accu 2023

THE IMPERATIVES MUST GO!

VICTOR CIURA

The Imperatives Must Go!

ACCU

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Visual C++

Abstract

Can a language whose official motto is “Avoid Success at All Costs” teach us new tricks in modern C++ ?

If Haskell is so great, why hasn't it taken over the world? My claim is that it has. But not as a Roman legion loudly marching in a new territory, rather as distributed Trojan horses popping in at the gates, masquerading as modern features or novel ideas in today’s mainstream languages. Functional Programming ideas that have been around for over 40 years will be rediscovered to solve our current software complexity problems.

Indeed, modern C++ has become more functional. From mundane concepts like lambdas & closures, std::function, values types and constants, to composability of STL algorithms, lazy ranges, folding, mapping or even higher-order functions in STL. Did I mention Rust yet?

In this session we’ll analyze a bunch of FP techniques in C++ and see how they help make our code shorter, clearer and faster, by embracing a declarative vs. an imperative style. We’ll visit the functional parts of current STL, use algebraic data types (ADT) and learn about the new FP stuff coming in the next C++ standard, like ranges or monadic extensions to std::future, std::optional and std::expected. Brace yourselves for a bumpy ride including composition, lifting, currying, partial application, pure functions, maybe even pattern matching and lazy evaluation.

About me

Advanced Installer

Clang Power Tools

Visual C++

@ciura_victor

1/n

This is meant as an introductory presentation to the concepts to follow.

A sequel will cover some of these topics in depth (WIP).

Don't worry, there are no cliffhangers...

\fp 10

FP in 10

Functional Programming

What is it all about ?

pipelines

ranges

optional

IO monad

algorithms

Maybe | Just

lifting

monoids

lambdas & closures

fold

values types

lazy evaluation

declarative vs imperative

algebraic data types

monads

higher order functions

map

composition

pattern matching

FP

expressions vs statements

pure functions

currying

partial application

category theory

recursion

Paradox of Programming

Machine / Human impedance mismatch:

- Local / Global perspective
- Progress / Goal oriented
- Detail / Idea
- Vast / Limited memory
- Pretty reliable / Error prone
- Machine language / Mathematics / Logic

A Crash Course in Category Theory - Bartosz Milewski https://www.youtube.com/watch?v=JH_Ou17_zyU

Paradox of Programming

Machine / Human impedance mismatch:

- Local / Global perspective
- Progress / Goal oriented
- Detail / Idea
- Vast / Limited memory
- Pretty reliable / Error prone
- Machine language / Mathematics / Logic

Is it easier to think like a machine than to do math?

A Crash Course in Category Theory - Bartosz Milewski https://www.youtube.com/watch?v=JH_Ou17_zyU

What is Functional Programming ?

- Functional programming is a **style** of programming in which the basic method of computation is the ***application of functions*** to arguments

- A functional **language** is one that supports and encourages the ***functional style***

Let's address the 🐘 in the room...

Let's address the 🐘 in the room...

Haskell

A functional language is one that supports and encourages the `functional style`

What do you mean ?

Summing the integers 1 to 10 in C++/Java/C#

```
int total = 0;
for (int i = 1; i ≤ 10; i++)
   total = total + i;
```

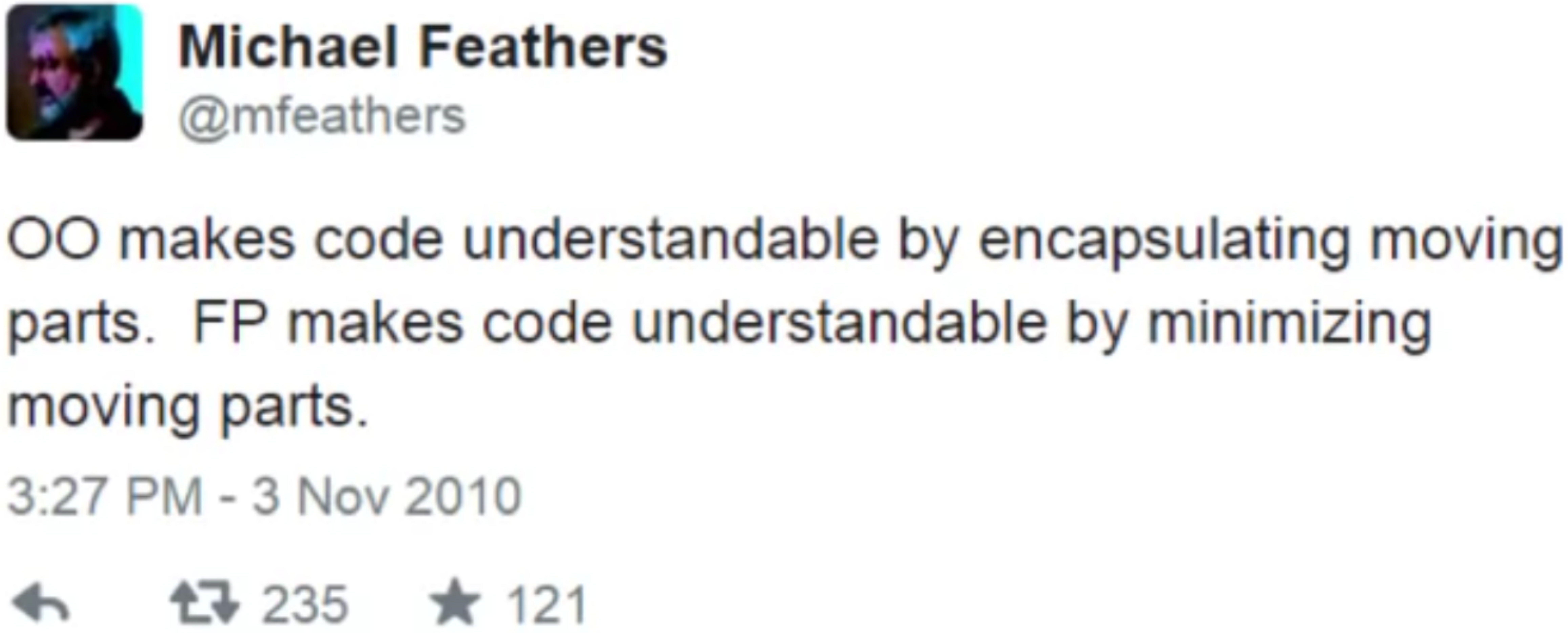
The computation method is variable assignment.

Summing the integers 1 to 10 in Haskell

```
sum [1..10]
```

The computation method is function application.

Functional	Imperative
WHAT	HOW



Michael Feathers
@mfeathers

OO makes code understandable by encapsulating moving parts. FP makes code understandable by minimizing moving parts.

3:27 PM - 3 Nov 2010

235 121

Historical Background

Historical Background

Most of the "new" ideas and innovations in modern programming languages are actually very old...

Historical Background

1930s

Alonzo Church develops the lambda calculus,
a simple but powerful *theory of functions*

Historical Background

1950s

John McCarthy develops Lisp, the *first functional language*, with some influences from the lambda calculus, but retaining *variable assignments*

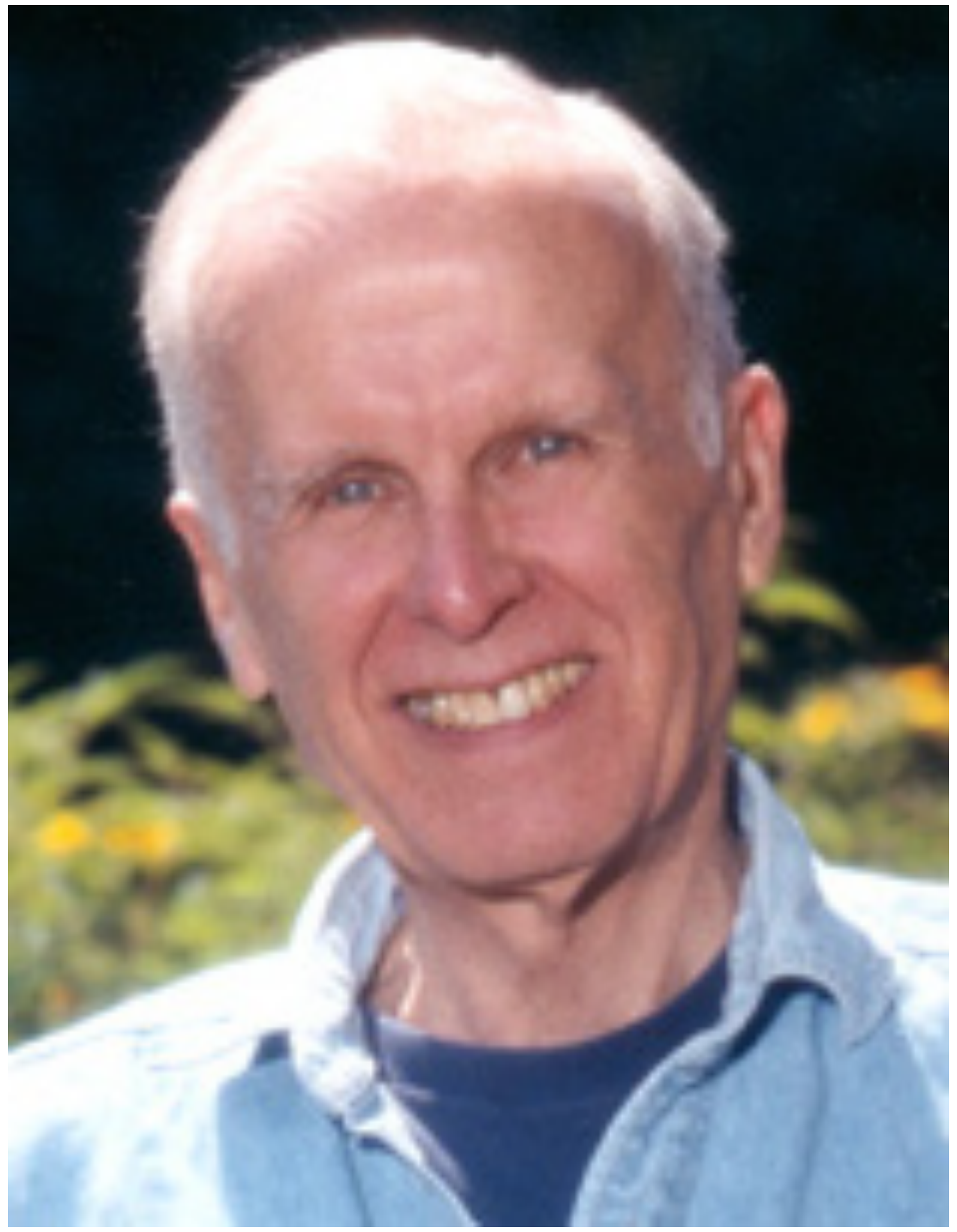
Historical Background

1960s

Peter Landin develops ISWIM, the first *pure functional language*, based strongly on the lambda calculus, with *no assignments*

Historical Background

1970s



John Backus develops FP, a functional language that emphasizes *higher-order functions* and reasoning about programs

Historical Background

1970s

Robin Milner and others develop ML, the first modern functional language, which introduced *type inference* and *polymorphic types*

Historical Background

1970-80s

David Turner develops a number of lazy *functional languages*, culminating in the Miranda system

Historical Background

1987

Haskell

An advanced purely-functional programming language

An international committee starts the development of Haskell,
a standard *lazy functional language*

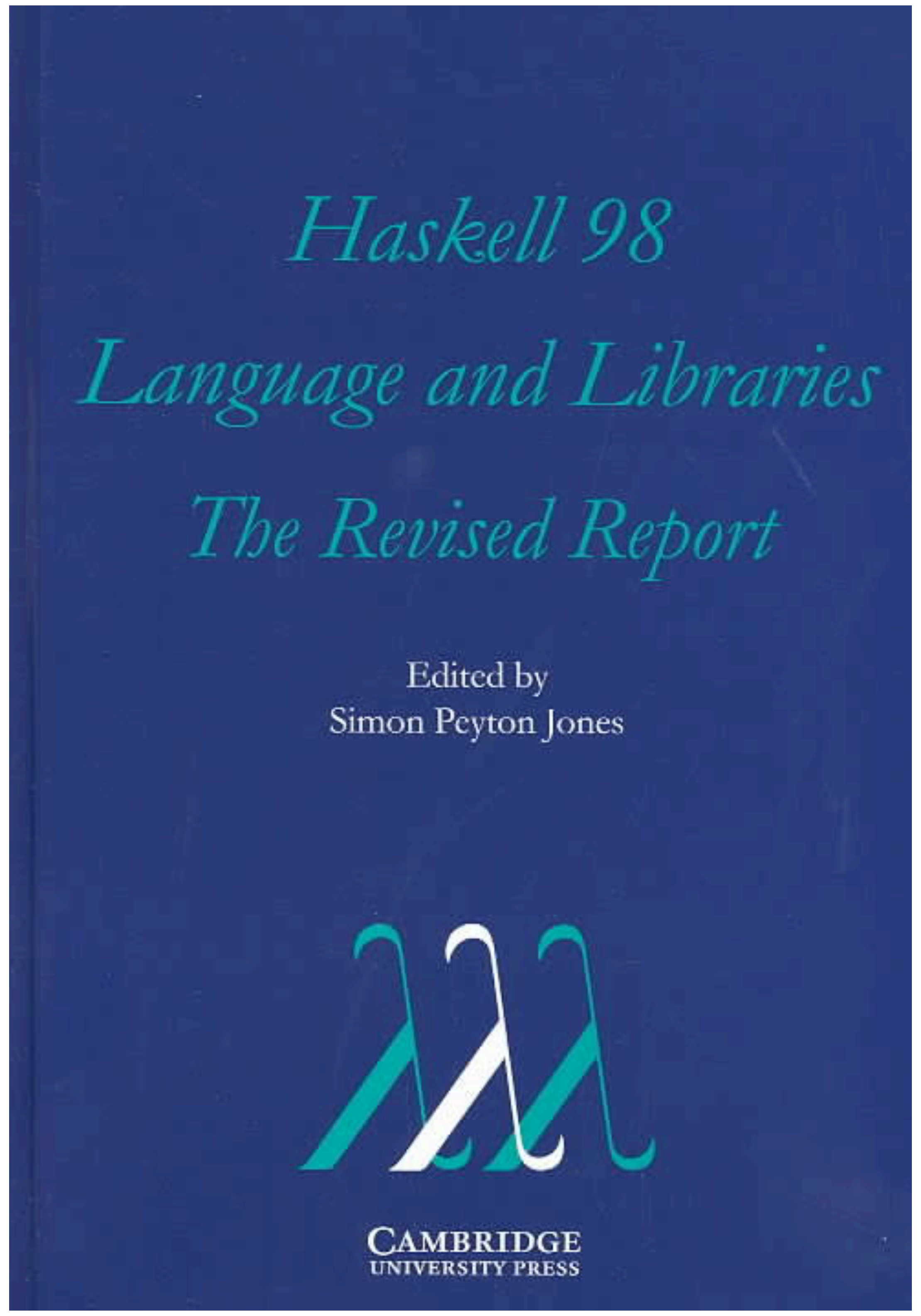
Historical Background

1990s

Phil Wadler and others develop type classes and monads, two of the main innovations of Haskell

Historical Background

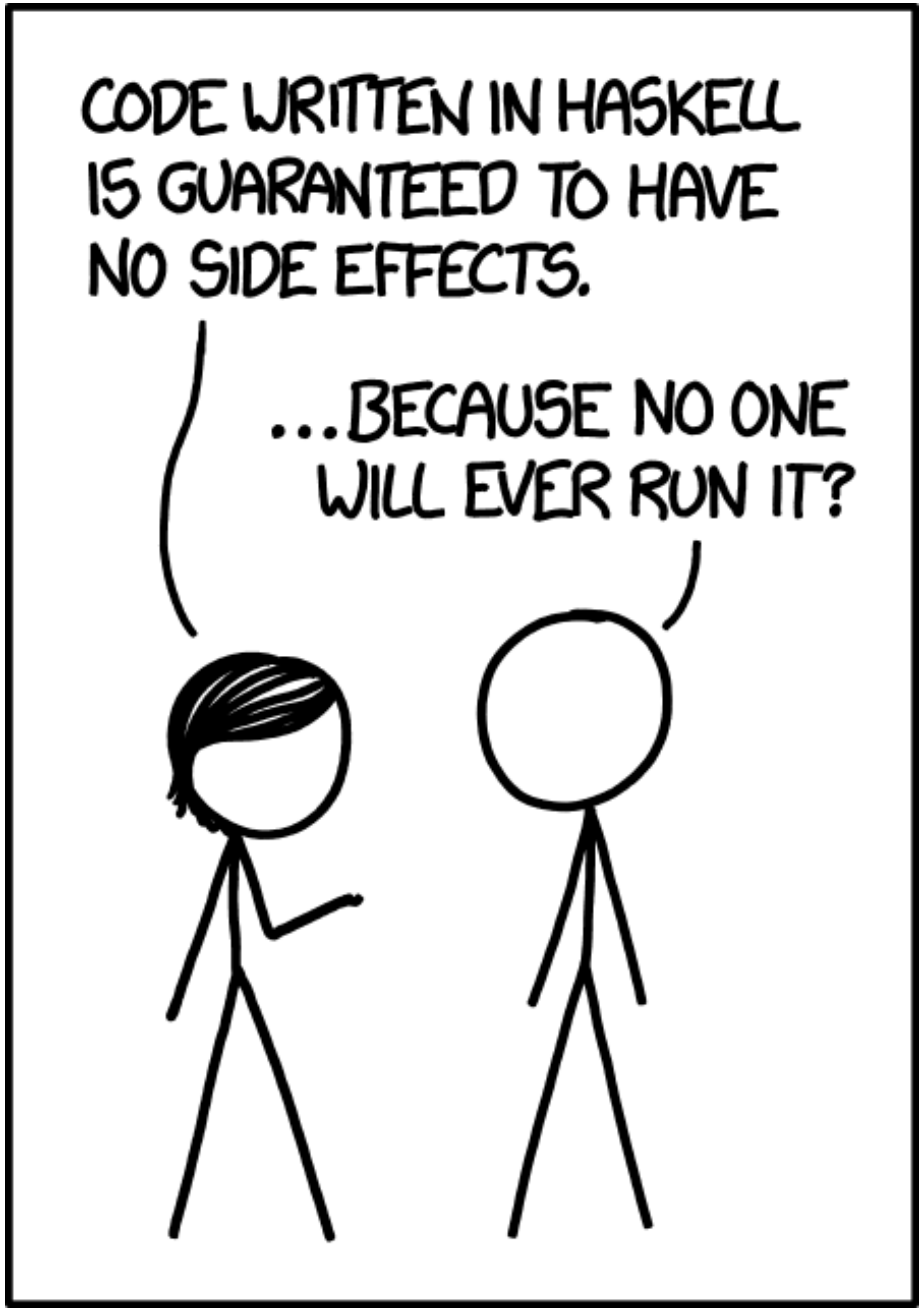
2003


Haskell 98
Language and Libraries
The Revised Report

Edited by
Simon Peyton Jones

CAMBRIDGE
UNIVERSITY PRESS

The committee publishes the Haskell Report, defining a stable version of the language


CODE WRITTEN IN HASKELL IS GUARANTEED TO HAVE NO SIDE EFFECTS.
...BECAUSE NO ONE WILL EVER RUN IT?

xkcd.com/1312/

Why (not) Haskell ?

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But not as a Roman legion loudly marching in a new territory, rather as distributed Trojan horses popping in at the gates, masquerading as modern features or novel ideas in today's mainstream languages.

Modern C++ is functional

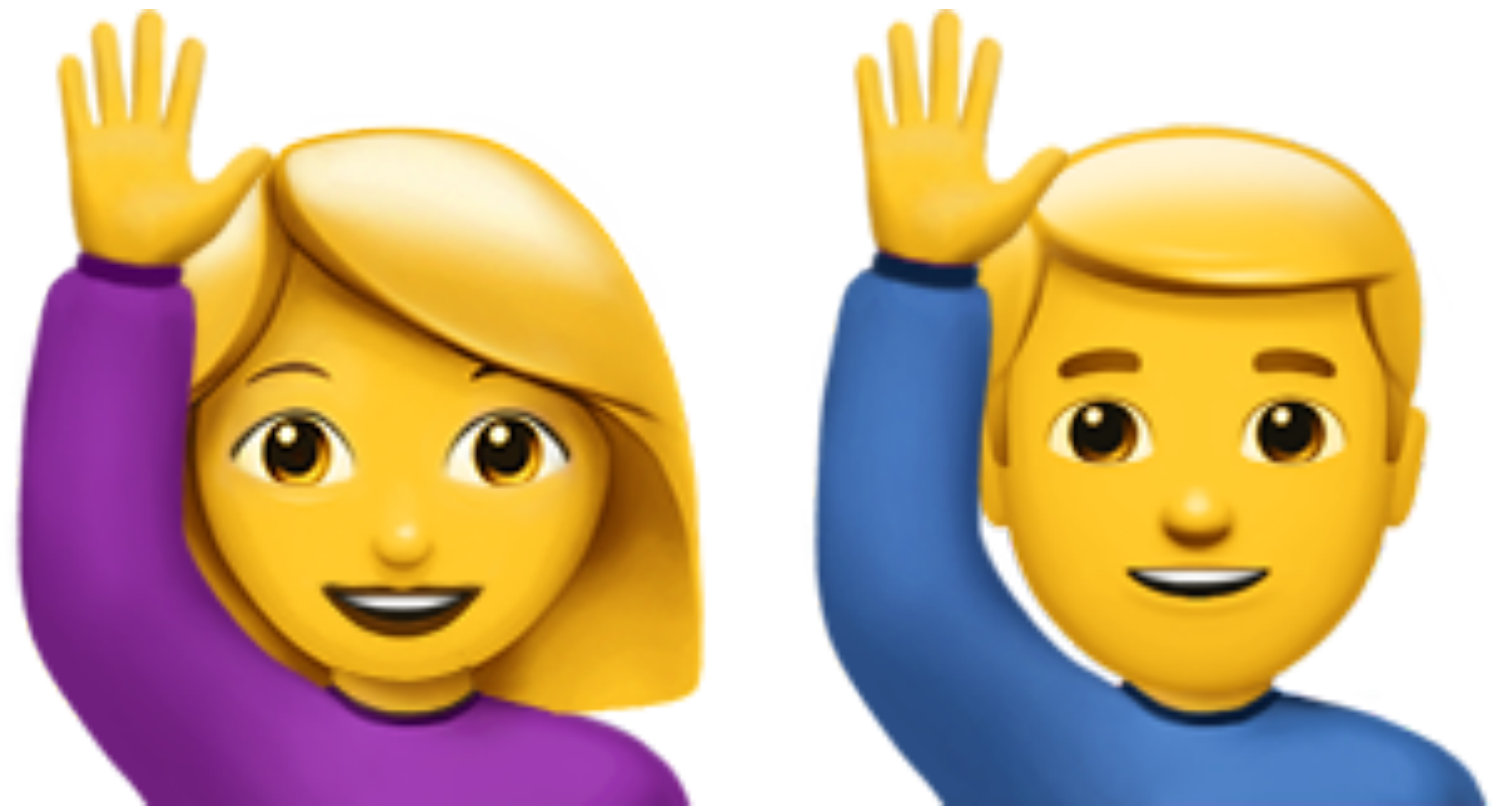
Functional Programming ideas that have been around for over 40 years are rediscovered to solve our current software complexity problems.

Indeed, contemporary C++ has become more functional.

From mundane concepts like lambdas & closures, std::function, values, ADT, to composability of STL algorithms, lazy ranges, folding, mapping, partial application, higher-order functions or even monads such as optional, future, expected ...

A Taste of Haskell

```
f []     = []
f (x:xs) = f ys ++ [x] ++ f zs
           where
              ys = [a | a ← xs, a ≤ x]
              zs = [b | b ← xs, b > x]
```



What does `f` **do ?**

Quick Sort

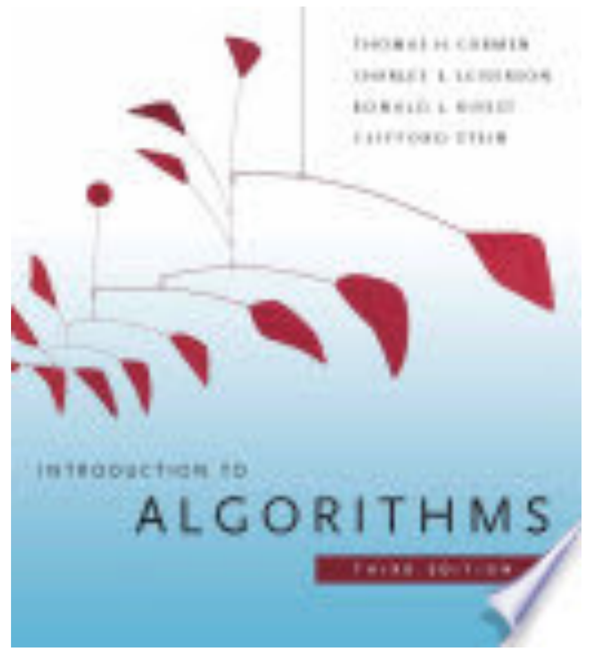
```
qsort :: Ord a ⇒ [a] → [a]
qsort []     = []
qsort (x:xs) =
   qsort smaller ++ [x] ++ qsort larger
   where
      smaller = [a | a ← xs, a ≤ x]
      larger  = [b | b ← xs, b > x]
```

Quick Sort

$$\begin{tikzcd}
 & & & \mathtt{q\ [3,2,4,1,5]} \arrow[d] & & & \\
 & \mathtt{q\ [2,1]} \arrow[d] & & \mathtt{++\ [3]\ ++} & & \mathtt{q\ [4,5]} \arrow[d] & \\
\mathtt{q\ [1]} \arrow[d] & \mathtt{++\ [2]\ ++} & \mathtt{q\ []} \arrow[d] & & \mathtt{q\ []} \arrow[d] & \mathtt{++\ [4]\ ++} & \mathtt{q\ [5]} \arrow[d] \\
\mathtt{[1]} & & \mathtt{[]} & & \mathtt{[]} & & \mathtt{[5]}
\end{tikzcd}$$

Quick Sort

```
void quickSort(arr[], low, high)
{
    if (low < high)
    {
        /* pi is partitioning index, arr[pi] is now
           at right place */
        pi = partition(arr, low, high);

        quickSort(arr, low, pi - 1);
        quickSort(arr, pi + 1, high);
    }
}
```



pseudo-code

```
/* This function takes last element as pivot, places
   the pivot element at its correct position in sorted
    array, and places all smaller (smaller than pivot)
   to left of pivot and all greater elements to right
   of pivot */
partition (arr[], low, high)
{
    // pivot (Element to be placed at right position)
    pivot = arr[high];

    i = (low - 1)  // Index of smaller element

    for (j = low; j <= high- 1; j++)
    {
        // If current element is smaller than or
        // equal to pivot
        if (arr[j] <= pivot)
        {
            i++;    // increment index of smaller element
            swap arr[i] and arr[j]
        }
    }
    swap arr[i + 1] and arr[high])
    return (i + 1)
}
```

True Story

1986:

Donald Knuth was asked to implement a program for the *”Programming pearls”* column in the **Communications of ACM** journal.

The task:

Read a file of text, determine the n most frequently used words, and print out a sorted list of those words along with their frequencies.

True Story

1986:

Donald Knuth was asked to implement a program for the *”Programming pearls”* column in the **Communications of ACM** journal.

The task:

Read a file of text, determine the n most frequently used words, and print out a sorted list of those words along with their frequencies.

His solution written in `Pascal` was **10 pages** long.

True Story

Doug McIlroy

wikipedia.org/wiki/Douglas_McIlroy

True Story

Doug McIlroy

His response was a 6-line shell script that did the same:

```
tr -cs A-Za-z '\n' |
    tr A-Z a-z     |
    sort           |
    uniq -c        |
    sort -rn       |
    sed ${1}q
```

wikipedia.org/wiki/Douglas_McIlroy

It's all about | pipelines

Taking inspiration from Doug McIlroy's UNIX shell script,

write an algorithm in `your favorite programming language`,

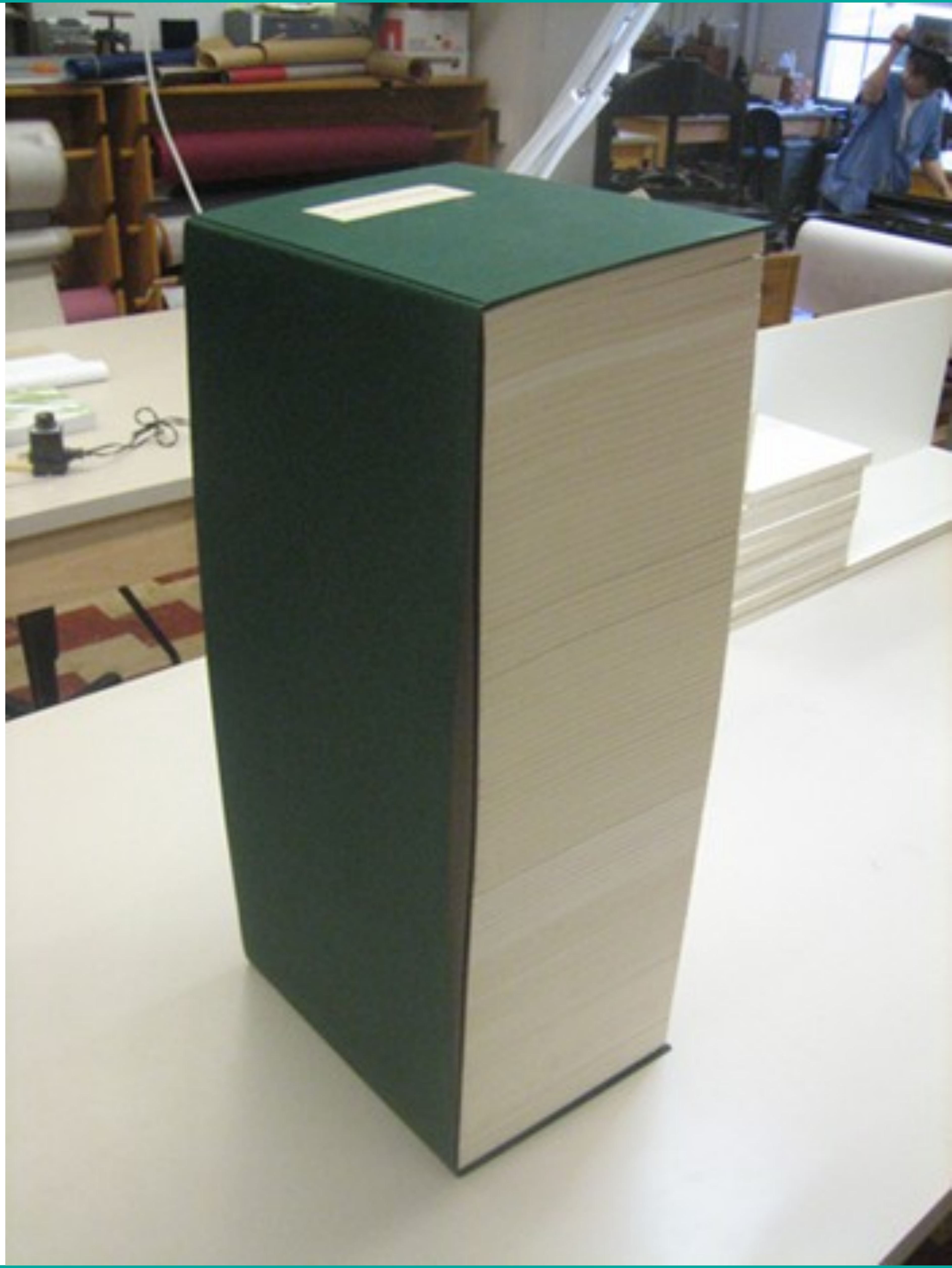
that solves the same problem: word frequencies

FP...

How do I start on this journey?

Prerequisites

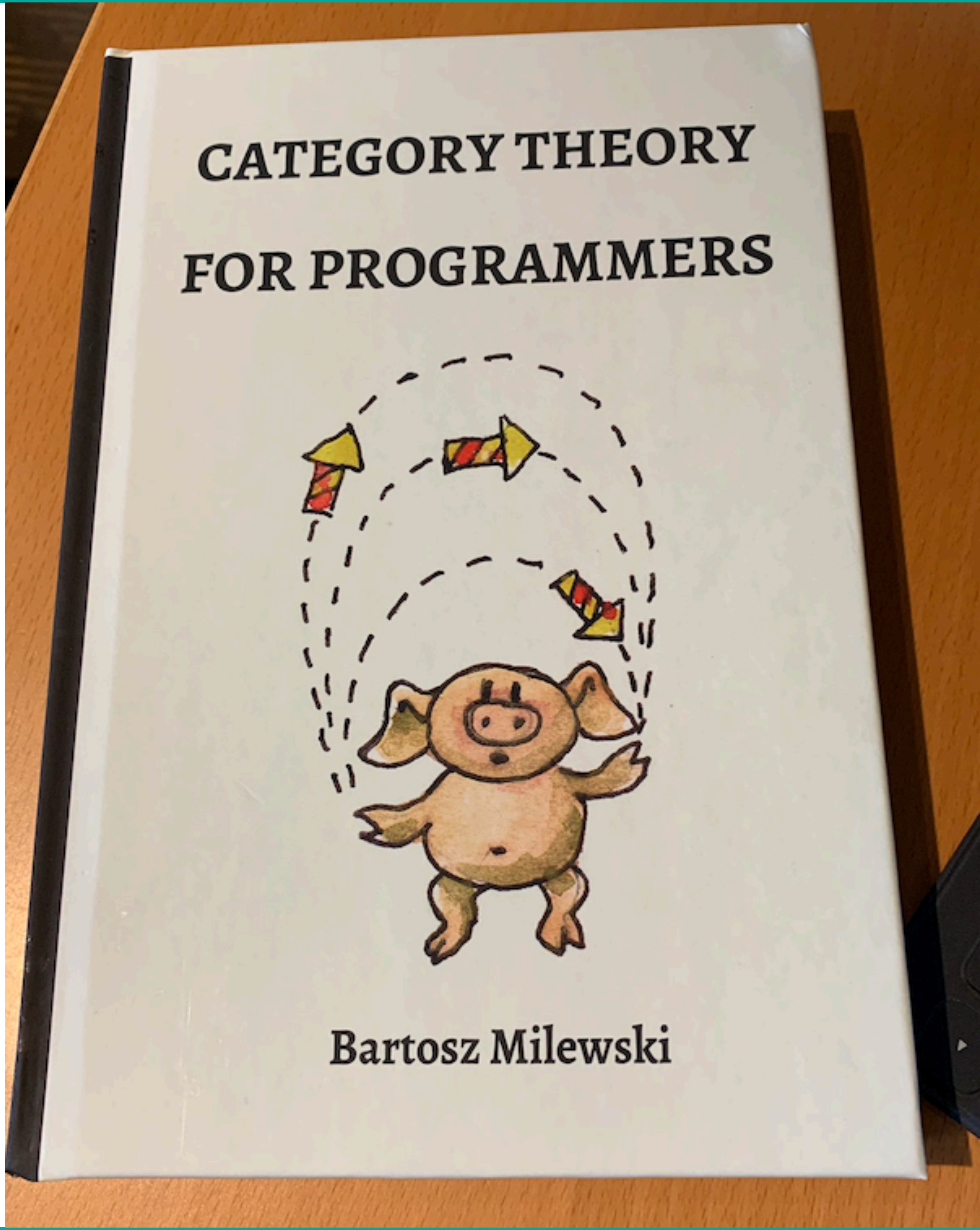
Category Theory
for Programmers
😅



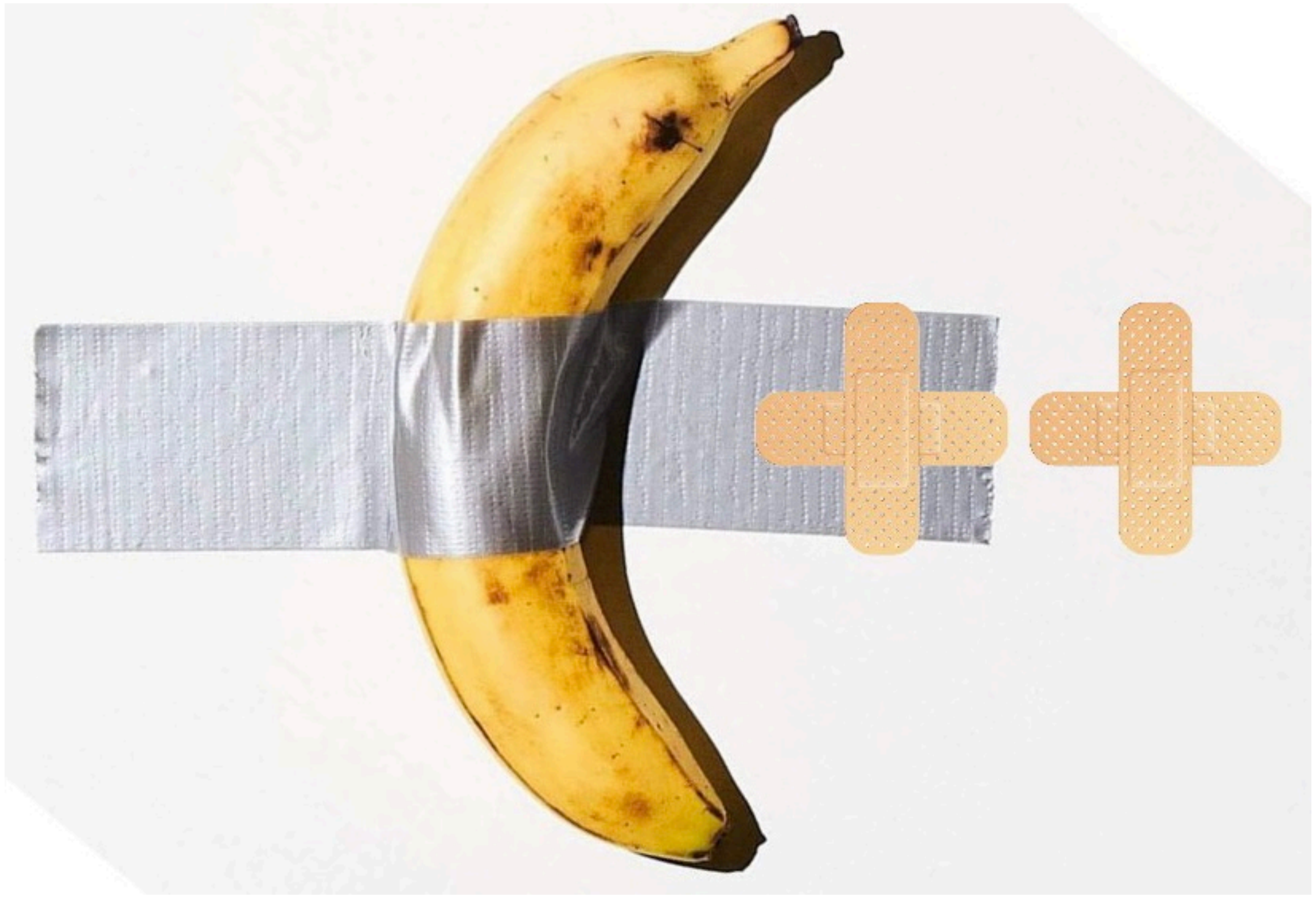
The Book

Bartosz Milewski
@BartoszMilewski

github.com/hmemcpy/milewski-ctfp-pdf



Modern C++

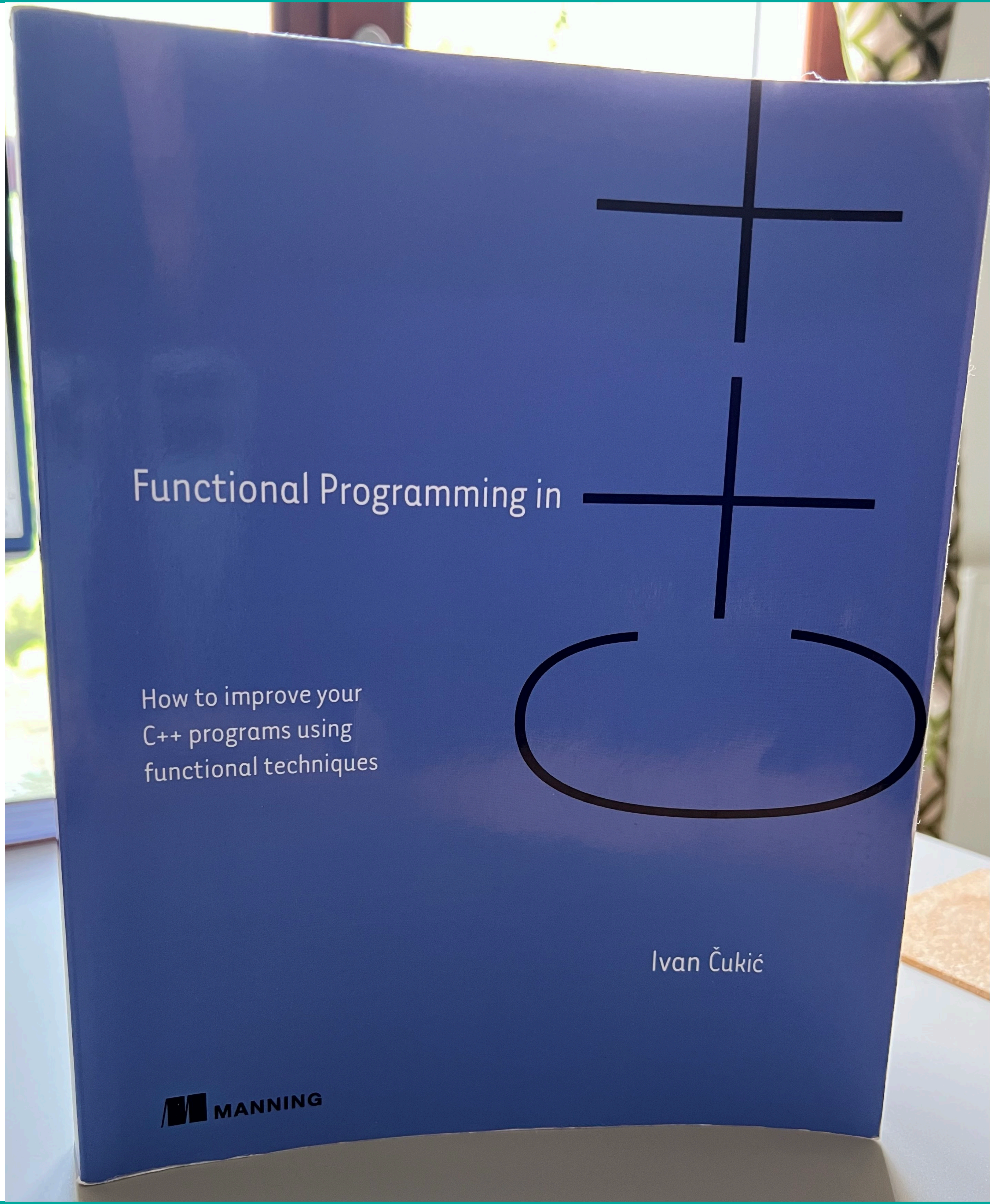


twitter.com/tvaneerd/status/1387

The Book

Ivan Čukić
@ivan_cukic

amazon.com/Functional-Programming-programs-functional-techniques


Functional Programming in C++
How to improve your C++ programs using functional techniques
Ivan Čukić
MANNING

Need a lift?

Lift ⬆️

Need a lift?

Higher-Order Functions

`boost::hof`

boost.org/doc/libs/develop/libs/hof/doc/html/doc/

Need a lift?

A C++17 library of simple constexpr higher order functions of predicates and for making functional composition easier.

These help reduce code duplication and improve clarity, for example in code using STL <algorithm>

github.com/rollbear/lift

Need a lift?

Higher order functions

- `equal`
- `not_equal`
- `less_than`
- `less_equal`
- `greater_than`
- `greater_equal`
- `negate`
- `compose`
- `when_all`
- `when_any`
- `when_none`
- `if_then`
- `if_then_else`
- `do_all`

Need a lift?

```
struct Employee {
  std::string name;
  unsigned    number;
};

const std::string& select_name(const Employee& e) { return e.name; }
unsigned select_number(const Employee& e) { return e.number; }

std::vector<Employee> staff;

// sort employees by name
std::sort(staff.begin(), staff.end(),
          lift::compose(std::less<>{}, select_name));

// retire employee number 5
auto i = std::find_if(staff.begin(), staff.end(),
                      lift::compose(lift::equal(5), select_number));
if (i != staff.end()) staff.erase(i);
```

Need a lift?

If you're using C++20 ranges you can get this (and more).

Projections... Oh my!

Need a lift?

Lifts overloaded functions named 'X' to one callable that can be used with other higher order functions.

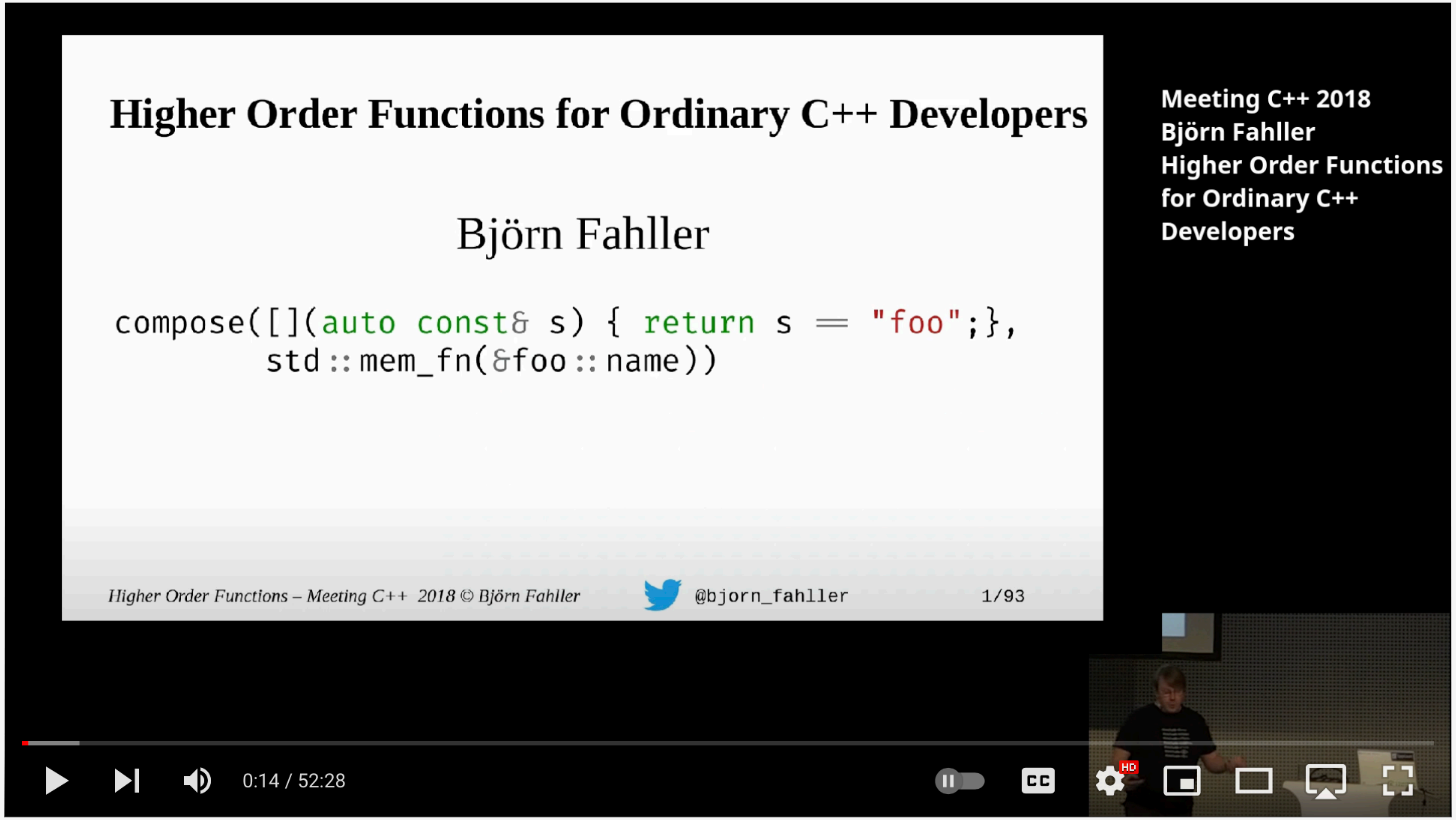
```
#define LIFT_THRICE(...)                          \
       noexcept(noexcept(__VA_ARGS__))  \
        -> decltype(__VA_ARGS__)         \
        {                                \
          return __VA_ARGS__;            \
        }

#define LIFT_FWD(x) std::forward<decltype(x)>(x)

#define LIFT(lift_func) [](auto&& ... p)
                         LIFT_THRICE(lift_func(LIFT_FWD(p)...))
```

Need a lift?

Lifts overloaded functions named 'X' to one callable that can be used with other higher order functions.

```
std::vector<int> vi;
... ⬇️
std::vector<std::string> vs;

std::transform(std::begin(vi), std::end(vi),
               std::back_inserter(vs),
               LIFT(std::to_string)); //lift overloaded set of 9 functions
```

Need a lift?



Higher Order Functions for Ordinary C++ Developers

Björn Fahller

```
compose([](auto const& s) { return s == "foo";},
        std::mem_fn(&foo::name))
```

Higher Order Functions – Meeting C++ 2018 © Björn Fahller @bjorn_fahller 1/93

Meeting C++ 2018
Björn Fahller
Higher Order Functions for Ordinary C++ Developers

Higher Order Functions for ordinary developers - Björn Fahller - Meeting C++ 2018

youtube.com/watch?v=qL6zUn7iiLg

Boxes 📦

Type Constructors

There are various ways to hide 📦 a value:

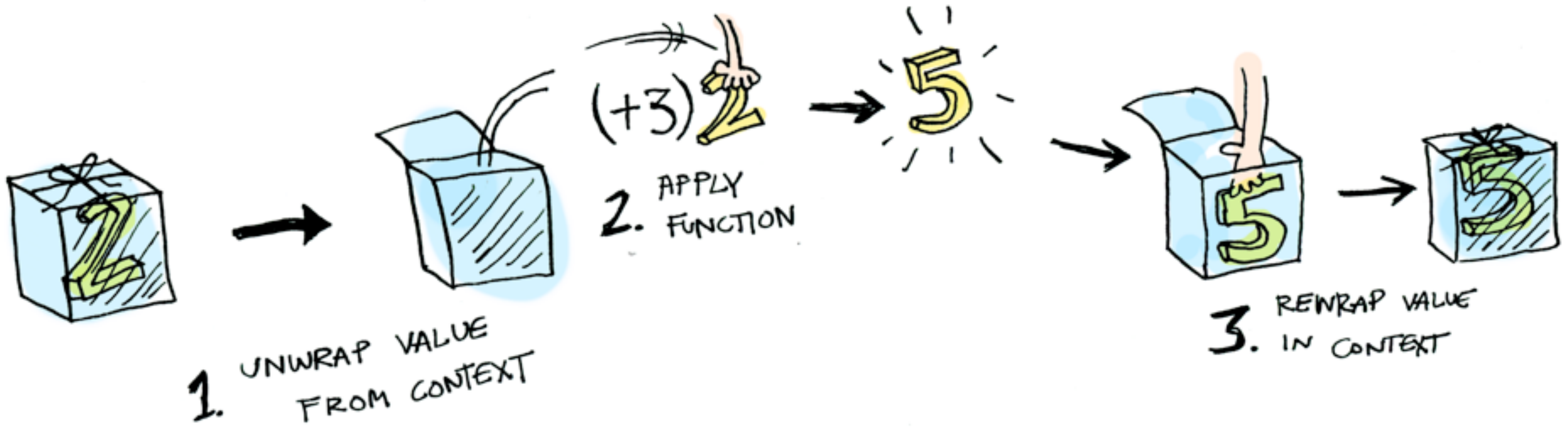
- `unique_ptr<T> p;`
- `shared_ptr<T> p;`
- `vector<T> v;`
- `optional<T> o;`
- `function<T(int)> f;`

Access the value within:

- `*p| p.get()`
- `*p| p.get()`
- `v[0] | *v.begin()`
- `*o| o.value()`
- `f(5)`

Functor | Applicative | Monad

Performing actions on the hidden value, without breaking the 📦 BOX.



adit.io/posts/2013-04-17-functors,_applicatives,_and_monads_in_pictures

📦 The Box

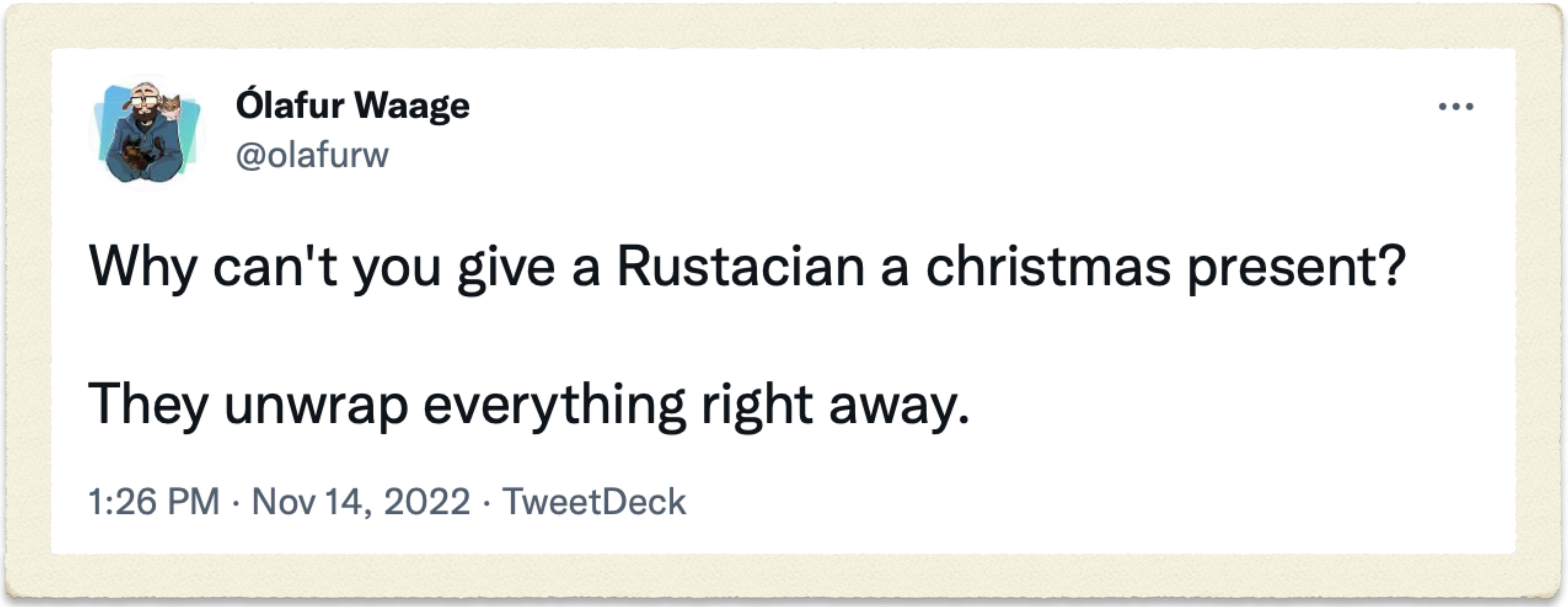
`std::optional` can simplify code

- don't look inside the 📦 box (unwrap)
- don't use optional for error handling
- when in doubt, draw inspiration from other languages:

  Haskell (`Maybe`) or Rust (`Option<T>`)

fmap (+3)
2
SOME MAGIC HAPPENS
5

📦 The Box


Ólafur Waage
@olafurw

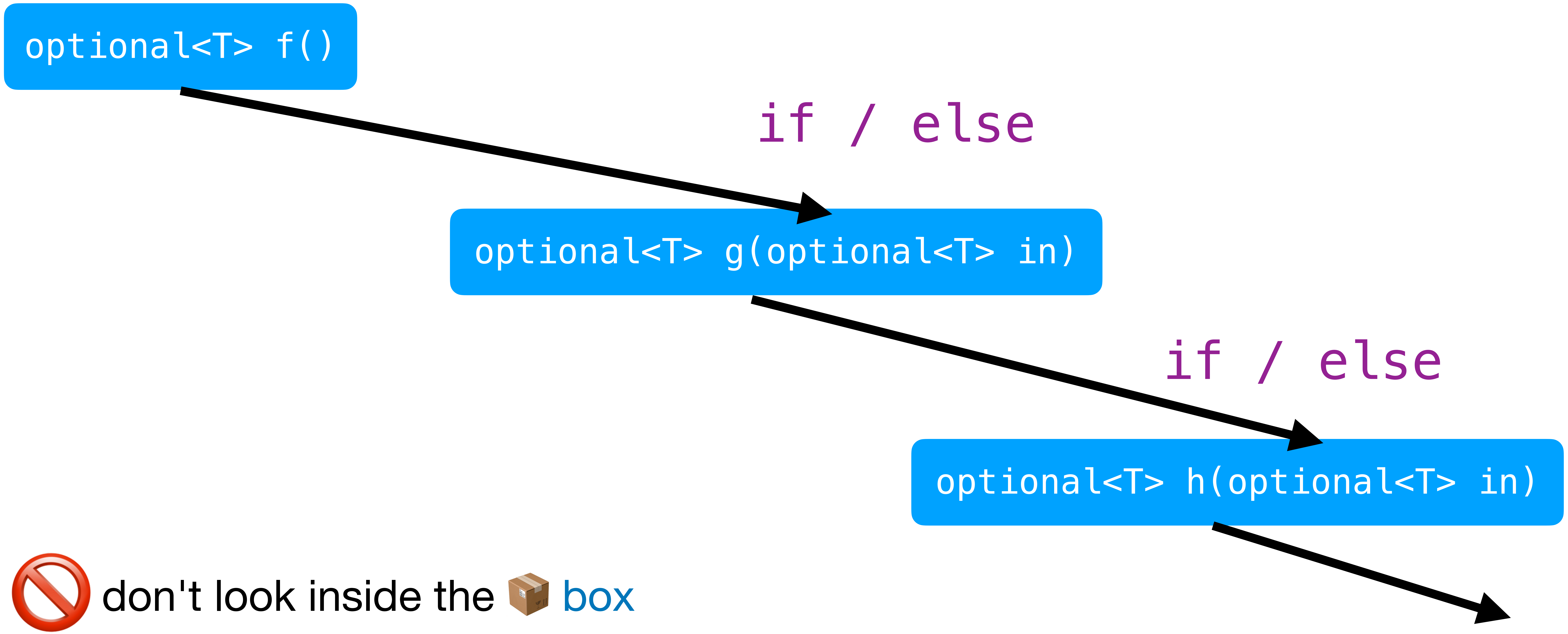
Why can't you give a Rustacian a christmas present?

They unwrap everything right away.

1:26 PM · Nov 14, 2022 · TweetDeck

doc.rust-lang.org/rust-by-example/error/option_unwrap

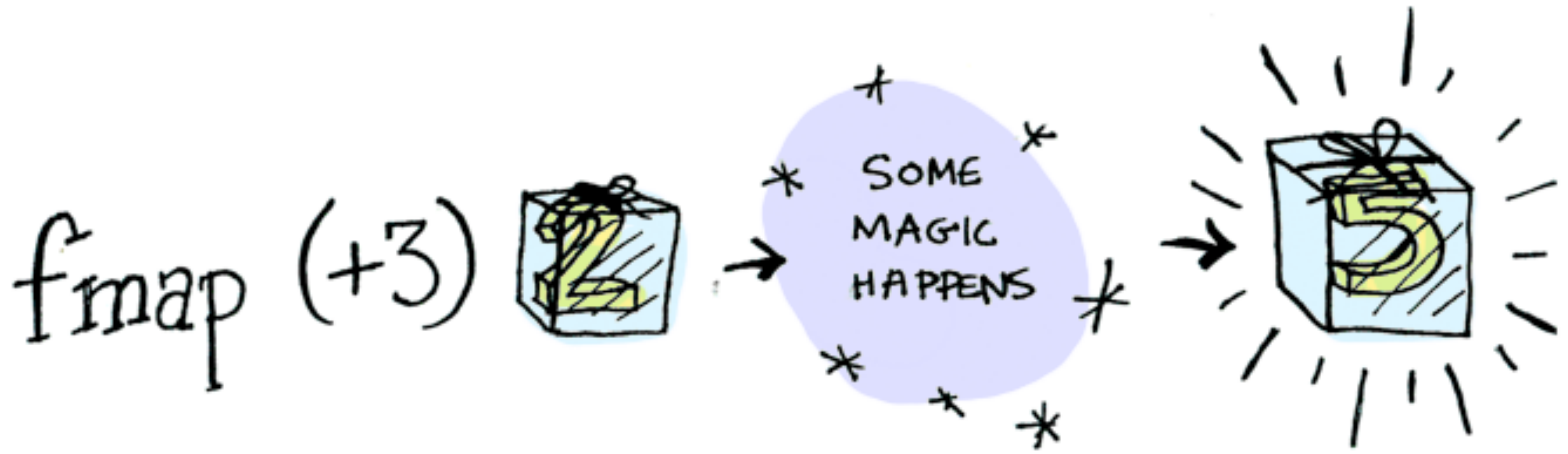
📦 The Box

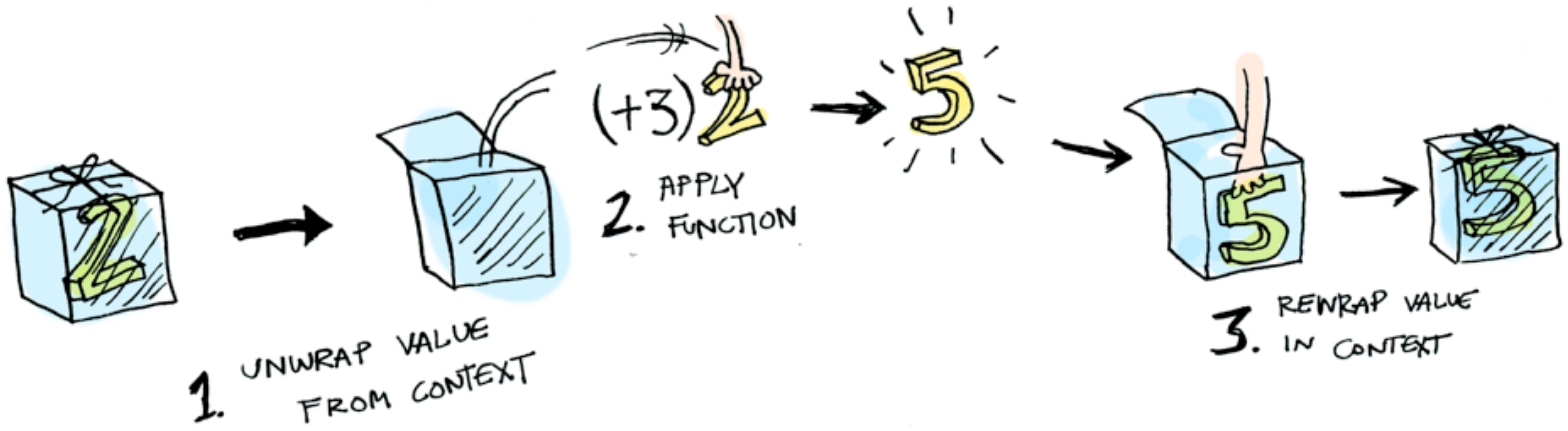


```
optional<T> f()
optional<T> g(optional<T> in)
optional<T> h(optional<T> in)
```

🚫 don't look inside the 📦 box

📦 The Box





adit.io/posts/2013-04-17-functors,_applicatives,_and_monads_in_pictures

Example

Calling the a function on the `std::string` value inside the `std::optional` box.

```
string capitalize(string str);
...

optional<string> str = ...; // from an operation that could fail

string cap;
if (str)
  cap = capitalize(str.value()); // capitalize(*str);
```

Example

Calling the a function on the `std::string` value inside the `std::optional` box.

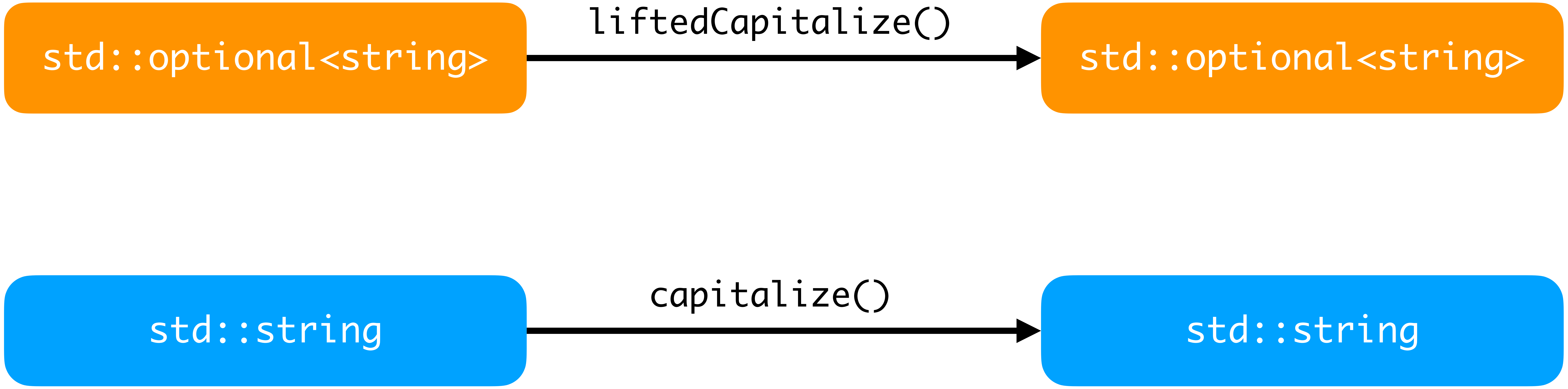
```
string capitalize(string str);
...

optional<string> str = ...; // from an operation that could fail

optional<string> cap;
if (str)
  cap = capitalize(str.value()); // capitalize(*str);
```

Lifting `capitalize()`

Lifted `capitalize()` operates on `optional<string>` and produces `optional<string>`

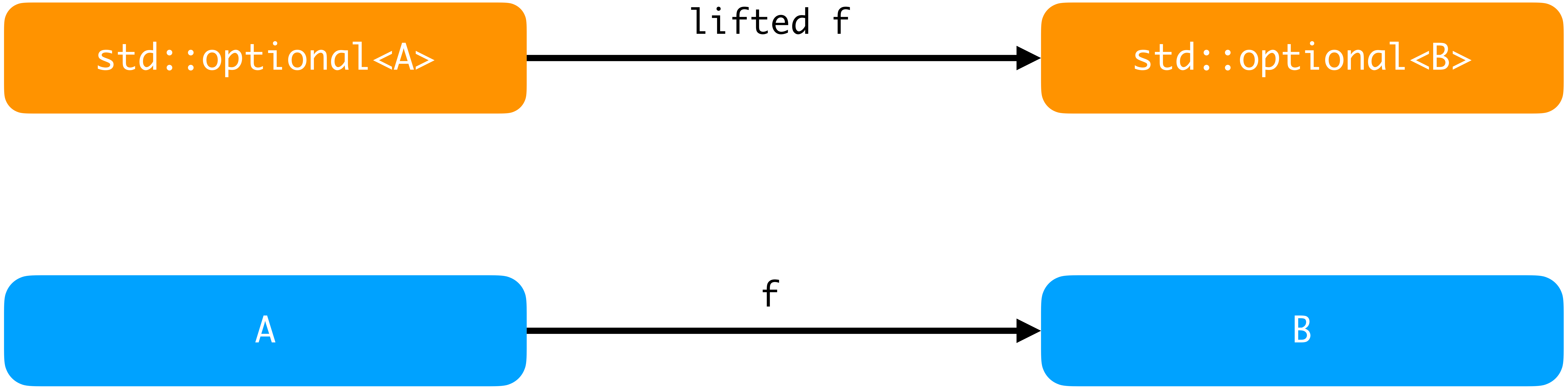
```
optional<string> liftedCapitalize(const optional<string> & s)
{
  optional<string> result;
  if (s)
    result = capitalize(*s);

  return result;
}
```

Lifting capitalize()



$$\begin{tikzcd} \texttt{std::optional<string>} \arrow[r, "\texttt{liftedCapitalize()}"] & \texttt{std::optional<string>} \\ \texttt{std::string} \arrow[r, "\texttt{capitalize()}"] & \texttt{std::string} \end{tikzcd}$$

Lifting any function



Lifting any function

"Lifted `f`" operates on `optional<A>` and produces `optional<B>`

```
template<class A, class B>
optional<B> fmap(function<B(A)> f, const optional<A> & o)
{
  optional<B> result;
  if (o)
    result = f(*o); // wrap a <B>

  return result;
}
```

Lifting any function (take 2)

```
template<typename T, typename F>
auto fmap(const optional<T> & o, F f) -> decltype( f(o.value()) )
{
  if (o)
    return f(o.value());
  else
    return {}; // std::nullopt
}
```

Lifting a function to a vector

"Lifted `f`" operates on `vector<A>` and produces `vector<B>`

```
template<class A, class B>
vector<B> fmap(function<B(A)> f, vector<A> v)
{
  vector<B> result;
  result.reserve(v.size());
  std::transform(v.begin(), v.end(), back_inserter(result), f);
  return result;
}



vector<string> names{ ... };

vector<int> lengths = fmap<string, int>(&length, names);
```

Composition of lifted functions

The real power of lifted functions shines when composing functions.

```
optional<string> str{"  Some text  "};

auto len = fmap<string, int>(&length,
                             fmap<string, string>(&trim, str));
```

liftedTrim
liftedLength
std::optional<string>
std::optional<string>
std::optional<int>
trim
length
std::string
std::string
int

Composition Example

Let’s build a symbol table for a debugged program.

```
optional<int64_t> current_pc = ... ; // function address
...

optional<string> debug_location()
{
  if (!current_pc)
    return {};

  const auto function = dsym::load_symbol(current_pc.value());
  if (!function)
    return {};

  return dsym::to_string(function.value()); // function name
}
```

Composition Example (take 2)

Let’s build a symbol table for a debugged program.

```
optional<int64_t> current_pc = ... ; // function address
...

optional<string> debug_location()
{
  return fmap(
    fmap(current_pc, dsym::load_symbol),
    dsym::to_string
  );
}
```

Composition Example (take 3)

We could create an `fmap` transformation that has the pipe | syntax, like ranges:

```
optional<int64_t> current_pc = ... ; // function address
...

optional<string> debug_location()
{
  return current_pc
           | fmap(dsym::load_symbol)
           | fmap(dsym::to_string);
}
```

Functor (recap)

Type constructor

- create a **`box`** type that wraps another type
- encapsulates the values of another type into a *context*

Function lifting

- create a *higher-order* function (eg. `fmap`)
- for any function `A->B` create a function `box<A> -> box<B>`

Why?

- no need to break encapsulation (no peek in 📦)
- better composition (chaining, continuation)

📦 The Box

Monadic `std::optional` (C++23 P0798)

```
optional<int> string_view_to_int(string_view sv)
{
  const auto first = sv.data();
  const auto last  = first + sv.size();
  int val = -1;
  const auto result = std::from_chars(first, last, val);

  if (result.ec == errc{} && result.ptr == last)
    return val;
  else
    return nullopt;
}
```

📦 The Box

Monadic `std::optional` (C++23 P0798)

```
cout << string_view_to_int(sv)
          .and_then([=](int val) -> optional<int> {
                    const int logs = clamp(val, 0, max_logs);
                    if (logs > 0)
                      return logs;
                    else
                      return std::nullopt;
                  })
          .transform([](int val) {
                     return std::format("Collecting in {} logs.", val);
                   })
          .or_else([] {
                    return optional<string>{"Log error"};
                 })
          .value()
```

Heritage

```
enum Option<T> {
    None,
    Some(T),
}


let second = ["Haskell", "Rust"].get(1);
println!("{:?}", second); // prints: Some("Rust")


let langs = ["C++", "Rust", "Carbon", "Val"];
let successor_lang : Option<&i32> = langs.get(4);
println!("{:?}", successor_lang); // prints: None
```

Heritage

```haskell
data Maybe a = Just a | Nothing


getFirst :: [a] -> Maybe a
getFirst (x : _) = Just x
getFirst [] = Nothing


print $ getFirst ["Haskell", "Rust", "C++"]
-- prints: Just "Haskell"

print $ getFirst []
-- prints: Nothing
```

Heritage / Concepts

`transform()`	**functor**	`fmap`
`and_then()`	**monad**	`>>= (bind)`

No value - Why?

std::optional - great for expressing that some operation produced no value,

but it gives us no information to help us understand why the operation failed.

No value - Why?

```
std::expected<T,E>
```

either the expected **T** value

or some **E** telling you what went wrong (why there is no value)

Expected

```
cout << string_view_to_int(sv)
         .and_then([=](int val) -> std::expected<int, ParseErr> {
                  const int logs = clamp(val, 0, max_logs);
                  if (logs > 0)
                    return logs;
                  else
                    return std::unexpected(ParseErr("out of range"));
                })
         .transform([](int val) {
                   return val + 1; // guard against off-by-one errors 😄
                 })
         .or_else([] {
                 return std::unexpected(ParseErr("not an integer"));
                })
         .value()
```

Heritage

```
enum Result<T, E> {
    Ok(T),
    Err(E),
}

fn safe_div(a: i32, b: i32) -> Result<i32, DivisionByZero> {
    match b {
        0 => Err(DivisionByZero),
        _ => Ok(a / b),
    }
}
```

```
#[derive(Debug)]
struct DivisionByZero;
```

```
println!("{:?}", safe_div(42, 2)); // prints: Ok(21)

println!("{:?}", safe_div(42, 0)); // prints: Err(DivisionByZero)
```

Result?

Heritage

```haskell
data Either a b = Left a | Right b
```

```haskell
safeDiv :: Int -> Int -> Either DivisionByZero Int
safeDiv x y = case y of
  0 -> Left DivisionByZero
  _ -> Right $ x `div` y

print $ safeDiv 42 2
-- prints: Right 21

print $ safeDiv 42 0
-- prints: Left DivisionByZero
```

```haskell
data DivisionByZero = DivisionByZero
  deriving (Show)
```

Availability

std::optional

- libstdc++ GCC 7
- libc++ Clang 4
- Microsoft STL VS2017 15.2

C++ 17

Availability

std::expected

- libstdc++ GCC 12
- libc++ Clang 16
- Microsoft STL VS2022 17.3

C++ 23

Availability

`.then()`

Monadic operations for std::optional (P0798)

- libstdc++ GCC 12
- libc++ Clang 14
- Microsoft STL VS2022 17.6

C++ 23

Monadic operations for std::expected (P2505)

- libstdc++ GCC 13
- libc++ Clang N/A
- Microsoft STL VS2022 17.6

Availability

Are we there yet?

- tl::optional
  - https://github.com/TartanLlama/optional

- tl::expected
  - https://github.com/TartanLlama/expected

C++11/14/17 functional interfaces, as single-header libraries

Read more

Sy Brand

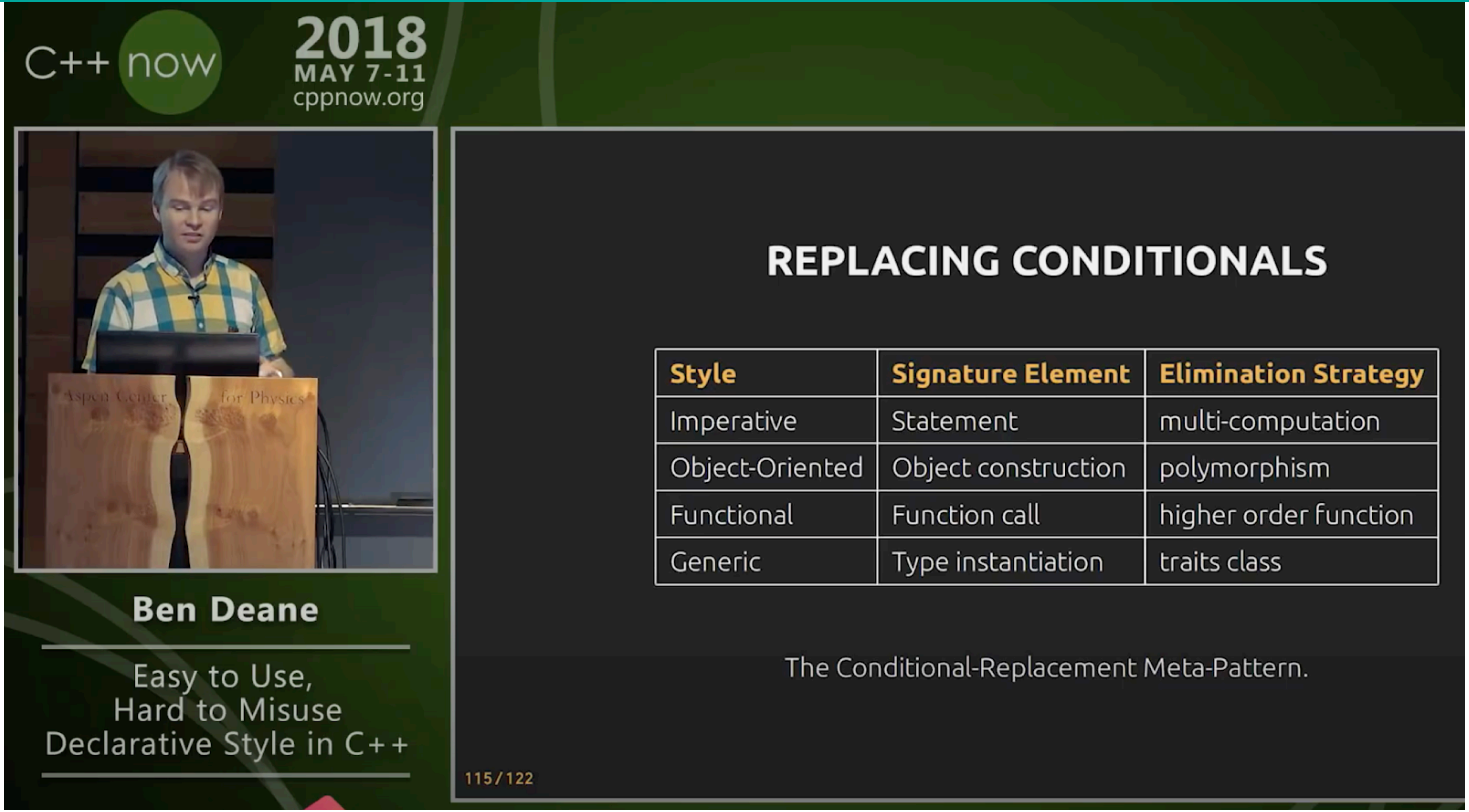
Functional exception-less error handling with C++23's optional and expected

https://devblogs.microsoft.com/cppblog/cpp23s-optional-and-expected/

Values

Expressions yield **values**, Statements do not;

Declarative style



REPLACING CONDITIONALS

Style	Signature Element	Elimination Strategy
Imperative	Statement	multi-computation
Object-Oriented	Object construction	polymorphism
Functional	Function call	higher order function
Generic	Type instantiation	traits class

The Conditional-Replacement Meta-Pattern.

115/122

youtube.com/watch?v=2ouxETt75R4

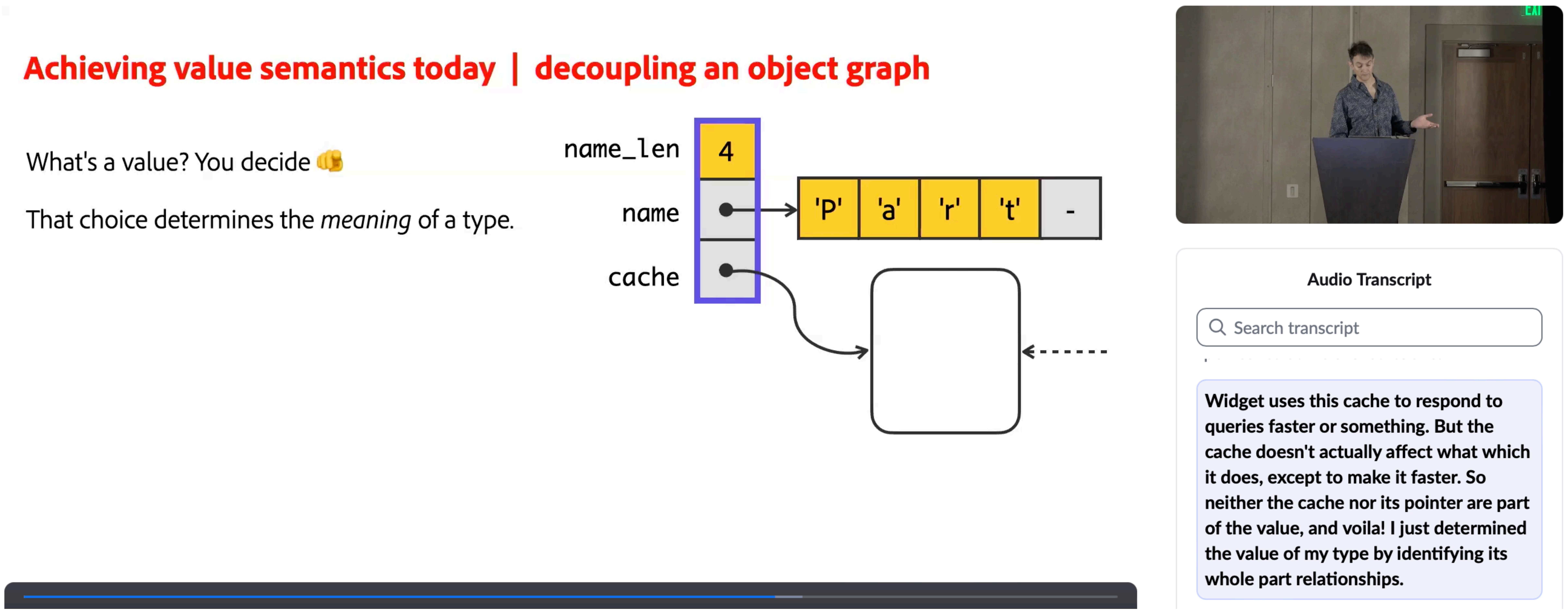
Must watch

youtube.com/watch?v=QthAU-t3PQ4

Cppcon The C++ Conference 2022
September 12th-16th
Dave Abrahams
Values: Safety, Regularity, Independence, and the Future of Programming
Values
Regularity, Independence, Projection, and the Future of Programming
DAVE ABRAHAMS
Video Sponsorship Provided By:
think-cell
0:10 / 1:00:45 • Introduction

Value Semantics: Safety, Independence, Projection, & Future of Programming - Dave Abrahams CppCon 22

Values: whole-part semantics



Achieving value semantics today | decoupling an object graph

What's a value? You decide 👊

That choice determines the *meaning* of a type.

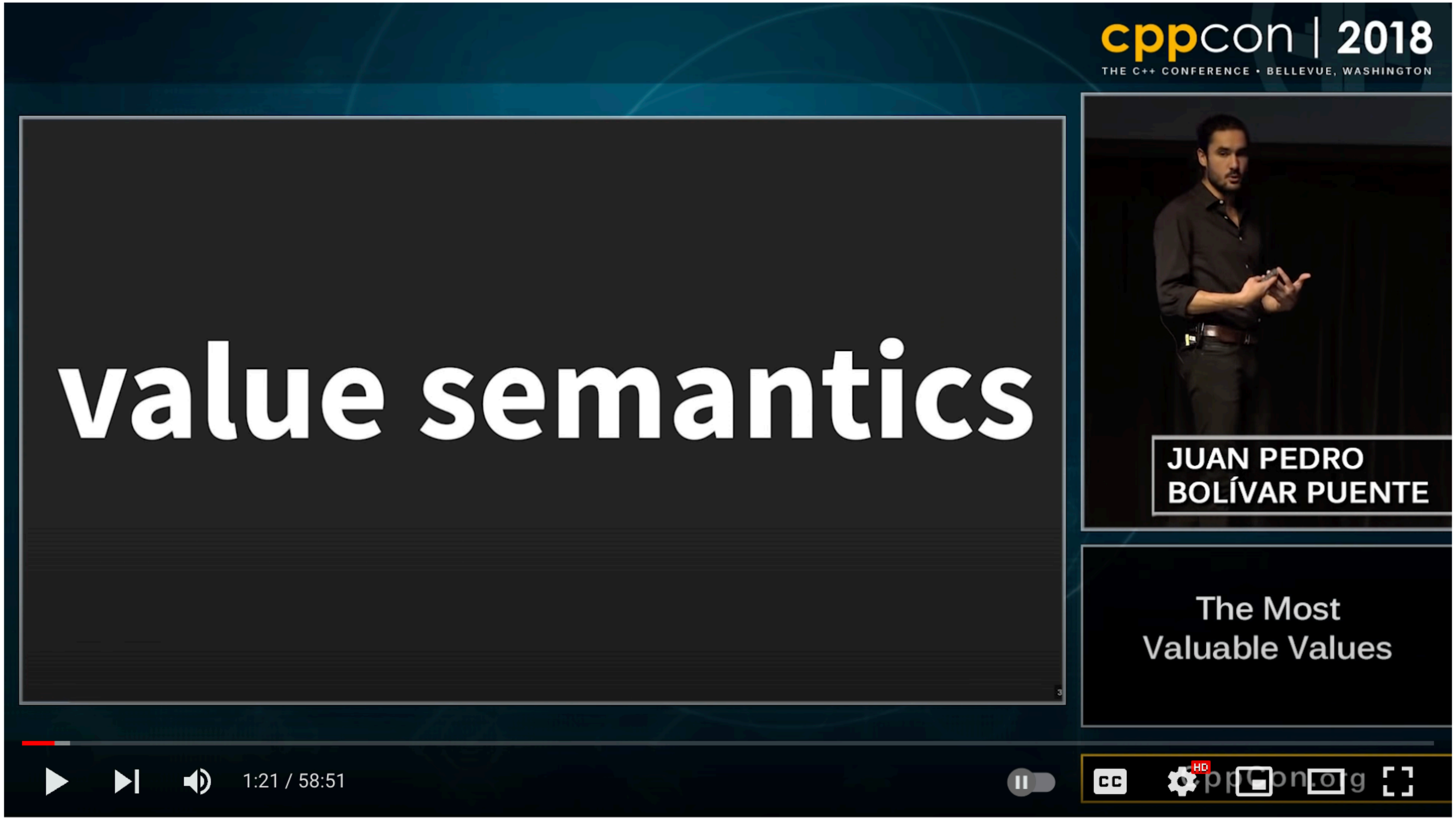
Audio Transcript

Search transcript

Widget uses this cache to respond to queries faster or something. But the cache doesn't actually affect what which it does, except to make it faster. So neither the cache nor its pointer are part of the value, and voila! I just determined the value of my type by identifying its whole part relationships.

youtube.com/watch?v=QthAU-t3PQ4

Values



CppCon 2018: Juan Pedro Bolivar Puente “The Most Valuable Values”

youtube.com/watch?v=_oBx_NbLghY

Most valuable Values

Value-oriented design reconciles functional and procedural programming by focusing on *value semantics*.

Like functional programming, it promotes local reasoning and composition.

It is however *pragmatic* and can be implemented in idiomatic C++,
in existing codebases.

Juan Pedro Bolívar Puente

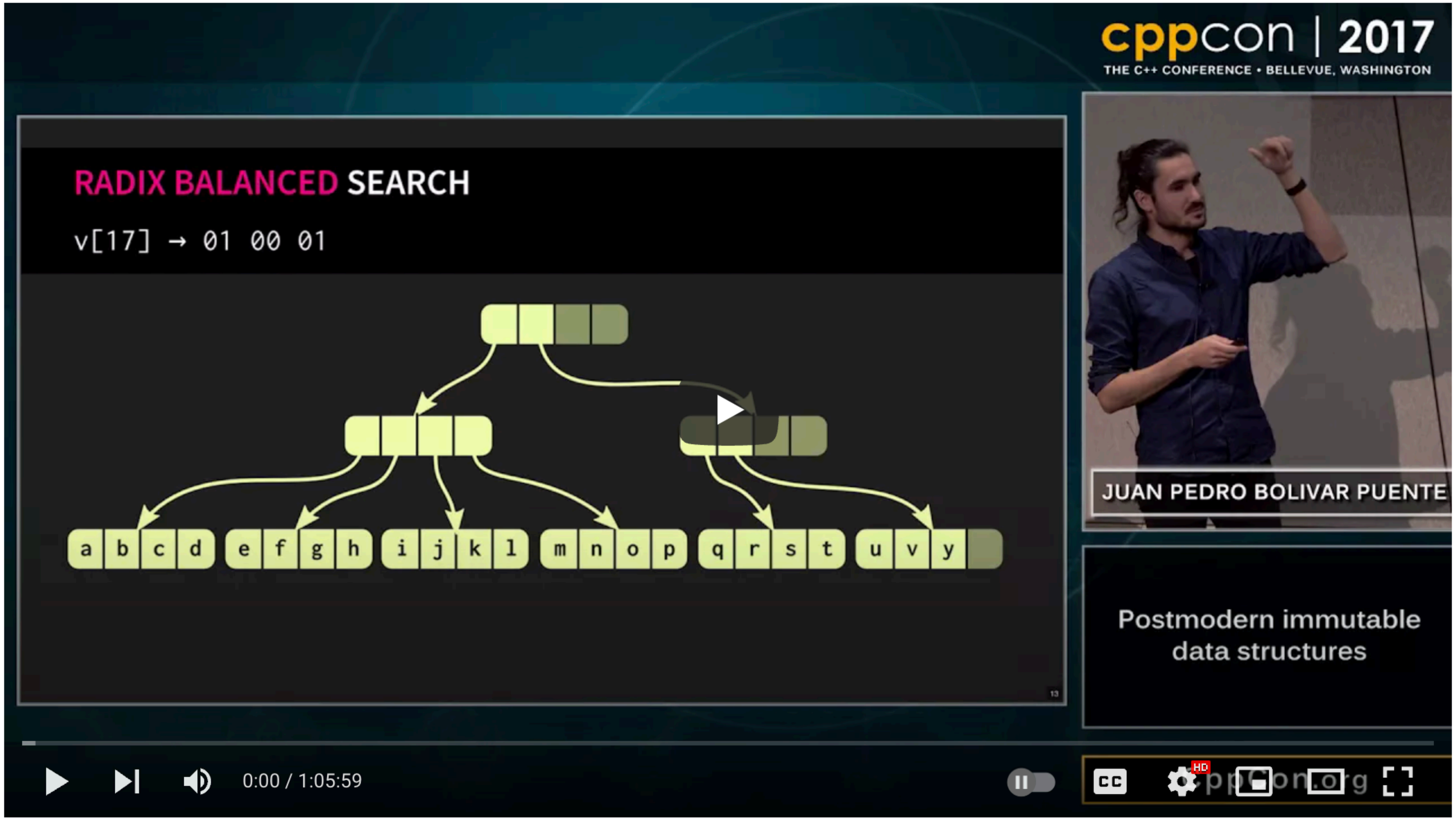
Values

Juan Pedro Bolivar Puente
Squaring the circle: value-oriented design in an object-oriented system
0:00 / 1:29:28

Value-oriented design in an object-oriented system - Juan Pedro Bolivar Puente [C++ on Sea 2020]

youtube.com/watch?v=SAMR5GJ_GqA

Immutable DS



cppcon | 2017
THE C++ CONFERENCE • BELLEVUE, WASHINGTON

RADIX BALANCED SEARCH

v[17] → 01 00 01

a b c d e f g h i j k l m n o p q r s t u v y
JUAN PEDRO BOLIVAR PUENTE
Postmodern immutable data structures
0:00 / 1:05:59

CppCon 2017

CppCon 2017: Juan Pedro Bolivar Puente "Postmodern immutable data structures"

youtube.com/watch?v=sPhpelUfu8Q

All the ra(n)ge...

C++ 20 Ranges

The beginning of the end for [begin, end)

Jeff Garland

Ranges

Adaptors

New algorithms

Pipelines

Ranges

Views

Actions

Lazy evaluation

Projections

Very efficient generated code

A taste of ranges

Print only the **even** elements of a range in **reverse** order:

```
std::for_each(
   crbegin(v), crend(v),
   [](auto const i)
   {
      if(is_even(i))
         cout << i;
   });
```

```
for (auto const i : v
                  | reverse
                  | filter(is_even))
{
   cout << i;
}
```

A taste of ranges

Skip the first **2** elements of the range and print only the **even** numbers of the **next 3** in the range:

```
auto it = cbegin(v);
std::advance(it, 2);
auto ix = 0;
while (it != cend(v) && ix++ < 3)
{
   if (is_even(*it))
      cout << (*it);
   it++;
}
```

```
for (auto const i : v
                  | drop(2)
                  | take(3)
                  | filter(is_even))
{
   cout << i;
}
```

A taste of ranges

Modify an *unsorted* range so that it retains only the **unique** values but in **reverse** order.

```
vector<int> v{ 21, 1, 3, 8, 13, 1, 5, 2 };

std::sort(begin(v), end(v));

v.erase(
   std::unique(begin(v), end(v)),
   end(v));

std::reverse(begin(v), end(v));
```

```
vector<int> v{ 21, 1, 3, 8, 13,
               1, 5, 2 };

v = std::move(v)
    | sort
    | unique
    | reverse;
```

A taste of ranges

Create a range of ***strings*** containing the **last 3** numbers **divisible to 7** in the range **[101, 200]**, in **reverse** order.

```
vector<string> v;

for (int n = 200, count = 0;
     n >= 101 && count < 3; --n)
{
   if (n % 7 == 0)
   {
      v.push_back(to_string(n));
      count++;
   }
}
```

```
auto v = iota_view(101, 201)
       | reverse
       | filter([](auto v) { return v%7==0; })
       | transform(to_string)
       | take(3)
       | to<vector>();
```

It's all about | pipelines

Taking inspiration from Doug McIlroy's UNIX shell script:

```
tr -cs A-Za-z '\n' |
    tr A-Z a-z     |
    sort           |
    uniq -c        |
    sort -rn       |
    sed ${1}q
```

Word frequencies

```
const auto words =
      input_range<string>(std::cin)
      | view::transform(string_to_lower)
      | view::transform(string_only_alnum)
      | view::remove_if(&string::empty)
      | ranges::sort
      | ranges::to<vector>();
```

Word frequencies

```
const auto results = words
  | view::group_by(equal_to())
  | view::transform([] (const auto & grp) {
      const auto size = distance(begin(grp), end(grp));
      const string word = *begin(grp);
      return make_pair(size, word);
    })
  | ranges::sort
  | ranges::to<vector>();
```

Word frequencies

```
for (auto value : results | view::reverse
                          | view::take(n))
{
  cout << value.first << ": " << value.second << "\n";
}
```

Gotchas with ranges / views*

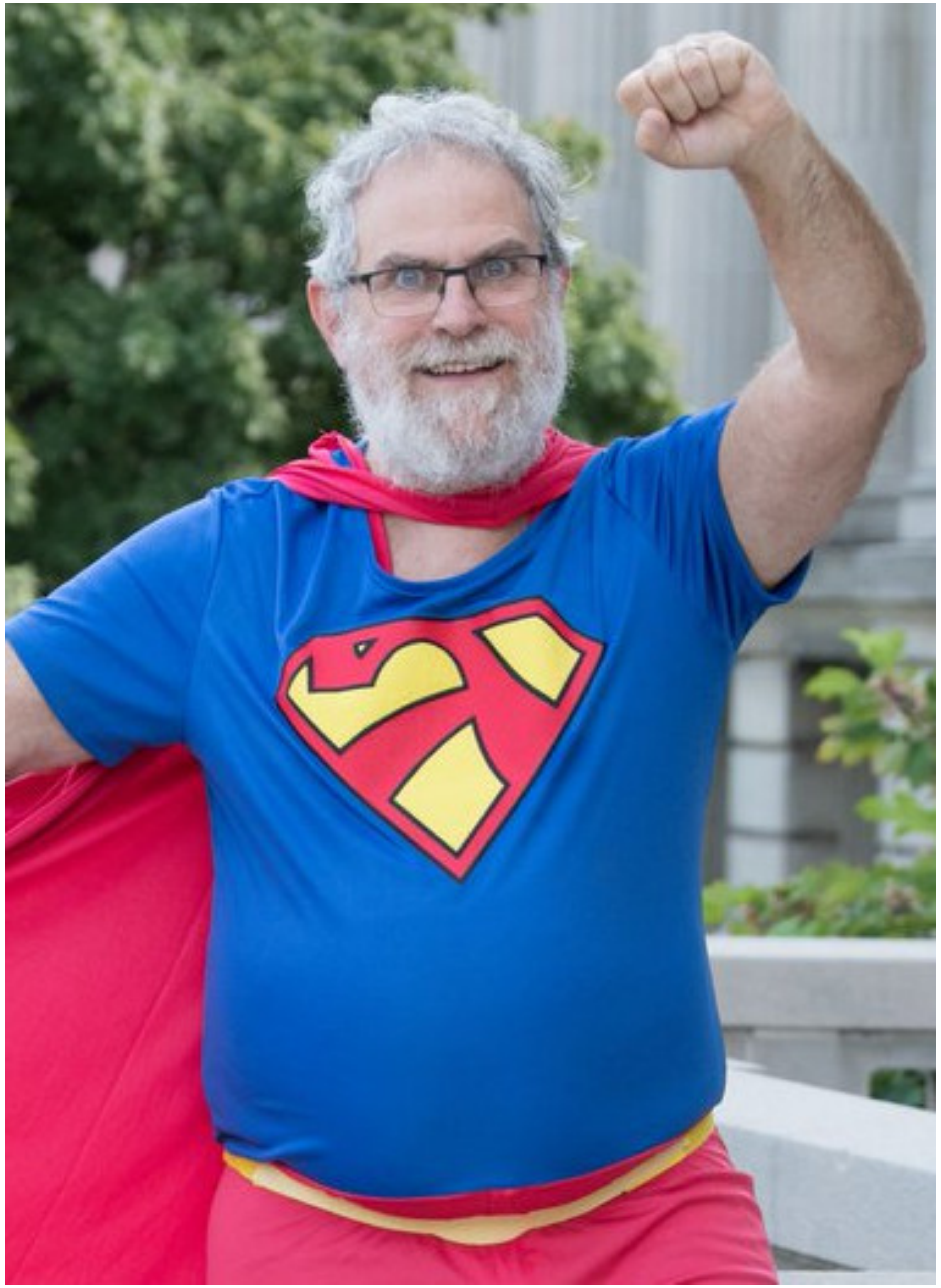
C++20 ranges library is fantastic tool, but watch out for gotchas ⚠️

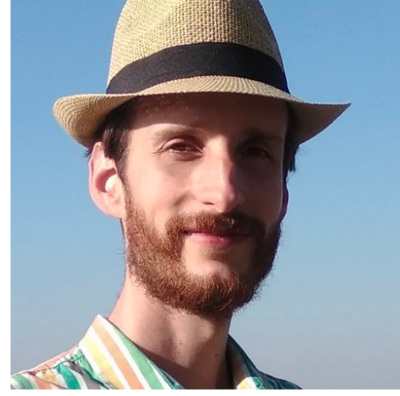
- views have *reference* semantics => all the reference gotchas apply
- as always with C++, **const** is shallow and doesn't propagate (as you might expect)
- some functions do caching, eg. `begin()`, `empty()`, `| filter | drop`
- don't hold on to views or try to reuse them
  - safest to use them ad-hoc, as temporaries
  - if needed, better "copy" them (cheap) for reuse

* the Nico slide :)

Remember him?

Phil Wadler and others develop type classes and monads, two of the main innovations of Haskell





<*> Čukić

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

Phil Wadler

The Imperatives Must Go!

ACCU

April 2023

@ciura_victor
@ciura_victor@hachyderm.io

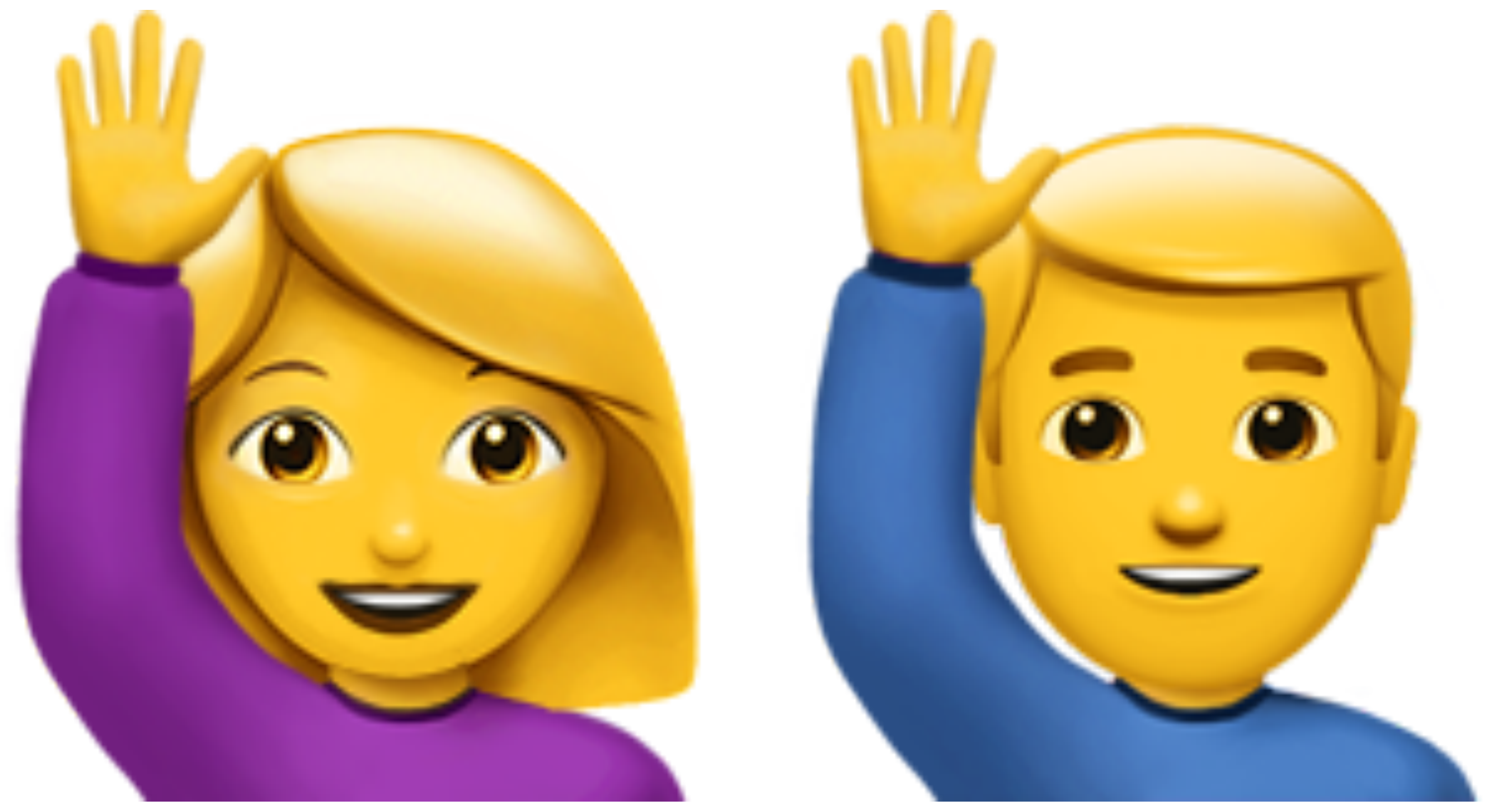
Victor Ciura
Principal Engineer
Visual C++

Extra

Bonus problem

Counting adjacent repeated values in a sequence.

How many of you solved this textbook exercise before ?
(in any programming language)



Counting adjacent repeated values in a sequence

```
{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }
```

Counting adjacent repeated values in a sequence

Visual hint:

```
{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }
```

Counting adjacent repeated values in a sequence

Visual hint:

{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }

{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }

Counting adjacent repeated values in a sequence

Visual hint:

```
{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }
```

```
{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }
```

Counting adjacent repeated values in a sequence

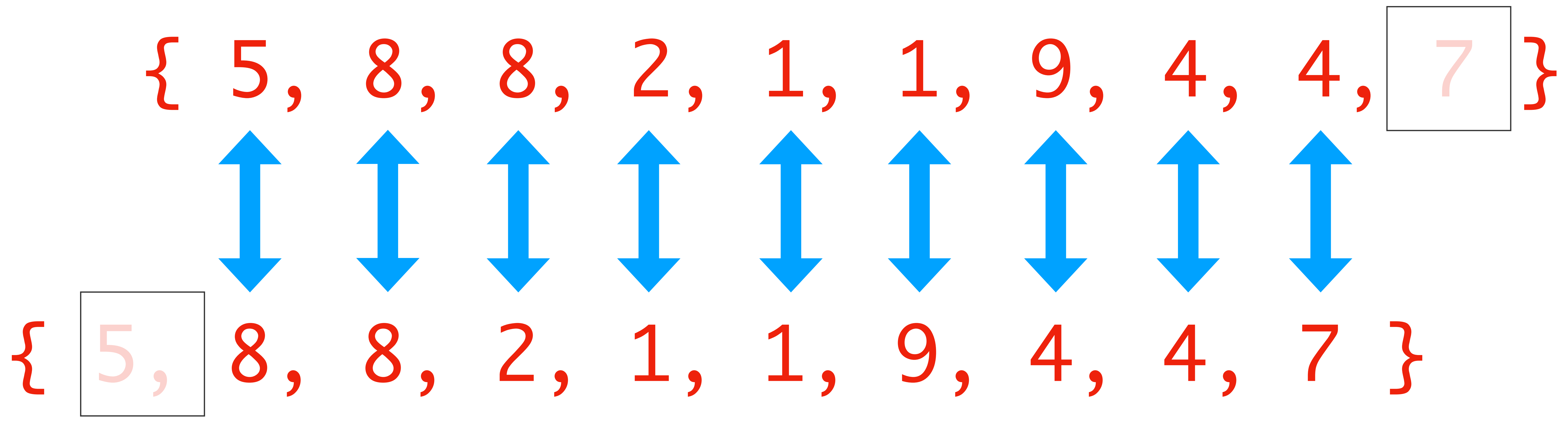
Visual hint:

$$\{\ 5,\ 8,\ 8,\ 2,\ 1,\ 1,\ 9,\ 4,\ 4, \boxed{\ 7\ }\}$$

$$\{ \boxed{5,}\ 8,\ 8,\ 2,\ 1,\ 1,\ 9,\ 4,\ 4,\ 7\ \}$$

Counting adjacent repeated values in a sequence

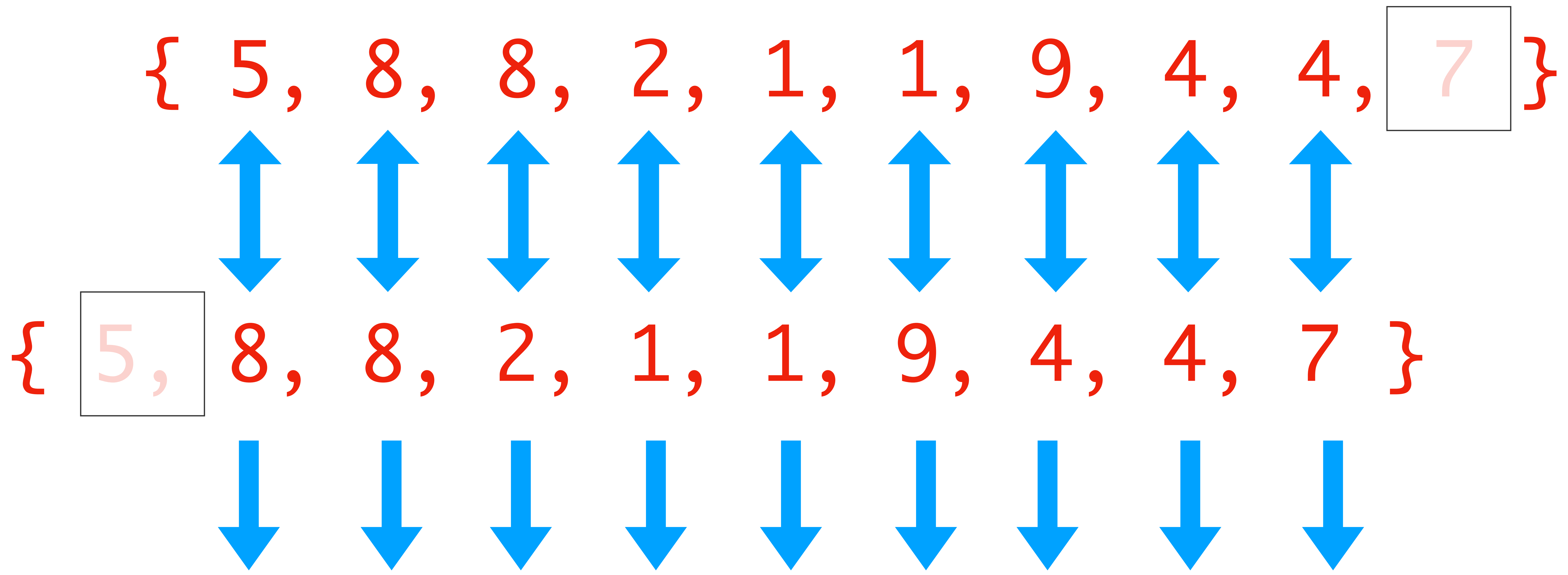
Visual hint:



```
{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }
{ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 }
```

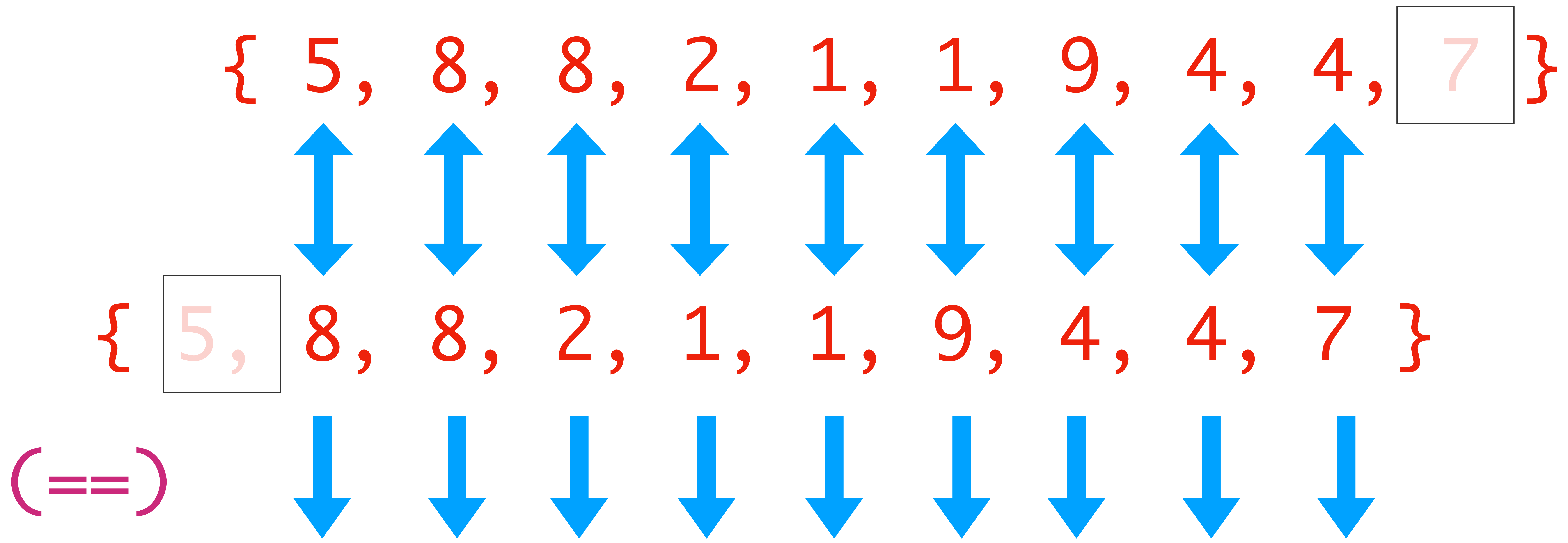
Counting adjacent repeated values in a sequence

Visual hint:



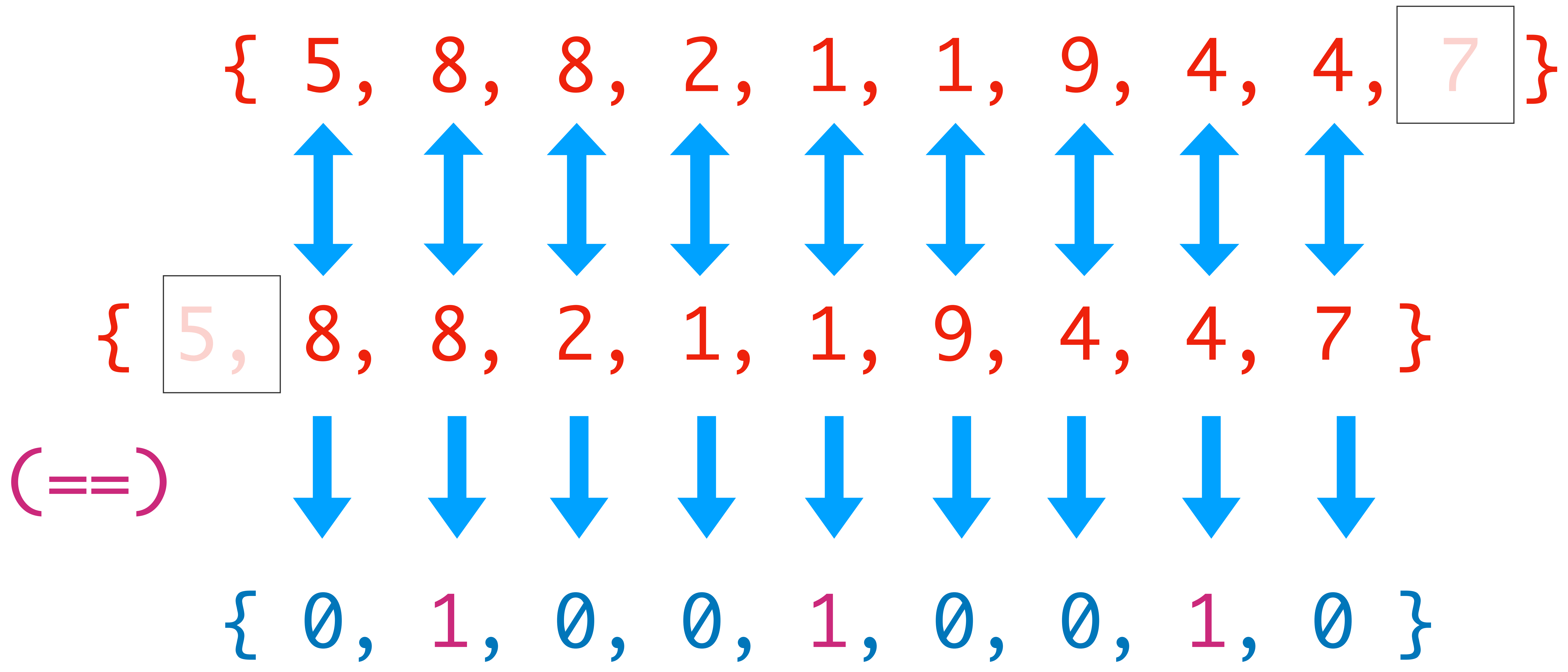
Counting adjacent repeated values in a sequence

Visual hint:



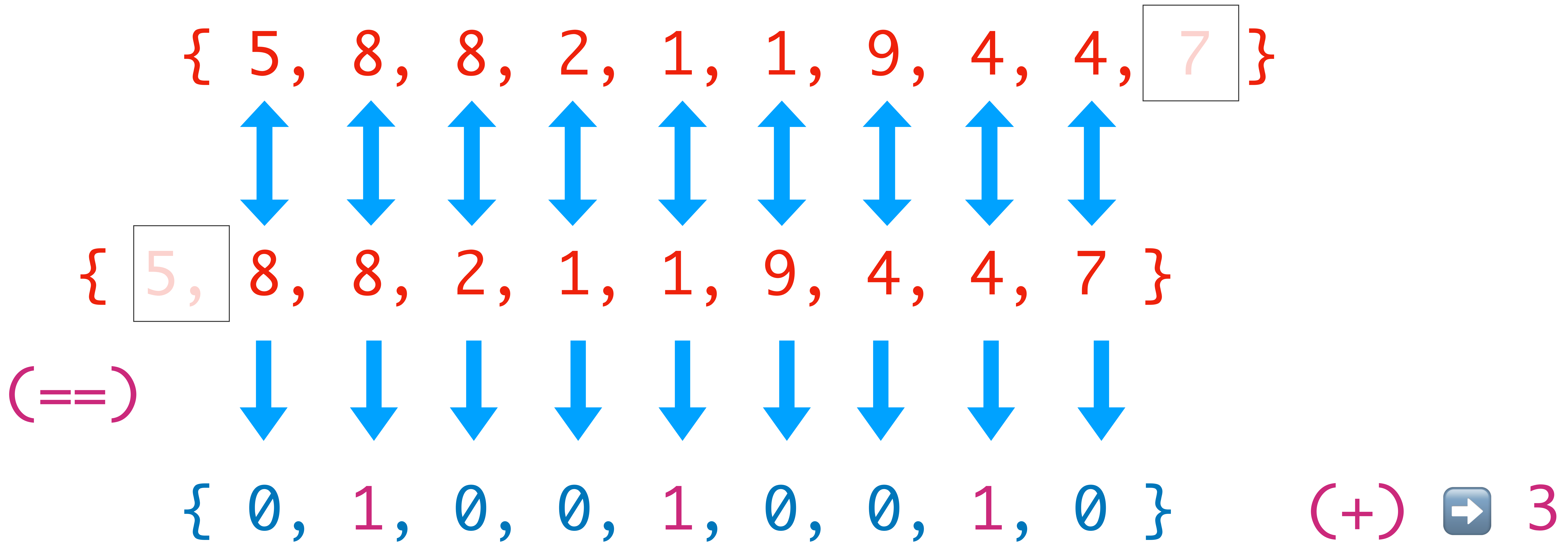
Counting adjacent repeated values in a sequence

Visual hint:



Counting adjacent repeated values in a sequence

Visual hint:



Counting adjacent repeated values in a sequence

Let me guess... a bunch of `for` loops, right ?

Counting adjacent repeated values in a sequence

Let me guess... a bunch of `for` loops, right ?

How about something shorter ?

An STL `algorithm` maybe ?

C++

Counting adjacent repeated values in a sequence

```
template<class InputIt1, class InputIt2,
         class T,
         class BinaryOperation1, class BinaryOperation2>
T inner_product(InputIt1 first1, InputIt1 last1,
                InputIt2 first2, T init,
                BinaryOperation1 op1  // "sum" function
                BinaryOperation2 op2) // "product" function
{
  while (first1 != last1)
  {
     init = op1(init, op2(*first1, *first2));
     ++first1;
     ++first2;
  }
  return init;
}
```

https://en.cppreference.com/w/cpp/algorithm/inner_product

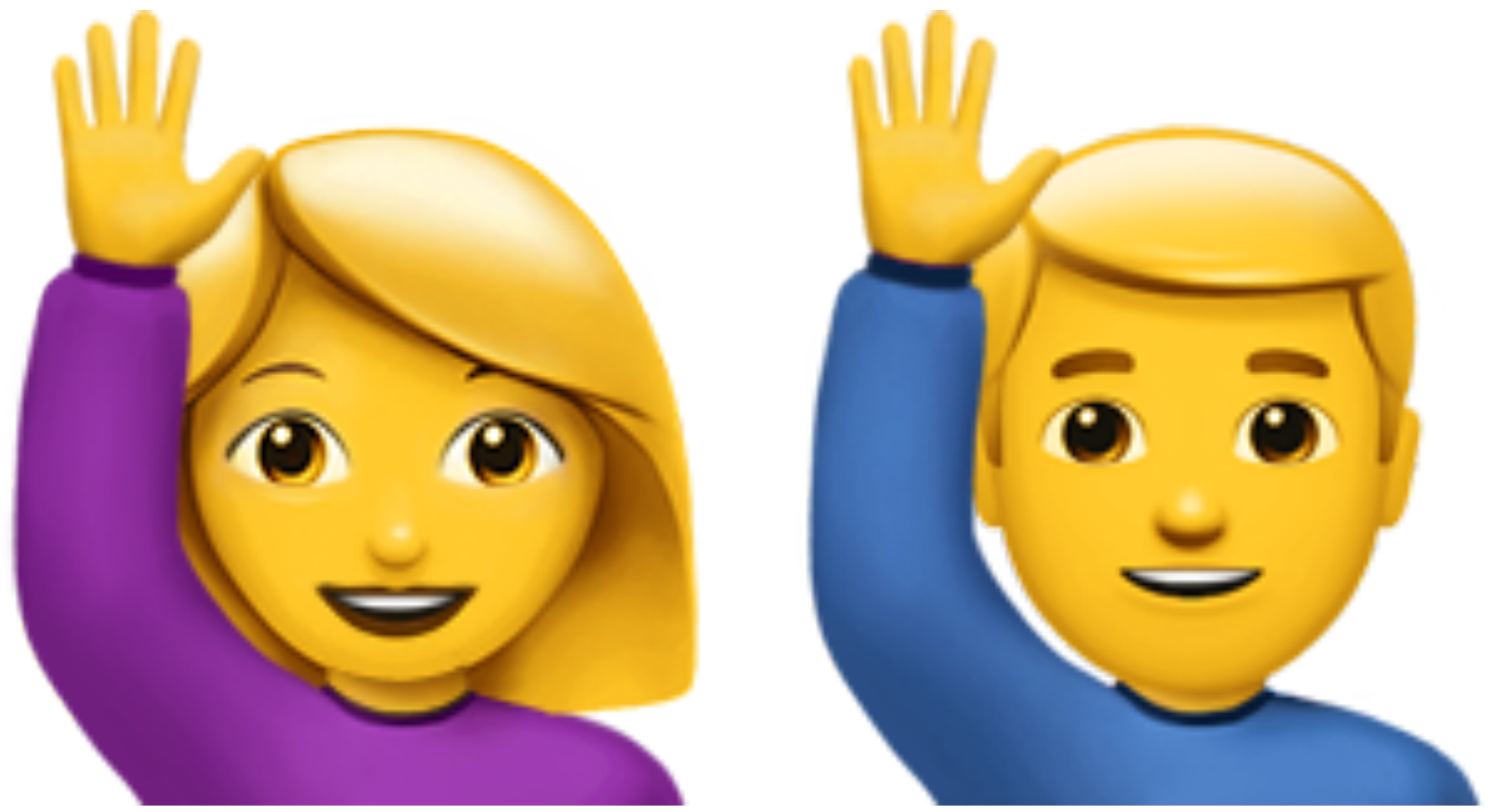
C++ Counting adjacent repeated values in a sequence

```
template <typename T>
int count_adj_equals(const T & xs) // requires non-empty range
{
  return std::inner_product(
    std::cbegin(xs), std::cend(xs) - 1, // to penultimate elem
    std::cbegin(xs) + 1,                // collection tail
    0,
    std::plus{},
    std::equal_to{}); // yields boolean => 0 or 1
}
```

C++ Counting adjacent repeated values in a sequence

❓

If you found that piece of code in a code-base,
would you **understand** what it does* ?



* without my cool diagram & animation

Counting adjacent repeated values in a sequence

Let's go back to Haskell for a few minutes...

Counting adjacent repeated values in a sequence

Visual hint:

```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
```

Counting adjacent repeated values in a sequence

Visual hint:

```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
```

```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
```

Counting adjacent repeated values in a sequence

Visual hint:

```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
```

```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
```

Counting adjacent repeated values in a sequence

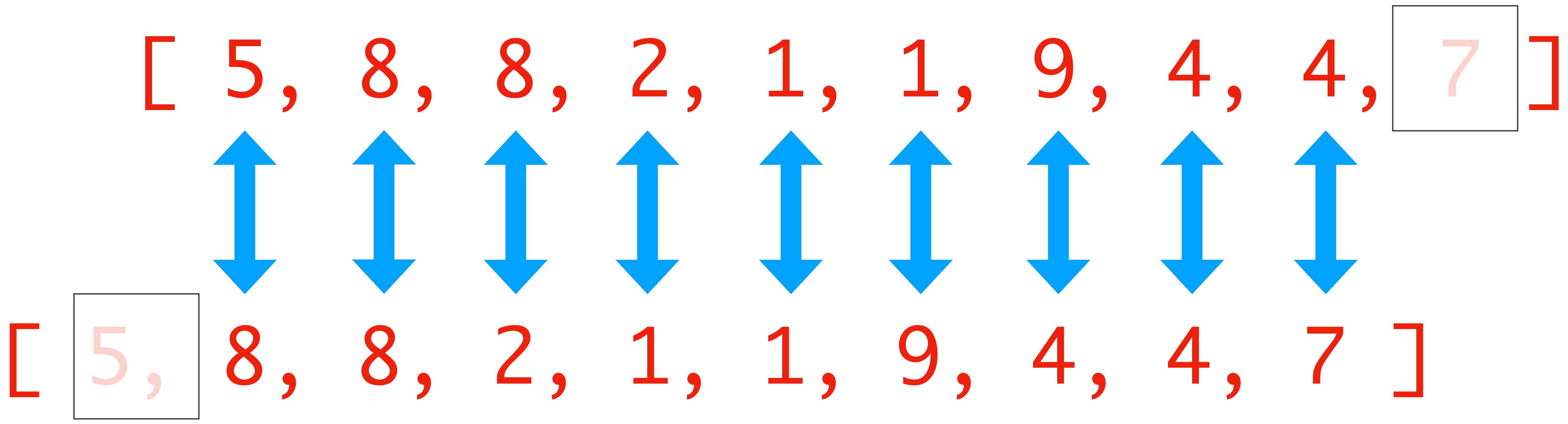
Visual hint:

[5, 8, 8, 2, 1, 1, 9, 4, 4, $\boxed{7}$]

[$\boxed{5,}$ 8, 8, 2, 1, 1, 9, 4, 4, 7]

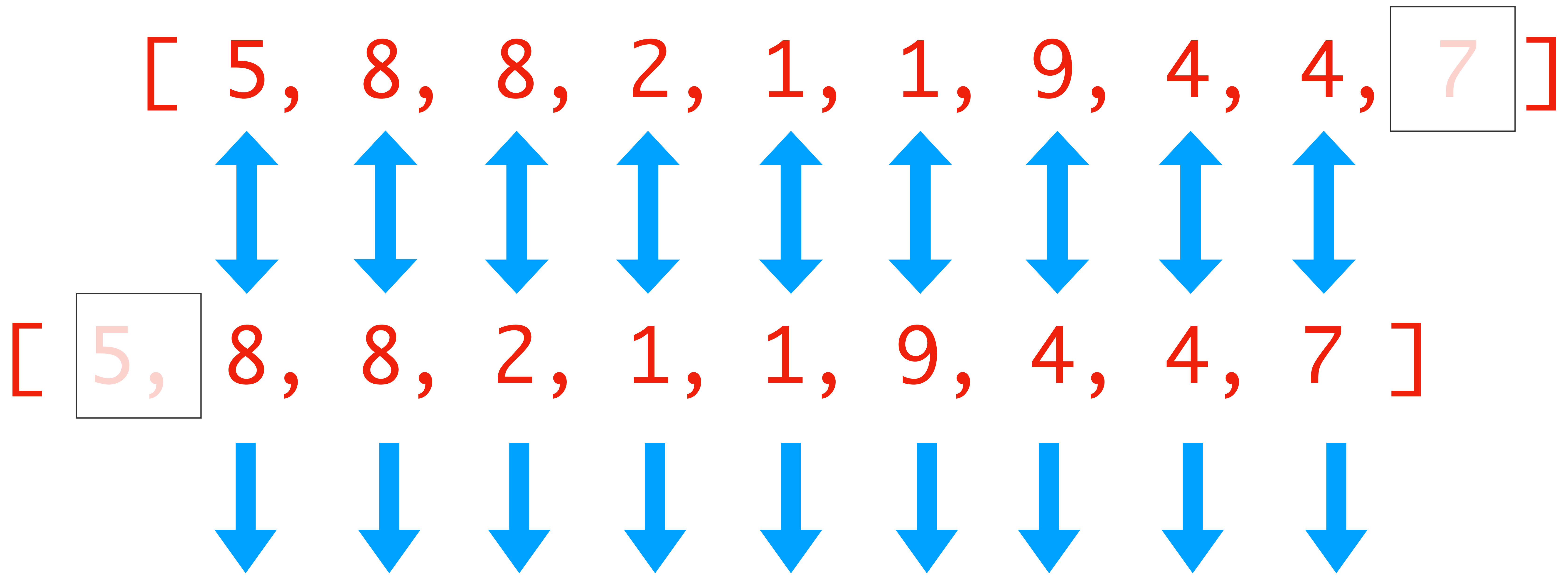
Counting adjacent repeated values in a sequence

Visual hint:



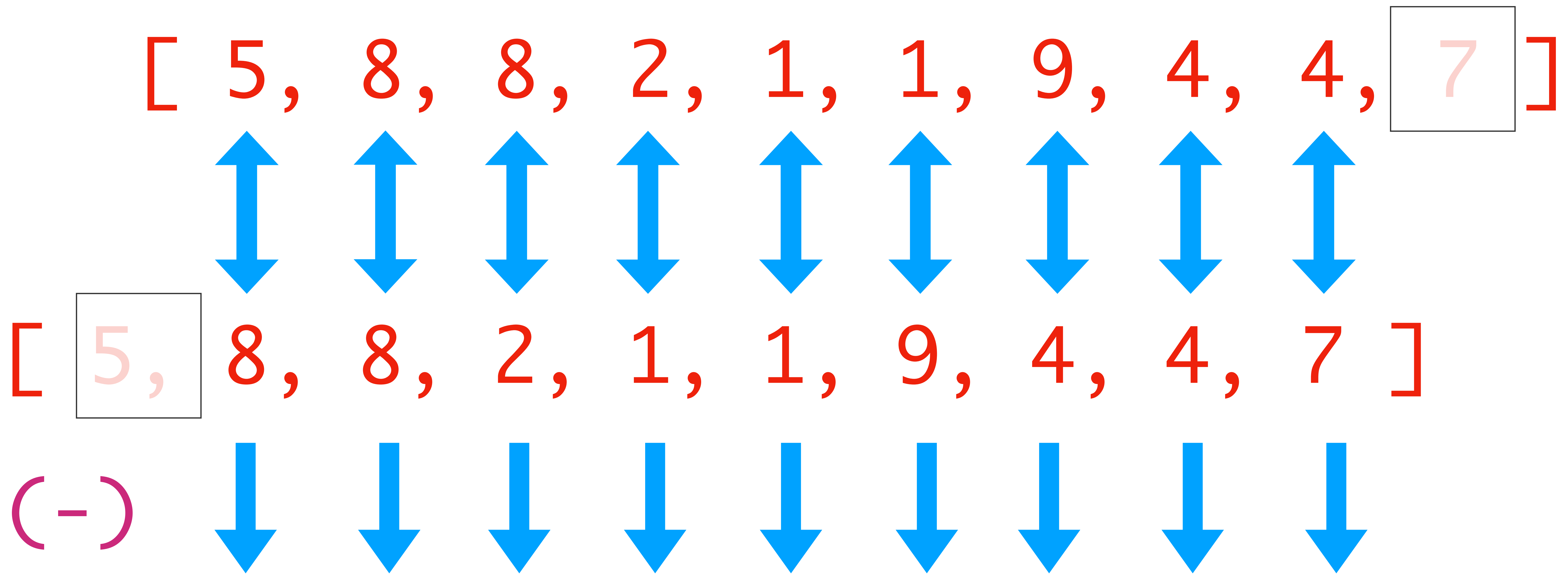
Counting adjacent repeated values in a sequence

Visual hint:



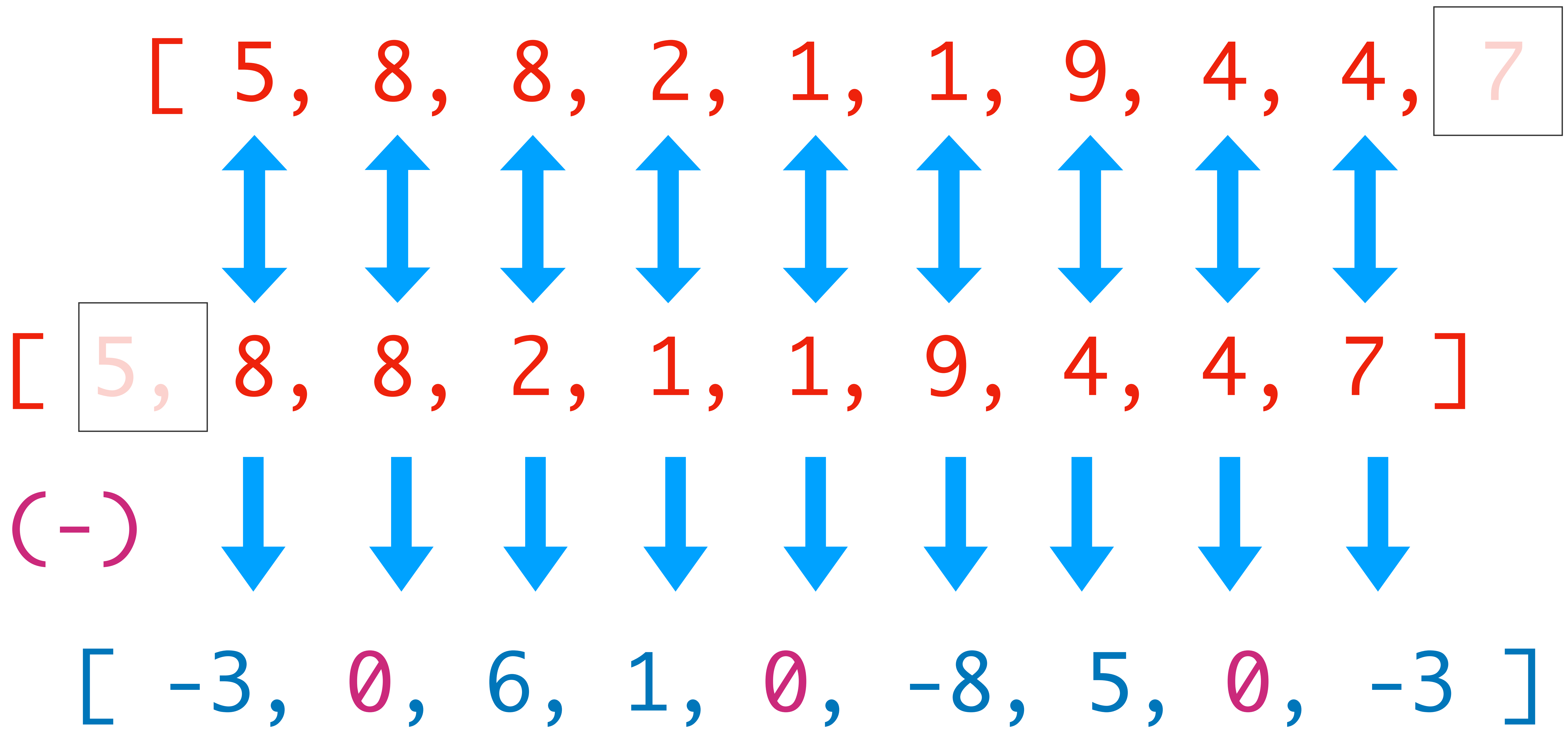
Counting adjacent repeated values in a sequence

Visual hint:



Counting adjacent repeated values in a sequence

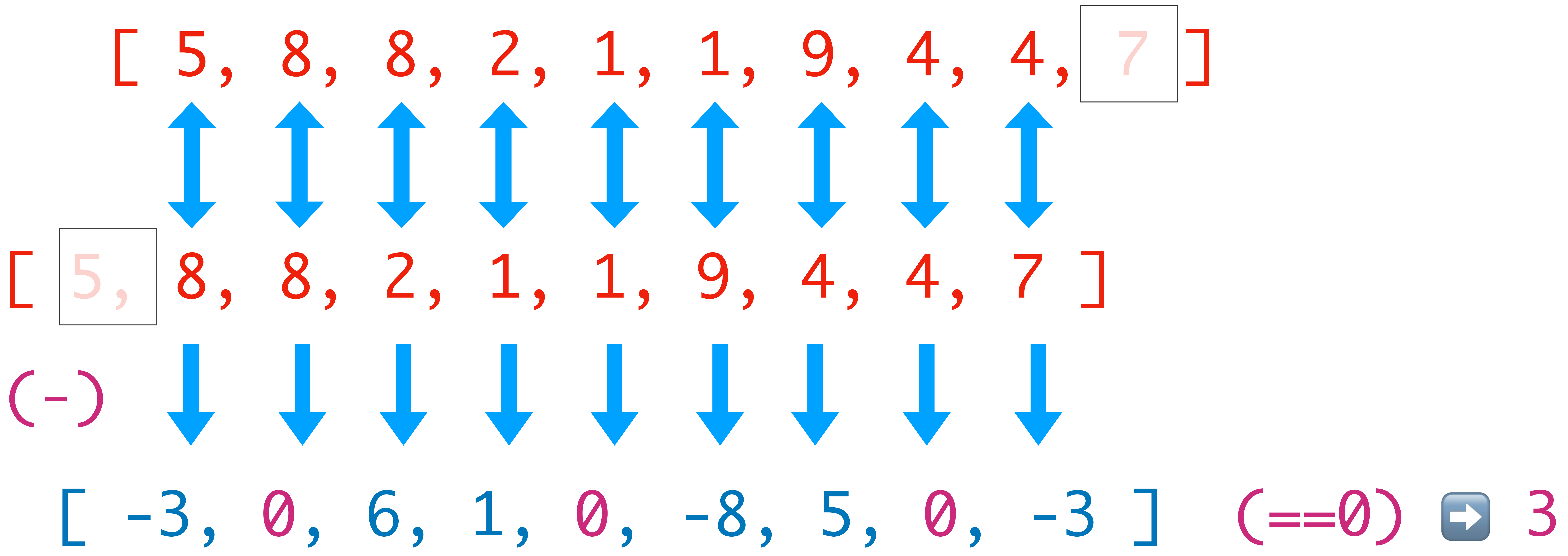
Visual hint:



```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]

[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
(-)
[ -3, 0, 6, 1, 0, -8, 5, 0, -3 ]
```

Counting adjacent repeated values in a sequence

Visual hint:



```
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
[ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]
(-)
[ -3, 0, 6, 1, 0, -8, 5, 0, -3 ]  (==0) ➡️ 3
```

Counting adjacent repeated values in a sequence

```
let xs = [ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]

count_if f = length . filter f
adj_diff = mapAdjacent (-)
count_adj_equals = count_if (==0) . adj_diff

> count_adj_equals xs
3
```

That's it !

Counting adjacent repeated values in a sequence

Let's break it down:

```
// C++                                            // Haskell
[](auto a, auto b) { return a + b; }              (\a b -> a + b)
plus{}                                            (+)

[](auto e) ->bool { return e == 1; }              (\e -> e == 1)
                                                  (==1)
```

Lambdas & sections

Counting adjacent repeated values in a sequence

Let's break it down:

```
length::[a] -> Int
filter::(a->Bool) -> [a] -> [a]

=>

count_if::(a->Bool) -> [a] -> Int
count_if f = length . filter f
```

Counting adjacent repeated values in a sequence

Let's break it down:

```
mapAdjacent::(a->a->b) -> [a] -> [b]
mapAdjacent _ [] = []
mapAdjacent f xs = zipWith f xs (tail xs)
```

Counting adjacent repeated values in a sequence

Let's break it down:

```
mapAdjacent::(a->a->b) -> [a] -> [b]
mapAdjacent _ [] = []
mapAdjacent f xs = zipWith f xs (tail xs)

      (-)::a -> a -> a
      adj_diff = mapAdjacent (-)

      =>

      adj_diff::[a] -> [a]
```

Counting adjacent repeated values in a sequence

Let's break it down:

```
    (==0)::a -> Bool
    count_if::(a->Bool) -> [a] -> Int
    adj_diff::[a] -> [a]
```

```
count_adj_equals::[a] -> Int
count_adj_equals = count_if (==0) . adj_diff
```

Counting adjacent repeated values in a sequence

Let's break it down:

```
let xs = [ 5, 8, 8, 2, 1, 1, 9, 4, 4, 7 ]

> let ds = adj_diff xs
[ -3, 0, 6, 1, 0, -8, 5, 0, -3 ]

> count_if(==0) ds
3
```

Counting adjacent repeated values in a sequence

The algorithm

```
count_if f = length . filter f
adj_diff = mapAdjacent (-)
count_adj_equals = count_if (==0) . adj_diff
```

C++ Counting adjacent repeated values in a sequence

Back to modern C++

C++ Counting adjacent repeated values in a sequence

Back to modern C++

```
template <typename T>
int count_adj_equals(const T & xs)
{
  return accumulate(0,
           zip(xs, tail(xs)) | transform(equal_to{}));
}
```

C++ Counting adjacent repeated values in a sequence

Back to modern C++

```
template <typename T>
int count_adj_equals(const T & xs)
{
  return accumulate(0,
           zip(xs, tail(xs)) | transform(equal_to{}));
}
```

Ranges FTW