Swift ABI Resilience

Meeting C++

November 2023

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Principal Engineer

Visual C++

Abstract

No, this is not an "ABI - Now or Never" talk. What happens in Prague, stays in Prague :)
But wg21.link/P1863 will probably come up in the discussions, so we might as well prepare for it.

We're taking a different route, by following the design and evolution of the Swift ABI model and seeing what we can learn from it. From ABI stability & dynamic linking to designing for ABI resilience - a journey through resilient type layout, reabstraction & materialization, resilience in library evolution and (opt-out) performance costs.

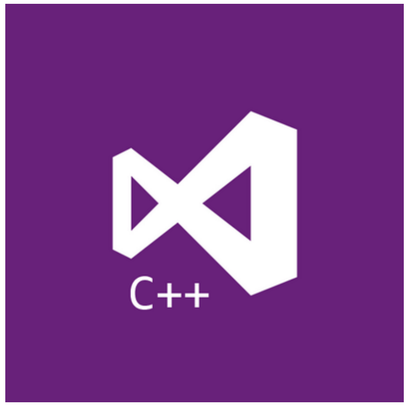
What can we learn from Swift's ABI resilience?

Can C++ be liberated from the ABI conundrum?

About me

Advanced Installer

Clang Power Tools



Visual C++

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Disclaimer

I'm just an engineer, with some opinions on stuff...

What is ABI, anyway?

I grabbed 2 bottles from the fridge...

@ Meeting C++ 2023 (Berlin)

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What is ABI, anyway?

ABI can mean a lot of different things to different people.

Is it platform, HW ABI, calling conv, language, compilers, std libraries, your code?

At the end of the day it’s a *catch-all* term for “implementation details" that at least two things need to agree on for everything to work.

What is ABI, anyway?

ABI stability isn’t technically a property of a programming language.

It’s really a property of a system and its toolchain.

ABI is something defined by the *platform*.

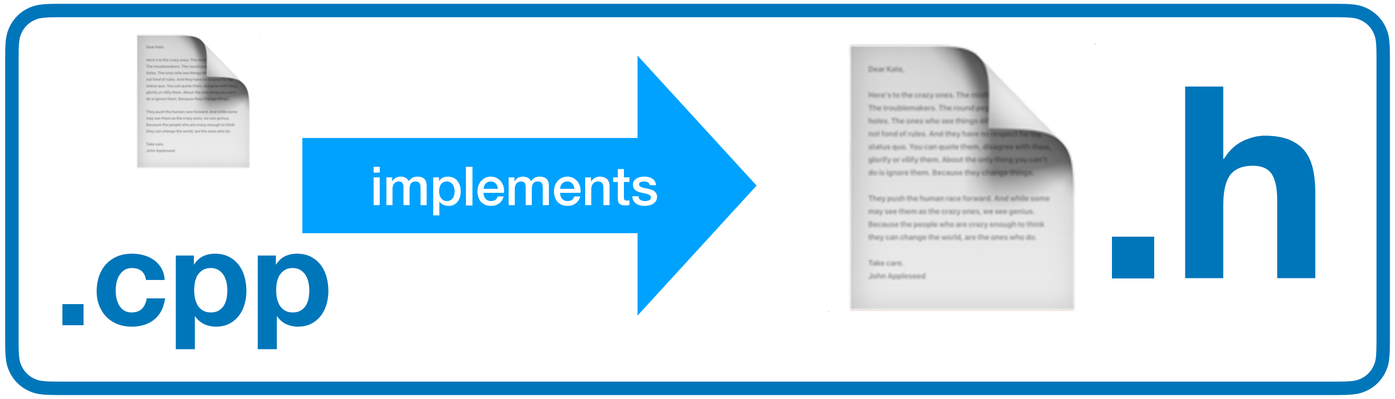
The platform owner can just require you to use a particular compiler toolchain that happens to implement their "stable" ABI.

If you care about *dynamic linking* (shared libraries).

What is ABI, anyway?

- layout of types
  - size & alignment (stride*)
  - offsets & types of fields
  - vtable entries
- calling conventions
- name mangling (symbols)
- metadata (if applicable)

What is ABI, anyway?



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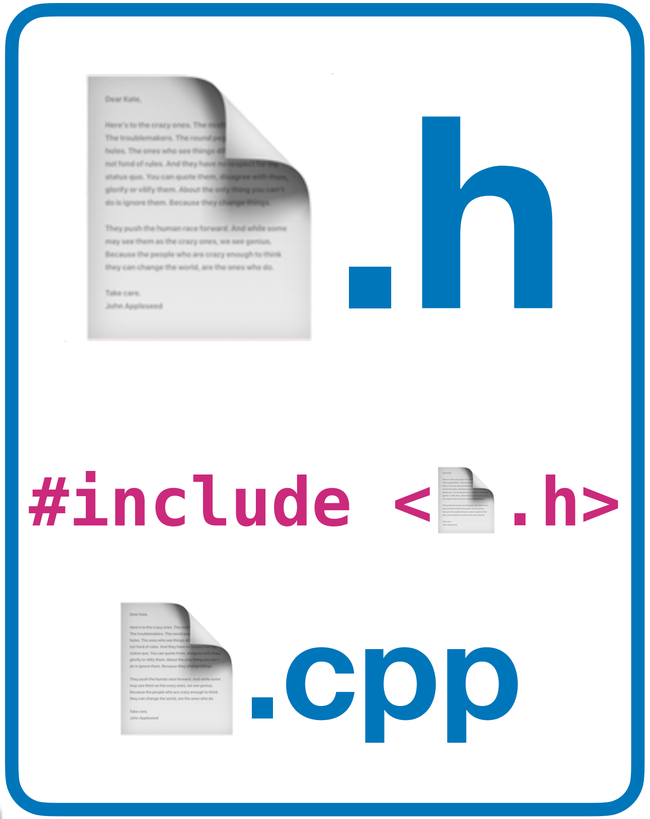

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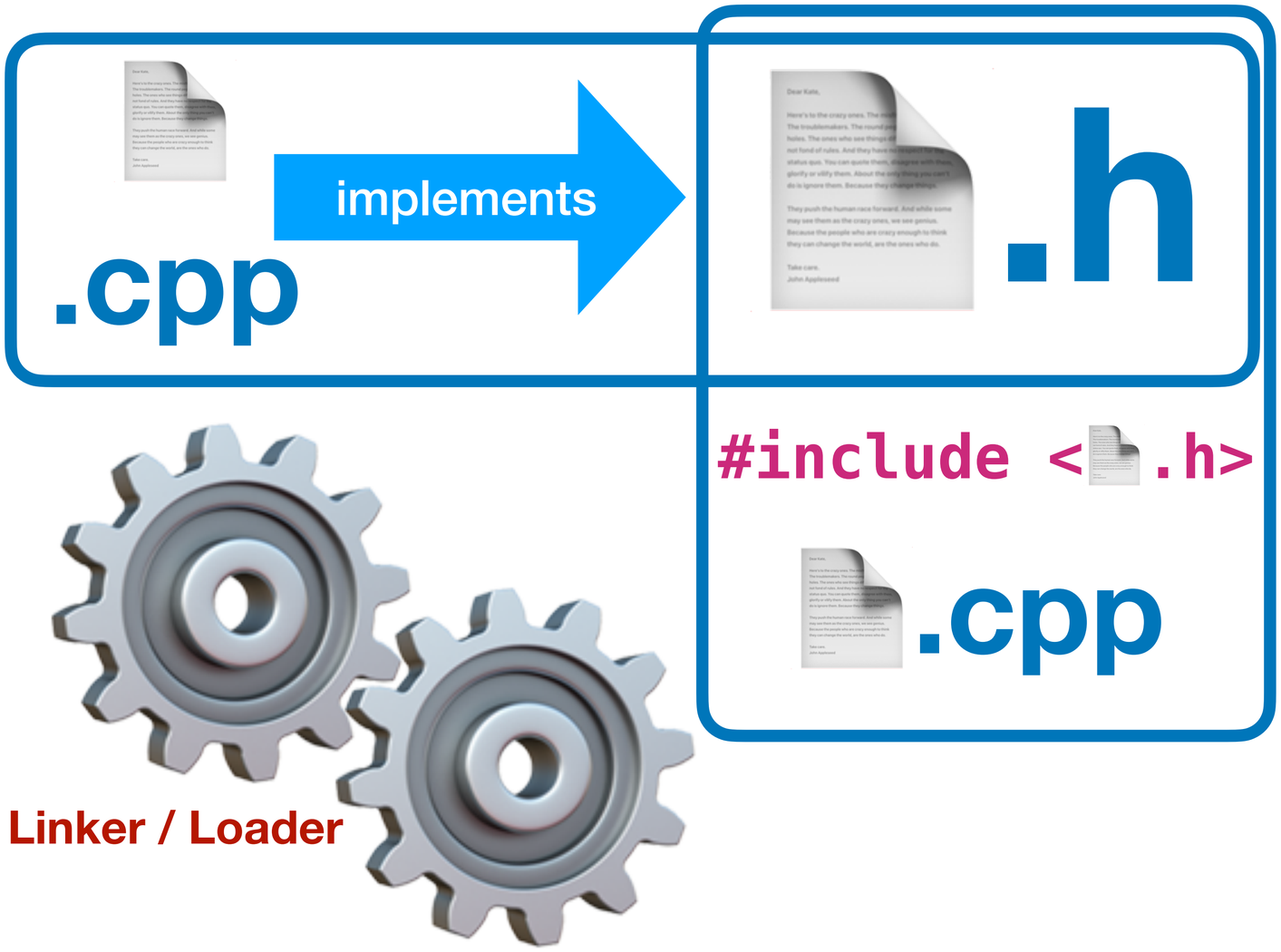
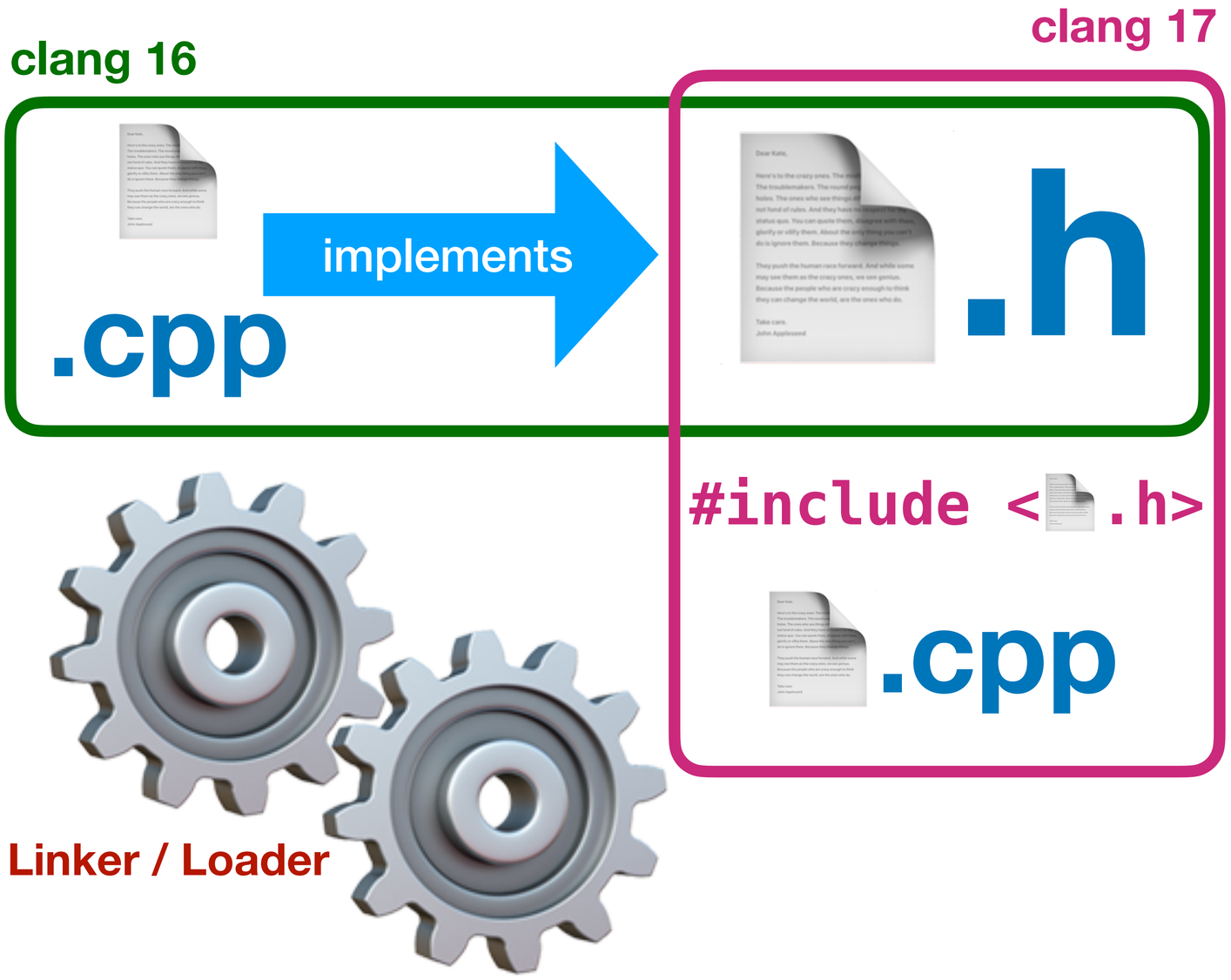


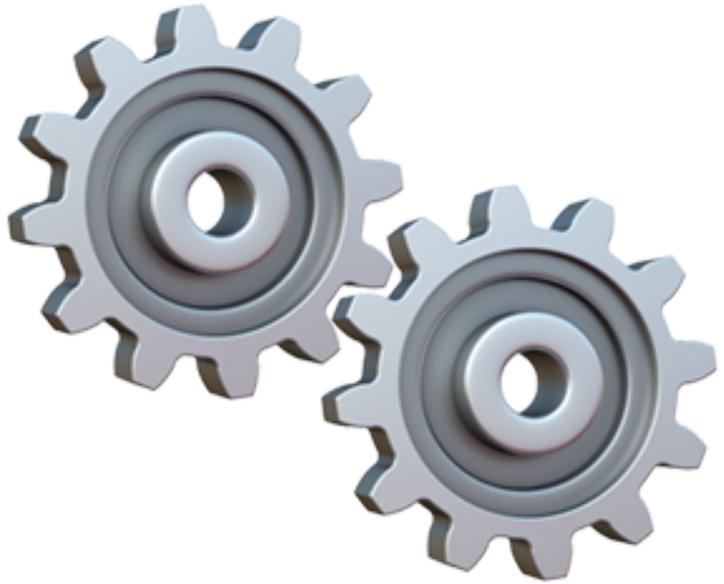
Binary compatibility between separately-compiled artifacts

What is ABI, anyway?



ABI Stability: binary compatibility across compiler versions

ABI Stability - Why?



- You don’t have to share the source code of your library
- You can use the most recent compiler for your library
- You don’t have to recompile everything
- Binaries can be shipped and updated independently (patches)
- Multiple programs can share the same library (incl. std lib)

ABI Stability - When?

- Don't shut the door on future compiler & lib optimizations
- Stabilizing the ABI (too early)™ might miss optimizations
  - implement a faster custom calling convention
  - implement optimal structure layout
  - improve the way a std utility works
- NB. These are not impossible things!
  - They are just tough engineering problems
  - We need to invest a lot of time and brain power to solve them

ABI Stability - Evolution of Software Libraries

- Developers want to evolve their software libraries without breaking ABI
  - add new functionality
  - fix bugs
  - improve performance
- A lot of these activities can break ABI
  - add a field to a class
  - add a virtual function
  - (re)use existing padding for a new field?

ABI Stability

Can we have stable ABI, pretty please?

- Go: NO
- Rust: NO
- Carbon: NO
- Zig: NO
- C++: 🤷‍♂️
- Swift: YES (most important thing ever!)

ABI Stability

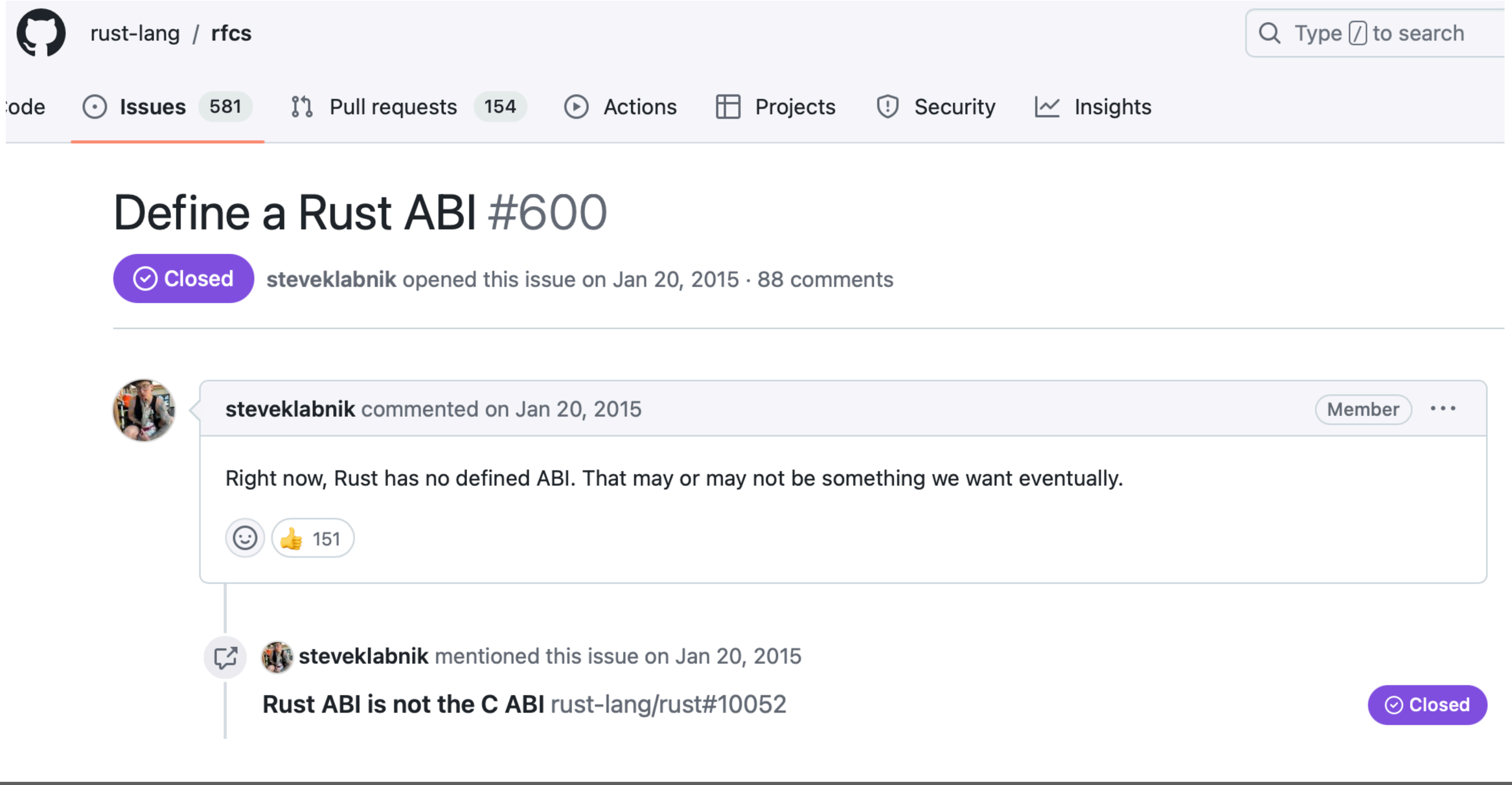
Carbon / non-goals 🙂

github.com/carbon-language/carbon-lang#language-goals

We also have explicit non-goals for Carbon, notably including:

- a stable application binary interface (ABI) for the entire language and library
- perfect backwards or forwards compatibility

ABI Stability



ABI Stability

Zig natively supports C ABIs for *extern* things; which C ABI is used depends on the target you are compiling for (e.g. CPU architecture, operating system).

This allows for near-seamless interoperation with code that was not written in Zig; the usage of C ABIs is standard amongst programming languages.

Zig internally does not use an ABI, meaning code should explicitly conform to a C ABI where reproducible and defined binary-level behavior is needed.

ABI Stability

Go internal ABI specification

Go's ABI defines the layout of data in memory and the conventions for calling between Go functions.

This ABI is unstable and will change between Go versions.

If you’re writing assembly code, please instead refer to Go’s assembly documentation, which describes Go’s stable ABI, known as ABI0.

Design Choices

What we want

What we need

Stability ∞

The greatest champion of ABI stability:

pimpl

* one level of indirection solves every problem

Stability ∞

The greatest champion of ABI stability:

std::any

erase every trace of rigor (and performance)

Stability ∞

The greatest champion of ABI stability and dynamic linking:

C

That's plain old **C**, not Carbon, by the way :)

The 90s are calling...

- COM interfaces
  - change API to hide implementation changes (break ABI)
  - `IWidgetSomething, IWidgetSomething2, IWidgetSomething3`

- Objective-C msg-send APIs
  - ~unstructured data
  - type erasure / everything dynamic / indirections

STL ~ ABI

Consistency

Jonathan Müller @foonathan · Feb 3, 2020

What's the point of standard library containers if they can't give the best performance?

2 9

Titus Winters @TitusWinters · Feb 3, 2020

They're common and readily available? (Which does have some value.)

Committing to ABI is like admitting that the standard library is aiming to be McDonald's - It's everywhere, it's consistent, and it technically solves the problem.

5 3 18

JF Bastien 🔗 **@jfbastien@mastodon.social** @jfbastien · Feb 3, 2020

The rumors of STL pink slime are wildly overblown 🤡

1 5

May I have some ABI?

Sean Parent @SeanParent · Feb 4, 2020

A stable ABI means you can link against the platform API, shared library APIs including the standard, evolve your product without breaking plugins. C++ needs a strategy on how to specify and maintain ABI compatibility - not some "one time break" for efficiency. See @SwiftLang

Chandler Carruth
@chandlerc1024

You could have an independent mechanism for accessing platform libraries. We (almost) have that on Linux with their C APIs & ABIs.

Pinning all of C++ (and its standard library) down with a stable ABI for the entire thing largely blocks evolving any of them for performance.

May I have some ABI?

Doug Gregor @dgregor79 · Feb 4, 2020

A stable C++ ABI is useless for platform APIs if it doesn't encompass the standard library. That said, you could have a compilation mode choose between resilience (library impl can change without breaking you) or fragility (performance without ABI stability)

Sean Parent @SeanParent · Feb 4, 2020

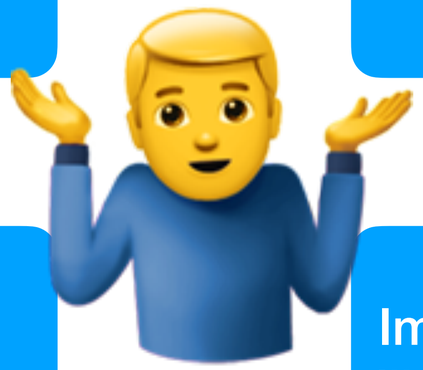
I didn't say lock everything. Define what can be used in an ABI stable interface, and how it is versioned. A single app needs to be able to link against multiple versions of the same lib without an ODR violation. C++ currently is _not_ ABI stable.

twitter.com/TitusWinters/status/1224351257479077889?s=20

C++ the king of mix signals and ambivalent behavior

C++ does not have an ABI resilience model (it's not stable)

The committee will reject any proposal that could cause ABI breaks in existing STL components



C++ will not officially commit to guaranteeing ABI stability

Implementors* will not change/improve library components if it would cause an ABI break for clients

ABI - Now or Never

In Feb 2020, in Prague, the ISO C++ committee took a series of polls on whether to break ABI, and decided not to... sort of.

There was no applause 😐

"I'm not sure we fully understood what we did and the consequences it could have. I do believe none of the consequences will be good."

-- not so anonymous C++ committee member

The king of mix signals and ambivalent behavior

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- WG21 will take time to consider proposals requiring an ABI break (read: ignore)
- WG21 will not promise stability forever
- WG21 wants to keep prioritizing performance over stability

Is change even possible?

Quick recap: A "**lost decade**" pattern

MSVC 6 — ~12 years
- Shipped in **1998**
- "10 is the new 6" fanfare in **2010**

C99 `_Complex` and VLAs — ~12 years
- Added in **1999**
- Walked them back to "optional" in **2011**

C++11 `std::string` — ~11 years
- Banned RC for std::string in **2008/2010**
- Major Linux distro enabled it in **2019**

Python 3 — ~12 years
- Shipped 3.0 in **2008**
- 10% still using 2.x as of early **2020**

If you don't build a strong backward compatibility bridge, expect to slow your adoption down by

~10 years

(absent other forces)

youtube.com/watch?v=8U3hl8XMm8c

ABI - Now or Never

February 24, 2020

The Day The Standard Library Died

cor3ntin.github.io/posts/abi/

Why do we want to break ABI

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Quality of implementation fixes:

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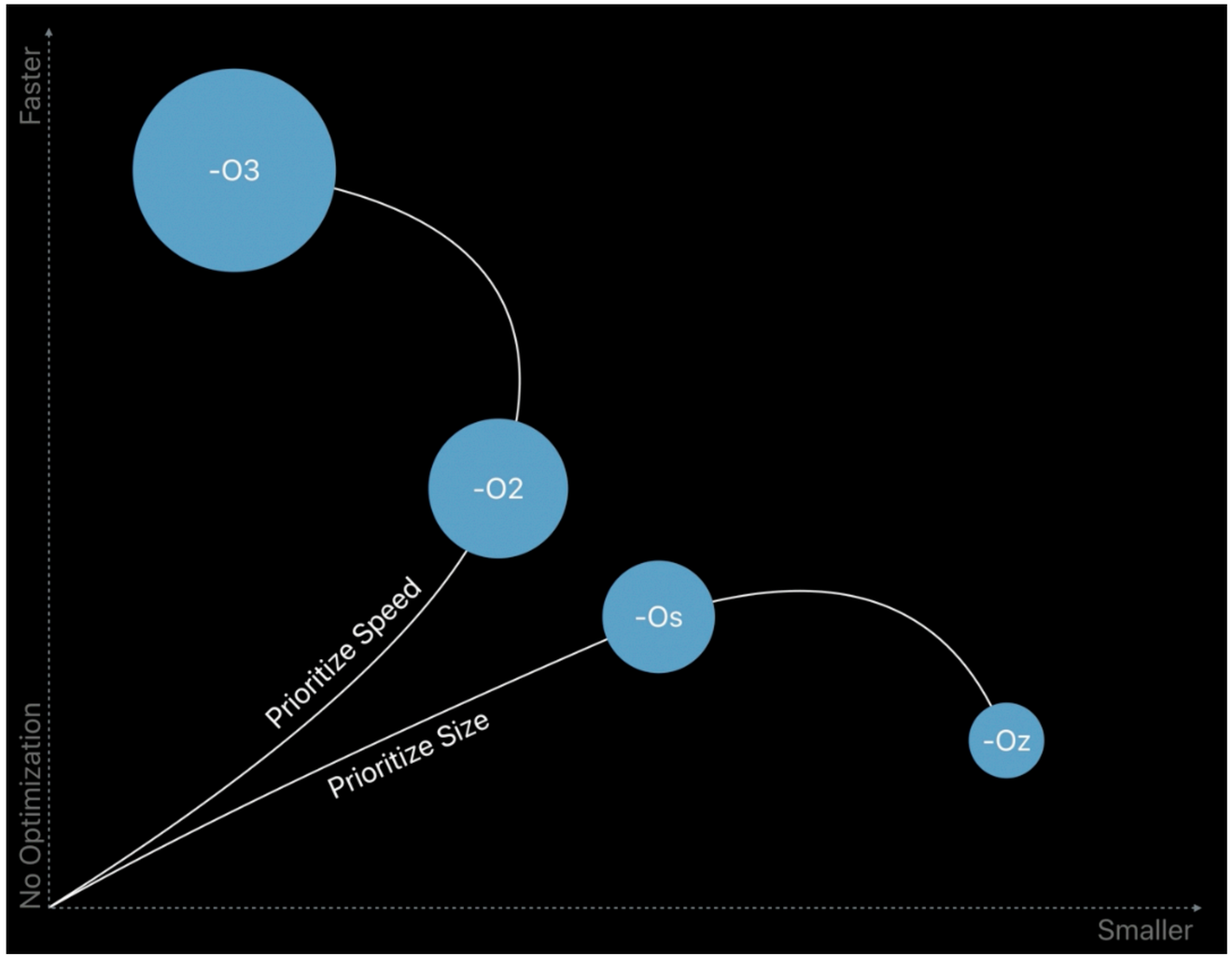
- improving std::shared_ptr, eg. lock_exclusive()
- improving perf of std::mutex (std::shared_mutex is faster!)

Design Choices

C++ / Rust / Carbon / ...	Swift
Fast code	Favor small code (icache)
Heavy inlining	Outlining
CPU utilization/saturation	CPU power usage
Mostly static linking	Dynamic linking (shared libraries)

Outlining



LLVM Outlininer

`–Oz`

Outlining:
Replacing repeated sequences of instructions with calls to equivalent functions.
(smaller code => icache)

Jessica Paquette "Reducing Code Size Using Outlining"
youtube.com/watch?v=yorld-WSOeU

Jessica Paquette, JF Bastien "What's New in Clang and LLVM"
developer.apple.com/videos/play/wwdc2019/409/

Swift who?

- Ahead-Of-Time (AOT) compiled, but has a large runtime library
- created to replace Objective-C on Apple's platforms (native interop with Obj-C)
- has classes and inheritance
- interfaces, generics, closures, enums with payloads
- Automatic Reference Counting (ARC)
- simple function-scoped mutable borrows (inout)
- emphasis on value semantics
- structs/primitives ("values") are "mutable xor shared" & stored inline
- classes are mutably shared and boxed (using ARC) -> reference semantics
- collections implement value semantics by being CoW (using ARC)

Language designed for Library Evolution

Principles for ABI-stable library evolution:

- make all promises explicit
- delineate what can and cannot change in a stable ABI
- provide a performance model that indirects only when necessary
- let the authors of libraries & consumers be in control

Doug Gregor
Implementing Language Support for
ABI-Stable Software Evolution in Swift and LLVM
youtube.com/watch?v=MgPBetJWkmc

Evolving a struct

```
public struct Person {
  public var name: String
  public let birthDate: Date?
  let id: Int
}
```

```
public struct Person {
  let id: Int
  public let birthDate: Date?
  public var name: String
}
```

```
public struct Person {
  let id: UUID
  public var birthDate: Date?
  public var name: String
}
```

```
public struct Person {
  let id: UUID
  public var birthDate: Date?
  public var name: String
  public var favoriteColor: Color?
}
```

- Person struct changes size when new fields are added
- Offset of fields changes whenever layout changes

Using the struct

```
import PersonLibrary
struct Classroom {
  var teacher: Person
  var students: [Person]

  func getTeacherName() -> String { teacher.name }
  var numStudents: Int { students.count }
}
```

The Library

Type Layout should be as-if we had the whole program:

- *Person* library should layout the type without indirection
- Expose metadata with layout information:
  - size/alignment of type
  - offsets of each of the public fields

```
size_t Person_size = 32;
size_t Person_align = 8;
size_t Person_name_offset = 0;
size_t Person_birthDate_offset = 8;
```

Client/External Code

Client code (external) indirects through layout metadata

- Access a field:
  - read the metadata for the field offset
  - add that offset to the base object
  - cast the new pointer and load the field
- Store an instance on the stack:
  - read the metadata for instance size
  - emit alloca instruction, to setup as needed

Library Code

Library code (internal) eliminates all indirection

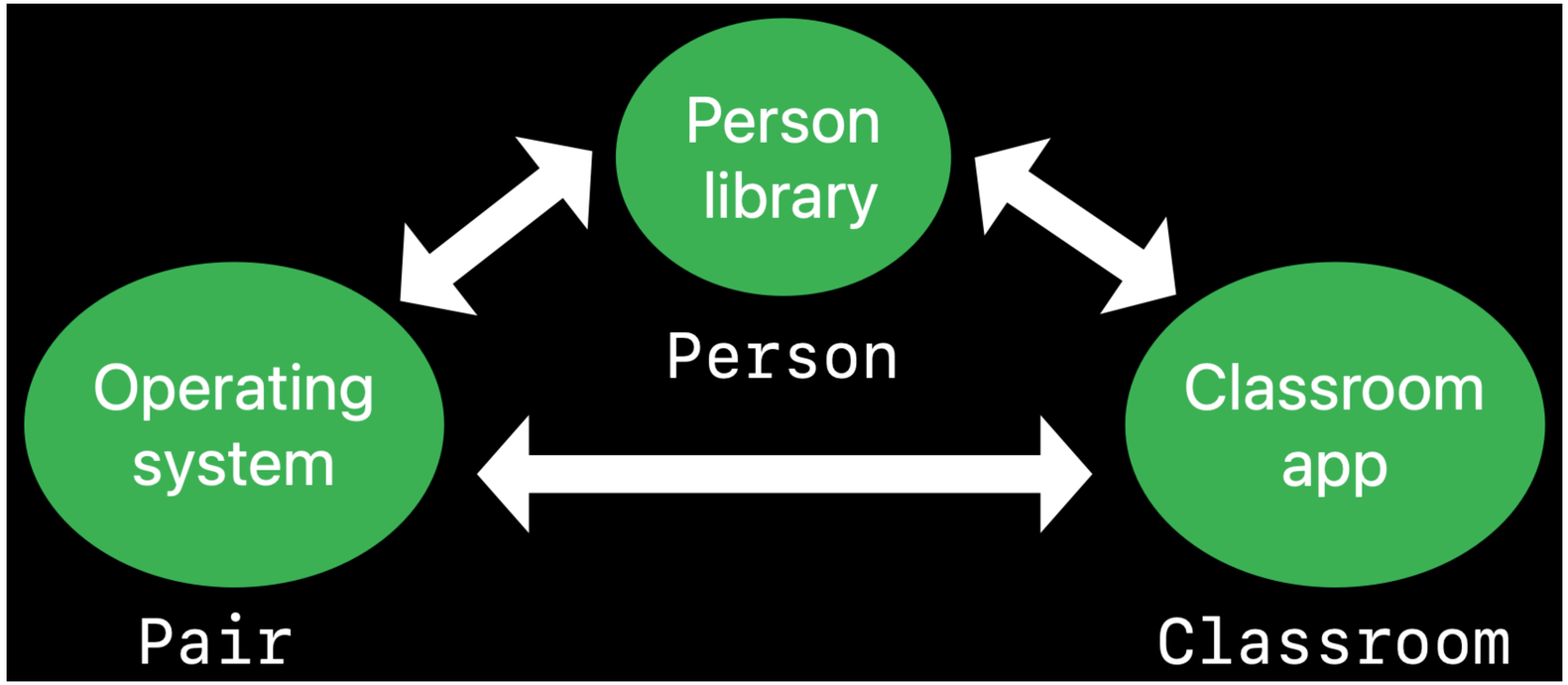
- Access a field:
  - ~~read the metadata for the field offset~~
  - add that offset to the base object
  - cast the new pointer and load the field
- Store an instance on the stack:
  - ~~read the metadata for instance size~~
  - emit alloca instruction, to setup as needed

LLVM dynamically-sized things

- LLVM's support for dynamically-sized things on the stack has been good for Swift
- Swift makes heavy use of this for of ABI-stable value types:
  - you have local variable of some struct defined in an ABI-stable library
  - so you don't know it's size until load time
- Dynamic allocs can handle this nicely (with minimal perf impact)
- C++ desperately want all objects to have compile-time-constant size
- The notion of sizeof/alignof being runtime values just grates against the whole C++ model :(

sfba.social/@dgregor79/111058162167016107

Resilience Domains



A resilience domain contains code that will always be compiled together.

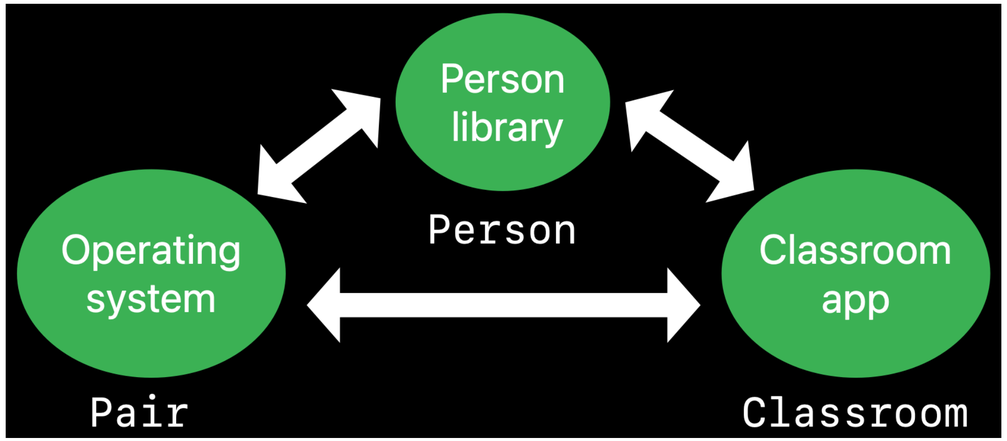
A program can be composed of many different resilience domains.

Resilience domains control where the costs of ABI stability are paid.

Resilience Domains

Optimization and Resilience Domains

- Across resilience domains => maintain stable ABI
- Within a resilience domain => all implementation details are fair game
  - no indirections (direct access, no computed metadata)
  - no guarantees made
- Optimizations need to be aware of resilience domain boundaries



Resilience Domains

What if there is only 1 resilience domain?

- There are no ABI-stable boundaries
  - all type layouts are *fixed* at compile time
  - stable ABI is completely irrelevant
- You don’t pay for library evolution when you don’t use it

Resilient Type Layout

By default, a type that is defined by a dylib has a resilient layout.

- size, alignment, stride of that type aren’t statically known to the application
  - it must ask the dylib for that type’s value witness table (at runtime!)
- value witness table is just the “vtable" of stuff you might want to know about any type
- this results in resilient types having to be "boxed" and passed around as a pointer
  - not quite...
- inside the boundaries of the dylib (where all of its own implementation details are statically known)
  - the type is handled as if it wasn’t resilient (no indirections & perf costs)

Escape Hatches

Swift ABI resilience is the DEFAULT.

You have to Opt-Out of Resilience, if you don't want it.

Escape Hatches

Trading future evolution for client performance:

- Explicit inline code exposed to the client
  - enables caller optimization, generic specialization
  - prevents any changes to the function’s semantics

```
@inline public func swapped()
{
}
```

Escape Hatches

Trading future evolution for client performance:

- Fixed-layout types promise never to change layout
  - enables layout of types in client code
  - gives up ability to add/remove/reorder fields

```
@fixedLayout
public struct Pair<First, Second>
{
}
```

Swift Challenges

- Large runtime component (with compiler abilities)
  - Runtime type layout
  - Handling metadata at runtime
  - Witness tables & indirections
  - Generics<T> are particularly hard (monomorphization, reabstraction)
- Every language feature is harder to design
- Older Swift runtimes don’t support new language features

Clang libc++ ABI stability

libcxx.llvm.org/DesignDocs/ABIVersioning.html

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A couple of interesting scenarios, exploring this space:

maskray.me/blog/2023-06-25-c++-standard-library-abi-compatibility

Swift ABI Resilience

Meeting C++

November 2023

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Victor Ciura

Principal Engineer

Visual C++