Monadic Operations in C++23

ROBERT SCHIMKOWITSCH

https://mastodon.social/@asperamanca
https://github.com/Asperamanca/
https://cppusergroupvienna.org/

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?

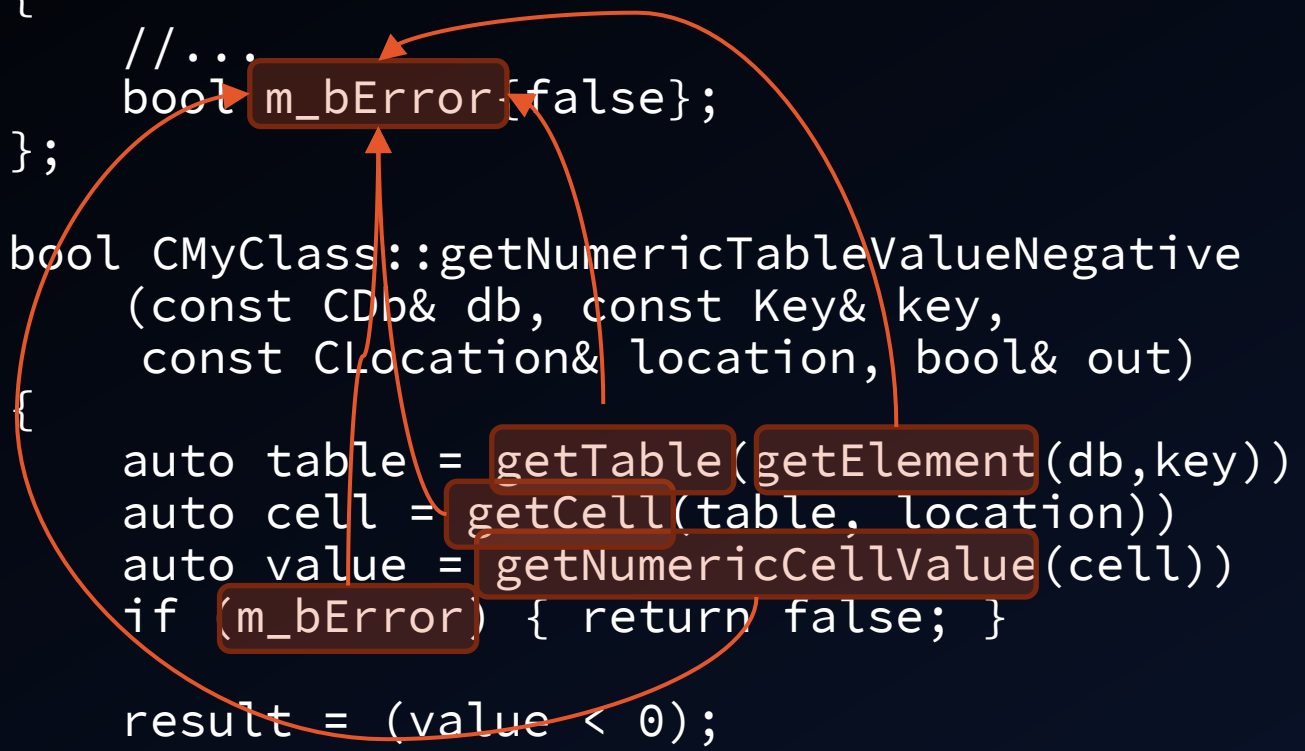
```
class CMyClass
{
    //...
    bool m_bError{false};
};

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?

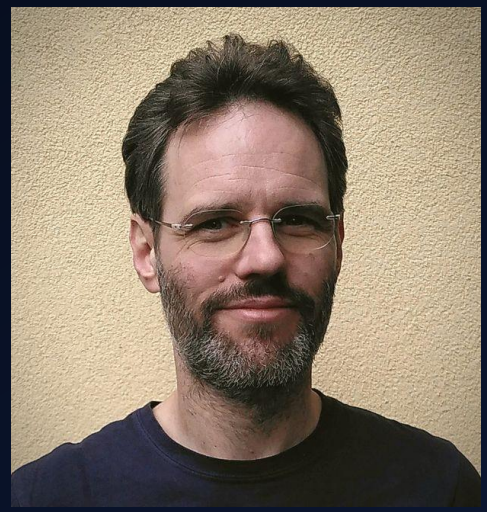
```
std::optional<bool> isNumericTableCellValueNegative
      (const CDb& db, const Key& key, const CLocation& location)
{
      auto oElement = getElement(db,key);
      if ( ! oElement.has_value()) { return {}; }

      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);
}
```

Robert Schimkowitsch

https://mastodon.social/@asperamanca
https://github.com/Asperamanca/
https://cppusergroupvienna.org/



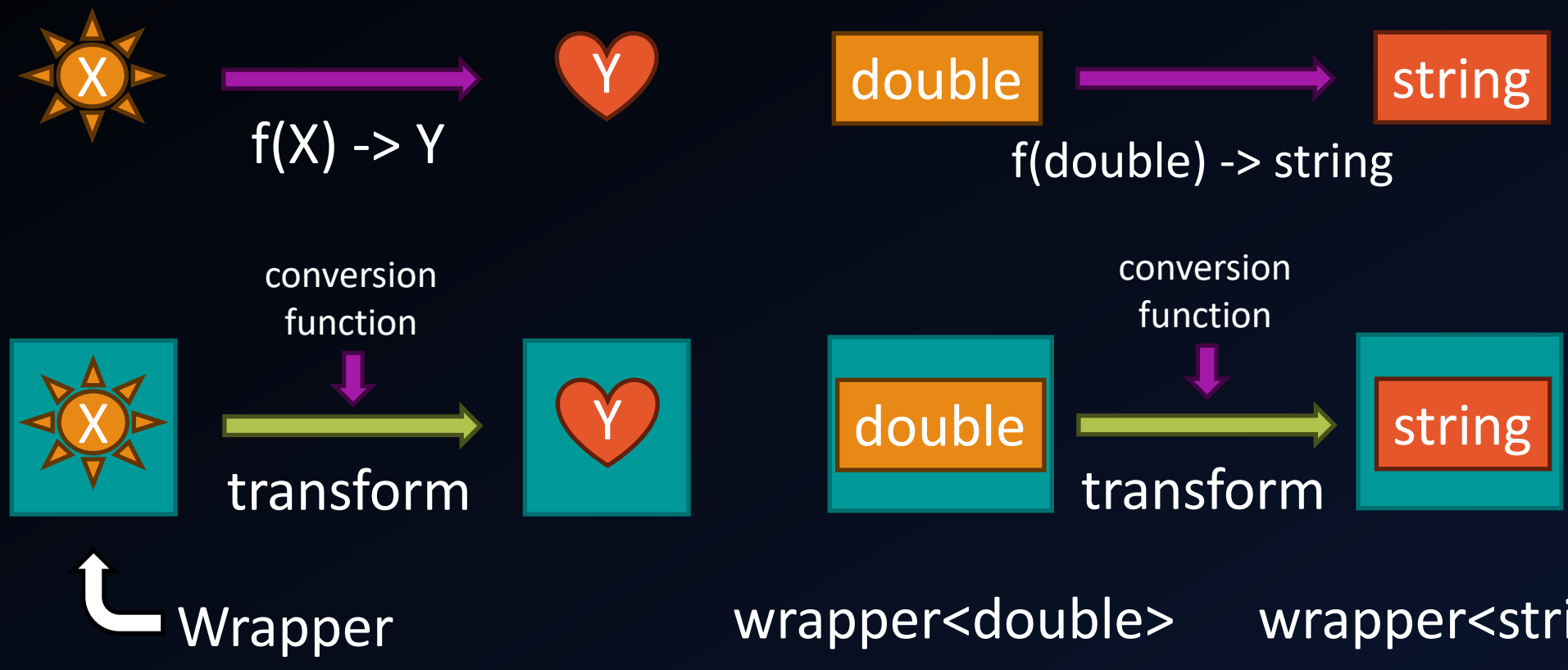
Functors

WRAP & TRANSFORM

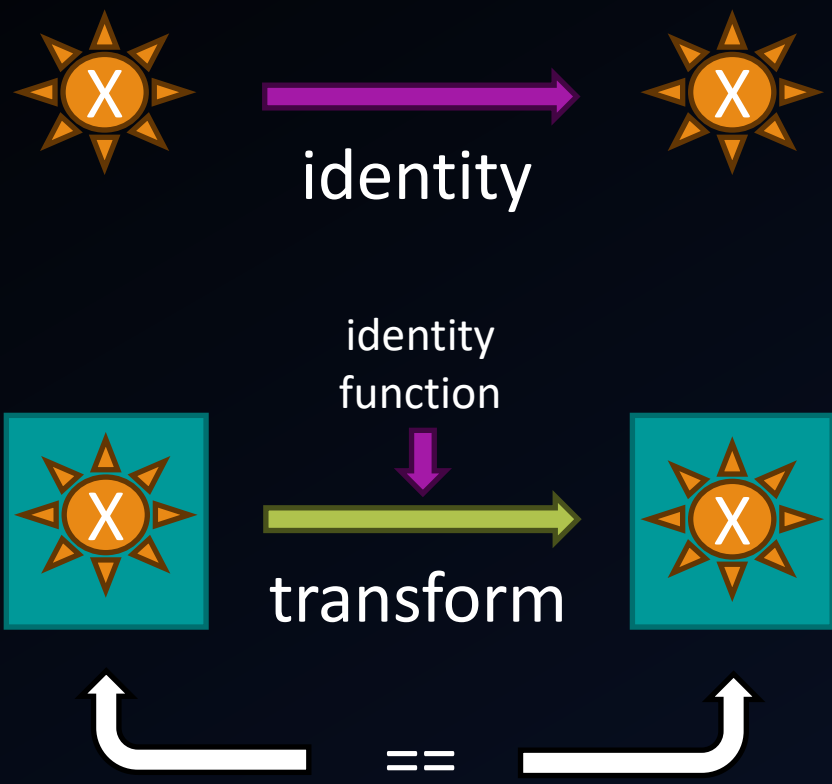
What is a Functor?

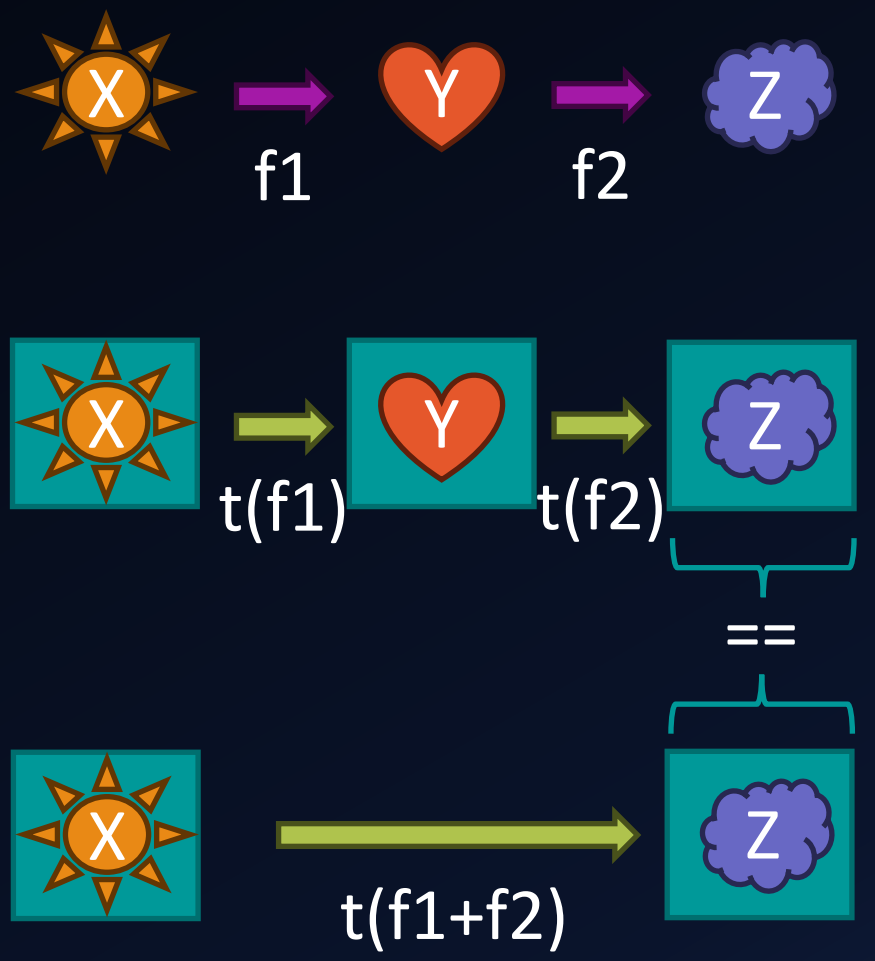
```
class CNegator
{
public:
    int operator()(const int value) const
    {
        return -value;
    }
};

// ...

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(dblToStr(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);
}
```

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(v,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(dblToStr(makeSquared(value)));
}
```

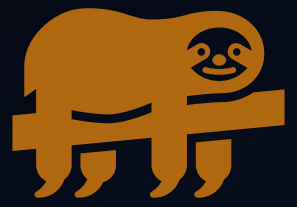
```
auto strings = v
             | std::views::transform(makeSquared)
             | std::views::transform(dblToStr);
```

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(dblToStr(makeSquared(value)));
}
```

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



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)
  >
```

auto

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(dblToStr);

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

Inlining functions that return views

```
inline auto getSquaredNumerbersAsString
   (const std::vector<int>& vector)
{
   using namespace std;

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

   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);
```

Callables: (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)

Callables: 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))
   | //...
```

Callables: 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))
   | //...
```

Callables: 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)
   | //...
```

Callables: 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)
   | //...
```

Callables: 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)> fAnyFuncDblInDblRet
   = makeSquared;

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

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

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)
      | //...
}
```

Callables: 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();})
```

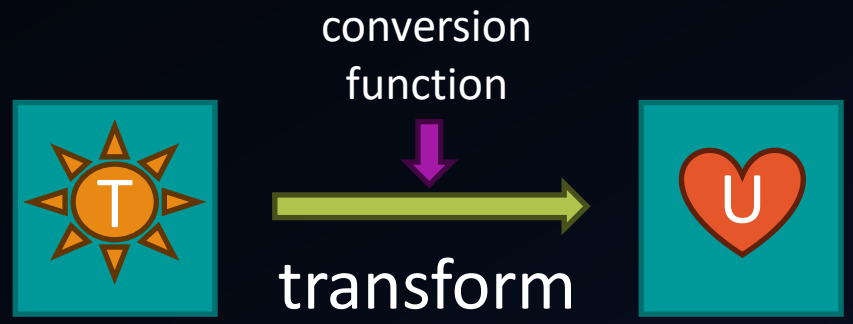
Member with param

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

Inject callable

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

Functors: Summary



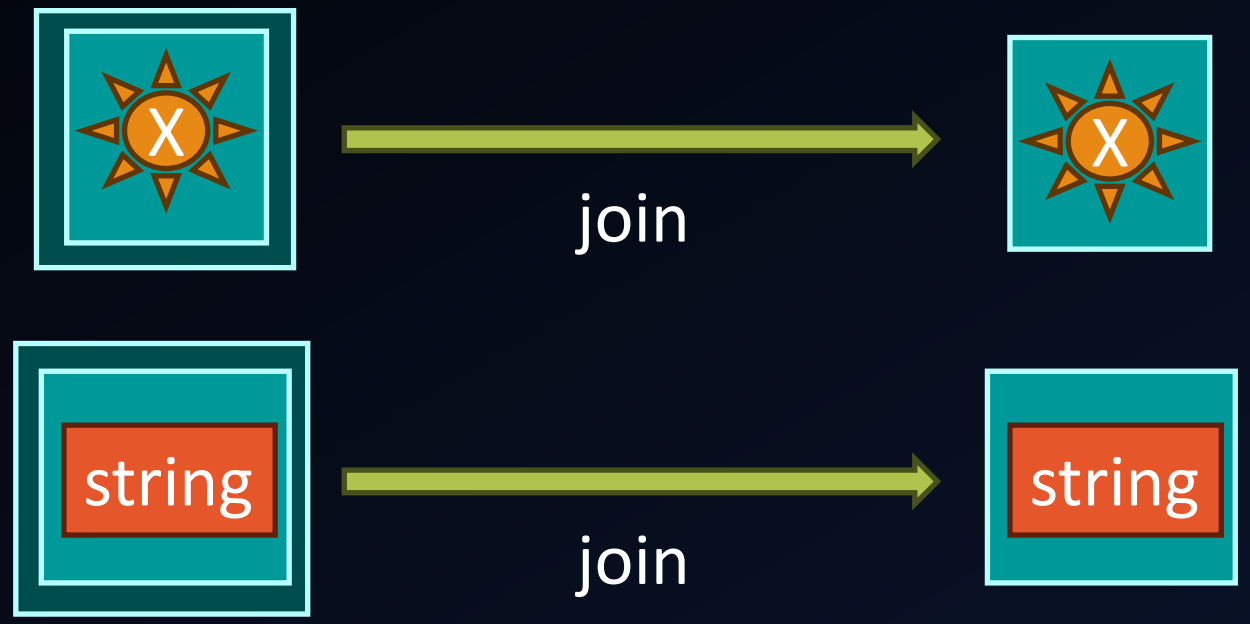

```
auto strings = v
             | std::views::transform(makeSquared)
             | std::views::transform(dblToStr);
```

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

Monads

FUNCTORS+JOIN

Monad = Functor + Join



wrapper<wrapper<string>>

wrapper<string>

Usage of Join

Printing Diagnostics: Conversion Functions

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

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

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

Printing Diagnostics: Conversion Functions

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

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

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

Printing Diagnostics: Conversion Functions

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

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

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

Printing Diagnostics: Classic Loop

```
for(const auto& folder : folders)
{
   auto files = getFilesInProject(folder);

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

Printing Diagnostics: Classic Loop

```
for(const auto& folder : folders)
{
   auto files = getFilesInProject(folder);

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

Printing Diagnostics: Classic Loop

```
for(const auto& folder : folders)
{
   auto files = getFilesInProject(folder);

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

Printing Diagnostics: Classic Loop

```
for(const auto& folder : folders)
{
   auto files = getFilesInProject(folder);

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

Printing Diagnostics: Classic Loop

```
for(const auto& folder : folders)
{
   auto files = getFilesInProject(folder);

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

Printing Diagnostics: Classic Loop

```
for(const auto& folder : folders)
{
   auto files = getFilesInProject(folder);

   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 = folders
     | 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 = folders
     | 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 = folders
    | 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 = folders
    | 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 = folders
    | 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 = folders
     | 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 = folders
    | vw::transform(getFilesInProject) | vw::join
    | vw::transform(compile)           | vw::join;
```

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

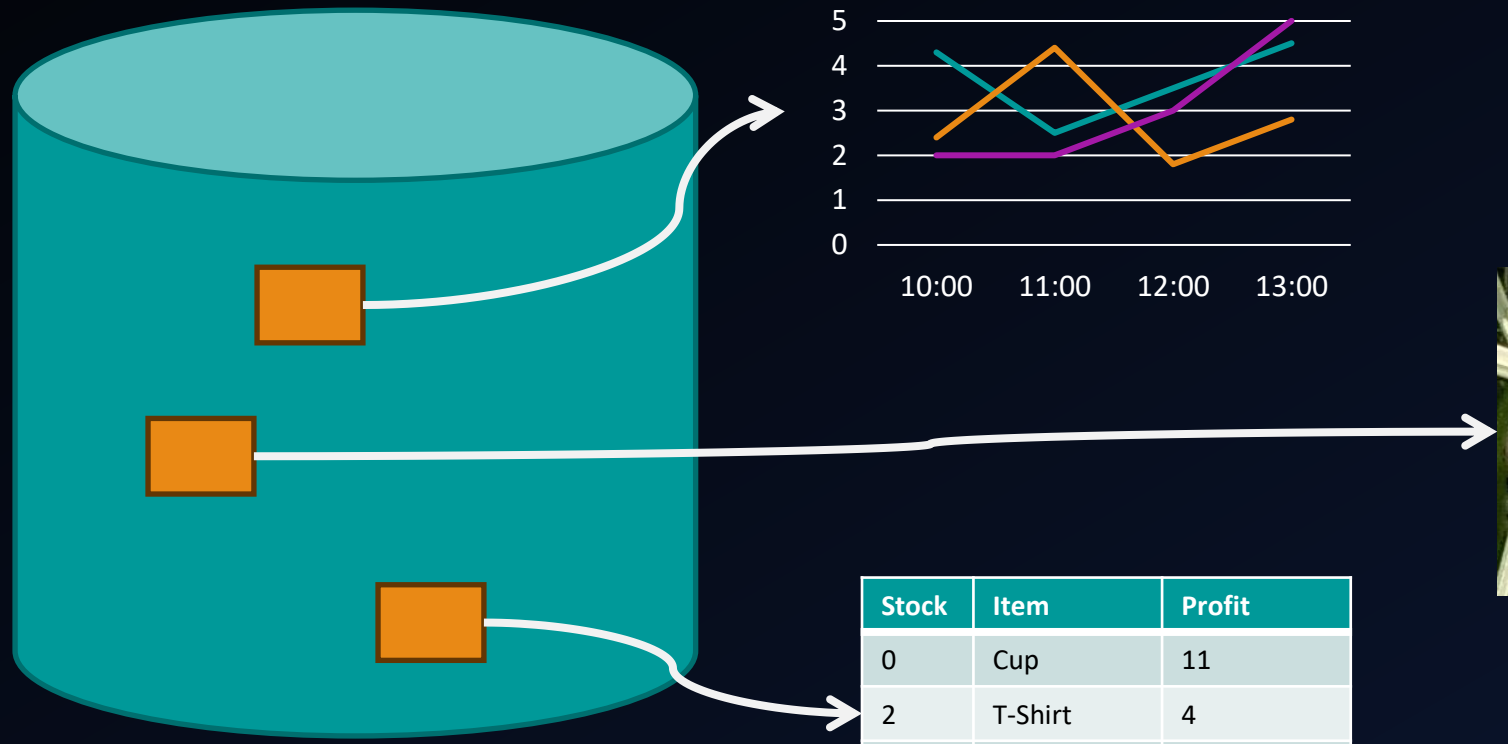
Printing Diagnostics: Code comparison

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

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

Handling Failure

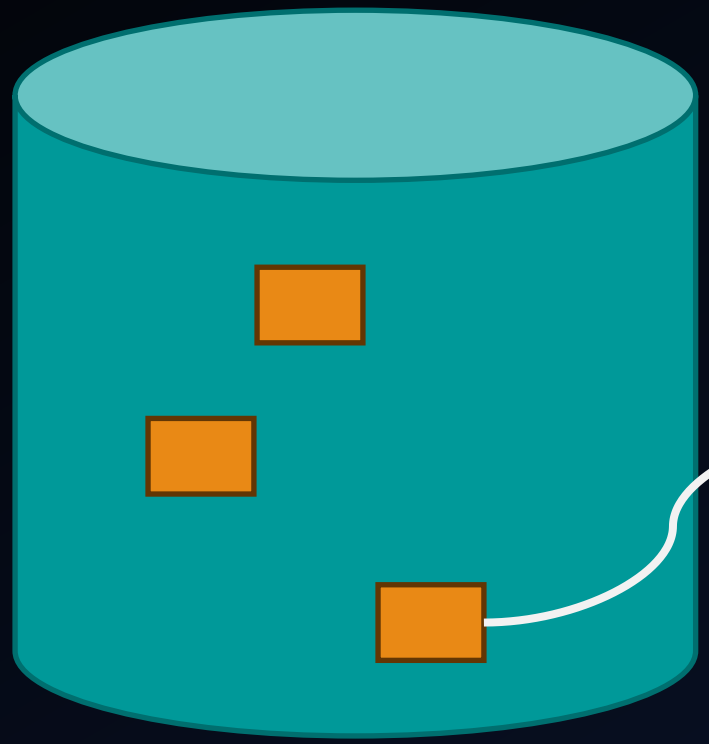
THE OPTIONAL AND EXPECTED MONADS

Chaining Functions That Can Fail



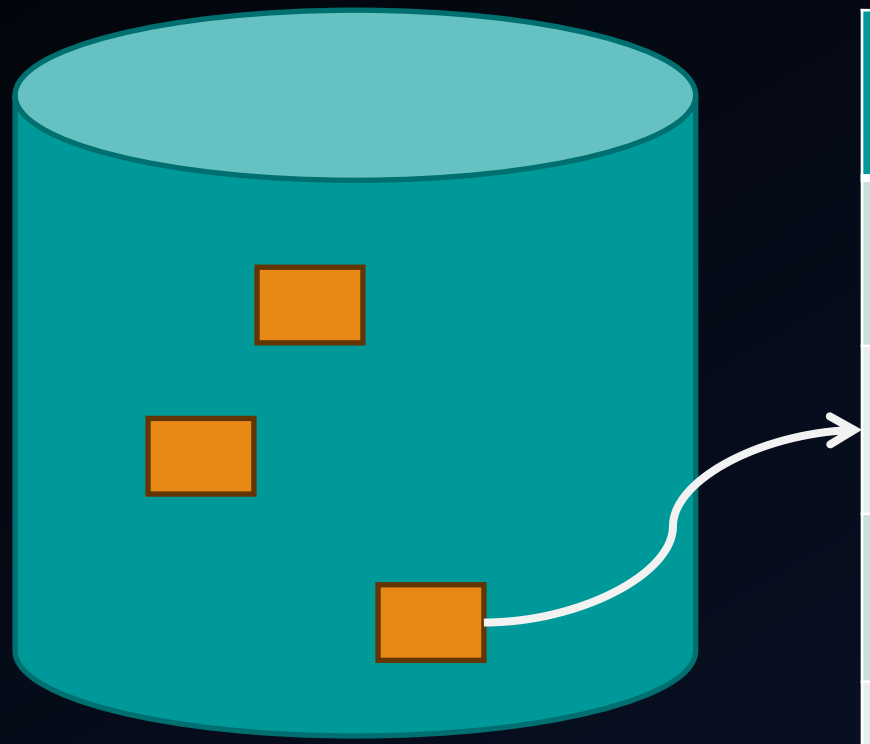
Stock	Item	Profit
0	Cup	11
2	T-Shirt	4
0	Poster	16
0	Statuette	-8

Chaining Functions That Can Fail



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

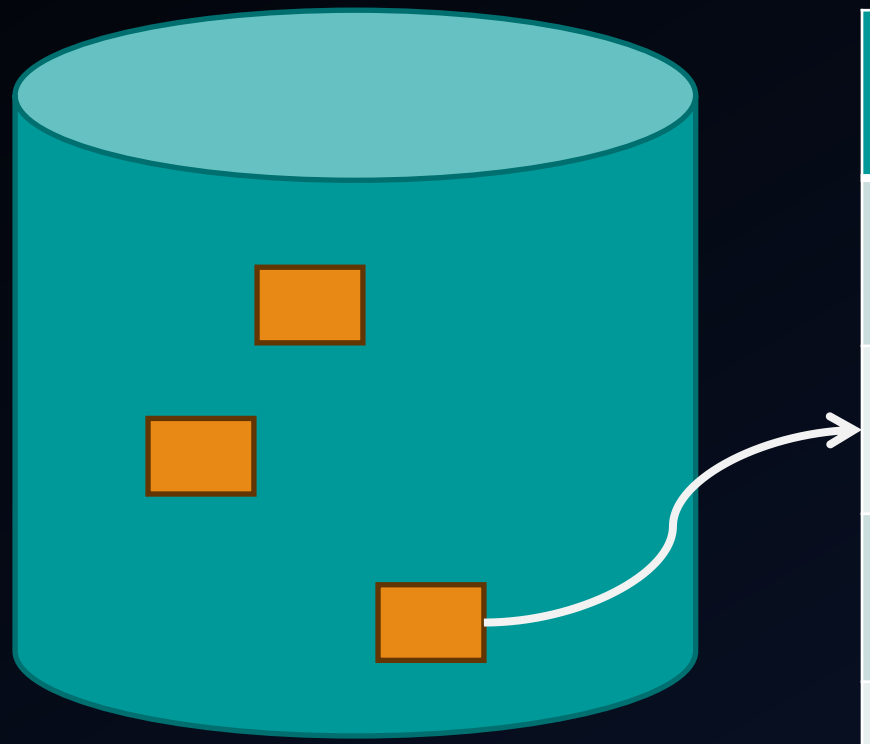
Chaining Functions That Can Fail



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

Number?

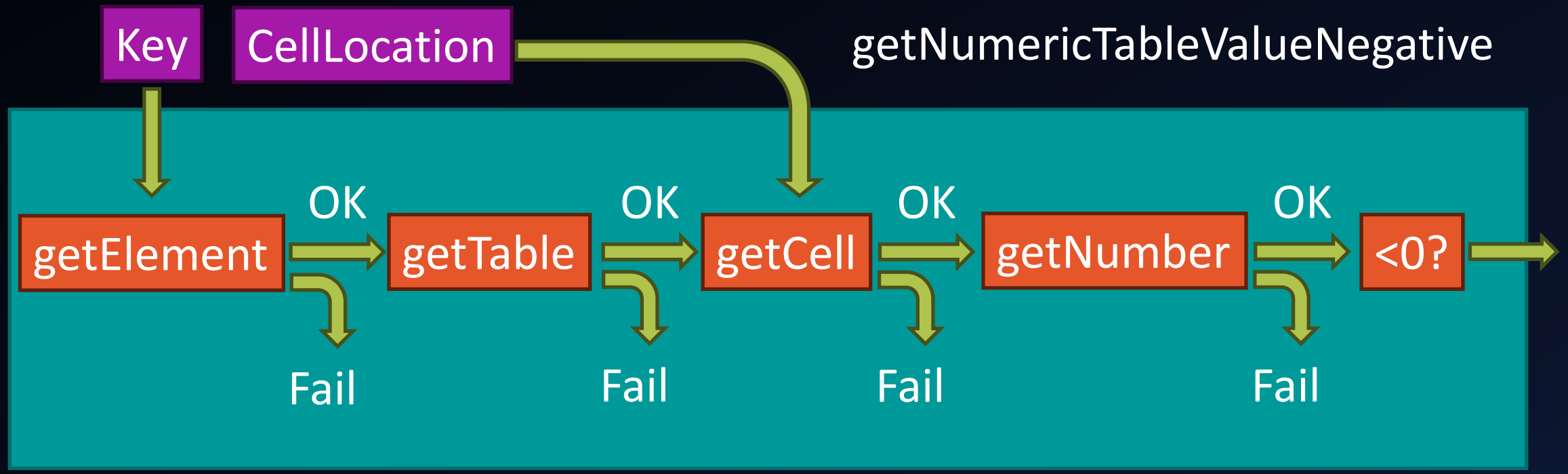
Chaining Functions That Can Fail



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);
}
```

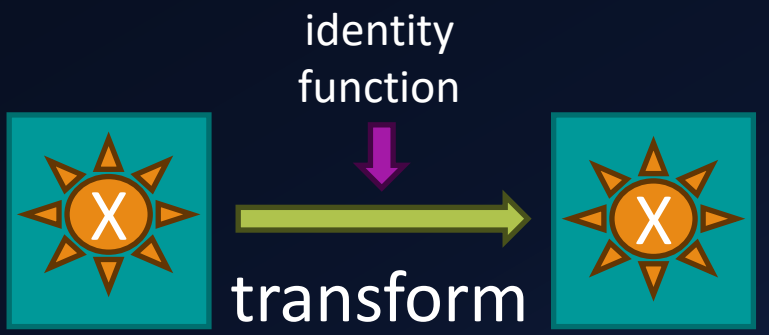
Quiz Time! – What makes this a monad?

```
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

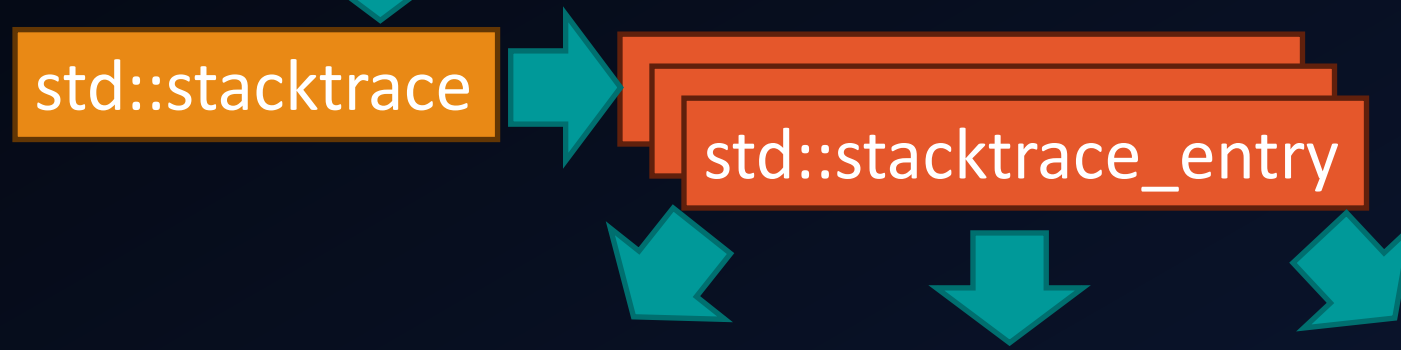
```
std::optional<bool> isNumericTableCellValueNegative
  (const CDb& db, const Key& key, const CLocation& location)
{
    return getElement(db, key)
             .and_then(getTable)
             .and_then(std::bind_back(&getCell,cellLocation))
             .and_then(getNumericCellValue)
           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

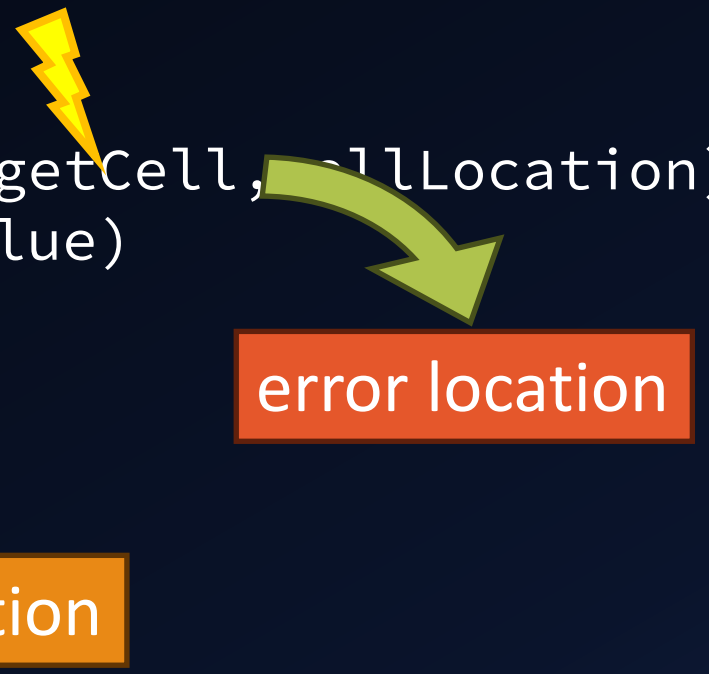


Catching failure: or_else

```
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>);
}
```



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

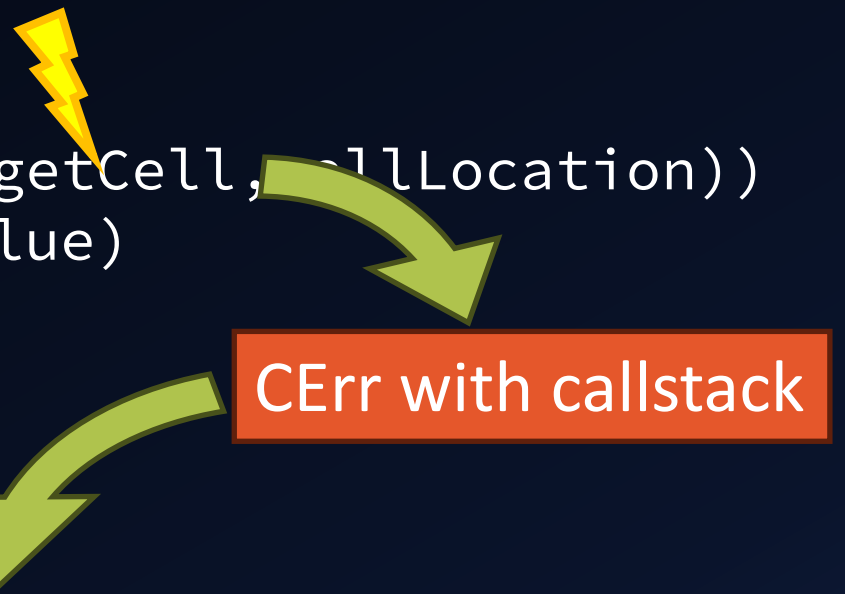
```
std::expected<CElement,CErr> getElement(const CDb& db,
                                        const ElementKey& key)
{
    //...
    if (/* Key not found */)
    {
        return std::unexpected{CErr("Key not found")};
    }
    CElement elem = //...
    return elem;
}
```

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, cellLocation))
             .and_then(getNumericCellValue)
             .transform(isNegative)
           .or_else(log<bool>);
}

template<class TRet>
std::expected<TRet> log(const CErr& 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

```
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);
}
```

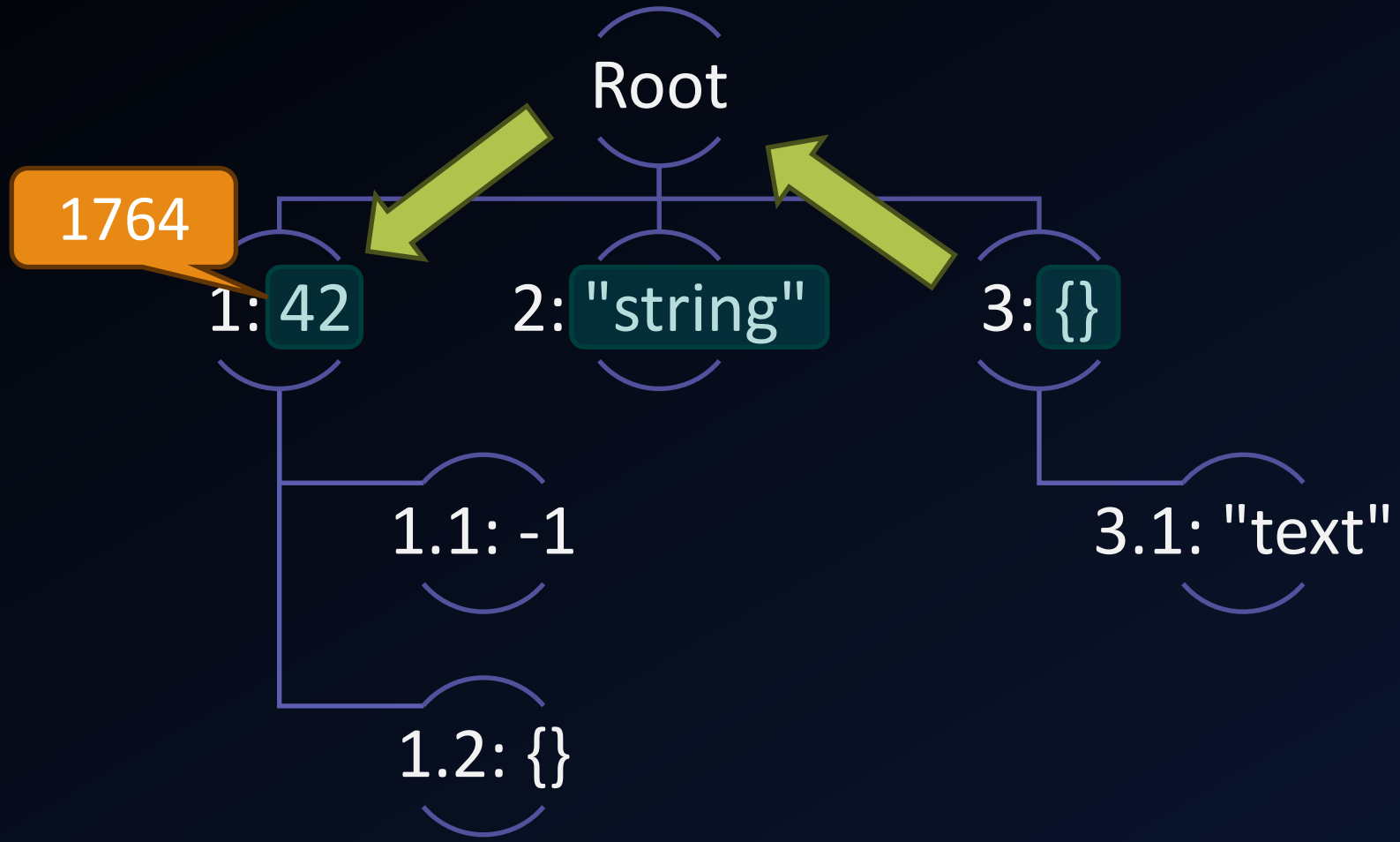
Compiler Support (Minimum Required Version)

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<cIsPointer 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<cIsPointer 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>
CPtr<TPtr >::CPtr(const TPtr& ptr)
    : m_Ptr(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{};
};
```

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<cIsPointer 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

```
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

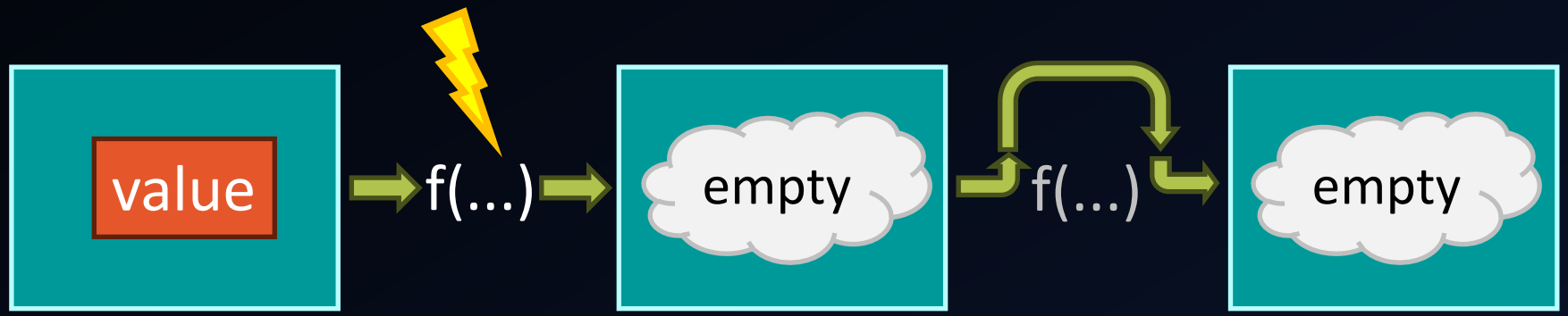
WHAT ELSE YOU CAN DO WITH THEM

Ranges Monad

transform

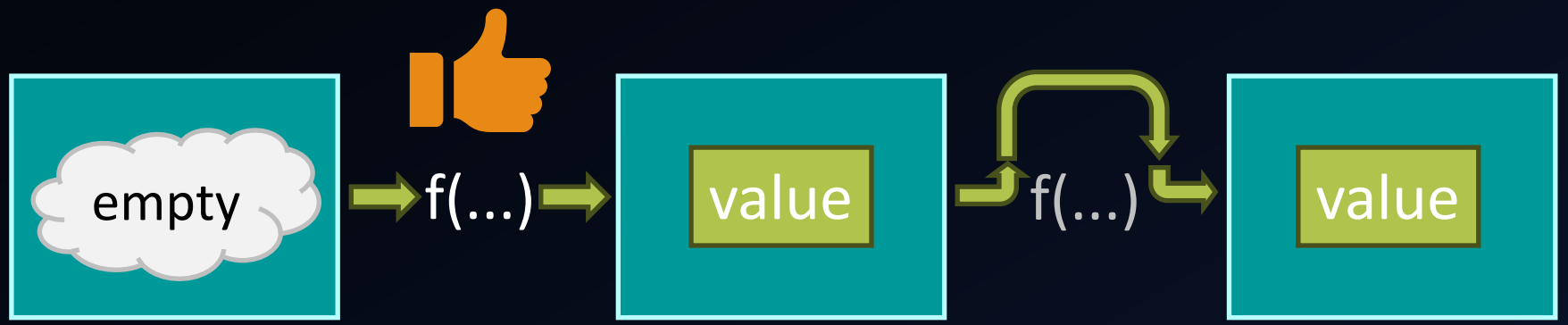
join

Optional ("Maybe") Monad



and_then and_then

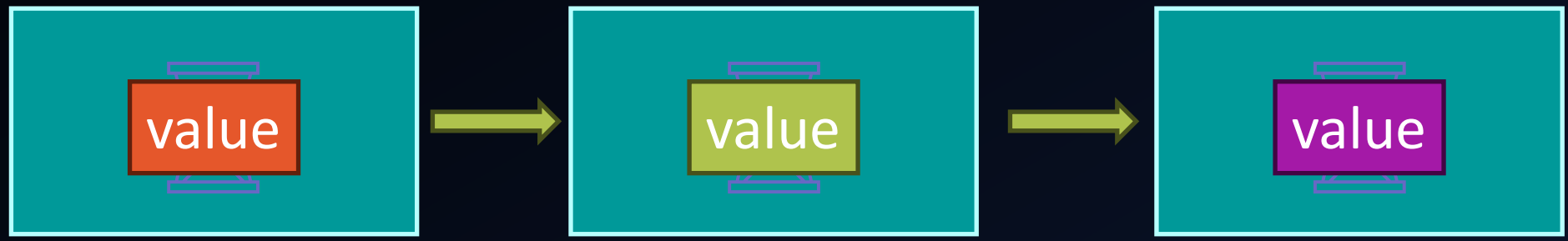
Default Monad



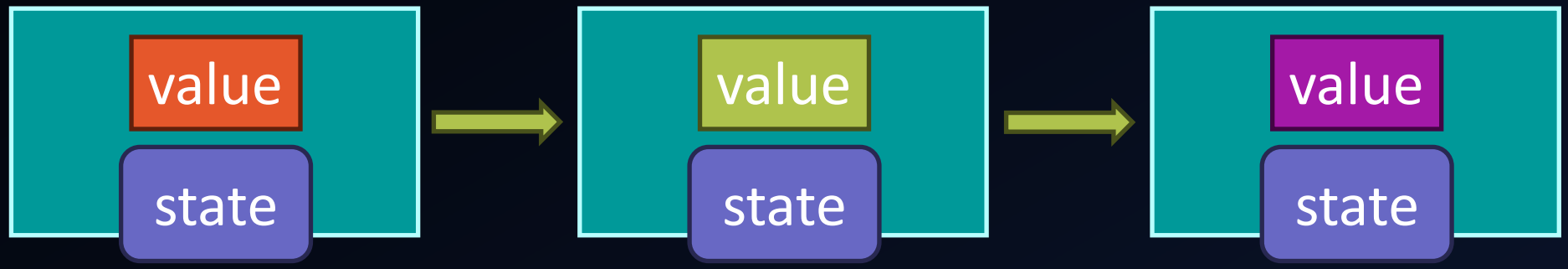
or_else

or_else

Continuation Monad

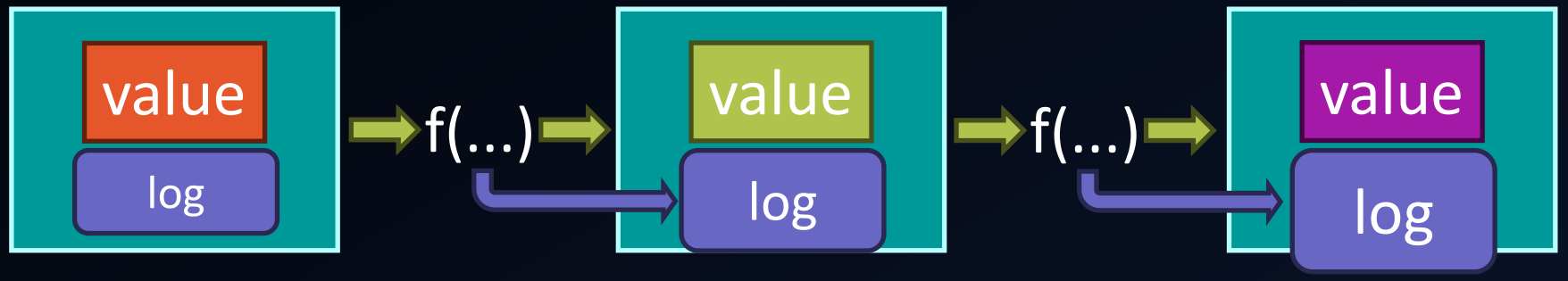


State Monad

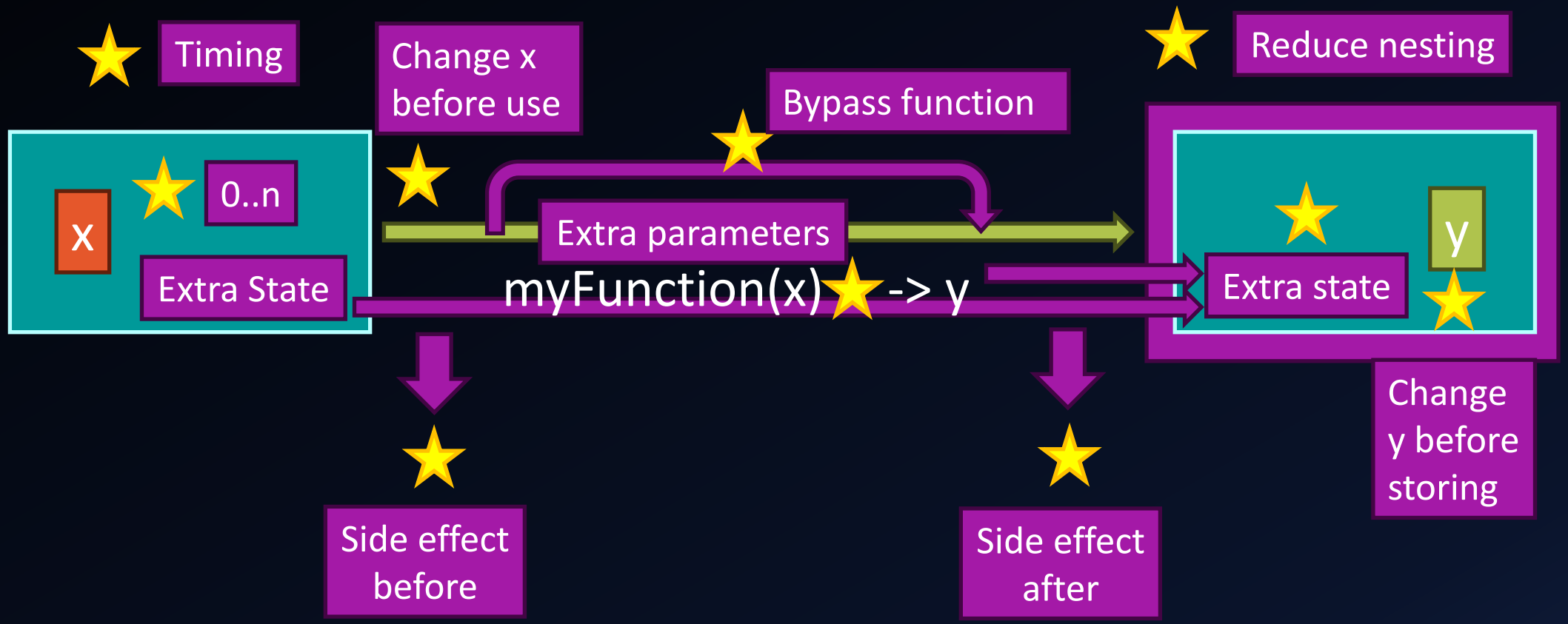


newValue = f(value, state);

Writer Monad



The Power of Monads



Getting started

```
auto diagnostics = folders
     | 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 = folders
     | 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 = folders
     | 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 = folders
     | 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 = folders
     | 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

ROBERT SCHIMKOWITSCH

https://mastodon.social/@asperamanca
https://github.com/Asperamanca/
https://cppusergroupvienna.org/

References

https://github.com/Asperamanca/monadic_operations_cpp23