9. Handling of Exceptions

9. Handling of Exceptions

9.1. Assertions and debuggers

A way to ensure that a condition always should hold at some stage in the code: If the expression supplied to **assert()** is false (0), the program *aborts* at the statement with an error.

example00.cpp

```
#include <iostream>  // use of std::cout, std::cin
#include <cstdlib>   // std::rand()
#include <ctime>     // std::time()
#include <cassert>   // assert()
int main() {
  std::srand( std::time(nullptr) );  // time seeds random generator (nullptr)
  double myValue = ( std::rand() % 4 ) - 2;  // gets a random value
  assert(myValue != 0);  // since we'll divide by myValue, it shouldn't be zero
  myValue = 5 / myValue;  // integer division by 0 leads to undefined behavior
  std::cout << myValue << '\n';
}
```

9. Handling of Exceptions

9.1. Assertions and debuggers

Assert is a macro and depends on another macro, NDEBUG: If it is defined as a macro name (i.e., `#define NDEBUG`) before <cassert> is included, then assert will be disabled.

The program's state at particular points (e.g., after an assertion fails) can be checked in a ***debugger*** to allow watching the state of a running program. Examples: stop execution at a given code line (breakpoint), examine call stack, print / modify contents of variables, print type definitions, execute line-by-line

examples: ddd or gdbgui , both use gdb , or lldb ⟶ try on the previous code:

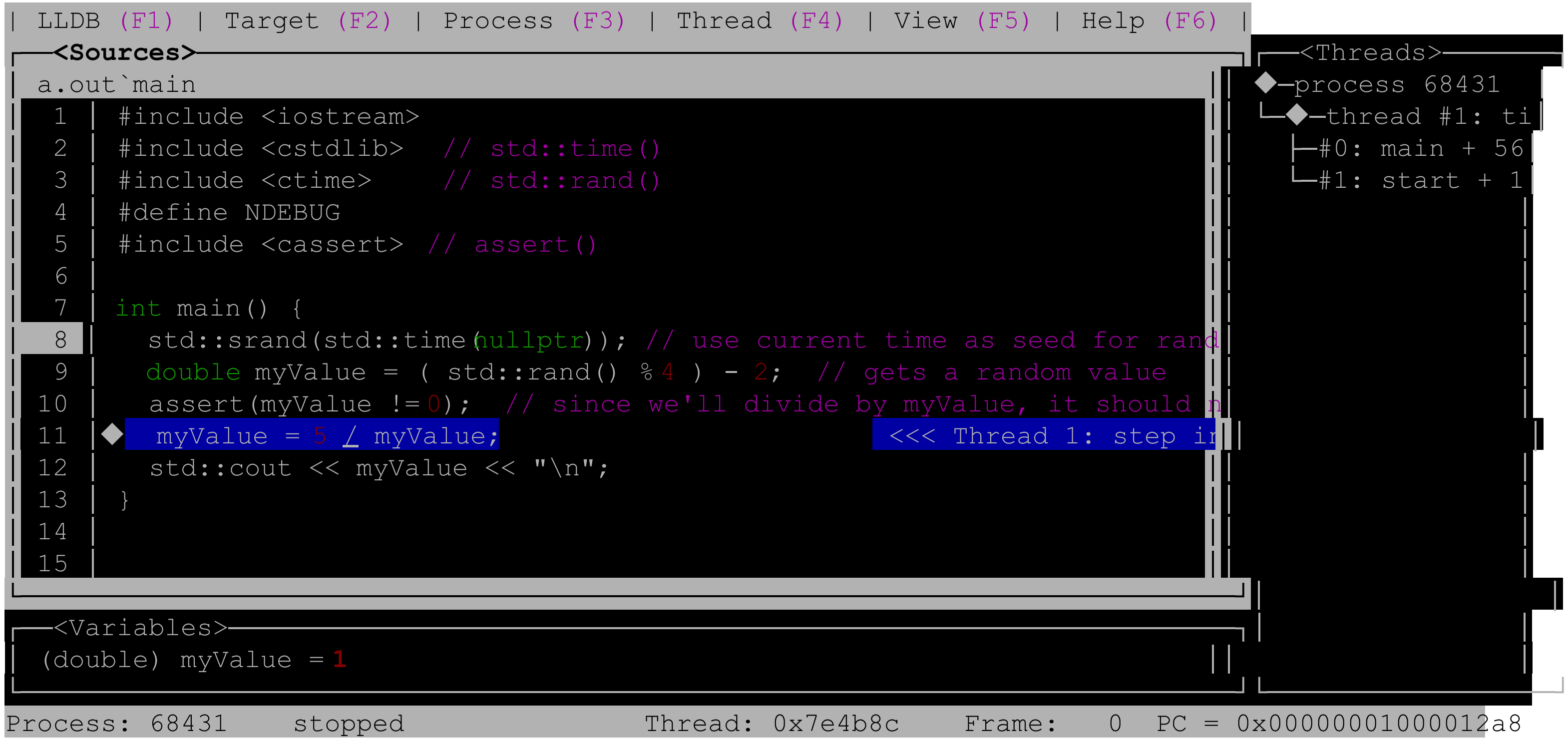
```
> g++ -g example00.cpp
> lldb a.out
```

9. Handling of Exceptions

9.1. Assertions and debuggers -- lldb example

```
> lldb a.out
bash-5.1$ lldb a.out
(lldb) target create "a.out"
Current executable set to '/Users/kvl/sciebo/UbiComp/Teaching/AdvancedCPP_43UCO1118V/a.out'
(x86_64).
(lldb) b main
Breakpoint 1: where = a.out`main + 15 at example00.cpp:8:14, address = 0x000000010000127f
(lldb) run
Process 68431 launched: '/Users/kvl/sciebo/UbiComp/Teaching/AdvancedCPP_43UCO1118V/a.out'
(x86_64)
Process 68431 stopped
* thread #1, queue = 'com.apple.main-thread', stop reason = breakpoint 1.1
    frame #0: 0x000000010000127f a.out`main at example00.cpp:8:14
   5        #include <cassert>  // assert()
   6
   7        int main() {
-> 8          std::srand(std::time(nullptr)); // use current time as seed for random generator
   9          double myValue = ( std::rand() % 4 ) - 2;  // gets a random value
   10         assert(myValue != 0);  // since we'll divide by myValue, it should not be zero
   11         myValue = 5 / myValue;  // integer division by 0 leads to undefined behavior
Target 0: (a.out) stopped.
(lldb) gui
```

9.1. Assertions and debuggers -- lldb example



```
| LLDB (F1) | Target (F2) | Process (F3) | Thread (F4) | View (F5) | Help (F6) |
<Sources>                                                        <Threads>
a.out`main                                                       ◆—process 68431
#include <iostream>                                              └◆—thread #1: ti
#include <cstdlib>   // std::time()                                 ├—#0: main + 56
#include <ctime>     // std::rand()                                 └—#1: start + 1
#define NDEBUG
#include <cassert>  // assert()

int main() {
  std::srand(std::time(nullptr)); // use current time as seed for rand
  double myValue = ( std::rand() %4 ) - 2;  // gets a random value
  assert(myValue !=0);  // since we'll divide by myValue, it should n
◆ myValue = 5 / myValue;                        <<< Thread 1: step ir
  std::cout << myValue << "\n";
}


<Variables>
 (double) myValue = 1

Process: 68431    stopped          Thread: 0x7e4b8c    Frame:   0  PC = 0x00000001000012a8
```

9. Handling of Exceptions

9.1. Assertions and debuggers

Assertions versus exceptions

Both detect run-time errors in a program, *but*:

- Assert() aborts the program, for the developer to fix their code
- Exceptions allow the program to recover and continue the execution from the first matching catch
  - Examples are any areas where variables obtain values outside the developer's control (e.g., others supply your code with file names which do not exist, or array sizes that do not fit in memory)
  - When no exception matches, the program will still abort

9.2. **`try`**, **`throw`**, **`catch`**

- When an error occurs, functions or methods may *throw* an exception, to be handled later when *catch*ing the exception.
- If an exception is *thrown* in the *try*-block, the *try*-block is exited and the associated *catch*-block is executed. `catch (...)` will catch the remaining thrown exceptions.
- Exceptions that go uncaught will cause the program to halt.

```
try {
  throw 0.07f;  // throw an exception of type float
}
catch (float f) {  // float is thrown
  std::cout << "Exception: " << f << '\n';
}
catch (...) { std::cout << "Exception\n"; }  // default catch
```

9. Handling of Exceptions

9.2. try, throw, catch

throw supplies an instance of an exception class. This can be a built-in type, but more commonly is a class derived from the **std::exception** class:

```cpp
#include <iostream>  // std::cout, std::runtime_error, std::exception, std::cerr

int divBy(int a, int b) {
  if (b == 0)
    throw std::runtime_error("Divided by 0.");  // exception type runtime_error
  return a / b;
}

int main() {
  try { divBy(7, 0);  // this function throws an exception when b == 0
  }
  catch (const std::exception& e) {
    std::cerr << "Exception handled: " << e.what() << '\n';
  }
}
```

9. Handling of Exceptions

9.2. try, throw, catch

Throwing a *custom exception* requires a custom exception class, which inherits from **std::exception** and overrides its **what** method to return an error message:

example01.cpp

```cpp
#include <iostream>  // std::cout, std::runtime_error, std::exception, std::ce

class MyException : public std::exception {
 public:
  MyException(const char * msg) : message(msg) {}  // Constructor sets exception message
  const char * what() { return message.c_str(); }  // Override what() to return own message
 private:
  std::string message;
};

int main() {
  try { throw MyException("Oops, my bad."); }  // create and throw object of MyException
  catch (MyException& e) { std::cerr << "Exception handled: " << e.what() << "\n"; }
}
```

9. Handling of Exceptions

9.2. `try`, `throw`, `catch`

The **std::exception** class has many subclasses for specific exceptions:

- logic_error
  - invalid_argument
  - domain_error
  - length_error
  - out_of_range
  - future_error (since C++11)
- bad_typeid
- bad_cast
  - bad_any_cast (since C++17)
- bad_optional_access (since C++17)
- bad_expected_access (since C++23)
- bad_weak_ptr (since C++11)
- bad_function_call (since C++11)
- bad_alloc
  - bad_array_new_length (since C++11)
- runtime_error
  - range_error
  - overflow_error
  - underflow_error
  - regex_error (since C++11)
  - system_error (since C++11)
  - ios_base::failure (since C++11)
  - filesystem::filesystem_error (since C++17)
  - tx_exception (TM TS)
  - nonexistent_local_time (since C++20)
  - ambiguous_local_time (since C++20)
  - format_error (since C++20)
- bad_exception
- ios_base::failure (until C++11)
- bad_variant_access (since C++17)

9. Handling of Exceptions

9.3. Function try blocks

Function try blocks build an exception handler around a method or function's body,
instead of a block of code inside the function body.

```
#include <iostream>  // std::cout, std::runtime_error, std::exception, std::cerr
class Superclass {
 public:
  Superclass(int x) : x(x) { if (x < 0) throw 1; }  // an exception can be thrown here
  int x;
};
class Subclass : public Superclass {
 public:       // what if we want to catch Superclass's constructor thrown exception here? …
  Subclass(int x) : Superclass(x) {}
};
int main() {   // … instead of here?
  try { Subclass sub(-5); } catch (int) { std::cout << "Oops, my bad.\n"; }
}
```

9. Handling of Exceptions

9.3. Function try blocks

So instead the function try block can be wrapped around:

example02.cpp

```
#include <iostream>  // std::cout,std::runtime_error,std::exception,std::cerr
class Superclass {
 public:
  Superclass(int x) : x(x) { if (x < 0) throw 1; }  // an exception can be thrown here
  int x;
};

class Subclass : public Superclass {
 public:
  // exceptions from A's constructor are now caught here -- but note the throw --- …
  Subclass(int x) try : Superclass(x) {}
                  catch (int) { std::cerr << "Oops, my bad."; throw; }
};

int main() {    // … instead of here
  try { Subclass sub(-5); } catch (int) { std::cout << "Oops, my bad.\n"; }
}
```

9. Handling of Exceptions

9.3. Function try blocks

Function try blocks *for constructors* are limited: They *cannot* resolve the thrown exception:

```
class Subclass : public Superclass {
 public:
  // exceptions from A's constructor are now caught here -- but note the throw --- ...
  Subclass(int x) try : Superclass(x) {}
                  catch (int) { std::cerr << "Oops, my bad."; throw; }
};
```

- Once the end of the catch block is reached, exceptions will be implicitly re-thrown
- *Other* methods and destructors can throw, rethrow, or resolve the current exception via a return statement
- Reaching the end of the catch block will:
  - implicitly resolve the exception for void-returning functions, and
  - produces undefined behavior for value-returning functions (hence: avoid).

9. Handling of Exceptions

9.4. **noexcept**

Exception handling comes at a (mostly small) cost.
Since C++11, **noexcept** can be added for a class method or function declaration, to specify that the function could throw exceptions or not:

```
int funct() noexcept;  // funct() does not throw (same as noexcept(true))
void (*fp)() noexcept(false);  // fp points to a function that may throw
```

This allows the compiler to optimize the performance, by skipping the processes that do exception handling, thus resulting in faster execution of the program.

The **noexcept** *operator* can be used since C++11 to check at compile time whether an expression is declared to not throw any exceptions:

```
noexcept( funct() );  // returns true, see the function declaration above
```

9.4. **noexcept** -- Example

example03.cpp

```
#include <iostream>  // use of std::cout, std::cerr

int divBy(int a, int b) {  // divBy could throw exceptions (noexcept omitted)
  if (b == 0)
    throw std::runtime_error("Error: Division by zero");
  return a / b;
}

int safeDivBy(int a, int b) noexcept {  // safeDivBy won't throw exceptions (noexcept)
  if (b == 0) {
    std::cerr << "Division by zero in safeDivBy\n";
    std::terminate();
  }
  return a / b;
}

int main() {
  std::cout << "divBy: " << noexcept(divBy(7, 0)) << '\n';          // → "divBy: 0"
  std::cout << "safeDivBy: " << noexcept(safeDivBy(7, 0)) << '\n';  // → "safeDivBy: 1"
}
```

9. Handling of Exceptions

9.5. **std::nested_exception** and **std::throw_with_nested**

In C++11 and beyond: Nesting exceptions allow to recursively stack exceptions, generated at the point of the error, without runtime overhead.

example04.cpp

```
#include <iostream>  // std::cout
#include <fstream>   // std::ifstream

void run();  // catch exception + wrap it in nested exception
void open_file(const std::string & s);  // catch exception + wrap it

// Nested exception adds 'level' spaces + prints messages via recursion & polymorphism
void print_exception(const std::exception & e, int level = 0) {
  std::cerr << std::string(level, ' ') << "exception: " << e.what() << '\n';
  try { std::rethrow_if_nested(e); }
  catch (const std::exception& nestedException) {
    print_exception(nestedException, level+1);
  }
}
```

9. Handling of Exceptions

9.5. `std::nested_exception` and `std::throw_with_nested`

```
int main() {  // runs run() and prints the caught exception
  try { run(); } catch (const std::exception & e) { print_exception(e); }
}


void run() {  // catch exception + wrap it in nested exception
  try { open_file("nonExistentFile.txt"); }
  catch (...) { std::throw_with_nested(std::runtime_error("run() fail")); }
}

void open_file(const std::string & s) {  // catch exception + wrap it
  try {
    std::ifstream file(s);  // open file and create an IO fail on next line:
    file.exceptions(std::ios_base::failbit);  // raise exception here
  }
  catch (...) {
    std::throw_with_nested(std::runtime_error("file error: " + s));
  }
}
```