

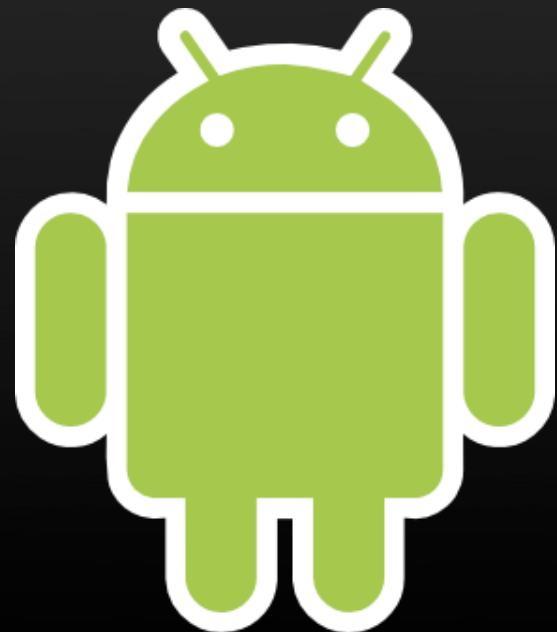


ANDROID

# Android Anatomy and Physiology

# Agenda

- Android Anatomy
  - Linux Kernel
  - Native Libraries
  - Android Runtime
  - Application Framework
- Android Physiology
  - Start-up Walkthrough
  - Layer Interaction



# Android Anatomy



## APPLICATIONS

Home    Dialer    SMS/MMS    IM    Browser    Camera    Alarm    Calculator  
Contacts    Voice Dial    Email    Calendar    Media Player    Albums    Clock    ...

## APPLICATION FRAMEWORK

Activity Manager    Window Manager    Content Providers    View System    Notification Manager  
Package Manager    Telephony Manager    Resource Manager    Location Manager    ...

## LIBRARIES

Surface Manager    Media Framework    SQLite  
OpenGL|ES    FreeType    WebKit  
SQL    SSL    Libc

## ANDROID RUNTIME

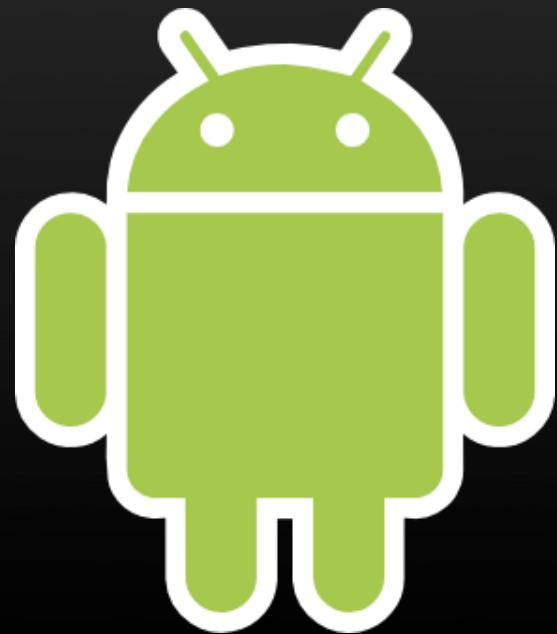
Core Libraries  
Dalvik Virtual Machine

## LINUX KERNEL

Display Driver    Camera Driver    Bluetooth Driver    Shared Memory Driver    Binder (IPC) Driver  
USB Driver    Keypad Driver    WiFi Driver    Audio Drivers    Power Management

# Agenda

- Android Anatomy
  - Linux Kernel
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# Linux Kernel



- Android is built on the Linux kernel, but Android is not Linux
- No native windowing system
- No glibc support
- Does not include the full set of standard Linux utilities

## LINUX KERNEL

Display Driver

Camera Driver

Bluetooth Driver

Shared Memory  
Driver

Binder (IPC) Driver

USB Driver

Keypad Driver

WiFi Driver

Audio  
Drivers

Power  
Management

ANDROID

# Linux Kernel



- Standard Linux 2.6.24 Kernel
- Patch of “kernel enhancements” to support Android

## LINUX KERNEL

Display Driver

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Driver

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# Why Linux Kernel?



- Great memory and process management
- Permissions-based security model
- Proven driver model
- Support for shared libraries
- It's already open source!



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# Kernel Enhancements



- Alarm
- Ashmem
- Binder
- Power Management
- Low Memory Killer
- Kernel Debugger
- Logger



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# Binder: Problem



- Applications and Services may run in separate processes but must communicate and share data
- IPC can introduce significant processing overhead and security holes



android

# Binder: Solution

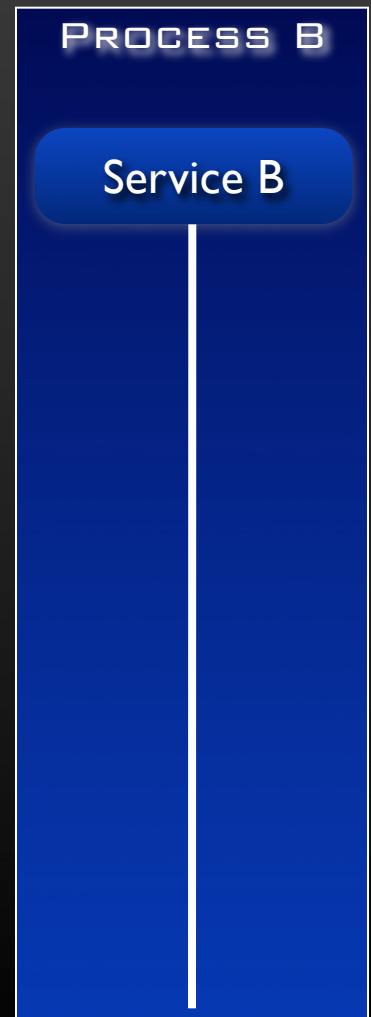
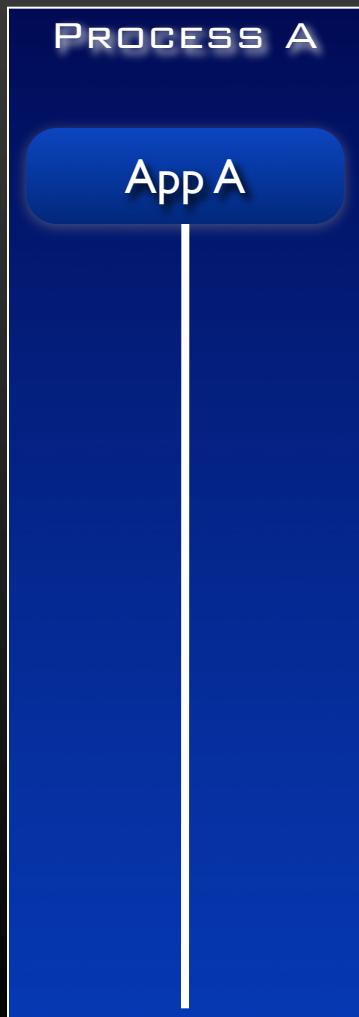


- Driver to facilitate inter-process communication (IPC)
- High performance through shared memory
- Per-process thread pool for processing requests
- Reference counting, and mapping of object references across processes 
- Synchronous calls between processes



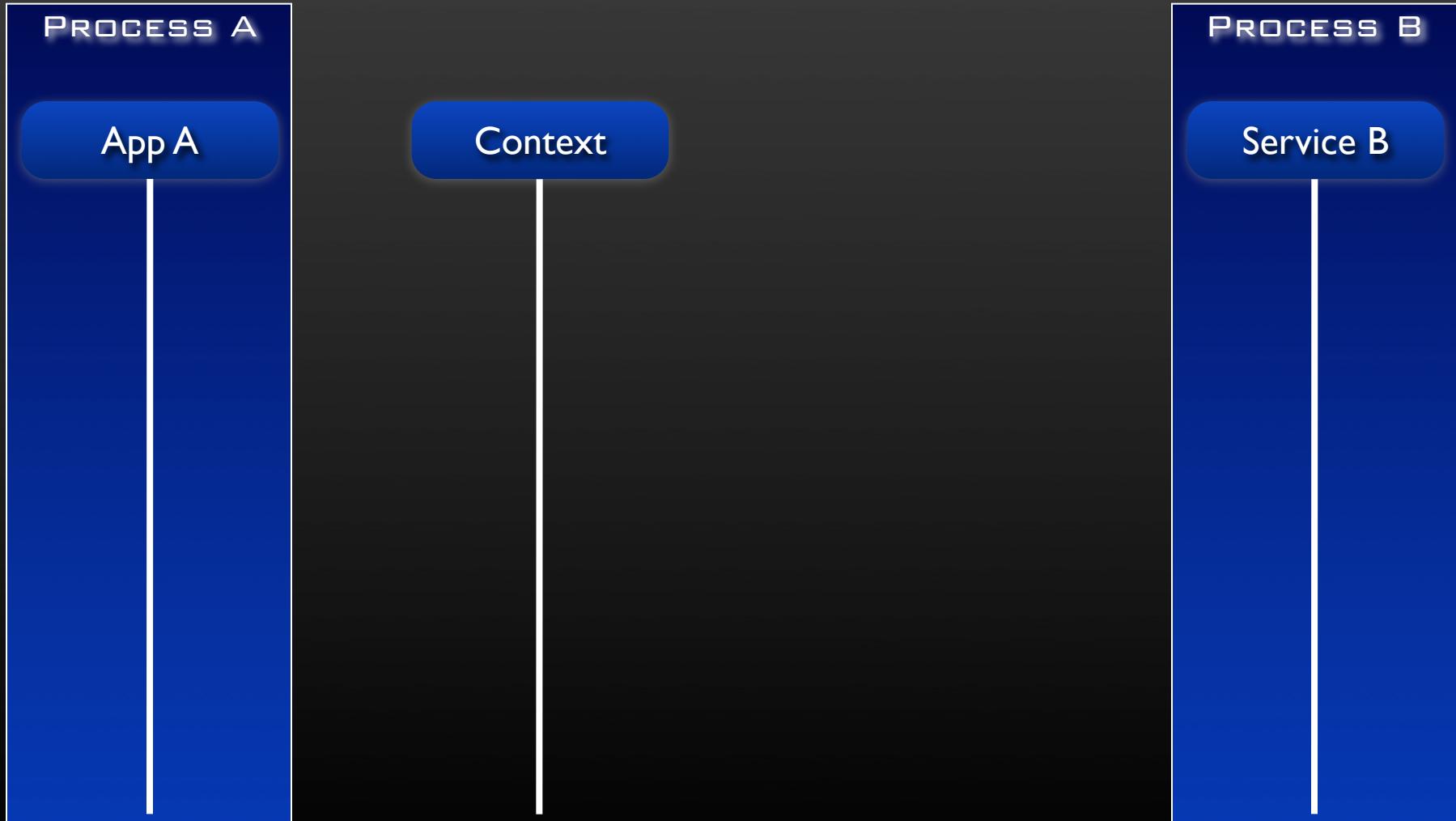
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# Binder in Action



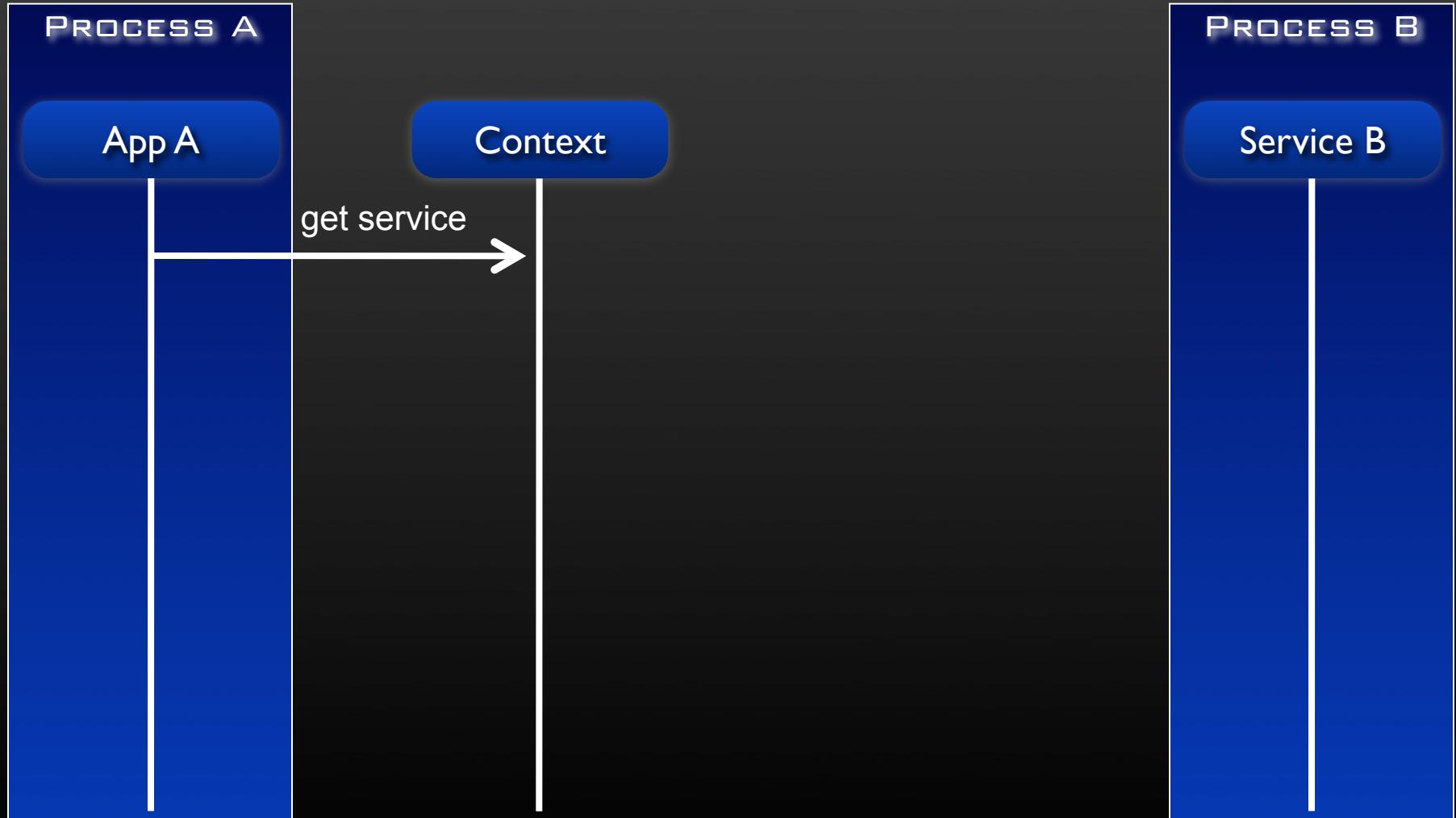
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# Binder in Action



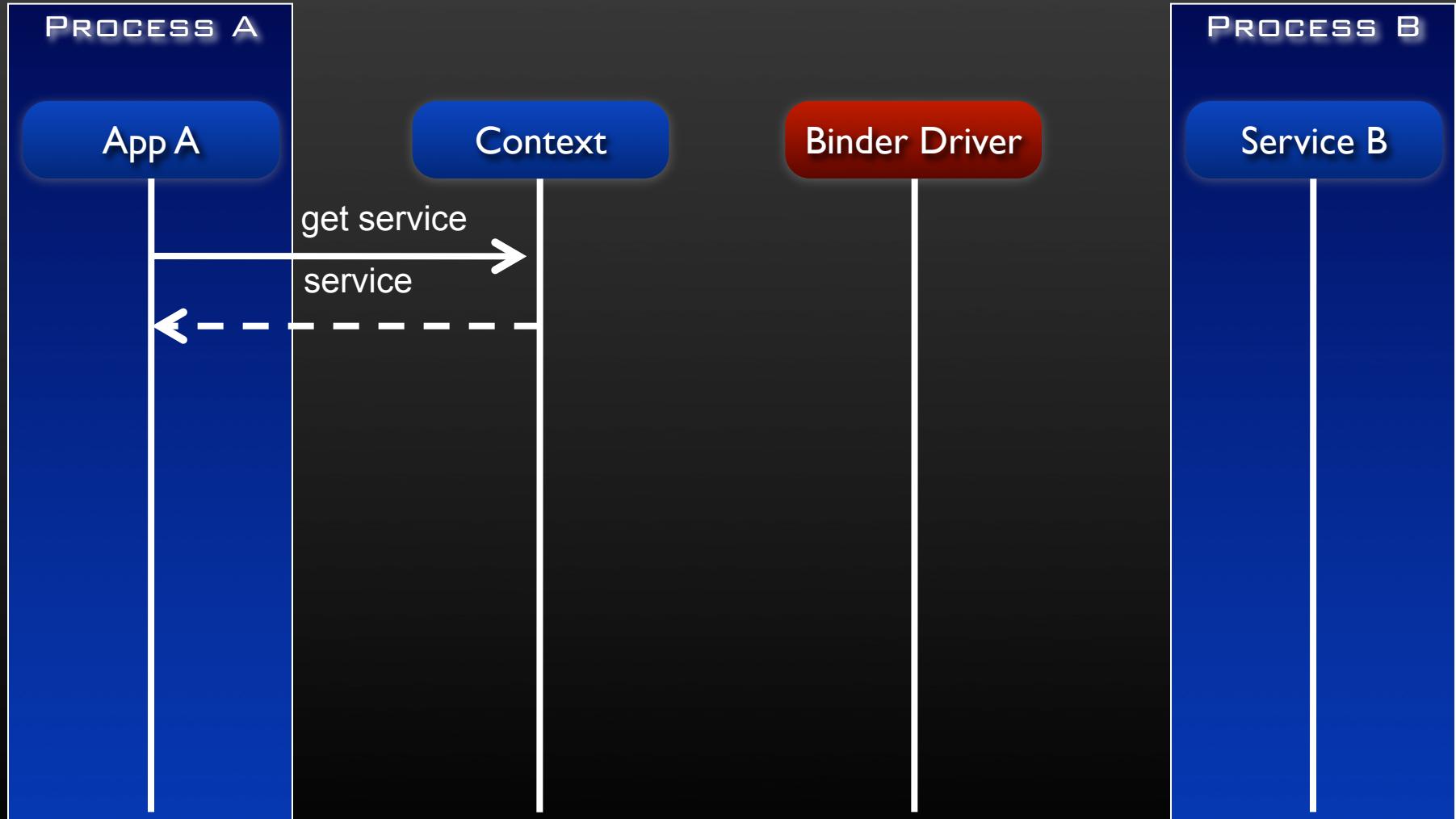
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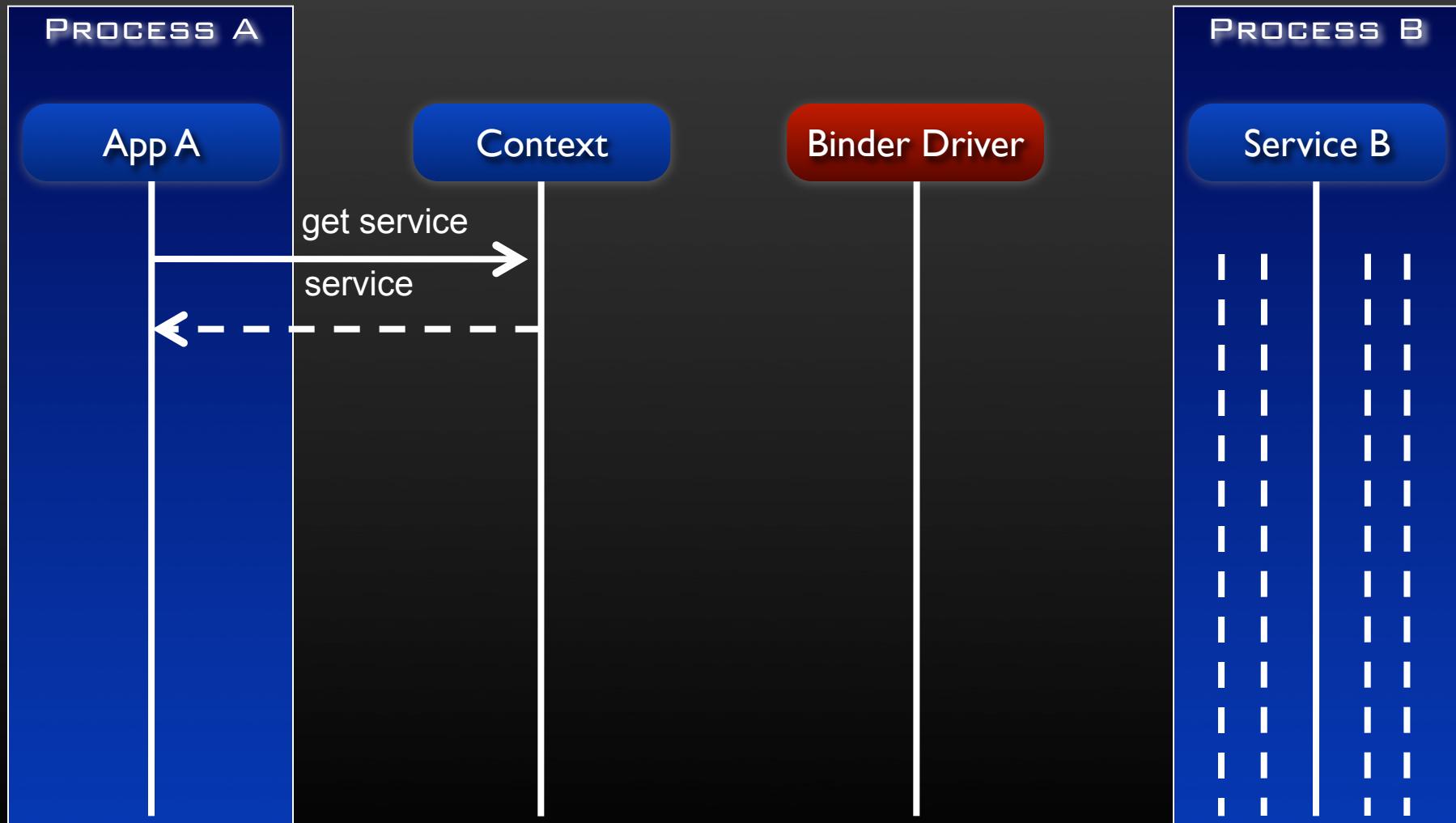
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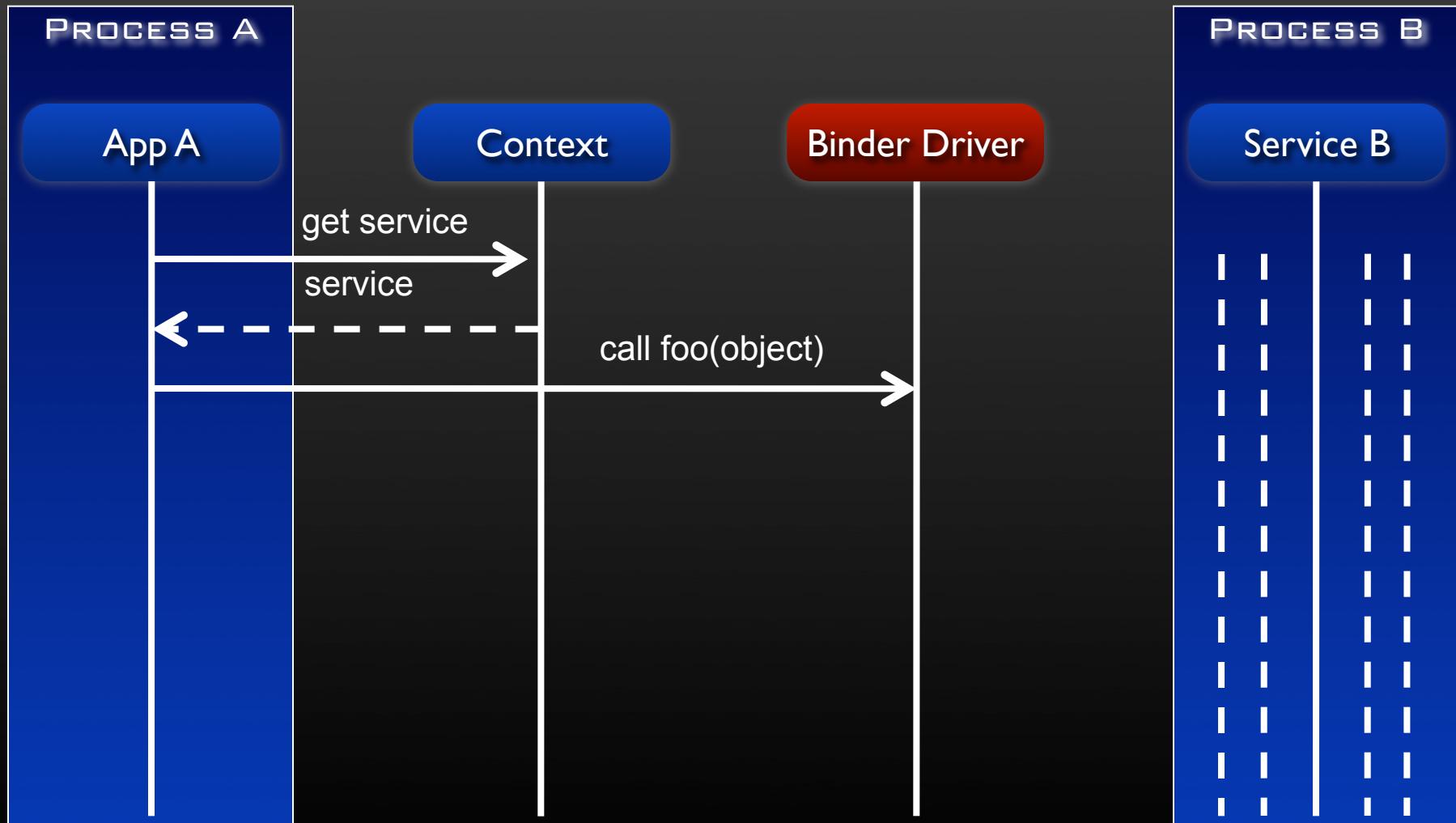
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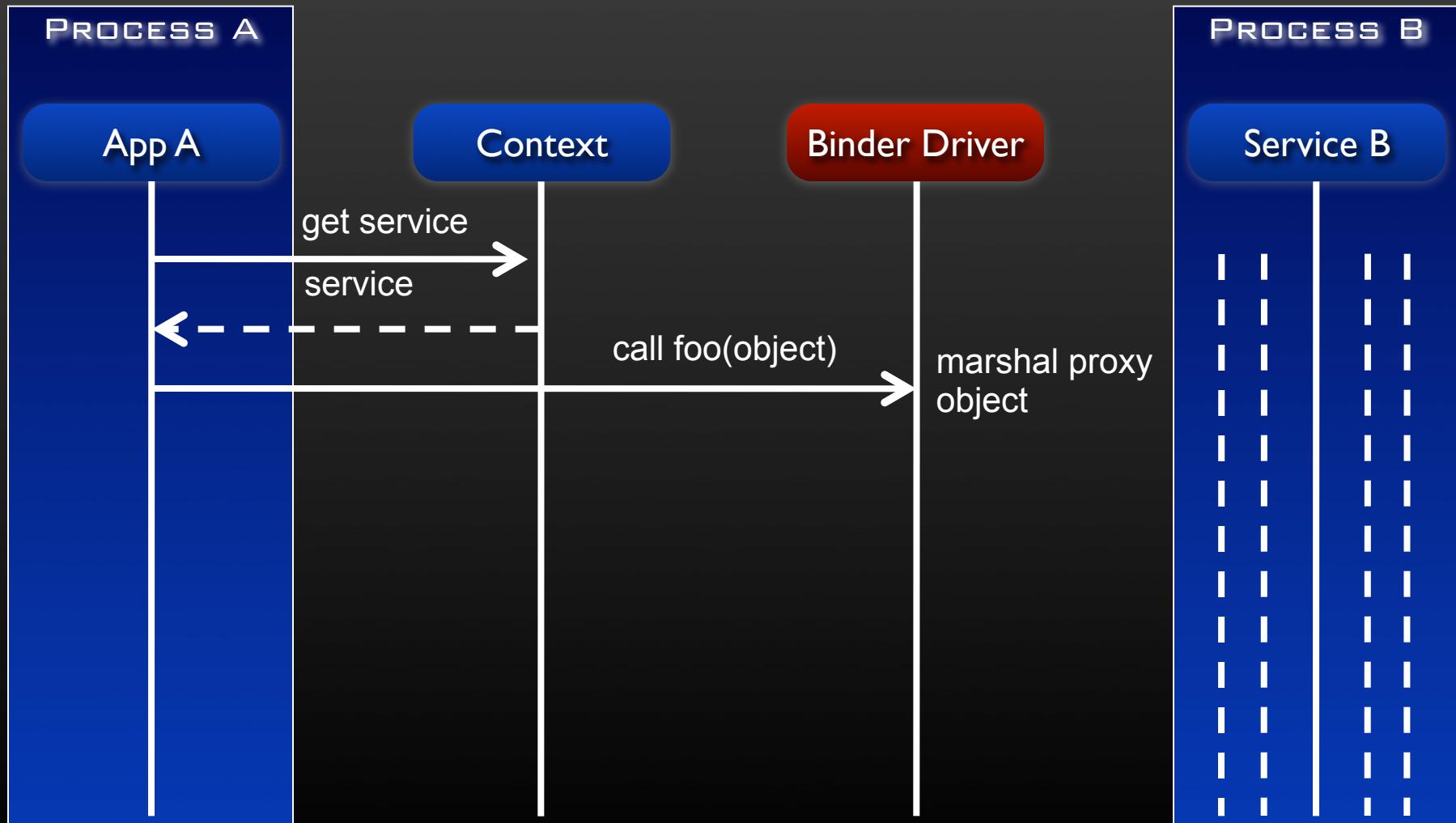
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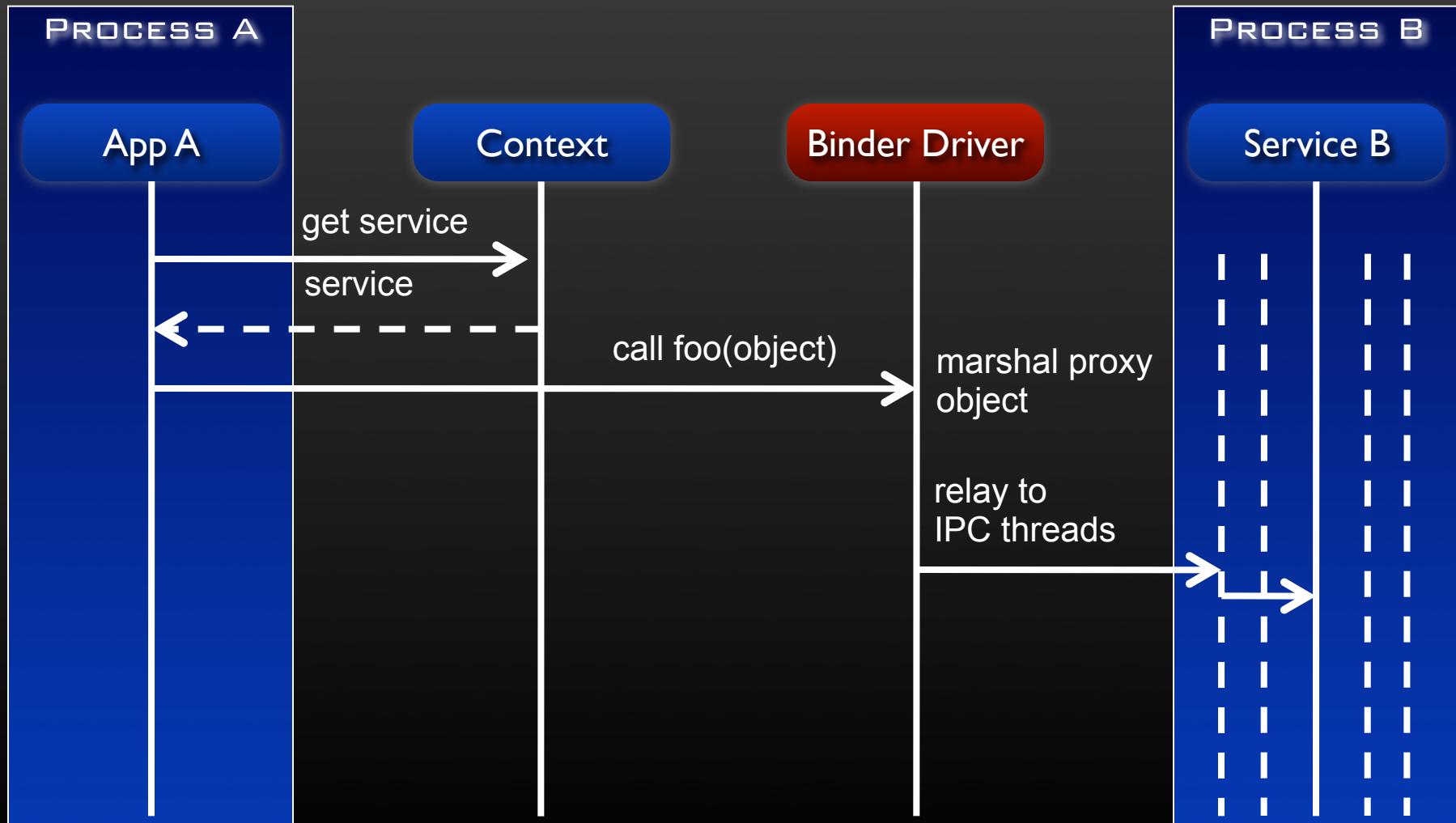
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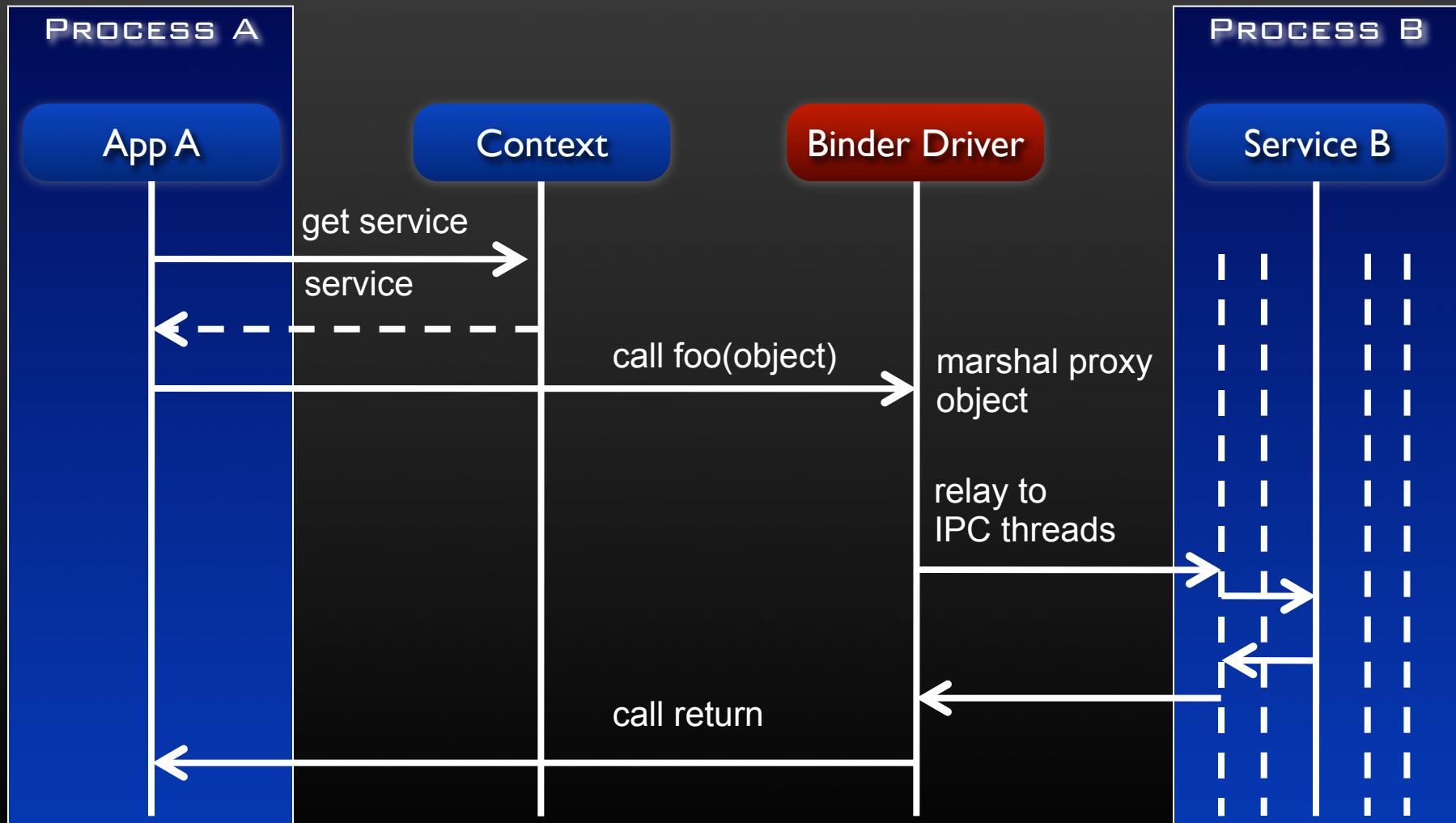
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# Binder in Action



android

# Binder in Action



ANDROID

# Binder



## Android Interface Definition Language (AIDL)

- <http://code.google.com/android/reference/aidl.html>



android

# PM Problem



- Mobile devices run on battery power
- Batteries have limited capacity



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# PM Solution



- Built on top of standard Linux Power Management (PM)
- More aggressive power management policy
- Components make requests to keep the power on through “*wake locks*”
- Supports different types of wake locks



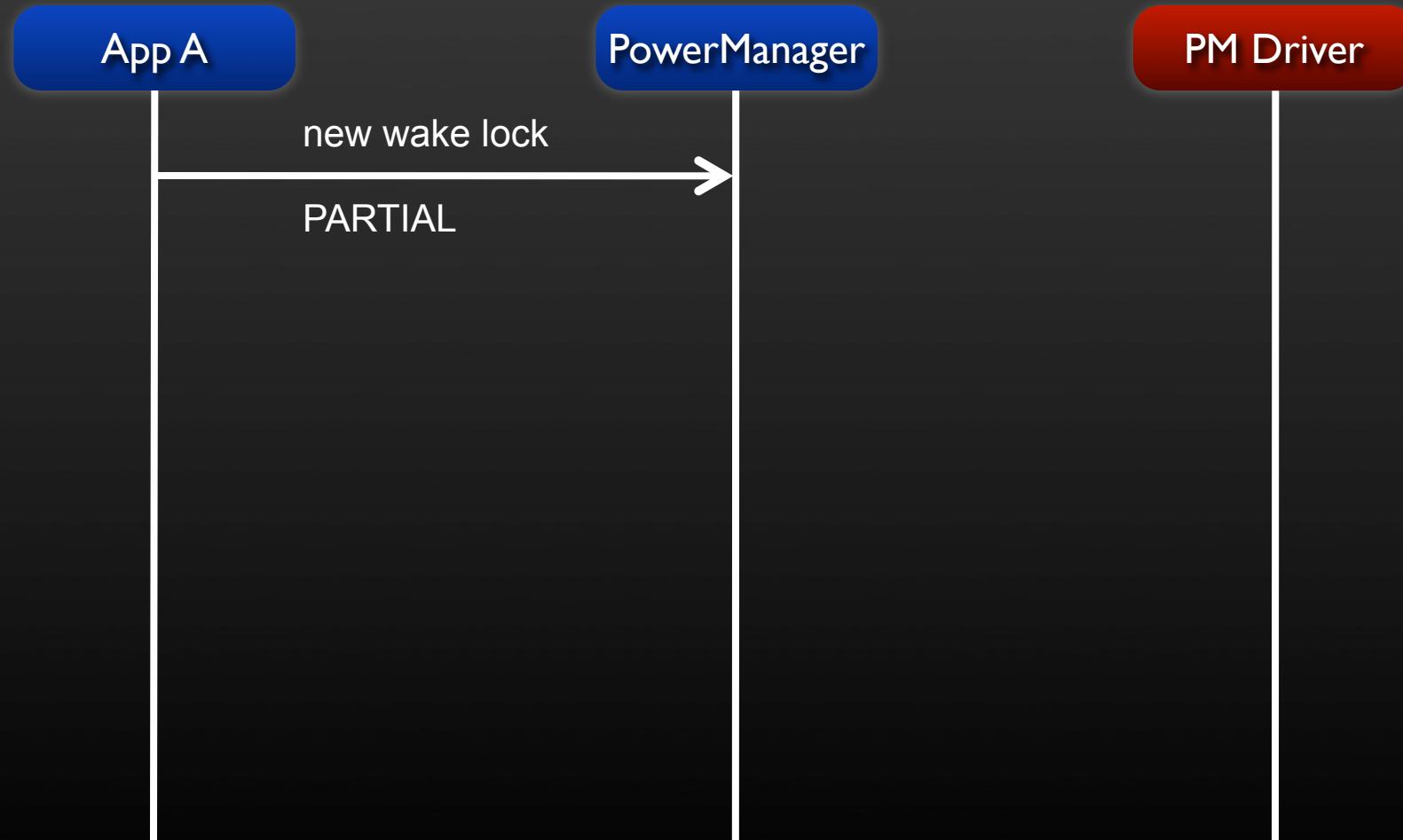
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# Android PM in Action



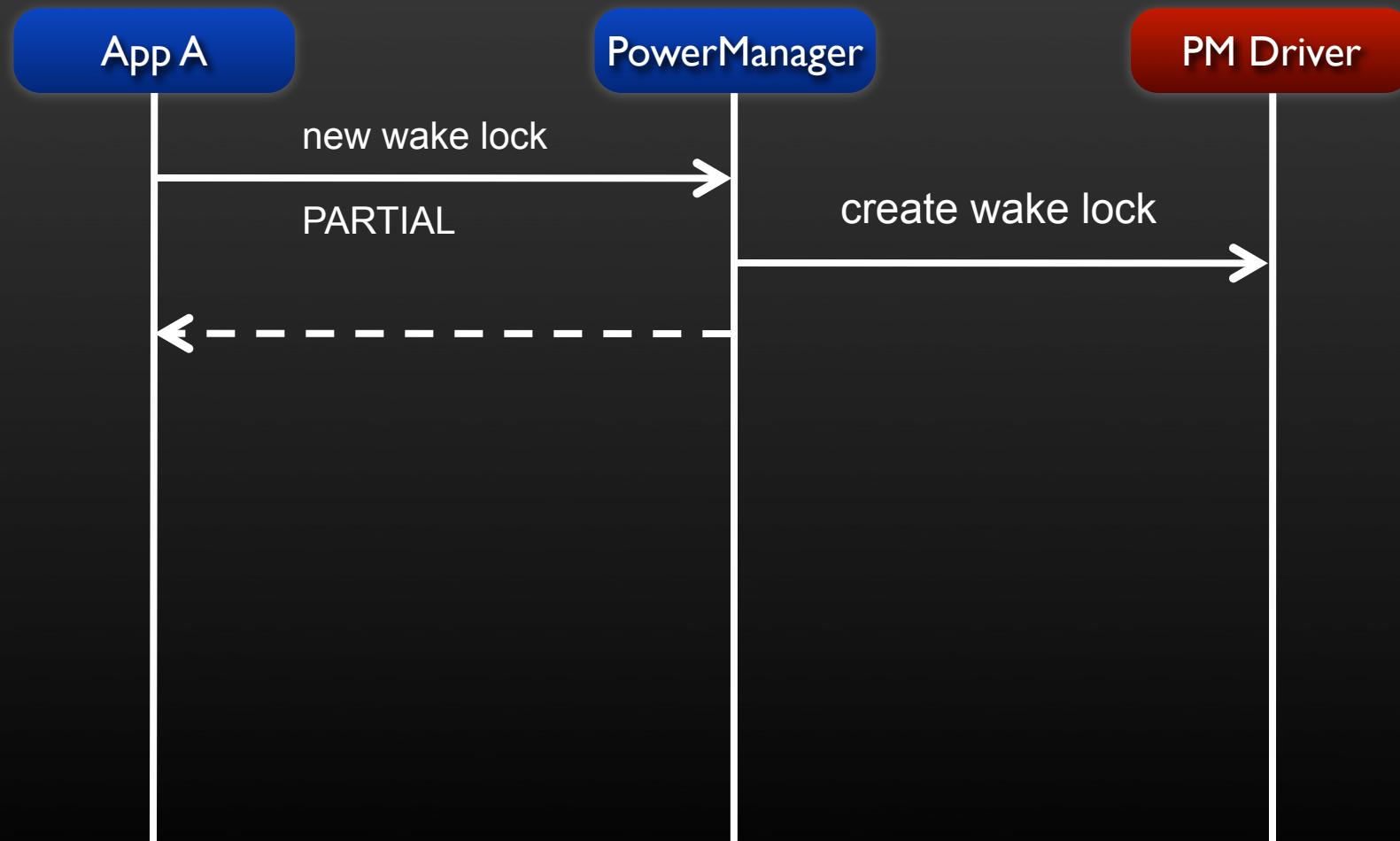
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# Android PM in Action



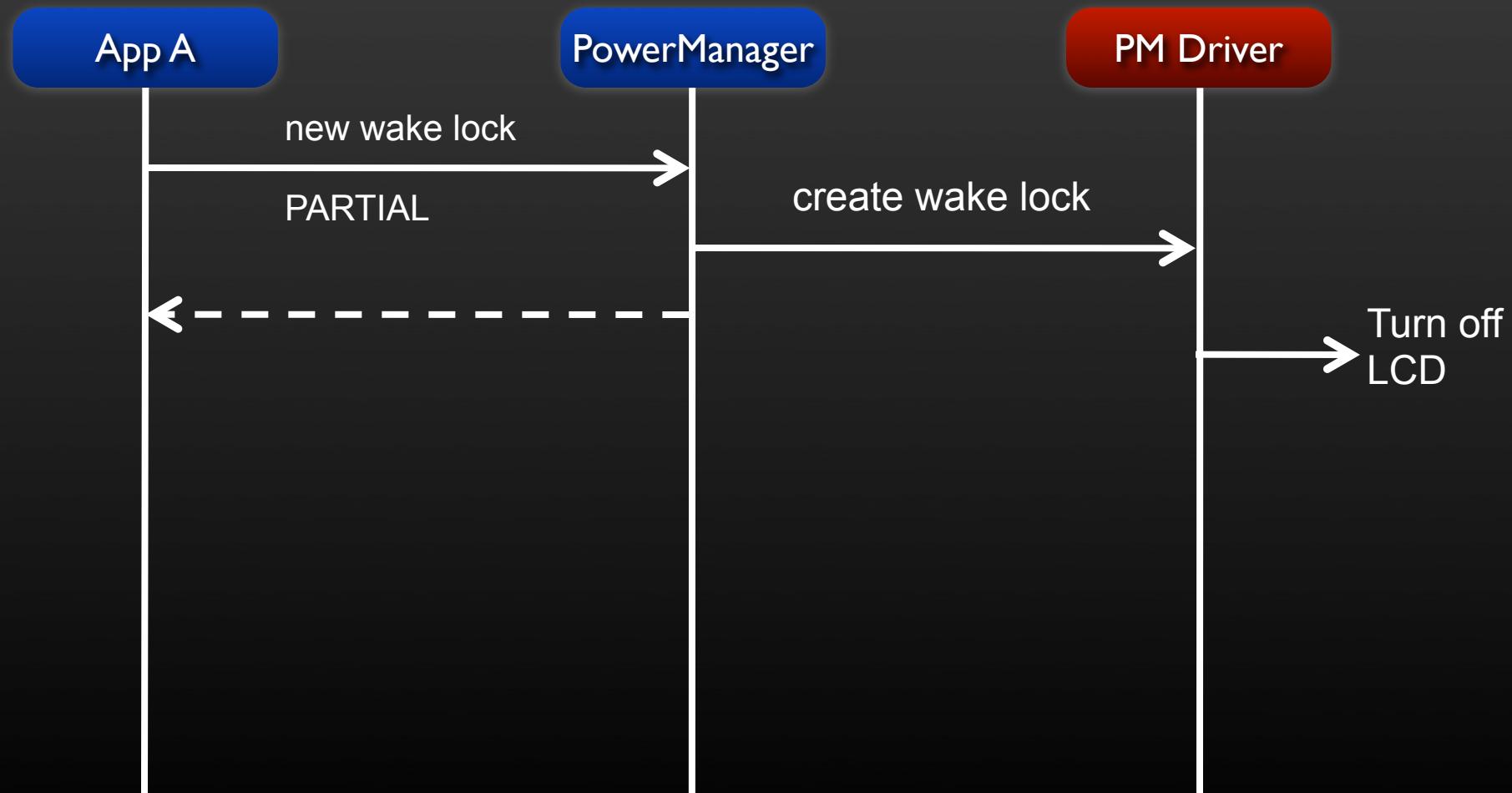
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# Android PM in Action



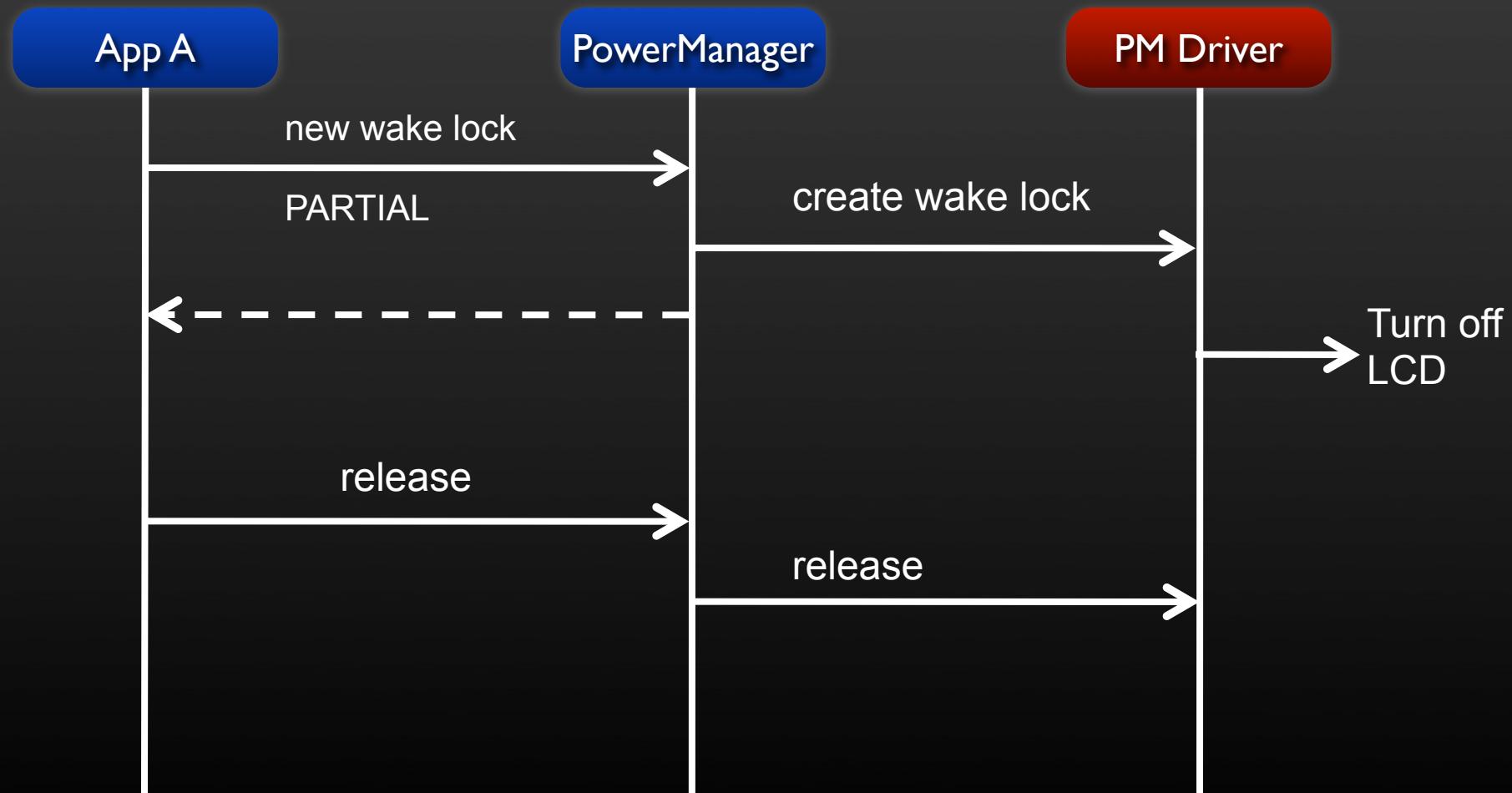
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# Android PM in Action



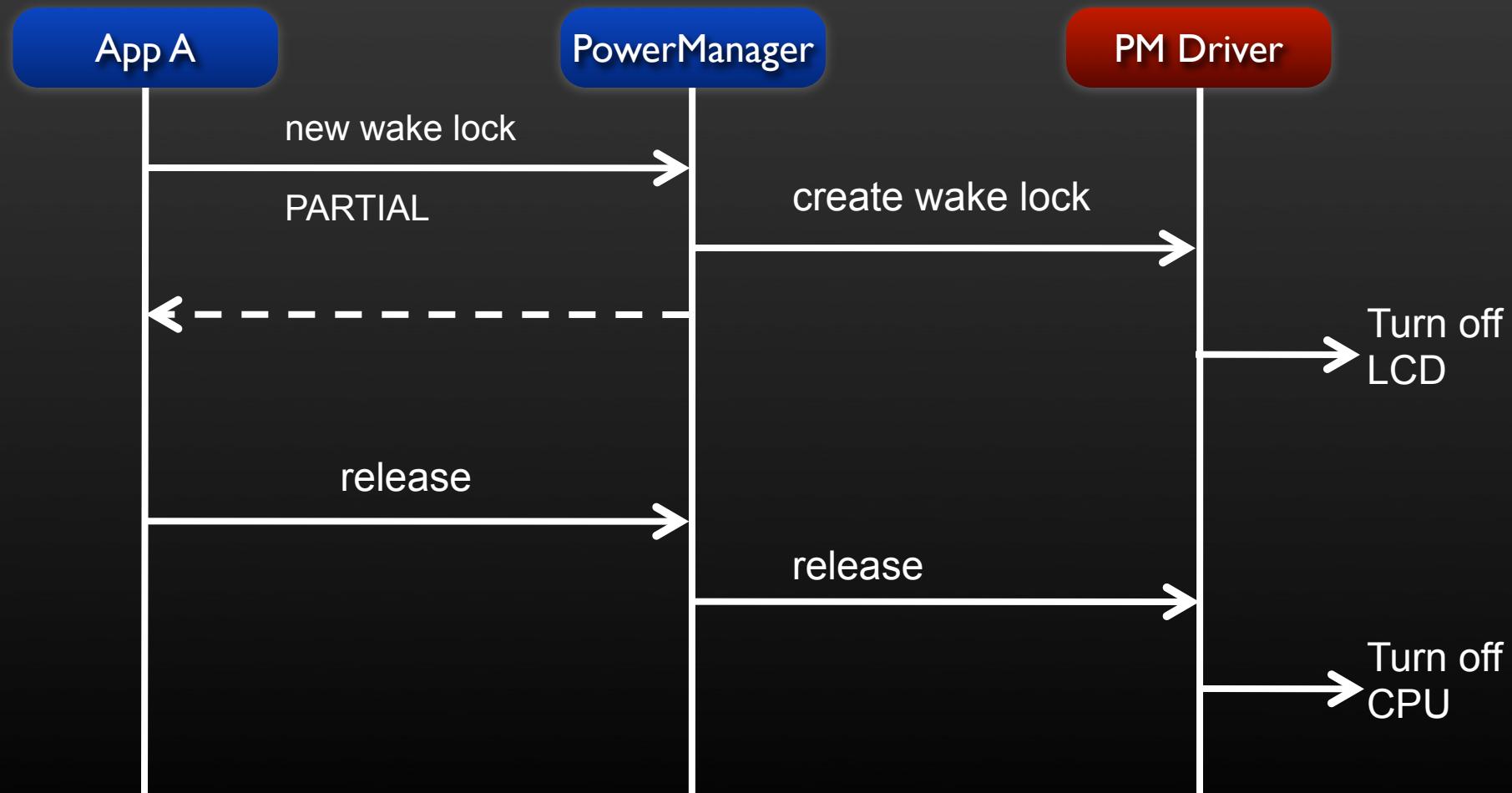
android

# Android PM in Action



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# Android PM in Action



android

# Android PM



## android.os.PowerManager

- Use wake locks carefully!
- `userActivity(long when, ...);`



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# Kernel



The Android kernel source is available today at:

<http://git.android.com>

## LINUX KERNEL

Display Driver

Camera Driver

Bluetooth Driver

Shared Memory  
Driver

Binder (IPC) Driver

USB Driver

Keypad Driver

WiFi Driver

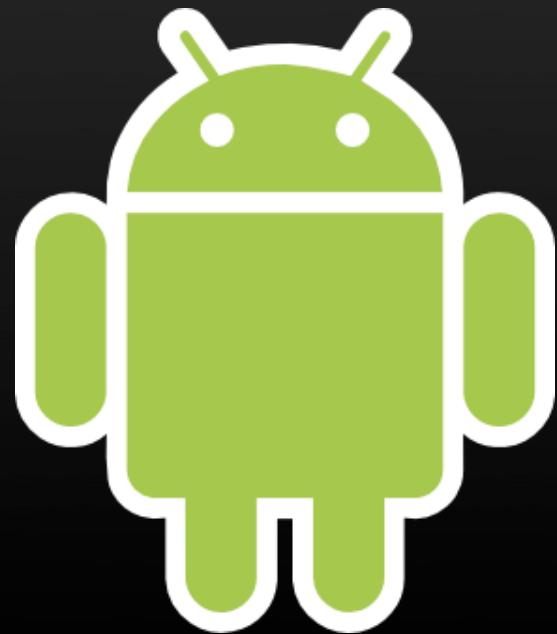
Audio  
Drivers

Power  
Management

ANDROID

# Agenda

- Android Anatomy
  - Linux Kernel
  - Native Libraries
  - Android Runtime
  - Application Framework
- Android Physiology
  - Start-up Walkthrough
  - Layer Interaction



# Android Anatomy



## LIBRARIES

Surface Manager

Media Framework

SQLite

OpenGL|ES

FreeType

WebKit

SGL

SSL

Libc

## LINUX KERNEL

Display Driver

Camera Driver

Bluetooth Driver

Shared Memory  
Driver

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WiFi Driver

Audio  
Drivers

Power  
Management

# Native Libraries



- Bionic Libc
- Function Libraries
- Native Servers
- Hardware Abstraction Libraries

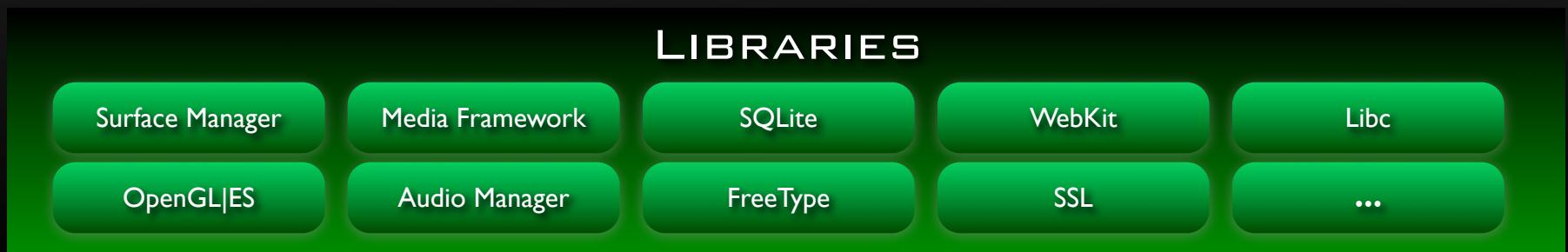


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# Native Libraries



- Bionic Libc
- Function Libraries
- Native Servers
- Hardware Abstraction Libraries

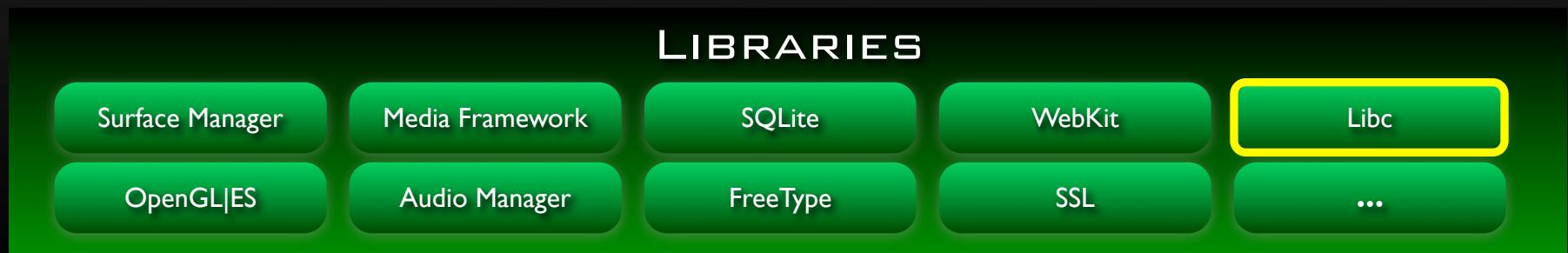


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# What is Bionic?



- What is bionic?
  - Custom libc implementation, optimized for embedded use.



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# Why Bionic?



Why build a custom libc library?

- License: we want to keep GPL out of user-space
- Size: will load in each process, so it needs to be small
- Fast: limited CPU power means we need to be fast



## LIBRARIES

Surface Manager

Media Framework

SQLite

WebKit

Libc

OpenGL|ES

Audio Manager

FreeType

SSL

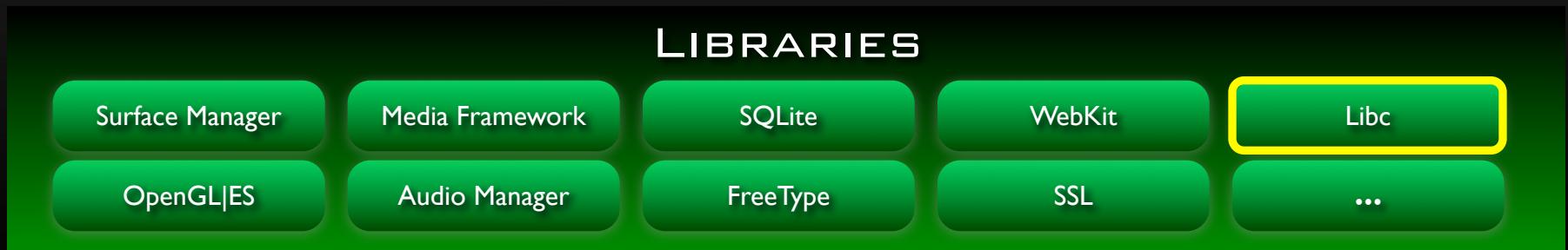
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# Bionic libc



- BSD License
- Small size and fast code paths
- Very fast and small custom pthread implementation



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# Bionic libc



- Built-in support for important Android-specific services
  - system properties

```
getprop("my.system.property", buff, default);
```

- log capabilities

```
LOGI("Logging a message with priority 'Info'");
```

## LIBRARIES

Surface Manager

Media Framework

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OpenGL|ES

Audio Manager

FreeType

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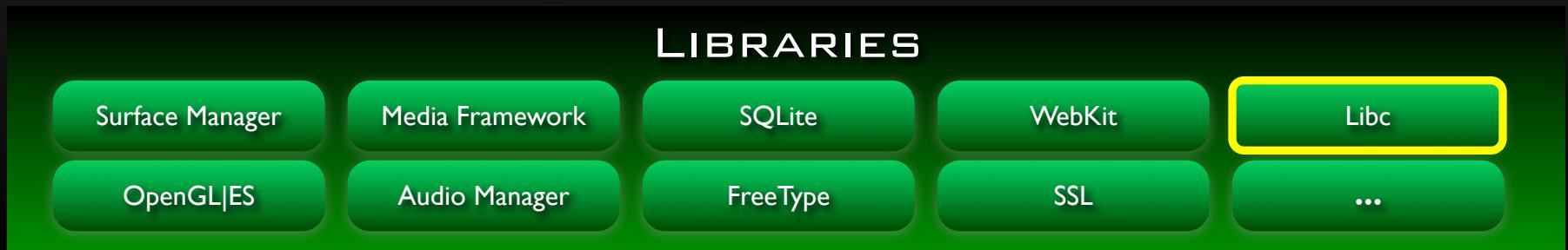
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# Bionic libc



- Doesn't support certain POSIX features
- Not compatible with Gnu Libc (glibc)
- All native code must be compiled against bionic



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# Native Libraries



- Bionic Libc
- Function Libraries
- Native Servers
- Hardware Abstraction Libraries



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# WebKit



- Based on open source WebKit browser: <http://webkit.org>
- Renders pages in full (desktop) view
- Full CSS, Javascript, DOM, AJAX support
- Support for single-column and adaptive view rendering

## LIBRARIES

Surface Manager

Media Framework

SQLite

WebKit

Libc

OpenGL|ES

Audio Manager

FreeType

SSL

...

ANDROID

# Media Framework



- Based on PacketVideo OpenCORE platform
- Supports standard video, audio, still-frame formats
- Support for hardware / software codec plug-ins

## LIBRARIES

Surface Manager

Media Framework

SQLite

WebKit

Libc

OpenGL|ES

Audio Manager

FreeType

SSL

...

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# SQLite



- Light-weight transactional data store
- Back end for most platform data storage



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# Native Libraries

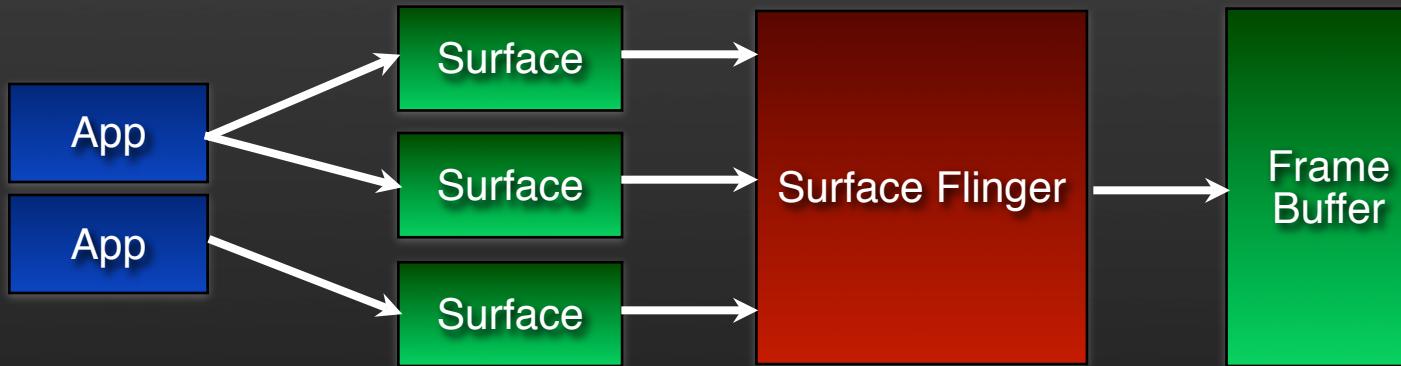


- Bionic Libc
- Function Libraries
- Native Servers
- Hardware Abstraction Libraries



ANDROID

# Surface Flinger



- Provides system-wide surface “composer”, handling all surface rendering to frame buffer device
- Can combine 2D and 3D surfaces and surfaces from multiple applications

## LIBRARIES

Surface Manager

Media Framework

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WebKit

Libc

OpenGL|ES

Audio Manager

FreeType

SSL

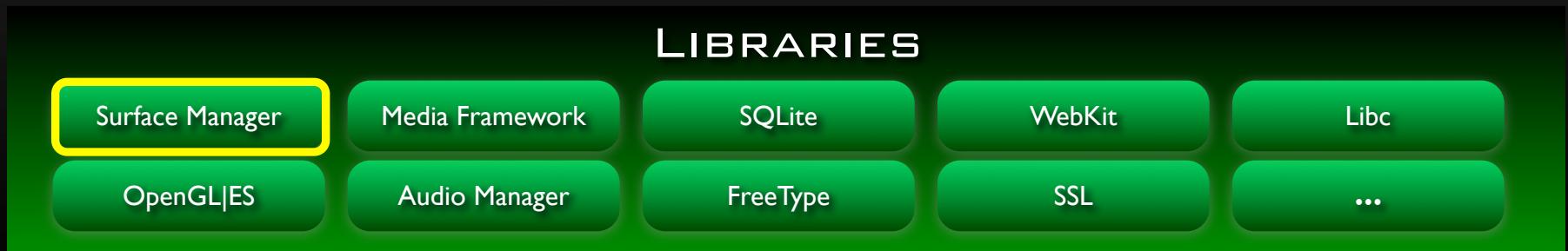
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# Surface Flinger

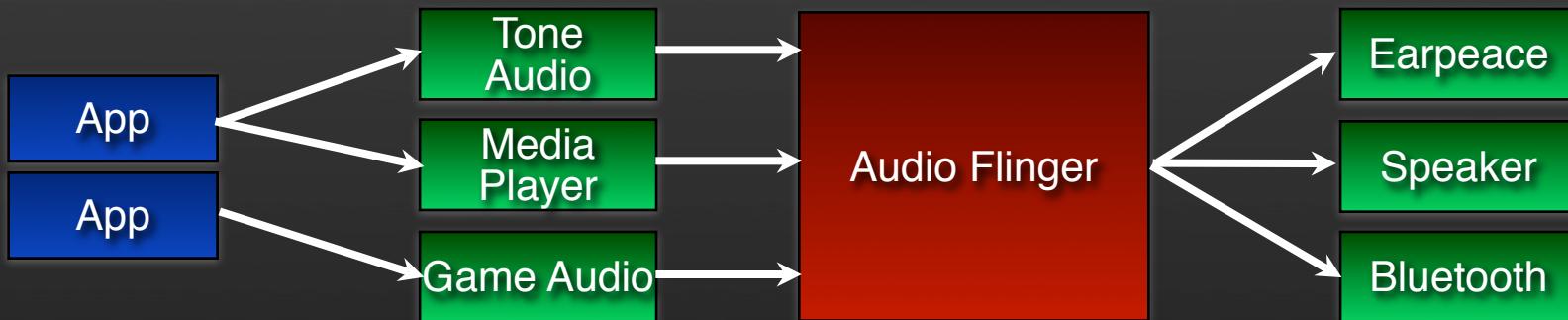


- Surfaces passed as buffers via Binder IPC calls
- Can use OpenGL ES and 2D hardware accelerator for its compositions
- Double-buffering using page-flip



ANDROID

# Audio Flinger



- Manages all audio output devices
- Processes multiple audio streams into PCM audio out paths
- Handles audio routing to various outputs

## LIBRARIES

Surface Manager

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WebKit

Libc

OpenGL|ES

Audio Manager

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SSL

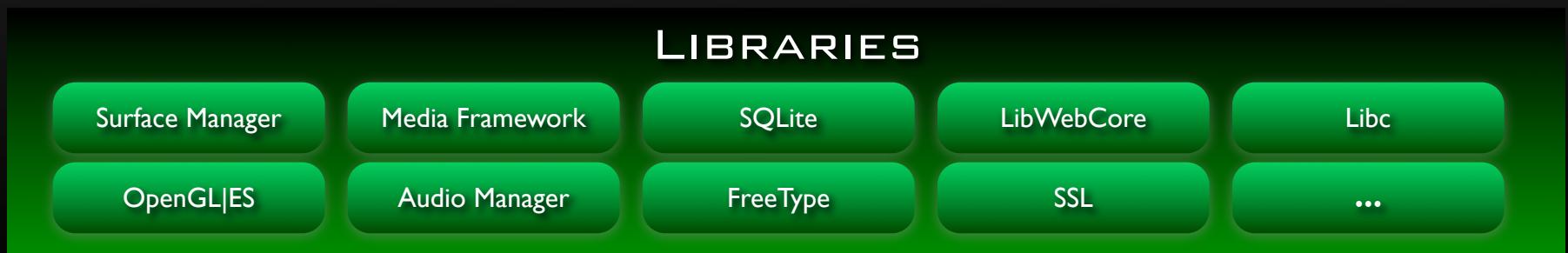
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# Native Libraries



- Bionic Libc
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# Hardware Abstraction Layer



## APPLICATIONS

Home    Dialer    SMS/MMS    IM    Browser    Camera    Alarm    Calculator  
Contacts    Voice Dial    Email    Calendar    Media Player    Photo Album    Clock    ...

## APPLICATION FRAMEWORK

Activity Manager    Window Manager    Content Providers    View System    Notification Manager  
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## ANDROID RUNTIME

Core Libraries  
Dalvik Virtual Machine

## HARDWARE ABSTRACTION LAYER

Graphics    Audio    Camera    Bluetooth    GPS    Radio (RIL)    WiFi    ...

## LINUX KERNEL

Display Driver    Camera Driver    Bluetooth Driver    Shared Memory Driver    Binder (IPC) Driver  
USB Driver    Keypad Driver    WiFi Driver    Audio Drivers    Power Management

# Hardware Abstraction Libraries



- User space C/C++ library layer
- Defines the interface that Android requires hardware “drivers” to implement
- Separates the Android platform logic from the hardware interface

HARDWARE ABSTRACTION LAYER

Graphics

Audio

Camera

Bluetooth

GPS

Radio (RIL)

WiFi

...

ANDROID

# Hardware Abstraction Libraries



## Why do we need a user-space HAL?

- Not all components have standardized kernel driver interfaces
- Kernel drivers are GPL which exposes any proprietary IP
- Android has specific requirements for hardware drivers

### HARDWARE ABSTRACTION LAYER

Graphics

Audio

Camera

Bluetooth

GPS

Radio (RIL)

WiFi

...

ANDROID

# HAL Header Example



```
// must be provided by each Acme hardware implementation
typedef struct {
    int (*foo)( void );
    char (*bar)( void );
    ...
} AcmeFunctions;
```

```
const AcmeFunctions *Acme_Init(const struct Env *env, int argc, char **argv);
```

## HARDWARE ABSTRACTION LAYER

Graphics

Audio

Camera

Bluetooth

GPS

Radio (RIL)

WiFi

...

ANDROID

# Hardware Abstraction Libraries



- Libraries are loaded dynamically at runtime as needed

```
dlHandle = dlopen("/system/lib/libacme.so", RTLD_NOW);  
...  
acmeInit = (const AcmeFunctions **)(const struct Env *,  
    int, char ***)dlsym(dlHandle, "Acme_Init");  
...  
acmeFuncs = acmeInit(&env, argc, argv);
```

## HARDWARE ABSTRACTION LAYER

Graphics

Audio

Camera

Bluetooth

GPS

Radio (RIL)

WiFi

...

ANDROID

# Agenda

- Android Anatomy
  - Linux Kernel
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  - Android Runtime
  - Application Framework
- Android Physiology
  - Start-up Walkthrough
  - Layer Interaction



# Android Anatomy



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# Dalvik Virtual Machine



- Android's custom clean-room implementation virtual machine
  - Provides application portability and runtime consistency
  - Runs optimized file format (.dex) and Dalvik bytecode
  - Java .class / .jar files converted to .dex at build time



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# Dalvik Virtual Machine



- Designed for embedded environment
  - Supports multiple virtual machine processes per device
  - Highly CPU-optimized bytecode interpreter
  - Uses runtime memory very efficiently



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# Core Libraries



- Core APIs for Java language provide a powerful, yet simple and familiar development platform
  - Data structures
  - Utilities
  - File access
  - Network Access
  - Graphics
  - ...



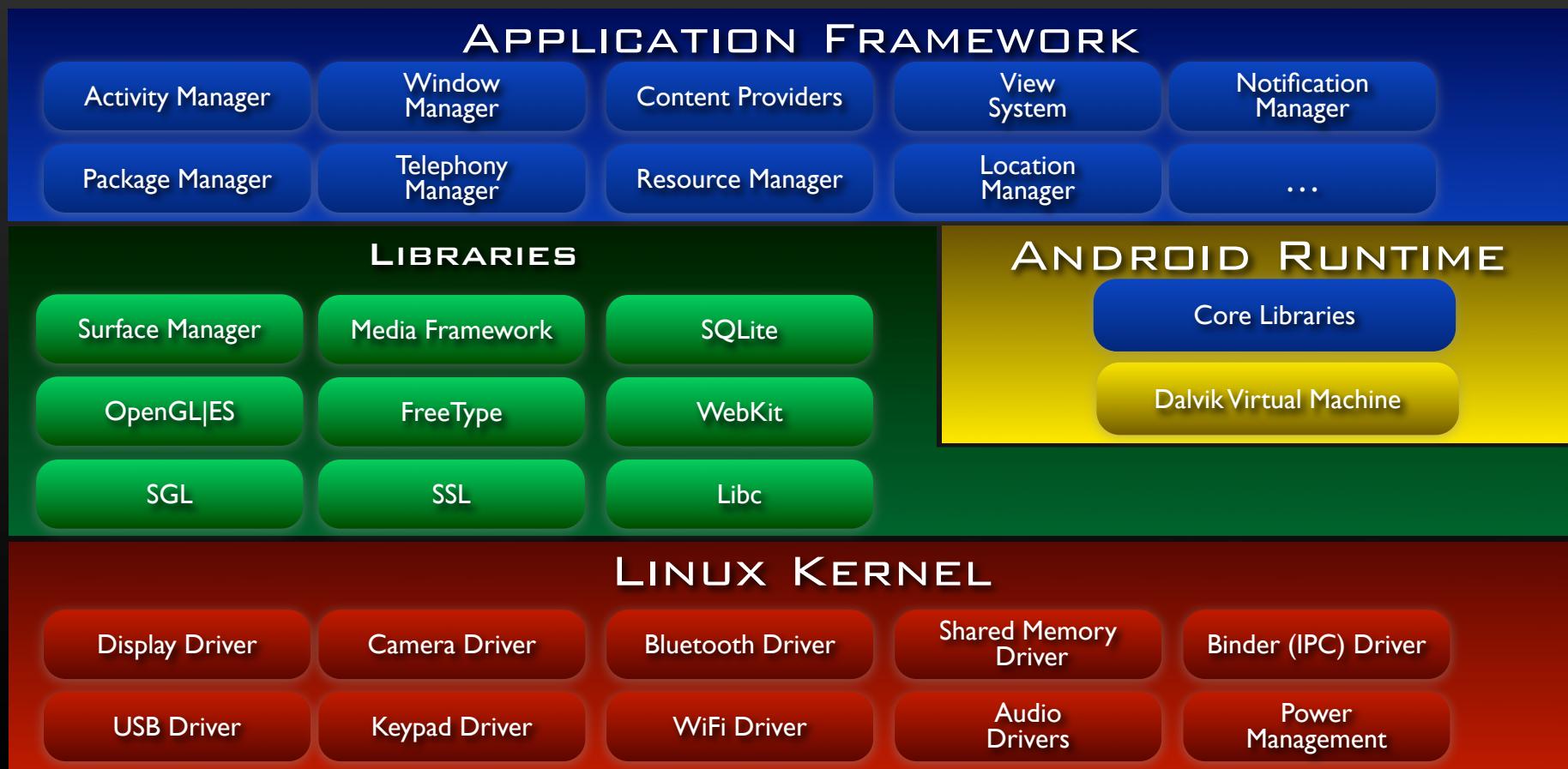
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# Android Anatomy



# Core Platform Services



- Services that are essential to the Android platform
- Behind the scenes - applications typically don't access them directly

## APPLICATION FRAMEWORK

Activity Manager

Window Manager

Content Providers

View System

Notification Manager

Package Manager

Telephony Manager

Resource Manager

Location Manager

...

ANDROID

# Core Platform Services



- Activity Manager



android

# Core Platform Services



- Activity Manager
- Package Manager



android

# Core Platform Services



- Activity Manager
- Package Manager
- Window Manager



android

# Core Platform Services



- Activity Manager
- Package Manager
- Window Manager
- Resource Manager



android

# Core Platform Services



- Activity Manager
- Package Manager
- Window Manager
- Resource Manager
- Content Providers



android

# Core Platform Services



- Activity Manager
- Package Manager
- Window Manager
- Resource Manager
- Content Providers
- View System



android

# Hardware Services



- Provide access to lower-level hardware APIs



android

# Hardware Services



- Provide access to lower-level hardware APIs
- Typically accessed through local *Manager* object

```
LocationManager lm = (LocationManager)  
    Context.getSystemService(Context.LOCATION_SERVICE);
```



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# Hardware Services



- Telephony Service



android

# Hardware Services



- Telephony Service
- Location Service



android

# Hardware Services



- Telephony Service
- Location Service
- Bluetooth Service



android

# Hardware Services



- Telephony Service
- Location Service
- Bluetooth Service
- WiFi Service



android

# Hardware Services



- Telephony Service
- Location Service
- Bluetooth Service
- WiFi Service
- USB Service



android

# Hardware Services



- Telephony Service
- Location Service
- Bluetooth Service
- WiFi Service
- USB Service
- Sensor Service



android

# Application Framework



## More Information

- At Google I/O
  - “Inside the Android Application Framework”
- Online
  - <http://code.google.com/android>



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# Android Anatomy



## APPLICATIONS

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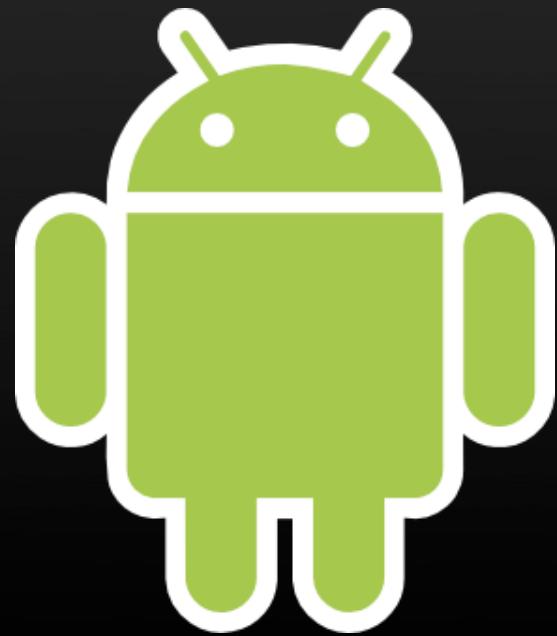
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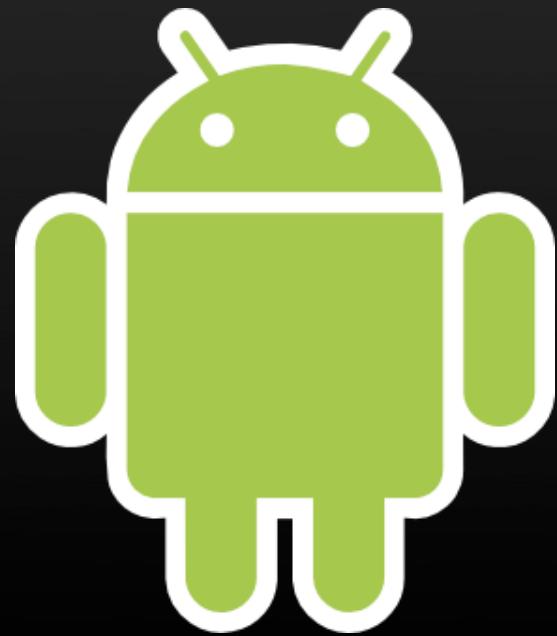
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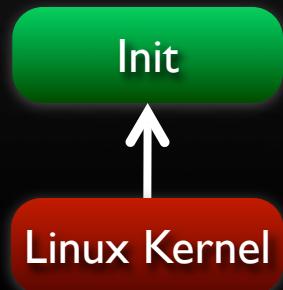


# Runtime Walkthrough



It all starts with init...

Similar to most Linux-based systems at startup, the bootloader loads the Linux kernel and starts the init process.



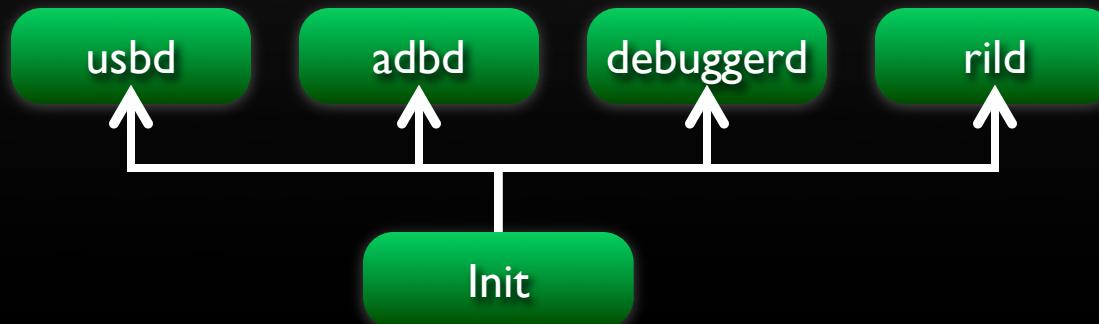
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# Runtime Walkthrough



Init starts Linux daemons, including:

- USB Daemon (usbd) to manage USB connections
- Android Debug Bridge (adbd) to manage ADB connections
- Debugger Daemon (debuggerd) to manage debug processes requests (dump memory, etc.)
- Radio Interface Layer Daemon (rild) to manage communication with the radio



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# Runtime Walkthrough



Init process starts the zygote process:

- A nascent process which initializes a Dalvik VM instance
- Loads classes and listens on socket for requests to spawn VMs
- Forks on request to create VM instances for managed processes
- Copy-on-write to maximize re-use and minimize footprint



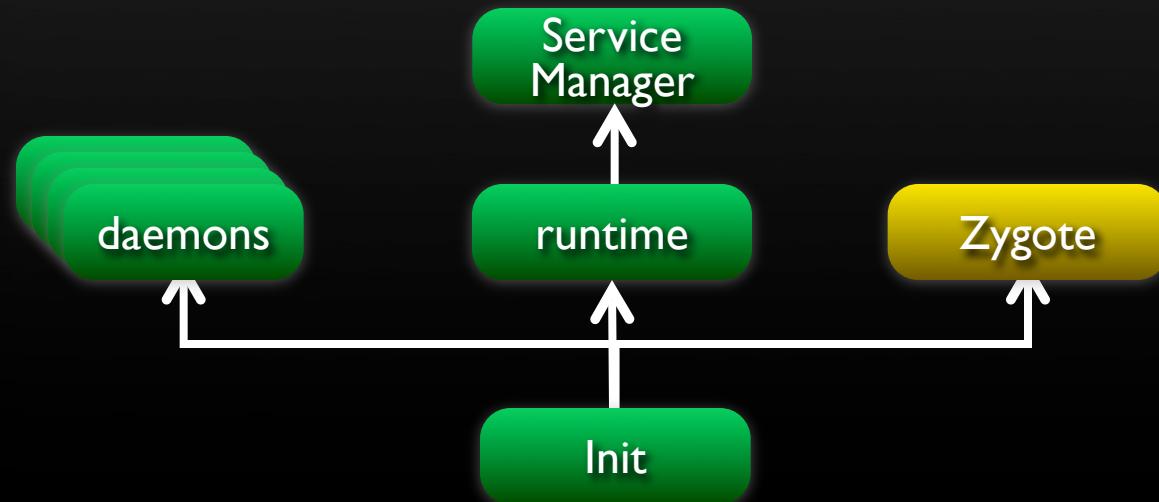
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# Runtime Walkthrough



Init starts runtime process:

- Initializes Service Manager – the context manager for Binder that handles service registration and lookup
- Registers Service Manager as default context manager for Binder services

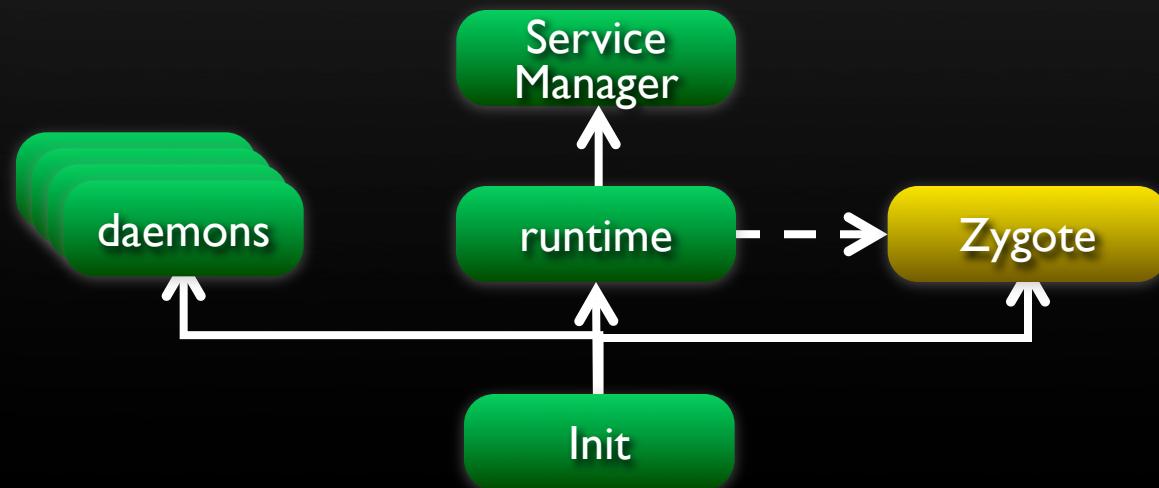


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# Runtime Walkthrough



Runtime process sends request for Zygote to start System Service



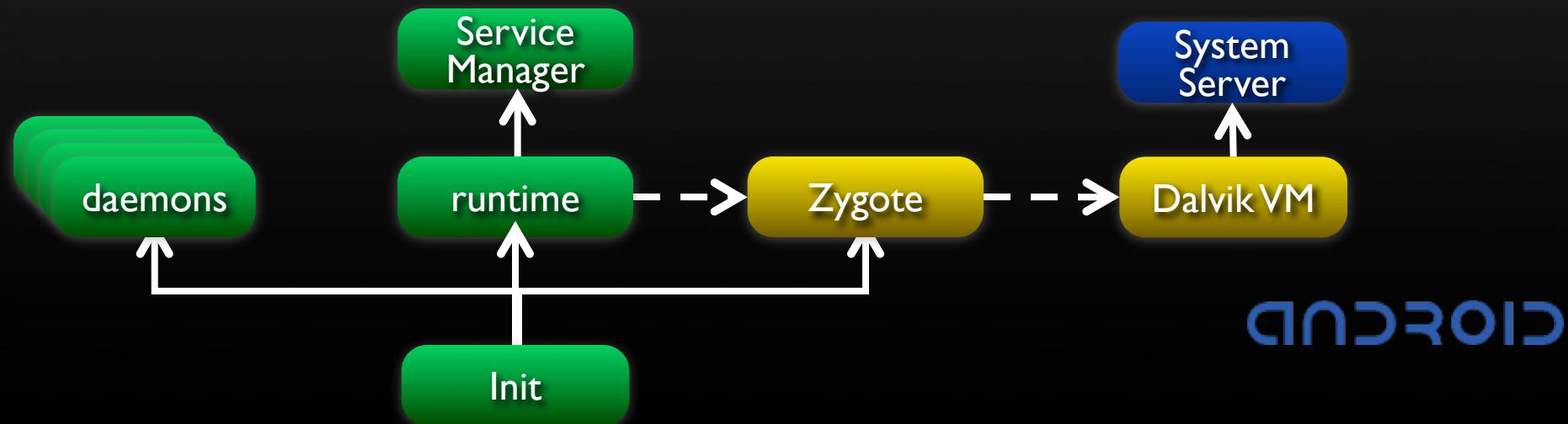
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# Runtime Walkthrough



Runtime process sends request for Zygote to start System Server

- Zygote forks a new VM instance for the System Service process and starts the service

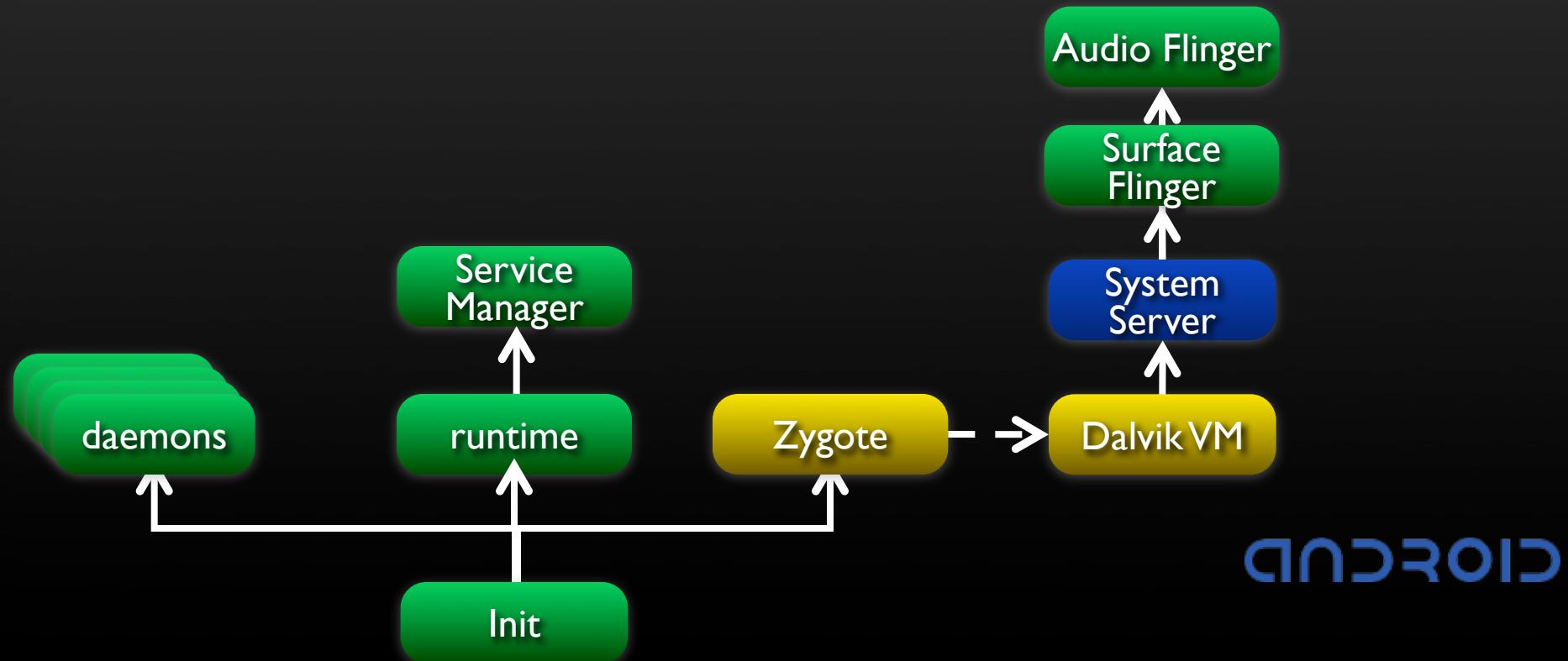


# Runtime Walkthrough



System Service starts the native system servers, including:

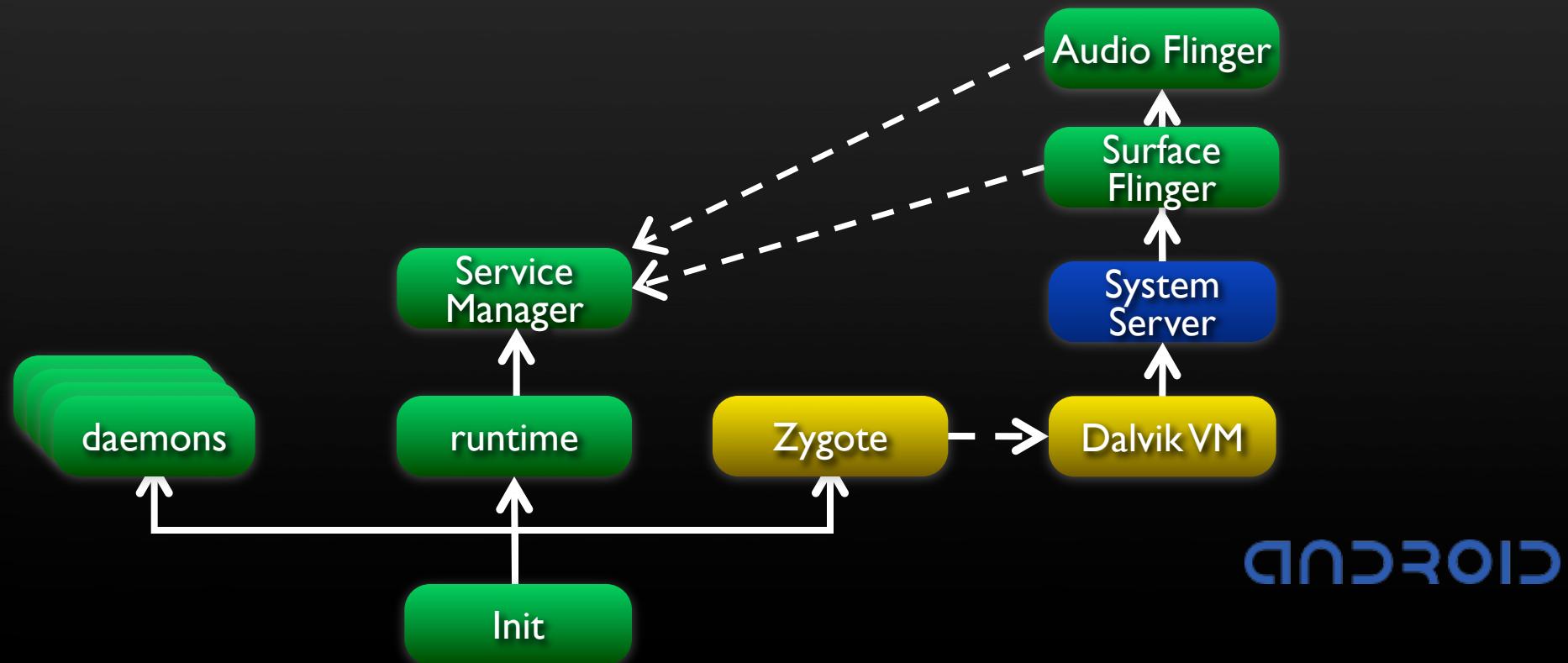
- Surface Flinger
- Audio Flinger



# Runtime Walkthrough



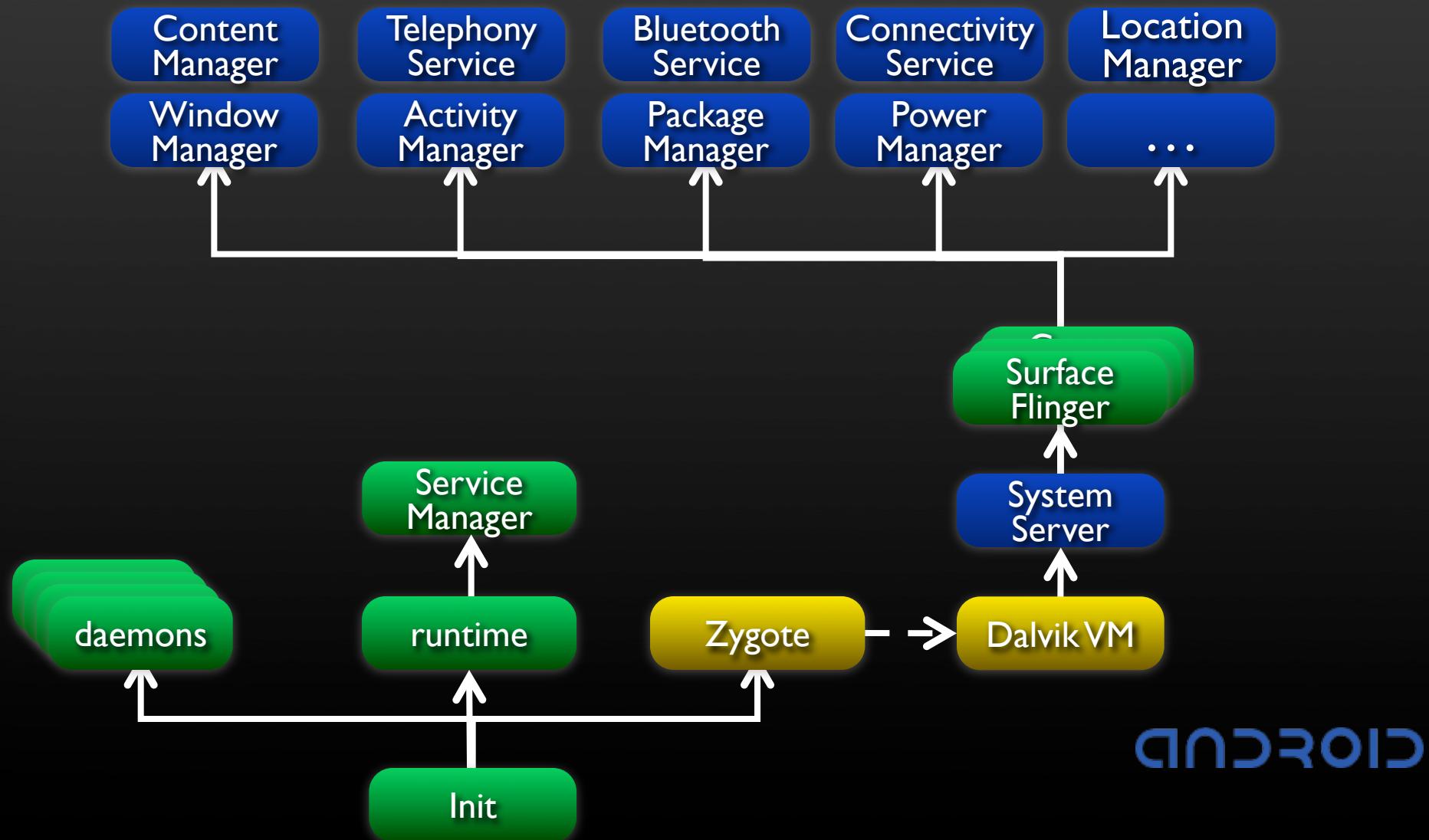
Native system servers register with Service Manager as IPC service targets:



# Runtime Walkthrough



System Service starts the Android managed services:

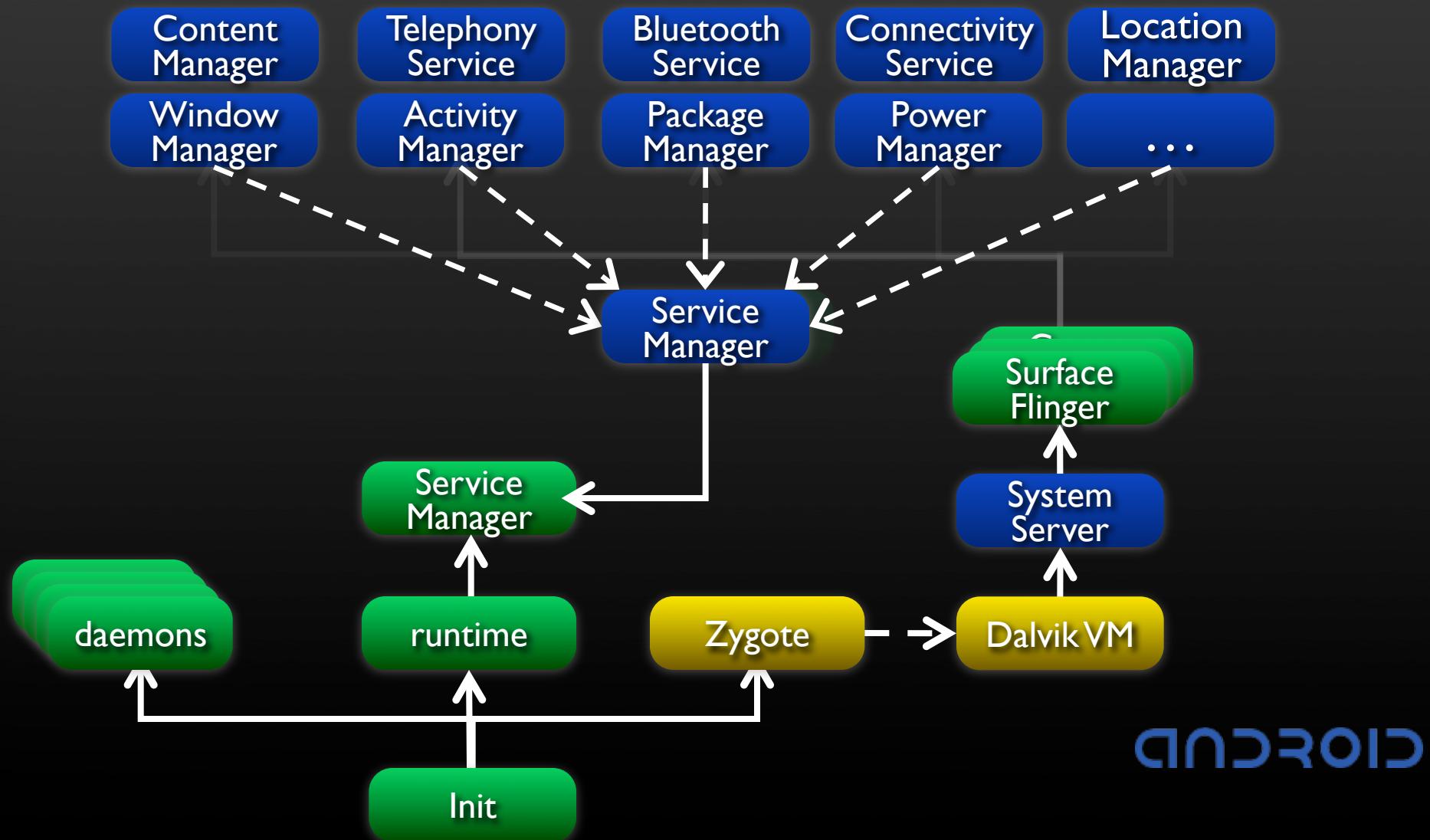


ANDROID

# Runtime Walkthrough

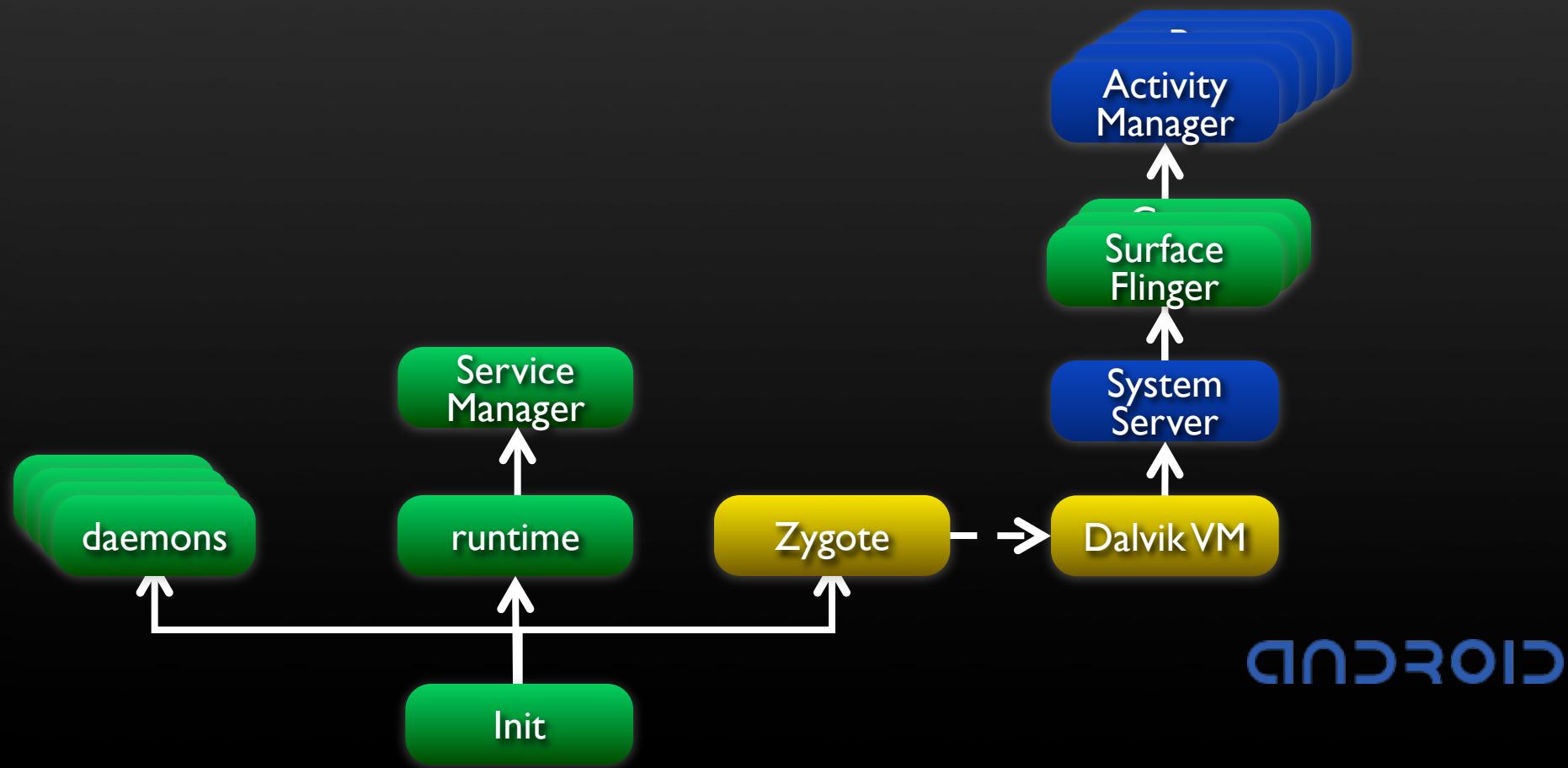


Android managed Services register with Service Manager:



ANDROID

# Runtime Walkthrough



ANDROID

# Runtime Walkthrough



After system server loads all services, the system is ready...



# Runtime Walkthrough



After system server loads all services, the system is ready...



# Runtime Walkthrough



After system server loads all services, the system is ready...



# Runtime Walkthrough

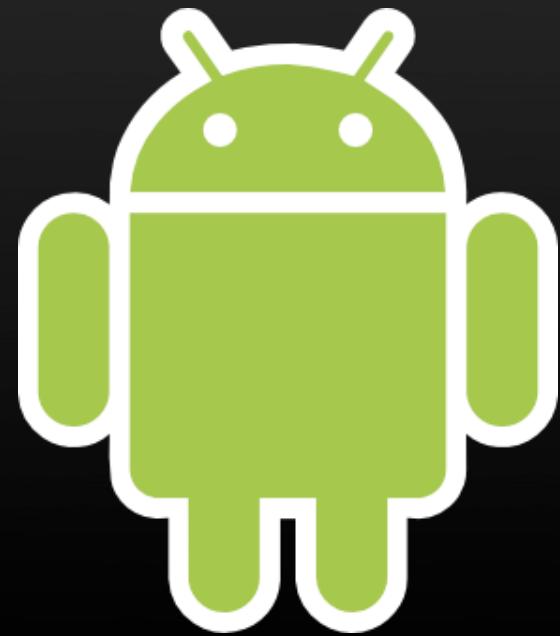


Each subsequent application is launched in it's own process



# Agenda

- Android Anatomy
  - Linux Kernel
  - Native Libraries
  - Framework Services
- Android Physiology
  - Start-up Walkthrough
  - Layer Interaction



# Layer Interaction



There are 3 main flavors of Android layer cake:

- App → Runtime Service → lib
- App → Runtime Service → Native Service → lib
- App → Runtime Service → Native Daemon → lib

# Layer Interaction



There are 3 main flavors of Android layer cake:

- App → Runtime Service → lib
- App → Runtime Service → Native Service → lib
- App → Runtime Service → Native Daemon → lib



# Android Runtime Services



APPLICATIONS

Application

Binder IPC

APPLICATION FRAMEWORK

Runtime Service

LIBRARIES

LINUX KERNEL

Kernel Driver

ANDROID

# Android Runtime Services



APPLICATIONS

Application

Binder IPC

APPLICATION FRAMEWORK

Runtime Service

JNI

LIBRARIES

Native Service Binding

LINUX KERNEL

Kernel Driver

ANDROID

# Android Runtime Services



APPLICATIONS

Application

Binder IPC

APPLICATION FRAMEWORK

Runtime Service

JNI

LIBRARIES

Native Service Binding

Dynamic load

LINUX KERNEL

HAL Library

Kernel Driver

ANDROID

# Android Runtime Services



APPLICATIONS

Application

Binder IPC

APPLICATION FRAMEWORK

Runtime Service

JNI

LIBRARIES

Native Service Binding

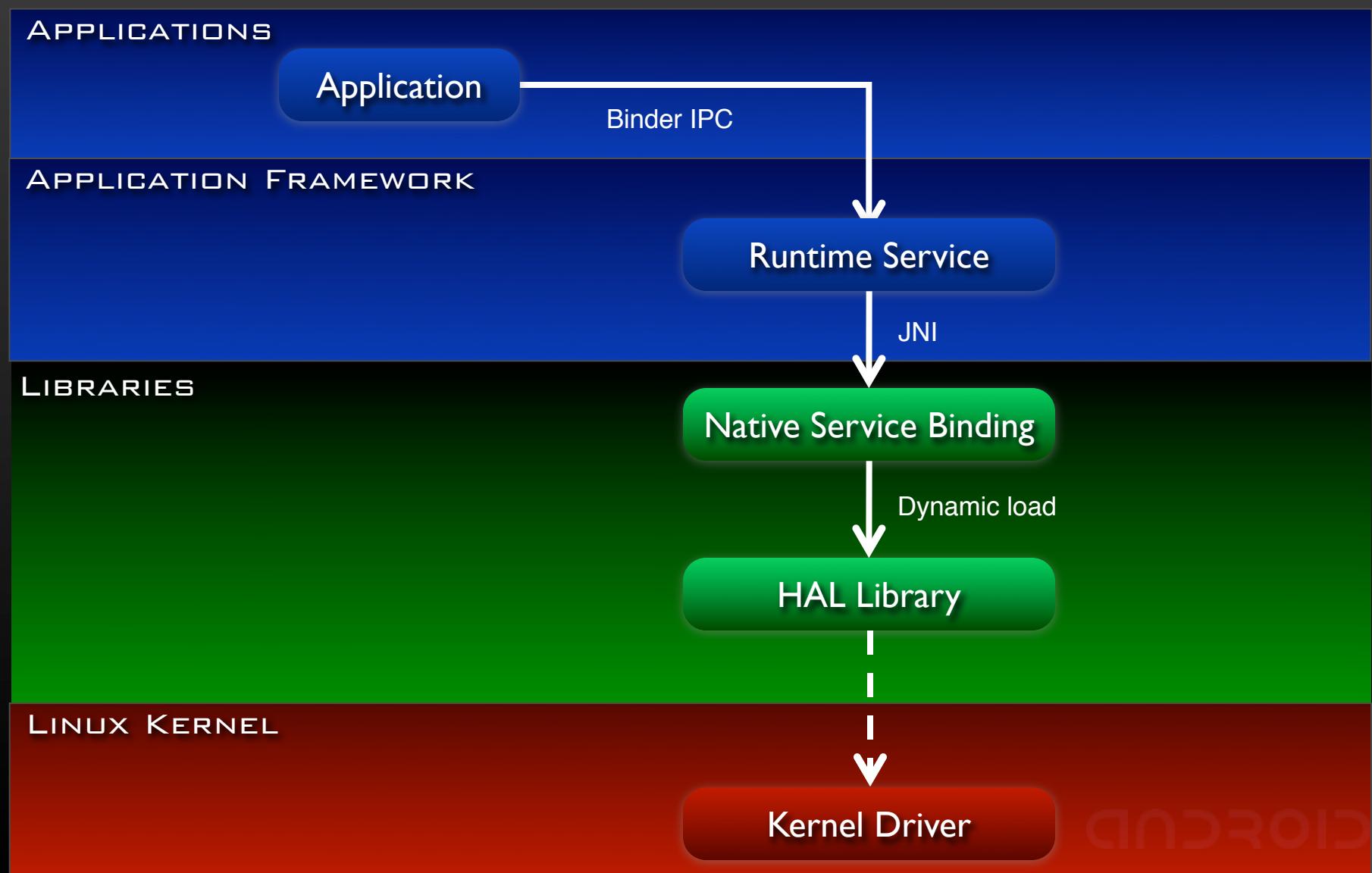
Dynamic load

HAL Library

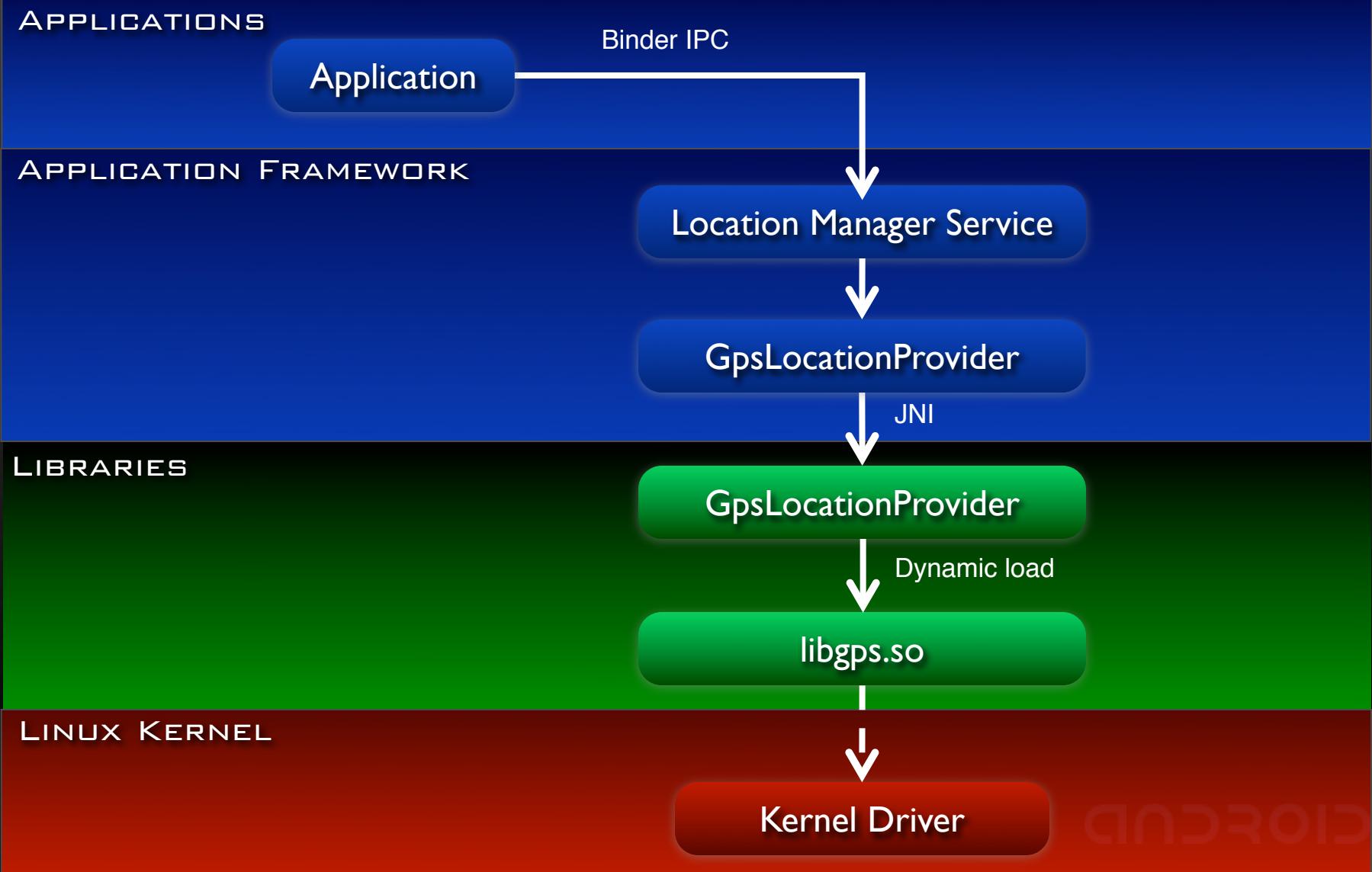
LINUX KERNEL

Kernel Driver

ANDROID



# Example: Location Manager



# Layer Interaction



There are 3 main flavors of Android layer cake:

- App → Runtime Service → lib
- App → Runtime Service → Native Service → lib
- App → Runtime Service → Native Daemon → lib



# Android Native Services



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

## LIBRARIES

Runtime  
Service

JNI

Native Service  
Binding

## LINUX KERNEL

ANDROID

# Android Native Services



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

Runtime Service

## LIBRARIES

Native Service Binding

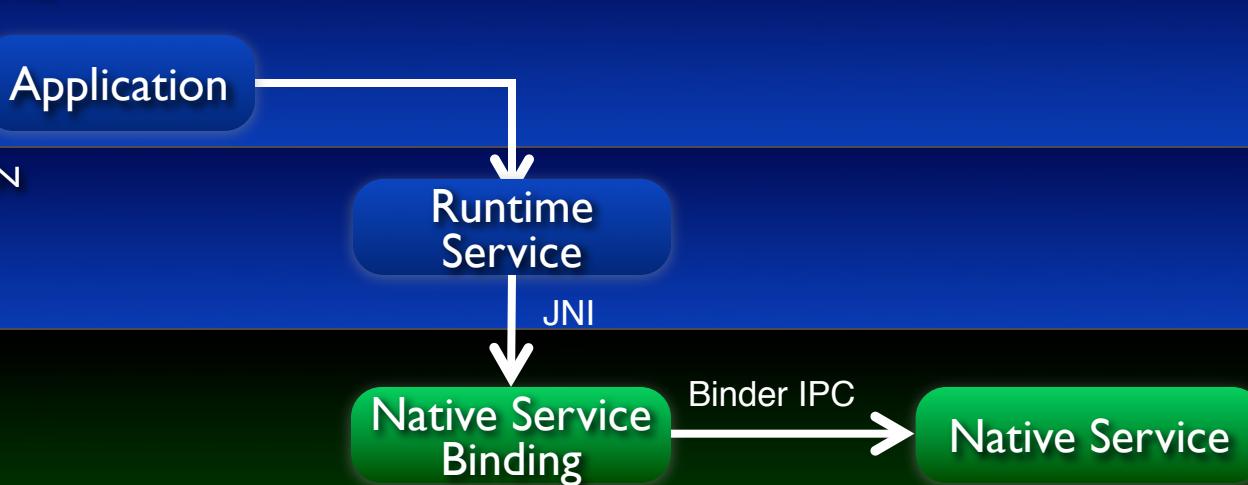
## LINUX KERNEL

Native Service

JNI

Binder IPC

ANDROID



# Android Native Services



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

Runtime Service

## LIBRARIES

Native Service Binding

## LINUX KERNEL

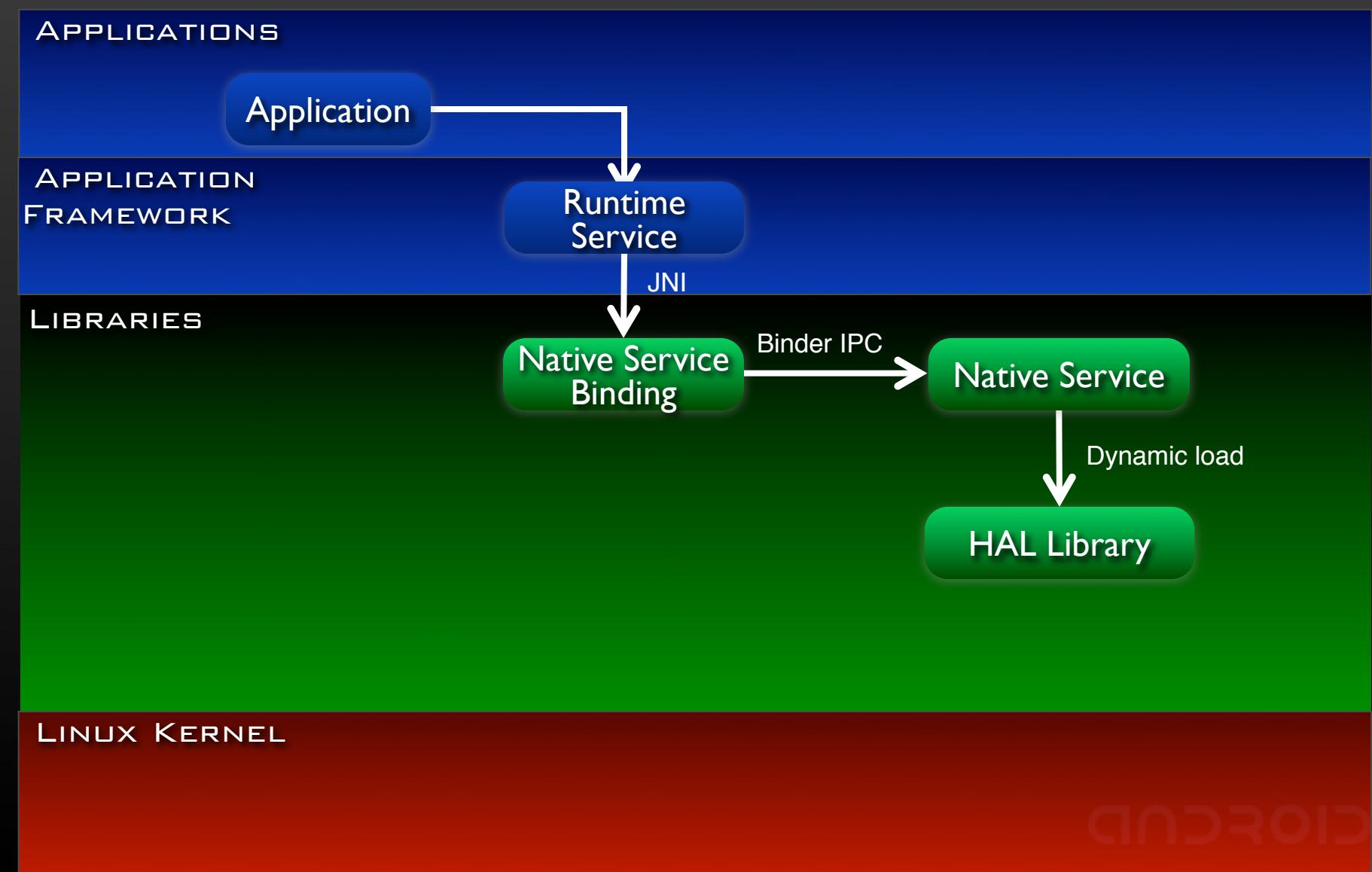
ANDROID

JNI

Binder IPC

Dynamic load

HAL Library



# Android Native Services



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

Runtime Service

## LIBRARIES

Native Service Binding

Native Service

## LINUX KERNEL

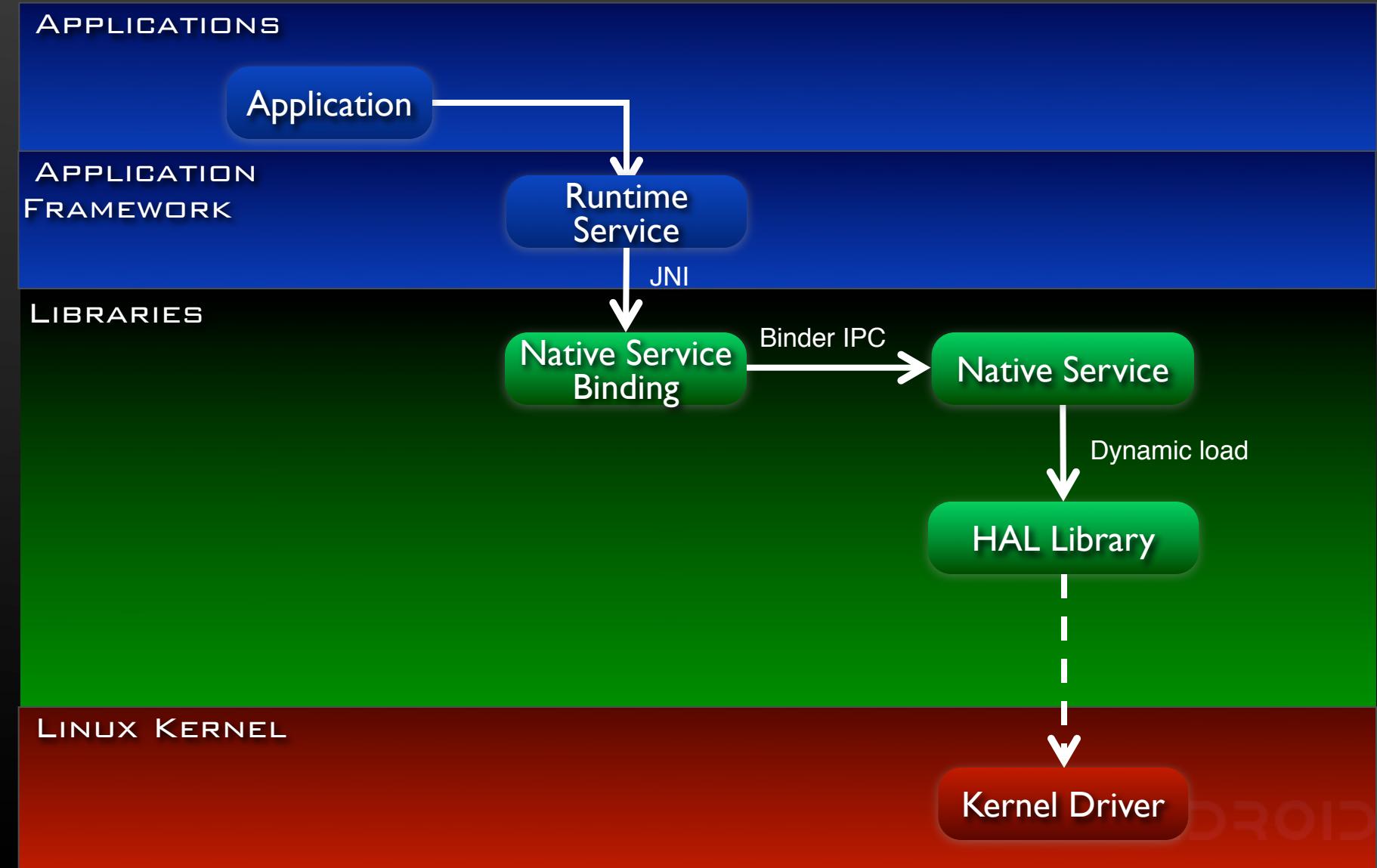
HAL Library

Kernel Driver

JNI

Binder IPC

Dynamic load



# Android Native Services



APPLICATIONS

Application

APPLICATION  
FRAMEWORK

MediaPlayer

LIBRARIES

MediaPlayer

Media  
Framework

LINUX KERNEL

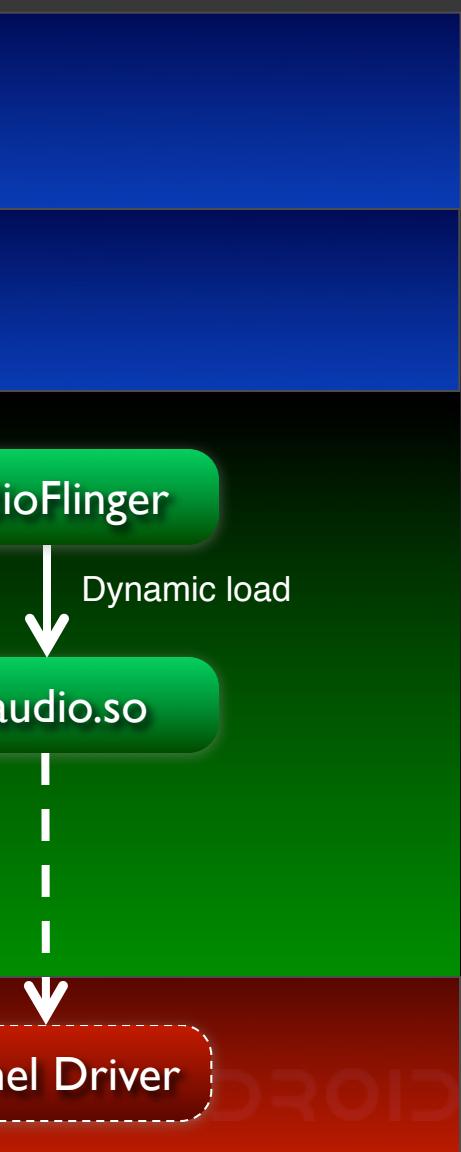
JNI

Binder IPC

Dynamic load

libaudio.so

Kernel Driver



# Android Native Services



APPLICATIONS

Application

APPLICATION  
FRAMEWORK

MediaPlayer

LIBRARIES

MediaPlayer

Media  
Framework

LINUX KERNEL

Kernel Driver

JNI

Binder IPC

Dynamic load

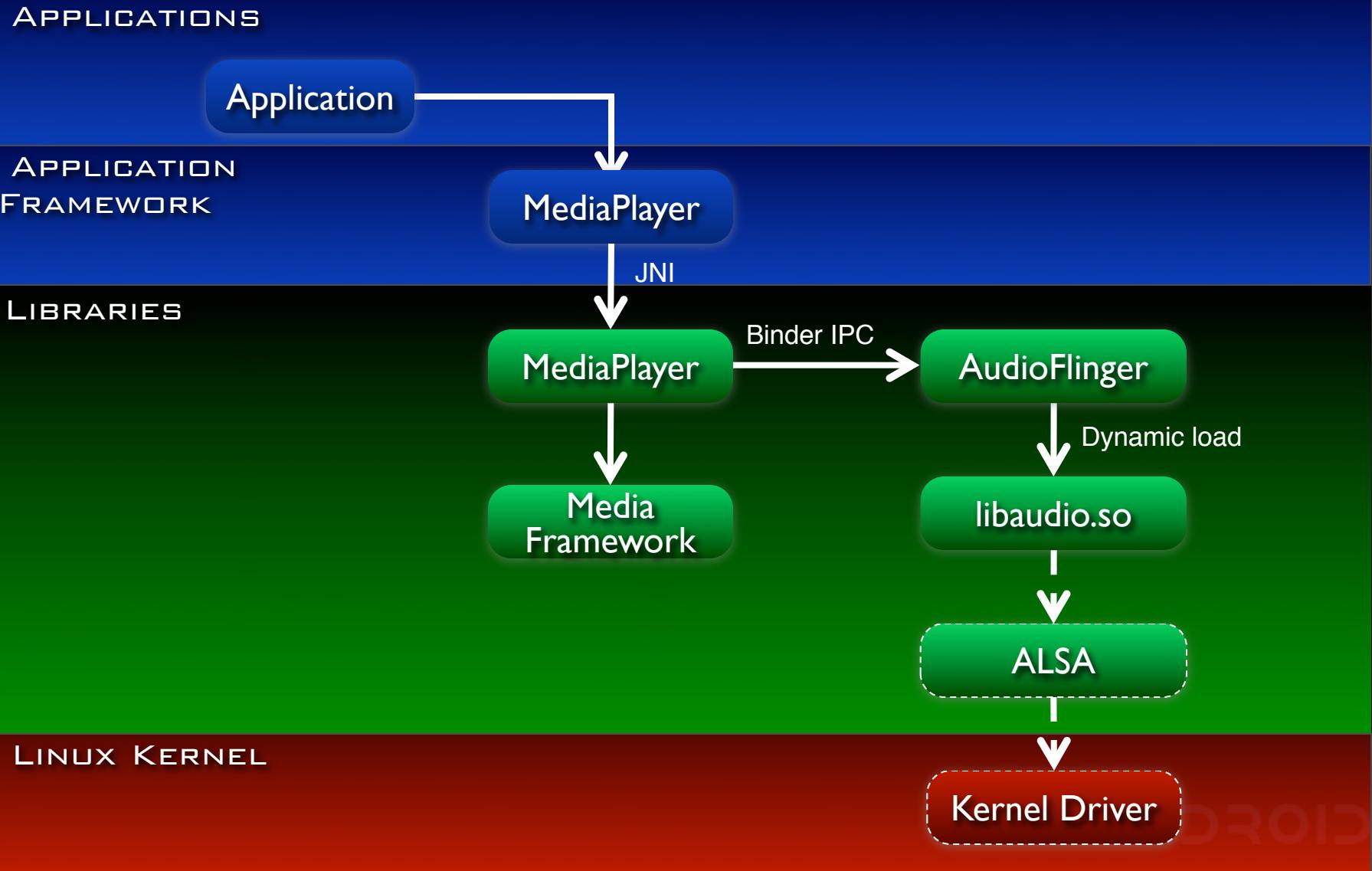
libaudio.so

I

ALSA

I

Kernel Driver



# Android Native Services



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

MediaPlayer

## LIBRARIES

MediaPlayer

Media Framework

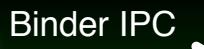
Binder IPC

AudioFlinger

Dynamic load

libaudio.so

Proprietary  
Audio Driver



## LINUX KERNEL

ANDROID

# Layer Interaction



There are 3 main flavors of Android layer cake:

- App → Runtime Service → lib
- App → Runtime Service → Native Service → lib
- App → Runtime Service → Native Daemon → lib

# Daemon Connection



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

## LIBRARIES

Runtime  
Service

JNI

Native Service  
Binding

## LINUX KERNEL

Kernel Driver

# Daemon Connection



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

Runtime  
Service

## LIBRARIES

Native Service  
Binding

JNI

sockets

Daemon

## LINUX KERNEL

Kernel Driver

# Daemon Connection



## APPLICATIONS

Application

## APPLICATION FRAMEWORK

Runtime Service

## LIBRARIES

Native Service Binding

## LINUX KERNEL

Kernel Driver

JNI

sockets

Daemon

Dynamic load

HAL Library

ANDROID



# Daemon Connection



## APPLICATIONS

Application

Telephony Manager

## APPLICATION FRAMEWORK

## LIBRARIES

Telephony Manager

rild

libril.so

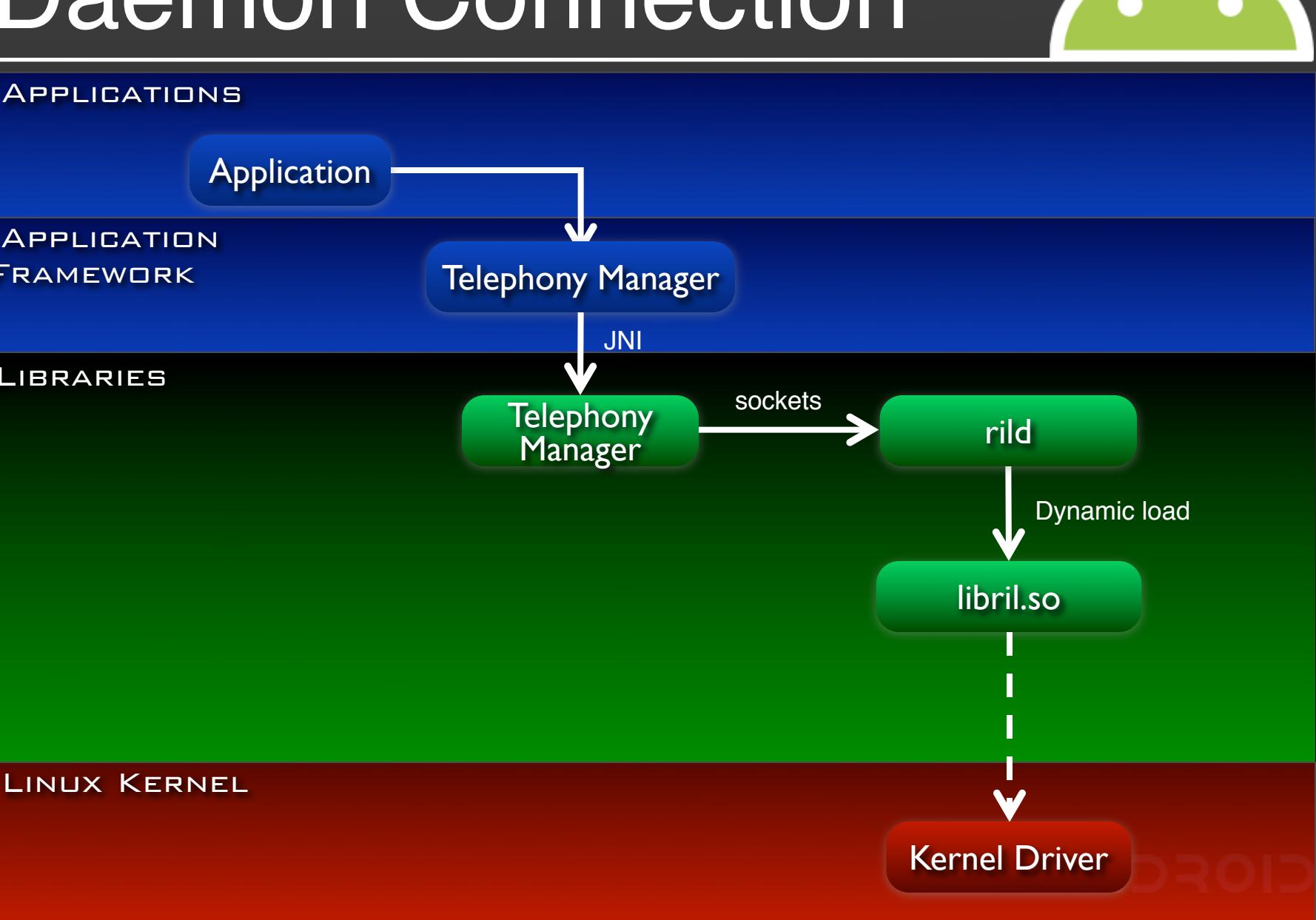
## LINUX KERNEL

Kernel Driver

JNI

sockets

Dynamic load



# Layer Interaction



There are 3 main flavors of Android layer cake:

- App → Runtime Service → lib
- App → Runtime Service → Native Service → lib
- App → Runtime Service → Native Daemon → lib

# Android Anatomy



## APPLICATIONS

Home    Dialer    SMS/MMS    IM    Browser    Camera    Alarm    Calculator  
Contacts    Voice Dial    Email    Calendar    Media Player    Albums    Clock    ...

## APPLICATION FRAMEWORK

Activity Manager    Window Manager    Content Providers    View System    Notification Manager  
Package Manager    Telephony Manager    Resource Manager    Location Manager    ...

## LIBRARIES

Surface Manager    Media Framework    SQLite  
OpenGL|ES    FreeType    WebKit  
SQL    SSL    Libc

## ANDROID RUNTIME

Core Libraries  
Dalvik Virtual Machine

## LINUX KERNEL

Display Driver    Camera Driver    Bluetooth Driver    Shared Memory Driver    Binder (IPC) Driver  
USB Driver    Keypad Driver    WiFi Driver    Audio Drivers    Power Management

# The End

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[code.google.com](http://code.google.com)

# Questions

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# Q&A

android