1 Introduction

This is a grammar for the Fall 2020 semester’s C- programming language. This language is very similar to C and has a lot of features in common with a real-world programming language. There are also some real differences between C and C-. For instance the declaration of procedure arguments, the loops that are available, what constitutes the body of a procedure, assignment is not a simple expression, array operators, etc. Also because of time limitations this language unfortunately does not have any heap related structures. It would be great to do a lot more, but we’ll save for a second semester of compilers ©. NOTE: this grammar is not a Bison grammar! You’ll have to fix that as part of your assignment.

For the grammar that follows here are the types of the various elements by type font or symbol:

- **Keywords are in this type font.**
- **TOKEN CLASSES ARE IN THIS TYPE FONT.**
- **Nonterminals are in this type font.**
- The symbol $\epsilon$ means the empty string in a CS grammar sense.
- The token $|$ is denoted ‘|’ to distinguish it from the alternation symbol in the defining grammar.

1.1 Some Token Definitions

- **letter** = a | ... | z | A | ... | Z | _
- **digit** = 0 | ... | 9
- **letdig** = digit | letter
- **ID** = letter letdig*
- **NUMCONST** = digit+
- **CHARCONST** = is a representation for a single character by placing that character in **single quotes**. A backslash is an escape character. Any character preceded by a backslash is interpreted as that character. For example \x is the letter x, \’ is a single quote, \ is a single backslash. There are only two exceptions to this rule: \n is a newline character and \0 is the null character.
- **STRINGCONST** = any series of zero or more characters enclosed by **double quotes**. A backslash is an escape character. Any character preceded by a backslash is interpreted as that
character without meaning to the string syntax. For example \x is the letter x, \" is a double quote, \' is a single quote, \ is a single backslash. There are only two exceptions to this rule: \n is a newline character and \0 is the null character. The string constant can be an empty string: a string of length 0. All string constants are terminated by the first unescaped double quote. String constants must be entirely contained on a single line, that is, they contain no unescaped newlines!

- **White space** (a sequence of blanks and tabs) is ignored. Whitespace may be required to separate some tokens in order to get the scanner not to collapse them into one token. For example: “intx” is a single ID while “int x” is the type int followed by the ID x. The scanner, by its nature, is a greedy matcher.

- **Comments** are ignored by the scanner. Comments begin with // and run to the end of the line.

- All **keywords** are in lowercase. You need not worry about being case independent since not all lex/flex programs make that easy.

## 2 The Grammar

1. \textit{program} → \textit{declarationList}

2. \textit{declarationList} → \textit{declarationList} \textit{declaration} | \textit{declaration}

3. \textit{declaration} → \textit{varDeclaration} | \textit{funDeclaration}

4. \textit{varDeclaration} → \textit{typeSpecifier} \textit{varDeclList} ;

5. \textit{scopedVarDeclaration} → \textit{static} \textit{typeSpecifier} \textit{varDeclList} ; | \textit{typeSpecifier} \textit{varDeclList} ;

6. \textit{varDeclList} → \textit{varDeclList} , \textit{varDeclInitialize} | \textit{varDeclInitialize}

7. \textit{varDeclInitialize} → \textit{varDeclId} | \textit{varDeclId} : \textit{simpleExpression}

8. \textit{varDeclId} → \textit{ID} | \textit{ID} [ \textit{NUMCONST} ]

9. \textit{typeSpecifier} → \textit{int} | \textit{bool} | \textit{char}

10. \textit{funDeclaration} → \textit{typeSpecifier} \textit{ID} ( \textit{params} ) \textit{statement} | \textit{ID} ( \textit{params} ) \textit{statement}

11. \textit{params} → \textit{paramList} | ε

12. \textit{paramList} → \textit{paramList} ; \textit{paramTypeList} | \textit{paramTypeList}

13. \textit{paramTypeList} → \textit{typeSpecifier} \textit{paramIdList}
14. paramIdList → paramIdList , paramId | paramId

15. paramId → ID | ID [ ]

16. statement → expressionStmt | compoundStmt | selectionStmt | iterationStmt | returnStmt | breakStmt

17. expressionStmt → expression ; | ;

18. compoundStmt → { localDeclarations statementList }

19. localDeclarations → localDeclarations scopedVarDeclaration | ε

20. statementList → statementList statement | ε

21. selectionStmt → if ( simpleExpression ) statement | if ( simpleExpression ) statement else statement

22. iterationStmt → while ( simpleExpression ) statement | for ( ID in ID ) statement

23. returnStmt → return ; | return expression ;

24. breakStmt → break ;

25. expression → mutable = expression | mutable += expression | mutable -= expression | mutable *= expression | mutable /= expression | mutable ++ | mutable -- | simpleExpression

26. simpleExpression → simpleExpression '!' andExpression | andExpression

27. andExpression → andExpression & unaryRelExpression | unaryRelExpression

28. unaryRelExpression → ! unaryRelExpression | relExpression

29. relExpression → sumExpression relop sumExpression | sumExpression

30. relop → <= | < | > | >= | == | !=

31. sumExpression → sumExpression sumop mulExpression | mulExpression

32. sumop → + | -

33. mulExpression → mulExpression mulop unaryExpression | unaryExpression

34. mulop → * | / | %

35. unaryExpression → unaryop unaryExpression | factor
36. $\text{unaryop} \rightarrow - \mid \ast \mid ?$

37. $\text{factor} \rightarrow \text{immutable} \mid \text{mutable}$

38. $\text{mutable} \rightarrow \text{ID} \mid \text{mutable} [\text{expression}]$

39. $\text{immutable} \rightarrow (\text{expression}) \mid \text{call} \mid \text{constant}$

40. $\text{call} \rightarrow \text{ID} (\text{args})$

41. $\text{args} \rightarrow \text{argList} \mid \epsilon$

42. $\text{argList} \rightarrow \text{argList},\text{expression} \mid \text{expression}$

43. $\text{constant} \rightarrow \text{NUMCONST} \mid \text{CHARCONST} \mid \text{STRINGCONST} \mid \text{true} \mid \text{false}$

3 Semantic Notes

- The only numbers are ints.

- There is no conversion or coercion between types such as between ints and bools or bools and ints.

- There can only be one function with a given name. There is no function overloading. The function name space is the same as the variable name space so a function and a variable cannot have the same name in the same scope.

- The unary asterisk takes an array as an argument and returns the size of the array.

- The STRINGCONST token translates to a fixed size char array.

- The logical operators & and ‘|’ are NOT short cutting. Although it is easy to do, we have plenty of other stuff to implement.

- In if statements the else is associated with the most recent if. The above grammar allows for ambiguous associations between else and if. In your assignment you will have to fix this.

- Expressions are evaluated in order consistent with operator associativity and precedence found in mathematics. Also, no reordering of operands is allowed.

- A char occupies the same space as an integer or bool. This is an artifact of the virtual machine.

- A string is a constant char array.

- Initialization of variables can only be done with expressions that are constant, that is, they are able to be evaluated to a constant at compile time. For this class, it is not necessary that you actually evaluate the constant expression at compile time. But you will have to keep track of whether the expression is constant. Type of variable and expression must match (see exception for char arrays below).
• Array assignment works. The source array is copied to the target array. If the target array is smaller the source array is trimmed. If the target array is larger all the source elements are copied and the remainder of the target is zero filled (this is false in bool, and end of string in char). There is hardware support for this.

• To be clear, assignment of a string (char array) to a char array works as if it is any other array assignment. It will not overrun the end of the lhs array. If it is too short it will pad the lhs array with null characters which are equivalent to zeroes.

• Passing of arrays is done by reference implemented as pointers. Functions cannot return an array, but they can modify the content of an array passed in.

• Array comparison works. There is hardware support for this.

• Assignments in expressions happen at the time the assignment operator is encountered in the order of evaluation. The value returned is value of the rhs of the assignment. Assignments include the ++ and -- operator. That is, the ++ and -- operator do NOT behave as in C or C++. NOTE: assignment does NOT occur in a simpleExpression without enclosing parens.

• The initializing a char array to a string behaves like an array assignment to the whole array.

• Initializing an array to a scalar constant fills the array with that constant.

• Function return type is specified in the function declaration, however, if no type is given to the function in the declaration then it is assumed the function does not return a value. To aid discussion of this case, the type of the return value is said to be void, even though there is no void keyword for the type specifier.

• Code that exits a procedure without a return returns a 0 for an function returning int and false for a function returning bool and a blank for a function returning char.

• All variables, functions must be declared before use.

• ?n generates a uniform random integer in the range 0 to |n| – 1 with the sign of n attached to the result. ?5 is a random number in the range 0 to 4. ? –5 is a random number in the range 0 to –4. ?0 is undefined.

• The for loop is a simple loop for going through all the elements of an array. It takes two ID’s of the same type, the first of which is a scalar and the second is an array. It successively assigns each element of the array to the scalar. It opens a new scope at the keyword for and the first ID is declared in the new scope to be of the type of the array on the right of the in. Note the array is not an expression it is simply an array.
4 An Example of C- Code

char zev[10]:"corgis";
char yurt[20];
int x:42, y:666;

int ant(int bat, cat[]; bool dog, elk; int fox; char gnu)
{
    int goat, hog[100];

    gnu = 'W';
    goat = hog[2] = 3**cat; // hog is 3 times the size of array passed to cat
    if (dog & elk | bat > cat[3]) dog = ! dog;
    else fox++;
    if (bat <= fox) {
        while (dog) {
            static int hog;  // hog in new scope
            hog = fox;
            dog = fred(fox++, cat)>666;
            if (hog>bat) break;
            else if (fox!=0) fox += 7;
        }
    }

    for (c in zev) outputc(c);
    if (zev > "dog") outputs("bark");
    yurt = zev;
    yurt[3] = zev[?*zev];

    return (fox+bat*cat[bat])/-fox;
}

// note that functions are defined using a statement
int max(int a, b) if (a>b) return a; else return b;
Table 1: A table of all operators in the language to help with type checking and showing what operations are allowed. Note that C- supports = for all types of arrays. Initialization is listed as an operator for type checking purposes and could have been implemented as an operator but I chose not to for no good reason. But the type checking needs to work.

<table>
<thead>
<tr>
<th>Binary Operator</th>
<th>Operands</th>
<th>Return Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>initialization</td>
<td>equal types + arrays</td>
<td>N/A</td>
</tr>
<tr>
<td>&amp;</td>
<td>bool,bool</td>
<td>bool</td>
</tr>
<tr>
<td>‘</td>
<td>’</td>
<td>bool,bool</td>
</tr>
<tr>
<td>==</td>
<td>equal types + arrays</td>
<td>bool</td>
</tr>
<tr>
<td>!=</td>
<td>equal types + arrays</td>
<td>bool</td>
</tr>
<tr>
<td>&lt;=</td>
<td>equal types + arrays</td>
<td>bool</td>
</tr>
<tr>
<td>&lt;</td>
<td>equal types + arrays</td>
<td>bool</td>
</tr>
<tr>
<td>&gt;=</td>
<td>equal types + arrays</td>
<td>bool</td>
</tr>
<tr>
<td>&gt;</td>
<td>equal types + arrays</td>
<td>bool</td>
</tr>
<tr>
<td>=</td>
<td>equal types + arrays</td>
<td>type of lhs</td>
</tr>
<tr>
<td>+=</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>-=</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>*=</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>/=</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>*</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>+</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>-</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>/</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>%</td>
<td>int,int</td>
<td>int</td>
</tr>
<tr>
<td>[]</td>
<td>array,int</td>
<td>type of lhs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unary Operator</th>
<th>Operands</th>
<th>Return Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>--</td>
<td>int</td>
<td>int</td>
</tr>
<tr>
<td>++</td>
<td>int</td>
<td>int</td>
</tr>
<tr>
<td>!</td>
<td>bool</td>
<td>bool</td>
</tr>
<tr>
<td>*</td>
<td>array</td>
<td>int</td>
</tr>
<tr>
<td>-</td>
<td>int</td>
<td>int</td>
</tr>
<tr>
<td>?</td>
<td>int</td>
<td>int</td>
</tr>
</tbody>
</table>
Table 2: A table of just the array operators.

<table>
<thead>
<tr>
<th>Binary Operator</th>
<th>Operands</th>
<th>Return Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>equal types</td>
<td>bool</td>
</tr>
<tr>
<td>! =</td>
<td>equal types</td>
<td>bool</td>
</tr>
<tr>
<td>&lt;=</td>
<td>equal (int/char)</td>
<td>bool</td>
</tr>
<tr>
<td>&lt;</td>
<td>equal (int/char)</td>
<td>bool</td>
</tr>
<tr>
<td>&gt;=</td>
<td>equal (int/char)</td>
<td>bool</td>
</tr>
<tr>
<td>&gt;</td>
<td>equal (int/char)</td>
<td>bool</td>
</tr>
<tr>
<td>=</td>
<td>equal types</td>
<td>type of lhs</td>
</tr>
<tr>
<td>[]</td>
<td>array,int</td>
<td>type of lhs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unary Operator</th>
<th>Operands</th>
<th>Return Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>any</td>
<td>int</td>
</tr>
</tbody>
</table>