Error handling and testing

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1. Programming and correctness

Find your favorite example of costly programming mistakes . . .

What to do about it?

- Never make mistakes.
- Prove that your program is correct.
- Test your program before deploying it.
- Handle errors as they occur.

Error handling

2. Use assertions during development

```
#include <cassert>
...
assert( bool expression )
```

Assertions are disabled by

```
#define NDEBUG
```

before the include.

You can pass this as compiler flag:
`icpc -DNDEBUG yourprog.cxx`

3. Using assertions

```
#include <cassert>

// this function requires x<y
// it computes something positive
float f(x,y) {
  assert( x<y );
  return /* some result */;
}

float positive_outcome = f(x,y);
assert( positive_outcome>0 );
```

4. Example

```
int collatz_next( int current ) {
  assert( current>0 );
  int next{-1};
  if (current%2==0) {
    next = current/2;
    assert(next<current);
  } else {
    next = 3*current+1;
    assert(next>current);
  }
  return next;
}
```

5. Exceptions

Have you seen the following?

Code:

```
vector<float> x(5);
x.at(5) = 3.14;
```

Output

```
[except] boundthrow:

libc++abi.dylib: terminating with
    uncaught exception of type std
    ::out_of_range: vector
make[2]: *** [run_boundthrow]
    Abort trap: 6
```

The Standard Template Library (STL) can generate many exceptions.

- You can let your program crash, and start debugging
- You can try to catch and handle them yourself.

6. Exceptions

Assume a routine only works for certain values, and you want to generate an error if called with an inappropriate value.

```
double compute_root(double x) {
  if (x<0) throw(1);
  return sqrt(x);
}
int main() {
  try {
    y = compute_root(x);
  } catch (...) { // literally three dots!
    /* handle error */
  }
```

See book for more details.

Unit testing and test-driven development (TDD)

7. Dijkstra quote

> *Today a usual technique is to make a program and then to test it. But: program testing can be a very effective way to show the presence of bugs, but is hopelessly inadequate for showing their absence. (cue laughter)*

Still . . .

8. Types of testing

- *Unit tests* that test a small part of a program by itself;
- *System tests* test the correct behavior of the whole software system; and
- *Regression tests* establish that the behavior of a program has not changed by adding or changing aspects of it.

9. Test-driven development

Develop code and tests hand-in-hand:

- Both the whole code and its parts should always be testable.
- When extending the code, make only the smallest change that allows for testing.
- With every change, test before and after.
- Assure correctness before adding new features.

10. Unittesting frameworks

Testing is important, so there is much software that assists you.

Popular choice with C++ programmers: Catch2
`https://github.com/catchorg`

11. Program to be tested

```
#include "functions.h"
int main() {
  for ( int i=10; i>-1; i-- )
    cout << "One more than the positive number "
         << i << " is "
         << increment_positive_only(i)
         << "\n";
```

Note the include file!

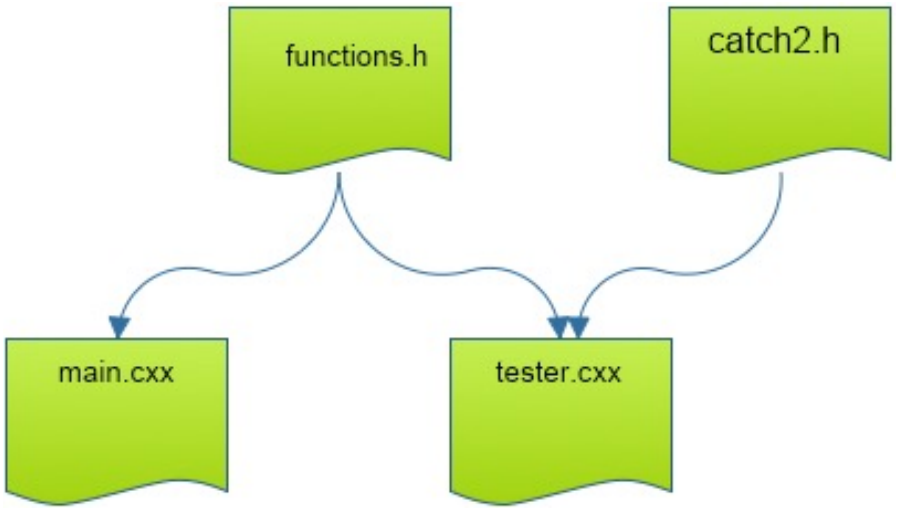
12. Functionality testing

```
#include "functions.h"

#define CATCH_CONFIG_MAIN
#include "catch2/catch_all.hpp"

TEST_CASE( "test the increment function" ) {
  /* ... */
}
```

The testing framework creates its own main.

13. File structure

- All program functionality in a ‘library’ file
- Main program really short
- Second main with only tests.



14. Compile and link options

Variables:

```
INCLUDES = -I${TACC_CATCH2_INC}
EXTRALIBS = -L${TACC_CATCH2_LIB} -lCatch2Main -lCatch2
```

One-line solution:

```
g++ -o tester test_main.cxx \
    -I${TACC_CATCH2_INC}-L${TACC_CATCH2_LIB} \
    -lCatch2Main -lCatch2
```

Exercise 1: File structure

Make three files:

1. Include file with the functions.
2. Main program that uses the functions.
3. Tester main file, contents to be determined.

15. Correctness through 'require' clause

- *TEST_CASE* acts like independent program.
- Can contain (multiple) tests for correctness.

```
TEST_CASE( "test that f always returns positive" ) {
  for (int n=0; n<1000; n++)
    REQUIRE( f(n)>0 );
}
```

16. What if it is not correct?

Print info for failing tests:

```
TEST_CASE( "test that f always returns positive" ) {
  for (int n=0; n<1000; n++)
    INFO( "function fails for `` << n );
    REQUIRE( f(n)>0 );
}
```

17. Positive tests

Let's continue with our simple example of slide 14:

```
for (int i=1; i<10; i++)
  REQUIRE( increment_positive_only(i)==i+1 );
```

18. Test for exceptions

```
TEST_CASE( "test that g only works for positive" ) {
  for (int n=-100; n<+100; n++)
    if (n<=0)
      REQUIRE_THROWS( g(n) );
    else
      REQUIRE_NOTHROW( g(n) );
}
```

19. Negative tests

Make sure your function throws an exception at illegal inputs:

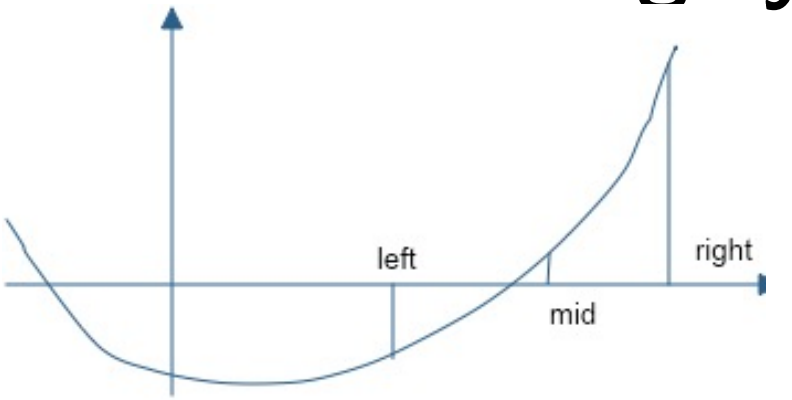
```
for (int i=0; i>-10; i--)
  REQUIRE_THROWS( increment_positive_only(i) );
```

20. Setup and teardown

```
TEST_CASE( "commonalities" ) {
  // common setup:
  double x,y,z;
  REQUIRE_NOTHROW( y = f(x) );
  // two independent tests:
  SECTION( "g function" ) {
    REQUIRE_NOTHROW( z = g(y) );
  }
  SECTION( "h function" ) {
    REQUIRE_NOTHROW( z = h(y) );
  }
  // common followup
  REQUIRE( z>x );
}
```

TDD example: Bisection

21. Root finding by bisection



- Start with bounds where the function has opposite signs.

$$x_- < x_+, \qquad f(x_-) \cdot f(x_+) < 0,$$

- Find the mid point;
- Adjust either left or right bound.

22. Coefficient handling

$$f(x) = c_d x^d + \cdots + c_1 x^1 + c_0$$

We implement this by storing the coefficients in a `vector<double>`.
Proper:

```
TEST_CASE( "coefficients are polynomial","[1]" ) {
  auto coefficients = set_coefficients();
  REQUIRE( coefficients.size()>0 );
  REQUIRE( coefficients.front()!=0. );
}
```

Exercise 2: Proper polynomials

Write a routine *set_coefficients* that constructs a vector of coefficients:

```
vector<double> coefficients = set_coefficients();
```

and make it satisfy the above conditions.

At first write a hard-coded set of coefficients, then try reading them from the command line.

Exercise 3: One test for properness

Write a test *proper_polynomial* and write unit tests for it, both passing and failing.

23. Test on polynomials evaluation

```
// correct interpretation: 2x^2 + 1
vector<double> second{2,0,1};
REQUIRE( proper_polynomial(second) );
REQUIRE( evaluate_at(second,2) == Catch::Approx(9) );
// wrong interpretation: 1x^2 + 2
REQUIRE( evaluate_at(second,2) != Catch::Approx(6) );
```

Exercise 4: Implementation

Write a function *evaluate_at* which computes

$$y \leftarrow f(x).$$

For bonus points, look up Horner's rule and implement it.

Exercise 5: Odd degree polynomials only

With odd degree you can always find bounds x_-, x_+.
Reject even degree polynomials:

```
if ( not is_odd(coefficients) ) {
  cout << "This program only works for odd-degree polynomials\n";
  exit(1);
}
```

Gain confidence by unit testing:

```
vector<double> second{2,0,1}; // 2x^2 + 1
REQUIRE( not is_odd(second) );
vector<double> third{3,2,0,1}; // 3x^3 + 2x^2 + 1
REQUIRE( is_odd(third) );
```

Exercise 6: Find bounds

Write a function *find_outer* which computes x_-, x_+ such that

$$f(x_-) < 0 < f(x_+) \quad \text{or} \quad f(x_+) < 0 < f(x_-)$$

(can you write that more compactly?)
Unit test:

```
right = left+1;
vector<double> second{2,0,1}; // 2x^2 + 1
REQUIRE_THROWS( find_outer(second,left,right) );
vector<double> third{3,2,0,1}; // 3x^3 + 2x^2 + 1
REQUIRE_NOTHROW( find_outer(third,left,right) );
REQUIRE( left<right );
```

How would you test the function values?

Exercise 7: Put it all together

Make this call work:

```
auto zero = find_zero(coefficients,left,right);
cout << "Found root " << zero
     << " with value " << evaluate_at(coefficients,zero) << "\n";
```

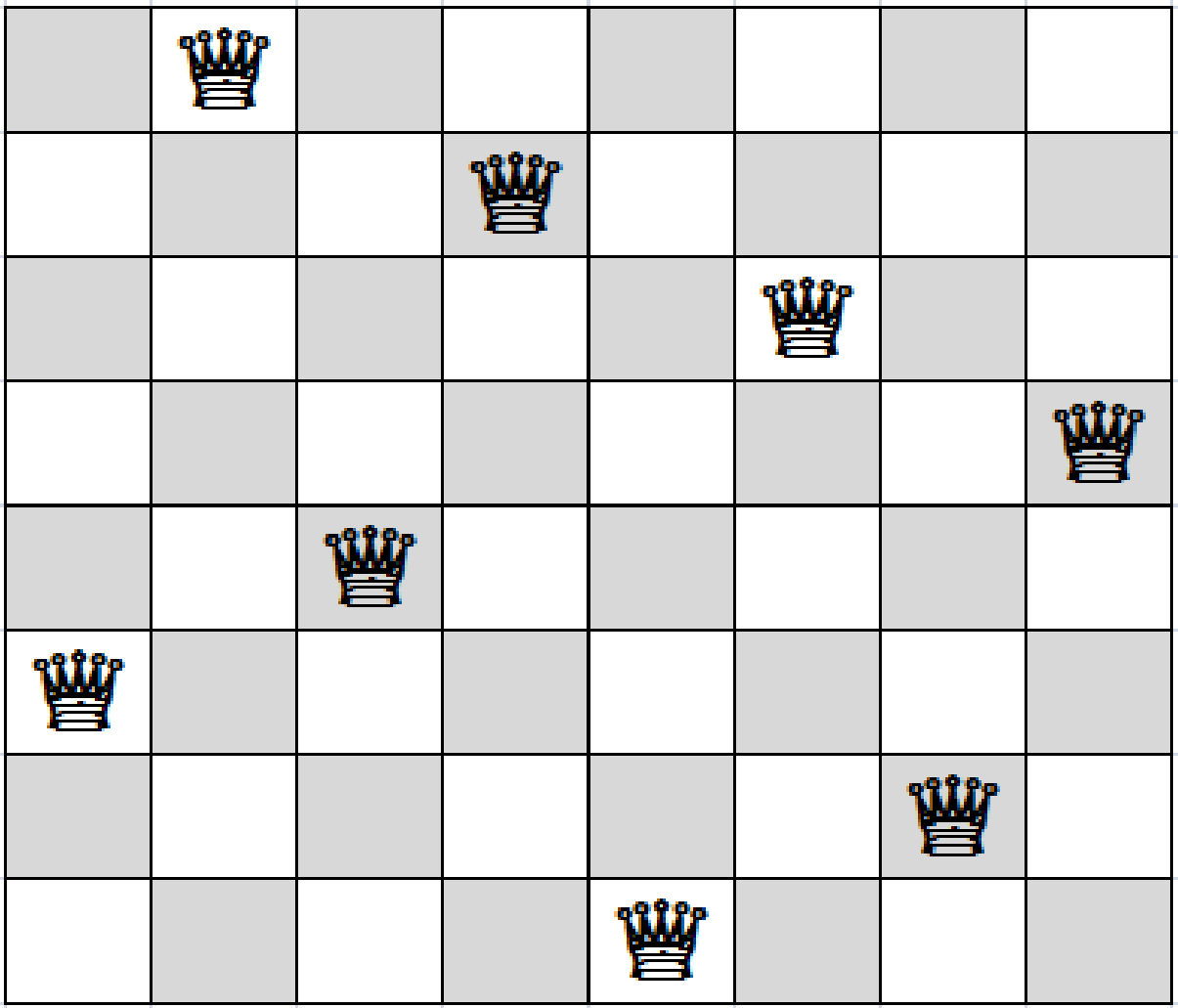
Add an optional precision argument to the root finding function.

Design unit tests, including on the precision attained, and make sure your code passes them.

Eight queens problem

24. Problem statement

Can you place eight queens on a chess board so that no pair threatens each other?

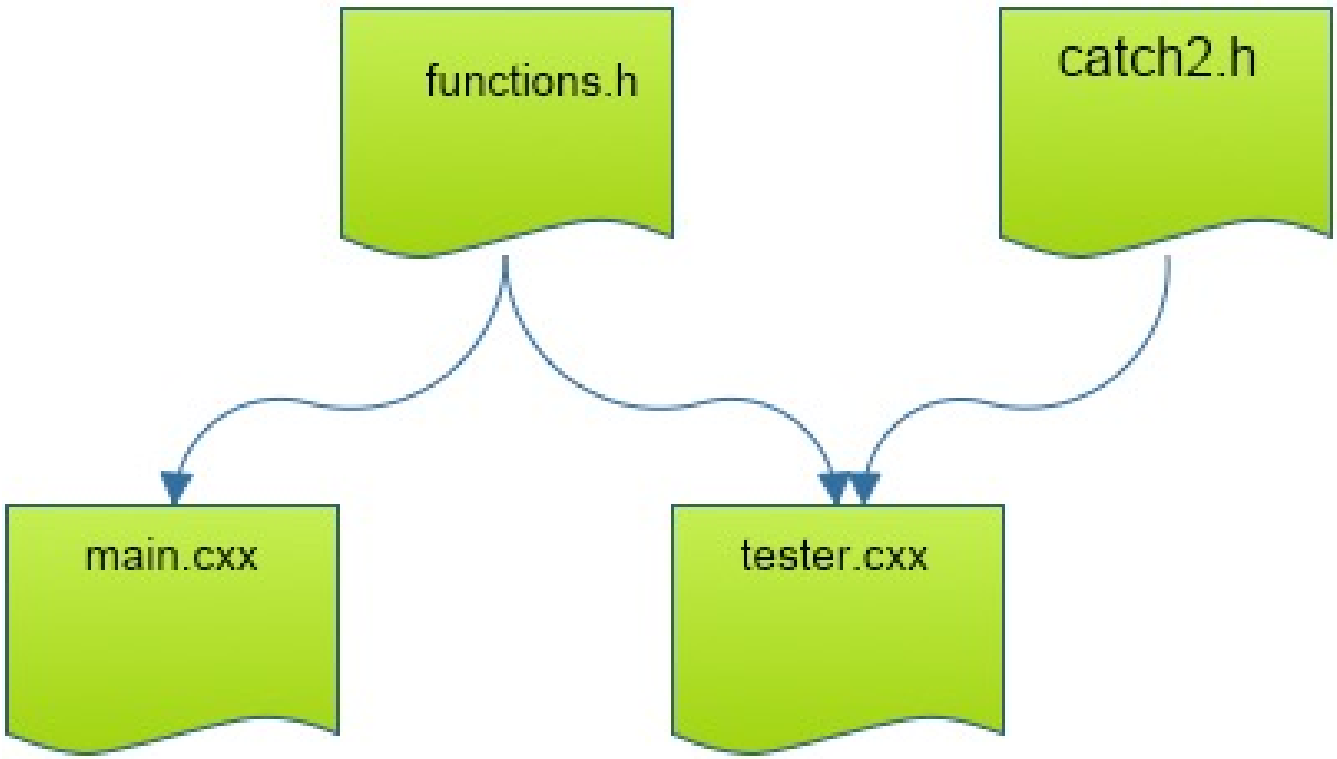


25. Sort of test-driven development

You will solve the 'eight queens' problem by

- designing tests for the functionality
- then implementing it

26. File structure



27. Basic object design

Object constructor of an empty board:

```
board(int n);
```

Test how far we are:

```
int next_row_to_be_filled() const;
```

First test:

```
TEST_CASE( "empty board" ) {
  constexpr int n=10;
  board empty(n);
  REQUIRE( empty.next_row_to_be_filled()==0 );
}
```

Exercise 8: Board object

Start writing the *board* class, and make it pass the above test.

Exercise 9: Board method

Write a method for placing a queen on the next row,

```
void place_next_queen_at_column(int i);
```

and make it pass this test (put this in a *TEST_CASE*):

```
auto one(empty);
REQUIRE_THROWS( one.place_next_queen_at_column(-1) );
REQUIRE_THROWS( one.place_next_queen_at_column(n) );
REQUIRE_NOTHROW( one.place_next_queen_at_column(0) );
REQUIRE( one.next_row_to_be_filled()==1 );
```

Exercise 10: Test for collisions

Write a method that tests if a board is collision-free:

```
bool feasible() const;
```

This test has to work for simple cases to begin with. You can add these lines to the above tests:

```
REQUIRE( empty.feasible() );

REQUIRE( one.feasible() );

auto collide(one);
collide.place_next_queen_at_column(0);
REQUIRE( not collide.feasible() );
```

Exercise 11: Test full solutions

Make a second constructor to 'create' solutions:

```
board( vector<int> cols );
```

Now we test small solutions:

```
board five( {0,3,1,4,2} );
REQUIRE( five.feasible() );
```

Exercise 12: No more delay: the hard stuff!

Write a function that takes a partial board, and places the next queen:

```
optional<board> place_queen(const board& current);
```

Test that the last step works:

```
board almost( {1,3,0,board::magic::empty} );
auto solution = place_queen(almost);
REQUIRE( solution.has_value() );
REQUIRE( solution->filled() );
```

Alternative to using *optional*:

```
bool place_queen( const board& current, board &next );
// true if possible, false is not
```

Exercise 13: Test that you can find solutions

Test that there are no 3×3 solutions:

```
TEST_CASE( "no 3x3 solutions" ) {
  board three(3);
  auto solution = place_queen(three);
  REQUIRE( not solution.has_value() );
}
```

but 4×4 solutions do exist:

```
TEST_CASE( "there are 4x4 solutions" ) {
  board four(4);
  auto solution = place_queen(four);
  REQUIRE( solution.has_value() );
}
```