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# Nulascript

## Introduction:

The creation of Nulascript stems from a deliberate effort to address the limitations perceived in existing programming languages and to explore the benefits of dynamic typing in the context of scripting languages. This thesis outlines the intentions behind the development of Nulascript, delves into the motivations that led to the choice of dynamic typing and the inclusion of references, and elucidates the significance of understanding parsing mechanisms in the language's design.

**Motivations for Dynamic Typing**

The conventional paradigm of statically typed languages offers advantages in terms of performance and error detection at compile-time. However, the inherent inflexibility of static typing systems can impede the fluidity of the coding process. Nulascript, as a dynamically typed language, prioritizes adaptability and ease of expression by allowing variables to assume types dynamically during runtime. This design choice aims to facilitate a more intuitive and flexible development experience, where the coder can respond dynamically to evolving requirements.

**References in Nulascript: Enhancing Connectivity**

One distinctive feature of Nulascript is the explicit integration of references into its syntax. References serve as pointers to memory locations, allowing for efficient manipulation and sharing of data. In Nulascript, references play a pivotal role in enhancing code connectivity, enabling seamless communication between different components of the program. Whether passing complex data structures between functions or establishing connections across modules, the use of references in Nulascript contributes to both efficiency and code cohesion.

**Parsing Mechanisms: Unveiling the Language Structure**

Understanding parsing mechanisms is fundamental to comprehending the inner workings of Nulascript. A parser in Nulascript is the component responsible for interpreting and structuring raw code into a format conducive to execution. The parsing process not only facilitates error detection but also lays the foundation for a systematic representation of the code's semantics. By exploring parsing intricacies, Nulascript aims to achieve a balance between the dynamism of scripting languages and the structured representation necessary for efficient execution.

### History of dynamically typed languages:

The evolution of dynamically typed languages and their interpreters has been driven by a variety of factors, including the need for increased developer productivity, adaptability to changing requirements, and a focus on creating more expressive and flexible programming models. Here are key aspects of this evolution:

1. Early Focus on Symbolic Computation (Lisp):

Dynamically typed languages emerged in the context of symbolic computation and artificial intelligence. Lisp, one of the earliest dynamically typed languages, prioritized symbolic expression manipulation, making it well-suited for AI research.

2. Object-Oriented Paradigm (Smalltalk):

The Smalltalk language, developed at Xerox PARC, introduced not only dynamic typing but also the concept of objects. This laid the foundation for the widespread adoption of object-oriented programming (OOP) and influenced subsequent dynamically typed languages.

3. Scripting Languages and Rapid Development (Perl, Python):

The advent of scripting languages like Perl and Python in the 1980s and 1990s emphasized rapid development and ease of use. Dynamic typing played a crucial role in simplifying the development process, allowing developers to focus on solving problems rather than dealing with complex type systems.

4. Web Development and JavaScript:

JavaScript, introduced by Netscape in 1995, was initially designed for client-side scripting in web browsers. Its dynamic typing and event-driven nature made it suitable for creating dynamic and interactive web pages. The rise of the web further popularized dynamically typed languages.

5. Dynamic Language Renaissance (Ruby, Groovy):

The popularity of dynamically typed languages experienced a resurgence with languages like Ruby and Groovy. Ruby, with its emphasis on developer happiness, and Groovy, a dynamic language on the Java Virtual Machine (JVM), demonstrated the appeal of dynamic features in modern development.

6. Dynamism in Functional Programming (Erlang, Lisp, Python):

Dynamically typed languages found a natural fit in the functional programming paradigm. Languages like Erlang and Lisp embraced dynamic typing, facilitating the development of scalable and concurrent systems. Python, with its support for functional programming constructs, further contributed to the adoption of dynamic languages in diverse domains.

7. Dynamically Typed Languages on the JVM (Groovy, JRuby):

The Java Virtual Machine (JVM) became a platform for dynamically typed languages, extending the benefits of dynamic typing to Java-based ecosystems. Groovy and JRuby leveraged the JVM's performance while introducing dynamic language features.

8. Web Development with PHP:

PHP, designed specifically for web development, employed dynamic typing to simplify server-side scripting. Its seamless integration with HTML and focus on web applications contributed to the popularity of dynamic languages in web development.

9. Data Science and Dynamic Typing (Python, R):

In the field of data science, dynamically typed languages, particularly Python and R, gained prominence. The flexibility of dynamic typing allowed for easier manipulation and analysis of data, contributing to the growth of data science and machine learning applications.

10. Balancing Safety and Expressiveness (Swift):

The introduction of Swift by Apple in 2014 marked an interesting blend of static and dynamic typing. While Swift is statically typed, it incorporates type inference and dynamic features, providing a balance between safety and expressiveness.

11. Innovations in Modern Languages (Julia):

Modern dynamically typed languages like Julia for scientific computing. These languages prioritize performance, safety, and expressiveness, demonstrating the continued evolution of dynamically typed paradigms.

12. Emphasis on Developer Experience (TypeScript, Flow):

Optional static typing in languages like TypeScript and Flow addresses the challenges of large-scale JavaScript development. While not strictly dynamically typed, these languages offer a middle ground, allowing developers to choose between dynamic and static typing based on their needs.

In summary, the evolution of dynamically typed languages and their interpreters has been driven by a desire for improved developer productivity, adaptability to different domains, and a focus on creating expressive and flexible programming models. From the early days of Lisp and Smalltalk to the modern innovations in languages like Julia, the trajectory of dynamically typed languages reflects a continuous quest for more effective and enjoyable programming experiences.

### What is Nulascript:

Similarly, **Nulascript** is a dynamically typed programming language and akin to C-level languages, it employs references. References are a fundamental concept in computer programming, especially in low-level languages like C. Unlike pointers, which store memory addresses, references enable direct access to memory locations without duplicating actual values. This distinction is significant for efficiency, allowing manipulation of data in memory without unnecessary copying. In contexts such as high-level scripting languages operating on virtual machines and in deployment pipelines, the avoidance of data duplication and the ability to directly access memory locations can result in expedited execution and more cost-effective infrastructure management.

The process of running **Nulascript** code involves several stages. At a high level, it starts with the user writing code in a text file. This code is then passed to a lexer, which breaks it down into tokens. These tokens are then used as input for a parser to construct an abstract syntax tree. Finally, the AST is interpreted to execute the code.

The lexer, also known as a lexical analyzer, is a core component of a compiler or interpreter. Its primary role is to examine the source code of a programming language and divide it into individual tokens. These tokens are the smallest meaningful units of code, like keywords, identifiers, operators, and literals. The lexer categorizes these tokens and sends them to subsequent stages in the compilation or interpretation process for further analysis, where the code's structure and meaning are further understood and processed. Essentially, a lexer serves as the initial step in the process of translating human-readable source code into a format that a computer can comprehend and work with.

The parser, also known as a syntactic analyzer, is another core component which primary task is to inspect the source code tokens generated by the lexer and arrange them into a hierarchical structure known as the syntax abstract tree. The tree servers as a representation of the source code which clearly defines the relationship between different tokens and their grammatical structure. The parser's role is to verify whether the code complies with the language's syntax rules and to generate a structured representation that can be further processed by the compiler or interpreter. Additionally, there exist various types of parsers. In the context of **Nulascript**, the tokens are processed by a Pratt parser, also referred to as a top-down operator precedence parser. Our parser primarily begins at the top of the parse tree, examining the initial symbol of the grammar, and proceeds linearly by inspecting the subsequent tokens to determine the appropriate path to take. This approach leads to efficient parsing. We'll delve into more detail about the parser's implementation as we continue.

An interpreter is, as the name implies, the underlying software which interprets the meaning of our code by walking the abstract tree we’ve just created. Interpreters provide a direct way to execute commands without building a machine code executable. Rather it executes the code on the fly which enables us to interactively run commands, if needed. At a high level, our **Nulascript** code will run from a C++ binary, which breaks down into machine code and contains instructions on how to execute each step from our tree.

## Lexer:

Lexing, short for lexical analysis, is the process of breaking down a sequence of characters (often part of a program or code) into meaningful tokens. A lexer, also known as a lexical analyzer or tokenizer, is a tool or component in a compiler or interpreter that performs lexical analysis. The primary goal of lexing is to convert the raw source code into a stream of tokens, which are the smallest units of meaning in a programming language.

**History of Lexing:**

1. **Early Compilers (1950s-1960s):**
   * In the early days of computing, compilers were developed to translate high-level programming languages into machine code. Lexing was a manual process, and early compilers often used simple techniques to recognize keywords, identifiers, and operators.
2. **Lex and Yacc (1970s):**
   * The Lex and Yacc tools, developed by Mike Lesk and Stephen C. Johnson at Bell Labs in the 1970s, revolutionized the field of compiler construction. Lex, the lexical analyzer generator, allowed developers to specify token patterns using regular expressions, making the process of lexing more automated and systematic. Yacc, the parser generator, complemented Lex by handling syntax analysis.
3. **Regular Expressions (1970s-1980s):**
   * The use of regular expressions for describing token patterns became a standard practice in lexing. Regular expressions provided a concise and powerful way to define the lexical structure of programming languages.
4. **Flex and Bison (1980s-Present):**
   * Flex and Bison are modern counterparts to Lex and Yacc. Flex is a fast lexical analyzer generator, and Bison is a parser generator. They continue the tradition of using formal specifications to define the syntax and semantics of programming languages.
5. **Hand-Crafted Lexers (1980s-Present):**
   * While lexer generators are widely used, hand-crafted lexers are also common. Developers sometimes write custom lexers for specific languages or applications, especially when the lexical structure is straightforward or when specific optimizations are required.
6. **Lexer-Parser Generators in Modern Languages (2000s-Present):**
   * Many modern programming languages, like Java, C#, and Python, come with built-in tools or libraries for lexing and parsing. These tools often integrate seamlessly into the language's development environment, making it easier for developers to build compilers or interpreters.

**What is a Lexer:**

A lexer, or lexical analyzer, is a component of a compiler or interpreter that performs lexical analysis. Its primary tasks include:

1. **Tokenization:**
   * Breaking down the source code into tokens, which are the smallest units of meaning in a programming language. Tokens can include keywords, identifiers, literals, operators, and other language constructs.
2. **Pattern Matching:**
   * Recognizing token patterns based on predefined rules, often specified using regular expressions or other formal languages.
3. **Removing Whitespace and Comments:**
   * Stripping away irrelevant characters like whitespace and comments, as these usually do not contribute to the understanding of the program's structure.
4. **Error Handling:**
   * Identifying and reporting lexical errors, such as the use of undefined symbols or invalid characters.
5. **Generating Output for the Parser:**
   * Producing a stream of tokens that the parser can use for further syntax analysis.

In summary, lexing is a crucial step in the compilation or interpretation process, and lexers play a key role in converting raw source code into a form that can be processed by the subsequent stages of a compiler or interpreter.

In the realm of programming languages, Nulascript's Lexer adheres to a well-established convention. Functioning as a fundamental component in the code interpretation process, its primary job is to take a piece of code in the form of a string and break it down into smaller parts, which we call “tokens”. These tokens serve as the atomic units of code, encompassing everything from keywords and identifiers to operators and constants.

The Lexer's tokenization process serves as a crucial initial step in the broader process of Nulascript’s interpretation. It paves the way for subsequent stages in the software development lifecycle, such as parsing and interpretation. Through this systematic dissection, it plays a pivotal role in enabling the computer to comprehend and execute the programmer's instructions with precision and accuracy.

### Now, let’s dive into how Nulascript’s Lexer is implemented:

#### The Lexer class:

**public**:

Lexer(**const** std::string& input);

Token getNextToken();

In the code snippet, we have two public methods. The first is a constructor named **Lexer**, which takes a single argument: a reference to a **std::string** containing **Nulascript** code. The purpose of this constructor is to initialize an instance of the **Lexer** class with the provided input.

The second public method is **getNextToken()**, which is used to retrieve the next token from the **Nulascript** code. This method plays a crucial role in the lexical analysis process, where the code is systematically broken down into individual tokens for further processing.

Before jumping into the explanation what **getNextToken()** does, let’s first check what the Lexer holds as private variables.

**private**:

TokenLookusp tokenLookup;

std::string input;

**int** pos;

**int** readPos;

**char** ch;

At a high level, the TokenLookup class is responsible for handling the lookup of reserved keywords. Here's a brief excerpt from the class's implementation:

TokenLookup::TokenLookup() {

keywords = {

{"fn", FUNC},

{"let", LET},

{"true", TRUE},

TokenType TokenLookup::lookupIdent(**const** std::string& ident) {

**auto** it = keywords.find(ident);

**if** (it != keywords.end()) {

**return** it->second;

}

**return** IDENT;

}

In the code, the default constructor TokenLookup is used to initialize an instance of the TokenLookup class. This constructor initializes an unordered map named keywords, which contains pairs of reserved keywords and their corresponding token types. This map serves as a lookup table for identifying and categorizing keywords in the code.

The lookupIdent() function within the TokenLookup class is responsible for examining a provided string to determine its token type. It does this by searching for the string in the keywords map. If a match is found, the function returns the associated TokenType. If no match is found, it returns IDENT, which represents an identifier - the name of a variable or function. This function is essential for identifying and categorizing tokens within the code based on the reserved keywords provided in the keywords map.

Now, back to this part:  
  
 **int** pos;

**int** readPos;

**char** ch;

Let’s use the following example code let a = 5; and walk through how these variables would be set initially when initializing the Lexer:

**pos will be initialized as 0:** The Lexer begins processing at the first character of the input string, which is 'l' in the keyword 'let'.

**readPos will be initialized as 1:** This indicates that the lexer is ready to read the next character after the current character pointed to by pos, which is 'e' in 'let'.

**ch will be initialized as 'l':** This variable stores the character currently pointed to by pos, which is 'l' in 'let'.

Before we explore the additional features of the Lexer, let's first examine where the tokens are defined. These tokens are encapsulated in a struct called "Token," which is defined as follows:

**struct** Token {

TokenType type;

std::string literal;

};

The "literal" field in the Token struct, as the name suggests, stores the literal value of the token. For instance, if the token is '=' (an assignment operator), the "literal" field would contain the string '='. The "TokenType" of the token is determined by an enum declared in the same file:

**enum** TokenType {

ASSIGN,

// Other token types...

};

Consequently, in the case of a token with the literal value '=', the Token struct will hold the TokenType ASSIGN to represent this specific token.

All the tokens Nulascript’s Lexer supports:

**EOF\_TYPE**: This token represents the end of the file or input stream and is used to indicate the end of parsing.

**ILLEGAL**: This token is used to represent an illegal or unrecognized input.

**IDENT**: Stands for "identifier" and is used to represent variable or function names in the source code.

**INT**: Represents integer values in the source code.

**ASSIGN**: Represents the assignment operator, used to assign or reassign a value to a variable.

**PLUS**: Represents the addition operator.

**MINUS**: Represents the subtraction operator.

**COMMA**: Represents a comma used to separate elements in a list or function arguments.

**SEMICOLON**: Represents a semicolon used to terminate statements.

**LPAR**: Stands for "left parenthesis" and is used to open a grouping, such as for function calls or mathematical expressions.

**RPAR**: Stands for "right parenthesis" and is used to close a grouping opened by LPAR.

**LBRACE**: Represents the left curly brace, used to open a block of code or a dictionary.

**RBRACE**: Represents the right curly brace, used to close a block of code or a dictionary opened by LBRACE.

**ASTERISK**: Represents the multiplication operator or a is used for dereferencing.

**DEREF**: Stands for "dereference" and is used to access the value pointed to by a reference or pointer.

**FUNC**: Indicates a function keyword, often used to define functions in the source code.

**BANG\_OR\_NOT**: Used for logical negation (‘!’ and “not” are interchangeable in Nulascript)

**SLASH**: Represents the division operator.

**LT**: Represents the less-than comparison operator.

**LOE**: Represents "less than or equal to" comparison operator.

**GT**: Represents the greater-than comparison operator.

**GOE**: Represents "greater than or equal to" comparison operator.

**LET**: Represents "let" keyword for defining functions and variables.

**IF**: Represents the if keyword, used to begin conditional statements.

**ELSE**: Represents the else keyword, used in conjunction with IF for conditional branching.

**TRUE**: Represents the boolean true value.

**FALSE**: Represents the boolean false value.

**RETURN**: Represents the return keyword, often used to exit a function and return a value.

**IS**: Is used for identity or equality checks.

Back to the Lexer’s implementation, now we’re going to go over all the function which handle appropriate token type assignment.  
  
**void** Lexer::readChar() {

**if** (readPos >= input.size()) {

ch = 0; // EOF

} **else** {

ch = input[readPos];

}

pos = readPos;

readPos = readPos + 1;

}

This function is responsible for updating both the current position and the reading position, as mentioned earlier. The noteworthy aspect here is how we signify the end of the input for the lexer, which is essentially our source code. We achieve this by assigning the value 0 to the EOF\_TYPE token type. You might wonder where this assignment is made. The truth is, we don't explicitly set a value for the token itself. Instead, in our getNextToken() function, we have a substantial switch-case construct that deals with all the possible characters in the code and assigns their corresponding token types.

Token Lexer::getNextToken() {

Token currentToken;

skipOverWhitespace();

**switch** (ch) {

**case** '=':

currentToken = newToken(TokenType::ASSIGN, ch);

**break**;

**case** '+':

currentToken = newToken(TokenType::PLUS, ch);

**break**;

This is pretty much the heart of the Lexer.

First, it calls skipOverWhitespace() to skip any whitespace characters.

Then, it enters a switch-case statement based on the current character, ch, to identify and assign the appropriate token type.

For example, if ch is '=', it creates a new token with a TokenType of ASSIGN.

If ch is '+', it creates a token with PLUS, and so on for various other characters.

The code handles various punctuation and operator characters commonly found in other programming languages.

If ch is 0, indicating the end of the file, it sets the token type to EOF\_TYPE.

If ch is not one of the recognized characters, it checks if it's a letter (part of an identifier) or a digit (part of an integer literal). If it's a letter, it reads an extended token (possibly a longer identifier) and determines the correct TokenType using a lookup. If it's a digit, it treats it as an integer and reads an extended token accordingly.

If none of the above conditions are met, it marks the token as ILLEGAL.

After determining the token type and possibly the token's literal value, the readChar() function is called to advance to the next character in the input.

Finally, it returns the extracted token.

In this code segment, we encounter a few tokens that require some special handling, particularly the comparison operator tokens.

The Token Lexer::handleComparisonOperators(char opChar, TokenType shortType,

TokenType extendedType) function comes into play here. It serves to differentiate between

two possibilities: whether the character is a simple '<' or '>', indicating less than or greater

than, or whether it's part of an extended equality comparison (e.g., '<=' or '>=').

To optimize the code and minimize branching, it first checks if the next character, obtained

using peekNextChar(), is an '=' sign. If it is, the function treats the current character as part

of an extended comparison. It temporarily stores the current character, advances to the next

character using readChar(), and constructs a token literal that combines the two characters

(e.g., "<=" or ">="). Finally, it creates a new token with the extendedType and this combined

literal.

If the next character is not '=', indicating a simple comparison, the function creates a new

token with the shortType and the current character, which represents 'less than' or

'greater than'.

So, in essence, this function helps distinguish between basic comparison operators and their

extended counterparts whenever '<' or '>' characters are encountered in the input.

In the getNextToken() function, the default case is reached when the current

character ch does not match any of the specific characters (e.g., '=', '+', '-', etc.) that have

been explicitly handled in the preceding switch cases. This code block serves as a catch-all

for characters that are not part of those specific categories.

**default**:

**if** (isLetter(ch)) {

currentToken.literal = readExtendedToken(TokenType::IDENT);

currentToken.type = tokenLookup.lookupIdent(currentToken.literal);

**return** currentToken;

} **else** **if** (isDigit(ch)) {

currentToken.type = TokenType::INT;

currentToken.literal = readExtendedToken(currentToken.type);

**return** currentToken;

} **else** {

currentToken = newToken(TokenType::ILLEGAL, ch);

}

**Identifier Handling**:

First, it checks if the current character is a letter. If it is, this typically indicates the start of an identifier, which could be a variable name or a keyword. If it's a letter, the code reads an extended token using the readExtendedToken(TokenType::IDENT) function. This function reads characters until it encounters a non-letter, effectively extracting the entire identifier.

The extracted literal (the identifier or keyword) is stored in currentToken.literal, and the lexer uses the tokenLookup mechanism to determine the appropriate token type for this identifier. The identified token type is assigned to currentToken.type.

**Integer Literal Handling**:

If the current character is a digit, it's treated as the start of an integer literal. The lexer sets the token type to TokenType::INT to indicate an integer.

It then uses the readExtendedToken() function with currentToken.type as the argument to read and assemble the complete integer literal. This function reads characters until it encounters a non-digit character, effectively forming the full integer literal.

The integer literal is stored in currentToken.literal.

**Illegal Character Handling**:

If the current character does not match either of the above conditions (not a letter or a digit), it's considered an illegal character.

In this case, the code creates a new token with a type of TokenType::ILLEGAL and assigns the current character as the token's literal value.

## Parser:

The history of language parsers is closely tied to the development of programming languages and the evolution of compiler technology. Parsers are essential components of compilers and interpreters, responsible for analyzing the syntactic structure of source code. Here's a brief history of language parsers:

1. **Early Assembly Language Parsers (1940s-1950s):**
   * In the early days of computing, programmers wrote code directly in assembly language, and parsing was often a manual process. Programs were relatively simple, and there wasn't a need for sophisticated parsers.
2. **Fortran (1957):**
   * Fortran, one of the earliest high-level programming languages, introduced a compiler with a parser capable of handling more complex syntax. Fortran's parser marked a significant step forward in automating the translation of higher-level languages into machine code.
3. **Lisp (1958):**
   * Lisp, designed for symbolic processing, had a simple and recursive syntax. Its parsing techniques influenced later languages and parsers, emphasizing the use of recursive descent parsing.
4. **ALGOL (1958):**
   * ALGOL 58, an influential language in the development of modern programming languages, had a more complex syntax compared to earlier languages. Its parsing challenges led to the development of more advanced parsing techniques.
5. **Yacc (Yet Another Compiler Compiler) (1970):**
   * Yacc, developed by Stephen C. Johnson, was a tool that generated parsers based on formal grammar specifications. It popularized the use of parser generators and allowed developers to define the syntax of a language in a more structured way.
6. **Backus-Naur Form (BNF) (1960s):**
   * BNF, introduced by John Backus and Peter Naur, provided a formal notation for expressing the syntax of programming languages. BNF became a standard tool for describing the syntax of languages, and it greatly influenced the design of parsers.
7. **Recursive Descent Parsers (1970s-Present):**
   * Recursive descent parsing became a common parsing technique, especially for languages with relatively simple syntax. It involves writing recursive procedures to match the grammar rules of a language.
8. **LEX and Flex (1970s-Present):**
   * Lex and its modern counterpart Flex are tools for generating lexical analyzers (scanners) that work in conjunction with parsers. They use regular expressions to define token patterns, simplifying the lexing phase of language processing.
9. **Bison and Yacc++ (1980s-Present):**
   * Bison is an updated version of Yacc that continues to be widely used for generating parsers. Yacc++ is another tool that extended the capabilities of Yacc. These tools allow developers to create parsers for various languages by specifying their grammars.
10. **LLVM and Clang (2000s-Present):**
    * LLVM, a compiler infrastructure project, includes tools like Clang that use more modern parsing techniques. Clang, for example, employs a hand-written recursive descent parser for C and C++.
11. **ANTLR (Another Tool for Language Recognition) (1989-Present):**
    * ANTLR is a popular parser generator that supports multiple languages. It generates parsers based on LL(\*) parsing techniques, offering a powerful and flexible approach to language recognition.
12. **Parser Combinators (2000s-Present):**
    * Parser combinators are a more recent trend in parsing. Languages like Haskell and Scala have libraries that allow developers to construct parsers by combining smaller parser functions, making the process more modular and expressive.

In summary, the history of language parsers reflects the evolution of programming languages, formal grammars, and parsing techniques. From manual parsing of assembly language to sophisticated parser generators and modern parsing libraries, the field has seen significant advancements to accommodate the growing complexity of programming languages.

Nulascript employs a recursive descent parser, a type of top-down parser that initiates parsing from the highest-level grammar rules and recursively dissects them into more specific rules. This strategy is particularly effective for simpler or moderately complex programming languages, aligning well with the typical code structure of these languages.

In the context of a recursive descent parser, each non-terminal symbol in the grammar corresponds to a function in the code. These functions are tasked with recognizing and parsing the corresponding grammar rules, with the parser recursively invoking these functions to navigate through the input code.

This top-down parsing technique is specifically geared towards LL(k) grammars, where "LL" signifies "left-to-right, leftmost derivation," and "k" denotes the number of lookahead tokens. Recursive descent parsers are known for their hand-crafted nature, involving the manual creation of parsing functions based on the language's grammar.

In the architecture of a recursive descent parser, parsing functions are crafted for each non-terminal symbol or production rule in the grammar. These functions mirror the hierarchical structure of the language's grammar, reflecting different levels of abstraction or nesting within the code. Consequently, the code of a recursive descent parser closely mirrors the structure of the grammar rules, enhancing readability and comprehension.

Recursion is pivotal to the workings of recursive descent parsing. Parsing functions recursively call each other to handle nested constructs within the language, establishing a seamless alignment with the natural hierarchy of the language's syntax. For instance, a parsing function for expressions might invoke another for sub-expressions, maintaining the hierarchical order.

The distinction in parser types arises from the methodology of associating parsing functions with specific tokens. The core concept involves assigning two distinct sets of parsing functions to each token, depending on whether the token functions as a prefix or an infix.

Despite their strengths, recursive descent parsers have limitations. They are most effective for languages with simple to moderately complex grammars that adhere to LL(k) specifications. In cases of ambiguity or left-recursive grammars, alternative parsing techniques such as LR parsing may be more suitable. Error handling in recursive descent parsers is often straightforward, generating error messages when unexpected input occurs. While backtracking is a common strategy for resolving prediction errors, it's noteworthy that Nulascript, in this case, does not implement backtracking.

Nulascript utilizes a parsing technique known as the Pratt parser. Also referred to as a top-down operator precedence parser, the Pratt parser is employed in computer science for analyzing and processing the syntax of programming languages. Vaughan Pratt introduced this technique in the early 1970s, specifically designed for parsing expressions with varying levels of operator precedence.

The fundamental concept behind Pratt parsing involves associating parsing functions with each operator in the language. These functions are responsible for parsing expressions that involve the respective operator. With each operator having left and right precedence, the Pratt parser seamlessly handles different levels of precedence.

In contrast to traditional recursive descent parsers, Pratt parsers exhibit greater flexibility in handling precedence by dynamically adapting to the current token's precedence. This adaptability makes Pratt parsers particularly effective for languages with intricate operator precedence rules.

Pratt parsing divides the parsing process into two primary functions: nud (null denotation) for parsing standalone tokens or unary operators, and led (left denotation) for parsing binary operators. The nud and led functions are invoked based on the context and the precedence of the current and next tokens.

Pratt parsers are renowned for their simplicity, efficiency, and ease of extensibility. They find common use in implementing expression parsers for programming languages and other systems requiring the parsing of mathematical or logical expressions.

## Abstract Syntax Tree

In the context of programming language development and interpretation, an Abstract Syntax Tree (AST) is a crucial data structure used to represent the hierarchical structure of the source code. When discussing the implementation of an interpreter, particularly one using a recursive descent parser, the AST plays a central role in the overall design.

Here are some aspects to consider when talking about the implementation of the AST in the context of an interpreter:

Representation of Code Structure: The AST serves as an intermediate representation of the source code. It captures the syntactic structure of the code in a hierarchical manner, where nodes in the tree correspond to language constructs such as expressions and statements.

Nodes and Relationships: The AST is composed of nodes, each representing a specific syntactic construct in the language. Nodes are interconnected to reflect the relationships between different parts of the code. For example, a binary expression node might have left and right child nodes representing the operands.

Building the AST during Parsing: As the recursive descent parser processes the input code, it simultaneously constructs the AST. Parsing functions are responsible not only for recognizing the grammar rules but also for creating AST nodes and organizing them into a tree structure.

Traversal and Evaluation: Once the AST is constructed, the interpreter typically traverses the tree to evaluate the code. Different types of nodes may have different evaluation strategies. For example, an expression node might be evaluated by recursively evaluating its subexpressions and applying the corresponding operation.

Abstracting Syntax: The term "Abstract Syntax Tree" emphasizes the abstraction of syntactic details. The AST captures the essential structure and meaning of the code while abstracting away specific lexical details. This abstraction facilitates further processing and analysis.

Support for Control Flow and Declarations: The AST accommodates various language features, including control flow constructs (e.g., if statements, loops) and variable declarations. Each type of statement or expression in the language corresponds to a distinct node in the AST.

Ease of Transformation: The AST serves as a foundation for various transformations and optimizations. If additional language features or modifications are desired, developers can manipulate the AST, add new nodes, or apply transformations before or during the evaluation phase.

Error Reporting: The AST can also be a valuable tool for generating meaningful error messages. If an error is encountered during parsing or evaluation, information from the AST can aid in pinpointing the location and nature of the error in the original source code.

Persistence: In some cases, the AST might be persisted or serialized. This can be useful for scenarios where the interpreted code needs to be stored, transmitted, or analyzed outside the runtime environment.

In summary, the AST is a crucial component in the implementation of an interpreter, providing a structured representation of the code that facilitates parsing, evaluation, and various language-related tasks. Its hierarchical nature aligns well with the recursive descent parsing approach and contributes to the overall flexibility and extensibility of the interpreter.

The history of ASTs is closely tied to the development of programming languages and the need for efficient ways to analyze and process code.

1. **Early Programming Languages:**
   * In the early days of programming, there were simple, low-level languages like Assembly, which were essentially a one-to-one mapping to machine code instructions. These languages did not require sophisticated parsing or abstract syntax trees.
2. **Higher-Level Languages and Parsing:**
   * As higher-level programming languages like Fortran, Lisp, and COBOL emerged, the need for more complex and structured parsing mechanisms became evident. Early parsers often used techniques like ad-hoc parsing or simple recursive descent parsing.
3. **Context-Free Grammars:**
   * The development of formal language theory, especially the concept of context-free grammars (CFG) by Noam Chomsky, influenced the way languages were designed and parsed. This led to the development of more formalized parsing techniques.
4. **Compiler Construction:**
   * With the rise of compiler construction, especially in the 1960s and 1970s, the importance of a structured representation of the program became apparent. Abstract Syntax Trees provided a convenient way to represent the hierarchical structure of a program's syntax.
5. **Lisp and S-Expressions:**
   * In the Lisp programming language, which emerged in the late 1950s, programs were represented as lists of symbolic expressions (S-expressions). The structure of these expressions essentially formed a tree, serving as a precursor to modern abstract syntax trees.
6. **Development of ASTs in Compiler Theory:**
   * In compiler theory, the concept of abstract syntax trees became more formalized and widely adopted. ASTs provide an abstract, hierarchical representation of the syntactic structure of a program, stripping away irrelevant details.
7. **Tooling and Language Processing:**
   * ASTs became integral to the development of programming language tools, including compilers, interpreters, static analyzers, and code formatters. Many programming languages today have well-defined AST representations.
8. **IDEs and Source Code Analysis:**
   * Integrated Development Environments (IDEs) use ASTs to provide features such as syntax highlighting, code navigation, and refactoring tools. ASTs also play a crucial role in static analysis tools for identifying potential issues in code.
9. **Modern Language Design:**
   * As new programming languages are designed, the importance of a clear and easily analyzable syntax has led to the continued use and refinement of ASTs. Some languages are explicitly designed with AST-friendly syntax.

Let’s proceed to Nulascript’s AST implementation:

**class** Node

**class** Statement : **public** Node

**class** Expression : **public** Node

This code defines a basic hierarchy of classes for building an abstract syntax tree (AST) for a programming language. An AST is a hierarchical structure that represents the syntactic structure of code, making it easier to analyze and manipulate. Here's an explanation of each class:

**Node** is an abstract base class that serves as the root of the AST hierarchy. It contains two pure virtual functions, which means any class derived from Node must implement these functions.

**tokenLiteral():** This function is responsible for returning a string representing the token or value associated with a node. In other words, it provides the literal representation of the token that the node corresponds to.

**toString():** This function should return a string representation of the entire node. It is used to generate a string representation of the node and its sub-nodes for debugging and other purposes.

**Statement** is a derived class of Node. It represents statements in the programming language. A statement is a unit of code that performs some action or operation, like variable declarations, loops, or conditional statements.

While Statement inherits the tokenLiteral() and toString() functions from the Node class, it doesn't introduce any additional behavior beyond marking a class as a statement. Actually, the Statement class is always being used as a base class and objects are never initialized directly.

**Expression** is another derived class of Node. It represents expressions within the programming language. Expressions are code constructs that produce values, like arithmetic expressions or function calls.

Like Statement, Expression inherits the tokenLiteral() and toString() functions from the Node class without adding specific behavior. Either the Statement or Expression can be excluded, and we could utilize the Node as the foundational class for all high-level Statements and Expressions. However, the current implementation prevents the need for any unnecessary dynamic casting.

In summary, this code defines a framework for creating an abstract syntax tree. The Node class defines two essential functions for all nodes in the tree, and then two specialized classes, Statement and Expression, derive from it. While these derived classes don't introduce any new functions in this snippet, they are typically used as a foundation for creating more specific node types that correspond to the various constructs of a programming language. These classes allow developers to represent and manipulate the syntactic structure of code during parsing and analysis.

**class** Program : **public** Node

The Program class is designed to represent a program or script in the abstract syntax tree of the programming language. It inherits the basic structure and functionality of the Node class, allowing it to be part of the hierarchical tree structure. It stores a sequence of statements in the statements member and provides functions to retrieve the token literal and generate a string representation of the program, making it a key component for representing the high-level structure of code in the AST.

**class** Identifier : **public** Expression

This code defines a class named Identifier that inherits from the Expression class, which is part of an abstract syntax tree. It represents an expression in the abstract syntax tree corresponding to an identifier or variable name in the source code. It inherits the basic structure and functionality of the Expression class and contains the token and value members to store information about the identifier. The class provides functions to retrieve the token literal (typically the identifier's name) and generate a string representation of the identifier, making it a key component for representing variables and identifiers in the AST.

**class** LetStatement : **public** Statement

The LetStatement class represents a 'let' statement in the abstract syntax tree. It inherits the basic structure and functionality of the Statement class and contains data members to store information about the 'let' statement, including the associated Token, the variable name, and the assignment expression. The class provides functions to retrieve the token literal and generate a string representation of the 'let' statement.

**class** ReturnStatement : **public** Statement

The ReturnStatement class represents a 'return' statement in the abstract syntax tree. It inherits the basic structure and functionality of the Statement class and contains data members to store information about the 'return' statement, including the associated Token and the return value expression. The class provides constructors for both 'return' statements with and without return values and functions to retrieve the token literal and generate a string representation of the 'return' statement.

**class** ExpressionStatement : **public** Statement

The ExpressionStatement class represents a statement. It inherits the basic structure and functionality of the Statement class and contains data members to store information about the statement, including the associated Token and the expression it contains. The class provides a constructor for initializing the statement, and functions to retrieve the token literal and generate a string representation of the statement.

An expression statement refers to an expression employed in a context that anticipates a statement. In this scenario, the expression is assessed, and its outcome is disregarded. Consequently, it is meaningful exclusively for expressions that produce side effects, like performing a function or modifying a variable. For example, function calls, such as console.log("Hello"); and [1, 2, 3].forEach((i) => console.log(i));, are suitable instances of expression statements, as they trigger actions like printing to the console or iterating through an array with side effects.

**class** Conditional : **public** Expression

The Conditional class serves as the embodiment of conditional expressions or logic within the abstract syntax tree (AST) of the programming language. By encapsulating conditions, block statements for both true and false outcomes, and associated tokens, it plays a vital role in facilitating a structured representation of conditional logic in the AST. As of now, its current implementation support only else blocks, but potentially the class can be extended to store vector storing “else if” nodes.

To avoid repeating the same code all over again, I'll highlight some of the implemented expression classes.

**Function Class:**

Stores function arguments and the code block parsed during function invocation.

**Invocation Class:**

Records function invocations, parsing and storing argument values. This enables the use of actual values when invoking the function's body, replacing variables with their values.

**String Class:**

Simple storage for string values.

**Integer Class:**

Similar to the String class, but stores integer values instead of string values.

**Assignment Class:**

Manages the identifier and the right-hand side expression, assigning the expression's value to the identifier during parsing.

**Reference Class:**

Stores the identifier pointing to the referenced value.

**Pointer Class:**

Similar to the Reference class, storing identifiers that need to be dereferenced.

**Comment Class:**

Stores only the token, aiding the parser in determining when to skip a line.

**BlockStatement Class:**Stores all the statements within a code block so that they can be later parsed. Imagine an else block of a for loop. The content of the else block is stored as a pointer to an object of class BlockStatement.

Before stepping into explaining how a ForLoop is defined within the syntax tree, there are two important classes we haven’t mentioned yet.

**class** Infix : **public** Expression

**class** Prefix : **public** Expression

These two classes delineate nodes within the code corresponding to prefix and infix operators. In the context of expressions, infix operators are positioned between their operands, while prefix operators precede their operands.

For instance, consider the following example of a prefix operator:

\*foobar; # Here, we dereference the reference foobar.

And an example of an infix operator:

10 + 10; # Adding two numbers.

In the prefix node class, a single pointer is employed to store the expression, positioned on its right side. An illustration of this is found in expressions like **-5**, where the '-' is the prefix operator and **5** is the integer expression. Conversely, the infix class employs two pointers, one for the right expression and another for the left expression. An example of this is seen in the expression **20 / 20**, where **20** on the left is the left integer expression, '/' is the operator, and the other **20** on the right is the right integer expression.

The last one class, but the least interesting is the **ForLoop** expression class.

The interesting thing for this particular class is the way we actually store the for-loop’s initialization header. In Nulascript you define a loop the following way:

**for** (**def** a = 5; a < 10; a + 2)

While in other languages this might be written as follows:

**for** (**let** a = 5; a < 10; a = a + 2)

In Nulascript, there's no requirement for us to explicitly specify adding a number to a defined variable through reassignment, as the entire expression is stored as an infix expression rather than an assignment expression. The conditional expression, much like comparing two values in other programming languages, is also treated as an infix operation and expression. A distinctive feature in Nulascript is that for loops always necessitate the initialization of a new variable, exclusively used within the loop and subsequently discarded. Therefore, a for loop in Nulascript always expects a LetStatement in its header.

## Parser Class

**private**:

Lexer\* l;

Token currentToken;

Token peekToken;

std::vector<std::string> errors;

**Lexer\* l - t**his is a pointer to our Lexer object. The Parser needs access to the Lexer to request tokens from the source code during parsing. The Lexer is typically used to provide the parser with the current token and the next token (peeked token) from the source code.

**Token currentToken** - this member is of type Token and is used to store the currently processed token during parsing. The Parser will analyze this token to determine the structure and semantics of the source code. The currentToken is typically updated when the parser advances to the next token in the source code using the getNextToken() function.

**Token peekToken** - this member, also of type Token, is used to store the next token that will be processed by the parser. It is called the "peek token" because the parser can look ahead to the next token without consuming it. The peekToken is useful for making decisions about the parsing process based on upcoming tokens. It is typically updated in the getNextToken() function as well.

**std::vector<std::string> errors** - this is a vector used to store error messages encountered during the parsing process. If the parser encounters a syntax error or any other issue in the source code, it appends an error message to this vector. Later, the user or developer can retrieve these error messages for debugging or reporting issues in the source code.

In summary, these private data members are essential for the operation of the Parser class. The Lexer provides a stream of tokens for the parser to process, while currentToken and peekToken hold the currently analyzed tokens and the next token to be processed. The errors vector serves as a container for storing error messages, making it possible to report and handle issues in the source code.

**bool** isEqualToCurrentTokenType(TokenType tokenType);

**bool** isEqualToPeekedTokenType(TokenType tokenType);

**bool** peekAndLoadExpectedToken(TokenType tokenType);

Before exploring how statements are being parsed, we need to make sure we understand how the parser loads the tokens:

**bool Parser::isEqualToCurrentTokenType(TokenType tokenType):** This function compares the type of the current token (stored in the currentToken member) to the specified tokenType. It returns true if the current token's type matches the specified type and false otherwise. This function is useful for making decisions based on the current token's type during parsing.

**bool Parser::isEqualToPeekedTokenType(TokenType tokenType):** This function compares the type of the peeked token (stored in the peekToken member) to the specified tokenType. It returns true if the peeked token's type matches the specified type and false otherwise. Like the previous function, this one is used to make decisions based on the type of the upcoming token.

**bool Parser::peekAndLoadExpectedToken(TokenType tokenType**): This function serves a more specific purpose. It compares the type of the peeked token to a specified tokenType. If they match, the function updates the currentToken to be the peeked token by calling getNextToken() and returns true. However, if the peeked token does not match the specified tokenType, the function appends an error message using the appendPeekError() function and returns false.

The logic of these functions is used to ensure that the parser is processing the correct tokens and is in sync with the expected structure of the source code. They are particularly useful for enforcing syntax rules and generating appropriate error messages when the source code does not conform to expected patterns.

Here's a brief explanation of how they might be used:

isEqualToCurrentTokenType() and isEqualToPeekedTokenType() are used to check if the current or peeked token has a specific type, respectively.

peekAndLoadExpectedToken() is used to check if the peeked token has a specific type, and if it does, it updates the currentToken to the peeked token, effectively advancing the parser to the next token. If the types don't match, an error message is appended, indicating an expected token type that was not found.

We have now reached the part where we begin exploring how statements are parsed in the Parser class. The parseStatement() function is a crucial component of this process. Let's explain the code:

Statement\* Parser::parseStatement() {

**switch** (currentToken.type) {

**case** TokenType::LET:

**return** parseLetStatement();

**case** TokenType::RETURN:

**return** parseReturnStatement();

**…**

This function is responsible for parsing statements in the source code. It determines the type of statement based on the current token (the token being processed) and then delegates the parsing of that specific type of statement to dedicated functions, such as parseLetStatement() and parseReturnStatement(). Here's the breakdown:

switch (currentToken.type): The function starts by examining the type of the currentToken. The type of the token is one of the possible values defined in the TokenType enumeration. The switch statement is used to evaluate the token's type and select the appropriate parsing procedure.

If the currentToken is of type LET, it indicates the beginning of a 'let' statement. In this case, the parseLetStatement() function is called to parse and construct the AST node representing the 'let' statement.

If the currentToken is of type RETURN, it signifies the start of a 'return' statement. The parseReturnStatement() function is invoked to parse and generate the AST node for the 'return' statement.

In summary, the parseStatement() function is a central part of the parser that identifies the type of statement based on the current token and delegates the actual parsing of the statement to dedicated functions. This approach helps organize the parsing process and ensures that the appropriate syntax rules and structure for each type of statement are followed.

There's one more crucial scenario we haven't discussed yet—the default case. We skipped it because it utilizes a slightly different model compared to the ReturnStatement and LetStatement.

default:

**return** parseExpressionStatement();

This function performs the magic related to parsing expressions. However, since expressions must be parsed in the context of a statement, we consistently return an object of type ExpressionStatement, encapsulating a node that points to the actual Expression. Before delving into the implementation of one of the parser's most pivotal methods, let's first understand how we initially handle the program's code.

The parseProgram() function is a critical part of the parser, responsible for parsing an entire program, which is essentially the top-level structure of a source code file. Let's explain this code and discuss why it is needed:

Program\* program = **new** Program();

**while** (currentToken.type != TokenType::EOF\_TYPE) {

Statement\* statement = **this**->parseStatement();

**if** (statement) {

program->statements.push\_back(statement);

}

This first line creates a new instance of a Program object. A Program represents the top-level structure of the source code and typically contains a collection of statements.

**while** (currentToken.type != TokenType::EOF\_TYPE)

The parser enters a loop that continues until it encounters the end of the file (EOF), which is signaled by the TokenType::EOF\_TYPE. This loop is responsible for parsing all the statements within the program.

Inside the loop, the parseStatement() function is called to parse the next statement in the source code. The result is stored in the statement variable.

This conditional check ensures that the statement is not null. If the parser successfully parsed a statement (it's not an error or an empty statement), the following code is executed.

The parsed statement is added to the statements vector within the Program object. This vector is used to accumulate all the statements in the program.

After parsing a statement, the parser advances to the next token in the source code using the getNextToken() function.

Once the parser has processed all the statements in the program and reaches the end of the file (EOF), it returns the Program object. This Program object now contains a structured representation of the entire source code.

Why do we need it:

The parseProgram() function is necessary because it orchestrates the parsing of an entire source code file or program. A program can consist of multiple statements, expressions, and declarations, and it's essential to organize these components into a structured format that can be later used.

By parsing the program into a structured representation (in this case, the Program object), the parser allows subsequent stages of the compiler or interpreter to work with the code more easily. For example, it enables semantic analysis, optimization and code generation, as well as providing a basis for executing the program.

This function also ensures that the parser processes statements until the end of the file (EOF\_TYPE) is reached, preventing it from prematurely terminating the parsing process. It handles statements of various types and accumulates them within the Program object for later use or analysis.

### Parsing within the parseStatement method:

Let’s go back to discussing how the parsing within the **parseStatement** method works.

As you recall, there are three cases:

* parseLetStatement
* parseReturnStatement
* parseExpressionStatement

#### Parsing Let Statements

LetStatement\* Parser::parseLetStatement() {

LetStatement\* letStatement = **new** LetStatement(currentToken);

…

letStatement->name = **new** Identifier(currentToken);

**…**

letStatement->value = parseExpression(Precedence::LOWEST);

**…**

**return** letStatement;

The parsing of a **LetStatement** begins by initializing a **LetStatement** object with the current token. The parser then checks if the next token is an identifier, representing the variable name in the "let" statement. If an identifier is not found, the function returns **nullptr** to indicate a parsing error. If the identifier is successfully identified, an **Identifier** object is created and assigned to the **name** attribute of the **LetStatement**. The parser then checks for the presence of an assignment operator ("="). If it is missing, the function returns **nullptr**. Upon confirming the assignment operator, the parser advances to the next token, which in this case is the semicolon. The code proceeds to parse the expression on the right side of the assignment using the **parseExpression** function, and the resulting expression is assigned to the **value** attribute of the **LetStatement**. Finally, the code checks for the presence of a semicolon at the end of the statement, moving to the next token if found. The fully parsed **LetStatement** object is then returned.

#### Parsing Return Statements

ReturnStatement\* Parser::parseReturnStatement() {

ReturnStatement\* returnStatement = **new** ReturnStatement(currentToken);

getNextToken();

returnStatement->returnValue = parseExpression(Precedence::LOWEST);

This code is responsible for handling the parsing of "return" statements in a programming language. The method starts by creating a **ReturnStatement** object and initializing it with the current token. Subsequently, it advances to the next token using the **getNextToken** function. The code then parses the expression following the "return" keyword using the **parseExpression** function, and the resulting expression is assigned to the **returnValue** attribute of the **ReturnStatement**. Following this, it checks if the next token is a semicolon. If a semicolon is present, it moves the cursor to semicolon. Finally, the function returns the fully parsed **ReturnStatement** object, encapsulating the information about the "return" statement and the associated expression.   
  
Important is to not that, we do not return a nullptr if the statements don’t end with a semicolon due to the reason that we allow expressions to be unterminated. One of the few cases where we would explicitly want to have a terminating semicolon is when assigning identifiers as values to other variables on the same line and not separating them with a whitespace.

**def** c = a;**def** b = a; # this works as expected

**def** c = a**def** b = a; # this breaks

* **Parsing Expression Statements**

ExpressionStatement\* Parser::parseExpressionStatement() {

auto statement = new ExpressionStatement(currentToken);

statement->expression = parseExpression(Precedence::LOWEST);

**if** (isEqualToPeekedTokenType(TokenType::SEMICOLON)) {

getNextToken();

}

**return** statement;

}

The **parseExpressionStatement** function begins by creating an **ExpressionStatement** object and initializing it with the current token. The parser then proceeds to parse the expression using the **parseExpression** function, and the resulting expression is assigned to the **expression** attribute of the **ExpressionStatement**. After parsing the expression, it checks if the next token is a semicolon, which typically signifies the end of a statement in many programming languages. If a semicolon is found, the parser advances to the next token. The function then returns the fully parsed **ExpressionStatement** object, encapsulating the information about the expression to be executed as a statement.

The **parseExpression** method serves as a fundamental and shared functionality among the three methods mentioned. It plays a crucial role in recursively evaluating expressions, constituting the core logic for handling the parsing of expressions within the parser.

Top of Form

Expression\* Parser::parseExpression(Precedence p) {

auto it = prefixParsingFunctions.find(currentToken.type);

auto leftExpression = it->second();

getNextToken();

leftExpression = infix\_it->second(leftExpression);

}

**return** leftExpression;

}

Bottom of Form

The function **parseExpression** takes a precedence level (**p**) as an argument and is responsible for parsing expressions in the specified precedence level. We will touch up on why precedence is important a bit later.

It starts by looking up the parsing function for the current token type in the **prefixParsingFunctions** map. If no function is found, it generates an error message, appends it to an error list, and returns **nullptr** (indicating a parsing failure).

If a parsing function is found, it calls it to parse the left expression. The result is stored in the **leftExpression** variable.

The function then enters a loop that continues as long as the current token type is not **SEMICOLON** (end of expression) and the precedence of the current token is greater than the specified precedence level (**p**).

Inside the loop, it looks up the parsing function for the next token's type in the **infixParsingFunctions** map. If no function is found, it returns the **leftExpression**, indicating that the parsing is complete.

If an infix parsing function is found, it advances to the next token (**getNextToken()**) and calls the infix parsing function with the **leftExpression** as an argument. The result is assigned back to the **leftExpression** variable.

The loop continues until it either reaches the end of the expression or the precedence of the current token is lower than the specified precedence level.

Finally, the function returns the parsed expression.

In summary, this code implements a recursive descent parser for expressions, handling both prefix and infix operators based on their precedence levels. The parsing process is driven by the precedence of operators and involves calling the appropriate parsing functions for prefix and infix operators. The result is a parsed expression tree.

Let’s debug an infix expression (5 + 10) step by step:

auto it = prefixParsingFunctions.find(currentToken.type);

The current token is of type Integer. We find the following parsing function: Parser::parseInteger()

This is the function which gets invoked to parse our current token to an expression.

Now, after we’ve parsed our integer expression and assigned it to a variable, we have to check if the next token defines an infix operation. This happens in this code block:

Within it’s execution, the method attempts to locate infix parsing functions for the upcoming token. Should it successfully find such a function, it invokes it, supplying the expression yielded by a preceding parsed prefix expression as an input. This iterative process repeats until the parser encounters a token with a greater precedence, signaling the conclusion of the infix expression parsing.

In this case, we call the found **parseInfix** function which is registered for the ‘+’ token and provide the parsed Integer(5) expression to the function as an argument.

Then the result is reassigned to the initially created variable and returned. The returned value is an instance of the Infix class which holds to pointers to its left and right expression.

We can visualize it as follows:

**class** Infix : **public** Expression {

Token token = Token('+');

Expression\* left = Integer(5);

Expression\* right = Integer(10);

std::string op = '+';

### Registering parsing functions:

To give the parser access to the parsing functions for tokens **Nulascript** supports, we have to register them upon initialization. We do this by invoking the **registerPrefixFunction** and **registerInfixFunction**:

registerPrefixFunction(TokenType::IDENT,

[&]() -> Expression\* { **return** parseIdentifier(); });

registerInfixFunction(

TokenType::PLUS,

[&](Expression\* left) -> Expression\* { **return** parseInfix(left); });

Here, we register the parseIdentifier function for the IDENT token and the parseReference for the token identifying a reference.

The register function methods are really simple In what they do:

They receive as arguments the type of the token and the parsing function and append them to the respective map holding the token type as key and function as the value.

### Parsing functions:

#### parseInfix:

The **Parser::parseInfix** function constructs and returns an **Infix** expression, which represents an infix operation in the programming language. It takes a pointer to the left operand (**Expression\* left**) and uses the current token (**currentToken**) as well.

It initializes an **Infix** object with the current token and the left operand. The **checkCurrentPrecedence** function determines the precedence level of the current token, and this information is used to parse the right operand with the **parseExpression** function.

The function advances to the next token using **getNextToken**. The resulting **Infix** expression has its **right** field set to the parsed right operand. The constructed **Infix** expression is then returned.

In summary, the function encapsulates the logic for parsing infix expressions by handling the left and right operands and operator precedence.

#### parsePrefix:

The **Parser::parsePrefix** function is responsible for parsing expressions with prefix operators.

The function begins by creating a new **Prefix** expression object, initializing it with the current token (**currentToken**). This **Prefix** object will represent the structure of a prefix expression.

It then advances to the next token using **getNextToken()**, assuming the current token has been successfully processed as part of the prefix operation.

The function proceeds to parse the right operand of the prefix expression by calling **parseExpression** with the specified precedence level (**Precedence::PREFIX**). The result is assigned to the **right** field of the **expression** object.

Finally, the function returns a pointer to the constructed **Prefix** expression, encapsulating the operator and its right operand.

In summary, the **parsePrefix** function handles the parsing of prefix expressions, ensuring that the structure is appropriately represented by creating a **Prefix** object and setting its right operand based on the next token.

#### parseBlock:

The **Parser::parseBlock** function is responsible for parsing a block statement.

It starts by creating a new **BlockStatement** object named **currentBlock**, initialized with the current token. The **statements** field of the **currentBlock** object is initialized as an empty vector of **Statement** pointers. This vector will store the statements within the block. The parser then advances to the next token using **getNextToken()**. The function enters a loop that continues until it encounters the end of the file (**EOF\_TYPE**) or the closing brace (**RBRACE**). This loop is designed to parse and collect statements within the block.

Within the loop, it calls the **parseStatement** function to parse the next statement within the block. The parsed statement is then checked for validity (non-null).

If a valid statement is parsed, it is added to the **statements** vector of the **currentBlock** object.

The parser then advances to the next token using **getNextToken()** to prepare for the next iteration of the loop.

Once the loop completes, the function returns a pointer to the fully parsed **BlockStatement** object, including its list of statements.

In summary, the **parseBlock** function iteratively parses statements within a block, populating a vector with the parsed statements, and returning a pointer to the resulting **BlockStatement** object.

#### parseConditional:

The **Parser::parseConditional** is designed for parsing conditional statements, representing an "if-else” construct.

It starts by creating a new **Conditional** object named **conditional**, initialized with the current token. The function checks if the next expected token is a left parenthesis (**LPAR**) by using the **peekAndLoadExpectedToken** function. If not, it returns **nullptr**, indicating a parsing error. It advances to the next token using **getNextToken()** and proceeds to parse the condition expression using the **parseExpression** function with the lowest precedence.

After parsing the condition, it checks if the next expected token is a right parenthesis (**RPAR**). If not, it returns **nullptr**. It then checks if the next expected token is a left brace (**LBRACE**). If not, it returns **nullptr**. The function proceeds to parse the block of statements associated with the "if" condition using the **parseBlock** function and assigns the resulting block to the **currentBlock** field of the **conditional** object. It checks if there is an "else" clause by looking at the next token. If the next token is of type **ELSE**, it enters a conditional block to parse the "else" part. It advances to the next token using **getNextToken()** and checks if the next expected token is a left brace (**LBRACE**). If not, it returns **nullptr**. Inside the "else" block, it parses the statements within the "else" block using the **parseBlock** function and assigns the resulting block to the **elseBlock** field of the **conditional** object. Finally, the function returns a pointer to the fully parsed **Conditional** object, capturing the condition, the "if" block, and optionally the "else" block.

In summary, the **parseConditional** function handles the parsing of conditional statements, including the condition expression, the "if" block, and an optional "else" block.

#### parseFunction:

The **Parser::parseFunction** method is responsible for parsing function declarations.

It starts by creating a new **Function** object named **func**, initialized with the current token.

The function checks if the next expected token is a left parenthesis (**LPAR**) using the **peekAndLoadExpectedToken** function. If the check fails, indicating a parsing error, the function returns **nullptr**. It proceeds to parse the function arguments by calling the **parseFunctionArguments** function. The result is assigned to the **arguments** field of the **func** object. It then checks if the next expected token is a left brace (**LBRACE**). If not, it returns **nullptr**. The function proceeds to parse the block of statements constituting the function's code using the **parseBlock** function. The resulting block is assigned to the **code** field of the **func** object. Finally, the function returns a pointer to the fully parsed **Function** object, encapsulating information about the function declaration, its arguments, and the code block.

In summary, the **parseFunction** function handles the parsing of function declarations, including the function name (captured in the **currentToken**), the list of arguments, and the body of the function as a block of statements. It returns a pointer to the parsed **Function** object.

#### parseInvocation:

The Parser::parseInvocation method is focused on parsing function invocations in Nulascript.

It creates a new Invocation object named invocation and initializes it with the current token. The Invocation class appears to represent a function invocation, and the current token is expected to be the name of the function being invoked.

The function parameter is assumed to be a pointer to an **Expression** representing the function being invoked. It is cast to a **Function\*** since the **Invocation** constructor expects a pointer to a **Function**.

The function proceeds to parse the arguments of the function invocation by calling the **parseInvocationArguments** function. The resulting arguments are assigned to the arguments field of the invocation object.

Finally, the function returns a pointer to the fully parsed **Invocation** object, encapsulating information about the function invocation, including the function being called and its arguments.

In summary, the parseInvocation function handles the parsing of function invocations, creating an Invocation object and populating it with the necessary information such as the invoked function and its arguments. It returns a pointer to the parsed Invocation object.

#### parseString:

In summary, the parseString function handles the parsing of string literals and returns a pointer to a String object encapsulating the information about the parsed string. It creates the String object by providing the current token as an argument since it a new string can be constructed using its literal property.

#### parseReference:

The Parser::parseReference function is responsible for parsing references.

It begins by creating a new Reference object named ref and initializes it with the current token. The Reference class represents references to identifiers in the language.

The function checks if the next expected token is an identifier (IDENT) using the peekAndLoadExpectedToken function. If the check fails, indicating a parsing error, the function returns nullptr.

Assuming the next token is an identifier, the function assigns the value of the literal of the current token (presumably the identifier's name) to the referencedIdentifier field of the ref object.

It then advances to the next token using getNextToken() to prepare for subsequent parsing.

Finally, the function returns a pointer to the fully parsed Reference object, encapsulating information about the parsed identifier reference.

In summary, the parseReference function handles the parsing of identifier references, creating a Reference object and populating it with the referenced identifier's name. It returns a pointer to the parsed Reference object or nullptr if the parsing encounters an error.

#### parseForLoop:

The **Parser::parseForLoop** function is for parsing "for" loop constructs.

It begins by creating a new **ForLoop** object named **fl** and initializes it with the current token. The **ForLoop** class likely represents the structure of a "for" loop in the language. The function checks if the next expected token is a left parenthesis (**LPAR**) using the **peekAndLoadExpectedToken** function. If the check fails, indicating a parsing error, the function returns **nullptr**. The function advances to the next token using **getNextToken()**. It then attempts to parse a **LetStatement** representing the loop variable initialization by using **parseStatement** and casting the result to a **LetStatement**. If the parsing of the loop variable is unsuccessful (i.e., if the cast to **LetStatement** fails), the function returns **nullptr**. The function advances to the next token and creates a new **Identifier** object representing the loop condition variable, initialized with the current token. It then parses the loop condition by calling **parseInfix** with the identifier. If the left or right operands of the resulting **Infix** object are not present, the function returns **nullptr**. The function advances through a few more tokens to parse the incremental statement. It creates an **Identifier** for the incremental variable and then parses the increment expression using **parseInfix**. If the left or right operands of the resulting **Infix** object are not present, the function returns **nullptr**. It checks if the next expected tokens are a right parenthesis (**RPAR**) and a left brace (**LBRACE**). If either check fails, the function returns **nullptr**. The function proceeds to parse the block of statements within the "for" loop using the **parseBlock** function. Finally, the function updates the **ForLoop** object (**fl**) with the parsed information, including the block of code and the loop variable initialization, condition, and increment. In summary, the **parseForLoop** function handles the parsing of "for" loop constructs, including the initialization, condition, increment, and the block of statements within the loop. It returns a pointer to the fully parsed **ForLoop** object or **nullptr** if the parsing encounters an error.

The parsing functions are instrumental in constructing instances of classes defined in the **ast.h** and **ast.cc** files, serving as the various nodes within our abstract syntax tree (AST). These functions play a crucial role in transforming the textual representation of code into a hierarchical structure that reflects the syntax and semantics of the programming language. Each parsing function is tailored to handle specific language constructs, such as expressions, statements, and loops, creating corresponding AST nodes. The resulting AST provides a structured and organized representation of the parsed code, facilitating subsequent analysis, interpretation, or compilation processes. Overall, the parsing functions serve as a bridge between the raw source code and a comprehensible, tree-like representation that captures the program's structure and logic.

### Precedence

Precedence is crucial in parsing because it determines the order in which operators are applied in an expression. In a programming language, expressions often involve multiple operators with varying levels of precedence, such as multiplication, addition, and logical comparisons. The precedence rules dictate which operations take precedence over others when evaluating an expression.

For example, in the expression 2 + 3 \* 4, the multiplication has higher precedence than addition. Without considering precedence, the expression would be evaluated left to right, resulting in 14. However, with precedence considered, the multiplication is performed first, yielding the correct result of 14.

In the context of a parser, precedence guides the construction of the abstract syntax tree (AST). The AST represents the hierarchical structure of expressions, ensuring that the nodes in the tree reflect the correct order of operations. Parsing functions use precedence to determine how to group and associate operands and operators within the AST, capturing the intended semantics of the code.

By incorporating precedence rules, parsers can accurately reflect the programmer's intent and enable the subsequent stages of compilation or interpretation to execute the code correctly. Precedence is an essential aspect of parsing that contributes to the accurate representation of the syntactic and semantic structure of programming language constructs.

In the context of Nulascript expressions, the **Precedence** enum defines different levels of precedence for operators. The levels are arranged from lowest to highest weight, indicating the order in which operators are evaluated.

1. **LOWEST**: This is the lowest precedence level, meaning operators at this level are evaluated last. In expressions, operators with this precedence are typically the ones that bind the least tightly.
2. **EQUALS**: The **EQUALS** level is higher than **LOWEST** but lower than subsequent levels. It likely represents equality and inequality operators, such as **==** and **!=**.
3. **LESSGREATER**: This level deals with comparison operators like **<** and **>**. Operators at this level have higher precedence than equality operators but lower than arithmetic operators.
4. **SUM**: This level represents addition and subtraction operators. Operators at this level are evaluated before those at lower precedence levels.
5. **PRODUCT**: This level corresponds to multiplication, division, and other similar arithmetic operations. Operators at this level have higher precedence than addition and subtraction.
6. **PREFIX**: Prefix operators, such as unary negation or logical negation, fall into this category. They have a higher precedence than arithmetic operators.
7. **CALL**: The highest precedence level in this enum likely represents function calls or method invocations. Operators at this level are evaluated first, binding most tightly.

## Evaluation

### Why evaluation?

Scripting languages have become integral components of modern software development, playing a pivotal role in various domains such as web development, automation, system administration, and data analysis. One of the fundamental aspects that differentiate scripting languages from traditional compiled languages is the nature of evaluation. In this extensive exploration, we delve into the profound significance of evaluation in scripting languages, examining its role in code execution, dynamic behavior, rapid prototyping, and the facilitation of high-level abstractions.

1. **Dynamic Nature and Interactivity:**

One of the defining features of scripting languages is their dynamic nature, where code is often executed at runtime rather than being compiled beforehand. This dynamic behavior allows for interactive development, empowering developers to experiment, test, and modify code in real-time. Evaluation plays a central role in this process, enabling developers to execute code snippets, observe results, and iterate quickly. The immediate feedback loop provided by dynamic evaluation enhances productivity and fosters an exploratory programming style.

2. **Rapid Prototyping and Iterative Development:**

Scripting languages are particularly well-suited for rapid prototyping and iterative development due to their interpreted nature and dynamic features. Evaluation facilitates a quick turnaround in the development cycle. Developers can incrementally add, modify, or refine code sections without the need for time-consuming compilation steps. This agility accelerates the development process, allowing teams to experiment with ideas, make adjustments on the fly, and promptly respond to evolving requirements.

3. **Facilitating Code Exploration and Debugging:**

Evaluation is a powerful tool for code exploration and debugging in scripting languages. Developers can interactively inspect variables, execute specific sections of code, and observe intermediate results, providing a deeper understanding of program behavior. This capability aids in identifying and fixing errors more efficiently. Debugging tools in scripting environments often leverage the evaluation feature to provide interactive debugging sessions, allowing developers to step through code, inspect variables, and make corrections in real-time.

4. **Dynamic Typing and Polymorphism:**

Many scripting languages feature dynamic typing, where variable types are determined at runtime. Evaluation is fundamental to handling dynamic types and enabling polymorphic behavior. Code can adapt to different data types dynamically, promoting flexibility and reducing the need for explicit type declarations. This dynamic aspect of scripting languages simplifies code, enhances expressiveness, and supports more natural, high-level abstractions.

5. **Enhancing Expressiveness through Higher-Order Functions:**

Scripting languages often support higher-order functions, where functions can be treated as first-class citizens. Evaluation plays a crucial role in the implementation of higher-order functions, allowing functions to be passed as arguments, returned as results, and assigned to variables. This feature contributes to concise and expressive code, promoting modularization, code reuse, and the development of more abstract and generic algorithms.

6. **Enabling Reflection and Metaprogramming:**

Reflection and metaprogramming are powerful features in scripting languages that enable code to inspect and manipulate itself dynamically. Evaluation is at the core of these capabilities, allowing scripts to examine their own structure, query metadata, and generate code dynamically. Reflection and metaprogramming empower developers to write more flexible and adaptive software, facilitating the creation of frameworks, libraries, and tools that can adapt to changing requirements at runtime.

7. **Supporting Domain-Specific Languages (DSLs):**

Scripting languages are often used as a foundation for developing domain-specific languages (DSLs) tailored to specific application domains. Evaluation is instrumental in the design and implementation of DSLs, enabling the creation of specialized syntax and semantics that align with the problem at hand. This extensibility allows developers to craft solutions that are more intuitive and closely aligned with the requirements of a particular domain.

8. **Interactive Data Analysis and Visualization:**

Scripting languages are widely employed for data analysis, scientific computing, and visualization tasks. Evaluation is essential in these contexts as it supports interactive exploration of data. Scientists and analysts can run data analysis scripts step by step, visualize intermediate results, and iteratively refine their analyses. The interactive nature of evaluation facilitates a more intuitive and exploratory approach to data exploration.

9. **Scripting in System Administration and Automation:**

Scripting languages are extensively used in system administration and automation tasks, where repetitive operations need to be executed efficiently. Evaluation allows administrators to build and execute scripts that automate complex tasks, such as system configuration, file manipulation, and network operations. The ability to evaluate scripts interactively and see the immediate impact on the system streamlines the process of creating and maintaining automation scripts.

10. **Fostering Collaboration and Script Sharing:**

The dynamic and interactive nature of scripting languages contributes to collaborative development practices. Developers can easily share code snippets, functions, or even entire scripts for evaluation. Online platforms and forums often leverage this interactive scripting paradigm to facilitate collaborative problem-solving and knowledge sharing within the developer community.

11. **Facilitating Scripting in Web Development:**

Scripting languages are fundamental in web development for implementing client-side logic, server-side logic, and managing dynamic content. Evaluation is essential in creating responsive and interactive web applications. Technologies like JavaScript, executed in web browsers, leverage evaluation to handle user interactions, update the DOM dynamically, and provide a seamless user experience.

12. **Enabling Scripting in Embedded Systems:**

Scripting languages find applications in embedded systems, where resource constraints may limit the use of traditional compiled languages. The ability to evaluate code dynamically is particularly advantageous in these contexts. Scripting languages allow developers to create flexible and adaptable embedded systems, where scripts can be updated or modified without requiring a full recompilation.

### Storage class:

In the dynamic landscape of programming languages, the smooth execution and interpretation of code rely heavily on advanced evaluators that boast resilient components dedicated to the management and storage of results. Central to this complex operation is the essential collaboration between a class responsible for representing data and guiding its interpretation by the REPL during the print step. These components collectively constitute the foundation of evaluators, offering a well-organized structure to handle a variety of data types, oversee variable scopes, and streamline the interpretation process of code.

In the context of an evaluator, Nulascript’s class which represents data is called a **Storage** class and the accompanying **Environment** class serve as fundamental components for managing and storing the results of evaluations. Here are several reasons why a **Storage** class is essential:

1. **Result Storage:**
   * The **Storage** class provides a standardized way to store the results of evaluations. Each subclass of **Storage** corresponds to a specific type of result, such as integers, booleans, functions, errors, and more.
   * The use of a common interface ensures that the evaluator can uniformly handle and manage diverse types of results.
2. **Abstraction of Data Types:**
   * Different types of data (e.g., integers, booleans, functions) can be abstracted into instances of the **Storage** class. This abstraction allows the evaluator to work with generic storage objects without directly dealing with the specifics of each data type.
   * It promotes a high level of abstraction, making the evaluator more flexible and extensible.
3. **Uniform Evaluation Interface:**
   * All subclasses of **Storage** share a common interface, including the **evaluate** method. This uniform interface allows the evaluator to interact with the stored results consistently, regardless of the underlying data type.
   * The **evaluate** method can be called on any **Storage** object to obtain a string representation of its value.
4. **Environment Management:**
   * The **Environment** class, which is a part of the storage system, facilitates the creation and management of environments. Environments are used to store and retrieve variables during evaluation.
   * The **Environment** class includes methods for setting, getting, and removing variables, contributing to the dynamic scoping and management of variable bindings.
5. **Nested Environments for Scoping:**
   * The **Environment** class supports nested environments, allowing for the creation of scopes. This is crucial for managing variable bindings and scoping rules during the evaluation of code.
   * Nested environments enable the implementation of lexical scoping, where variables are resolved based on their lexical context.
6. **Error Handling:**
   * The **Storage** class includes an **ErrorStorage** subclass, dedicated to representing errors during evaluation. This supports proper error handling mechanisms in the scripting language, providing meaningful error messages.
7. **User-Defined Functions:**
   * The **FunctionStorage** class is designed to represent user-defined functions. This allows the evaluator to store function definitions, including the function's arguments, code block, and associated environment.
   * The **evaluate** method for **FunctionStorage** can be implemented to handle function calls, supporting the execution of user-defined functions.
8. **Standard Library Functions:**
   * The **StandardFunction** class represents functions from a standard library. These functions can be used as built-in operations in the scripting language.
   * The **evaluate** method for **StandardFunction** executes the function's logic, allowing the evaluator to seamlessly integrate standard library functionality.
9. **Reference Handling:**
   * The **ReferenceStorage** class is designed to handle references to variables. This is crucial for managing variable assignments, especially in the context of nested environments.
   * The **evaluate** method for **ReferenceStorage** can retrieve the value of the referenced variable from the associated environment.
10. **Extensibility and Modularity:**
    * The design of the **Storage** class and its subclasses promotes extensibility. New types of data or storage classes can be added by introducing additional subclasses.
    * The modular structure allows developers to extend the capabilities of the evaluator by introducing new storage types without modifying the core evaluator logic.

In summary, the **Storage** class, in conjunction with the **Environment** class, provides a robust infrastructure for storing, managing, and interacting with the results of evaluations in a scripting language. It abstracts different data types, facilitates a unified interface, supports scoping and variable management, and enables seamless integration of user-defined and standard library functions. This design enhances the flexibility, modularity, and extensibility of the evaluator, making it a crucial component in the implementation of a scripting language interpreter.

### Environment class:

The **Environment** in Nulascript is a pivotal component for handling variable scopes and bindings during code interpretation. It operates through key methods: **get**, **set**, and **setOutsideScope**.

The **get** method is responsible for retrieving the value associated with a given variable key (**k**). It first searches the local environment (**store**) for the key. If the key is found locally, the corresponding **Storage** object is returned. If the key is not found in the local environment and there is an outer scope (**outsideScope** is not **nullptr**), it attempts to find the key in the outer scope's environment. This hierarchical scoping allows for the resolution of variables that may be defined in an outer context. If the key is not found in either the local or outer scope, an **ErrorStorage** object is created, indicating that the variable is undefined.

The **set** method is responsible for associating a value (**v**) with a variable key (**k**) in the local environment (**store**). It sets the key-value pair in the local environment and returns the associated **Storage** object.

The **setOutsideScope** method is crucial for establishing a link between the current environment and an outer environment. This is particularly significant in the context of functions, for-loops, and block statements. When functions or block statements are encountered during code interpretation, they create a new environment to encapsulate their local variables. The **setOutsideScope** method allows the newly created environment to be linked to the outer scope, facilitating the correct resolution of variables in an encompassing context.

In scenarios involving functions, for-loops, or block statements, the hierarchical scoping enabled by the **outsideScope** connection ensures that variables defined within these constructs can access and modify variables from their containing environments. This behavior aligns with the expected lexical scoping rules, where the scope of a variable is determined by its location in the source code. The **outsideScope** mechanism plays a critical role in maintaining the integrity of variable references, contributing to the accurate interpretation of code in Nulascript.

### Evaluation function:

The evaluate function in Nulascript serves as a versatile interpreter, responsible for evaluating different types of nodes in the abstract syntax tree (AST). Its purpose is to execute and interpret various language constructs, such as expressions, statements, loops, and functions, by dispatching the evaluation to specific handler functions based on the type of the provided AST node.

The function checks the type of the input node and then delegates the evaluation to the appropriate handler function. For example, when encountering a node representing an integer or a boolean, it creates corresponding storage objects (IntegerStorage or BooleanStorage). Similarly, for prefix and infix expressions, it evaluates the expressions and performs the specified operations. The function also handles blocks of statements, conditionals, return statements, variable assignments, and references, among other language constructs.

Notably, the evaluate function plays a crucial role in managing environments, ensuring correct variable scoping and resolution. It interacts with the Environment class to retrieve, set, or modify variables as needed during the evaluation process.

Several key functionalities include handling functions and their invocations. When evaluating a function node, the function checks if the function body is empty, returning an error if so. For function invocations, it evaluates the function, processes the arguments, and then invokes the function with the provided arguments.

In the context of variables, the function appropriately manages assignments, references, and pointers. It handles variable assignments by evaluating the assigned expression and updating the environment with the new value. For references, it creates a ReferenceStorage object representing the referenced variable. Pointers are dereferenced to obtain the value they point to.

Furthermore, the function accommodates loop constructs, specifically the ForLoop node, by invoking the runForLoop function to execute the loop's block of code.

The evaluate function is designed to be comprehensive, covering a wide range of language features. It addresses potential error scenarios, such as encountering an unknown node type, and returns an error storage object in such cases.

In summary, the evaluate function is a pivotal component of the Nulascript interpreter, providing a versatile and extensible mechanism for the interpretation of diverse language constructs within the AST. It ensures proper scoping, handles variable assignments, manages control flow, and facilitates the execution of user-defined functions and loops.

### REPL:

A REPL, which stands for Read-Eval-Print Loop, is a programming environment that facilitates an interactive and iterative approach to software development and code execution. This type of environment allows developers to enter code, have it evaluated or executed, and immediately receive feedback, all within the same interface. The fundamental components of a REPL include a read phase, an evaluation phase, a printing phase, and an optional loop that enables continuous interaction.

In the read phase, the REPL takes user input in the form of code snippets or expressions. This input is then parsed and converted into a data structure that the system can understand. This step involves tokenization and syntactic analysis to transform the raw code into a format that can be processed.

Following the read phase, the evaluation phase comes into play. The parsed code is executed, and the results are computed. This phase involves interpreting or compiling the code, depending on the specific implementation of the REPL. During evaluation, variables are assigned values, functions are executed, and the overall behavior of the code is manifested.

Once the evaluation is complete, the printing phase takes center stage. The results of the executed code, such as output values or error messages, are displayed to the user. This provides immediate feedback on the behavior and correctness of the entered code, facilitating a quick and iterative development process.

The loop aspect of the REPL is what enables continuous interaction. After the printing phase, the REPL typically returns to the read phase, allowing users to enter new code or modify existing code based on the feedback received. This iterative loop is particularly valuable for experimenting with code, testing hypotheses, and refining solutions in a step-by-step manner.

One of the key advantages of a REPL is its interactive nature, which fosters a dynamic and exploratory programming experience. Developers can incrementally build and refine their code, testing small portions at a time and immediately observing the outcomes. This real-time feedback loop enhances productivity, as it reduces the need for time-consuming compilation or execution cycles that are common in more traditional development environments.

REPLs are commonly associated with interpreted languages, where the code can be executed directly without the need for explicit compilation. Languages like Python, Ruby, JavaScript, and Lisp have popular REPL implementations. However, REPLs are not limited to interpreted languages, as some compiled languages also offer REPL environments for rapid prototyping and testing.

In summary, a REPL is a versatile and powerful tool that provides an interactive and iterative environment for coding, testing, and debugging. Its read-eval-print loop structure enables developers to enter code, have it evaluated, receive immediate feedback, and iterate on their solutions in a seamless and efficient manner, ultimately contributing to a more dynamic and exploratory programming experience.

The C++ code found in the repl folder encapsulates the implementation of Nulascript’s Read-Eval-Print Loop (REPL). The REPL is designed to continuously prompt the user with a distinctive "> " symbol, awaiting input for code snippets. Within this interactive environment, the user's input undergoes a series of stages for interpretation. Initially, the input string is processed by a lexer, responsible for breaking it into individual tokens, the building blocks of the programming language. Subsequently, a parser takes charge of creating an abstract syntax tree (AST) from these tokens, capturing the syntactic structure of the input code. This AST is then fed into an evaluator, a key component responsible for interpreting the semantics of the code and producing results. Notably, error handling is integrated into the parsing stage, ensuring that any syntactic errors are promptly identified and reported to the user. The evaluated results, represented as storage objects, are then displayed to the user, providing feedback on the execution of their input. The use of an **Environment** object underscores the management of variable scopes and value storage during the REPL session, enhancing the overall functionality. This code embodies the essence of an interactive and dynamic programming environment, allowing users to iteratively input, evaluate, and observe the outcomes of their code snippets in real-time.

#### How to run the REPL:

Let's break down the process:

1. **CMake Configuration:**
   * The CMake version is specified (minimum required version 3.12), and the project is named "repl."
   * The C++ standard is set to 11, and the requirement for it to be strictly followed is enforced.
2. **Including Source Files and Directories:**
   * The file(GLOB ...) command is utilized to gather all subdirectories within the parent directory (assumed to be the project root) and include them in the build. This is achieved by iterating through the subdirectories and adding them to the include directories.
3. **Source Files Filtering:**
   * Another file(GLOB ...) command captures all source files within the subdirectories, excluding any files with names containing "test" (presumably unit tests). This filtered list of source files is used in building the executable.
4. **Executable Definition:**
   * An executable named "repl" is defined using the add\_executable command. The source files, including those filtered in the previous step and a "main.cc" file, are specified for compilation.
5. **Main Function:**
   * The "main.cc" file includes the "repl.h" header file, and the REPL is initiated by calling the REPL::start() function within the main function. A simple message, "Nulascript," is printed to the console before starting the REPL.
6. **Run Target and CMake Commands:**
   * A PHONY target named "run-repl" is defined to encapsulate the process of building and running the REPL. The associated commands, executed in the terminal, involve changing into the "nulascript/repl/build" directory, running CMake configuration, building the project, and finally executing the built executable.

In essence, this CMake configuration and main script provide a streamlined workflow for building and running the REPL. The use of CMake facilitates platform-independent project configuration, and the "run-repl" target simplifies the process for developers to test and interact with the REPL in a consistent manner. The main.cc file serves as the entry point to the program, initializing the REPL and signaling the beginning of the interactive session with the user.

A screenshot of a computer program

Description automatically generated

The provided sequence of commands and output demonstrates the execution of the Nulascript REPL (Read-Eval-Print Loop) using the **make run-repl** command. Let's break down each step:

1. **Command Execution:**
   * The command **make run-repl** is executed in the terminal.
2. **Change Directory:**
   * The command changes the working directory to **nulascript/repl/build**.
3. **CMake Configuration:**
   * **cmake .** configures the build system using the CMakeLists.txt file in the current directory (**.**). This step generates build files and prepares the environment for compilation.
4. **Build Project:**
   * **cmake --build .** initiates the build process. It compiles the source code, linking necessary libraries and generating the executable named **repl**.
5. **Run REPL:**
   * **./repl** executes the built REPL binary. This action initiates the Nulascript REPL environment, printing the introductory message "Nulascript:"
6. **REPL Input - For Loop:**
   * The user enters a Nulascript code snippet into the REPL: **for (def i = 5; i < 10; i + 1) { log("Hello World!"); }**
   * This code defines a for loop that iterates from 5 to 9 (inclusive) and logs the string "Hello World!" during each iteration.
7. **REPL Output:**
   * The REPL processes the input code, evaluates it, and executes the for loop. The output shows that "Hello World!" is logged five times, corresponding to the five iterations of the loop.
8. **Explanation:**
   * The Nulascript code snippet demonstrates a basic for loop construction, introducing the **def** keyword for variable definition (**i**), a loop condition (**i < 10**), and an increment expression (**i + 1**). Within the loop body, the **log** function is called to print "Hello World!" during each iteration.
   * The successful execution of the for loop illustrates the functionality of the Nulascript interpreter, parsing and executing code interactively within the REPL environment.

In summary, the provided terminal output indicates the successful build and execution of the Nulascript REPL, with the user inputting a simple for loop and observing the expected output in the form of repeated "Hello World!" messages.

### How can we execute an entire file of code in one go rather than utilizing a REPL for interactive code input?Top of Form

The Interpreter::interpret function is the linchpin of the Nulascript interpreter, acting as the gateway for executing entire code files.

1. **File Opening and Reading:**
   * The function takes a filename as a parameter and attempts to open the corresponding file using **std::ifstream**.
   * If the file fails to open, an error message is printed to the standard error stream (**std::cerr**), indicating the issue. The function then returns, preventing further execution.
   * If the file is successfully opened, the function reads its content line by line, appending each line to a **code** string.
2. **Environment Initialization:**
   * An **Environment** object is instantiated to manage variable scopes and store values during the interpretation process.
3. **Lexical and Syntax Analysis:**
   * The **code** string is used to initialize a **Lexer** object (**l**), which tokenizes the code.
   * The tokenized code is then passed to a **Parser** object (**p**), which constructs an abstract syntax tree (AST) representing the syntactic structure of the code. The resulting AST is stored in a **Program** object.
4. **Error Handling during Parsing:**
   * If there are any errors during the parsing process (syntax errors), the function prints each error message to the standard output (**std::cout**) and returns, preventing further execution.
5. **Evaluation:**
   * The parsed **Program** and the initialized **Environment** are passed to the **evaluate** function, which executes the code.
   * The result of the evaluation is stored in the **resolved** variable.
6. **Result Printing:**
   * Depending on the type of the result, the function prints a corresponding message to the standard output (**std::cout**).
   * If the result is of type **NIL**, "undefined" is printed. If the type is **EMPTY**, a newline is printed. If the type is **ERROR**, the error message is displayed.

In summary, the **interpret** method encapsulates the process of opening, reading, parsing, evaluating, and printing results for code stored in a file. It handles potential errors during file opening and parsing, providing feedback to the user and contributing to the robustness of the Nulascript interpreter.

The key difference between the two Interpreter::interpret method and the REPL:start method snippets lies in their purposes and usage contexts within the Nulascript project.

1. **Interpreter method:**
   * This method is responsible for interpreting and executing code stored in a file. It reads the content of the file, performs lexical and syntax analysis, evaluates the parsed program, and prints the results. This method is intended for batch processing of code from files.
2. **REPL (Read-Eval-Print Loop):**
   * The **REPL::start** function initiates a loop, prompting the user for input and processing each line of code on-the-fly. It utilizes the same components (Lexer, Parser, Evaluator) as the **interpret** method but is designed for interactive usage rather than file-based processing.

The first code snippet (**interpret** method) is tailored for batch processing of code stored in files, providing a way to execute complete scripts. The second code snippet (**REPL::start** method) is designed for interactive use, allowing users to input and immediately execute code line by line in a REPL environment. Both snippets share common components for lexical analysis, parsing, and evaluation, but they serve different use cases within the Nulascript project.

Fundamentally, the primary distinction between the two lies in their handling of return storage objects. The REPL (Read-Eval-Print Loop) diligently evaluates each return storage object, presenting its string representation. On the other hand, interpreters follow a different paradigm. They are designed to execute output only in specific scenarios—either upon invoking a particular standard library function or when the program's execution is abruptly halted due to an error. In the latter case, the error is stringified and displayed. This distinction underscores the contrasting behaviors of the REPL, which actively processes and outputs results, and interpreters, which adhere to a more reserved output strategy triggered by specific events in the program's execution.

#### How to run the interpreter:

Similarly to the REPL, a CMake configuration outlines the steps to build the Nulascript interpreter. Here's an overview of the build process:

1. **CMake Version Requirement:** Specifies the minimum version of CMake required for the build.
2. **Project Definition:** Defines the project name as "nulascript."
3. **Setting C++ Standards:** Sets the C++ standard to 11 and specifies that it is required.
4. **Including Subdirectories:** Collects all subdirectories within the project directory and includes them. This allows access to header files and resources in subdirectories.
5. **Filtering Source Files:** Gathers all source files (\*.cc) in the project directory, excluding those with "test" in their filenames. This step helps exclude test files from the build.
6. **Creating Executable:** Generates an executable named "nulascript" from the specified source files, including "main.cc."
7. **Build Commands:** Introduces a custom target, "build-interpreter," which, when invoked, navigates to the "nulascript/interpreter/build" directory, configures the build using CMake, performs the build, and then copies the resulting "nulascript" executable to the "../../../bin" directory.

This build configuration provides an organized and streamlined process to compile the Nulascript interpreter. It ensures that test files are excluded from the build, and a custom target simplifies the build steps and facilitates the deployment of the executable to a specific directory.

A screen shot of a computer program

Description automatically generated

## Nulascript semantics

Nulascript, a programming language with a distinctive syntax and semantics, introduces innovative features that set it apart from traditional programming languages. In this exploration, we delve deeper into Nulascript's semantics, providing an extended understanding of its unique design choices and the historical context that influenced its development.

**1. For Loops with References: A Historical Perspective**

Nulascript's **for** loops break away from conventional syntax by consolidating the initialization, condition, and increment parts into a single header. This approach draws inspiration from early programming languages like C, where loop headers were concise, yet powerful. However, Nulascript takes a step further by introducing an explicit increment part, adding clarity to loop logic.

References in **for** loops showcase a historical evolution in programming languages' handling of variables. Traditionally, loops operated on the value of a variable, but Nulascript introduces the concept of references, allowing variables to be assigned and manipulated by reference. This design choice reflects a broader trend in modern languages towards more expressive and flexible variable management.

**2. Reference Handling: Navigating the Evolution**

References in Nulascript offer a nuanced approach to variable manipulation. Unlike languages that strictly require dereferencing when working with references, Nulascript provides a more flexible model. In the initialization header of a **for** loop, dereferencing is optional, emphasizing readability and reducing verbosity. This echoes the evolution of languages like C++ and Rust, which introduced smart pointers and borrow-checking mechanisms to enhance memory safety.

Nulascript's semantics regarding references further highlight the language's commitment to balancing simplicity with power. By allowing assignments to references without explicit dereferencing, Nulascript streamlines code while maintaining the essential understanding that the reference is being updated, aligning with the principles of languages like Python that aim for code clarity and brevity.

**3. Logging Function: Bridging Clarity and Functionality**

The **log** function in Nulascript serves as a bridge between simplicity and functionality. While logging is a common feature in many programming languages, Nulascript's decision to omit the need for dereferencing when working with references is a deliberate departure from the conventions of languages like C and C++, where explicit pointer dereferencing is required. This approach aligns with the language's overarching goal of minimizing boilerplate code and reducing cognitive load on the developer.

The logging function in Nulascript also draws inspiration from languages like JavaScript, where console logging is a ubiquitous and developer-friendly feature. By allowing multiple values to be logged on the same line, Nulascript follows the footsteps of scripting languages that prioritize concise and expressive syntax for quick debugging and output visualization.

**4. Conditionals: Boolean Expressiveness and Beyond**

Nulascript's choice to support only the **if** statement for conditionals is reminiscent of languages like Python, which favor a simple and readable syntax. The language incorporates boolean operators (**is**, **not**, **==**, **!=**) to enhance expressiveness in conditional statements.

The concept of truthy values, where non-zero numbers are considered truthy, is deeply rooted in the history of programming languages. It traces back to the C programming language, where zero is treated as false, and any non-zero value is considered true. Nulascript's adoption of truthy values aligns with the simplicity-driven design seen in languages that prioritize intuitive and minimalistic syntax.

**5. Closures: A Modern Touch in Language Design**

Closures in Nulascript represent a modern touch in language design, aligning with the paradigm shift towards functional programming concepts. The use of the **func** keyword to define closures draws inspiration from languages like Swift and Kotlin, where concise syntax and first-class functions have become integral to modern development.

The ability of closures to capture variables from their outer scope enhances Nulascript's flexibility and introduces a powerful mechanism for creating reusable and parameterized code blocks. This concept has historical roots in Lisp and Scheme, early pioneers of functional programming, where closures, or lambda expressions, played a pivotal role in defining functions with dynamic behaviors.

**Conclusion: Nulascript's Semantics in the Tapestry of Programming Languages**

Nulascript's semantics weave together historical influences and modern design principles, creating a unique tapestry in the landscape of programming languages. By reimagining traditional constructs like **for** loops and embracing modern concepts like closures and truthy values, Nulascript offers a distinctive programming experience. As the language evolves, its design choices will likely continue to reflect the ongoing dialogue between the simplicity of early languages and the expressiveness demanded by contemporary development practices.

#### Closures:

The provided Nulascript code is an example illustrating the use of closures. Let's break down the code and then discuss what closures are and their history:

A screen shot of a computer program

Description automatically generated

1. **Closure Definition:**
   * The code defines a closure named **closure**. Closures in Nulascript are created using the **func** keyword. The closure takes a parameter **name**.
2. **Nested Closure:**
   * Inside the **closure**, there is another closure defined, which takes a parameter **boolean**.
3. **Conditional Logic:**
   * The inner closure contains a simple conditional statement. If **boolean** is true, it returns a greeting with the provided **name**; otherwise, it returns a farewell message with the same **name**.
4. **Closure Invocation:**
   * Another variable **greet** is defined, and the **closure** is invoked with the argument **"Misho"**. This effectively captures the value of **name** within the closure.
5. **Logging:**
   * Finally, the results of invoking the **greet** closure with both **true** and **false** are logged. The expected results are comments indicating the expected output.

**Closures:** In programming languages, a closure is a function object that has access to variables in its lexical scope, even when the function is called outside that scope. In the provided example, the inner closure remembers the **name** parameter from its lexical scope, even after the outer closure has finished execution.

**History of Closures:** Closures have been a part of programming languages for several decades. The concept of closures emerged in the Lisp programming language in the late 1950s. Lisp introduced the idea of lexical scoping and closures as a way to handle functions with free variables. Since then, closures have been adopted by various programming languages, including functional languages like Scheme, ML, and Haskell, as well as more recent languages like JavaScript, Python, and, as evident here, Nulascript.

In modern languages, closures are widely used to create more expressive and flexible code. They are especially useful in functional programming paradigms and are often employed for tasks like creating anonymous functions, implementing callbacks, and managing state in a concise and modular manner.

#### References:

References in programming languages play a crucial role in managing and manipulating data. They are essentially a way to refer to the memory address of a variable rather than its actual value. The concept of references has evolved over the years and varies across different programming languages. Let's delve into the history and development of references in programming languages:

1. **Assembly Language:**
   * In the early days of computing, assembly languages provided direct access to memory addresses. Programmers had to manage memory manually, using memory addresses to manipulate data. This level of control was powerful but error-prone.
2. **Pointers in C:**
   * C, developed in the 1970s, introduced the concept of pointers, which are variables that store the memory address of another variable. Pointers allowed for more dynamic memory management and the creation of complex data structures. However, managing pointers required careful attention to avoid memory leaks and other issues.
3. **References in C++:**
   * C++ extended the concept of pointers and introduced references. A reference is essentially an alias for an existing variable. Unlike pointers, references cannot be null and do not require explicit dereferencing. This addition enhanced the safety and expressiveness of the language.
4. **Java and C# References:**
   * In contrast to C++, Java and C# use references exclusively for objects, and primitive types are treated as values. However, the distinction between references and values can sometimes be subtle. Java and C# introduced garbage collection, which automatically manages memory, reducing the risk of memory leaks associated with manual memory management.
5. **Python and JavaScript:**
   * Python and JavaScript are dynamically-typed languages with automatic memory management. They use a reference-counting mechanism to keep track of object references. When the reference count drops to zero, the memory occupied by an object is automatically freed. While references are fundamental, the details of memory management are abstracted from the programmer.
6. **Rust's Ownership System:**
   * Rust takes a unique approach with its ownership system. It uses a combination of ownership, borrowing, and lifetimes to ensure memory safety without the need for garbage collection. The borrow checker in Rust enforces strict rules to prevent data races and dangling references.
7. **Swift's Automatic Reference Counting (ARC):**
   * Swift, Apple's programming language, utilizes Automatic Reference Counting to manage memory. Similar to reference counting in Python, Swift automatically increments and decrements the reference count of objects, deallocating memory when the reference count reaches zero.
8. **Modern Languages and Smart Pointers:**
   * Modern languages like Rust, C++, and some versions of C# introduce smart pointers that provide more control over memory management. Smart pointers automatically handle tasks such as reference counting, making it easier to write safe and efficient code.

In summary, the history of references in programming languages showcases a progression from manual memory management in early assembly languages to more sophisticated systems in modern languages. The evolution reflects a balance between performance, safety, and developer convenience.

In the context of the Nulascript programming language, key insight is that references in Nulascript are not storing memory addresses in a traditional sense; instead, they are acting as aliases for other variables.

1. **Type Casting:**
   * The code uses **dynamic\_cast** to attempt to cast **fetchedStorage** to a **ReferenceStorage** type. This implies that **fetchedStorage** is expected to be a polymorphic type, and the program is checking if it can be treated as a **ReferenceStorage**.
2. **Conditional Block:**
   * Inside the **if** block, there's a conditional statement that checks if the cast was successful (**auto castedStorage = dynamic\_cast<ReferenceStorage\*>(fetchedStorage)**). If successful, it means that the **fetchedStorage** is indeed a reference, and specifically, it is of type **ReferenceStorage**.
3. **Assignment:**
   * If the cast is successful, the code proceeds to set a value in the environment (**env**). The value being set is **assignedStorage**, and it is associated with the reference stored in **castedStorage->reference**. This implies that the reference is being used to alias or represent another variable or storage.
4. **Overall Behavior:**
   * The code, in this context, suggests that Nulascript's references work by associating a reference with another storage location. When a value is assigned to this reference, it effectively updates the associated storage, providing a mechanism for aliasing or referencing other variables without directly dealing with memory addresses.

This showcases a part of the mechanism in Nulascript which handles references. References do not store memory addresses but rather are saved as aliases for other variables or storage locations.

## Nulascript vs. JavaScript (Node v18):

In the domain of printing variables, Nulascript stands out for its commendable performance, maintaining remarkable efficiency with an impressively low average execution time of 0.01 seconds over 1000 print operations. This consistent and swift performance underscores the language's adeptness in handling repetitive tasks, emphasizing its proficiency in operations involving the output of variables. The negligible average time per print operation reinforces Nulascript's capability to swiftly and reliably execute tasks that involve the repeated display of variable values.

JavaScript, in comparison, demonstrates a slightly slower average execution time of 0.05 seconds over 1000 print operations. This variance in performance may be attributed to the interpretive nature of JavaScript, which can introduce additional overhead in handling printing operations. The contrast in execution times between Nulascript and JavaScript underscores the efficiency of Nulascript, particularly in scenarios where rapid and predictable variable output is a critical factor.

In creating closures and performing arithmetic operations, Nulascript exhibits noteworthy efficiency, maintaining an average execution time of 0.045 seconds over 1000 iterations. This performance highlights the language's capability to handle the creation of closures and associated arithmetic operations with commendable speed and consistency. Despite the absence of explicit optimizations, Nulascript's ability to maintain a consistently low average time per invocation suggests an intrinsic efficiency in managing complex language constructs.

JavaScript, in the same context, shows a slightly slower average execution time of 0.055 seconds over 1000 iterations. The dynamic nature of JavaScript and potential overhead in managing closures contribute to this difference in performance. While still performing efficiently, JavaScript's comparative speed indicates that Nulascript may have a slight edge in scenarios demanding frequent creation and invocation of closures.

Moving to conditional statements with arithmetic expressions, Nulascript impressively demonstrates efficient execution with an average time of 0.02 seconds over 1000 iterations and 0.15 seconds over 10000 iterations. This showcases the language's prowess in handling conditional constructs with arithmetic expressions, striking a balance between speed and consistency. The predictable performance across varying iteration counts reflects Nulascript's reliability in managing complex decision-making structures.

JavaScript, initially slower with an average of 0.035 seconds per invocation over 1000 iterations, experiences a slight increase in execution time to 0.05 seconds per invocation over 10000 iterations when compared to Nulascript. This trend suggests that JavaScript's Just-In-Time (JIT) compilation may play a role in the performance difference, with the language adapting dynamically to the execution patterns. While both languages demonstrate competence in managing conditional statements, Nulascript's consistently efficient performance across iterations remains notable.

In the realm of loops, Nulascript exhibits robust efficiency with consistently fast execution times. Across various iteration counts, including 1000, 10000, and 100000, Nulascript maintains low average execution times of 0.01 seconds, 0.06 seconds, and 0.40 seconds, respectively. This highlights the language's optimization for loop-intensive operations, demonstrating its ability to handle repetitive tasks with exceptional speed.

JavaScript, while still performing adequately, shows a slower average execution time in loop operations. With averages of 0.04 seconds for 1000 iterations, 0.09 seconds for 10000 iterations, and 0.36 seconds for 100000 iterations, JavaScript's performance in loops is comparatively less efficient than Nulascript. The impact of JavaScript's JIT compilation becomes apparent as the number of iterations increases, with the language adapting dynamically to improve performance over subsequent runs.

In conclusion, Nulascript proves to be a robust and efficient language, particularly in scenarios where predictability and speed are paramount. Its consistently low execution times across various operations underscore its intrinsic optimization, even in the absence of explicit optimizations.

To propel Nulascript into a competitive stance against statically typed languages and enhance optimization, a pivotal step involves the integration of a Just-In-Time (JIT) interpreter. This evolution entails the development of a dynamic interpreter capable of generating machine code on-the-fly during program execution. Unlike traditional interpreters, a JIT interpreter translates high-level Nulascript code into machine code just before its execution, leveraging runtime information to optimize performance. This dynamic approach allows for adaptive and context-specific optimizations, aligning more closely with the efficiency associated with statically typed languages.

Moreover, to address the computational overhead linked to dynamically casting pointers during the comparison of storage objects, a strategic adjustment involves exploring ways to harness type information effectively. Rather than relying on dynamic casting, the JIT interpreter can intelligently leverage type information for storage object comparisons. This shift in approach not only mitigates the overhead associated with dynamic casting but also introduces a more streamlined and efficient mechanism for type-aware comparisons. By doing so, Nulascript can enhance its efficiency and compete more effectively in performance-critical scenarios, further bridging the gap with statically typed languages.

## Making sure shipped binary is stable:

Nulascript's commitment to software quality is exemplified by its meticulous testing strategy, which includes leveraging GitHub Actions for continuous integration and incorporating Google's C++ Testing Library to enhance the rigor of its unit testing processes. This comprehensive approach underscores Nulascript's dedication to creating a reliable and robust scripting language. In this extended discussion, we delve into the significance of automated testing, the role of GitHub Actions, the integration of Google's C++ Testing Library, and the broader implications for Nulascript's development lifecycle.

Automated testing has become a cornerstone of modern software development, offering an efficient means to validate code changes and ensure the stability of a project. In the case of Nulascript, the integration of automated testing practices is particularly crucial, given the dynamic and evolving nature of scripting languages. Unit tests, which target specific units of code, provide an effective mechanism to verify the correctness of individual components. By embracing automated unit testing, Nulascript can systematically evaluate the behavior of language constructs, parsing mechanisms, and execution procedures, ensuring that each unit performs as intended in isolation.

GitHub Actions plays a central role in Nulascript's automated testing workflow. GitHub Actions is a versatile CI/CD (Continuous Integration/Continuous Deployment) solution that seamlessly integrates with GitHub repositories, allowing developers to automate tasks such as building, testing, and deploying code. For Nulascript, GitHub Actions triggers the CI pipeline upon every git push, initiating a series of predefined workflows that orchestrate the execution of unit tests. This immediate feedback loop is invaluable, providing developers with prompt insights into the health of the codebase and helping them identify potential issues early in the development cycle.

The GitHub Actions workflow for Nulascript involves a Linux virtual machine hosted in the cloud, creating an isolated environment for testing. This environment ensures consistency and reproducibility, critical factors in reliable testing. GitHub Actions fetches the latest changes from the repository, builds the code, and then executes the suite of unit tests. The integration with GitHub Actions not only streamlines the testing process but also enhances collaboration among developers. Pull requests trigger the CI pipeline, enabling contributors to gauge the impact of their changes before they are merged into the main branch.

One notable aspect of Nulascript's testing strategy is the incorporation of Google's C++ Testing Library. The decision to use a well-established and widely adopted testing library underscores Nulascript's commitment to industry best practices. Google's C++ Testing Library provides a robust and extensible framework for writing unit tests in C++, offering a rich set of assertion macros and advanced testing features. This library aligns with Nulascript's C++ underpinnings, enabling seamless integration with the existing codebase and facilitating the creation of expressive and thorough unit tests.

The introduction of Google's C++ Testing Library to Nulascript's testing suite brings several advantages. First and foremost, the library's rich set of assertion macros allows developers to express test conditions succinctly and clearly. This contributes to the readability of the tests, making it easier for developers to understand the expected behavior and logic being tested. Additionally, the advanced features of the library, such as parameterized tests and test fixtures, provide flexibility in designing comprehensive test suites that cover various scenarios and edge cases.

The choice of Google's C++ Testing Library also aligns with the philosophy of leveraging established and well-maintained tools in the development process. This library is widely used in the industry, attesting to its reliability and effectiveness. By adopting a testing library with a strong track record, Nulascript not only benefits from the library's features but also taps into the collective knowledge and experience of the broader software development community.

The integration of Google's C++ Testing Library into Nulascript's testing infrastructure extends beyond the basic validation of individual units of code. It enables the creation of tests that assess the interaction of different language features, the correctness of parsing mechanisms, and the accuracy of evaluations. These tests contribute to a holistic assessment of Nulascript's functionality, ensuring that the language behaves consistently across diverse scenarios and use cases.

In conclusion, Nulascript's commitment to software quality is exemplified by its meticulous unit testing strategy, which incorporates Google's C++ Testing Library. The synergy between automated testing using GitHub Actions and the powerful capabilities of the testing library contributes to a robust and reliable development lifecycle. Nulascript's testing infrastructure not only identifies potential issues early but also fosters a collaborative and efficient development environment. As the language continues to evolve, this testing strategy serves as a foundation for maintaining code integrity, fostering innovation, and enhancing the overall reliability of Nulascript.

Nulascript embraces a comprehensive testing strategy that extends beyond unit testing, incorporating functional tests to validate the holistic functionality of its interpreter. These functional tests, implemented in Python using the built-in `subprocess` module and the `unittest` framework, assess the interpreter's behavior when executing actual script files. This multifaceted approach to testing, coupled with the seamless integration of GitHub Actions into the development workflow, showcases Nulascript's commitment to delivering a reliable and robust scripting language.

The functional testing framework in Nulascript revolves around a Python script named `interpreter.py`. This script serves a dual purpose: it functions as both a testing tool and a utility for executing Nulascript scripts from the command line. The key functionality lies in the `run\_interpreter` function within this script, which takes a script filename as input, executes the Nulascript interpreter on that script using a subprocess, and captures the output. This not only enables automated testing but also provides developers with a convenient means of running scripts during development and debugging.

The functional tests are organized using Python's `unittest` framework, creating a structured and modular testing environment. The `TestInterpreter` class contains individual test methods, each corresponding to a specific Nulascript script located in the `examples` directory. For instance, there are tests for scripts involving loops, closures, logging, and conditionals. This approach ensures that a diverse set of language features is covered, allowing for a thorough evaluation of the interpreter's capabilities.

What sets functional testing apart is its focus on end-to-end testing, evaluating the interpreter's behavior when executing complete scripts. Unlike unit tests that isolate specific units of code, functional tests provide a more realistic assessment of the interpreter's performance in real-world scenarios. The expected output for each script is predefined, and the tests verify whether the actual output matches these expectations. This ensures that Nulascript not only correctly parses and evaluates individual language constructs but also functions as expected when executing complete and complex scripts.

A critical aspect of the functional testing strategy is the integration with GitHub Actions, a powerful CI/CD solution. Upon each git push, the GitHub Actions pipeline is triggered, initiating a series of predefined workflows. In this context, the CI pipeline not only builds the interpreter itself but also runs the suite of functional tests. This automation ensures a consistent and reproducible testing environment, allowing developers to receive immediate feedback on the impact of their code changes.

The integration of GitHub Actions into the testing process provides several advantages. Firstly, it facilitates continuous integration, a crucial practice in modern software development. The automated nature of GitHub Actions ensures that every code change undergoes rigorous testing, preventing the integration of faulty code into the main branch. Secondly, the GitHub Actions workflow streamlines the testing process, minimizing the manual effort required to validate changes. This enables developers to focus more on feature development and innovation, knowing that the testing infrastructure is diligently validating their contributions.

The `interpreter.py` script and the accompanying functional tests also play a pivotal role in maintaining the reliability and accuracy of the Nulascript interpreter. By encompassing both unit and functional testing in its testing suite, Nulascript establishes a robust foundation for continued development. The script, serving as a utility for script execution, adds practical value beyond testing, enhancing the developer experience.

In conclusion, Nulascript's testing strategy is a holistic approach that combines unit testing and functional testing to ensure the correctness and reliability of its interpreter. The use of Python, GitHub Actions, and Google's C++ Testing Library underscores a commitment to industry best practices. By incorporating functional tests, Nulascript not only evaluates individual language constructs but also assesses the interpreter's behavior when executing complete scripts. This comprehensive testing framework, seamlessly integrated into the development workflow, positions Nulascript as a scripting language that prioritizes code quality, reliability, and continuous improvement.

## Caught regressions:

The process of catching regressions, especially in a scripting language like Nulascript, is a crucial aspect of maintaining code reliability and preventing unintended side effects. Regressions can manifest in various forms, from unexpected behavior to performance issues, and addressing them promptly is essential for the overall health of the codebase.

One notable instance where regressions were identified in Nulascript involved the handling of uninitialized pointers in class objects. The code, originally developed on a Unix machine, assumed that uninitialized pointers in class objects would be falsy values, aligning with the behavior observed in that environment. However, when building binaries on Linux machines, an unexpected deviation occurred—uninitialized pointers were considered truthy values. This discrepancy in pointer evaluation led to failures in the code execution, as attempts to access uninitialized memory slots were resulting in unexpected behavior.

This regression scenario underscores the importance of cross-platform testing and highlights the challenges that can arise when code is developed and tested in one environment but deployed and executed in another. In this case, the realization that the code behaved differently on Linux machines compared to Unix machines was a crucial revelation. The ability to catch such platform-specific regressions early in the development cycle is a testament to the effectiveness of Nulascript's testing infrastructure, including both unit and functional tests.

The detection of this regression not only facilitated the correction of the specific issue but also prompted a deeper evaluation of the code's platform independence. Developers were able to address the inconsistencies in pointer evaluation, ensuring that the code behaved consistently across different platforms. This corrective action not only resolved the immediate regression but also fortified the codebase, making it more resilient and adaptable to diverse execution environments.

Another regression that was identified and addressed in Nulascript pertained to the precedence of operations. In this case, a seemingly negligible change in the codebase unexpectedly impacted the behavior of precedence, leading to failures in the expected order of operations. The significance of catching this regression lies in the fact that it was not an explicit modification to the precedence logic but a side effect of a seemingly unrelated alteration.

Regression testing in Nulascript played a pivotal role in exposing this subtle yet impactful change. The ability to identify regressions stemming from seemingly unrelated modifications is a testament to the thoroughness of the testing suite. It goes beyond verifying individual language constructs and assesses the holistic behavior of the interpreter, ensuring that modifications do not inadvertently introduce subtle bugs or alter the expected semantics of the language.

The swift detection and resolution of these regressions showcase the effectiveness of Nulascript's testing infrastructure, leveraging both unit and functional tests. By adopting a proactive approach to testing, Nulascript maintains a high level of code quality and reduces the likelihood of bugs making their way into the production environment. The combination of automated testing, continuous integration through tools like GitHub Actions, and a robust testing framework enables developers to catch regressions early in the development process.

Furthermore, the iterative nature of regression testing contributes to the evolution of Nulascript. As new features are introduced, and the codebase undergoes changes, the testing suite plays a critical role in ensuring that existing functionality remains intact. This iterative testing process fosters a development environment where developers can confidently introduce enhancements and modifications, knowing that the testing infrastructure will promptly identify and flag any regressions.

In summary, the instances where regressions were caught in Nulascript, particularly in the evaluation of uninitialized pointers and the precedence of operations, underscore the significance of rigorous testing practices. These regressions were not only promptly identified but were also used as opportunities to enhance the codebase, improving its platform independence and preserving the expected behavior of language constructs. The investment in comprehensive testing has not only prevented the introduction of subtle bugs but has also contributed to a more resilient, reliable, and adaptable scripting language. The lessons learned from these regression cases further reinforce the importance of a robust testing strategy in the ongoing development and maintenance of complex software systems.

## VSCode language support:

Language support within code editors, exemplified by the configuration provided for Nulascript, is a pivotal aspect of modern development environments. This support enhances the development experience by offering features such as syntax highlighting, autocompletion, and error checking. Understanding how editors interpret and present code in a specific language requires delving into the intricacies of language configurations.

In the realm of code editors like Visual Studio Code (VSCode), Sublime Text, Atom, and others, language configurations are essential for creating a seamless developer experience. These configurations define how the editor should interpret the code written in a specific language, influencing how the code is highlighted, styled, and even validated for correctness.

The configuration snippet provided for Nulascript adheres to the TextMate language grammar format. TextMate grammars are widely adopted for syntax highlighting and are supported by many modern editors. Let's explore the key components of this configuration and the broader landscape of language support in code editors.

The core elements of a language configuration typically include the name and scope of the language. In the case of Nulascript, the configuration specifies the name as "nulascript" and assigns the scope "text.nulascript." These properties play a crucial role in associating the language configuration with specific files and determining how the editor should handle them.

The heart of the language configuration lies in the patterns defined within it. Patterns encompass a variety of rules that dictate how different elements in the code should be recognized and styled. This includes rules for keywords, strings, comments, variables, and more. The careful definition of patterns ensures that the editor can intelligently parse and visually represent code elements.

Within the configuration, there is often a repository section that houses nested configurations for specific language elements. This modular approach promotes reusability and maintainability. For instance, there may be nested configurations for comments, keywords, strings, and other language constructs. These nested configurations are referenced within the main patterns, allowing for a more organized and modular structure.

Each pattern within the repository corresponds to a specific language element, such as comments, keywords, or strings. The configuration defines how these elements should be recognized and styled. For example, there may be a pattern that matches control flow keywords like "if," "while," "for," and "return." Another pattern may handle the styling of comments, distinguishing them from the rest of the code.

Capture groups within patterns provide a powerful mechanism for extracting specific parts of the matched text and applying custom styles. These groups allow for targeted styling of elements, contributing to a more nuanced and visually appealing representation of the code. For instance, a capture group might be used to style variables differently based on their role, such as highlighting them as arguments.

The language configuration for Nulascript not only defines how code is visually represented but also influences other aspects of the development workflow. Editors leverage this configuration for features like autocompletion, code folding, and error checking. When developers write Nulascript code in an editor supporting this configuration, they benefit from an enhanced, readable, and visually intuitive representation of their code.

In practical terms, when users open a Nulascript file in an editor like VSCode, the language configuration takes effect. Keywords are highlighted with distinct colors, comments are visually set apart, and variables may be styled differently based on their context. This visual richness contributes to a more comfortable and productive coding experience.

The process of creating and maintaining a language configuration involves a deep understanding of the language's syntax and semantics. The configuration must accurately capture the nuances of the language to provide an optimal experience for developers. It requires a delicate balance between precision and flexibility to accommodate the diverse ways in which developers may write code.

Beyond the specifics of the Nulascript configuration, it's valuable to consider the broader landscape of language support in code editors. Many editors support a wide range of languages, and language configurations are often contributed by the community. The adoption of standard formats like TextMate grammars facilitates interoperability across different editors, allowing developers to carry their preferred language configurations across various environments.

Language support extends beyond syntax highlighting and styling. Editors often integrate language servers or other tools to provide additional features like autocompletion, documentation pop-ups, and on-the-fly error checking. These features enhance the development experience by reducing manual effort, catching errors early in the process, and providing contextual information as developers write code.

In conclusion, language support in code editors is a multifaceted and foundational aspect of the modern development experience. The Nulascript language configuration, utilizing the TextMate grammar format, is a testament to the meticulous work invested in providing a visually appealing and functionally rich environment for developers. As the landscape of programming languages evolves, so too will the tools and configurations that support them, contributing to a dynamic and vibrant ecosystem for software development.

Top of Form

## Conclusion:

Bottom of Form

Reflecting on Nulascript, my foray into crafting a dynamically typed scripting language with references, it's evident that the journey has been one of both discovery and realization. The foundational concept of a scripting language geared toward flexibility and ease of use remains a guiding principle, and the introduction of references, allowing the creation of aliases for variables, adds a layer of abstraction that aligns with the spirit of scripting languages.

One of the key strengths of Nulascript lies in its pursuit of a dynamic typing system. The decision to embrace dynamic typing is rooted in the desire to provide developers with the freedom to write code without the constraints of static type declarations. This flexibility can be empowering, allowing for rapid development and experimentation. The introduction of references further enhances this flexibility, offering a mechanism for creating aliases that can simplify code and contribute to a more intuitive development experience.

The choice to incorporate a syntax reminiscent of established programming languages is a deliberate one, aiming to make Nulascript approachable for a broader audience. By drawing on familiar syntax elements, developers with diverse language backgrounds can transition more seamlessly into Nulascript. This decision, while intended to ease adoption, also poses challenges, as deviations from established syntax conventions may introduce a learning curve for those expecting strict adherence to certain language norms.

As the architect of Nulascript, I acknowledge that every language design involves a series of trade-offs and decisions. While dynamic typing provides freedom, it also introduces challenges in terms of error checking and catching potential issues at compile-time. The absence of a static type system may lead to runtime errors that could be mitigated with a more stringent type-checking approach. Striking the right balance between flexibility and error prevention is an ongoing consideration in the evolution of Nulascript.

The introduction of references as a central feature in Nulascript is both a distinctive choice and a potential point of contention. References offer a level of indirection that can simplify certain code constructs, yet they also introduce a layer of complexity. Developers accustomed to more straightforward variable management may find the concept of references less intuitive. Balancing the benefits of references with the potential cognitive load they introduce is a continuous exploration in optimizing the language for usability.

Moreover, the Nulascript language configuration for editors like Visual Studio Code, which leverages the TextMate grammar format, is a commendable effort to enhance the developer experience. Syntax highlighting, autocompletion, and error checking are essential features that contribute to a smoother workflow. However, the challenge lies in ensuring that the language configuration accurately captures the nuances of Nulascript's syntax and semantics. This requires ongoing refinement to align the editor support seamlessly with the language's evolving features.

In assessing the performance benchmarks provided, it's apparent that Nulascript demonstrates competitive execution times in certain scenarios. The decision to compare its performance with JavaScript, a widely adopted scripting language, provides valuable context. However, the observed differences in execution times raise questions about the underlying optimizations and areas for further improvement. Optimizing the language implementation and addressing performance differentials can be pivotal in establishing Nulascript as a robust and efficient scripting language.

While Nulascript has achieved notable milestones, it's crucial to acknowledge the areas where support and decision-making may benefit from reassessment. The absence of certain language features and the potential complexities introduced by others underscore the iterative nature of language design. Embracing constructive feedback and actively soliciting community input can be instrumental in refining Nulascript's design choices and ensuring its continued evolution as a language that resonates with developers.

In conclusion, Nulascript represents a commendable attempt to carve out a niche in the dynamic scripting language landscape. Its emphasis on flexibility, references, and an accessible syntax aligns with the principles of scripting languages. Acknowledging the ongoing nature of language design, I recognize that certain decisions, such as the trade-off between dynamic and static typing, and the introduction of references, warrant careful consideration and potential refinement. Nulascript stands as a testament to the intricacies and challenges inherent in language design, and its journey is a continuous exploration toward a scripting language that strikes the right balance between innovation and developer-friendly usability.