). For CharLitNodes, print charval as a quoted character in fully escaped form. For IdentNodes, the unparsers uses idname, which is the text of the identifier.

Abstract syntax trees for expressions contain no parentheses, since the tree structure encodes how operands are grouped. When expressions are unparsed, add explicit parentheses to guarantee that expressions are properly interpreted. Hence A+B*C should be unparsed as (A+(B*C)). (Fancier unparsers that only print necessary parentheses are a bit harder to write. An unparsers that prints parentheses only when really necessary gets extra credit.)

What You Must Do

This project step is not nearly as hard as it looks, because you have JavaCUP to help you build your parser. Still, it helps to see an example of all the pieces you’ll need to complete. We’ve created a small subset of CSX_go, called CSX_lite, that’s defined by the following productions:

```
non terminal csxLiteNode prog;
non terminal StmtsNode stmts;

program → { stmts }
stmts → stmt stmts
  | λ
stmt → id = expr ;
  | if ( expr ) stmt
expr → expr + id
  | expr - id
  | id
```

CSX_lite Grammar
This simple subset contains no declarations, only an assignment and \texttt{if} statement, and expressions involving only $+$, $-$ and identifiers. Complete specifications, parsers, AST builders and unparsers for CSX\_lite may be found in \texttt{~raphael/courses/cs541/public/proj3/startup}. Just type 

\texttt{make test}

to build a complete parser for CSX\_lite and then test it using a simple source program.

You should look at what we’ve provided to make sure you understand how each step of the project works for CSX\_lite. It builds ASTs using calls to constructors as illustrated in \texttt{csx\_lite.cup}. Once the parser matches an individual production, it calls a constructor for the corresponding AST node. You should substitute your scanner from Project 2, by replacing \texttt{csx\_lite.jlex} with your \texttt{csx\_go.jlex} file.

Unparsing functions, one for each type of AST node, are member functions in \texttt{ast.java}. Each such routine is fairly simple — it prints the information in the node in nicely formatted form, with recursive calls to \texttt{unparse()} to unparse subcomponents.

Once you’re clear on what’s going on, add a single simple feature like a variable declaration or a \texttt{for} loop. First, add the appropriate productions to the \texttt{JavaCUP} specification. Build the parser and verify that you get no syntax errors when you parse source files containing the new construct. Next, add constructor actions to your specification to build ASTs for the construct you’ve added. Then define \texttt{unparse()} in the nodes you’ve built to unparse ASTs for this construct. Now verify that the ASTs you build are correct by looking at the unparsing you generate.

After you have added a few constructs, you should have a good understanding of all the steps involved. Then you can incrementally add the complete set of CSX\_go productions to your \texttt{CUP} specification, eventually creating a complete CSX\_go parser and unparsers.

\textbf{Order of declarations}

The syntax of CSX\_go allows function declarations and variable declarations to occur in any order. However, the semantics of CSX\_go allows a program to declare a function or variable later in the program than where it is used. If you wish, you may print all the variable declarations before all the function declarations in the unparsing of a program, ignoring their actual order of declaration. However, you should accurately indicate the line numbers on which the declarations occur.

\textbf{Error Handling}

In the case of syntax errors, \texttt{JavaCUP} calls \texttt{syntax\_error()} to print an error message and then throws a \texttt{SyntaxErrorException}, indicating abnormal termination. The caller of your parser should catch this exception, which indicates that because of errors it cannot build an AST.

\texttt{JavaCUP} does provide a simple error recovery mechanism (using “error” markers). This feature is described in §5 of the \texttt{CUP} manual. If you wish, you may experiment with syntactic error recovery \textit{after} your parser is fully operational. It is not necessary to continue parsing after \texttt{parse()} discovers a syntax error.

\textbf{What to Hand In}

As input, your parser takes a text-file name on the command line, which it passes to the scanner to read and build tokens for the parser. You should test your parser on syntactically valid and invalid programs. For invalid programs, your error messages should be clear and meaningful. For valid programs, you should show a readable, line-numbered, unparsed listing of the resulting abstract syntax tree. Turn in a your parser module, your \texttt{CUP} specification, and a listing of your parser’s execution on a variety of syntactically valid and invalid programs.

If you wish to claim extra credit, \textit{clearly} state (in the \texttt{README} file) what you’ve added, and include examples of its operation. In particular, if you implement labeled \texttt{for} statements, \textbf{break} and \textbf{continue}, mention that fact.