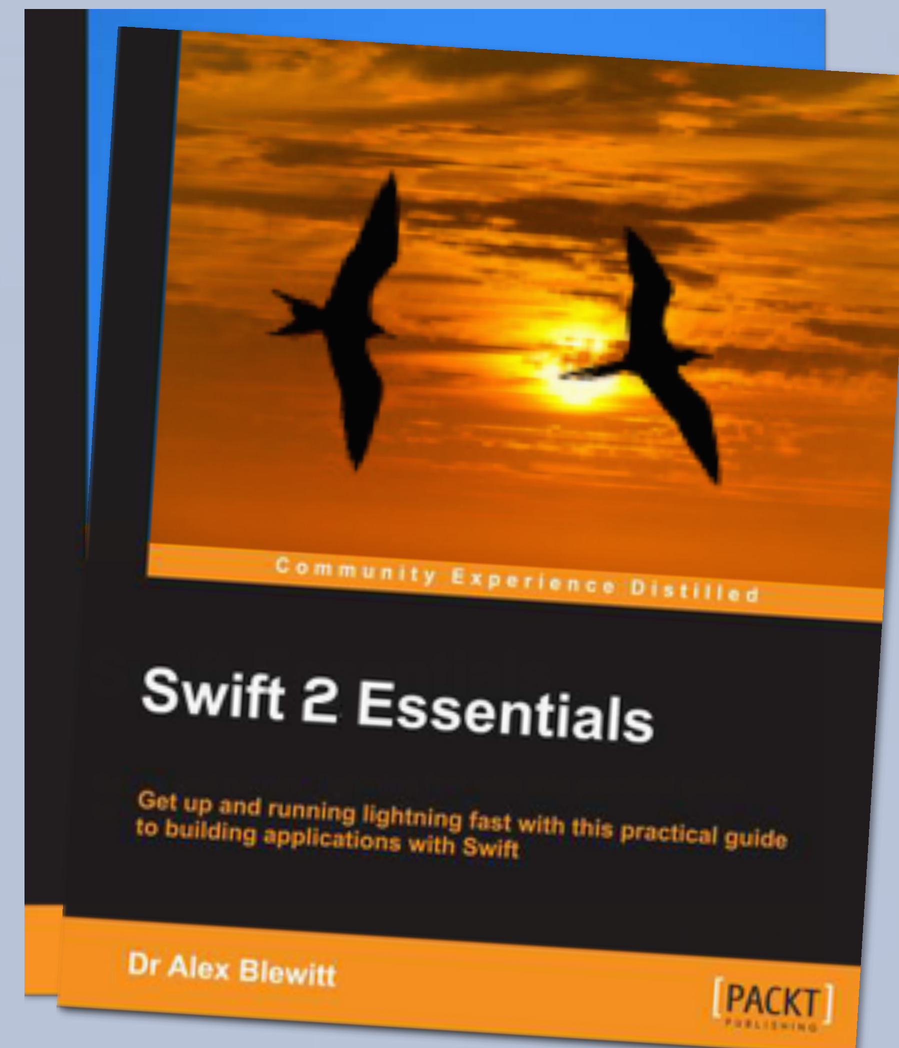
Swift 2 Under the Hood

BERLIN INTERNATIONAL SOFTWARE DEVELOPMENT CONFERENCE

About This Talk

Based on Swift 2.1, the public release in December 2015

- Overview
  - Where did Swift come from?
  - What makes Swift fast?
  - Where is Swift going?
- Alex Blewitt @alblue
  - NeXT owner and veteran Objective-C programmer
  - Author of Swift Essentials http://swiftessentials.org



Where did Swift come from?

Pre-history

- Story starts in 1983 with Objective-C
    - Created as a Smalltalk like runtime on top of C
- NeXT licensed Objective-C in 1988
- NextStep released in 1989 (and NS prefix)
- Apple bought NeXT in 1996
- OSX Server in 1999
- OSX 10.0 Beta in 2000, released in 2001

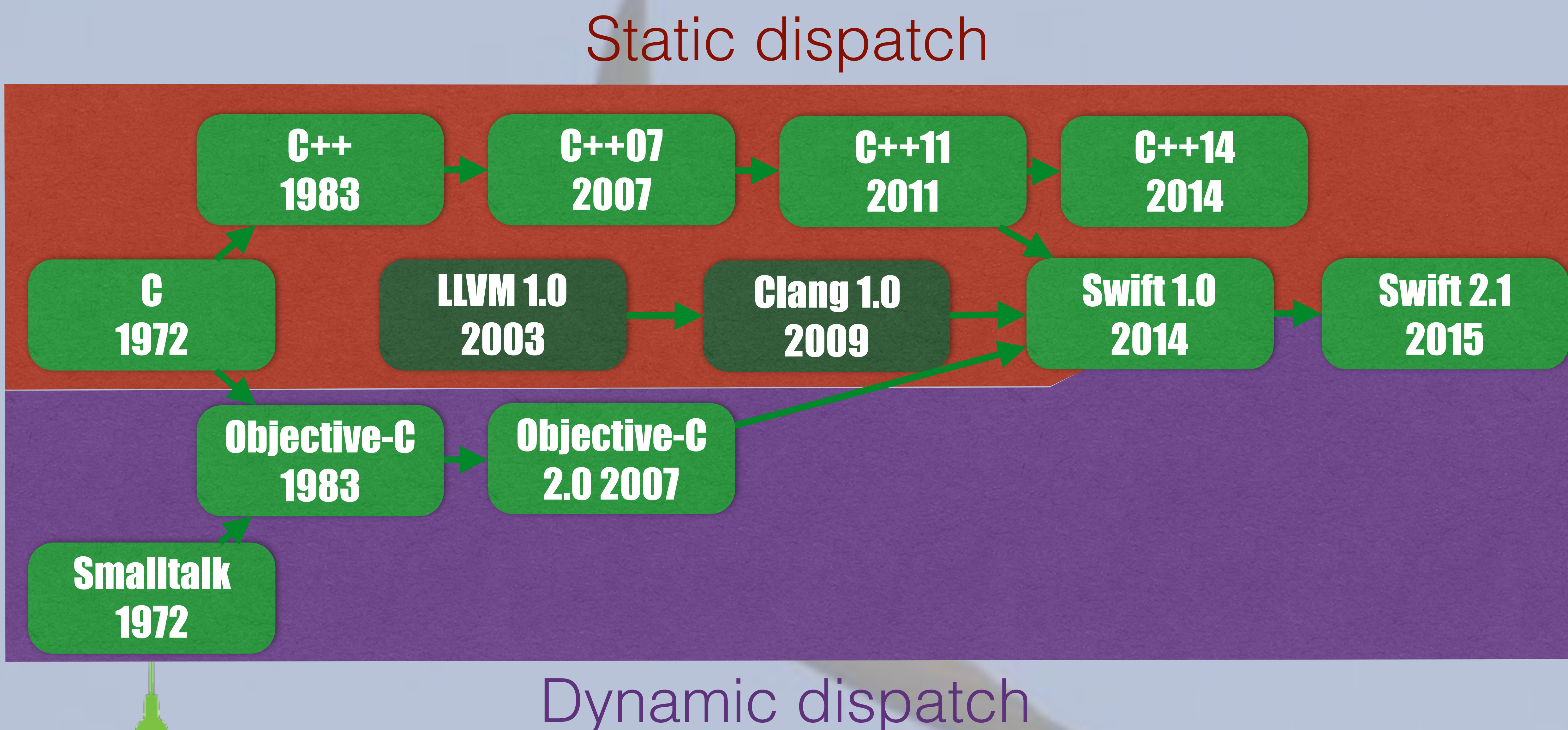
Objective-C

- Originally implemented as a pre-processor for C
  - Rewrote Objective-C code as C code
- Enhanced and merged into GCC
  - Compiler integrated under GPL
  - Runtime libraries open source (and GNUStep)

```
/*
* Copyright (c) 1999 Apple Computer, Inc. All rights reserved.
* objc.h
* Copyright 1988-1996, NeXT Software, Inc.
 */
```

http://www.opensource.apple.com/source/objc4/objc4-208/runtime/objc.h

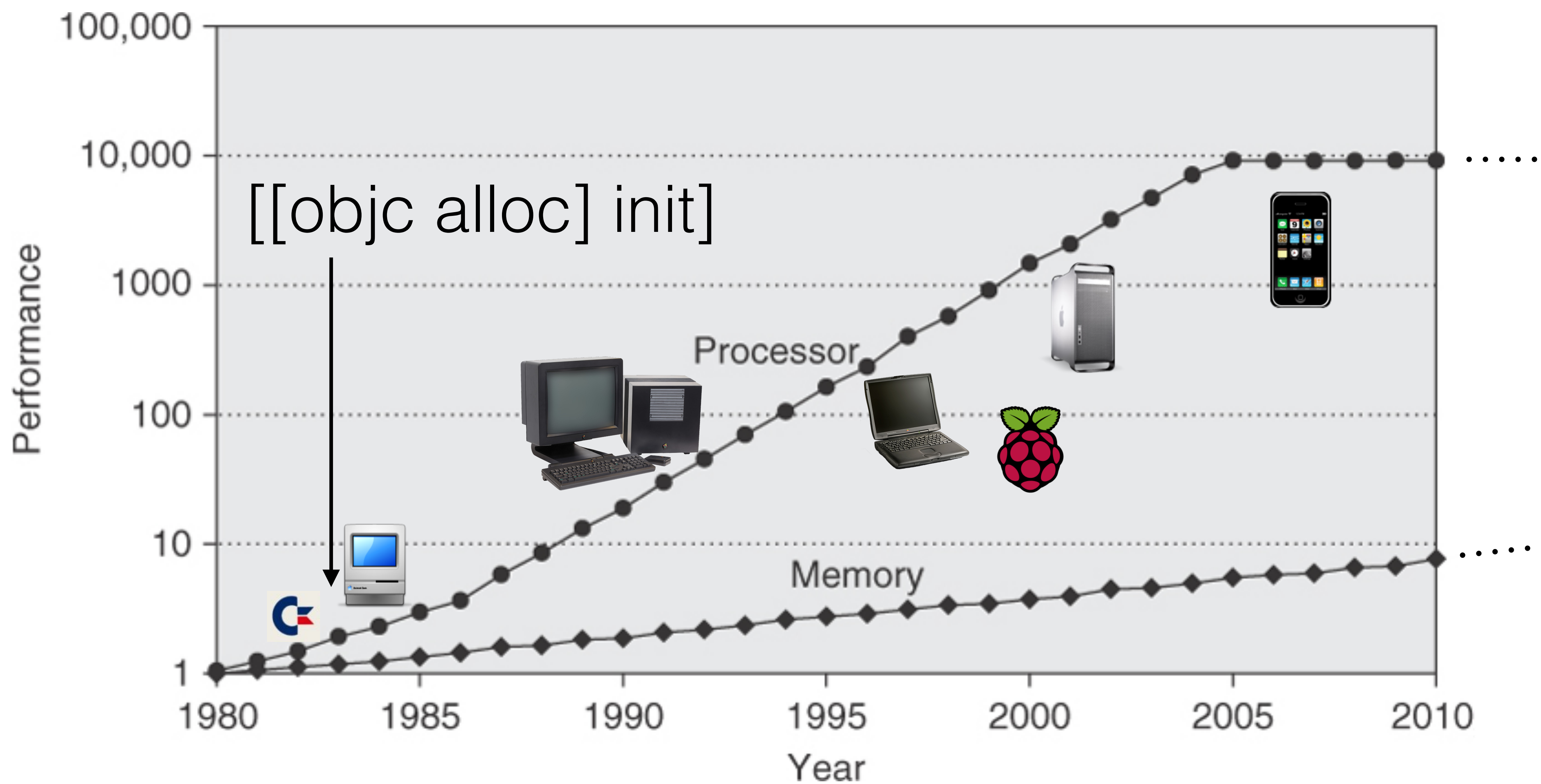
Timeline


Static dispatch
C++
1983
C++07
2007
C++11
2011
C++14
2014
C
1972
LLVM 1.0
2003
Clang 1.0
2009
Swift 1.0
2014
Swift 2.1
2015
Objective-C
1983
Objective-C
2.0 2007
Smalltalk
1972
Dynamic dispatch

A lot has changed …

- CPU speed has risen for most of the prior decades
  - Plateaued about 3GHz for desktops
  - Mobile devices still rising; around 1-2GHz today
- More performance has come from more cores
  - Most mobiles have dual-core, some have more
  - Mobiles tend to be single-socket/single CPU
  - Memory has not increased as fast

CPU speed



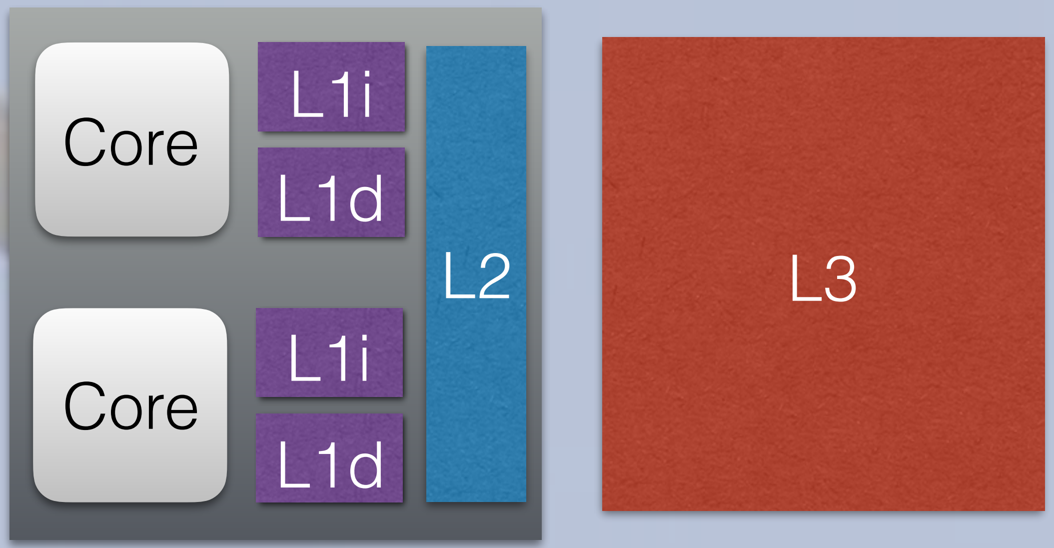
"Computer Architecture: A Quantitive Approach"

http://booksite.elsevier.com/9780123838728/

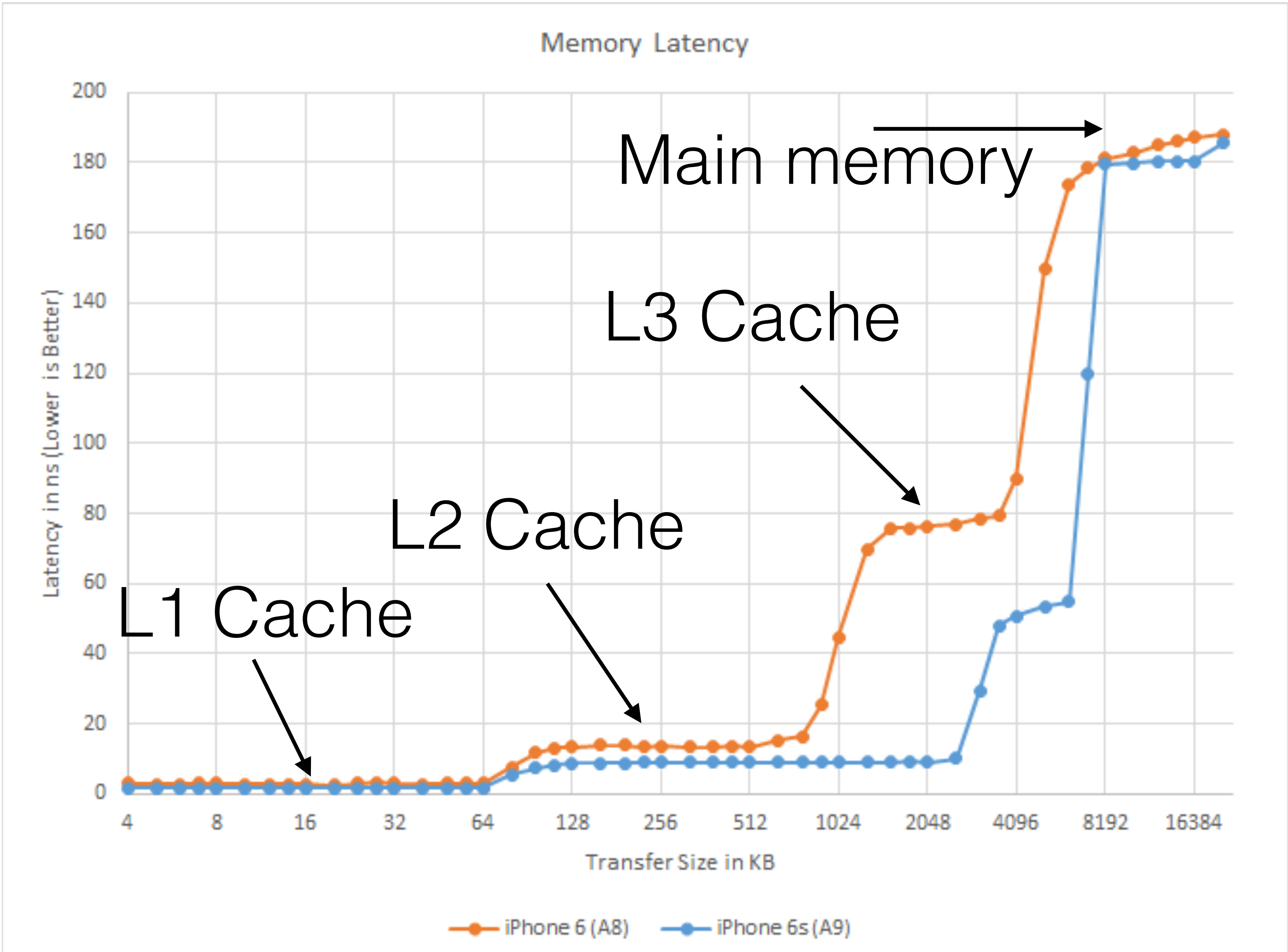
Memory latency

- Memory latency is a significant bottleneck
- CPU stores near-level caches for memory
  - L1 - per core 64k instruction / 64k data (~1ns)
  - L2 - 1-3Mb per CPU (~10ns)
  - L3 - 4-8Mb shared with GPU (~50-80ns)
- Main memory 1-2Gb (~180ns)

Numbers based on the iPhone 6 and iPhone 6s (A8 and A9)



Memory latency



AnandTech review of iPhone 6s
http://www.anandtech.com/show/9686/the-apple-iphone-6s-and-iphone-6s-plus-review/4

Why Swift?

Why Swift?

- Language features
  - Namespaces/Modules
  - Reference or Struct value types
  - Functional constructs
- Importantly
  - Interoperability with Objective-C
  - No undefined behaviour or nasal daemons

Modules

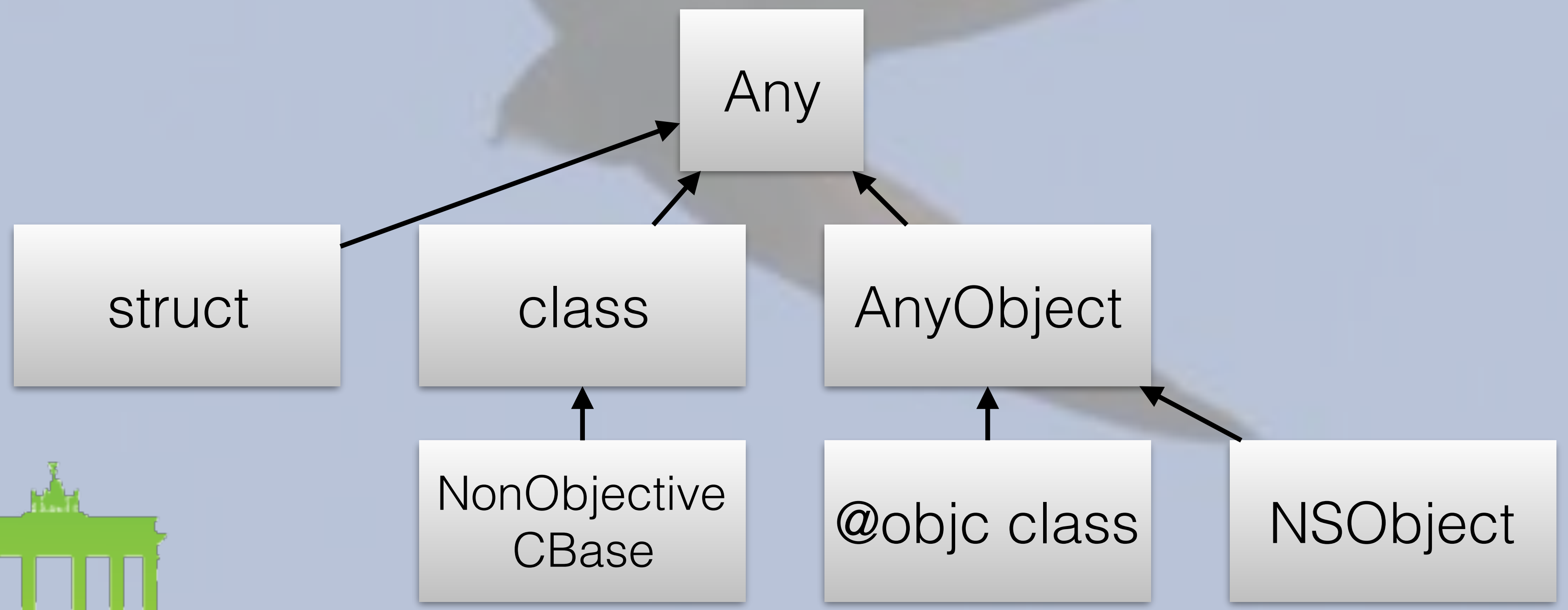
- Modules provide a namespace and function partition
- Objective-C
  - Foundation, UIKit, SpriteKit
- C wrappers
  - Dispatch, simd, Darwin
- Swift
  - Swift (automatically imported), Builtin

Darwin provides bindings with native C libraries e.g. random()

Builtin provides bindings with native types e.g. `Builtin.Int256`

Types

- Reference types: class (either Swift or Objective-C)
- Value types: struct
- Protocols: provides an interface for values/references
- Extensions: add methods/protocols to existing type



Numeric values

- Numeric values are represented as structs
  - Copied by value into arguments
  - Structs can inherit protocols and extensions

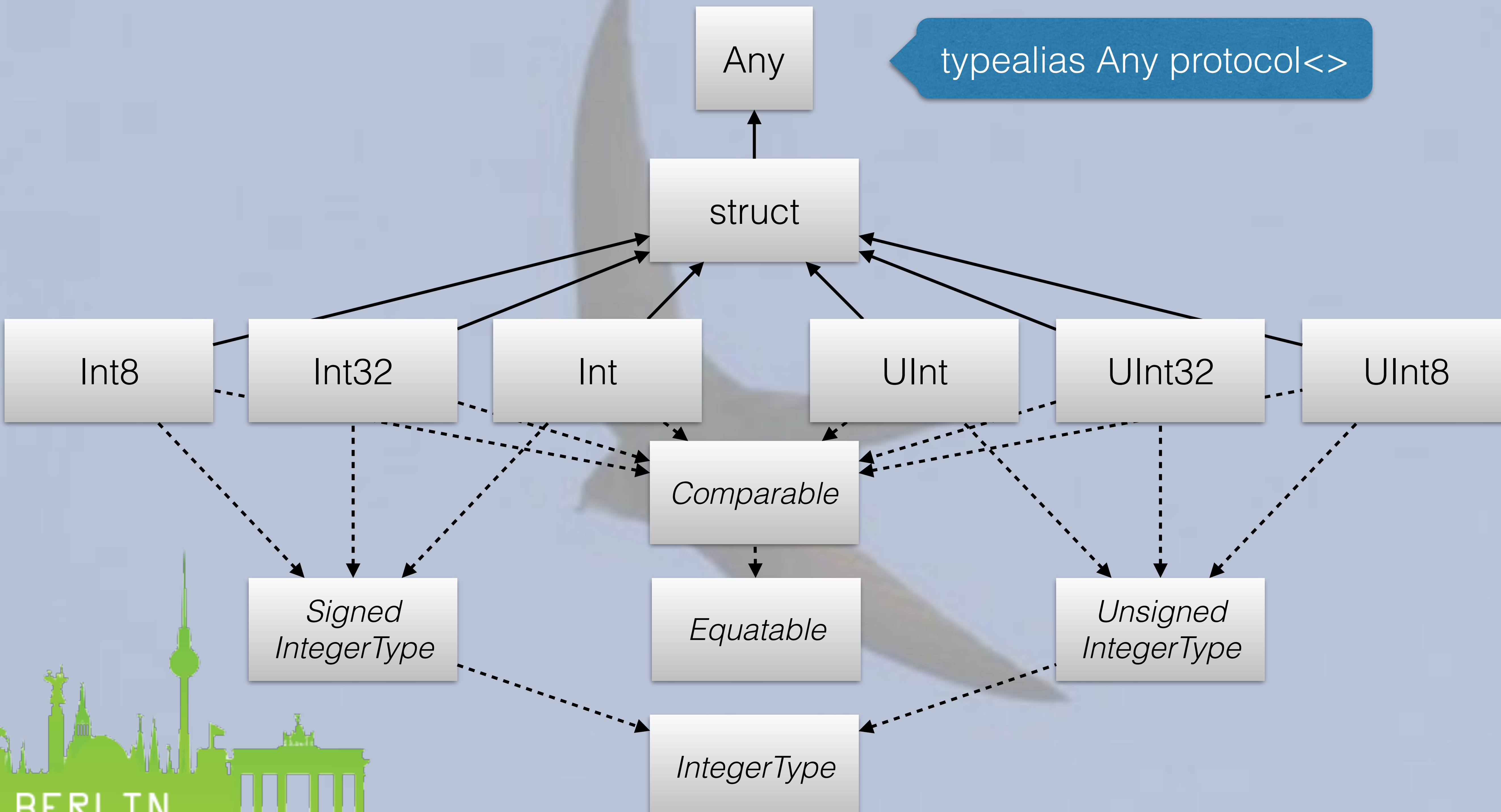
```
public struct Int : SignedIntegerType, Comparable {
  public var value: Builtin.Int64
  public static var max: Int { get }
  public static var min: Int { get }
}
public struct UInt: UnsignedIntegerType, Comparable {
  public var value: Builtin.Int64
  public static var max: Int { get }
  public static var min: Int { get }
}
```

sizeof(Int.self) == 8

sizeof(UInt.self) == 8

Protocols

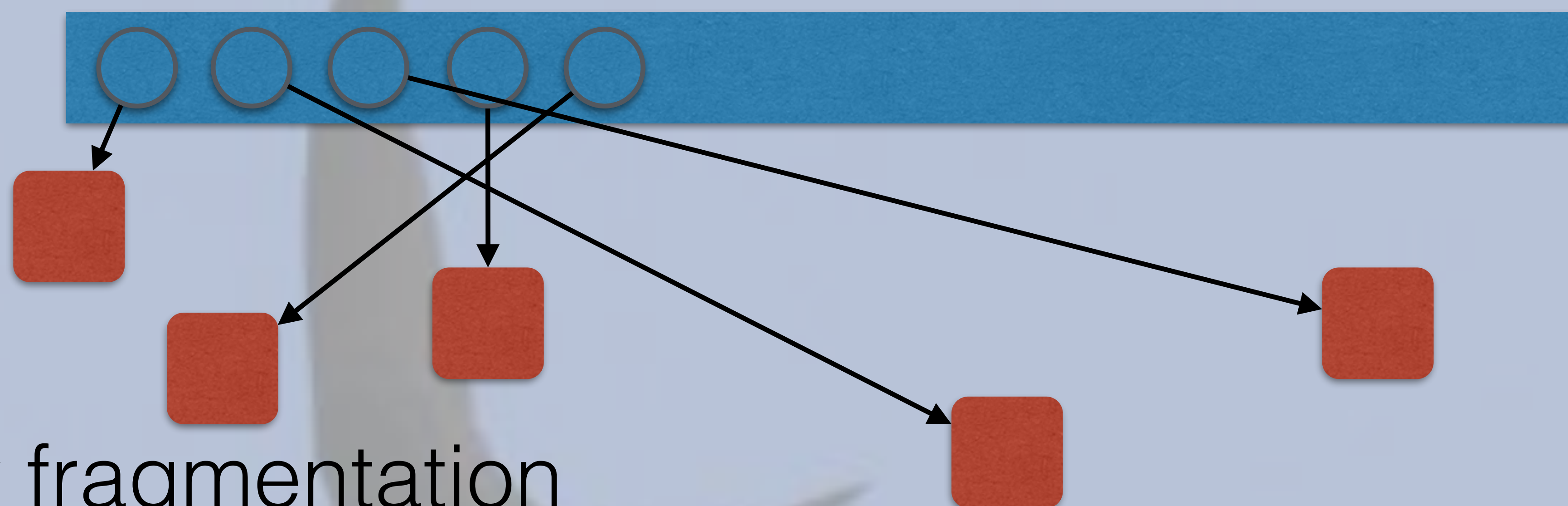
- Most methods are defined as protocols on structs



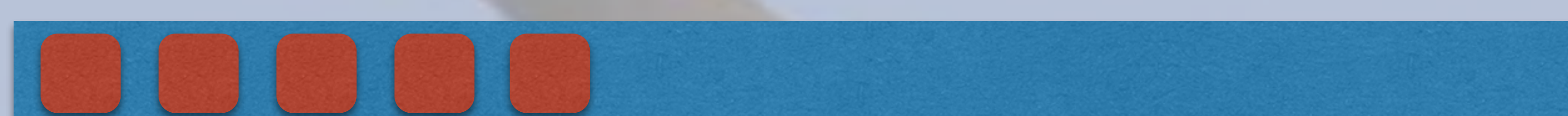
What makes Swift fast?

Memory optimisation

- Contiguous arrays of data vs objects
- `NSArray`



  - Diverse
  - Memory fragmentation
  - Limited memory load benefits for locality
- `Array<…>`



- Iteration is more performant over memory

Static and Dynamic?

- Static dispatch (used by C, C++, Swift)
  - Function calls are known precisely
  - Compiler generates **`call`**/**`callq`** to direct symbol
  - Fastest, and allows for optimisations
- Dynamic dispatch (used by Objective-C, Swift)
  - Messages are dispatched through **`objc_msgSend`**
  - Effectively `call(cache["methodName"])`

Swift can generate Objective-C classes and use runtime

Static Dispatch

```
a() -> b() -> c()
```

a → b → c

Optimises to `abc`

Dynamic Dispatch

```
[a:] -> [b:] -> [c:]
```

a ↘ objc_msgSend ↗ b ↘ objc_msgSend ↗ c

Cannot be optimised

objc_msgSend

- **Every** Objective-C message calls `objc_msgSend`
  - Hand tuned assembly – fast, but still overhead

Optimisations

- Most optimisations rely on inlining
  - Increases code size
- Instead of `a() -> b()`, have `ab()` instead
- Reduces function prologue/epilog (stack/reg spill)
- Reduces branch miss and memory jumps
- May unlock peephole optimisations
  - `func foo(i:Int) {if i<0 {return}…}`
  - `foo(-1)`
    - `foo(`*`negative`*`)` can be optimised away completely

Whole Module Optimisation

- Whole Module Optimisation/Link Time Optimisation
  - Instead of writing out x86_64 .o files, writes LLVM
  - LLVM linker reads all files, optimises
  - Can see optimisations where single file cannot
- `final` methods and data structures can be inlined
  - Structs are always `final` (no subclassing)
  - `private` (same file) `internal` (same module)

Swift and LLVM

- Swift and clang are both built on LLVM
    - Originally stood for Low Level Virtual Machine
- Family of tools (compiler, debugger, linker etc.)
- Abstract assembly language
    - Intermediate Representation (IR), Bitcode (BC)
    - Infinite register RISC typed instruction set
    - Call and return convention agnostic

Bad name, wasn't really VMs

Swift compile pipeline

- AST - Abstract Syntax Tree representation
- Parsed AST - Types resolved
- SIL - Swift Intermediate Language, high-level IR
  - Platform agnostic (Builtin.Word abstracts size)
- IR - LLVM Intermediate Representation
  - Platform dependencies (e.g. word size)
- Output formats (assembly, bitcode, library output)

Swift compile pipeline

Example C based IR

- The ubiquitous Hello World program…

```
#include <stdio.h>

int main() {
  puts("Hello World")
}
```

```
clang helloWorld.c -emit-llvm -c -S -o -
```

```
@.str = private unnamed_addr constant [12 x i8] ⤢
 c"Hello World\00", align 1

define i32 @main() #0 {
  %1 = call i32 @puts(i8* getelementptr inbounds
   ([12 x i8]* @.str, i32 0, i32 0))
  ret i32 0
}
```

```
_main
  pushq %rbp
  movq  %rsp, %rbp
  leaq  L_.str(%rip), %rdi
  callq _puts
  xorl  %eax, %eax
  popq  %rbp
  retq
.section  __TEXT
L_.str:    ## was @.str
  .asciz  "Hello World"
```

main function

stack management

rdi = &L_.str

puts(rdi)

eax = 0

return(eax)

L_.str = "Hello World"

```
clang helloWorld.c -emit-assembly -S -o -
```

```
@.str = private unnamed_addr constant [12 x i8] ↩
 c"Hello World\00", align 1

define i32 @main() #0 {
  %1 = call i32 @puts(i8* getelementptr inbounds
   ([12 x i8]* @.str, i32 0, i32 0))
  ret i32 0
}
```

Advantages of IR

- LLVM IR can still be understood when compiled
- Allows for more accurate transformations
    - Inlining across method/function calls
    - Elimination of unused code paths
    - Optimisation phases that are language agnostic

Example Swift based IR

- The ubiquitous Hello World program…

```
print("Hello World")
```

```
swiftc helloWorld.swift -emit-ir -o -
```

```
@0 = private unnamed_addr constant [12 x i8] ⤦
 c"Hello World\00"

define i32 @main(i32, i8**) {
  …
  call void
   @_TFSs5printFTGSaP__9separatorSS10terminatorSS_T_
   %swift.bridge* %6, i8* %17, i64 %18, i64 %19,
   i8* %21, i64 %22, i64 %23)

  ret i32 0
}
```

Name Mangling

- Name Mangling is source → assembly identifiers
  - C name mangling: `main` → `_main`
  - C++ name mangling: `main` → `__Z4mainiPPc`
    - `__Z` = C++ name
    - `4` = 4 characters following for name (main)
    - `i` = int
    - `PPc` = pointer to pointer to char (i.e. `char**`)

Swift Name Mangling

- With the Swift symbol `_TFSs5printFTGSaP__9separatorSS10terminatorSS_T_`
  - `_T` = Swift symbol
  - `F` = function
  - `Ss` = "`Swift`" (module, as in `Swift.print`)
  - `5print` = "`print`" (function name)
  - `TGSaP___` = tuple containing generic array protocol ([protocol<>])
  - `9separator` = "`separator`" (argument name)
  - `SS` = `Swift.String` (special case)
  - `T_` = empty tuple `()` (return type)

Swift Name Mangling

- With the Swift symbol `_TFSs5printFTGSaP__9separatorSS10terminatorSS_T_`

```
$ echo "_TFSs5printFTGSaP__9separatorSS10terminatorSS_T_" |
 xcrun swift-demangle

Swift.print ([protocol<>],
 separator : Swift.String,
 terminator : Swift.String) -> ()
```

- `5print` = "`print`" (function name)
- `TGSaP___` = tuple containing generic array protocol ([protocol<>])
- `9separator` = "`separator`" (argument name)
- `SS` = `Swift.String` (special case)
- `T_` = empty tuple `()` (return type)

Swift Intermediate Language

- Similar to IL, but with some Swift specifics

```
print("Hello World")
```

```
swiftc helloWorld.swift -emit-sil -o -
```

```
sil_stage canonical

import Builtin
import Swift
import SwiftShims

// main
sil @main : $@convention(c) (Int32,
UnsafeMutablePointer<UnsafeMutablePointer<Int8>>) ->
Int32 {
  // function_ref Swift.print (Swift.Array<protocol<>>,
separator : Swift.String, terminator : Swift.String) ->
```

Swift vTables

- Method lookup in Swift is like C++ with vTable

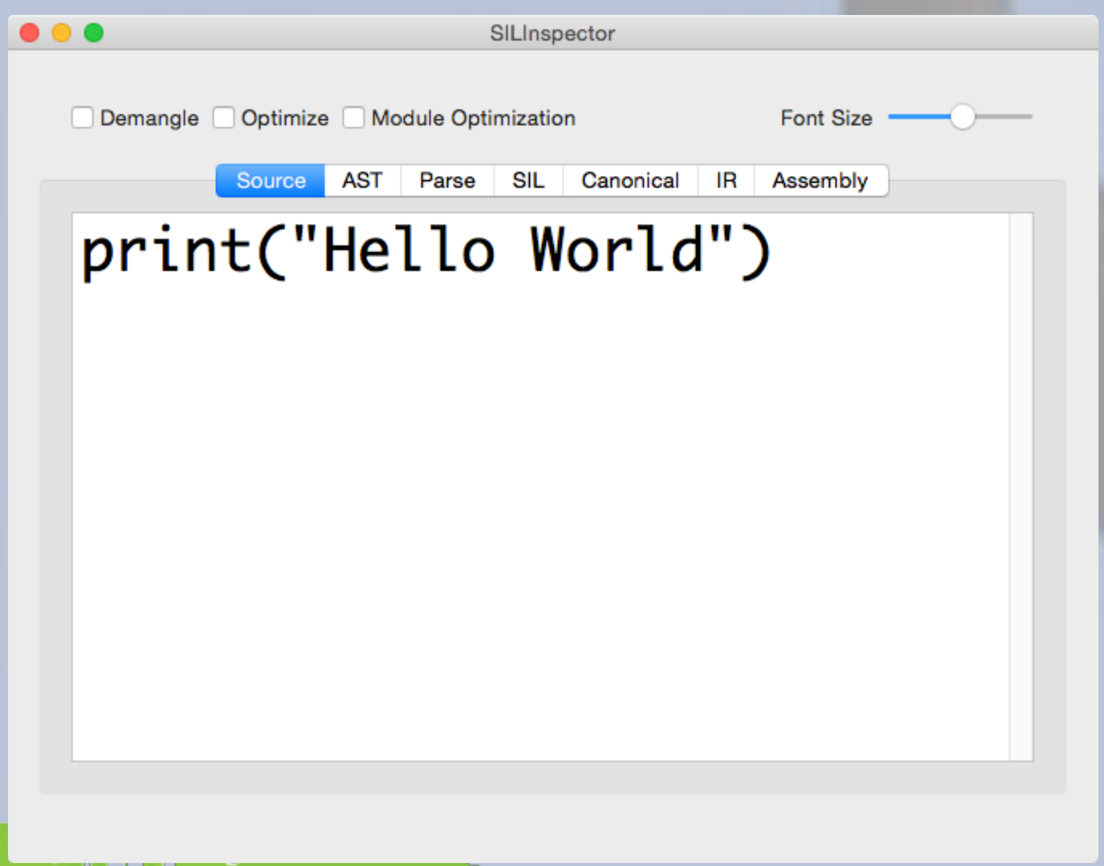
```
class World { func hello() {…} }
```

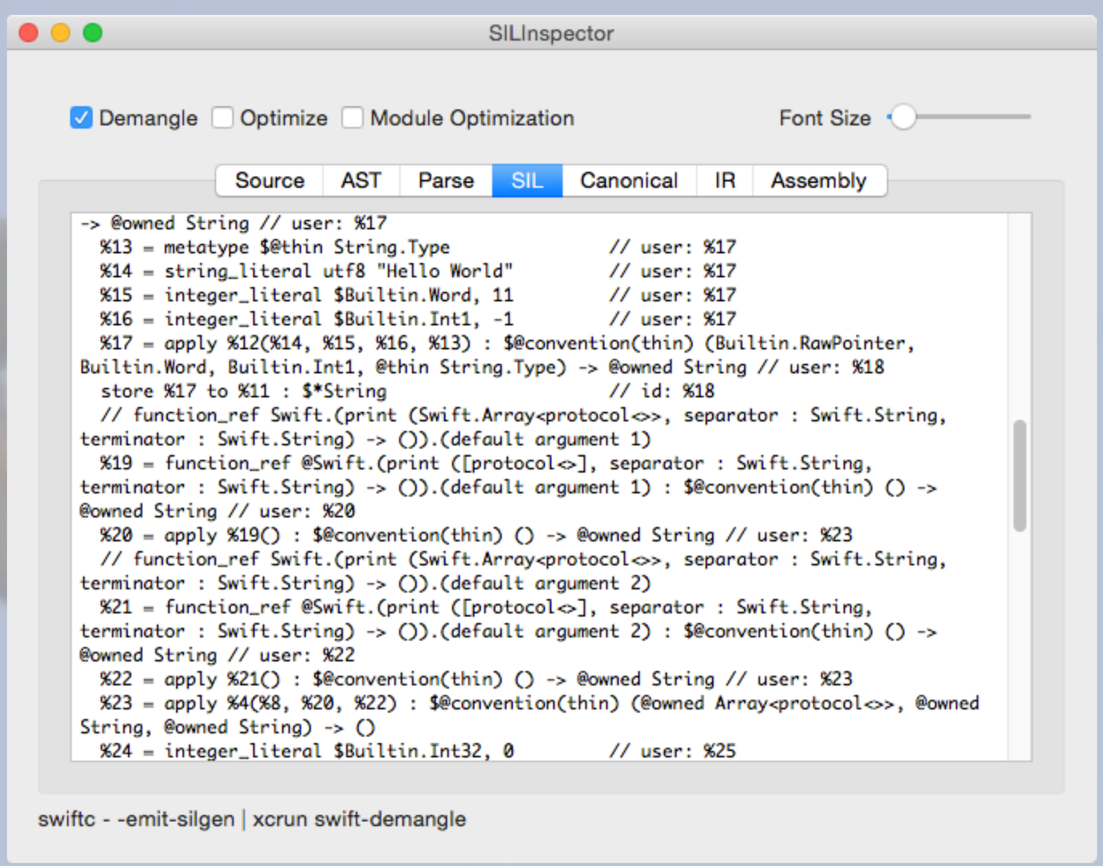
```
swiftc helloWorld.swift -emit-sil -o -
```

```
 sil_stage canonical
import Builtin; import Swift; import SwiftShims
…
sil_vtable World {
 // main.World.hello (main.World)() -> ()
 #World.hello!1: _TFC4main5World5hellofS0_FT_T_

 // main.World.__deallocating_deinit
 #World.deinit!deallocator: _TFC4main5WorldD

 // main.World.init (main.World.Type)() -> main.World
 #World.init!initializer.1: _TFC4main5WorldcfMS0_FT_S0_
}
```

SIL Inspector

- Allows Swift SIL to be inspected
- Available at GitHub
- https://github.com/alblue/SILInspector





SwiftObject and ObjC

- Swift objects can also be used in Objective-C
  - Swift instance in memory has an `isa` pointer
  - Objective-C can call Swift code with no changes
- Swift classes have `@objc` to use dynamic dispatch
  - Reduces optimisations
  - Automatically applied when using ObjC
    - Protocols, Superclasses

Where is Swift going?

Is Swift swift yet?

- Is Swift as fast as C?
  - Wrong question
- Is Swift as fast, or faster than Objective-C?
  - As fast or faster than Objective-C
  - Can be faster for data/struct processing
- More optimisation possibilities in future

Swift

- Being heavily developed – 3 releases in a year
- Provides a transitional mechanism from ObjC
  - Existing libraries/frameworks will continue to work
- Can drop down to native calls when necessary
- Used as replacement language in LLDB
- Future of iOS development?
- Future of server-side development?

Summary

- Swift has a long history coming from LLVM roots
- Prefers static dispatch but also supports objective-c
- Values can be laid out in memory efficiently
- In-lining leads to further optimisations
- Whole-module optimisation will only get better
- Modular compile pipeline allows for optimisations