# Futuristic Error Handling

Error handling in C++ today and tomorrow

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# Why am I here?

Why should we bother with error handling?

# Recommendable error handling mechanism

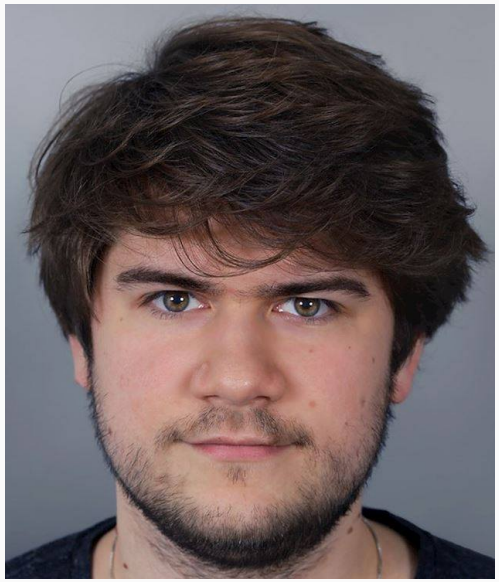
Which error mechanism would you choose?

There exist two common strategies for error handling:

- error codes?
- exceptions?

# Who am I?

- Senior Software Developer in TomTom
- Member of the ISO/JTC1/SC22/WG21
- C++ blog writer and C++ ewangelist



# Error codes nowadays

# What are the error codes?

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- error code is an enumerated message,
- that corresponds to the status of a specific software application.
- They are typically used to identify faults, such as those in faulty hardware, software, or incorrect user input

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- Machine friendly.
- Super fast.
- Used till today.

# Error code example

```
int sqlite3_open( const char *filename, sqlite3 **ppDb );
```

# Error code example

```c
int sqlite3_open( const char *filename, sqlite3 **ppDb );
```

---

```c
int open_status = sqlite3_open(/* ... */ );
if(open_status == SQLITE_OK){
  // make use of opened database
} else if( open_status == SQLITE_CANTOPEN_ISDIR ) {
  // handle the error
}
```

# Handle the error

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- `std::terminate()`
- take the error callback
- propagate the error to the caller

# Error codes - propagation

# Propagation

```
void foo_bar(int& errc /*...*/){
  errc = foo();
  // ...
  errc = bar();
  // ...
}
```

# Error translation

```
void foo_bar(foo_bar_errc errc&){
  foo_errc ferrc = foo();
  errc = translate_foo(ferrc);
  // ...
  bar_errc berrc = bar();
  errc = translate_foo(berrc);
}
```

# C-style error codes summary

So we can see serious disadvantages (except for obvious advantages):

- success path same as error path

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- boiler plate code

# C-style error codes summary

So we can see serious disadvantages (except for obvious advantages):

- success path same as error path
- boiler plate code
- cluttering code with translations

# Error codes - modern approach

# Standard library support - what do we need?

- A way to define new error codes
- A way to distinguish domain of the error codes

# Standard library support - what we get?

We get three new major types:

- std::error_code
- std::error_category
- std::error_condition

# std::error_code in action

```
std::error_code errcode;
is_regular_file("non_existent_directory", errcode);

std::cout << errcode << std::endl;
std::cout << errcode.value() << std::endl;
std::cout << errcode.message() << std::endl;
std::cout << errcode.category().name() << std::endl;
```

---

**output**

```
$ generic:2
$ 2
$ No such file or directory
$ generic
```

# Acting upon error

```
std::error_code errcode;
is_regular_file("non_existent_file", errcode);

if(errcode == errc::no_such_file_or_directory){
  // creating a file
}
```

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Steps to create own error code:

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- define custom error condition
  - define error condition enum

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  - inform the world about new error condition enum

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  - make conversion function from new error code to error condition

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Steps to create own error code:

- define custom enum with error codes
- inform, that the enum is an error code
- create custom error category (or use existing one)
- create enum to error code factory function
- define custom error condition
  - define error condition enum
  - inform the world about new error condition enum
  - make conversion function from new error code to error condition
- enjoy!

# Error codes - defining custom error codes

# Step 1 - define custom enum with error codes

```
enum class map_access_error {
  SUCCESS, // zero means success
  MAP_NOT_INSTALLED,
  LACK_OF_PERMISSION,
  MAP_CORRUPTED,
};
```

# Step 2 - inform the world about new error code type

```
namespace std{
  template <> struct
  is_error_code_enum<map_access_error> : std::true_type{};
}
```

# Step 3 - custom error category

```
struct map_access_domain : std::error_category {
  const char *name() const noexcept override;
  std::string message(int errc) const override;
};
```

# Step 3 - custom error category

```
const char* map_access_domain::name() const noexcept{
  return "Map Access Error";
}
```

# Step 3 - custom error category

```
std::string map_access_domain::message(int errc) const{
  switch (static_cast<map_access_error>(errc)){
    case map_access_error::SUCCESS:
      return "SUCCESS";
    case map_access_error::MAP_NOT_INSTALLED:
      return "MAP IS NOT INSTALLED ON THE DEVICE";
    case map_access_error::LACK_OF_PERMISSION:
      return "MISSING PERMISSIONS TO READ THE MAP";
    case map_access_error::MAP_CORRUPTED:
      return "MAP IS CORRUPTED. REINSTALLATION NEEDED";
    default:
      return "ERROR UNKNOWN";
  }
}
```

# Step 4 - factory function

```
namespace std{
  template <typename ErrorCode>
  error_code(typename std::enable_if<
                          is_error_code_enum<
                            ErrorCode>
                          ::value, ErrorCode>
                        ::type errcode) noexcept
              : error_code(make_error_code(errcode))
  {}
}
```

# Step 4 - factory function

```
std::error_code make_error_code(map_access_error errc){
  return {static_cast<int>(errc), map_access_error_domain};
}
```

# Step 5 - custom error condition

```
enum class calculate_route_error : int {
  SUCCESS,
  MAP_ERROR,
  COULD_NOT_FIND_PATH,
  WRONG_ARGUMENTS
};
```

# Step 5 - custom error condition

```
namespace std{
  template <> struct
  is_error_condition_enum<calculate_route_error>
                              : std::true_type{};
}
```

# Step 5 - custom error condition

```
struct calculate_route_error_domain : std::error_category{
  const char *name() const noexcept override;
  std::string message(int errc) const override;
  bool equivalent(const std::error_code &errc, int condition)
                                          const noexcept override;
};
```

# Step 5 - custom error condition

```
bool calculate_route_error_domain::equivalent(
          const std::error_code &errc, int condition)
                                        const noexcept{

  switch (static_cast<calculate_route_error>(condition)){
    case calculate_route_error::SUCCESS:
      if(errc.value() == 0)
        return true;
    case calculate_route_error::MAP_ERROR:
      if(errc.category().name() == map_access_domain().name())
        return true;

    // other cases
  }
  return false;
}
```

# Step 6 - Enjoy - real life example

```
std::error_code errcode;
auto route = calculate_route({}, {}, {}, errcode);

if(!errcode)
  return route;

std::cout << errcode.category().name() << " : " <<
             errcode.message() << std::endl;

if(errcode == calculate_route_error::MAP_ERROR)
  reinstall_map();
else if (errcode == calculate_route_error::COULD_NOT_FIND_PATH)
  inform_user_no_path_found();
else if (errcode == calculate_route_error::WRONG_ARGUMENTS)
  std::terminate();
```

# Step 6 - Enjoy - real life example

```
route calculate_route(point a, point b, route_options options,
                      std::error_code& errc){
  auto map_database = database(errc);
  if (errc) return {};

  auto a_handle = map_database.find(a, errc);
  if(errc) return {};
  auto b_handle = map_database.find(b, errc);
  if(errc) return {};

  route result_route = find_path(a_handle, b_handle,
                                 options, errc);
  if(errc) return {};

  return result_route;
}
```

# Error codes - summary

# Error codes summary

Pros

- Performance
  - speed
  - small (occupied memory)
  - speed predictability
  - memory occupation predictability
  - C compatibility

Cons

- business logic cluttering
- massive amount of boilerplate code
- template magic in case of std::error_code

# Exceptions to the rescue (?)

# Brief look at the example

```
try{
  auto route = calculate_route(/*arguments*/);
} catch(map_error& err){
  // logic
} catch(path_not_found& err){
  // logic
} /* catch(std::invalid_argument){

} */
```

# Brief look at the example

```
route calculate_route(point a, point b,
                      route_options options){

  auto map_database = database();

  auto a_handle = map_database.find(a);
  auto b_handle = map_database.find(b);

  route result_route = find_path(a_handle, b_handle, options);

  return result_route;
}
```

# Defining custom exception

```
class map_error : public std::runtime_error{};
```

# Dark side of the exceptions

- Still translation of exceptions is needed

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- Still translation of exceptions is needed
- For performance reasons 50% of projects have disabled exceptions

# C++ - zero overhead rule

# What is zero overhead?

- language features can introduce overhead

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# What is zero overhead?

- language features can introduce overhead
- "you don't pay for what you don't use"
- if you use a feature it should be as afficient as handcoded version.

# Exceptions not to the rescue

Exceptions break the zero overhead rule.

But why?

# Exceptions - how do they work?

# Approaches towards implementation

Two major kinds of implementation:

- additional data added to the frame stack

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- additional data added to the frame stack
- additional data added to someplace on the heap

# Implementations' consequences

| implementation | performance | |
|---|---|---|
| | without throwing | with throwing |
| frame-based | overhead | fast |
| table-based | almost no overhead | slow |

No matter the strategy binaries with exceptions enabled result in a big binary.

# Exceptions summary

Pros

- differentiated error and success paths
- automagical error propagation
- little/no boilerplate code

Cons

- Performance
  - slow
  - not deterministic speed
  - not deterministic storage occupation
  - not compatible with C
  - not usable in any safety standards (e.g. MISRA)

# Possible future of error handling.

# Perfect error handling mechanism

| feature | exceptions | std::error_code |
|---|---|---|
| distinct error path | yes | no |
| distinct success path | yes | no |
| unhandled error propagation | yes | no |
| unhandled error is visible | no | yes |
| uncluttered business logic | yes | no |
| RTTI required | yes | no |
| deterministic space/time occupation | no | yes |
| time cost == return | no | yes |
| C compatibility | no | no |

# Key idea for improvement

**Key ideas**

- Let's use the return channel to return the std::error

Let's call those *static exceptions*

# Key idea for improvement

**Key ideas**

- Let's use the return channel to return the std::error
- Let the compiler generate boilerplate code for error propagation

Let's call those *static exceptions*

# What is std::error

- size of error_code is explicitly defined
- has same properties as std::error_code
- implements trivially relocatable semantics

# How to use return channel for std::error

We can do that manually using variant:

```
using Result =
      variant<T, std::error>;
Result foo();
```

But this can be nicer with syntax sugar:

```
T foo() throws;
```

# Static exceptions example

```
string f() throws {
  if (flip_a_coin()) throw arithmetic_error::something;
  return "xyzzy"s + "plover";
}

string g() throws { return f() + "plugh"; }

int main() {
  try {
    auto result = g();
    cout << "success, result is: " << result;
  } catch(error err) {
    cout << "failed, error is: " << err.error();
  }
}
```

# Compiler's support in handling errors

```
int f1() throws;
int f2() throws;

int main(){
// return f1() + f2(); // error
try return f1() + f2();// ok, covers both
return try f1()+ f2();
}
```

# Cool! But what about C compatibility

It is possible, that C will be ABI compatible with static exceptions!

This implies:

- Exceptions could be thrown from C++, passed through C and catched again in C++
- We could handle C++ exceptions in C
- We could handle C exceptions in C++

# Short story about C language

```
_Either(int, std_error) somefunc(int a){
  return a > 5 ? _Expected(a) : _Unexpected(a);
}

// ...

_Either(int, std_error) ret = somefunc(a);
if(ret)
  printf("%d\n", ret.expected);
else
  printf("%f\n", ret.unexpected);
```

# Static exceptions summary

| feature | static exceptions |
|---|---|
| distinct error path | yes |
| distinct success path | yes |
| unhandled error propagation | yes |
| unhandled error is visible | yes |
| uncluttered business logic | yes |
| RTTI required | no |
| deterministic space/time occupation | yes |
| time cost == return | yes |
| C compatibility | maybe |

# Possible issue

We will end up having 3 ways to handle error codes:

- dynamic exceptions
- static exceptions
- old style error codes

# Bibliography

This presentation wouldn't be possible without:

- Herb Sutter - author of the proposal (code examples, exception features taken from his proposal) - p0709r1
- Andrzej Krzemiński for his blog about error codes and error conditions - Your own error code

# Thank you

Thank you for your attention!

Questions?