Dr Ivan Čukić KDAB

THE EXPECTED OUTCOME

INTRODUCTION
VALUE OR ERROR
BASIC IDIOMS
CONVERSIONS
BEYOND

Meeting C++ 2022

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ABOUT ME

- KDAB

  I assure you we're open^Whiring!
- Author of "Functional Programming in C++"

  available in English, Chinese, Korean, Russian, Polish
- Trainer / Consultant
- KDE developer
- University professor

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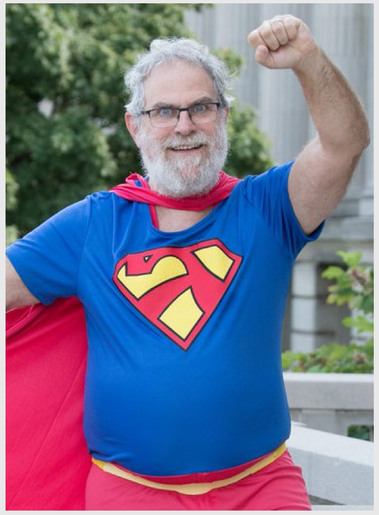
DISCLAIMER



Make your code readable. Pretend the next person who looks at your code is a psychopath and they know where you live. – Philip Wadler

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DISCLAIMER

The code snippets are optimized for presentation,
it is not production-ready code.

std namespace is omitted, value arguments used instead

of references to const or forwarding references, etc.

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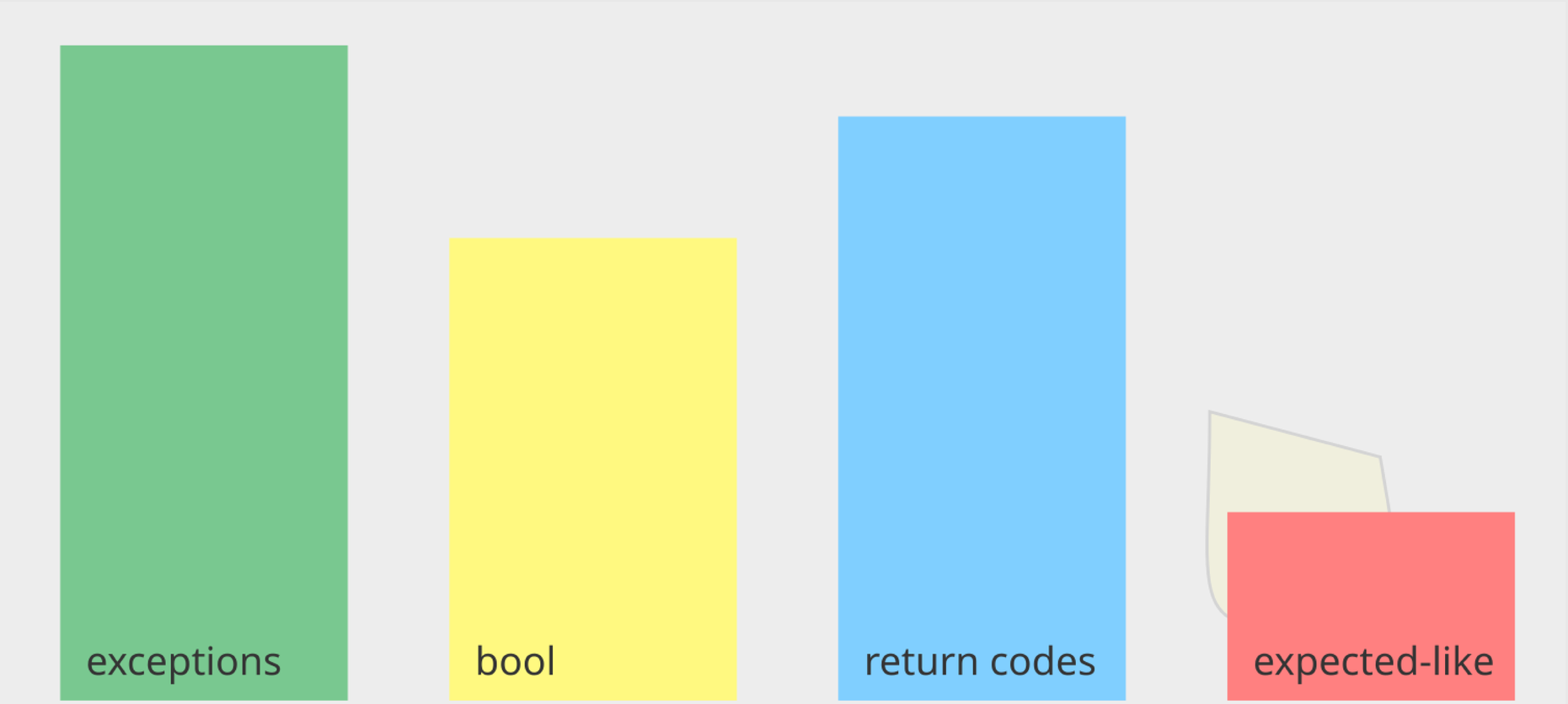
WHY AGAIN?



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EXCEPTIONS

```
email_t parse_email(string email) {
    if (!email_regex.matches(email)) {
        throw email_parsing_error
            {"not a valid e-mail address"};
    }

    :::
}
```

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EXCEPTIONS

- Forbidden in many projects
- Slow sad path
- Increase the binary size
- Execution paths are not obvious
- Easy to ignore

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EXCEPTIONS

- Not really a part of the API
- noexcept as the final nail

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OUT PARAMETERS

```
bool parse_email(string email, email_t& result) {
    if (!email_regex.matches(email)) {
        return false;
    }

    :::
```

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OUT PARAMETERS

- Obvious, but awful API design
- Easy to ignore (nodiscard to the rescue)

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SPECIAL RETURN VALUES

```
email_t parse_email(string email) {
    if (!email_regex.matches(email)) {
        return email_t
            { "invalid char in username", "ERROR" };
    }

    :::
```

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SPECIAL RETURN VALUES

- Which values are special?
- Easy to ignore, nodiscard doesn’t help

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VALUE OR ERROR TYPES

- return a valid value or throw an exception
- return a valid value or a special one denoting the error
- return a valid value via out parameter or a failure

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VALUE OR ERROR TYPES

```
variant<
    Value,
    Error>
```

A long time ago in a galaxy far away ...

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SIMPLE WRAPPERS

```
template<typename T, typename ValidationPolicy>
class Result {
private:
    T _value;

public:
    bool has_value() const;
    T value() const;
    T error() const;
};
```

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SIMPLE WRAPPERS

Policies:

- value ≥ 0, errors negative
- value = 0, errors positive
- value ≠ 0, error zero
- value → true, error otherwise

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SIMPLE WRAPPERS

```
if (result.has_value()) {
    process(result.value());
}
```

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SIMPLE WRAPPERS

```
if (result) {
    process(*result);
}
```

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VALUE OR ERROR TYPES

```
variant<
    Value,
    Error> result = :::;

if (result) {
    process(*result);
}
```

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- P0323: Vicente Botet, JF Bastien, Jonathan Wakely
- P2505: Jeff Garland

It’s a bug, not a feature.

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STD::EXPECTED

```
expected<email_t, err_t> parse_email(string email) {
    if (!email_regex.matches(email)) {
        return unexpected
            ("not a valid e-mail address");
    }

    :::
}
```

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STD::EXPECTED

```
// -> expected<string, err_t>

expected<string, err_t> input = get_input();
if (!input) return input;

auto email = parse_email(*input);
if (!email) return email;

auto html = format_link(email->user, *email);

return html;
```

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STD::EXPECTED

```
// -> expected<string, err_t>

expected<string, err_t> input = get_input();
if (!input) return unexpected(input.error());

auto email = parse_email(*input);
if (!email) return unexpected(email.error());

auto html = format_link(email->user, *email);

return html;
```

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STD::EXPECTED

- Predictable execution path
- Unlimited number of errors in the air
- No magic
- Storage – files, databases…
- Transfer over thread and process boundaries, network…

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TWO NOTATIONS

As we don’t have UCS:

```
voe.some_function();

some_function(voe);

some_other_function(
    some_function(voe), arg1, arg2);
```

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TWO NOTATIONS

As we don’t have UCS:

```
voe | lf::some_function()
    | lf::some_other_function(arg1,
                              arg2);
```

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TWO NOTATIONS

As we don’t have UCS:

```
voe | some_function()
    | some_other_function(arg1,
                          arg2);
```

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TWO NOTATIONS

```
struct some_function {};

auto operator| (auto object, some_function)
{
    return object.some_function();
    // or: some_function(object);
}
```

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CHANGING VALUES

```
// email: expected<email_t, err_t>

if (!email) return unexpected(email.error());
auto html = format_link(*email);

return html;
```

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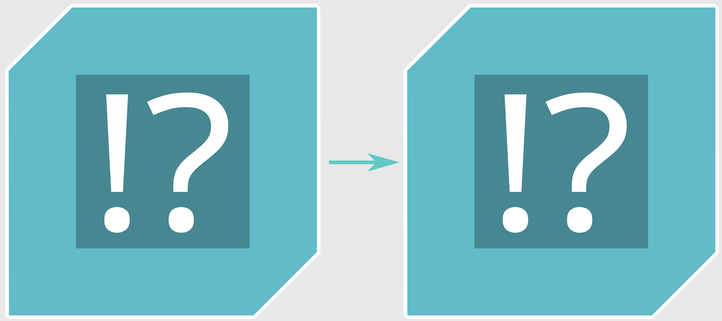
CHANGING VALUES



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CHANGING VALUES

```
// email: expected<email_t, err_t>

auto html = email | transform(format_link);
```

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CHANGING VALUES

```
// email: expected<email_t, err_t>

auto html = email | transform(
    [] (email_t email) {
        return format_link(email.user,
                           email);
    });
```

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CHANGING VALUES

```
// input: expected<string, err_t>

if (!input) return unexpected(input.error());
auto email = parse_email(*input);

:::
```

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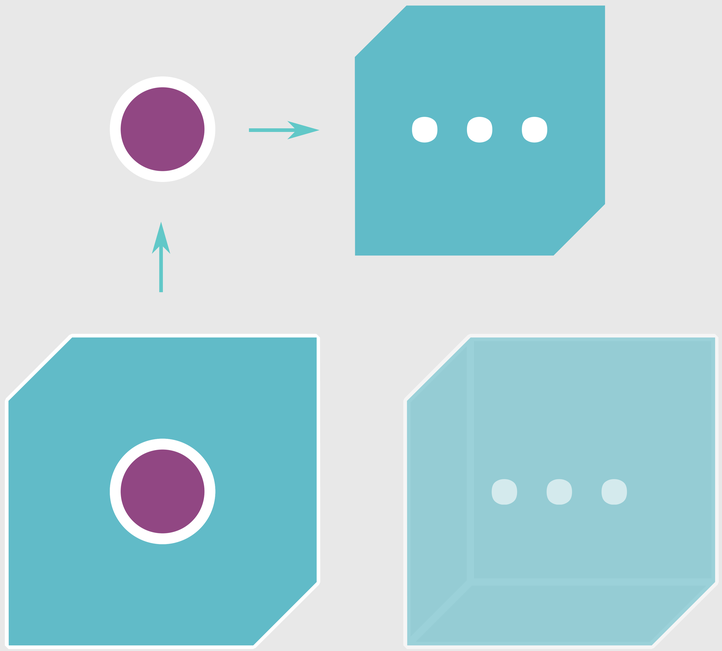
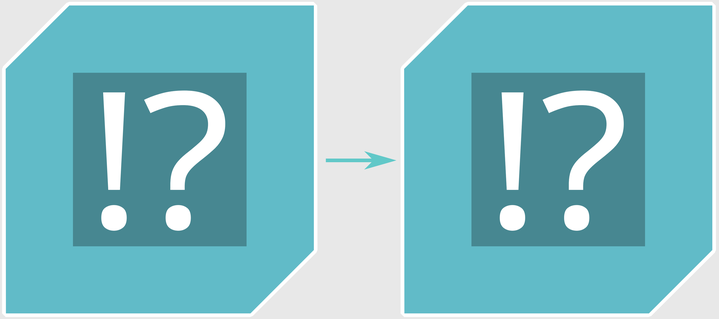
CHANGING VALUES





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CHANGING VALUES

```
// -> expected<string, err_t>

auto email = input | and_then(parse_email);

:::
```

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CHANGING VALUES

```
return get_input()
       | and_then(parse_email)
       | transform(
           [] (email_t email) {
               return format_link(email.user,
                                  email);
       });
```

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FALLBACK

```
return get_input()
       | and_then(parse_email)
       | transform(:::)
       | value_or(string{});
```

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FALLBACK

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FALLBACK

```
return get_input()
       | and_then(parse_email)
       | transform(:::)
       | or_else([] (err_t err) -> ::: {
           if (err == err_t::empty)
               return {};
           else
               return err;
       });
```

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FROM SPECIAL VALUES

- Just use the simple wrappers
- Write conversion functions between wrappers and expected

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FROM EXCEPTIONS

```
class err_t {
    err_t(exception_ptr ep);
};
```

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FROM EXCEPTIONS

```
template <typename Err, typename Func,
          typename Result = invoke_result_t<Func>>
expected<Result, Err> ex_try(Func function)
    try { return function(); }
    catch (...) {
        return unexpected(
            Err(current_exception()));
    }
```

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TO EXCEPTIONS

```
result.value();

// unlike *value;
```

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FROM OUT PARAMETERS

```
// int parse_email(string email, email_t& result)
template <typename Value, typename Err, typename Func>
expected<Value, Err> ex_from_out(Func function) {
    Value result;
    if (auto error = function(result)) {
        return unexpected(error);
    }
    return result;
}
```

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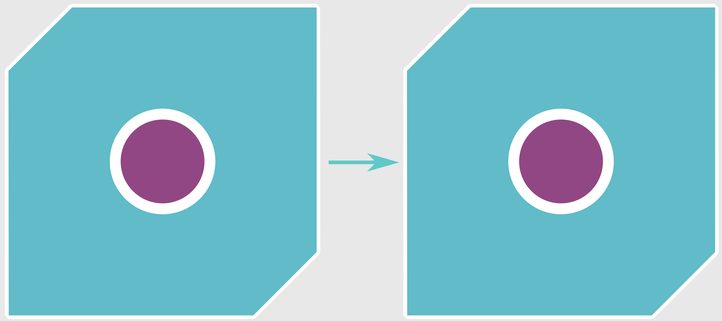
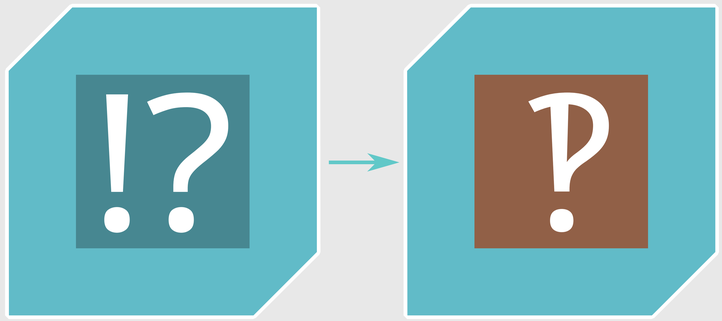
FROM OTHER EXPECTEDS





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FROM OTHER EXPECTEDS

```
// get_email_link() -> expected<string, err_t>

// to_error_code(err_t error) -> error_code

get_email_link() | transform_error(to_error_code);
```

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FROM OTHER EXPECTEDS

Or rely on conversion:

```
expected<Value, OldErrorType> ->
        expected<Value, NewErrorType>
```

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FROM OTHER EXPECTEDS

```
struct my_error_t {
    my_error_t(err_t e);
};

// get_email_link() -> expected<string, err_t>
expected<string, my_error_t> link =
    get_email_link();
```

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FROM OTHER EXPECTEDS

```
using my_error_t =
    variant<err_t, some_other_err_t, ...>;


// get_email_link() -> expected<string, err_t>
expected<string, my_error_t> link =
    get_email_link();
```

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CALLING FUNCTIONS

What about functions with multiple arguments?

```
value –[transform]–> result
value –[and_then]–> result
```

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CALLING FUNCTIONS

```
// email: expected<email_t, err_t>

auto html = email | transform(
    [] (email_t email) {
        return format_link(email.user,
                           email);
    });
```

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CALLING FUNCTIONS

```
f: (arg_1, arg2, ..., arg_n) -> result

ex_invoke(f, ex_1, ex_2, ..., ex_n)
                  -> expected<result, ???>;
```

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DEDUCING ERRORS

How to deduce the error type

- Explicitly specify error type
- Use the first error type found
- Use variant of all found error types

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DEDUCING ERRORS

```
template <typename... Expecteds
          >
using find_first_expected =
    typename tag_t::list<Expecteds...>
    ::template transform<remove_cvref_t>
    ::template filter<is_expected_instantiation>
    ::first;
```

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DEDUCING ERRORS

```
template <typename... Expecteds
          >
using errors_variant =
    typename tag_t::list<Expecteds...>
    ::template transform<remove_cvref_t>
    ::template filter<is_expected_instantiation>
    ::uniq
    ::template pass_to<variant>;
```

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DEDUCING ERRORS

```
template <template <typename...> Custom,
          typename... Expecteds>
using errors_as_custom_type =
    typename tag_t::list<Expecteds...>
    ::template transform<remove_cvref_t>
    ::template filter<is_expected_instantiation>
    ::uniq
    ::template pass_to<Custom>;
```

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CALLING FUNCTIONS

```
template<typename Function, typename... Expecteds>
auto ex_invoke(Function function, Expecteds ...expecteds) -> ...
{
    auto error = find_error(expecteds...);
    if (error) return unexpected(*error);

    auto value_for = []<typename Value>(Value value) {
        return value.value();
    };
    return current_expected(
        function(value_for(expecteds)...));
```

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CALLING FUNCTIONS

```
ex_invoke(format_link,
          email | transform(&email_t::user),
          email);
```

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CALLING FUNCTIONS

```
auto value_for = []<typename Value>(Value value) {
    if constexpr (is_expected_instantiation_v<Value>) {
        return value.value();
    } else {
        return value;
    }
};
```

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CALLING FUNCTIONS

```
ex_invoke(format_link,
          email | transform(&email_t::user),
          email,
          "email-link"s);
```

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CALLING FUNCTIONS

```
template<typename Function, typename... Expecteds>
auto ex_coalesce(Function function, Expecteds ...expecteds) -> ...
{
    auto value = find_valid(expecteds...);
    if (!value) return unexpected(value.error());

    return current_expected(
        function(*value));
}
```

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CALLING FUNCTIONS

- ex_invoke – calling n-ary functions
- ex_coalesce – calling unary functions with first valid value

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CALLING FUNCTIONS

- ex_invoke – calling n-ary functions
- ex_coalesce – calling unary functions with first valid value
- ex_lazy_invoke – calling n-ary functions with early exit
- ex_lazy_coalesce – calling unary functions with first valid result

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CALLING FUNCTIONS

```
auto value_for = []<typename Value>(this auto self, Value value) {
    if constexpr (is_invocable_v<Value>) {
        return self(value());
    } if constexpr (is_expected_instantiation_v<Value>) {
        return value.value();
    } else {
        return value;
    }
};
```

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CALLING FUNCTIONS

```
auto value_for = []<typename Value>(this auto self, Value value) {
    if constexpr (is_lazy_instantiation_v<Value>) {
        return self(value());
    } if constexpr (is_expected_instantiation_v<Value>) {
        return value.value();
    } else {
        return value;
    }
};
```

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CALLING FUNCTIONS

```
// cool is not good, precise is better

ex_invoke(format_link,
          email | transform(&email_t::user),
          email,
          lazy(:::));
```

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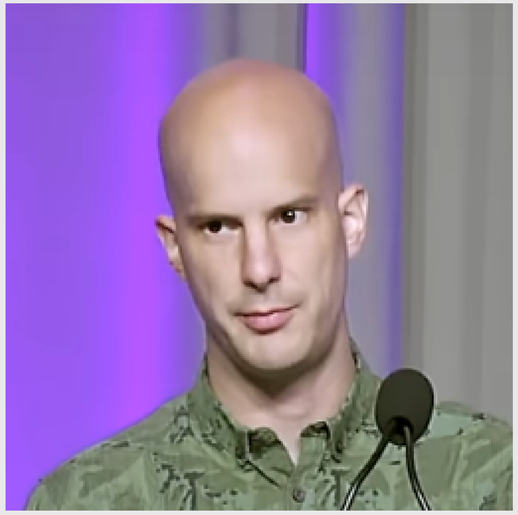

Andreas Weis

Coroutine Basics - Asynchronous computation

```
auto [ec, bytes_read] = read(socket, buffer);
// ...

async_read(socket, buffer,
  [](std::error_code ec, std::size_t bytes_read) {
    // ...
  });
```

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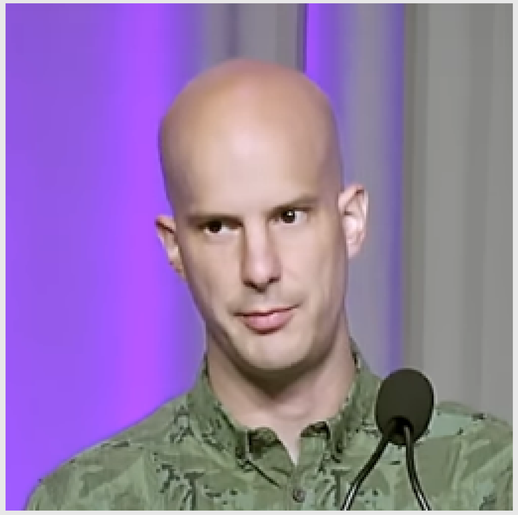

Andreas Weis

Coroutine Basics - Asynchronous computation

```
auto [                    ] = read(                    );
// ...

async_read(                    ,
  [](                                                  ) {
    // ...
  });
```

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EXPECTED & CO.

```
task<string> current_user_name() {
    task<user_t> user_task = current_user();
    user_t = co_await user_task;

    task<string> name_task = user.name();
    string name = co_await name_task;

    co_return name;
}
```

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EXPECTED & CO.

```
task<string> current_user_name() {
    return current_user()
           | and_then([] (user_t user) {
                 return user.name();
             })
           | and_then([] (string name) {
                 return mke(name);
             });
}
```

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EXPECTED & CO.

```
task<string> current_user_name() {
    return current_user()
           | and_then(&user_t::name);
}
```

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EXPECTED & CO.

```
expected<string, err_t> get_email_link() {
    string input = co_await get_input();
    auto email = co_await parse_email(*input);
    auto html = format_link(email->user, *email);

    co_return html;
}
```

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- Outcome…
- Value x Error

SUMMARY

- Errors in values
- Outside of domain types
- Interoperability with other mechanisms
- Easy conversion
- Easy composition
- Can simulate exception-like syntax when needed

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