

DM560
Introduction to Programming in C++

Error Handling

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[Based on slides by Bjarne Stroustrup]

Outline

1. Error Handling

2. Debugging

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1. Error Handling

2. Debugging

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- Kinds of errors
- Argument checking
 - Error reporting
 - Error detection
 - Exceptions
- Debugging
- Testing

Kinds of Errors

- **Compile-time errors:**
 - Syntax errors
 - Type errors
- **Link-time errors**
- **Run-time errors:**
 - Detected by computer (crash)
 - Detected by library (exceptions)
 - Detected by user code
- **Logic errors:**
 - Detected by programmer (code runs, but produces incorrect output)

Check your Inputs

Before trying to use an input value, check that it meets your expectations/requirements

1. Function arguments
2. Data from input (istream)

Bad Function Arguments

The compiler helps:

Number and types of arguments must match

```
int area(int length, int width)
{
    return length*width;
}

int x1 = area(7);           // error: wrong number of arguments
int x2 = area("seven", 2);  // error: 1st argument has a wrong type
int x3 = area(7, 10);       // ok
int x5 = area(7.5, 10);     // ok, but dangerous: 7.5 truncated to 7;
                           // most compilers will warn you
int x = area(10, -7);       // this is a difficult case:
                           // the types are correct,
                           // but the values make no sense
```

Bad Function Arguments

So, how about `int x = area(10, -7);`?

Bad Function Arguments

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Alternatives:

- Just don't do that
Rarely a satisfactory answer
- The `caller` should check
Hard to do systematically
- The `function` should check
 - Return an `error value` (not general, problematic)
 - Set an `error status` indicator (not general, problematic – don't do this)
 - `Throw an exception`

Note: sometimes we can't change a function that handles errors in a way we do not like because someone else wrote it and we can't or don't want to change their code

How to Report an Error

- Return an **error value** (not general, problematic)

```
int area(int length, int width)    // return a negative value for bad input
{
    if(length <=0 || width <= 0) return -1;
    return length*width;
}
```

- So, “let the caller beware”

```
int z = area(x,y);
if (z<0) error("bad area computation");
// ...
```

Problems

- What if I forget to check that return value?
- For some functions there isn't a "bad value" to return (e.g., `max()`)

How to Report an Error

- Set an **error status** indicator (not general, problematic, don't!)

```
int errno = 0; // used to indicate errors
int area(int length, int width)
{
    if (length<=0 || width<=0) errno = 7; // || means or
    return length*width;
}
```

- So, "let the caller check"

```
int z = area(x,y);
if (errno==7) error("bad area computation");
// ...
```

Problems

- What if I forget to check **errno**?
- How do I pick a value for **errno** that is different from all others?
- How do I deal with that **error**?

How to Report an Error

The right way

- Report (**Throw**) an error by throwing an exception

```
class Bad_area { }; // a class is a user defined type
                    // Bad_area is a type to be used as an exception

int area(int length, int width)
{
    if (length<=0 || width<=0) throw Bad_area{}; // note the {} - a value
    return length*width;
}
```

- **Catch** and deal with the error (e.g., in `main()`)

```
try {
    int z = area(x,y); // if area() doesn't throw an exception
} // make the assignment and proceed
catch(Bad_area) { // if area() throws Bad_area{}, respond
    cerr << "oops! Bad area calculation - fix program\n";
}
```

Exceptions

- Exception handling is general
 - You can't forget about an exception: the program will terminate if someone doesn't handle it (using a `try ... catch`)
 - Just about every kind of error can be reported using exceptions
- You still have to figure out what to do about an exception (every exception thrown in your program)
Error handling is never really simple

Out of Range

Try this:

```
vector<int> v(10);          // a vector of 10 ints,
                           // each initialized to the default value, 0,
                           // referred to as v[0] .. v[9]
for (int i = 0; i<v.size(); ++i) v[i] = i;      // set values
for (int i = 0; i<=10; ++i)                    // print 10 values (???)
    cout << "v[" << i << "] == " << v[i] << endl;
```

`vector's operator[]` (subscript operator) reports a bad index (its argument) by throwing a `Range_error` if you use `#include "std_lib_facilities.h"` (`#include<stdexcept>`)

The default behavior can differ: in `-std-lib=c++14` compare `[]` with `at()`

You can't make this mistake with a `range-for`

Exceptions

For now, just use exceptions to terminate programs gracefully, like this

```
int main()
try
{
    // ...
}
catch (out_of_range&) { // out_of_range exceptions
    cerr << "oops - some vector index out of range\n";
}
catch (...) {           // all other exceptions
    cerr << "oops - some exception\n";
}
```

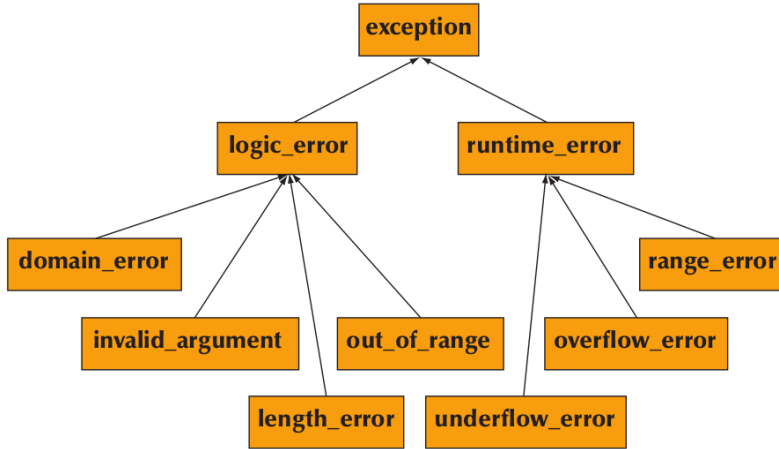
A function `error()`

Here is a simple `error()` function as provided in `std_lib_facilities.h`. This allows you to print an error message by calling `error()`. It works by disguising throws, like this:

```
void error(string s)      // one error string
{
    throw runtime_error(s);
}

void error(string s1,  string s2)      // two error strings
{
    error(s1 + s2);      // concatenates
}
```


Exception Class Hierarchy



Using `error()`

Example

```
cout << "please enter integer in range [1..10]\n";
int x = -1;    // initialize with unacceptable value (if possible)
cin >> x;
if (!cin)      // check that cin read an integer
    error("I did not get a value");
if (x < 1 || 10 < x) // check if value is out of range
    error("x is out of range");
// if we get this far, we can use x with confidence
```

Using `error()`

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```
please enter integer in range [1..10]
-1
terminate called after throwing an instance of 'std::runtime_error'
  what():  x is out of range
Aborted
```

Link-time errors

Example

```
int area(int length, int width);  
  
double area(double x, double y) { };  
  
int main() {  
    int x = area(2,3);  
}
```

Outline

1. Error Handling

2. Debugging

How to Look for Errors

When you have written (drafted?) a program, it will have errors (commonly called [bugs](#)). It will do something, but not what you expected

- How do you find out what it actually does?
- How do you correct it?
- This process is usually called [debugging](#)

Program Structure

Make the program easy to read so that you have a chance of spotting the bugs:

- **Comment**: explain design ideas
- Use meaningful **names**
- **Indent**
 - Use a consistent layout
 - Your IDE tries to help - look for “format” (but it can’t do everything)
You are the one responsible
- Break code into small **functions**
Try to avoid functions longer than a page
- **Avoid complicated** code sequences
Try to avoid nested loops, nested if-statements, etc.
(But, obviously, you sometimes need those)
- **Use library** facilities

In Atom: Edit -> Preferences -> Install

atom-clang provides code completion and Linting (analyzer of source code to flag programming errors, bugs, stylistic errors, and suspicious constructs)

clang-format to format code (ctrl+shift+P **format**)

First Get the Program to Compile

- Is every string literal terminated?

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cout << "Hello, << name << '\n';           // oops!
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- Is every block terminated?

```
if (a>0) { /* do something */  
    else { /* do something else */ } // oops!
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- Is every set of parentheses matched?

```
if (a           // oops!  
x = f(y);
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if (a           // oops!  
x = f(y);
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- The compiler generally reports this kind of error “late” It doesn’t know you didn’t mean to close “it” later

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Did you spell all names correctly?

```
int count;          /* ... */ ++Count;          // oops!  
char ch;            /* ... */ Cin>>c;            // double oops!
```

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```
int count;          /* ... */ ++Count;          // oops!  
char ch;            /* ... */ Cin>>c;            // double oops!
```

- Did you terminate each expression statement with a semicolon?

```
x = sqrt(y)+2      // oops!  
z = x+3;
```

Debugging

- Carefully follow the program through the specified sequence of steps
Pretend you're the computer executing the program
Does the output match your expectations?
If there isn't enough output to help, add a few **debug output statements**:

```
cerr << "x == " << x << ", y == " << y << '\n';
```


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```

- Be very careful
See what the program specifies, not what you think it should say
That's much harder to do than it sounds

```
for (int i=0; 0<month.size(); ++i) { // oops!  
for( int i = 0; i<=max; ++j) { // oops! (twice)
```

Debugging

- When you write the program, insert some checks (**sanity checks**) that variables have “reasonable values”

Function argument checks are prominent examples of this.

```
if (number_of_elements < 0)
    error("impossible: negative number of elements");

if (largest_reasonable < number_of_elements)
    error("unexpectedly large number of elements");

if (x < y) error("impossible: x < y");
```

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- Alternatively, use **assert** which can be disabled in production with **#define NDEBUG** or option **-DNDEBUG** when compiling.
- Consider also to use the options **-fsanitize=address** and or **-fsanitize=undefined** when compiling
- Design these checks so that some can be left in the program even after you believe it to be correct: \rightsquigarrow It's almost always better for a program to stop than to give wrong results

Debugging

Pay special attention to **end cases** (beginnings and ends):

- Did you **initialize** every variable (with a reasonable value)?

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- Did you handle the **empty case** correctly?
No elements
No input

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No elements
No input
- Did you open your **files** correctly? (more on this in chapter 11)

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Did the function return the right value?
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- Did you handle the **empty case** correctly?
No elements
No input
- Did you open your **files** correctly? (more on this in chapter 11)
- Did you actually read/write that input?

Pre-conditions

What a function requires of its arguments is called a [pre-condition](#)
Sometimes, it's a good idea to check it

```
int area(int length, int width) // calculate area of a rectangle
// length and width must be positive
{
    if (length<=0 || width <=0) throw Bad_area{};
    return length*width;
}
```

Post-condition

What must be true when a function returns is called a **post-condition**

```
int area(int length, int width) // calculate area of a rectangle
// length and width must be positive
{
    if (length<=0 || width <=0) throw Bad_area{};
    // the result must be a positive int that is the area
    // no variables had their values changed
    int a = length*width;
    if (a < 0) error('‘area()  post-condition’,’);
    return a;
}
```

Post-condition

What must be true when a function returns is called a **post-condition**

```
int area(int length, int width) // calculate area of a rectangle
// length and width must be positive
{
    if (length<=0 || width <=0) throw Bad_area{};
    // the result must be a positive int that is the area
    // no variables had their values changed
    int a = length*width;
    if (a < 0) error('area() post-condition',');
    return a;
}
```

Can you find inputs that satisfy the pre-condition but not the post-condition?

Pre and Post-Conditions

- Always think about them
- If nothing else write them as comments
- Check them “where reasonable”
- Check a lot when you are looking for a bug
- This can be tricky
 - How could the post-condition for `area()` fail after the pre-condition held?

Testing

How do we test a program?

- Be systematic
“pecking at the keyboard” is okay for very small programs and for very initial tests, but is insufficient for real systems
- Think of testing and correctness from the very start
When possible, test parts of a program in isolation
E.g., when you write a complicated function write a little program that simply calls it with a lot of arguments to see how it behaves in isolation before putting it into the real program (this is typically called [unit testing](#))
- See Chapter 26

Performance

- Computation time

```
> time primes # only in Linux
```

Otherwise:

```
#include <iostream>
#include <chrono>

using namespace std;
using namespace std::chrono;

int main (int argc, char **argv) {
    int iterations = atoi(argv[1]);
    auto t1=system_clock::now();

    for (int i = 0; i<iterations; i++) system("primes");

    auto t2 = system_clock::now();
    cout << iterations << "iterations took "
         << duration_cast<milliseconds>(t2-t1).count()<<" milliseconds\n";
}
```

- Memory usage

Summary

1. Error Handling

2. Debugging