601.220 Intermediate Programming

Exceptions

Exceptions

- We use exceptions to indicate a **fatal error** has occurred, where there is *no reasonable way to continue from the point of the error*
- But it might be possible to continue from **somewhere else**, but not from the point of the error

```
// exceptions1.cpp
1  #include <iostream>
2
3  int main() {
4      size_t mem = 1;
5      while(true) {
6          char *lots_of_mem = new char[mem];
7          delete[] lots_of_mem;
8          mem *= 2;
9      }
10     std::cout << "Forever is a long time" << std::endl;
11     return 0;
12 }
```

Exceptions

```
// exceptions1.cpp

#include <iostream>

int main() {
    size_t mem = 1;
    while(true) {
        char *lots_of_mem = new char[mem];
        delete[] lots_of_mem;
        mem *= 2;
    }
    std::cout << "Forever is a long time" << std::endl;
    return 0;
}
```

```
$ g++ -o exceptions1 exceptions1.cpp -std=c++11 -pedantic -Wall -Wextra
```

```
terminate called after throwing an instance of 'std::bad_alloc'
  what():  std::bad_alloc
Aborted (core dumped)
```

Exceptions

The program keeps allocating bigger arrays until an allocation fails

The exception has been thrown here and it makes sense:

- Any pointer returned by `new[]` would be unusable; program doesn't necessarily expect that
- Program can signal that it **does** expect that by **catching** the appropriate exception
    - Since we **don't** do so here, the exception crashes the program

Exceptions

```
char *lots_of_mem = new char[mem];
```

Why not have `new[]` return `NULL` on failure, like `malloc`?

- When the call stack is deep: `f1() -> f2() -> ...` propagating errors backward requires much coordination
- If any function fails to propagate error back, chain is broken
- Error encoding must be managed (e.g. 1 = success, 2 = out of memory, ...); no standard (enum helps but not perfect)

Exceptions are more flexible; often less error prone, more concise than manually propagating errors back through the chain of callers

Exceptions

Looking in documentation for `new`/`new T[n]`, you can see the exception thrown is of type `bad_alloc`

function

operator new[]

<new>

C++98 | C++11

```
  throwing (1)  void* operator new[] (std::size_t size);
   nothrow (2)  void* operator new[] (std::size_t size, const std::nothrow_t& nothrow_value) noexcept;
placement (3)  void* operator new[] (std::size_t size, void* ptr) noexcept;
```

Allocate storage space for array

Default *allocation functions* (array form).

(1) throwing allocation

Allocates *size* bytes of storage, suitably aligned to represent any object of that size, and returns a non-null pointer to the first byte of this block.
On failure, it throws a `bad_alloc` exception.
The default definition allocates memory by calling `operator new`: `::operator new (size)`.
If replaced, both `operator new` and `operator new[]` shall return pointers with identical properties.

(2) nothrow allocation

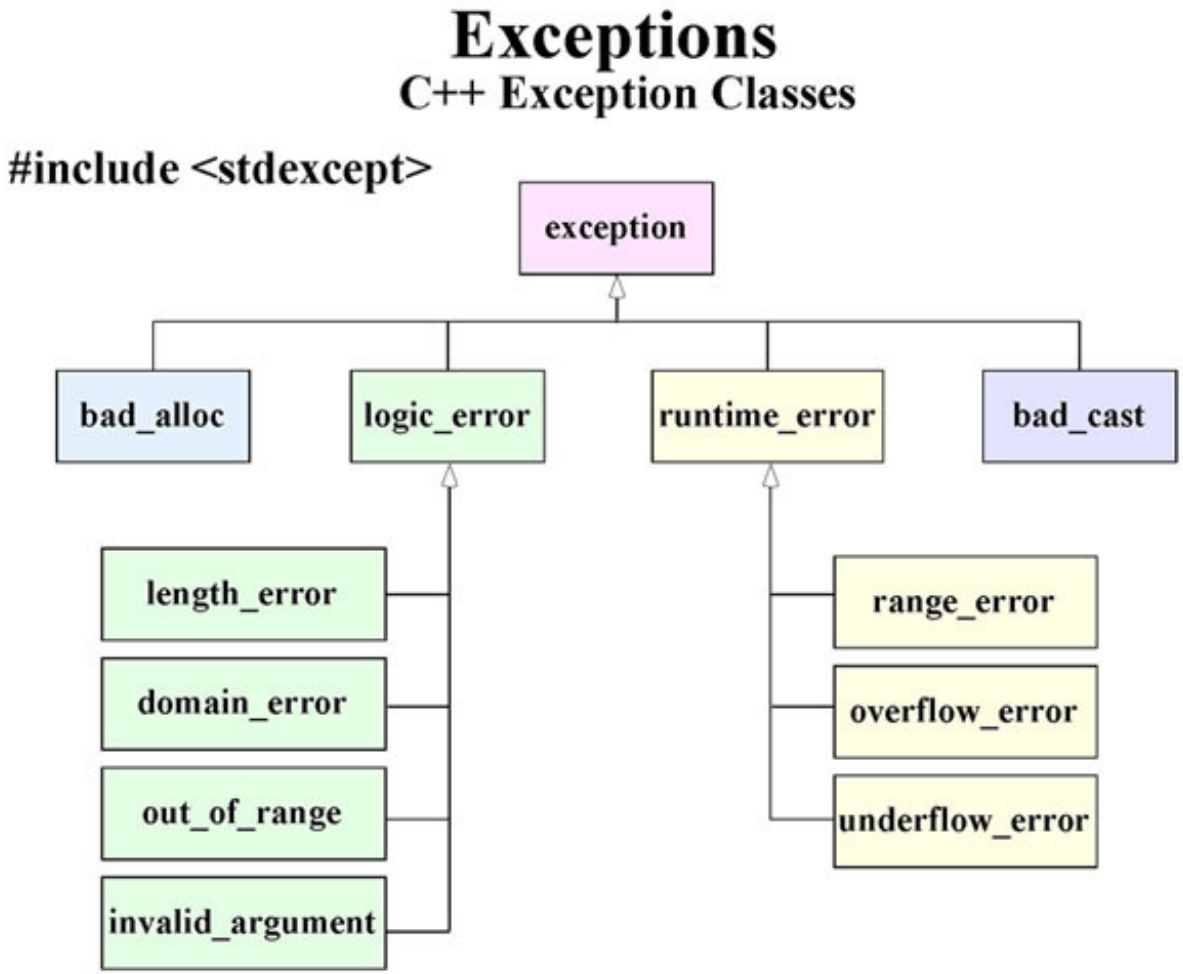
Same as above *(1)*, except that on failure it returns a *null pointer* instead of throwing an exception.

C++98 | C++11

The default definition allocates memory by calling the `nothrow` version of `operator new`: `::operator new (size,nothrow)`.
If replaced, both `operator new` and `operator new[]` shall return pointers with identical properties.

Exceptions

Standard exceptions:



Exceptions

```
    // exceptions2.cpp

1   #include <iostream>
2   #include <new> // bad_alloc defined here
3
4   int main() {
5       size_t mem = 1;
6       char *lots_of_mem;
7       try {
8           while(true) {
9               lots_of_mem = new char[mem];
10              delete[] lots_of_mem;
11              mem *= 2;
12          }
13      }
14      catch(const std::bad_alloc& ex) {
15          std::cout << "Got a bad_alloc!"
16            << std::endl << ex.what() << std::endl;
17      }
18      std::cout << "Forever is a long time"
19        << std::endl;
20      return 0;
21  }
```

```
$ g++ -o exceptions2 exceptions2.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./exceptions2

Got a bad_alloc!
std::bad_alloc
Forever is a long time
```

- `std::bad_alloc` object is created at line 9 on failure
- it was thrown and caught at line 14
- program continues after the `catch` block, no crashes
- error contents (accessed via `.what()`) describe what's wrong

Exceptions

Another example:

```
// exceptions3.cpp

#include <iostream>
#include <vector>
#include <stdexcept> // standard exception classes defined

int main() {
    std::vector<int> vec = {1, 2, 3};
    try {
        std::cout << vec.at(3) << std::endl;
    } catch(const std::out_of_range& e) {
        std::cout << "Exception: " << std::endl << e.what() << std::endl;
    }
    return 0;
}
```

```
$ g++ -o exceptions3 exceptions3.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./exceptions3

Exception:
vector::_M_range_check: __n (which is 3) >= this->size() (which is 3)
```

Exceptions

Keyword `try` marks block of code where an exception might be thrown

```
try {
    while(true) {
        lots_of_mem = new char[mem];
        delete[] lots_of_mem;
        mem *= 2;
    }
}
```

It tells C++: "exceptions might be thrown, and I'm ready to handle some or all of them"

Exceptions

The `catch` block, immediately after the `try` block, says what to do in the event of a particular exception

```
catch(const bad_alloc& ex) {
    std::cout << "Yep, got a bad_alloc" << std::endl;
}
```

If you catch a base exception class, you can handle a family of exceptions that inherits from this base exception class
e.g. catch `std::exception` to handle all exceptions,
catch `std::runtime_error` to handle `std::range_error`, `std::overflow_error`, `std::underflow_error`

Exceptions

The point in the program where the exception is actually thrown is the **throw point**

When exception is thrown, we **don't** proceed to the next statement, instead we follow a process of "unwinding"

Unwinding: keep moving "up" to wider enclosing scopes; stop at `try` block with relevant `catch` clause

If we unwind all the way to the point where our scope is an entire function, we jump back to the caller and continue the unwinding

If exception is never caught – i.e. we unwind all the way through `main` – exception info is printed to console & program exits

Exceptions

Example 1: Keep moving "up" t wider enclosing scopes, stop at `try` block and continue with the relevant `catch` block

```
if(a == b) {
    try {
        while(c < 10) {
            try {
                if(d % 3 == 1) {
                    throw std::runtime_error("!");
                }
            }
            catch(const bad_alloc &e) {
                ...
            }
        }
    }
    catch(const runtime_error &e) {
        // after throw, control moves here
        ...
    }
}
```

Exceptions

Example 2: jump back to the caller and continue unwinding

```
void fun2() { // (called by fun1)
    while(...) {
        try {
            // unwinding from here...
            throw std::runtime_error("whoa");
        } catch(const bad_alloc& e) {
            // only catches bad_alloc, not runtime_error
            ...
        }
    }
}

void fun1() {
    try {
        fun2();
    } catch(const runtime_error& e) {
        // ends up here...
        ...
    }
}
```

Exceptions

Example 3: never caught and program exits

```
#include <iostream>

int main() {
    size_t mem = 1;
    while(true) {
        char *lots_of_mem = new char[mem];
        delete[] lots_of_mem;
        mem *= 2;
    }
    std::cout << "Forever is a long time" << std::endl;
    return 0;
}
```

Exceptions

Example 4: unwinding until exception is handled in `main`

```
// exceptions4.cpp

#include <iostream>
#include <stdexcept>

using std::cout;  using std::endl;

void fun2() {
    cout << "fun2: top" << endl;
    throw std::runtime_error("runtime_error in fun2");
    cout << "fun2: bottom" << endl;
}

void fun1() {
    cout << "fun1: top" << endl;
    fun2();
    cout << "fun1: bottom" << endl;
}

int main() {
    try {
        cout << "main: try top" << endl;
        fun1();
        cout << "main: try bottom" << endl;
    } catch(const std::runtime_error &error) {
        cout << "Exception handled in main: "
        << error.what() << endl;
    }
    cout << "main: bottom" << endl;
    return 0;
}
```

```
$ g++ -o exceptions4 exceptions4.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./exceptions4

main: try top
fun1: top
fun2: top
Exception handled in main: runtime_error in fun2
main: bottom
```

Exceptions

What happens if unwinding causes local variables to go out of scope?

Destructors always called when object goes out of scope, regardless of whether scope is exited because of reaching end, `return`, `break`, `continue`, `exception`, ...

```
// hello_goodbye.h

#include <iostream>
#include <string>

// Prints messages upon construction and destruction
class HelloGoodbye {
public:
    HelloGoodbye(const std::string& nm) : name(nm) {
        std::cout << name << ": hello" << std::endl;
    }

    ~HelloGoodbye() {
        std::cout << name << ": goodbye" << std::endl;
        }
private:
    std::string name;
};
```

Exceptions

```
// hello_goodbye.cpp

#include <iostream>
#include <stdexcept>
#include "hello_goodbye.h"

using std::cout;  using std::endl;

void fun2() {
    HelloGoodbye fun2_top("fun2_top");
    throw std::runtime_error("runtime_error in fun2");
    HelloGoodbye fun2_bottom("fun2_bottom");
}

void fun1() {
    HelloGoodbye fun1_top("fun1_top");
    fun2();
    HelloGoodbye fun1_bottom("fun1_bottom");
}

int main() {
    try {
        HelloGoodbye main_top("main_top");
        fun1();
        HelloGoodbye main_bottom("main_bottom");
    }
    catch(const std::runtime_error &error) {
        cout << "Exception handled in main: "
        << error.what() << endl;
    }
    return 0;
}
```

```
$ g++ -o hello_goodbye hello_goodbye.cpp -std=c++11 -pedantic -Wall -Wextra

$ ./hello_goodbye

main_top: hello
fun1_top: hello
fun2_top: hello
fun2_top: goodbye
fun1_top: goodbye
main_top: goodbye
Exception handled in main: runtime_error in fun2
```

Quiz - answers

What output is printed by the following program?

```
1   #include <iostream>
2   #include <vector>
3
4   int main(void) {
5       std::vector<int> v = {1, 2, 3};
6       try {
7           std::cout << 'A' << ' ';
8           std::cout << v[3] << ' ';
9           std::cout << 'B' << ' ';
10      } catch (const std::logic_error &e) {
11          std::cout << "exception!" << std::endl;
12      }
13      return 0;
14  }
```

A. `A exception!`
B. `A 3 B`
C. `A 0 B`
D. Output is impossible to predict
E. None of the above