# CSCI 468 - COMPILERS

# CAPSTONE PORTFOLIO

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**Section 1:**

A zip file, ‘source.zip’, has been included, containing all source code. It is located within the ‘capstone/uml/’ directory.

**Section 2:**

Team Member 1 contributed to my capstone by providing test cases to run my program against (located within ‘src/test/java/edu.montana.csci.csci468/capstone/CapstoneTests.java’) and developing detailed documentation for me to use in my implementation process; I did the same for him. We spent an equal amount of time on the capstone (~60 hours each, not counting studying) as we were working in parallel to implement our own software.

**Section 3:**

I used the memoization design pattern from line 50 to 59 in my CatscriptType.java file

```
  static HashMap<CatscriptType, ListType> cache = new HashMap<>();
  public static CatscriptType getListType(CatscriptType type) {
      if (cache.containsKey(type)) {
          return cache.get(type);
      } else {
          ListType newListType = new ListType(type);
          cache.put(type, newListType);
          return newListType;
      }
```

```
    }
```

This design pattern has several benefits:

**Performance Optimization:** Storing previous results and reusing them reduces time complexity during repeat inputs.

**Reduction in Computational Overhead:** As this is recursive, memoization cuts down on function calls, saving resources and speeding up execution.

**Simple to Implement:** Memoization keeps core functionality clean and focused despite adding logic, making it easy to handle.

## Section 4:

The following is the generated markdown of my documentation, provided by Team Member 1.

# Catscript

## Introduction

Catscript is a simple scripting langauge. Catscript can be compiled into Java bytecode so that it can be run on a number of machines. Here is an example of some simple catscript code:

```
var x = "foo"
print(x)
```

## Grammar and Features

#### Catscript Program

A program in catscript is written using zero or more program statements (see below). An example of a catscript program can be seen in the introduction.

```
catscript_program = { program_statement };
```

### Statements

#### Program Statement

Program statements form the base of any catscript program. A program statement consists of either a statement or a function declaration statement (see both below).

```
program_statement = statement |
                    function_declaration;
```

Examples of program statements:

```
var x = 1
```

```
function foo(x : bool) { print(x) }
```

#### Statement

A statement consists of the one of the basic functional components of the catscript language. These components include control flow statements such as for loops, if/else statements, and function calls as well as statements for making variables and assigning values to them. Refer to a specific type of statement to see an example of each.

```
statement = for_statement |
            if_statement |
            print_statement |
            variable_statement |
            assignment_statement |
            function_call_statement;
```

#### For Statement

For statements are used to loop over the values of a list and perform the statements in the body of the for statement. A for statement has a local variable that iterates through the values of the given list. This local variable can then be used inside the body of the for statement. Once the for statement reaches the end of the list, the for statement finishes and the rest of the code under the for statement is executed. It should be noted that nested for loops are possible in catscript.

```
for_statement = 'for', '(', IDENTIFIER, 'in', expression ')',
                '{', { statement }, '}';
```

Example:

```
for (x in [1,2,3]) { print(x) }
```

Result: 1 2 3

### If Statement

If statements are a form of control flow that allows for conditional code execution. In catscript, an if statement consists of an expression (that reduces down to a boolean value), a body made up of statements executed if the expression is true, and an optional *else* branch to be executed if the expression is false. Additionally, more branches can be created by adding an *else if* condition to the if statement. Due to the nature of the catscript grammar, nesting if statements inside other if statements is possible just like in other similar languages.

```
if_statement = 'if', '(', expression, ')', '{',
                    { statement },
               '}' [ 'else', ( if_statement | '{', { statement }, '}' ) ];
```

Examples (assume `x` is an existing variable of type `int`:

```
if (true) { print("if") }

if (x >= 10) { print(x) } else { print(-1) }

if (x >= 2) {
    print(1)
} else if (x == 1) {
    print(2)
} else {
    print (3)
}
```

### Print Statement

A print statement is used to print out a given value or the result of a given expression. Every data type (except `object`) can be used in a print statement. In addition, as long as an expression results in a single value, that expression can be used inside the parentheses of a print statement to print out the resulting value.

```
print_statement = 'print', '(', expression, ')'
```

Examples:

```
print(1)
print(true)
print("hello world")
print([1, 2, 3])
```

### Variable Statement

Variable statements are used to create variables for data storage in a catscript program. A variable statement consists of a variable name, an optional data type for the variable, and an expression that should reduce down to one value. This expression can be a simple data value (string, integer, boolean, etc) or it can be a function call to a function that returns a value to be stored in the variable. If a type is not specified for a variable, then the type will be determined from the expression's type.

```
variable_statement = 'var', IDENTIFIER,
     [':', type_expression, ] '=', expression;
```

Examples:

```
var x = 1
var y : bool = true
var z : list<int> = [1, 2, 3]
```

### Assignment Statement

Similar to the variable statement except the variable must already exist in the given scope to be used in an assignment statement. Once a variable is assigned a value, the variable's type is set and cannot be changed to a different type using an assignment statement. For example, a variable that has been declared with an integer value or of an integer type cannot be assigned a boolean value afterward. However, a variable with a defined type and a null value can be assigned to value of the variable's type. Also, a function call can be assigned to a variable as long as the function being called returns a value.

```
assignment_statement = IDENTIFIER, '=', expression;
```

Examples (assume `x`, `y`, and `z` are existing variables):

```
x = 1
y = false
z = [0, 4, 5]
```

### Return Statement

```
return_statement = 'return' [, expression];
```

Examples (assume `x` and `a` are vars in this context):

```
return
return x
return 12
return a >= 9
return "hello"
```

## Function Statements

### Function Declaration Statement

```
function_declaration = 'function', IDENTIFIER, '(', parameter_list, ')' +
                      [ ':' + type_expression ], '{',  { function_body_statement },  '}';
```

### Function Body Statement

The function body is composed of one or more statements that perform specified tasks within the scope of the function. Additionally, if a function has a specified type then the function body must contain a reachable return statement that returns a value with that same type. If the function has no type, then an empty return statement in the function can be used to interrupt or end the execution of the function.

```
function_body_statement = statement |
                          return_statement;
```

### Function Call Statement

See Documentation for *function call expression*.

```
function_call_statement = function_call;
```

### Function Parameters

A parameter list is just a list of locally-scoped variables that exist inside a given function. Parameters can be of different types or no type at all.

```
parameter_list = [ parameter, {',' parameter } ];
```

```
parameter = IDENTIFIER [ , ':', type_expression ];
```

## Expressions

### Type Expression

A type expression is used to identify data types. This type of expression is used in the following statement types: *parameters*, *function declarations*, and *variable statements*. Not all types are compatible with each other, for instance both `int` 's and `bool` 's are compatible with `string` 's, but `int` 's are not compatible with `bool` 's. This means the code, `print(1+"a")`, will produce the string "1a" however, `print(1+true)` results in a parse error. It is important to keep these type compatibilities in mind when using *type expressions* in catscript.

```
type_expression = 'int' | 'string' | 'bool' | 'object' | 'list' [, '<' , type_expression, '>']
```

### Expression

An expression is the basis for any simple instruction in the catscript language. Expressions include basic tests such as comparison and equality tests as well as

basic operations such as add, subtracting, multiplying, and dividing. Function calls and lists are also expressions in the catascript language. An expression could even be as simple as a basic string, integer, or boolean value.

```
expression = equality_expression;
```

### Equality Expression

Equality expressions are used to compare two expressions to each other. Equality expressions always result in a boolean value (true or false) based on the input expressions. There are two ways to compare expressions, *equals* ( `==` ) and *not equals* ( `!=` ). The *equals* comparison results in a true value if the two expressions on either side are the same but will result in a false value if the two expressions are not the same. The *not equals* comparison does the inverse of the *equals* comparison. In addition to basic values, lists and variables can be compared to other lists or basic values.

```
equality_expression = comparison_expression { ("!=" | "==") comparison_expression };
```

Examples:

```
1 != 0
1 == 2
"hello" == "hello"

x == y
```

Results: true, false, true, depends on the values of x and y

### Comparison Expression

The comparison expression is similar to the equality expression in that the comparison expression results in a boolean value depending on the input expressions and the specified comparison. There are four comparison that can be performed: *greater than* `>` , *greater than or equal* `>=` , *less than* `<` , and *less than or equal* `<=` . These comparisons can only be made between two `int` 's or variables of `int` type.

```
comparison_expression = additive_expression { (">" | ">=" | "<" | "<=" ) additive_expression };
```

### Additive Expression

An additive expression is used to add or subtract two or more integers together as well as concatenating two or more strings. Adding and subtracting integer values is pretty simple, however string concatenating is more complicated. Both boolean values and integer values can be concatenated with string values without any type casting. However, integer values and boolean values cannot be added or concatenated together.

```
additive_expression = factor_expression { ("+" | "-" ) factor_expression };
```

Examples:

```
1 + 2
"asdf" + "ghjk"
```

Results: 3, "asdfghjk"

### Factor Expression

A factor expression is used to multiply or divide two or more integer values together. An error will be thrown if non-integer values are used.

```
factor_expression = unary_expression { ("/" | "*" ) unary_expression };
```

```
1 * 2
9*6
10 * 15
```

Results: 2, 54, 150

### Unary Expression

Unary expressions are used to negate boolean values/expressions and integer values. The *not* keyword is used for boolean expressions/values and turns a true value to false and vice versa. The minus sign turns a positive integer into negative integer and vice versa. Unary expression can be stacked so `not not true` is a valid unary expression which is the same as `true` . Similarly, `--1` is the same as `1` .

```
unary_expression = ( "not" | "-" ) unary_expression | primary_expression;
```

### Primary Expression

A primary expression is either an identifier (variable name, function name, non-key phrase, etc.), string value, integer value, boolean value, null value, list literal, function call, or parenthesized expression. A parenthesized expression is an expression surrounded by parentheses and is used to establish a hierarchy for evaluating expressions in catscript. An example of a parenthesized expression would be `1 + (1 * 2)` .

```
primary_expression = IDENTIFIER | STRING | INTEGER | "true" | "false" | "null"|
list_literal | function_call | "(", expression, ")"
```

List literals consist of a list of values surrounded by square brackets with each value seperated by a comma. These values can be in the form of an expression as long as it evaluates to a singular value.

```
list_literal = '[', expression,  { ',', expression } ']';
```

### Function Call Expression

Function calls work by referencing the name of a declared function along with any specified parameters. If a function call does not include an argument list despite the function having parameters or the data types in the argument list do not match the data types in the parameter list then catscript will throw an error. If a function does not have any parameters, then the function call should not have any arguments between the braces.

```
function_call = IDENTIFIER, '(', argument_list , ')'
```

Examples:

```
function foo(): { print("foo") }
foo()

function bar(x: int, y: bool) { if(y) { print(x) } }
bar(1, true)
```

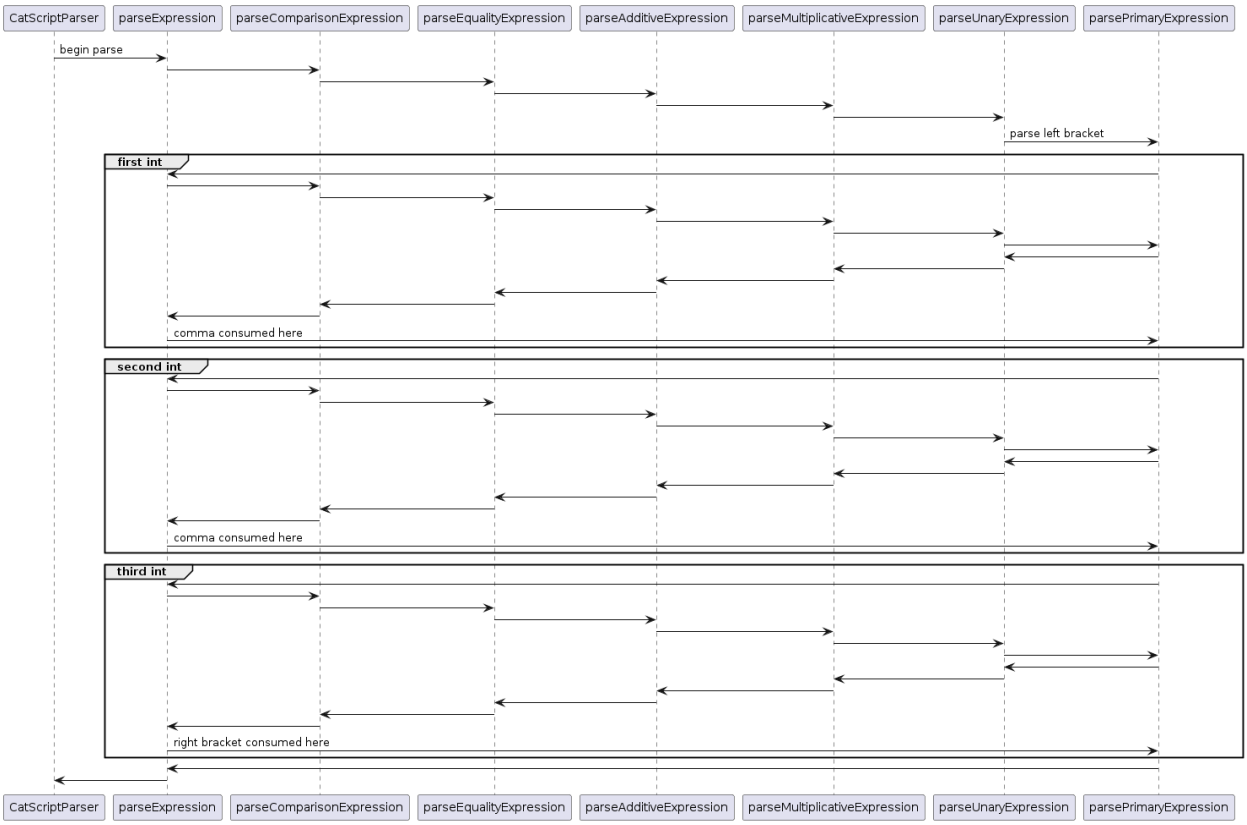
An argument list is basically the same as a list literal except the data is not enclosed in brackets.

```
argument_list = [ expression , { ',' , expression } ]
```

## Types

- **int**: Represents any 32 bit integer
- **string**: Java-style string immutable string
- **bool**: Boolean value (true or false)
- **list<x>**: A list of values of type 'x'
- **null**: Represents the *null* value
- **object**: A base type of any value Catscript.md 13 KB

## Section 5:




The above is a sequence diagram clearly showcasing the recursive nature of the parser as it parses a list literal expression '[1, 2, 3]'.

## Section 6:

Comparing the design of a Recursive Descent Parser to a Parser Generator, the former has several benefits:

**Control and Flexibility:** I have complete control over the parsing process. This allows for detailed error reporting, handling of edge cases, and integration of custom behaviors directly in the parsing logic.

**Ease of Understanding and Implementation:** For the complexity of a parser, this was not any harder to implement than any other program I've written; recursive descent does not require any additional tools or special knowledge.

**No Additional Dependencies:** Since the parser is hand-coded, there are no dependencies on external libraries or tools

There was one main detraction compared to Parser Generators, however:

**Time-consuming:** This was laborious to write, and debugging was an absolute nightmare due to the sheer amount of failure points present. If I may, I feel as if I have lost some years of my life due to this project.

To contrast this with a parser generator, which is a tool that generates a parser from a grammar:

**Efficiency with Complex Grammars:** Parser generators are well-suited for handling complex grammars. Catscript is not complex, so this is a moot point.

**Support for Different Types of Parsers:** Parser generators can produce different types of parsers, allowing developers to choose the best type for their specific needs.

**Maintenance and Scalability:** Parser updates with a generator only really involve updating the grammar, simplifying maintenance greatly.

Regarding the downsides:

**Learning Curve:** I would not know where to start using a parser generator; I would need to develop extensive knowledge of one to use it properly.

**Less Control:** There would be a general lack of control regarding the parser, as I would not have direct access to its code or know how to edit any of it if I did.

Overall, for my skill level and the goals of this class, recursive descent was the correct option, especially as a capstone. It acts as a culmination of everything I learned, instead of a class about learning how to use a parser generator or something similar.

**Section 7:**

We used Test Driven Development for this project. I generally think it helped simplify the complex set of use cases that could be a point of failure in a parser into a clearly defined group, but at the same time, not all cases were covered, and this led to some issues for me down the line which were difficult to resolve. It is always difficult working with code you haven't written, and it was sometimes unclear whether I should be editing a piece of code or not. Overall, though, I can't really imagine myself or any student writing a compiler from scratch, so I think Test Driven Development was the best option for this class. It allowed students to clearly define where they were going wrong, even if figuring out why was sometimes more than a little obscure.