# Errors and exceptions

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## Functions

- A `function` is a named block of code that can be passed arguments and returns a value to the caller
- We can declare a function by writing a `declarator` of the form `f(args)`, where `f` is the name being introduced and `args` is the parameter list, for example:
  - `double mult2(double d);`
  - Note: the `base type` specifies the `return type` of the `function`
- We can define a function by including the declaration with the definition provided in {} directly following the parameter list (like a compound statement, we don't have a terminating semi-colon)
  - `double mult2(double d) { return d*2; }`

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## Functions

- We will get into more details about `functions` later, but its helpful to understand them as they help motivate the necessity of `exceptions`

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## Errors

- When we write programs, errors are natural and unavoidable; the question is, how do we deal with them?
  - Organize software to minimize errors
  - Eliminate most of the errors we made anyway
    - Debugging
    - Testing

*"My guess is that avoiding, finding, and correcting errors is 95% or more of the effort for serious software development."*
– Bjarne Stroustrup

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## Sources of errors

- Poor specification
  - "What's this suppose to do?"
- Incomplete programs
  - "but I'll get around to it... tomorrow..."
- Unexpected arguments to functions
  - "but `sqrt()` isn't suppose to be called with `-1` as its argument"
- Unexpected input
  - "but the user was suppose to input an integer"
- Code that simply doesn't do what it was supposed to do
  - "so fix it..."

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## Your program

- Should produce the desired results for all legal inputs
- Should give reasonable error messages for all illegal inputs
- Need not worry about misbehaving hardware
- Need not worry about misbehaving system software
- Is allowed to terminate after finding an error

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## Kinds of errors

Compile-time errors Errors found by the compiler
- Syntax errors
- Type errors

Link-time errors Errors found by the linker when it is trying to combine object files into an executable program

Run-time errors Errors found by checks made during a running program; that is, errors detected by
- the computer (hardware and/or the operating system)
- by a library (e.g., the standard library)
- by user code

Logic errors Errors found by the programmer looking for the causes of erroneous results

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  How to report an error
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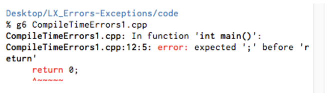
## Compile-time errors : Syntax errors

```
#include <iostream>
#include <vector>
#include <string>
using namespace std;

int main ( ) {
    string first_name = "Michael";
    string last_name = "Nowak";
    string full_name = first_name + '␣' + last_name;
    cout << full_name << endl

    return 0;
}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 CompileTimeErrors1.cpp
CompileTimeErrors1.cpp: In function 'int main()':
CompileTimeErrors1.cpp:12:5: error: expected ';' before 'r
eturn'
     return 0;
     ^~~~~~
```

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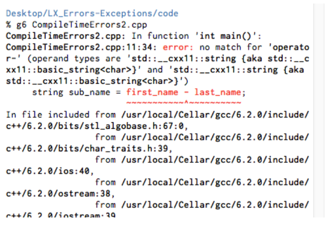
## Compile-time errors : Type errors

```
#include <iostream>
#include <vector>
#include <string>
using namespace std;

int main ( ) {
    string first_name = "Michael
    string last_name = "Nowak";


    string sub_name = first_name - last_name;
    cout << sub_name;

    return 0;
}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 CompileTimeErrors2.cpp
CompileTimeErrors2.cpp: In function 'int main()':
CompileTimeErrors2.cpp:11:34: error: no match for 'operato
r-' (operand types are 'std::__cxx11::string {aka std::__c
xx11::basic_string<char>}' and 'std::__cxx11::string {aka
std::__cxx11::basic_string<char>}')
     string sub_name = first_name - last_name;
                       ~~~~~~~~~~~^~~~~~~~~~~
In file included from /usr/local/Cellar/gcc/6.2.0/include/
c++/6.2.0/bits/stl_algobase.h:67:0,
                 from /usr/local/Cellar/gcc/6.2.0/include/
c++/6.2.0/bits/char_traits.h:39,
                 from /usr/local/Cellar/gcc/6.2.0/include/
c++/6.2.0/ios:40,
                 from /usr/local/Cellar/gcc/6.2.0/include/
c++/6.2.0/ostream:38,
                 from /usr/local/Cellar/gcc/6.2.0/include/
c++/6.2.0/iostream:39
```

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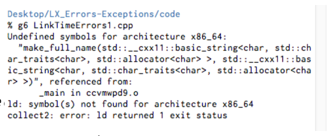
## Link-time errors

```
#include <iostream>
#include <vector>
#include <string>
using namespace std;

/*
    declaration, for an undefine
*/
string make_full_name (string f, string l);


int main ( ) {
    string first_name = "Michael";
    string last_name = "Nowak";
    string full_name = make_full_name(first_name, last_name);

    return 0;
}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 LinkTimeErrors1.cpp
Undefined symbols for architecture x86_64:
  "make_full_name(std::__cxx11::basic_string<char, std::ch
ar_traits<char>, std::allocator<char> >, std::__cxx11::bas
ic_string<char, std::char_traits<char>, std::allocator<cha
r> >)", referenced from:
      _main in ccvmwpd9.o
ld: symbol(s) not found for architecture x86_64
collect2: error: ld returned 1 exit status
```

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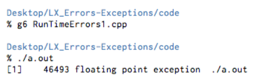
## Run-time errors : detected by the computer

```
#include <iostream>
#include <vector>
using namespace std;

int main ( ) {

    int x = −1;
    int y = 0;
    /*
        divide by zero
    */
    int z = x / y;
    cout << z;

    return 0;
}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 RunTimeErrors1.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
[1]    46493 floating point exception  ./a.out
```

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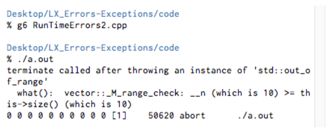
## Run-time errors : detected by a library

```
#include <iostream>
#include <vector>
 using namespace std;

 int main ( ) {

     vector<int> v(10);
     /*
         when we are at v.size(), we are out of
         v's range of elements
     */
     for (int i = 0 ; i <= v.size() ; ++i)
         cout << v.at(i) << '␣';

     return 0;
 }
```



```
Desktop/LX_Errors-Exceptions/code
% g6 RunTimeErrors2.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
terminate called after throwing an instance of 'std::out_o
f_range'
  what():  vector::_M_range_check: __n (which is 10) >= th
is->size() (which is 10)
0 0 0 0 0 0 0 0 0 0 [1]    50620 abort      ./a.out
```

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## Run-time errors : detected by user-code

- We can find errors through various checks made during a running program...

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## Local run-time errors

- Easy to do for local run-time errors

  -
    ```
    int i;
    std::cin >> i;
    if (i < 0)
        return 1;
    ```

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## Non-local run-time errors

- How can we handle non-local errors during run-time?

```
// necessary #includes...

int area (int length, int width) { return length * width; }
int framed_area (int x, int y) { return area(x-2, y-2); }

int main ( ) {
    int x = -1;
    int y = 2;
    int z = 4;
    // ...
    int area1 = area(x, y);
    int area2 = framed_area(1, z);
    int area3 = framed_area(y, z);
    double ratio = double(area1)/area3;
    return 0;
}
```

- Need some means of error reporting... will discuss this shortly

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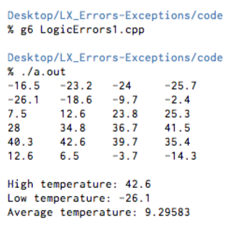
## Logic errors

```
#include <iostream>
#include <vector>
#include <string>
using namespace std;

int main ( ) {

    vector<double> temps {-16.5, -23.2, -24.0, -25.7, -26.1, -18.6, -9.7, -2.4,
        7.5, 12.6, 23.8, 25.3, 28.0, 34.8, 36.7, 41.5, 40.3, 42.6, 39.7, 35.4,
        12.6, 6.5, -3.7, -14.3};

    double sum = 0;
    double high_temp = 0;
    double low_temp = 0;

    for (double t : temps) {
        if (t > high_temp) high_temp = t;
        if (t < low_temp) low_temp = t;
        sum += t;
    }

    double avg_temp = sum/temps.size();
    for (int i = 1 ; i <= temps.size() ; ++i) {
        cout << temps.at(i-1) << '\t';
        if (i % 4 == 0) cout << endl;
    }
    cout << endl;
    cout << "High␣temperature:␣" << high_temp << endl;
    cout << "Low␣temperature:␣" << low_temp << endl;
    cout << "Average␣temperature:␣" << avg_temp << endl;

}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 LogicErrors1.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
-16.5   -23.2   -24     -25.7
-26.1   -18.6   -9.7    -2.4
7.5     12.6    23.8    25.3
28      34.8    36.7    41.5
40.3    42.6    39.7    35.4
12.6    6.5     -3.7    -14.3

High temperature: 42.6
Low temperature: -26.1
Average temperature: 9.29583
```

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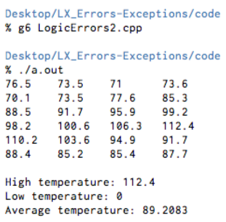
## Logic errors

```
#include <iostream>
#include <vector>
#include <string>
using namespace std;

int main ( ) {

    vector<double> temps {76.5, 73.5, 71.0, 73.6, 70.1, 73.5, 77.6, 85.3, 88.5,
        91.7, 95.9, 99.2, 98.2, 100.6, 106.3, 112.4, 110.2, 103.6, 94.9, 91.7,
        88.4, 85.2, 85.4, 87.7};

    double sum = 0;
    double high_temp = 0;
    double low_temp = 0;

    for (double t : temps) {
        if (t > high_temp) high_temp = t;
        if (t < low_temp) low_temp = t;
        sum += t;
    }

    double avg_temp = sum/temps.size();
    for (int i = 1 ; i <= temps.size() ; ++ i) {
        cout << temps.at(i-1) << '\t';
        if (i % 4 == 0) cout << endl;
    }
    cout << endl;
    cout << "High␣temperature:␣" << high_temp << endl;
    cout << "Low␣temperature:␣" << low_temp << endl;
    cout << "Average␣temperature:␣" << avg_temp << endl;

}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 LogicErrors2.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
76.5    73.5    71      73.6
70.1    73.5    77.6    85.3
88.5    91.7    95.9    99.2
98.2    100.6   106.3   112.4
110.2   103.6   94.9    91.7
88.4    85.2    85.4    87.7

High temperature: 112.4
Low temperature: 0
Average temperature: 89.2083
```

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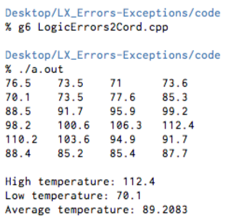
## Logic errors

```
#include <iostream>
#include <vector>
#include <string>
using namespace std;

int main ( ) {

    vector<double> temps {76.5, 73.5, 71.0, 73.6, 70.1, 73.5, 77.6, 85.3, 88.5,
        91.7, 95.9, 99.2, 98.2, 100.6, 106.3, 112.4, 110.2, 103.6, 94.9, 91.7,
        88.4, 85.2, 85.4, 87.7};

    double sum = 0;
    double high_temp = temps[0];
    double low_temp = temps[0];

    for (double t : temps) {
        if (t > high_temp) high_temp = t;
        if (t < low_temp) low_temp = t;
        sum += t;
    }

    double avg_temp = sum/temps.size();
    for (int i = 1 ; i <= temps.size() ; ++ i) {
        cout << temps.at(i-1) << '\t';
        if (i % 4 == 0) cout << endl;
    }
    cout << endl;
    cout << "High␣temperature:␣" << high_temp << endl;
    cout << "Low␣temperature:␣" << low_temp << endl;
    cout << "Average␣temperature:␣" << avg_temp << endl;

}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 LogicErrors2Cord.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
76.5    73.5    71      73.6
70.1    73.5    77.6    85.3
88.5    91.7    95.9    99.2
98.2    100.6   106.3   112.4
110.2   103.6   94.9    91.7
88.4    85.2    85.4    87.7

High temperature: 112.4
Low temperature: 70.1
Average temperature: 89.2083
```

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## Handling non-local errors at run-time

- The caller deals with the error
```
int area1 = area(x, y);
if (area1 < 0)
   /* handle error */
else
    /* no error, continue program execution */
```
- The callee deals with errors
```
int area (int length, int width) {
    dobule a = length * width;
    if (a < 0)
        return 0;
    else
        return a;
}
```
- Error reporting

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## How to report an error

- Return an "error value" (not general, problematic)
```
int area(int length, int width)
{
    if(length<=0 || width<=0) return -1;
    return length*width;
}
```
- So, "let the caller beware"
```
int z = area(x,y);
if (z<0) return error(‘‘bad area’’);
//...
```
- Problems:
  - What if I forget to check the value returned?
  - For some functions, there isn't a "bad value"

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## How to report an error

- Set an error status indicator (not general, problematic, don't)
  ```
  int errno = 0;
  int area(int length, int width)
  {
      if(length<=0 || width<=0) errno = 7;
      return length*width;
  }
  ```
- So, “let the caller check”
  ```
  int z = area(x,y);
  if (errno==7) return error(‘‘bad area’’);
  //...
  ```
- Problems:
  - What if I forget to check `errno`?
  - How do I pick a value for `errno` that's different from all others?
  - How do I deal with that error?

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## How to report an error

- The previous means of error reporting are not general...
- Consider that, most of the time we can't change a function that handles errors in a way we don't like...
  - The author of the `std::vector` can detect run-time errors; however, he/she has no idea what the user would like to do about them
  - The user of the `std::vector` knows how to cope with such errors; however, he/she cannot detect them (otherwise he/she would find them in his/her own code; not left for the library to find)
- So we need a means of reporting errors in a general way...

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## Exceptions

- Exceptions are C++'s means of separating error reporting from error handling in a general way
  - Just about every kind of error can be reported using exceptions
  - Moreover, you can't forget about an exception: the program will terminate if someone does't handle it...
- You still have to figure out what to do about an exception (every exception thrown in your program)

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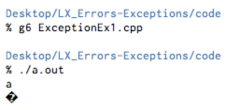
## Exceptions : Example 1

```cpp
#include <iostream>
#include <stdexcept>
#include <limits>
using namespace std;

char to_char(int i) {
        return static_cast<char>(i);
}

int main () {
    cout << to_char(97) << endl;
    cout << to_char(155) << endl;
    return 0;
}
```



```
Desktop/LX_Errors-Exceptions/code
% g6 ExceptionEx1.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
a
�
```

Notes

## Exceptions : Throw, Try and Catch

```cpp
char to_char(int i) {
    if (i < numeric_limits<char>::min() || numeric_limits<char>::max() < i) {
        const string s = to_string(i);
        throw runtime_error("int␣" + s + "␣is␣not␣within␣the␣range␣of␣char␣");
    }
    // we get here if and only if an exception is not thrown
    return static_cast<char>(i);
}
```

- When an unexpected condition happens, we can `throw` an exception
  - `to_char` will either return the corresponding *char* of the numeric value `i`
  - **or** it will throw a `runtime_error`

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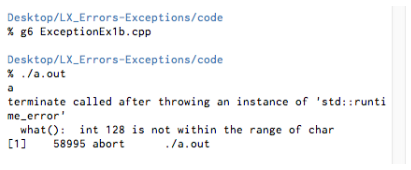
## Exceptions : Example 1b



```
Desktop/LX_Errors-Exceptions/code
% g6 ExceptionEx1b.cpp

Desktop/LX_Errors-Exceptions/code
% ./a.out
a
terminate called after throwing an instance of 'std::runti
me_error'
  what():  int 128 is not within the range of char
[1]    58995 abort      ./a.out
```

```cpp
#include <iostream>
#include <string>
#include <stdexcept>
#include <limits>
using namespace std;
char to_char(int i) {
    if (i < numeric_limits<char>::min() || numeric_limits<char>::max() < i) {
        const string s = to_string(i);
        throw runtime_error("int␣" + s + "␣is␣not␣within␣the␣range␣of␣char␣");
    }
    // we get here if and only if an exception is not thrown
    return static_cast<char>(i);
}
int main () {
    cout << to_char(97) << endl;
    cout << to_char(128);
    return 0;
}
```

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## Exceptions : Throw, Try and Catch

- In order to handle the problem, we must indicate that we are willing to `catch` the exception of the type used to report the problem
- If we do not catch the exception anywhere, the program will terminate (as seen in the previous example)
- Therefore, we introduce a try-block around the code where an exception might occur

```cpp
try {
    cout << to_char(97) << endl;
    cout << to_char(128);
}
```

- The try-block is followed by the *exception handler*, which specifies the type of objects that it can catch

```cpp
catch (const runtime_error& e) { // exception handler
    cerr << "Exception:␣" << e.what() << endl;
}
```

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## References

- Lippman, B., Lajoie, Josee, & Moo, B. E. (2016). *C++ primer* (5th ed.). Addison-Wesley.
- Stroustrup, B. (2014). *Programming: principles and practice using C++* (2nd ed.). Addison-Wesley.

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