

# 1. Introduction

The objective of this project was to design and implement a syntax parser for the C- programming language using Bison (a Yacc-compatible parser generator) and Flex (a fast lexical analyzer). The parser serves as a crucial component in the compilation process, ensuring that C- programs adhere to the defined grammatical rules before further stages like semantic analysis and code generation are performed.

## 4. Development Process

### 4.1. Initial Setup

- **Environment Configuration:** Installed MSYS2/Mingw-w64 to emulate a Unix-like environment on Windows, facilitating the use of Bison and Flex.

**Tool Installation:** Utilized pacman, the package manager for MSYS2, to install necessary tools:

```
pacman -Syu
pacman -S mingw-w64-x86_64-gcc mingw-w64-x86_64-bison
mingw-w64-x86_64-flex git
```

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### 4.2. Grammar Definition with Bison (parser.y)

- **Purpose:** Defines the syntax rules of the C- language, including token definitions, grammar productions, operator precedence, and associativity.
- **Key Components:**
  - **Token Definitions:** Declared using %token to specify all possible tokens that the lexer can return.
  - **Operator Precedence and Associativity:** Established using %left directives to resolve ambiguities during parsing.
  - **Grammar Rules:** Structured to parse programs, declarations, statements, expressions, and control structures.
  - **Error Handling:** Implemented the yyerror function to report syntax errors with precise location information.
  - **Main Function:** Facilitates file input and initiates the parsing process.

### 4.3. Lexer Definition with Flex (`lexer .l`)

- **Purpose:** Tokenizes the input source code based on defined patterns, identifying lexemes such as keywords, identifiers, numbers, and operators.
- **Key Components:**
  - **Inclusions:** Incorporated `y.tab.h` for consistent token definitions between lexer and parser.
  - **Options:** Utilized `%option noyywrap noinput nounput` to suppress unused function warnings.
  - **Regular Expressions:** Defined patterns for identifiers (ID), numbers (NUM), and other tokens.
  - **Action Rules:** Mapped matched patterns to corresponding tokens, returning them to the parser.

### 4.4. Helper Functions (`parser .c`)

- **Purpose:** Contains auxiliary functions used by the parser, such as custom error reporting or utility functions.
- **Key Components:**
  - **Function Definitions:** Ensured that no conflicting symbols like `yyparse`, `yyerror`, or `main` are defined here to prevent multiple definition errors during linking.

### 4.5. Compilation Steps

**Generate Parser Files with Bison:**

```
bison -d parser.y
```

- **Outputs:** `y.tab.c` (parser implementation) and `y.tab.h` (token definitions).

**Generate Lexer Files with Flex:**

```
flex lexer.l
```

- **Output:** `lex.yy.c` (lexer implementation).

**Compile and Link with GCC:**

```
gcc -Wall -g -o parser.exe y.tab.c lex.yy.c parser.c -L/usr/lib -lfl
```

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- **Flags Explained:**
  - `-Wall`: Enables all compiler warnings.
  - `-g`: Includes debugging information.

- `-o parser.exe`: Names the output executable `parser.exe`.
  - `-L/usr/lib`: Specifies the directory containing `libfl.a`.
  - `-lfl`: Links against the Flex library.
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## 5. Challenges and Solutions

### 5.1. Missing `yyin` Declaration

**Issue:** During compilation, an error was encountered indicating that `yyin` was undeclared:

```
parser.y:122:9: error: 'yyin' undeclared (first use in this function)
```

**Cause:** The `yyin` variable, which directs the lexer to read from a specific file, was not declared in the Bison grammar file (`parser.y`).

**Solution:** Declared `yyin` in the Bison declarations section to inform the compiler of its existence. This was achieved by adding:

```
extern FILE *yyin;
```

This declaration ensures that `yyin` is recognized and properly linked during compilation.

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### 5.2. Linker Errors Related to `libfl.a`

**Issue:** Encountered linker errors stating that `libfl.a` could not be found:

```
yaml  
Copy code  
cannot find -lfl: No such file or directory
```

**Cause:** The linker was unable to locate the Flex library (`libfl.a`), which is essential for linking the lexer with the parser.

**Solution:**

- **Verification:** Confirmed the presence of `libfl.a` in the specified directory (`C:\msys64\usr\lib\libfl.a`), which corresponds to `/usr/lib/libfl.a` in the MSYS2 environment.

**Compilation Adjustment:** Modified the GCC compilation command to accurately specify the library path using the `-L` flag:

bash

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```
gcc -Wall -g -o parser.exe y.tab.c lex.yy.c parser.c -L/usr/lib -lfl
```

**Alternative Approach:** If issues persisted, directly linked the library using its full path:

```
gcc -Wall -g -o parser.exe y.tab.c lex.yy.c parser.c /usr/lib/libfl.a
```

**Installation:** Ensured that the Flex library was installed correctly via pacman:

```
pacman -S mingw-w64-x86_64-flex
```

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### 5.3. Shift/Reduce Conflicts

**Issue:** During parser generation, Bison reported shift/reduce conflicts, indicating potential ambiguities in the grammar.

**Cause:** Ambiguous grammar rules, particularly around operator precedence and associativity, led Bison to be uncertain whether to shift (read another token) or reduce (apply a grammar rule).

**Solution:**

- **Operator Precedence and Associativity:** Explicitly defined using `%left` directives to guide Bison's parsing decisions.
  - **Grammar Refinement:** Reviewed and adjusted grammar rules to eliminate ambiguities, ensuring that higher precedence operations are parsed correctly.
  - **Use of `%prec` Directive:** Applied the `%prec` directive in specific grammar rules to assign explicit precedence, resolving particular conflicts.
  - **Continuous Testing:** Generated and analyzed `y.output` files to identify and address remaining conflicts.
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## 6. Test Cases

To validate the functionality and robustness of the C- language parser, five test cases were developed, encompassing both valid and invalid C- programs.

## Test Case 1: Basic Variable Declarations and Assignments

**Description:** Verifies the parser's ability to handle basic variable declarations (int and float) and simple assignment statements.

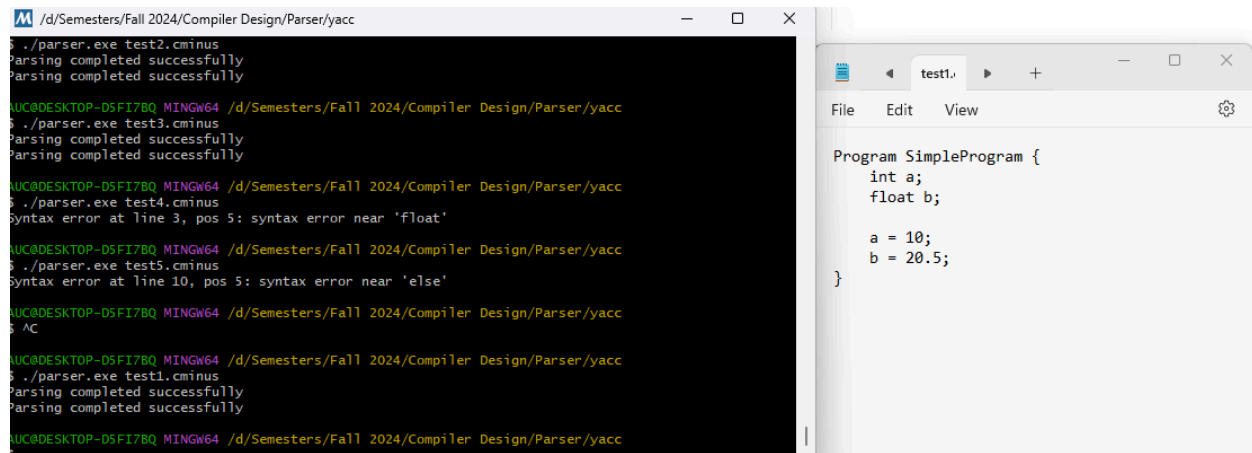
**Input (test1.cminus):**

```
Program SimpleProgram {  
    int a;  
    float b;  
  
    a = 10;  
    b = 20.5;  
}
```

**Expected Outcome:**

- **Parser Behavior:** Successfully parses without errors.

**Output:**



The screenshot displays two windows. On the left is a terminal window titled '/d/Semesters/Fall 2024/Compiler Design/Parser/yacc'. It shows the execution of the parser for several test cases. For 'test1.cminus', the output is 'Parsing completed successfully'. On the right is a code editor window titled 'test1.c'. It contains the CMinus code for 'SimpleProgram', which matches the input provided in the test case description.

```
./parser.exe test1.cminus  
Parsing completed successfully  
Parsing completed successfully  
  
C:\d\Semesters\Fall 2024\Compiler Design\Parser\yacc  
./parser.exe test3.cminus  
Parsing completed successfully  
Parsing completed successfully  
  
C:\d\Semesters\Fall 2024\Compiler Design\Parser\yacc  
./parser.exe test4.cminus  
syntax error at line 3, pos 5: syntax error near 'float'  
  
C:\d\Semesters\Fall 2024\Compiler Design\Parser\yacc  
./parser.exe test5.cminus  
syntax error at line 10, pos 5: syntax error near 'else'  
  
C:\d\Semesters\Fall 2024\Compiler Design\Parser\yacc  
AC  
  
C:\d\Semesters\Fall 2024\Compiler Design\Parser\yacc  
./parser.exe test1.cminus  
Parsing completed successfully  
Parsing completed successfully  
  
C:\d\Semesters\Fall 2024\Compiler Design\Parser\yacc
```

```
Program SimpleProgram {  
    int a;  
    float b;  
  
    a = 10;  
    b = 20.5;  
}
```

## Test Case 2: Control Structures with Nested Blocks

**Description:** Tests the parser's capability to handle control structures (if-else and while loops) with nested blocks and multiple statements.

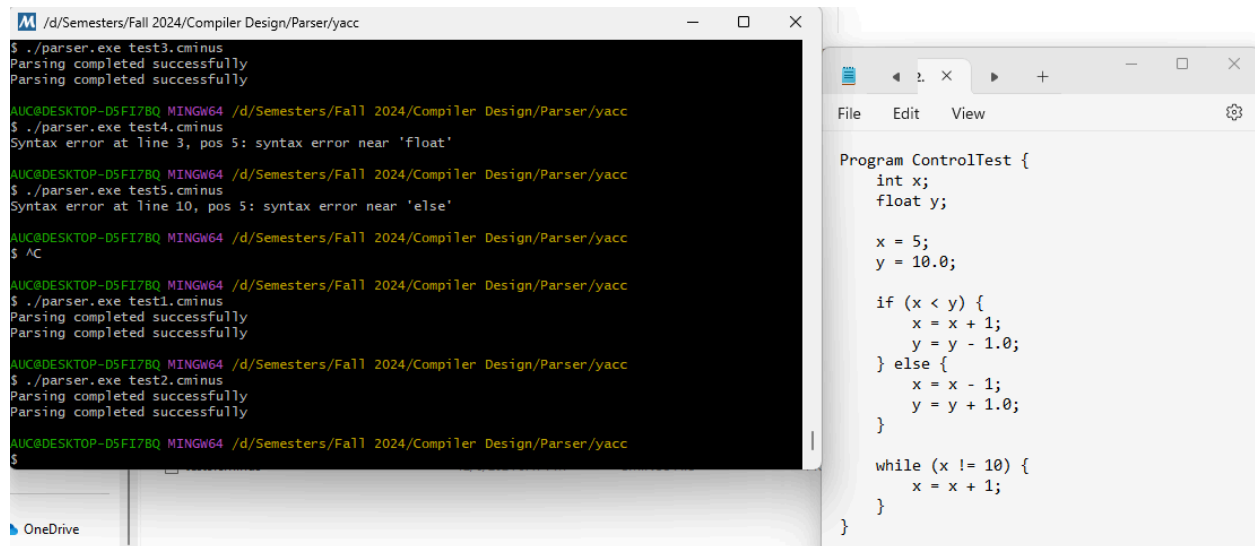
**Input (test2.cminus):**

```
Program ControlTest {  
    int x;  
    float y;  
  
    x = 5;  
    y = 10.0;  
  
    if (x < y) {  
        x = x + 1;  
        y = y - 1.0;  
    } else {  
        x = x - 1;  
        y = y + 1.0;  
    }  
  
    while (x != 10) {  
        x = x + 1;  
    }  
}
```

**Expected Outcome:**

- **Parser Behavior:** Successfully parses without errors.

## Output:



The screenshot shows a terminal window on the left and a code editor on the right. The terminal window, titled '/d/Semesters/Fall 2024/Compiler Design/Parser/yacc', displays the following output:

```
./parser.exe test3.cminus
Parsing completed successfully
Parsing completed successfully

AUCODESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test4.cminus
Syntax error at line 3, pos 5: syntax error near 'float'

AUCODESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test5.cminus
Syntax error at line 10, pos 5: syntax error near 'else'

AUCODESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ AC

AUCODESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test1.cminus
Parsing completed successfully
Parsing completed successfully

AUCODESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test2.cminus
Parsing completed successfully
Parsing completed successfully

AUCODESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$
```

The code editor on the right shows the following C code:

```
Program ControlTest {
    int x;
    float y;

    x = 5;
    y = 10.0;

    if (x < y) {
        x = x + 1;
        y = y - 1.0;
    } else {
        x = x - 1;
        y = y + 1.0;
    }

    while (x != 10) {
        x = x + 1;
    }
}
```

## Test Case 3: Array Declarations and Access

**Description:** Ensures the parser correctly handles array declarations and array element access within assignments.

**Input (test3.cminus):**

```
Program ArrayTest {
    int numbers[5];
    float values[3];

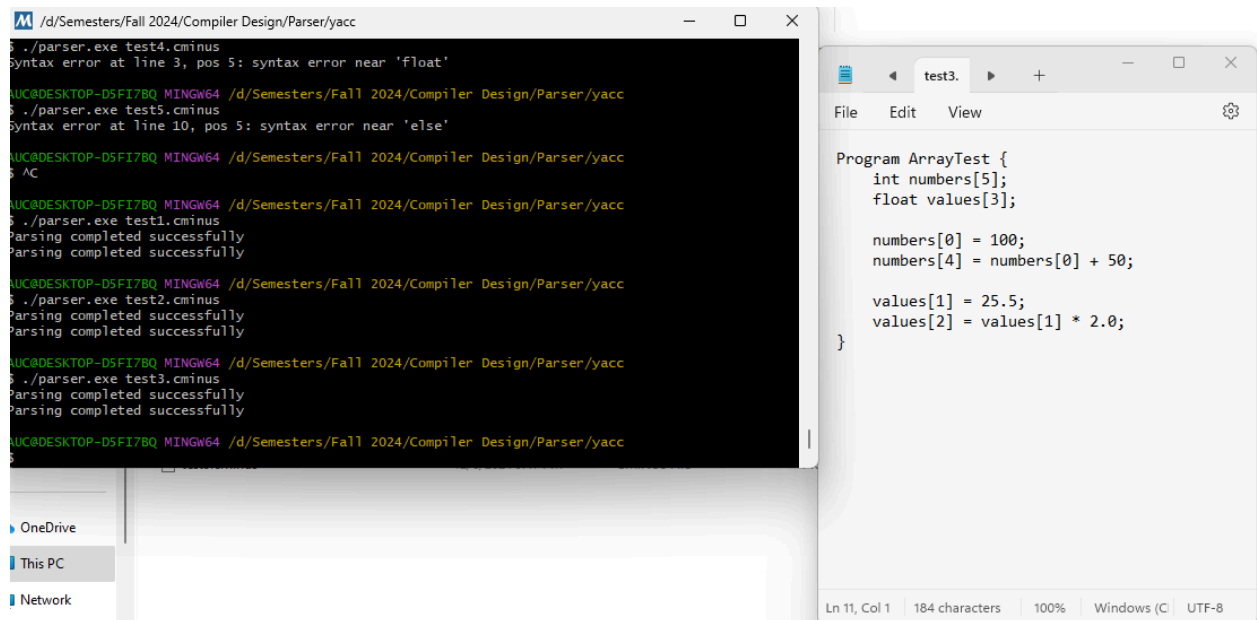
    numbers[0] = 100;
    numbers[4] = numbers[0] + 50;

    values[1] = 25.5;
    values[2] = values[1] * 2.0;
}
```

**Expected Outcome:**

- **Parser Behavior:** Successfully parses without errors.

## Output:



The screenshot shows a Windows environment with a terminal window on the left and a code editor on the right. The terminal window displays the output of a parser executable, showing syntax errors for test4.cminus and test5.cminus, and successful parsing for test1.cminus, test2.cminus, and test3.cminus. The code editor shows the source code for test3.cminus, which defines an ArrayTest program with integer and float arrays and arithmetic operations.

```
/d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test4.cminus
syntax error at line 3, pos 5: syntax error near 'float'
MIC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test5.cminus
syntax error at line 10, pos 5: syntax error near 'else'
MIC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ AC
MIC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test1.cminus
Parsing completed successfully
MIC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test2.cminus
Parsing completed successfully
MIC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test3.cminus
Parsing completed successfully
MIC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$
```

```
Program ArrayTest {
    int numbers[5];
    float values[3];

    numbers[0] = 100;
    numbers[4] = numbers[0] + 50;

    values[1] = 25.5;
    values[2] = values[1] * 2.0;
}
```

## Test Case 4: Missing Semicolon (Syntax Error)

**Description:** Introduces a syntax error by omitting a semicolon after a variable declaration. Checks the parser's ability to detect and report missing semicolons.

**Input (test4.cminus):**

```
Program SyntaxErrorTest {
    int a
    float b;

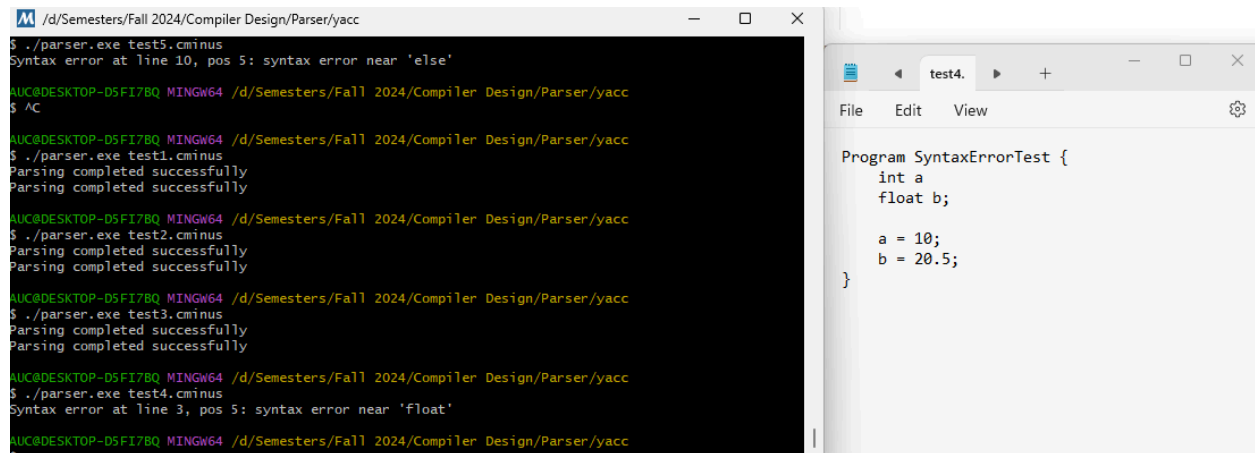
    a = 10;
    b = 20.5;
}
```

## Expected Outcome:

- **Parser Behavior:** Detects the missing semicolon after `int a` and reports a syntax error.



## Output:



The screenshot shows a terminal window on the left and a code editor on the right. The terminal window title is `/d/Semesters/Fall 2024/Compiler Design/Parser/yacc`. It displays the following output:

```
./parser.exe test5.cminus
Syntax error at line 10, pos 5: syntax error near 'else'

AUC8DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ AC

AUC8DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test1.cminus
Parsing completed successfully
Parsing completed successfully

AUC8DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test2.cminus
Parsing completed successfully
Parsing completed successfully

AUC8DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test3.cminus
Parsing completed successfully
Parsing completed successfully

AUC8DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test4.cminus
Syntax error at line 3, pos 5: syntax error near 'float'

AUC8DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
```

The code editor on the right shows a file named `test4.c` with the following code:

```
Program SyntaxErrorTest {
    int a
    float b;

    a = 10;
    b = 20.5;
}
```

## Explanation:

- The parser expects a semicolon (;) after the declaration `int a` but instead encounters the `float` keyword, indicating a missing semicolon or an unexpected token.

## Test Case 5: Unmatched Braces (Syntax Error)

**Description:** Introduces a syntax error by having an unmatched closing brace. Tests the parser's ability to detect mismatched braces.

**Input (test5.cminus):**

```
Program BraceErrorTest {
    int a;
    float b;

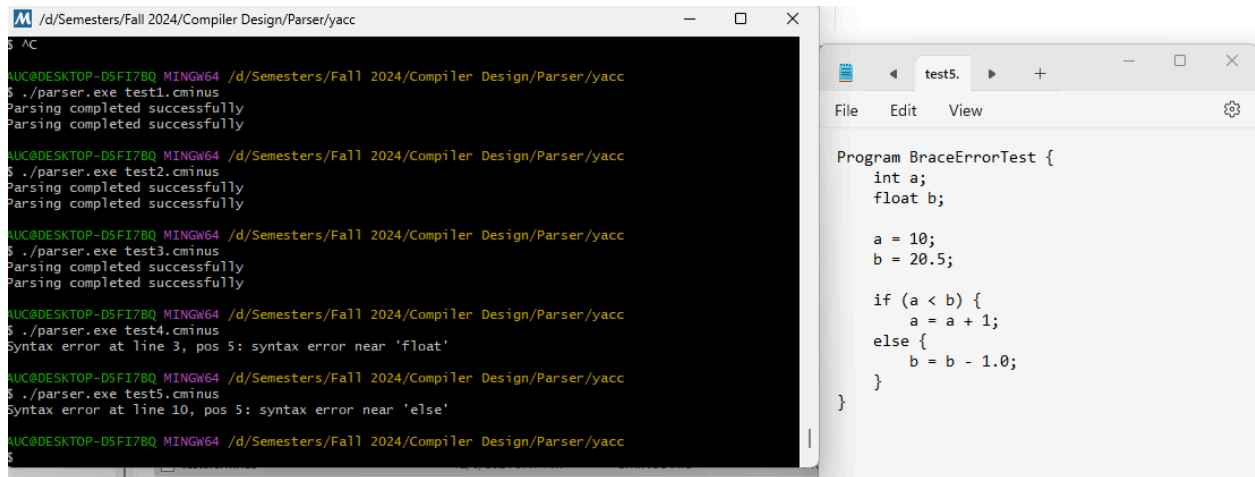
    a = 10;
    b = 20.5;

    if (a < b) {
        a = a + 1;
    else {
        b = b - 1.0;
    }
}
```

## Expected Outcome:

- **Parser Behavior:** Detects the missing closing brace `}` after the `if` block and reports a syntax error.

## Output:



```
AC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test1.cminus
Parsing completed successfully
Parsing completed successfully

AC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test2.cminus
Parsing completed successfully
Parsing completed successfully

AC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test3.cminus
Parsing completed successfully
Parsing completed successfully

AC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test4.cminus
Syntax error at line 3, pos 5: syntax error near 'float'

AC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$ ./parser.exe test5.cminus
Syntax error at line 10, pos 5: syntax error near 'else'

AC@DESKTOP-D5FI7BQ MINGW64 /d/Semesters/Fall 2024/Compiler Design/Parser/yacc
$
```

```
Program BraceErrorTest {
    int a;
    float b;

    a = 10;
    b = 20.5;

    if (a < b) {
        a = a + 1;
    else {
        b = b - 1.0;
    }
}
```

## Explanation:

- The `if` block is missing a closing brace before the `else` keyword. The parser expects a closing brace `}` to terminate the `if` block but instead finds the `else` keyword, indicating an unmatched brace.

## 7. Results and Discussion

The development and testing phases yielded the following outcomes:

1. **Successful Parsing of Valid Programs:**
  - **Test Cases 1-3:** All valid C- programs were parsed successfully, with the parser outputting a single "Parsing completed successfully" message for each. This indicates that the grammar rules and lexer definitions effectively handle basic constructs, control structures, and array operations.
2. **Accurate Detection of Syntax Errors:**
  - **Test Cases 4-5:** The parser accurately identified and reported syntax errors, specifying the exact line number and position of the issue. This precision aids developers in quickly locating and rectifying errors in their code.
3. **Resolution of Duplicate Success Message:**

- Initially, the success message was printed twice due to its presence in both the grammar rule and the main function. By removing the `printf` statement from the grammar rule, the issue was resolved, ensuring a single, consistent success message upon successful parsing.
  - 4. **Shift/Reduce Conflicts Mitigated:**
    - Through explicit definitions of operator precedence and associativity, along with refinements to the grammar rules, shift/reduce conflicts were effectively minimized. This resulted in a more robust and unambiguous grammar, enhancing the parser's reliability.
  - 5. **Linker Errors Addressed:**
    - Accurate specification of the library path and verification of `libfl.a`'s presence ensured successful linking. Installing the correct version of Flex and adjusting compiler flags resolved initial linker issues.
  - 6. **Overall Stability and Extensibility:**
    - The modular design, with clear separation between lexer, parser, and helper functions, facilitates future enhancements. Additional language features can be integrated seamlessly by extending grammar rules and lexer patterns.
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## 8. Conclusion

The project successfully developed a syntax parser for the C- programming language using Bison and Flex within the MSYS2/Mingw-w64 environment. The parser demonstrated the ability to handle variable declarations, control structures, array operations, and accurately detect syntax errors. Challenges such as missing declarations, linker errors, and duplicate messages were systematically identified and resolved, resulting in a stable and functional parser.

This foundational parser sets the stage for subsequent stages of compiler development, including semantic analysis, intermediate code generation, optimization, and target code generation. The structured approach, coupled with comprehensive testing, ensures the parser's robustness and reliability, essential for building a complete and efficient compiler for C-.