OOP (C++): Exceptions

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Plan

1. About Errors
2. Exception in OOP
   - Case Study: Parsing Regular Expressions
3. Exceptions as part of function specification
4. Standard Exceptions
5. Handling Unexpected Exceptions

What the Experts Say

- "... I realized that from now on a large part of my life would be spent finding and correcting my own mistakes."
  Maurice Wilkes, 1949 (EDSAC computer), Turing Award in 1967
- "My guess is that avoiding, finding, and correcting errors is 95% or more of the effort for serious software development."
  "Error handling is a difficult task for which the programmer needs all the help that can be provided."
  Bjarne Stroustroup (C++ creator)

This rate can be improved by using the right programming skills!

Three Main Requirements for a Program

- to produce the desired outputs, as specified, for legal inputs (correctness)
- to give reasonable error messages for illegal entries
- to allow termination in case of an error

A Taxonomy of Errors

- compilation errors
  - detected by the compiler
  - generally easy to fix
- linking errors
  - functions/methods not implemented
  - library access
- run-time errors
  - the source may be the computer, a component of a library, or the program itself
- logical errors
  - the program does not have the desired behavior
  - can be detected by the programmer (by testing)
    ... or by the user (customer)

Errors Must be Reported

```
int PolygonalLine::length() {
  if (n <= 0)
    return -1
  else {
    // ...
  }
}

int p = L.length();
if (p < 0)
  printError("Bad computation of a polygonal line");
// ...
```

How to Report an Error?

- error reporting must be uniform: same message for the same type of error (location information may differ)
- . . . therefore an "error indicator" must be managed
- association of numbers for errors is a solution but it can be problematic
- OOP has the necessary means to smartly organize the detection and reporting of errors

Error vs Exception

- often the two terms are confused
- however, there is a (subtle) difference between the meanings of the two notions
- error = abnormal behavior detected during operation to be eliminated by repairing the program
- exception = unforeseen behavior that can occur in rare or very rare situations
- exceptions should be handled in the case of programs
- an untreated exception is an error!

In this lecture we discuss more about exceptions.

Plan

General Principles

- the exceptions in OOP were designed with the intention of separating the business logic from the mechanism of error transmission
- the purpose is to allow the handling of errors, which occur as exceptions, at an appropriate level that does not interfere with business logic

Plan

Recall from Algorithm Design 1/3

Syntax for regular expressions:

```
expression ::= term ("+" term)*
term ::= maybeStar
       | maybeStar ("." maybeStar)*
maybeStar ::= factor ["*"]
            /* equiv to  factor | factor "*"  */

factor ::=
    empty
    | Sigma
    | "(" expression ")"
 Sigma ::= "a" | "b" | ...
```

Recall from Algorithm Design 1/3

Syntax for regular expressions:

```
expression ::= term ("+" term)*
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factor ::=
    empty
    | Sigma
    | "(" expression ")"
 Sigma ::= "a" | "b" | ...
```

Recall from Algorithm Design 2/3

Alk data structure for AST: *ast*(e)

- *empty*: [ ]
- ε: ["", <>]
- $a \in \Sigma$: ["a", <>]
- $e_1 e_2 \ldots$: ["_._", <*ast*(e_1), *ast*(e_2), . . .>]
- $e_1 + e_2 + \cdots$: ["_+_", <*ast*(e_1), *ast*(e_2), $\cdots$>]
- $e*$: ["_*", <*ast*(e)>]

Example: (ab + b)*(ba)

["_._", <["_*", <["_+_", <["_._", <["a", <>],
["b", <>]>], ["b", <>]>]>], ["_._", <["b",
<>], ["a", <>]>>]

Recall from Algorithm Design 2/3

Alk data structure for AST: *ast*(e)

- *empty*: []
- ε: ["", <>]
- $a \in \Sigma$: ["a", <>]
- $e_1 e_2 \ldots$: ["_._", <$ast(e_1), ast(e_2), \ldots$>]
- $e_1 + e_2 + \cdots$: ["_+_", <$ast(e_1), ast(e_2), \cdots$>]
- $e*$: ["_*", <$ast(e)$>]

Example: (ab + b)*(ba)

["_._", <["_*", <["_+_", <["_._", <["a", <>], ["b", <>]>], ["b", <>]>]>], ["_._", <["b", <>], ["a", <>]>>]

Recall from Algorithm Design 2/3

Alk data structure for AST: $ast(e)$

- *empty*: `[]`
- ε: `["", <>]`
- $a \in \Sigma$: `["a", <>]`
- $e_1 e_2 \ldots$: `["_._", <`$ast(e_1), ast(e_2), \ldots$`>]`
- $e_1 + e_2 + \cdots$: `["_+_", <`$ast(e_1), ast(e_2), \cdots$`>]`
- $e*$: `["_*", <`$ast(e)$`>]`

Example: `(ab + b)*(ba)`

```
["_._", <["_*", <["_+_", <["_._", <["a", <>],
["b", <>]>], ["b", <>]>]>], ["_._", <["b",
<>], ["a", <>]>>]
```

Recall from Algorithm Design 2/3

Alk data structure for AST: $ast(e)$

- *empty*: `[]`
- ε: `["", <>]`
- $a \in \Sigma$: `["a", <>]`
- $e_1 e_2 \ldots$: `["_._",` $<ast(e_1), ast(e_2), \ldots>$`]`
- $e_1 + e_2 + \cdots$: `["_+_",` $<ast(e_1), ast(e_2), \cdots>$`]`
- $e*$: `["_*",` $<ast(e)>$`]`

Example: `(ab + b)*(ba)`

```
["_._", <["_*", <["_+_", <["_._", <["a", <>],
["b", <>]>], ["b", <>]>]>], ["_._", <["b",
<>], ["a", <>]>>]
```

Recall from Algorithm Design 2/3

Alk data structure for AST: *ast*(*e*)

- *empty*: [ ]
- ε: ["", <>]
- $a \in \Sigma$: ["a", <>]
- $e_1 e_2 \ldots$: ["_._", <$ast(e_1), ast(e_2), \ldots$>]
- $e_1 + e_2 + \cdots$: ["_+_", <$ast(e_1), ast(e_2), \cdots$>]
- $e*$: ["_*", <$ast(e)$>]

Example: (ab + b)*(ba)

["_._", <["_*", <["_+_", <["_._", <["a", <>], ["b", <>]>], ["b", <>]>]>], ["_._", <["b", <>], ["a", <>]>>]

Recall from Algorithm Design 2/3

Alk data structure for AST: $ast(e)$

- *empty*: `[]`
- ε: `["", <>]`
- $a \in \Sigma$: `["a", <>]`
- $e_1 e_2 \ldots$: $\texttt{["\_.\_",\ <}ast(e_1), ast(e_2), \texttt{...>]}$
- $e_1 + e_2 + \cdots$: $\texttt{["\_+\_",\ <}ast(e_1), ast(e_2), \cdots\texttt{>]}$
- $e*$: $\texttt{["\_*",\ <}ast(e)\texttt{>]}$

Example: `(ab + b)*(ba)`

```
["_._", <["_*", <["_+_", <["_._", <["a", <>],
["b", <>]>], ["b", <>]>]>], ["_._", <["b",
<>], ["a", <>]>>]
```

Recall from Algorithm Design 2/3

Alk data structure for AST: $ast(e)$

- *empty*: []
- ε: ["", <>]
- $a \in \Sigma$: ["a", <>]
- $e_1 e_2 \ldots$: ["_._", $<ast(e_1), ast(e_2), \ldots>$]
- $e_1 + e_2 + \cdots$: ["_+_", $<ast(e_1), ast(e_2), \cdots>$]
- $e*$: ["_*", $<ast(e)>$]

Example: (ab + b)*(ba)

["_._", <["_*", <["_+_", <["_._", <["a", <>], ["b", <>]>], ["b", <>]>]>], ["_._", <["b", <>], ["a", <>]>>]

Recall from Algorithm Design 3/3

Some functions from AST domain:

```
// number of children
chldNo(ast) {
  if (ast.size() > 0) return ast[1].size();
  return 0;
}

// the i-th child of an AST
chld(ast, i) {
  if (ast.size() > 0 && i < ast[1].size()) {
    return ast[1].at(i);
  }
}
```

From Alk to C++: Class for ASTs, First Attempt

```
class Ast {
 private:
  string label;
  vector<Ast*> children;

 public:
  AstNonEmpty(string aLabel = "",
              vector<Ast*> aList = vector<Ast*>())
    {
      label = aLabel;
      children = aList;
    }
  ...
};
```

We have a problem: how to represent the empty AST ("[]")?
In the above declaration, the default constructor builds the AST for the empty string ε.

From Alk to C++: Class for ASTs, Second Attempt

```
class Ast {       //abstract class
 public:
  virtual int chldNo() = 0;
  virtual Ast* child(int i) = 0;
  ...
};
class AstEmpty : public Ast {      //empty AST []
 public:
  AstEmpty() {}       //empty object
  ...
};
class AstNonEmpty : public Ast {   //non empty AST ["...",<...>]
 private:
  string label;
  vector<Ast*> children;
 public:
  AstNonEmpty(string aLabel = "",
              vector<Ast*> aList = vector<Ast*>())
    {
      label = aLabel;
      children = aList;
    }
  ...
};
```

Implementation of `AstEmpty` (partial)

```
int AstEmpty::chldNo() {
   #??    is it OK to return -1? ⇐ exception
}
Ast* AstEmpty::child(int i) {
   #??    is it OK to return new AstEmpty? ⇐ exception
}
```

Implementation of `AstNonEmpty` (partial)

```
Ast* AstNonEmpty::child(int i) {
  if (0 <= i and i < chldNo()) {
    return children[i];
  }
  #??    is it OK to return new AstEmpty? ⇐ exception
}
```

Recall from Algorithm Design: the Parser

Global variables:

- `input` - the expression given as input
- `sigma` - the alphabet
- `index` - the current position in the input

- the current symbol:

```
sym() modifies index, input {
  if (index < input.size())
    return input.at(index);
  return "\0";
}
```

- next symbol

```
nextSym() modifies index, input {
  if (index < input.size()) {
    index++;
  } else
    error("nextsym: expected a symbol");
}
```

- ...

Recall from Algorithm Design: the Parser

Global variables:

`input` - the expression given as input
`sigma` - the alphabet
`index` - the current position in the input

- the current symbol:

```
sym() modifies index, input {
  if (index < input.size())
    return input.at(index);
  return "\0";
}
```

- next symbol

```
nextSym() modifies index, input {
  if (index < input.size()) {
    index++;
  } else
    error("nextsym: expected a symbol");
}
```

- ...

From Alk description to C++ 1/3

```
class Parser {
 private:
  string input;
  vector<char> sigma;
  int index;
 public:
  Parser(vector<char> alphabet = vector<char>()) {
    sigma = alphabet;
    input = "";
    index = 0;
  }
 ....
```

From Alk description to C++ 2/3

```cpp
char Parser::sym() {
  if (index < input.size()) {
    return input[index];
  }
  return '\0';
}

void Parser::nextSym() {
  if (index < input.size()) {
    index++;
  }
  else {
    error("nextsym: expected a symbol"); // ⇐exception
  }
}
```

From Alk description to C++ 3/3

Alk	C++

Alk

```
factor() {
    s = sym();
    if (acceptSigma()) {
      return [s,<>];
    } else if (accept("(")) {
        ast = expression();
        expect(")");
        return ast;
    }
}
```

C++

```
Ast* Parser::factor() {
  Ast* past;
  char s = sym();
  if (acceptSigma()) {
    past =
      new AstNonEmpty(string(1, s));
  } else if (accept('(')) {
    past = expression();
    expect(')');
  }
  // else ?? ⇐ exception
  return past;
}
```

Similar the other methods.

Testing

Test source:

```
int main() {
  vector<char> alph{'a', 'b', 'c'};  // c++11
  Parser parser(alph);
  parser.setInput("(a.b+");  // wrong expression
  past = parser.expression();
  past->print();
  return 0;
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser.cpp -std=c++11
$ ./a.out
Bus error: 10
```

try, throw and catch

From the manual:

- **try** block is used to enclose one or more statements that might throw an exception (business component)
- **throw** expression signals that an exceptional condition—often, an error—has occurred in a try block. You can use an object of any type as the operand of a throw expression. Typically, this object is used to communicate information about the error
- **catch** blocks are implemented immediately following a try block. Each catch block specifies the type of exception it can handle (error handling component)

try – throw – catch play

try
(business logic)

throw

catch
(error handling)

`Ast` Hierarchy with exceptions

Consider only problematic methods:

```
int AstEmpty::chldNo() {
  throw "Error: trying to access children of an empty AST";
}

Ast* AstEmpty::child(int i) {
  throw "Error: trying to access children of an empty AST";
}

Ast* AstNonEmpty::child(int i) {
if (0 <= i and i < chldNo()) {
  return children[i];
}
throw "Error: index out of bounds.";
}
```

Testing, w/o Try

Test source:

```
int main() {
  AstEmpty  ast;
  cout << "ast.child(1)->print(): ";
  ast.child(1)->print();
  cout << endl;
  cout << "ast.chldNo(): ";
  cout << ast.chldNo();
  cout << endl;
  return 0;
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-ast-empty.cpp -std=c++11
$ ./a.out
libc++abi.dylib: terminating with uncaught exception
    of type char const*
ast.child(1)->print(): Abort trap: 6
```

Testing, w/o Try

Test source:

```
int main() {
  AstEmpty  ast;
  cout << "ast.child(1)->print(): ";
  ast.child(1)->print();
  cout << endl;
  cout << "ast.chldNo(): ";
  cout << ast.chldNo();
  cout << endl;
  return 0;
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-ast-empty.cpp -std=c++11
$ ./a.out
libc++abi.dylib: terminating with uncaught exception
    of type char const*
ast.child(1)->print(): Abort trap: 6
```

Testing, w/ Try

Test source:

```
try {      //business logic block
  AstEmpty  ast;
  cout << "ast.child(1)->print(): ";
  ast.child(1)->print();
  cout << endl;
  cout << "ast.chldNo(): ";
  cout << ast.chldNo();
  cout << endl;
}
catch (char const* msg) { //exception handling block
  cout << msg << endl;
  cout << "Here the exceptions can be handled." << endl;
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-ast-empty-w-try.cpp -std=c++11
$ ./a.out
ast.child(1)->print(): Error: trying to access children
     of an empty AST
Here the exceptions can be handled.
```

Testing, w/ Try

Test source:

```
try {      //business logic block
  AstEmpty  ast;
  cout << "ast.child(1)->print(): ";
  ast.child(1)->print();
  cout << endl;
  cout << "ast.chldNo(): ";
  cout << ast.chldNo();
  cout << endl;
}
catch (char const* msg) { //exception handling block
  cout << msg << endl;
  cout << "Here the exceptions can be handled." << endl;
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-ast-empty-w-try.cpp -std=c++11
$ ./a.out
ast.child(1)->print(): Error: trying to access children
     of an empty AST
Here the exceptions can be handled.
```

Parser Class with exceptions 1/2

Only problematic methods:

```
void Parser::nextSym() {
  if (index < input.size()) {
    index++;
  }
  else {
    throw "Error: index out of input size";
  }
}

//bool Parser::expect(char s) {
void Parser::expect(char s) {
  if (accept(s)) {
    // return true;
    return;
  }
  // error("unexpected symbol at position " + to_string(index)
  // return false;
  throw s;
}
```

Parser Class with exceptions 2/2

Only problematic methods:

```
Ast* Parser::factor() {
  Ast* past;
  char s = sym();
  if (acceptSigma()) {
    past = new AstNonEmpty(string(1, s));
  } else if (accept('(')) {
    past = expression();
    expect(')');
  }
  // else ???
  else
    throw "expected alphabet symbol or (.";
  return past;
}
```

Testing, w/ Try 1/3

Test source:

```
try{
  vector<char> alph{'a', 'b', 'c'};  // c++11
  Parser parser(alph);
  parser.setInput("(a.b+");  // wrong expression
  Ast* past = parser.expression();
  past->print();
}
catch (char const* msg) {
  cout << msg << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser-exc2.cpp -std=c++11
$ ./a.out
expected alphabet symbol or (.
Here the parsing exceptions can be handled.
```

Testing, w/ Try 1/3

Test source:

```
try{
  vector<char> alph{'a', 'b', 'c'};   // c++11
  Parser parser(alph);
  parser.setInput("(a.b+");   //  wrong expression
  Ast* past = parser.expression();
  past->print();
}
catch (char const* msg) {
  cout << msg << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser-exc2.cpp -std=c++11
$ ./a.out
expected alphabet symbol or (.
Here the parsing exceptions can be handled.
```

Testing, w/ Try 2/3

Test source:

```
try{
  vector<char> alph{'a', 'b', 'c'};   // c++11
  Parser parser(alph);
  parser.setInput("(a.b+c");   // wrong expression
  Ast* past = parser.expression();
  past->print();
}
catch (char const* msg) {
  cout << msg << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser-exc2.cpp -std=c++11
$ ./a.out
libc++abi.dylib: terminating with uncaught exception
     of type char
Abort trap: 6
```

Testing, w/ Try 2/3

Test source:

```
try{
  vector<char> alph{'a', 'b', 'c'};   // c++11
  Parser parser(alph);
  parser.setInput("(a.b+c");   // wrong expression
  Ast* past = parser.expression();
  past->print();
}
catch (char const* msg) {
  cout << msg << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser-exc2.cpp -std=c++11
$ ./a.out
libc++abi.dylib: terminating with uncaught exception
     of type char
Abort trap: 6
```

Testing, w/ Try 3/3

Test source:

```
try{
  vector<char> alph{'a', 'b', 'c'};   // c++11
  Parser parser(alph);
  parser.setInput("(a.b+c");   // wrong expression
  Ast* past = parser.expression();
  past->print();
}
catch (char const* msg) {   // catching C string exceptions
  cout << msg << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
catch (char s) {   // catching char exceptions
  cout << "expected character " << s << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser-exc2.cpp -std=c++11
$ ./a.out
expected character )
Here the parsing exceptions can be handled.
```

Testing, w/ Try 3/3

Test source:

```
try{
  vector<char> alph{'a', 'b', 'c'};   // c++11
  Parser parser(alph);
  parser.setInput("(a.b+c");   // wrong expression
  Ast* past = parser.expression();
  past->print();
}
catch (char const* msg) {   // catching C string exceptions
  cout << msg << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
catch (char s) {   // catching char exceptions
  cout << "expected character " << s << endl;
  cout << "Here the parsing exceptions can be handled." << e
}
```

Test Run:

```
$ g++ ast.cpp parser.cpp test-parser-exc2.cpp -std=c++11
$ ./a.out
expected character )
Here the parsing exceptions can be handled.
```

Hierarchy of Exceptions 1/3

It is recommended to organize the exceptions into a hierarchy.
AST exceptions I:

```
class MyException {
 public:
  virtual void debugPrint() {
    std::cout << "Exception: ";
  }
};

class AstException : public MyException {
 public:
  virtual void debugPrint() {
    this->MyException::debugPrint();
    std::cout << "AST: ";
  }
};

class EmptyAstException : public AstException {
 public:
  virtual void debugPrint() {
    this->AstException::debugPrint();
    std::cout << "trying to access an empty tree.";
  }
};
```

Hierarchy of Exceptions 2/3

AST exceptionsII:

```
class NonEmptyAstException : public AstException {
 private:
  int badIndex;
 public:
  void setBadIndex(int j) {
    badIndex = j;
  }
  virtual void debugPrint() {
    this->AstException::debugPrint();
    std::cout << "index out of bounds (" << badIndex << ").\n"
  }
};
```

Hierarchy of Exceptions 3/3

Parser exceptions:

```
class ParserException : public MyException {
 public:
 private:
  int badPos;
  std::string errMsg;
 public:
  void setBadPos(int j) {
    badPos = j;
  }
  void setErrMsg(std::string msg) {
    errMsg = msg;
  }
  virtual void debugPrint() {
    this->MyException::debugPrint();
    std::cout << "Parsing: " << errMsg
              << " at input position " << badPos << ".\n";
  }
};
```

`Ast` Hierarchy with exceptions, revisited

Consider only problematic methods:

```
int AstEmpty::chldNo() {
  throw EmptyAstException();
}

Ast* AstEmpty::child(int i) {
   throw EmptyAstException();
}

Ast* AstNonEmpty::child(int i) {
   if (0 <= i and i < chldNo()) {
     return children[i];
   }
   NonEmptyAstException exc;
   exc.setBadIndex(i);
   throw exc;
}
```

`Parser` Class with exceptions, revisited 1/2

Only problematic methods:

```
void Parser::nextSym() {
  if (index < input.size()) {
    index++;
  }
  else {
    ParserException exc;
    exc.setBadPos(index);
    throw exc;
  }
}

void Parser::expect(char s) {
  if (accept(s)) {
    return;
  }
  ParserException exc;
  exc.setErrMsg(string("unexpected symbol"));
  exc.setBadPos(index);
  throw exc;
}
```

`Parser` Class with exceptions, revisited 2/2

Only problematic methods:

```
Ast* Parser::factor() {
  Ast* past;
  char s = sym();
  if (acceptSigma()) {
    past = new AstNonEmpty(string(1, s));
  } else if (accept('(')) {
    past = expression();
    expect(')');
  } // else ???
  else {
    ParserException exc;
    exc.setErrMsg(string("expected alphabet symbol or ("));
    exc.setBadPos(index);
    throw exc;
  }
  return past;
}
```

Testing 1/3

Menu function:

```
void printMenu() {
  cout << "\n1. Empty AST exception.\n";
  cout << "2. Nonempty AST exception.\n";
  cout << "3. Parser exception.\n";
  cout << "0. Exit.\n";
  cout << "Option: ";
}
```

Testing 2/3

Test source:

```
while (opt != 0) {
  try{
    printMenu();
    cin >> opt;
    switch (opt) {
    case 1: {
      AstEmpty* peast = new AstEmpty();
      peast->child(0)->print();
      break;
    }
    ...
    }
  }
  catch (MyException& exc) {
    exc.debugPrint();
    cout « endl;
  }
}
```

Testing 3/3

Test Run:

```
$ ./a.out
1. Empty AST exception.
2. Nonempty AST exception.
3. Parser exception.
0. Exit.
Option: 1
Exception: AST: trying to access an empty tree.
1. Empty AST exception.
2. Nonempty AST exception.
3. Parser exception.
0. Exit.
Option: 2
Exception: AST: index out of bounds (2).
1. Empty AST exception.
2. Nonempty AST exception.
3. Parser exception.
0. Exit.
Option: 3
Exception: Parsing: expected alphabet symbol or (at input position
7.
1. Empty AST exception.
2. Nonempty AST exception.
3. Parser exception.
0. Exit.
Option: 0
```

Plan

Specify what exceptions are thrown

```
Ast* Parser::factor() throw(ParserException) {
  Ast* past;
  char s = sym();
  if (acceptSigma()) {
    past = new AstNonEmpty(string(1, s));
  } else if (accept('(')) {
    past = expression();
    expect(')');
  } else {
    ParserException* pexc = new ParserException();
    pexc->setErrMsg(string("expected alphabet symbol or ("));
    pexc->setBadPos(index);
    throw pexc;
  }
  return past;
}
```

Empty `throw` Specification

- C++ 2003

```
void f() throw();
```

- C++ 2011

```
void f() noexcept(true);
```

Example 1/2

Exceptions in destructors may lead to unpredictable behavior:

```
class A {
    public:
        ~A() {
            throw "Thrown by Destructor";
        }
};
int main() {
    try {
        A   a;
    }
    catch(const char *exc){
      std::cout << "Print " << exc;
    }
```

Output:

```
libc++abi.dylib: terminating with uncaught exception
    of type char const*
Abort trap: 6
```

Example 2/2

Using `noexcept` spec we get predictable behavior:

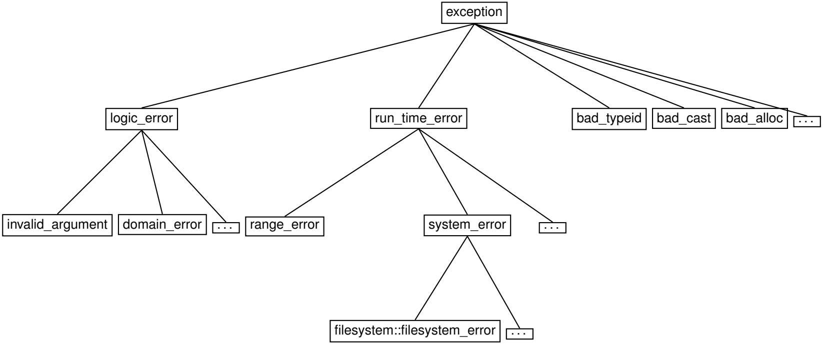
```
class A {
    public:
        ~A() noexcept(false) {
            throw "Thrown by Destructor";
        }
};
```

Output:

```
Print This Thrown by Destructor
```

Plan

Standard Exceptions Hirerarchy (partial)



Example: regex-error (<regex>)

Source code:

```
try {
  std::regex re("[a-z]*[a");
}
catch (const std::regex_error& e) {
  std::cout << "regex_error caught: " << e.what() << '\n';
  if (e.code() == std::regex_constants::error_brack) {
    std::cout << "The code was error_brack\n";
  }
}
```

Testing:

```
$ g++ regex-error.cpp -std=c++11
$ ./a.out
regex_error caught:
  The expression contained mismatched [ and ].
  The code was error_brack
```

Example: bad-function-call (<functional>)

Source code:

```
std::function<int()> f = nullptr;
try {
  f();
} catch(const std::bad_function_call& e) {
  std::cout << "bad_function_call caught: " << e.what() << '
}
return 0;
```

Testing: Mac OS

```
$ g++ bad-function-call.cpp -std=c++11
$ ./a.out
bad_function_call caught: std::exception
```

Windows:

```
> cl bad-function-call.cpp /std:c++14
> bad-function-call.exe
bad_function_call caught: bad function call
```

Example: bad-alloc (<new>) 1/3

Source code:

```
int negative = -1;
int small = 1;
int large = INT_MAX;
int opt = -1;
while (opt != 0) {
  try {
    printMenu();
    cin >> opt;
    switch (opt) {
    case 1: new int[negative]; break;
    case 2: new int[small]{1,2,3};  break;
    case 3: new int[large][1000000]; break;
    default: opt = 0;
    }
  }catch(const std::bad_array_new_length &e) {
    cout << "bad_array_new_length caught: " << e.what() << '\n';
  } catch(const std::bad_alloc &e) {
    cout << "bad_alloc caught: " << e.what() << '\n';
  } catch(...) {
    cout << "unknown exceptions caught.";
  }
}
```

Example: bad-alloc (<new>) 2/3

Testing Mac OS:

```
1. Negative.
2. Small.
3. Large.
Option: 1
bad_alloc caught: std::bad_alloc

1. Negative.
2. Small.
3. Large.
Option: 2
bad_alloc caught: std::bad_alloc

1. Negative.
2. Small.
3. Large.
Option: 3
a.out(21194,0x11e7b15c0) malloc: can't allocate region
*** mach_vm_map(size=8589934588002304) failed (error code=3)
a.out(21194,0x11e7b15c0) malloc: *** set a breakpoint in malloc_error_
bad_alloc caught: std::bad_alloc

1. Negative.
2. Small.
3. Large.
Option:
```

Example: bad-alloc (<new>) 3/3

Testing Windows:

```
1. Negative.
2. Small.
3. Large.
Option: 1
bad_array_new_length caught: bad array new length

1. Negative.
2. Small.
3. Large.
Option: 2

1. Negative.
2. Small.
3. Large.
Option: 3
bad_array_new_length caught: bad array new length
```

exception Class

```
class exception {
public:
  exception () throw();
  exception (const exception&) throw();
  exception& operator= (const exception&) throw();
  virtual ~exception() throw();
  virtual const char* what() const throw();
  // ...
}
```

Deriving from `exception`

```
class MyException : public exception {
 public:
   const char * what () const throw ()
   {
     return "Division by zero. ";
   }
};

int safeDiv(int divident, int divisor)
{
  if (divisor == 0)
    throw MyException();
  return divident / divisor;
}
```

Testing

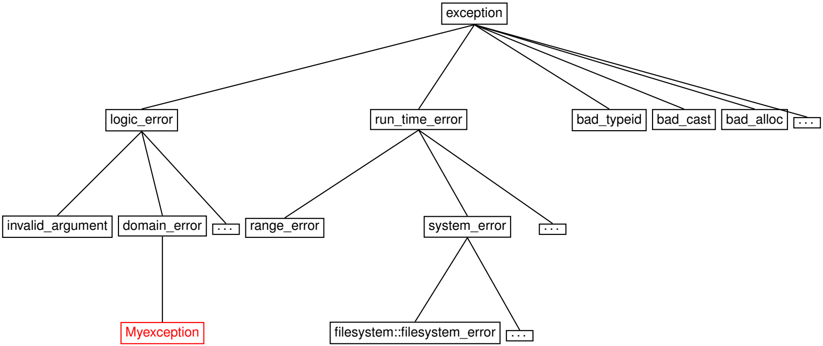
Source:

```
try {
    safeDiv(3, 0);
}  catch(MyException& exc) {
    std::cout << "MyException caught" << std::endl;
    std::cout << exc.what() << std::endl;
} catch(std::exception& e) {
    //Other errors
}
```

Output:

```
$ g++ demo.cpp
$ ./a.out
MyException caught
Division by zero.
```

Deriving from Standard Exceptions



Plan

1. About Errors
2. Exception in OOP
   - Case Study: Parsing Regular Expressions
3. Exceptions as part of function specification
4. Standard Exceptions
5. Handling Unexpected Exceptions

Missing a Throw 1/2

```
class One :  public exception { };
class Two :  public exception { };
void g() {
  throw "Surprise.";
}
void fct(int x) throw (One, Two) {
  switch (x){
  case 1: throw One();
  case 2: throw Two();
  }
  g();
}
```

Missing a Throw 2/2

Testing source:

```
cout << "Option (1-3): "; cin >> option;
try {
  fct(option);
} catch (One) {
  cout << "Exception one" << endl;
} catch (Two)  {
  cout << "Exception two" << endl;
}
```

Output:

```
$ ./a.out
Option (1-3): 2
Exception two
$ ./a.out
Option (1-3): 3
libc++abi.dylib: terminating with unexpected exception
  of type char const*
Abort trap: 6
```

Using set_unexpected

Write a function to be executed when an unexpected exception occurs:

```
void my_unexpected() {
  cout << "My unexpected exception.\n";
  exit(1);
}
```

In the main program set it as such a function:

```
  set_unexpected(my_unexpected);
```

Testing:

```
$ g++ missed-throw.cpp
$ ./a.out
Option (1-3): 3
My unexpected exception.
```

`noexcept()` Operator

- tests whether or not an expression throws an exception
- returns `false` if there is any subexpression that can throw exceptions, i.e., if there is any expression that is not specified with `noexcep(true)` or `throw()`
- returns true if all subexpressions are specified with noexcept (true) or throw ()
- very useful when moving objects (e.g., `reserve()` method)

`noexcept()`: Example

```
class A {
public:
  A() noexcept(false) {
    throw 2;
  }
};

class B {
public:
  B() noexcept(true) {  }
};
```

Source:

```
template <typename T>
void f() {
  if (noexcept(T()))
    std::cout << "NO Exception in Constructor" << std::e
  else
    std::cout << "Exception in Constructor" << std::endl
}

int main() {
  f<A>();
  f<B>();
}
```

Output:

```
$ g++ noexcept-operator.cpp -std=c++11
$ ./a.out
Exception in Constructor
NO Exception in Constructor
```

`noexcept(T(std::declval<T>()))`

Tests whether exceptions are possible when constructing or destroying an object.

Declaration of `declval`:

```
template <typename T>
  typename std::add_rvalue_reference<T>::type
       declval() noexcept;
```

"Converts any type T to a reference type, making it possible to use member functions in decltype expressions without the need to go through constructors."

Intermezzo on `decltype` and `declval`

An example to understand how `declval` is used with `decltype` (and hence to understand better `declval`).

```
class A {
public:
  A() = delete; // no default constructor
  double f();
}
int main(void) {
  // decltype(A().f()) x = f();  Error!  No constructor A().
  decltype(declval<A>().f()) x = f();
      // x has the type double
}
```

noexcept(T(std::declval<T>())): Example 1/2

```
class C {
public:
  C() noexcept(true) {}
  ~C() {}
}
template <typename T>
void g() {
  if (noexcept(T(std::declval<T>())))
    std::cout << "NO Exception in Any Constructor or Destructo
  else
    std::cout << "Possible Exception in a Constructor  or Dest
}
```

Testing source:

```
int main() {
  g<C>();
}
```

Output:

```
$ g++ noexceptop.cpp -std=c++11
$ ./a.out
NO Exception in Any Constructor or Destructor
```

noexcept(T(std::declval<T>())): Example 2/2

Source:

```
class C {
public:
  C() noexcept(true) {}
  C(const C&) {}
  ~C() {}
}
```

Output:

```
Possible Exception in a Constructor or Destructor
```

Source:

```
class C {
public:
  C() noexcept(true) {}
  ~C() noexcept(false) {}
}
```

Output:

```
Possible Exception in a Constructor or Destructor
```

More Experiments ...

```
class C {
public:
  C() noexcept(true)
  ~C() {}
};
template <typename T>  void g1() {
  if  (noexcept(T(std::declval<T>())))
    ...
}
template <typename T>  void g2() {
  if  (noexcept(T()))
    ...
}
```

Testing source:

```
int main() {
  g1<C>();
  g2<C>();
}
```

Output:

```
NO Exception in Constructor or Destructor
NO Exception in Constructor or Destructor
```

More Experiments ....

```
class C {
public:
  C() noexcept(true)
  ~C() {}
  C(const C&)
};
template <typename T>  void g1() {
  if  (noexcept(T(std::declval<T>())))
    ...
}
template <typename T>  void g2() {
  if  (noexcept(T()))
    ...
}
```

Testing source:

```
int main() {
  g1<C>();
  g2<C>();
}
i
```

Output:

```
Possible Exception in a Constructor  or Destructor
NO Exception in Constructor or Destructor
```

More Experiments ...

```
class C {
  int a;
public:
  C() noexcept(true)
  ~C() {}
  C(int x) noexcept(false) :  a(x)
};
template <typename T>  void g1() {
  if  (noexcept(T(std::declval<T>())))
    ...
}
template <typename T>  void g2() {
  if  (noexcept(T()))
    ...
}
```

Testing source:

```
int main() {
  g1<C>();
  g2<C>();
}
i
```

Output:

```
NO Exception in Constructor or Destructor
NO Exception in Constructor or Destructor
```

C++2017: `noexcept` is a Part of Function Type

Source:

```
void g() noexcept {}
int main()
{
    auto f = g;
    std::cout << std::boolalpha  \
              << noexcept(f()) << std::endl;
}
```

Output:

```
$ g++ -std=c++17 exc-part-of-type.cpp
$ ./a.out
true
```

Recommendations

- always specify exceptions
- always start with standard exceptions
- declare the exceptions of a class within it
- uses exception hierarchies
- captures by references
- throw exceptions in constructors
- attention to memory release for partially created objects
- be careful how you test if an object has been created OK
- do not cause exceptions in destructors unless it is a must and then do it very carefully (preferably in C ++ 2011 or after)

Recommendations

Some reasons why it is not recommended to throw exceptions by constructors/destructors

- if a constructor throws an exception when the stack is in an unstable state, then program execution ends
- it is almost impossible to design predictable and accurate containers in the presence of exceptions in destructors
- certain pieces of C ++ code may have undefined behavior when destructors throw exceptions
- what happens to the object whose "destruction" failed (because the destructor method threw an exception)?