

Exception Handling and Exception Safety

GKxx

July 8, 2022

Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees
Exception
Specifications
Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- throw
- try-catch
- User-defined Exception Classes

3 Exception Safety

- Exception-safety Guarantees
- Exception Specifications
- Example: Copy Control

Input Failure

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
int num_of_people;  
std::cin >> num_of_people;
```

What happens when the input is not an integer?

strcpy

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

You are asked to write a strcpy function...

```
void strcpy(char *dest, const char *source) {  
    while (*source)  
        *dest++ = *source++;  
    *dest = '\0';  
}
```

strcpy

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

You are asked to write a strcpy function...

```
void strcpy(char *dest, const char *source) {  
    while (*source)  
        *dest++ = *source++;  
    *dest = '\0';  
}
```

In reality, things may go wrong:

- Null pointers?
- Buffer overflow?

Detecting buffer overflow may not be easy.

Which is Better?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

1. Terminate the program on failure and report the error.

```
void strcpy(char *dest,  
            const char *source) {  
    if (!dest || !source) {  
        std::cerr << "Invalid  
            arguments for  
            strcpy.\n";  
        exit(1);  
    }  
    while (*source)  
        *dest++ = *source++;  
    *dest = '\0';  
}
```

2. Return false on failure:

```
bool strcpy(char *dest,  
            const char *source) {  
    if (!dest || !source)  
        return false;  
    while (*source)  
        *dest++ = *source++;  
    *dest = '\0';  
    return true;  
}
```

Which is Better?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

3. Be silent to errors.

```
void strcpy(char *dest,  
            const char *source) {  
    if (dest && source) {  
        while (*source)  
            *dest++ = *source++;  
        *dest = '\0';  
    }  
}
```

4. Use assertions.

```
void strcpy(char *dest,  
            const char *source) {  
    assert(dest != NULL);  
    assert(source != NULL);  
    while (*source)  
        *dest++ = *source++;  
    *dest = '\0';  
}
```

<https://blog.csdn.net/myan/article/details/1921>

Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
`throw`
`try-catch`
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees
Exception
Specifications
Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- `throw`
- `try-catch`
- User-defined Exception Classes

3 Exception Safety

- Exception-safety Guarantees
- Exception Specifications
- Example: Copy Control

Throwing an Exception

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

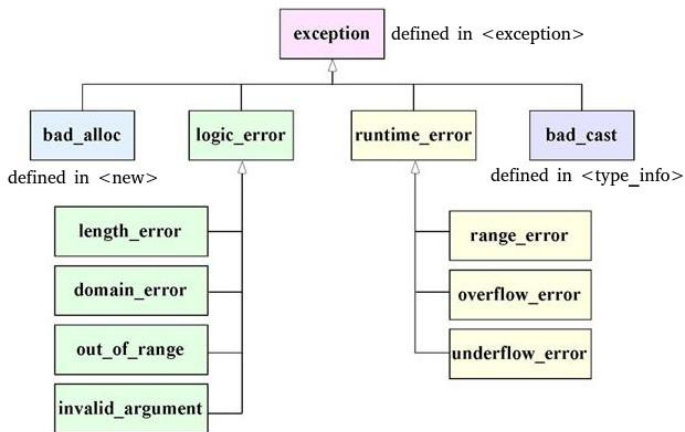
Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void strcpy(char *dest, const char *source) {  
    if (!dest || !source)  
        throw std::invalid_argument("Null pointers passed  
            to strcpy.");  
    while (*source)  
        *dest++ = *source++;  
    *dest = '\0';  
}
```

Standard Exceptions



- `logic_error`, `runtime_error` and their subclasses are defined in `<stdexcept>`.

Standard Exceptions

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

- The normal `new` and `new[]` operators throw `std::bad_alloc` when running out of memory.
- `dynamic_cast` for references throws `std::bad_cast` when the casting fails.
 - `dynamic_cast` for pointers does not throw. It returns `nullptr` on failure.

Standard Exceptions

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

- The normal `new` and `new[]` operators throw `std::bad_alloc` when running out of memory.
- `dynamic_cast` for references throws `std::bad_cast` when the casting fails.
 - `dynamic_cast` for pointers does not throw. It returns `nullptr` on failure.
- `std::system_error` is thrown in many cases, especially in functions that interface with [OS facilities](#), e.g. the constructor of `std::thread`.
- `<chrono>` defines `std::nonexistent_local_time` and `std::ambiguous_local_time`.

Standard Exceptions

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

`operator[]` for STL containers does not check boundaries, but `at()` does.

```
std::vector<int> v;  
v.at(0) = 42; // Throws std::out_of_range.  
v[0] = 42; // Does not throw, but probably causes a  
            segmentation fault.
```

We will see that exceptions `thrown` could be `catch`-ed and handled.

Standard Exceptions

Let our Array do the same thing?

```
template <typename T>
class Array {
public:
    const T &at(std::size_t n) const {
        if (n >= m_size)
            throw std::out_of_range("Array subscript out of
                                   range.");
        return m_data[n];
    }
    T &at(std::size_t n) {
        return const_cast<T &>(
            static_cast<const Array<T> *>(this)->at(n)
        ); // see Effective C++ Item 3
    }
    // ...
};
```

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

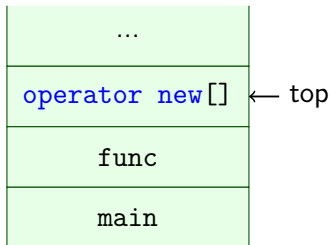
Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```



Suppose `operator new[]` encounters shortage of memory...

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong


Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
     int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.
- 2 Control flow returns to `func`.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.
- 2 Control flow returns to `func`.
- 3 `x` is destroyed.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.
- 2 Control flow returns to `func`.
- 3 `x` is destroyed.
- 4 `n` is destroyed.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.
- 2 Control flow returns to `func`.
- 3 `x` is destroyed.
- 4 `n` is destroyed.
- 5 Control flow returns to `main`.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.
- 2 Control flow returns to `func`.
- 3 `x` is destroyed.
- 4 `n` is destroyed.
- 5 Control flow returns to `main`.
- 6 `size` is destroyed.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    int size = 100;  
    func(size);  
    // ...  
}
```

- 1 `std::bad_alloc` is raised in `operator new[]`.
- 2 Control flow returns to `func`.
- 3 `x` is destroyed.
- 4 `n` is destroyed.
- 5 Control flow returns to `main`.
- 6 `size` is destroyed.

Notice

Stack unwinding is only guaranteed to happen for **caught** exceptions. If an exception is not caught, whether the stack is unwound is **implementation-defined**.

Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- throw

- try-catch

- User-defined Exception Classes

3 Exception Safety

- Exception-safety Guarantees

- Exception Specifications

- Example: Copy Control

Catch an Exception

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void func(int n) {  
    int x = 42;  
    int *p = new int[n];  
    // ...  
}  
  
int main() {  
    try {  
        int size = 100;  
        func(size);  
    } catch (const std::bad_alloc &e) {  
        // deal with shortage of memory here.  
    }  
    // ...  
}
```

More Effective C++ Item 13: Catch exceptions by reference.

what

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined

Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

The error message could be obtained via the 'what' member function, which is `virtual`, `const` and `noexcept`.

```
void fun() {  
    throw std::runtime_error("I love watermelons.");  
}  
  
int main() {  
    try {  
        fun();  
    } catch (const std::runtime_error &re) {  
        std::cout << re.what() << std::endl;  
    }  
}
```

Output:

I love watermelons.

Catch an Exception

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees


Exception
Specifications

Example: Copy
Control

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v;  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns.\n";  
}
```

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v;  
         int x = copy.at(100);           throws std::out_of_range  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n";  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v; 'copy' is destroyed  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n";  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;           'i' is destroyed  
        std::vector<int> copy = v;  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n";  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v;  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) { Not matched  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n";  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v;  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) { Matched  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n";  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v;  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n";  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch an Exception

Suppose `std::out_of_range` is raised.

```
void f(const std::vector<int> &v) {  
    try {  
        int i = 42;  
        std::vector<int> copy = v;  
        int x = copy.at(100);  
        g(x);  
    } catch (const std::bad_alloc &ba) {  
        // deal with shortage of memory  
    } catch (const std::out_of_range &oor) {  
        // deal with illegal subscript '100'  
    } catch (...) {  
        // What else may happen? idk  
        throw; // Throw the exception again.  
    }  
    std::cout << "returns\n"; Control flow continues here  
}
```

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Catch by Base Class

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

`operator new[]` raises `std::bad_alloc` when out of memory.

- But if the array-new length is obviously invalid, an instance of `std::bad_array_new_length` is raised.

```
new int[-1]; // negative size
new int[3]{2, 3, 4, 6, 8}; // too many initializers
new int[LONG_MAX][100]; // too large
```

Catch by Base Class

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

`operator new[]` raises `std::bad_alloc` when out of memory.

- But if the array-new length is obviously invalid, an instance of `std::bad_array_new_length` is raised.

```
new int[-1]; // negative size
new int[3]{2, 3, 4, 6, 8}; // too many initializers
new int[LONG_MAX][100]; // too large
```

- `catch (const std::bad_alloc &)` also catches it, because of **inheritance**:



Catch by Base Class

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
try {  
    do_something();  
} catch (const std::runtime_error &re) {  
    // deal with runtime_error  
}  
catch (const std::exception &e) {  
    // deal with other kinds of exceptions  
}  
catch (...) {  
    // deal with other things  
}
```

Catch by Base Class

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
try {  
    do_something();  
} catch (const std::runtime_error &re) {  
    // deal with runtime_error  
}  
catch (const std::exception &e) {  
    // deal with other kinds of exceptions  
}  
catch (...) {  
    // deal with other things  
}
```

Note: Other things (e.g. a string) can also be **thrown**.

```
throw "I don\'t want to talk to you.";
```

In this case, these things are caught by **catch (...)**.

Catch by Base Class

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

`catch` clauses are examined one-by-one.

```
try {  
    do_something();  
} catch (const std::exception &e) {  
    std::cout << "exception\n";  
} catch (const std::runtime_error &re) {  
    std::cout << "runtime_error\n";  
} catch (...) {  
    // deal with other things  
}
```

If an instance of `std::runtime_error` is thrown, it will be caught by “`const std::exception &`” instead of “`const std::runtime_error &`” in this case.

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void fun() {  
    int i = 42;  
    std::vector<int> v;  
    ⚠ v.at(i) = 10;    throws std::out_of_range  
}  
  
int main() {  
    try {  
        std::string str("Hello");  
        fun();  
    } catch (...) {}  
}
```

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void fun() {  
    int i = 42;  
    std::vector<int> v; 'v' is destroyed  
    v.at(i) = 10;  
}  
  
int main() {  
    try {  
        std::string str("Hello");  
        fun();  
    } catch (...) {}  
}
```


Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void fun() {  
    int i = 42;    'i' is destroyed  
    std::vector<int> v;  
    v.at(i) = 10;  
}  
  
int main() {  
    try {  
        std::string str("Hello");  
        fun();  
    } catch (...) {}  
}
```

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void fun() {  
    int i = 42;  
    std::vector<int> v;  
    v.at(i) = 10;  
}  
  
int main() {  
    try {  
        std::string str("Hello");  
        fun();  
    } catch (...) {}  
}
```

Control flow returns here

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void fun() {  
    int i = 42;  
    std::vector<int> v;  
    v.at(i) = 10;  
}  
  
int main() {  
    try {  
        std::string str("Hello");  
        fun();  
    } catch (...) {}  
}
```

std::string str("Hello"); 'str' is destroyed

Stack Unwinding

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
void fun() {  
    int i = 42;  
    std::vector<int> v;  
    v.at(i) = 10;  
}  
  
int main() {  
    try {  
        std::string str("Hello");  
        fun();  
    } catch (...) {} The exception is caught.  
}
```

Notes

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

- The **try** block and **catch** blocks are independent scopes. Objects declared in the **try** block cannot be used in **catch** blocks.
- When an exception occurs, local objects in the **try** block are destroyed before the exception is caught.
- Stack unwinding is only guaranteed to happen for **caught** exceptions.
- If an exception is thrown and not caught, 'std::terminate' will be called to terminate the program. (defined in <exception>)

try-catch for Constructors

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array(std::size_t n)
        try : m_size(n), m_data(new T[n]{{}}) {}
        catch (const std::bad_alloc &ba) {
            std::cerr << "No enough memory.\n";
            throw;
        }
};
```

Notes:

- Exceptions raised both in **constructor initializer list** and **function body** can be caught.
- Non-static data members cannot be referred to in such **catch** blocks. (Why?)

Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
**User-defined
Exception Classes**

Exception
Safety

Exception-safety
Guarantees
Exception
Specifications
Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- throw
- try-catch
- **User-defined Exception Classes**

3 Exception Safety

- Exception-safety Guarantees
- Exception Specifications
- Example: Copy Control

User-defined Exceptions

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Wrong_answer : public std::logic_error {  
public:  
    Wrong_answer(std::size_t line_no)  
        : std::logic_error("Wrong answer on line "  
            + std::to_string(line_no)) {}  
};  
  
#define assert(X) \\\br/>    { if (!(X)) throw Wrong_answer(__LINE__); }  
  
int main() {  
    int a = rand(), b = rand();  
    int ans = add(a, b);  
    assert(ans == a + b);  
    return 0;  
}
```


Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

**Exception-safety
Guarantees**

Exception
Specifications

Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- throw
- try-catch
- User-defined Exception Classes

3 Exception Safety

- **Exception-safety Guarantees**
- Exception Specifications
- Example: Copy Control

Exception-safety Guarantees

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Exception-safe functions offer one of three guarantees:

- **Nothrow guarantee:** Promise never to throw exceptions.
- **Strong guarantee:** Promise that if an exception is thrown, the state of the program is unchanged (as if the function had not been called).
- **Weak guarantee (basic guarantee):** Promise that if an exception is thrown, everything in the program remains in a valid state.
 - No objects or data structures become corrupted.
 - All class invariants are satisfied.

Effective C++ Item 29: Strive for exception-safe code.

Exception-safety Guarantees

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

**Exception-safety
Guarantees**

Exception
Specifications

Example: Copy
Control

Effective C++ Item 29:

*A software system is **either exception-safe or it's not**. There's no such thing as a partially exception-safe system. If a system has **even a single function** that's not exception-safe, the system as a whole is not exception-safe.*

Exception-safety Guarantees

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Effective C++ Item 29:

*A software system is **either exception-safe or it's not**. There's no such thing as a partially exception-safe system. If a system has **even a single function** that's not exception-safe, the system as a whole is not exception-safe.*

*A function can usually offer a guarantee no stronger than the **weakest** guarantee of the functions it calls.*

Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- throw
- try-catch
- User-defined Exception Classes

3 Exception Safety

- Exception-safety Guarantees
- Exception Specifications
- Example: Copy Control

noexcept vs throw()

Exception Handling and Exception Safety

GKxx

Things Tend to Go Wrong

Exception Handling

- throw
- try-catch
- User-defined Exception Classes

Exception Safety

Exception-safety Guarantees

Exception Specifications

Example: Copy Control

Before C++11, a function may declare in advance what exception it may throw.

```
void *operator new(std::size_t size) throw(std::bad_alloc);
```

noexcept vs throw()

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

Before C++11, a function may declare in advance what exception it may throw.

```
void *operator new(std::size_t size) throw(std::bad_alloc);
```

To declare that a function does not throw exceptions:

```
int add(int a, int b) noexcept {  
    return a + b;  
}
```

noexcept vs throw()

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined

Exception Classes

Exception
Safety

Exception-safety

Guarantees

**Exception
Specifications**

Example: Copy
Control

People came to realize that it is **whether the function throws exceptions or not** that really matters.

noexcept vs throw()

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

People came to realize that it is **whether the function throws exceptions or not** that really matters.

Since C++11, declare **noexcept** for non-throwing functions.

```
template <typename T>
void swap(Array<T> &a, Array<T> &b) noexcept {
    a.swap(b);
}
```

noexcept vs throw()

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

People came to realize that it is **whether the function throws exceptions or not** that really matters.

Since C++11, declare **noexcept** for non-throwing functions.

```
template <typename T>
void swap(Array<T> &a, Array<T> &b) noexcept {
    a.swap(b);
}
```

The `throw()` specifiers have been deprecated and removed in modern C++.

noexcept

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety
Exception-safety
Guarantees
Exception
Specifications
Example: Copy
Control

The `noexcept` specifier makes it possible for more optimization.

- When an exception is thrown inside a `noexcept` function, the stack is *possibly* unwound.
 - Compilers need not keep the runtime stack in an unwindable state.
- Certain functions must be `noexcept` so that they can be called by standard library functions.
 - Move constructors and move assignment operators.

noexcept

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling

throw

try-catch

User-defined

Exception Classes

Exception
Safety

Exception-safety

Guarantees

**Exception
Specifications**

Example: Copy
Control

`noexcept` is not checked in compile-time. A `noexcept` function may still

- call functions that are not `noexcept`, or
- throw exceptions under certain circumstances.

Arguments to noexcept

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

`noexcept` may take one argument that is a **constant expression** and is convertible to `bool`.

```
// noexcept iff T is nothrow-copy-constructible.  
template <typename T>  
void fun() noexcept(  
    std::is_nothrow_copy_constructible<T>::value) {  
    // ...  
}
```

`noexcept` is equivalent to `noexcept(true)`.

The noexcept Operator

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

`noexcept` can also work as an operator, which returns a `bool` value indicating whether an expression throws exceptions.

```
template <typename T>
class Box {
    T thing;
public:
    void swap(Box<T> &other)
        noexcept(noexcept(std::swap(thing, other.thing)))
    {
        std::swap(thing, other.thing);
    }
};
```

Contents

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

1 Things Tend to Go Wrong

2 Exception Handling

- throw
- try-catch
- User-defined Exception Classes

3 Exception Safety

- Exception-safety Guarantees
- Exception Specifications
- Example: Copy Control

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
    int *m_data;  
    std::size_t m_size;  
  
public:  
    Array &operator=(const Array &other) {  
        if (this != &other) {  
            delete[] m_data;  
            m_data = new int[other.m_size];  
            std::copy(other.m_data,  
                      other.m_data + other.m_size, m_data);  
            m_size = other.m_size;  
        }  
        return *this;  
    }  
};
```


Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
    int *m_data;  
    std::size_t m_size;  
  
public:  
    Array &operator=(const Array &other) {  
        if (this != &other) {  
            delete[] m_data;  
            m_data = new int[other.m_size];  
            std::copy(other.m_data,  
                      other.m_data + other.m_size, m_data);  
            m_size = other.m_size;  
        }  
        return *this;  
    }  
};
```

It does not offer even the basic guarantee.

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
public:  
    Array &operator=(const Array &other) {  
        auto new_data = new int[other.m_size];  
        std::copy(other.m_data,  
                  other.m_data + other.m_size, new_data);  
        delete[] m_data;  
        m_data = new_data;  
        m_size = other.m_size;  
        return *this;  
    }  
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
public:  
    Array &operator=(const Array &other) {  
        auto new_data = new int[other.m_size];  
        std::copy(other.m_data,  
                  other.m_data + other.m_size, new_data);  
        delete[] m_data;  
        m_data = new_data;  
        m_size = other.m_size;  
        return *this;  
    }  
};
```

Strong guarantee.

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
public:  
    Array &operator=(const Array &other) {  
        m_size = other.m_size;  
        auto new_data = new int[m_size];  
        std::copy(other.m_data,  
                  other.m_data + m_size, new_data);  
        delete[] m_data;  
        m_data = new_data;  
        return *this;  
    }  
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
public:  
    Array &operator=(const Array &other) {  
        m_size = other.m_size;  
        auto new_data = new int[m_size];  
        std::copy(other.m_data,  
                  other.m_data + m_size, new_data);  
        delete[] m_data;  
        m_data = new_data;  
        return *this;  
    }  
};
```

No exception-safety guarantee.

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
public:  
    void swap(Array &other) noexcept {  
        using std::swap;  
        swap(m_size, other.m_size);  
        swap(m_data, other.m_data);  
    }  
    Array &operator=(const Array &other) {  
        Array(other).swap(*this);  
        return *this;  
    }  
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
class Array {  
public:  
    void swap(Array &other) noexcept {  
        using std::swap;  
        swap(m_size, other.m_size);  
        swap(m_data, other.m_data);  
    }  
    Array &operator=(const Array &other) {  
        Array(other).swap(*this);  
        return *this;  
    }  
};
```

Strong guarantee.

Which Part may Throw?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
// For simplicity, assume T is default-constructible
    and copy-assignable.
template <typename T>
class Array {
    T *m_data;
    std::size_t m_size;

public:
    Array(const Array &other)
        : m_data(new T[other.m_size]),
          m_size(other.m_size) {
        std::copy(other.m_data,
                  other.m_data + other.m_size, m_data);
    }
};
```


Which Exception-safety Guarantee?

Exception Handling and Exception Safety

GKxx

Things Tend to Go Wrong

Exception Handling
throw
try-catch
User-defined
Exception Classes

Exception Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array(const Array &other)
        : m_data(new T[other.m_size]),
          m_size(other.m_size) {
        std::copy(other.m_data,
                  other.m_data + other.m_size, m_data);
    }
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array(const Array &other)
        : m_data(new T[other.m_size]),
          m_size(other.m_size) {
        std::copy(other.m_data,
                  other.m_data + other.m_size, m_data);
    }
};
```

No guarantee. If an exception occurs when copying, `m_size` and `m_data` will be destroyed, resulting in **memory leak**.

Make it Exception-safe

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array(const Array &other)
        : m_data(new T[other.m_size]),
          m_size(other.m_size) {
        try {
            std::copy(other.m_data,
                      other.m_data + other.m_size, m_data);
        } catch (...) {
            delete[] m_data; // Avoid memory leak
            throw; // Let the caller know it!
        }
    }
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array &operator=(const Array &other) {
        auto new_data = new T[other.m_size];
        std::copy(other.m_data,
                  other.m_data + other.m_size, new_data);
        delete[] m_data;
        m_data = new_data;
        m_size = other.m_size;
        return *this;
    }
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array &operator=(const Array &other) {
        auto new_data = new T[other.m_size];
        std::copy(other.m_data,
                  other.m_data + other.m_size, new_data);
        delete[] m_data;
        m_data = new_data;
        m_size = other.m_size;
        return *this;
    }
};
```

No guarantee.

Make it Exception-safe

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    Array &operator=(const Array &other) {
        auto new_data = new T[other.m_size];
        try {
            std::copy(other.m_data,
                      other.m_data + other.m_size, new_data);
        } catch (...) {
            delete[] new_data;
            throw;
        }
        delete[] m_data;
        m_data = new_data;
        m_size = other.m_size;
        return *this;
    }
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    void swap(Array &other) noexcept {
        using std::swap;
        swap(m_size, other.m_size);
        swap(m_data, other.m_data);
    }
    Array &operator=(const Array &other) {
        Array(other).swap(*this);
        return *this;
    }
};
```

Which Exception-safety Guarantee?

Exception
Handling and
Exception
Safety

GKxx

Things Tend
to Go Wrong

Exception
Handling
throw
try-catch
User-defined
Exception Classes

Exception
Safety

Exception-safety
Guarantees

Exception
Specifications

Example: Copy
Control

```
template <typename T>
class Array {
public:
    void swap(Array &other) noexcept {
        using std::swap;
        swap(m_size, other.m_size);
        swap(m_data, other.m_data);
    }
    Array &operator=(const Array &other) {
        Array(other).swap(*this);
        return *this;
    }
};
```

Strong guarantee.