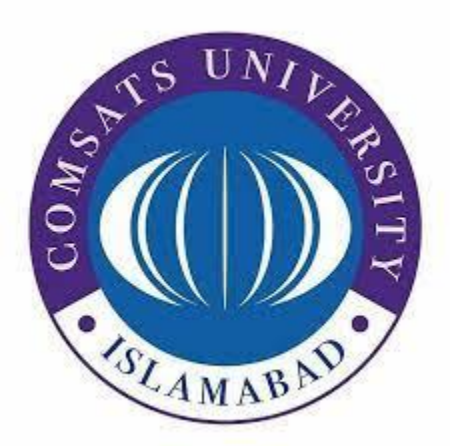
COMSATS UNIVERSITY ISLAMABAD

ATTOCK CAMPUS



Submitted To

Sir Bilal Haider

Submitted By

MUHAMMAD UMAR FAROOQ

(SP22-BCS-040)

ABDULLAH QAISAR

(SP22-BCS-001)

30th May, 2025.

MINI-COMPILER

Introduction and Overview

Project Overview

This mini compiler is a complete implementation of a programming language compiler written in C#. It demonstrates all major phases of compilation from source code to executable instructions, providing a practical example of compiler construction principles.

Supported Language Features

- **Data Types**: int, float, bool
- **Variables**: Declaration and assignment
- **Expressions**: Arithmetic, logical, and comparison operations
- **Control Flow**: if/else statements, while loops
- **Built-in Functions**: print statement for output
- **Operators**:
    - Arithmetic: +, -, *, /, %
    - Comparison: ==, !=, <, >, <=, >=
    - Logical: &&, | |, !

Target Platform

The compiler generates code for a custom stack-based virtual machine (VM), making it platform-independent while maintaining educational clarity.

Educational Value

This implementation serves as a learning tool for understanding:

- Compiler construction phases
- Abstract Syntax Tree (AST) generation
- Symbol table management
- Intermediate code generation
- Virtual machine execution

Compiler Architecture and Design

Seven-Phase Architecture

The compiler follows the traditional compilation pipeline with seven distinct phases:

Phase 1: Lexical Analysis (Tokenization)

- **Component**: Lexer class
- **Purpose**: Converts source code into tokens
- **Output**: List of tokens with type, value, and position information
- **Features**: Handles keywords, identifiers, literals, operators, and comments

Phase 2: Syntax Analysis (Parsing)

- **Component**: Parser class
- **Purpose**: Builds Abstract Syntax Tree from tokens
- **Algorithm**: Recursive descent parser
- **Grammar**: Supports operator precedence and associativity

Phase 3: Semantic Analysis

- **Component**: SemanticAnalyzer class
- **Purpose**: Type checking and symbol table management
- **Features**: Scope management, type compatibility verification, initialization checking

Phase 4: Intermediate Code Generation

- **Component**: IRGenerator class
- **Purpose**: Generates platform-independent intermediate representation
- **Format**: Three-address code style instructions

Phase 5: Optimization

- **Component**: Optimizer class
- **Purpose**: Code improvement (basic implementation)
- **Note**: Currently minimal, designed for future enhancement

Phase 6: Code Generation

- **Component**: CodeGenerator class
- **Purpose**: Translates IR to target machine code
- **Target**: Stack-based VM instructions

Phase 7: Execution

- **Component**: StackVM class
- **Purpose**: Executes generated code
- **Architecture**: Stack-based virtual machine with memory management

Design Patterns Used

- **Visitor Pattern**: For AST traversal in semantic analysis
- **Strategy Pattern**: For different optimization techniques
- **Interpreter Pattern**: For VM instruction execution

Language Specification and Grammar

Lexical Specification

Keywords

int, float, bool, void, if, else, while, for, function, return, print, true, false

Operators and Delimiters

Arithmetic: + - * / %

Assignment: =

Comparison: == != < > <= >=

Logical: && | | !

Delimiters: ; , ( ) { } .

Literals

- **Integer**: Sequences of digits (e.g., 42, 0, 123)
- **Float**: Numbers with decimal points (e.g., 3.14, 0.5)
- **Boolean**: true or false

- **String**: Quoted text with escape sequences

Grammar Specification (BNF-style)

bnf

```
program        → statement*

statement      → varDecl | assignment | ifStmt | whileStmt
               | printStmt | block | ";"

varDecl        → type IDENTIFIER ("=" expression)? ";"
assignment     → IDENTIFIER "=" expression ";"
ifStmt         → "if" "(" expression ")" statement ("else" statement)?
whileStmt      → "while" "(" expression ")" statement
printStmt      → "print" expression ";"
block          → "{" statement* "}"

expression     → logicalOr
logicalOr      → logicalAnd ("||" logicalAnd)*
logicalAnd     → equality ("&&" equality)*
equality       → comparison (("==" | "!=") comparison)*
comparison     → term ((">" | ">=" | "<" | "<=") term)*
term           → factor (("+" | "-") factor)*
factor         → unary (("*" | "/" | "%") unary)*
unary          → ("!" | "-") unary | primary
primary        → NUMBER | FLOAT | BOOLEAN | IDENTIFIER
               | "(" expression ")"

type           → "int" | "float" | "bool"
```

Operator Precedence (Highest to Lowest)

1. Unary operators (!, -)
2. Multiplicative (*, /, %)
3. Additive (+, -)
4. Relational (<, >, <=, >=)
5. Equality (==, !=)
6. Logical AND (&&)
7. Logical OR (||)

Type System

- **Static Typing**: All variables must be declared with explicit types
- **Type Compatibility**: Automatic promotion from int to float in mixed expressions
- **Type Checking**: Compile-time verification of type consistency

Implementation Details

Key Data Structures

Token Structure

csharp

```
public class Token {
    public TokenType Type { get; set; }
    public string Value { get; set; }
    public int Line { get; set; }
    public int Column { get; set; }
}
```

AST Node Hierarchy

- **Base Class**: ASTNode with type and position information
- **Expression Nodes**: BinaryOpNode, UnaryOpNode, NumberNode, etc.

- **Statement Nodes**: VarDeclarationNode, AssignmentNode, IfNode, etc.

Symbol Table

```
csharp
public class Symbol {
    public string Name { get; set; }
    public DataType Type { get; set; }
    public int Scope { get; set; }
    public int Address { get; set; }
    public bool IsInitialized { get; set; }
}
```

Error Handling Strategy

- **Custom Exception**: CompilerException with line/column information
- **Error Recovery**: Continues parsing after errors when possible
- **Semantic Errors**: Detailed type mismatch and undeclared variable messages

Memory Management

- **Stack-based VM**: Uses evaluation stack for expression computation
- **Variable Storage**: Array-based memory with address allocation
- **Scope Management**: Hierarchical symbol table with scope stack

Intermediate Representation

The IR uses a simple instruction set:

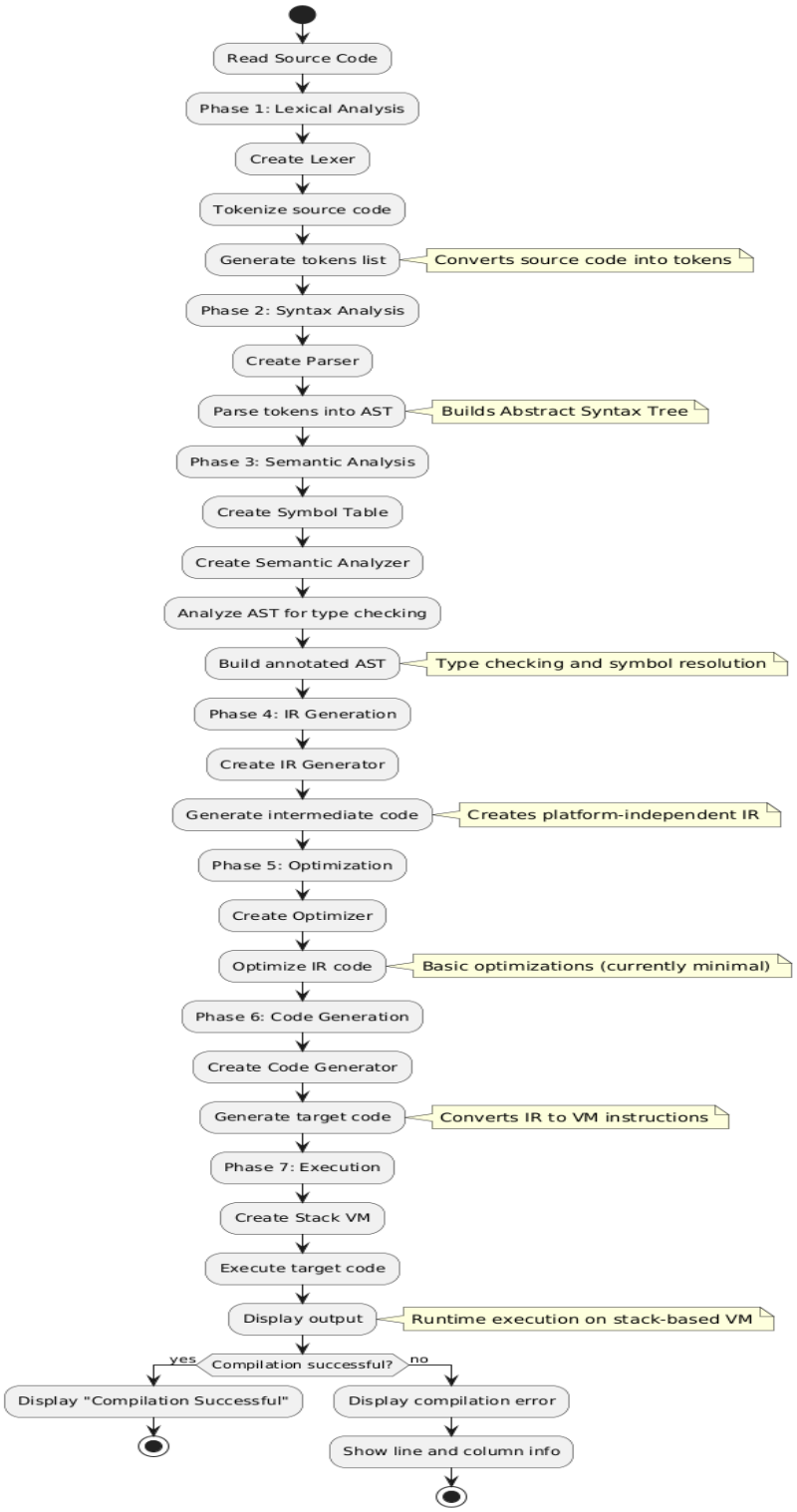
- **Data Movement**: LOAD_CONST, LOAD_VAR, STORE_VAR
- **Arithmetic**: ADD, SUB, MUL, DIV, MOD
- **Comparison**: CMP_EQ, CMP_NEQ, CMP_LT, etc.
- **Control Flow**: JUMP, JUMP_IF_FALSE, LABEL
- **I/O**: PRINT

Virtual Machine Architecture

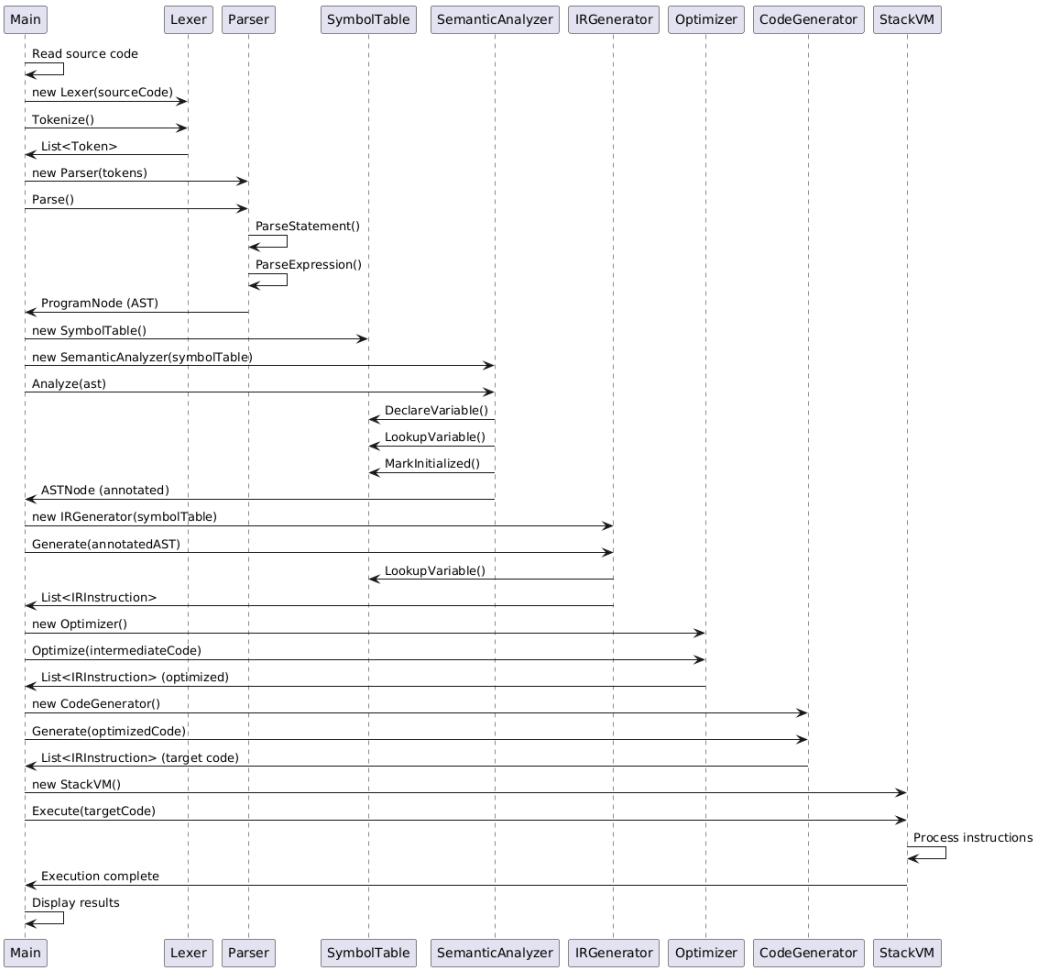
- **Stack-based Execution**: Operands pushed/popped from evaluation stack
- **Memory Model**: Linear array for variable storage
- **Instruction Pointer**: Sequential execution with jump capabilities
- **Type Handling**: Dynamic type conversion during arithmetic operations

Diagrams

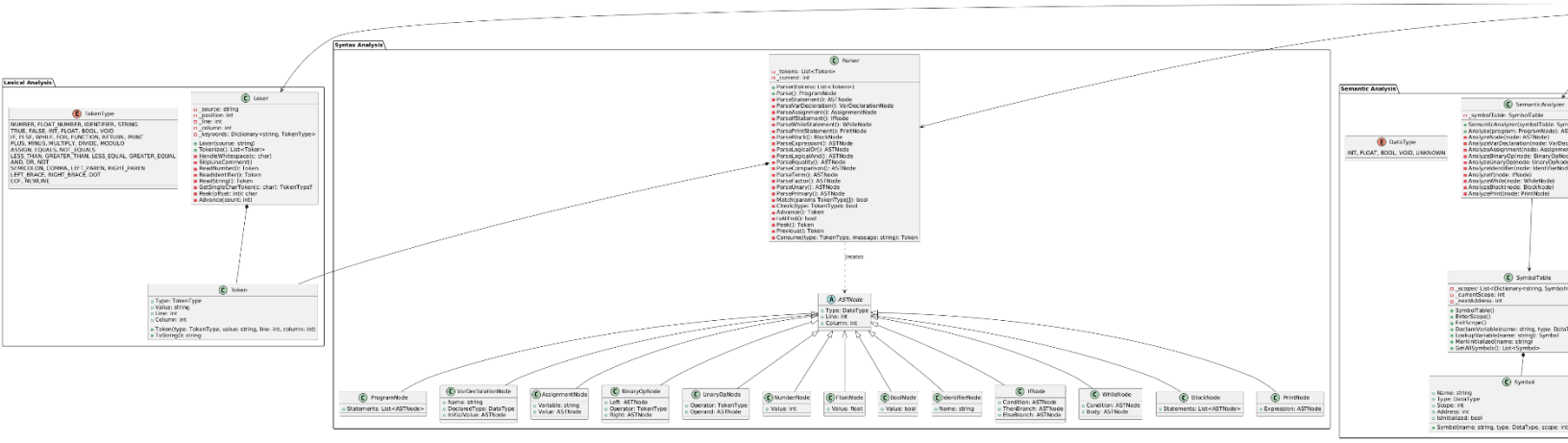
Activity Diagram:



Sequence Diagram:



Class Diagram:



GitHub Repository

https://github.com/UMAR-CUI/Mini-Compiler-SP22.git