

# CS 343 Winter 2023 – Assignment 1

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**Due Date: Monday, January 23, 2023 at 22:00**

**Late Date: Wednesday, January 25, 2023 at 22:00**

January 3, 2023

This assignment introduces exception handling and coroutines in  $\mu$ C++. Use it to become familiar with these new facilities, and ensure you use these concepts in your assignment solution. Unless otherwise specified, writing a C-style solution for questions is unacceptable and receives little or no marks. (You may freely use the code from these [example programs](#).)

1. (a) Transform the C++ program in Figure 1 replacing the **throw/catch** for exceptions Ex1, Ex2, and Ex3 with:
  - i. C++ program using global status-flag variables. Return codes may NOT be returned from the routines.
  - ii. C++ program using a C++17 variant return-type as return codes. There are two approaches: passing the exceptions by value or pointer (using inheritance) in the variant return-type.
  - iii. C program using a tagged **union** return-type as return codes, and multi-level exits in the program main to handle command-line arguments.

Output from the transformed programs must be identical to the original program. Use printf format “%g” to print floating-point numbers in C.

- (b) i. Compare the original and transformed programs with respect to performance by doing the following:

- Time the executions using the time command:

```
$ /usr/bin/time -f "%Uu %Ss %E" ./a.out 100000000 10000 1003
3.21u 0.02s 0:03.32
```

Output from time differs depending on the shell, so use the system time command. Compare the *user* time (3.21u) only, which is the CPU time consumed solely by the execution of user code (versus system and real time).

- If necessary, change the first command-line parameter times to adjust program execution into the range 1 to 100 seconds. (Timing results below 1 second are inaccurate.) Use the same command-line values for all experiments, if possible; otherwise, increase/decrease the arguments as necessary and scale the difference in the answer.
  - Run the experiments again after recompiling the programs with compiler optimization turned on (i.e., compiler flag `-O2`).
  - Include the 8 timing results to validate the experiments.
- ii. State the performance difference (larger/smaller/by how much) between the original and transformed programs, and the reason for the difference.
  - iii. State the performance difference (larger/smaller/by how much) between the original and transformed programs when compiler optimization is used.
- (c) i. Run a similar experiment with compiler optimization turned on but vary the exception period (second command-line parameter `eperiod`) with values 1000, 100, and 50.
    - Include the 12 timing results to validate the experiments.
  - ii. State the performance difference (larger/smaller/by how much) between the original and transformed programs as the exception period decreases, and the reason for the difference.

2. (a) Transform the C++ program in Figure 2, p. 3 by replacing *only* the **throw/catch** for exceptions E with `longjmp/setjmp`. No changes are allowed to the return type or parameters of routine Ackermann. No dynamic allocation is allowed, but creation of a global variable is allowed. No more calls to `setjmp` are allowed than the number of **try ... catch( E )** statements. Note, type `jmp_buf` is an array allowing instances to be passed to `setjmp/longjmp` without having to take the address of the argument. Output from the transformed program must be identical to the original program, **except for one aspect, which you will discover in the transformed program.**

```

#include <iostream>
#include <cstdlib> // access: rand, srand
#include <cstring> // access: strcmp
using namespace std;
#include <unistd.h> // access: getpid

struct Ex1 { short int code; };
struct Ex2 { int code; };
struct Ex3 { long int code; };

intmax_t eperiod = 10000; // exception period
int randcnt = 0;
int Rand() { randcnt += 1; return rand(); }

double rtn1( double i ) {
    if ( Rand() % eperiod == 0 ) throw Ex1{ (short int)Rand() }; // replace
    return i + Rand();
}
double rtn2( double i ) {
    if ( Rand() % eperiod == 0 ) throw Ex2{ Rand() }; // replace
    return rtn1( i ) + Rand();
}
double rtn3( double i ) {
    if ( Rand() % eperiod == 0 ) throw Ex3{ Rand() }; // replace
    return rtn2( i ) + Rand();
}

static intmax_t convert( const char * str ); // copy from https://student.cs.uwaterloo.ca/~cs343/examples/uIO.cc

int main( int argc, char * argv[] ) {
    intmax_t times = 100000000, seed = getpid(); // default values
    try {
        switch ( argc ) {
            case 4: if ( strcmp( argv[3], "d" ) != 0 ) { // default ?
                seed = convert( argv[3] ); if ( seed <= 0 ) throw 1; }
            case 3: if ( strcmp( argv[2], "d" ) != 0 ) { // default ?
                eperiod = convert( argv[2] ); if ( eperiod <= 0 ) throw 1; }
            case 2: if ( strcmp( argv[1], "d" ) != 0 ) { // default ?
                times = convert( argv[1] ); if ( times <= 0 ) throw 1; }
            case 1: break; // use all defaults
            default: throw 1;
        } // switch
    } catch( ... ) {
        cerr << "Usage: " << argv[0] << " [ times > 0 | d [ eperiod > 0 | d [ seed > 0 | d ] ] ] " << endl;
        exit( EXIT_FAILURE );
    } // try
    srand( seed );

    double rv = 0.0;
    int ev1 = 0, ev2 = 0, ev3 = 0;
    int rc = 0, ec1 = 0, ec2 = 0, ec3 = 0;

    for ( int i = 0; i < times; i += 1 ) {
        try { rv += rtn3( i ); rc += 1; } // replace
        // analyse exception
        catch( Ex1 ev ) { ev1 += ev.code; ec1 += 1; } // replace
        catch( Ex2 ev ) { ev2 += ev.code; ec2 += 1; } // replace
        catch( Ex3 ev ) { ev3 += ev.code; ec3 += 1; } // replace
    } // for
    cout << "randcnt " << randcnt << endl;
    cout << "normal result " << rv << " exception results " << ev1 << ' ' << ev2 << ' ' << ev3 << endl;
    cout << "calls " << rc << " exceptions " << ec1 << ' ' << ec2 << ' ' << ec3 << endl;
}

```

Figure 1: Dynamic Multi-Level Exit

```

#include <iostream>
#include <cstdlib> // access: rand, srand
#include <cstring> // access: strcmp
using namespace std;
#include <unistd.h> // access: getpid
#ifdef NOOUTPUT
#define PRINT( stmt )
#else
#define PRINT( stmt ) stmt
#endif // NOOUTPUT
struct E {}; // exception type
intmax_t eperiod = 100, excepts = 0, calls = 0, dtors = 0, depth = 0; // counters
PRINT( struct T { ~T() { dtors += 1; } }; )
long int Ackermann( long int m, long int n, long int depth ) {
    calls += 1;
    if ( m == 0 ) {
        if ( rand() % eperiod <= 2 ) { PRINT( T t; ) excepts += 1; throw E(); } // replace
        return n + 1;
    } else if ( n == 0 ) {
        try { return Ackermann( m - 1, 1, depth + 1 ); } // replace
        catch( E ) { // replace
            PRINT( cout << " depth " << depth << " E1 " << m << " " << n << " | " );
            if ( rand() % eperiod <= 3 ) { PRINT( T t; ) excepts += 1; throw E(); } // replace
        } // try
        PRINT( cout << " E1X " << m << " " << n << endl );
    } else {
        try { return Ackermann( m - 1, Ackermann( m, n - 1, depth + 1 ), depth + 1 ); } // replace
        catch( E ) { // replace
            PRINT( cout << " depth " << depth << " E2 " << m << " " << n << " | " );
            if ( rand() % eperiod == 0 ) { PRINT( T t; ) excepts += 1; throw E(); } // replace
        } // try
        PRINT( cout << " E2X " << m << " " << n << endl );
    } // if
    return 0; // recover by returning 0
}
static intmax_t convert( const char * str ); // copy from https://student.cs.uwaterloo.ca/~cs343/examples/uIO.cc
int main( int argc, char * argv[] ) {
    volatile intmax_t m = 4, n = 6, seed = getpid(); // default values (volatile needed for longjmp)
    try { // process command-line arguments
        switch ( argc ) {
            case 5: if ( strcmp( argv[4], "d" ) != 0 ) { // default ?
                eperiod = convert( argv[4] ); if ( eperiod <= 0 ) throw 1; }
            case 4: if ( strcmp( argv[3], "d" ) != 0 ) { // default ?
                seed = convert( argv[3] ); if ( seed <= 0 ) throw 1; }
            case 3: if ( strcmp( argv[2], "d" ) != 0 ) { // default ?
                n = convert( argv[2] ); if ( n < 0 ) throw 1; }
            case 2: if ( strcmp( argv[1], "d" ) != 0 ) { // default ?
                m = convert( argv[1] ); if ( m < 0 ) throw 1; }
            case 1: break; // use all defaults
            default: throw 1;
        } // switch
    } catch( ... ) {
        cerr << "Usage: " << argv[0] << " [ m (>= 0) | d [ n (>= 0) | d "
            << " [ seed (> 0) | d [ eperiod (> 0) | d ] ] ] " << endl;
        exit( EXIT_FAILURE );
    } // try
    srand( seed ); // seed random number
    try { // replace
        PRINT( cout << "Arguments " << m << " " << n << " " << seed << " " << eperiod << endl );
        long int val = Ackermann( m, n, 0 );
        PRINT( cout << "Ackermann " << val << endl );
    } catch( E ) { // replace
        PRINT( cout << "E3" << endl );
    } // try
    cout << "calls " << calls << " exceptions " << excepts << " destructors " << dtors << endl;
}

```

Figure 2: Throw/Catch

- (b) i. Explain why the output is not the same between the original and transformed program.
- ii. Compare the original and transformed programs with respect to performance by doing the following:
- Recompile both the programs with preprocessor option `-DNOOUTPUT` to suppress output.
  - Time the executions using the time command:  

```
$ /usr/bin/time -f "%Uu %Ss %E" ./a.out 12 12 103 28
3.21u 0.02s 0:03.32
```

Output from time differs depending on the shell, so use the system time command. Compare the *user* time (3.21u) only, which is the CPU time consumed solely by the execution of user code (versus system and real time).
  - If necessary, change the command-line parameters to adjust program execution into the range 1 to 100 seconds. (Timing results below 1 second are inaccurate.) Use the same command-line values for all experiments, if possible; otherwise, increase/decrease the arguments as necessary and scale the difference in the answer.
  - Run the experiments again after recompiling the programs with compiler optimization turned on (i.e., compiler flag `-O2`).
  - Include the 4 timing results to validate the experiments.
- iii. State the performance difference (larger/smaller/by how much) between the original and transformed programs, and the reason for the difference.
- iv. State the performance difference (larger/smaller/by how much) between the original and transformed programs when compiler optimization is used.
3. This question requires the use of  $\mu$ C++, which means compiling the program with the `u++` command, which is available on the [undergraduate computing environment](#).

Write a *semi-coroutine* with the following public interface (you may only add a public destructor and private members):

```
_Coroutine IntegerLiteral {
    char ch;                                // character passed by caller
    // YOU ADD MEMBERS HERE
    void main();                            // coroutine main
public:
    enum { EOT = '\003' };                  // end of text
    _Event Match {                          // last character match
    public:
        unsigned long int value;            // value of integer literal
        Match( unsigned long int value ) : value( value ) {}
    };
    _Event Error {};                        // last character invalid
    void next( char c ) {
        ch = c;                            // communication input
        resume();                          // activate
    }
};
```

which verifies a string of characters corresponds to a C++ integer literal described by the following grammar:

```
integer-literal :
    decimal-literal integer-suffixopt
    | octal-literal integer-suffixopt
    | hexadecimal-literal integer-suffixopt
decimal-literal :
    nonzero-digit
    | decimal-literal digit
digit : "0" | "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9"
octal-literal :
    "0"
    | octal-literal octal-digit
```

```

hexadecimal-literal :
    "0x" hexadecimal-digit
    | "0X" hexadecimal-digit
    | hexadecimal-literal hexadecimal-digit
nonzero-digit : "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9"
octal-digit : "0" | "1" | "2" | "3" | "4" | "5" | "6" | "7"
hexadecimal-digit :
    "0" | "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9"
    | "a" | "b" | "c" | "d" | "e" | "f"
    | "A" | "B" | "C" | "D" | "E" | "F"
integer-suffix :
    | unsigned-suffix long-suffixopt
    | long-suffix unsigned-suffixopt
unsigned-suffix : "u" | "U"
long-suffix : "l" | "L"

```

Where  $X_{opt}$  means  $X$  may be empty. In addition, there is a maximum of 20 digits for decimal, 22 digits for octal, 16 digits for hexadecimal. Note, these limits allow maximum values greater than  $2^{64}$ , so the returned integer value may be incorrect. For example, the following are valid C++ integer literals:

```

123      // decimal
0123     // octal
0x123    // hexadecimal
123u     // unsigned decimal
123L     // long decimal
123ul    // unsigned long decimal

```

To simplify parsing, assume a *valid* integer literal has no leading zeros, other than the octal prefix, and starts at the beginning of an input line, i.e., there is no leading whitespace. No checking is required for these assumptions and no test data contains examples of this form. Finally, there is a cheap and cheerful C pattern for creating the value of an integer literal from the character digits; marks will be deducted for expensive approaches for creating the integer value.

After creation, the coroutine is resumed with a series of characters from a string (one character at a time). The coroutine raises one of the following exceptions at its resumer:

- Match means the characters form a valid string.
- Error means the last character forms an invalid string.

After the coroutine raises an exception at its last resumer, it must NOT be resumed again; sending more characters to the coroutine after this point is undefined and should generate an error.

Write a program `integerliteral` that checks if a string is a C++ integer-literal. The shell interface to the `integerliteral` program is as follows:

```
integerliteral [ infile ]
```

(Square brackets indicate optional command line parameters, and do not appear on the actual command line.) If no input file name is specified, input comes from standard input. Output is sent to standard output. *For any specified command-line file, check it exists and can be opened. You may assume I/O reading and writing do not result in I/O errors.*

The program main should:

- read a line from the input file into a string,
- create a `IntegerLiteral` coroutine,
- pass characters from the input line to the coroutine one at a time, plus an EOT (end-of-text) character after all characters are passed and there is no error,
- print an appropriate message when the coroutine returns exception `Match` or `Error`, or if there are no more characters to send,

- check for extra characters,
- terminate the coroutine, and
- repeat these steps for each line in the file.

For every non-empty input line, print the line, how much of the line is parsed, and the string `yes` if the string is valid and `no` otherwise. If there are extra characters (including whitespace) on a line after parsing, print these characters with an appropriate warning. Print an appropriate warning for an empty input line, i.e., a line containing only `'\n'`. The following is some example output:

```
'123' : '123' yes, value 123
'0123' : '0123' yes, value 83
'0x123' : '0x123' yes, value 291
'123u' : '123u' yes, value 123
'123L' : '123L' yes, value 123
'123ul' : '123ul' yes, value 123
'' : Warning! Blank line.
'07777' : '07777' yes, value 4095
'9999' : '9999' yes, value 9999
'0xffffffff' : '0xffffffff' yes, value 16777215
'07777L' : '07777L' yes, value 4095
'9999U' : '9999U' yes, value 9999
'0xffffffffUL' : '0xffffffffUL' yes, value 16777215
'' : Warning! Blank line.
'0xeh' : '0xeh' no
'1234HIJ' : '1234H' no – extraneous characters 'IJ'
```

See the C library routine `isdigit(c)` and `isxdigit(c)`, which return `true` if character `c` is an appropriate decimal/hexadecimal.

**WARNING:** When writing coroutines, try to reduce or eliminate execution “state” variables and control-flow statements using them. A state variable contains information that is not part of the computation and exclusively used for control-flow purposes (like flag variables). Use of execution state variables in a coroutine usually indicates you are not using the ability of the coroutine to remember prior execution information. *Little or no marks will be given for solutions explicitly managing “state” variables.* See Section 3.1.3 in the [Course Notes](#) for details on this issue. Also, make sure a coroutine’s public methods are used for passing information to the coroutine, but not for doing the coroutine’s work, which must be done in the coroutine’s main.

## Submission Guidelines

Follow these guidelines carefully. Review the [Assignment Guidelines](#) and [C++ Coding Guidelines](#) *before* starting each assignment. **Each text or test-document file, e.g., `*.{txt,testdoc}` file, must be ASCII text and not exceed 500 lines in length, using the command `fold -w120 *.testdoc | wc -l`.** Programs should be divided into separate compilation units, i.e., `*.{h,cc,C,cpp}` files, where applicable. Use the [submit](#) command to electronically copy the following files to the course account.

1. `q1returnglobal.{cc,C,cpp}`, `q1returntype.{cc,C,cpp}`, `q1returntypec.c` – code for question [1a, p. 1](#). **No program documentation needs to be present in your submitted code. No test documentation is to be submitted for this question. Output for this question is checked via a marking program, so it must match exactly with the given program.**
2. `q1returntype.txt` – contains the information required by questions [1b, p. 1](#) and [1c, p. 1](#).
3. `q2longjmp.{cc,C,cpp}` – code for question [2a, p. 1](#). **No program documentation needs to be present in your submitted code. No test documentation is submitted for this question. Output for this question is checked via a marking program, so it must match exactly with the given program.**
4. `q2longjmp.txt` – contains the information required by question [2b, p. 4](#).
5. `q3*.{h,cc,C,cpp}` – code for question [3, p. 4](#). Split your code across `*.h` and `*.{cc,C,cpp}` files as needed. **Program documentation must be present in your submitted code. No test documentation is submitted for this question. Output for this question is checked via a marking program, so it must match exactly with the given program.**

6. Modify the following Makefile to compile the programs for question 1, p. 1, question 2a, p. 1, and question 3, p. 4 by inserting the object-file names matching your source-file names.

```

OUTPUT = OUTPUT
GVERSION = -10
CXX = u++                                # compiler
CXXFLAGS = -g -Wall -Wextra -MMD -Wno-implicit-fallthrough -D${OUTPUT} # compiler flags
MAKEFILE_NAME = ${firstword ${MAKEFILE_LIST}} # makefile name

OBJECTS01 = q1exception.o                # optional build of given program
EXEC01 = exception                       # given executable name

OBJECTS1 = q1returnglobal.o              # 1st executable object files
EXEC1 = returnglobal                     # 1st executable name

OBJECTS2 = q1returntype.o                # 2nd executable object files
EXEC2 = returntype                       # 2nd executable name

OBJECTS3 = q1returntypec.o               # 3rd executable object files
EXEC3 = returntypec                     # 3rd executable name

OBJECTS02 = q2throwcatch.o               # optional build of given program
EXEC02 = throwcatch                     # given executable name

OBJECTS4 = q2longjmp.o                   # 4th executable object files
EXEC4 = longjmp                         # 4th executable name

OBJECTS5 = # object files forming 5th executable with prefix "q3"
EXEC5 = integerliteral                   # 5th executable name

OBJECTS = ${OBJECTS1} ${OBJECTS2} ${OBJECTS3} ${OBJECTS4} ${OBJECTS5}
DEPENDS = ${OBJECTS:.o=.d}
EXECS = ${EXEC1} ${EXEC2} ${EXEC3} ${EXEC4} ${EXEC5}

#####

.PHONY : all clean

all : ${EXECS}                          # build all executables

${EXEC01} : ${OBJECTS01}                  # optional build of given program
    g++${GVERSION} ${CXXFLAGS} $^ -o $@

q1%.o : q1%.cc                            # change compiler 1st executable, ADJUST SUFFIX (for .C/.cpp)
    g++${GVERSION} ${CXXFLAGS} -std=c++17 -c $< -o $@

${EXEC1} : ${OBJECTS1}                    # compile and link 1st executable
    g++${GVERSION} ${CXXFLAGS} $^ -o $@

${EXEC2} : ${OBJECTS2}                    # compile and link 2nd executable
    g++${GVERSION} ${CXXFLAGS} $^ -o $@

q1%.o : q1%.c                             # change compiler 2nd executable
    gcc${GVERSION} ${CXXFLAGS} -c $< -o $@

```



```

${EXEC02} : ${OBJECTS02}                # optional build of given program
      g++${GVERSION} ${CXXFLAGS} $^ -o $@

${EXEC3} : ${OBJECTS3}                  # compile and link 3rd executable
      g++${GVERSION} ${CXXFLAGS} $^ -o $@

q2%.o : q2%.cc                          # change compiler 4th executable, ADJUST SUFFIX (for .C/.cpp)
      g++${GVERSION} ${CXXFLAGS} -c $< -o $@

${EXEC4} : ${OBJECTS4}                  # compile and link 4th executable
      g++${GVERSION} ${CXXFLAGS} $^ -o $@

${EXEC5} : ${OBJECTS5}                  # compile and link 5th executable
      ${CXX} ${CXXFLAGS} $^ -o $@

#####

${OBJECTS} : ${MAKEFILE_NAME}           # OPTIONAL : changes to this file => recompile

-include ${DEPENDS}                    # include *.d files containing program dependences

clean :                                # remove files that can be regenerated
      rm -f *.d *.o ${EXEC01} ${EXEC02} ${EXEC5}

```

This makefile is used as follows:

```

$ make returnglobal
$ ./returnglobal ...
$ make returntype
$ ./returntype ...
$ make returntypepec
$ ./returntypepec ...
$ make longjmp
$ ./longjmp ...
$ make integerliteral
$ ./integerliteral ...

```

Put this Makefile in the directory with the programs, name the source files as specified above, and then type `make returnglobal`, `make returntype`, `make returntypepec`, `make longjmp`, or `make integerliteral` in the directory to compile the programs. This Makefile must be submitted with the assignment to build the program, so it must be correct. Use the web tool [Request Test Compilation](#) to ensure you have submitted the appropriate files, your makefile is correct, and your code compiles in the testing environment.

**Follow these guidelines. Your grade depends on it!**