CSE340 Spring 2020 Project 1: A Simple Compiler!

Due: **Wednesday, February 14, 2020 by 11:59 pm MST**

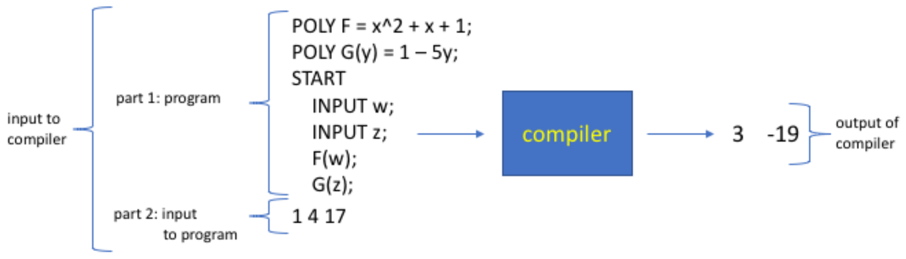
1 Introduction

I will start with a high-level description of the project and its tasks in this section and then, in subsequent sections, I will go into a detailed description on how to achieve these tasks. The goal of this project is to implement a simple compiler for a simple programming language. By implementing this simple compiler, you will do basic parsing and use some simple data structures which would be useful for the other projects.

The input to your program will have two parts:

1. The first part of the input is a program which is a list of polynomial declarations followed by a `START` section.
2. The second part of the input is a sequence of integers which will be used as the input to the program given in the first part.

Your compiler will read the program and makes sure that its syntax and semantics are correct. If the syntax or semantics are not correct, the compiler will output an error message as described later. If both the syntax and semantics are correct, the compiler should evaluate the polynomials in the `START` section of the program and the output of the compiler is the sequence of values resulting from the evaluations of the polynomials in the `START` section. More details about the input format and the expected output of your program are given in subsequent sections. The following is a high-level illustration of what your compiler should do for a particular example program whose syntax and semantics are correct.



The remainder of this document is organized as follows.

- The second section describes the input format.
- The third section describes the expected output when the syntax or semantics are not correct.
- the fourth section describes the output when the program syntax and semantics are correct.
- The fifth section describes the requirements on your solution.
- The sixth section gives **instructions for this programming assignment and additional instructions that apply to ALL programming assignments in this course**.

2 Input Format

2.1 Grammar and Tokens

The input of your program is specified by the following context-free grammar:

```
input                        →  program inputs
program                      →  poly_decl_section start
poly_decl_section            →  poly_decl
poly_decl_section            →  poly_decl poly_decl_section
poly_decl                    →  POLY polynomial_header EQUAL polynomial_body SEMICOLON
polynomial_header            →  polynomial_name
polynomial_header            →  polynomial_name LPAREN id_list RPAREN
id_list                      →  ID
id_list                      →  ID COMMA id_list
polynomial_name              →  ID
polynomial_body              →  term_list
term_list                    →  term
term_list                    →  term add_operator term_list
term                         →  monomial_list
term                         →  coefficient monomial_list
term                         →  coefficient
monomial_list                →  monomial
monomial_list                →  monomial monomial_list
monomial                     →  ID
monomial                     →  ID exponent
exponent                     →  POWER NUM
add_operator                 →  PLUS
add_operator                 →  MINUS
coefficient                  →  NUM
start                        →  START statement_list
inputs                       →  NUM
inputs                       →  NUM inputs
statement_list               →  statement
statement_list               →  statement statement_list
statement                    →  input_statement
statement                    →  poly_evaluation_statement
poly_evaluation_statement    →  polynomial_evaluation SEMICOLON
input_statement              →  INPUT ID SEMICOLON
polynomial_evaluation        →  polynomial_name LPAREN argument_list RPAREN
argument_list                →  argument
argument_list                →  argument COMMA argument_list
argument                     →  ID
argument                     →  NUM
argument                     →  polynomial_evaluation
```

The code that we provided has a class `LexicalAnalyzer` with methods `getToken()` and `ungetToken()`. Your parser will use the provided functions to get or unget tokens as needed. You do not need to change the functions `getToken()` and `ungetToken()`; you just use them as provided. To use the methods, you should first instantiate a `lexer` object of the class `LexicalAnalyzer` and call the methods on this instance. The definition of the tokens is given below for completeness (you can ignore it for the most part if you want).

```
char      =   a | b | ... | z | A | B | ... | Z  | 0 |  1 | ... | 9
letter    =   a | b | ... | z | A | B | ... | Z
pdigit    =   1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
digit     =   0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
```

```
SEMICOLON      =  ;
COMMA          =  ,
PLUS           =  +
MINUS          =  -
POWER          =  ^
EQUAL          =  =
LPAREN         =  (
RPAREN         =  )
POLY           =  (P).(O).(L).(Y)
START          =  (S).(T).(A).(R).(T)
INPUT          =  (I).(N).(P).(U).(T)
NUM            =  0 | pdigit . digit*
ID             =  letter . char*
```

What you need to do is to write a parser to parse the input according to the grammar and store the information being parsed by your parser in appropriate data structures to allow your program to *execute* the input `program` on the `inputs`. For now do not worry how that is achieved. I will explain that in details.

2.2 Examples

The following are examples of inputs (to your compiler) with corresponding outputs. The output will be explained in more details in the later sections.

1.
   ```
   POLY F = x^2 + 1;
   POLY G = x + 1;
   START
   F(4);
   G(2);
   1 2 3 18 19
   ```

   This example shows two polynomial declarations and a `START` section in which the polynomials are evaluated with arguments 4 and 2 respectively. The output of the program will be

   ```
     17 3
   ```

   The sequence of numbers at the end (the input to the program) does not affect the output of the program.

2.
   ```
   POLY F = x^2 + 1;
   POLY G = x + 1;
   START
   INPUT X;
   INPUT Y;
   F(X);
   G(Y);
   1 2 3 18 19
   ```

   This is similar to the previous example, but here we have two `input` statements. The first `input` statement reads a value for `X` from the sequence of numbers and `X` gets the value 1. The second `input` statement reads a value for `Y` which gets the value 2. Here the output will be

   ```
    2 3
   ```

   Note that the values 3, 18 and 19 are not read and do not affect the execution of the program.

3.
   ```
   1: POLY F = x^2 + 1
   2: POLY G = x + 1;
   3: START
   4: INPUT X;
   ```

```
5: INPUT Y;
6: F(X);
7: G(Y);
8: 1 2 3 18 19
```

Note that there are line numbers added to this example. These line numbers are not part of the input and are added only to refer to specific lines of the program. In this example, which looks almost the same as the previous example, there is a syntax error because there is a missing semicolon on line 1. The output of the program should be

```
SYNTAX ERROR !!!
```

4.
```
1: POLY F = x^2 + 1;
2: POLY G(X,Y) = X Y^2 + X Y;
3: START
4: INPUT Z;
5: INPUT W;
6: F(Z);
7: G(Z,W);
8: 1 2 3 18 19
```

In this example, the polynomial G has two variables which are given explicitly (in the absence of explicitly named variables, the variable is lower case x by default). The output is

```
2 6
```

5.
```
1: POLY F = x^2 + 1;
2: POLY G(X,Y) = X Y^2 + X Z;
3: START
4: INPUT Z;
5: INPUT W;
6: F(Z);
7: G(Z,W);
8: 1 2 3 18 19
```

This example is similar to the previous one but it has a problem. The polynomial G has two variables X and Y but its formula has Z which is different from X and Y. The output captures this error (see below for error codes and their format)

```
Error Code 2: 2
```

3 Syntax and Semantic Error Checking

Your solution should detect syntax and semantic errors in the input program as specified in this section.

3.1 Syntax Checking

If the input is not correct syntactically, your program should output

```
SYNTAX ERROR !!!
```

If there is syntax error, the output of your program should exactly match the output given above. No other output should be produced in this case and your program should exit after producing the syntax error message.

3.2 Semantic Checking

Semantic checking also checks for invalid input. Unlike syntax checking, semantic checking requires knowledge of the specific lexemes and does not simply looks at the input as a sequence of tokens (token types). I start by giving the rules for semantic checking and then I give examples for each rule. We have the following rules for semantic checking.

- **Polynomial declared more than once. Error Code 1**. If the same `polynomial_name` is used in two or more different `polynomial_header`'s, then we have the error *polynomial declared more than once.* The output in this case should be of the form

  ```
  Error Code 1: <line no 1> <line no 2> ... <line no k>
  ```

  where `<line no 1>` through `<line no k>` are the numbers of each of the lines in which a duplicate `polynomial_name` declaration occurs sorted from smallest to largest. For example, if the input is (recall that line numbers are not part of the input and are just for reference):

  ```
  1: POLY F1 =
  2:            x^2 + 1;
  3: POLY F2 = x^2 + 1;
  4: POLY F1 = x^2 + 1;
  5: POLY F3 = x^2 + 1;
  6: POLY G = x^2 + 1;
  7: POLY F1 = x^2 + 1;
  8: POLY G(X,Y) = X Y^2 + X Y;
  9: START
  10: INPUT Z;
  11: INPUT W;
  12: 1 2 3 18 19
  ```

  then the output should be

  ```
  Error Code 1: 1 4 6 7 8
  ```

  because on each of these lines the name of the polynomial in question has a duplicate declaration.

- **Invalid monomial name. Error Code 2**. There are two kinds of polynomials headers. In the first kind, only the polynomial name (`ID`) is given and no parameter list (`id_list` in the header) is given. In the second kinds, the header has the form `polynomial_name LPAREN id_list RPAREN`. In a polynomial with the first kind of header, the polynomial should be univariate (one variable) and the variable name should be lower case "x". In a polynomials with the second kind of header, the `id_list` is the list variables that can appear in the polynomial body. A monomial that appears in the body of a polynomial should have an `ID` that is equal to one of the variables of the polynomial. If that is not the case, we say that we have an *invalid monomial name error* and the output in this case should be of the form:

  ```
  Error Code 2: <line no 1> <line no 2> ... <line no k>
  ```

  where `<line no 1>` through `<line no k>` are the numbers of each of the lines in which a duplicate an `ID` declaration occurs sorted from smallest to largest.

- **Attempted evaluation of undeclared polynomial. Error Code 3**. If there is no polynomial declaration with the same name used in a polynomial evaluation, then we have *attempted evaluation of undeclared polynomial error.* In this case, the output should be of the form

  ```
  Error Code 3: <line no 1> <line no 2> ... <line no k>
  ```

  where `<line no 1>` through `<line no k>` are the numbers of each of the lines in which a `polynomial_name` appears in a `polynomial_evaluation` but for which there is no `polynomial_declaration` with the same name. The line numbers should be listed from the smallest to the largest. For example if the input is:

  ```
  1: POLY F1 =
  2:            x^2 + 1;
  3: POLY F2 = x^2 + 1;
  4: POLY F3 = x^2 + 1;
  5: POLY F4 = x^2 + 1;
  6: POLY G1 = x^2 + 1;
  ```

```
7: POLY F5 = x^2 + 1;
8: POLY G2(X,Y) = X Y^2 + X Y;
9: START
10: INPUT Z;
11: INPUT W;
12: G1(Z);
13: F(Z);
14: F5(W);
15: G(Z);
14: 1 2 3 18 19
```

then the output should be

```
Error Code 3: 13 15
```

Because on line 13, there is an evaluation of polynomial `F` but there is no declaration for polynomial `F` and on line 15, there is an evaluation of polynomial `G` but there is no declaration of polynomial `G`.

- **Wrong number of arguments. Error Code 4**. If the number of arguments in a polynomial evaluation is different from the number of parameters in the polynomial declaration, then we say that we have *wrong number of arguments error* and the output should be of the form:

  ```
  Error Code 4: <line no 1> <line no 2> ... <line no k>
  ```

  where `<line no 1>` through `<line no k>` are the numbers of each of the lines in which `polynomial_name` appears in a `polynomial_evaluation` but the number of arguments in the polynomial evaluation is different from the number of parameters in the corresponding polynomial declaration. The line numbers should be listed from the smallest to the largest. For example if the input is:

  ```
  1: POLY F1 =
  2:              x^2 + 1;
  3: POLY F2(x,y,z) = x^2 + y + z + 1;
  4: POLY F3(y) = y^2 + 1;
  5: POLY F4 = x^2 + 1;
  6: POLY G1 = x^2 + 1;
  7: POLY F5 = x^2 + 1;
  8: POLY G2(X,Y) = X Y^2 + X Y;
  9: START
  10: INPUT X;
  11: INPUT Y;
  12: INPUT Z;
  13: INPUT W;
  14: F1(Z);
  15: F2(X,Z);
  16: F3(X);
  17: F4(X,Y);
  18: G2(X,Y,Z);
  19: 1 2 3 18 19
  ```

  then the output will be

  ```
  Error Code 4:  15 17 18
  ```

- **Uninitialized argument. Error Code 5**. If an `argument` in an `argument_list` in a `polynomial_evaluation` does not appear in an `input_statement` before the polynomial evaluation, then we say that we have an *uninitialized argument error* and the output should be of the form:

  ```
  Error Code 5: <line no 1> <line no 2> ... <line no k>
  ```

where `<line no 1>` through `<line no k>` are the numbers of each of the lines in which an `argument` appears in a `polynomial_evaluation` for which there is no previous `input_statement` in which the `argument` appears. The line numbers should be listed from the smallest to the largest. For example if the input is:

```
1: POLY F1 =
2:            x^2 + 1;
3: POLY F2(x,y,z) = x^2 + y + z + 1;
4: POLY F3(y) = y^2 + 1;
5: POLY F4(x,y) = x^2 + y+ 1;
6: POLY G1 = x^2 + 1;
7: POLY F5 = x^2 + 1;
8: POLY G2(X,Y,Z,W) = X Y^2 + X Z + W + 1;
9: START
11: INPUT Y;
12: INPUT Z;
13: F1(Z);
14: F2(X,Z,Z);
15: F3(X);
16: F4(X,Y);
17: G2(X,W,Z
18: W);
19: 1 2 3 18 19
```

then the output will be

```
Error Code 5:  14 15 16 17 17 18
```

Notice that line 17 is repeated in the output because both `X` and `W` on line 17 are not initialized before they appear in the polynomial evaluation `G2(X,W,Z,W)`. Also note that W appears twice as an argument and for each instance the corresponding line number is printed (17 and 18 respectively).

You can assume that an input program will have only one kind of semantic errors. So, if a test case has Error Code 2, it will not have any other kind of error.

4 Program Output in the Absence of Errors

In the absence of errors, your program should output the results of all the polynomial evaluations in the propram. In this section I give a precise definition of the meaning of the input and the output that your compiler should generate. In a separate document that I will upload a little later, I will give an implementation guide that will help you plan your solution. You do not need to wait for the implementation guide to write the parser!

4.1 Variables and Locations

The program uses names to refer to variables. For each variable name, we associate a unique locations that will hold the value of the variable. This association between a variable name and its location is assumed to be implemented with a function `location` that takes a `string` as input and returns an integer value. We assume that there is a variable `mem` which is an array with each entry corresponding to one variable.

To support allocation of variables to `mem` entries, you can have a simple table or map (which I will call the *location* table) that associates a variable name with a location. As your parser parses the input program, if it encounters a variable name in an `input_statement`, it needs to determine if this name has been previously encountered or not by looking it up in the location table. If the name is a new variable name, a new location needs to be associated with it and the mapping from the variable name to the location needs to be added to the location table. To associate a location with a variable, you can simply keep a counter that tells you how many locations have been used (associated to variable names). Initially the counter is 0. The first variable to be associated a location will get the location whose index is 0 (`mem`[0]) and the counter will be incremented to become 1. The next variable to be associated a location will get the location whose index is 1 and the counter will be incremented to become 2 and so on.

For example, if the input program is

```
POLY F1 =
           x^2 + 1;
POLY F2(x,y,z) = x^2 + y + z + 1;
POLY F3(y) = y^2 + 1;
POLY F4(x,y) = x^2 + y^2;
POLY G1 = x^2 + 1;
POLY F5 = x^2 + 1;
POLY G2(X,Y,Z,W) = X Y^2 + X Z + W + 1;
START
INPUT X;
INPUT Z;
F1(Z);
F2(X,Z,Z);
INPUT X;
INPUT Y;
INPUT Z;
F3(X);
F4(X,Y);
INPUT X;
INPUT Z;
INPUT W;
G2(X,Z,W
Z);
1 2 3 18 19 22 33 12 11 16
```

Then the locations of variables will be

```
X 0
Z 1
Y 2
W 3
```

4.2 Statements

We explain the semantics of the two kinds of statements in the program.

4.2.1 Input statements

Input statements get their input from the sequence of `inputs`. We refer to i'th value that appears in `inputs` as `i'th input`. The i'th input statement in the program of the form `INPUT X` is equivalent to:

```
mem[location("X")] = i'th input
```

4.2.2 Polynomial Evaluation

The polynomial evaluation depends on the evaluation of arguments and the correspondence between the arguments in the polynomial evaluation and the parameters in the polynomial declaration.

Argument Evaluation. The *value* of a variable X at a given point in the program is equal to the last value assigned to X before that point. The definition of what an argument evaluates to depends on the definition of what a polynomial evaluates to because an argument can be a polynomial evaluation. An argument is evaluated as follows:

- If the argument is an ID whose lexeme is "X", then it evaluates to the value of "X" at that point.
- If the argument is a polynomial evaluation, then it evaluates to what the polynomial evaluates to (see below).

Correspondence Between Arguments and Parameters. In a polynomial declaration, the list of parameters is given by the id_list in the header or if the header has no id_list, then the parameter is the unique variable "x" (lower case). In a polynomial evaluation, the argument list is given by the argument_list. We say that the i'th argument in a polynomial evaluation *corresponds to* the i'th parameter of the polynomial declaration.

Evaluation of a coefficient. A coefficient whose lexeme is L evaluates to the integer represented by L.

Evaluation of an exponent. An exponent whose lexeme is L evaluates to the integer represented by L.

Evaluation of a monomial. There are a number of cases to consider

- A monomial of the form ID whose lexeme is "X" evaluates to the argument corresponding to "X"
- A monomial of the form ID exponent where the lexeme of the ID is "X" evaluates to v^e where e is the value that the exponent evaluate to and v is the value that the argument corresponding to "X" evaluates to.

Evaluation of a monomial_list . A monomial_list of the form monomial evaluates to the value that monomial evaluates to. A monomial_list of the form monomial monomial_list' evaluates to the product of v (the value that monomial evaluates to) and v' (the value that monomial_list' evaluates to).

Evaluation of a term. A term of the form coefficient monomial_list, where coefficient evaluates to c and monomial_list evaluates to v, evaluates to $c \times v$ (the product of c and v).

Evaluation of a term_list. Aterm_list of the form term evaluate to the value that term evaluates to. A term_list of the form term add_operator term_list', where term evaluates to v and term_list' evaluates to v', evaluates to $v + v'$ if the add_operator is PLUS and to $v - v'$ if the add_operator is MINUS.

Evaluation of a polynomial_body. A polynomial_body of the form term_list evaluates to the value that the term_list evaluates to.

Evaluation of a polynomial. A polynomial evaluates to the value that its polynomial_body evaluates to.

4.3 Assumptions

You can assume that the following semantic errors are not going to be tested

1. You can assume that if there is a polynomial declaration with a given polynomial name, then there is no variable with the same name in the program.

2. If you want to use an array for the `mem` variable, you can use an array of size 1000 which should be enough for all test cases, but make sure that your code handles overflow (more than 1000 variables in the program) because that is good programming practice.

5 Requirements

You should write a program to generate the correct output for a given input as described above. You should start by writing the parser and make sure that it correctly parses the input before attempting to implement the rest of the project.

You will be provided with a number of test cases. Since this is the first project, the number of test cases provided with the project will be relatively large, but it will not be complete. It is still your responsibility to make sure that your implementation satisfies the requirements given in this document.

6 Instructions

Follow these steps:

- Download the `lexer.cc`, `lexer.h`, `inputbuf.cc` and `inputbuf.h` files accompanying this project description.
- Design a solution before you start coding. It is really very important that you have a clear overall picture of what the project will require before starting coding. Deciding on data structures and how you will use them is crucial. One possible exception is the parser, which you can and should write first before the rest of the solution.
- Write your code and make sure to compile your code using GCC (7.4.0) on **Ubuntu 18.04** (Ubuntu). These are the versions available on the second floor computer lab in the Brickyard. If you want to test your code on your personal machine, you should install a virtual machine with Ubuntu 18.04 and the correct version of GCC on it. You will need to use the `g++` command to compile your code in a terminal window. See section 4 for more details on how to compile using GCC. **You are required to compile and test your code on Ubuntu using the GCC compiler**, but you are free to use any IDE or text editor on any platform while developing your code as long as you compile it and test it on Ubuntu/GCC before submitting it.
- Test your code to see if it passes the provided test cases. You will need to extract the test cases from the zip file and run the provided test script `test1.sh`. See section 5 for more details.
- Submit your code through canvas.
- **Only the last version you submit is graded. There are no exceptions to this. This will be the case for all programming assignments.**

Keep in mind that

- You should use C++11, no other programming languages or versions of C++ are allowed.
- All programming assignments in this course are individual assignments. Students must complete the assignments on their own.
- You should submit your code through canvas, no other submission forms will be accepted.
- You should familiarize yourself with the Ubuntu environment and the GCC compiler. Programming assignments in this course might be very different from what you are used to in other classes.

6.0.1 Evaluation

The submissions are evaluated based on the automated test cases on the submission website. For the parsing test cases, as I explained in class, your submission should pass ALL the test cases to get credit for parsing. For the other categories, your grade will be proportional to the number of test cases that your submission passes. If your code does not compile when you submit it, you will not receive any points even if it runs correctly in a different environment (Windows/Visual Studio for example). Here is the grade breakdown for the various categories:

1. Parsing: 30%
2. Error Code 1: 10%
3. Error Code 2: 10%
4. Error Code 3: 10%
5. Error Code 4: 10%
6. Error Code 5: 10%
7. No errors: 20%

NOTE: The next two sections apply to all programming assignments.

You should use the instructions in the following sections to compile and test your programs for all programming assignments in this course.

6.0.2 Compiling your code with GCC

You should compile your programs with the GCC compilers. GCC is a collection of compilers for many programming languages. There are separate commands for compiling C and C++ programs. Use the `g++` command to compile C++ programs

Here is an example of how to compile a simple C++ program:

```
$ g++ test_program.cpp
```

If the compilation is successful, it will generate an executable file named `a.out` in the same directory (folder) as the program. You can change the executable file name by using the `-o` option. For example, if you want the executable name to be `hello.out`, you can execute

```
$ g++ test_program.cpp -o hello.out
```

To enable C++11, with `g++`, which you should do for projects in this class, use the `-std=c++11` option:

```
$ g++ -std=c++11 test_program.cpp -o hello.out
```

The following table summarizes some useful compiler options for g++:

Option	Description
`-o path`	Change the filename of the generated artifact
`-g`	Generate debugging information
`-ggdb`	Generate debugging information for use by GDB
`-Wall`	Enable most warning messages
`-std=c++11`	Compile C++ code using 2011 C++ standard

Compiling projects with multiple files

If your program is written in multiple source files that should be linked together, you can compile and link all files together with one command:

```
$ g++ file1.cpp file2.cpp file3.cpp
```

Or you can compile them separately and then link:

```
$ g++ -c file1.cpp
$ g++ -c file2.cpp
$ g++ -c file3.cpp
$ g++ file1.o file2.o file3.o
```

The files with the `.o` extension are object files but are not executable. They are linked together with the last statement (g++ file1.o file2.o file3.o) and the final executable will be `a.out`.

6.0.3 Testing your code on Ubuntu

Your programs should not explicitly open any file. You can only use the **standard input** and **standard output** in C++. The provided lexical analyzer already reads the input from standard input and you should not modify it. In C++, standard input is `std::cin` and standard output is `std::cout`. In C++, any output that your program produces should be done with `cout`. To read input from a file or produce output to a file, we use IO redirection outside the program. The following illustrates the concept.

Suppose we have an executable program `a.out`, we can run it by issuing the following command in a terminal (the dollar sign is not part of the command):

```
$ ./a.out
```

If the program expects any input, it waits for it to be typed on the keyboard and any output generated by the program will be displayed on the terminal screen.

To get the input to the program from a file, we can redirect the standard input to a file:

```
$ ./a.out < input_data.txt
```

Now, the program will not wait for keyboard input, but rather read its input from the specified file as if the file `input_data.txt` is standard input. We can redirect the output of the program as well:

```
$ ./a.out > output_file.txt
```

In this way, no output will be shown in the terminal window, but rather it will be saved to the specified file[1].

Finally, it's possible to do redirection for standard input and standard output simultaneously. For example,

```
$ ./a.out < input_data.txt > output_file.txt
```

will read standard input from `input_data.txt` and produces standard output to `output_file.txt`.

Now that we know how to use standard IO redirection, we are ready to test the program with test cases.

Test Cases

For a given input to your program, there is an *expected* output which is the correct output that should be produced for the given input. So, a test case is represented by two files:

- `test_name.txt`
- `test_name.txt.expected`

The input is given in `test_name.txt` and the expected output is given in `test_name.txt.expected`.

To test a program against a single test case, first we execute the program with the test input data:

```
$ ./a.out < test_name.txt > program_output.txt
```

[1]Programs have access to another standard stream which is called standard error e.g. `std::cerr` in C++. Any such output is still displayed on the terminal screen. It is possible to redirect standard error to a file as well, but we will not discuss that here

With this command, the output generated by the program will be stored in `program_output.txt`. To see if the program generated the correct expected output, we need to compare `program_output.txt` and `test_name.txt.expected`. We do that using the `diff` command which is a command to determine differences between two files:

```
$ diff -Bw program_output.txt test_name.txt.expected
```

If the two files are the same, there should be no difference between them. The options `-Bw` tell `diff` to ignore whitespace differences between the two files. If the files are the same (ignoring the whitespace differences), we should see no output from `diff`, otherwise, `diff` will produce a report showing the differences between the two files.

We consider that the test **passed** if `diff` could not find any differences, otherwise we consider that the test **failed**.

Our grading system uses this method to test your submissions against multiple test cases. In order to avoid having to type the commands shown above for running and comparing outputs for each test case manually, we provide you with a script that automates this process. The script name is `test1.sh`. `test1.sh` will make your life easier by allowing you to test your code against multiple test cases with one command.

Here is how to use `test1.sh` to test your program:

- Store the provided test cases zip file in the same directory as your project source files
- Open a terminal window and navigate to your project directory
- Unzip the test archive using the `unzip` command: `bash    $ unzip tests.zip`

This will create a directory called `tests`

- Store the `test1.sh` script in your project directory as well
- Make the script executable: `bash    $ chmod +x test1.sh`
- Compile your program. The test script assumes your executable is called `a.out`
- Run the script to test your code: `bash    $ ./test1.sh`

The output of the script should be self explanatory. To test your code after you make changes, you will just perform the last two steps (compile and run `test1.sh`).