The Design of an Experimental Programming Language and its Translator

The Nuua Programming Language

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of the requirements for the degree of
ICT Systems Engineer

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Abstract

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"When you want to know how things really work, study them when they're coming apart."

— William Gibson, *Zero History*

To my family and many friends that encouraged me and emotionally supported me during all those years. Especially to my *mother*.

Acknowledgements

I would like to thank all the professors who have participated in my education, dedicating their time to help me develop my skills as an engineer. Especially the professors from the department of mining, industrial and ICT engineering. Special thanks to Sebastia Vila Marta who guided me during the development of this thesis.

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1 Introduction

> *"Any fool can write code that a computer can understand. Good programmers write code that humans can understand."*
>
> — Martin Fowler, *Refactoring: Ruby Edition, p.36*

Programming languages are used every day by millions of engineers as part of their daily routine. A programming language is used to tell a computer what to do. When somebody wants a computer to do something, it needs to write a program using a programming language. Then, a compiler needs to translate it into machine code to be executed.

To design a programming language it's important to understand the theory behind a compiler and to learn about all the steps involved to make a computer understand and execute a program.

1.1 Objectives

The main objective of this thesis is to design an experimental programming language and implement an interpreter to execute any program written with it. The different challenges that are faced during the design and implementation process are also explained and solved in their respective chapters. The experimental language built in this thesis is called *Nuua*.

The objective can be partitioned into the following points.

- Learn all the steps involved in a common compiler implementation and reproduce them according to the project needs.
- Design the Nuua Programming Language. The grammar must be simple, elegant and yet it needs to follow the most common programming language's specifications to have a low learning curvature.
- Choose an efficient programming language to build the compiler and the interpreter with. Among other options, the languages that satisfy the previous statement are low-level programming languages like C [Bri88], C++ [Bja13], D [D L], Rust [Theb] or Go [Thea] among others.
- Define a robust system architecture to design the compiler and the interpreter. The system architecture needs to be scalable.

- Build a compiler and an interpreter for the Nuua programming language and a very simple standard library.

1.2 Preliminary overview

This section briefly introduces some of the concepts found in this thesis, introducing preliminary concepts of language grammar, compilers and interpreters. This preliminary overview won't deal with details and only explains the basics to understand the whole system without deep knowledge. Further chapters contain expanded information respective to some of the details mentioned here.

1.2.1 Language grammar

Context-free grammar is a notation used to specify the syntax of a programming language. Following the syntax definition explained in [Alf06, Section 2.2] a context-free grammar consists of four components:

1. A group of terminal symbols also known as tokens. In a programming language tokens may be literal symbols like '+', '*' or numbers and identifiers.
2. A group of non-terminals that can be reduced to terminals based on the production rules.
3. A group of production rules that consists of a non-terminal on the left side and a sequence of terminals and/or non-terminals on the right side.
4. A non-terminal start symbol.

This thesis will use the *extended Backus-Naur form* also known as *EBNF* to express the context-free grammar representation of Nuua. EBNF is often used in different ways due to the big amount of variants that exist. To EBNF syntax that this thesis is uses is shown in the Table 1.1. More information may be found in the EBNF grammar article [Fed17].

Symbol	Definition
`:`	Used to define a production rule.
`space`	Used to concatenate patterns (space separated).
`A|B`	Used to define a union of A and B.
`A+`	Used to define a one or more pattern of A.
`A*`	Used to define a zero or more pattern.
`A?`	Used to define an optional pattern.
`(A)`	Used to group a pattern.
`"T"` or `'T'`	Used to define a terminal symbol.
`@A`	Used to indicate anything except A.
`;`	Used to terminate a given production rule.

Table 1.1: Variation of EBNF syntax used by this thesis

As a simple example, to define a language that consists of a single integer, the following EBNF grammar could be used:

```
integer
     :  ("-" | "+")?  digit+
     ;
digit
     :  "0"|"1"|"2"|"3"|"4"|"5"|"6"|"7"|"8"|"9"
     ;
```

This variation is often used by many parser generators since it introduces a more visible and versatile approach to write the language grammar.

1.2.2 Compilers

The job of a compiler is to take an input program written in a programming language and translate it into another as shown in Figure 1.1. The compiler term is often used to express a translation to a much different level of abstraction, that usually means that the input is written in a high-level language and further translated into another low-level language.

Figure 1.1: Compiler overview

Phases of a compiler

A compiler can also be decoupled into different parts. Each part does a very different job but they are all connected to each other. In a typical compiler architecture, we may find all the different phases described in Figure 1.2.

Those phases are often found to be different depending on the implementation of the language. However, it's important to note what they do, since they are often implemented in one way or another. More implementation details are explained in their respective chapters but in this section, a small introduction to each phase is needed to understand the Nuua's system.

- *Lexical analysis*: In this phase, the input source is transformed from a character string into a token list, this is also called tokenization. Lexemes found in the source program are translated into individual tokens using different patterns. For example, some tokens might include integers, symbols (+, -, *, etc.), identifiers or keywords ('if', 'while', etc.).
- *Syntax analysis*: In this phase, the implementation may vary among compilers, some of them work close to the lexical analysis since they can work together. However, its purpose is to perform operations given the token list to parse the input and create an Abstract Syntax Tree (AST). As seen in [Kei11, Section 5.2.1], an AST is a data structure that represents the input program. (AST). As seen in [Kei11, Section 5.2.1], an AST is a data structure that represents the input program. This stage determines if it's a valid program based on the language grammar and the specified rules. There are also scanner-less parsers that take the lexical analysis and the syntax analysis into a single step. It is harder to understand and debug compared to the modularity of splitting these two phases but it has some advantages like removing the token classification as mentioned in [Wik19].
- *Semantic analysis*: This phase analyzes the AST and creates a symbol table while analyzes the input source with things like type checking or variable declarations, if some operations can be performed (for example adding a number with a string). A symbol table is a structure used by further phases to see information attached to specific source code parts. For example, it can store information about a variable (if it's global, exported, etc.).
- *Intermediate code generator*: An Intermediate representation (IR) can be avoided but it's often used to have a platform independent optimizer. Usually the code

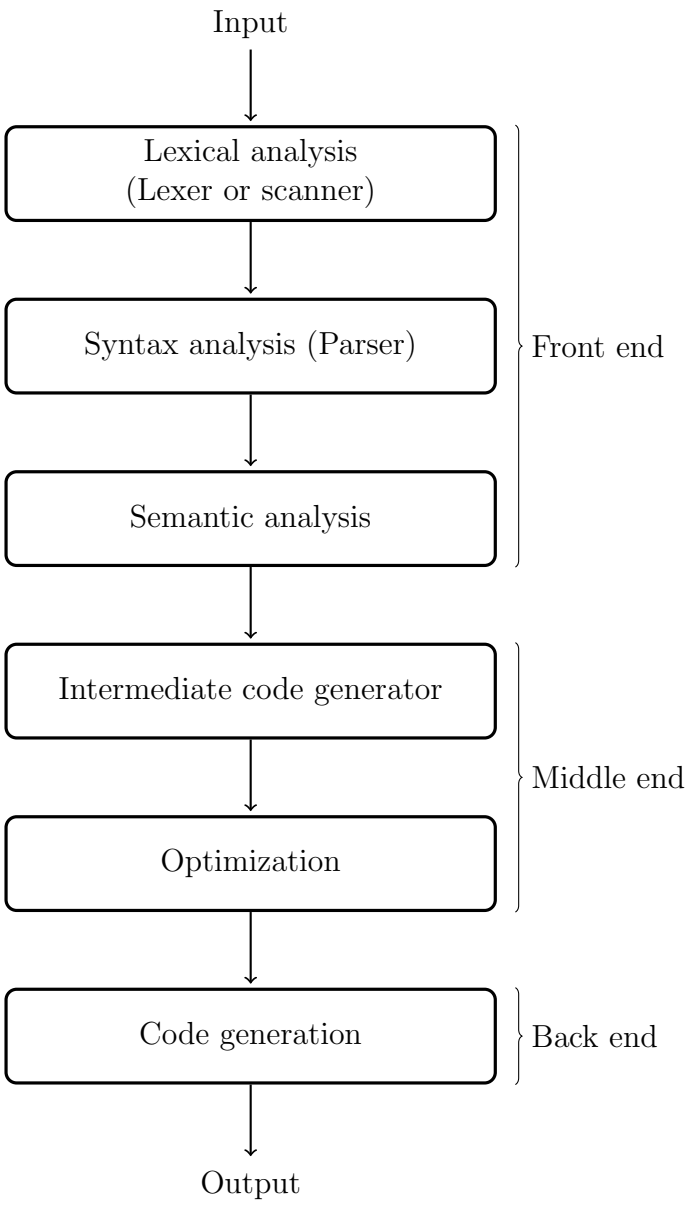


Figure 1.2: Common compiler phases

generation targets a specific architecture and would require different optimizers depending on each architecture. However, by having an IR it's possible to have a single optimizer. A much used IR is Three Address Code (TAC) that can be organized in quadruples or triples as seen by some examples in [Agg12].

- *Optimization*: This optimization is often performed on the IR and performs different tasks to allow a faster and smaller output. For example, it may remove dead code, perform loop optimizations, etc.
- *Code generation*: This is where the real translation takes place, it translates the IR into a different language output. For example machine code. This phase often has to deal with instruction scheduling or register allocation while they have to output a fully working program.

1.2.3 Interpreters

There are different ways to interpret a program. Among the most popular options we can find a bytecode interpreter and an AST interpreter.

- *Bytecode interpreter*: The program is first compiled to bytecode instructions and further interpreted. Bytecode interpreters are often implemented as virtual machines since most of the times bytecode instructions are very similar to real hardware instructions. The usual choices are stack or register machines. There have been many discussions on the advantages and the inconveniences of both of them, more information may be seen at [Yun05]. An example of a virtual machine is the Lua virtual machine [Rob05].
- *Abstract syntax tree interpreter*: This kind of interpreters just need the AST to work with, so no extra compilation to bytecode is needed and therefore, they are easier to implement. However, due it's nature, they are much slower to execute and debug due to the recursiveness of working with tree data structures.

1.2.4 Just-in-time compilers

Just-in-time compilers (often called JIT compilers) are an intermediate approach between a compiler that generates machine code and an interpreter. JIT compilers compile chunks of code at specific moments while the program run to speed up portions of the code that is being interpreted (for example functions that are called frequently). Essentially, the JIT compiler needs to decide when to compile a specific part of the code at runtime and adds a small overhead in exchange for a machine-language performance on specific parts of the program.

More information about JIT compilers and the tools that can be used can be found at [Tim10].

1.3 System architecture

To design the system architecture of Nuua, consideration of existing system architectures needs to be taken since existing architectures often work better than the custom-made ones and they often lead to greater project scalability. It's trivial to make this choice before starting the project since changing a system architecture after it's initial development phases becomes a very bad choice and may lead to a big ball of mud. Two choices in software development might be hierarchical or layered systems. Nuua's architecture is based on a *layered system* [Fel00].

A layered system has specific requirements regarding code communication. Specifically, a layered system consists of different layers arranged vertically. Those layers have a specific criterion that needs to be met. As a matter of fact, each layer can only use the layer below and gives an API for the layer above (if any) to use its functions. For example, the Figure 1.3 shows a simple 3-tier layered system. Layer 3 can only use Layer 2, and the output comes from Layer 2. Layer 3 cannot use Layer 1 nor expect any outputs from it. It's the Layer 2 responsibility to use the Layer 1 and process its output before it can give its own output.

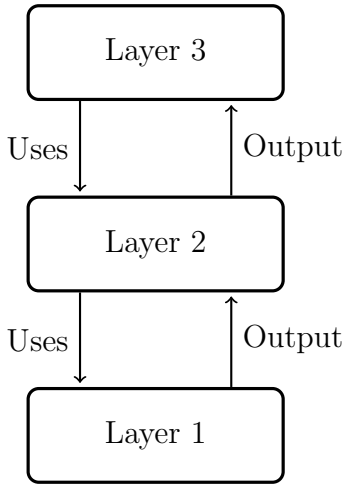


Figure 1.3: Layered system

This system is known to be robust, easy to test and with a high ease of development as mentioned in [Mar15]. It's very easy to understand and a widely used system. This system is also used for other complex software systems, such as operating systems or complex protocols like TCP/IP.

By using a layered system each layer gets completely isolated and works independently by just using the layer below, creating a way to scale-up or upgrade existing parts of the system without damaging the others. This introduces a very powerful *separation of concerns* among all the system layers since each layer has a specific role and only deals with the logic that pertains to it. However, a consistent API should, in fact, be

established from the ground up to avoid backward incompatible changes. If the API is maintained, the individual layers may be upgraded independently without the need for extra work.

Figure 1.4 shows the Nuua architecture. An independent module called Logger is found on the left side of the figure. This module is a logger used by all layers to output messages if needed (for example error reporting).

- *Logger*: Used by all layers to debug or log errors. In case of a fatal error, the logger outputs an error stack in a fancy way and terminates the application.
- *Application*: This layer is used to decode the command line arguments and fire up the compiler toolchain. In short, the purpose is to analyze the command line arguments and fire the application accordingly.
- *Virtual Machine*: The virtual machine is the interpreter that runs Nuua. It's a register-based virtual machine that acts as the Nuua runtime environment.
- *Code generator*: Is responsible for the translation of the AST to the virtual machine bytecode. This acts as the code generation part of a compiler architecture.
- *Semantic analyzer*: Does all the semantic analysis of the compiler and optimizes the AST for faster and smaller output.
- *Parser*: Acts as the syntax analyzer, it uses a list of tokens and generates a fully valid AST.
- *Lexer*: Scans the source code and translates the characters to tokens, creating a list of tokens representing the original source code.

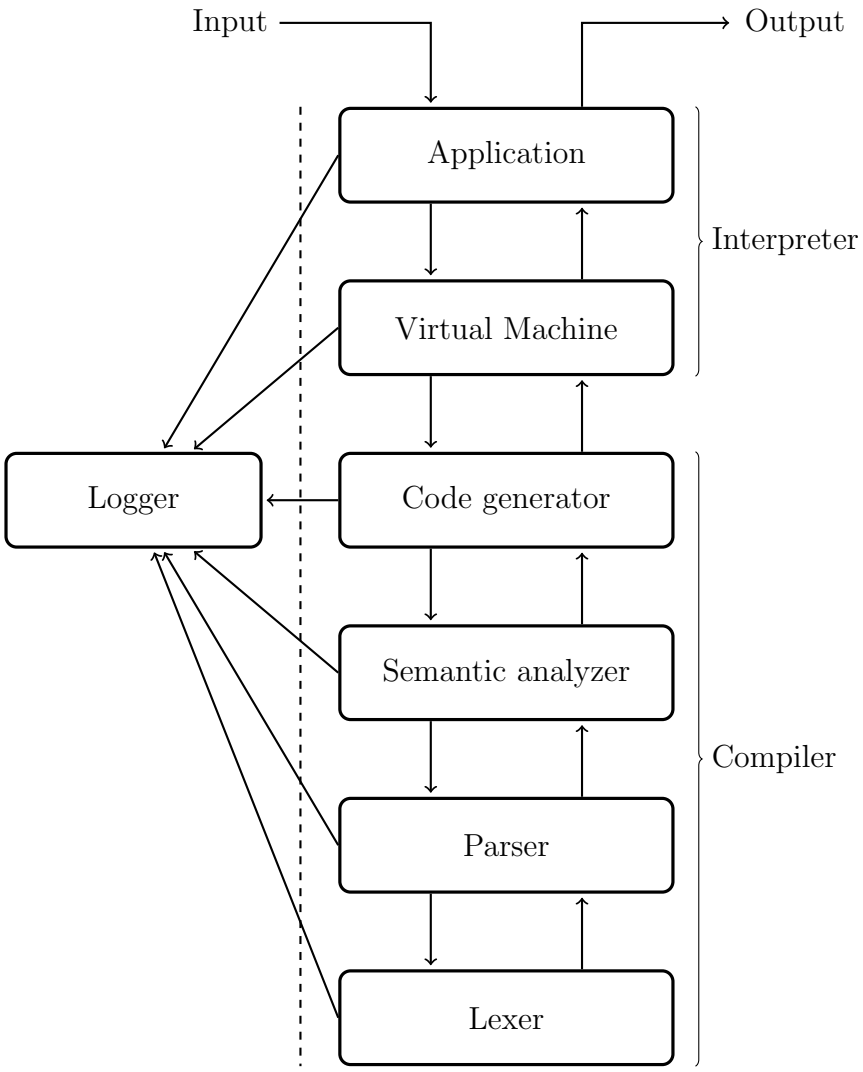


Figure 1.4: Nuua's architecture diagram (Layered System)

2 The Nuua Language

> *"Progress comes from finding better ways to do things. Don't be afraid of innovation. Don't be afraid of ideas that are not your own."*
>
> — Douglas Crockford, *December 21, 2006*

This chapter defines the Nuua programming language. Nuua is a general purpose programming language with an imperative paradigm and a statically typed system. The Nuua compiler and virtual machine explained in this thesis are written in C++ with a zero-dependency policy. The interpreter is a register-based bytecode virtual machine.

Nuua's system architecture built in this thesis, as described in section 1.3, consists of a compiler that translates a program written in Nuua into bytecode instructions and of a virtual machine interpreter that executes those bytecode instructions.

2.1 Grammar

Nuua's grammar is inspired by other existing programming languages by taking advantage of some of the best features some of them offer. Inspiration comes especially from Python [Pyt], Rust [Theb] and Go [Thea].

The precedence relationship between expressions is heavily inspired by C [Bri88], D [D L], Rust [Theb], and Dart [Goo]. The official documentation for those languages exposes similar tables for operator precedences and Nuua has taken akin levels of precedence as those.

Nuua does not make use of the `";"` to separate statements, instead, it uses the same separator as Go. Statements can be separated by a `"\n"` but it does not make use of the `"\t"` to indicate statements inside blocks, and uses the typical block separator `"{"` ... `"}"`.

2.1.1 Lexical Grammar

Lexical grammar is used by the lowest layer of the Nuua system to scan the source language and identify different terminal symbols. The main difference with the syntax

grammar, as exposed in [Bob18, Appendix I], is that the syntax grammar is a context-free grammar and lexical grammar is a regular grammar.

Nuua's lexical rules are as follows:

```
DIGIT
    : "0" | ... | "9"
    ;
```

Digits are any character from '0' to '9'.

```
ALPHA
    : "a" | ... | "z"
    | "A" | ... | "Z"
    | "_"
    ;
```

Alpha are characters that are part of the English alphabet in lower or upper case. It also includes '_' as a special character.

```
ALPHANUM
    : DIGIT
    | ALPHA
    ;
```

Alphanum are characters that are either part of the alphabet or are digits.

```
INTEGER_EXPR
    : DIGIT+
    ;
```

Integers are a single digit or more found sequentially without spaces. The integer sign is not represented here.

```
FLOAT_EXPR
    : DIGIT+ "." DIGIT+
    ;
```

Floats are like integers but require a dot followed by a digit or more, creating a decimal number.

```
BOOL_EXPR
    : "true"
    | "false"
    ;
```

Bools are either 'true' or 'false', that are keywords.

```
STRING_EXPR
    : '"' @'"' '"'
    ;
```

Strings represent a character string with the possibility to escape '"' by using a '\' as a prefix, more on that in the upcoming sections.

```
IDENTIFIER
    : ALPHA ALPHANUM*
    ;
```

Identifiers are an alpha character followed by an optional one or more alphanumeric character.

2.1.2 Syntax Grammar

The syntax grammar is used by the parser to build the abstract syntax tree that determines the program's execution flow. These rules include all top-level declarations, statements, and expressions.

Program and Top Level Declarations

```
program
    : top_level_declaration*
    ;
```

A Nuua program is a list of top-level declarations.

```
top_level_declaration
    : use_declaration "\n"
    | fun_declaration "\n"
    | class_declaration "\n"
```

```
    | export_declaration "\n"
    ;
```

A top-level declaration can only be one of the specified rules. Top-level declarations are a special type of declaration that can only be declared on the module and not inside other blocks.

```
use_declaration
    : "use" STRING_EXPR
    | "use" IDENTIFIER ("," IDENTIFIER)* "from" STRING_EXPR
    ;
```

A use declaration is used to import other top-level declarations from other modules. By using the first rule, Nuua imports all the exported targets of the module pointed by STRING_EXPR. Otherwise, Nuua imports the specified targets from the modules.

```
fun_declaration
    : "fun" IDENTIFIER "(" parameters? ")" (":" type)? fun_body;
    ;
parameters
    : variable_declaration ("," variable_declaration)*
    ;
fun_body
    : "->" expression "\n"
    | "=>" statement
    | "{" "\n" statement* "}" "\n"
    ;
```

A function is defined using the keyword `fun` followed by the function name, and a list of optional parameters enclosed in parentheses. The function type is specified after the parameter list by using `:`. The return type might not be present if the function has no return value. The function body is specified in three different ways depending on the type of the function body that is expected.

```
class_declaration
    : "class" "{" class_statement* "}"
    ;
class_statement
    : variable_declaration
    | fun_declaration
    ;
```

A class uses a keyword `class` and expects zero or more class statements.

```
export_declaration
    : "export" top_level_declaration
    ;
```

An export declaration marks the following top-level declaration as exported, making it available for other modules to import it using the use declaration.

```
statement
    : variable_declaration "\n"
    | if_statement "\n"
    | while_statement "\n"
    | for_statement "\n"
    | return_statement "\n"
    | delete_statement "\n"
    | print_statement "\n"
    | expression_statement "\n"
    ;
```

Statements are used to change the program's flow or indicate simple actions like declaring a variable.

```
variable_declaration
    : IDENTIFIER ":" type
    | IDENTIFIER ":" type "=" expression
    | IDENTIFIER ":" "=" expression
    ;
```

A variable declaration may have a type assigned with it, or the declaration type will be inferred from the initializer.

```
if_statement
    : "if" expression if_body el_if* else?
    ;
if_body
    : "=>" statement "\n"
    | "{" "\n" statement* "}"
    ;
el_if
```

```
    : "elif" expression if_body
    ;
else
    : "else" expression if_body
    ;
```

An `if` statement is declared with the `if` keyword followed by the expression of its condition. The `if` body may be declared in two different ways depending on the if body. The `elif` word may be used as a shorthand to an `else` followed by an "if" inside. An optional `else` condition may be added at the end of the `if`.

```
while_statement
    : "while" expression while_body
    ;
while_body
    : "=>" statement "\n"
    | "{" "\n" statement* "}"
    ;
```

A `while` statement uses the `while` keyword followed by the expression of the condition and the `while` body, that can be specified in two different ways depending on the body contents.

```
for_statement
    : "for" IDENTIFIER ("," IDENTIFIER)? "in" expression for_body
    ;
for_body
    : "=>" statement
    | "{" "\n" statement* "}"
    ;
```

A `for` statement acts is a way to interate a nuua iterator Table 2.3. It gets declared by using the `for` keyword followed by an identifier that will be used to store the element in the iterator. An optional second identifier may be given in case the loop index needs to be stored as well. Those values change in every iteration. After the identifiers, the `in` keyword is expected, followed by the iterator expression and the `for` body, that can be declared in two different ways depending on its content.

```
return_statement
    : "return" expression?
    ;
```

A `return` statement uses the `return` keyword and an optional expression to return.

```
delete_statement
    : "delete" expression
    ;
```

A `delete` statement uses the `delete` keyword and an expression willing to delete.

```
print_statement
    : "print" expression?
    ;
```

The `print` expression is a statement that outputs an expression to the screen. This is a temporary statement used while Nuua is not able to properly read and write to files (stdout / stdin) in this specific case.

```
expression_statement
    : expression
    ;
```

An expression statement may be used as an expression whose value is not used or no value is returned from it.

Expressions

Expressions are grouped in different production rules depending on their precedence, this is done due to the parsing strategy used and helps to visualize the precedence by reading the grammar.

```
expression
    : assignment
    ;
```

An expression is reduced to an assignment.

```
assignment
    : range ("=" range)*
    ;
```

An assignment expression is written by an expression on the left-hand side and on the right-hand side with a `=` in the middle.

```
range
    : logical_or (".." | "...") logical_or)*
    ;
```

A range expression is written by an expression on the left-hand side and on the right-hand side with a `..` or `...` in the middle. Depending if the range is exclusive or inclusive.

```
logical_or
    : logical_and ("or" logical_and)*
    ;
```

A logical `or` is a binary operation with the keyword `or` in the middle.

```
logical_and
    : equality ("and" equality)*
    ;
```

A logical `and` is a binary operation with the keyword `and` in the middle.

```
equality
    : comparison ("!=" | "==") comparison)*
    ;
```

An equality comparison is a binary operation with a `!=` or `==` in the middle depending if the check needs to be negated or not.

```
comparison
    : addition (">" | ">=" | "<" | "<=") addition)*
    ;
```

A comparison is similar to equality but checks the values to determine if the left-hand side is greater, greater than, lower and lower than the right-hand side.

```
addition
    : multiplication ("-" | "+") multiplication)*
    ;
```

An addition is used to perform an addition or subtraction of two values.

```
multiplication
    : cast (("/" | "*") cast)*
    ;
```

Multiplication is used to perform multiplication or division of two values.

```
cast
    : unary_prefix ("as" type)*
    ;
```

A cast performs a type cast of the values on the left-hand side to the value of the right-hand side by using the `as` keyword.

```
unary_prefix
    : ("!" | "+" | "-") unary_prefix
    | unary_postfix
    ;
```

The unary prefixes are used to change a value state by prefixing the operation.

```
unary_postfix
    : primary unary_p*
    ;
unary_p
    : "[" expression "]"
    | slice
    | "(" arguments? ")"
    | "." IDENTIFIER;
    ;
slice
    : "[" expression? ":" expression? (":" expression?)? "]"
    ;
arguments
    : expression ("," expression)*
    ;
```

The unary postfixes are used to either access a value or mutate it's content, to slice it's contents, to call a value or to access a value property.

```
primary
    : BOOL_EXPR
    | INTEGER_EXPR
    | FLOAT_EXPR
    | STRING_EXPR
    | IDENTIFIER
    | LIST_EXPR
    | DICTIONARY_EXPR
    | OBJECT_EXPR
    | "(" expression ")"
    ;
```

Primary expressions have the highest precedence and are mostly native types, with the exception of the expression group.

```
OBJECT_EXPR
    : IDENTIFIER "{" object_args? "}"
    ;
object_args
    : IDENTIFIER ":" expression ("," IDENTIFIER ":" expression)*
    ;
```

An object is defined by an identifier containing the class name, followed by optional arguments surrounded by { and } to initialize the class properties.

```
LIST_EXPR
    : "[" expression ("," expression)* "]"
    ;
```

Lists can't be empty, so at least one expression must be provided.

```
DICTIONARY_EXPR
    : "{" IDENTIFIER ":" expression ("," IDENTIFIER ":" expression)* "}"
    ;
```

Dictionaries, like lists, can't be empty, so at least one expression must be provided.

2.1.3 Operator Precedence

Given that expressions are grouped by their precedence, the operator precedence table of Nuua is as follows:

Level	Operators	Associativity
1	`A[B], A[B:C:D], A(B, C, D, ...), A.B`	Left-to-right
2	`!A, +A, -A`	Right-to-left
3	`A as B`	Left-to-right
4	`A/B, A*B`	Left-to-right
5	`+A, -A`	Left-to-right
6	`A>B, A>=B, A<B, A<=B`	Left-to-right
7	`A!=B, A==B`	Left-to-right
8	`A and B`	Left-to-right
9	`A or B`	Left-to-right
10	`A..B, A...B`	Left-to-right
11	`A=B`	Right-to-left

Table 2.1: Nuua operator precedence from highest to lowest with the associativity

2.1.4 Keywords and Reserved Words

Keywords are a special subset of identifiers that have a special meaning in a Nuua program. A reserved word is an identifier that can't be used as such, and in Nuua, no keywords can be used as identifiers therefore making all keywords reserved words at the same time. All keywords can already be identified by looking at the grammar rules, the following list shows all of the keywords in Nuua.

(i)	`true`	(ii)	`false`	(iii)	`as`	(iv)	`or`
(v)	`and`	(vi)	`if`	(vii)	`else`	(viii)	`for`
(ix)	`in`	(x)	`while`	(xi)	`return`	(xii)	`print`
(xiii)	`class`	(xiv)	`fun`	(xv)	`use`	(xvi)	`from`
(xvii)	`elif`	(xviii)	`export`				

More information about the `print` keyword and why it does exist can be found in subsection 2.5.11.

2.1.5 Escaped Characters

There are some characters that can be escaped in Nuua, for example when the value `'"'` wants to be used inside a string where the delimiters are also `'"'`. To escape a character, the prefix \ needs to be used followed by the character willing to escape. The following list gives a view of all the available characters that allow beeing escaped found in Nuua.

(i) \
(ii) `'`
(iii) `"`
(iv) `n`
(v) `t`
(vi) `r`
(vii) `b`
(viii) `f`
(ix) `v`
(x) `0`

2.2 Scopes

Scopes refer to the visible area of the variables, in other words, it determines where the association between a variable name and its value (known as name binding) is valid. This area is known as a scope block.

Nuua have two levels of scope blocks:

1. *Module scope*: Any top-level declaration found in Nuua is bound to the module scope. Any other module won't see that top-level declaration unless it is exported and the module is trying to use it.
2. *Block scope*: Any declaration found in any statement that contains blocks (statements found in Table 2.2) is only valid inside of the block.

Statement	**Blocks**
Function declaration	Body
Class declaration	Body
If statement	Then and Else
While statement	Body
For statement	Body

Table 2.2: Nuua statements with scope blocks

2.3 Entry point

A Nuua program requires an entry point to start executing the instructions. The entry point in a Nuua program is a function that must be called `main`. This function must exist in the initial module. If the function does not exist an error is thrown prior to execution. The `main` function needs at least one argument of type `[string]` that does contain the command line arguments.

The Nuua virtual machine does automatically call the `main` function upon starting executing the bytecode with the command line arguments of the call.

An example `main` may be as follows:

```
fun main(argv: [string]) {
    // ...
}
```

2.4 Data types

This section defines all the Nuua data types that are supported. Each value in Nuua has a type associated with it, meaning that each value must belong to a certain data type. A value can't belong to multiple data types at once but can be cast to others if a change is required.

2.4.1 Integers

Integers are named as `int` and they are a subset of $\mathbb{Z}$. It includes 0 and the integers are stored using 64 bits using two's complement. Meaning its range for a given integer x is:

$$-2^{64-1} < x < 2^{64-1} - 1$$

2.4.2 Floats

Floats are named as `float` and they are C++ `double` precision points that use a total of 64 bits. 52 fraction bits, 11 bits of exponent and 1 sign bit.

2.4.3 Booleans

Booleans are named as `bool` and they are simple booleans, they can be either `true` or `false` and they are stored in a C++ `bool` type, usually using 8 bits to store it.

Examples

```
true
false
```

2.4.4 Strings

Strings are named as `string` and they are used to manipulate arrays of chars. It's implementation uses a C++ `std::string` and it's planned to support wider characters as mentioned in Chapter 10. It can store any text that's surrounded by `'"'`.

2.4.5 Lists

Lists are named as `[type]` and they are used to manipulate a list of other values. They can only have a single type as the inner list items, so all the list items need to be of the same type.

2.4.6 Dictionaries

Dictionaries are named as {`type`} and they are used to store values of the same type. However, unlike lists, they use a string-based mapping, allowing each value to be bound to a specific string key, instead of an integer index as the key. Dictionaries, like lists, can only store 1 type of values. So each key can only store the same type.

2.4.7 Functions

The only way to define a function is by using the "fun" keyword as noted in section 2.1.2. However, functions in Nuua act as first-class values, meaning that values can contain a function, allowing the function to change without actually changing its type. The function type needs to be consistent. So even if the function changes, it will always accept the same arguments and it will return the same data type. Function types are named as `(T1, T2, ..., TN -> TR)`. where `T1` to `TN` are the types of the function parameters. If the function has a return type, say `TR`, it needs to be specified with a simple arrow pointing at it the end of the function type.

To see how functions are declared head to subsection 2.5.2

Examples

Function without parameters nor return type.

```
()
```

Function with 2 parameters of type int and a float return type.

```
(int, int -> float)
```

Function without parameters and a return type of a list of strings.

```
(-> [string])
```

Function with two parameters of type int and bool and no return type.

```
(int, bool)
```

2.4.8 Objects

Objects are named according to the class they represent. If a class is named `Person` the type name is `Person`.

2.5 Statements

This section explains and gives examples to all statements found in Nuua.

Some of the statements may have already been mentioned briefly in section 2.1.2.

2.5.1 Use Declaration

The use declaration is used when a module needs to use a top-level declaration that is found in another module. The target module is the string given in the use declaration. A path system is used to search for the file, first trying to find it relatively from the current module path, ending at the standard library folder that comes with Nuua.

The use declaration comes in two different shapes. By using the use declaration with a single string it imports all the top level declarations that are exported in the target module. Instead, by determining the "use" identifiers, you may import only selected top-level declarations.

Caveats

- The target module path given in the use declaration can use a relative or absolute path.
- If the target module path does not have the `".nu"` extension, it will be added automatically.
- If the target module is not found in any path, an error is thrown before any execution starts.

- If a target top-level declaration is not found in the target module an error is thrown before any execution starts.
- If the top level declaration is not exported another error will be thrown prior to execution.

Examples

Import all exported targets in a relative file path named "test.nu"

```
use "test"
```

Import `a` and `b` from a relative file path named "test.nu"

```
use a, b from "./test.nu"
```

Import `a` from an absolute file path in "C:/Nuua/test.nu"

```
use a from "C:/Nuua/test.nu"
```

2.5.2 Function Declaration

A function declaration creates a function value and a data type given the function parameters and return value. Once the function value is created, it's then added in a new variable with the function name. That variable can be modified since functions are first-class values in Nuua. The variations in a function body exist to minimize the code length in certain situations (When a function is a single return expression, a single statement or a block of statements).

Caveats

- No function overloading is allowed.
- Function parameters do not allow default values.
- If the function returns a value, you are expected to, at least, write a single return statement in the top level of the function block.
- Functions without return type can't be used as formal expressions since they contain no values.

Examples

Function without parameters and no return type.

```
fun a() {
    print "Hello, World"
}
```

Function without parameters and return type.

```
fun b(): string {
    return "Hello, World"
}
```

Function with parameters and no return type.

```
fun c(x: string) {
    print "Hello, " + x
}
```

Function with parameters and return type.

```
fun d(x: string): string {
    return "Hello, " + x
}
```

Single statement function.

```
fun e(x: string): string => return "Hello, " + x
```

Single expression function.

```
fun f(x: string): string -> "Hello, " + x
```

2.5.3 Class Declaration

A class declaration creates a data type of the given class structure. This type can then be used as a regular type to specify values of the given class. To create an object of a given class you can use the object expression as explained in subsection 2.6.7. Classes act as structs with the fact that they can also contain methods bound to them. Class methods have a variable called `"self"` as a self-reference to the object to mutate its state.

Caveats

- Class properties can't have default values. Values are defined when creating the object using an object expression.
- Self-references to the same type are allowed.
- There is no class inheritance.

Examples

Simple class to represent a person.

```
class Person {
    name: string
    age: int
    fun show() {
        print self.name + ", " + self.age as int
    }
}
```

2.5.4 Export Declaration

The export declaration is used when a module wants to make a top-level declaration available to use for other modules. Marking a top-level declaration as exported allows other modules to import and use it.

Caveats

- You can't export another export.

Examples

Export a function

```
export fun add(a: int, b: int): int {
    return a + b
}
```

Export a class.

```
export class Person {
    name: string
    age: int
}
```

2.5.5 Variable Declaration

Variable declarations are scoped to the block where they are declared as mentioned in section 2.2. They can be used from the block they have been declared and on the lexical blocks that may exist inside of it. A variable with the same name can't be declared in the same lexical block but multiple lexical blocks may have the same variable name. When getting the value of a variable, the lookup starts from the current block and goes back to previous blocks.

Caveats

- Even if multiple blocks have the same variable name, they all point to different values.
- If a variable is declared with an initializer, the type can be inferred by leaving the type empty.
- If a variable is declared without an initializer, the value is default initialized to a zero-state.
- If a variable is declared in a block that already contains a variable with the same name, an error is thrown before execution.

Examples

Simple variable declaration (defaults to `int`'s zero state, in this case 0).

```
a: int
```

Variable declaration with an initializer.

```
b: int = 10
```

Variable declaration with an inferred `int` type.

```
c := 10
```

2.5.6 If Statement

An `if` statement is used to execute a block of code when a certain expression (known as condition) evaluates to `true` known as the `then` block. The `if` statement can also execute another block if the condition is `false` known as the `else` block. The `else` block can be defined using the `"else"` keyword. An if statement has a shorthand for defining another if inside the `else` block, making nested if statements easier to write. This syntax uses the `"elif"` keyword and acts the same way as defining an `else` block with another if statement inside. Additionally, the if statement body may be defined in different ways depending on the body type. If the body consists of a single statement, shorthands can be used to minimize the lines of code.

Caveats

- The condition must always be a boolean. Explicit casting is needed.

Examples

Simple if statement.

```
if condition {
    print "Condition is true"
}
```

If statement with an else block.

```
if condition {
    print "Condition is true"
} else {
    print "Condition is false"
}
```

If statement with multiple nested conditions.

```
if number == 0 {
    print "The number is 0"
} elif number == 1 {
    print "The number is 1"
} else {
    print "The number is not 0 nor 1"
}
```

If statement with the shorthand body.

```
if number == 0 => print "The number is 0"
elif number == 1 => print "The number is 1"
else => print "The number is not 0 nor 1"
```

2.5.7 While Statement

A while statement is used to repeat a block of code while a certain expression (known as a condition) evaluates to `true`. The condition is evaluated every time the loop is about to begin. If the while block is executed the program counter jumps back to the condition to evaluate it again. When the condition is no longer true, the program counter skips the block and continues execution. The while statement also has a shorthand to define its body when it only consists of a single statement.

Caveats

- The condition must be a value of `bool` type. Explicit casting is needed.

Examples

Simple while statement.

```
while condition {
    print "Condition is true"
}
```

Using the shorthand for single statements.

```
while condition => print "Condition is true"
```

Real world while example

```
a: int = 0
while a < 10 => {
    print a
    a = a + 1
}
```

2.5.8 For Statement

A for statement is very similar to a while statement but instead of working with a condition it works with an iterator. An iterator is a data type that supports indexation and therefore, can be iterated. Nuua iterators are:

Data type	Value Type	Index Type
`string`	`string` (a single character)	`int`
`[T]`	`T`	`int`
`{T}`	`T`	`string`

Table 2.3: Nuua iterators

Indexation is done with the *Access* expression. The for loop defines up to two variables to its block. One containing the current value of the indexed item and another optional variable containing the current index being used.

Caveats

- The value and the index are variables that are automatically declared with their respective types in the "for" block.
- The value and the index types are automatically inferred according to Table 2.3.

Examples

Simple for statement.

```
for char in "string" {
    print char
}
```

For statement with the index.

```
for letter, index in ["A", "B", "C"] {
    print index as string + ": " + letter
}
```

For statement with the shorthand.

```
for num in 0..10 => print num
```

2.5.9 Return Statement

A return statement is used inside the function to determine its execution should end, and optionally return a value as the result. Return statements are mandatory in functions that have a return type.

Caveats

- If the function has a return type, at least one return at the top level of the function block is required. Otherwise, an error is thrown prior to execution.
- Return expression type must match the function's return type.

Examples

A simple return statement.

```
fun a() {
    return
    print "Never executed"
}
```

A return statement returning a value.

```
fun b(): int {
    return 10
}
```

2.5.10 Delete Statement

The delete statement is used to delete a specific index of a target. The target must be a Nuua iterator as shown in Table 2.3. The rule must be an access expression to indicate the exact element to delete.

Caveats

- The target must be a Nuua iterator and the rule must be an access.

Examples

A simple delete statement.

```
a: [int] = [1, 2, 3]
delete a[1]
// a is now [1, 3]
```

2.5.11 Print Statement

The print statement is used to write a register to the `stdout` file. This statement will be finally deleted alongside the keyword when a propper I/O is added into the language as mentioned in Chapter 10.

Caveats

- Any data type can be printed with this statement. Even functions and objects.

Examples

A simple print statement.

```
print "Hello, World"
```

A print of a function

```
fun a(): int {
    print a
    return 10
}
```

2.6 Expressions

Expressions can always be reduced up to a value of a single data type. This section explains all the expressions that can be found in Nuua.

Some of the expressions may have already been mentioned briefly in section 2.1.2.

2.6.1 Integer Expression

The integer expressions can be written as an integer number directly in the source code. Integer expressions return a value with the `int` data type.

Caveats

- There are no prefix/postfix indicators to change the integer bit size or base (Like LL, 0x, etc.).

Examples

```
0
25
81237
-6378
-1
```

2.6.2 Float Expression

The float expressions can be written as any floating point number, using a `"."` as the decimal delimiter, directly in the source code. Float expressions return a value with the `float` data type.

Caveats

- An integer followed by a `"."` without any other number on the right-hand side, it's considered an error. An explicit number must be written in the right-hand side to create a float expression, even to indicate `.0`.

Examples

```
0.0
25.5
81237.11111
-6378.673
-1.9
```

2.6.3 Boolean Expression

The boolean expressions can be written as either `true` or `false` directly in the source code. Boolean expressions return a value with the `bool` data type.

Examples

```
true
false
```

2.6.4 String Expression

The string expressions can be written as any text enclosed between `'"'` directly in the source code. String expressions return a value with the `string` data type.

Caveats

- As for June 5, 2019, the strings use a bare-bones C++ `std::string` to represent the string, that means that the string is a list of single-byte characters (characters in the ASCII character table). A plan to support wider characters is mentioned in Chapter 10.

Examples

```
"A string is represented like this"
```

2.6.5 List Expression

The list expressions can be written as list of expressions separated by comma enclosed between `"["` and `"]"` directly in the source code. A list inner type, say `T`, is determined by the type of the first expression of the list. List expressions return a value with the `[T]` data type.

Caveats

- List expression can't be empty due to an unknown type. Even when assigning them to a variable with a defined type. If there's the need for an empty list of a given type, declare a variable with the type and don't initialize it.
- Lists can only have a single type stored on it, therefore, if a list expression have more than one expression on it, the types must match. If a type does not match the first type of the list, an error is thrown prior to execution.

Examples

A list expression that return a value of type `[string]`.

```
["this", "is", "a", "valid", "list", "of", "strings"]
```

A list expression that return a value of type `[int]`.

```
[1]
```

2.6.6 Dictionary Expression

The dictionary expressions can be written as a list of comma-separated pairs of `key: expression` The key is an identifier representing the dictionary key willing to be used. directly in the source code. A dictionary inner type, say `T`, is determined by the type of the first expression of the list. Dictionary expressions return a value with the {`T`} data type.

Caveats

- Dictionary expression can't be empty due to an unknown type. Even when assigning them to a variable with a defined type. If there's the need for an empty dictionary of a given type, declare a variable with the type and don't initialize it.
- Dictionaries can only have a single type stored on it, therefore, if a dictionary expression have more than one expression on it, the types must match. If a type does not match the first type of the dictionary, an error is thrown prior to execution.

Examples

A dictionary expression that return a value of type {`string`}.

```
{name: "Erik", occupation: "Student", color: "#ff0000"}
```

A dictionary expression that return a value of type {`int`}.

```
{left: 10, right: 20, sum: 30}
```

2.6.7 Object Expression

The object expression is used to initialize an object of a given class. The object expression is used by writing the identifier of the class followed by a `!` and list of comma-separated pairs of `key: expression` (where the key is an identifier) enclosed between { and }. The keys in the argument list are the class properties willing to initialize and the expression is the value that the property is going to be assigned to.

Caveats

- The keys found in the arguments must exist in the class properties. If one of the keys does not correspond to an existing class property an error is thrown prior to execution.
- The expressions of the keys in the argument list must match the class property type they want to initialize. If there's a type mismatch, an error is thrown prior to execution.

Examples

An example class to provide the examples.

```
class Person {
    name: string
    born_at: int
}
```

An object of class Person without arguments.

```
Person!{}
```

An object of class Person with arguments.

```
Person!{name: "Erik", born_at: 1997}
```

2.6.8 Group Expression

The group expression is used to give certain operations priority over the default operator precedence. The group expression is an expression enclosed between `(` and `)`.

Examples

```
(1 + 2) * 3 // 9
(1 + 4 - 3) * (2 * (2 + 2)) // 16
```

2.6.9 Access Expression

The access expression is used to access an inner value of another expressions. In short, the access expression can be used in any Nuua iterator and the returned value is the inner value found on its index with the respective type as shown in Table 2.3.

Caveats

- Only nuua iterators can be accessed.

Examples

A string access.

```
"Hello"[1] // "e"
```

A list access.

```
["Hello", "World"][1] // "World"
```

A dictionary access.

```
{key1: "Hello", key2: "World"}["key1"] // "Hello"
```

2.6.10 Slice Expression

Slices act the same way as python slices and this explanation can be found in [Prz15]. Basically, it's a way to get a range of inner values in a Nuua iterator (Only those that can be index with an `int` type). The supported parameters are:

Parameter	Explanation
`start`	Starting index of the slice. Defaults to 0.
`end`	The last index of the slice or the number of items to get. Defaults to the length of the iterator
`step`	Optional. Extended slice syntax. Step value of the slice. Defaults to 1.

Table 2.4: Slice parameters

Caveats

- Only Nuua iterators whose inner value can be accessed using an `int` type can be sliced.

Examples

```
"Hello"[1:3] // "el"
"Hello"[1:] // "ello"
"Hello"[:3] // "Hel"
"Hello"[::2] // "Hlo"
"Hello"[::-1] // "olleH"
```

2.6.11 Call Expression

The call expression is used to call a value. The value needs to be callable and Therefore the value must be a function. When a call expression is used, its return value is the value returned from the function. The call accepts the arguments that will be passed to the function as the function parameters. The call expression is the caller and the target function is the callee.

Caveats

- If the callee has no return value, then the caller is banned from being treated as an expression, only being able to be used where its value is not used.

Examples

An example function acting as a callee.

```
fun test(a: int): int -> a + 1
```

An example call.

```
test(10) // 11
```

2.6.12 Property Expression

The property expression is used to access a specific property in an object, meaning that the target expression can only be an object. The property name is the identifier used after the dot.

Caveats

- If the object class has no property named as the identifier, an error is thrown prior to execution.
- If the object is not initialized, a runtime segmentation fault error is thrown.

Examples

An example class to work with.

```
class Person {
    name: string
}
```

An example property expression.

```
Person!{name: "Erik"}.name // "Erik"
```

2.6.13 Unary Expression

The unary expression is an expression that has an operation attached to it. Prefix notation is used to specify the operation to the expression. The list of available unary operations is found in Table 2.5.

Operation symbol	Operation
`-`	Unary negation of the expression on the right. The right expression must be an `int`, a `float` or a `bool`
`+`	Positive version of the `-`. Can be used to cast a `bool` to an `int`. The right expression must be an `int`, a `float` or a `bool`
`!`	Logical negation, the right expression must be a `bool`.

Table 2.5: Unary operations

Caveats

- A positive sign can be used to cast a `bool` to an int, although conventional casting can be used.

Examples

Example unary operations

```
-10 // -10
-(10 + 2) // -12
!false // true
+true // 1
```

2.6.14 Cast Expression

The cast expression is used to perform type conversion on values. The casts are checked prior to execution, and the supported list of casts is show in Table 2.6.

Input type	Cast type	Notes
`int`	`float`	Possible data loss.
`int`	`bool`	`false` when the value is `0`, otherwise `true`.
`int`	`string`	Conversion to a string representation.
`float`	`int`	Decimals are truncated. Possible data loss.
`float`	`bool`	`false` when the value is `0.0`, otherwise `true`.
`float`	`string`	Conversion to a string representation.
`bool`	`int`	`0` when the value is `false`, otherwise `1`.
`bool`	`float`	`0.0` when the value is `false`, otherwise `1.0`.
`bool`	`string`	Conversion to a string representation.
`string`	`bool`	`false` when the string length is `0`, otherwise `true`
`string`	`int`	Returns the string length.
`[T]`	`string`	Conversion to a string representation.
`[T]`	`bool`	`false` when the list length is `0`, otherwise `true`
`[T]`	`int`	Returns the list length.
{T}	`string`	Conversion to a string representation.
{T}	`bool`	`false` when the dictionary length is `0`, otherwise `true`
{T}	`int`	Returns the dictionary length.

Table 2.6: Nuua casts

Examples

Example casting operations.

```
10 as float // 10.0
25.8 as int // 25
false as string // "false"
[1, 2, 3] as string // "[1, 2, 3]"
[20, 30] as int // 2
```

2.6.15 Binary Expression

The binary expression is used to perform an operation that require two values to be done with the exception of the logical expression that is treated differently. The binary operations that can be performed are shown in Table 2.7, Table 2.8, Table 2.9 and Table 2.10.

Left type	Operation	Right type	Result type	Notes
`int`	`+`	`int`	`int`	`int` addition.
`float`	`+`	`float`	`float`	`float` addition.
`string`	`+`	`string`	`string`	`string` concatenation.
`bool`	`+`	`bool`	`int`	`bool` addition.
`[T]`	`+`	`[T]`	`[T]`	`[T]` concatenation.
`{T}`	`+`	`{T}`	`{T}`	`{T}` concatenation.

(i) Addition

Left type	Operation	Right type	Result type	Notes
`int`	`-`	`int`	`int`	`int` subtraction.
`float`	`-`	`float`	`float`	`float` subtraction.
`bool`	`-`	`bool`	`int`	`bool` subtraction.

(ii) Substraction

Table 2.7: Nuua additive binary operations

Left type	Operation	Right type	Result type	Notes
`int`	`*`	`int`	`int`	`int` multiplication.
`float`	`*`	`float`	`float`	`float` multiplication.
`bool`	`*`	`bool`	`int`	`bool` multiplication.
`int`	`*`	`string`	`string`	`string` repetition.
`string`	`*`	`int`	`string`	`string` repetition.
`int`	`*`	`[T]`	`[T]`	`[T]` repetition.
`[T]`	`*`	`int`	`[T]`	`[T]` repetition.

(i) Multiplication

Left type	Operation	Right type	Result type	Notes
`int`	`/`	`int`	`float`	`int` division.
`float`	`/`	`float`	`float`	`float` division.
`string`	`/`	`int`	`[string]`	`string` division.
`[T]`	`/`	`int`	`[[T]]`	`[T]` division.

(ii) Division

Table 2.8: Nuua multiplicative binary operations

Left type	Operation	Right type	Result type	Notes
`int`	`==`	`int`	`bool`	`int` equality.
`float`	`==`	`float`	`bool`	`float` equality.
`string`	`==`	`string`	`bool`	`string` equality.
`bool`	`==`	`bool`	`bool`	`bool` equality.
`[T]`	`==`	`[T]`	`bool`	`[T]` equality.
{`T`}	`==`	{`T`}	`bool`	{`T`} equality.

(i) Equality

Left type	Operation	Right type	Result type	Notes
`int`	`!=`	`int`	`bool`	`int` inequality.
`float`	`!=`	`float`	`bool`	`float` inequality.
`string`	`!=`	`string`	`bool`	`string` inequality.
`bool`	`!=`	`bool`	`bool`	`bool` inequality.
`[T]`	`!=`	`[T]`	`bool`	`[T]` inequality.
{`T`}	`!=`	{`T`}	`bool`	{`T`} inequality.

(ii) Inequality

Table 2.9: Nuua relational equality binary operations

Left type	Operation	Right type	Result type	Notes
`int`	`>`	`int`	`bool`	`int` higher than.
`float`	`>`	`float`	`bool`	`float` higher than.
`string`	`>`	`string`	`bool`	`string` higher than.
`bool`	`>`	`bool`	`bool`	`bool` higher than.

(i) Higher than

Left type	Operation	Right type	Result type	Notes
`int`	`>=`	`int`	`bool`	`int` higher than or equal.
`float`	`>=`	`float`	`bool`	`float` higher than or equal.
`string`	`>=`	`string`	`bool`	`string` higher than or equal.
`bool`	`>=`	`bool`	`bool`	`bool` higher than or equal.

(ii) Higher than or equal

Left type	Operation	Right type	Result type	Notes
`int`	`<`	`int`	`bool`	`int` lower than.
`float`	`<`	`float`	`bool`	`float` lower than.
`string`	`<`	`string`	`bool`	`string` lower than.
`bool`	`<`	`bool`	`bool`	`bool` lower than.

(iii) Lower than

Left type	Operation	Right type	Result type	Notes
`int`	`<=`	`int`	`bool`	`int` lower than or equal.
`float`	`<=`	`float`	`bool`	`float` lower than or equal.
`string`	`<=`	`string`	`bool`	`string` lower than or equal.
`bool`	`<=`	`bool`	`bool`	`bool` lower than or equal.

(iv) Lower than or equal

Table 2.10: Nuua relational ordering binary operations

Examples

Example binary operations.

```
10 + 20 // 30
```

```
20 < 50 // true
"sample" == "sample"
"abc" * 2 // "abcabc"
"erik" / 4 // ["e", "r", "i", "k"]
```

2.6.16 Logical Expression

The logical expression is used to perform a logical operation on two values. The logical operations supported are the `and` and the `or` operations that perform a logical conjunction and a logical disjunction respectively.

Caveats

- The values on both sides of the logical expression are required to be of type `bool`. Explicit casting is needed.
- If one or both values are not of type bool, an error is thrown prior to execution.

Examples

Example logical `and`.

```
true and false // false
true and true // true
```

Example logical `or`.

```
true or false // true
true or true // true
```

2.6.17 Range Expression

The range expression is used to create a list ranging from a `start` index to an `end` index. This expression allows for quick lists to be created and ready to worth with a single line. The range can be inclusive or exclusive depending on the number of dots found in the expression.

Caveats

- The `start` and the `end` index must be of type `int`. If not, an error is thrown prior to execution.
- Inclusive ranges use three dots, while an exclusive range uses two dots.

Examples

Example ranges.

```
0..3 // [0, 1, 2]
-2...2 // [-2, -1, 0, -1, -2]
```

2.6.18 Assignment Expression

The assignment expression is used to assign a value to a target. Target may be a variable, an access expression or a property expression. The left side (target) is then assigned the expression on the right side (value). The assignment expression returns the assignment value.

Caveats

- The types of the target and the value must match to perform an assignment. If not, an error is thrown prior to execution.

Examples

Example variable assignment.

```
test: int
test = 20 // 20
```

Example access assignment.

```
l := [1, 2, 3]
l[1] = 4 // 4
// The value of l will now be [1, 4, 3]
d := {"a": 10, "b": 20}
d["a"] = 5 // 5
// The value of d will now be {"a": 5, "b": 20}
```

Example property assignment.

```
class Person {
    name: string
}
p := Person!{name: "Erik"}
p.name = "User" // "User"
// The value of p will now be Person!{name: "User"}
```

2.7 Comments

Comments in Nuua can be written by using a double backslash (\\) followed by the comment text. The comment text lasts till a \n character is found. Therefore, multi-line comments can be done by manually writing the double backslash on each different line.

Comment blocks are not part of the language grammar and therefore they are totally discarded from the AST. When the lexer finds the double backslash, it proceeds to discard the whole line.

```
// Some comment here
fun test() {
    print "Hello"
    // Some other comment here
    print "Hello again"
}
```

3 Logger

This chapter starts the implementation of the Nuua system. Specifically, this chapter deals with the creation of the independent logger module found in the Nuua system diagram on Figure 1.4.

The logger is responsible for dealing with the error reporting of the system, so any layer can tell the logger to store messages (a log) and at the appropriate moment a layer could make the application crash (throw an error). Those crashes are controlled and must output a message to the user with information regarding the issue that caused the problem.

The errors that the application can throw must always include the source file, the line and the column where the error happened. However, there might be the possibility for a crash before any source code is analyzed, meaning that a crash without this information is still possible.

In case of an error, the reported error must be formatted accordingly and written in the standard error stream (stderr).

3.1 Error Design

Error reporting plays a very important job in a compiler. Recently, GCC released a new version that improves the diagnostics that the compiler outputs to have user-friendly errors similar to how rust does error reporting. Therefore, the error design must be taken into consideration when designing the Nuua logger.

The Figure 3.1 shows the concept for the error design.

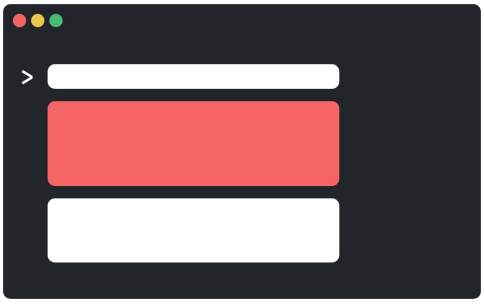


Figure 3.1: Error logging concept

The first white line should include the *absoltute* path of the source file followed by the line and the column where the error happened.

The red paragraph should include an error description of the error that caused the crash. This paragraph must have a fixed width to ensure the error has a readable format.

The last white paragraph contains the line as seen in the source code of the program. The line must also include a reference to the column where the error happened so that a quick look at the line can determine the problem.

3.2 Logger Entities

The logger entity has all the properties that are mandatory fora log. This includes the absolute file path of the source program, the line of the file where the error happened and the column. Additionally, the error message that it has associated. A code representation is shown in the Listing 1.

```
// Represents a log entity.
class LoggerEntity {
    public:
        // Stores the file where the log comes from.
        const std::shared_ptr<const std::string> file;
        // Stores the line of the log.
        const line_t line;
        // Stores the column of the log.
        const column_t column;
        // Stores the message of the log.
        const std::string msg;
        // Creates a new log entity.
        LoggerEntity(
            const std::shared_ptr<const std::string> &file,
            const line_t line,
            const column_t column,
            const std::string &msg
        ) : file(file), line(line), column(column), msg(msg) {}
};
```

Listing 1: Logger entity class

3.3 Logger Class

Listing 2 shows a logger class implementation that satisfies all the previous statements. In short, it stores a list of all the log entities and provides methods to add and remove

logs. It also provides a crash method that outputs the logs and returns an exit code without calling `exit()`.

```
// Represents the logger used in the whole toolchain.
class Logger
{
    // Stores all the log entities.
    std::vector<LoggerEntity> entities;
    // Displays a specific log entity.
    void display_log(const uint16_t index, const bool red) const;
    public:
        // Stores the executable path.
        std::string executable_path;
        // Adds a new entity to the entity stack.
        void add_entity(
            const std::shared_ptr<const std::string> &file,
            const line_t line,
            const column_t column,
            const std::string &msg
        );
        // Pops an entity from the entity stack.
        void pop_entity();
        // Crashes the program by displaying the entity stack
        // and further returning an apropiate exit code.
        int crash() const;
};
```

Listing 2: Logger entity class

3.4 Cross-platform Caveat

Due to the fact that Nuua is supported in multiple platforms, there is an important feature mentioned that must be handled manually. The colored red output must be portable across all the major platforms. Windows is the platform that is most special and therefore, special treatment must be taken.

For windows platforms, the C++ header `windows.h` must be included. This header includes special functions to work with the windows terminal. The preprocessor macros `_WIN32` and `_WIN64` can be used to determine if the windows header is needed.

Figure Listing 3 shows the implementation of a red `printf` function working under all the major platforms.

```
#if defined(_WIN32) || defined(_WIN64)
    #include <windows.h>
#endif
#include <stdio.h>
#include <stdarg.h>
#include <cstdlib>

static int red_printf(const char *format, ...)
{
    va_list arg;
    int result;
    va_start(arg, format);
    #if defined(_WIN32) || defined(_WIN64)
        HANDLE hConsole = GetStdHandle(STD_OUTPUT_HANDLE);
        CONSOLE_SCREEN_BUFFER_INFO consoleInfo;
        WORD saved_attributes;
        GetConsoleScreenBufferInfo(hConsole, &consoleInfo);
        saved_attributes = consoleInfo.wAttributes;
        SetConsoleTextAttribute(hConsole, FOREGROUND_RED);
        result = vfprintf(stderr, format, arg);
        SetConsoleTextAttribute(hConsole, saved_attributes);
    #else
        // \x1b[31m\x1b[0m = (9 + '\0')
        char *fmt = malloc(sizeof(char) * (strlen(format) + 10));
        strcpy(fmt, "\x1b[31m");
        strcat(fmt, format);
        strcat(fmt, "\x1b[0m");
        result = vfprintf(stderr, fmt, arg);
        free(fmt);
    #endif
    va_end(arg);
    return result;
}
```

Listing 3: Red printf function

4 Lexer

The lexer is the lowest layer in the Nuua system as shown in Figure 1.4. The lexer job is to transform the program source code into a list of tokens. This step is also known as lexical analysis or tokenization.

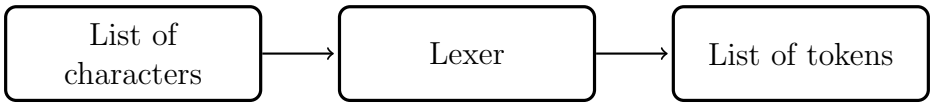


Figure 4.1: Lexer overview

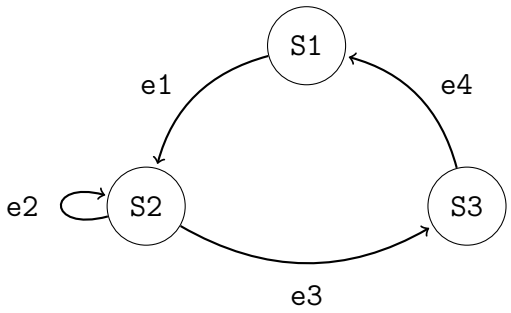
The lexer needs to provide an API to the layer above and one of the parameters of the scan function is the path of the source file to scan. The lexer is also responsible for opening the file and creating a `char` array with its contents. This can be done in the lexer class constructor seen in Listing 5. When the layer above wishes to scan the tokens the tokenization begins and therefore a list of tokens is built and returned.

4.1 Strategy

The strategy of the lexer is to use a state machine to determine the pattern of the tokens and be able to identify what token type it's being scanned. The state machine finds a pattern and creates a specific token depending on the state it landed. The state machine can also lead to no pattern. If there's a sequence of characters that don't match a pattern, an error is then thrown using the logger module as described in Chapter 3.

The implementation uses a C++ `switch` statement to match the first character of the pattern and further continues if needed depending on the patterns.

In case a `\n` is found, the lexer line is incremented and the column is reset to 0. Since the current line and column are properties in the lexer instance they only affect a single instance allowing multiple instances to scan different files at the same time. Figure 4.2 shows an example pattern found in the lexer.



(i) Diagram

State	Explanation
`S1`	Initial state of the state machine.
`S2`	Build string. `s += c`
`S3`	Create token

(ii) State table

Event	Condition	Action
`e1`	`c == '"'`	`c = next_char()`
`e2`	`c != '"'`	`c = next_char()`
`e3`	`c == '"'`	`-`
`e4`	`-`	`c = next_char()`

(iii) Event table

Figure 4.2: Example finite state machine for strings

As shown in Figure 4.3, an efficient way to scan the file is using two pointers to some of the `chars` found in the source file. The first pointer points to the start of the token being scanned and the second one advances accordingly with the help of the state machine. When the state machine determines that a new token must be created the start pointer is used as the first character pointer in the token as explained in section 4.2 and the length of the token can be determined by using pointer arithmetic given:

$$\texttt{length} = \texttt{current\_ptr} - \texttt{start\_ptr} + 1$$

Since the string values can ignore the two `'"'` found at the start and at the end of the token, the length will be decremented by two and the start pointer is incremented by one to get only the string value. When a blank space is found in the initial state of the state machine the `start_ptr` pointer address is then set to the `current_ptr` address and the current parser column increases.

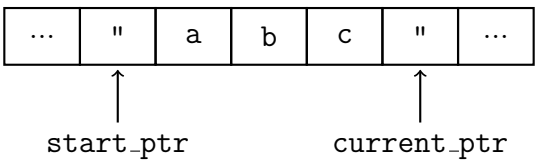


Figure 4.3: Lexer scan technique

4.2 Tokens

Tokens represent specific lexeme patterns. The list of the patterns and the tokens associated with it can be seen on Table 4.1, Table 4.2 and Table 4.3. The tokens must also take into consideration escaping characters. For example, a string representation might be willing to use the char '"' as part of the string value and not determine the end of the string. Therefore, there is a list of escaped chars that are taken into consideration as shown in subsection 2.1.5.

Pattern	Token
\n	TOKEN_NEW_LINE
(	TOKEN_LEFT_PAREN
)	TOKEN_RIGHT_PAREN
{	TOKEN_LEFT_BRACE
}	TOKEN_RIGHT_BRACE
,	TOKEN_COMMA
.	TOKEN_DOT
..	TOKEN_DOUBLE_DOT
...	TOKEN_TRIPLE_DOT
-	TOKEN_MINUS

(i)

Pattern	Token
+	TOKEN_PLUS
/	TOKEN_SLASH
*	TOKEN_STAR
->	TOKEN_RIGHT_ARROW
!	TOKEN_BANG
!=	TOKEN_BANG_EQUAL
=	TOKEN_EQUAL
==	TOKEN_EQUAL_EQUAL
>	TOKEN_HIGHER
>=	TOKEN_HIGHER_EQUAL

(ii)

Table 4.1: Nuua tokens (1)

Pattern	Token
=>	TOKEN_BIG_RIGHT_ARROW
:	TOKEN_COLON
return	TOKEN_RETURN
print	TOKEN_PRINT

(i)

Pattern	Token
use	TOKEN_USE
from	TOKE_FROM
elif	TOKEN_ELIF
in	TOKEN_IN
export	TOKEN_EXPORT

(ii)

Table 4.2: Nuua tokens (2)

Pattern	Token	Pattern	Token
<	TOKEN_LOWER	fun	TOKEN_FUN
<=	TOKEN_LOWER_EQUAL	else	TOKEN_ELSE
<IDENTIFIER>	TOKEN_IDENTIFIER	true	TOKEN_TRUE
<STRING_EXPR>	TOKEN_STRING	false	TOKEN_FALSE
<INTEGER_EXPR>	TOKEN_INTEGER	while	TOKEN_WHILE
<FLOAT_EXPR>	TOKEN_FLOAT	for	TOKEN_FOR
as	TOKEN_AS	if	TOKEN_IF
or	TOKEN_OR	\0	TOKEN_EOF
and	TOKEN_AND	[	TOKEN_LEFT_SQUARE
class	TOKEN_CLASS	]	TOKEN_RIGHT_SQUARE
(i)		(ii)	

Table 4.3: Nuua tokens (3)

To make an efficient token representation, instead of copying the `char` array (lexeme) that matches that token pattern a reference to the first character of the token is saved into the token instance and then the length is specified to know how many chars it does consist of. That way, no unnecessary memory is added to each token. The only needed thing is to keep the source code `char` array in memory and avoid reallocations till the token instance is not needed anymore. Figure 4.4 shows a visual representation. Listing 4 shows the token representation that is used in the Nuua compiler.

Among other information, the type of the token (as shown in Table 4.1, Table 4.2 and Table 4.3) is also stored as part of the token. Additionally, the line and column where that token was found is also stored.

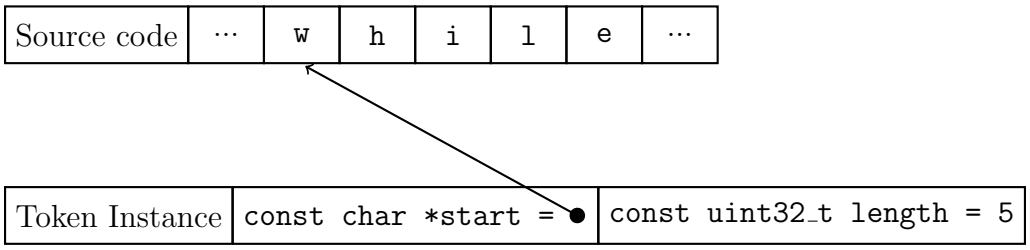


Figure 4.4: Lexer token technique

```
class Token
{
    public:
        // The type of the token.
        const TokenType type;
        // A pointer to the first char.
        // (Not used as a null terminated char array)
        const char *start;
        // The length of the token.
        const uint32_t length;
        // The line where it is found.
        const line_t line;
        // The column where it is found.
        const column_t column;
        // String representation of the token names.
        static std::vector<std::string> token_names;
        // Pattern matching a token name.
        static std::vector<std::string> type_names;
        // Contains the escaped chars of the language.
        static const std::unordered_map<char, char> escaped_chars;
        // Create a new instance of a token given the
        // required parameters.
        Token(
            const TokenType type,
            const char *start,
            const uint32_t length,
            const line_t line,
            const column_t column
        ) : type(type), start(start), length(length),
            line(line), column(column) {}
        // Debug the token by printing it on the
        // screen with the correct format.
        void debug_token() const;
        // Convert the token to a string representation.
        std::string to_string() const;
        // Convert the token to its pattern string representation.
        std::string to_type_string() const;
};
```

Listing 4: Token class

4.3 Lexer Class

The lexer class represents a lexer instance to scan a file and return a list of tokens. Listing 5 shows the code used in the Nuua compiler to transform a `char` array corresponding to the source file to a list of token instances.

```
class Lexer
{
    // Stores the file where the tokens are being scanned.
    std::shared_ptr<const std::string> file;
    // Stores the start char of the token being scanned.
    const char *start;
    // Stores the current char of the token beeing scanned.
    const char *current;
    // Stores the current line in the source file.
    line_t line;
    // Stores the current column in the source file.
    column_t column;
    // Stores a list of reserved words for the identifiers.
    static const std::unordered_map<std::string, TokenType>
    ↪  reserved_words;
    // Generates a token error.
    const std::string token_error() const;
    // Build the token and set the start char to the current one.
    Token make_token(TokenType type);
    // Helper to build tokens.
    bool match(const char c);
    TokenType is_string(bool simple);
    TokenType is_number();
    TokenType is_identifier();
    // Reads a file and stores the contents in the current instance.
    void read_from_file(const std::shared_ptr<const std::string> &file);
    public:
        // Stores the source code of the file.
        std::unique_ptr<std::string> source;
        // Scans the source and stores the tokens.
        void scan(std::unique_ptr<std::vector<Token>> &tokens);
        // Initializes a lexer given a file name.
        Lexer(const std::shared_ptr<const std::string> &file);
};
```

Listing 5: Lexer class

5 Parser

The job of the parser is to transform the list of tokens returned by the Lexer into an abstract syntax tree.

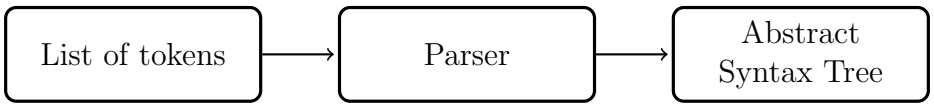


Figure 5.1: Parser overview

There are a lot of different algorithms and strategies for parsing different set of grammars. There are also a lot of parser generators out there that can help building a parser. However, this thesis implements a hand written top down recursive descend predictive parser for the following reasons:

1. To have as much control as needed over the parser. Specially for error reporting.
2. To enforce a zero-dependency policy.
3. Easy to build and fast enough for the job.
4. To learn how to build a recursive descend parser and learn how it works.

Recursive descend parsers are probably the simplest way to build a parser as mentioned in [Bob18, Section 6]. In fact, even if it's a simple parser it's used in very famous and large projects like `GCC` or `V8`.

As can be seen on [Joh08] the top down parers can be classified into the ones using backtracking and the ones using a predictive technique.

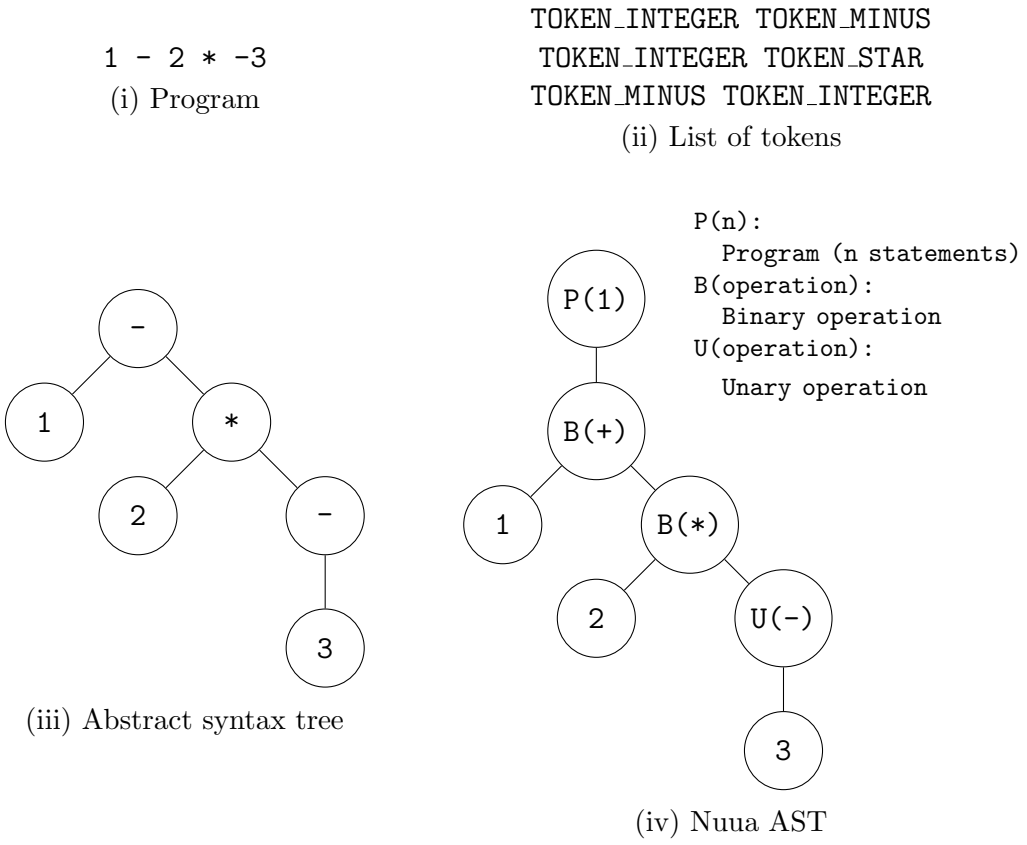
- *Backtracking parsers*: Backtracking parsers try to guess the correct production rule based on the current token. This guess can however, lead to a dead-end and therefore a backtrack is needed to go back and make anothe decision. This is however, very inefficient for programming languages due the ammount of nonterminals found in them.
- *Predictive parsers*: Predictive parsers choose the production rule acording to the current token and the next token found. The next tooken is called a lookahead token. Predictive parsers have a major issue with left-recursion and therefore,

the language grammar needs to be adapted to it. The Nuua grammar as seen on section 2.1 is already adapted for left-recursion based on the solution mentioned on [Bob18, Section 6].

A recursive descend parser is a possible technique for implementing a top-down predictive parser that consists in the creation of a funciton for each nonterminal found in the grammar and then calling the functions depending on the current token and the lookahead.

5.1 Abstract Syntax Tree

The abstract syntax tree (AST) is the data structure used to represent the program in memory. This tree contains the representation of the program starting from an initial node `program` as seen in section 2.1.2. Figure 6.1 shows an example AST.



(i) Program

(ii) List of tokens

(iii) Abstract syntax tree

(iv) Nuua AST

Figure 5.2: Example abstract syntax tree

5.2 Data Types

The parser layer is responsible for creating the type class used in the nodes and in the blocks to determine the type of the values. Since some nodes will store information about their type and it will be added when the semantic analyzer runs. The blocks also need the type of the variables stores so it's convinient to define it here.

The data types supported in nuua are already explained in section 2.4, therefore Listing 6 shows the available data types supported with the addition of a value type that contains no type. This is used in call expression to functions that don't have a return type. This type is only used by the compiler and not the interpreter.

```
1 // Determines the available native types in nuua.
2 typedef enum : uint8_t {
3     VALUE_INT, VALUE_FLOAT, VALUE_BOOL,
4     VALUE_STRING, VALUE_LIST, VALUE_DICT, VALUE_FUN,
5     VALUE_OBJECT, VALUE_NO_TYPE
6 } ValueType;
```

Listing 6: Nuua data types

The type class is very complex. In fact, it must store the `VALUE_TYPE` and additional information about the type, for example the inner type for values like lists or dictionaries. For the function type it must store the function parameter types and its return type. For class types it must store the class name used. Listing 7 shows the type class used in the Nuua compiler. As it can be seen, there are lot of additional methods bound to it to help working with types. Those include copy methods, reset methods, type comparisons and additionally, methods that help dealing with the long list of casts, unary and binary operations found in section 2.6.

```
class Type
{
    // Stores the asociation between the types
    // as string and the value type.
    static const std::unordered_map<std::string, ValueType> value_types;
    // Determines the string representation
    // of the value types.
    static const std::vector<std::string> types_string;
    public:
        // Stores the type.
        ValueType type;
        // Stores the inner type if needed.
        // Used as return type for functions.
        std::shared_ptr<Type> inner_type;
        // Class name.
        std::string class_name;
        // Store the parameters of a function type.
        std::vector<std::shared_ptr<Type>> parameters;
        // Create a value type given the type.
        Type() : type(VALUE_NO_TYPE) {}
        Type(const ValueType type)
            : type(type) {}
        // Create a type given a value type and the inner type.
        Type(
            const ValueType type,
            const std::shared_ptr<Type> &inner_type
        ) : type(type), inner_type(inner_type) {}
        // Create a type given a string representation of it.
        Type(const std::string &name);
        // Create a type given an expression and a
        // list of code blocks to know the variable values.
        Type(
            const std::shared_ptr<Expression> &rule,
            const std::vector<std::shared_ptr<Block>> *blocks
        );
        // Create a function type given the function itself.
        Type(const std::shared_ptr<Function> &fun);
        // Additional methods used as helpers for casts,
        // unary and binary operations and for other operations
        // like copy or
        // ...
};
```

Listing 7: Type class

5.3 Block Scope and symbol table

The parser layer will also create the block representation explained in section 2.2. The way the scope block is built must be explained here since it will be attached as part of some of the AST nodes. This acts as a symbol table for the specific scope.

A symbol table is used to store the name of the variables in the block and further verify if they are declared or get specific data of them. For example, the symbol table can verify if a variable is declared, the type of the variable, the register where it is placed, etc. Aditionally, the block does also store the defined classes. This is done due the fact that the block class is also used as the module scope internaly.

5.3.1 Block Variable Type

The block variable type is the representation of a variable stores in the block. A variable must include the following fields:

- The variable type.
- The AST node where it appears (The declaration).
- A register where this variable is stored.
- If the variable is exported or not.
- The node where it was last used.

The variable name however, is not part of this class, since to reference this variable class, a hashmap is used and the hashmap key is variable name.

Listing 8 shows the class representation of a block variable type.

```
class BlockVariableType
{
    public:
        // Represents the variable type.
        std::shared_ptr<Type> type;
        // Stores the AST node where this variable is.
        std::shared_ptr<Node> node;
        // Represents the register where it's stored.
        register_t reg = 0;
        // Determines in the variable is exported.
        // (only applies to TLDs).
        bool exported = false;
        // Represents the last use of the variable (Variable life).
        std::shared_ptr<Node> last_use;
        // Constructors.
        BlockVariableType() {};
        BlockVariableType(
            const std::shared_ptr<Type> &type,
            const std::shared_ptr<Node> &node,
            const bool exported = false
        ) : type(type), node(node), exported(exported) {}
};
```

Listing 8: BlockVariableType class

5.3.2 Block Class Type

The block class type is similar to the block variable type but stores much less fields. Also this information is only used in the module scope. The block class type stores the following information:

- The block scope of the class.
- If the class is exported or not.
- The node where it was last used.

Listing 9 shows the class representation of the block class type. It can be seen that a forward declaration to the block class must be used till its defined.

```
class Block; // Forward declaration.
class BlockClassType
{
    public:
        // Stores the block scope of the class.
        std::shared_ptr<Block> block;
        // Determines if the class is exported.
        bool exported = false;
        // Stores the AST node where this variable is.
        std::shared_ptr<Node> node;
        // Constructors.
        BlockClassType() {}
        BlockClassType(
            const std::shared_ptr<Block> &block,
            const std::shared_ptr<Node> &node,
            const bool exported = false
        ) : block(block), node(node), exported(exported) {}
};
```

Listing 9: BlockClassType class

5.3.3 Block Class

With the form of the variables and the classes that are stored in the block the final definition for a block can be given, therefore, the block must then be able to store variables, classes and additionally provide with methods to help perform different opterations on them.

Listing 10 shows the block class used in the Nuua compiler. As it can be seen, two hashmaps are used to store the relation between variable names and its class shown in Listing 8 and the same with the class name with its class shown in Listing 9.

```
class Block
{
    public:
        // Stores the variable name and the type of it.
        std::unordered_map<std::string, BlockVariableType> variables;
        // Stores the custom types of the block.
        std::unordered_map<std::string, BlockClassType> classes;
        // Gets a variable from the current block or returns nullptr.
        BlockVariableType *get_variable(const std::string &name);
        // Gets a class from the current block or returns nullptr.
        BlockClassType *get_class(const std::string &name);
        // Sets a variable.
        void set_variable(const std::string &name, const
        ↪  BlockVariableType &var);
        // Sets a class.
        void set_class(const std::string &name, const BlockClassType
        ↪  &c);
        // Determines if a variable is exported.
        bool is_exported(const std::string &name);
        // Determines if a class is exported.
        bool is_exported_class(const std::string &name);
        // Determines if the block have a variable.
        bool has(const std::string &name);
        // Determines if the block have a class.
        bool has_class(const std::string &name);
        // Debug the block by printing it to the screen.
        void debug() const;
        // Helper to get a single variable out of a list of blocks.
        // It iterates through it starting from the end till the front.
        static BlockVariableType *get_single_variable(const std::string
        ↪  &name, const std::vector<std::shared_ptr<Block>> *blocks);
};
```

Listing 10: Block class

5.4 Tree Nodes

A node in the AST is represented by the class found Listing 11

```
class Node
{
    public:
        // Stores the real rule of the node.
        const Rule rule;
        // Stores the file where it's found.
        std::shared_ptr<const std::string> file;
        // Stores the line where it's found.
        line_t line;
        // Stores the column where it's found.
        column_t column;
        // Constructor.
        Node(
            const Rule r,
            const std::shared_ptr<const std::string> &f,
            const line_t l, const column_t c
        ) : rule(r), file(f), line(l), column(c) {};
};
```

Listing 11: Node class

However, nodes are categorized into two sections. Nodes can be either statements or expressions. Therefore, two classes are used as nodes instead as shown in Listing 12.

```
class Expression : public Node
{
    public:
        explicit Expression(const Node &node)
            : Node(node) {};
};
class Statement : public Node
{
    public:
        explicit Statement(const Node &node)
            : Node(node) {};
};
```

Listing 12: Expression and Statement classes

This two classes extend the node class so they inherit all the attributes from it.

To work with all the nodes in a more effective way, the definition in Listing 13 is added.

```
#define NODE_PROPS std::shared_ptr<const std::string> &file, const
↪  line_t line, const column_t column
```

Listing 13: Node properties definition

5.4.1 Integer Node

The integer node only needs the value that corresponds to it. In this case a C++ `int64_t` type is used as shown in Listing 14.

```
class Integer : public Expression
{
    public:
        int64_t value;
        Integer(NODE_PROPS, const int64_t v)
            : Expression({ RULE_INTEGER, file, line, column }),
              value(v) {};
};
```

Listing 14: Integer Node

5.4.2 Float Node

The float node only needs the value that corresponds to it. In this case a C++ `double` type is used as shown in Listing 15.

```
class Float : public Expression
{
    public:
        double value;
        Float(NODE_PROPS, const double v)
            : Expression({ RULE_FLOAT, file, line, column }),
              value(v) {};
};
```

Listing 15: Float Node

5.4.3 String Node

The string node only needs the value that corresponds to it. In this case a C++ `std::string` type is used as shown in Listing 16.

```
class String : public Expression
{
    public:
        std::string value;
        String(NODE_PROPS, const std::string &v)
            : Expression({ RULE_STRING, file, line, column }),
              value(v) {};
};
```

Listing 16: String Node

5.4.4 Boolean Node

The boolean node only needs the value that corresponds to it. In this case a C++ `bool` type is used as shown in Listing 17.

```
class Boolean : public Expression
{
    public:
        bool value;
        Boolean(NODE_PROPS, const bool v)
            : Expression({ RULE_BOOLEAN, file, line, column }),
              value(v) {};
};
```

Listing 17: Boolean Node

5.4.5 List Node

The list node needs the value that corresponds to it and a type parameter that's filled in by the semantic analyzer. In this case a C++ `std::vector<std::shared_ptr<Expression>>` type is used as shown in Listing 18. The vector contains other expressions found inside the list.

```
class List : public Expression
{
    public:
        std::vector<std::shared_ptr<Expression>> value;
        // Stores the list type since it's complex to analyze later.
        std::shared_ptr<Type> type;
        List(
            NODE_PROPS,
            const std::vector<std::shared_ptr<Expression>> &v
        ) : Expression({ RULE_LIST, file, line, column }),
            value(v) {};
};
```

Listing 18: List Node

5.4.6 Dictionary Node

The dictionary node needs the key value pairs of strings and expressions and the key order. In this case a C++ `std::unordered_map<std::string, std::shared_ptr<Expression>>` type is used as shown in Listing 19. The type is also added and used by the semantic analyzer.

```
class Dictionary : public Expression
{
    public:
        std::unordered_map<std::string, std::shared_ptr<Expression>>
        ↪ value;
        std::vector<std::string> key_order;
        // Stores the dict type since it's complex to analyze later.
        std::shared_ptr<Type> type;
        Dictionary(
            NODE_PROPS,
            const std::unordered_map<std::string,
            ↪ std::shared_ptr<Expression>> &v,
            const std::vector<std::string> &ko
        ) : Expression({ RULE_DICTIONARY, file, line, column }),
            value(std::move(v)),
            key_order(std::move(ko)) {};
};
```

Listing 19: Dictionary Node

5.4.7 Group Node

The group node consists of a single expression as seen in Listing 20.

```
class Group : public Expression
{
    public:
        std::shared_ptr<Expression> expression;
        Group(NODE_PROPS, const std::shared_ptr<Expression> &v)
            : Expression({ RULE_GROUP, file, line, column }),
              expression(std::move(v)) {};
};
```

Listing 20: Group Node

5.4.8 Unary Node

The unary node consists of the token operation to do and the right expression. It also stores the type of unary operation as seen in subsection 2.6.13. Listing 21 shows the representation of the unary node.

```
class Unary : public Expression
{
    public:
        Token op;
        std::shared_ptr<Expression> right;
        // Determines what type of unary operation
        // will be performed, no need to store a Type.
        UnaryType type = (UnaryType) NULL;
        Unary(NODE_PROPS, const Token &o, const
        ↪  std::shared_ptr<Expression> &r)
            : Expression({ RULE_UNARY, file, line, column }),
              op(o),
              right(std::move(r)) {};
};
```

Listing 21: Unary Node

5.4.9 Binary Node

The binary node consists of the token operation to do and the left and right expression. It also stores the type of binary operation as seen in subsection 2.6.15. Listing 22 shows the representation of the binary node.

```
class Binary : public Expression
{
    public:
        std::shared_ptr<Expression> left;
        Token op;
        std::shared_ptr<Expression> right;
        // Determines what type of binary operation will be performed.
        BinaryType type = (BinaryType) NULL;
        Binary(
            NODE_PROPS,
            const std::shared_ptr<Expression> &l,
            const Token &o,
            const std::shared_ptr<Expression> &r
        ) : Expression({ RULE_BINARY, file, line, column }),
            left(std::move(l)),
            op(o),
            right(std::move(r)) {};
};
```

Listing 22: Binary Node

5.4.10 Variable Node

The variable node consists of the the name of the variable. Listing 23 shows the representation of the variable node.

```
class Variable : public Expression
{
    public:
        std::string name;
        Variable(NODE_PROPS, const std::string &n)
            : Expression({ RULE_VARIABLE, file, line, column }),
              name(n) {};
};
```

Listing 23: Variable Node

5.4.11 Assign Node

The assign node consists of the target (the expression to be assigned) and the value of the assignment. Listing 24 shows the representation of the assign node. It also stores a boolean that determines if the assignment is done to an access target (an inner value of a Nuua iterator). This boolean is used by the semantic analyzer.

```
class Assign : public Expression
{
    public:
        std::shared_ptr<Expression> target;
        std::shared_ptr<Expression> value;
        bool is_access = false;
        Assign(
            NODE_PROPS,
            const std::shared_ptr<Expression> &t,
            const std::shared_ptr<Expression> &v
        ) : Expression({ RULE_ASSIGN, file, line, column }),
            target(std::move(t)),
            value(std::move(v)) {};
};
```

Listing 24: Assign Node

5.4.12 Logical Node

The logical node consists the logical operation (`or` or `and`) and the left and right expressions. Listing 25 shows the representation of the logical node.

```
class Logical : public Expression
{
    public:
        std::shared_ptr<Expression> left;
        Token op;
        std::shared_ptr<Expression> right;
        Logical(
            NODE_PROPS,
            const std::shared_ptr<Expression> &l,
            const Token &o,
            const std::shared_ptr<Expression> &r
        ) : Expression({ RULE_LOGICAL, file, line, column }),
            left(std::move(l)),
            op(o),
            right(std::move(r)) {};
};
```

Listing 25: Logical Node

5.4.13 Call Node

The call node consists the calle target and of the arguments provided to perform the call. Listing 26 shows the representation of the call node. It also stores if the call has a return depending on the callee. This helps the semantic analyzer determine where and when this call can be used since this expression may have no value.

```
class Call : public Expression
{
    public:
        std::shared_ptr<Expression> target;
        std::vector<std::shared_ptr<Expression>> arguments;
        // Determines if the call target returns a value or not.
        bool has_return = false;
        Call(
            NODE_PROPS,
            const std::shared_ptr<Expression> &t,
            const std::vector<std::shared_ptr<Expression>> &a
        ) : Expression({ RULE_CALL, file, line, column }),
            target(std::move(t)),
            arguments(a) {};
};
```

Listing 26: Call Node

5.4.14 Access Node

The access node consists the target to access and the index for it. Listing 27 shows the representation of the access node. The type represents the type of access (the type of iterator to access).

```
class Access : public Expression
{
    public:
        std::shared_ptr<Expression> target;
        std::shared_ptr<Expression> index;
        AccessType type = (AccessType) NULL;
        Access(
            NODE_PROPS,
            const std::shared_ptr<Expression> &t,
            const std::shared_ptr<Expression> &i
        ) : Expression({ RULE_ACCESS, file, line, column }),
            target(std::move(t)),
            index(std::move(i)) {};
};
```

Listing 27: Access Node

5.4.15 Cast Node

The cast node consists the expression to cast and the type to cast it to. Listing 28 shows the representation of the access node. The type of cast as show in subsection 2.6.14 is also stored and further used by the analyzer.

```
class Cast : public Expression
{
    public:
        std::shared_ptr<Expression> expression;
        std::shared_ptr<Type> type;
        CastType cast_type = (CastType) NULL;
        Cast(
            NODE_PROPS,
            const std::shared_ptr<Expression> &e,
            std::shared_ptr<Type> &t
        ) : Expression({ RULE_CAST, file, line, column }),
            expression(std::move(e)),
            type(std::move(t)) {}
};
```

Listing 28: Cast Node

5.4.16 Slice Node

The slice node consists the expressions of the target and the expressions of the start, end and step indexes. Listing 29 shows the representation of the access node. The additional `is_list` represents if the slice is done to a list or a string and it's used by the semantic analyzer.

```
class Slice : public Expression
{
    public:
        std::shared_ptr<Expression> target;
        std::shared_ptr<Expression> start;
        std::shared_ptr<Expression> end;
        std::shared_ptr<Expression> step;
        // Determines if it's a list or a string, used by Analyzer.
        bool is_list = false;
        Slice(
            NODE_PROPS,
            const std::shared_ptr<Expression> &t,
            const std::shared_ptr<Expression> &s,
            const std::shared_ptr<Expression> &e,
            const std::shared_ptr<Expression> &st
        ) : Expression({ RULE_SLICE, file, line, column }),
            target(std::move(t)),
            start(std::move(s)),
            end(std::move(e)),
            step(std::move(st)) {}
};
```

Listing 29: Slice Node

5.4.17 Range Node

The range node consists the expressions of the start and end indexes. Listing 30 shows the representation of the access node. The inclusive fields indicates if the range is inclusive or exclusive.

```
class Range : public Expression
{
    public:
        std::shared_ptr<Expression> start;
        std::shared_ptr<Expression> end;
        bool inclusive;
        Range(
            NODE_PROPS,
            const std::shared_ptr<Expression> &s,
            const std::shared_ptr<Expression> &e,
            const bool i
        ) : Expression({ RULE_RANGE, file, line, column }),
            start(std::move(s)),
            end(std::move(e)),
            inclusive(i) {}
};
```

Listing 30: Range Node

5.4.18 Delete Node

The delete node consists the target expression to delete. Listing 30 shows the representation of the access node.

```
class Delete : public Expression
{
    public:
        std::shared_ptr<Expression> target;
        Delete(
            NODE_PROPS,
            const std::shared_ptr<Expression> &t
        ) : Expression({ RULE_DELETE, file, line, column }),
            target(std::move(t)) {}
};
```

Listing 31: Delete Node

5.4.19 Function Value Node

The function value node represents a value to build a function. The node must know the function name, the parameters of it, the return type and the body. Aditionally the scope block is also stored for further use. Listing 32 shows the representation of the FunctionValue node.

```
class FunctionValue : public Expression
{
    public:
        std::string name;
        std::vector<std::shared_ptr<Declaration>> parameters;
        std::shared_ptr<Type> return_type;
        std::vector<std::shared_ptr<Statement>> body;
        std::shared_ptr<Block> block;
        FunctionValue(
            NODE_PROPS,
            const std::string &n,
            const std::vector<std::shared_ptr<Declaration>> &p,
            std::shared_ptr<Type> &rt,
            const std::vector<std::shared_ptr<Statement>> &b
        ) : Expression({ RULE_FUNCTION, file, line, column }),
            name(n), parameters(p),
            return_type(std::move(rt)),
            body(b) {}
};
```

Listing 32: FunctionValue Node

5.4.20 Object Node

The object node represents an object expression. The required informations are the class name and the arguments to initialize the instance (as a key value pair). Aditionally the scope block is also stored for further use. Listing 33 shows the representation of the Object node.

```
class Object : public Expression
{
    public:
        std::string name;
        std::unordered_map<std::string, std::shared_ptr<Expression>>
        ↪  arguments;
        Object(
            NODE_PROPS,
            const std::string &n,
            const std::unordered_map<std::string,
            ↪  std::shared_ptr<Expression>> &a
        ) : Expression({ RULE_OBJECT, file, line, column }),
            name(n),
            arguments(a) {}
};
```

Listing 33: Object Node

5.4.21 Property Node

The property node represents an access to an object property. The information needed is the expression to access and the name of the property. Listing 34 shows the representation of the Property node.

```
class Property : public Expression
{
    public:
        std::shared_ptr<Expression> object;
        std::string name;
        Property(
            NODE_PROPS,
            const std::shared_ptr<Expression> &o,
            const std::string &n
        ) : Expression({ RULE_PROPERTY, file, line, column }),
            object(o),
            name(n) {}
};
```

Listing 34: Property Node

5.4.22 Print Node

The print node only requires the expression to print. Listing 35 shows the representation of the Print node.

```
class Print : public Statement
{
    public:
        std::shared_ptr<Expression> expression;
        Print(
            NODE_PROPS,
            const std::shared_ptr<Expression> &e
        ) : Statement({ RULE_PRINT, file, line, column }),
            expression(std::move(e)) {}
};
```

Listing 35: Print Node

5.4.23 Expression Statement Node

The expression statement node is used as a wrapper to treat an expression as a valid statement. Listing 36 shows the representation of the ExpressionStatement node.

```
class ExpressionStatement : public Statement
{
    public:
        std::shared_ptr<Expression> expression;
        ExpressionStatement(
            NODE_PROPS,
            const std::shared_ptr<Expression> &e
        ) : Statement({ RULE_EXPRESSION_STATEMENT, file, line, column
        ↪ }),
            expression(std::move(e)) {}
};
```

Listing 36: ExpressionStatement Node

5.4.24 Declaration Node

The declaration node is requires the name of the variable to declare and then a combination of the type and the initializer. The type may be empty if the initializer is set, and the initializer may be empty if the type is set. Both of them may also be set but not empty. Listing 37 shows the representation of the Declaration node.

```
class Declaration : public Statement
{
    public:
        std::string name;
        std::shared_ptr<Type> type;
        std::shared_ptr<Expression> initializer;
        Declaration(
            NODE_PROPS,
            const std::string &n, std::shared_ptr<Type> &t,
            const std::shared_ptr<Expression> &i
        ) : Statement({ RULE_DECLARATION, file, line, column }),
            name(n),
            type(std::move(t)),
            initializer(std::move(i)) {};
};
```

Listing 37: Declaration Node

5.4.25 Return Node

The return node does not need an expression to be valid, but one may be provided. Listing 38 shows the representation of the Return node.

```
class Return : public Statement
{
    public:
        std::shared_ptr<Expression> value;
        Return(
            NODE_PROPS,
            const std::shared_ptr<Expression> &v =
            ↪  std::shared_ptr<Expression>()
        ) : Statement({ RULE_RETURN, file, line, column }),
            value(std::move(v)) {}
};
```

Listing 38: Return Node

5.4.26 If Node

The if node does need the condition expression and the then branch followed by the then block. Aditionally, it may have an else branch and an else scope block. Listing 39 shows the representation of the If node.

```
class If : public Statement
{
    public:
        std::shared_ptr<Expression> condition;
        std::vector<std::shared_ptr<Statement>> then_branch;
        std::vector<std::shared_ptr<Statement>> else_branch;
        std::shared_ptr<Block> then_block, else_block;
        If(
            NODE_PROPS,
            const std::shared_ptr<Expression> &c,
            const std::vector<std::shared_ptr<Statement>> &tb,
            const std::vector<std::shared_ptr<Statement>> &eb
        ) : Statement({ RULE_IF, file, line, column }),
            condition(std::move(c)),
            then_branch(tb),
            else_branch(eb) {};
};
```

Listing 39: If Node

5.4.27 While Node

The while node does need the condition expression and the body of it. It also stores the scope block for further use. Listing 40 shows the representation of the While node.

```
class While : public Statement
{
    public:
        std::shared_ptr<Expression> condition;
        std::vector<std::shared_ptr<Statement>> body;
        std::shared_ptr<Block> block;
        While(
            NODE_PROPS,
            const std::shared_ptr<Expression> &c,
            const std::vector<std::shared_ptr<Statement>> &b
        ) : Statement({ RULE_WHILE, file, line, column }),
            condition(std::move(c)),
            body(b) {};
};
```

Listing 40: While Node

5.4.28 For Node

The for node does require the iterator and the variable to store the loop value. Aditionally it may have the index in case it's needed as part of the loop. It also stores the scope block for further use. Listing 41 shows the representation of the For node.

```
class For : public Statement
{
    public:
        std::string variable;
        std::string index;
        std::shared_ptr<Expression> iterator;
        std::vector<std::shared_ptr<Statement>> body;
        std::shared_ptr<Block> block;
        // Stores the type of the iterator.
        std::shared_ptr<Type> type;
        For(
            NODE_PROPS,
            const std::string &v,
            const std::string &i,
            const std::shared_ptr<Expression> &it,
            const std::vector<std::shared_ptr<Statement>> &b
        ) : Statement({ RULE_FOR, file, line, column }),
            variable(v),
            index(i),
            iterator(std::move(it)), body(b) {}
};
```

Listing 41: For Node

5.4.29 Function Node

The function node wraps the `FunctionValue` node as a statement. Listing 42 shows the representation of the Function node.

```
class Function : public Statement
{
    public:
        std::shared_ptr<FunctionValue> value;
        Function(const std::shared_ptr<FunctionValue> &v)
            : Statement({ RULE_FUNCTION, v->file, v->line, v->column }),
                value(v) {}
};
```

Listing 42: Function Node

5.4.30 Use Node

The use node requires the module name to import and an optional target list. Targets can be empty and all exported targets will be imported. It also requires a property to store the code of the module (the AST of that particular module) and the module scope block of it. Listing 43 shows the representation of the Use node.

```
class Use : public Statement
{
    public:
        std::vector<std::string> targets;
        std::shared_ptr<const std::string> module;
        std::shared_ptr<std::vector<std::shared_ptr<Statement>>> code;
        std::shared_ptr<Block> block;
        Use(
            NODE_PROPS,
            const std::vector<std::string> &t,
            const std::shared_ptr<const std::string> &m
        ) : Statement({ RULE_USE, file, line, column }),
            targets(t),
            module(std::move(m)) {};
};
```

Listing 43: Use Node

5.4.31 Export Node

The export node just requires the statement that is exporting. Listing 44 shows the representation of the Export node.

```
class Export : public Statement
{
    public:
        std::shared_ptr<Statement> statement;
        Export(NODE_PROPS, const std::shared_ptr<Statement> &s)
            : Statement({ RULE_EXPORT, file, line, column }),
                statement(std::move(s)) {}
};
```

Listing 44: Export Node

5.4.32 Class Node

The class node needs the class name, the body of the class and it saves the scope block of the class for further use. Listing 45 shows the representation of the Class node.

```
class Class : public Statement
{
    public:
        std::string name;
        std::vector<std::shared_ptr<Statement>> body;
        std::shared_ptr<Block> block;
        Class(
            NODE_PROPS,
            const std::string &n,
            const std::vector<std::shared_ptr<Statement>> &b
        ) : Statement({ RULE_CLASS, file, line, column }),
            name(n),
            body(b) {}
};
```

Listing 45: Class Node

5.5 Parser Class

The parser class is able to parse the program tree by using some recursive logic. When a use declaration is found when parsing, the contents of the imported module are parsed using a new instance of the parser class. That way, the first parser class contains the AST of all the program. It's also good to note that the parser class formats the given paths to absolute paths and checks for the file location to determine if the imported module belongs to a relative file or the standard library. The parser class uses a similar technique as the Lexer when dealing with the current token. The parser have a pointer

to the current token beeing parser and the lookahead token can be calculated by using pointer arithmentic. Listing 46 shows the implementation of the parser.

```
class Parser
{
    // Stores the current parsing file.
    std::shared_ptr<const std::string> file;
    // Stores a pointer to the current token beeing parsed.
    Token *current = nullptr;
    // Consumes a token and returns it for futher use.
    Token *consume(const TokenType type, const std::string &message);
    // Returns true if the token type matches the current token.
    bool match(const TokenType token);
    // Returns true if any of the given token types matches the current
    ↪ token.
    bool match_any(const std::vector<TokenType> &tokens);
    // Expressions
    std::shared_ptr<Expression> primary();
    std::shared_ptr<Expression> unary_postfix();
    // ... Other expression production rules.
    // Statements
    std::shared_ptr<Statement> fun_declaration();
    std::shared_ptr<Statement> use_declaration();
    // ... Other statement production rules.
    public:
        // Parses a given source code and returns the code.
        void parse(
            std::shared_ptr<std::vector<std::shared_ptr<Statement>>>
            ↪ &code
        );
        // Creates a new parser and formats the path.
        Parser(const char *file);
        // Creates a new parser with a given formatted and initialized
        ↪ path.
        Parser(std::shared_ptr<const std::string> &file)
            : file(file) {}
        // ... Other helpers and debugging methods.
};
```

Listing 46: Parser class

5.6 Module In-memory Cache

During the parsing of a module, this might require the use of other modules. When importing a module, the required module is first parser. However, The module might have already been parser by a previous import, so there's no need to parse that file again. This is prevented by having an in-memory cache to avoid re-parsing files more than once.

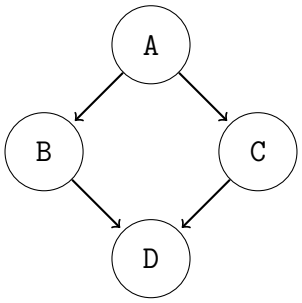


Figure 5.3: A use case for the in-memory parser cache

This situation increases performance when a library is used by a lot of modules. Figure 5.3 ilustrates this situation by having a module `D` imported more than once. The in-memory cache will prevent the second parse and will assign that use node the right AST parsed previously.

6 Semantic Analyzer

The semantic analyzer is run after the AST has been generated and therefore the program is all in the same data structure. The job of the semantic analyzer is not to transform the AST but to analyze it. There is the possibility for optimizations to be performed during the analysis to improve the AST. This includes for instance loop unrolling, constant folding or dead code elimination. However, those things are not part of this thesis and therefore those optimizations have been mentioned in Chapter 10. However, this thesis deals with other types of optimizations. Specifically, bytecode optimization is performed to some extent.

In short, the job of the analyzer is to perform the following things:

- Create the symbol table for each scope and block found. This includes all module scopes and each block scope found.
- Get all the type information from the expressions.
- Perform the semantic checks on all the statements and expressions found in the AST. All the requirements for those nodes are explained in section 2.5 and section 2.6 respectively.
- Add specific node information. This information has been mentioned individually on each tree node on section 5.4.

6.1 Technique

Before any analysis begins, a full module scope analysis needs to be performed. This is done to ensure that when functions are analyzed (and so do their statements) the module scope is already valid and contains the information needed to have a correct statement analysis. For instance, if a function has a statement that makes a call to another function on the module, that callee function must be known, so its signature needs to be analyzed first.

To solve this, a first analysis is performed only on the top level declarations (module scope) found in the module. If one of the top-level declarations is a use declaration, then that module is first analyzed completely before the current analysis can continue. The top-level analysis just gets information about the top-level declarations and does not perform further analysis. That means that it just gets the information of the functions,

classes and so on without analyzing the function bodies. Top level classes are also analyzed only on the top level of their bodies. Once all this phase is complete, the code analysis begins in an arbitrary order. This can be done as the top level is already analyzed and therefore all the symbol table for the module block is already built and the types are known.

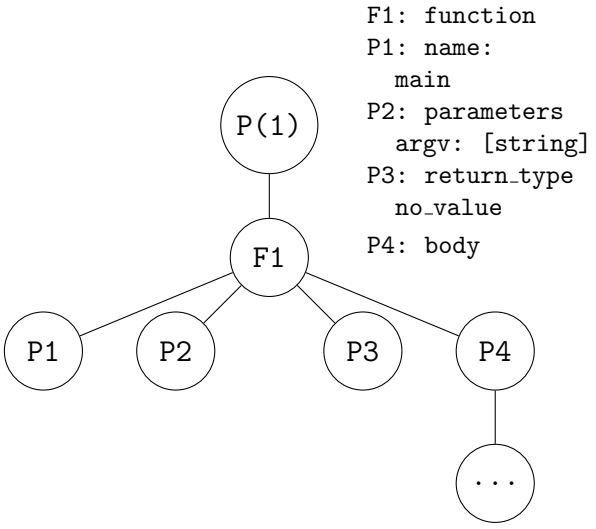
Once the code analysis begins the function bodies are analyzed and so do classes methods. The analysis run by recursively walking the AST and further performing all the checks mentioned in section 2.5 and on section 2.6 depending on the type of node being analyzed. This analysis is also recursive.

```
fun main(argv:  [string]) {
    // ...
}
```

(i) Program

```
TOKEN_FUN TOKEN_IDENTIFIER
TOKEN_LEFT_PAREN TOKEN_IDENTIFIER
TOKEN_COLON TOKEN_LEFT_SQUARE
TOKEN_IDENTIFIER
TOKEN_RIGHT_SQUARE
TOKEN_RIGHT_PAREN
TOKEN_LEFT_BRACE TOKEN_NEW_LINE
TOKEN_RIGHT_BRACE TOKEN_NEW_LINE
TOKEN_EOF
```

(ii) List of tokens



(iii) Abstract Syntax Tree

Variable	Type
main	([string])

(iv) Module scope symbol table

Figure 6.1: Example program top-level analysis

Among other mentioned checks that are specific to certain nodes, some of the checks the analyzer performs are:

- Declared variables.
- Function return value match.
- Functions without return type usage.
- Argument type match.
- Assignment type match.
- List / String / Dictionary index type.
- Variable lifetime (`last_use`).
- Use only exported declarations.
- Check for iterator (must be list / dict).
- Type matching.
- `main([string])` required on the main module.

6.2 Type Inference

Type inference is done in Nuua by the `Type` class seen on Listing 7. However, it is used in this layer to get the expression types of the program. Type inference is ability to get the type of the expressions at compile time. Type inference is a step needed to perform type checks on the AST. Most nodes require a type check at some point and therefore, type inference can be used to get the type of the expressions on such nodes. The `Type` class has a constructor that accepts an expression and a list of blocks. This constructor can determine the expression type and if the expression contains variables, their type is obtained from the block list, starting from the last block going back till the first block of the list. Although errors are checked, the expression should always be analyzed prior to any type inference to avoid issues.

6.3 Module class

The module class is used to analyze a module. It automatically creates a new instance of it when it needs to analyze the AST of a use declaration.

Listing 47 shows the implementation of the module class used by the analyzer

```
1 class Module
2 {
3     // Stores the file name of that module.
4     std::shared_ptr<const std::string> file;
5     // Stores the code of that module.
```

```
6       std::shared_ptr<std::vector<std::shared_ptr<Statement>>> code;
7       // Stores the blocks used while analyzing the module.
8       std::vector<std::shared_ptr<Block>> blocks;
9       // Return variable if needs to be checked. Only 1 can exist since
10      // it can only analyze 1 function at a time.
11      std::shared_ptr<Type> return_type;
12      // Analyzes the TLDs of the current module.
13      void analyze_tld();
14      // Analyzes the given top level declaration.
15      void analyze_tld(const std::shared_ptr<Statement> &tld, const bool
        ↪  set_exported = false);
16      // Analyzes the class top level declarations.
17      // void analyze_class_tld(const std::shared_ptr<Class> &c);
18      void analyze_class_tld(const std::shared_ptr<Statement> &tld, const
        ↪  std::shared_ptr<Block> &block);
19      // Analyzes the code.
20      void analyze_code();
21      // Analyzes the statement.
22      void analyze_code(const std::shared_ptr<Statement> &rule, bool
        ↪  no_declare = false);
23      // Analyzes the expression.
24      void analyze_code(const std::shared_ptr<Expression> &rule, const
        ↪  bool allowed_noreturn_call = false);
25      // Analyzes the block.
26      std::shared_ptr<Block> analyze_code(
27          const std::vector<std::shared_ptr<Statement>> &code,
28          const std::vector<std::shared_ptr<Declaration>> &initializers =
            ↪  std::vector<std::shared_ptr<Declaration>>(),
29          const std::shared_ptr<Node> &initializer_node =
            ↪  std::shared_ptr<Node>()
30      );
31      // Declares a variable to the most top level block.
32      void declare(const std::shared_ptr<Declaration> &dec, const
        ↪  std::shared_ptr<Node> &node = std::shared_ptr<Node>());
33      // Check if the given module have all the classes defined.
34      bool check_classes(const std::vector<std::string> &classes, const
        ↪  std::shared_ptr<Node> &fail_at);
35      public:
36          // Stores the main block of that module.
37          std::shared_ptr<Block> main_block = std::make_shared<Block>();
38          // Main module constructor
39          Module(std::shared_ptr<const std::string> &file)
40              : file(file) {}
```

```
41          // Analyzes the module and adds it's entry to the modules symbol
            ↪ table.
42          std::shared_ptr<Block>
            ↪ analyze(std::shared_ptr<std::vector<std::shared_ptr<Statement>>>
            ↪ &code, const bool require_main = false);
43  };
```

Listing 47: Module class

6.4 Module In-memory Cache

Since a module might be imported more than once as shown in Figure 5.3 the analyzer have an in-memory cache to know when a module has been analyzed to avoid redundant analyses. Once a module has been analyzed it is added into a list of analyzed modules and when a new module is required to be analyzed is first checked if it has been. If the module has already been analyzed it returns its module scope symbol table and otherwise, it gets analyzed.

7 Code generator

The code generation...

8 Virtual Machine

The virtual machine...

9 Application

The application layer is responsible for firing the application. In short, the job of this layer is to parse the command line arguments and run the virtual machine.

This layer exists so that the main file is not populated and the fact that this layer could evolve by providing different ways to run the program.

```
1 typedef enum : uint8_t {
2     APPLICATION_FILE
3 } ApplicationType;
```

Listing 48: Application types

Listing 48 shows the supported application types. Additional types might be included in here, such as a prompt type or a string type. At the moment, the supported application is a file application, meaning the program must come from a file path. The application layer decides based on the command line arguments, the type of the application and performs the nessesary actions acordingly.

This layer is also responsible for creating the argv parameter of the virtual machine. This parameter is a list of strings, so the C++ main arguments `argc` and `argv` are transformed into a vector of strings and further passed to the virtual machine so it can inject it into the main function call.

9.1 Application class

The application class is the implementation of the application layer, the implementation is very simple and can be seen in Listing 49

```
class Application
{
    // Defines the application type described above.
    ApplicationType application_type;
    // Stores the vritual machine used by the application.
    VirtualMachine virtual_machine;
    // Stores the file name if the application type requires it.
    std::string file_name;
    // Stores the command line arguments.
    std::vector<std::string> argv;
    // Run the application based on an input string.
    void string(const std::string &string);
    public:
        // The constructor determines the type of the application
        // based on the command line arguments.
        Application(int argc, char *argv[]);
        // Starts (runs) the application.
        int start();
};
```

Listing 49: Application class

10 Forthcoming Features

> *"Manufacturing is more than just putting parts together. It's coming up with ideas, testing principles and perfecting the engineering, as well as final assembly."*
>
> — James Dyson

Although Nuua is currently in a very advanced phase, a lot of features are still missing, features that are present in most mature programming languages. This chapter defines a set of features that are planned to be implemented into the language and the compiler.

- A C foreign function interface (FFI) to call C code using Nuua. This should allow the use of libc and other existing C code.
- A propper I/O interface to read and write to files, including stdin, stdout, stderr and removing the print statement.
- Function overloading.
- Extend and create a proper useful standard library.
- A website (nuua.io) to announce, showcase and write all the documentation.
- A centralized package/module manager to automate the process of using external modules at a certain version.
- Use a wider string representation for the compiler. Change from `std::string` to something wider like `std::u16string` or `std::wstring`.
- Support more binary operators such as `%, +=, -=, /= or *=`.
- Add more optimizations to the compiler.

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