

Modular Architecture on iOS and macOS



Building Large Scalable iOS and macOS Apps and
Frameworks With Domain-Driven Design

Cyril Cermak

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Dedication

“To my Mom and Dad, because they really tried.”

&&

“To all my non-tech friends for whom I am always fixing various problems: not enough disk space, printers not working, forgotten passcodes etc., and who will never in their lives read this line.”

&&

“To the community, rule no. 5 of my childhood hero Arnold Schwarzenegger says; Don’t just take, give something back. This is me giving back.”

&&

“Finally, to my current girlfriend ... whoever she might be”

About the Author

Hi, I am Cyril, a software engineer by heart and the author of this book. Most of my professional career was spent building iOS apps or iOS frameworks. My professional career began at Skoda Auto Connect App in Prague, continued for Freelancer Ltd in Sydney building iOS platform, included numerous start-ups along the way, and, currently, has me as an iOS Architect Porsche AG, in Stuttgart. In this book, I am describing different approaches for building modular iOS architectures and will be providing some mechanisms and essential knowledge that should help one decide which approach would fit the best or should be considered for a project.

About the Reviewer

Greetings, I am Kristopher K. Kruger, the unintentional and forever grateful reviewer of this book in both its current and previous editions. My professional journey as an iOS Software Developer took an unexpected turn when I met the illustrious Cyril while working on the same groundbreaking project. Our paths first crossed amidst a whirlwind of iOS Swift code, Ruby code, and GitHub Actions during the development of the aforementioned project. In this book, I provided a meticulous, albeit whimsical, review of modular iOS architectures, contributing not just technical insights but also arcane wisdom gathered from my vast and varied experiences. My reviews are known for their unique blend of hard-hitting analysis and absurd humor, ensuring that even the driest of subjects can elicit a hearty chuckle.

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Introduction

In the software engineering field, people are going from project to project, gaining a different kind of experience out of it. In particular, on iOS, mostly the monolithic approaches are used. In some cases it makes total sense, so nothing against it. However, scaling up the team, or even better, the team of teams on a monolithically built app is horrifying and nearly impossible without some major build time impacts on a daily basis. Numerous problems will rise, that limit the way iOS projects are built or managed at the organisational level.

Scaling up the monolithic approach to a team of e.g 10+ developers will most likely result in hell. By hell, I mean, resolving [xcodeproj](#) issues, where in the worst case, both parties renamed, edited, or deleted the same source code file or touched the same {storyboard|xib} file. That is, both worked on the same file which would resolve in classic merge conflicts. Somehow, we all become accustomed to those issues and have learned we will just need to live with them.

The deal-breaker comes when your PO/PM/CTO/CEO or anybody higher on the company's food chain than you are will come to the team to announce that he or she is planning to release a new flavour of the app or to divide the current app into two separate parts. Afterwards, the engineering decision needs to be made to either continue with the monolithic approach or implement something different. Continuing with the monolithic approach, likely would result in creating different targets, assigning files towards the new flavour of the app and continuing on living in multiplied hell all the while hoping that some requirement such as shipping core components of the app to a subsidiary or open-sourcing it as a framework will not come into play.

Not surprisingly, a better approach would be to start refactoring the app using a modular approach, where each team can be responsible for particular frameworks (parts of the app) that are then linked towards final customer-facing apps. That will most certainly take time as it will not be easy to transform it but the future of the company's mobile engineering will be faster, scalable, maintainable and even ready to distribute or open-source some SDKs of it to the outer world.

Another scenario could be that you are already working on an app that is set up in a modular way but your app takes around 20 mins to compile because it is a huge legacy codebase that has been in development for the past ten or so years and has linked every possible 3rd party library along the way. The decision was made to modularise it with Cocoapods therefore, you cannot link easily already pre-compiled libraries with Carthage and every project clean means you can take a double shot of espresso. I have been there, trust me, it is another type of hell, definitely not a place where anyone would like to be. I described the whole migration process of such a project [in an article on Medium in 2018](#). Of course, in this book you will read about it in more detail.

Nowadays, as an iOS System Architect, I am often getting asked some questions all over again from new teams or new colleagues with regards to those topics. Thereafter, I decided to sum it up and tried to get the whole subject covered in this book. The purpose of it is to help developers working on such architectures to gain the background knowledge and experience in order to more quickly and correctly implement these

ideas.

Hopefully, this introduction provided enough motivation that you will want to dive further into this book.

What you Need

The latest version of [Xcode](#) for compiling the demo examples, [brew](#) to install some mandatory dependencies, [Ruby](#), and [bundler](#) for running scripts and downloading some ruby gems.

What is this book about

This book describes the essentials of building a modular architecture on iOS which further can be extended to all Apple platforms. You will find examples of different approaches, framework types, their pros and cons, common problems and so on. By the end of this book, you should have a very good understanding of what benefits such an architecture will bring to your project, whether it is necessary at all, and which way would be the best for modularising the project. This book focuses on high level architecture, modularisation of a project, and collaboration in way to be the most efficient.

What is this book NOT about

SwiftUI.

Modular Architecture

Modular, *adjective - employing or involving a module or modules as the basis of design or construction: “modular housing units”*

In the introduction, I briefly touched on the motivation for building the project in a modular way. To summarise, modular architecture will give us much more freedom when it comes to the product decisions that will influence the overall app engineering. These include building another app for the same company, open-sourcing some parts of the existing codebase, scaling the team of developers, and so on. With the already existing mobile foundation, the whole development process will be done way faster and cleaner.

To be fair, maintaining such a software foundation of a company might be also really difficult. By maintaining, I mean, taking care of the CI/CD (Continuous Integration / Continuous Delivery), maintaining old projects developed on top of the foundation that was heavily refactored in the meantime, legacy code, keeping it up-to-date with the latest development tools and so on. It goes without saying that on a very large project, this could be the work of one standalone team.

This book describes building such a large scalable architecture with domain-driven design and does so by using examples; The software foundation for the [International Space Station](#).

In the context of this book a module is the standalone drawn box, or in practice an Xcode project which encapsulates frameworks, test bundles etc. Further to quote [Apple](#): *A framework is a hierarchical directory that encapsulates shared resources, such as a dynamic shared library, nib files, image files, localized strings, header files, and reference documentation in a single package. Multiple applications can use all of these resources simultaneously. The system loads them into memory as needed and shares the one copy of the resource among all applications whenever possible.*

Design

In this book, I chose to use the architecture that I think is the most flexible. It is a five-layer architecture that consists of the following layers:

- Application
- Domain
- Service
- Core
- Shared

Each layer is explained in the following section.

Nevertheless, the same principles can be applied for other architectural structures as well. An example is a simplified feature-oriented architecture where the layers could be defined as follows:

- Application

- Feature
- Core

This whole setup with layers and modules in them is further in the book referenced as [Application Framework](#).

Now to the specific layers.

Layers

Let us have a look now at each layer and its purpose. Further, we will look at the particular modules within layers and their internal structure.

Application Layer

The application layer consists of the final customer-facing products: applications. Applications assemble all the necessary parts from the Application Framework together, linking domains, services, and so on. Further the app is instantiating the UI stack, primarily domain coordinators (if such pattern is used) and objects such as NetworkService, CashierService, etc. The app also has its unique app configuration, which hosts information such as app flavour, app variant, enabled feature toggles, keychain configuration etc. Patterns that will help achieve such requirements will be described later.

Additionally, the App might also contain some necessary application implementations like receiving push notifications, handling deep linking, requesting permissions, and many more.

In the Application Framework, the App is just a container that stitches pieces together.

As an example, an app in an e-commerce business could be [The Shop](#) for online customer and [Cashier](#) for the employees of that company.

Domain Layer

Domain layer links services and other modules from layers below and uses them to implement the business domain needs of the company or the project. Domains will contain, for example, the user flow within the particular domain part of the app. Furthermore, the domain will have the necessary components for the flow like; coordinators, view controllers, views, models and view models. Obviously it depends on the team's preferences and technical experience which pattern will be used for creating screens. Personally, the reactive MVVM+C is my favourite but more on that later.

Continuing with our example of an e-commerce app, a domain could be [Checkout](#) or [Store Items](#) and a shared domain could be a [User](#) which would based on a configuration display flow for an employee or a customer.

Service Layer

Services are modules supporting domains. Each domain can link several services to achieve desired outcomes. Such services will most likely talk to the backend, obtaining data from it, persisting the data in its storage, and exposing the data to domains.

A service in our theoretical e-commerce app could be a [Checkout Service](#). This service would handle all of the necessary communication with the backend so as to proceed with the credit card payments etc.

Core Layer

The core layer is the enabler for the whole app. Services will link the necessary modules out of it for e.g communicating with the backend or providing a general abstraction of persisting the data. Domains will link e.g UI components for easier implementation of screens and so on.

A core module in our e-commerce app could be [Network](#) or [UIComponents](#).

Shared Layer

The shared layer is a supporting layer for the whole framework. It can happen that this layer might not need to exist, therefore, it is not considered in all diagrams. However, a perfect example of the shared layer is some logging mechanism. Even core layer modules may want to log some output and that could potentially lead to duplicates. This duplicated code could be solved by the shared layer or by following principles of clean architecture. Nevertheless, more on that topic later.

For example, a shared module in an e-commerce app could be [Logging](#) or [AppAnalytics](#).

Example: International Space Station

Now in this example, we will have a look at how such architecture could look like for the [International Space Station](#). The diagram below shows the five-layer architecture with the modules and links. This structure is henceforth referenced to as Application Framework throughout this work.

While this chapter is rather theoretical, in the following chapters everything will be explained and showcased in practice.

The example has three applications.

- [Overview](#): app that shows astronauts the overall status of the space station
- [Cosmonaut](#): app where a Cosmonaut can control his spacesuit as well as his supplies and personal information
- [Laboratory](#): app from which the laboratories on the space station can be controlled

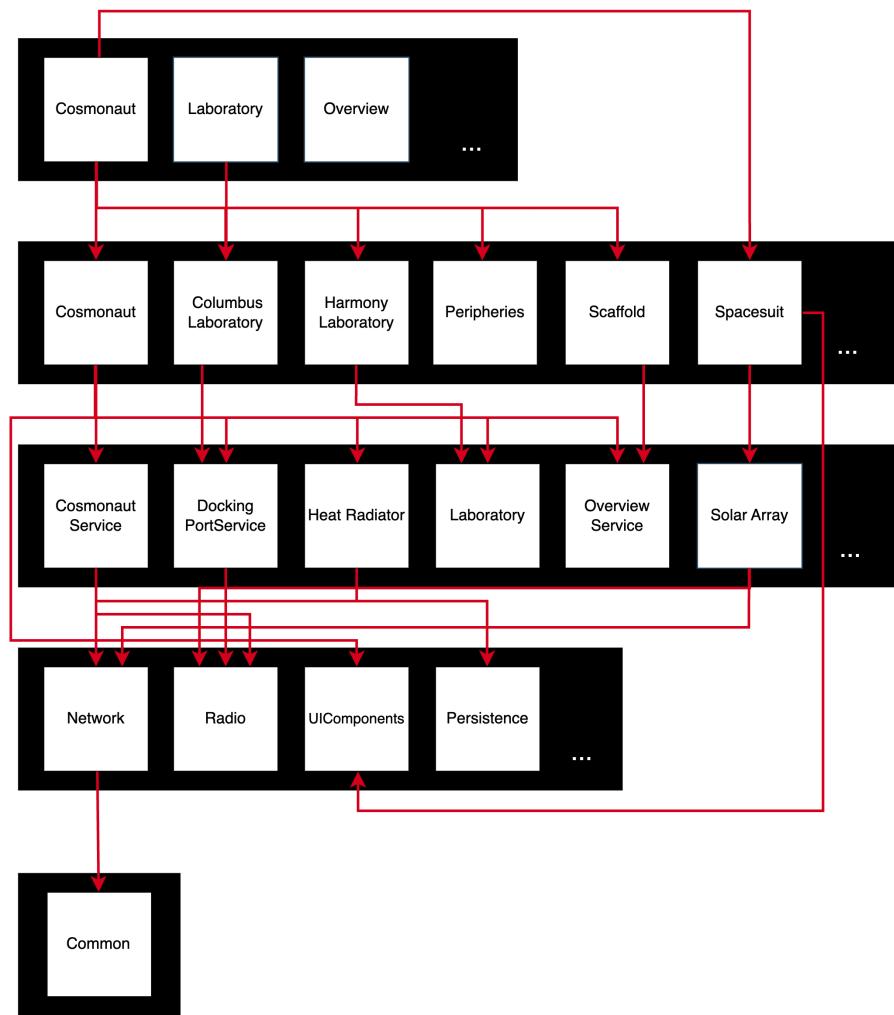


Figure 1 – Application Framework

As described above, all apps link the Scaffold module which provides the bootstrapping for the app while the app itself behaves like a container.

Overview

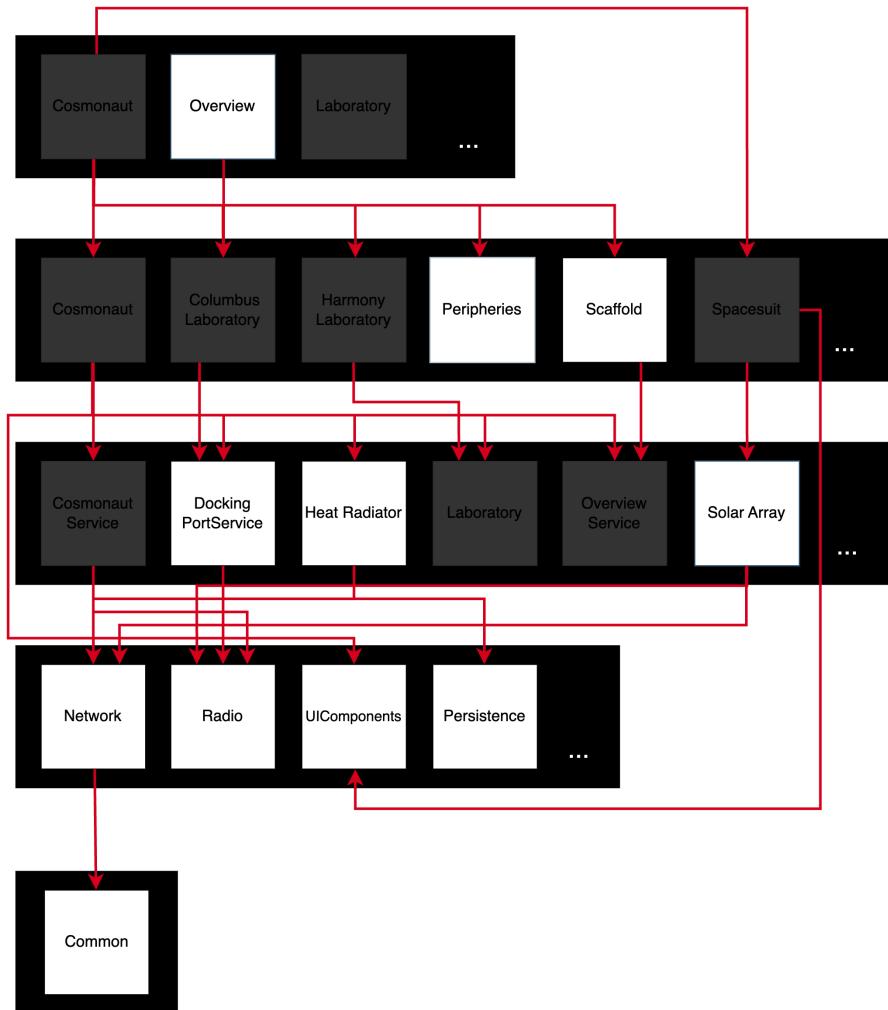


Figure 2 – Overview app

The diagram above describes the concrete linking of modules for the app. Let us have a closer look at it.

The [Overview](#) app links the domain [Peripheries](#), which implements logic and screens for peripheries of the station.

The [Peripheries](#) domain links the [Heat Radiator](#), [Solar Array](#), and [Docking Port](#) services from which data about those peripheries are gathered so as [UIComponents](#) for bootstrapping the screens' development.

The linked services use the [Network](#) and [Radio](#) core modules. These provide the foundation for the communication with other systems via network protocols. [Radio](#) in this case could implement some communi-

cation channel via BLE (Bluetooth Low Energy) or other technology which would connect to the solar array or heat radiator. Further, [UIComponents](#) are used to bootstrap the design and [Persistence](#) is used for database operations.

Cosmonaut

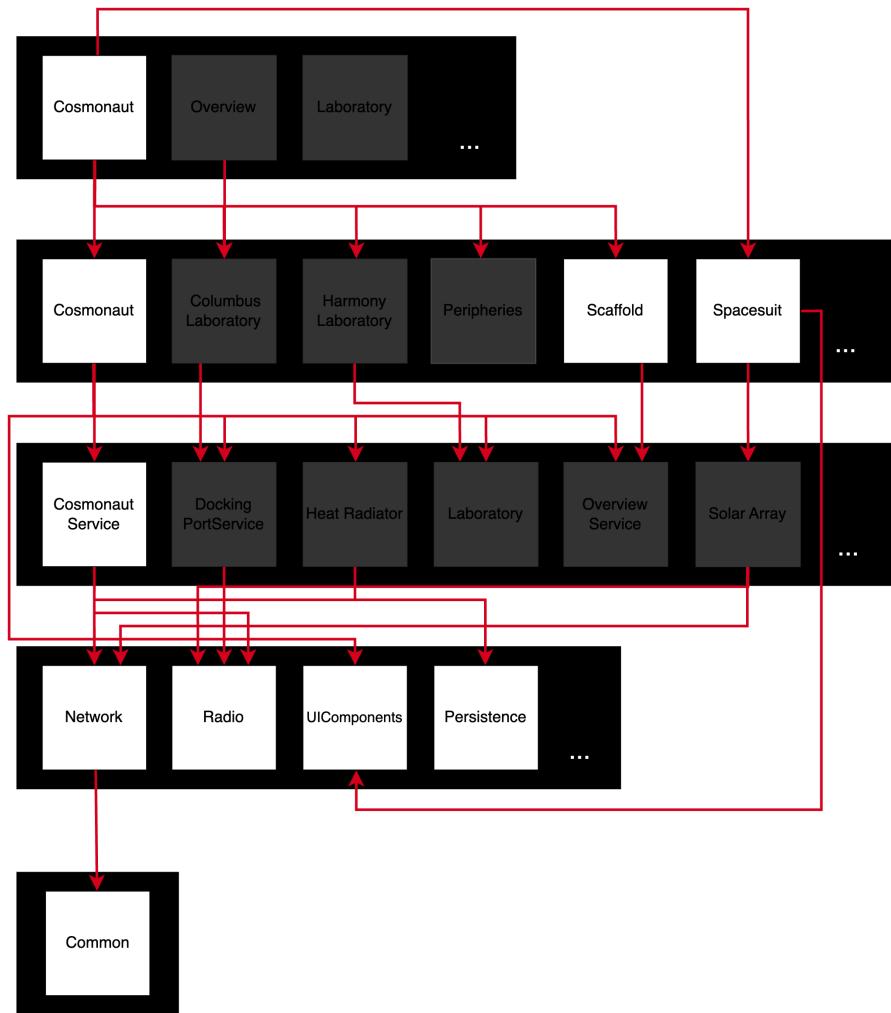


Figure 3 – Cosmonaut app

The [Cosmonaut](#) app links the [Spacesuit](#) and [Cosmonaut](#) domains. This is the same for every other domain, each domain is responsible for screens and users flow through the part of the app.

[Spacesuit](#) and [Cosmonaut](#) domains link [Spacesuit Service](#) and [Cosmonaut Service](#), services that provide data for domain-specific screens. [UIComponents](#) provides the UI parts.

[Spacesuit](#) service is using [Radio](#) for communication with cosmonauts spacesuit via BLE or another type of radio technology. [Cosmonaut](#) service uses [Network](#) for updating Houston about the current state of the [Cosmonaut](#) and uses [Persistence](#) for storing the data of the cosmonaut for offline usage.

Laboratory

I will leave this one for the reader to figure out.

Conclusion

As you can probably imagine, scaling the architecture as described above should not be a problem. When it comes to extending the Overview app for another ISS periphery, for example, a new domain module can be easily added with some service modules etc.

When a requirement comes for creating a new app for e.g. cosmonauts, the new app can already link the battlefield proven and tested [Cosmonaut](#) domain module with other necessary modules that are required. Development of the new app will thus become much easier.

The knowledge of the software that remains in one repository where developers have access to and can learn from is also very beneficial.

There are of course some disadvantages as well. For example, onboarding new developers on such an architecture might take a while, especially when there is already a huge existing codebase. In such a case, pair programming comes into play so as a proper project onboarding, software architecture document and the overall documentation of modules which helps newcomers to get on the right track.

Libraries on Apple's ecosystem

Before we deep dive into the development of previously described architecture, there is some essential knowledge that needs to be explained. In particular, we will need some background in the type of library that is going to be used for building such a project and its behaviour.

In Apple's ecosystem as of today, we have two main options when it comes to creating a library. The library can either be statically or dynamically linked. Previously known as [Cocoa Touch Framework](#), the dynamically linked library is nowadays referred to simply as [Framework](#). The statically linked library is known as the [Static Library](#).

Actually, at this point, a short note deserves also Swift Package and Swift Package Manager (SPM). SPM is part of the Swift's ecosystem rather than Apple's. A swift package describes how a source code should be attached to a target, leaving up to the swift package developer if static or dynamic linking is used. By default, SPM uses static linking and similarly as a Framework can have additional resources attached to it. SPM is not designed to share a compiled executables, it is designed to share source code files with ease. It also became a common practice to share a [XCFramework](#) via SPM, in that case SPM servers just as a wrapper around the attached compiled binary.

What is a library?

To quote Apple: “*Libraries define symbols that are not built as part of your target.*”

What are symbols? *Symbols reference to chunks of code or data within binary.*

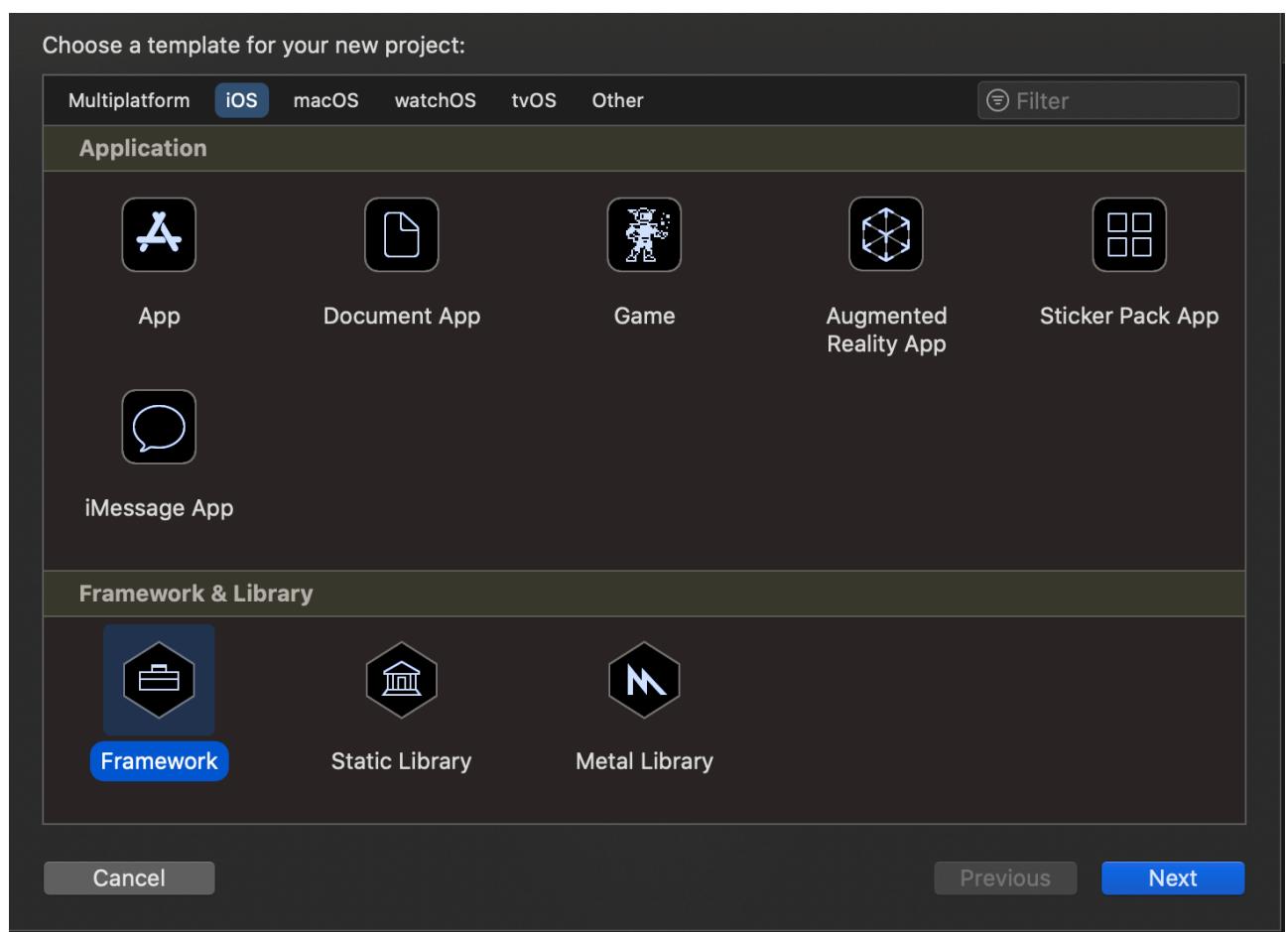


Figure 4 – Xcode Framework Types

Types of libraries:

1) Dynamically linked

- **Dylib:** Library that has its own Mach-O (explained later) binary. ([.dylib](#))
- **Framework:** Framework is a bundle that contains the binary and other resources the binary might need during the runtime. ([.framework](#))
- **TBDs:** Text Based Dynamic Library Stubs is a text stubbed library (symbols only) around a binary without including it as the binary resides on the target system, used by Apple to ship lightweight SDKs for development. ([.tbd](#))
- **XCFramework:** From Xcode 11, the XCFramework was introduced which allows grouping a set of frameworks for different platforms e.g `macOS`, `iOS`, `iOS simulator`, `watchOS` etc. ([.xcframework](#))

2) Statically linked

- **Archive:** Archive of a compiler produced object files with object code. ([.a](#))
- **Framework:** Framework contains the static binary or static archive with additional resources the library might need. ([.framework](#))
- **XCFramework:** Same as for dynamically linked library the XCFramework can be used with statically linked. ([.xcframework](#))

We can look at a framework as some bundle that is standalone and can be attached to a project with its own binary. Nevertheless, the binary cannot run by itself, it must be part of some runnable target. So what is exactly the difference?

Dynamic vs static library?

The main difference between a static and dynamic library is in the Inversion Of Control (IoC) and how they are linked towards the main executable. When you are using something from a static library, you are in control of it as it becomes part of the main executable during the build process (linking). On the other hand, when you are using something from a dynamic framework you are passing responsibility for it to the framework as the framework is dynamically linked to the executable's process on app start. I'll delve more into IoC in the paragraph below. Static libraries, at least on iOS, cannot contain anything other than the executable code unless they are wrapped into a static framework. A framework (dynamic or static) can contain everything you can think of e.g storyboards, XIBs, images and so on...

As mentioned above, the way dynamic framework code execution works is slightly different than in a classic project or a static library. For instance, calling a function from the dynamic framework is done through a framework's interface. Let's say a class from a framework is instantiated in the project and then a specific method is called on it. When the call is being made, you are passing the responsibility for it to the dynamic framework and the framework itself then makes sure that the specific action is executed and the results

then passed back to the caller. This programming paradigm is known as Inversion Of Control. Thanks to the umbrella file and module map you know exactly what you can access and instantiate from the dynamic framework after the framework was built.

A dynamic framework does not support any Bridging-Header file; instead, there is an umbrella.h file. An umbrella file should contain all Objective-C imports as you would normally have in the bridging-Header file. The umbrella file is one big interface for the dynamic framework and it is usually named after the framework name e.g `myframework.h`. If you do not want to manually add all the Objective-C headers, you can just mark `.h` files as public. Xcode generates headers for ObjC for public files when building. It does the same thing for Swift files as it puts the `ClassName-Swift.h` into the umbrella file and exposes the publicly available Swift interfaces via the swiftmodule definition. You can check the final umbrella file and swiftmodule under the derived data folder of the compiled framework.

On the other hand, a statically linked library is attached directly to the main executable during linking as the library contains already a pre-compiled archive of the source files with symbols. That being said, there is no need for an umbrella file as is the case with IoC in a dynamic framework.

It goes without saying that classes and other structures must be marked as public in order to be visible outside of a framework or a library. Not surprisingly, only objects that are needed for clients of a framework or a library should be exposed.

PROS & CONS

Now let's have a look at some pros & cons of both.

Dynamic:

- **PROS**

- Can be opened on demand, therefore, might not get opened at all if user does not open specific part of the app (`dlopen`).
- Can be linked transitively to other dynamic libraries without any difficulty.
- Can be exchanged without the recompile of the main executable just by replacing the framework with a new version.
- Is loaded into a different memory space than the main executable.
- Can be shared between applications especially useful for system libraries.
- Can be loaded partially, only the needed symbols can be loaded into the memory (`dlsym`).
- Can be loaded lazily, only objects that are referenced will be loaded.
- Can be re-used between targets e.g an iOS app and its app extensions, an watch app and its extensions.
- Library can perform some cleanup tasks when it is closed (`dlclose`).
- Potentially faster app start time as if a library is linked lazily, and opened in the runtime.

- Mergeable libraries, Xcode 15 feature could be used for production builds to combine all dynamic libraries into a single framework leveraging the best from the both worlds.
- Hard separation of the codebase improves the compile time of the application.

- **CONS**

- Slower app launch as each dynamic library must be opened, and loaded to memory separately. At the very worst case, a library can run some computational difficult algorithm on the dlopen initialiser which could slow the start up time even further.
- The target must copy all dynamic libraries else the app crashes on the start or during runtime with `dyld library not found`.
- The overall size of the binary is bigger than the static one as the compiler can strip symbols from the static library during the compile-time while in dynamic library the symbols at least the public ones must remain.
- Potential replacement of a dynamic library with a new version with different interfaces can break the main executable.
- Slower library API calls as it is loaded into a different memory space and called via library interface.
- Launch time of the app might take longer if all dynamic libraries are opened during the launch time.

Static:

- **PROS**

- Faster app start up, as just one executable is loaded into the memory
- Is part of the main executable and therefore the app cannot crash during launch or runtime due to a missing library.
- Overall smaller size of the final executable as the unused symbols can be stripped.
- In terms of call speed, there is no difference between the main executable and the library as the library is part of the main executable.
- Compiler can provide some extra optimisation during the build time of the main executable.

- **CONS**

- The library must NOT be linked transitively as each link of the library would add it again. The library must be present only once in the memory either in the main executable or one of its dependencies otherwise the app will need to decide on startup which library is going to be used.
- The main executable must be recompiled when the library has an update even though the library's interface remains the same.
- Compile time is slower as there are no hard interfaces and the build system must always figure out what to re-compile

Essentials

When building any kind of modular architecture, it is crucial to keep in mind that a static library is attached to the executable while a dynamic one is opened and linked at the launch time. Thereafter, if there are two frameworks linking the same static library the app will launch with warnings `Class loaded twice ... one of them will be used`. issue. That causes even slower app starts as the app needs to decide which of those classes will be used. Furthermore, when two different versions of the same static library are used the app will use them interchangeably. Debugging will become a horror in that case. That being said, it is very important to be sure that the linking was done right and no warnings appear.

All that is the reason why using dynamically linked frameworks for internal development is the way to go. However, working with static libraries is, unfortunately, inevitable especially when working with 3rd party libraries. Big companies like Google, Microsoft or Amazon are using static libraries for distributing their SDKs. As of now, for example: `GoogleMaps`, `GooglePlaces`, `Firebase`, `MSAppCenter` and all subsets of those SDKs are linked statically.

When using 3rd party dependency manager like Cocoapods for linking one static library attached to more than one project (App or Framework) it would fail the installation with `target has transitive dependencies that include static binaries`. Therefore, it takes extra effort to link static binaries into multiple frameworks.

Let's have a look at how to link such a static library into a dynamically linked SDK.

Exposing static 3rd party library

As mentioned above, it takes extra effort to link a static library or static framework into a dynamically linked project correctly. The crucial part is to make sure that it is linked only in one place. Either it can be linked towards one dynamic framework or towards the app target. When linked toward a dynamic framework, the static library can be exposed via umbrella file and made available everywhere the framework is linked. When linked toward the app target, the static library or framework cannot be exposed anywhere else directly but can be passed through to other frameworks on the code level via some level of abstraction. The same applies to the static framework.

As an example of such umbrella file exposing `GoogleMaps` library that was linked to it could be:

```
1 // MyFramework.h - Umbrella file
2 #import <UIKit/UIKit.h>
3 #import "GoogleMaps/GoogleMaps.h"
```

The import of the header file of `GoogleMaps` into the frameworks umbrella file exposes all public headers of the `GoogleMaps` because the `GoogleMaps.h` has all the `GoogleMaps` public headers.

```
1 // GoogleMaps.h
2 #import "GMSIndoorBuilding.h"
3 #import "GMSIndoorLevel.h"
```

```
4 #import "GMSAddress.h"
5 ...
```

The library becomes available as soon as the `MyFramework` import precedes the `GoogleMaps` one.

```
1 // MyFileInApp.swift
2 import MyFramework
3 import GoogleMaps
4 ...
```

In case of the static `GoogleMaps` framework, it is necessary to copy its bundle towards the app because it is there that the `GoogleMaps` binary is looking for its resources (translations, images, and so on).

Examining library

Let us have a look at some of the commands that comes in handy when solving some problems when it comes to compiler errors or receiving compiled closed source dynamic framework or a static library. To give it a quick start let's have a look at a binary we all know very well; UIKit. The path to the `UIKit.framework` is: `/Applications/Xcode.app/Contents/Developer/Platforms/iPhoneOS.platform/Library/Developer/CoreSimulator/Profiles/Runtimes/iOS.simruntime/Contents/Resources/RuntimeRoot/System/Library/Frameworks/UIKit.framework`

Apple ships various different tools for exploring compiled libraries and frameworks. On the `UIKit` framework, I will demonstrate only essential commands that I often find quite useful.

Mach-O file format

Before we start, it is crucial to know what we are going to be exploring. In the Apple ecosystem, the file format of any binary is called Mach-O (Mach object). Mach-O has a pre-defined structure starting with Mach-O header, following by segments, sections, load commands and so on.

Since you are surely a curious reader, by now you have many questions about where it all comes from. The answer to that is quite simple. Since it is all part of the system, you can open up Xcode and look for a file in a global path `/usr/include/mach-o/loader.h`. In the `loader.h` file for example the Mach-O header struct is defined.

```
1 /*
2 * The 64-bit mach header appears at the very beginning of object files for
3 * 64-bit architectures.
4 */
5 struct mach_header_64 {
6     uint32_t    magic;        /* mach magic number identifier */
7     cpu_type_t  cputype;     /* cpu specifier */
8     cpu_subtype_t cpusubtype; /* machine specifier */
9     uint32_t    filetype;    /* type of file */
10    uint32_t    ncmds;       /* number of load commands */
```

```
11     uint32_t    sizeofcmds; /* the size of all the load commands */
12     uint32_t    flags;      /* flags */
13     uint32_t    reserved;   /* reserved */
14 };
```

When the compiler produces the final executable the Mach-O header is placed at a concrete byte position in it. Therefore, tools that are working with the executables knows exactly where to look for desired information. The same principle applies to all other parts of Mach-O as well.

For further exploration of Mach-O file, I would recommend reading the following [article](#).

Fat headers

First, let's have a look at what Architectures the binary can be linked on (fat headers). For that, we are going to use `otool`; the utility that is shipped within every macOS. To list fat headers of a compiled binary we will use the flag `-f` and to produce a symbols readable output I also added the `-v` flag.

```
1 otool -fv ./UIKit
```

Not surprisingly, the output produces two architectures. One that runs on the Intel mac (`x86_64`) when deploying to the simulator and one that runs on iPhones as well as on the recently introduced M1 Mac (`arm64`).

```
1 Fat headers
2 fat_magic FAT_MAGIC
3 nfat_arch 2
4 architecture x86_64
5 cputype CPU_TYPE_X86_64
6 cpusubtype CPU_SUBTYPE_X86_64_ALL
7 capabilities 0x0
8 offset 4096
9 size 26736
10 align 2^12 (4096)
11 architecture arm64
12 cputype CPU_TYPE_ARM64
13 cpusubtype CPU_SUBTYPE_ARM64_ALL
14 capabilities 0x0
15 offset 32768
16 size 51504
17 align 2^14 (16384)
```

When the command finishes successfully while not printing any output it simply means that the binary does not contain the fat header. That being said, the library can run only on one architecture and to see which architecture that is, we have to print out the Mach-O header of the executable.

```
1 otool -hv ./UIKit
```

From the output of the Mach-O header we can see that the `cputype` is `X86_64`. We can also see some extra information like with which `flags` the library was compiled, the `filetype`, and so on.

```

1 Mach header
2     magic cputype cpusubtype  caps      filetype ncmds sizeofcmds
3 MH_MAGIC_64  X86_64          ALL  0x00      DYLIB    21      1400
4
5     flags
6 NOUNDEF DYLDLINK TWOLEVEL APP_EXTENSION_SAFE

```

Executable type

Second, let us determine what type of library we are dealing with. For that, we will use again the `otool` as mentioned above. Mach-O header specifies `filetype`. So running it again on the `UIKit.framework` with the `-hv` flags produces the following output:

```

1 Mach header
2     magic cputype cpusubtype  caps      filetype ncmds sizeofcmds
3 MH_MAGIC_64  X86_64          ALL  0x00      DYLIB    21      1400
4
5     flags
6 NOUNDEF DYLDLINK TWOLEVEL APP_EXTENSION_SAFE

```

From the output's `filetype` we can see that it is a dynamically linked library. From its extension, we can say it is a dynamically linked framework. As described earlier, a framework can be dynamically or statically linked. The perfect example of a statically linked framework is `GoogleMaps.framework`. When running the same command on the binary of `GoogleMaps` from the output we can see that the binary is NOT dynamically linked as its type is `OBJECT` aka object files which means that the library is static and linked to the attached executable at the compile time.

```

1 Mach header
2     magic cputype cpusubtype  caps      filetype ncmds sizeofcmds
3 MH_MAGIC_64  X86_64          ALL  0x00      OBJECT   4      2688
4
5     flags
6 SUBSECTIONS_VIA_SYMBOLS

```

The reason for wrapping the static library into a framework was the necessary inclusion of `GoogleMaps.bundle` which needed to be copied to the target in order for the library to work correctly with its resources.

Now, let's try to run the same command on the static library archive. As an example we can use again one of the Xcode's libraries located at `/Applications/Xcode.app/Contents/Developer/Toolchains/XcodeDefault.xctoolchain/usr/lib/swift/iphoneos/libswiftCompatibility50.a`. From the library extension we can immediately say the library is static. Running the `otool -hv libswiftCompatibility50.a` just confirms that the `filetype` is `OBJECT`.

```

1 Archive : ./libswiftCompatibility50.a (architecture armv7)
2 Mach header

```

```

3      magic  cputype cpusubtype  caps      filetype ncmds sizeofcmds
4      MH_MAGIC      ARM          V7  0x00      OBJECT      4      588
5
6      flags
7  SUBSECTIONS_VIA_SYMBOLS
8
9 Mach header
10     magic  cputype cpusubtype  caps      filetype ncmds sizeofcmds
11     MH_MAGIC      ARM          V7  0x00      OBJECT      5      736
12
13     flags
14  SUBSECTIONS_VIA_SYMBOLS
15 ...

```

While static library archive ending with `.a` is a clearly static one with a framework to be sure that the library is dynamically linked it is necessary to check the binary for its `filetype` in the Mach-O header.

Dependencies

Third, let's have a look at what the library is linking. For that the `otool` provides `-L` flag.

```
1 otool -L ./UIKit
```

The output lists all dependencies of the UIKit framework. For example, here you can see that UIKit is linking `Foundation`. That's why the `import Foundation` is no longer needed when importing `UIKit` into a source code file.

```

1 ./UIKit:
2 /System/Library/Frameworks/UIKit.framework/UIKit ...
3 /System/Library/Frameworks/FileProvider.framework/FileProvider ...
4 /System/Library/Frameworks/Foundation.framework/Foundation ...
5 /System/Library/PrivateFrameworks/DocumentManager.framework/DocumentManager
...
6 /System/Library/PrivateFrameworks/UIKitCore.framework/UIKitCore ...
7 /System/Library/PrivateFrameworks/ShareSheet.framework/ShareSheet ...
8 /usr/lib/libobjc.A.dylib ...
9 /usr/lib/libSystem.B.dylib ...

```

Symbols table

Fourth, it is also useful to know which symbols are defined in the framework. For that, the `nm` utility is available. To print all symbols including the debugging ones I added `-a` flag as well as `-C` to print them demangled. Name mangling is a technique of adding extra information about the language data type (class, struct, enum ...) to the symbol during compile time in order to pass more information about it to the linker. With a mangled symbol, the linker will know that this symbol is for a class, getter, setter etc and can work with it accordingly.

```
1 nm -Ca ./UIKit
```

Unfortunately, the output here is very limited as those symbols listed are the ones that define the dynamic framework itself. The limitation is because Apple ships the binary obfuscated and when reverse-engineering the binary with for example Radare2 disassembler, all we can see is a couple of `add byte` assembly instructions. It is still possible to dump the list of symbols, but for that we would have to either use `lldb` and have the UIKit framework loaded in the memory space or dump the memory footprint of the framework and explore it decrypted. That is unfortunately not part of this book.

```
1 00000000000000ff0 s _UIKitVersionNumber
2 00000000000000fc0 s _UIKitVersionString
3 U dyld_stub_binder
```

Just to give an example of how the symbols would look, I printed out compiled realm framework by running `nm -Ca ./Realm`.

```
1 ...
2 2c4650 T realm::Table::do_move_row(unsigned long, unsigned long)
3 2cb1e8 T realm::Table::do_set_link(unsigned long, unsigned long, unsigned long)
4 4305e0 S realm::Table::max_integer
5 4305e8 S realm::Table::min_integer
6 2c44b4 T realm::Table::do_swap_rows(unsigned long, unsigned long)
7 2ce9bc T realm::Table::find_all_int(unsigned long, long long)
8 2cb3ac T realm::Table::get_linklist(unsigned long, unsigned long)
9 2c4d64 T realm::Table::set_subtable(unsigned long, unsigned long, realm::Table const*)
10 2bd9f8 T realm::Table::create_column(realm::ColumnType, unsigned long, bool,
realm::Allocator&)
11 2bf3fc T realm::Table::discard_views()
12 ...
```

It seems like Realm was developed in C++ but it can be clearly seen what kind of symbols are available within the binary. Let us look at one more example but for Swift with Alamofire. There we can, unfortunately, see that the `nm` was not able to demangle the symbols.

```
1 ...
2 34d00 T _$s9Alamofire7RequestC8delegateAA12TaskDelegateCvM
3 34dc0 T _$s9Alamofire7RequestC4taskSo16NSURLSessionTaskCSvgv
4 34e20 T _$s9Alamofire7RequestC7sessionSo12NSURLSessionCvg
5 34e50 T _$s9Alamofire7RequestC7request10Foundation10URLRequestVSvgv
6 350c0 T _$s9Alamofire7RequestC8responseSo17NSHTTPURLResponseCSvgv
7 351e0 T _$s9Alamofire7RequestC10retryCountSvpf
8 ...
```

To demangle swift manually following command can be used.

```
1 nm -a ./Alamofire | awk '{ print $3 }' | xargs swift demangle {} \;
```

Which produces the mangled symbol name with the demangled explanation.

```
1 ...
2 _$s9Alamofire7RequestC4taskSo16NSURLSessionTaskCSvgv
3   ---> Alamofire.Request.task.getter : __CNSURLSessionTask?
4 _$s9Alamofire7RequestC4taskSo16NSURLSessionTaskCSvgvTq
5   ---> method descriptor for Alamofire.Request.task.getter : __CNSURLSessionTask?
6 _$s9Alamofire7RequestC10retryCountSvpfI
7   ---> variable initialization expression of Alamofire.Request.retryCount :
8     Swift.UInt
9 ...
10 ...
```

Strings

Last but not least, it can be also helpful to list all strings that the binary contains. That could help catch developers' mistakes such as not obfuscated secrets and some other strings that should not be part of the binary. To do that we will use `strings` utility again on the Alamofire binary.

```
1 strings ./Alamofire
```

The output is a list of plain text strings found in the binary.

```
1 ...
2 Could not fetch the file size from the provided URL:
3 The URL provided is a directory:
4 The system returned an error while checking the provided URL for
5 reachability.
6 URL:
7 The URL provided is not reachable:
8 ...
```

Build system

The last piece of information that is missing now is how it all gets glued together. As Apple developers, we are using Xcode for developing apps for Apple products that are then distributed via App Store or other distribution channels. Xcode under the hood is using `Xcode Build System` for producing final executables that run on `X86` and `ARM` processor architectures.

The Xcode build system consists of multiple steps that depend on each other. Xcode build system supports C based languages (C, C++, Objective-C, Objective-C++) compiled with `clang` as well as Swift language compiled with `swiftc`.

Let's have a quick look at what Xcode does when the build is triggered.

1. Preprocessing

Preprocessing resolves macros, removes comments, imports files and so on. In a nutshell, it prepares the code for the compiler. The preprocessor also decides which compiler will be used for which source code file. Not surprisingly, Swift source code file will be compiled by `swiftc` and other C like files will use `clang`.

2. Compiler (`swiftc, clang`)

As mentioned above, the Xcode build system uses two compilers; `clang` and `swiftc`. The compiler consists of two parts, front-end and back-end. Both compilers use the same back-end, LLVM (Low-Level Virtual Machine) and language-specific front-end. The job of a compiler is to compile the post-processed source code files into object files that contain object code. Object code is simply human-readable assembly instructions that can be understood by the CPU.

3. Assembler (`asm`)

The assembler takes the output of the compiler (assembly) and produces relocatable machine code. Machine code is recognised by a concrete type of processor (ARM, X86). The opposite of relocatable machine code would be absolute machine code. While relocatable code can be placed at any position in memory by loader the absolute machine code has its position set in the binary.

4. Linker (`ld`)

The final step of the build system is linking. The linker is a program that takes object files (multiple compiled files) and links (merges) them together based on the symbols those files are using as well as static and dynamic libraries as needed. In order to be able to link libraries the linker needs to know the paths where to look for them. Linker produces the final single file; Mach-O executable.

5. Loader (`loader`)

After the executable was built, the job of a loader is to bring the executable into memory and start the program execution. Loader is a system program operating on the kernel level. Loader assigns the memory space and loads Mach-O executable to it.

Now you should have a high-level overview of what phases the Xcode build system goes through when the build is started.

Conclusion

I hope this chapter provided a clear understanding of the essential differences between static and dynamic libraries as well as provided some clear examples showing to examine them. It was quite a lot to grasp, so now it's time for a double shot of espresso or any kind of preferable refreshment.

I would highly recommend to deep dive into this topic even more. Here are some resources I would recommend;

[Exploring iOS-es Mach-O Executable Structure](#)

[Static and Dynamic Libraries](#)

[Difference in between static and dynamic library from our beloved StackOverflow](#)

[Dynamic Library Programming Topics](#)

[Xcode Build System : Know it better](#)

[Mach-O Executables](#)

[LLVM website](#)

[Behind the Scenes of the Xcode Build Process](#)

[Building Faster in Xcode](#)

Used binaries:

[GoogleMaps](#)

[Alamofire](#)

[Realm](#)

Swift Compiler (optional)

Since we touched the Xcode's build system in the previous chapter it would be unfair to the `swiftc` to leave it untouched. Even though knowing how compiler works is not mandatory knowledge it is really interesting and it gives a good closure of the whole process from writing human-readable code to running it on bare metal. In this chapter we are going to look at how a library can be built purely in Swift's ecosystem.

While other chapters are rather essential for having a good understanding of the development of modular architecture, this chapter is optional.

Compiler Architecture

To fully understand swift's compiler architecture and its process, let us have a look at the documentation provided by swift.org and do some practical examples based on it.

The following image describes the `swiftc` architecture. It consists of seven steps, which are explained in subchapters.



Figure 5 – Swiftc Architecture

For demonstration purposes, I prepared two simple swift source code files. First, `employee.swift` and second `main.swift`. The file `employee.swift` is standalone source code while `main.swift` requires the Employee being linked to it as a library. All compiler steps are explained on the `employee.swift` but in the end, the employee source code will be created as a library that the main file will consume and use.

`employee.swift`

```
1 import Foundation
2
3 public protocol Address {
4     var houseNo: Int { get }
5     var street: String { get }
6     var city: String { get }
7     var state: String { get }
8 }
9
10 public protocol Person {
11     var firstName: String { get }
12     var lastName: String { get }
13     var address: Address { get }
14 }
15
16 public class Employee: Person {
17     public let firstName: String
```

```

18     public let lastName: String
19     public let address: Address
20
21     public init(firstName: String, lastName: String, address: Address) {
22         self.firstName = firstName
23         self.lastName = lastName
24         self.address = address
25     }
26
27     public func printEmployeeInfo() {
28         print("\(firstName) \(lastName)")
29         print("\(address.houseNo). \(address.street), \(address.city), \
30             \(address.state)")
31     }
32
33     public struct EmployeeAddress: Address {
34         public let houseNo: Int
35         public let street: String
36         public let city: String
37         public let state: String
38
39         public init(houseNo: Int, street: String, city: String, state: String) {
40             self.houseNo = houseNo
41             self.street = street
42             self.city = city
43             self.state = state
44         }
45     }

```

main.swift

```

1 import Foundation
2 import Employee
3
4 let employee = Employee(firstName: "Cyril",
5                         lastName: "Cermak",
6                         address: EmployeeAddress(houseNo: 1, street: "
7                             PorschePlatz", city: "Stuttgart", state: "Germany
8 "))
8 employee.printEmployeeInfo()

```

Parsing

The parser is a simple, recursive-descent parser (implemented in lib/Parse) with an integrated, hand-coded lexer. The parser is responsible for generating an Abstract Syntax Tree (AST) without any semantic or type information, and emit warnings or errors for grammatical problems with the input source.

Source: swift.org

First in the compilation process is **parsing**. As the definition says, the parser is responsible for the lexical syntax check without any type check. The following command prints the parsed AST.

```
1 swiftc ./employee.swift -dump-parse
```

In the output, you can notice that the types are not resolved and end with errors.

```
1 (source_file "./employee.swift"
2 // Importing Foundation
3   (import_decl range=[./employee.swift:1:1 - line:1:8] 'Foundation')
4 // Address protocol declaration
5   (protocol range=[./employee.swift:3:8 - line:8:1] "Address" <Self :
6     Address> requirement signature=<null>
7     (pattern_binding_decl range=[./employee.swift:4:5 - line:4:28]
8       (pattern_typed
9         (pattern_named 'houseNo')
10        (type_ident
11          (component id='Int' bind=none))))
12 // houseNo variable declaration
13   (var_decl range=[./employee.swift:4:9 - line:4:9] "houseNo" type='<null
14     type>' readImpl=getter immutable
15     (accessor_decl range=[./employee.swift:4:24 - line:4:24] 'anonname=0
16       x7fc1e408db80' get_for=houseNo
17     // Not recognized Int type
18     (parameter "self"./employee.swift:4:18: error: cannot find type 'Int
19       ' in scope
20     var houseNo: Int { get }
21       ^
22     )
23 ...
24 // Employee class declaration
25   (class_decl range=[./employee.swift:16:8 - line:31:1] "Employee" inherits: <
26     null>
27     (pattern_binding_decl range=[./employee.swift:17:12 - line:17:27]
28       (pattern_typed
29         (pattern_named 'firstName')
30         (type_ident
31           (component id='String' bind=none))))
32 // Employee class vars declaration
33   (var_decl range=[./employee.swift:17:16 - line:17:16] "firstName" type='
34     <null type>' let readImpl=stored immutable)
35   (pattern_binding_decl range=[./employee.swift:18:12 - line:18:26]
36     (pattern_typed
37       (pattern_named 'lastName'))
```

```
32     (type_ident
33         (component id='String' bind=none)))
34 ...
```

From the parsed AST we can see that it is really descriptive. The source code of `employee.swift` has 47 lines of code while its parsed AST without type check has 270.

Out of curiosity, let us have a look at how the tree would look with a syntax error. To do so, I added the winner of all times in hide and seek, a semi-colon ;, to the protocol declaration.

```
1 public protocol Address {
2     var houseNo: Int; { get }
```

After running the same command we can see a syntax error at the declaration of `houseNo` variable. That is the error Xcode would show as soon as it type checks the source file.

```
1 ...
2 (var_decl range=[./employee.swift:4:9 - line:4:9] "houseNo" type='<null type
>' ./employee.swift:4:9: error: property in protocol must have explicit {
    get } or { get set } specifier
3     var houseNo: Int; { get }
4 ...
```

Semantic analysis

Semantic analysis (implemented in lib/Sema) is responsible for taking the parsed AST and transforming it into a well-formed, fully-type-checked form of the AST, emitting warnings or errors for semantic problems in the source code. Semantic analysis includes type inference and, on success, indicates that it is safe to generate code from the resulting, type-checked AST.

Source: swift.org

After parsing, comes the **semantic analysis**. From its definition, we should see fully type-checked parsed AST. Executing the following command will give us the answer.

```
1 swiftc ./employee.swift -dump-ast
```

In the output all types are resolved and recognised by the compiler and the errors no longer appear.

```
1 // Address protocol with resolved types
2 (protocol range=[./employee.swift:3:8 - line:8:1] "Address" <Self : Address>
3   interface type='Address.Protocol' access=public non-resilient
4   requirement signature=<Self>
5   (pattern_binding_decl range=[./employee.swift:4:5 - line:4:18]
6     trailing_semi
7     (pattern_typed type='Int'
8       (pattern_named type='Int' 'houseNo')
9       (type_ident
10        (component id='Int' bind=Swift.(file).Int))))
11 ...
12 // EmployeeAddress conforming to the Address protocol
13 (struct_decl range=[./employee.swift:33:8 - line:45:1] "EmployeeAddress"
14   interface type='EmployeeAddress.Type' access=public non-resilient
15   inherits: Address
16   (pattern_binding_decl range=[./employee.swift:34:12 - line:34:25]
17     (pattern_typed type='Int'
18       (pattern_named type='Int' 'houseNo')
19       (type_ident
20        (component id='Int' bind=Swift.(file).Int))))
21 // Variable declaration on EmployeeAddress
22 (var_decl range=[./employee.swift:34:16 - line:34:16] "houseNo" type='Int'
23   interface type='Int' access=public let readImpl=stored immutable
24   (accessor_decl implicit range=[./employee.swift:34:16 - line:34:16] '
25     anonname=0x7fd2821409e8' interface type='(EmployeeAddress) -> () ->
26     Int' access=public get_for=houseNo
27   (parameter "self" type='EmployeeAddress' interface type='
28     EmployeeAddress')
29   (parameter_list)
30   (brace_stmt implicit range=[./employee.swift:34:16 - line:34:16]
31     (return_stmt implicit
32      (member_ref_expr implicit type='Int' decl=employee.(file).
33        EmployeeAddress.houseNo@./employee.swift:34:16
34        direct_to_storage
35        (declref_expr implicit type='EmployeeAddress' decl=employee.(file).
36          EmployeeAddress.<anonymous>.self@./employee.swift
```

```
:34:16 function_ref=unapplied)))))
```

Not surprisingly, when using an unknown type, the command results in an error.

```
1 public protocol Address {  
2     var houseNo: Foo { get }
```

```
1 /employee.swift:4:18: error: cannot find type 'Foo' in scope  
2     var houseNo: Foo { get }  
3     ^~~  
4 (source_file "./employee.swift"  
5  (import_decl range=[./employee.swift:1:1 - line:1:8] "Foundation")  
6  (protocol range=[./employee.swift:3:8 - line:8:1] "Address" <Self :  
    Address> interface type='Address.Protocol' access=public non-resilient  
    requirement signature=<Self>  
7   (pattern_binding_decl range=[./employee.swift:4:5 - line:4:28]  
8     (pattern_typed type='<<error type>>'
```

Clang importer

The Clang importer (implemented in lib/ClangImporter imports Clang modules and maps the C or Objective-C APIs they export into their corresponding Swift APIs. The resulting imported ASTs can be referred to by semantic analysis.

Source: swift.org

The third in the compilation process is the **clang importer**. This is the well-known bridging of C/ObjC languages to the Swift API's and vice versa.

SIL generation

The Swift Intermediate Language (SIL) is a high-level, Swift-specific intermediate language suitable for further analysis and optimization of Swift code. The SIL generation phase (implemented in lib/SILGen) lowers the type-checked AST into so-called “raw” SIL. The design of SIL is described in docs/SIL.rst.

Source: swift.org

The fourth step in the compilation process is the **Swift Intermediate Language**. Are you curious about how it looks? To print it, we can use the following command.

```
1 swiftc ./employee.swift -emit-sil
```

In the output, we can see the `witness tables`, `vtables` and `message dispatch` tables alongside with other intermediate declarations. Unfortunately, an explanation of this is out of the scope of this book. More about these topics can be obtained in the article about [method dispatch](#).

```

1 ...
2 // protocol witness for Address.state.getter in conformance EmployeeAddress
3 sil shared [transparent] [serialized] [thunk]
4     @$s8employee15EmployeeAddressVAA0C0A2aDP5stateSSvgTW : $@convention(
5         witness_method: Address) (@in_guaranteed EmployeeAddress) -> @owned
6         String {
7             // %0
8             bb0(%0 : $*EmployeeAddress):
9                 %1 = load %0 : $*EmployeeAddress
10                // user: %1
11                // function_ref EmployeeAddress.state.getter
12                %2 = function_ref @$s8employee15EmployeeAddressV5stateSSvg : $@convention(
13                    method) (@guaranteed EmployeeAddress) -> @owned String // user: %3
14                %3 = apply %2(%1) : $@convention(method) (@guaranteed EmployeeAddress) ->
15                    @owned String // user: %4
16                return %3 : $String
17            // id: %4
18        } // end sil function '$s8employee15EmployeeAddressVAA0C0A2aDP5stateSSvgTW'
19
20 sil_vtable [serialized] Employee {
21     #Employee.init!allocator: (Employee.Type) -> (String, String, Address) ->
22         Employee :
23             @$s8employee8EmployeeC9firstName04lastNameD07addressACSS_SSAA7Address_ptcfC
24                 // Employee.__allocating_init(firstName:lastName:address:)
25             #Employee.printEmployeeInfo: (Employee) -> () -> () :
26                 @$s8employee8EmployeeC05printB4InfoyyF // Employee.printEmployeeInfo
27             #Employee.deinit!deallocator: @$s8employee8EmployeeCfD // Employee.
28                 __deallocating_deinit
29 }
30
31 sil_witness_table [serialized] Employee: Person module employee {
32     method #Person.firstName!getter: <Self where Self : Person> (Self) -> ()
33         -> String : @$s8employee8EmployeeCAA6PersonA2aDP9firstNameSSvgTW //
34             protocol witness for Person.firstName.getter in conformance Employee
35     method #Person.lastName!getter: <Self where Self : Person> (Self) -> () ->
36         String : @$s8employee8EmployeeCAA6PersonA2aDP8lastNameSSvgTW //
37             protocol witness for Person.lastName.getter in conformance Employee
38     method #Person.address!getter: <Self where Self : Person> (Self) -> () ->
39         Address : @$s8employee8EmployeeCAA6PersonA2aDP7addressAA7Address_pvgTW
40             // protocol witness for Person.address.getter in conformance
41             Employee
42 }
43
44 sil_witness_table [serialized] EmployeeAddress: Address module employee {
45     method #Address.houseNo!getter: <Self where Self : Address> (Self) -> ()
46         -> Int : @$s8employee15EmployeeAddressVAA0C0A2aDP7houseNoSivgTW //
47             protocol witness for Address.houseNo.getter in conformance
48             EmployeeAddress
49     method #Address.street!getter: <Self where Self : Address> (Self) -> () ->
50         String : @$s8employee15EmployeeAddressVAA0C0A2aDP6streetSSvgTW //
51             protocol witness for Address.street.getter in conformance
52             EmployeeAddress
53     method #Address.city!getter: <Self where Self : Address> (Self) -> () ->
54         String : @$s8employee15EmployeeAddressVAA0C0A2aDP4citySSvgTW //
55

```

```
    protocol witness for Address.city.getter in conformance
    EmployeeAddress
29   method #Address.state!getter: <Self where Self : Address> (Self) -> () ->
        String : @$s8employee15EmployeeAddressVAA0C0A2aDP5stateSSvgTW  //
        protocol witness for Address.state.getter in conformance
        EmployeeAddress
30 }
31 ...
```

Furthermore, the SIL must go through next two phases; guaranteed transformation and optimisation.

SIL guaranteed transformations: The SIL guaranteed transformations (implemented in lib/SILOptimizer/Mandatory) perform additional dataflow diagnostics that affect the correctness of a program (such as a use of uninitialized variables). The end result of these transformations is “canonical” SIL.

Source: swift.org

SIL Optimizations: The SIL optimizations (implemented in lib/Analysis, lib/ARC, lib/LoopTransforms, and lib/Transforms) perform additional high-level, Swift-specific optimizations to the program, including (for example) Automatic Reference Counting optimizations, devirtualization, and generic specialization.

Source: swift.org

LLVM IR Generation

IR generation (implemented in lib/IRGen) lowers SIL to LLVM IR, at which point LLVM can continue to optimize it and generate machine code.

Source: swift.org

The final step in the compilation process is that of the IR (Intermediate Representation) for LLVM. To get the IR from the swiftc we can use the following command:

```
1 swiftc ./employee.swift -emit-ir | more
```

Here we can see a snippet of the LLVM's familiar code declaration. In the next step, the code would be transformed by LLVM into the machine code.

```
1 ...
2 entry:
3     %1 = getelementptr inbounds %__opaque_existential_type_1, %
        __opaque_existential_type_1* %0, i32 0, i32 1
4     %2 = load %swift.type*, %swift.type** %1, align 8
5     %3 = getelementptr inbounds %__opaque_existential_type_1, %
        __opaque_existential_type_1* %0, i32 0, i32 0
6     %4 = bitcast %swift.type* %2 to i8***
7     %5 = getelementptr inbounds i8**, i8*** %4, i64 -1
8     %.valueWitnesses = load i8**, i8*** %5, align 8, !invariant.load !64, !
    dereferenceable !65
9     %6 = bitcast i8** %.valueWitnesses to %swift.vwtable*
10    %7 = getelementptr inbounds %swift.vwtable, %swift.vwtable* %6, i32 0,
        i32 10
11    %flags = load i32, i32* %7, align 8, !invariant.load !64
12    %8 = and i32 %flags, 131072
13    %flags.isInline = icmp eq i32 %8, 0
14    br i1 %flags.isInline, label %inline, label %outline
15 ...
```

Exporting dylib

Finally, we can explore how to manually create a library out of the source code and link it towards the executable.

The following command will export the `employee.swift` file as an `Employee.dylib` with its module definition. Instead of using the parameter `-emit-module` we could use `-emit-object` to obtain a statically linked library.

```
1 swiftc ./employee.swift -emit-library -emit-module -parse-as-library -module  
-name Employee
```

After executing the command, the following files should be created.

```
1 380B Apr 2 13:36 Employee.swiftdoc  
2 19K Apr 3 20:52 Employee.swiftmodule  
3 2.9K Apr 3 20:52 Employee.swiftsourceinfo  
4 1.1K Apr 3 20:52 employee.swift  
5 57K Apr 3 20:52 libEmployee.dylib
```

Now we can import the Employee library into the `main.swift` file and proceed with the compile. However, here we have to tell the compiler and linker where to find the Employee library. In this example, I placed the library into a directory named `Frameworks` which resides on the same level as the `main.swift`.

```
1 swiftc main.swift -emit-executable -lEmployee -I ./Frameworks -L ./  
Frameworks
```

To give it a bit more explanation the command `swiftc -h` describes those flags as follows:

```
1 ...  
2 -emit-executable          Emit a linked executable  
3 -I <value>                Add directory to the import search path  
4 -L <value>                Add directory to library link search path  
5 -l<value>                Specifies a library which should be linked against  
6 ...
```

Hurrray, the executable was created with the linked library! Unfortunately, it crashes right on start with the following:

```
1 dyld: Library not loaded: libEmployee.dylib  
2   Referenced from: /Users/cyrilcermak/Programming/iOS/  
      modular_architecture_on_ios/example./main  
3   Reason: image not found  
4 [1]    92481 abort      ./main
```

Using the knowledge from the previous chapter we can check where the binary expects the library to be with the command `otool -l ./main`.

```
1 Load command 15  
2           cmd LC_LOAD_DYLIB
```

```
3      cmdsize 48
4          name libEmployee.dylib (offset 24)
5      time stamp 2 Thu Jan  1 01:00:02 1970
6          current version 0.0.0
7 compatibility version 0.0.0
```

The binary expects the libEmployee.dylib to be at the same path. This can be easily fixed with one more tool, `install_name`. It changes the path to the linked library in the main executable. It can be used as follows;

```
1 install_name_tool -change libEmployee.dylib @executable_path/Frameworks/
    libEmployee.dylib main
```

Running it again prints the desired output:

```
1 Cyril Cermak
2 1. PorschePlatz, Stuttgart, Germany
```

Conclusion

In this chapter, the basics of Swift compiler architecture were explored. I hope this (optional) chapter gave a high-level overview and brought more curiosity into the topic of how compilers work. For more study I would refer to the following sources:

[Swift Compiler](#)

[Understanding Swift Performance](#)

[Understanding method dispatch in Swift](#)

[Method Dispatch in Swift](#)

[Getting Started with Swift Compiler Development](#)

[executable path, load path and rpath](#)

Development of the Modular Architecture

The necessary theory about Apple's libraries and some essentials were explained. Finally, it is time to deep dive into the building phase.

First, let us do it manually and automate the process of creating libraries later on so that the newcomers do not have to copy-paste much of the boilerplate code when starting a new team or new part of the application framework.

For demonstration purposes, I chose the Cosmonaut app with all its necessary dependencies. Nevertheless, the same principle applies to all other apps within our future iOS/macOS ISS foundational framework.

You can look at the `iss_modular_architecture` folder and fully focus on the step by step explanations in the book or you can build it on your own up until a certain point.

As a reminder, the following schema showcases the Cosmonaut app with its dependencies.

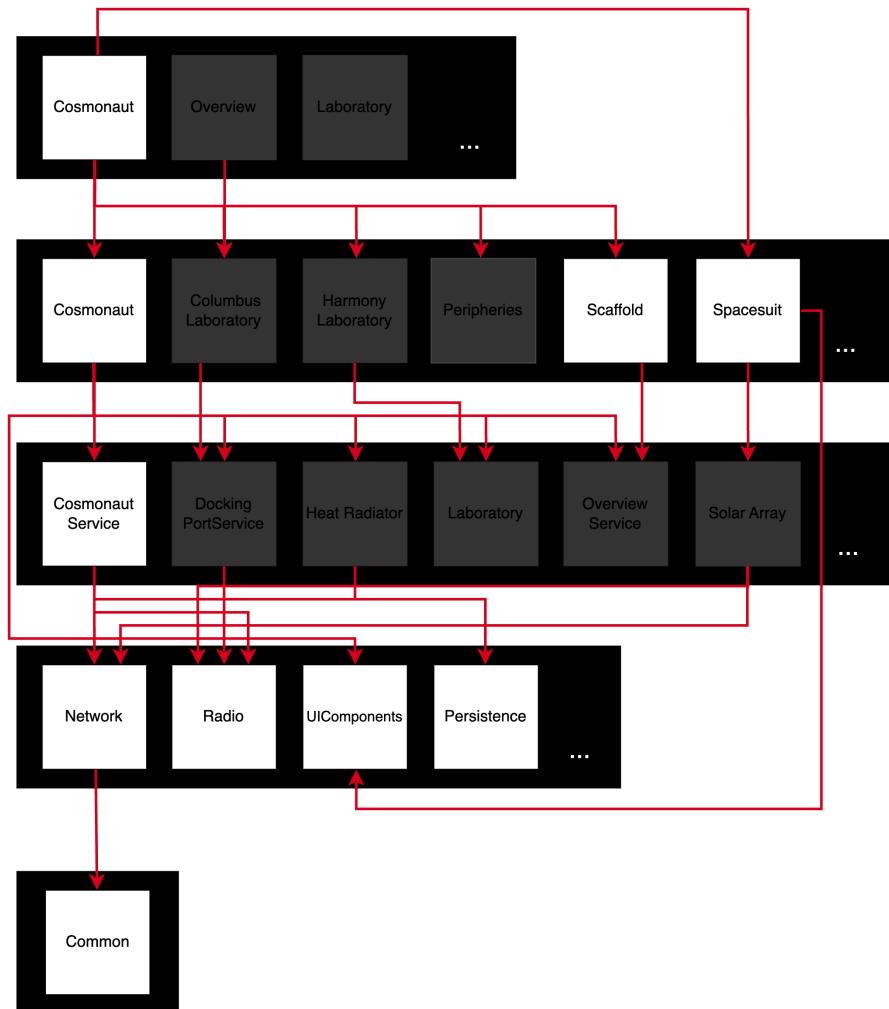


Figure 6 – Cosmonaut app

Creating workspace structure

First, let us manually create the Cosmonaut app from Xcode under the `iss_application_framework/app/` directory. To achieve that, simply create a new App from the Xcode's menu and save it under the predefined folder path with the `Cosmonaut` name. An empty project app should be created, you can run it if you want. Nevertheless, for our purposes, the project structure is not optimal. We will be working in a workspace that will contain multiple projects (apps and frameworks).

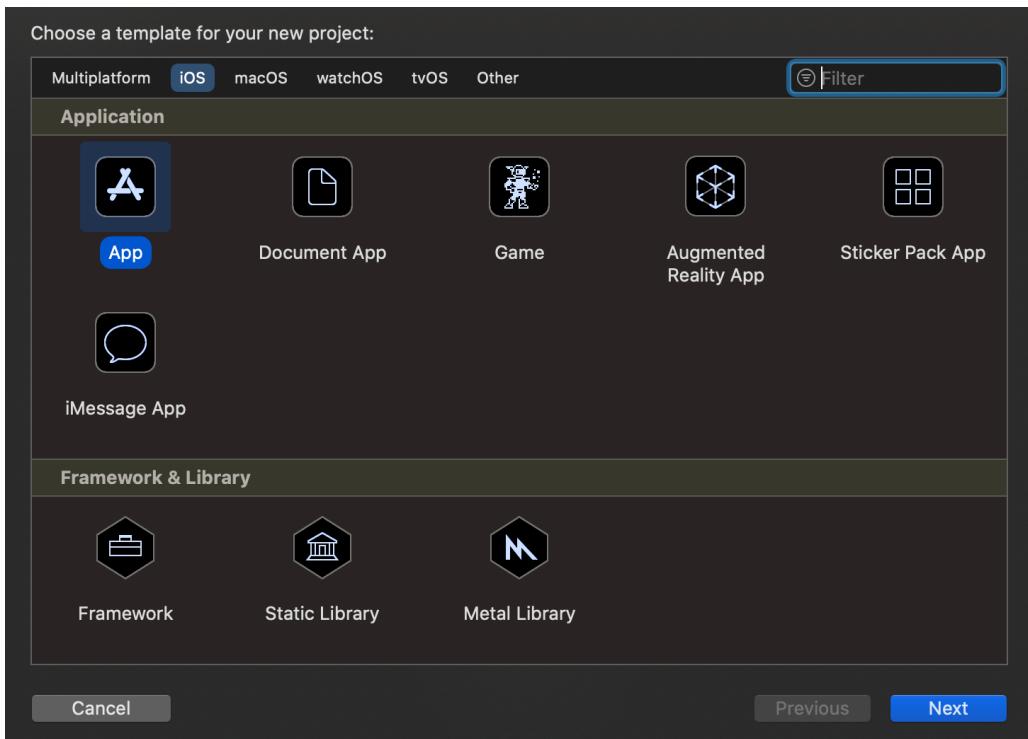


Figure 7 – Create New App

Since we do not have `Cocopods` yet, which would convert the project into a workspace, we have to do it manually. In Xcode under `File`, select the option `Save As Workspace`. Close the project and open the Workspace that was newly created by Xcode. So far the workspace contains only the App. Now it is time to create the necessary dependencies for the `Cosmonaut` app.

Going top-down through the diagram first comes the `Domain` layer where `Spacesuit`, `Cosmonaut` and `Scaffold` is needed to be created. For creating the `Spacesuit` let us use Xcode one last time. Under the new project select the framework icon, name it `Cosmonaut` and save it under the `iss_application_framework/domain/` directory.

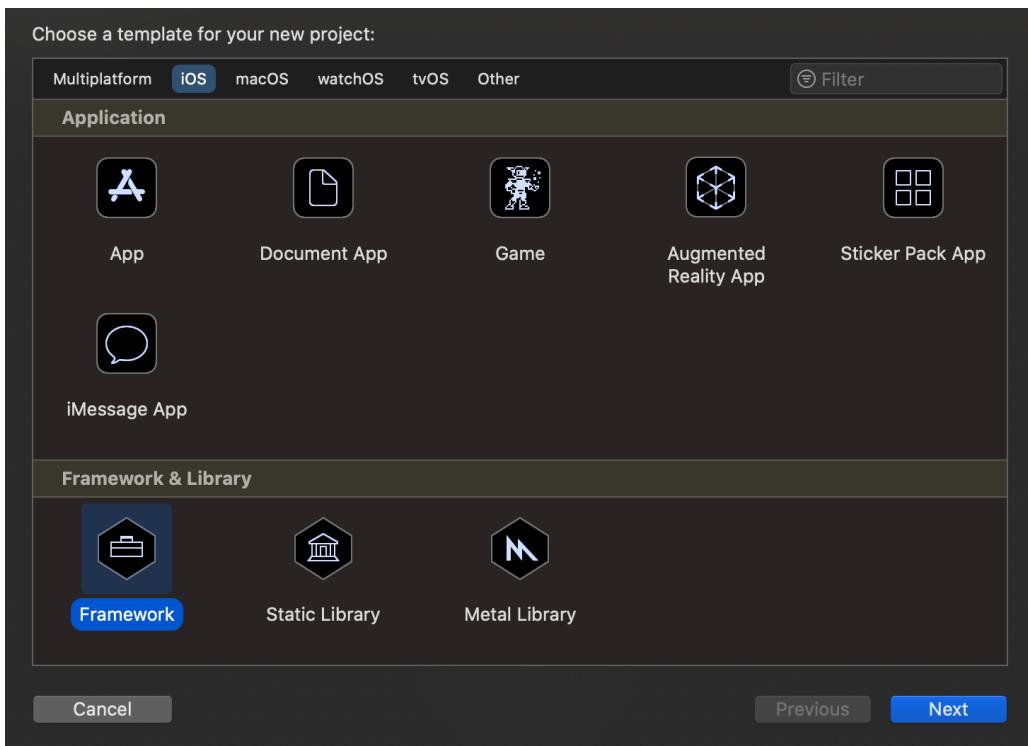


Figure 8 – Create New Framework

Automating the process

While creating new frameworks and apps is not a daily business, the process still needs to assure that correct namespaces and conventions are used across the whole application framework. This usually leads to copy-pasting an existing framework or app to create a new one with the same patterns. Now is a good time to create the first script that will support the development of the application framework.

If you are building the application framework from scratch please copy the `{PROJECT_ROOT}/fastlane` directory from the repository into your `root` directory.

The scripting around the framework with `Fastlane` is explained later on in the book. However, all you need to know now is that Fastlane contains lane `make_new_project` that takes three arguments; `type {app|framework}`, `project_name` and `destination_path`. The lane in Fastlane simple uses the instance of the `ProjectFactory` class located in the `{PROJECT_ROOT}/fastlane/scripts/ProjectFactory/project_factory.rb` file.

The `ProjectFactory` creates a new framework or app based on the `type` parameter that is passed to it from the command line. As an example of creating the Spacesuit domain framework, the following command can be used.

```
1 fastlane make_new_project type:framework project_name:Spacesuit
   destination_path:../domain/Spacesuit
```

In case of Fastlane not being installed on your Mac, you can install it via `brew install fastlane` or later on via Ruby `gems` defined in `Gemfile`. For installation please follow the official [manual](#).

Furthermore, now that we have the script, all the remaining dependencies can be created with it.

The overall ISS Application Framework should look as follows:

```
➜ iss_modular_architecture git:(master) ✘ tree -L 2
.
├── app
│   ├── Cosmonaut
│   ├── Laboratory
│   └── Overview
├── core
│   ├── Network
│   ├── Persistence
│   ├── Radio
│   └── UIComponents
├── domain
│   ├── Columbus\ Laboratory
│   ├── Cosmonaut
│   ├── Harmony\ Laboratory
│   ├── Peripheries
│   ├── Scaffold
│   └── Spacesuit
└── fastlane
    ├── Fastfile
    ├── README.md
    ├── build_settings.yml
    ├── report.xml
    └── scripts
        └── service
            ├── CosmonautService
            ├── Docking\ Port
            ├── Heat\ Radiator
            ├── Laboratory
            ├── Solar\ Array
            └── SpacesuitService

25 directories, 4 files
```

Figure 9 – Tree structure

Each directory contains an Xcode project which is either a framework or an app created by the script. From now on, every onboarded team or developer should use the script when adding a framework or an app.

Xcode's workspace

Last but not least, let us create the same directory structure in Xcode's Workspace so that we can, later on, link those frameworks together and towards the app. The workspace `Cosmonaut.xcworkspace` resides in the folder `Cosmonaut` under the `app` folder. An `xcworkspace` is simply a structure that contains:

- `xcshareddata`: Directory that contains schemes, breakpoints and other shared information
- `xcuserdata`: Directory that contains information about the current users interface state, opened/-modified files of the user and so on

- `contents.xcworkspacedata`: An XML file that describes what projects are linked towards the workspace such that Xcode can understand it

The workspace structure can be created either by drag and drop all necessary framework projects for the `Cosmonaut` app or by directly modifying the `contents.xcworkspacedata` XML file. No matter which way was chosen the final `xcworkspace` should look as follow:

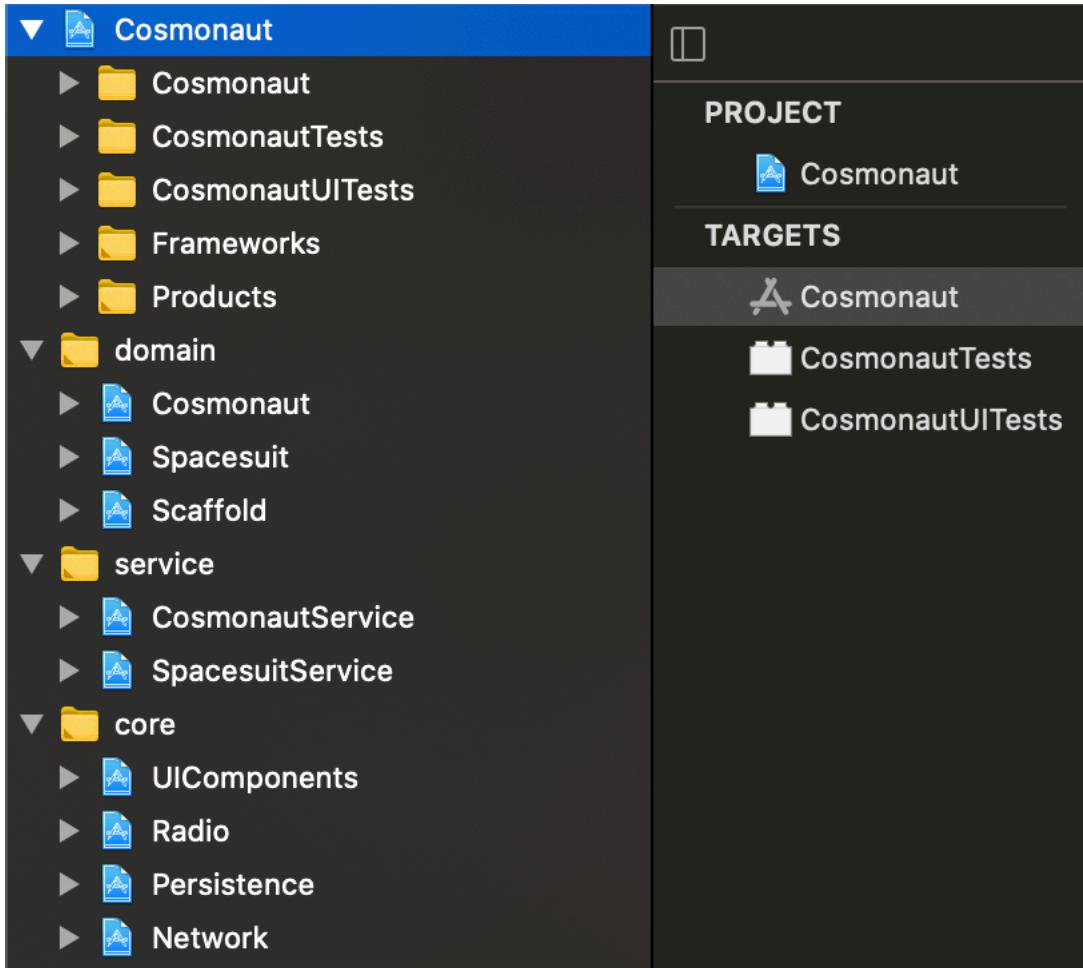


Figure 10 – Workspace strucutre

Generating projects

You might have noticed `project.yml` file that was created with every framework or app. This file is used by `XCodeGen` (will be introduced in a second) to generate the project based on the settings described in the yaml file. This will avoid conflicts in Apple's infamous `project.pbxproj` files that represent each project. In modular architecture, this is particularly useful as we are working with many projects across the workspace.

Conflicts in the `project.pbxproj` files are very common when more than one developer is working on

the same codebase. Besides the build settings for the project, this file contains and tracks files that are included for the compilation. It also tracks the targets to which these files belong. A typical conflict happens when one developer removes a file from the Xcode's structure while another developer was modifying it in a separate branch. This will resolve in a merge conflict in the `pbxproj` file which is very time consuming to fix as the file is using Apple's mystified language no one can understand.

Since programmers are lazy creatures, it very often also happens that a file removed from an Xcode project still remains in the repository as the file itself was not moved to the trash. That could lead to git continuing to track a now unused and undesired file. Furthermore, it could also lead to the file being re-added to the project by the developer who was modifying it.

Hello XcodeGen

Fortunately, in the Apple ecosystem, we can use `xcodegen`, a program that generates the `pbxproj` file for us based on the well-arranged yaml file. In order to use it, we have to first install it via `brew install xcodegen` or via other ways described on its homepage.

As an example, let us have a look at the Cosmonaut app `project.yml`.

`app/Cosmonaut/project.yml`

```
1 # Import of the main build_settings file
2 include:
3   - ../../fastlane/build_settings.yml
4
5 # Definition of the project
6 name: Cosmonaut
7 settings:
8   groups:
9     - BuildSettings
10
11 # Definition of the targets that exists within the project
12 targets:
13
14   # The main application
15   Cosmonaut:
16     type: application
17     platform: iOS
18     sources: Cosmonaut
19     dependencies:
20       # Domains
21       - framework: ISSCosmonaut.framework
22         implicit: true
23       - framework: ISSSpacesuit.framework
24         implicit: true
25       - framework: ISSScaffold.framework
26         implicit: true
27       # Services
28       - framework: ISSSpacesuitService.framework
```

```

29      implicit: true
30  - framework: ISSCosmonautService.framework
31      implicit: true
32  # Core
33  - framework: ISSNetwork.framework
34      implicit: true
35  - framework: ISSRadio.framework
36      implicit: true
37  - framework: ISSPersistence.framework
38      implicit: true
39  - framework: ISSUIComponents.framework
40      implicit: true
41
42 # Tests for the main application
43 CosmonautTests:
44   type: bundle.unit-test
45   platform: iOS
46   sources: CosmonautTests
47   dependencies:
48     - target: Cosmonaut
49   settings:
50     TEST_HOST: $(BUILT_PRODUCTS_DIR)/Cosmonaut.app/Cosmonaut
51
52 # UITests for the main application
53 CosmonautUITests:
54   type: bundle.ui-testing
55   platform: iOS
56   sources: CosmonautUITests
57   dependencies:
58     - target: Cosmonaut

```

Even though the YAML file speaks for itself, let me explain some of it.

First of all, let us look at the `include` in the very beginning.

```

1 # Import of the main build_settings file
2 include:
3   - ../../fastlane/build_settings.yml

```

Before xcodegen starts generating the pbxproj project it processes and includes other YAML files if the `include` keyword is found. In case of the application framework, this is extremely helpful as the build settings for each project can be described just by one YAML file.

Imagine a scenario where the iOS deployment version must be bumped up for the app. Since the app links also many frameworks which are being compiled before the app, their deployment target also needs to be bumped up. Without XcodeGen, each project would have to be modified to have the new deployment target. Even worse, when trying some build settings out instead of modifying it on each project a simple change in one file that is included in the others will do the trick.

A simplified build settings YAML file could look like this:

`fastlane/build_settings.yml`

```

1 options:
2   bundleIdPrefix: com.iss
3   developmentLanguage: en
4 settingGroups:
5   BuildSettings:
6     base:
7       # Architectures
8       SDKROOT: iphoneos
9       # Build Options
10      ALWAYS_EMBED_SWIFT_STANDARD_LIBRARIES: $(inherited)
11      DEBUG_INFORMATION_FORMAT: dwarf-with-dsym
12      ENABLE_BITCODE: false
13     # Deployment
14     IPHONEOS_DEPLOYMENT_TARGET: 13.0
15     TARGETED_DEVICE_FAMILY: 1
16 ...

```

Worth mentioning is that in the `BuildSettings` the key in the YAML matches with Xcode build settings which can be seen in the inspector side panel. As you can see the `BuildSettings` key is then referred inside the `project.yml` file under the settings right after the project name.

```

1 name: Cosmonaut
2 settings:
3   groups:
4     - BuildSettings

```

The following key is `targets`. In the case of the Cosmonaut application, we are setting three targets. One for the app itself, one for unit tests and finally one for UI tests. Each key sets the name of the target and then describes it with `type`, `platform`, `dependencies` and other parameters XcodeGen supports.

Next, let us have a look at the dependencies:

```

1 dependencies:
2   # Domains
3   - framework: ISSCosmonaut.framework
4     implicit: true
5   - framework: ISSSpacesuit.framework
6     implicit: true
7   - framework: ISSScaffold.framework
8     implicit: true
9 ...

```

The dependencies section links the specified frameworks toward the app. On the snippet above, you can see which dependencies the app is using. The `implicit` keyword with the framework means that the framework is not pre-compiled and requires compilation to be found. That being said, the framework needs to be part of the workspace in order for the build system to work. Another parameter that can be stated there is `embeded: {true|false}`. This parameter sets whether the framework will be embedded with the app and copied into the target. By default XcodeGen has `embeded: true` for applications as they have to copy the compiled framework to the target in order for the app to launch successfully and `embeded:`

false for frameworks. Since the framework is not a standalone executable and must be part of some application it is expected that the application copies it.

Full documentation of XcodeGen can be found on its GitHub [page](#):

Finally, let's generate the projects and build the app with all its frameworks. For that, a simple lane in Fastlane was created.

```
1 lane :generate do
2   # Finding all projects within directories
3   Dir["../**/project.yml"].each do |project_path|
4     # Skipping the template files
5     next if project_path.include? "fastlane"
6
7     UI.success "Generating project: #{project_path}"
8     `xcodgen -s #{project_path}`
9   end
10 end
```

Simply executing the `fastlane generate` command in the root directory of the application framework generates all projects and we can open the workspace and press run. The output of the command should look as follows:

```
→ iss_modular_architecture git:(master) ✘ fastlane generate
[✓] 🚀
[19:07:54]: Get started using a Gemfile for fastlane https://docs.fastlane.tools/getting-started/ios/setup/#use-a-gemfile
[19:07:59]: Driving the lane 'generate' 🚀
[19:07:59]: Generating project: ./core/Radio/project.yml
[19:07:59]: Generating project: ./core/Network/project.yml
[19:07:59]: Generating project: ./core/UIComponents/project.yml
[19:07:59]: Generating project: ./core/Persistence/project.yml
[19:07:59]: Generating project: ./app/Cosmonaut/project.yml
[19:07:59]: Generating project: ./service/SpacesuitService/project.yml
[19:07:59]: Generating project: ./service/CosmonautService/project.yml
[19:08:00]: Generating project: ./domain/Cosmonaut/project.yml
[19:08:00]: Generating project: ./domain/Spacesuit/project.yml
[19:08:00]: Generating project: ./domain/Scaffold/project.yml
[19:08:00]: fastlane.tools finished successfully 🎉
```

Figure 11 – fastlane generate output

Ground Rules

Looking at the ISS architecture, two very important patterns are being followed.

First of all, any framework does NOT allow linking modules on the same layer. Doing so is meant to prevent creating cross-linking cycles in between frameworks. For example, if the Network module would link Radio module and the Radio module would link Network module we would be in serious trouble. Surprisingly, Xcode does not fail to build every time in such a setup. However, it will have a really hard time with compiling and linking, up until one day it starts failing.

Second of all, each layer can link frameworks only from its sublayer. This ensures the vertical linking pattern. That being said, the cross-linking dependencies will also not happen on the vertical level.

Let us have a look at some examples of cross-linking dependencies.

Cross-linking dependencies

Let us say that the build system will jump on compiling the Network module where the Radio is being linked to. When it comes to the point where the Radio needs to be linked it jumps to compile the Radio module without finishing the compilation of the Network. The Radio module now requires a Network module to continue compiling, however, the Network module has not finished compiling yet, therefore, no `swiftmodule` and other files were yet created. The compiler will continue compiling up until one file will be referencing some part (e.g a class in a file) of the other module and the other module will be referencing the caller.

That's where the compiler will stop.

Needless to say, each layer is defined to contain stand-alone modules that are just in need of some sub-dependencies. In theory this is all nice and makes sense. In practice, however, it can happen that one domain will require something from another domain (for example, the Cosmonaut domain will require something from the Spacesuit domain). It can be some domain-specific logic, views or even the whole flow of screens. In that case, there are some options for how to tackle the issue. Either, a new module on the service layer can be created and the necessary source code files that are shared across multiple domains being moved there. Another option is to shift those files from the domain layer to the service layer. A third option would be to use abstraction and achieve the same result not from the module level but from the code level. The ideal solution solely depends on the use case. There is yet another possibility, to separate the interfaces into a separate framework which will be introduced in the next section.

A simple example could be that some flow is represented by a protocol that has a `start` function on it. That could for example be a `coordinator` pattern that would be defined for the whole framework and all modules would be following it. That protocol must then be defined in one of the lower layers frameworks in this case since it is related to a flow of view controllers, the UIComponents could be a good place for it. Due to that, in the framework, we can rely on all domains understanding it. Thereafter, the Cosmonaut app could instantiate the coordinator from the Spacesuit domain and pass it down or assign it as a child coordinator to the Cosmonaut domain.

Vertical linking

As with horizontal layer linking, vertical linking is also very important and must be followed to avoid the aforementioned compiler issues. In practice, such a scenario can also happen very easily. Imagine, that your team designed a new framework on the Core layer that will provide some extended logging functionality and some data analytics. After a while, some team will want to use the logging functionality, for example in the Radio module, to provide more debugging details for developers for the Bluetooth module.

Unlike in the cross-linking dependencies scenario, in this case, the abstraction was defined on the core level already. Thereafter, there is no way of passing it in the code from the top down. In this case, the new layer needs to be created, let us say shared or common. The supporting layer will contain mostly some shared functionality for the Core layer as well as some protocols that would allow passing references from the top down.

Another solution would be to separate the core public protocols and models of the framework such that the framework can be exposed and linked towards more frameworks on the same layer. On the higher level, the instantiation would take place and the instances would be passed to the implementations on the lower layer as they both linked towards the newly created core framework of that module. This, however, has the downside of having an extra framework that needs to be linked and maintained. However, with this approach, the so-called [Clean Architecture](#) would be followed. More about that in the next section.

Needless to say, any higher-level layer framework can link any framework from any lower layer. So for example, the Cosmonaut app can link anything from the Core or the newly defined Shared layer.

Core Framework

For most cases, the architecture described until now would be sufficient. However, as teams and the Application Framework grow, there will be more and more use cases where the services will have to interact. There is always a possibility to connect the services on a higher level, in this case described they could be interacting either on a domain level or if more domains would be in need of it, even on the app level.

Let us look at the concrete example. We can take a [CosmonautService](#) abstracted by a public protocol [CosmonautServicing](#) and [SpacesuitService](#) abstracted by a public protocol [SpacesuitServicing](#) each implemented in the relevant framework. A valid architectural need could be that [CosmonautService](#) must somehow interact with the [SpacesuitService](#) meaning knowing the public interface of the [SpacesuitService](#) such that an instance conforming to the public protocol can be passed in. The easiest way would be to interconnect those services via callbacks on a domain level or the app level, where an output of [CosmonautService](#) would be observed and trigger the needed functionality of the [SpacesuitService](#). Having one case like that is probably fine, however, as such interaction grows the code will get ugly, luckily there is a way to improve our existing architecture by introducing something we can call a [Core](#) framework.

Using Core Framework

Core framework is essentially another Framework target within the [SpacesuitService](#) Xcode project of the main framework. In our example of [SpacesuitService](#), a core framework would be [SpacesuitServiceCore](#). The [SpacesuitServiceCore](#) framework would however have to follow yet another set of rules to avoid any kind of cross compile issues.

In XcodeGen the Core framework could be defined as follows;

```

1 ...
2 # The service framework containing implementations
3 ISSSpacesuitService:
4   type: framework
5   platform: iOS
6   sources: SpacesuitService
7   dependencies:
8     # Linking and implements the `ISSSpacesuitServiceCore` protocols
9     - framework: ISSSpacesuitServiceCore.framework
10    implicit: true
11 ...
12
13 # Core Framework for ISSSpacesuitServiceCore
14 # defines interfaces and plain public types
15 ISSSpacesuitServiceCore:
16   type: framework
17   platform: iOS
18   sources: SpacesuitServiceCore
19   dependencies:
20     # Linking and uses only interfaces from the NetworkCore
21     - framework: ISSNetworkCore.framework
22     implicit: true
23 ...

```

Consequently, the `SpacesuitServiceCore` can be linked and used in the `CosmonautService` framework. Making all publicly available protocols and types available to the `CosmonautService`.

```

1 ...
2 # The service framework containing implementations
3 ISSCosmonautService:
4   type: framework
5   platform: iOS
6   sources: CosmonautService
7   dependencies:
8     # Linking the SpacesuitServiceCore in order to be able to use
9     # the public interfaces from it.
10    - framework: ISSSpacesuitServiceCore.framework
11    implicit: true
12 ...

```

In Xcode another target would just appear under the available targets and within the `Cosmonaut` project.

Core Framework Usage and Best Practices

Not surprisingly, when introducing e.g a new service framework, the best practice would be to start simple. For starters, having just the main framework with the protocols, types and implementations all mixed in. As the use cases of re-using some of the public parts of the service within another framework on the same layer emerge, the main framework could be split and the core parts could be moved out of the main framework to the core one.

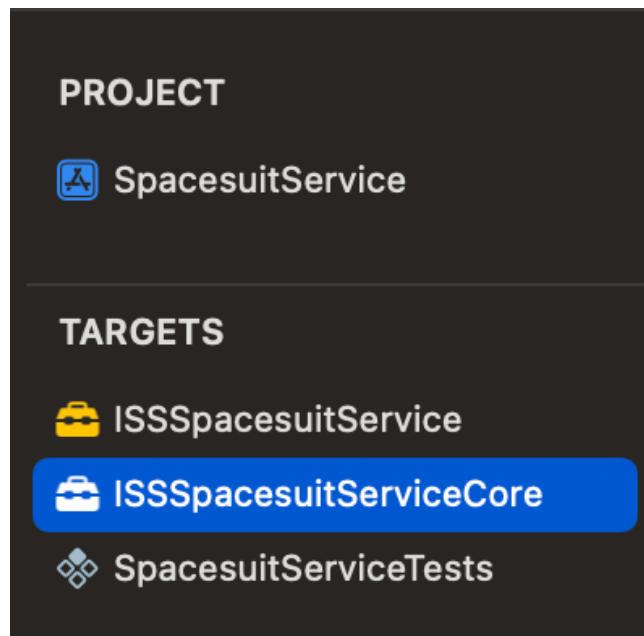


Figure 12 – SpacesuitService with Core

The core framework should contain only plain protocols, type definitions and basic data objects to really express only the “core”. Certainly, in the ideal world, the core framework would not have any concrete implementations, however, in practice sometimes it is inevitable to add some helper class or a small class there.

Core Framework linking and advantages

The most brilliant part about the Core framework is actually not only its reusability on the same layer while ensuring no cross compile issues but also the linking abstraction. As soon as the Core framework exists, it is no longer needed to link the main implementation heavy framework in services or domains. Instead, the Core is used as a dependency to higher layers. The framework that is linking the core framework will depend on the lightweight abstraction part of it. This further brings couple of wins.

Compile time decrease

A compile time could be heavily decreased. Let us have a look at why. Since now on the broader scope services and domains would depend on core frameworks representing protocols and basic types only, build system would not have to recompile or re-check to ensure the stability of dependent frameworks. If any implementation is changed within the main framework, the change affects only the main framework which ideally is linked only to the main app in order to instantiate the objects. Therefore, everything else within the Application Framework dependent on the core framework remains untouched. The build system instead of re-building the whole tree and checking recursively all dependencies would just have to re-compile the implementation. That already is a big win. However, no need to say that this applies to changes that are

not modifying the core. If for example a protocol would be updated in the core module then no compile time would be saved. Yet another reason to focus and design protocols well - this however applies and is absolutely crucial in a later stage of development.

Tests needed to run decrease

Similarly to compile time, the tests that need to run to ensure stability and health of the Application Framework would also decrease. In our scenario where `CosmonautService` uses the `SpacesuitServiceCore`, the `CosmonautService` no longer depends on the implementations, therefore, instead of in tests working with concrete classes stubs and mocks are implemented based on the protocols - which at this point we are sure that remained the same. `CosmonautServiceTests` on a change in main `SpacesuitService` framework won't need to run at all. Because there is no direct dependency between those two frameworks. The tests would have to run only if the `SpacesuitServiceCore` would change. The lesser linking of main frameworks within the Application Framework the faster the testing. Especially on big project this brings lots of wins, imagine a project with hundreds of frameworks each having hundreds or even thousands of tests, which need to run before merge. Optimising the amount of frameworks needed to be tested on each PR at this point is crucial.

Framework Control And Encapsulation

A less significant benefit is, the fact that clients of the linked framework can no longer instantiate objects on their own. There is no concrete implementation within the Core. The main framework would have to be linked in order to let the client instantiate the objects. This particular case can improve the code a lot. Due to the fact that each client depends on the abstraction only and for example only the app instantiates the concrete objects which are then passed down to lower layers or registered in a dependency injection pool, all by the abstracted protocols. This further is ensuring single instances of classes are used across the app lifecycle rather than random clients using and creating new instances as they like.

Core Framework disadvantages

As with everything in our industry, core frameworks also have some downsides. First and foremost it is yet another framework that must be properly linked within the Application Framework and taken care of. In our example project that might be very simple but on big projects the Application Framework can contain hundreds of frameworks and the core parts potentially at some points doubles the amount.

Further, worth mentioning point is the app start time, as not surprisingly core frameworks introducing new dynamic frameworks that must be linked and copied to the main app which will make the cold starts slower, as each dynamic framework must be loaded and opened on the app start which takes time, especially on older devices.

Mergeable Libraries

Mergeable libraries to the rescue, Apple introduced in WWDC2023 new compiler feature which can merge dynamic frameworks into one shared framework, drastically improving the start up time while leaving de-

velopers with the flexibility of dynamic linking. Unfortunately, as of now, almost one year after this feature was introduced the mergeable libraries are still having lots of issues. Certainly, those will be fixed with new Xcode updates and then the disadvantage of slower app start will be heavily improved. [Apple Documentation - Mergable Libraries](#)

Core Framework Rules

Generally, a core framework should not have many dependencies. However, it is possible to link lower layer frameworks, ideally abstracted by the core framework but also the concrete implementation if such pattern on lower framework was not applied. Furthermore, a core framework can potentially link another core framework on the same layer. Delving on our `CosmonautServiceCore` and `SpacesuitServiceCore`, each could link one and other. Given that there are no concrete implementations in it no issues should arise. However such case should be carefully evaluated to avoid tangling and yet again the compiler issues when cross linking.

Certainly, linking the framework downwards should not be allowed in our example, `CosmonautServiceCore` should never be linked to `NetworkService` or any of its parts as lower layer must be agnostic of the upper layer.

Testing

Since we already have a good working structure of our highly modular Application Framework let us have a look at how to test it in the most efficient and effective way. On small projects time spent on testing might not play very significant part as tests might be finished within a couple of minutes contrary on a big project and in our case tests could easily take hours to finish. Accordingly, the test strategy must be designed, developed, and supported locally and on the CI systems.

Unit Testing in Isolation

First and foremost, let us look at unit testing and the ability to run tests in isolation. Not surprisingly, each Xcode project created should also contain unit tests for the implementations of the main framework. Continuing on the example, the test bundle can be added just by extending the configuration in the `project.yml`.

```
1 ...
2 # The service framework containing implementations
3 ISSCosmonautService:
4   type: framework
5   platform: iOS
6   sources: CosmonautService
7   dependencies:
8     - framework: ISSNetworkCore.framework
9       implicit: true
```

```

10    ...
11 ...
12 CosmonautServiceTests:
13   type: bundle.unit-test
14   platform: iOS
15   sources: CosmonautServiceTests
16   dependencies:
17     - target: ISSCosmonautService
18 ...

```

Something definitely worth mentioning when developing in the Application Framework is the run in isolation. A developer no longer needs to compile the whole app consisting of lots frameworks but can set and build the desired framework just by setting it as a run/build target in Xcode. This allows beautiful tunnel focus isolation on a particular framework from the whole Application Framework. By doing so, the setup is the most optimal way to do test driven development, especially for a lower level UI free frameworks.

To ensure the stability and good health of a framework, tests should run on any change within the framework so as on any change of the dependent framework listed in dependencies. In our example, `CosmonautService` links `ISSNetwork`, therefore, if `ISSNetworkCore` has changes, everything that depends on the `ISSNetwork` must also be compiled and tested. To ensure that a change in a pull request does not break the integrity before the merge all relevant frameworks must be tested.

In the example, of a change in the `ISSNetworkCore` on the core layer, lots of frameworks would have to undergo the testing because of the framework is widely used across the application framework and provides essential functionality. On the other hand when a change in a domain like e.g `Cosmonaut` happen, there are no dependencies to a domain besides the app, therefore, only tests for the domain itself would have to run so as the main app or apps that are having this domain as a dependencies would have to be compiled or also run their unit tests.

Further, in development usually a mixture of those two scenarios combined together is very often seen. As if `ISSNetworkCore` extends its protocol the developer also must adjust the affected code in other modules.

Hint, as described already, an app in the Application Framework behaves like a container and usually does not have any logic implemented. Therefore, it can be that such app does not have many tests.

I hope those two different examples gave a good idea of how drastically the time can differ on the CI when testing a change. From lets say testing a one domain and an app to running tests of the whole application framework. Unfortunately, Apple does not provide any tools that would count with those scenarios, but thanks to XcodeGen and its yaml description such testing can be scripted before the project is generated.

Application Framework App

Up until now, the testing happened under one umbrella of an app in the Application Framework. However, Application Framework can have multiple applications consisting of the frameworks available. Those frame-

works does not necessarily have to be related. There might be frameworks solely dedicated to one app, but leveraging the foundational work of the application framework. Meaning, using the same core frameworks for e.g Networking, Persistence etc.

This scenario somehow forces us to introduce something we can call [Application Framework App](#), which is a dummy application living on the app level consisting of all frameworks available within the Application Framework. The app does not necessarily have to do anything. It is there just to provide a container, an encapsulation of the whole Application Framework. The app by default can have all frameworks in, including one or more XCTestPlans defining the testing strategy and all test targets.

Unit Testing in Application Framework App

Application Framework App is the perfect place for developers to ensure that their change, let's continue with the example, in [ISSNetworkCore](#) does compile within the whole Application Framework and not only within the singular app.

On the CI, however, this app could be scripted and created on the fly based on the identified changes compared to the targeted branch. The scripted app would consist only of the needed frameworks for compilation so as already adjusted the targets needed to test in the test plan. It would be a subset of the Application Framework agnostic of any other app.

UITesting in Isolation

Similarly to unit testing the UI tests can be developed and executed. Unlike unit tests, UI tests need an app to run in, as there is the actual UI. The first logical idea that comes to mind is to implement and maintain the UI tests on the app level. There the full application is created and can be deployed to a simulator or a device to run those tests. While this is surely the most intuitive way of introducing UI tests to the project it is not the ideal one. Imagine a scenario, where a domain, e.g [ISSUser](#) which provides the user's sign up / sign in functionality, profile details its flows etc. should be UI tested. Such a common business domain can be easily re-used across different apps. As those apps would grow, they would also aim for the UI testing strategy, and here we have the conflict. Either one app would give up on UI testing the user profile part of the app; if even possible. As login might be required to test some of the app's functionalities or the tests would be simply duplicated. In case of UI tests, the code duplication could be a significant which is something, we as good citizens of Application Framework should badly avoid doing.

Yet another stunningly beautiful part of this highly modular architecture comes in to play. Let us call it UI Tests in isolation. Instead of defining the UI Tests on the app level, they can directly be defined on the domain level. A domain e.g [ISSCosmonaut](#), can have its own so called by Apple [HostingApp](#). The hosting app would be created within the Xcode project of the Cosmonaut domain and be nicely encapsulated in the Xcode's project. All this can be easily defined in project.yml.

```

1 ...
2 ISSCosmonaut:
3   type: framework
4   platform: iOS
5   sources: Cosmonaut
6   dependencies:
7     # Service
8     - framework: ISSCosmonautService.framework
9     implicit: true
10    ...
11
12 # Tests for the main application
13 CosmonautTests:
14   type: bundle.unit-test
15   platform: iOS
16   sources: CosmonautTests
17   dependencies:
18     - target: ISSCosmonaut
19
20 CosmonautUITestsHostApp:
21   type: application
22   platform: iOS
23   sources: CosmonautUITestsHostApp
24   dependencies:
25     # The host app must have all the dependencies from the ISSCosmonaut
26     # Service
27     - framework: ISSCosmonautService.framework
28     implicit: true
29     ...
30
31 CosmonautUITests:
32   type: bundle.ui-testing
33   platform: iOS
34   sources:
35     - path: CosmonautUITests
36 ...

```

UITestsHostApp brings again another level of testing in isolation. Independently from the whole Application Framework, the app can be deployed and UI tested. An ideal scenario is when a domain is represented by a coordinator or many coordinators which take over the screen. The UITestsHostApp would simply mock the services those coordinators need to interact with and set up the app just as simply as instantiating the coordinators stack.

Within such architecture the UITestsHostApp could be up and ready in no time, leaving the adequate team to develop the UI Tests. Essentially, the UITestsHostApp would just copy the instantiating boilerplate from the main app to ensure the consistency.

This could be done for every domain that provides screen flows through the application, covering the Application Framework with as many tests as possible.

UITesting in Application Framework App

Similarly to unit tests the UI tests would also have their place in the grouped app. By default in this case it could be a UI test plan defined in the `xctestplan` consisting of all hosting apps and their UI tests from the whole Application Framework, leaving developers with singular place to run all those tests for all available targets in one go.

No need to mention that this UI `xctestplan` could be also scripted on the CI and only tests that are relevant to a change would be compiled and run on a Pull Request.

Sadly, UI tests are usually very expensive to run, it is not a surprise that sometimes those tests take hours before finishing, therefore, they could run on a nightly basis or another development workflow relevant time.

Mock Framework

As the tests grow there will be a pattern emerging, lots of frameworks will start implementing their own stubs and mocks from linked framework. As an example, a `CosmonautServiceTests` could instantiate the `CosmonautService` with stubbed `NetworkService`, in order to provide the data or return mocked responses. This mocked `NetworkService` however will get implemented pretty much in every tests of a framework that is linking and using the `NetworkService`. Therefore, over time those stubs and mocks will be by each test module that needs them, making very difficult to adjust the `NetworkService` protocol because on such change all conformed objects will have to be adapted. Making the developer go through all tests and adapt the mocks and stubs accordingly.

Luckily, yet again, there is a beautiful solution for such problem in our modular architecture. Let us call it a Mock framework. A Mock framework sits again within the same Xcode project as the main framework and just simply provide generic stubs and mocks which can then further be extended or adapted as needed for the tests.

There are many advantages of the Mock framework. First of all, it enforces a developer to make one great mock or a stub which is highly flexible and re-usable. Having a mock framework drastically reduces the need of creating such class in the test modules all over again. It also nicely separates the mock objects from the main production framework, pre-compiler macros would achieve the same but when mocking lots of classes, separating them completely to a different framework is even better.

Worth mentioning is that mock frameworks are specifically used for testing, and should not be linked and used in the production app - that would be an anti-pattern. In `project.yml` such mocked framework could be defined as follows:

```
1 ...
2 ISSNetworkMock:
3   type: framework
4   platform: iOS
```

```
5 sources: NetworkMocks
6 dependencies:
7   - framework: ISSNetworkCore.framework
8     implicit: true
9 ...
```

For the test from dependent frameworks bundles, only change would be to link the mocked framework in order to get access to mocks and stubs it provides.

Final Look at One Fully Fledged Xcode Project (module)

Finally, let us have a look at one fully fledged module which is featuring everything previously described. In our example `CosmonautService` seems like the ideal candidate that leverages everything described in here.

The `CosmonautService` has

- **CosmonautServiceTests** - Ensuring stability via unit testing
- **CosmonautServiceUITests** - Ensuring stability via UI testing in the `CosmonautServiceUITestsHostApp`
- **CosmonautServiceUITestsHostApp** - A special container app that allows the service to profile its features and run them in isolation from the whole Application Framework
- **CosmonautService** - The main framework for developing the `CosmonautService` module
- **CosmonautServiceCore** - The core framework for the main, ensuring that across others only the interfaces are used so as enabling the same layer re-usability

Conclusion

In this chapter we delved on the modularisation of the whole Application Framework, further slicing a framework and separating it into its Core, or adding the `UITestingHostApp` to it which further allows running the framework in complete isolation from the rest. I hope that the benefits of this approach are now well understood. Like everything, there is a pros and cons, this scalable architecture would be a big overhead for a team of two or three developers. However, when having many teams contributing to the codebase on a daily basis this would definitely be a huge benefit. I can tell from my experience where at Porsche we scaled from two teams to nowadays ~30 teams with this approach. The development of frameworks can and should start simply, when needed the architecture can be enhanced.

In the next chapter we are going to have a look at other possibilities of modularisation. Particularly, we are going to focus on the difference between static and dynamic linking, launch time of the app based on the number of modules, and compile time of each different approach from on a developer's change in the codebase to a full clean build and similar to an incremental build.

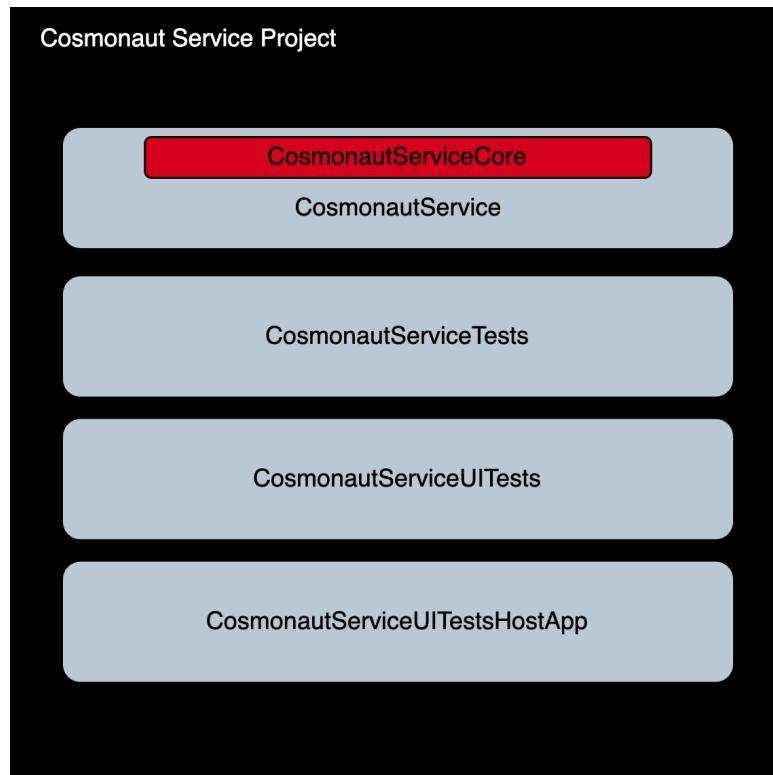


Figure 13 – Cosmonaut Service Fully Fledged Framework

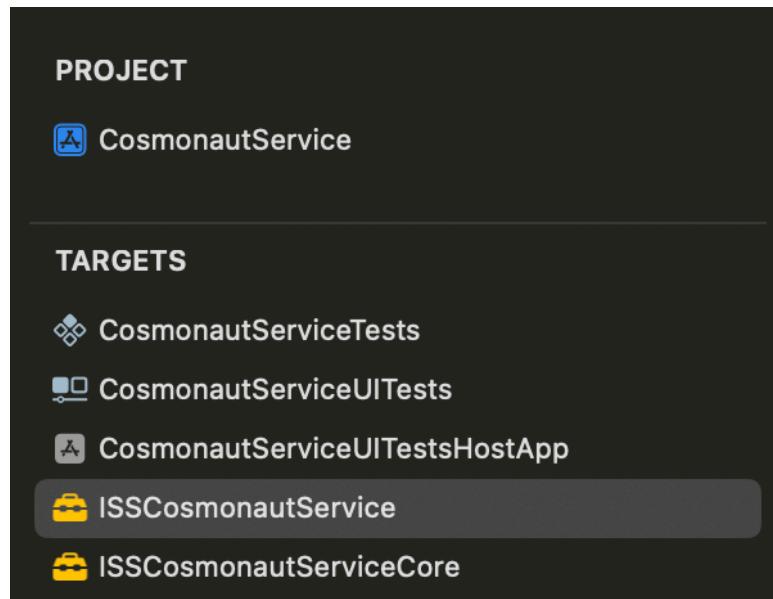


Figure 14 – Cosmonaut Service - Xcode project

Benchmarking of Modular Architecture

When choosing an architecture for an application or any type of application framework, there are several performance metrics and working structures to consider. The metrics we will focus on in the following section are application size, application compile time, memory usage and, most interestingly, application launch time. These metrics are compared for static and dynamic linking for different architectures.

The first architecture to be benchmarked is the four-layer modular architecture described in the previous chapters, but without the separation of frameworks into core and implementation. The second architecture is similar to the previous one, but with a combined domain and service layer, resulting in a three-layer architecture. The third and final architecture is similar to the approach of separating modules into their protocols and implementation frameworks, as described in previous chapters with core modules.

A monolithic application is used as a baseline for comparison. In this application, the code is not separated into different modules. All code is added directly to the main application project in Xcode. It therefore does not use any linking at all. In the following comparisons, it is often compared to the statically linked applications, as monoliths are closer to statically linked applications than dynamically linked ones. At launch time, monolith and statically linked applications behave similarly.

Test setup

In order to test the different architectures, it wasn't feasible to migrate a working application of significant size to the different architectures, as this would take a lot of time and effort. Instead, a code generator was written.

The generator can dynamically generate enums, protocols and corresponding implementations according to a template and replace the name of the file. These files also reference each other, so an implementation of protocol A will reference protocol B. As these files are generated, they are automatically structured by the generator according to the architectures being benchmarked against each other.

The content of the files tries to resemble real-world projects, using complex features such as `Combine` and generics. The generated swift files were then included into an iOS app project using `xcodegen` to generate the corresponding Xcode project files.

Using this method, several different applications were created: A monolithic application as a baseline; four applications using the described four-layer architecture; four applications using a three-layer architecture; and four applications using the separated core module architecture of the four-layer architecture.

For each of the architectures (excluding the monolithic application), four variants of the applications were generated: two statically linked and two dynamically linked applications. One of these two applications has 30 modules and the other has 300 modules.

With this strategy, it is possible to compare all architectures for each linking method and how the metrics change with increasing number of modules.

The total number of applications tested is 13 (4 different architectures x 2 different linking methods x 2 different number of modules + 1 monolith).

For the generation of the swift files, the following templates were used for enums:

```
1 public enum EnumName<T1, T2, T3, T4, T5> {
2     case case0
3     ...
4     case case6(
5         T1, T2, T3, T4, T5, T1, T2, T3, T4, T5, T1, T2, T3, T4, T5, T1, T2, T3,
6         T4, T5, T1, T2, T3, T4,
7         T5)
8     ...
9     case case12(URLSession, UIView, UIViewController, UINavigationController,
10        any View)
11
12     public var comment: String {
13         switch self {
14             case .case0:
15                 return "case0"
16             ...
17             case .case6(
18                 let t1 as URL, let t2 as CurrentValueSubject<Any, Never>,
19                 let t3 as CurrentValueSubject<Any, Never>, let t4, let t5, let t12,
20                 let t22, let t32, let t42,
21                 let t52, let t13,
22                 let t23, let t33, let t43, let t53, let t14, let t24, let t34, let t44
23                 , let t54, let t15,
24                 let t25, let t35, let t45, let t55):
25                 let just = Just(t1)
26                 let combined = t2.combineLatest(t3, just).sink { _ in
27                     print("Received values")
28                 }
29                 return
30                 "case6 combined: \(combined.hashValue) \(t1) \(t2) \(t3) \(t4) \(t5)
31                     \(t12) \(t22) \(t32) \(t42) \(t52) \(t13) \(t23) \(t33) \(t43)
32                     \(t53) \(t14) \(t24) \(t34) \(t44) \(t54) \(t15) \(t25) \(t35)
33                     \(t45) \(t55)"
34             ...
35             case .case12(
36                 let urlsession, let uiView, let vc, let nvc,
37                 let view):
38                 return
39                 "case 12 \(urlsession.description) \(uiView.isExclusiveTouch) \(vc.
40                     isViewLoaded) \(nvc.description) \(view)"
41             default:
42                 return "default"
43             }
44         }
45     }
```

for protocols:

```

1 public protocol ProtocolName {
2     var getProp1: String { get }
3     var getProp2: String { get }
4     var getProp3: String { get }
5     var getProp4: String { get }
6     var getProp5: String { get }
7     var getProp6: String { get }
8     var getProp7: String { get }
9     var getProp8: String { get }
10    var getProp9: String { get }
11    var getProp10: String { get }
12    var getProp11: String { get }
13    var getProp12: String { get }
14    var getProp13: String { get }
15    var getProp14: String { get }
16    var getProp15: String { get }
17
18    var combineProp: CurrentValueSubject<URL?, Never> { get set }
19
20    var getSetProp16: String? { get set }
21    var getSetProp17: String? { get set }
22    var getSetProp18: String? { get set }
23    var getSetProp19: String? { get set }
24    var getSetProp20: String? { get set }
25    var getSetProp21: String? { get set }
26    var getSetProp22: String? { get set }
27    var getSetProp23: String? { get set }
28    var getSetProp24: String? { get set }
29    var getSetProp25: String? { get set }
30    var getSetProp26: String? { get set }
31    var getSetProp27: String? { get set }
32    var getSetProp28: String? { get set }
33    var getSetProp29: String? { get set }
34    var getSetProp30: String? { get set }
35
36    func function31(prop1: String, prop2: Bool) -> String
37    func function32(prop1: String, prop2: Bool) -> String
38    func function33(prop1: String, prop2: Bool) -> String
39    func function34(prop1: String, prop2: Bool) -> String
40    func function35(prop1: String, prop2: Bool) -> String
41    func function36(prop1: String, prop2: Bool) -> String
42    func function37(prop1: String, prop2: Bool) -> String
43    func function38(prop1: String, prop2: Bool) -> String
44 }

```

and the corresponding protocol implementation:

```

1 public class ##name##: ##protocol## {
2     public var cancellables = Set<AnyCancellable>()
3
4     public var otherProtocolImpl: ##otherProto##?
5
6     public init(otherProtocolImpl: ##otherProto##?) {

```

```

7      self.otherProtocolImpl = otherProtocolImpl
8  }
9
10     public var getProp1: String {
11         "prop1"
12     }
13     ...
14
15     public var combineProp: CurrentValueSubject<URL?, Never> =
16         CurrentValueSubject(URL(string: "demo"))
17
18     public var getSetProp16: String?
19     ...
20
21     public func function31(prop1: String, prop2: Bool) -> String {
22         combineProp
23             .sink { url in
24                 print(url?.description ?? "default value")
25             }
26             .store(in: &cancelables)
27         combineProp.send(URL(string: "two"))
28         otherProtocolImpl?.combineProp.send(URL(string: "https://hello.from.
29             other.implementation.com/"))
30         return prop1 + "\\(prop2)" + (getSetProp16 ?? "") + (getSetProp17 ?? ""
31     }
32
33     public func function32(prop1: String, prop2: Bool) -> String {
34         combineProp
35             .sink { url in
36                 print(url?.description ?? "default value")
37             }
38             .store(in: &cancelables)
39         return prop1 + "\\(prop2)" + (getSetProp18 ?? "") + (getSetProp19 ?? ""
40     }
41 }
```

Each application contains 1000 generated enums, 1000 generated protocols and 1000 protocol implementations. The only variables are the linking methods, the architectures and the number of frameworks used.

For `mergeable libraries`, the dynamically linked app in the four-layer architecture was enabled. As similar results to the statically linked frameworks are expected, this application is only used as a comparison that mergeable libraries behave as expected thus can indeed achieve the start up time of a statically linked application. Let's find out!

Test results

The following sub-sections show the results of the applications described in terms of the four metrics mentioned: application size, memory usage, compile time and cold start time.

App size

App Size [MB]

Architecture	Dynamic		Static	
	300 modules	30 modules	300 modules	30 modules
Monolith	89,6			
4-layered modular	116,7	84,3	88,4	80,7
3-layered modular	110,3	83,8	90,8	81,0
Protocol-modular	100,6	83,1	80,3	80,2

The results of the application size measurements are shown in the table above. Dynamic and static linking are shown in the columns, while the four different architectures are shown in the rows.

The results of the statically linked application for the four-layer and protocol modular architectures show the expected results of having a similar size to the monolithic application, although slightly smaller.

The four-layer dynamically linked application is about 30% larger than the static monolithic application, showing the overhead of packaging the same code in 300 different dynamic frameworks.

The core-separated application has an application bundle size that is about 22% larger than either the monolithic application or the comparable statically linked application, showing that the overhead for 200 dynamic frameworks is less than for 300 frameworks. It can be concluded that 100 dynamic frameworks have an overhead of approximately 10MB.

Outliers from this data are both the dynamically and statically linked three-layer applications. They show a significant reduction in bundle size, application size and frameworks folder size respectively. Even after multiple retests, the results remained the same. A possible explanation could be a specific Swift compiler optimisation for this architecture, although this is unlikely. Confirming that all 200 dynamic frameworks were part of the application bundle also failed to explain the significantly smaller size. Since each of the dynamic frameworks is about the same size as the frameworks in the other applications, there is no explanation for this discrepancy.

They are all very similar in size to the monolithic application. In fact, the main executable for the dynamically compiled applications in the table is exactly the same size. The only measurable size difference was then seen in the size of the dynamic frameworks folder.

Memory usage

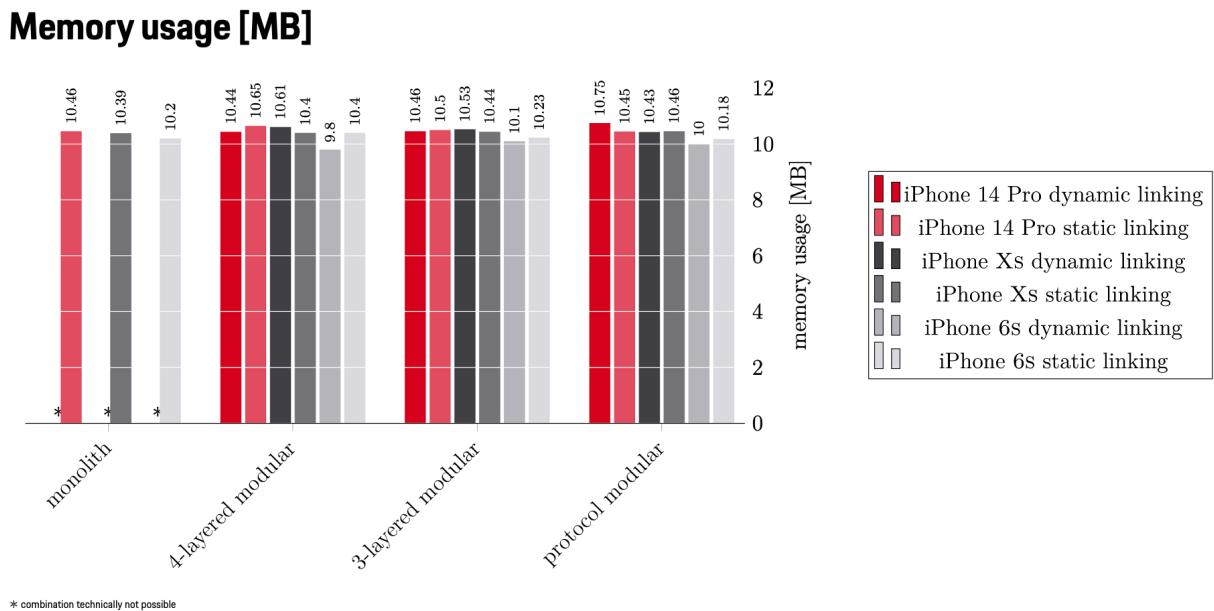


Figure 15 – Memory usage benchmarking results

The results of the memory usage measurements show the expected results as shown in the table above. All readings are in the range of (10.3 ± 0.5) MB, regardless of device age, architecture and linking method.

As all applications load the same view at startup, this result is expected. The small remaining difference can only be explained by run-to-run variations. As this measurement showed no deviation, it was not measured for the test cases with fewer dynamic frameworks. It would be expected that the memory usage would also be in the same range.

Compile time

The results of the compile-time measurements are shown in the graph below. The incremental build results are marked accordingly.

Compiling the monolith application took 115.8 s. Compiling the four-layer modular, three-layer modular and protocol modular static linked applications was about 5 to 20 s faster than the monolith application at 109.5 s, 105.3 s and 95.4 s respectively. This increase in speed could be due to an increase in parallel compilation of the different static frameworks. With a monolith application, Xcode may not be as optimised to compile the different source files in parallel.

Compiling the dynamically linked four-layer application took about 32% longer than the statically linked application. This increase may be due to the overhead of compiling the various dynamic frameworks and linking them to the main executable.

Compile time [s]

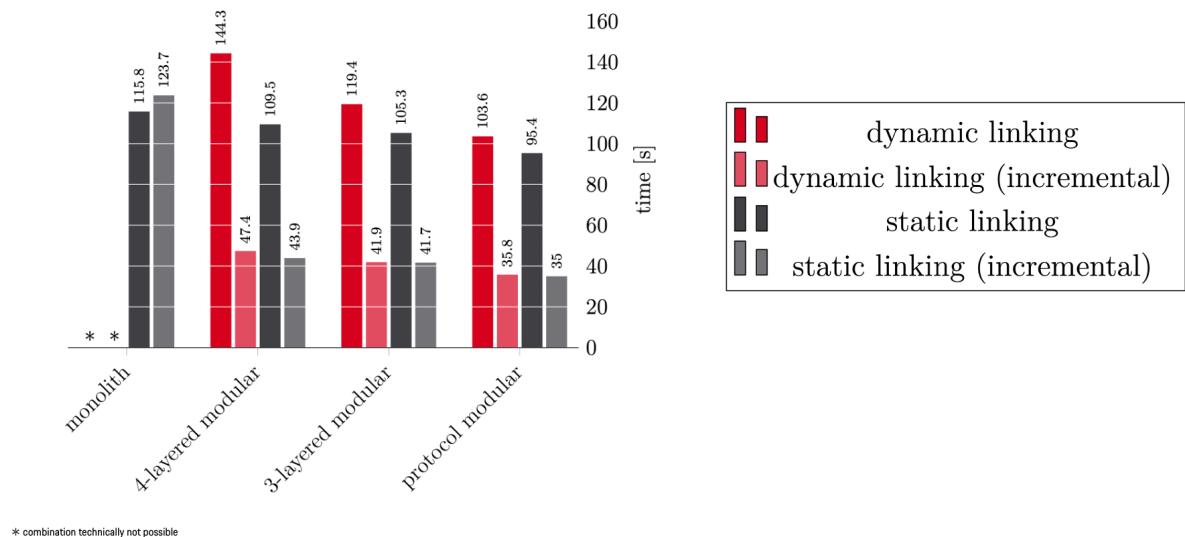


Figure 16 – Compile time benchmarking results

For the protocol modular and three-layer application, there is no noticeable difference in build time compared to the statically linked counterpart. In contrast, there is an increase for the four-layer application. Incremental builds for all modular application architectures are then faster than the clean build by a factor of 2-3. There is no such decrease for the monolithic application. This is probably because Xcode recompiles all files in the monolithic module, resulting in the same build time as a clean build (or even slightly longer, as seen in this example).

Compared to the compile times for the applications with fewer static and dynamic frameworks (by a factor of 10), as shown in the graph, the clean build time is drastically reduced. For example, for the four-layer application, the dynamically linked application now compiles in 47.4 seconds instead of 144.3 seconds.

The other two application architectures see a similar reduction in compile time, although not as drastic as the four-layer applications. The dynamically linked three-layer and protocol modular applications now compile faster than their statically linked counterparts. As this is not the case for the four-layer application, there seems to be a threshold somewhere between 20 and 30 frameworks (for the configurations tested in this benchmark) under which it is faster to compile dynamically. Above this threshold, static linking seems to be faster.

Launch time

The launch time of the application is highly dependent on the device used. For this reason, the tests were carried out on iPhones of different generations.

The phones tested were an iPhone 6s, an iPhone Xs and an iPhone 14 Pro. These phones were not brand

new at the time of the tests and had already been used extensively for app development. Even though these phones were in use, the results should still be valid, as all of the devices still showed high performance mode in their battery health settings.

The following three graphs show the cold start times of the tested applications on the different iPhones (6s, Xs and 14 Pro):

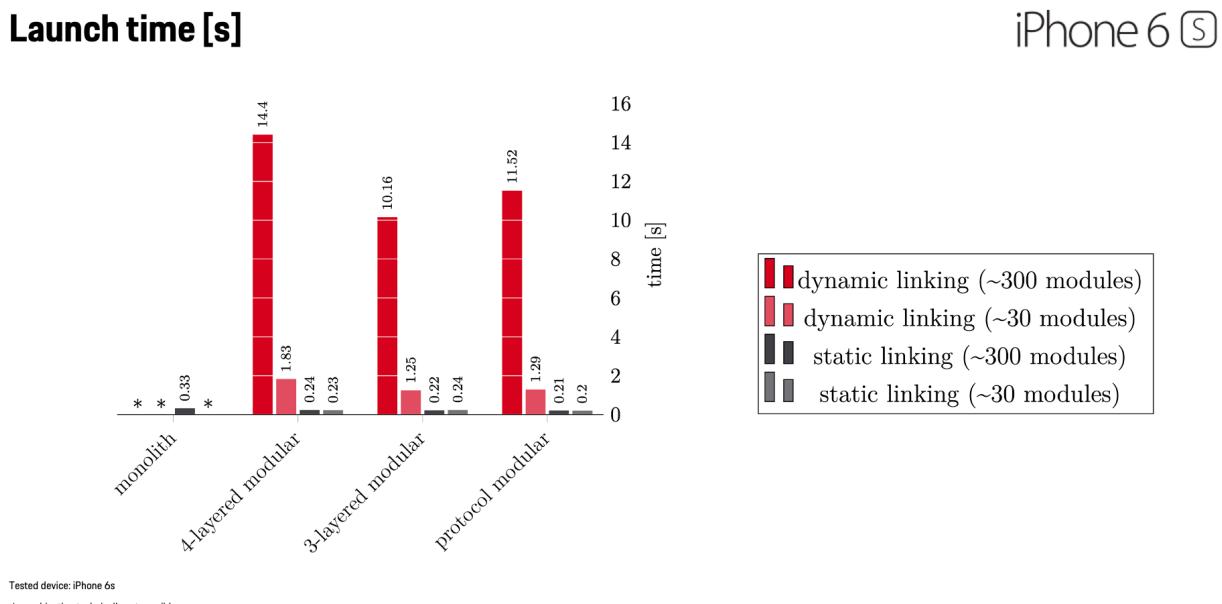


Figure 17 – Launch time usage benchmarking results

The difference in age and processing power between the iPhone 6s and the 14 Pro is clearly visible here. The older device launches the same application (four-layer modular with dynamic linking) about 10 times slower than the new device, while the iPhone Xs is about half as fast as the latest iPhone. While the iPhone 6s takes 14.4 s to launch the four-layer modular application with dynamic linking, the iPhone Xs takes 2.94 s and the iPhone 14 Pro takes 1.54 s. This reduction in launch time for the newer iPhone models is greater than the improvement in device specifications over the years.

The figures also clearly show that having more dynamic frameworks is the biggest contributor to application startup time. While the tested four-layer application has 300 frameworks, and the three-layer and core-separated application have around 200 frameworks, there is a clear increase in launch time from the three-layer to the four-layer application across all devices. This effect is also seen with fewer frameworks (by a factor of 10, resulting in 30 frameworks for the four-layer application and 20 frameworks for the 3-layer and core-separated), but with a smaller margin. The results with fewer dynamic frameworks are marked accordingly. However, the reduction in startup time with 10 times fewer dynamic frameworks does not translate into a 10 times reduction in startup time. For the iPhone 14 Pro, the reduction from 300 to 30 frameworks in the four-layer modular architecture results in a decrease of the start time by a factor of about 7.7.

With static linking, no dynamic frameworks need to be loaded at all. This results in a very fast application

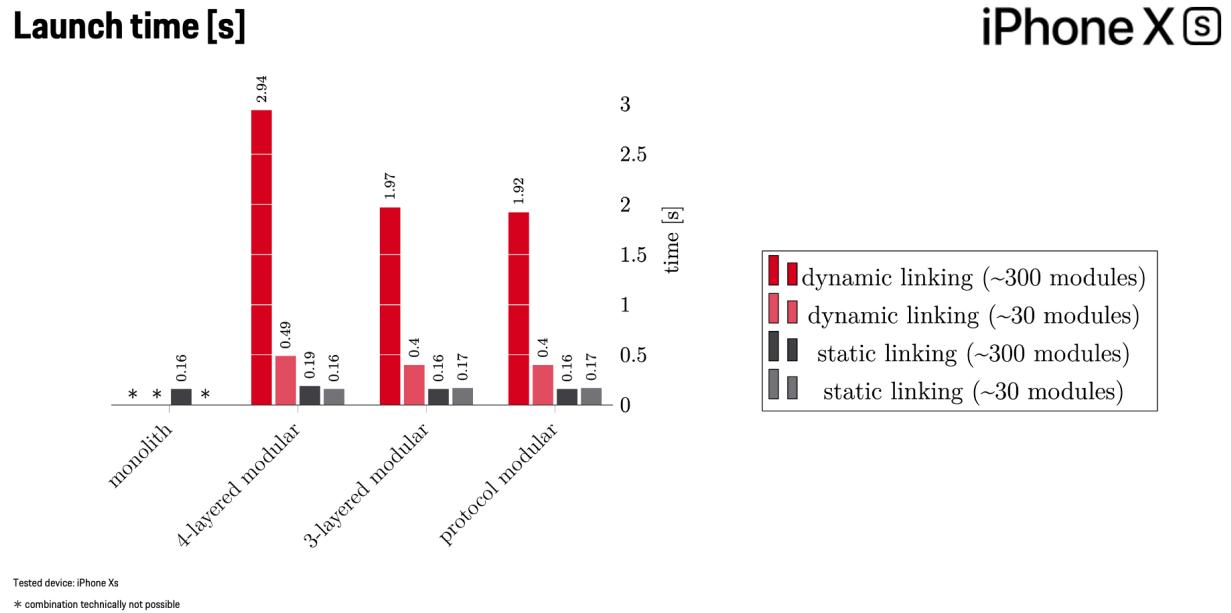


Figure 18 – Launch time usage benchmarking results

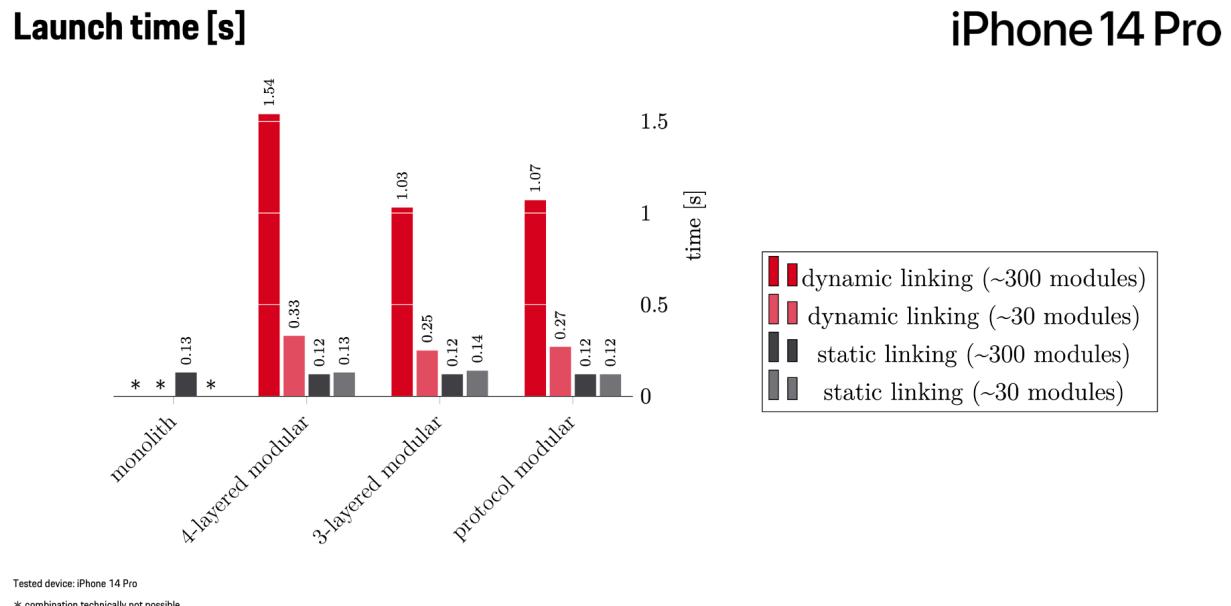


Figure 19 – Launch time usage benchmarking results

cold launch time for all three devices, comparable to the monolith launch time. While the iPhone 6s is still only about half as fast as the iPhone 14 Pro, a launch time of 0.13s, 0.16s and 0.33s respectively is still fast compared to the launch times with dynamic linking.

Mergeable libraries can significantly reduce the startup time of production-built applications. Any dynamic frameworks that are not needed in your app extensions are merged into the main executable as if they were statically linked. This means that the frameworks no longer need to be dynamically loaded on app startup.

Frameworks that are shared with your app extensions (for example, a widget) cannot be merged into the main app executable because the app extensions still depend on these dynamic frameworks. If they were also merged into the app extensions, the code inside the frameworks would be shipped twice to all users: once merged into the main executable and once merged into the app extension. The frameworks are only merged for release builds, meaning that debug builds still have all the benefits of dynamically linked libraries.

The generated app in the four-layer architecture was also tested for launch time: the same app that took 1.5 seconds to launch on the iPhone 14 Pro took only 0.15 seconds to launch with mergeable libraries enabled. The same application with static linking took 0.12 seconds to launch. This suggests that apps built with mergeable libraries take about the same time to launch as statically linked apps.

Conclusion

When building applications in the modular architecture described above, the benchmark results suggest a number of considerations.

1. If mergeable libraries are not enabled, adding a new framework to an application framework should be done with absolute care. Splitting the application into several smaller frameworks could result in longer startup times for users of that application.
2. If at all possible, mergeable libraries should be enabled. The result is essentially the launch time of a statically built app. For the sample app tested on the iPhone 14, it reduces the launch time by about 90%!
3. Separating the modules into their core and implementation parts may speed up your application's compile time. If no protocol or interface changes are made, the modules that only depend on the core part of the framework do not need to be recompiled. Only the main application, which depends on the concrete implementation module, needs to be recompiled, which has to be done anyway. Other advantage of this architecture, however, is that it allows linking at the same level.

SPM (maybe v3? or never)

// TODO: Building the same with SPM

Application Framework - Best Practices

At this point, we have a very well designed and benchmarked architecture, let us continue in this chapter with the best practices of contribution and collaboration on the modularised Application Framework.

App secrets

Project secrets could be API keys, SDK keys, encryption keys, as well as configuration files or certificates containing sensitive information that could cause potential harm to the app. Considering, many developers are working in the same repository on the same project, keeping project secrets stored securely such that they are exposed only to appropriate developers can be challenging. Essentially, any piece of sensitive information should not be exposed to anyone not working directly on the project. By any means, secrets should NOT be stored in the repository and should not be part of the compiled binary as plain strings.

The app ideally should decrypt encrypted secret during its runtime. Even though, on a jailbroken iPhone the potential attacker could gain runtime access and print out the secrets while debugging or bypass SSLPinning and sniff the secrets from the network. Considering, the SSLPinning was in a place like it should. In any case, it will take much more effort than just dumping binary strings that contain secrets.

If taking it a step further, in an ideal scenario all application's secrets should be used by the backend. The front end mobile client should be free of those secrets, however, for directly integrated SDK's like GoogleMaps or any vendor's SDKs the keys are sometimes necessary.

About two years ago me and my colleague Jörg Nestele had a look at the problem and over few weekends we came out with an open-source project written purely in Ruby called Mobile Secrets which solves this problem in a Swiftly way.

Now, let us have a look at how to handle secrets in the project.

How to handle secrets

First thing first, as mentioned above any secret must be obfuscated, without a doubt. String obfuscation is a technique that via XOR, AES or other encryption algorithms modifies the confidential string or a file such that it cannot be de-obfuscated without the initial encryption key.

Unfortunately, obfuscating strings or files and committing them to the repository might not be enough. What if there is a colleague who has access to the source repository or someone who might want to steal these secrets and hand them out? Simply downloading the repository and printing the de-obfuscated string into a console would do it.

Essentially, the secret should be visible only for the right developer in any circumstances. Especially, for mono-repository projects where many teams are contributing simultaneously. That is where GPG comes into play.

The GnuPG (GPG)

GPG is an asymmetric key management system that creates a hash for encryption from the public keys of all participants. In the initialisation process, GPG will generate a private and public key. The public key is saved in the `.gpg` folder under the user's email visible to everyone. The private key is saved in `~/.gnupg` and is protected by a password chosen by the user.

To instal GPG on the mac, following command can be used: `brew install gnupg` and `gem install dotgpg` to install `dotgpg`, Ruby program that simplifies the usage of GPG.

To add a developer into the authorised group, the developer needs to provide a public key from his machine, simply executing `dotgpg key` will print the key. This key must then be added by the already authorised person via `dotgpg add`.

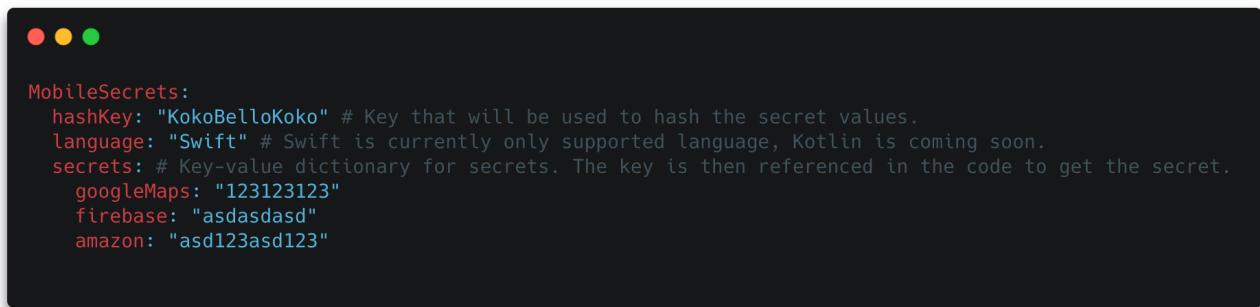
The file encrypted by GPG containing all project secrets can be then thoughtfully committed to the repository since only authorised developers who possess the private key can decrypt it.

GEM: Mobile Secrets

[Mobile Secrets](#) gem uses an XOR cipher alongside with GPG to handle the whole process. To install MobileSecrets simply execute `gem install mobile-secrets`.

Mobile Secrets itself can then initialise the GPG for the current project if it has not been done yet by running: `mobile-secrets --init-gpg ..`

When GPG is initialised, a template YAML file can be created by running: `mobile-secrets --create-template`.



```
MobileSecrets:
  hashKey: "KokoBelloKoko" # Key that will be used to hash the secret values.
  language: "Swift" # Swift is currently only supported language, Kotlin is coming soon.
  secrets: # Key-value dictionary for secrets. The key is then referenced in the code to get the secret.
    googleMaps: "123123123"
    firebase: "asdasdasd"
    amazon: "asd123asd123"
```

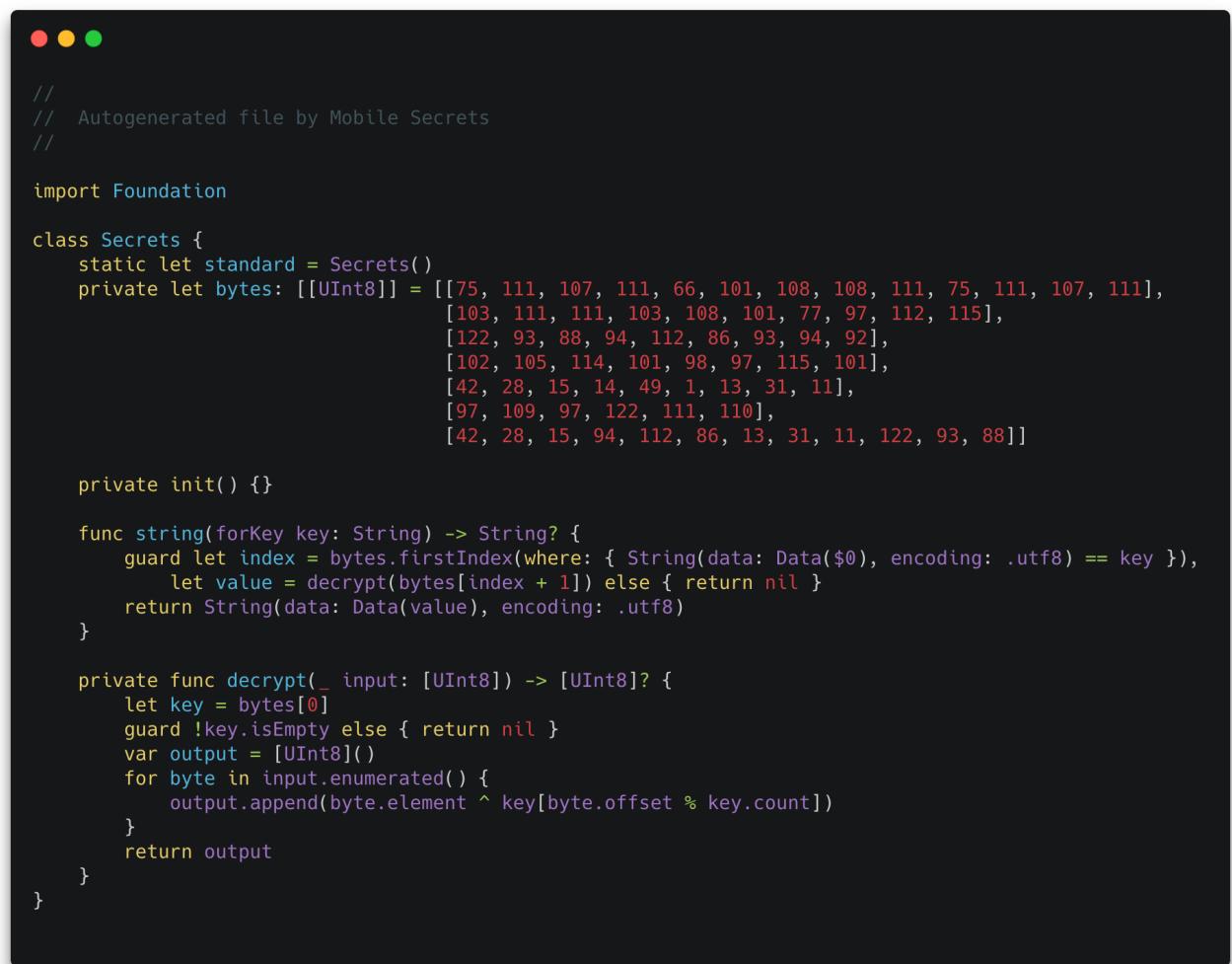
Figure 20 – MobileSecrets.yml

The `MobileSecrets.yml` file contains the hash key used for obfuscation of secrets with the key-value dictionary of secrets that must be adjusted to the project needs. All secrets of the project including the initial hashing key are then being organised in this structure encrypted by GPG. When everything was edited simply import the configuration file by running the command.

mobile-secrets --import ./MobileSecrets.yml and it will be stored under secrets.gpg

Finally, we can run: mobile-secrets --export ./Output/Path/ to export the swift file with obfuscated secrets.

Mobile Secrets exported Swift source code will look like the example below. Last but not least, the path to this file must be added to the .gitignore. The secrets source code must be generated locally alongside with generating the projects.



```
//
// Autogenerated file by Mobile Secrets
//

import Foundation

class Secrets {
    static let standard = Secrets()
    private let bytes: [[UInt8]] = [[75, 111, 107, 111, 66, 101, 108, 108, 111, 75, 111, 107, 111],
        [103, 111, 111, 103, 108, 101, 77, 97, 112, 115],
        [122, 93, 88, 94, 112, 86, 93, 94, 92],
        [102, 105, 114, 101, 98, 97, 115, 101],
        [42, 28, 15, 14, 49, 1, 13, 31, 11],
        [97, 109, 97, 122, 111, 110],
        [42, 28, 15, 94, 112, 86, 13, 31, 11, 122, 93, 88]]

    private init() {}

    func string(forKey key: String) -> String? {
        guard let index = bytes.firstIndex(where: { String(data: Data($0), encoding: .utf8) == key }),  
              let value = decrypt(bytes[index + 1]) else { return nil }
        return String(data: Data(value), encoding: .utf8)
    }

    private func decrypt(_ input: [UInt8]) -> [UInt8]? {
        let key = bytes[0]
        guard !key.isEmpty else { return nil }
        var output = [UInt8]()
        for byte in input.enumerated() {
            output.append(byte.element ^ key[byte.offset % key.count])
        }
        return output
    }
}
```

Figure 21 – Exported Swift secrets source file

The ugly and brilliant part of the Secrets source code

What happened under the hood of the mobile-secrets? Out of the YAML configuration, secrets were obfuscated with the specified hash key via XOR and converted into bytes. Therefore, it ended up with an array of

UInt8 arrays.

The first item in the bytes array is the hash key. The second item is the key for a secret, the third item contains the obfuscated secret, the fourth is again the key and fifth is the value, and so forth.

To get the de-obfuscated key just call the `string(forKey key: String)` function. It will iterate over the bytes array, convert the bytes into a string and comparing it with the given key. If the key was found, the `decrypt` function will be called with a value on the next index.

Since we have the array of UInt8 arrays(`[[UInt8]]`) mixed with the hash key, keys and obfuscated secrets, it would take a significant effort to reverse-engineer the binary and get the algorithm. Even to get the bytes array of arrays would take a significant effort. Doing so also made it hard to get the secrets out of the binary. Yet, the secrets can still be obtained when the attacker gains control over the runtime of the app like mentioned before.

Workflow

While this book is mostly focused on the development aspects of modular architecture, some management essentials must also be mentioned. Not surprisingly, developing software for a large organisation can be a real challenge. Imagine a scenario where around ~100 developers per platform (iOS/Android/Backend) are working on the same project towards the same goal. Those developers are usually divided into multiple cross-functional teams that are working independently as toward each team's own goals.

A cross-functional team usually consists of a product owner or a product manager, designers, who are defining the UI/UX and behaviour on each platform, developers from each platform, and last but not least, the quality assurance. Obviously the particular combination is highly dependent upon the company and its structure as well as the agile methodologies the company is using.

For example, the team goal can be developing some specific business domain where the team then becomes the domain expert and is further responsible for developing, improving, and integrating that domain into the final customer-facing application.

It could also be that the team develops a standalone application on top of the framework. If the team followed the same patterns defined in the framework, usually by technical leads. The app can be then easily later on integrated as a part of some bigger application that for example groups those functionalities in one app. Or the other way around splits one big app into multiple smaller ones. Like for example, Facebook did with their Messenger app.

Teams

Teams and their management play a crucial role in the success of the project. The modular architecture by any means helps define boundaries of teams. From the developers POV, each developer is responsible

for developing the frameworks belonging to the team. In our Cosmonaut example, it could be the Cosmonaut domain alongside with Cosmonaut service. While Spacesuit domain and Spacesuit service would be developed by another team.

That does not necessarily mean that the team Cosmonaut, let us say, cannot develop or modify the source code in the domain or service of Spacesuit. It should however mean that changes team Cosmonaut makes to team Spacesuit's domain code should seek review and approval from the Spacesuit team.

Luckily, there is one simple solution supported by many CI/CD platforms for it: code owners. The code owner file simply defines who is the owner of which part of the codebase. This already briefly touched the topic of git which is covered in the following subchapter.

Git & Contribution

While there are many different approaches on how to contribute to the repository via git in our modular architecture, I find one particular the most helpful: The [GitHub flow](#). I am sure you have heard of it at some point or if you have not you could be using it without knowing.

Most likely, on projects developed by a single team, the whole workflow heavily depends on the team how they will decide to contribute to the repository. Nevertheless, in the case of a team of teams, contributing to a mono-repository with the GitHub flow, coupled with the four eyes principle, is the way to go.

The four eyes principle simply means that in order to merge a pull request, the pull request must first be reviewed by another set of eyes, another person. That being said, in the team, each platform must have at least two developers so that the team can develop autonomy and work independently.

When making changes in another team's code, a dedicated code owner from the team must approve the changes. Once approved, the team can stay ahead and maintain the overview of its part of the codebase and domain knowledge. Without defining the code owners early on in the project's lifetime, everyone would be working everywhere and it could all turn into chaos.

Looking at the framework structure, it is quite clear where each team has its boundaries. However, there is one part that is very difficult to maintain and takes the most effort. That part will be the core layer. While the core layer could be developed by the creators of the application framework in the very early stages, it is surely the part everybody is relying on. Therefore, great test coverage plays a crucial role when developing anything in the core layer. Later on, any change in any interface of an object will affect everybody who is using it. Since it is the lowest layer (since we are not counting the utils layer), it will be highly likely that it will be used by many frameworks in the higher layers.

After all the desired functionality has been implemented and known bugs have been fixed, the core layer will not need much of a focus. However, teams may still need to extend the functionality on that layer. This could result in those teams opening a PR with their needed functionality or with suggestions of improvements. In this case, the tech leads should be seen as being code owners of the code in question since they are the ones with the duty of maintaining the overall vision of the project.

Scalability

As mentioned already in the book, modular architecture is designed to be highly scalable. With the pre-defined scripts, the new team can simply create a new framework or app and start the implementation right away. Nevertheless, the onboarding of a new colleague or the whole team takes time which needs to be considered by the project management.

Most likely, scaling to a Nth team working on the framework will require quite an extensive onboarding session. Due to the amount of code, design patterns, CI/CD, code style and so on, it may take a lot of time for newcomers to get the speed. In such a case, platform technical leads bring new members up to speed via pair programming, code reviews, and further onboarding up until the newcomers are familiar with the development concept, patterns, and so on.

Application Framework & Distribution

Architecture-wise, the application framework can be used as the software foundation for a company. Different products can now be easily created with the pre-built foundation which encapsulates the entire company's knowledge in software development. Needless to say, from the engineering point of view, this is a big win for the whole company. With the application framework in hand, software engineers can provide much more accurate estimates and do so with more confidence and speed. Software engineers will be able to forecast development time and make note of the biggest risks and challenges of development.

Nevertheless, there are many more use cases where such an architecture would be helpful. Due to modularisation, standalone frameworks can be exported and used for development without affecting the current development workflow. This could be particularly helpful when, for example, a subsidiary would be developing another software product. With pre-built core components, most importantly the UI part facing the customers, new products in the subsidiary can be built much faster and without gaining access to the confidential parts held in service or domain layers. However, in such case the team responsible for developing the distributed components, or let us say the SDK, will become the support team for the consumers of the SDK. In that case, a new process and workflow must be established. The responsible team could be opened to submitting bug reports and distributing the new versions of the SDK bi-weekly, or whenever it is suitable.

Common Problems

While praising such architecture pretty much all the time, like everything, it comes with its disadvantages as well.

Maintenance

First things first, the maintenance of the application framework can be very inefficient and difficult. The application framework will not go far without technical leads who can align the company strategy for the

development of the framework and products. Thereafter, technical leads give the directions for the development technically backed up by system and solution architects. Since there can be many teams working and contributing to the repository some maintenance might be happening daily. The most affected part is probably the CI/CD chain. On the CI/CD things can break quickly, furthermore, maintenance of failing unit-tests, legacy code, supporting apps that are no longer in development etc is needed.

In case of the maintenance, a particular difficulty (challenge) could be maintaining apps or frameworks that are no longer in development. Let us say, an app consisting of domains and services was successfully delivered to the customers and there is no more development planned for it. This results in code that runs in production. Therefore, it is very important. Since it relies on the e.g service layer frameworks that are still in development the tests will start failing. Interfaces need to be updated and so on. In the end, this will require additional effort for one of the teams to just take care of it until a further decision is made for development.

Another approach would be to archive it, remove it from the actively developed codebase and when the time comes, put it back. Furthermore, update all interfaces and changes that happened in the framework and then happily continue the development.

Code style

Since many different developers are working together, collaborating on the same code base, following the same code style, principles and patterns can be a challenge. Everybody has different preferences and different experiences. Getting people on the same board can sometimes be quite difficult.

Nevertheless, following the ground rules and overall framework patterns is what matters the most. In this case, what helps is having the code itself and framework being well documented. Good documentation should be complemented by a proper onboarding process that ideally consists of pair programming, code reviews, and ad-hoc one on one sessions. Changes in the code style, importing new libraries, introducing new patterns and so on can be discussed in developers guild meetings where everybody can vote for what seems to be the best option. In guilds, everybody can make suggestions for improvements and vote for changes he or she likes.

Not fully autonomous teams

In theory, each team should have its own autonomy. Nevertheless, in practice it can be slightly more complicated. In some cases, teams might depend upon each other. If so, challenges of increased inter team collaboration and increased team communication may need to be addressed. Without adequately dealing with these circumstances, a worst case may be teams failing to meet their goals due to unfulfilled promises of the dependent team.

As more teams become increasingly dependent on one another, more meetings and alignments are needed. The increase in these syncs can, unfortunately, slows down the teams.

Conclusion

In this chapter, we had a look at how the development of modular architecture could look in practice. We explored ground rules, generated projects with XcodeGen, securely handled secrets, and addressed some common problems people working on such projects will be facing.

I hope it all provided a good understanding of how to work in such a setup.

Dependency Managers

Generally, a good practice when working on large codebases is not to import many 3rd party libraries, especially the huge ones, for example, RxSwift, Alamofire, Moja, etc. Those libraries are extraordinarily big and it is highly likely that some of their functionality will never be used. This will result in having dead code attached to the project. Needless to say, the binary size, compilation time, and, most importantly, the maintenance will increase heavily. With each API change of the library every part of the codebase will have to be adapted. Obviously, essential vendor SDKs, like GoogleMaps, Firebase, AmazonSDK and so on will still have to be linked to the project. However, using libraries to provide wrappers around the native iOS code should be avoided and instead libraries should be developed specifically to the project's needs.

In one of the projects I worked on, the compile time of the whole application was at about 20-25 minutes. The project had been in development for about 8 years and had approximately 80 3rd party dependencies linked via Cocoapods. This alone accounted for the largest percentage of build time. I do remember that I spent nearly three full months refactoring the huge codebase into the modular architecture described here. Before the transformation, the project was modularised with internally developed pods. While refactoring, I also removed some of the unused libraries. Furthermore, and most importantly, I removed Alamofire, RxSwift, RxCocoa, and other big libraries from being included via Cocoapods and linked them via Carthage instead. This change decreased the compile time drastically.

Cocoapods libraries are compiled every time the project is cleaned while Carthage is compiled only once. Carthage produces binaries that are then linked to a project. Cleaning a project was a pretty common thing to do, and Xcode has improved in that sense a lot, but with the first Swift versions it was nowhere near perfection and with a clean build most issues disappeared immediately. After the refactoring, the compile time after cleaning the project was decreased to 10 minutes. Most of this time was the compilation of the project source code and the few 3rd party libraries that remained linked via Cocoapods for convenience.

The way third party libraries are managed and linked to the project matters a lot, especially, when the project is big or is aiming to be big. Now let us have a look at the three most commonly used dependency managers when developing for iOS and how to use them in modular architecture. They are as follows: Cocoapods, Carthage, and Apple's new Swift Package Manager.

Cocoapods

The most used and well-known dependency manager on iOS are [Cocoapods](#). Cocoapods are great to start with, it is really easy to integrate a new library so as to remove it. Cocoapods manage everything for the developer under the hood, therefore, there is no further work required to start using the library. When Cocoapods are installed, with `pod install`, they are attached to the workspace as an Xcode project that contains all libraries that are specified in the Podfile. During the compilation of the project, dependencies are compiled as they are needed. This is good for small projects, or even big ones, but the libraries must be linked carefully as every library takes some time to compile and eventually requires maintenance, like

mentioned earlier.

Quite often Cocoapods are also used for in-house framework development which is very convenient. However, all the fun stops when the project grows and the internal dependencies are using many big libraries. Then the whole project depends on the in-house developed pods which are internally linking the 3rd party pods. This scenario can easily result in a very long compilation phase as there is no legit way of replacing the linked 3rd party frameworks via their compiled versions. It goes without saying then that Cocoapods also will not let you integrate a static library to more than one framework because of transitive dependencies. Therefore some dynamic library wrappers might need to be introduced to avoid it.

In such cases, it might be necessary to move away from internally developed Cocoapods and integrate a similar approach like described in this book which gives the project complete freedom. This could lead to days or even weeks of work, depending on how big and how well structured the project is. Nevertheless, moving away from such a design will improve the everyday compile time for each developer. Like mentioned before, for small projects it could really be the way to go but it has its limits.

Integration with the application framework

Surprisingly, integrating Cocoapods in the whole application framework might not be as easy as you might think. Cocoapods must keep the same versions of libraries across all frameworks and on each app developed upon those frameworks. This will require a little bit of Ruby programming. Essentially, the application framework must have one shared [Podfile](#) that will define pods for each framework. Thereafter, every app can easily reuse it. Furthermore, each app has its own [Podfile](#) that specifies which pods must be installed for which framework to avoid unnecessarily linking frameworks the app will not need.

Let us have a look now how the app's [Podfile](#) could look for the Cosmonaut example. [app/Cosmonaut /Podfile](#)

```
1 # Including the shared podfile
2 require_relative "../../fastlane/Podfile"
3
4 platform :ios, '13.0'
5 workspace 'CosmonautApp'
6
7 # Linking pods for desired frameworks from the shared Podfile
8 # Domain
9 spacesuit_sdk
10 cosmonaut_sdk
11 scaffold_sdk
12 # Service
13 spacesuitservice_sdk
14 cosmonautservice_sdk
15 # Core
16 network_sdk
17 radio_sdk
18 uicomponents_sdk
19 persistence_sdk
```

```

20
21
22 # Installing pods for the Application target
23 target 'CosmonautApp' do
24   use_frameworks!
25
26   pod $snapKit.name, $snapKit.version
27
28   # Linking all dynamic libraries required from any used framework towards
29   # the main app target
30   # as only app can copy frameworks to the target
31   add_linked_libs_from_sdks_to_app
32
33   # Dedicated tests for the application
34   target 'CosmonautAppTests' do
35     inherit! :search_paths
36   end
37
38   target 'CosmonautAppUITests' do
39     # Pods for testing
40   end
41 end

```

Firstly, the shared `Podfile` that defines pods for all frameworks is included. After setting the platform and workspace, the installation for all linked frameworks takes place. Last but not least, the well known app target is defined, potentially with some extra pods. Here, special attention goes to the `add_linked_libs_from_sdks_to_app` function which will be explained in a second.

To fully understand what is happening inside of the app's `Podfile` we have to have a look at the shared `Podfile.fastlane/Podfile.rb`

```

1 require 'cocoapods'
2 require 'set'
3
4 Lib = Struct.new(:name, :version, :is_static)
5 $linkedPods = Set.new
6
7 ### available libraries within the whole Application Framework
8 $snapKit = Lib.new("SnapKit", "5.0.0")
9 $siren = Lib.new("Siren", "5.8.1")
10 ...
11
12 ### Project paths with required libraries
13 # Domains
14 $scaffold_project_path = '../../../../../domain/Scaffold/Scaffold.xcodeproj'
15 $spacesuit_project_path = '../../../../../domain/Spacesuit/Spacesuit.xcodeproj'
16 ...
17
18 # Linked libraries
19 $network_libs = [$trustKit]
20 $cosmonaut_libs = [$snapKit]
21 ...

```

```

22
23  ### Domain
24  def spacesuit_sdk
25      target_name = 'ISSSpacesuit'
26      install target_name, $spacesuit_project_path, []
27  end
28
29  def cosmonaut_sdk
30      target_name = 'ISSCosmonaut'
31      test_target_name = 'CosmonautTests'
32      install target_name, $cosmonaut_project_path, $cosmonaut_libs
33
34      install_test_subdependencies $cosmonaut_project_path, target_name,
35          test_target_name, []
36  end
37  ...
38 # Helper wrapper around Cocoapods installation
39  def install target_name, project_path, linked_libs
40      target target_name do
41          use_frameworks!
42          project project_path
43
44          link linked_libs
45      end
46  end
47
48 # Helper method to install pods that
49 # track the overall linked pods in the linkedPods set
50  def link libs
51      libs.each do |lib|
52          pod lib.name, lib.version
53          $linkedPods << lib
54      end
55  end
56
57 # Helper method called from the app target to install
58 # dynamic libraries, as they must be copied to the target
59 # without that the app would be crashing on start
60  def add_linked_libs_from_sdks_to_app
61      $linkedPods.each do |lib|
62          next if lib.is_static
63          pod lib.name, lib.version
64      end
65  end
66
67 # Maps the list of dependencies from YAML files to the global variables
68 # defined on top of the File
69 # e.g ISSUIComponents.framework found in subdependencies will get mapped to
70 # the uicomponents_libs.
71 # From all dependencies found a Set of desired libraries is taken and
72 # installed
73  def install_test_subdependencies project_path, target_name, test_target_name

```

```
    , found_subdependencies  
71 ...  
72 end
```

Here we can see, at the top of the file, the struct `Lib` that represents a Cocoapod library. In the next lines, `Lib` is used to describe the libraries that can be used within the whole framework and apps. Furthermore, each framework is defined by a function, e.g. `spacesuit_sdk`, which is then called from the main app `Podfile` to install the libraries for those required frameworks. Finally, helper functions are defined to simplify the whole workflow.

Those two functions require some explanation. First, the `add_linked_libs_from_sdks_to_app` mentioned in the app's `Podfile` must be called from within the app's target to add all the dependencies of the linked frameworks. Without it, we would end up in the so-called dependency hell. The app would be crashing with e.g `TrustKit library not loaded... referenced from: ISSNetwork`, because the libraries were linked towards the frameworks, however, frameworks do not copy linked libraries into the target. Therefore, the App must do it for us. Frameworks then can find their libraries at the `@rpath` (Runpath Search Paths).

The second function is `install_test_subdependencies`. This is the same scenario as for the previous function but for the tests. In order to launch tests, tests have to link all dependencies of the linked frameworks towards the XCTests. Lucky enough, thanks to Xcodegen, we can iterate over all `project.yml` files and find the linked frameworks and within the shared `Podfile` then use the defined pods for those frameworks.

In the source code everything is well commented so it should be easy to understand.

Carthage

While Cocoapods is a true 3rd party dependency manager that does everything for the developer under the hood, `Carthage` leaves developers with free hands. Frameworks to be included via Carthage are listed in the `Cartfile`. Frameworks listed within this file will be fetched and either built locally or pre-compiled XCFramework will be downloaded. Executing Carthage's build command with `carthage update --platform iOS` will fetch all the dependencies and produces the compiled versions. Such a task can be time consuming, especially, when some of the 3rd party libraries included are some of the aforementioned big ones. Nevertheless, such a command is usually executed only once. Compiled libraries can then be stored in some cloud storage where each developer or CI will pull them into the pre-defined git ignored project's folder or possibly update them if it is necessary. That being said, a dependency maintenance and sharing strategy needs to be in place.

As mentioned above, Carthage only builds the libraries. Thus it is up to the developer to dictate how they are linked toward the frameworks and apps. Luckily, XcodeGen helps a lot when linking Carthage libraries. In the YAML file, it can be easily defined where the Carthage executables are stored as well as which ones we want to link. Linking a static framework can easily be performed by specifying the `linkType`.

```

1 # Definition of the targets that exists within the project
2 targets:
3
4     # The main application
5     Cosmonaut:
6         type: application
7         platform: iOS
8         sources: Cosmonaut
9         # Considering the Carthage is stored in the root folder of the project
10        carthageBuildPath: ../../Carthage/build
11        carthageExecutablePath: ../../Carthage
12        dependencies:
13            - carthage: Alamofire
14            - carthage: SnapKit
15            - carthage: MSAppCenter
16            linkType: static
17            # Domains
18            - framework: ISSCosmonaut.framework
19            implicit: true
20            - framework: ISSSpacesuit.framework
21            implicit: true
22            - framework: ISSScaffold.framework
23            implicit: true
24        ...

```

At build time, the compiled binaries are linked to the frameworks and apps. The expensive compile time is no longer required for each build. When the build is started, Xcode looks at the library search paths for compiled binaries to link. In comparison to compiling all 3rd party libraries from source code, linking takes only seconds.

By the end of the day, Carthage will require much more work in order to have it properly configured and maintained in the project. Updating one library will require recompiling the library and its dependencies, uploading it somewhere to the server where it can be accessible by all developers and, finally, downloading the latest Carthage builds by developers locally. Surely, each developer can also recompile the libraries locally but that can take away again a lot of time from each developer, depends on the amount of libraries used.

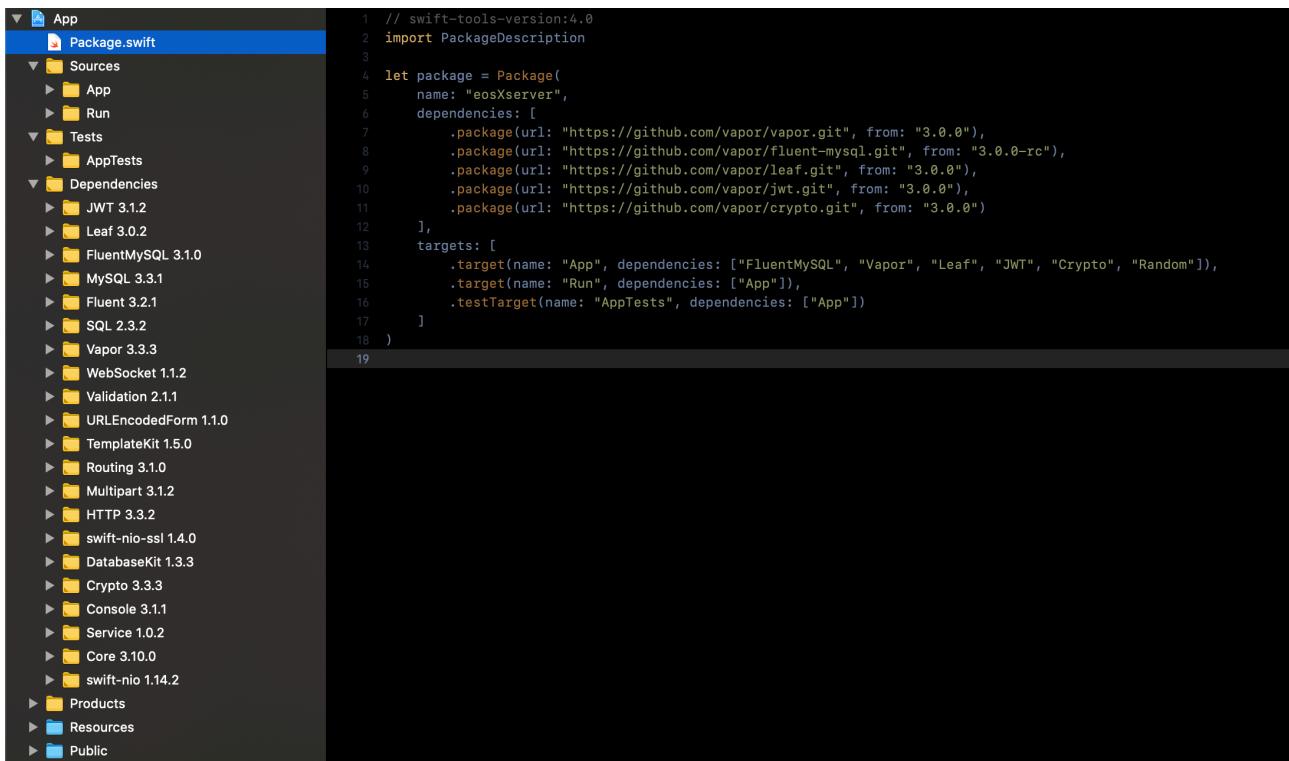
One last thing worth mentioning is ABI (Application Binary Interface) interoperability. Since with Carthage the binaries are being linked, the compiler must be interoperable with the compiler that produced the binaries. In the end that might be a big problem, as the whole team will have to update Xcode at the same time. Furthermore, the vendors of those libraries might need to update their source code to be compatible with the higher version of Swift. ABI is a very interesting topic in language development. I would highly encourage reading about it in the official Swift [repository](#).

SwiftPM

[Swift Package Manager](#) is the official dependency manager provided by Apple. It works on a similar basis

as Cocoapods. Each framework or app is described with its dependencies in a `Package.swift` file and compiled during the build. The benefit of using SwiftPM is that it can be used for script development or even cross-platform development. Cocoapods on the other hand is AppleOS dependent. Nevertheless, SwiftPM can be used for iOS/macOS development with ease. In comparison with Cocoapods, SwiftPM does not require extra actions in order to fetch the dependencies, Xcode simply takes care of it. SwiftPM also does not require using a Workspace for development as it directly adds the dependencies to the current Xcode project. In contrast, Cocoapods requires working with an Xcode Workspace as the Pods are attached as a standalone project that contains all the binaries.

One of the example projects using the SwiftPM for cross-platform development is the Swift server-side web framework, [Vapor](#). Vapor runs happily on both macOS and Linux instances. Nevertheless, developing Swift code for both platforms might not be as easy as you imagine. There are many differences in the Foundation developed for Apple OSes and Linux versions. Therefore, some alignments might be necessary in order to run the code on both systems and this may be the reason why some libraries cannot simply be used on both systems.



The screenshot shows the Xcode interface with a Vapor application project open. On the left is the Project Navigator, displaying the project structure:

- App** (selected)
- Package.swift**
- Sources** (expanded)
 - App
 - Run
- Tests** (expanded)
 - AppTests
- Dependencies** (expanded)
 - JWT 3.1.2
 - Leaf 3.0.2
 - FluentMySQL 3.1.0
 - MySQL 3.3.1
 - Fluent 3.2.1
 - SQL 2.3.2
 - Vapor 3.3.3
 - WebSocket 1.1.2
 - Validation 2.1.1
 - URLEncodedForm 1.1.0
 - TemplateKit 1.5.0
 - Routing 3.1.0
 - Multipart 3.1.2
 - HTTP 3.3.2
 - swift-nio-ssl 1.4.0
 - DatabaseKit 1.3.3
 - Crypto 3.3.3
 - Console 3.1.1
 - Service 1.0.2
 - Core 3.10.0
 - swift-nio 1.14.2
- Products**
- Resources**
- Public**

On the right is the Editor pane, showing the contents of the `Package.swift` file:

```

1 // swift-tools-version:4.0
2 import PackageDescription
3
4 let package = Package(
5   name: "eosXserver",
6   dependencies: [
7     .package(url: "https://github.com/vapor/vapor.git", from: "3.0.0"),
8     .package(url: "https://github.com/vapor/fluent-mysql.git", from: "3.0.0-rc"),
9     .package(url: "https://github.com/vapor/leaf.git", from: "3.0.0"),
10    .package(url: "https://github.com/vapor/jwt.git", from: "3.0.0"),
11    .package(url: "https://github.com/vapor/crypto.git", from: "3.0.0")
12  ],
13  targets: [
14    .target(name: "App", dependencies: ["FluentMySQL", "Vapor", "Leaf", "JWT", "Crypto", "Random"]),
15    .target(name: "Run", dependencies: ["App"]),
16    .testTarget(name: "AppTests", dependencies: ["App"])
17  ]
18 )
19

```

Figure 22 – SwiftPM with Vapor application

Conclusion

This chapter gave an introduction to the most common package managers that could be used for managing 3rd party frameworks with ease. Choosing the right one might, unfortunately, not be as obvious as we would

wish for. There are trade offs for each one of them. Choosing Cocoapods or SwiftPM at the start and then potentially replacing some of the big libraries with Carthage, to reduce compile times as needed, might be a good way to go. That being said, with the hybrid approach, the project benefits from both feature sets which could speed up everyday development dramatically.

Design Patterns

Design patterns help developers to solve complex problems in a known, organised, and structured way. Furthermore, when new developers are onboarded, they might already know the patterns used for solving such problem which helps them to gain speed and confidence for development in the new codebase.

The purpose of this book is not to focus on design patterns in detail as there are plenty of books about them already. However, some patterns that are particularly useful when developing such modular architecture are highlighted here.

Coordinator

First of all, let us have a look at the Coordinator pattern, one of the most well known navigation patterns of all times when it comes to iOS development. Coordinator, as its name says, takes care of coordinating the user's flow throughout the app. In our Application Framework, each domain framework can be represented by its coordinator as an entry point to that domain. The coordinator can then internally instantiate view controllers and their view models and coordinate the presentation flow. For the client, who is using it, all the necessary complexity is abstracted and held in one place. Coordinators usually need to be triggered to take charge with a `start` method. Such a method could also provide an option for a `link` or a `route` which is a deep link which the coordinator can decide to handle or not.

While there are many different implementations of such a pattern, for the sake of the example and our CosmonautApp I chose the simplest implementation.

First, let us have a look at some protocols: File: `core/UIComponents/UIComponents/Source/Coordinator.swift`

```
1 // DeepLink represents a linking within the coordinator
2 public protocol DeepLink {}
3
4 public protocol Coordinator: AnyObject {
5
6     var childCoordinators: [Coordinator] { get set }
7     var finish: ((DeepLink?) -> Void)? { get set }
8
9     func start()
10    func start(link: DeepLink) -> Bool
11 }
12
13 // Representation of a coordinator who is using navigationController
14 public protocol NavigationCoordinator: Coordinator {
15     var navigationController: UINavigationController { get set }
16 }
17
18 // Representation of a coordinator who is using tabBarController
19 public protocol TabBarController: Coordinator {
20     var tabBarController: UITabBarController { get set }
```

```

21     var tabViewController: TabBarController { get }
22 }
23
24 public protocol TabBarController: UIViewController {
25     var tabBarImage: UIImage { get }
26     var tabBarName: String { get }
27 }
```

To see how those protocols are used in action we can have a look at the CosmonautCoordinator. File: domain/Cosmonaut/Cosmonaut/Source/CosmonautCoordinator.swift

```

1  public class CosmonautCoordinator: NavigationCoordinator {
2      public enum CosmonautLink {
3          case info
4      }
5
6      public lazy var navigationController: UINavigationController =
7          UINavigationController()
8
9      public var childCoordinators: [Coordinator] = []
10
11     public init() {}
12
13     public func start() {
14         navigationController.setViewControllers([
15             makeCosmonautViewController(),
16         ], animated: false)
17     }
18
19     public func start(link: DeepLink) -> Bool {
20         guard let link = link as? CosmonautLink else { return false }
21
22         // TODO: handle route
23         return true
24     }
25
26     private func makeCosmonautViewController() -> UIViewController {
27         return ComsonautViewController()
28     }
}
```

After hooking up the coordinator into the App window, with for example the main `AppCoordinator` defined in the `Scaffold` module, simply calling `start()` or `start(link: CosmonautLink.info)` will take over the flow of the particular domain or user's flow.

Strategy

One of my favourite patterns is Strategy, even though I create it in a slightly different way than it was originally intended. Strategy pattern is particularly helpful when developing reusable components, like for example views. Such a view can be initialised with a certain `strategy` or a `type`. In traditional book examples,

strategy pattern is often described and defined via protocols and the ability to exchange the protocol with a different implementation that conforms to it. However, there is a much more Swift-like way to achieve the same goal with ease, [enum](#). Enum can simply represent a strategy for each case for the object and via enum functions, the necessary logic can be implemented. Surely, the enum can be abstracted by some protocol.

Configuration

Configuration is great for all the services and components that serve more than one purpose which will highly likely happen as we are developing many apps on top of the same reusable services. Configuration is a simple object that describes how an instance of the desired object should look or behave. That could be as simple as setting SSLPinning for a network service or setting a name to a CoreData context and so on.

As an example in the Application Framework, we can have a look at the [AppCoordinator](#) where the Configuration is defined in its extension. File: [domain/Scaffold/Scaffold/Source/AppCoordinator.swift](#)

```
1 extension AppCoordinator {
2     public struct Configuration {
3         public enum PresentatinStyle {
4             case tabBar, navigation
5         }
6
7         public var style: PresentatinStyle
8         public var menuCoordinator: Coordinator?
9
10        public init(style: PresentatinStyle, menuCoordinator: Coordinator?) {
11            self.style = style
12            self.menuCoordinator = menuCoordinator
13        }
14    }
15 }
```

AppCoordinator takes the configuration object and performs necessary actions based on its values to provide the desired behaviour.

File: [domain/Scaffold/Scaffold/Source/AppCoordinator.swift](#)

```
1 public class AppCoordinator: Coordinator {
2     ...
3     public init(window: UIWindow, configuration: Configuration) {
4         self.configuration = configuration
5         self.window = window
6     }
7     ...
8 }
```

Decoupling

It can surely happen that at some point a different implementation of some protocol must be used. However, that may prove to be much harder than you might think. Imagine a scenario where a `CosmonautService` (protocol) is used all over our `CosmonautApp`. Then imagine it was decided that this app will have two different flavours, one for US cosmonaut and one for Russian cosmonaut. The cosmonaut service logic can be huge, 3rd party libraries that are used might also differ and surely we do not want to include unused libraries with our US `CosmonautApp` or vice versa, that would be shipping a dead code! In that case, we have to decouple those two frameworks and provide a common interface to them in a separate framework.

In such a case we have to make one exception to our Application Framework linking law. For example, let us call it the `CosmonautServiceCore` framework that would be representing the public interfaces for the higher layers. It would contain protocols and necessary objects that need to be exposed out of the framework to the outer world. `USCosmonautService` and `RUCosmonautService` would then link the `CosmonautServiceCore` on the same hierarchy level and would provide the implementations of protocols defined there.

In such a case, since there is no cross-linking of those interfaces, frameworks, and their implementations, it is fine to link it that way. The higher level framework or, even better, the main App itself, in our example, `CosmonautApp` would then be based on the availability of the linked framework instantiated the objects represented in the `CosmonautServiceCore` from the framework that was linked to it. Which would be either `USCosmonautService` or `RUCosmonautService`.

This example is not part of the source code demo although such a scenario can happen. Nonetheless it is important to keep the solution for such a problem in mind.

MVVM + C

Probably no need for much explanation for Model, View, ViewModel with Coordinator pattern, however, there are many different approaches and implementations. First of all, sometimes it is not necessary to use MVVM as the plain old classic MVC can do the trick as well without the necessity of having an extra object. Second of all, the way in which objects are bound together matters.

Protocol Oriented Programming (POP)

The most beautiful way of extending any kind of functionality of an object is probably via protocols and their extensions. In some cases, like for structs or enums, it is also the only way. In Swift, structs and enums cannot use inheritance. On the other hand, protocols can use inheritance so as a composition for defining the desired behaviour which gives the developer the freedom to design fine granular components with all OOP features.

Conclusion

The purpose of this chapter was only to mention the most important patterns that helps when developing modular architecture. I would highly recommend deep diving more into this topic via books that are specially focused on such topic.

Project Automation

When it comes to a project where many developers are contributing simultaneously, automation will become a crucial part of its success. It might be hard in the very beginning to imagine what kind of tasks might be automated but it will become crystal clear during the development phase. It can be as simple as generating the `xcodeproj` projects with XcodeGen like in our example to avoid conflicts. Automation can also be used to pull new translation strings, generate entitlements on the fly, and can be used to build the app on the CI as well as publishing it to the AppStore or other distribution centre (CD).

Fastlane

First and foremost in the way of automation is iOS developers beloved [Fastlane](#). Fastlane is probably the biggest automation help when it comes to iOS development. It contains a countless amount of plugins that can be used to support project automation. With Fastlane, it is also easy to create your own plugins that will be project-specific only. Fastlane is developed in Ruby and its plugins are as well. However, since all is built with Ruby, Fastlane gives the freedom to import any other ruby projects or classes developed in plain Ruby and directly call them from the Fastlane's recognisable function so-called `lane`.

As an example, we can have a look at the Fastfile's `make_new_project` lane introduced in the very beginning. In this case the so-called `ProjectFactory` class is implemented in `/fastlane/scripts/ProjectFactory/` and imported into the Fastfile. Then it is used as a normal Ruby program. It is NOT purposely developed as a Fastlane's action. The reason being that it is much easier to develop a pure Ruby program as the program unlike Fastlane's action does not require the whole Fastlane's ecosystem to be launched. Launching Fastlane takes a couple of seconds at its best. Perhaps obviously, Fastlane's action surely comes with its advantages as well, like Fastlane's action listings, direct execution and so on.

`/fastlane/Fastfile`

```
1 require_relative "scripts/ProjectFactory/project_factory"
2
3 lane :make_new_project do |options|
4   type = options[:type] # Project type can be either app or framework
5   project_name = options[:project_name]
6   destination_path = options[:destination_path]
7
8   UI.error "app_name and destination_path must be provided." unless
9     project_name && destination_path
10
11   factory = ProjectFactory.new project_name, destination_path
12
13   type == "app" ? factory.make_new_app : factory.make_new_framework
14 end
```

Creating a proper Fastlane's plugin out of the Ruby program could be easily done by following this [documentation](#).

Fastlane gives the ultimate home for the whole project automation which will prevent script duplications and help with organising and finding necessary actions. To check what is available already in the house of automation, Fastlane can be executed out of the command line and it will give you the option to choose from the publicly available [lanes](#) that are already implemented.

Furthermore, we will need a central place where we can execute those scripts to free the developers' resources. There are many different CI/CD providers that offers pretty much the same solution with very similar setups and problems.

Continuous Integration (CI)

To grow a codebase that scales fast, it is crucial to maintain and ensure its quality. In order to achieve that developers are writing the following tests and checks that are then executed by the CI pipeline before the merge can proceed;

- *Unit tests*, ensure that the logic of the code remained the same
- *UI tests*, ensure that the UI looks the same after the change
- *Integration tests*, ensure that the app as a whole has all the libraries, launches fine, does not crash on start or at some parts
- *Acceptance tests*, ensure that the business level remains the same, meaning, the app provides the business defined value and even though the app might have some minor issues the business value is maintained
- *Others*, there might be other kinds of tests implemented within the tests, like for example test that all languages have 100% translations strings, latest app documents are attached, an offline database is updated and so on

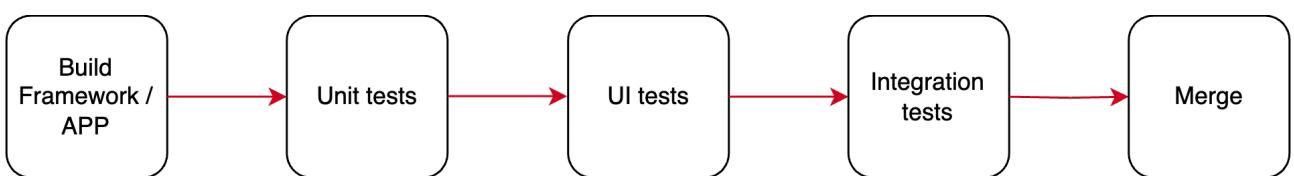


Figure 23 – CI Pipeline Success Example

If everything goes well and all tests are passing, the merge request can be approved and merged by the CI and CD takes it over. On the other hand, if something breaks, developers then need to provide fixes on their changes or adjustment to those tests to reflect their latest changes.

Continuous Delivery (CD)

As soon as the merge is done continuous delivery can start. In order to quickly detect if something goes wrong (fail fast) when, for example the pipeline has not detected a breaking change or due to any other reason, alpha builds are created. An Alpha build reflects the latest development state of the codebase. Ideally,

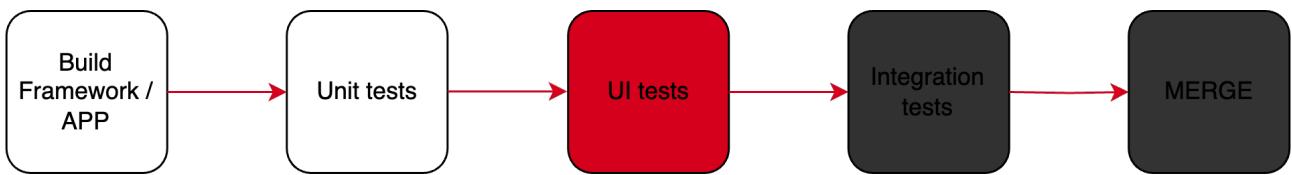


Figure 24 – CI Pipeline Failure Example

developers should work in a way where the development state of the codebase is always production-ready. They should do so in such a way that if some hot-fixes in production are needed the production build can be triggered from the development state immediately. This approach avoids any bug-fixing by cherry-picking and forces developers to commit high-quality atomic commits onto the codebase.

Based on the project, different build configurations can be produced. Build configurations could specify different environments, different identifiers, different secrets to service providers and so on.



Figure 25 – CD Pipeline Example

Ruby, programmer's best friend

If you have not learned it yet, do so, it's great.

Conclusion

CI/CD is a crucial part of every bigger project and unfortunately as of today maintaining pipelines is difficult. Especially in fast-paced projects. Many things can go wrong, 3rd party dependencies CDN might go down for some time, something works locally but not on the CI, different versioning of tools, failing tests, Xcode can cause lots of headaches and so on. Needless to mention the configuration of the CI/CD itself.

The purpose of this chapter was to introduce the concept on a higher level. To deep dive into CI/CD, the documentation of the provider is the best read.

Furthermore, to deep dive more into this topic, I would recommend this article and free ebook.

<https://blog.codemagic.io/the-complete-guide-to-ci-cd/> <https://codemagic.io/ci-cd-ebook/>

THE END

When everything goes well, containers will get shipped on the boat to the end customers and life of all is great. However, if it gets stuck at Suez same as the Evergreen ferry, do not panic. It is just software and everything is fixable (unless you ran bad code on top of the production database with Schrödinger's backup policy. In that case may all the network bandwidth be with you). Sometimes it just takes time and lots of work but in the end, the ferry with its containers will depart and leave towards the customers.



Figure 26 – Libraries ready to be dispatched

If you have reached this page then I would like to thank you very much for reading this book and I hope it enlightened you at least at some parts of the development of modular architecture.

Do not hesitate at all to shoot me an [email](#) or connect on [LinkedIn](#) if you have any questions, suggestions or just want to drop a few lines.

Thanks!

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