macOS Networking

macOS 10.15 • Xcode 11

STUDENT GUIDE

ABOUTOBJECTS

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Course Information

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Classroom materials for a course that provides a rapid introduction to macOS network programming. Geared to developers interested in learning to use Network Extensions on the Macintosh platform.

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macOS Networking

STUDENT GUIDE

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Section 1: Security

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Kernel Extensions

- Kernel Extensions (kexts) deprecated in macOS Catalina.
- As of release10.15.4
  - Use of a kext notifies user that the software includes deprecated API.
  - Suggests that user contact developer for an alternative.
- Kexts run in kernel space so errors/malicious code can:
  - Compromise security
  - Crash the operating system

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Rootless Filesystem

- An earlier release of macOS added System Integrity Protection (SIP) and disabled write access to `/System`, `/bin`, `/usr/` and `/sbin`.
- In Catalina, entire OS is in a separate, read-only partition named **Macintosh HD**.
  - Only code signed by Apple can update.
  - Root directory (`/`) isn't writeable.

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Catalina Security Features

🔒 Access Control

- Catalina apps must get user permission to access user folders and volumes (e.g., **Documents**, **Desktop**, and **Downloads)**.
- Users enable access via **System Preferences | Security & Privacy | Privacy** tab.

 Gatekeeper

- Enforces app code signing and notarization.
- Apps quarantined by default until verified by Gatekeeper or explicitly enabled by user.

WWDC 2019 Video: Advances in macOS Security

https://developer.apple.com/videos/play/wwdc2019/701

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Code Signing

- Certifies that an app was created by a given developer.
- Requires a developer ID provided by an account on developer.apple.com.
- Done automatically during Xcode builds.
- Can optionally be performed via `codesign` command-line tool.

Example

To view entitlements for Coolness.app:

```
codesign –d ––entitlements :– Coolness.app
```

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App Sandbox

- An environment in which apps are executed that limits:
  - The visibility of the filesystem
  - An app's capabilities (i.e., access to system resources)
- Enables privilege separation, wherein an app delegates certain behaviors to one or more sandboxed processes that have additional privileges not available to the app itself.
  - XPC was added in 10.7 to make this easier to implement.
- Each sandboxed app is restricted to its own, unique container directory, in which it has full read-write access.
  - User can give an app permission to access specific files outside its sandbox on a case-by-case basis.
  - An app also has some access to specific world-readable locations, e.g. `tmp` directories, `bin` directories, etc.
  - If an app requests an app group entitlement, it can also access sandbox directories of other apps within its group.

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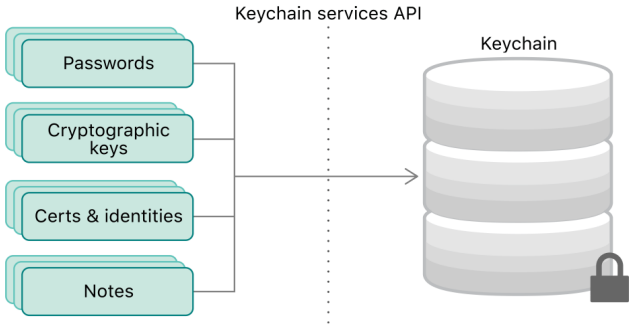
Keychain

- Managed by user through Keychain Access app.
- Managed by apps via Keychain Services C API.

Securing User Secrets



- On macOS, each item is bound to a collection of apps and operations (ACL) governing access.
    - System automatically checks ACLs whenever an app requests access to a protected item.
    - If not, the system automatically prompts the user for confirmation.
    - If user confirms, the system automatically adds the app to the list of trusted apps for that item.

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App Transport Security

- Enforces consistent use of TLS on network connections made by apps and app extensions that use the URL Loading System.
  - Automatically blocks connections that don't meet security requirements.
  - Exceptions can be requested in Info.plist.
  - Exceptions may trigger additional App Store review.
- Doesn't apply to calls made by apps using lower-level networking interfaces.

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Section 2: Concurrency

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Run Loops

- **NSRunLoop** objects manage input sources and timers.
- Example input sources:
  - Touch, motion, and keyboard events
  - **performSelector:onThread:...** messages
- A run loop must be present and running in order for the following to work:
  - **performSelector…** methods
  - **NSTimer** instances
  - Keeping a thread alive to perform work periodically
  - Using Mach ports or custom input sources to communicate with other threads

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Run Loop Modes

- Run loops can run in several different *modes*.
  - Modes allow events from a given set of input sources to be funneled to a specific observer.
- Predefined modes are as follows:

  Default: **NSDefaultRunLoopMode**

  Modal: **NSModalPanelRunLoopMode**

  Event Tracking: **NSEventTrackingRunLoopMode**

  Common Modes: **NSRunLoopCommonModes**
- You can also define custom run loop modes.

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Multithreading

- In iOS, every thread must have its own:
  - autorelease pool
  - run loop
- If you create your own threads, you're responsible for creating and managing these yourself.
- Pitfalls of hand-written threading code:
  - Hard to write and debug
  - Resource intensive
- Instead use **Grand Central Dispatch** or higher-level APIs that are layered on top of GCD (e.g. **NSOperation**).

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Grand Central Dispatch

- Block-based, C API
- Creates and manages:
  - highly-optimized thread pool
  - global concurrent queue
  - main (serial) queue
- GCD tasks can be
  - grouped
  - dispatched based on timer intervals
  - dispatched in a loop

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DispatchSource

- Coordinates the processing of file-system events, timers, and UNIX signals.
- Provides API for
    - Receiving messages from Mach ports
    - Monitoring Unix signals
    - Being notified of changes to memory pressure
    - Monitoring reads and writes using a file descriptor
    - Monitoring timer events

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DispatchIO / DispatchData

DispatchIO

- Manages operations on a file descriptor.
- May be either stream-based or random access.

DispatchData

- Manages a memory buffer.
- Capable of consolidating multiple, discontiguous blocks.

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NSOperation

- **NSOperation** is an abstract class used to encapsulate state and behavior for a given task.
  - Concrete subclasses are **NSInvocationOperation** and **NSBlockOperation**.
  - You can easily create your own custom subclasses if desired.
- Operations can be executed in either of two ways:
  - Directly (by sending them a **run** message)
  - By adding them to an **NSOperationQueue**.
- An operation can wrap one or more dependent operations.
  - Will not execute until all its dependent operations have completed.

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NSOperationQueue

- Operations start executing as soon as they're added to a queue.
  - Automatically removed from queue when finished.
  - Queue holds strong references to its operations.
- To add operations to a queue:

```
open func addOperation(_ op: Operation)

@available(OSX 10.6, *)
open func addOperations(_ ops: [Operation], waitUntilFinished wait: Bool)

@available(OSX 10.6, *)
open func addOperation(_ block: @escaping () -> Void)
```

- Supporting concurrent operations:

```
open var maxConcurrentOperationCount: Int
```

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Section 3: XPC Services

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Overview

- XPC Services is an API defined in `libSystem`.
- Lightweight mechanism for interprocess communication that runs in user space.
- Benefits
    - Increased stability (can make apps more crash-resistant)
    - Enhanced security via privilege separation
    - Distributed as part of app bundle, so no installer required.

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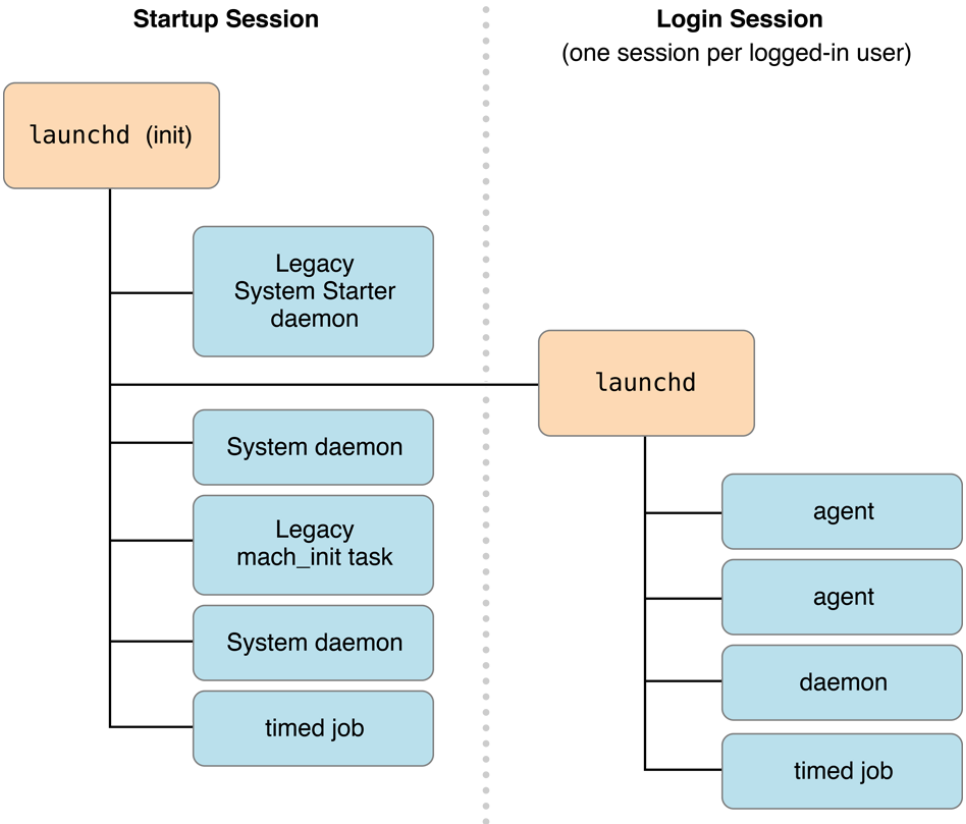
Working with launchd

- launchd can provide XPC services with the following:
  - Launch on demand
  - Restart on crash
  - Terminate when idle

launchd Session Contexts



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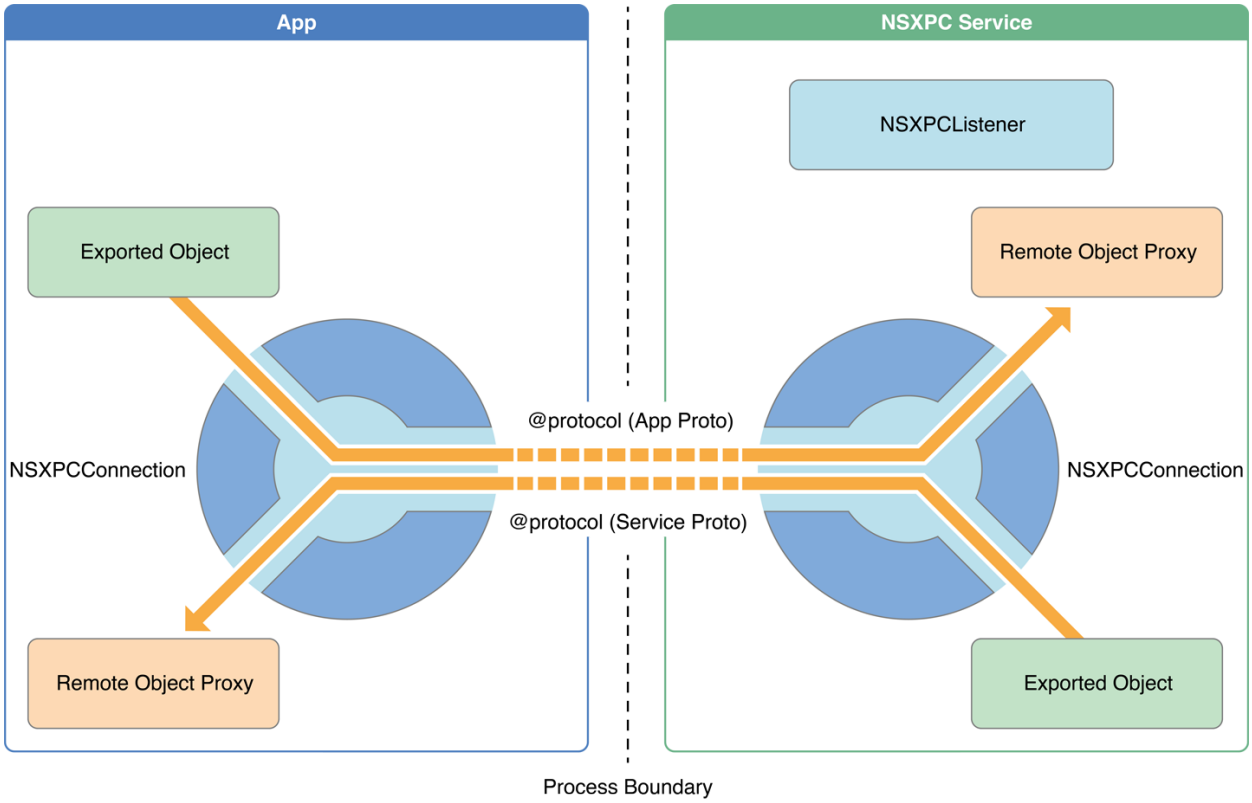
NSXPCConnection API

- An abstraction of a remote procedure call (RPC) interface.
- Allows objects in separate processes to call methods on one another.
    - Automatically serializes/deserializes objects and data structures as needed for data transmission.
    - Objects transported via an NSXPC connection must conform to `NSSecureCoding`.

NSXPC Architecture



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The NSSecureCoding Protocol

- Classes that adopt NSSecureCoding and override `initWithCoder(_:)` must override `supportsSecureCoding` and return `true`.

```
public protocol NSSecureCoding : NSCoding {
      static var supportsSecureCoding: Bool { get }
}
```

- The decoding methods in the NSSecureCoding API require passing the expected type as an additional parameter, for example:

```
public func decodeObject<DecodedObjectType>(of cls: DecodedObjectType.Type,
                                            forKey key: String) -> DecodedObjectType?
                                            where DecodedObjectType:
                                            NSObject, DecodedObjectType : NSCoding
```

- This prevents attacks that substitute a different class than the expected one

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Communicating Across XPC

- NSXPCConnection is primary means of creating and configuring the communication mechanism between two processes.
  - Your app creates an instance to connect to a service.
  - App then communicates through a remote object proxy.
- An XPC service implements the XPCListenerDelegate protocol to listen for a connection.
  - Publishes an API (protocol) for remote requests.
  - Configures an object that provides implementations of the defined API.

For More Information:
XPC · objc.io

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Section 4: System Extensions

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System Extensions

- Allow code running in user space to access system functionality that previously required writing kernel extensions.
- Distributed along with app as nested bundle.
- Deployed by the OS to a hidden system directory.
- Automatically started by the OS at boot time.

WWDC 2019 Video: System Extensions and DriverKit

https://developer.apple.com/videos/play/wwdc2019/702

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Frameworks

Set of frameworks includes:

- SystemExtensions
  - Installing and updating extensions
- DriverKit, USBDriverKit, NetworkingDriverKit, etc.
  - Fundamental device driver behaviors
- EndpointSecurity
  - C API for monitoring system events for malicious activity
- NetworkExtension
  - Customization of core networking features including DNS, WiFi, VPN, and content filtering

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Configuration

- Extension must match bundle identifier plus appropriate file extension
- Bundle ID typically reverse domain path.
  - Example: `com.aboutobjects.coolstuff`
- File extensions include `.systemextension`, `.dext`, etc.
  - Example extension ID:

```
com.aboutobjects.coolstuff.systemextension
```

- Use the same Team ID when signing the extension that was used to sign your app (unless the extension has the `com.apple.developer.system-extension.redistributable` entitlement).

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Section 5: Network Extensions

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Platform Modernization

- Apple announced deprecation of kernel extensions at WWDC 2019.
- Future OS releases won't load kernel extensions that use deprecated APIs without rework.
- Deprecated network filtering APIs include the following:

```
ipf_addv4
ipf_addv6
ipf_inject_input
ipf_inject_output
ipf_remove
sflt_attach
sflt_detach
sflt_register
sflt_unregister
sock_accept
sock_bind
sock_close
sock_connect
sock_getpeername
sock_getsockname
sock_getsockopt
sock_gettype
sock_inject_data_in
sock_inject_data_out
sock_ioctl
sock_isconnected
sock_isnonblocking
sock_listen
sock_receive
sock_receivembuf
sock_send
sock_sendmbuf
sock_setpriv
sock_setsockopt
sock_shutdown
sock_socket
sockopt_copyin
sockopt_copyout
sockopt_direction
sockopt_level
sockopt_name
sockopt_valsize
```

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NetworkExtension Framework

- Some features are iOS-only or require App Store distribution.
- Supports the following capabilities:
  - Changing the system's Wi-Fi configuration (iOS only)
  - Integration with hotspot network subsystem (iOS only)
  - Creating and managing VPN configurations using built-in or custom VPN protocols (Mac App Store only)
  - Implementing an app proxy (Mac App Store only)
  - Content filtering
  - Packet tunneling
  - Implementing a DNS proxy
- Require the System Extension entitlement.
- Key: `com.apple.developer.system-extension.install`

WWDC 2019 Video: Network Extensions for the Modern Mac

https://developer.apple.com/videos/play/wwdc2019/714/

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Content Filtering

Consists of two providers that collaborate with one another as follows:

- A filter data provider examines network content and decides whether it should be blocked or allowed.
    - Runs in highly restrictive sandbox.
    - Sandbox prevents user network content from escaping.
- A filter control provider provides needed configuration information to the filter data provider.
    - Has access to network, but not user network content.
- Requires Network Extensions entitlement.
- Key: `com.apple.developer.networking.networkextension`

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Section 6: The Network Framework

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Overview

- Provides direct access to protocols like TLS, TCP, and UDP.
- Underpins the URL Loading System (URLSession, etc.)

WWDC 2019 Videos: Advances in Networking, Parts 1 and 2

https://developer.apple.com/videos/play/wwdc2019/712

https://developer.apple.com/videos/play/wwdc2019/713

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Section 7: Web Services

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The URL Loading System

- Provides on-disk and in-memory cache on a per-application basis.
    - Individual URL requests can specify their desired cache policy.
    - Can also control caching policy by implementing a delegate callback.
- Supports authentication and credentials, including configurable credential persistence in memory while the app is running, or for greater durations via the user's keychain.
- Provides object-oriented access to cookies.
- Built-in support for **http**, **https**, **file**, and **ftp** protocols, as well as custom protocols.

Apple's *URL Loading System Programming Guide* is an excellent resource.

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URL Connections

- **NSURLConnection** has three related delegate protocols:
  - **NSURLConnectionDelegate** – asynchronous callbacks sent to the delegate during authentication challenges, as well as to notify the delegate of connection failure.
  - **NSURLConnectionDataDelegate** – asynchronous callbacks sent to the delegate as the connection is downloading data.
  - **NSURLConnectionDownloadDelegate** – asynchronous sent to notify the delegate about download progress.
- Asynchronous loading:
  - Implement delegate callbacks; or
  - Use block-based API

```
+ (void)sendAsynchronousRequest:(NSURLRequest *) request
                          queue:(NSOperationQueue *) queue
              completionHandler:(void (^)(NSURLResponse *response,
                                          NSData *data,
                                          NSError *connectionError)) handler;
```

- Synchronous loading methods also available.
  - *Avoid using on the main thread*.

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URL Sessions

- **NSURLSession** creates and manages instances of **NSURLSessionTask**.
  - Session task manages an **NSURLConnection**.
- Session tasks are created in suspended state.
  - Send a **resume** message to execute.
- Subclasses of **NSURLSessionTask**:

  NSURLSessionDataTask — Loads URL resource in memory as instance of **NSData**.

  NSURLSessionUploadTask — Initialized with a file, data object, or stream to upload.

  NSURLSessionDownloadTask — Downloads response data directly to a file. Notifies its delegate when download complete.

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Working with URL Sessions

- `NSURLSession` provides a global session via its `+sharedSession` method.
- You can also create your own sessions.
- Custom sessions can be configured as background sessions.
  - Managed by macOS.
  - Can continue download when app is not running.
  - macOS will relaunch app when download completes.

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URL Protocols (Optional)

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Reachability

- Add input sources to main run loop to receive notifications about changes to reachability of network endpoints.
- File SCNetworkReachability.h in SystemConfiguration framework declares C functions for:
  - Configuring callbacks
  - Scheduling and unscheduling in run loop
- Callback structure includes flags with detailed network status.

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Testing Tips

- Apple provides **Network Link Conditioner**
  - System Preferences plugin
  - Simulates various network conditions, including performance degradation.
- **Wireshark** and similar tools provide rich network monitoring.
- Consider providing a way to use dummy data in development when web services are unavailable.

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