

Monadic Operations in C++23



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Calling successive functions that might fail

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))           { return false; }

    CTableData table;
    if ( ! getTable(element, table))               { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))         { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))       { return false; }

    result = (value < 0);
    return true;
}
```

Calling successive functions that might fail

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))           { return false; }

    CTableData table;
    if ( ! getTable(element, table))               { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))         { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))      { return false; }

    result = (value < 0);
    return true;
}
```

...with exceptions

```
throw std::out_of_range("row out of bounds");
```

```
bool getNumericTableValueNegative(const CDb& db, const Key& key,  
                                  const CLocation& location)  
{  
    auto table = getTable(getElement(db, key));  
    auto cell = getCell(table, cellLocation);  
    return (getNumericCellValue(cell) < 0);  
}
```

```
catch (const std::invalid_argument& e)  
{  
    //...  
}  
catch (const std::out_of_range& e)  
{  
    //...  
}  
catch (...) //...
```

But I can't use exceptions!

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))           { return false; }

    CTableData table;
    if ( ! getTable(element, table))               { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))         { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))      { return false; }

    result = (value < 0);
    return true;
}
```

Does an error flag help?

```
class CMyClass
{
    //...
    bool m_bError{false};
};

bool CMyClass::getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    auto table = getTable(getElement(db,key))
    auto cell = getCell(table, location)
    auto value = getNumericCellValue(cell)
    if (m_bError) { return false; }

    result = (value < 0);
    return true;
}
```

Does an error flag help?

```
class CMyClass
{
    //...
    bool m_bError{false};
};

bool CMyClass::getNumericTableValueNegative
(const CDb& db, const Key& key,
const CLocation& location, bool& out)
{
    auto table = getTable(getElement(db, key))
    auto cell = getCell(table, location)
    auto value = getNumericCellValue(cell)
    if (m_bError) { return false; }

    result = (value < 0);
    return true;
}

CTableData CMyClass::getTable
{
    if (m_bError)
    {
        return{};
    }
    //...
}
```

Does an error flag help?



```
class CMyClass
{
    //...
    bool m_bError{false};
};

bool CMyClass::getNumericTableValueNegative
(const CDb& db, const Key& key,
const CLocation& location, bool& out)
{
    auto table = getTable(getElement(db, key))
    auto cell = getCell(table, location)
    auto value = getNumericCellValue(cell)
    if (m_bError) { return false; }

    result = (value < 0);
    return true;
}
```


Can std::optional help?

```
std::optional<bool> isNumericTableCellValueNegative
(const CDb& db, const Key& key, const CLocation& location)
{
    auto oElement = getElement(db, key);
    if ( ! oElement.has_value()) { return {}; }

    auto oTable = getTable(oElement.value());
    if ( ! oTable.has_value())    { return {}; }

    auto oCell = getCell(oTable.value(), location);
    if ( ! oCell.has_value())    { return {}; }

    auto oValue = getNumericCellValue(oCell.value());
    if ( ! oValue.has_value())    { return {}; }

    return (oValue.value() < 0);
}
```

C++23: Begone, Boilerplate!

```
std::optional<bool> isNumericTableCellValueNegative  
    (const CDb& db, const Key& key, const CLocation& location)  
{  
    return getElement(db, key)  
        .and_then(getTable)  
        .and_then(std::bind_back(&getCell, location))  
        .and_then(getNumericCellValue)  
        .transform(isNegative);  
}
```

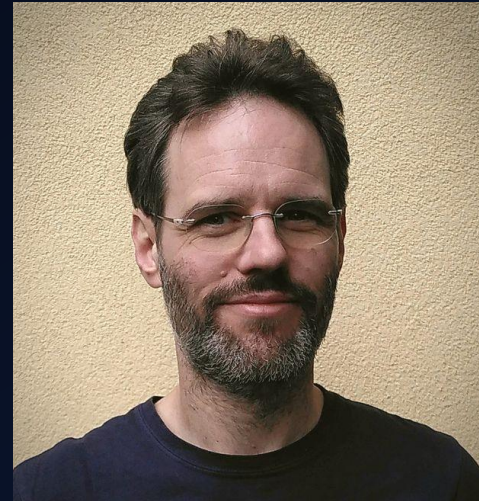


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Functors

WRAP & TRANSFORM



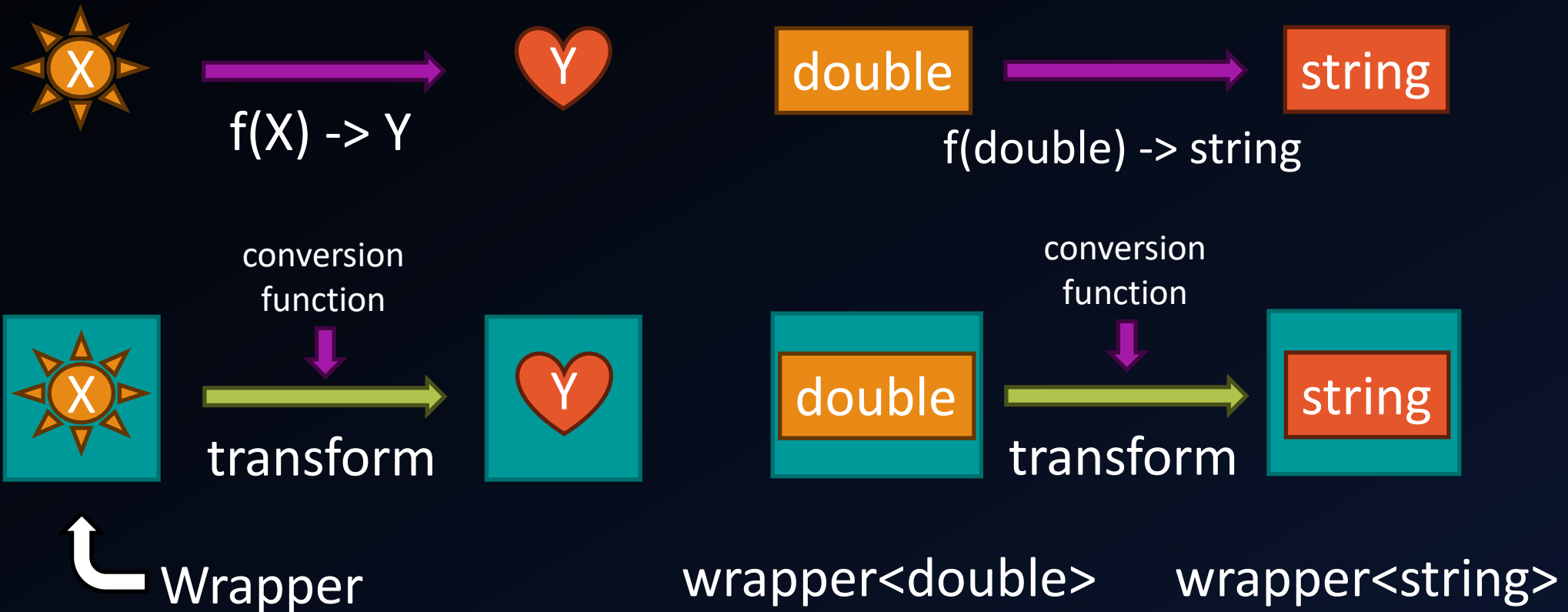
What is a Functor?

```
class CNegator
{
public:
    int operator()(const int value) const
    {
        return -value;
    }
};
```

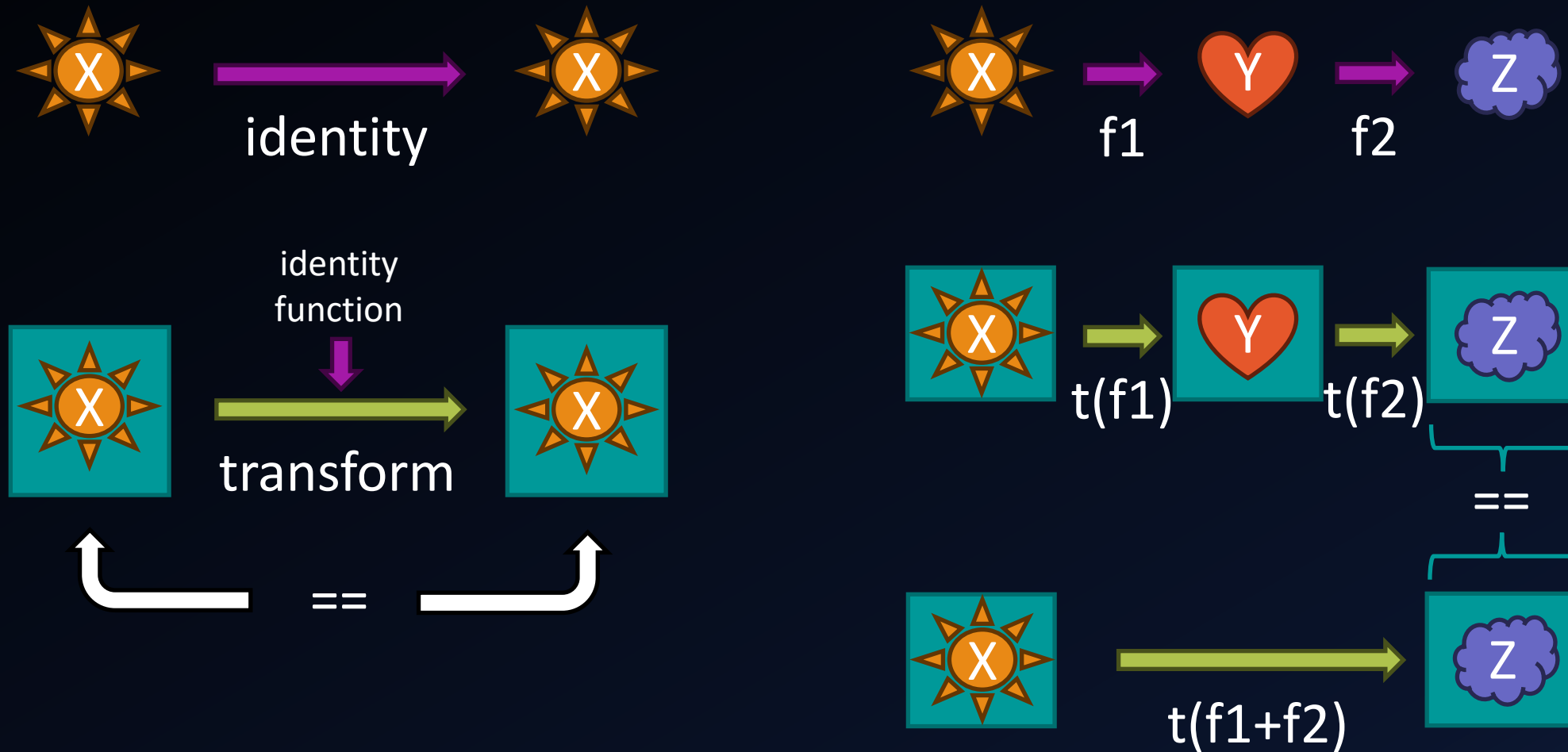
```
// ...
```

```
CNegator negator;
auto x = negator(5); // -5
```

Now really, what is a Functor?



Two rules for the Transformation



Example: From Classic Loop to Functor

```
auto v = std::vector{1.5,2.0,2.5};
```

```
std::vector<std::string> strings;  
for(const auto& value : v)  
{  
    strings.push_back(std::format("{:}",  
                                  std::pow(value,2.0)));  
}  
// 'strings' now contains {"2.25","4","6.25"}
```



Example: From Classic Loop to Functor

```
auto v = std::vector{1.5,2.0,2.5};  
  
std::vector<std::string> strings;  
for(const auto& value : v)  
{  
    strings.push_back(std::format("{:}",  
                                std::pow(value,2.0)));  
}  
// 'strings' now contains {"2.25","4","6.25"}
```



Example: From Classic Loop to Functor

```
auto v = std::vector{1.5,2.0,2.5};

std::vector<std::string> strings;
for(const auto& value : v)
{
    strings.push_back(std::format("{:}",
                                   std::pow(value,2.0)));
}
// 'strings' now contains {"2.25","4","6.25"}
```



Example: From Classic Loop to Functor

```
auto v = std::vector{1.5,2.0,2.5};

std::vector<std::string> strings;
for(const auto& value : v)
{
    strings.push_back(std::format("{:}",
                                   std::pow(value,2.0)));
}
// 'strings' now contains {"2.25","4","6.25"}
```



Example: From Classic Loop to Functor

```
auto v = std::vector{1.5,2.0,2.5};

std::vector<std::string> strings;
for(const auto& value : v)
{
    strings.push_back(std::format("{:}",
                                   std::pow(value,2.0)));
}
// 'strings' now contains {"2.25","4","6.25"}
```



Example: From Classic Loop to Functor

```
#include <format>
```

```
double makeSquared(const double value)
{
    return std::pow(value,2.0);
}
```

```
std::string dblToStr(const double value)
{
    return std::format("{:}",value);
}
```

Example: From Classic Loop to Functor

```
auto v = std::vector{1.5,2.0,2.5};

std::vector<std::string> strings;
for(const auto& value : v)
{
    strings.push_back(dbToStr(makeSquared(value)));
}

// 'strings' now contains {"2.25","4","6.25"}
```



Example: From Classic Loop to Functor

```
#include <format>
```

```
double makeSquared(const double value)
{
    return std::pow(value, 2.0);
}
```

```
std::string dblToStr(const double value)
{
    return std::format("{:}", value);
}
```



Example: From Classic Loop to Functor

```
#include <format>
```

```
double makeSquared(const double value)
{
    return std::pow(value, 2.0);
}
```

```
std::string dblToStr(const double value)
{
    return std::format("{:}", value);
}
```

A thought bubble containing the text "KYSS" in a stylized font. The "K" and "S" are teal, and the "Y" is orange. The bubble has a grey outline and three small circles leading to it.

KYSS

Example: From Classic Loop to Functor

```
#include <ranges>

auto v = std::vector{1.5, 2.0, 2.5};

auto strings = std::views::transform
               (std::views::transform(v, makeSquared),
                dblToStr);

// {"2.25", "4", "6.25"}
```



Example: From Classic Loop to Functor

```
#include <ranges>
```

```
auto v = std::vector{1.5,2.0,2.5};
```

```
auto strings = std::views::transform  
               (std::views::transform(v,makeSquared),  
                dblToStr);
```

```
// {"2.25", "4", "6.25"}
```



Example: From Classic Loop to Functor

```
#include <ranges>
```

```
auto v = std::vector{1.5,2.0,2.5};
```

```
auto strings = std::views::transform  
               (std::views::transform(v,makeSquared),  
                dblToStr);
```

```
// {"2.25", "4", "6.25"}
```



The Pipe to the Rescue

```
#include <ranges>

auto v = std::vector{1.5, 2.0, 2.5};

auto strings = v
    | std::views::transform(makeSquared)
    | std::views::transform(dblToStr);

// {"2.25", "4", "6.25"}
```




The Pipe to the Rescue

```
#include <ranges>

auto v = std::vector{1.5, 2.0, 2.5};

auto strings = v | std::views::transform(makeSquared)
                | std::views::transform(dblToStr);

// {"2.25", "4", "6.25"}
```



Classic Solution vs. Functor Solution

```
std::vector<std::string> strings;  
for(const auto& value : v)  
{  
    strings.push_back(dbToStr(makeSquared(value)));  
}
```

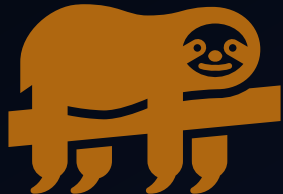
```
auto strings = v  
    | std::views::transform(makeSquared)  
    | std::views::transform(dbToStr);
```

View: Does not own or copy its data

Classic Solution vs. Functor Solution

```
std::vector<std::string> strings;  
for(const auto& value : v)  
{  
    strings.push_back(dbToStr(makeSquared(value)));  
}
```

```
auto strings = v  
| std::views::transform(makeSquared)  
| std::views::transform(dbToStr);
```



It's a Trap!

```
struct CEntry {  
    int m_X{};  
    int m_Y{};  
    std::string m_Text{}; };  
  
CEntry getNearestEntry(const int x) {...}  
  
using namespace std;  
auto v = vector{1,3,7};  
  
auto strings = v  
    | views::transform(getNearestEntry)  
    | views::transform(&CEntry::m_Text);  
  
printOutput(strings);
```



It's a Trap!

```
struct CEntry {  
    int m_X{};  
    int m_Y{};  
    std::string m_Text{}; };
```

```
CEntry getNearestEntry(const int x) {...}
```

```
using namespace std;  
auto v = vector{1,3,7};
```

```
auto strings = v  
    | views::transform(getNearestEntry)  
    | views::transform(&CEntry::m_Text);
```

```
printOutput(strings);
```



It's a Trap!

```
struct CEntry {  
    int m_X{};  
    int m_Y{};  
    std::string m_Text{}; };
```

```
CEntry getNearestEntry(const int x) {...}
```

```
using namespace std;  
auto v = vector{1,3,7};
```


```
auto strings = v  
    | views::transform(getNearestEntry)  
    | views::transform(&CEntry::m_Text);
```

```
printOutput(strings);
```



The Type of the Resulting View

```
class std::ranges::transform_view
<class std::ranges::transform_view
  <class std::ranges::ref_view
    <class std::vector
      <double, class std::allocator<double>>
    >, double (__cdecl*)(double)
  >,
class std::basic_string
  <char, struct std::char_traits<char>,
    class std::allocator<char>
  > (__cdecl*)(double)
>
```



Converting the output of views into a container

```
std::vector<std::string> convertViewResultToContainer()
{
    using namespace std;
    auto v = vector{1.5, 2.0, 2.5};

    auto strings = v
        | views::transform(makeSquared)
        | views::transform(db1ToStr);

    return ranges::to<vector<string>>(strings);
}
```



Inlining functions that return views

```
inline auto getSquaredNumbersAsString  
    (const std::vector<int>& vector)  
{  
    using namespace std;  
  
    auto strings = v  
        | views::transform(makeSquared)  
        | views::transform(db1ToStr);  
  
    return strings;  
}
```



Callables

DIFFERENT WAYS TO
FEED YOUR FUNCTOR (OR MONAD)



Callables: Free functions

```
double makeSquared(const double value) {...}
```

```
auto v = vector{1.5,2.0,2.5};  
auto strings = v  
    | std::views::transform(makeSquared)  
    | std::views::transform(dblToStr);
```



Callable: (Class) Static Functions

```
class CConv
{
public:
    static double makeSquaredStatic(const double value);
    //...
};
//...

auto v = vector{1.5,2.0,2.5};
auto strings = v
    | std::views::transform(CConv::makeSquaredStatic)
    | //...
```

Callables: Inline Lambda

```
using namespace std;

auto v = vector{1.5,2.0,2.5};
auto strings = v
    | views::transform([](const double& value)
        {return value * value;})
    | //...
```



Callables: Pick overload with Inline Lambda

```
double makeSquared(const double value) {...}  
int makeSquared(const int value) {...}
```

```
auto v = vector{1.5, 2.0, 2.5};  
auto strings = v  
    | std::views::transform([](auto&& val)  
                           {return makeSquared(val);})  
    | std::views::transform(dblToStr);
```



Callables: Inject Parameters via Inline Lambda

```
using namespace std;

const double power = 2.0;
auto v = vector{1.5, 2.0, 2.5};
auto strings = v
    | views::transform([power](const double& value)
        {return std::pow(value, power);})
    | ...
```



Callables: Inject Parameters via std::bind*

```
foo( int , bool , double )
```

```
std::bind_front ( foo, 42 , true ) -> f(double)
```

```
std::bind_back ( foo, true , 3.14 ) -> f(int)
```



Callable: Inject Parameters via `std::bind_back`

```
using namespace std;
```

```
const double power = 2.0;
```

```
auto v = vector{1.5, 2.0, 2.5};
```

```
auto strings = v
```

```
    | views::transform(
```

```
    |   std::bind_back(std::pow<double, double>, power)
```

```
    | //...
```



Callable: Inject Parameters via `std::bind_back`

```
using namespace std;

const double power = 2.0;
auto v = vector{1.5, 2.0, 2.5};
auto strings = v
    | views::transform(
        std::bind_back(std::pow<double, double>, power))
    | //...
```



Callable: Member Functions with std::mem_fn

```
struct CValue
{
    double getValue() const;
    //...
};

auto strings = std::vector{CValue{1.5},CValue{2.0}}
    | std::views::transform
      (std::mem_fn(&CValue::getValue))
    | std::views::transform(makeSquared)
    | //...
```



Callable: Member Functions with Lambda

```
struct CValue
{
    double getValue() const;
    //...
};

auto strings = std::vector{CValue{1.5},CValue{2.0}}
| std::views::transform(
    [](const CValue& obj){return obj.getValue();})
| std::views::transform(makeSquared)
| //...
```



Callable: Member Function from Params (std::bind*)

```
class CConv
{
public:
    double makeSquared(const double value);
};
//...

using namespace std;
CConv conv;
auto v = vector{1.5,2.0,2.5};
auto strings = v
    | views::transform(std::bind_front(&CConv::makeSquared, &conv))
    | //...
```


Callables: Member Functions from Params (Lambda)

```
class CConv
{
public:
    double makeSquared(const double value);
};
//...
```

```
using namespace std;
CConv conv;
auto v = vector{1.5,2.0,2.5};
auto strings = v
    | views::transform([&conv](const double& value)
        {return conv.makeSquaredMember(value);})
    | //...
```

Callables: Named Lambda

```
auto makeSquaredLocalLambda = [](const double value)
{
    return std::pow(value, 2.0);
};
```

```
auto v = vector{1.5, 2.0, 2.5};
auto strings = v
| std::views::transform(makeSquaredLocalLambda)
| //...
```



Callables: Function Object

```
struct CMakeSquared  
{  
    double operator()(const double value) const;  
};
```

```
CMakeSquared makeSquaredFunctionObject;  
auto v = vector{1.5, 2.0, 2.5};  
auto strings = v  
    | std::views::transform(makeSquaredFunctionObject)  
    | //...
```

Callables: std::function

```
#include <functional>
```

```
std::function<double(double)> fAnyFuncDb1InDb1Ret  
    = makeSquared;
```

```
//...
```

```
// Function could be a passed parameter, adding flexibility
```

```
auto v = vector{1.5,2.0,2.5};
```

```
auto strings = v
```

```
    | std::views::transform(fAnyFuncDb1InDb1Ret)  
    | //...
```

Callables: Template Parameter

```
template<class TMakeSquared>
```

```
void foo(const TMakeSquared& fMakeSquaredTemplate)
{
    auto v = vector{1.5,2.0,2.5};
    auto strings = v
        | std::views::transform(fMakeSquaredTemplate)
        | ...
}
```



Callables: Template Parameter

```
template<class TMakeSquared>
    requires std::invocable<TMakeSquared,double>
void foo(const TMakeSquared& fMakeSquaredTemplate)
{
    auto v = vector{1.5,2.0,2.5};
    auto strings = v
        | std::views::transform(fMakeSquaredTemplate)
        | //...
}
```



Callable: Summary

Inline Code `[] (const double& value)
{return value * value;}`

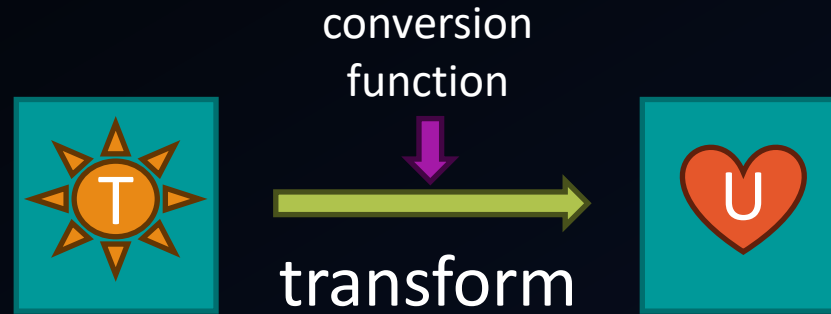
Extra Param `[power] (const double& value)
{return std::pow(value, power);})`

**Member
from instance** `[] (const CValue& obj){return obj.getValue();})`

**Member
with param** `[&conv] (const double& value)
{return conv.makeSquaredMember(value);}`

**Inject
callable** `std::function<double(double)> fMakeSquared
= makeSquared;`

Functors: Summary



```
auto strings = v
| std::views::transform(makeSquared)
| std::views::transform(dbToStr);
```

Functions, Class Instances, Lambdas,
std::function, Template parameter,...



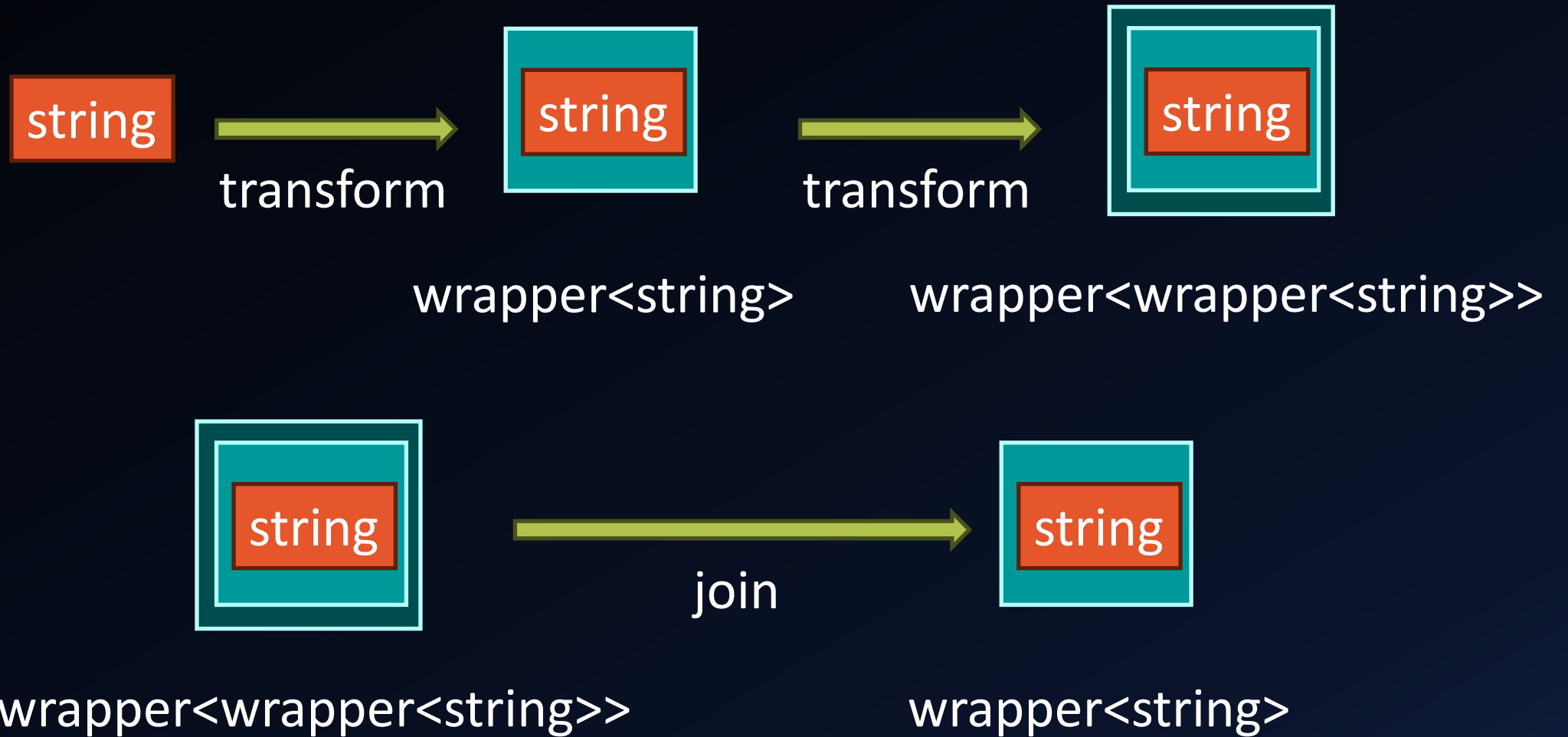
Monads

FUNCTORS+JOIN





Usage of Join



Printing Diagnostics: Conversion Functions

```
void printDiagnostic(const CDiagnostic& info);
```

```
std::vector<CDiagnostic> compile(const CFile& input);
```

```
std::vector<CFile> getFilesInProject(const CProject& input);
```



Printing Diagnostics: Conversion Functions

```
void printDiagnostic(const CDiagnostic& info);
```

```
std::vector<CDiagnostic> compile(const CFile& input);
```

```
std::vector<CFile> getFilesInProject(const CProject& input);
```



Printing Diagnostics: Conversion Functions

```
void printDiagnostic(const CDiagnostic& info);
```

```
std::vector<CDiagnostic> compile(const CFile& input);
```

```
std::vector<CFile> getFilesInProject(const CProject& input);
```



Printing Diagnostics: Classic Loop

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);

    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}
```

Printing Diagnostics: Classic Loop

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);

    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}
```


Printing Diagnostics: Classic Loop

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);

    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}
```

Printing Diagnostics: Classic Loop

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);

    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}
```

Printing Diagnostics: Classic Loop

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);

    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}
```

Printing Diagnostics: Classic Loop

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);

    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}
```

Printing Diagnostics: Range Monad

```
namespace vw = std::views;  
auto diagnostics = projects  
    | vw::transform(getFilesInProject) | vw::join  
    | vw::transform(compile)          | vw::join;  
  
std::ranges::for_each(diagnostics, printDiagnostic);
```

Printing Diagnostics: Range Monad

```
namespace vw = std::views;  
auto diagnostics = projects  
    | vw::transform(getFilesInProject) | vw::join  
    | vw::transform(compile)          | vw::join;  
  
std::ranges::for_each(diagnostics, printDiagnostic);
```

Printing Diagnostics: Range Monad

```
namespace vw = std::views;  
auto diagnostics = projects  
    | vw::transform(getFilesInProject) | vw::join  
    | vw::transform(compile)          | vw::join;  
  
std::ranges::for_each(diagnostics, printDiagnostic);
```



Printing Diagnostics: Range Monad

```
namespace vw = std::views;  
auto diagnostics = projects  
    | vw::transform(getFilesInProject) | vw::join  
    | vw::transform(compile)          | vw::join;  
  
std::ranges::for_each(diagnostics, printDiagnostic);
```


Printing Diagnostics: Range Monad

```
namespace vw = std::views;
auto diagnostics = projects
    | vw::transform(getFilesInProject) | vw::join
    | vw::transform(compile)          | vw::join;

std::ranges::for_each(diagnostics, printDiagnostic);
```

Printing Diagnostics: Range Monad

```
namespace vw = std::views;  
auto diagnostics = projects  
    | vw::transform(getFilesInProject) | vw::join  
    | vw::transform(compile)          | vw::join;  
  
std::ranges::for_each(diagnostics, printDiagnostic);
```

Printing Diagnostics: Range Monad

```
namespace vw = std::views;  
auto diagnostics = projects  
    | vw::transform(getFilesInProject) | vw::join  
    | vw::transform(compile)          | vw::join;  
  
std::ranges::for_each(diagnostics, printDiagnostic);
```



Printing Diagnostics: Code comparison

```
for(const auto& project : projects)
{
    auto files = getFilesInProject(project);
    for(const auto& file : files)
    {
        auto diagnostics = compile(file);
        for(const auto& diagnostic : diagnostics)
        {
            printDiagnostic(diagnostic);
        }
    }
}

namespace vw = std::views;
auto diagnostics = projects
    | vw::transform(getFilesInProject) | vw::join
    | vw::transform(compile)           | vw::join;
std::ranges::for_each(diagnostics, printDiagnostic);
```

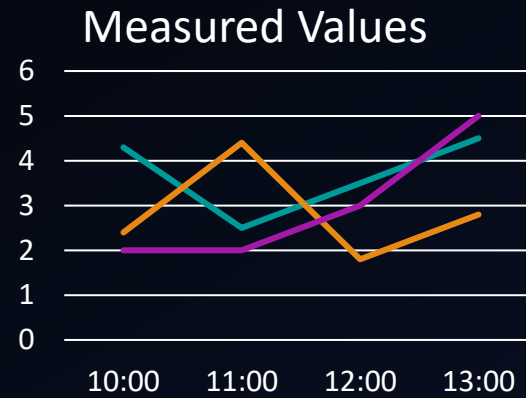
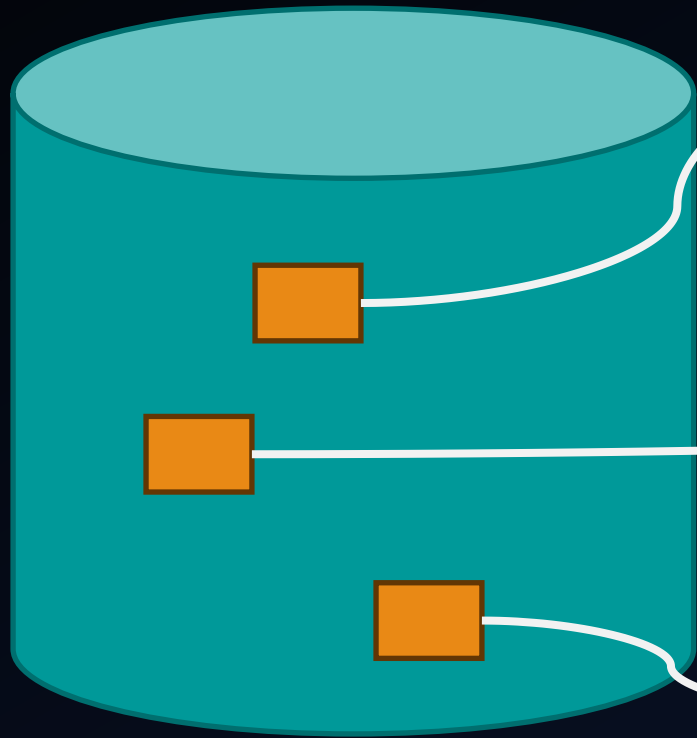


Handling Failure

THE OPTIONAL AND EXPECTED MONADS



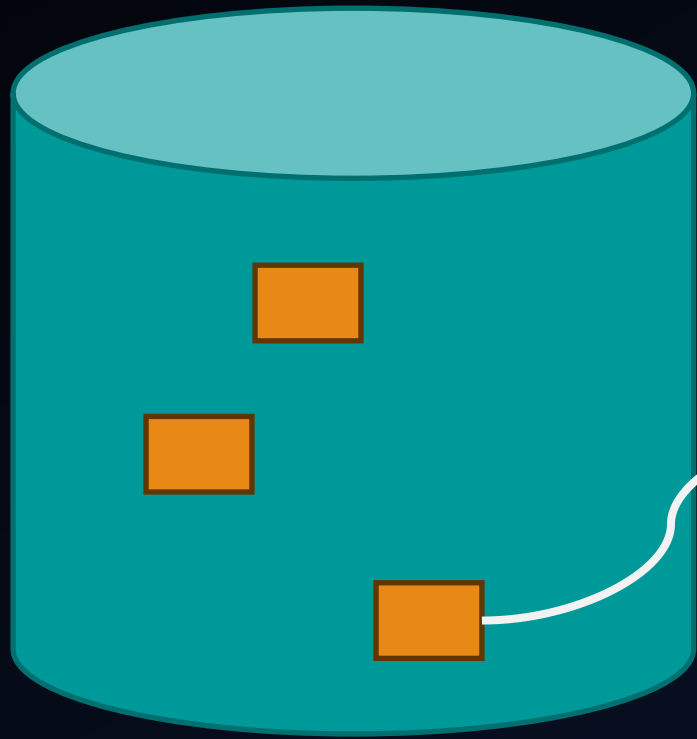
Chaining Functions That Can Fail



Stock	Item	Profit
0	Cup	11
2	T-Shirt	4
0	Poster	16
0	Statuette	-8

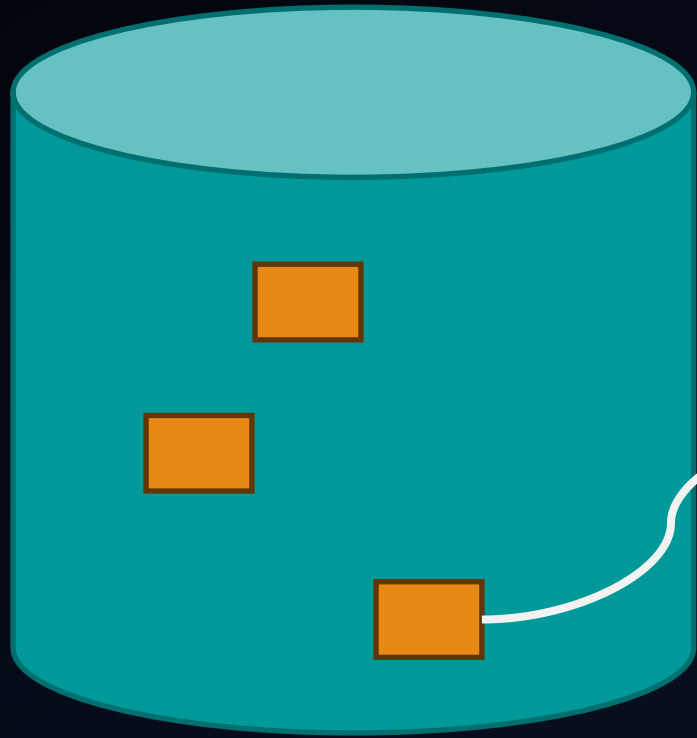


Chaining Functions That Can Fail



Stock	Item	Profit
0	Cup	11
2	T-Shirt	4
0	Poster	16
0	Statuette	-8

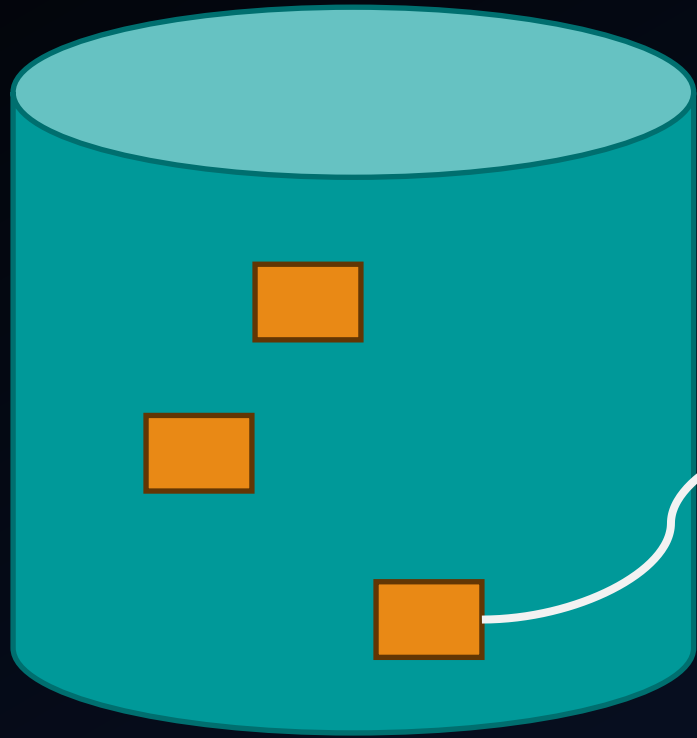
Chaining Functions That Can Fail



Stock	Item	Profit
0	Cup	
2	T-Shirt	
0	Poster	
0	Statuette	-8

Number?

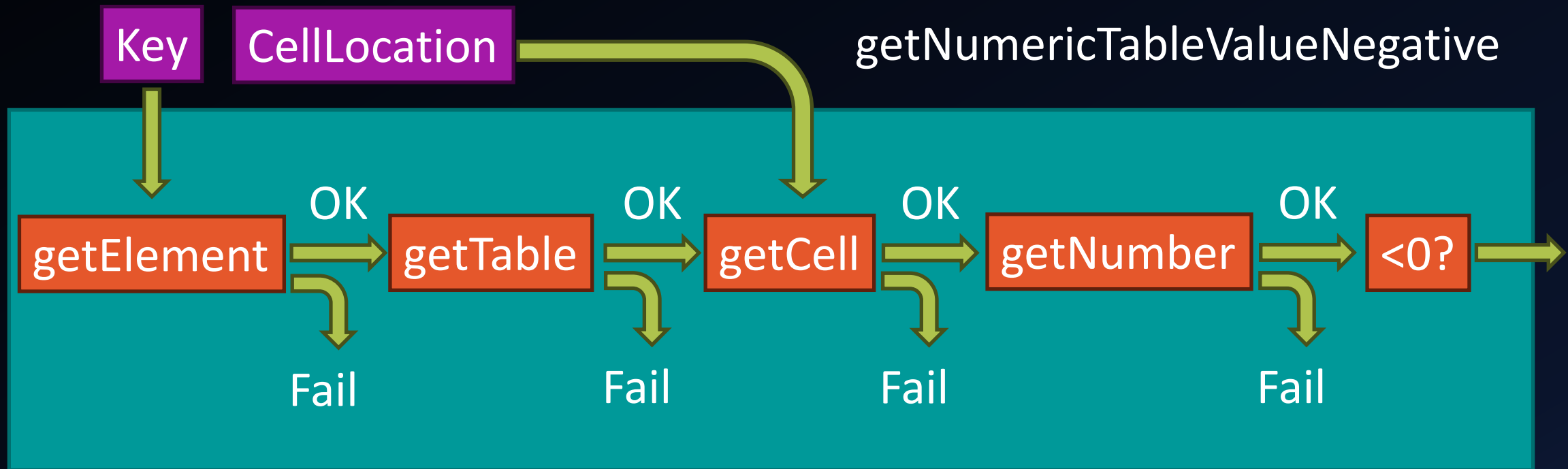
Chaining Functions That Can Fail



Stock	Item	Profit
0	Cup	
2	T-Shirt	
0	Poster	
0	Statuette	-8

Negative?

Chaining Functions That Can Fail



Chaining Functions That Can Fail: Classic Way

```
bool getElement(const CDb& db, const ElementKey& key,  
               CElement& out);
```

```
bool getTable(const CElement& element, CTable& out);
```

```
bool getCell(const CTable& table,  
            const CLocation& location CCell& out);
```

```
bool getNumericCellValue(const CCell& cell, int& out)
```



Chaining Functions That Can Fail: Classic Way

```
bool getElement(const CDb& db, const ElementKey& key,  
               CElement& out);
```

```
bool getTable(const CElement& element, CTable& out);
```

```
bool getCell(const CTable& table,  
            const CLocation& location CCell& out);
```

```
bool getNumericCellValue(const CCell& cell, int& out)
```



Chaining Functions That Can Fail: Classic Way

```
bool getElement(const CDb& db, const ElementKey& key,  
                CElement& out);
```

```
bool getTable(const CElement& element, CTable& out);
```

```
bool getCell(const CTable& table,  
             const CLocation& location CCell& out);
```

```
bool getNumericCellValue(const CCell& cell, int& out)
```



Chaining Functions That Can Fail: Classic Way

```
bool getElement(const CDb& db, const ElementKey& key,  
               CElement& out);
```

```
bool getTable(const CElement& element, CTable& out);
```

```
bool getCell(const CTable& table,  
            const CLocation& location CCell& out);
```

```
bool getNumericCellValue(const CCell& cell, int& out)
```



Chaining Functions That Can Fail: Classic Way

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))        { return false; }

    CTableData table;
    if ( ! getTable(element, table))            { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))      { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))    { return false; }

    result = (value < 0);
    return true;
}
```

Chaining Functions That Can Fail: Classic Way

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))        { return false; }

    CTableData table;
    if ( ! getTable(element, table))            { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))      { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))    { return false; }

    result = (value < 0);
    return true;
}
```


Chaining Functions That Can Fail: Classic Way

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))        { return false; }

    CTableData table;
    if ( ! getTable(element, table))            { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))      { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))    { return false; }

    result = (value < 0);
    return true;
}
```

Chaining Functions That Can Fail: Classic Way

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))        { return false; }

    CTableData table;
    if ( ! getTable(element, table))            { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))      { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))    { return false; }

    result = (value < 0);
    return true;
}
```

Chaining Functions That Can Fail: Classic Way

```
bool getNumericTableValueNegative
(const CDb& db, const Key& key,
 const CLocation& location, bool& out)
{
    CElement element;
    if ( ! getElement(db, key, element))           { return false; }

    CTableData table;
    if ( ! getTable(element, table))               { return false; }

    CTableCell cell;
    if ( ! getCell(table, location, cell))         { return false; }

    int value;
    if ( ! getNumericCellValue(cell, value))      { return false; }

    result = (value < 0);
    return true;
}
```

Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,  
                                     const ElementKey& key);
```

```
std::optional<CTable> getTable(const CElement& element);
```

```
std::optional<CCell> getCell(const CTable& tableData,  
                             const CLocation& location);
```

```
std::optional<int> getNumericCellValue(const CCell& cell);
```

```
bool isNegative(const int value);
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,
                                     const ElementKey& key)
{
    //...
    if (/* Key not found */)
    {
        return{}; // or: return std::nullopt;
    }
    CElement elem = //...
    return elem;
}
```

Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,
                                     const ElementKey& key)
{
    //...
    if (/* Key not found */)
    {
        return{}; // or: return std::nullopt;
    }
    CElement elem = //...
    return elem;
}
```

Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,  
                                     const ElementKey& key);
```

```
std::optional<CTable> getTable(const CElement& element);
```

```
std::optional<CCell> getCell(const CTable& tableData,  
                             const CLocation& location);
```

```
std::optional<int> getNumericCellValue(const CCell& cell);
```

```
bool isNegative(const int value);
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,  
                                     const ElementKey& key);
```

```
std::optional<CTable> getTable(const CElement& element);
```

```
std::optional<CCell> getCell(const CTable& tableData,  
                             const CLocation& location);
```

```
std::optional<int> getNumericCellValue(const CCell& cell);
```

```
bool isNegative(const int value);
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,  
                                     const ElementKey& key);
```

```
std::optional<CTable> getTable(const CElement& element);
```

```
std::optional<CCell> getCell(const CTable& tableData,  
                             const CLocation& location);
```

```
std::optional<int> getNumericCellValue(const CCell& cell);
```

```
bool isNegative(const int value);
```

Chaining Functions That Can Fail: The Optional Monad

```
std::optional<CElement> getElement(const CDb& db,  
                                     const ElementKey& key);
```

```
std::optional<CTable> getTable(const CElement& element);
```

```
std::optional<CCell> getCell(const CTable& tableData,  
                             const CLocation& location);
```

```
std::optional<int> getNumericCellValue(const CCell& cell);
```

```
bool isNegative(const int value);
```

Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative  
    (const CDb& db, const Key& key, const CLocation& location)  
{  
    return getElement(db, key)  
        .and_then(getTable)  
        .and_then(std::bind_back(&getCell, cellLocation))  
        .and_then(getNumericCellValue)  
        .transform(isNegative);  
}
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative  
    (const CDb& db, const Key& key, const CLocation& location)  
{  
    return getElement(db, key)  
        .and_then(getTable)  
        .and_then(std::bind_back(&getCell, cellLocation))  
        .and_then(getNumericCellValue)  
        .transform(isNegative);  
}
```



Quiz Time! – What makes this a monad?

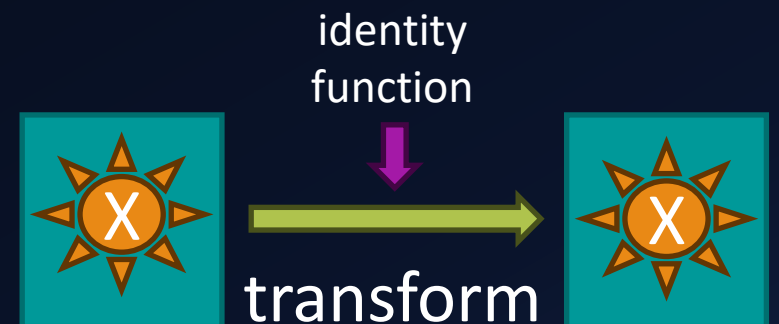
```
getElement(...) -> std::optional<CElement>
```

```
getElement(db, key)
    .and_then(getTable)
    //...
```

```
getTable(std::optional<CElement>) -> std::optional<CTable>
```

```
auto wrapped = std::optional<std::optional<int>>{5};
```

```
std::optional<int> unwrapped =  
    wrapped.and_then(std::identity{});
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative  
    (const CDb& db, const Key& key, const CLocation& location)  
{  
    return getElement(db, key)  
        .and_then(getTable)  
        .and_then(std::bind_back(&getCell, cellLocation))  
        .and_then(getNumericCellValue)  
        .transform(isNegative);  
}
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative  
    (const CDb& db, const Key& key, const CLocation& location)  
{  
    return getElement(db, key)  
        .and_then(getTable)  
        .and_then(std::bind back(&getCell, cellLocation))  
        .and_then(getNumericCellValue)  
        .transform(isNegative);  
}
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative  
    (const CDb& db, const Key& key, const CLocation& location)  
{  
    return getElement(db, key)  
        .and_then(getTable)  
        .and_then(std::bind_back(&getCell, cellLocation))  
        .and_then(getNumericCellValue)  
        .transform(isNegative);  
}
```



What you can do with an `std::optional`

```
std::optional<TRet> result = foo();
```

```
if (result.has_value())  
{  
    auto value = result.value();  
    //...  
}  
else  
{  
    //...  
}
```

What you can do with an `std::optional`

```
std::optional<TRet> result = foo();
```

```
if (result.has_value())  
{  
    auto value = result.value();  
    //...  
}  
else  
{  
    //...  
}
```

Chaining Functions That Can Fail: Code Comparison

```
CElement element;
if ( ! getElement(db, key, element))           { return false; }
CTableData table;
if ( ! getTable(element, table))               { return false; }
CTableCell cell;
if ( ! getCell(table, location, cell))         { return false; }
int value;
if ( ! getNumericCellValue(cell, value))      { return false; }
result = (value < 0); return true;

return getElement(db, key)
    .and_then(getTable)
    .and_then(std::bind_back(&getCell, cellLocation))
    .and_then(getNumericCellValue)
    .transform(isNegative);
```

Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative
(const CDb& db, const Key& key, const CLocation& location)
{
    return getElement(db, key)
        .and_then(getTable)
        .and_then(std::bind_back(&getCell, cellLocation))
        .and_then(getNumericCellValue)
        .transform(isNegative)
        .or_else(log<bool>);
}
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative
(const CDb& db, const Key& key, const CLocation& location)
{
    return getElement(db, key)
        .and_then(getTable)
        .and_then(std::bind_back(&getCell, cellLocation))
        .and_then(getNumericCellValue)
        .transform(isNegative)
        .or_else(log<bool>);
}
```

```
template<class TRet>
std::optional<TRet> log();
```



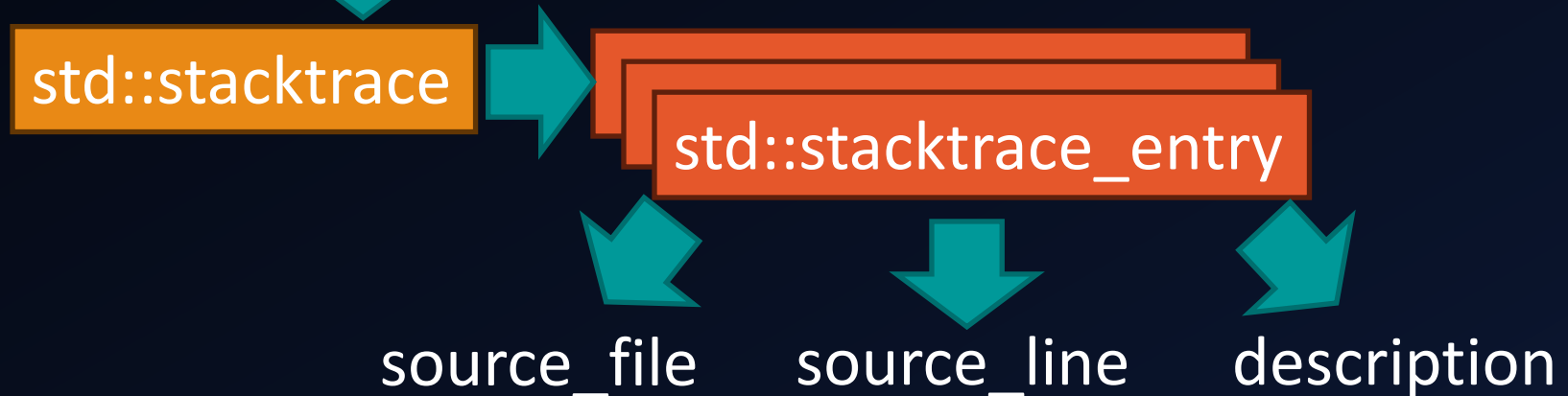
Catching failure: or_else

```
template<class TRet>
std::optional<TRet> COptionalMonad::log()
{
    std::println("Error:");
    dumpStack(std::stacktrace::current());
    return std::nullopt;
}
```



Catching failure: or_else

```
template<class TRet>
std::optional<TRet> COptionalMonad::log()
{
    std::println("Error at:");
    dumpStack(std::stacktrace::current());
    return std::nullopt;
}
```



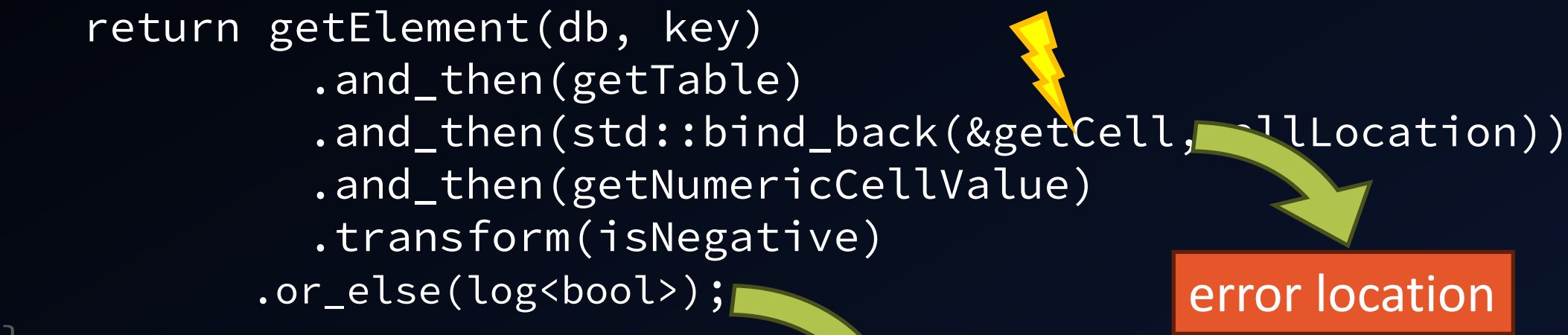
Catching failure: or_else

```
template<class TRet>
std::optional<TRet> COptionalMonad::log()
{
    std::println("Error:");
    dumpStack(std::stacktrace::current());
    return std::nullopt;
}
```



Chaining Functions That Can Fail: The Optional Monad

```
std::optional<bool> isNumericTableCellValueNegative
(const CDb& db, const Key& key, const CLocation& location)
{
    return getElement(db, key)
        .and_then(getTable)
        .and_then(std::bind_back(&getCell, cellLocation))
        .and_then(getNumericCellValue)
        .transform(isNegative)
        .or_else(log<bool>);
}
```



The diagram illustrates the error location in the provided C++ code. A yellow lightning bolt icon points to the `std::bind_back` function call in the `and_then` chain. A green arrow points from this location to an orange box labeled "error location". Another green arrow points from the `log<bool>` function call to the same "error location" box.

error location

call stack location



Returning Error State: The Expected Monad

```
std::optional<CElement> getElement  
    (const CDb& db, const ElementKey& key);
```

```
std::optional<CTable> getTable  
    (const CElement& element);
```

```
std::optional<CCell> getCell  
    (const CTable& tableData, const CLocation& location);
```

```
std::optional<int> getNumericCellValue  
    (const CCell& cell);
```

```
bool isNegative(const int value);
```

Returning Error State: The Expected Monad

```
std::expected<CElement, CErr> getElement  
    (const CDb& db, const ElementKey& key);
```

```
std::expected<CTable, CErr> getTable  
    (const CElement& element);
```

```
std::expected<CCell, CErr> getCell  
    (const CTable& tableData, const CLocation& location);
```

```
std::expected<int, CErr> getNumericCellValue  
    (const CCell& cell);
```

```
bool isNegative(const int value);
```



Returning Error State: The Expected Monad

```
std::expected<CElement, CErr> getElement(const CDb& db,
                                           const ElementKey& key)
{
    //...
    if (/* Key not found */)
    {
        return std::unexpected{CErr("Key not found")};
    }
    CElement elem = //...
    return elem;
}
```

Returning Error State: The Expected Monad

```
std::expected<CElement, CErr> getElement(const CDb& db,
                                           const ElementKey& key)
{
    //...
    if (/* Key not found */)
    {
        return std::unexpected{CErr("Key not found")};
    }
    CElement elem = //...
    return elem;
}
```

Returning Error State: The Expected Monad

```
std::expected<bool> isNumericTableCellValueNegative
(const CDb& db, const Key& key, const CLocation& location)
{
    return getElement(db, key)
        .and_then(getTable)
        .and_then(std::bind_back(&getCell, cellLocation))
        .and_then(getNumericCellValue)
        .transform(isNegative);
}
```



Returning Error State: The Expected Monad

```
std::expected<bool, CErr> isNumericTableCellValueNegative
(const CDb& db, const Key& key, const CLocation& location)
{
    return getElement(db, key)
        .and_then(getTable)
        .and_then(std::bind_back(&getCell, allLocation))
        .and_then(getNumericCellValue)
        .transform(isNegative)
        .or_else(log<bool>);
}
```

```
template<class TRet>
std::expected<TRet> log(const CErr& errorInfo);
```



CErr with callstack

Returning Error State: The Expected Monad

```
template<class TRet>
std::expected<TRet, CErr> CExpectedMonad::log
    (const CErr& errorInfo)
{
    std::println("Error: {:}", errorInfo.m_Message);
    dumpStack(errorInfo.m_Stack);
    return std::unexpected{errorInfo};
}
```


Returning Error State: The Expected Monad

```
template<class TRet>
std::expected<TRet, CErr> CExpectedMonad::log
                                   (const CErr& errorInfo)
{
    std::println("Error: {:}", errorInfo.m_Message);
    dumpStack(errorInfo.m_Stack);
    return std::unexpected{errorInfo};
}
```

Returning Error State: The Expected Monad

```
std::expected<TRet, CErr> result = foo();
```

```
if (result.has_value())  
{  
    auto value = result.value();  
    //...  
}  
else  
{  
    auto errorInfo = result.error();  
    //...  
}
```

Returning Error State: The Expected Monad

```
std::expected<TRet, CErr> result = foo();
```

```
if (result.has_value())  
{  
    auto value = result.value();  
    //...  
}  
else  
{  
    auto errorInfo = result.error();  
    //...  
}
```

Returning Error State: The Expected Monad

```
std::expected<TRet, CErr> result = foo();
```

```
if (result.has_value())  
{  
    auto value = result.value();  
    //...  
}  
else  
{  
    auto errorInfo = result.error();  
    //...  
}
```



The Default Monad

THE OTHER SIDE OF `STD::OPTIONAL`



Picking First Success: The Default Monad

```
std::optional<ELanguage> getLanguageFromCommandLine();  
std::optional<ELanguage> getLanguageFromRegistry();  
std::optional<ELanguage> getLanguageFromEnvironment();  
  
//Fallback: ELanguage::English
```



Picking First Success: The Default Monad

```
std::optional<ELanguage> getLanguageFromCommandLine();  
std::optional<ELanguage> getLanguageFromRegistry();  
std::optional<ELanguage> getLanguageFromEnvironment();  
  
//Fallback: ELanguage::English
```



Picking First Success: The Default Monad

```
std::optional<ELanguage> getLanguageFromCommandLine();  
std::optional<ELanguage> getLanguageFromRegistry();  
std::optional<ELanguage> getLanguageFromEnvironment();  
  
//Fallback: ELanguage::English
```



Picking First Success: The Default Monad

```
std::optional<ELanguage> getLanguageFromCommandLine();  
std::optional<ELanguage> getLanguageFromRegistry();  
std::optional<ELanguage> getLanguageFromEnvironment();  
  
//Fallback: ELanguage::English
```



Picking First Success: The Default Monad

```
std::optional<ELanguage> getLanguageFromCommandLine();
```

```
std::optional<ELanguage> getLanguageFromRegistry();
```

```
std::optional<ELanguage> getLanguageFromEnvironment();
```

```
//Fallback: ELanguage::English
```



Picking First Success: The Default Monad

```
ELanguage getStartupLanguage()  
{  
    return getLanguageFromCommandLine()  
           .or_else(getLanguageFromRegistry)  
           .or_else(getLanguageFromEnvironment)  
           .value_or(ELanguage::English);  
}
```



Picking First Success: The Default Monad

```
ELanguage getStartupLanguage()  
{  
    return getLanguageFromCommandLine()  
        .or_else(getLanguageFromRegistry)  
        .or_else(getLanguageFromEnvironment)  
        .value_or(ELanguage::English);  
}
```



Compiler Support (Minimum Required Version)

Feature	C++ Version	GCC	Clang	MSVC
std::format	20	13	17	19.29
std::views::transform	20	10	15	19.29
std::ranges::to	23	14	17	19.34
std::bind_front	20	9	13	19.25
std::bind_back	23	14	19	19.34
std::optional::and_then / or_else	23	12	14	19.32
std::print / std::println	23	14	18	19.37
std::stacktrace	23	-	-	19.34
std::expected	23	12	16	19.33
Current compiler version		14.2	19.1	19.40

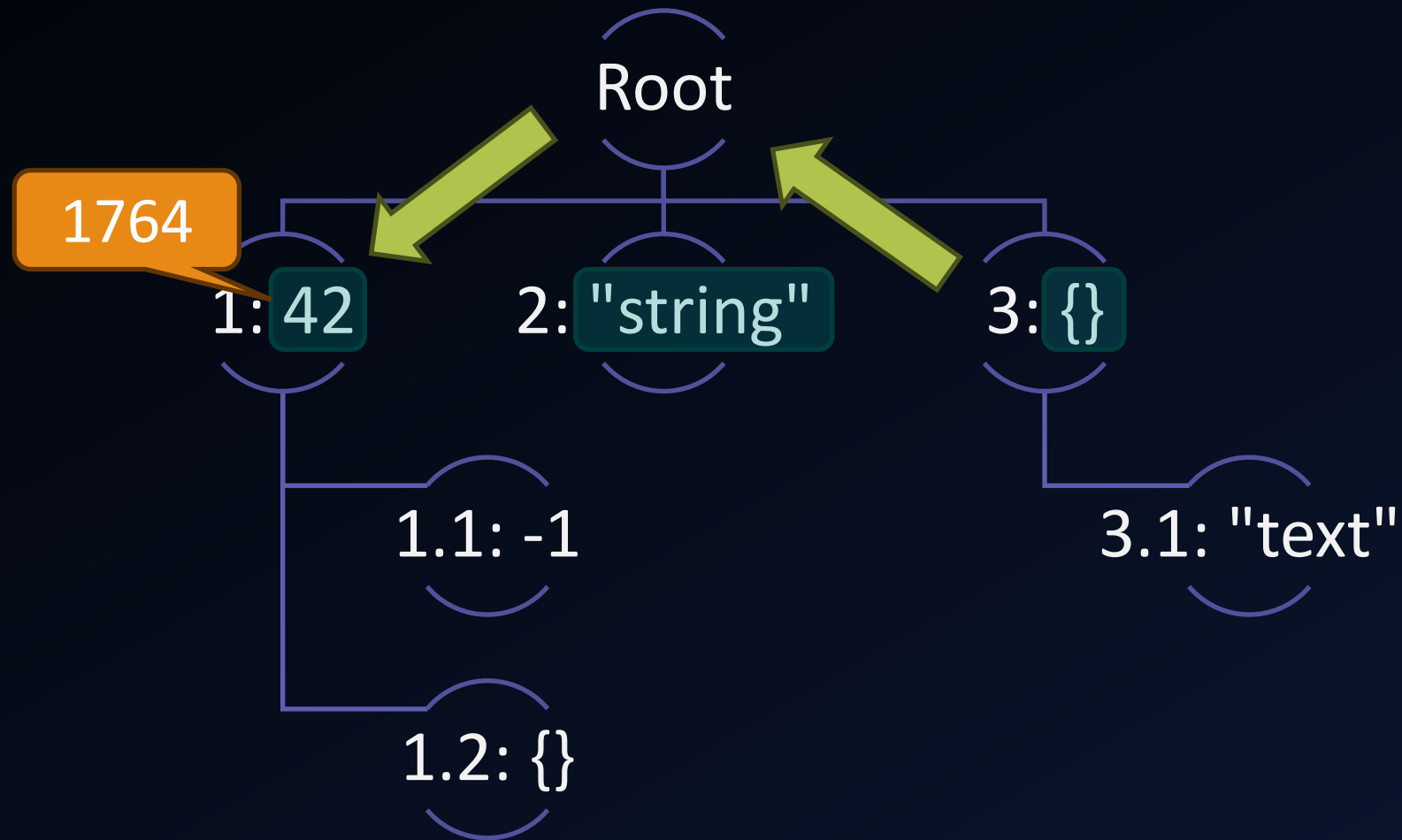


Beyond C++23

MORE MONADS



Maybe Null: Chaining Functions That Return Pointers



Maybe Null: Chaining Functions That Return Pointers

```
using CContent = std::variant<std::monostate, int, std::string>;

class CNode
{
public:
    //...
    CNode* getParent();
    CNode* getChild(const CNodeKey nodeKey);

    CContent getContent() const;
    void setContent(const CContent& arg);
    //...
};
```


Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    if ( ! pNodeStart)        { return{}; }  
  
    auto* const pParent = pNodeStart->getParent();  
    if ( ! pParent)          { return{}; }  
  
    auto* const pSibling = pParent->getChild(siblingKey);  
    auto oNumericValue = getNodeNumericValue(pSibling);  
    return oNumericValue.transform(makeSquared);  
}
```

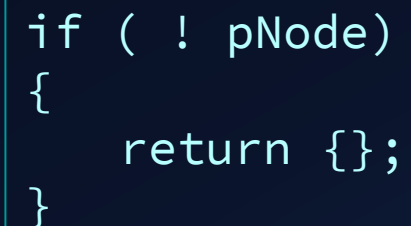


Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    if ( ! pNodeStart)        { return{}; }  
  
    auto* const pParent = pNodeStart->getParent();  
    if ( ! pParent)          { return{}; }  
  
    auto* const pSibling = pParent->getChild(siblingKey);  
    auto oNumericValue = getNodeNumericValue(pSibling);  
    return oNumericValue.transform(makeSquared);  
}
```

Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    if ( ! pNodeStart)          { return{}; }  
  
    auto* const pParent = pNodeStart->getParent();  
    if ( ! pParent)          { return{}; }  
  
    auto* const pSibling = pParent->getChild(siblingKey);  
    auto oNumericValue = getNodeNumericValue(pSibling);  
    return oNumericValue.transform(makeSquared);  
}
```



```
if ( ! pNode)  
{  
    return {};  
}
```

Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    if ( ! pNodeStart)        { return{}; }  
  
    auto* const pParent = pNodeStart->getParent();  
    if ( ! pParent)          { return{}; }  
  
    auto* const pSibling = pParent->getChild(siblingKey);  
    auto oNumericValue = getNodeNumericValue(pSibling);  
    return oNumericValue.transform(makeSquared);  
}
```

Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    return CPtr(pNodeStart)  
        .and_then(std::mem_fn(&CNode::getParent))  
        .and_then(std::mem_fn(&CNode::getChild), siblingKey)  
        .and_then(getNodeNumericValue)  
        .transform(makeSquared);  
}
```



Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    return CPtr(pNodeStart)  
        .and_then(std::mem_fn(&CNode::getParent))  
        .and_then(std::mem_fn(&CNode::getChild), siblingKey)  
        .and_then(getNodeNumericValue)  
        .transform(makeSquared);  
}
```



Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    return CPtr(pNodeStart)  
        .and_then(std::mem_fn(&CNode::getParent))  
        .and_then(std::mem_fn(&CNode::getChild), siblingKey)  
        .and_then(getNodeNumericValue)  
        .transform(makeSquared);  
}
```



Maybe Null: Chaining Functions That Return Pointers

```
std::optional<int> getNodeNumericValue(CNode& node)
{
    auto content = node.getContent();
    if ( ! std::holds_alternative<int>(content)) { return{}; }

    return std::get<int>(content);
}
```



Implementing A Pointer Monad

```
template<class TPtr>
struct CPtr {
    CPtr() = default;
    explicit CPtr(const TPtr& ptr);

    TPtr operator->() const;
    operator bool() const;
    bool operator!() const;

    //...
private:
    TPtr m_Ptr{};
};
```

Implementing A Pointer Monad

```
template<cIsPointer TPtr>
struct CPtr {
    CPtr() = default;
    explicit CPtr(const TPtr& ptr);

    TPtr operator->() const;
    operator bool() const;
    bool operator!() const;

    //...
private:
    TPtr m_Ptr{};
};
```

```
template<class T>
concept cIsPointer = std::is_pointer_v<T>;
```

Implementing A Pointer Monad

```
template<class TPtr>
struct CPtr {
    CPtr() = default;
    explicit CPtr(const TPtr& ptr);

    TPtr operator->() const;
    operator bool() const;
    bool operator!() const;

    //...
private:
    TPtr m_Ptr{};
};
```

Implementing A Pointer Monad

```
template<class TPtr>
CPtr<TPtr>::CPtr(const TPtr& ptr)
    : m_Ptr(ptr)
{}
```



Implementing A Pointer Monad

```
template<class TPtr>
struct CPtr {
    CPtr() = default;
    explicit CPtr(const TPtr& ptr);
```

```
    TPtr operator->() const;
    operator bool() const;
    bool operator!() const;
```

```
    //...
private:
    TPtr m_Ptr{};
};
```



Implementing A Pointer Monad

```
template<cIsPointer TPtr>
T CPtr<TPtr>::operator->>() const
{ return m_Ptr; }
```

```
template<cIsPointer TPtr>
CPtr<TPtr>::operator bool() const
{ return m_Ptr; }
```

```
template<cIsPointer TPtr>
bool CPtr<TPtr>::operator!() const
{ return ! m_Ptr; }
```



Implementing A Pointer Monad

```
template<class TPtr>
struct CPtr {
    //...
```

```
    template<class TCall, class... TArgs>
    auto and_then(TCall&& fInvoke, TArgs... args);
```

```
private:
    TPtr m_Ptr{};
};
```

Implementing A Pointer Monad

```
template<cIsPointer TPtr>
template<class TCall, class... TArgs>
auto CPtr<TPtr>::and_then(TCall&& fInvoke, TArgs... args)
{
    using TRef = std::add_lvalue_reference_t<std::remove_pointer_t<TPtr>>;
    using TRet = std::invoke_result_t<TCall,TRef,TArgs...>;
    static_assert(std::is_invocable_v<TCall,TRef, TArgs...>);
    if constexpr (cIsPointer<TRet>)
    {
        //...return type is a pointer
    }
    else
    {
        //...return type is NOT a pointer
    }
}
```


Implementing A Pointer Monad

```
template<cIsPointer TPtr>
template<class TCall, class... TArgs>
auto CPtr<TPtr>::and_then(TCall&& fInvoke, TArgs... args)
{
    using TRef = std::add_lvalue_reference_t<std::remove_pointer_t<TPtr>>;
    using TRet = std::invoke_result_t<TCall,TRef,TArgs...>;
    static_assert(std::is_invocable_v<TCall,TRef, TArgs...>);
    if constexpr (cIsPointer<TRet>)
    {
        //...return type is a pointer
    }
    else
    {
        //...return type is NOT a pointer
    }
}
```

Implementing A Pointer Monad

```
template<cIsPointer TPtr>
template<class TCall, class... TArgs>
auto CPtr<TPtr>::and_then(TCall&& fInvoke, TArgs... args)
{
    using TRef = std::add_lvalue_reference_t<std::remove_pointer_t<TPtr>>;
    using TRet = std::invoke_result_t<TCall,TRef,TArgs...>;
    static_assert(std::is_invocable_v<TCall,TRef, TArgs...>);
    if constexpr (cIsPointer<TRet>)
    {
        //...return type is a pointer
    }
    else
    {
        //...return type is NOT a pointer
    }
}
```

Implementing A Pointer Monad

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template<cIsPointer TPtr>
template<class TCall, class... TArgs>
auto CPtr<TPtr>::and_then(TCall&& fInvoke, TArgs... args)
{
    using TRef = std::add_lvalue_reference_t<std::remove_pointer_t<TPtr>>;
    using TRet = std::invoke_result_t<TCall, TRef, TArgs...>;
    static_assert(std::is_invocable_v<TCall, TRef, TArgs...>);
    if constexpr (cIsPointer<TRet>)
    {
        //...return type is a pointer
    }
    else
    {
        //...return type is NOT a pointer
    }
}
```

Implementing A Pointer Monad

```
template<cIsPointer TPtr>
template<class TCall, class... TArgs>
auto CPtr<TPtr>::and_then(TCall&& fInvoke, TArgs... args)
{
    using TRef = std::add_lvalue_reference_t<std::remove_pointer_t<TPtr>>;
    using TRet = std::invoke_result_t<TCall,TRef,TArgs...>;
    static_assert(std::is_invocable_v<TCall,TRef, TArgs...>);
    if constexpr (cIsPointer<TRet>)
    {
        //...return type is a pointer
    }
    else
    {
        //...return type is NOT a pointer
    }
}
```

Implementing A Pointer Monad

```
if constexpr (cIsPointer<TRet>)
{
    if (m_Ptr)
    {
        return CPtr<TRet>(std::invoke(std::forward<TCall>(fInvoke),
                                       *m_Ptr, std::forward<TArgs>(args)...));
    }
    return CPtr<TRet>{};
}
```



Implementing A Pointer Monad

```
if constexpr (cIsPointer<TRet>)
{
    if (m_Ptr)
    {
        return CPtr<TRet>(std::invoke(std::forward<TCall>(fInvoke),
                                       *m_Ptr, std::forward<TArgs>(args)...));
    }
    return CPtr<TRet>{};
}
```



Implementing A Pointer Monad

```
if constexpr (cIsPointer<TRet>)
{
    if (m_Ptr)
    {
        return CPtr<TRet>(std::invoke(std::forward<TCall>(fInvoke),
                                       *m_Ptr, std::forward<TArgs>(args)...));
    }
    return CPtr<TRet>{};
}
```

Implementing A Pointer Monad

```
if constexpr (cIsPointer<TRet>)
{
    if (m_Ptr)
    {
        return CPtr<TRet>(std::invoke(std::forward<TCall>(fInvoke),
                                       *m_Ptr, std::forward<TArgs>(args)...));
    }
    return CPtr<TRet>{};
}
```


Implementing A Pointer Monad

```
if constexpr (cIsPointer<TRet>)
{
    if (m_Ptr)
    {
        return CPtr<TRet>(std::invoke(std::forward<TCall>(fInvoke),
                                       *m_Ptr, std::forward<TArgs>(args)...));
    }
    return CPtr<TRet>{};
}
```

Rolling Our Own: A Pointer Monad

```
template<cIsPointer TPtr>
template<class TCall, class... TArgs>
auto CPtr<TPtr>::and_then(TCall&& fInvoke, TArgs... args)
{
    using TRef = std::add_lvalue_reference_t<std::remove_pointer_t<TPtr>>;
    using TRet = std::invoke_result_t<TCall,TRef,TArgs...>;
    static_assert(std::is_invocable_v<TCall,TRef, TArgs...>);
    if constexpr (cIsPointer<TRet>)
    {
        //...return type is a pointer
    }
    else
    {
        //...return type is NOT a pointer
    }
}
```

Implementing A Pointer Monad

```
else // Return type is not a pointer
{
    using TValue = TRet::value_type;
    static_assert(std::is_same_v<std::optional<TValue>, TRet>,
        "Return type is neither pointer nor std::optional");
    if (m_Ptr)
    {
        return std::invoke(std::forward<TCall>(fInvoke),
            *m_Ptr, std::forward<TArgs>(args)...);
    }
    return std::remove_cvref_t<TRet>{};
}
```

Implementing A Pointer Monad

```
else // Return type is not a pointer
{
    using TValue = TRet::value_type;
    static_assert(std::is_same_v<std::optional<TValue>, TRet>,
        "Return type is neither pointer nor std::optional");
    if (m_Ptr)
    {
        return std::invoke(std::forward<TCall>(fInvoke),
            *m_Ptr, std::forward<TArgs>(args)...);
    }
    return std::remove_cvref_t<TRet>{};
}
```

Implementing A Pointer Monad

```
else // Return type is not a pointer
{
    using TValue = TRet::value_type;
    static_assert(std::is_same_v<std::optional<TValue>, TRet>,
        "Return type is neither pointer nor std::optional");
    if (m_Ptr)
    {
        return std::invoke(std::forward<TCall>(fInvoke),
            *m_Ptr, std::forward<TArgs>(args)...);
    }
    return std::remove_cvref_t<TRet>{};
}
```

Implementing A Pointer Monad

```
else // Return type is not a pointer
{
    using TValue = TRet::value_type;
    static_assert(std::is_same_v<std::optional<TValue>, TRet>,
        "Return type is neither pointer nor std::optional");
    if (m_Ptr)
    {
        return std::invoke(std::forward<TCall>(fInvoke),
            *m_Ptr, std::forward<TArgs>(args)...);
    }
    return std::remove_cvref_t<TRet>{};
}
```

Implementing A Pointer Monad

```
if constexpr (cIsPointer<TRet>)
{
    if (m_Ptr)
    {
        return CPtr<TRet>(std::invoke(std::forward<TCall>(fInvoke), //...
    }
    return CPtr<TRet>{};
}
else // Return type is not a pointer
{
    if (m_Ptr)
    {
        return std::invoke(std::forward<TCall>(fInvoke), //...
    }
    return std::remove_cvref_t<TRet>{};
}
```

Implementing A Pointer Monad

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    return CPtr(pNodeStart)  
        .and_then(std::mem_fn(&CNode::getParent))  
        .and_then(std::mem_fn(&CNode::getChild), siblingKey)  
        .and_then(getNodeNumericValue)  
        .transform(makeSquared);  
}
```


Implementing A Pointer Monad

```
std::optional<int> getSiblingValueSquared  
    (CNode* pNodeStart, const CNodeKey& siblingKey)  
{  
    return CPtr(pNodeStart)  
        .and_then(std::mem_fn(&CNode::getParent))  
        .and_then(std::mem_fn(&CNode::getChild), siblingKey)  
        .and_then(getNodeNumericValue)  
        .transform(makeSquared);  
}
```



Pointer Monad – Features Beyond this Talk

- Support functions returning CPtr
- Support functions returning values and references (transform)
- Add or_else
- Test functions with const return values / const parameters
- Consider adding error information (like std::expected)
- Test edge cases and make error messages nice



Pointer Monad – Summary

- Writing monads does not need a lot of code
- General advice for writing template code applies
 - Test for specific types
 - Think about how different value categories affect your code
 - Use concepts and `static_assert` to prevent misuse at compile time



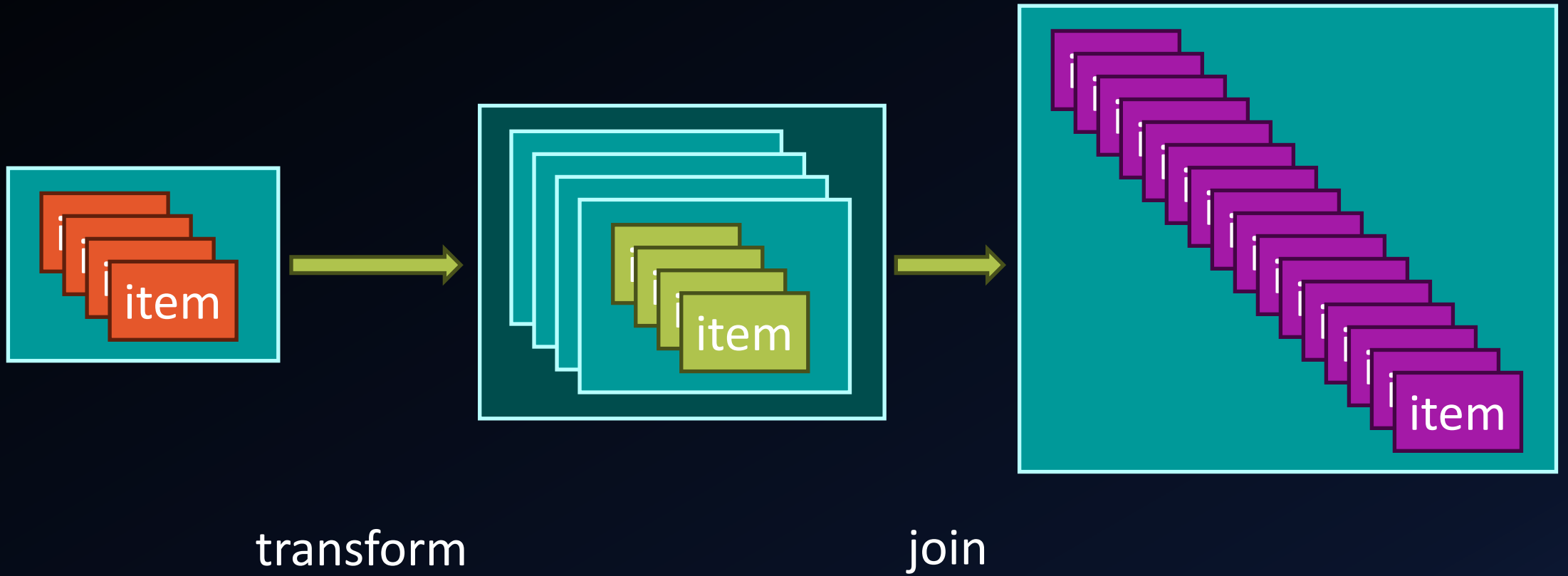


Monad Use Cases

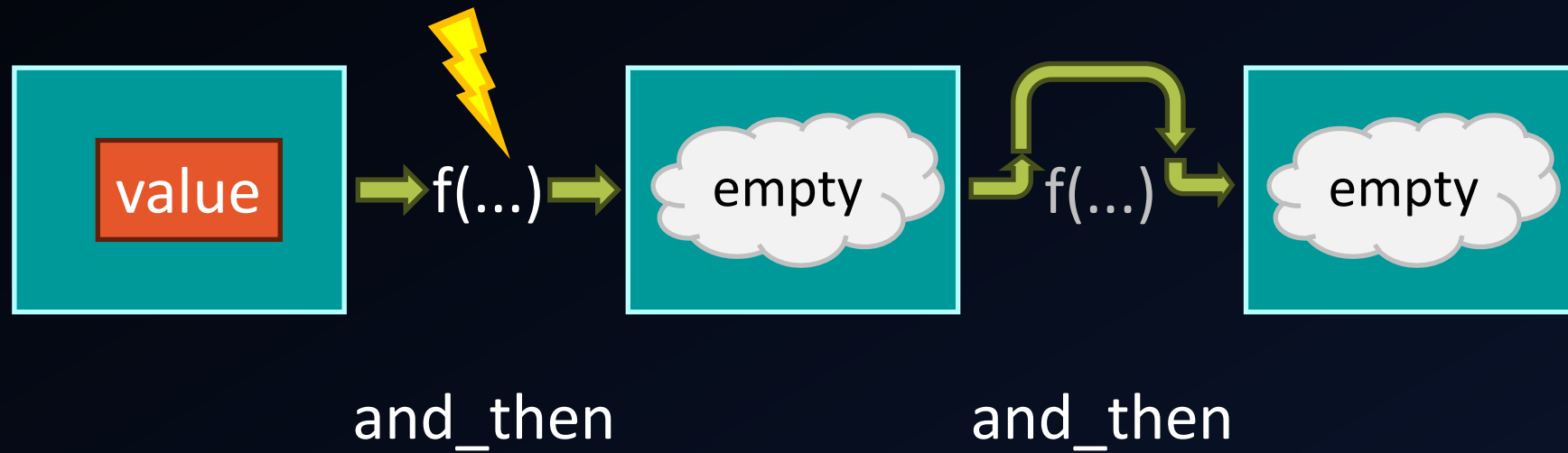
WHAT ELSE YOU CAN DO WITH THEM



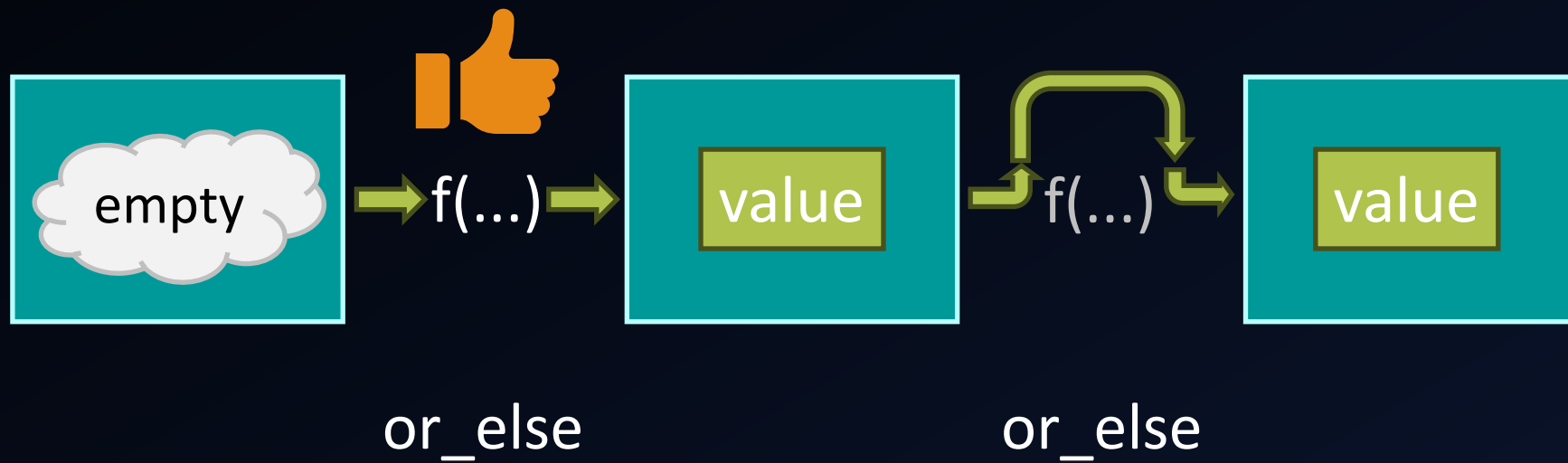
Ranges Monad



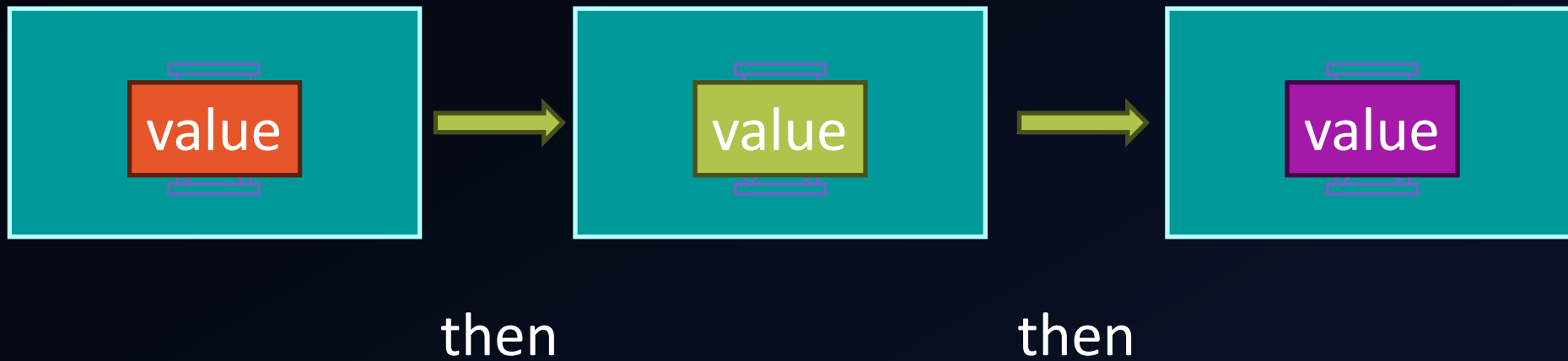
Optional ("Maybe") Monad



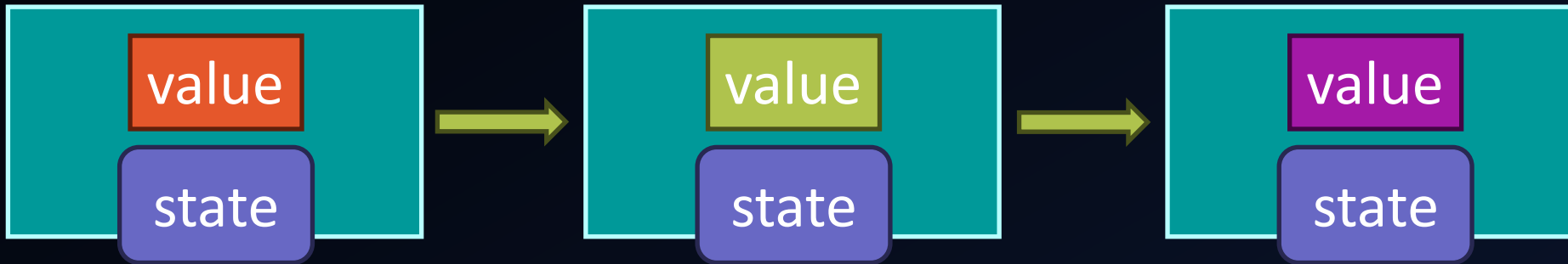
Default Monad



Continuation Monad

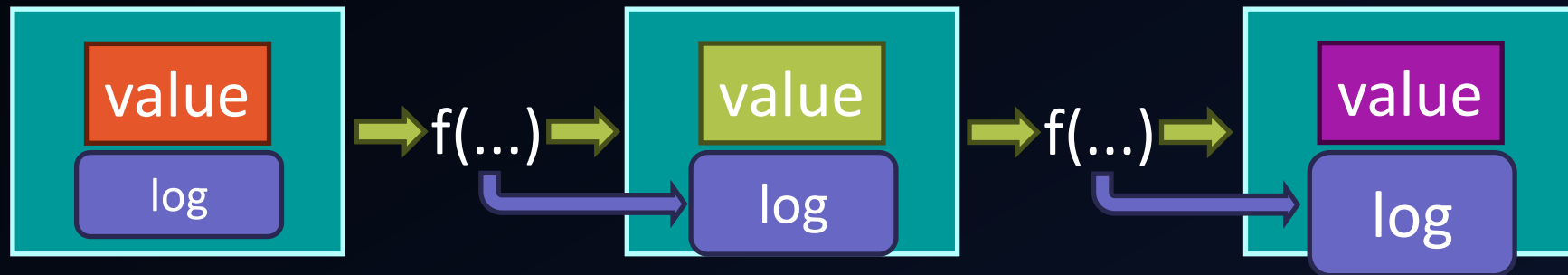


State Monad

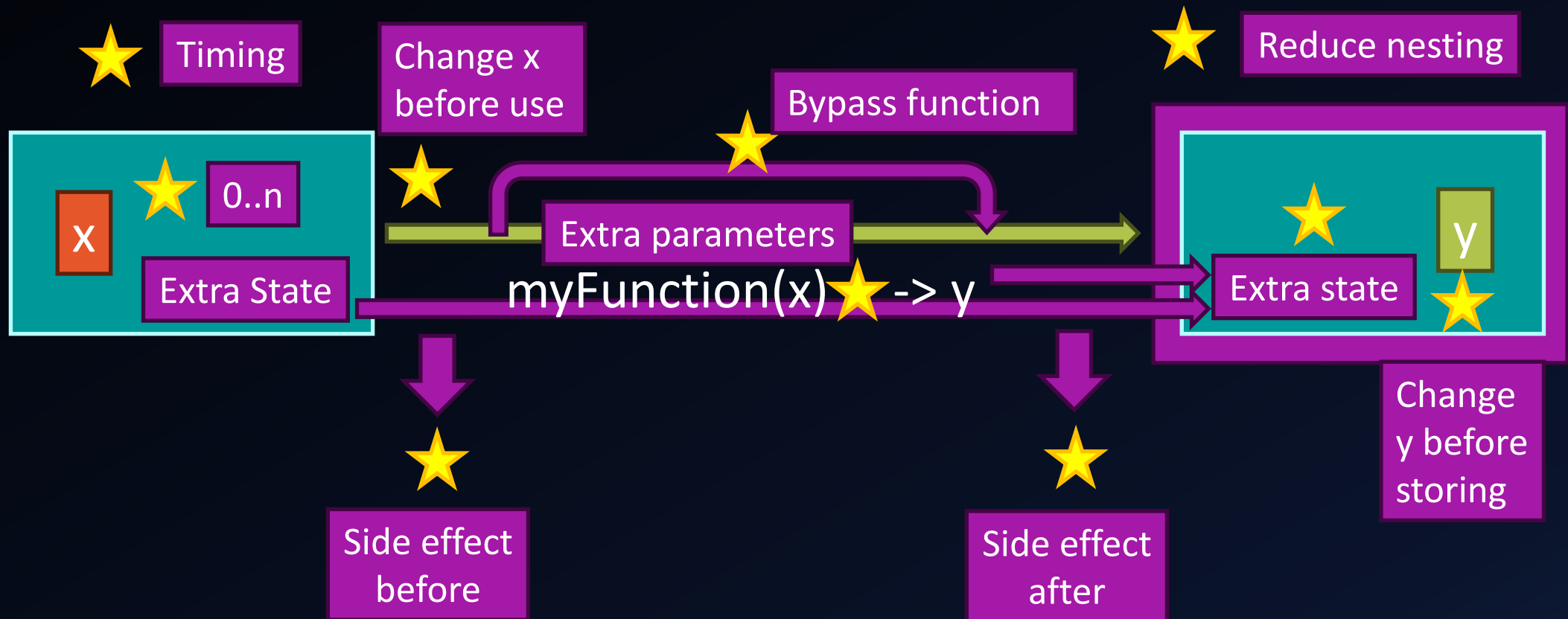


```
newValue = f(value, state);
```

Writer Monad



The Power of Monads



Getting started

```
auto diagnostics = projects
    | vw::transform(getFilesInProject)           | vw::join
    | vw::transform(compile)                     | vw::join;

return getElement(db, key)
    .and_then(getTable)
    .and_then(std::bind_back(&getCell, cellLocation))
    .and_then(getNumericCellValue)
    .transform(isNegative);

return getLanguageFromCommandLine()
    .or_else(getLanguageFromRegistry)
    .or_else(getLanguageFromEnvironment)
    .value_or(ELanguage::English);
```

Getting started

```
auto diagnostics = projects
    | vw::transform(getFilesInProject)          | vw::join
    | vw::transform(compile)                   | vw::join;

return getElement(db, key)
    .and_then(getTable)
    .and_then(std::bind_back(&getCell, cellLocation))
    .and_then(getNumericCellValue)
    .transform(isNegative);

return getLanguageFromCommandLine()
    .or_else(getLanguageFromRegistry)
    .or_else(getLanguageFromEnvironment)
    .value_or(ELanguage::English);
```

Getting started

```
auto diagnostics = projects
    | vw::transform(getFilesInProject)      | vw::join
    | vw::transform(compile)               | vw::join;
```

```
return getElement(db, key)
    .and_then(getTable)
    .and_then(std::bind_back(&getCell, cellLocation))
    .and_then(getNumericCellValue)
    .transform(isNegative);
```

```
return getLanguageFromCommandLine()
    .or_else(getLanguageFromRegistry)
    .or_else(getLanguageFromEnvironment)
    .value_or(ELanguage::English);
```

Getting started

```
auto diagnostics = projects
    | vw::transform(getFilesInProject)           | vw::join
    | vw::transform(compile)                     | vw::join;

return getElement(db, key)
    .and_then(getTable)
    .and_then(std::bind_back(&getCell, cellLocation))
    .and_then(getNumericCellValue)
    .transform(isNegative).or_else(log<bool>);

return getLanguageFromCommandLine()
    .or_else(getLanguageFromRegistry)
    .or_else(getLanguageFromEnvironment)
    .value_or(ELanguage::English);
```

Getting started

```
auto diagnostics = projects
    | vw::transform(getFilesInProject)           | vw::join
    | vw::transform(compile)                     | vw::join;

return getElement(db, key)
    .and_then(getTable)
    .and_then(std::bind_back(&getCell, cellLocation))
    .and_then(getNumericCellValue)
    .transform(isNegative).or_else(log<bool>);

return getLanguageFromCommandLine()
    .or_else(getLanguageFromRegistry)
    .or_else(getLanguageFromEnvironment)
    .value_or(ELanguage::English);
```


Monadic Operations in C++23



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<https://github.com/Asperamanca/>

<https://cppusergroupvienna.org/>

References



https://github.com/Asperamanca/monadic_operations_cpp23