Exercises week 2

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November 28, 2017

Exercise 11

Learn to appreciate catching references when throwing exceptions

A simple class `Object` is made. It has a data member `d_name` that stores an internal name. If an object is made via the copy constructor, 'copy' is added to this internal name. The constructor, copy constructor and destructor print what they did together with the internal name. A function `hello()` is added that says hello and prints the internal name.

object/object.h

```
1  #ifndef INCLUDED_OBJECT_
2  #define INCLUDED_OBJECT_
3
4  #include <string>
5
6  class Object
7  {
8      std::string d_name;
9
10     public:
11         Object(std::string const &name);          // 1
12         Object(Object const &other);              // 2
13         ~Object();
14         void hello();
15 };
16
17 #endif
```

object/object.ih

```
1 #include "object.h"
2 #include <iostream>
3 #include <string>
4
5 using namespace std;
```

object/destructor.cc

```
1 #include "object.ih"
2
3 Object::~Object()
4 {
5     cout << "Destructed '" << d_name << "'\n";
6 }
```

object/hello.cc

```
1 #include "object.ih"
2
3 void Object::hello()
4 {
5     cout << "Hello, this is '" << d_name << "'\n";
6 }
```

object/object1.cc

```
1 #include "object.ih"
2
3 Object::Object(string const &name)
4 :
5     d_name(name)
6 {
7     cout << "Constructed '" << d_name << "'\n";
8 }
```

object/object2.cc

```
1  #include "object.ih"
2
3  Object::Object(Object const &other)
4  :
5      d_name(other.d_name + " (copy)")
6  {
7      cout << "Copy constructed '" << d_name << "'\n";
8  }
```

Below a main function (`main1.cc`) is shown, in which within a try block, an object of the class `Object` is made. This object is then thrown. The exception handler catches an object of the class `Object` (by value). The output of the program is given below the code of main1. We see that the object is properly constructed and says hello. Then when it is thrown, first a copy is made and the original object is destructed. The copy is passed to the exception handler. Here an additional copy is made, because it receives the object by value. Therefore, within the exception handler, the copy of the copy of the object says hello.

main1.cc

```
1  #include "object/object.h"
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7      try
8      {
9          Object object{ "object" };
10         object.hello();
11         throw object;
12     }
13     catch (Object caughtObject)
14     {
15         cout << "Caught exception\n";
16         caughtObject.hello();
17     }
18 }
```

Output of main1.cc

```
Constructed 'object'
Hello, this is 'object'
Copy constructed 'object (copy)'
Destructed 'object'
Copy constructed 'object (copy) (copy)'
Caught exception
Hello, this is 'object (copy) (copy)'
Destructed 'object (copy) (copy)'
Destructed 'object (copy)'
```

The following main function (`main2.cc`) does the same as the previous, except that the exception handler catches *a reference* to an object of the class `Object`. From the output we see that no second copy is made. This is more efficient and therefore exception handlers should catch references to objects.

main2.cc

```
1  #include "object/object.h"
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7      try
8      {
9          Object object{ "object" };
10         object.hello();
11         throw object;
12     }
13     catch (Object &caughtObject)
14     {
15         cout << "Caught exception\n";
16         caughtObject.hello();
17     }
18 }
```

Output of main2.cc

```
Constructed 'object'
Hello, this is 'object'
Copy constructed 'object (copy)'
Destructed 'object'
Caught exception
Hello, this is 'object (copy)'
Destructed 'object (copy)'
```

In the previous two programs, we saw that a copy of the object is thrown. This is because the original object is a local object that only lives inside the try block. The same is true when a reference to an object is thrown, as can be seen from the output that the following code produces:

main3.cc

```
1  #include "object/object.h"
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7      try
8      {
9          Object object{ "object" };
10
11         Object &ref = object;
12         ref.hello();
13         throw ref;
14     }
15     catch (Object &caughtObject)
16     {
17         cout << "Caught exception\n";
18         caughtObject.hello();
19     }
20 }
```

Output of main3.cc

```
Constructed 'object'
Hello, this is 'object'
Copy constructed 'object (copy)'
Destructed 'object'
Caught exception
Hello, this is 'object (copy)'
Destructed 'object (copy)'
```

The following main function (`main4.cc`) has two exception levels. In the inner level, an object of the class `Object` is thrown and caught as a reference. Then it is rethrown to a more shallow level where it is again caught as a reference. From the shown output, we conclude that '`throw;`' results in throwing the currently available exception and not a copy of that exception.

main4.cc

```
1  #include "object/object.h"
2  #include <iostream>
3  using namespace std;
4
5  int main()
6  {
7      try
8      {
9          try
10         {
11             Object object{ "object" };
12             object.hello();
13             throw object;
14         }
15         catch (Object &caughtObject)
16         {
17             cout << "Caught exception in inner block\n";
18             caughtObject.hello();
19             throw;
20         }
21     }
22     catch (Object &caughtObject)
```

```
23      {
24          cout << "Caught exception in outer block\n";
25          caughtObject.hello();
26      }
27  }
```

Output of main4.cc

```
Constructed 'object'
Hello, this is 'object'
Copy constructed 'object (copy)'
Destructed 'object'
Caught exception in inner block
Hello, this is 'object (copy)'
Caught exception in outer block
Hello, this is 'object (copy)'
Destructed 'object (copy)'
```

Exercise 12

Study the way `delete[]` works

We used the following code,

maxfour/maxfour.h

```
1  #ifndef EX12_MAXFOUR_H
2  #define EX12_MAXFOUR_H
3
4  #include <iosfwd>
5
6  class Maxfour
7  {
8      static size_t s_nObj;
9
10     public:
11         Maxfour();
12         ~Maxfour();
13     private:
14 };
15
16 #endif
```

maxfour/maxfour.ih

```
1  #include "maxfour.h"
2  #include <iostream>
3
4  using namespace std;
```

maxfour/data.cc

```
1  #include "maxfour.ih"
2
3  size_t Maxfour::s_nObj = 0;
```

maxfour/destructor.cc

```
1  #include "maxfour.ih"
2
3  Maxfour::~Maxfour()
4  {
5      --s_nObj;
6
7      cout << "Number of objects decreased by one (total: "
8           << s_nObj
9           << ")\n";
10 }
```

main.ih

```
1  #include "maxfour/maxfour.h"
```

main.cc

```
1  #include "main.ih"
2
3  int main()
4  try
5  {
6      Maxfour *array = new Maxfour[10];
7
8      delete[] array;      // In case the array is succesfully constructed
9  }
10 catch (...)
11 {}
```

Output of main.cc

```
Number of objects increased by one (total: 1)
Number of objects increased by one (total: 2)
Number of objects increased by one (total: 3)
Number of objects increased by one (total: 4)
max. number of objects reached
Number of objects decreased by one (total: 3)
```

```
Number of objects decreased by one (total: 2)
Number of objects decreased by one (total: 1)
Number of objects decreased by one (total: 0)
```

Explain why the solution is so simple

The solution is so simple because when an exception is thrown during the construction of an array of 10 Maxfour objects, stack unwinding will destroy the already allocated objects. No explicit call of the destructor is needed. Furthermore we do not need to keep track of the already allocated objects.

Exercise 13

Learn to create an exception safe class

We modified the following code of the matrix class solution,

matrix/matrix.h

```
1  #ifndef INCLUDED_MATRIX_
2  #define INCLUDED_MATRIX_
3
4  #include <iosfwd>
5  #include <initializer_list>
6
7  class Matrix
8  {
9      size_t d_nRows = 0;
10     size_t d_nCols = 0;
11     double *d_data = 0;                        // in fact R x C matrix
12
13     public:
14         typedef std::initializer_list<std::initializer_list<double>> IniList
15
16         Matrix() = default;
17         Matrix(size_t nRows, size_t nCols);          // 1
18         Matrix(Matrix const &other);                 // 2
19         Matrix(Matrix &&tmp);                        // 3
20         Matrix(IniList inilist);                     // 4
21
22         ~Matrix();
23
24         Matrix &operator=(Matrix const &rhs);
25         Matrix &operator=(Matrix &&tmp);
26
27         double *row(size_t idx);
28         double const *row(size_t idx) const;
29
30         size_t nRows() const;
31         size_t nCols() const;
32         size_t size() const;              // nRows * nCols
33
```

```
34          static Matrix identity(size_t dim);
35
36          Matrix &tr();                       // transpose (must be square)
37          Matrix transpose() const;           // any dim.
38
39          void swap(Matrix &other) noexcept;
40
41          double &at(size_t rowIdx, size_t colIdx);   // NEW
42
43      private:
44          double &el(size_t row, size_t col) const;
45          void transpose(double *dest) const;
46  };
47
48  inline double *Matrix::row(size_t row)
49  {
50      return &el(row, 0);
51  }
52
53  inline double const *Matrix::row(size_t row) const
54  {
55      return &el(row, 0);
56  }
57
58  inline size_t Matrix::nCols() const
59  {
60      return d_nCols;
61  }
62
63  inline size_t Matrix::nRows() const
64  {
65      return d_nRows;
66  }
67
68  inline size_t Matrix::size() const
69  {
70      return d_nRows * d_nCols;
71  }
72
73  inline double &Matrix::el(size_t row, size_t col) const
74  {
```

```
75      return d_data[row * d_nCols + col];
76  }
77
78  #endif
```

matrix/matrix.ih

```
1   #include "matrix.h"
2
3   #include <cstring>
4   #include <iostream>
5   #include <exception> // NEW
6
7   using namespace std;
```

matrix/at.cc

```
1   #include "matrix.ih"
2
3   double &Matrix::at(size_t rowIdx, size_t colIdx)
4   {
5       try
6       {
7           if (rowIdx >= d_nRows)
8               throw out_of_range{"Exception: Out of bounds"};
9           if (colIdx >= d_nCols)
10              throw out_of_range{"Exception: Out of bounds"};
11          return el(rowIdx, colIdx);
12      }
13      catch (exception &exc)
14      {
15          cout << exc.what() << '\n';
16          throw;
17      }
18  }
```

why is this safe? See the exercise's text. Same for many of the following functions.

you're thinking for your users: they might not want to use cout...

matrix/identity.cc

```
1  // This function offers the basic guarantee. If it cannot make an identity
2  // matrix, the allocated memory is returned (handled in the corresponding
3  // constructor).
4
5  #include "matrix.ih"
6
7  // static
8  Matrix Matrix::identity(size_t dim)
9  try
10 {
11     Matrix ret(dim, dim);
12
13     for (size_t idx = 0; idx != dim; ++idx)
14         ret.el(idx, idx) = 1;
15
16     return ret;
17 }
18 catch (...)
19 {
20     cerr << "Could not make identity matrix\n";
21     throw;
22 }
```

matrix/matrix1.cc

```
1  #include "matrix.ih"
2
3  Matrix::Matrix(size_t nRows, size_t nCols)
4  try
5  :
6      d_nRows(nRows),
7      d_nCols(nCols),
8      d_data(0)
9  {
10     d_data = new double[size()]();
11 }
12 catch (...)
13 {
```

```
14      cerr << "Memory allocation failed\n";
15  }
```

matrix/matrix2.cc

```
1   #include "matrix.ih"
2
3   Matrix::Matrix(Matrix const &other)
4   try
5   :
6       d_nRows(other.d_nRows),
7       d_nCols(other.d_nCols),
8       d_data(0)
9   {
10      d_data = new double[size()];
11      memcpy(d_data, other.d_data, size() * sizeof(double));
12  }
13  catch (...)
14  {
15      cerr << "Memory allocation failed\n";
16  }
```

matrix/matrix4.cc

```
1   #include "matrix.ih"
2
3   Matrix::Matrix(IniList iniList)
4   try
5   :
6       d_nRows(iniList.size()),
7       d_nCols(iniList.begin()->size()),
8       d_data(0)
9   {
10      d_data = new double[size()];
11      auto ptr = d_data;
12      for (auto &list: iniList)
13      {
14          if (list.size() != d_nCols)
15              throw "Matrix(IniList): varying number of elements in rows";
```

```
16
17          memcpy(ptr, &*list.begin() , list.size() * sizeof(double));
18          ptr += list.size();
19      }
20  }
21  catch (char const *message)
22  {
23      cerr << "Exception: " << message << '\n';
24      delete[] d_data;
25  }
26  catch (...)
27  {
28      cerr << "Memory allocation failed\n";
29      // delete[] operator is not required, because if memory allocation fails
30      // memory is automatically returned
31  }
```

matrix/operatorassign1.cc

```
1  // This function offers the strong guarantee. The copy construction might
2  // throw an exception, but this keeps the current data intact. Only if the
3  // copying succeeds, the data is transferred to the current object
4  // by using operations which are guaranteed not to throw.
5
6  #include "matrix.ih"
7
8  Matrix &Matrix::operator=(Matrix const &other)
9  {
10     Matrix tmp(other);
11     swap(tmp);
12     return *this;
13 }
```

matrix/operatorassign2.cc

```
1  // This function offers the nothrow guarantee, because both
2  // of its operations offer this.
3
4  #include "matrix.ih"
```

```
5
6  Matrix &Matrix::operator=(Matrix &&tmp)
7  {
8      swap(tmp);
9      return *this;
10 }
```

matrix/swap.cc

```
1  // The swap function satisfies the nothrow guarantee, because it uses
2  // only primitive type operations and the C-function memcpy.
3  // We add the noexcept specifier to indicate that our
4  // code was not written to cope with a throw.
5
6  #include "matrix.ih"
7
8  void Matrix::swap(Matrix &other) noexcept
9  {
10     char buffer[sizeof(Matrix)];
11     memcpy(buffer, this,   sizeof(Matrix));
12     memcpy(this,   &other, sizeof(Matrix));
13     memcpy(&other, buffer, sizeof(Matrix));
14 }
```

matrix/tr.cc

```
1  // This function offers the strong guarantee.
2  // The data is only modified if no exception is thrown by
3  // the preceding operations/checks
4
5  #include "matrix.ih"
6
7  Matrix &Matrix::tr()
8  {
9      double *dest = 0;                // RAII
10     try
11     {
12         if (d_nRows != d_nCols)
13             throw "Matrix::tr requires square matrix";
```

```
14
15          dest = new double[size()];
16          transpose(dest);
17          delete[] d_data;
18          d_data = dest;
19          return *this;
20      }
21      catch (char const *message)
22      {
23          cerr << "Exception: " << message << '\n';
24          throw;
25      }
26      catch (...)
27      {
28          delete[] dest;
29          cerr << "Could not make transpose\n";
30          throw;
31      }
32  }
```

matrix/transpose.cc

```
1   // This function offers the basic guarantee. If it cannot make a transpose,
2   // the allocated memory is returned.
3
4   #include "matrix.ih"
5
6   Matrix Matrix::transpose() const
7   {
8       Matrix ret;
9       try
10      {
11          ret.d_nCols = d_nRows;                  // prepare the return Matrix
12          ret.d_nRows = d_nCols;
13          ret.d_data = new double[size()];
14
15          transpose(ret.d_data);
16
17          return ret;
18      }
```

```
19      catch (...)
20      {
21          delete[] ret.d_data;
22          cerr << "Could not make transpose\n";
23          throw;
24      }
25  }
```

so... data is destroyed before Matrix ret is destroyed at the end of transpose: its destructor also destroys ret.d_data, which is now a wild pointer. So

main.cc

```
1   #include "main.ih"
2
3   int main()
4   try
5   {
6       Matrix mat{ {1,2}, {3,4}, {5,6} };
7       mat.at(5,0) = 3;              // will throw out of bounds
8       cout << "Will not be executed" << '\n';
9   }
10  catch (...)
11  {}
```

13:0

Why not do something useful?

Exercise 16

Learn how to end a program safely

How do you end a program in such a situation?

In main wordt een object geconstruct en een functie aangeroepen die throwt. Deze functie doet vervolgens hetzelfde net als de functie daar weer in. In het diepste nested level wordt de throw operator daadwerkelijk aangeroepen, de exception gethrowd en vervolgens gerethrowd. Zodra de exception gethrowd wordt en de exception het try-block verlaat, wordt de destructor aangeroepen, net als in de levels daarboven. Op deze manier worden alle constructed objects netjes vernietigd.

De volgende code verduidelijkt dit,

demo/demo.h

```
1  #ifndef EX16_DEMO_H
2  #define EX16_DEMO_H
3
4  class Demo
5  {
6      public:
7          Demo();
8          ~Demo();
9  };
10
11 #endif
```

demo/demo.ih

```
1  #include "demo.h"
2
3  #include <iostream>
4
5  using namespace std;
```

demo/demo.cc

```
1  #include "demo.ih"
```

```
2
3  Demo::Demo()
4  {
5      cout << "Constructor called\n";
6  }
```

demo/destructor.cc

```
1  #include "demo.ih"
2
3  Demo::~Demo()
4  {
5      cout << "Destructor called\n";
6  }
```

main.ih

```
1  #include <iostream>
2
3  #include "demo/demo.h"
4
5  using namespace std;
6
7  void function1();
8  void function2();
9  void function3();
```

main.cc

```
1  #include "main.ih"
2
3  int main()
4  try
5  {
6      Demo demo1;
7      function1();
8      cout << "Not executed\n";
9  }
```

```
10 catch (...)
11 {
12     cout << "Program stops\n";
13 }
```

function1.cc

```
 1 #include "main.ih"
 2
 3 void function1()
 4 try
 5 {
 6     Demo demo2;
 7     function2();
 8     cout << "Not executed\n";
 9 }
10 catch (...)
11 {
12     throw;
13 }
```

function2.cc

```
 1 #include "main.ih"
 2
 3 void function2()
 4 try
 5 {
 6     Demo demo3;
 7     function3();
 8     cout << "Not executed\n";
 9 }
10 catch (...)
11 {
12     throw;
13 }
```

function3.cc

```
1  #include "main.ih"
2
3  void function3()
4  try
5  {
6      Demo demo4;
7      throw "Exception at deepest level is thrown";
8      cout << "Not executed\n";
9  }
10 catch (char const *message)
11 {
12     cout << message << '\n';
13     throw;
14 }
```

Exercise 17

Learn to understand how throw lists and noexept work

A small class `ShowExcepts` is made. It has a constructor and two functions `asAthrowList()` and `asNoexcept()`, that behave as if `throw (int, std::string)` or the keyword `noexcept` is specified, respectively, while this is not actually specified. When this would be speciefied, the compiler generates additional code, and this code is now already provided by us, thus simualiting the use of the specifications. The two member functions call a function `test()`, which prints that it is called and throws an exception (below the code, the output is discussed when this exception is an int or a double).

showexcepts/showexcepts.h

```
1  #ifndef INCLUDED_SHOWEXCEPTS_
2  #define INCLUDED_SHOWEXCEPTS_
3
4  class ShowExcepts
5  {
6      void (*d_fp)();
7
8      public:
9          ShowExcepts(int value, void (*fp)());
10         void asAthrowList() const ;
11         void asNoexcept() const;
12 };
13
14 #endif
```

showexcepts/showexcepts.ih

```
1  #include "showexcepts.h"
2  #include <string>
3  #include <exception>
4
5  using namespace std;
```

showexcepts/showexcepts1.cc

```
1  #include "showexcepts.ih"
2
3  ShowExcepts::ShowExcepts(int value, void (*fp)())
4  :
5      d_fp(fp)
6  {}
```

showexcepts/asathrowlist.cc

```
1  #include "showexcepts.ih"
2
3  void ShowExcepts::asAthrowList() const
4  try
5  {
6      // function code throwing exceptions, e.g. :
7      (*d_fp)();
8  }
9  catch (int)
10 {
11     throw;
12 }
13 catch (string)
14 {
15     throw;
16 }
17 catch (...)
18 {
19     throw bad_exception{};
20 }
```

showexcepts/asnoexcept.cc

```
1  #include "showexcepts.ih"
2
3  void ShowExcepts::asNoexcept() const
4  try
5  {
6      (*d_fp)();
```

```
}
catch (...)
{
    terminate();
}
```

main.ih

```
#include <iostream>
#include "showexcepts/showexcepts.h"
#include <exception>

using namespace std;

void test();
```

main.cc

```
#include "main.ih"

int main()
{
    ShowExcepts object(1, &test);
    try
    {
        object.asAthrowList();      // throws an exception
    }
    catch (bad_exception &bad)
    {
        cout << bad.what() << '\n';
    }
    catch (...)
    {
        cout << "Caught exception in main\n";
    }
    try
    {
        object.asNoexcept();        // terminates program
    }
```


use function try blocks

```
22      catch (...)
23      {
24          cout << "Will not be reached\n";
25      }
26  }
```

test.cc

```
1  #include "main.ih"
2
3  void test()
4  {
5      cout << "test called\n";
6      throw 1.5;          // case 1
7      //throw 1;          // case 2
8  }
```

If `test()` throws a double (e.g. 1.5), the output shown below is produced. In `asathrowlist`, the double is not caught by the int or string catcher, but by the catch-all, throwing a `bad_exception`.

In the second try block, `asnoexcept` is called, which calls `std::terminate()`, terminating the program. Therefore, the cout statement in `main`'s final catch clause is not reached.

Output when `test()` throws a double (1.5)

```
test called
std::bad_exception
test called
terminate called after throwing an instance of 'double'
Aborted (core dumped)
```

If `test()` throws an int (e.g. 1), the output shown below is produced. In `asathrowlist`, the int is caught by the int catcher, and then rethrown. In `main`, it is then caught by the catch-all handler, giving the shown output.

Output when `test()` throws an int (1)

```
test called
Caught exception in main
```

```
test called
terminate called after throwing an instance of 'int'
Aborted (core dumped)
```

Exercise 18

Learn to identify points where exceptions may be thrown

See 10.10 Annotations ;-)