Adobe

Local Reasoning in ~~Any Language~~ C++

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Local Reasoning

- *Local Reasoning* is the ability to reason about a defined unit of code and verify its correctness without understanding all the contexts in which it is used or the implementations upon which it relies.
- The two units of code this talk is concerned with are:
  - Functions
  - Classes

Terminology

- Local Reasoning is concerned with both sides of an API
  - The *client* code is the code calling a function or holding an instance of a class
  - The *implementor* code is the implementation of a function or class

Functions

```
void f();
```

Functions

```
// Does nothing
void f();
```

Functions

```
// Does nothing
void f() { }
```

Functions

```
// Returns the successor of `x`.
int f(int x) { return x + 1; }
```

Function Arguments

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// Increments the value of `x` by 1
void a(int& x) { x += 1; }
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```
// Increments the value of `x` by 1
// Precondition: no other thread of execution is accessing `x`
//     during this operation
void a(int& x) { x += 1; }
```

General Preconditions:

- Arguments passed to a function by non-const reference cannot be accessed by other threads during the operation
- Arguments passed to a function by const reference cannot be written by another thread during the operation
  - Unless otherwise specified

Function Arguments

```
// Increments the value of `x` by 1
void a(int& x) { x += 1; }
```

Transformations and Actions

There is a duality between transformations and the corresponding actions: An action is defined in terms of a transformation, and vice versa:

```
void a(T& x) { x = f(x); } // action from transformation
```

and

```
T f(T x) { a(x); return x; } // transformation from action
```

– *Elements of Programming, Section 2.5*

Argument Passing

- *let* arguments
  - `const T&`
- *inout* arguments
  - `T&`
- *sink* arguments
  - `T&&,` use a constraint when T is deduced

```
template <class T>
void f(T&&) requires std::is_rvalue_reference_v<T&&>;
```

Argument Qualifiers

- *let* arguments
  - Postcondition: The client value is not modified
- *inout* arguments
  - Postcondition: The client value may be modified
- *sink* arguments
  - Postcondition: The client value is (assumed to be) consumed
  - The client value may be assigned to, or destructed

A more complex action

```
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  x += n;
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offset(x, x);

println("{}", x);
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4

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// Offsets the value of x by n
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  for (int i = 0; i != n; ++x) ;
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- What will this print?

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int x{2};
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println("{}", x);
```

A more complex action

```
vector a{ 0, 1, 1, 0 };

erase(a, a[0]);

println("{}", a);
```

A more complex action

```
vector a{ 0, 1, 1, 0 };

erase(a, a[0]);

println("{}", a);
```

- What will this print?

```
[1, 0]
```

– *https://godbolt.org/z/hP1dsTPsa*

General Preconditions:

- inout and sink arguments cannot be accessed except directly by the implementation for the duration of the call
- let arguments passed by reference cannot be mutated for the duration of the call
  - Unless otherwise specified

Swift Law of Exclusivity

To achieve memory safety, Swift requires exclusive access to a variable in order to modify that variable. In essence, a variable cannot be accessed via a different name for the duration in which the same variable is being modified as an inout argument or as self within a mutating method.

– *Swift 5 Exclusivity Enforcement*

Rust Borrowing

Mutable references have one big restriction: if you have a mutable reference to a value, you can have no other references to that value.

– *The Rust Programming Language: References and Borrowing*

Projections

Function Results

```
// Returns the successor of `x`.
int f(int x) { return x + 1; }
```

Return-by-reference

```
vector a{0, 1, 2, 3};
a.back() = 42;

println("{}", a);
```

`[0, 1, 2, 42]`

Projection Qualifiers

- Projections qualifiers mirror argument qualifiers
  - *Mutable* (T&) projections allows the projected objects to be modified
  - *Constant* (`const T&`) projections do not allow the projected object to be modified
  - *Consumable* (T&&) projections allow the projected objects to be consumed

Projection Qualifiers

- Returning consumable projections are uncommon
  - Usually return by-value is used but consumables may be more efficient when extracting a value from an rvalue:

```
T&& extract() &&;
```

  - Mutable projections may also be consumed but require an additional operation to restore invariants on the owning object. i.e.

```
auto e{std::move(a.back());}
a.pop_back(); // erase the moved-from object
```

Projection Validity

- A projection is invalidated when:
  - The object they are projected from is modified other than through a projection

```
vector a{0};
int& p{a[0]};   // p is a projection
a.push_back(1); // p is invalidated
```

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const e& = a.back();
a.clear(); // invalidates e
```

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  - The lifetime of the object they are projected from ends

```
int& p{vector{0}[0]}; // p is invalidated right after creation!
```

Projecting Multiple Values

- Iterator pairs, views, and spans project a collection of values from an object
- They follow the same rules as reference projections

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```
vector a{3, 2, 1, 0};
copy(begin(a), begin(a) + 2, begin(a) + 1); // Invalid – overlapping
```

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- Iterator pairs, views, and spans project a collection of values from an object
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vector a{3, 2, 1, 0};
copy(begin(a), begin(a) + 2, begin(a) + 1); // Invalid – overlapping

vector a{3, 2, 1, 0};
copy(begin(a), begin(a) + 2, begin(a) + 2); // OK – not overlapping
```

Objects

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void f(shared_ptr<widget> p);
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- To understand `f()` we need to understand the *extent* `p`

Equational Reasoning

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- Equational reasoning explains how code works and is a component part of larger proofs.

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- Equational reasoning explains how code works and is a component part of larger proofs.
- To know if two values are equal, we need to know the *extent* of the values.

Equality

- *Equality* is an equivalence relation (reflexive, symmetric, and transitive)
- Equality connects to *copy* (equal and disjoint)

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– *Elements of Programming, Section 2.5*

Composite Objects and Whole-Part Relationships

- A *composite object* is made up of other objects, called its *parts*.
- The whole–part relationship satisfies the four properties of *connectedness*, *noncircularity*, *disjointness*, and *ownership*

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```
vector a{ 0, 1, 2, 3 };

struct {
  string name{ "John" };
  int id{0}
} b;
```

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void f(widget& p);
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void f(widget& p);
```

- This should only modify an instance of `widget`
- It should be possible to express this as:

```
widget f(widget&& p);
```

Extrinsic Relationships

Extrinsic Relationships

- An *extrinsic relationship* is a relationship that is not a whole-part relationship

```
vector a{0, 1, 2, 3};
```

  - `a[0]` is before `a[1]` is an extrinsic relationship

Relationships

- A relationship is a connection between elements of two sets
- A relationship between objects may be severed by modifying either object
- A relationship may be *witnessed* by an object such as a pointer or **index**
  - An object that is a witness to a severed relationship may be *invalid*

Local Reasoning and Extrinsic Relationship

- To reason *locally* about extrinsic relationships they should be encapsulated into a class
- The relationships are maintained between parts by the class
- The class ensures the validity and correctness of the relationships by controlling access to the related objects
- An intrusive witness in a part should only be manipulated by the owning class, and explicitly severed if the object is moved or copied outside the whole

Free Relationships

Free relationships

- A *free relationship* is an extrinsic relationship that is not managed between parts of an object.
- If we assume local reasoning what meaningful structures can we build?

CALM

"Question: What is the family of problems that can be consistently computed in a distributed fashion without coordination, and what problems lie outside that family?"

– *Keeping CALM: WhenDistributed Consistency is Easy*

CALM

"Consistency As Logical Monotonicity (CALM). A program has a consistent, coordination-free distributed implementation if and only if it is monotonic."

– *Keeping CALM: WhenDistributed Consistency is Easy*

CALM

- Conflict-free replicated data types(CRDTs) provide an object-oriented framework for monotonic programming patterns
- An immutable variable is a monotonic pattern that transitions from undefined to its final value and never returns. Immutable variables generalize to immutable data structures

Summary

Summary

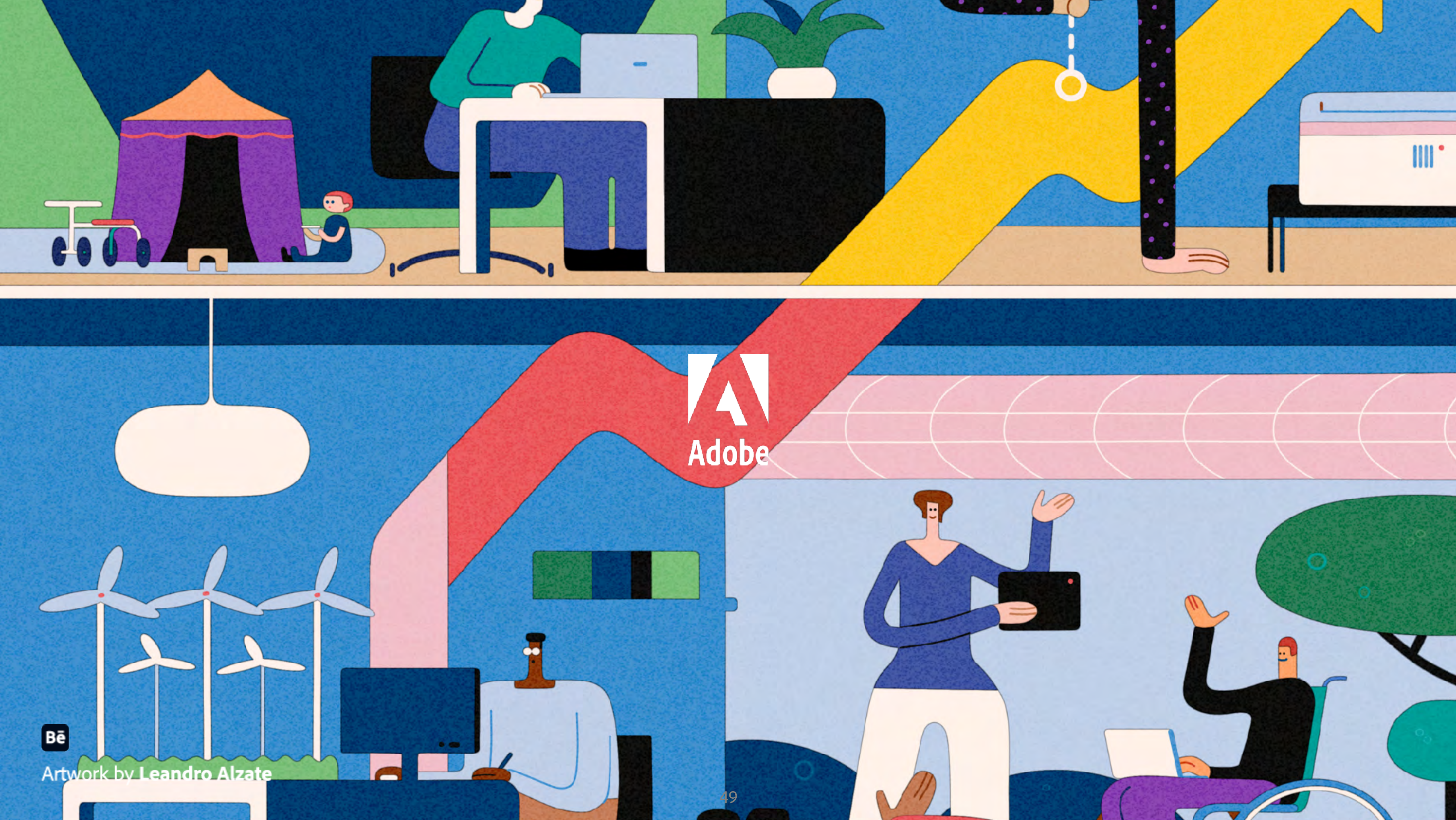
- Interfaces should make the scope of the operation clear
- Projections provide an efficient way to achieve value semantics and manipulate parts
- It is the client's responsibility to uphold the Law of Exclusivity
  - Don't pass projections that overlap an inout argument projection
- Implementors provide types with value semantics
- Confine extrinsic relationships between parts within a class

Leandro Alzate

Berlin-based illustrator Leandro Alzate mixes bright color palettes and stylized characters in his fanciful work for editorial and advertising clients. He draws inspiration from observing the ways people interact, and combines that with his passion for architectural shapes and spaces. He created this piece for the German Ministry of Economy to encourage people to explore work-from-home career opportunities. Working with brushes and vector shapes, Alzate created this piece entirely in Adobe Photoshop.

Made with

Adobe Photoshop



Artwork by **Leandro Alzate**