PatternScript Compiler

Compiler Construction [CS-2002]

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1. Introduction

1.1 Overview

PatternScript is a custom domain-specific language (DSL) designed to simplify the generation of numerical sequences and text-based visual patterns. While general-purpose languages often require verbose syntax for string manipulation and output formatting, PatternScript streamlines these tasks with specialized operators and a distinct, script-like syntax.

1.2 Key Design Features

- **The Stitch Operator (~):** A unique operator dedicated to seamless concatenation of strings and numbers, eliminating the need for explicit casting (e.g., plot "Value: " ~ 5:).
- **Distinct Syntax:** PatternScript utilizes the colon (:) as a mandatory statement terminator and note> for comments, giving it a unique visual identity distinct from C-style languages.
- **Pattern Logic:** The language supports high-level constructs like loop (for iteration) and choose (for pattern matching/switching), utilizing an arrow syntax (->) for clarity.
- **Implicit Typing:** Variables are dynamically typed, supporting Number and String primitive types with automatic inference.

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2. Language Specification

2.1 Lexical Rules

The lexical analyzer identifies the following token classes:

- **Keywords:** loop, check, else, choose, default, plot, ask, in
- **Operators:** +, -, *, /, %, ~ (Stitch), ==, !=, <, >, <=, >=, -> (Arrow)
- **Separators:** {, }, (,), :, .. (Range)
- **Comments:** Lines starting with note> are treated as comments and ignored by the parser.
- **Identifiers:** Alphanumeric strings starting with a letter or underscore.
- **Literals:** Integers ([0-9]+) and Double-Quoted Strings ("[^"]*").

2.2 Grammar (BNF)

The following Context-Free Grammar defines the syntax of PatternScript.

```
<program> ::= <stmt_list>
<stmt_list> ::= <stmt>
              | <stmt_list> <stmt>

<stmt> ::= <assign_stmt>
         | <io_stmt>
         | <control_stmt>
         | <loop_stmt>

<assign_stmt> ::= IDENT "=" <expr> ":"

<io_stmt> ::= "plot" <expr> ":"
            | "ask" IDENT ":"

<loop_stmt> ::= "loop" IDENT "in" <expr> ".." <expr> "{" <stmt_list>
"}"

<control_stmt> ::= <check_stmt>
                 | <choose_stmt>

<check_stmt> ::= "check" <expr> "{" <stmt_list> "}"
                 "else" "{" <stmt_list> "}"

<choose_stmt> ::= "choose" <expr> "{" <case_list> <default_case> "}"

<case_list> ::= <case_item>
              | <case_list> <case_item>

<case_item> ::= <literal> "->" <stmt_list>

<default_case> ::= "default" "->" <stmt_list>

<expr> ::= <logic_or>
         | <term>

<logic_or> ::= <logic_and>
             | <logic_or> "||" <logic_and>

<logic_and> ::= <equality>
              | <logic_and> "&&" <equality>

<equality> ::= <relational>
             | <equality> "==" <relational>
             | <equality> "!=" <relational>

<relational> ::= <additive>
               | <additive> "<" <additive>
               | <additive> ">" <additive>
               | <additive> "<=" <additive>
               | <additive> ">=" <additive>
```

```
<additive> ::= <term>
             | <additive> "+" <term>
             | <additive> "-" <term>
             | <additive> "~" <term>

<term> ::= <factor>
         | <term> "*" <factor>
         | <term> "/" <factor>
         | <term> "%" <factor>

<factor> ::= IDENT
           | <literal>
           | "(" <expr> ")"
           | "!" <factor>      // Logical NOT
           | "-" <factor>      // Unary Minus

<literal> ::= NUMBER
            | STRING
```

2.3 Syntax Design Notes

- **Terminator:** The colon (:) acts as the statement terminator.
- **Case Separation:** The arrow (->) separates case literals from their execution blocks in ‘choose’ statements.
- **Precedence:** The grammar is stratified to ensure correct order of operations (e.g., Unary Minus > Multiplication > Addition > Logic).

3. Compiler Implementation (The 6 Phases)

3.1 Phase 1: Lexical Analysis

We implemented the Lexer using Python's re library. A key challenge was distinguishing between the Greater Than operator (>) and the Comment start (note>). We solved this by ordering the regex rules so that note> is matched first.

- **Artifact Reference:** Please see Appendix A for the handwritten DFA for note> and loop.

3.2 Phase 2: Syntax Analysis

The parser utilizes a **Recursive Descent** strategy (Top-Down). Each non-terminal in the BNF corresponds to a Python function.

- **Error Handling:** The parser checks for missing colons (:) and unbalanced braces { }.
- **Artifact Reference:** Please see Appendix A for the handwritten Parse Trees.

3.3 Phase 3: Semantic Analysis

This phase enforces type safety and logic rules to prevent runtime errors.

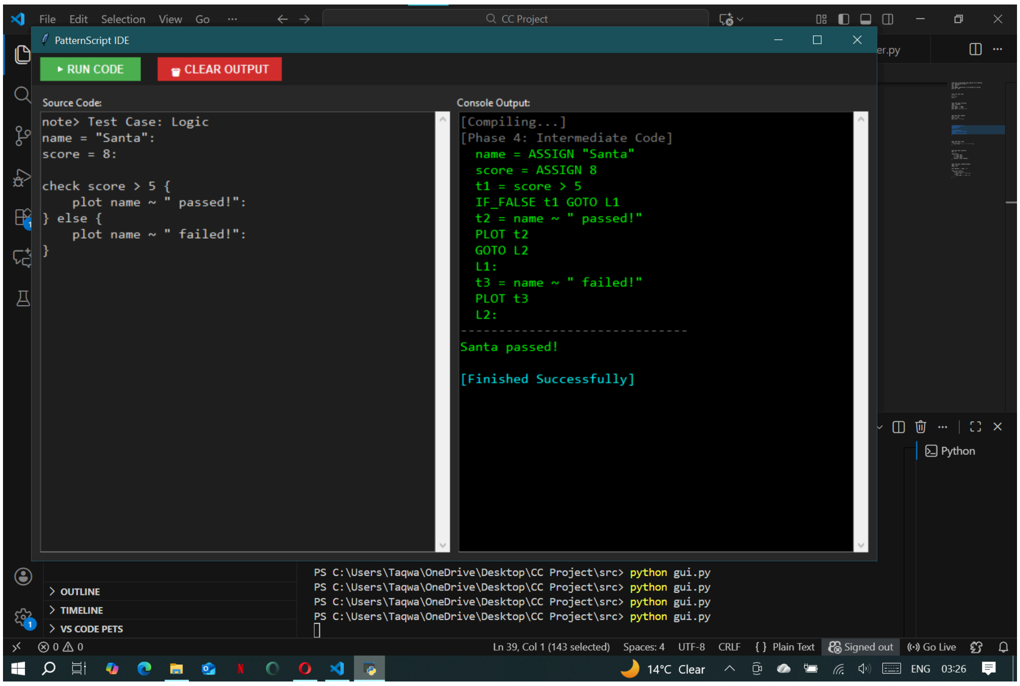
- **Symbol Table:** We implemented a symbol table to track variable scope. Variables declared inside a loop block (Scope Level 1) are removed from the table upon exit, ensuring they cannot be accessed globally.
- **Type Compatibility Rules:** The semantic analyzer enforces the following strict rules:
    1. **Arithmetic (+, -, /, %):** Both operands must be of type NUMBER
    2. **Repetition (*):** Supports NUMBER * NUMBER (Math) or STRING * NUMBER (Pattern Repetition).
    3. **Stitching (~):** Accepts mixed types. Numbers are automatically coerced to Strings for concatenation.
    4. **Relational (>, <):** Comparisons are only valid between operands of the same type.
- **Artifact Reference:** Please see Appendix A for the handwritten Symbol Table.

3.4 Phase 4: Intermediate Code Generation (ICG) The compiler translates the Abstract Syntax Tree (AST) into Three-Address Code (TAC). We utilized a Quadruple structure to handle control flow via explicit labels and jumps.

Generation Logic:

- **Assignments:** x = y + z converts to t1 = y + z followed by x = t1.
- **Loops:** The high-level loop construct is broken down into initialization, a conditional jump (IF_FALSE), a label for the body (L1), and a GOTO statement.

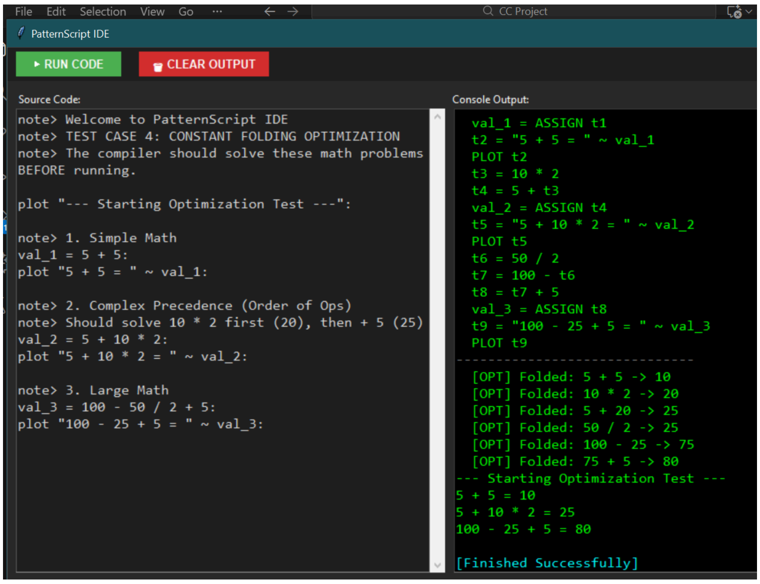
Example Derivation (From our Compiler Output):



3.5 Phase 5: Optimization

We implemented **Constant Folding**.

- **Logic:** Expressions containing only literals are computed at compile time.
- **Example:** The expression x = 2 * 3 + 5: is compiled directly as x = 11:, saving runtime cycles.



3.6 Phase 6: Code Generation (Interpreter)

The final phase is a Python-based interpreter. We developed a **custom GUI IDE** (see screenshots) that intercepts standard print() output to display it in a console window and handles ‘ask’ input via popup dialogs, creating a user-friendly experience.

4. Testing & Demonstration

Test Case 1: Mathematical Logic (Fibonacci)

Demonstrates: Loops, Assignment, Math.

Input:

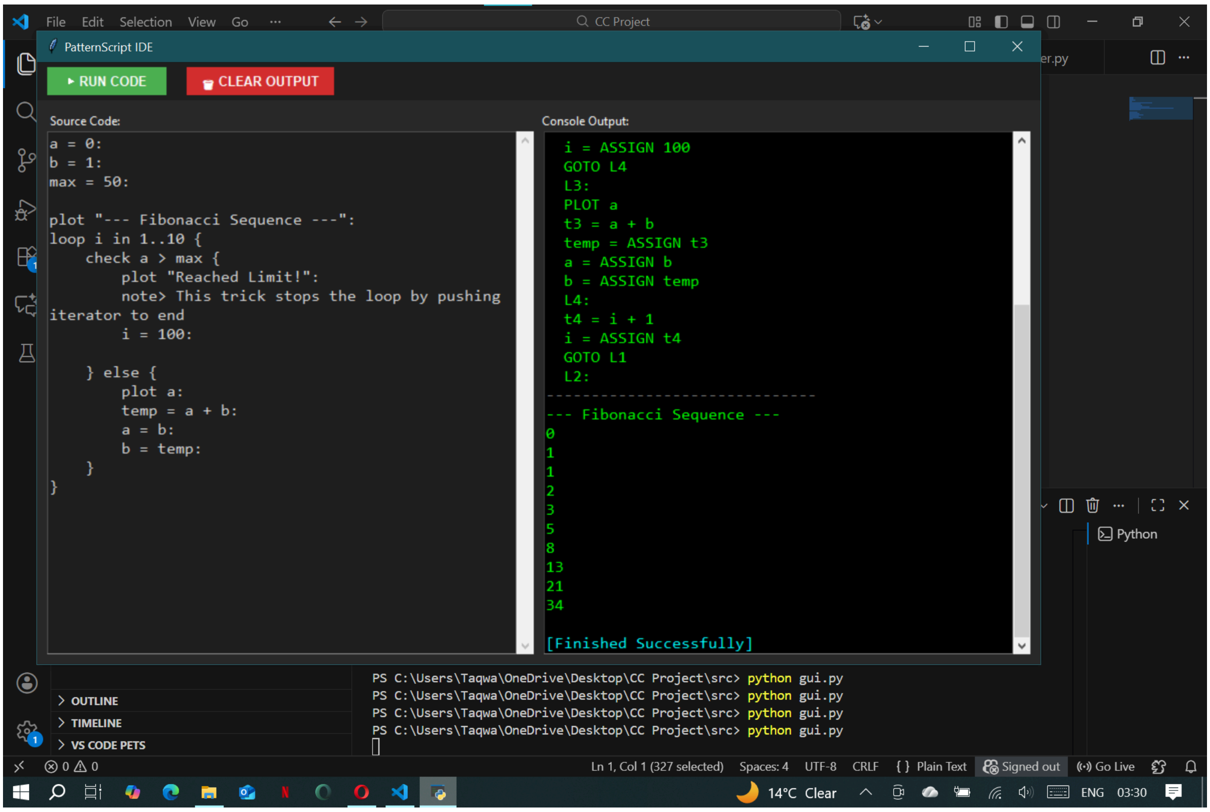
```
a = 0:
b = 1:
max = 50:

plot "--- Fibonacci Sequence ---":
loop i in 1..10 {
    check a > max {
        plot "Reached Limit!":
        note> This trick stops the loop by pushing iterator to end
        i = 100:
```

```
    } else {
        plot a:
        temp = a + b:
        a = b:
        b = temp:
    }
}
```

Expected Output:

```
0
1
1
2
3
5
8
13
21
34
```



Test Case 2: Pattern Generation

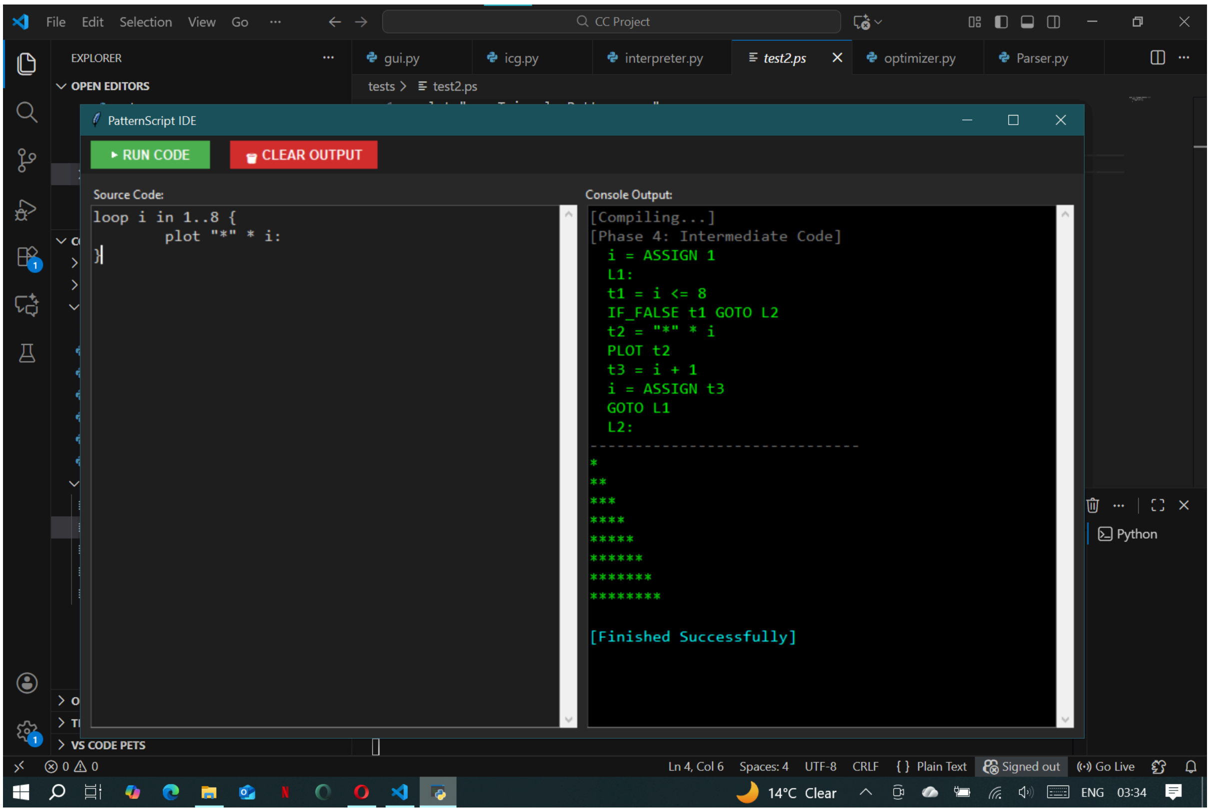
Demonstrates: The Repeat Operator (*) and Stitch Operator (~).

Input:

```
note> Triangle Pattern
loop i in 1..8 {
    plot "*" * i:
}
```

Expected Output:

```
*
**
***
****
*****
******
*******
********
```



Test Case 3: Logic & Input

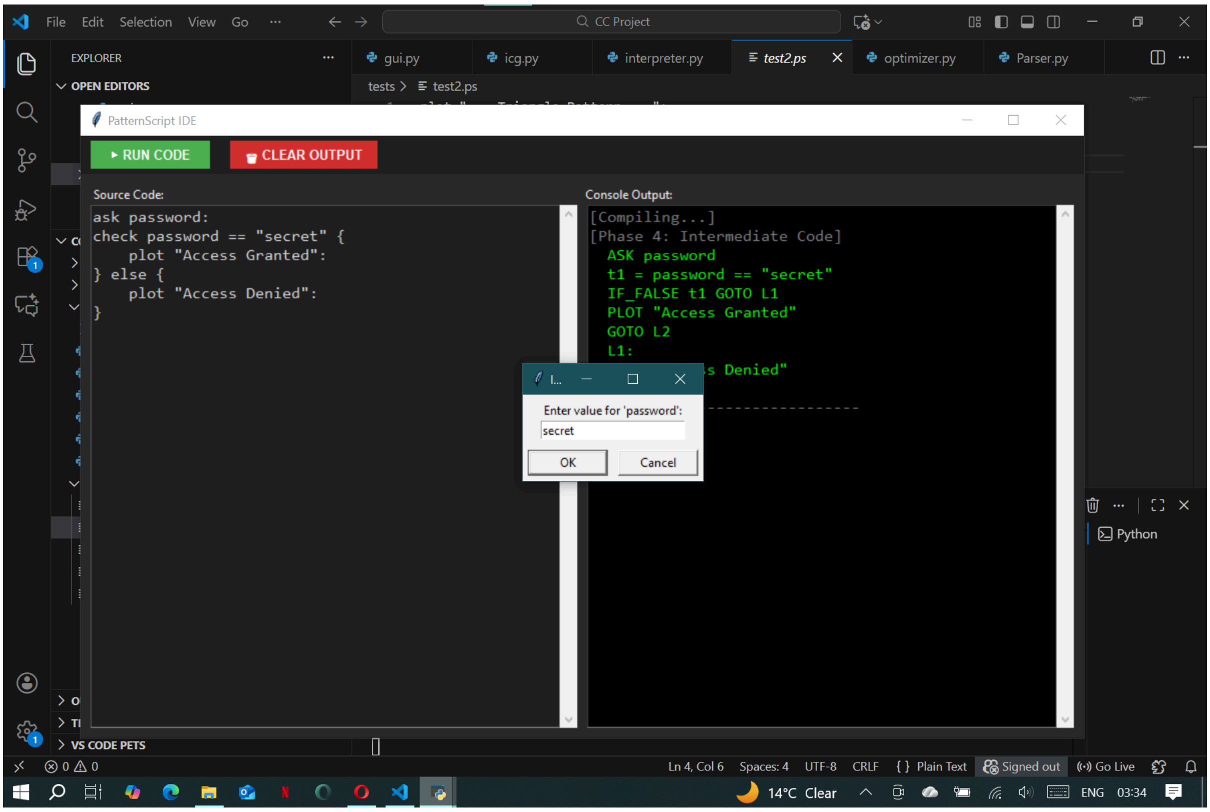
Demonstrates: ask input, check/else logic, and string comparison.

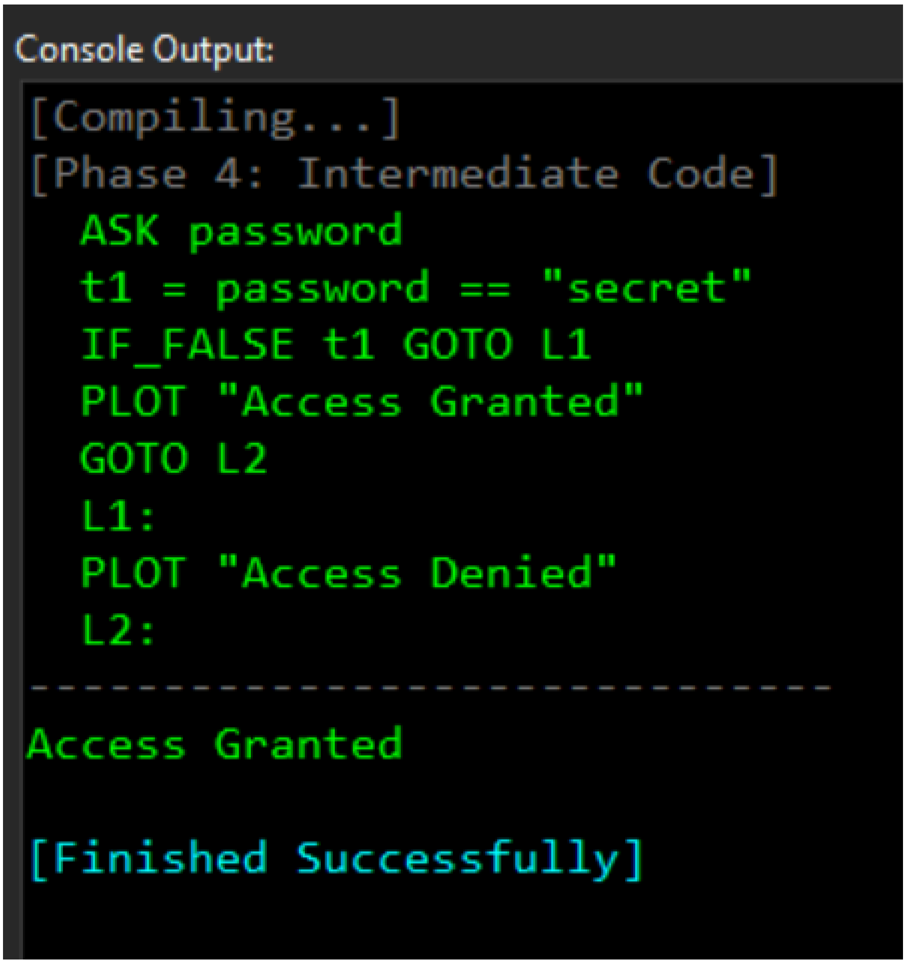
Input:

```
ask password:
check password == "secret" {
    plot "Access Granted":
} else {
    plot "Access Denied":
}
```

Expected Output:

```
(Assuming user types "secret") -> Access Granted
```





Console Output:

```
[Compiling...]
[Phase 4: Intermediate Code]
  ASK password
  t1 = password == "secret"
  IF_FALSE t1 GOTO L1
  PLOT "Access Granted"
  GOTO L2
  L1:
  PLOT "Access Denied"
  L2:
------------------------------
Access Granted

[Finished Successfully]
```

5. Reflection

Developing PatternScript provided deep insight into the internal workings of compilers.

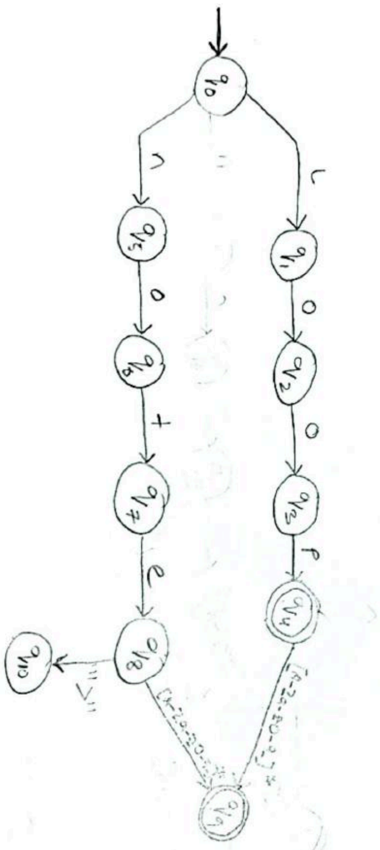
- **Key Learnings:** We learned how critical Operator Precedence is in grammar design. Initially, we struggled with expressions like 3 * 2 + 5, but layering the grammar rules (Term vs Factor) solved this.
- **Design Choices:** We initially considered a "Grid Loop" (loop x, y) but decided against it to ensure our Intermediate Code Generation (Phase 4) remained robust and bug-free. We instead focused on unique syntax features like the Arrow (->) and Stitch (~) operator.
- **Future Improvements:** Given more time, we would implement Function Declarations and Arrays to make the language fully Turing-complete.

Appendix A: Handwritten Artifacts

1. **DFA Diagram:**

DFA (lexical Analysis)

i) DFA for note> & loop keyword.



note> States q_1 through q_4 handles 'loop'. if the input stops here it is considered as keyword. if it continues to q_9 it will be considered identifier.

note> State q_8 checks the next character. if it is '>' then we enter Comment Mode. if its any other character it will considered as identifier.

2. **Parse Trees:**

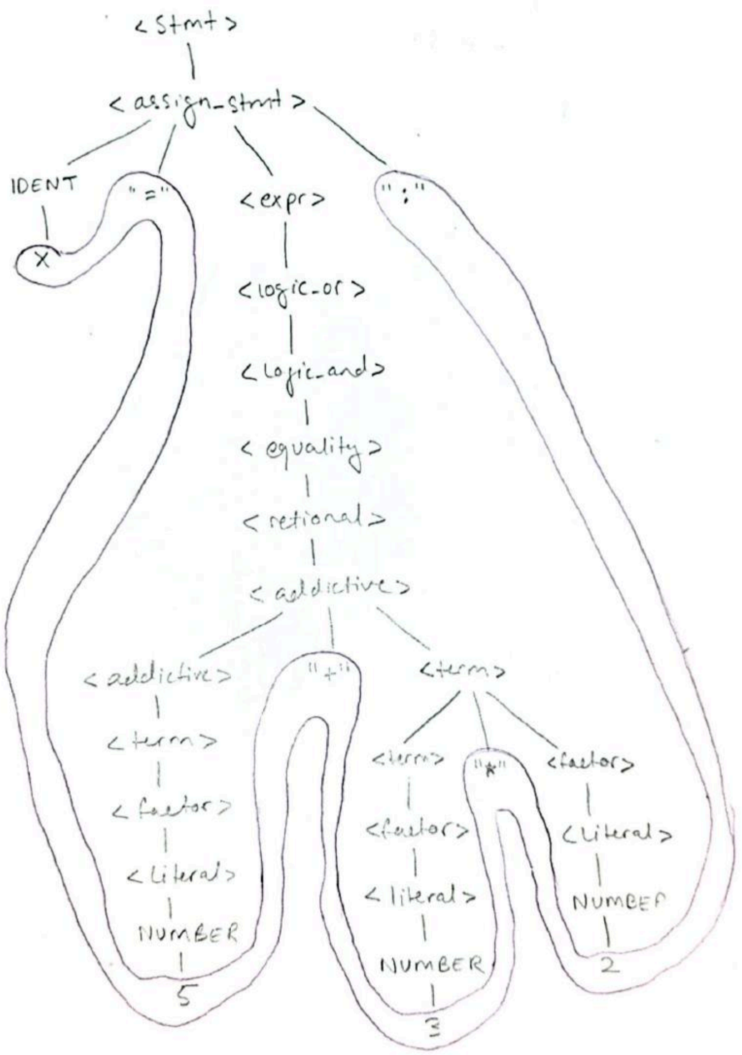
Parse tree (Syntax Analysis)

Rightmost derivation

Tree # 1 : The Math & precedence Tree

purpose : To show that precedence is correct.

Input :- x = 5 + 3 * 2 ; (3*2 will happen first).

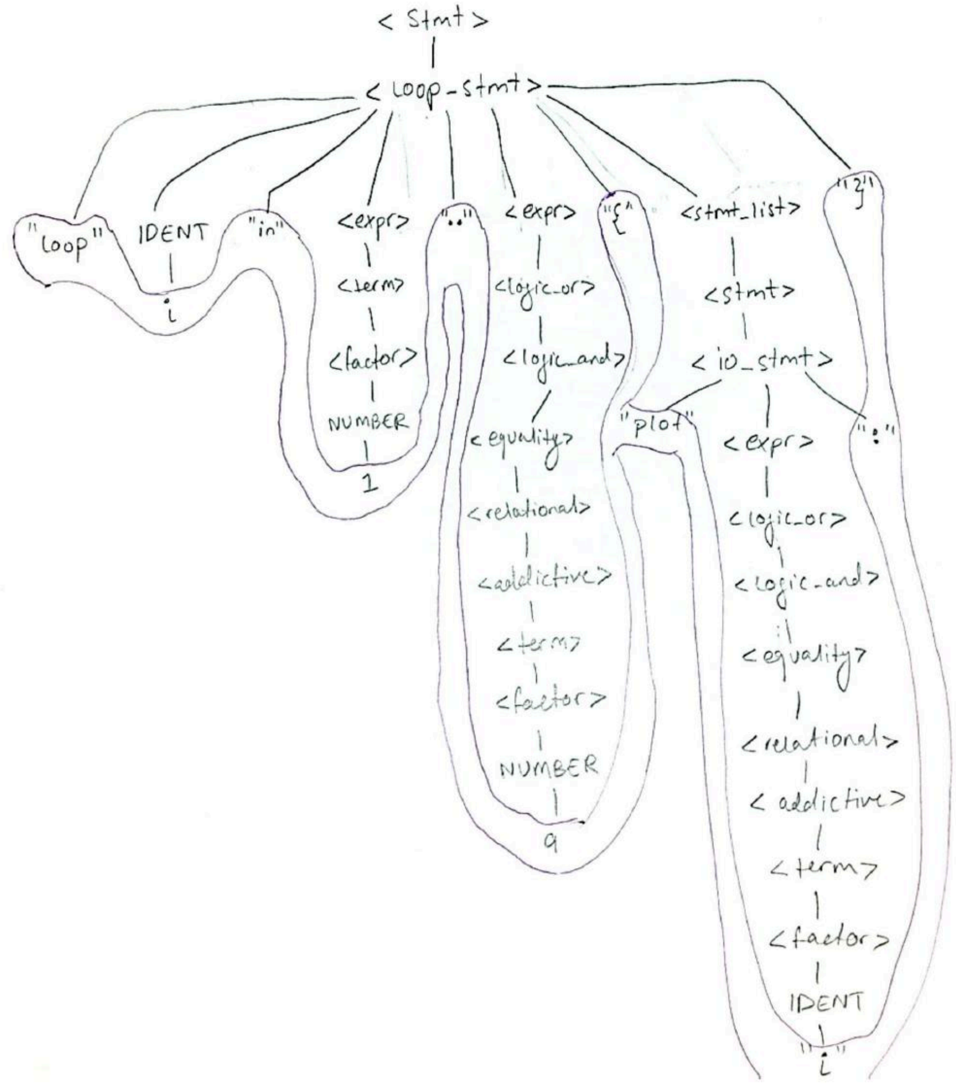


Tree #2: the loop structure explained

purpose : to show how the compiler parses complex statements.

input codes:-

```
loop i in 1..9 {
    plot i:
}
```



3. **Symbol Table:**

Symbol table (Semantic Analysis)

Example code :-

```
note> Symbol table test program
global_x = 50:
message = "Result: ":

note> Start of loop Scope (Block 1)
loop i in 1..3 {
      local_val = i * 10:
      global_x = global_x + local_val:
}
```

Semantic Error Example

if code contained: check
message > 5 {...}

Error: Type mismatch.
Cannot compare
STRING with NUMBER
using relational
operator

Name	Type	Scope level	value / offset
global_x	NUMBER	0 (Global)	50
message	STRING	0 (Global)	"Result: "
i	NUMBER	1 (loop block)	1
Local_val	NUMBER	1 (loop block)	10

Note:

* local_val is declared inside loop. when loop ends (Right brace "}"), then the local_val row is popped/removed from table.

* global_x is in global Scope (level 0). it is accessible inside the loop. The compiler resolves this by checking level 1 first, then level 0.

Appendix B: Source Code

https://github.com/TaqwaRasheed/Mini_Compiler