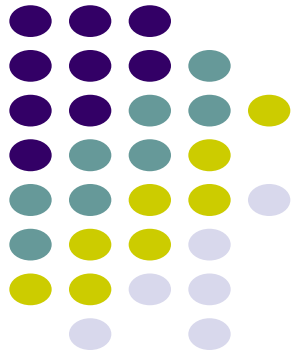
OS Designs

ECE 469, April 29

Aravind Machiry



Content copied from: https://slideplayer.com/slide/7115927/, Yanick Fratantonio, 王偉一, 江哲維, 洪心為

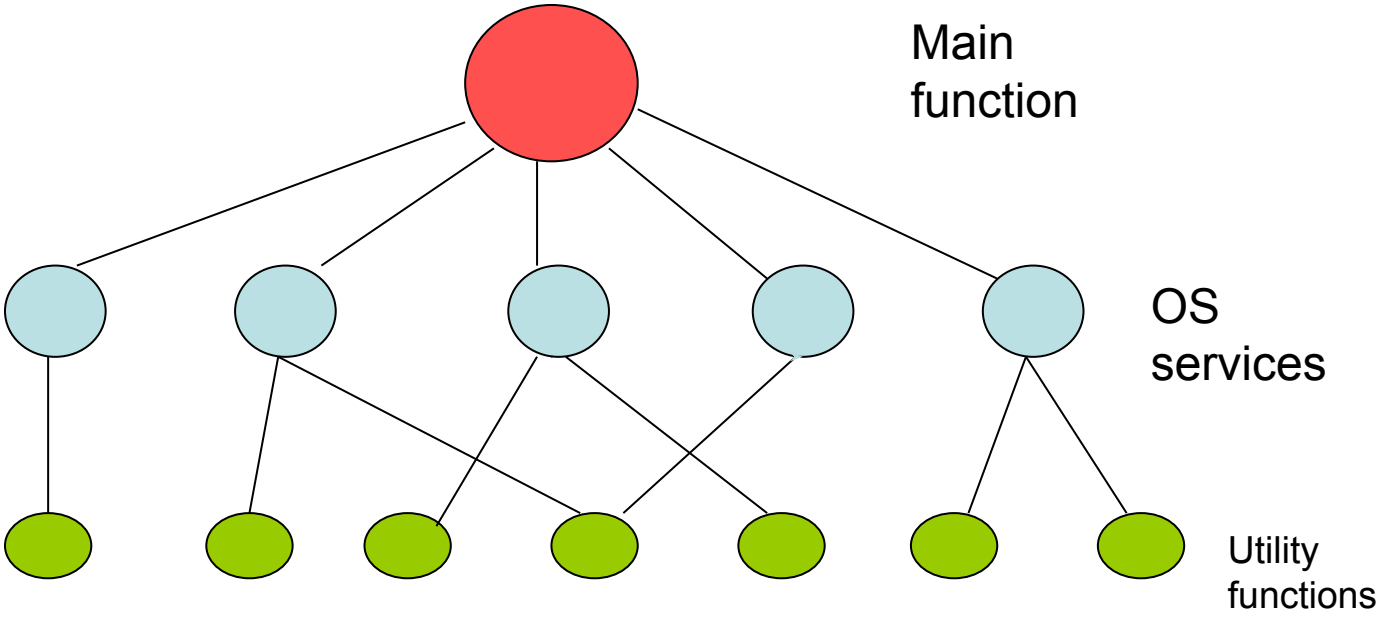
How to design a OS?

- Design: Components, organization of these components and interaction between the components.

- Also, called OS architectures.

Design 1: Monolithic

- All components bundled as a single entity.



Monolithic Kernel

- All OS functionality is included in a single program (address space)
  - E.g., UNIX, Linux, most commercial systems

- Advantages:
  - Easy to design and reason about.
  - Good performance.

- Disadvantages:
  - Poor separation: kernel components aren't protected from each other.
  - Cannot be easily extended.

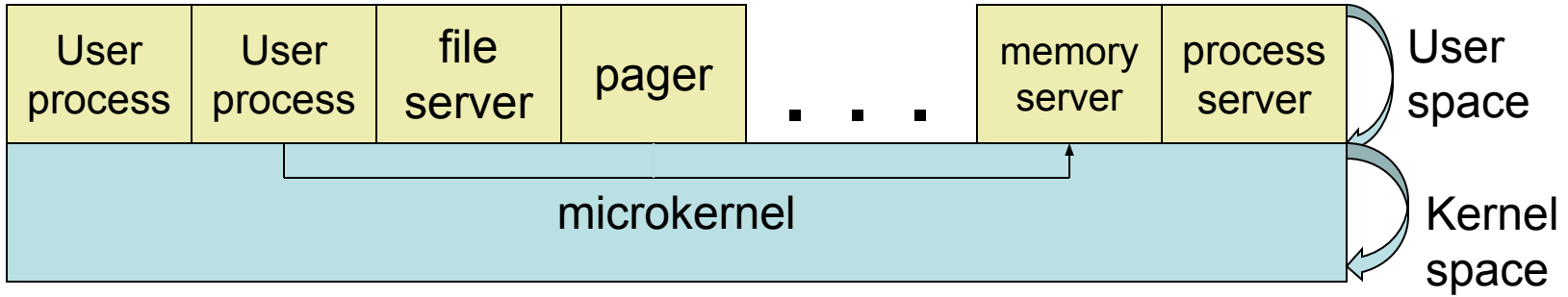
Linux Kernel

- Mainly monolithic.
- Extensible: Kernel modules.
- Fairly modular.

Microkernels - outline

- OS kernel is very small – minimal functionality.
- Other OS functions provided at user level by trusted servers.
  - User-level process, but trusted by kernel
- Advantage: Design reflects good software engineering practices
- Problem: performance

Microkernels



Microkernels - approach

- The microkernel layer provides a set of minimal core services and is the interface to the hardware layer.

- Other services (drivers, memory managers, etc.) are implemented as separate modules with clearly defined interfaces.

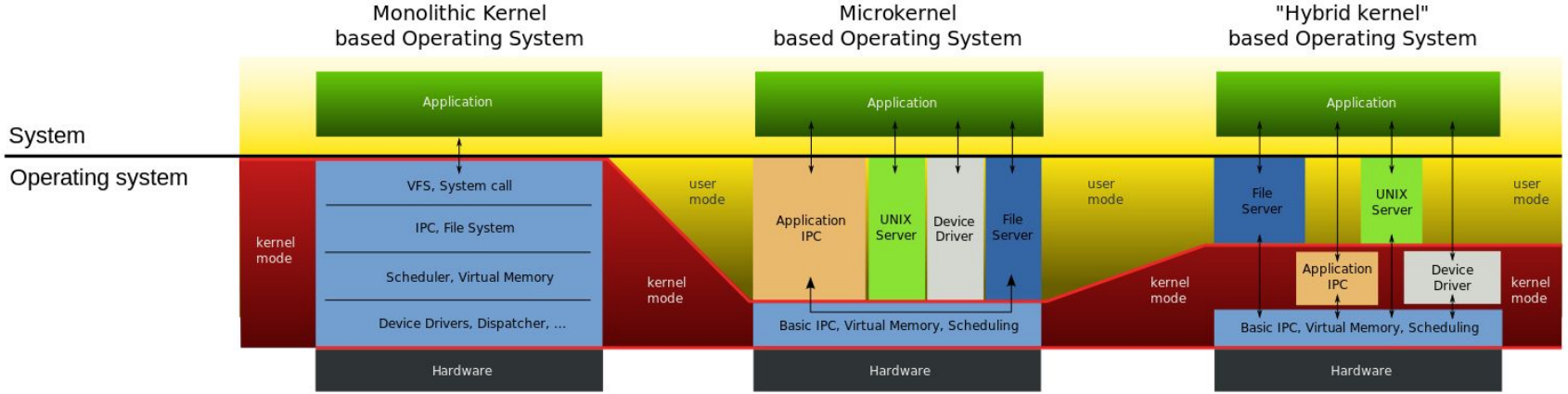
Microkernels - Advantages

- Modularity
- Flexibility and extensibility
  - Easier to replace modules – fewer dependencies
  - Different servers can implement the same service in different ways
- Safety (each server is protected by the OS from other servers) using standard OS memory protection techniques
- Servers are largely hardware independent
- Correctness
  - Easier to verify a small kernel
  - Servers are isolated; errors in one don’t affect others

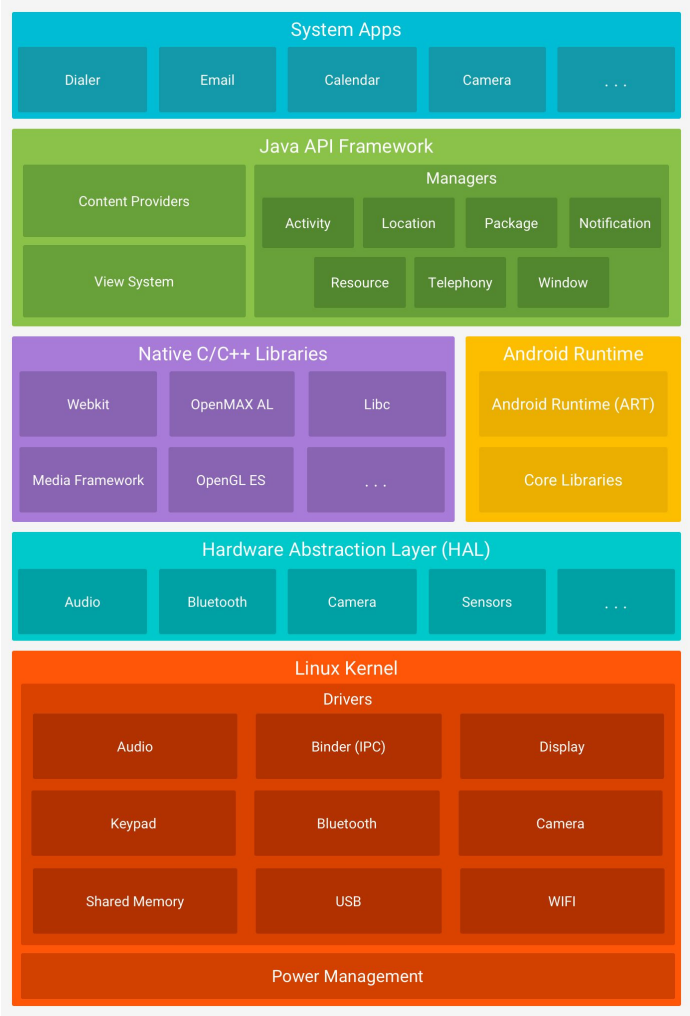
Microkernels - Disadvantages

- Slow – is this due to “cross-domain” information transfers? Maybe
  - Server-to-OS, OS-to-server IPC is thought to be a major source of inefficiency
  - Mode switches/context switches
- Generally it’s faster to communicate between two modules that are both in OS – no mode switching involved

Monolithic/Micro/Hybrid kernel



Case Study: Android



From the eyes of an app

- Android is based on Linux
- Each app has its own Linux user ID*
- Each app lives in its own security *sandbox*
  - Standard Linux process isolation
  - Restricted file system permissions

* There are ways to setup apps so that they share the user ID. See "sharedUserId".

App Installation

- The Android framework creates a new Linux user

- Each app is given a private directory
  - Also called "Internal Storage"
  - No other app can access it*

* There are ways to setup apps so that they share the user ID. See "sharedUserId".

App Isolation

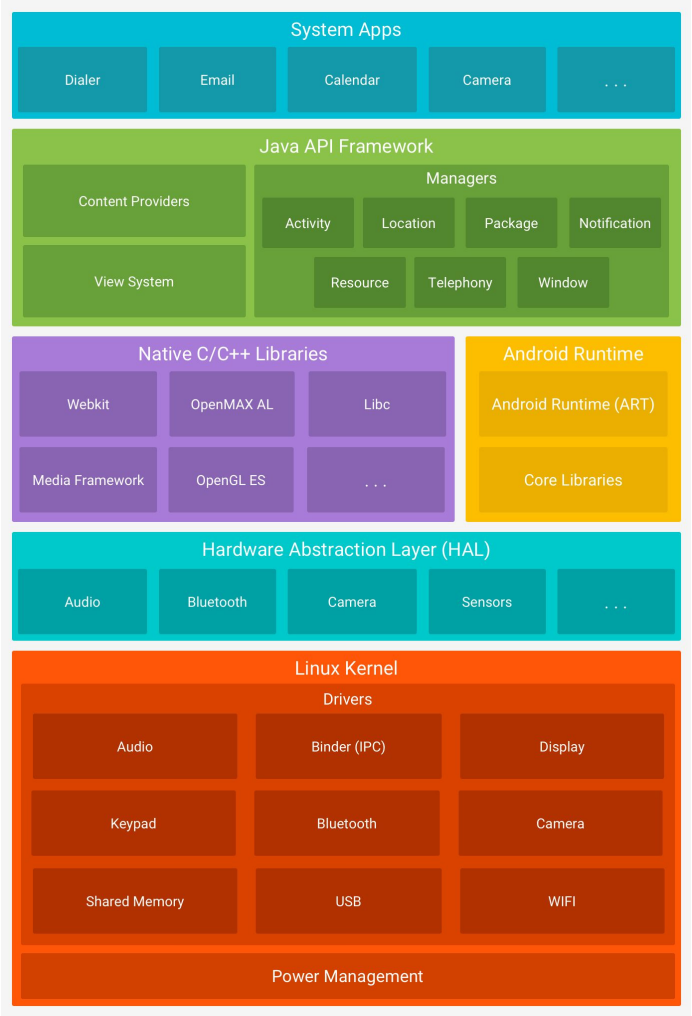
- Apps are run in separate processes
- Apps being in sandbox means that they can't
  - talk to each other
  - do anything security-sensitive
- Q: how can apps do anything interesting?
- This is when architecture & security get mixed up

Example: Saving a file

- Going down: Java ~> libc ~> syscalls
- fd = open(const char *filename, int flags, umode_t mode)
- n = write(unsigned int fd, char *buf, size_t count)
- close(unsigned int fd);

Not all requests are as easy as opening a file...

- Get current location?
- Send an SMS?
- Display something to the UI?
- Play a sound?
- Talk to other apps!?


System Apps
Dialer
Email
Calendar
Camera
. . .
Java API Framework
Content Providers
View System
Managers
Activity
Location
Package
Notification
Resource
Telephony
Window
Native C/C++ Libraries
Webkit
OpenMAX AL
Libc
Media Framework
OpenGL ES
. . .
Android Runtime
Android Runtime (ART)
Core Libraries
Hardware Abstraction Layer (HAL)
Audio
Bluetooth
Camera
Sensors
. . .
Linux Kernel
Drivers
Audio
Binder (IPC)
Display
Keypad
Bluetooth
Camera
Shared Memory
USB
WIFI
Power Management

Example: getLastLocation()

- App invokes Android API
  - LocationManager.getLastLocation() (ref)
  - We are still within the app's sandbox!

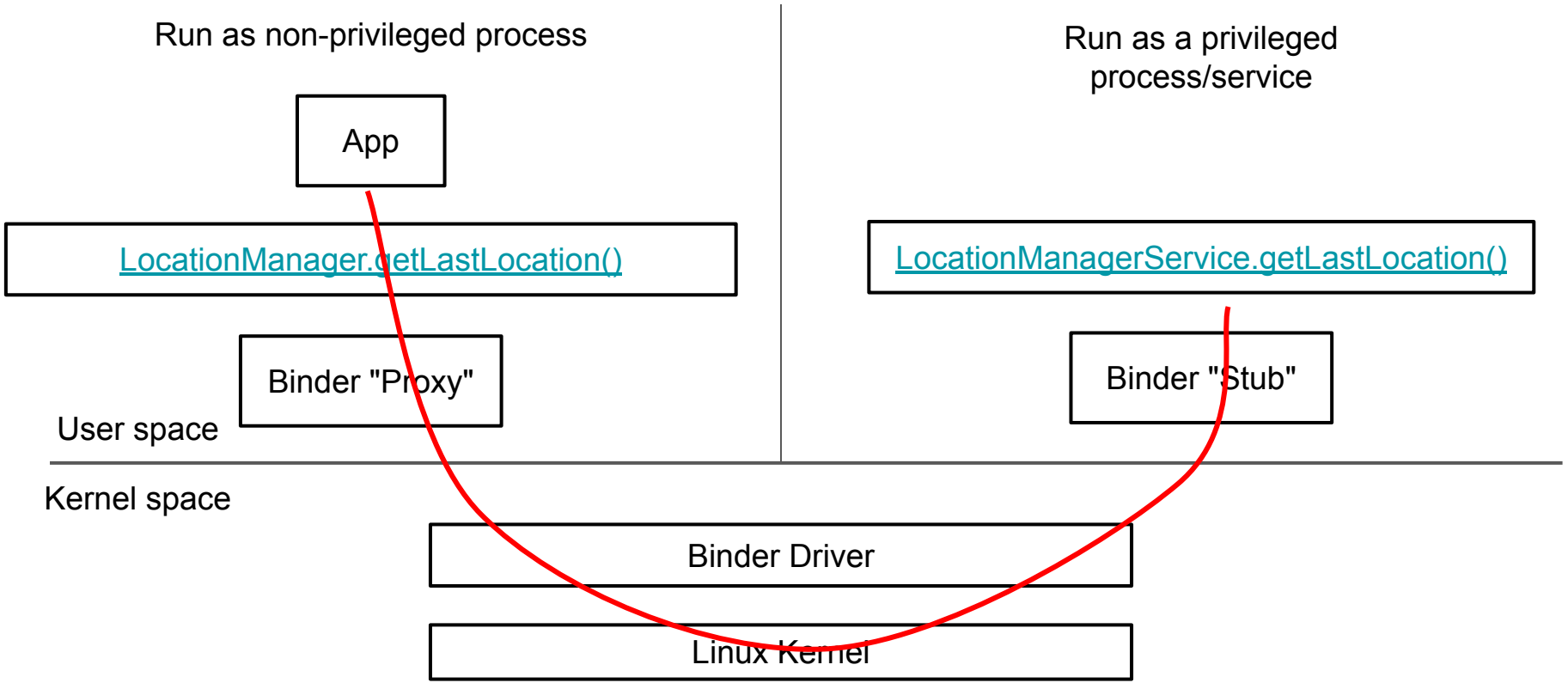
- Actual implementation of the privileged API
  - LocationManagerService.getLastLocation() (ref)
  - We are in a "privileged" service

- How do we go from one side to the other one?

Crossing the bridge

- Binder!
- Binder: one of the main Android's "extensions" over Linux
- It allows for
  - Remote Procedure Call (RPC)
  - Inter-Process Communication (IPC)

Binder RPC


Run as non-privileged process
Run as a privileged process/service
App
LocationManager.getLastLocation()
LocationManagerService.getLastLocation()
Binder "Proxy"
Binder "Stub"
User space
Kernel space
Binder Driver
Linux Kernel

Binder details

- Proxy and Stub are automatically generated starting from AIDL

- Binder internals
  - /dev/binder
  - ioctl syscall
    - Multi-purpose syscall, to talk to drivers
    - The Binder kernel driver takes care of it, dispatches messages and returns replies

Many "Managers"

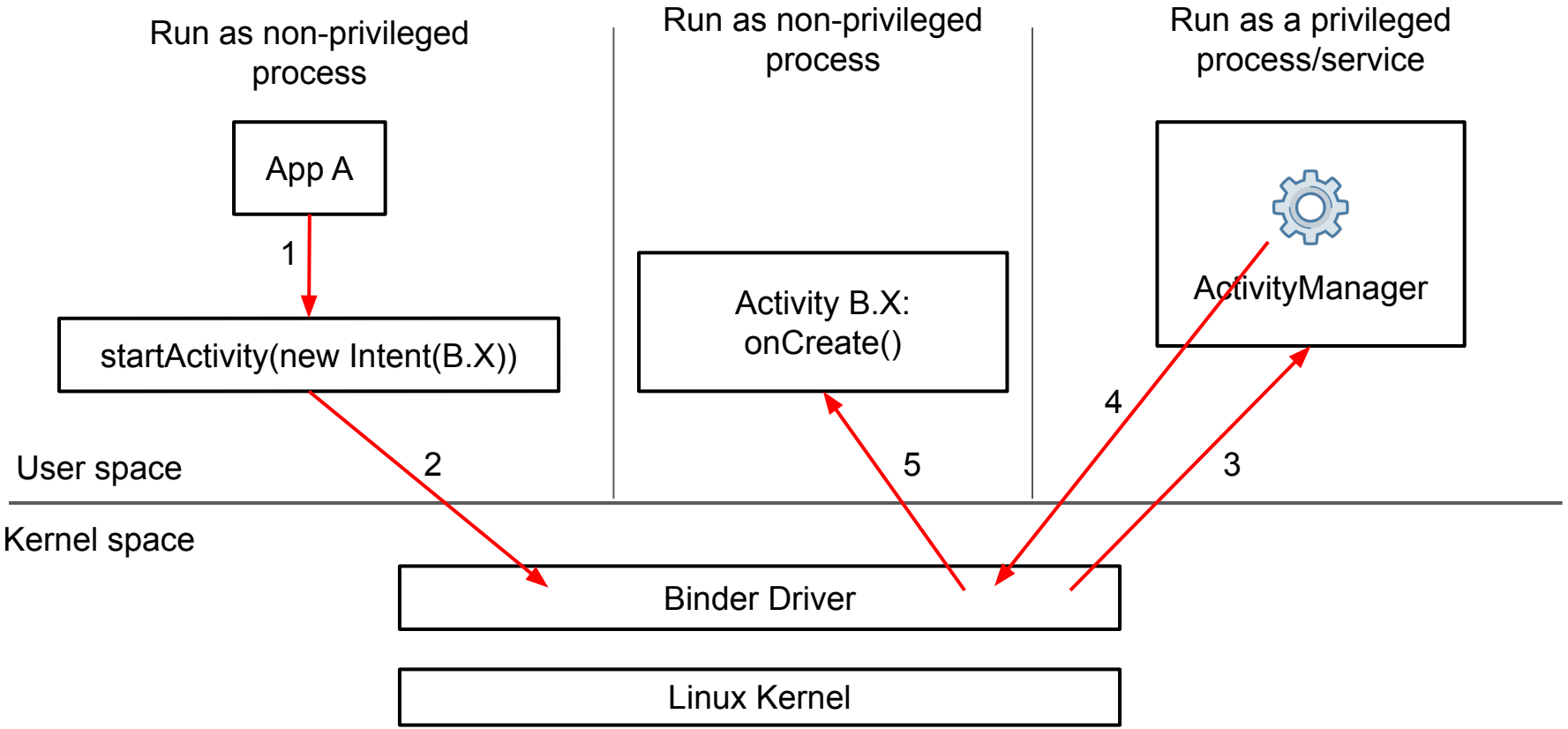
- Activity Manager
- Package Manager
- Telephony Manager
- Resource Manager
- Location Manager
- Notification Manager
- Resource Manager

```
$ adb shell service list
```

Binder as IPC mechanism

- How do apps talk to each other?
- High-level API: Intents
- Under the hood: Binder calls!

Binder IPC: A → B.X



What about security?

- Can an app always do all these things? Nope.
- It has a private folder... that's it?
  - It can start other apps (the main activity is always "exported")
  - It can show things on the screen (when the app is in foreground)
- It can't
  - Open internet connection
  - Get current location
  - Write on the external storage
  - ...

Android Permission System (overview, ref)

- Android framework defines a long list of permissions

- Each of these "protects" security-sensitive capabilities
  - The ability to "do" something sensitive
    - Open Internet connection, send SMS
  - The ability to "access" sensitive information
    - Location, user contacts, ...

Examples of Permissions

- INTERNET (string: "android.permission.INTERNET")

Examples of Permissions

- INTERNET (string: "android.permission.INTERNET")
- ACCESS_NETWORK_STATE, ACCESS_WIFI_STATE, CHANGE_NETWORK_STATE, READ_PHONE_STATE
- ACCESS_COARSE_LOCATION, ACCESS_FINE_LOCATION
- READ_SMS, RECEIVE_SMS, SEND_SMS
- ANSWER_PHONE_CALLS, CALL_PHONE, READ_CALL_LOG, WRITE_CALL_LOG
- READ_CONTACTS, WRITE_CONTACTS
- READ_CALENDAR, WRITE_CALENDAR
- READ_EXTERNAL_STORAGE, WRITE_EXTERNAL_STORAGE
- RECORD_AUDIO, CAMERA
- BLUETOOTH, NFC
- RECEIVE_BOOT_COMPLETED
- SYSTEM_ALERT_WINDOW
- SET_WALLPAPER

Permissions from an app's perspective

Permission Request

```
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
          package="com.example.awesomeapp">

    <uses-permission android:name="android.permission.SEND_SMS"/>
    <application ...>
        ...
    </application>
</manifest>
```

Custom Permissions (doc)

- Apps can define "custom" permissions!

```
<permission
  android:name="com.example.myapp.permission.DEADLY_STUFF"
  android:label="@string/permlab_deadlyStuff"
  android:description="@string/permdesc_deadlyStuff"
  android:permissionGroup="android.permission-group.DEADLY"
  android:protectionLevel="signature" />
```

- The "system" permissions are defined in the same way
  - AndroidManifest.xml

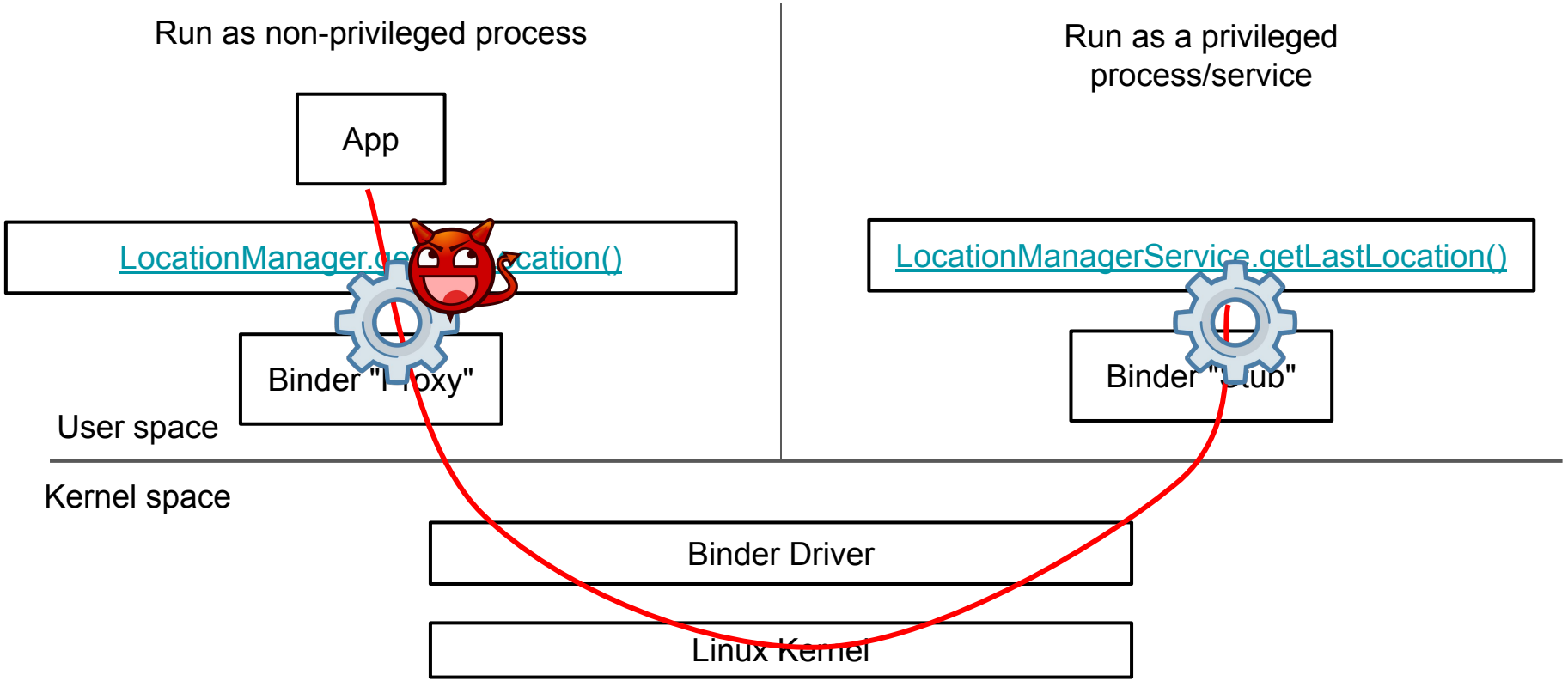
Permission Enforcement Implementation

- Two technical ways: Linux groups vs. explicit checks

- Linux groups
  - INTERNET permission ~> app's user is added to "inet" Linux group
  - BLUETOOTH permission ~> app's user is added to "bt_net" Linux group
  - Declaration in AOSP: code

- Explicit check

Binder RPC


Run as non-privileged process
Run as a privileged process/service
App
LocationManager.getLastLocation()
LocationManagerService.getLastLocation()
Binder "Proxy"
Binder "Stub"
User space
Kernel space
Binder Driver
Linux Kernel

Explicit Checks

- The service's code actually does a check
- LocationService
  - LocationManagerService.getLastLocation()
    - LocationManagerService.checkResolutionLevelIsSufficientForProviderUse()
- AudioFlinger
  - ServiceUtilities.recordingAllowed()
    - ContextImpl.checkPermission()
      - ActivityManagerService.checkPermission()
        - ActivityManagerService.checkComponentPermission()
          - ActivityManager.checkComponentPermission()
            - PackageManagerService.checkUidPermission()

Case Study: FreeRTOS

- A Real Time Operating System
- Written by Richard Barry & FreeRTOS Team
- Owned by Real Time Engineers Ltd but free to use
- Huge number of users all over the world
    - 6000 Download per month
- Simple but very powerful

Real Time Operating System?

- A type of an operating system
- It's all about scheduler :
  - multi user operating system(UNIX)— fair amount of the processing time
  - desktop operating system(Windows)— remain responsive to its user
  - ……
- RTOS scheduler focuses on predictable execution pattern

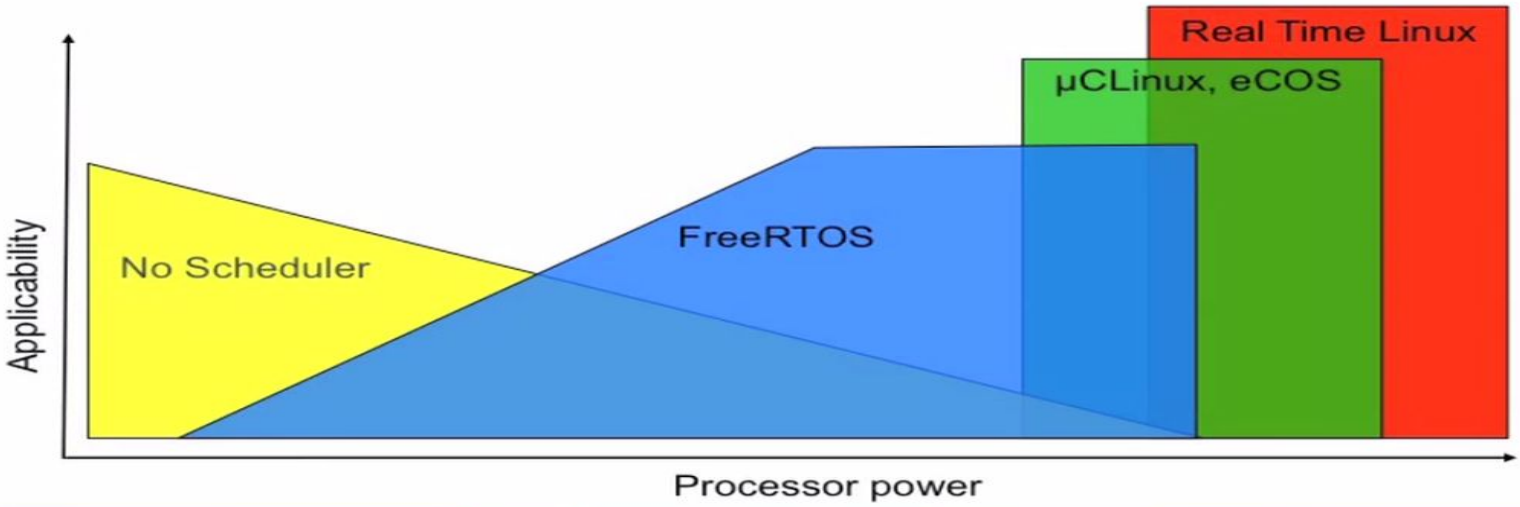
Why FreeRTOS?

- Abstract out timing information
- Maintainability/Extensibility
- Modularity
- Cleaner interfaces
- Easier testing (in some cases)
- Code reuse
- Improved efficiency?
- Idle time

……

……

When to use FreeRTOS?



FreeRTOS Architecture?

- Tasks (50%)
  - task.c and task.h do all the heavy lifting for creating, scheduling, and maintaining tasks.
- Communication (40%)
  - queue.c and queue.h handle FreeRTOS communication. Tasks and interrupts use queues to send data to each other and to signal the use of critical resources using semaphores and mutexes.
- Hardware Interfacing (6%)

User space/Kernel space

- No MMU => No Separation!

- Large Program:
  - Each task => Thread
  - Scheduling between tasks (i.e., threads) based on priority.

Ideal OS architecture?

- Hard.
- Different use cases / Hardware capabilities/ Requirements.
- Even the same OS is customized for different use cases:
  - Ubuntu => Desktop v/s Server.