

Marakana Android Internals

REVISION HISTORY			
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Contents

1	Overview	1
2	Android Stack	2
2.1	Android Linux Kernel Layer	3
2.1.1	Overview	3
2.1.2	Binder IPC	4
2.1.3	Ashmem (Anonymous SHared MEMory)	5
2.1.4	Pmem	5
2.1.5	Wakelocks	6
2.1.6	Early Suspend	7
2.1.7	Alarm	7
2.1.8	Low Memory Killer (a.k.a. Viking Killer)	7
2.1.9	Logger	9
2.1.10	Paranoid Network Security	9
2.1.11	Other Kernel Changes	10
2.2	Android User-Space Native Layer	11
2.2.1	Bionic Library	12
2.2.2	Changes From BSD libc	12
2.2.3	User-space Hardware Abstraction Layer (HAL)	13
2.2.4	Native Daemons	14
2.2.5	Flingers	16
	Surface Flinger	16
	Audio Flinger	16
2.2.6	Function Libraries	17
2.2.7	Dalvik	17
2.3	Android Application Framework Layer	19
2.3.1	Overview	19
2.3.2	Activity Manager Service	20
2.3.3	Package Manager Service	20
2.3.4	Power Manager Service	21
2.3.5	Alarm Manager Service	21
2.3.6	Notification Manager Service	21
2.3.7	Keyguard Manager Service	21
2.3.8	Location Manager Service	21
2.3.9	Sensor Manager Service	21
2.3.10	Search Manager Service	21
2.3.11	Vibrator Manager Service	21

2.3.12	Connectivity Manager Service	22
2.3.13	Wifi Manager Service	22
2.3.14	Telephony Manager Service	22
2.3.15	Input Method Manager Service	22
2.3.16	UI Mode Manager Service	22
2.3.17	Download Manager Service	23
2.3.18	Storage Manager Service	23
2.3.19	Audio Manager Service	23
2.3.20	Window Manager Service	23
2.3.21	Layout Inflater Manager Service	23
2.3.22	Resource Manager Service	23
2.3.23	Additional Manager Services	24
2.4	Android Applications Layer	24
2.4.1	Android Built-in Applications	25
2.4.2	Android Built-in Content Providers	26
2.4.3	Android Built-in Input Methods	26
2.4.4	Android Built-in Wallpapers	26
3	Android Native Development Kit (NDK)	26
3.1	What is in NDK?	26
3.2	Why NDK?	27
3.3	Java Native Interface (JNI)	27
3.3.1	JNI Overview	27
3.3.2	JNI Components	28
3.3.3	JNI By Example	28
3.3.4	Native Method Arguments	30
3.3.5	Primitive Type Mapping	30
3.3.6	Reference Type Mapping	31
3.3.7	Global and Local References	32
3.3.8	Using Strings	33
3.3.9	Arrays	35
3.3.10	Reflection	38
3.3.11	Exceptions	42
3.4	Using NDK	44
3.5	Fibonacci Example	44
3.5.1	Fibonacci - Java Native Function Prototypes	44
3.5.2	Fibonacci - Function Prototypes in a C Header File	45
3.5.3	Fibonacci - Provide C Implementation	46
3.5.4	Fibonacci - An Alternative Implementation (C++)	47

3.5.5	Fibonacci - Makefile	48
3.5.6	Fibonacci - Compile Our Shared Module	49
	Controlling CPU Application Binary Interface (ABI)	49
3.5.7	Fibonacci - Client	50
	Fibonacci - String Resources	50
	Fibonacci - User Interface (Layout)	51
	Fibonacci - <code>FibonacciActivity</code>	52
3.5.8	Fibonacci - Result	54
3.6	NDK's Stable APIs	54
3.6.1	Android-specific Log Support	54
3.6.2	ZLib Compression Library	54
3.6.3	The OpenGL ES 1.x Library	55
3.6.4	The OpenGL ES 2.0 Library	55
3.6.5	The <code>jnigraphics</code> Library	55
3.6.6	The OpenSL ES native audio Library	55
3.6.7	The Android native application APIs	56
3.7	Lab: NDK	56
4	Android Binder Inter Process Communication (IPC) with AIDL	57
4.1	Why IPC?	57
4.2	What is Binder?	58
4.3	What is AIDL?	58
4.4	Fibonacci Example: Building a Binder-based Service and Client	61
4.5	FibonacciCommon - Define AIDL Interface and Custom Types	61
4.6	FibonacciService - Implement AIDL Interface and Expose It To Our Clients	65
4.7	Implement AIDL Interface	65
4.8	Expose our AIDL-defined Service Implementation to Clients	66
4.9	FibonacciClient - Using AIDL-defined Binder-based Services	68
4.10	Async-IPC via Binder	73
	4.10.1 FibonacciCommon - Defining a <code>oneway</code> AIDL Service	73
	4.10.2 FibonacciService - Implementing our <code>async</code> AIDL service	73
	4.10.3 FibonacciClient - Implementing our <code>async</code> AIDL client	74
4.11	Lab: Binder-based Service with AIDL	78
5	Android Security	79
5.1	Android Security Architecture	79
5.2	Application Signing	80
	5.2.1 Platform Keys	81
5.3	User IDs	82

5.4	File Access	83
5.5	Using Permissions	84
5.6	Permission Enforcement	86
5.6.1	Kernel / File-system Permission Enforcement	86
5.6.2	UID-based Permission Enforcement	87
5.6.3	Static Permission Enforcement	87
5.6.4	Enforcing Permissions Dynamically	89
5.7	Declaring Custom Permissions	90
5.7.1	Permission Components	91
5.7.2	Adding Custom Permissions Dynamically	91
5.8	Fibonacci Example: Custom Permissions	92
5.8.1	Static Permission Enforcement	93
5.8.2	Dynamic Permission Enforcement	95
5.9	Lab: Custom Permissions	97
5.10	ContentProvider URI Permissions	98
5.11	Public vs. Private Components	99
5.12	Intent Broadcast Permissions	99
5.13	Pending Intents	99
5.14	Encryption	100
5.14.1	Data encryption	100
5.14.2	Whole Disk Encryption	103
5.14.3	VPN	105
5.14.4	Keystore and Keychain API	106
5.15	Rooting an Android device	107
5.15.1	Controlling access to /system/bin/su with <i>Superuser</i>	107
5.15.2	UDEV exploit (CVE-2009-1185)	108
5.15.3	ADB setuid exhaustion attack (CVE-2010-EASY)	108
5.15.4	Zimperlich attack against Zygote	109
5.15.5	Ashmem memory protection attack (CVE-2011-1149)	109
5.15.6	Buffer Overrun on vold exploit (CVE-2011-1823)	109
5.15.7	Linux Local Privilege Escalation via SUID /proc/pid/mem Write (CVE-2012-0056)	110
5.15.8	WebKit exploit	110
5.15.9	To Root or Not To Root?	111
5.15.10	Malware Rootkits	111
5.16	Security of Memory	111
5.17	Tap-Jacking on Android	112
5.18	Android Device Administration	113
5.18.1	Device Administration Overview	113
5.18.2	Device Administration Overview (cont.)	114

5.18.3	Security Policies	115
5.18.4	The Device Administration Classes	115
5.18.5	Creating the Manifest	115
5.18.6	Creating the Manifest (cont.)	116
5.18.7	The <code>DeviceAdminReceiver</code> Class	117
5.18.8	Testing Whether the Admin Application is Enabled	117
5.18.9	Enabling the Application	117
5.18.10	Setting Password Quality Policies	118
5.18.11	Setting Password Quality Policies, API 11	119
5.18.12	Setting the Device Password	119
5.18.13	Locking and Wiping the Device	120
5.18.14	Device Administration Demo	120
5.18.15	Android Manifest File	120
5.18.16	XML Resource File	121
5.18.17	Device Admin Receiver Component	121
5.18.18	Activity	122
5.18.19	Lab (Device Administration)	124
5.19	Malware	125
5.19.1	Lessons From The Field	125
5.19.2	Detection	126
5.19.3	Removal	128
5.20	SE Android (SE-Linux on Android)	128
5.21	Other Security Concerns	129
6	Building Android From Source	131
6.1	Why Build Android From Source?	131
6.2	Setting up the Build Environment	131
6.3	Downloading the Source Tree	132
6.4	Android Source Code Structure	132
6.5	Android Build System	133
6.6	Initializing the Build Environment	134
6.7	Choosing the Build Target	134
6.8	Compiling Android	136
6.8.1	Makefile targets	137
6.9	Examining the Built Images	137
6.10	Running Custom Android Build on Emulator	139
6.11	Running Custom Android Build on Real Hardware	140
6.12	Building the Linux Kernel	141
6.13	Getting the Kernel	141
6.13.1	Building Kernel for the Emulator (Goldfish)	141

7	Android Startup	144
7.1	Bootloading the Kernel	144
7.2	Android's <code>init</code> Startup	146
7.3	Zygote Startup	148
7.4	System Server Startup	149
8	Android Services	150
8.1	Vibrator	151
8.2	Power Service	152
8.2.1	Links	152
8.3	Alarm Service	153
8.4	Package Service	154
8.5	WiFi Service	154
8.5.1	Links	155
8.6	Location Service	156
8.7	Audio Service	157
8.7.1	Links	159
8.8	Android Media Framework	159
8.8.1	Introduction	159
8.8.2	Typical stack of function calls	160
8.8.3	The media server process	161
8.8.4	Stagefright	161
	Intro	161
	Example	161
	Pipeline	162
	Other components	162
8.8.5	OpenMAX IL 5.1 Overview	165
	OpenMAX IL in Stagefright	165
8.8.6	Adding a custom OpenMAX IL plugin	166
	Implement an OMX core for the codecs	166
	Build <code>libstagefrighthw</code>	166
	Implement OMX components for the codecs	167
	Register the new OMX components	167
8.9	Telephony	167
8.9.1	Telephony Manager	167
8.9.2	Phone App	167
	Overview	168
	<code>OutgoingCallBroadcaster</code>	168
	<code>CallController</code>	168

PhoneUtils	169
CallManager	169
Phone Interface	170
GSMPhone	170
RIL (Java)	170
RIL Daemon	170
RIL Initialization	170
RIL Interaction	171
Solicited RIL Commands	171
Unsolicited RIL Commands	172
Implementing the RIL	172
8.9.3 Links	173
8.10 Device Policy Service	174
8.11 Surface Flinger	175
8.11.1 Initialization	176
8.11.2 Getting something to draw on	176
8.11.3 Drawing	176
8.11.4 Displaying what we drew on	176
8.11.5 Other	177
8.11.6 Links	177
8.12 Camera Service	177
8.12.1 Links	177
8.13 NFC Service	178
9 Customizing Android	178
9.1 Setting up Custom Device Directory Structure	179
9.2 Registering our Device with Android's Build System	180
9.3 Adding the Makefile Plumbing for our Device	181
9.4 Generating Our Own Platform Signing Keys (Optional)	183
9.5 Building our Device For The First Time	184
9.6 Adding a Custom Kernel to our Device	186
9.7 Adding a Custom Native Library and Executable to our Device	191
9.8 Using our Native Library via a Custom Daemon	196
9.9 Exposing our Native Library via Java (i.e. JNI)	199
9.10 Consuming our a Custom Java/JNI→Native Library via a Custom App (Optional)	204
9.11 Exposing our Custom Library via a Custom IPC/Binder Service	208
9.12 Building a Custom App Using a Custom Service Manager	215
9.13 Creating a Custom SDK Add-on (Optional)	218
9.13.1 Distributing our Custom SDK Add-on (Optional)	227

10 Android USB Support (Appendix)	228
10.1 Overview of Android USB Support	228
10.1.1 Android USB Host and Accessory Modes	228
10.1.2 Android USB Support	229
10.2 Android USB Host Mode	229
10.2.1 API Overview	229
10.2.2 Using the Manifest to Require USB Support	230
10.2.3 Working with Devices	230
10.2.4 Discovering a Device Using an Intent Filter, The Manifest	231
10.2.5 Discovering a Device Using an Intent Filter, The Resource File	231
10.2.6 Enumerating USB Devices	232
10.2.7 Obtaining Permission to Communicate With a Device	232
10.2.8 Communicating With a Device	233
10.2.9 Terminating Communication With a Device	234
10.3 Android USB Accessory Mode	234
10.3.1 Choosing the Right USB Accessory APIs	235
10.3.2 API Overview	235
10.3.3 Android Manifest Requirements	236
10.3.4 Working with Accessories	236
10.3.5 Discovering a Device Using an Intent Filter, The Manifest	237
10.3.6 Discovering a Device Using an Intent Filter, The Resource File	237
10.3.7 Enumerating Accessories	238
10.3.8 Obtaining Permission to Communicate With an Accessory	238
10.3.9 Communicating With an Accessory	239
10.3.10 Terminating Communication With an Accessory	240
10.3.11 The Android Open Accessory Development Kit	240
11 Legal Disclaimer	241

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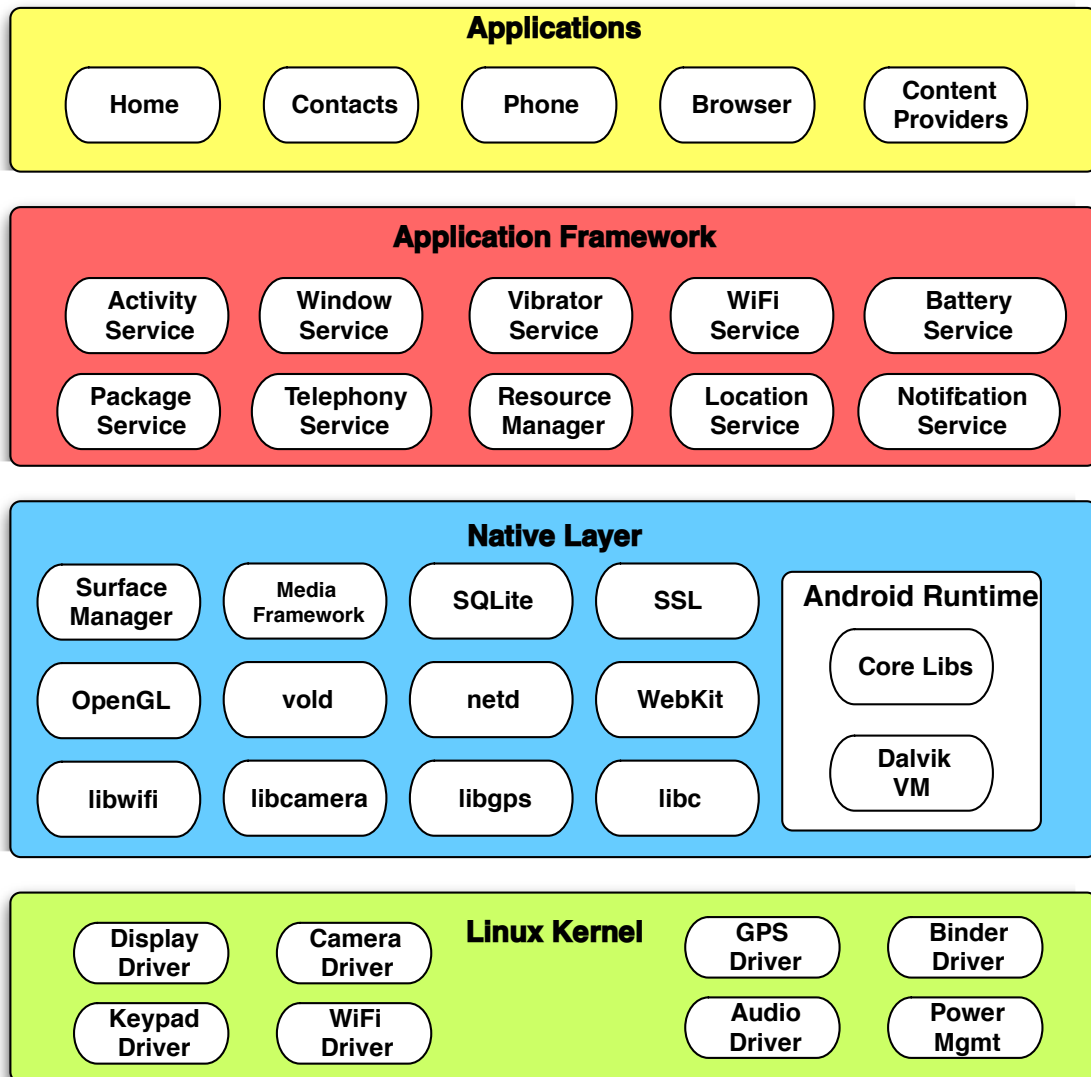
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1 Overview

- Android Overview
 - Android Stack
 - JNI/NDK on Android
 - IPC/Binder on Android
 - Android Security
 - Building Android from Source
 - Android Startup
 - Android Services
 - Android Customization
 - Appendix: USB on Android
-

2 Android Stack



- Exploring the anatomy of Android. A walk through the Android stack, starting from the bottom and moving up.
 - Linux Kernel Layer
 - Native Layer
 - Application Framework Layer
 - Applications Layer

2.1 Android Linux Kernel Layer

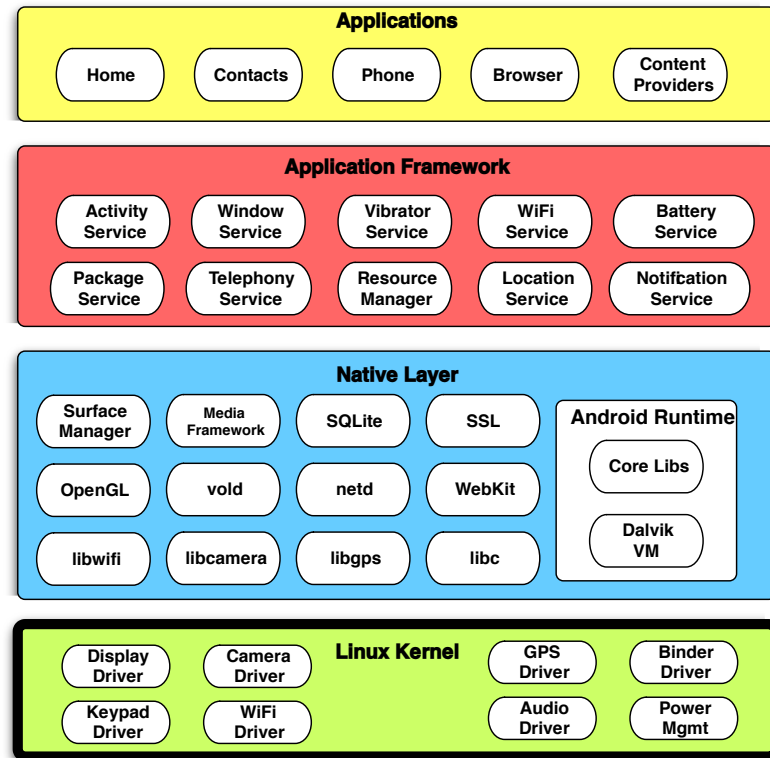


Figure 1: Android Linux Kernel Layer

2.1.1 Overview

- Android runs on a modified Linux kernel

Table 1: Android Version - Linux Kernel Version

Android Version	Kernel Version
1.0	2.6.25
1.5	2.6.27
1.6	2.6.29
2.2	2.6.32
2.3	2.6.35
3.0	2.6.36
4.0.1	3.0.1
4.0.3	3.0.8

- Android is **not** "Linux"
 - no glibc
 - no X11
 - many standard configuration files are missing: no `/etc/passwd`, no `/etc/fstab`, etc.

- many standard Linux utilities are missing: no `/bin/cp`, no `/bin/su`, etc.
- In the *Android Stack* Linux kernel provides
 - Hardware abstraction layer (low level)
 - * Well-understood driver model
 - * Many drivers for common devices
 - * "Free" drivers for future devices
 - Process and memory management
 - Simple, but secure, per-process sandboxing (permissions-based security model)
 - Support for shared libraries
 - Network stack
- Application developers and users never "see" the Linux kernel
- The `adb shell` command opens Linux shell (remember, limited standard utils)
- Maintains a separate "forked" git tree (<https://android.googlesource.com/>)

Table 2: Android Linux Kernel GIT Repositories

Android Version	Kernel Version
kernel/common.git	The "official" Android Kernel branch (used as the basis for others)
kernel/goldfish.git	Kernel tree for the "goldfish" emulator
kernel/experimental.git	The experimental extensions
kernel/linux-2.6.git	The mirror of Linus' kernel tree
kernel/lk.git	(L)ittle (K)ernel bootloader
kernel/msm.git	Kernel tree for MSM7XXX family and Android on MSM7XXX (Qualcomm)
kernel/omap.git	Kernel tree for TI's OMAP family SOCs on Android
kernel/samsung.git	Kernel tree for Samsung SOCs systems on Android
kernel/tegra.git	Kernel tree for NVIDIA Tegra family SOCs on Android

- Android introduces **many extensions**

The following are some of the changes/additions Android makes to the Linux kernel.

2.1.2 Binder IPC

- OpenBinder-based IPC driver enables "object-oriented operating system environment"
 - Exposed via `/dev/binder`
 - Runtime info at `/proc/misc/binder`
 - Like CORBA, but much simpler
 - Initially developed for BeOS later used by Palm (which acquired BeOS)
- By default, apps and services (including system services) run in separate processes, but often need to share data
- Traditional IPC leads to security challenges and adds overhead, which is amplified on a mobile device
- Most of Android infrastructure (services) is supported by Binder

- Binder is lightweight and high-performance
 - Bound services are automatically reference-counted and "garbage collected" when no longer in use
 - Provides automatic per-process thread pooling for services (with remote clients)
 - Remote (service) method calls are synchronous (feels like just a function call, even though it's IPC)
 - * Supports oneway (asynchronous) execution model as well
- Services defined/exposed via AIDL
- Implementation is at `drivers/misc/binder.c` with include at `include/linux/binder.h`

2.1.3 Ashmem (Anonymous SHared MEMory)

- A reference-counted, virtually mapped, named memory block that is shared between processes that the kernel is allowed to free
- Similar to POSIX SHM but with different behavior and a simpler file-based API (POSIX SHM does not allow the kernel to free shared memory)
- Programs open `/dev/ashmem`, use `mmap()` on it, and then share file handles via binder

```
int size = 4096;
int fd = ashmem_create_region("MySharedRegionName", size);
if (fd == 0) {
    data = mmap(NULL, size, PROT_READ | PROT_WRITE, MAP_SHARED, fd, 0);
    if (data != MAP_FAILED) {
        /* for security reasons, no other process can ashmem_create_region() with the same ↔
           name */
        /* instead, to share this memory, we send fd via Binder IPC to another process */
        /* that process then mmap()'s it the same way in order to access the shared memory */
    }
}
```

- When all processes `close(fd)` to the shared memory region, the kernel automatically reclaims that memory (because it is reference-counted)
- Supports a number of `ioctl()`-s: `ASHMEM_SET_NAME`, `ASHMEM_GET_NAME`, `ASHMEM_SET_SIZE`, `ASHMEM_GET_SIZE`, `ASHMEM_SET_PROT_MASK`, `ASHMEM_GET_PROT_MASK`, `ASHMEM_PIN`, `ASHMEM_UNPIN`, `ASHMEM_GET_PIN_STATUS`, `ASHMEM_PURGE_ALL_CACHES`
- Android uses ashmem to share resources to minimize redundancy across processes
- Kernel can discard unused shared blocks of memory when under pressure
- Implementation at `mm/ashmem.c` with include at `include/linux/ashmem.h`
- Represented in the Java layer as `android.os.MemoryFile`

2.1.4 Pmem

- Physical memory allocator
- Used to manage large (1-16+ MB) physically contiguous regions of memory shared between userspace and kernel drivers (DSP, GPU, etc.)
 - Unlike ashmem, pmem is not reference-counted: the process that allocates a pmem heap is required to hold the file descriptor until all the other references are closed, so that it can free it explicitly
- Originally developed for MSM7201A
- Implementation at `drivers/misc/pmem.c` with include at `include/linux/android_pmem.h`
- Supports a number of `ioctl()`-s: `PMEM_GET_PHYS`, `PMEM_MAP`, `PMEM_GET_SIZE`, `PMEM_UNMAP`, `PMEM_ALLOCATE`, `PMEM_CONNECT`, `PMEM_GET_TOTAL_SIZE`, `PMEM_CACHE_FLUSH`

2.1.5 Wakelocks

- Extended power management
- More aggressive power-manager policy than standard Linux PM
 - "CPU shouldn't consume power if no applications or services require power" - i.e. the CPU shuts down eagerly
 - Applications and services that wish to continue running (after a short timeout following a user activity) are required to request "wake locks" via the app framework or native libs
- Wake locks are used by applications and services to request CPU resources
 - WAKE_LOCK_SUSPEND: prevents a full system suspend
 - WAKE_LOCK_IDLE: prevents entering low-power states from idle to avoid large interrupt latencies (disabled interrupts) - so the system is more responsive
- Exposed to kernel as

```
#include <linux/wakelock.h>
wake_lock_init(struct wakelock *lock, int type, const char *name);
void wake_lock(struct wakelock *lock);
void wake_unlock(struct wakelock *lock);
void wake_lock_timeout(struct wakelock *lock, long timeout);
void wake_lock_destroy(struct wakelock *lock);
int wake_lock_active(struct wakelock *lock);
long has_wake_lock(int type);
```

- Exposed to user-space as

```
echo "MyLock" > /sys/power/wake_lock
echo "MyLock" > /sys/power/wake_unlock
```

- Also supports auto-release: `/sys/power/wake_lock <lock-name> <timeout-in-ns>`

- Support for different types of wake locks

Flag	CPU	Screen	Keybaord
PARTIAL_WAKE_LOCK	On	Off	Off
SCREEN_DIM_WAKE_LOCK	On	Dim	Off
SCREEN_BRIGHT_WAKE_LOCK	On	Bright	Off
FULL_WAKE_LOCK	On	Bright	On

- Also, there are two more flags that affect the screen behavior (not applicable with PARTIAL_WAKE_LOCK):

Flag	Notes
ACQUIRE_CAUSES_WAKEUP	Force screen to turn on as soon as the wake-lock is acquired (i.e. don't wait for user activity)
ON_AFTER_RELEASE	When set, the user activity timer will be reset when the wake-lock is released, causing the screen/keyboard illumination to remain on a bit longer (reduces flicker if code is cycling between wake-locks)

- Alls user-space wake-lock management must go through Java-based `PowerManagerService` (even from user-space native libraries)
- Baseband processor normally does not shut down, so network traffic still raises interrupts allowing CPU to wake up
- Stats exposed via `/proc/wakelocks`

- Implementation at `drivers/android/power.c` with include at `include/linux/wakelock.h`

2.1.6 Early Suspend

- An extension to the standard Linux power management stages
- Not meant for suspending the device
- Allows the system to power-down some of its components (like the screen, sensors, etc.)
- When user requested sleep state changes, kernel notifies drivers of early suspend
- User-space changes the sleep state by writing to `/sys/power/request_state: EARLY_SUSPEND_LEVEL_BLANK_SCREEN, EARLY_SUSPEND_LEVEL_STOP_DRAWING, EARLY_SUSPEND_LEVEL_DISABLE_FB, EARLY_SUSPEND_LEVEL_STOP_`
- The opposite of early suspend is "late resume" - the stage that resumes these devices
- Enabled by `EARLYSUSPEND`
- Configured in one of three modes:
 - `NO_USER_SPACE_SCREEN_ACCESS_CONTROL` - no user-space control
 - `CONSOLE_EARLYSUSPEND` - user-space control via the console
 - `FB_EARLYSUSPEND` - user-space control via the sysfs
- Implementation at `kernel/power/fbearlysuspend.c` (or `kernel/power/consoleearlysuspend.c`) with include at `include/linux/earlysuspend.h`
- See <http://lwn.net/Articles/416690/>

2.1.7 Alarm

- Kernel support for Android's `AlarmManager`
- User-space tells kernel when it would like to wake up
- Kernel schedules a time-based call-back (while holding a `WakeLock`) regardless of the sleep-state of the CPU
 - Apps can then run (need to hold their own `WakeLocks`)
- Implementation at `drivers/rtc/alarm.c` with include at `include/linux/android_alarm.h`
- Exposed via `/dev/alarm`
- Supports a number of `ioctl()`-s: `ANDROID_ALARM_CLEAR, ANDROID_ALARM_WAIT, ANDROID_ALARM_SET, ANDROID_ALARM_GET_TIME, ANDROID_ALARM_GET_TIME`
 - See <https://lwn.net/Articles/429925/>

2.1.8 Low Memory Killer (a.k.a. Viking Killer)

- Automatically SIGKILLs eligible least-recently-used processes when running low on memory
 - More aggressive than standard OOM handling
 - Implementation at `drivers/staging/android/lowmemorykiller.c` and `security/lowmem.c`
 - System sets up 6 priority slots via `init.rc` (writes to `/sys/module/lowmemorykiller/parameters/`) and user-space `ActivityManager` then sets each app's `/proc/<pid>/oom_adj` (from -16 to 15)
-

```
# Define the oom_adj values for the classes of processes that can be
# killed by the kernel. These are used in ActivityManagerService.
setprop ro.FOREGROUND_APP_ADJ 0
setprop ro.VISIBLE_APP_ADJ 1
setprop ro.PERCEPTIBLE_APP_ADJ 2
setprop ro.HEAVY_WEIGHT_APP_ADJ 3
setprop ro.SECONDARY_SERVER_ADJ 4
setprop ro.BACKUP_APP_ADJ 5
setprop ro.HOME_APP_ADJ 6
setprop ro.HIDDEN_APP_MIN_ADJ 7
setprop ro.EMPTY_APP_ADJ 15

# Define the memory thresholds at which the above process classes will
# be killed. These numbers are in pages (4k).
setprop ro.FOREGROUND_APP_MEM 2048
setprop ro.VISIBLE_APP_MEM 3072
setprop ro.PERCEPTIBLE_APP_MEM 4096
setprop ro.HEAVY_WEIGHT_APP_MEM 4096
setprop ro.SECONDARY_SERVER_MEM 6144
setprop ro.BACKUP_APP_MEM 6144
setprop ro.HOME_APP_MEM 6144
setprop ro.HIDDEN_APP_MEM 7168
setprop ro.EMPTY_APP_MEM 8192

# Write value must be consistent with the above properties.
# Note that the driver only supports 6 slots, so we have combined some of
# the classes into the same memory level; the associated processes of higher
# classes will still be killed first.
write /sys/module/lowmemorykiller/parameters/adj 0,1,2,4,7,15

write /proc/sys/vm/overcommit_memory 1
write /proc/sys/vm/min_free_order_shift 4
write /sys/module/lowmemorykiller/parameters/minfree 2048,3072,4096,6144,7168,8192

# Set init its forked children's oom_adj.
write /proc/1/oom_adj -16
```

- To application developers this means that low memory killer stacks processes based on the following order:
 1. Foreground processes - with an Activity that just ran `onResume()`, or a Service bound to it or started as foreground, or executing its callback methods, or a BroadcastReceiver executing `onReceive()`
 2. Visible processes - with an Activity that just ran `onPause()` but is still visible or a Service bound to a component from a visible process
 3. Service processes - with a Service that has been started with `Context.startService()`
 4. Background processes - with an Activity that just ran `onStop()`
 5. Empty processes - with no components (kept around just for caching purposes)
- See <http://developer.android.com/guide/topics/fundamentals/processes-and-threads.html>
- Everything directly started from `init.rc` (including the `system_server`) has its `oom_adj` set to `-16`
 - If we get to killing those, the system is toast anyway
- Applications can request that they be kept persistent (in memory) by setting `<application android:persistent="true" ...>` in their `AndroidManifest.xml` file
 - ActivityManager then starts persistent apps and initializes their `oom_adj` to `-12`

2.1.9 Logger

- System-wide logging facility (from Kernel all the way to apps)
- This is what `logcat` command reads from
- Supports four auto-rotating log buffers managed by the kernel
 - `/dev/log/main` (64KB)
 - * Destination for Android apps
 - * Most logging happens via `android.util.Log`
 - `/dev/log/system` (64KB)
 - * Destination for Android framework's system services and libraries
 - * Most logging happens via hidden `android.util.Slog` or directly via `liblog` library
 - `/dev/log/events` (256KB)
 - * Destination for Android system diagnostic events - e.g. garbage collections, activity manager state, system watchdogs, and other low level activity
 - * Logging via `android.util.EventLog` or directly via `liblog` library
 - * Binary-encoded - can be decoded via `/system/etc/event-log-tags`
 - `/dev/log/radio` (64KB)
 - * Destination for radio and phone-related information
- Log reading and writing is done via normal Linux file I/O
 - Calls to `open()`, `write()`, and `close()` are extremely low-overhead on these devices
 - Each `read()` returns exactly one log entry (up to 4KB) and can be both blocking and non-blocking
- Implementation at `drivers/misc/logger.c` (with a `logger.h` in the same directory)
- Supports a number of `ioctl()`-s: `LOGGER_GET_LOG_BUF_SIZE`, `LOGGER_GET_LOG_LEN`, `LOGGER_GET_NEXT_ENTRY_I`, `LOGGER_FLUSH_LOG`

2.1.10 Paranoid Network Security

- Restricts access to some networking features depending on the group of the calling process
- Enabled via `CONFIG_ANDROID_PARANOID_NETWORK` kernel build option, which defines process group IDs that have special network access:

include/linux/android_aid.h (kernel source-tree):

```
...
#define AID_NET_BT_ADMIN 3001
#define AID_NET_BT       3002
#define AID_INET         3003
...
```

net/ipv4/af_inet.c (kernel source-tree):

```
...
#include <linux/android_aid.h>

static inline int current_has_network(void)
{
    return in_egroup_p(AID_INET) || capable(CAP_NET_RAW);
}
...
```

```
static int inet_create(struct net *net, struct socket *sock, int protocol)
{
    ...
    if (!current_has_network())
        return -EACCES;
    ...
}
...
```

– Also in `net/ipv6/af_inet6.c` and `net/bluetooth/af_bluetooth.c`

- These are re-defined for Android user-space and assigned logical group-names

system/core/include/private/android_filesystem_config.h (Android source-tree)

```
...
#define AID_NET_BT_ADMIN 3001 /* bluetooth: create any socket */
#define AID_NET_BT 3002 /* bluetooth: create sco, rfcomm or l2cap sockets */
#define AID_INET 3003 /* can create AF_INET and AF_INET6 sockets */
...
static const struct android_id_info android_ids[] = {
    ...
    { "net_bt_admin", AID_NET_BT_ADMIN, },
    { "net_bt", AID_NET_BT, },
    ...
    { "inet", AID_INET, },
    ...
};
...
```

- Android app permissions are then mapped to group names

/system/etc/permissions/platform.xml (system image)

```
<permissions>
    ...
    <permission name="android.permission.BLUETOOTH_ADMIN" >
        <group gid="net_bt_admin" />
    </permission>

    <permission name="android.permission.BLUETOOTH" >
        <group gid="net_bt" />
    </permission>

    <permission name="android.permission.INTERNET" >
        <group gid="inet" />
    </permission>
    ...
</permissions>
```

2.1.11 Other Kernel Changes

- Timed output / Timed GPIO
 - Generic GPIO allows user space to access and manipulate GPIO registers
 - Timed GPIO allows changing a GPIO pin and having it restored automatically after a specified timeout
 - Implementation at `drivers/android/timed_output.c` and `drivers/android/timed_gpio.c`
 - Used by the vibrator by default
- Linux Scheduler

- Not a custom scheduler, just Android-specific configuration in `init.rc`

```
write /proc/sys/kernel/panic_on_oops 1
write /proc/sys/kernel/hung_task_timeout_secs 0
write /proc/cpu/alignment 4
write /proc/sys/kernel/sched_latency_ns 10000000
write /proc/sys/kernel/sched_wakeup_granularity_ns 2000000
write /proc/sys/kernel/sched_compat_yield 1
write /proc/sys/kernel/sched_child_runs_first 0
```

- Switch events - userspace support for monitoring GPIO used by `vold` to detect USB
- USB gadget driver for ADB (`drivers/usb/gadget/android.c`)
- yaffs2 flash filesystem, though this is switching to ext4
- RAM console
 - Kernel's `printk` goes to a RAM buffer
 - A kernel panic can be viewed in the next kernel invocation via `/proc/last_kmsg`
- Support in FAT filesystem for `FVAT_IOCTL_GET_VOLUME_ID`

2.2 Android User-Space Native Layer

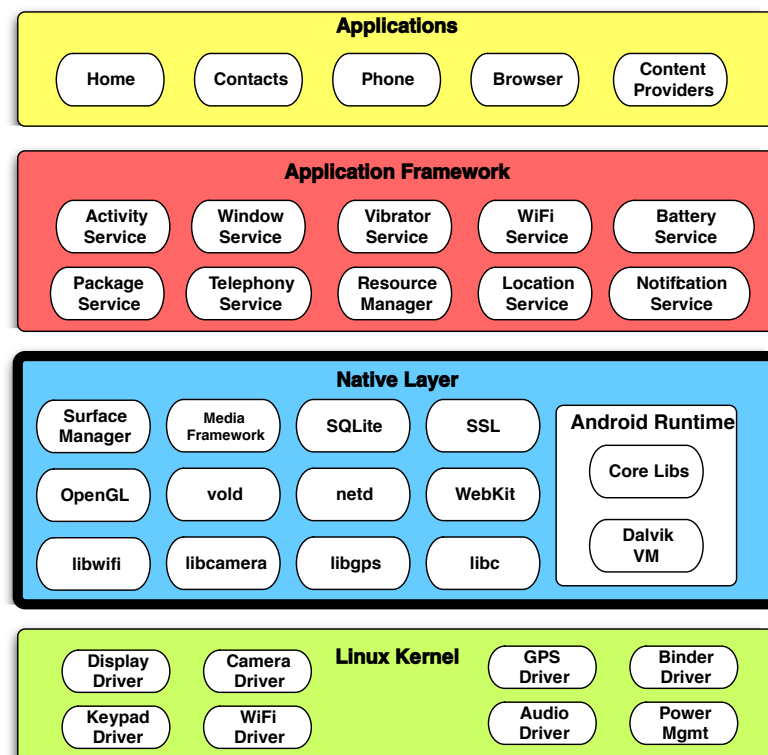


Figure 2: Android User-Space Native Layer

- Android user-space native layer is divided into multiple "logical" categories

2.2.1 Bionic Library

- Custom standard C library (libc) derived from BSD optimized for Android
- Why Bionic?
 - BSD licensed (business-friendly - i.e. keeps GPL out of user-space)
 - * Proprietary code linked to bionic can remain proprietary
 - Lean (~200KB, or about half the size of glibc)
 - * It is loaded into every process, so it needs to be small
 - Fast (custom pthread impl) - perfect for embedded use

2.2.2 Changes From BSD libc

- Support for arbitrary Android system-properties via `<sys/system_properties.h>`
 - Support for Android Kernel Logger Driver (via `liblog`)
 - Support for Android-specific user/group management
 - Enabled via `getpwnam()`, `getgrouplist()`, and, `getgrgid()`, which are aware of generated UIDs of the applications (>10000) and their corresponding synthetic user/group-names (e.g. `app_123`)
 - Basic UID/GIDs defined in `/system/core/include/private/android_filesystem_config.h`
 - Support for Android-specific `getservent()`, `getservbyport()`, and `getservbyname()` in place of `/etc/services`
 - No support for `/etc/protocol`
 - "Clean" kernel headers that allow user-space to use kernel-specific declarations (e.g. `ioctl`'s, structure declarations, constants, etc.)
 - Custom pthread implementation based on Linux `futexes`
 - Bundled-in (i.e. `-lpthread` not required)
 - Optimized for embedded use - strives to provide **very** short code paths for common operations
 - * Normal, recursive and error-check mutexes are supported
 - * No support for process-shared mutexes and condition variables (use Android's own Binder-IPC instead) as well as read/write locks, priority-ceiling in mutexes, `pthread_cancel()`, and other more advanced features (not a priority for embedded use)
 - * Provides only 64 as opposed to 128 thread-specific storage slots required by POSIX
 - * No support for read/write memory barriers (restricts SMP/multi-core on certain architectures)
 - Does not support all the relocations generated by other GCC ARM toolchains
 - No support for System V IPCs - to avoid denial-of-service
 - SysV has no way to automatically release a semaphore allocated in the kernel when
 - * a buggy or malicious process exits
 - * a non-buggy and non-malicious process crashes or is explicitly killed (e.g. via low-memory-killer)
 - Again, we use Android's own Binder-IPC instead
 - No support for locales (I18N done at the application/Dalvik layer via well-defined resource mechanism)
 - No support for wide chars (i.e. multi-byte characters)
 - `time_t` is 32-bit on 32-bit hardware
-

- Timezones are defined via `TZ` env-vars or via `persist.sys.timezone` system property
- NetBSD-derived DNS resolver library
 - Reads from `/system/etc/resolv.conf`
 - Uses name servers defined in `net.dns1`, `net.dns2` system properties
 - * Can be process specific: `net.dns1.<pid>`
- Built-in linker
 - Support pre-linked mapping files
- Support for x86, ARM and ARM thumb CPU instruction sets and kernel interfaces
- **Not binary compatible** with any other known Linux C library (glibc, ucLibc, etc.)
 - Not even fully POSIX-compliant
 - No support for C++ exceptions
 - **Requires recompile** of existing legacy code against bionic
- See `ndk/docs/system/libc/OVERVIEW.html` for more info (in the Android source tree)

2.2.3 User-space Hardware Abstraction Layer (HAL)

- User-space C/C++ hardware abstraction layer - as shared libraries
- Communicate with Linux drivers via `/dev/`, `/sys/`, or `/proc/`
- Why not just use Linux drivers directly?
 - Separates Android platform logic from specific hardware interfaces
 - Linux does not have common definitions of hardware that upper layers depend on
 - User-space HAL offer *standard* "driver" definitions for graphics, audio, camera, bluetooth, GPS, radio (RIL), WiFi, etc.
 - Makes porting easier
- OEMs implement "drivers" for specific hardware as shared libraries
 - `libhardware`
 - `libhardware_legacy`
 - The code can remain proprietary since the user-space drivers link against bionic, not the kernel (i.e. no GPL)
- Platform loads these HAL libs at runtime via pre-determined naming strategies
 - `libhardware` is a simple shared library that can load device-specific shared libraries via `hw_get_module(const char *id, const struct hw_module_t **module)`
 - * First checks under `/vendor/lib/hw/` and then `/system/lib/hw/` as follows:
 1. `<*_HARDWARE_MODULE_ID>.<ro.product.board>.so`
 2. `<*_HARDWARE_MODULE_ID>.<ro.board.platform>.so`
 3. `<*_HARDWARE_MODULE_ID>.<ro.arch>.so`
 4. `<*_HARDWARE_MODULE_ID>.default.so`
 - * For example, on a Nexus S (where `TARGET_BOARD_PLATFORM=s5pc110`, `board=herring`, and `/vendor/` → `/system/vendor`)
 - The GPS "driver" is loaded from `/system/vendor/lib/hw/gps.s5pc110.so` (where `GPS_HARDWARE_MODULE_ID` is `gps`)
 - The Sensors "driver" is loaded from `/system/lib/hw/sensors.herring.so` (where `SENSORS_HARDWARE_MODULE_ID` is `sensors`)
 - `libhardware_legacy` is a shared library for vibrator, wifi-module-loader, power, uevent, audio, camera, etc.

- * Some board-independent hardware (like vibrator, power, wifi, etc.) is directly supported by `/system/lib/libhardware_1` via well-defined paths on the file system (mostly via `/proc` or `/sys`) or well-defined system properties
- * Board-specific devices (like audio, camera, etc.) are supported by separate shared libraries loaded by well-defined names (e.g. `/system/lib/libaudio.so`, `/system/lib/libcamera.so`, etc.)
- Radio is a bit special, as its `rild` (Radio Interface Link Daemon) loads "libril" as defined by `rild.libpath` system property
- * On Nexus S, this is `/vendor/lib/libsec-ril.so`

2.2.4 Native Daemons

- `/system/bin/servicemanager`
 - *The naming service* for all other systemserver's (i.e. framework) services
 - Registers as `BINDER_SET_CONTEXT_MGR` on `/dev/binder` and starts reading from it (in a loop)
- `/system/bin/vold`
 - Volume Daemon used for mounting/unmounting removable media (like `/mnt/sdcard`) on demand
 - Configured via `/system/etc/vold.fstab`
 - For example, Nexus One's SD Card is automatically re/mounted:


```
dev_mount sdcard /mnt/sdcard auto /devices/platform/goldfish_mmc.0 /devices/platform/
msm_sdcc.2/mmc_host/mmc1
```
 - While Nexus S, has a "virtual" but fixed SDCard:


```
dev_mount sdcard /mnt/sdcard 3 /devices/platform/s3c-sdhci.0/mmc_host/mmc0/mmc0:0001/
block/mmcblk0
```
- `/system/bin/rild`
 - Acts as a bridge between platform framework services (TelephonyManager) and `libril`, which is OEM-specific interface to the baseband modem
 - Stateful - helps handle incoming calls/messages (unsolicited requests)
 - Interfaces with upper layers via a Unix socket connection
- `/system/bin/netd`
 - Manages network connections, routing, PPP, etc.
 - Enables tethering, connections over USB/Bluetooth, etc.
- `/system/bin/mediaserver`
 - Home of `AudioFlinger`, `MediaPlayerService`, `CameraService`, `AudioPolicyService`
- `/system/bin/installd`
 - Listens on a unix socket and performs installation/uninstallation of packages (i.e. apps)
 - Used by the `PackageManager`
- `/system/bin/keystore`
 - Listens on a unix socket and provides secured storage for key-value pairs
 - Keys are encoded in file names, and values are encrypted with checksums
 - The encryption key is protected by a user-defined password
- `/system/bin/debuggerd`

- Catches crashes of native processes and dumps their stack trace to `/data/tombtones/`
- When native processes initialize, they implicitly connect (through a unix socket) to `debuggerd` through a separate thread spawned by `bionic`
- `/system/bin/wpa_supplicant`
 - Handles WPA authentication for WiFi networks
- `/system/bin/dhcpd`
 - Requests (leases) IPs from DHCP servers
 - Handles network changes (e.g. 3G to Wifi)
- BlueZ (Bluetooth support daemons)
 - `/system/bin/dbus-daemon`
 - * A simple IPC (bus) framework
 - * Provides `systemserver` with a way to access `hcid` (Bluetooth Host Controller Interface Daemon)
 - `/system/bin/bluetoothd`
 - * Manages device pairings and the rest of the stack
 - `/system/bin/sdptool`
 - * Used to manage individual Bluetooth profile as services
 - `hfag` - Hands-Free Profile
 - `hsag` - Headset Profile
 - `opush` - Object Push Profile
 - `pbap` - Phonebook-Access Profile
 - etc.
- `/system/bin/racoon`
 - Assists with ipsec key negotiations (IKE)
 - Used for VPN connections
- `/system/ueventd`
 - Handles uevents from the Kernel and sets up correct ownership/permissions on the device file descriptors
 - Applies configuration from `/ueventd.rc`

```

...
/dev/urandom          0666   root    root
/dev/ashmem           0666   root    root
/dev/binder           0666   root    root
...
/dev/log/*            0662   root    log
...
/dev/ttyMSM0          0600   bluetooth bluetooth
...
/dev/alarm             0664   system  radio
...
/dev/cam              0660   root    camera
...
/dev/akm8976_pfffd    0640   compass system
/dev/lightsensor      0640   system  system
...
/dev/bus/usb/*        0660   root    usb
/sys/devices/virtual/input/input* enable 0660 root input
...

```

- `/sbin/adbd`
 - End-point of Android Debug Bridge
 - Accepts ADB connections over USB
 - Possible to accept network connections as well
- Vendor-specific daemons which facilitate interaction with the hardware
 - For example `/system/vendor/bin/gpsd` on Nexus S
- Other daemons, like `zygote` and `systemserver` will be discussed separately

2.2.5 Flingers

Surface Flinger

- `SurfaceFlinger` is Android's system-wide screen composer that draws into standard Linux frame-buffer (`/dev/fb0`)
- Apps draw (in 2D or 3D) into "windows", which are implemented as double-buffered `Surface` objects backed by the surface flinger
 - Front-buffer used for composition, back-buffer for drawing
 - Buffers are flipped after drawing
 - * Minimal buffer copying
 - * Avoids flickers and artifacts as the front-buffer is always available for composition
- Surface flinger expects the video driver to offer:
 - A linear address space of mappable memory
 - * Video memory is `mmap()`'ed to process address-space for direct writing
 - * Enough video memory for twice the physical screen area
 - Otherwise, regular system memory has to be used for buffering, and is copied on flips (slow!)
 - Support for RGB 565 pixel format

Audio Flinger

- `AudioFlinger` is Android's system-wide audio stream routing engine/mixer and audio input capture facility
 - Sits on top of device-specific `libaudio.so` implementation, which usually simply bridges to ALSA
- To play audio, apps send uncompressed mono/stereo PCM streams to audio flinger (usually via `MediaPlayer`)
 - Streams include ringtones, notifications, voice calls, touch tones, key tones, music
 - Audio flinger routes these streams to various outputs (earpiece, speakers, Bluetooth)
- To capture audio, apps request access to uncompressed input path managed by the audio flinger (usually via `MediaRecorder`)

2.2.6 Function Libraries

- Provide computation-intensive services to the rest of the platform
 - This is in addition to bionic
- Many pieces borrowed from other open source projects
 - LibWebCore/WebKit, V8, SQLite, OpenSSL, FreeType, etc.
 - Usually abstracted by Java counterparts
- Media Framework Libraries
 - Originally based on PacketVideo's OpenCORE platform
 - Switched to Stagefright with Gingerbread
 - Support for playback and recording of many popular audio and video formats, as well as static image files
 - * MPEG4, H.264, VP8/WebM, MP3, AAC, AMR, JPG, and PNG
 - Pluggable via Khronos' OpenMAX IL (supports for codecs in both software and hardware)
- 3D libraries
 - Support for OpenGL ES 1.0 and 2.0 APIs
 - Comes with highly optimized 3D software rasterizer - when hardware does not offer native OpenGL support
- 2D libraries
 - SGL (Skia) - the underlying 2D graphics engine

2.2.7 Dalvik



- Dalvik is a custom clean-room implementation of a virtual machine, semantically similar to a JVM but **not** a JVM
 - Licensed under Apache 2.0 open-source license
- Provides Android app portability and consistency across various hardware (like a JVM)
- Runs Dalvik byte-code, stored in `.dex` files (**not** Java byte code)

- Developers program in the Java language (i.e. `.java` files), which get compiled into Java byte-code (i.e. `.class` files)
 - Build-tools compile Java's `.class` files into a `.dex` file before packaging (into `.apk` files)
 - * 3rd party libraries are also re-compiled into dex code
 - Dalvik never sees any Java byte-code
 - Why not Java SE?
 - Java SE is too bloated for mobile environment
 - Would require too much redundancy (at the library level)
 - Not well-optimized for mobile (at the bytecode and interpreter level)
 - Why not Java ME?
 - Costs \$\$\$ - hinders adoption
 - Designed by a committee - hard to imagine iOS-like developer appeal
 - Apps share a single VM - not great for security sandboxing
 - Apps are second-rate citizens - don't get access to all the hardware
 - Dalvik is optimized for embedded environment:
 - Minimal-memory footprint while providing a secure sandboxing model
 - * Uncompressed `.dex` files are smaller than compressed `.jar` files due to more efficient bytecode
 - On average Dalvik byte code is 30% smaller than JVM byte code
 - Multiple classes in one `.dex` file
 - Shared constant pool (assumes 32-bit indexes)
 - Simpler class-loading
 - Because it is uncompressed, dex code can be memory-mapped and shared (i.e. `mmap()` -ed)
 - * Each app runs in a separate instance of Dalvik
 - At startup, system launches `zygote`, a half-baked Dalvik process, which is forked any time a new VM is needed
 - Due to copy-on-write support, large sections of the heap are shared (including 1800+ preloaded classes)
 - Since each VM runs in a separate process, we get great security isolation
 - Register-based fixed-width CPU-optimized byte-code interpreter
 - * Standard JVM bytecode executes 8-bit stack instructions - local variables must be copied to or from the operand stack by separate instructions
 - Memory speed to CPU speed is amplified on mobile CPUs - we want to minimize access to the main memory
 - * Dalvik uses 16-bit instruction set that works directly on local variables (managed via a 4-bit virtual register field)
 - With JIT support, as of Froyo (2-5x performance improvement in CPU-bound code)
 - * Trace-level granularity (more optimal than whole method-level compilations)
 - * Fast context-switching (interpreted mode to native mode and back)
 - * Well-balanced from performance vs. memory overhead perspective (~ 100-200KB overhead per app)
 - * ~ 1:8 ratio of Dalvik to native code (mostly due to optimizations, like inlining)
 - Includes support for instrumentation to allow tracing and profiling of running code
 - Core libraries based on Java SE 5 (mostly from Apache Harmony), with many differences
 - No support for `java.applet`, `java.awt`, `java.lang.management` and `javax.management (JMX)`, `java.rmi` and `javax.rmi`, `javax.accessibility`, `javax.activity`, `javax.imageio`, `javax.naming (JNDI)`, `javax.print`, `javax.security.auth.kerberos`, `javax.security.auth.spi`, `javax.security.s`, `javax.sound`, `javax.swing`, `javax.transaction`, `javax.xml` (except for `javax.xml.parsers`), `org.ietf`, `org.omg`, `org.w3c.dom.*` (subpackages)
-

- But support for Android APIs (including wrappers for OpenGL, SQLite, etc.), Apache HTTP Client (`org.apache.http`), JSON parser (`org.json`), XML SAX parser (`org.xml.sax`), XML Pull Parser (`org.xmlpull`), etc.



2.3 Android Application Framework Layer

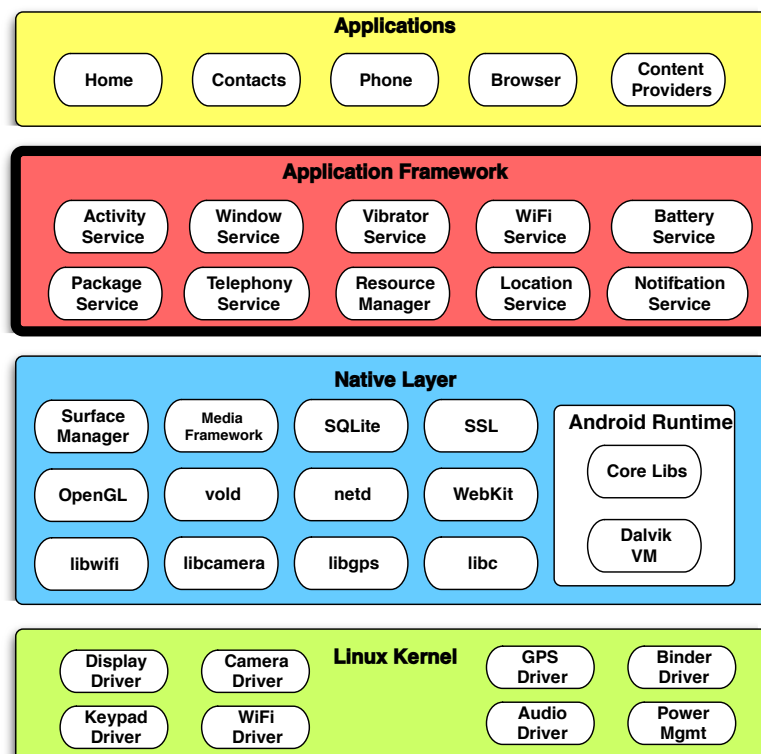


Figure 3: Android Application Framework Layer

2.3.1 Overview

- The rich set of system services wrapped in intuitive Java APIs

2.3.4 Power Manager Service

- Controls power management
- Provides access to wake locks

2.3.5 Alarm Manager Service

- Manages wake-up alarms for applications
- Supports inexact wakeup frequencies - helps consolidate wake-ups into fewer slots
- Uses power manager for wake locks

2.3.6 Notification Manager Service

- Used by apps and other services to notify the user of events that may be of interest
 - This is how background events "bubble up" as notifications
- Supports persistent notification, as well as notifications that use LEDs, screen backlight, sound, and/or vibration to notify the user

2.3.7 Keyguard Manager Service

- Manages locking/unlocking of the keyguard

2.3.8 Location Manager Service

- Handles geographic location updates (e.g. GPS) and distributes them to the listening applications
- Support proximity alerts (via Intents)
- Supports providers of different granularity (GPS, Network, WiFi)

2.3.9 Sensor Manager Service

- Provides a uniform access to the device's sensors
- Apps request sensor notifications via this manager
 - Sensor manager delivers sensor updates via a generic (timestamped) array of values (which are sensor-dependent)
- Supported sensor types: accelerometer, linear acceleration, gravity, gyroscope, light, magnetic field, orientation, pressure, proximity, rotation vector, temperature
 - Actual sensor support is (obviously) hardware-dependent

2.3.10 Search Manager Service

- Provides a framework for device-wide (global) or app-specific search

2.3.11 Vibrator Manager Service

- Provides simplistic access to the vibrator hardware
 - Can be used for simple haptic feedback (using patterns)
-

2.3.12 Connectivity Manager Service

- Monitors network connections (Wi-Fi, GPRS, UMTS, etc.) and
 - Send broadcast intents when network connectivity changes
 - Attempts to "fail over" to another network when connectivity to a network is lost
- Provides an API that allows applications to query the coarse-grained or fine-grained state of the available networks

2.3.13 Wifi Manager Service

- Unlike the connectivity manager, the Wifi Manager supports Wifi-specific operations
- Provides a list and allows management of configured networks
- Provides access to and management of the state of the currently active Wi-Fi network connection, if any
- Enables access point scans
- Broadcasts Intents on Wifi-connectivity state change events

2.3.14 Telephony Manager Service

- Provides access to information about the telephony services on the device
- Apps query Telephony Manager to determine telephony services and states, as well as to access some types of subscriber information (e.g. device id)
- Apps can also register a listener to receive notification of telephony state changes
- Handles tethering requests

2.3.15 Input Method Manager Service

- Central system to the overall input method framework (IMF) architecture
 - Arbitrates interaction between applications (each has a separate client) and the current input method
- Responsible for creating and running an input method (IME) to capture the actual input and translate it into text
 - Allows multiple apps to requests input focus and control over the state of IME

2.3.16 UI Mode Manager Service

- Provides access to the system UI mode
 - Enable/disable car-mode
 - Enable/disable night-mode
 - System uses it to implement automatic UI mode changes
 - Apps use it to manually control UI modes of the device
-

2.3.17 Download Manager Service

- Handles long-running HTTP downloads
- Clients request that a URI be downloaded to a particular destination file
- The download manager handles the download in the background, taking care of HTTP interactions and retrying downloads after failures or across connectivity changes and system reboots
- New as of Gingerbread (2.3, API 9)

2.3.18 Storage Manager Service

- Handles storage-related items such as Opaque Binary Blobs (OBBs)
- "OBBs contain a filesystem that maybe be encrypted on disk and mounted on-demand from an application. OBBs are a good way of providing large amounts of binary assets without packaging them into APKs as they may be multiple gigabytes in size. However, due to their size, they're most likely stored in a shared storage pool accessible from all programs. The system does not guarantee the security of the OBB file itself. . ."
- E.g. great for GPS/Mapping applications that need support for off-line maps
- New as of Gingerbread (2.3, API 9)

2.3.19 Audio Manager Service

- Provides access to volume and ringer mode control
- Allows management/querying for the state of the audio system
 - Set/Get the current mode: normal, ringtone, in-call, in-communications
 - Set/Get the current ringer mode: normal, silent, vibrate
 - Set/Get the state of audio channels: speaker, bluetooth headset, wired headset, speakerphone
 - Set/Get the volume
 - Get audio focus requests
- Allows playing of sound effects: clicks, key-presses, navigation, etc.

2.3.20 Window Manager Service

- Manages windows (z-order) composed in a surface
- Allows us to place custom views (windows)

2.3.21 Layout Inflater Manager Service

- Used to instantiate layout XML files into its corresponding `View` object trees

2.3.22 Resource Manager Service

- Provides access to non-code resources such as localized strings, graphics, and layout files
-

2.3.23 Additional Manager Services

- Lights Service: handles status lights on the device
- Throttle Service: answers queries about data transfer amounts and throttling
- Mount Service: mount/unmount removable storage
- Battery Service: reports on battery health/status
- Wallpaper Service: manages changes to the wallpaper
- Backup Agent: provides remote backup/restore capabilities
- Bluetooth Service: manages bluetooth pairings
- Headset, Dock, USB Observers: observe specific device connections

2.4 Android Applications Layer

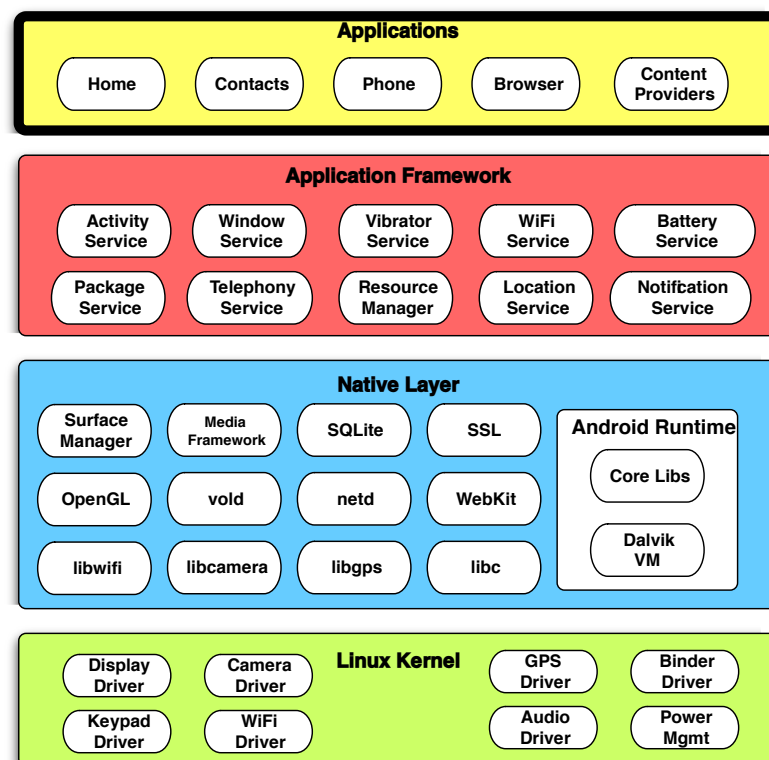


Figure 4: Android Applications Layer

- Android ships with a number of built-in "applications"
 - These are stored on the read-only `/system/` partition under `/system/app`
 - Cannot be uninstalled without re-flashing the ROM
- An Android application is a loose set of components, which may be used as
 - A single independent cohesive unit (a "traditional" application)
 - A set of re-usable modules used by other applications via binder and/or Intents (in form of an API)

- A combination of the two
- Applications are distributed as APKs (ZIP-compressed `.apk` files) consisting of
 - `AndroidManifest.xml` configuration file
 - Dalvik byte-code (`classes.dex`)
 - Optional native code as shared libraries (typically compiled for ARM)
 - Optional resources including layout/menu/preference definitions, drawables, text, audio, styles, etc.
 - Optional assets
 - Signature/public key (used for signing)

2.4.1 Android Built-in Applications

- AccountsAndSyncSettings
 - Bluetooth
 - Browser
 - Calculator
 - Calendar
 - Camera
 - CertInstaller
 - Contacts
 - DeskClock
 - Email
 - Gallery
 - Gallery3D
 - HTMLViewer
 - Launcher2
 - Mms
 - Music
 - Nfc
 - PackageInstaller
 - Phone
 - Protips
 - Provision
 - QuickSearchBox
 - Settings
 - SoundRecorder
 - SpeechRecorder
 - Stk
 - Tag
 - VoiceDialer
 - *OEM-specific application packages*
-

2.4.2 Android Built-in Content Providers

- ApplicationsProvider
- CalendarProvider
- ContactsProvider
- DownloadProvider
- DrmProvider
- MediaProvider
- TelephonyProvider
- UserDictionaryProvider
- *OEM-specific content providers*

2.4.3 Android Built-in Input Methods

- LatinIME
- OpenWnn
- PinyinIME
- *OEM-specific input methods (like Swype)*

2.4.4 Android Built-in Wallpapers

- Basic
- LivePicker
- MagicSmoke
- MusicVisualization
- *OEM-specific wallpapers*

3 Android Native Development Kit (NDK)

3.1 What is in NDK?

- Android's Dalvik VM allows our applications written in Java to call methods implemented in native code through the Java Native Interface (JNI)

– For example:

```
package com.marakana.android.fetchurl;
public class FetchUrl {
    public static native byte[] fetch(String url);
    static {
        System.loadLibrary("fetchurl");
    }
}
```

- NDK is a tool-chain to build and cross-compile our native code for the device-specific architecture
-

- At the moment, NDK supports ARMv5TE, ARMv7-A, and as of NDK r6 (July 2011) x86 ABIs
- For example, we would implement native `fetch` method in C and compile it into a library `libfetchurl.so`
- NDK offers a way to package our native code library (as `lib<something>.so`) into the APK file so we can distribute it with our application easily
 - For example, our library would be packaged as `libs/armeabi/libfetchurl.so` in the APK
- NDK provides a set of native system headers that will be supported for the future releases of Android platform (`libc`, `libm`, `libz`, `liblog`, `libjnigrpahics`, OpenGL/OpenSL ES, JNI headers, minimal C++ support headers, and Android native app APIs)
- Finally, NDK comes with extensive documentation, sample code and examples

3.2 Why NDK?

- NDK allows us to develop parts of our Android application in C/C++
- Generally, we do not develop native-only apps via NDK
 - Android's Gingerbread (2.3) release supports `NativeActivity`, which allows handling lifecycle callbacks in native code, so we can now develop native-only apps,
 - * No support for native services, broadcast receivers, content providers, etc.
- NDK code still subject to security sandboxing - we don't get extra permissions for running natively
- Main motivation for native code is performance (CPU-intensive, self-contained, low-memory footprint code) and the re-use of legacy code
 - For system integrators, NDK offers access to low-level libraries (e.g. access to user-space HAL)
 - **Using NDK always increases complexity** of applications, so it should only be used when it's essential to the application
 - Programming in Java offers richer APIs, memory protection and management, higher-level language constructs (OOP), all of which generally results in higher productivity

3.3 Java Native Interface (JNI)

3.3.1 JNI Overview

- An interface that allows Java to interact with code written in another language
- Motivation for JNI
 - Code reusability
 - * Reuse existing/legacy code with Java (mostly C/C++)
 - Performance
 - * Native code used to be up to 20 times faster than Java, when running in interpreted mode
 - * Modern JIT compilers (HotSpot, Dalvik) make this a moot point
 - Allow Java to tap into low level O/S, H/W routines
- JNI code is not portable!

Note

JNI can also be used to invoke Java code from within natively-written applications - such as those written in C/C++. In fact, the `java` command-line utility is an example of one such application, that launches Java code in a Java Virtual Machine.

3.3.2 JNI Components

- **javah** - JDK tool that builds C-style header files from a given Java class that includes native methods
 - Adapts Java method signatures to native function prototypes
- **jni.h** - C/C++ header file included with the JDK that maps Java types to their native counterparts
 - **javah** automatically includes this file in the application header files

3.3.3 JNI By Example

1. We start by creating a Java class with one or more native methods

src/com/marakana/jniexamples/Hello.java:

```
package com.marakana.jniexamples;

public class Hello {

    public static native void sayHi(String who, int times); // ❶

    static {
        System.loadLibrary("hello"); // ❷
    }

    public static void main(String[] args) {
        sayHi(args[0], Integer.parseInt(args[1])); // ❸
    }
}
```

- ❶ The method `sayHi(String, int)` will be implemented in C/C++ in separate files, which will be compiled into a shared library.
- ❷ Load the shared library by its *logical* name. The actual name is system-dependent: `libhello.so` (on Linux/Unix), `hello.dll` (on Windows), and `libhello.jnilib` (Mac OSX).
- ❸ Here we call our native method as a regular Java method.

2. Compile the Java code

```
$ mkdir -p bin
$ javac -d bin/ src/com/marakana/jniexamples/Hello.java
```

3. Using the **javah** tool, we generate the C header file from the compiled `com.marakana.jniexamples.Hello` class:

```
$ mkdir -p jni
$ javah -jni -classpath bin -d jni com.marakana.jniexamples.Hello
```

4. Observe the generated C header file:

jni/com_marakana_jniexamples_Hello.h:

```
/* DO NOT EDIT THIS FILE - it is machine generated */
#include <jni.h>
/* Header for class com_marakana_jniexamples_Hello */

#ifndef __Included_com_marakana_jniexamples_Hello
#define __Included_com_marakana_jniexamples_Hello
#ifdef __cplusplus
extern "C" {
#endif
```

```

/*
 * Class:      com_marakana_jniexamples_Hello
 * Method:     sayHi
 * Signature:  (Ljava/lang/String;I)V
 */
JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Hello_sayHi
    (JNIEnv *, jclass, jstring, jint);

#ifdef __cplusplus
}
#endif
#endif

```

Note

Method names resolve to C functions based on a pre-defined naming strategy: the prefix `Java_`, followed by a mangled fully-qualified class name, followed by an underscore ("`_`") separator, followed by a mangled method name. For overloaded native methods, two underscores ("`__`") followed by the mangled argument signature.

5. Provide the C implementation:

jni/com_marakana_jniexamples_Hello.c:

```

#include "com_marakana_jniexamples_Hello.h"

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Hello_sayHi
    (JNIEnv *env, jclass clazz, jstring who, jint times) {
    const char *name = (*env)->GetStringUTFChars(env, who, NULL);
    if (name != NULL) {
        jint i;
        for (i = 0; i < times; i++) {
            printf("Hello %s\n", name);
        }
        (*env)->ReleaseStringUTFChars(env, who, name);
    }
}

```

Note

Most of the time, we cannot just use Java data types directly in C. For example, we have to convert `java.lang.String` to `char *` before we can effectively use it in C.

Note

This code assumes: `#define NULL ((void *) 0)`

6. Compile the shared library

```

$ mkdir -p libs
$ gcc -o libs/libhello.jnilib -lc -shared \
    -I/System/Library/Frameworks/JavaVM.framework/Headers \
    jni/com_marakana_jniexamples_Hello.c
$ file libs/libhello.jnilib
libs/libhello.jnilib: Mach-O 64-bit dynamically linked shared library x86_64

```

Note

On Unix/Linux, compile as:

```
gcc -o libs/libhello.so -lc -shared -I$JAVA_HOME/include jni/com_marakana_jniexamples
```

7. Run our code

```
$ java -Djava.library.path=libs -classpath bin com.marakana.jniexamples.Hello Student 5
Hello Student
Hello Student
Hello Student
Hello Student
Hello Student
```

Note

Instead of specifying `-Djava.library.path=libs`, we could have preceded our `java` command with `export LD_LIBRARY_PATH=libs`.

Tip

Common mistakes resulting in `java.lang.UnsatisfiedLinkError` usually come from incorrect naming of the shared library (O/S-dependent), the library not being in the search path, or wrong library being loaded by Java code.

3.3.4 Native Method Arguments

- A C/C++ implementation of a native Java method accepts the following function arguments:
 - `JNIEnv *env`, an interface pointer (pointer to a pointer) to a **function table**, where each entry in the table is a pointer to a function that enables Java-to-C/C++ integration (e.g. type conversion)
 - The second argument varies depending on whether the native method is a `static` method or an instance (i.e. `non-static`) method:
 - In case of instance methods, the second argument is a `jobject obj`, which is a reference to the object on which the method is invoked
 - In case of `static` methods, the second is a `jclass clazz`, which is a reference to the class in which the method is defined
 - The remaining arguments correspond to regular Java method arguments (subject to the mapping described below)
- The native function can pass its result back to Java via the return value (or return `void`)

3.3.5 Primitive Type Mapping

- Java primitives have well-known size and are signed by default
- C/C++ primitives vary in size, depending on the platform (e.g. the size of the `long` depends on the size of the word)
- To provide inter-operability with C/C++, `jni.h` defines the following mappings:

Java Language Type	Native Type	Description	typedef (C99)	typedef (otherwise)
<code>boolean</code>	<code>jboolean</code>	unsigned 8 bits	<code>uint8_t</code>	unsigned char
<code>byte</code>	<code>jbyte</code>	signed 8 bits	<code>int8_t</code>	signed char
<code>char</code>	<code>jchar</code>	unsigned 16 bits	<code>uint16_t</code>	unsigned short
<code>short</code>	<code>jshort</code>	signed 16 bits	<code>int16_t</code>	short
<code>int</code>	<code>jint</code>	signed 32 bits	<code>int32_t</code>	int
<code>long</code>	<code>jlong</code>	signed 64 bits	<code>int64_t</code>	long long
<code>float</code>	<code>jfloat</code>	32-bit IEEE 754	<code>float</code>	float
<code>double</code>	<code>jdouble</code>	64-bit IEEE 754	<code>double</code>	double
<code>void</code>	<code>void</code>	N/A	N/A	N/A
N/A	<code>jsize</code>	used to describe cardinal indices and sizes	<code>jint</code>	<code>jint</code>

- Because `booleans` are treated as unsigned bytes, the following definitions are also useful

Java Boolean Value	Native Boolean Type	Definition
<code>false</code>	<code>JNI_FALSE</code>	<code>#define JNI_FALSE 0</code>
<code>true</code>	<code>JNI_TRUE</code>	<code>#define JNI_TRUE 1</code>

- Primitive data types are always *copied* between Java and native code

3.3.6 Reference Type Mapping

- The JNI includes a number of pre-defined reference types (passed as opaque references in C) that correspond to different kinds of Java object types:

Java Language Type	Native Type	typedef in C
<code>java.lang.Object</code>	<code>jobject</code>	<code>void*</code>
<code>java.lang.Class</code>	<code>jclass</code>	<code>jobject</code>
<code>java.lang.Throwable</code>	<code>jthrowable</code>	<code>jobject</code>
<code>java.lang.String</code>	<code>jstring</code>	<code>jobject</code>
<code>java.lang.ref.WeakReference</code>	<code>jweak</code>	<code>jobject</code>
<code>N/A</code>	<code>jarray</code>	<code>jobject</code>
<code>java.lang.Object[]</code>	<code>jobjectArray</code>	<code>jarray</code>
<code>boolean[]</code>	<code>jbooleanArray</code>	<code>jarray</code>
<code>byte[]</code>	<code>jbyteArray</code>	<code>jarray</code>
<code>char[]</code>	<code>jcharArray</code>	<code>jarray</code>
<code>short[]</code>	<code>jshortArray</code>	<code>jarray</code>
<code>int[]</code>	<code>jintArray</code>	<code>jarray</code>
<code>long[]</code>	<code>jlongArray</code>	<code>jarray</code>
<code>float[]</code>	<code>jfloatArray</code>	<code>jarray</code>
<code>double[]</code>	<code>jdoubleArray</code>	<code>jarray</code>

A note about reference types in C++

These reference types in C++ are defined as proper classes:

```
class _jobject {};
class _jclass : public _jobject {};
class _jstring : public _jobject {};
class _jarray : public _jobject {};
class _jobjectArray : public _jarray {};
class _jbooleanArray : public _jarray {};
class _jbyteArray : public _jarray {};
class _jcharArray : public _jarray {};
class _jshortArray : public _jarray {};
class _jintArray : public _jarray {};
class _jlongArray : public _jarray {};
class _jfloatArray : public _jarray {};
class _jdoubleArray : public _jarray {};
class _jthrowable : public _jobject {};

typedef _jobject*      jobject;
typedef _jclass*       jclass;
typedef _jstring*      jstring;
typedef _jarray*       jarray;
typedef _jobjectArray* jobjectArray;
typedef _jbooleanArray* jbooleanArray;
typedef _jbyteArray*   jbyteArray;
typedef _jcharArray*   jcharArray;
typedef _jshortArray*  jshortArray;
typedef _jintArray*    jintArray;
typedef _jlongArray*   jlongArray;
typedef _jfloatArray*  jfloatArray;
typedef _jdoubleArray* jdoubleArray;
typedef _jthrowable*   jthrowable;
typedef _jobject*      jweak;
```

A tip about NULL in Android NDK

Android's native development kit (NDK) does not define `NULL` in its `jni.h`, so the following definition can be useful when working with pointers and reference types:

```
#define NULL ((void *) 0)
```

**Warning**

Opaque references are C pointer types that refer to *internal* data structures in the JVM. It is an error to try to dereference opaque references and try to use them directly.

3.3.7 Global and Local References

- Unlike primitives, arbitrary Java objects are always passed by *reference*
- The VM must keep track of all objects that have been passed to the native code, so that these objects are not freed by the GC (i.e. these references are considered object *roots* while in use)
 - Consequently, the native code must have a way to tell the VM that it no longer needs references to objects
 - Additionally, the GC must be able to relocate an object referred to by native code (in the case of a copying GC), which means that these references must not be *dereferenced* by the native code

- We will access the fields/methods on these references via JNI accessor functions
- All objects passed to native code and returned from **JNI functions** are considered *local references*
 - Automatically "freed" after the native function call returns
 - * The VM creates a table of references before every function call, and frees it when the call completes
 - * Consequently, the native function calls are more expensive than regular method calls
 - Also possible to explicitly free using:

```
void DeleteLocalRef(JNIEnv *env, jobject localRef);
```

- Only valid in the thread in which they are created
- If we end up using more than 16 local references (default) within a native function scope, we can ask the VM for more:

```
jint EnsureLocalCapacity(JNIEnv *env, jint capacity);
jint PushLocalFrame(JNIEnv *env, jint capacity);
jobject PopLocalFrame(JNIEnv *env, jobject result);
```

- To hold on to an object beyond a single native function call, we can convert a local reference to a *global reference*

```
jobject NewGlobalRef(JNIEnv *env, jobject obj);
```

- Becomes our responsibility to explicitly delete the reference when no longer in use:

```
void DeleteGlobalRef(JNIEnv *env, jobject globalRef);
```

- Also supported are the weak global references

```
jweak NewWeakGlobalRef(JNIEnv *env, jobject obj);
void DeleteWeakGlobalRef(JNIEnv *env, jweak obj);
```

- JNI accessor functions do not make a distinction between the different reference types

3.3.8 Using Strings

- In C, a string is a pointer to a \0-terminated character array where each character is one byte
- In Java, an instance of `java.lang.String` is an immutable object which wraps a character array, which itself is an object (i.e. it knows its length so it is not \0-terminated), and each character is represented in UTF16 as *two bytes*
- **String Operations** are provided by `JNIEnv`:

```
/* On Unicode (UTF-16) Characters */
jstring NewString(JNIEnv *env, const jchar *unicodeChars, jsize len);
jsize GetStringLength(JNIEnv *env, jstring string);
const jchar * GetStringChars(JNIEnv *env, jstring string, jboolean *isCopy);
void ReleaseStringChars(JNIEnv *env, jstring string, const jchar *chars);
void GetStringRegion(JNIEnv *env, jstring str, jsize start, jsize len, jchar *buf);

/* On (modified) UTF-8 Characters */
jstring NewStringUTF(JNIEnv *env, const char *bytes);
jsize GetStringUTFLength(JNIEnv *env, jstring string);
const char * GetStringUTFChars(JNIEnv *env, jstring string, jboolean *isCopy);
void ReleaseStringUTFChars(JNIEnv *env, jstring string, const char *utf);
void GetStringUTFRegion(JNIEnv *env, jstring str, jsize start, jsize len, char *buf);
```

A note about GetString[UTF]Chars(...) functions

The pointer resulting from GetString[UTF]Chars(...) is valid until ReleaseString[UTF]Chars(...) is called. If isCopy is not NULL, then *isCopy is set to JNI_TRUE if a copy is made. When *isCopy == JNI_FALSE, the returned string is a *direct pointer* to the characters in the original java.lang.String instance, which is then pinned in memory. The native code must ensure **not to modify** the contents of the returned string, otherwise, it would be modifying the private data of the *immutable* java.lang.String object!

Regardless of isCopy, we have to call ReleaseString[UTF]Chars(...) when we are done using the character array, either to free the memory (when *isCopy == JNI_TRUE) or to un-pin the original string in memory (when *isCopy == JNI_FALSE).

A note about modified UTF-8 strings:

JNI's UTF string functions (that work with char *) return/assume \0-terminated character arrays that are encoded as UTF-8 character sequences, except that if the string *contains* a \u0000 character, it is represented by a pair of bytes 0xc0 0x80 (110000000100000000) instead of 0x00. When working with regular ASCII characters, each character is represented by exactly one byte.

• Examples:

– What **NOT** to do:

```
#include <stdio.h>
#include "com_marakana_jniexamples_HelloName.h"

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_HelloName_sayHelloName(JNIEnv *env, ↵
    jclass clazz, jstring name) {
    printf("Hello %s", name); /* ❶ */
}
```

- ❶ This example would not work (would likely crash the VM) since the jstring type represents strings in the Java virtual machine. This is different from the C string type (char *).

– Convert Java string to C string:

```
#include <stdio.h>
#include "com_marakana_jniexamples_HelloName.h"

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_HelloName_sayHelloName(JNIEnv *env, ↵
    jclass clazz, jstring name){
    const char *cName = (*env)->GetStringUTFChars(env, name, NULL); /* ❶ */
    if (cName == NULL) {
        return; /* OutOfMemoryError already thrown */
    } else {
        printf("Hello %s\n", cName);
        (*env)->ReleaseStringUTFChars(env, name, cName); /* ❷ */
    }
}
```

- ❶ This returns a pointer to an array of bytes representing the string in modified UTF-8 encoding; or NULL if we ran out of memory, in which case java.lang.OutOfMemoryError would also be thrown (upon returning back to the Java runtime).
- ❷ Calling ReleaseStringUTFChars indicates that the native method no longer needs the UTF-8 string returned by GetStringUTFChars, thus the memory taken by the UTF-8 string can be freed. Failure to do this would result in a memory leak, which could ultimately lead to memory exhaustion.

– Convert C string to Java string:

```
#include <stdio.h>
#include "com_marakana_jniexamples_GetName.h"
```

```
JNIEXPORT jstring JNICALL Java_com_marakana_jniexamples_ReturnName_GetName(JNIEnv *env, ↵
    jclass class) {
    char buf[20];
    fgets(buf, sizeof(buf), stdin);
    return (*env)->NewStringUTF(env, buf);
}
```

- Print each character of a Java string

```
#include <stdio.h>
#include "com_marakana_jniexamples_HelloName.h"

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_HelloName_sayHelloName(JNIEnv *env, ↵
    jclass clazz, jstring name) {
    char buf[4];
    jint i;
    jsize len = (*env)->GetStringUTFLength(env, name);
    fputs("Hello ", stdout);
    for (i = 0; i < len; i++) {
        (*env)->GetStringUTFRegion(env, name, i, 1, buf);
        putc(buf[0], stdout); /* assumes ASCII */
    }
    putc('\n', stdout);
}
```

3.3.9 Arrays

- As with Strings, Java arrays are different than C arrays; the former are objects (which *know* their length) whereas the latter are just pointers to memory addresses

- So, `int []` in Java is not the same as `jint []` in C/C++
- Instead, `int []` in Java, becomes `jintArray` in C/C++

- JNI provides **functions** for

- Creating arrays:

```
jobjectArray NewObjectArray(JNIEnv *env, jsize length, jclass elementClass, jobject ↵
    initialElement);
jbooleanArray NewBooleanArray(JNIEnv *env, jsize length);
jbyteArray NewByteArray(JNIEnv *env, jsize length);
jcharArray NewCharArray(JNIEnv *env, jsize length);
jshortArray NewShortArray(JNIEnv *env, jsize length);
jintArray NewIntArray(JNIEnv *env, jsize length);
jlongArray NewLongArray(JNIEnv *env, jsize length);
jfloatArray NewFloatArray(JNIEnv *env, jsize length);
jdoubleArray NewDoubleArray(JNIEnv *env, jsize length);
```

- Getting the length of an array

```
jsize GetArrayLength(JNIEnv *env, jarray array);
```

- Getting/Setting individual elements of object arrays

```
jobject GetObjectArrayElement(JNIEnv *env, jobjectArray array, jsize index);
void SetObjectArrayElement(JNIEnv *env, jobjectArray array, jsize index, jobject value);
```

- Converting Java arrays of primitives to C/C++ arrays:

```

jboolean* GetBooleanArrayElements(JNIEnv *env, jbooleanArray array, jboolean *isCopy);
jbyte*    GetByteArrayElements(JNIEnv *env, jbyteArray array, jboolean *isCopy);
jchar*    GetCharArrayElements(JNIEnv *env, jcharArray array, jboolean *isCopy);
jshort*   GetShortArrayElements(JNIEnv *env, jshortArray array, jboolean *isCopy);
jint*     GetIntArrayElements(JNIEnv *env, jintArray array, jboolean *isCopy);
jlong*    GetLongArrayElements(JNIEnv *env, jlongArray array, jboolean *isCopy);
jfloat*   GetFloatArrayElements(JNIEnv *env, jfloatArray array, jboolean *isCopy);
jdouble*  GetDoubleArrayElements(JNIEnv *env, jdoubleArray array, jboolean *isCopy);

void       ReleaseBooleanArrayElements(JNIEnv *env, jbooleanArray array, jboolean *elems, ←
    jint mode);
void       ReleaseByteArrayElements(JNIEnv *env, jbyteArray array, jbyte *elems, jint ←
    mode);
void       ReleaseCharArrayElements(JNIEnv *env, jcharArray array, jchar *elems, jint ←
    mode);
void       ReleaseShortArrayElements(JNIEnv *env, jshortArray array, jshort *elems, jint ←
    mode);
void       ReleaseIntArrayElements(JNIEnv *env, jintArray array, jint *elems, jint mode);
void       ReleaseLongArrayElements(JNIEnv *env, jlongArray array, jlong *elems, jint ←
    mode);
void       ReleaseFloatArrayElements(JNIEnv *env, jfloatArray array, jfloat *elems, jint ←
    mode);
void       ReleaseDoubleArrayElements(JNIEnv *env, jdoubleArray array, jdouble *elems, ←
    jint mode);

```

A note about memory

The pointer resulting from `GetTypeArrayElements(...)` is valid until `ReleaseTypeArrayElements(...)` is called (unless `mode == JNI_COMMIT`).

If `isCopy` is not NULL, then `*isCopy` is set to `JNI_TRUE` if a copy is made. When `*isCopy == JNI_FALSE`, the returned array is a *direct pointer* to the elements of the Java array, which is then pinned in memory.

Regardless of `isCopy`, we have to call `ReleaseTypeArrayElements(..., int mode)` when we are done using the native array, either to un-pin the Java array in memory when `*isCopy == JNI_FALSE`, or, when `*isCopy == JNI_TRUE`, to:

- * copy the native array over the Java array and free it (when `mode == 0`)
- * copy the native array over the Java array but **not** free it (when `mode == JNI_COMMIT`)
This option assumes that we will call `ReleaseTypeArrayElements(..., JNI_ABORT)` at some later point
- * leave the Java array intact and free the native array (when `mode == JNI_ABORT`)

JNI also supports a *critical* version of these functions:

```

void * GetPrimitiveArrayCritical(JNIEnv *env, jarray array, jboolean *isCopy);
void ReleasePrimitiveArrayCritical(JNIEnv *env, jarray array, void *carray, jint mode) ←
    ;

```

The function `GetPrimitiveArrayCritical(...)` is similar to `GetTypeArrayElements(...)`, except that the VM is more likely to return the pointer to the primitive array (i.e. `*isCopy == JNI_FALSE` is more likely). However, this comes with some caveats. The native code between `GetPrimitiveArrayCritical(...)` and `ReleasePrimitiveArrayCritical(...)` must not call other JNI functions, or make any system calls that may cause the current thread to block and wait for another Java thread. This is because the VM may temporarily suspend the garbage collection - in case it does not support memory pinning.

- Copying Java primitive arrays to and from C/C++ arrays:

```

void GetBooleanArrayRegion(JNIEnv *env, jbooleanArray array, jsize start, jsize len, ←
    jboolean *buf);
void GetByteArrayRegion(JNIEnv *env, jbyteArray array, jsize start, jsize len, jbyte *buf) ←
    ;

```

```

void GetCharArrayRegion(JNIEnv *env, jcharArray array, jsize start, jsize len, jchar *buf) ←
;
void GetShortArrayRegion(JNIEnv *env, jshortArray array, jsize start, jsize len, jshort * ←
buf);
void GetIntArrayRegion(JNIEnv *env, jintArray array, jsize start, jsize len, jint *buf);
void GetLongArrayRegion(JNIEnv *env, jlongArray array, jsize start, jsize len, jlong *buf) ←
;
void GetFloatArrayRegion(JNIEnv *env, jfloatArray array, jsize start, jsize len, jfloat * ←
buf);
void GetDoubleArrayRegion(JNIEnv *env, jdoubleArray array, jsize start, jsize len, jdouble ←
*buf);

void SetBooleanArrayRegion(JNIEnv *env, jbooleanArray array, jsize start, jsize len, ←
jboolean *buf);
void SetByteArrayRegion(JNIEnv *env, jbyteArray array, jsize start, jsize len, jbyte *buf) ←
;
void SetCharArrayRegion(JNIEnv *env, jcharArray array, jsize start, jsize len, jchar *buf) ←
;
void SetShortArrayRegion(JNIEnv *env, jshortArray array, jsize start, jsize len, jshort * ←
buf);
void SetIntArrayRegion(JNIEnv *env, jintArray array, jsize start, jsize len, jint *buf);
void SetLongArrayRegion(JNIEnv *env, jlongArray array, jsize start, jsize len, jlong *buf) ←
;
void SetFloatArrayRegion(JNIEnv *env, jfloatArray array, jsize start, jsize len, jfloat * ←
buf);
void SetDoubleArrayRegion(JNIEnv *env, jdoubleArray array, jsize start, jsize len, jdouble ←
*buf);

```

- For example, to sum the contents of a Java int array in C, we could:

```

JNIEXPORT jint JNICALL Java_com_marakana_jniexamples_Math_sum(JNIEnv *env, jclass clazz, ←
jintArray array) {
    jint *cArray = (*env)->GetIntArrayElements(env, array, NULL);
    if (cArray == NULL) {
        return 0;
    } else {
        jini len = (*env)->GetArrayLength(env, array);
        jint i;
        jint result = 0;
        for (i = 0; i < len; i++) {
            result += cArray[i];
        }
        (*env)->ReleaseIntArrayElements(env, array, cArray, JNI_ABORT);
        return result;
    }
}

```

- Alternatively, we could also extract the individual elements:

```

JNIEXPORT jint JNICALL Java_com_marakana_jniexamples_Math_sum(JNIEnv *env, jclass clazz, ←
jintArray array) {
    jint buf[1];
    jini len = (*env)->GetArrayLength(env, array);
    jint i;
    jint result = 0;
    for (i = 0; i < len; i++) {
        (*env)->GetIntArrayRegion(env, array, i, 1, buf);
        result += buf[0];
    }
    return result;
}

```

- To do the opposite, copy a C array to Java array, we would do:

```
JNIEXPORT jintArray JNICALL Java_com_marakana_jniexamples_Foo_getData(JNIEnv *env, jclass ↵
class) {
    jint cArray[10];
    jsize len = sizeof(cArray);
    jintArray jArray = (*env)->NewIntArray(env, len);
    if (jArray != NULL) {
        jint i;
        /* "get" the data */
        for (i = 0; i < len; i++) {
            cArray[i] = i;
        }
        (*env)->SetIntArrayRegion(env, jArray, 0, len, cArray);
    }
    return jArray;
}
```

- To avoid any chance of memory copying, we could also use direct memory buffers (`java.nio.ByteBuffer`):

```
jobject NewDirectByteBuffer(JNIEnv* env, void* address, jlong capacity);
void* GetDirectBufferAddress(JNIEnv* env, jobject buf);
jlong GetDirectBufferCapacity(JNIEnv* env, jobject buf);
```

- For example

In Java

```
public class Foo {
    public static void main(String[] args) {
        ...
        ByteBuffer buf = ByteBuffer.allocateDirect(1024);
        // populate buf
        processData(buf);
        ...
    }

    public native static void processData(ByteBuffer buf);
}
```

In C

```
JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Foo_processData(JNIEnv *env, jclass ↵
clazz, jobject buf) {
    char *cBuf = (*env)->GetDirectBufferAddress(env, buf);
    /* process cBuf from 0 to (*env)->GetDirectBufferCapacity(env, buf) */
}
```

3.3.10 Reflection

- JNI supports getting a reference to a Java class in native code:

```
jclass FindClass(JNIEnv *env, const char *name);
```

- The name argument is a fully-qualified classname (with / as the package separators)

```
/* load the java.lang.String class */
(*env)->FindClass(env, "java/lang/String");
```

- For arrays, we use `[Lclassname;` format


```
/* load the java.lang.String[] class */
(env)->FindClass(env, "[Ljava/lang/String;");
```

- Given a reference to a class, we can find out its super class, as well as whether it is assignable from another class:

```
jclass GetSuperclass(JNIEnv *env, jclass clazz);
jboolean IsAssignableFrom(JNIEnv *env, jclass clazz1, jclass clazz2);
```

- Given a reference to an object, we can find out its class, as well as whether it is an instance of another class:

```
jclass GetObjectClass(JNIEnv *env, jobject obj);
jboolean IsInstanceOf(JNIEnv *env, jobject obj, jclass clazz);
```

- Once we have a class, JNI offers functions to lookup, get/set fields and invoke methods of that class - based on the following field and method signatures:

Type Signature	Java Type
Z	boolean
B	byte
C	char
S	short
I	int
J	long
F	float
D	double
L <i>fully-qualified-class</i> ;	<i>fully-qualified-class</i>
[<i>type</i>	<i>type</i> []
(<i>arg-types</i>) <i>ret-type</i>	method type

- For fields, JNI offers functions to:

- Lookup a field ID based on its name/signature:

```
jfieldID GetStaticFieldID(JNIEnv *env, jclass clazz, const char *name, const char *sig);
jfieldID GetFieldID(JNIEnv *env, jclass clazz, const char *name, const char *sig);
```

- Get/set the value of a field based on the field ID:

```
jobject (*GetStaticObjectField)(JNIEnv*, jclass, jfieldID);
jboolean (*GetStaticBooleanField)(JNIEnv*, jclass, jfieldID);
jbyte (*GetStaticByteField)(JNIEnv*, jclass, jfieldID);
jchar (*GetStaticCharField)(JNIEnv*, jclass, jfieldID);
jshort (*GetStaticShortField)(JNIEnv*, jclass, jfieldID);
jint (*GetStaticIntField)(JNIEnv*, jclass, jfieldID);
jlong (*GetStaticLongField)(JNIEnv*, jclass, jfieldID);
jfloat (*GetStaticFloatField)(JNIEnv*, jclass, jfieldID);
jdouble (*GetStaticDoubleField)(JNIEnv*, jclass, jfieldID);

void (*SetStaticObjectField)(JNIEnv*, jclass, jfieldID, jobject);
void (*SetStaticBooleanField)(JNIEnv*, jclass, jfieldID, jboolean);
void (*SetStaticByteField)(JNIEnv*, jclass, jfieldID, jbyte);
void (*SetStaticCharField)(JNIEnv*, jclass, jfieldID, jchar);
void (*SetStaticShortField)(JNIEnv*, jclass, jfieldID, jshort);
void (*SetStaticIntField)(JNIEnv*, jclass, jfieldID, jint);
void (*SetStaticLongField)(JNIEnv*, jclass, jfieldID, jlong);
void (*SetStaticFloatField)(JNIEnv*, jclass, jfieldID, jfloat);
void (*SetStaticDoubleField)(JNIEnv*, jclass, jfieldID, jdouble);
```

```

jobject      (*GetObjectField)(JNIEnv*, jobject, jfieldID);
jboolean     (*GetBooleanField)(JNIEnv*, jobject, jfieldID);
jbyte        (*GetByteField)(JNIEnv*, jobject, jfieldID);
jchar        (*GetCharField)(JNIEnv*, jobject, jfieldID);
jshort       (*GetShortField)(JNIEnv*, jobject, jfieldID);
jint         (*GetIntField)(JNIEnv*, jobject, jfieldID);
jlong        (*GetLongField)(JNIEnv*, jobject, jfieldID);
jfloat       (*GetFloatField)(JNIEnv*, jobject, jfieldID);
jdouble      (*GetDoubleField)(JNIEnv*, jobject, jfieldID);

void         (*SetObjectField)(JNIEnv*, jobject, jfieldID, jobject);
void         (*SetBooleanField)(JNIEnv*, jobject, jfieldID, jboolean);
void         (*SetByteField)(JNIEnv*, jobject, jfieldID, jbyte);
void         (*SetCharField)(JNIEnv*, jobject, jfieldID, jchar);
void         (*SetShortField)(JNIEnv*, jobject, jfieldID, jshort);
void         (*SetIntField)(JNIEnv*, jobject, jfieldID, jint);
void         (*SetLongField)(JNIEnv*, jobject, jfieldID, jlong);
void         (*SetFloatField)(JNIEnv*, jobject, jfieldID, jfloat);
void         (*SetDoubleField)(JNIEnv*, jobject, jfieldID, jdouble);

```

– For example:

In Java

```

public class Foo {
    private String bar;
    ...
    public native void processBar();
}

```

In C

```

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Foo_processBar(JNIEnv *env, jobject <-
object) {
    /* Same as object.getClass() */
    jclass clazz = (*env)->GetObjectClass(env, object);
    if (clazz != NULL) { /* cannot be null in this case */
        /* Same as clazz.getField("bar") */
        jfieldID field = (*env)->GetFieldID(env, clazz, "bar", "Ljava/lang/String;");
        if (field != NULL) { /* make sure we got the field */
            /* Same as field.get(object) */
            jstring jString = (*env)->GetObjectField(env, object, field);
            if (jString != NULL) {
                /* Convert the value to a C (UTF-8) string */
                const char *cString = (*env)->GetStringUTFChars(env, jString, NULL);
                if (cString == NULL) {
                    return; /* Out of memory */
                }
                printf("Value of \"bar\" before the change: \"%s\"\n", cString);
                (*env)->ReleaseStringUTFChars(env, jString, cString);
            }
            /* Create a new String */
            jString = (*env)->NewStringUTF(env, "Bar2");
            if (jString != NULL) { /* make sure we are not out of memory */
                /* Same as field.set(object, jString) */
                (*env)->SetObjectField(env, object, field, jString);
            }
        }
    }
}

```

- For methods, JNI offers functions to:

- Lookup a method ID based on its name and signature:

```
jmethodID GetStaticMethodID(JNIEnv *env, jclass clazz, const char *name, const char *sig ↵
);
jmethodID GetMethodID(JNIEnv *env, jclass clazz, const char *name, const char *sig);
```

- Invoke a method based on the method ID:

```
jobject (*CallStaticObjectMethod)(JNIEnv*, jclass, jmethodID, ...);
jboolean (*CallStaticBooleanMethod)(JNIEnv*, jclass, jmethodID, ...);
jbyte (*CallStaticByteMethod)(JNIEnv*, jclass, jmethodID, ...);
jchar (*CallStaticCharMethod)(JNIEnv*, jclass, jmethodID, ...);
jshort (*CallStaticShortMethod)(JNIEnv*, jclass, jmethodID, ...);
jint (*CallStaticIntMethod)(JNIEnv*, jclass, jmethodID, ...);
jlong (*CallStaticLongMethod)(JNIEnv*, jclass, jmethodID, ...);
jfloat (*CallStaticFloatMethod)(JNIEnv*, jclass, jmethodID, ...);
jdouble (*CallStaticDoubleMethod)(JNIEnv*, jclass, jmethodID, ...);
void (*CallStaticVoidMethod)(JNIEnv*, jclass, jmethodID, ...);

jobject (*CallObjectMethod)(JNIEnv*, jobject, jmethodID, ...);
jboolean (*CallBooleanMethod)(JNIEnv*, jobject, jmethodID, ...);
jbyte (*CallByteMethod)(JNIEnv*, jobject, jmethodID, ...);
jchar (*CallCharMethod)(JNIEnv*, jobject, jmethodID, ...);
jshort (*CallShortMethod)(JNIEnv*, jobject, jmethodID, ...);
jint (*CallIntMethod)(JNIEnv*, jobject, jmethodID, ...);
jlong (*CallLongMethod)(JNIEnv*, jobject, jmethodID, ...);
jfloat (*CallFloatMethod)(JNIEnv*, jobject, jmethodID, ...);
jdouble (*CallDoubleMethod)(JNIEnv*, jobject, jmethodID, ...);
void (*CallVoidMethod)(JNIEnv*, jobject, jmethodID, ...);
```

Note

JNI also offers `Call... (...)` functions that take args in a form of `va_list` as well as an array of `jvalue`-s:

```
<Type> (*Call<Type>MethodV)(JNIEnv*, jobject, jmethodID, va_list);
<Type> (*CallStatic<Type>MethodV)(JNIEnv*, jobject, jmethodID, va_list);
<Type> (*Call<Type>MethodA)(JNIEnv*, jobject, jmethodID, jvalue*);
<Type> (*CallStatic<Type>MethodA)(JNIEnv*, jobject, jmethodID, jvalue*);
```

- For example:

In Java

```
public class Foo {
    private String bar;
    public void setBar(String bar) {
        this.bar = bar;
    }
    ...
    public native void processBar();
}
```

In C

```
JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Foo_processBar(JNIEnv *env, jobject ↵
object) {
    /* Same as object.getClass() */
    jclass clazz = (*env)->GetObjectClass(env, object);
    if (clazz != NULL) {
        /* Same as clazz.getMethod("setBar", String.class) - assuming non-static */
        jmethodID method = (*env)->GetMethodID(env, clazz, "setBar", "(Ljava/lang/String ↵
);V");
```

```

        if (method != NULL) { /* make sure we found the method */
            /* Create a new Java String */
            jstring jString = (*env)->NewStringUTF(env, "Bar2");
            if (jString != null) {
                /* Same as method.invoke(object, jString) */
                (*env)->CallVoidMethod(env, object, method, jString);
            }
        }
    }
}

```

3.3.11 Exceptions

- JNI permits us to throw exceptions from native code

- Assuming we have a Throwable *object*:

```
jint Throw(JNIEnv *env, jthrowable obj);
```

- Assuming we have a Throwable *class*, and that it has a constructor that takes a string message:

```
jint ThrowNew(JNIEnv *env, jclass clazz, const char *message);
```

- For example:

```

static void ThrowExceptionByClassName(JNIEnv *env, const char *name, const char *message ↵
) {
    jclass clazz = (*env)->FindClass(env, name);
    if (clazz != NULL) {
        (*env)->ThrowNew(env, clazz, message);
        (*env)->DeleteLocalRef(env, clazz);
    }
}
...
if (invalidArgument == TRUE) {
    ThrowExceptionByClassName(env, "java/lang/IllegalArgumentException", "This argument ↵
        is not valid!");
}

```

- Throwing an exception from native code just registers the throwable (as an exception pointer) with the current thread - it *does not interrupt* the current flow of the code!

- The pending exception gets "thrown" upon returning to the Java code
- While an exception is pending, we can only call the following JNI functions:

```

* DeleteGlobalRef
* DeleteLocalRef
* DeleteWeakGlobalRef
* ExceptionCheck
* ExceptionClear
* ExceptionDescribe
* ExceptionOccurred
* MonitorExit
* PopLocalFrame
* PushLocalFrame
* Release<PrimitiveType>ArrayElements
* ReleasePrimitiveArrayCritical

```

```

* ReleaseStringChars
* ReleaseStringCritical
* ReleaseStringUTFChars

```

- Calling methods on Java objects (e.g. via `CallObjectMethod`) can fail with an exception, but since exceptions don't automatically abort our function calls, we must explicitly check for existence of pending exceptions (e.g. with `ExceptionCheck`)
- Native code can "catch" an exception by calling `ExceptionCheck(...)` or `ExceptionOccurred(...)`, print its stack trace (to `stderr`) with `ExceptionDescribe(...)`, and "handle" it (i.e. clear it) with `ExceptionClear(...)`

```

jthrowable ExceptionOccurred(JNIEnv *env); /* NULL if no exception is currently being ↵
      thrown */
jboolean ExceptionCheck(JNIEnv *env);
void ExceptionDescribe(JNIEnv *env);
void ExceptionClear(JNIEnv *env);

```

- To get to the message of a throwable object we would do something like:

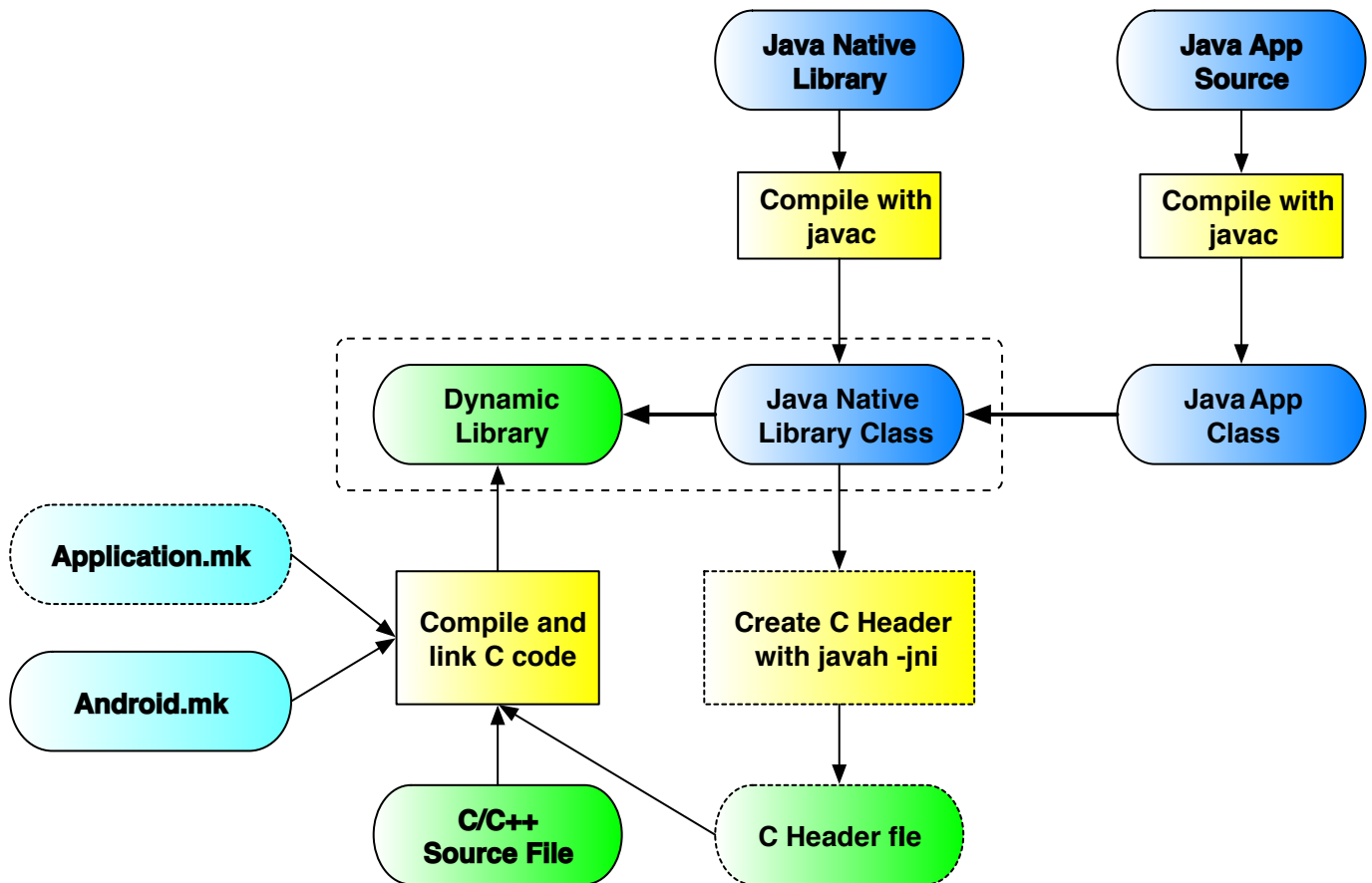
```

...
(env)->CallObjectMethod(env, ...); /* this can throw an exception */

if ((env)->ExceptionCheck(env)) {
    jthrowable throwable = (env)->ExceptionOccurred(env);
    jclass clazz = (env)->GetObjectClass(env, throwable);
    jmethodID getMessageMethod = (env)->GetMethodID(env, clazz, "getMessage", "()Ljava/ ↵
        lang/String;");
    jstring message = (env)->CallObjectMethod(env, throwable, getMessageMethod);
    const char *cMessage = (env)->GetStringUTFChars(env, message, NULL);
    if (cMessage) {
        printf("ERROR: %s\n", cMessage);
        (env)->ReleaseStringUTFChars(env, message, cMessage);
    }
    (env)->DeleteLocalRef(env, clazz);
    (env)->ExceptionDescribe(env); /* optionally dump the stack trace */
    (env)->ExceptionClear(env); /* mark the exception as "handled" */
}
...

```

3.4 Using NDK



3.5 Fibonacci Example

- NDK is best explained via an example (based on Fibonacci)
- The code is available
 - As a ZIP archive: <https://github.com/marakana/FibonacciNative/zipball/master>
 - By **Git**: `git clone https://github.com/marakana/FibonacciNative.git`
- Start by creating a new Android Project
 - Project Name: FibonacciNative
 - Build Target: Android 2.2 (API 8) or later
 - Application Name: Fibonacci Native
 - Package: `com.marakana.android.fibonaccinative`
 - Create Activity: `FibonacciActivity`

3.5.1 Fibonacci - Java Native Function Prototypes

We start off by defining C function prototypes as native Java methods (wrapped in some class):

FibonacciNative/src/com/marakana/android/fibonaccinative/FibLib.java

```

package com.marakana.android.fibonaccinative;

import android.util.Log;

public class FibLib {
    private static final String TAG = "FibLib";

    private static long fib(long n) {
        return n <= 0 ? 0 : n == 1 ? 1 : fib(n - 1) + fib(n - 2);
    }

    // Recursive Java implementation of the Fibonacci algorithm
    // (included for comparison only)
    public static long fibJR(long n) {
        Log.d(TAG, "fibJR(" + n + ")");
        return fib(n);
    }

    // Function prototype for future native recursive implementation
    // of the Fibonacci algorithm
    public native static long fibNR(long n);

    // Iterative Java implementation of the Fibonacci algorithm
    // (included for comparison only)
    public static long fibJI(long n) {
        Log.d(TAG, "fibJI(" + n + ")");
        long previous = -1;
        long result = 1;
        for (long i = 0; i <= n; i++) {
            long sum = result + previous;
            previous = result;
            result = sum;
        }
        return result;
    }

    // Function prototype for future iterative recursive implementation
    // of the Fibonacci algorithm
    public native static long fibNI(long n);

    static {
        // as defined by LOCAL_MODULE in Android.mk
        System.loadLibrary("com_marakana_android_fibonaccinative_FibLib");
    }
}

```

3.5.2 Fibonacci - Function Prototypes in a C Header File

We then extract our C header file with our function prototypes:

1. On the command line, change to your project's root directory

```
$ cd /path/to/workspace/FibonacciNative
```

2. Create jni sub-directory

```
$ mkdir jni
```

3. Extract the C header file from `com.marakana.android.fibonaccinative.FibLib` class:

```
$ javah -jni -classpath bin/classes -d jni com.marakana.android.fibonaccinative.FibLib
```

Note

Prior to ADT r14, compiled class files were kept directly in the `bin/` directory, so in our `javah` command we would've used `-classpath bin` instead.

4. Check out the resulting file:

FibonacciNative/jni/com_marakana_android_fibonaccinative_FibLib.h

```
/* DO NOT EDIT THIS FILE - it is machine generated */
#include <jni.h>
/* Header for class com_marakana_android_fibonaccinative_FibLib */

#ifndef _Included_com_marakana_android_fibonaccinative_FibLib
#define _Included_com_marakana_android_fibonaccinative_FibLib
#ifdef __cplusplus
extern "C" {
#endif
/*
 * Class:      com_marakana_android_fibonaccinative_FibLib
 * Method:     fibNR
 * Signature:  (J)J
 */
JNIEXPORT jlong JNICALL Java_com_marakana_android_fibonaccinative_FibLib_fibNR
    (JNIEnv *, jclass, jlong);

/*
 * Class:      com_marakana_android_fibonaccinative_FibLib
 * Method:     fibNI
 * Signature:  (J)J
 */
JNIEXPORT jlong JNICALL Java_com_marakana_android_fibonaccinative_FibLib_fibNI
    (JNIEnv *, jclass, jlong);

#ifdef __cplusplus
}
#endif
#endif
```

Note

The function prototype names are name-spaced to the classname they are found in.

3.5.3 Fibonacci - Provide C Implementation

We provide the C implementation of `com_marakana_android_fibonacci_FibLib.h` header file:

FibonacciNative/jni/com_marakana_android_fibonaccinative_FibLib.c

```
/* Include the header file that was created via "javah -jni" command */
#include "com_marakana_android_fibonaccinative_FibLib.h"
#include <android/log.h>

/* Recursive implementation of the fibonacci algorithm (in a helper function) */
static jlong fib(jlong n) {
```



```

    return n <= 0 ? 0 : n == 1 ? 1 : fib(n - 1) + fib(n - 2);
}

/* Actual implementation of JNI-defined 'fibNR' (recursive) function */
JNIEXPORT jlong JNICALL Java_com_marakana_android_fibonaccinative_FibLib_fibNR
(JNIEnv *env, jclass clazz, jlong n) {
    __android_log_print(ANDROID_LOG_DEBUG, "FibLib.c", "fibNR(%lld)", n);
    return fib(n);
}

/* Actual implementation of JNI-defined 'fibNI' (iterative) function */
JNIEXPORT jlong JNICALL Java_com_marakana_android_fibonaccinative_FibLib_fibNI
(JNIEnv *env, jclass clazz, jlong n) {
    jlong previous = -1;
    jlong result = 1;
    jlong i;
    __android_log_print(ANDROID_LOG_DEBUG, "FibLib.c", "fibNI(%lld)", n);
    for (i = 0; i <= n; i++) {
        jlong sum = result + previous;
        previous = result;
        result = sum;
    }
    return result;
}

```

3.5.4 Fibonacci - An Alternative Implementation (C++)

We could also use an alternative mechanism of linking native-code to managed code by pre-registering our functions. This leads to earlier detection of method-function mismatch issues, a slight performance improvement, and spares us the redundancy of the header file and the use of the `javah` command.

- See <http://java.sun.com/docs/books/jni/html/other.html#29535>

FibonacciNative/jni/com_marakana_android_fibonaccinative_FibLib.cpp

```

#include <jni.h>
#include <android/log.h>

namespace com_marakana_android_fibonaccinative {
    static jlong fib(jlong n) {
        return n <= 0 ? 0 : n == 1 ? 1 : fib(n - 1) + fib(n - 2);
    }

    static jlong fibNR(JNIEnv *env, jclass clazz, jlong n) {
        __android_log_print(ANDROID_LOG_DEBUG, "FibLib.c", "fibNR(%lld)", n);
        return fib(n);
    }

    static jlong fibNI(JNIEnv *env, jclass clazz, jlong n) {
        jlong previous = -1;
        jlong result = 1;
        jlong i;
        __android_log_print(ANDROID_LOG_DEBUG, "FibLib.c", "fibNI(%lld)", n);
        for (i = 0; i <= n; i++) {
            jlong sum = result + previous;
            previous = result;
            result = sum;
        }
        return result;
    }
}

```

```

static JNINativeMethod method_table[] = {
    { "fibNR", "(J)J", (void *) fibNR },
    { "fibNI", "(J)J", (void *) fibNI }
};
}

using namespace com_marakana_android_fibonaccinative;

extern "C" jint JNI_OnLoad(JavaVM* vm, void* reserved) {
    JNIEnv* env;
    if (vm->GetEnv(reinterpret_cast<void*>(&env), JNI_VERSION_1_6) != JNI_OK) {
        return JNI_ERR;
    } else {
        jclass clazz = env->FindClass("com/marakana/android/fibonaccinative/FibLib");
        if (clazz) {
            jint ret = env->RegisterNatives(clazz, method_table, sizeof(method_table) / ↵
                sizeof(method_table[0]));
            env->DeleteLocalRef(clazz);
            return ret == 0 ? JNI_VERSION_1_6 : JNI_ERR;
        } else {
            return JNI_ERR;
        }
    }
}
}

```

Note

Most of the Android's JNI-based shared libraries are built using this, "alternative", approach where the functions are pre-registered.

3.5.5 Fibonacci - Makefile

We need a `Android.mk` makefile, which will be used by NDK to compile our JNI code into a shared library:

FibonacciNative/jni/Android.mk

```

# Defines the root to all other relative paths
# The macro function my-dir, provided by the build system,
# specifies the path of the current directory (i.e. the
# directory containing the Android.mk file itself)
LOCAL_PATH := $(call my-dir)

# Clear all LOCAL_XXX variables with the exception of
# LOCAL_PATH (this is needed because all variables are global)
include $(CLEAR_VARS)

# List all of our C files to be compiled (header file
# dependencies are automatically computed)
LOCAL_SRC_FILES := com_marakana_android_fibonaccinative_FibLib.c

# The name of our shared module (this name will be prepended
# by lib and postfixed by .so)
LOCAL_MODULE := com_marakana_android_fibonaccinative_FibLib

# We need to tell the linker about our use of the liblog.so
LOCAL_LDLIBS += -llog

# Collects all LOCAL_XXX variables since "include $(CLEAR_VARS)"
# and determines what to build (in this case a shared library)

```

```
include $(BUILD_SHARED_LIBRARY)
```

Note

It's easiest to copy the `Android.mk` file from another (sample) project and adjust `LOCAL_SRC_FILES` and `LOCAL_MODULE` as necessary

Note

See `/path/to/ndk-installation-dir/docs/ANDROID-MK.html` for the complete reference of Android make files (build system)

3.5.6 Fibonacci - Compile Our Shared Module

Finally, from the root of our project (i.e. `FibonacciNative/`), we run `ndk-build` to build our code into a shared library (`FibonacciNative/libs/armeabi/libcom_marakana_android_fibonacci_FibLib.so`):

```
$ ndk-build
Compile thumb  : com_marakana_android_fibonaccinative_FibLib <=  ↵
                  com_marakana_android_fibonaccinative_FibLib.c
SharedLibrary  : libcom_marakana_android_fibonaccinative_FibLib.so
Install        : libcom_marakana_android_fibonaccinative_FibLib.so => libs/armeabi/ ↵
                  libcom_marakana_android_fibonaccinative_FibLib.so
```

Running `ndk-build clean` will clean all generated binaries.

Note

The command `ndk-build` comes from the NDK's installation directory (e.g. `/path/to/android-ndk-r5b`), so it's easiest if we add this directory to our `PATH`.

Note

The current version of NDK (at least up to r5b) on Windows depends on Cygwin (a Unix-like environment and command-line interface for Microsoft Windows), or specifically "shell" (bash) and "make" (gmake) programs available through Cygwin. To run `ndk-build` on Windows, we first need to run `bash` and then execute `ndk-build`. It is important that both `c:\path\to\cygwin\bin` and `c:\path\to\ndk` be defined in our `Path`.

Controlling CPU Application Binary Interface (ABI)

- By default, the NDK will generate machine code for the *armeabi* (i.e. ARMv5TE with support for Thumb-1) ABI
 - The target application library is packaged as `lib/armeabi/lib<name>.so`
 - Upon installation, it is copied to `/data/data/<package>/lib/lib<name>.so`
 - We could add support for ARMv7-A (including hardware FPU/VFPv3-D16, Thumb-2, VFPv3-D32/ThumbEE, and SIMD/NEON) via `APP_ABI` in a separate `Application.mk` file
 - `APP_ABI := armeabi-v7a`
 - * ARMv7-a only
 - * Packaged as `lib/armeabi-v7a/lib<name>.so`
 - `APP_ABI := armeabi armeabi-v7a x86`
 - * Builds **three** versions of the library, for ARMv5TE, ARMv7-a, and x86 in a single "fat binary"
-

- * Packaged as

- `lib/armeabi/lib<name>.so`
- `lib/armeabi-v7a/lib<name>.so`
- `lib/x86/lib<name>.so`

- * The Android system knows at runtime which ABI(s) it supports

- *primary* ABI for the device corresponds to the machine code of the system image
- *secondary* ABI (optional) corresponds to to another ABI that is also supported by the system image
- Upon installation, Android first scans `lib/<primary-abi>/lib<name>.so` then `lib/<secondary-abi>/lib<name>.so` and installs the first that it finds to `/data/data/<package>/lib/lib<name>.so`

- As an alternative to `Application.mk` file, we could also specify `APP_ABI` on the command-line:

```
ndk-build "APP_ABI=armeabi armeabi-v7a x86"
```

- Support for `x86` ABI (i.e. IA-32 instruction set) was added in NDK r6 (July 2011)

3.5.7 Fibonacci - Client

We can now build the "client" of our library (in this case a simple activity) to use our `FibLib` library.

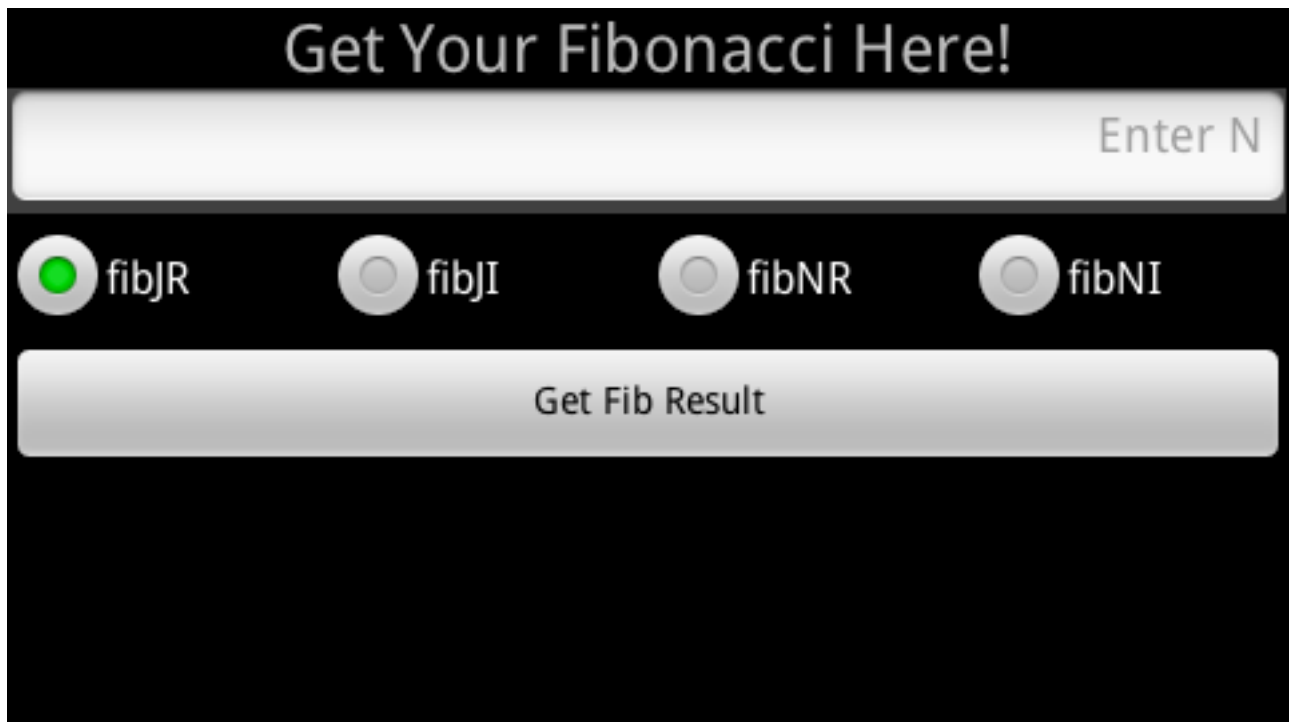
Fibonacci - String Resources

FibonacciNative/res/values/strings.xml

```
<?xml version="1.0" encoding="utf-8"?>
<resources>

    <string name="hello">Get Your Fibonacci Numbers Here!</string>
    <string name="fibJR">fibJR</string>
    <string name="fibJI">fibJI</string>
    <string name="fibNR">fibNR</string>
    <string name="fibNI">fibNI</string>
    <string name="app_name">FibonacciNative</string>
    <string name="button">Get Fibonacci Result</string>

</resources>
```

Fibonacci - User Interface (Layout)**FibonacciNative/res/layout/main.xml**

```
<?xml version="1.0" encoding="utf-8"?>
<LinearLayout xmlns:android="http://schemas.android.com/apk/res/android"
    android:layout_width="fill_parent"
    android:layout_height="fill_parent"
    android:orientation="vertical" >

    <!-- This is just a simple title ("Get Your Fibonacci Here!") -->
    <TextView
        android:layout_width="fill_parent"
        android:layout_height="wrap_content"
        android:gravity="center"
        android:text="@string/hello"
        android:textSize="25sp" />

    <!-- This is the entry box for our number "n" -->
    <EditText
        android:id="@+id/input"
        android:layout_width="match_parent"
        android:layout_height="wrap_content"
        android:ems="10"
        android:gravity="right"
        android:inputType="number" >
        <requestFocus />
    </EditText>

    <!-- This radio group allows the user to select the fibonacci implementation type -->
    <RadioGroup
        android:id="@+id/type"
        android:layout_width="match_parent"
        android:layout_height="wrap_content"
        android:orientation="horizontal" >
```

```
<RadioButton
    android:id="@+id/type_fib_jr"
    android:layout_width="match_parent"
    android:layout_height="wrap_content"
    android:layout_weight="1"
    android:text="@string/fibJR" />

<RadioButton
    android:id="@+id/type_fib_ji"
    android:layout_width="match_parent"
    android:layout_height="wrap_content"
    android:layout_weight="1"
    android:text="@string/fibJI" />

<RadioButton
    android:id="@+id/type_fib_nr"
    android:layout_width="match_parent"
    android:layout_height="wrap_content"
    android:layout_weight="1"
    android:text="@string/fibNR" />

<RadioButton
    android:id="@+id/type_fib_ni"
    android:layout_width="match_parent"
    android:layout_height="wrap_content"
    android:layout_weight="1"
    android:text="@string/fibNI" />
</RadioGroup>

<!-- This button allows the user to trigger fibonacci calculation -->
<Button
    android:id="@+id/button"
    android:layout_width="match_parent"
    android:layout_height="wrap_content"
    android:text="@string/button" />

<!-- This is the output area for the fibonacci result -->
<TextView
    android:id="@+id/output"
    android:layout_width="match_parent"
    android:layout_height="match_parent"
    android:gravity="center"
    android:textSize="20sp" />

</LinearLayout>
```

Fibonacci - FibonacciActivity

FibonacciNative/src/com/marakana/android/fibonaccinative/FibonacciActivity.java

```
package com.marakana.android.fibonaccinative;

import android.app.Activity;
import android.app.ProgressDialog;
import android.os.AsyncTask;
import android.os.Bundle;
import android.os.SystemClock;
import android.text.TextUtils;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.Button;
```

```
import android.widget.EditText;
import android.widget.RadioGroup;
import android.widget.TextView;

public class FibonacciActivity extends Activity implements OnClickListener {

    private EditText input;

    private RadioGroup type;

    private TextView output;

    @Override
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.main);
        this.input = (EditText) super.findViewById(R.id.input);
        this.type = (RadioGroup) super.findViewById(R.id.type);
        this.output = (TextView) super.findViewById(R.id.output);
        Button button = (Button) super.findViewById(R.id.button);
        button.setOnClickListener(this);
    }

    public void onClick(View view) {
        String s = this.input.getText().toString();
        if (TextUtils.isEmpty(s)) {
            return;
        }

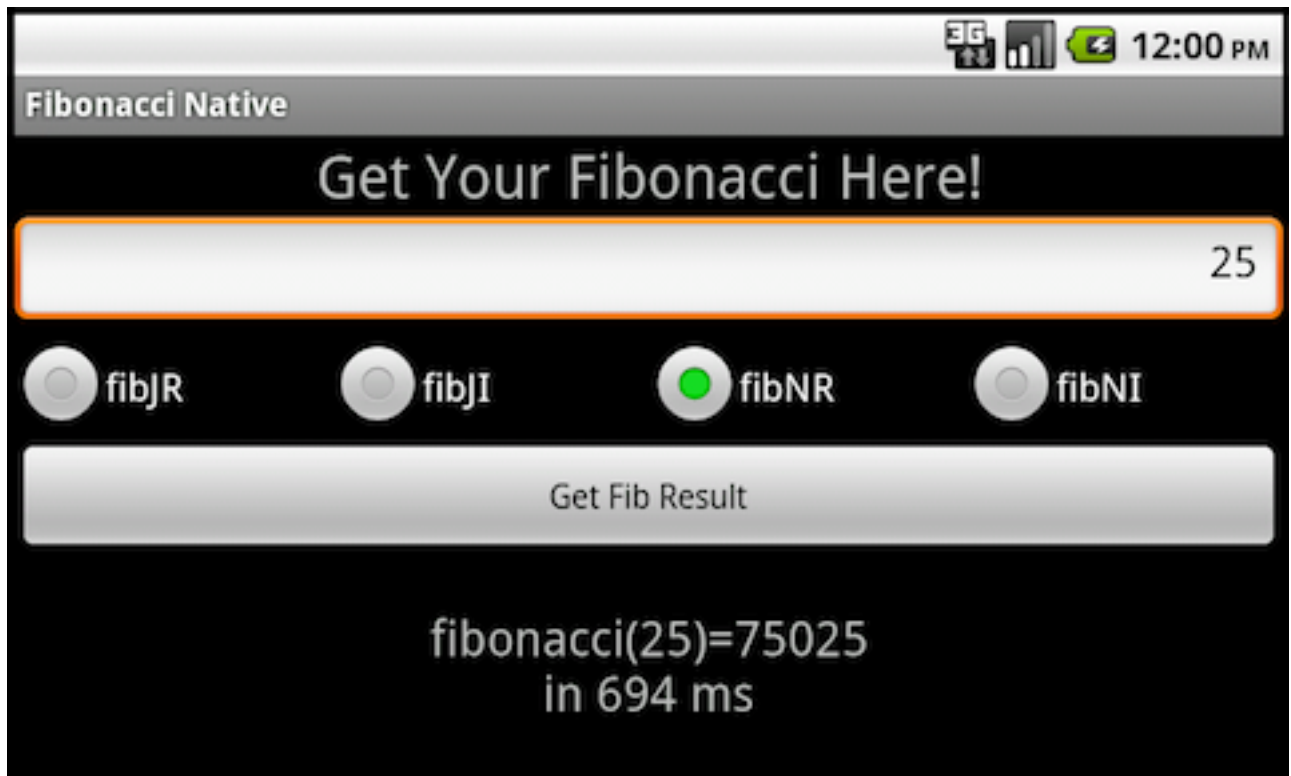
        final ProgressDialog dialog = ProgressDialog.show(this, "",
            "Calculating...", true);
        final long n = Long.parseLong(s);
        new AsyncTask<Void, Void, String>() {

            @Override
            protected String doInBackground(Void... params) {
                long result = 0;
                long t = SystemClock.uptimeMillis();
                switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
                    case R.id.type_fib_jr:
                        result = FibLib.fibJR(n);
                        break;
                    case R.id.type_fib_ji:
                        result = FibLib.fibJI(n);
                        break;
                    case R.id.type_fib_nr:
                        result = FibLib.fibNR(n);
                        break;
                    case R.id.type_fib_ni:
                        result = FibLib.fibNI(n);
                        break;
                }
                t = SystemClock.uptimeMillis() - t;
                return String.format("fib(%d)=%d in %d ms", n, result, t);
            }

            @Override
            protected void onPostExecute(String result) {
                dialog.dismiss();
                FibonacciActivity.this.output.setText(result);
            }
        }.execute();
    }
}
```

```
}  
}
```

3.5.8 Fibonacci - Result



3.6 NDK's Stable APIs

The header files for NDK stable APIs are available at `/path/to/ndk/platforms/<android-platform>/<arch-name>/u`

3.6.1 Android-specific Log Support

- Include `<android/log.h>` to access various functionality that can be used to send log messages to the kernel (i.e. `logcat` buffers) from our native code
- Requires that our code be linked to `/system/lib/liblog.so` with `LOCAL_LDLIBS += -llog` in our `Android.mk` file

3.6.2 ZLib Compression Library

- Include `<zlib.h>` and `<zconf.h>` to access ZLib compression library
 - See <http://www.zlib.net/manual.html> for more info on ZLib
- Requires that our code be linked to `/system/lib/libz.so` with `LOCAL_LDLIBS += -lz` in our `Android.mk` file

3.6.3 The OpenGL ES 1.x Library

- Include `<GLES/gl.h>` and `<GLES/glext.h>` to access OpenGL ES 1.x rendering calls from native code
 - The "1.x" here refers to both versions 1.0 and 1.1
 - * Using 1.1 requires OpenGL-capable GPU
 - * Using 1.0 is universally supported since Android includes software renderer for GPU-less devices
 - * Requires that we include `<uses-feature>` tag in our manifest file to indicate the actual OpenGL version that we expect
- Requires that our code be linked to `/system/lib/libGL ESv1_CM.so` with `LOCAL_LDLIBS += -lGL ESv1_CM.so` in our `Android.mk` file
- Since API 4 (Android 1.6)

3.6.4 The OpenGL ES 2.0 Library

- Include `<GLES2/gl2.h>` and `<GLES2/gl2ext.h>` to access OpenGL ES 2.0 rendering calls from native code
 - Enables the use of vertex and fragment shaders via the GLSL language
 - Since not all devices support OpenGL 2.0, we should include `<uses-feature>` tag in our manifest file to indicate this requirement
- Requires that our code be linked to `/system/lib/libGL ESv2.so` with `LOCAL_LDLIBS += -lGL ESv2.so` in our `Android.mk` file
- Since API 4 (Android 2.0)

3.6.5 The jnigraphics Library

- Include `<android/bitmap.h>` to reliably access the pixel buffers of Java bitmap objects from native code
- Requires that our code be linked to `/system/lib/libjnigraphics.so` with `LOCAL_LDLIBS += -ljnigraphics` in our `Android.mk` file
- Since API 8 (Android 2.2)

3.6.6 The OpenSL ES native audio Library

- Include `<SLES/OpenSLES.h>` and `<SLES/OpenSLES_Platform.h>` to perform audio input and output from native code
 - Based on Khronos Group OpenSL ES™ 1.0.1
- Requires that our code be linked to `/system/lib/libOpenSLES.so` with `LOCAL_LDLIBS += -lOpenSLES` in our `Android.mk` file
- Since API 9 (Android 2.3)

3.6.7 The Android native application APIs

- Makes it possible to write our entire application in native code
 - Mainly added for gaming
 - Our code still depends on the Dalvik VM since most of the platform features are managed in the VM and accessed via JNI (Native → Java)
- Include `<android/native_activity.h>` to write an Android activity (with its life-cycle callbacks) in native code
 - A native activity would serve as the main entry point into our native application
- Include `<android/looper.h>`, `<android/input.h>`, `<android/keycodes.h>`, and `<android/sensor.h>` to listen to input events and sensors directly from native code
- Include `<android/rect.h>`, `<android/window.h>`, `<android/native_window.h>`, and `<android/native_window.h>` for window management from native code
 - Includes ability to lock/unlock the pixel buffer to draw directly into it
- Include `<android/configuration.h>`, `<android/asset_manager.h>`, `<android/storage_manager.h>`, and `<android/obb.h>` for direct access to the assets embedded in our .apk files Opaque Binary Blob (OBB) files
 - All access is read-only
- Requires that our code be linked to `libandroid.so` with `LOCAL_LDLIBS += -landroid` in our `Android.mk` file
- Since API 9 (Android 2.3)



Caution

With the exception of the libraries listed above, the native system libraries in the Android platform are not considered "stable" and may change in future platform versions. Unless our library is being built for a specific Android ROM, we should only make use of the stable libraries provided by the NDK.

Note

All the header files are available under: `/path/to/ndk-installation-dir/platforms/android-9/arch-arm/usr/`

Note

See `/path/to/ndk-installation-dir/docs/STABLE-APIS.html` for the complete reference of NDK's stable APIs.

3.7 Lab: NDK

Create a simple Android application that allows the end-user to log to Android's logcat via functionality provided by `/system/lib/liblog.so` (i.e. you cannot use `android.util.Log`).

For example, this could be your `LogLib`:

```
package com.marakana.android.loglib;
public class LogLib {
    public static native void log(int priority, String tag, String msg);
    /* You'll need to load your library here */
}
```

The basic scaffolding for your application, along with the UI is already provided:

- As a ZIP archive: <https://github.com/marakana/LogNative/zipball/master>
- By **Git**: `git clone https://github.com/marakana/LogNative.git`

As a bonus:

- Throw `java.lang.IllegalArgumentException` if `priority` is not one of the allowed types
- Throw `java.lang.NullPointerException` if `tag` or `msg` are null

Tip

Don't forget to convert `tag` and `msg` strings from the Java format (`jstring`) to native format (`char *`) before trying to use them in `int __android_log_write(int prio, const char *tag, const char *text)`. Also, don't forget to *free* the native strings before returning from the native method. Finally, don't forget to tell the linker about your use of the *log* library.

The solution is provided:

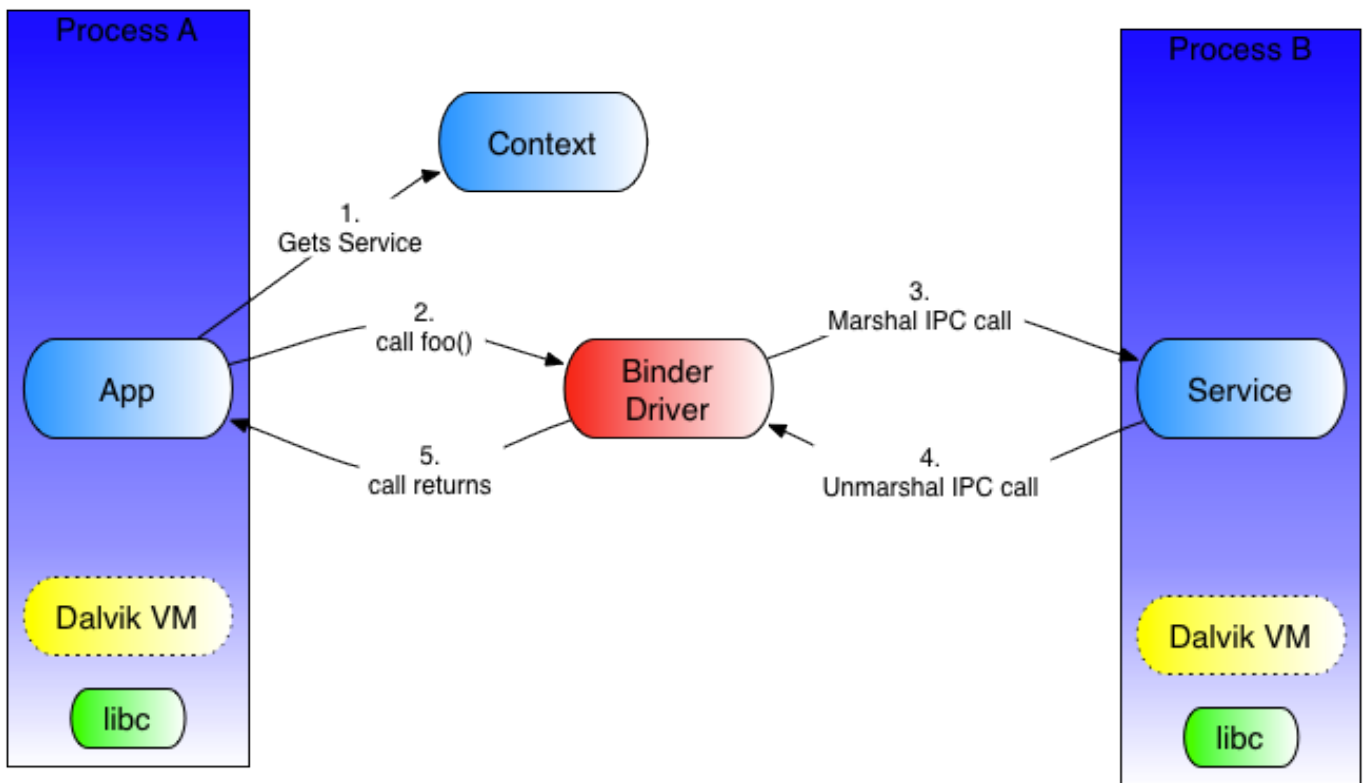
- As a ZIP archive: <https://github.com/marakana/LogNative/zipball/solution>
- By **Git**: `git clone https://github.com/marakana/LogNative.git -b solution`

4 Android Binder Inter Process Communication (IPC) with AIDL

4.1 Why IPC?

- Each Android application runs in a separate process
 - Android application-framework services also run in a separate process called `systemserver`
 - Often we wish to make use of services offered by other applications, or we simply wish to expose our applications' capabilities to 3rd party apps
 - Even Android's *Intent*-based IPC-like mechanism (used for starting activities and services, as well as delivering events), is internally based on Binder
 - By design (for security reasons), processes cannot directly access each other's data
 - To cross the process boundaries, we need support of a inter-process communication transport mechanism, which handles passing of data from one process (caller) to another (callee)
 - Caller's data is *marshaled* into tokens that IPC understands, copied to callee's process, and finally *unmarshaled* into what callee expects
 - Callee's response is also *marshaled*, copied to caller's process where it is *unmarshaled* into what caller expects
 - Marshaling/unmarshaling is automatically provided by the IPC mechanism
-

4.2 What is Binder?



- Binder provides a lightweight remote procedure call (RPC) mechanism designed for high performance when performing in-process and cross-process calls (IPC)
- Binder-capable services are described in Android Interface Definition Language (AIDL), not unlike other IDL languages
- Since Binder is provided as a Linux driver, the services can be written in both C/C++ as well as Java
 - Most Android services are written in Java
- All caller calls go through Binder's `transact()` method, which automatically marshals the arguments and return values via `Parcel` objects
 - `Parcel` is a generic buffer of data (decomposed into primitives) that also maintains some meta-data about its contents - such as object references to ensure object identity across processes
 - Caller calls to `transact()` are by default synchronous - i.e. provide the same semantics as a local method call
 - * On callee side, the Binder framework maintains a pool of transaction threads, which are used to handle the incoming IPC requests (unless the call is local, in which case the same thread is used)
 - * Callee methods can be marked as `oneway`, in which case caller calls do not block (i.e. calls return immediately)
- Callee' mutable state needs to be thread-safe - since callee's can accept concurrent requests from multiple callers
- The Binder system also supports recursion across processes - i.e. behaves the same as recursion semantics when calling methods on local objects

4.3 What is AIDL?

- Android Interface Definition Language is a Android-specific language for defining Binder-based service interfaces
- AIDL follows Java-like interface syntax and allows us to declare our "business" methods

- Each Binder-based service is defined in a separate `.aidl` file, typically named `IFooService.aidl`, and saved in the `src/` directory

src/com/example/app/IFooService.aidl

```
package com.example.app;
import com.example.app.Bar;
interface IFooService {
    void save(inout Bar bar);
    Bar getById(int id);
    void delete(in Bar bar);
    List<Bar> getAll();
}
```

- The `aidl` build tool (part of Android SDK) is used to extract a real Java interface (along with a `Stub` providing Android's `android.os.IBinder`) from each `.aidl` file and place it into our `gen/` directory

gen/com/example/app/IFooService.java

```
package com.example.app;
public interface IFooService extends android.os.IInterface
{
    public static abstract class Stub extends android.os.Binder
        implements com.example.app.IFooService {
        ...
        public static com.example.app.IFooService asInterface(
            android.os.IBinder obj) {
            ...
        }
        public android.os.IBinder asBinder() {
            return this;
        }
        ...
    }
    void save(com.example.app.Bar bar) throws android.os.RemoteException;
    com.example.app.Bar getById(int id) throws android.os.RemoteException;
    void delete(com.example.app.Bar bar) throws android.os.RemoteException;
    java.util.List<Bar> getAll() throws android.os.RemoteException;
}
```

Note

Eclipse ADT automatically calls `aidl` for each `.aidl` file that it finds in our `src/` directory

- AIDL supports the following types:

- `null`
 - `boolean`, `boolean[]`, `byte`, `byte[]`, `char[]`, `int`, `int[]`, `long`, `long[]`, `float`, `float[]`, `double`, `double[]`
 - `java.lang.CharSequence`, `java.lang.String`
 - `java.io.FileDescriptor`
 - * Gets transferred as a dup of the original file descriptor - while the `fd` is different, it points to the same underlying stream and position
 - `java.io.Serializable` (not efficient)
 - `java.util.List` (of supported types, including generic definitions)
 - * Internally, Binder always uses `java.util.ArrayList` as the concrete implementation
 - `java.util.Map` (of supported types)
 - * Internally, Binder always uses `java.util.HashMap` as the concrete implementation
-

- `java.lang.Object[]` (supporting objects of the same type defined here, but also primitive wrappers)
- `android.util.SparseArray`, `android.util.SparseBooleanArray`
- `android.os.Bundle`
- `android.os.IBinder`, `android.os.IInterface`
 - * The contents of these objects are not actually transferred - instead a special token serving as a self-reference is written
 - * Reading these objects from a parcel returns a handle to the original object that was written
- `android.os.Parcelable` (allowing for custom types):

src/com/example/app/Bar.java

```
package com.example.app;

import android.os.Parcel;
import android.os.Parcelable;

public class Bar implements Parcelable {
    private int id;
    private String data;

    public Bar(int id, String data) {
        this.id = id;
        this.data = data;
    }

    // getters and setters omitted
    ...

    public void writeToParcel(Parcel parcel, int flags) {
        parcel.writeInt(this.id);
        parcel.writeString(this.data);
    }

    public static final Parcelable.Creator<Bar> CREATOR = new Parcelable.Creator<Bar>() {
        {
            public Bar createFromParcel(Parcel parcel) {
                return new Bar(parcel.readInt(), parcel.readString());
            }
            public Bar[] newArray(int size) {
                return new Bar[size];
            }
        }
    };
}
```

- * These custom classes have to be declared in their own (simplified) `.aidl` files

src/com/example/app/Bar.aidl

```
package com.example.app;
parcelable Bar;
```

Note

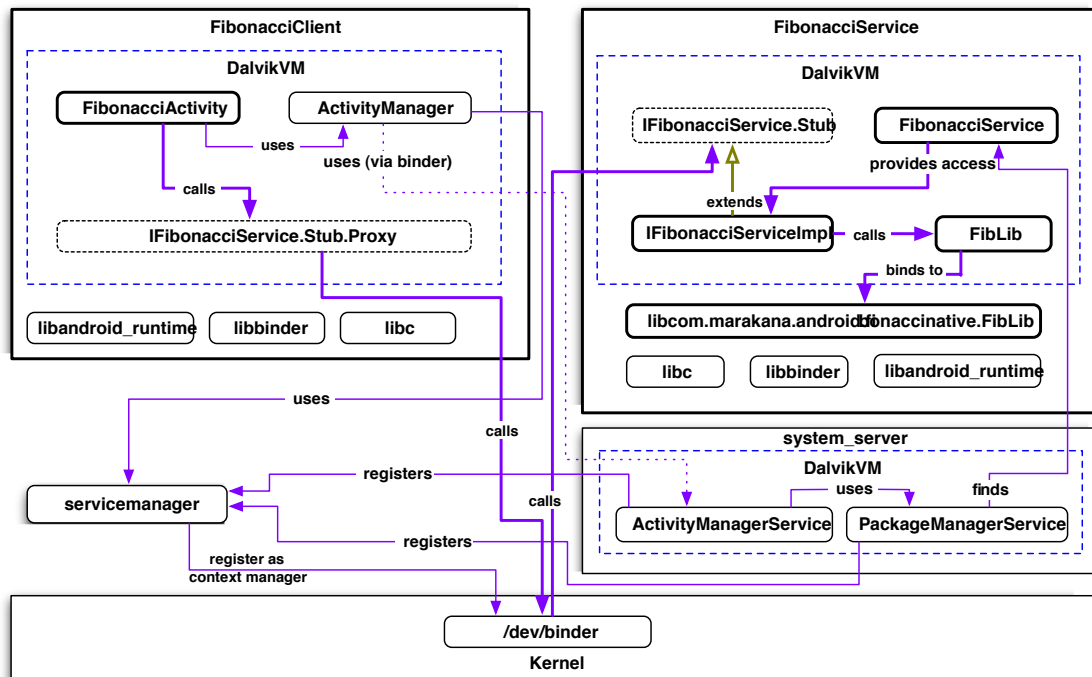
AIDL-interfaces have to import `parcelable` custom classes even if they are in the same package. In the case of the previous example, `src/com/example/app/IFooService.aidl` would have to import `com.example.app.Bar`; if it makes any references to `com.example.app.Bar` even though they are in the same package.

- AIDL-defined methods can take zero or more parameters, and must return a value or `void`
- All non-primitive parameters require a *directional tag* indicating which way the data goes: one of: `in`, `out`, or `inout`
 - * Direction for primitives is always `in` (can be omitted)

* The direction tag tells binder when to marshal the data, so its use has direct consequences on performance

- All `.aidl` comments are copied over to the generated Java interface (except for comments before the import and package statements).
- Static fields are not supported in `.aidl` files

4.4 Fibonacci Example: Building a Binder-based Service and Client



- To demonstrate an Binder-based service and client, we'll create three separate projects:
 1. `FibonacciCommon` library project - to define our AIDL interface as well as custom types for parameters and return values
 2. `FibonacciService` project - where we implement our AIDL interface and expose it to the clients
 3. `FibonacciClient` project - where we connect to our AIDL-defined service and use it
- The code is available
 - As a ZIP archive: <https://github.com/marakana/FibonacciBinderDemo/zipball/master>
 - By Git: `git clone https://github.com/marakana/FibonacciBinderDemo.git`

4.5 FibonacciCommon - Define AIDL Interface and Custom Types

- We start by creating a new Android (library) project, which will host the common API files (an AIDL interface as well as custom types for parameters and return values) shared by the service and its clients
 - Project Name: `FibonacciCommon`
 - Build Target: Android 2.2 (API 8) or later
 - Package Name: `com.marakana.android.fibonaccicommon`
 - Min SDK Version: 8

- No need to specify Application name or an activity
- To turn this into a *library project* we need to access project properties → Android → Library and check Is Library
 - We could also manually add `android.library=true` to `FibonacciCommon/default.properties` and re-fresh the project
- Since library projects are never turned into actual applications (APKs)

- We can simplify our manifest file:

FibonacciCommon/AndroidManifest.xml

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.marakana.android.fibonaccicommon" android:versionCode="1"
    android:versionName="1.0">
</manifest>
```

- And we can remove everything from `FibonacciCommon/res/` directory (e.g. `rm -fr FibonacciCommon/res/*`)
- We are now ready to create our AIDL interface

FibonacciCommon/src/com/marakana/android/fibonaccicommon/IFibonacciService.aidl

```
package com.marakana.android.fibonaccicommon;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;

interface IFibonacciService {
    long fibJR(in long n);
    long fibJI(in long n);
    long fibNR(in long n);
    long fibNI(in long n);
    FibonacciResponse fib(in FibonacciRequest request);
}
```

- Our interface clearly depends on two custom Java types, which we have to not only implement in Java, but define in their own .aidl files

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciRequest.aidl

```
package com.marakana.android.fibonaccicommon;

parcelable FibonacciRequest;
```

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciRequest.java

```
package com.marakana.android.fibonaccicommon;

import android.os.Parcel;
import android.os.Parcelable;

public class FibonacciRequest implements Parcelable {

    public static enum Type {
        RECURSIVE_JAVA, ITERATIVE_JAVA, RECURSIVE_NATIVE, ITERATIVE_NATIVE
    }

    private final long n;

    private final Type type;

    public FibonacciRequest(long n, Type type) {
```



```

        this.n = n;
        if (type == null) {
            throw new NullPointerException("Type must not be null");
        }
        this.type = type;
    }

    public long getN() {
        return n;
    }

    public Type getType() {
        return type;
    }

    public int describeContents() {
        return 0;
    }

    public void writeToParcel(Parcel parcel, int flags) {
        parcel.writeLong(this.n);
        parcel.writeInt(this.type.ordinal());
    }

    public static final Parcelable.Creator<FibonacciRequest> CREATOR = new Parcelable. ↵
        Creator<FibonacciRequest>() {
            public FibonacciRequest createFromParcel(Parcel in) {
                long n = in.readLong();
                Type type = Type.values()[in.readInt()];
                return new FibonacciRequest(n, type);
            }

            public FibonacciRequest[] newArray(int size) {
                return new FibonacciRequest[size];
            }
        };
}

```

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciResponse.aidl

```

package com.marakana.android.fibonaccicommon;

parcelable FibonacciResponse;

```

FibonacciCommon/src/com/marakana/android/fibonaccicommon/FibonacciResponse.java

```

package com.marakana.android.fibonaccicommon;

import android.os.Parcel;
import android.os.Parcelable;

public class FibonacciResponse implements Parcelable {

    private final long result;

    private final long timeInMillis;

    public FibonacciResponse(long result, long timeInMillis) {
        this.result = result;
        this.timeInMillis = timeInMillis;
    }
}

```

```

    public long getResult() {
        return result;
    }

    public long getTimeInMillis() {
        return timeInMillis;
    }

    public int describeContents() {
        return 0;
    }

    public void writeToParcel(Parcel parcel, int flags) {
        parcel.writeLong(this.result);
        parcel.writeLong(this.timeInMillis);
    }

    public static final Parcelable.Creator<FibonacciResponse> CREATOR = new Parcelable. ←
        Creator<FibonacciResponse>() {
            public FibonacciResponse createFromParcel(Parcel in) {
                return new FibonacciResponse(in.readLong(), in.readLong());
            }

            public FibonacciResponse[] newArray(int size) {
                return new FibonacciResponse[size];
            }
        };
}

```

- Finally we are now ready to take a look at our generated Java interface

FibonacciCommon/gen/com/marakana/android/fibonaccicommon/IFibonacciService.java

```

package com.marakana.android.fibonaccicommon;
public interface IFibonacciService extends android.os.IInterface
{
    public static abstract class Stub extends android.os.Binder
        implements com.marakana.android.fibonacci.IFibonacciService {
        ...
        public static com.marakana.android.fibonacci.IFibonacciService asInterface(
            android.os.IBinder obj) {
            ...
        }
        public android.os.IBinder asBinder() {
            return this;
        }
        ...
    }

    public long fibJR(long n) throws android.os.RemoteException;
    public long fibJI(long n) throws android.os.RemoteException;
    public long fibNR(long n) throws android.os.RemoteException;
    public long fibNI(long n) throws android.os.RemoteException;
    public com.marakana.android.fibonaccicommon.FibonacciResponse fib(
        com.marakana.android.fibonaccicommon.FibonacciRequest request)
        throws android.os.RemoteException;
}

```

4.6 FibonacciService - Implement AIDL Interface and Expose It To Our Clients

- We start by creating a new Android project, which will host the our AIDL Service implementation as well as provide a mechanism to access (i.e. bind to) our service implementation
 - Project Name: FibonacciService
 - Build Target: Android 2.2 (API 8) or later
 - Package Name: com.marakana.android.fibonacciservice
 - Application name: Fibonacci Service
 - Min SDK Version: 8
 - No need to specify an Android activity
- We need to link this project to the FibonacciCommon in order to be able to access the common APIs: project properties → Android → Library → Add... → FibonacciCommon
 - As the result, FibonacciService/default.properties now has android.library.reference.1=../FibonacciCommon and FibonacciService/.classpath and FibonacciService/.project also link to FibonacciCommon
- Our service will make use of the com.marakana.android.fibonaccinative.FibLib, which provides the actual implementation of the Fibonacci algorithms
- We copy (or move) this Java class (as well as the jni/ implementation) from the FibonacciNative project
 - Don't forget to run ndk-build under FibonacciService/ in order to generate the required native library

4.7 Implement AIDL Interface

- We are now ready to implement our AIDL-defined interface by extending from the auto-generated com.marakana.android.fibonacci.common.IFibonacciService (which in turn extends from android.os.Binder)

FibonacciService/src/com/marakana/android/fibonacciservice/IFibonacciServiceImpl.java

```
package com.marakana.android.fibonacciservice;

import android.os.SystemClock;
import android.util.Log;

import com.marakana.android.fibonacci.common.FibonacciRequest;
import com.marakana.android.fibonacci.common.FibonacciResponse;
import com.marakana.android.fibonacci.common.IFibonacciService;
import com.marakana.android.fibonaccinative.FibLib;

public class IFibonacciServiceImpl extends IFibonacciService.Stub {
    private static final String TAG = "IFibonacciServiceImpl";

    public long fibJI(long n) {
        Log.d(TAG, String.format("fibJI(%d)", n));
        return FibLib.fibJI(n);
    }

    public long fibJR(long n) {
        Log.d(TAG, String.format("fibJR(%d)", n));
        return FibLib.fibJR(n);
    }

    public long fibNI(long n) {
        Log.d(TAG, String.format("fibNI(%d)", n));
        return FibLib.fibNI(n);
    }
}
```

```

public long fibNR(long n) {
    Log.d(TAG, String.format("fibNR(%d)", n));
    return FibLib.fibNR(n);
}

public FibonacciResponse fib(FibonacciRequest request) {
    Log.d(TAG,
        String.format("fib(%d, %s)", request.getN(), request.getType()));
    long timeInMillis = SystemClock.uptimeMillis();
    long result;
    switch (request.getType()) {
        case ITERATIVE_JAVA:
            result = this.fibJI(request.getN());
            break;
        case RECURSIVE_JAVA:
            result = this.fibJR(request.getN());
            break;
        case ITERATIVE_NATIVE:
            result = this.fibNI(request.getN());
            break;
        case RECURSIVE_NATIVE:
            result = this.fibNR(request.getN());
            break;
        default:
            return null;
    }
    timeInMillis = SystemClock.uptimeMillis() - timeInMillis;
    return new FibonacciResponse(result, timeInMillis);
}
}

```

4.8 Expose our AIDL-defined Service Implementation to Clients

- In order for clients (callers) to use our service, they first need to bind to it.
- But in order for them to *bind* to it, we first need to expose it via our own `android.app.Service`'s `onBind(Intent)` implementation

FibonacciService/src/com/marakana/android/fibonacciservice/FibonacciService.java

```

package com.marakana.android.fibonacciservice;

import android.app.Service;
import android.content.Intent;
import android.os.IBinder;
import android.util.Log;

public class FibonacciService extends Service { // ❶

    private static final String TAG = "FibonacciService";

    private IFibonacciServiceImpl service; // ❷

    @Override
    public void onCreate() {
        super.onCreate();
        this.service = new IFibonacciServiceImpl(); // ❸
        Log.d(TAG, "onCreate() 'ed"); // ❹
    }
}

```

```

@Override
public IBinder onBind(Intent intent) {
    Log.d(TAG, "onBind()'ed"); // 5
    return this.service; // 6
}

@Override
public boolean onUnbind(Intent intent) {
    Log.d(TAG, "onUnbind()'ed"); // 7
    return super.onUnbind(intent);
}

@Override
public void onDestroy() {
    Log.d(TAG, "onDestroy()'ed");
    this.service = null;
    super.onDestroy();
}
}

```

- ❶ We create yet another "service" object by extending from `android.app.Service`. The purpose of `FibonacciService` object is to provide access to our Binder-based `IFibonacciServiceImpl` object.
 - ❷ Here we simply declare a local reference to `IFibonacciServiceImpl`, which will act as a singleton (i.e. all clients will share a single instance). Since our `IFibonacciServiceImpl` does not require any special initialization, we could instantiate it at this point, but we choose to delay this until the `onCreate()` method.
 - ❸ Now we instantiate our `IFibonacciServiceImpl` that we'll be providing to our clients (in the `onBind(Intent)` method). If our `IFibonacciServiceImpl` required access to the `Context` (which it doesn't) we could pass a reference to this (i.e. `android.app.Service`, which implements `android.content.Context`) at this point. Many Binder-based services use `Context` in order to access other platform functionality.
 - ❹ This is where we provide access to our `IFibonacciServiceImpl` object to our clients. By design, we chose to have only one instance of `IFibonacciServiceImpl` (so all clients share it) but we could also provide each client with their own instance of `IFibonacciServiceImpl`.
 - ❺, ❻, ❼ We just add some logging calls to make it easy to track the life-cycle of our service.
- Finally, we register our `FibonacciService` in our `AndroidManifest.xml`, so that clients can find it

FibonacciService/AndroidManifest.xml

```

<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.marakana.android.fibonacciservice" android:versionCode="1"
    android:versionName="1.0">
    <uses-sdk android:minSdkVersion="8" />
    <application android:icon="@drawable/icon" android:label="@string/app_name">
        <service android:name=".FibonacciService">
            <intent-filter>
                <action android:name="com.marakana.android.fibonacci.common. ↵
                    IFibonacciService" /> <!-- ❶ -->
            </intent-filter>
        </service>
    </application>
</manifest>

```

- ❶ The name of this action is arbitrary, but it is a common convention to use the fully-qualified name of our AIDL-derived interface.

4.9 FibonacciClient - Using AIDL-defined Binder-based Services

- We start by creating a new Android project, which will server as the client of the AIDL Service we previously implemented
 - Project Name: FibonacciClient
 - Build Target: Android 2.2 (API 8) or later
 - Package Name: com.marakana.android.fibonacciclient
 - Application name: Fibonacci Client
 - Create activity: FibonacciActivity
 - * We'll repurpose most of this activity's code from FibonacciNative
 - Min SDK Version: 8
- We need to link this project to the FibonacciCommon in order to be able to access the common APIs: project properties → Android → Library → Add... → FibonacciCommon
 - As the result, FibonacciClient/default.properties now has android.library.reference.1=../FibonacciCommon and FibonacciClient/.classpath and FibonacciClient/.project also link to FibonacciCommon
 - As an alternative, we could've avoided creating FibonacciCommon in the first place
 - * FibonacciService and FibonacciClient could have each had a copy of: IFibonacciService.aidl, FibonacciRequest.aidl, FibonacciResponse.aidl, FibonacciResult.java, and FibonacciResponse.java++
 - * But we don't like duplicating source code (even though the binaries do get duplicated at runtime)
- Our client will make use of the string resources and layout definition from FibonacciNative application

FibonacciClient/res/values/strings.xml

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
    <string name="hello">Get Your Fibonacci Here!</string>
    <string name="app_name">Fibonacci Client</string>
    <string name="input_hint">Enter N</string>
    <string name="input_error">Numbers only!</string>
    <string name="button_text">Get Fib Result</string>
    <string name="progress_text">Calculating...</string>
    <string name="fib_error">Failed to get Fibonacci result</string>
    <string name="type_fib_jr">fibJR</string>
    <string name="type_fib_ji">fibJI</string>
    <string name="type_fib_nr">fibNR</string>
    <string name="type_fib_ni">fibNI</string>
</resources>
```

FibonacciClient/res/layout/main.xml

```
<?xml version="1.0" encoding="utf-8"?>
<LinearLayout xmlns:android="http://schemas.android.com/apk/res/android"
    android:orientation="vertical" android:layout_width="fill_parent"
    android:layout_height="fill_parent">
    <TextView android:text="@string/hello" android:layout_height="wrap_content"
        android:layout_width="fill_parent" android:textSize="25sp" android:gravity="center" ↵
        />
    <EditText android:layout_height="wrap_content"
        android:layout_width="match_parent" android:id="@+id/input"
        android:hint="@string/input_hint" android:inputType="number"
        android:gravity="right" />
    <RadioGroup android:orientation="horizontal"
        android:layout_width="match_parent" android:id="@+id/type"
        android:layout_height="wrap_content">
        <RadioButton android:layout_height="wrap_content"
```

```

        android:checked="true" android:id="@+id/type_fib_jr" android:text="@string/ ↵
        type_fib_jr"
        android:layout_width="match_parent" android:layout_weight="1" />
<RadioButton android:layout_height="wrap_content"
        android:id="@+id/type_fib_ji" android:text="@string/type_fib_ji"
        android:layout_width="match_parent" android:layout_weight="1" />
<RadioButton android:layout_height="wrap_content"
        android:id="@+id/type_fib_nr" android:text="@string/type_fib_nr"
        android:layout_width="match_parent" android:layout_weight="1" />
<RadioButton android:layout_height="wrap_content"
        android:id="@+id/type_fib_ni" android:text="@string/type_fib_ni"
        android:layout_width="match_parent" android:layout_weight="1" />
</RadioGroup>
<Button android:text="@string/button_text" android:id="@+id/button"
        android:layout_width="match_parent" android:layout_height="wrap_content" />
<TextView android:id="@+id/output" android:layout_width="match_parent"
        android:layout_height="match_parent" android:textSize="20sp" android:gravity=" ↵
        center|top"/>
</LinearLayout>

```

- We are now ready to implement our client

FibonacciClient/src/com/marakana/android/fibonacciclient/FibonacciActivity.java

```

package com.marakana.android.fibonacciclient;

import android.app.Activity;
import android.app.AlertDialog;
import android.content.ComponentName;
import android.content.Intent;
import android.content.ServiceConnection;
import android.os.AsyncTask;
import android.os.Bundle;
import android.os.IBinder;
import android.os.RemoteException;
import android.os.SystemClock;
import android.text.TextUtils;
import android.util.Log;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.Button;
import android.widget.EditText;
import android.widget.RadioGroup;
import android.widget.TextView;
import android.widget.Toast;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;

public class FibonacciActivity extends Activity implements OnClickListener,
        ServiceConnection {

    private static final String TAG = "FibonacciActivity";

    private EditText input; // our input n

    private Button button; // trigger for fibonacci calculation

    private RadioGroup type; // fibonacci implementation type

    private TextView output; // destination for fibonacci result

```

```
private IFibonacciService service; // reference to our service

@Override
public void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    super setContentView(R.layout.main);
    // connect to our UI elements
    this.input = (EditText) super.findViewById(R.id.input);
    this.button = (Button) super.findViewById(R.id.button);
    this.type = (RadioGroup) super.findViewById(R.id.type);
    this.output = (TextView) super.findViewById(R.id.output);
    // request button click call-backs via onClick(View) method
    this.button.setOnClickListener(this);
    // the button will be enabled once we connect to the service
    this.button.setEnabled(false);
}

@Override
protected void onResume() {
    Log.d(TAG, "onResume()'ed");
    super.onResume();
    // Bind to our FibonacciService service, by looking it up by its name
    // and passing ourselves as the ServiceConnection object
    // We'll get the actual IFibonacciService via a callback to
    // onServiceConnected() below
    if (!super.bindService(new Intent(IFibonacciService.class.getName()),
        this, BIND_AUTO_CREATE)) {
        Log.w(TAG, "Failed to bind to service");
    }
}

@Override
protected void onPause() {
    Log.d(TAG, "onPause()'ed");
    super.onPause();
    // No need to keep the service bound (and alive) any longer than
    // necessary
    super.unbindService(this);
}

public void onServiceConnected(ComponentName name, IBinder service) {
    Log.d(TAG, "onServiceConnected()'ed to " + name);
    // finally we can get to our IFibonacciService
    this.service = IFibonacciService.Stub.asInterface(service);
    // enable the button, because the IFibonacciService is initialized
    this.button.setEnabled(true);
}

public void onServiceDisconnected(ComponentName name) {
    Log.d(TAG, "onServiceDisconnected()'ed to " + name);
    // our IFibonacciService service is no longer connected
    this.service = null;
    // disabled the button, since we cannot use IFibonacciService
    this.button.setEnabled(false);
}

// handle button clicks
public void onClick(View view) {
    // parse n from input (or report errors)
    final long n;
    String s = this.input.getText().toString();
```



```
if (TextUtils.isEmpty(s)) {
    return;
}
try {
    n = Long.parseLong(s);
} catch (NumberFormatException e) {
    this.input.setError(super.getText(R.string.input_error));
    return;
}

// build the request object
final FibonacciRequest.Type type;
switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
case R.id.type_fib_jr:
    type = FibonacciRequest.Type.RECURSIVE_JAVA;
    break;
case R.id.type_fib_ji:
    type = FibonacciRequest.Type.ITERATIVE_JAVA;
    break;
case R.id.type_fib_nr:
    type = FibonacciRequest.Type.RECURSIVE_NATIVE;
    break;
case R.id.type_fib_ni:
    type = FibonacciRequest.Type.ITERATIVE_NATIVE;
    break;
default:
    return;
}
final FibonacciRequest request = new FibonacciRequest(n, type);

// showing the user that the calculation is in progress
final ProgressDialog dialog = ProgressDialog.show(this, "",
    super.getText(R.string.progress_text), true);
// since the calculation can take a long time, we do it in a separate
// thread to avoid blocking the UI
new AsyncTask<Void, Void, String>() {
    @Override
    protected String doInBackground(Void... params) {
        // this method runs in a background thread
        try {
            long totalTime = SystemClock.uptimeMillis();
            FibonacciResponse response = FibonacciActivity.this.service
                .fib(request);
            totalTime = SystemClock.uptimeMillis() - totalTime;
            // generate the result
            return String.format(
                "fibonacci(%d)=%d\nin %d ms\n(+ %d ms)", n,
                response.getResult(), response.getTimeInMillis(),
                totalTime - response.getTimeInMillis());
        } catch (RemoteException e) {
            Log.wtf(TAG, "Failed to communicate with the service", e);
            return null;
        }
    }
}

@Override
protected void onPostExecute(String result) {
    // get rid of the dialog
    dialog.dismiss();
    if (result == null) {
        // handle error
        Toast.makeText(FibonacciActivity.this, R.string.fib_error,
```

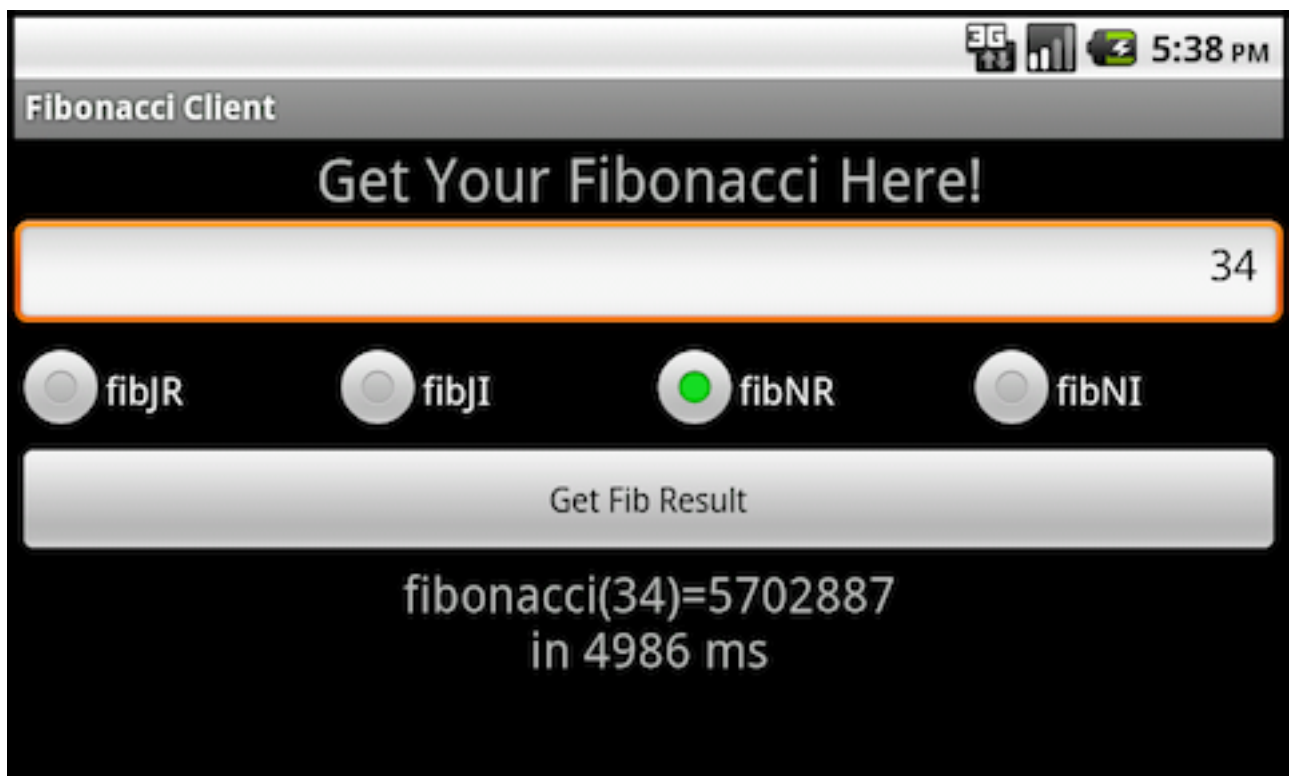
```
        Toast.LENGTH_SHORT).show();
    } else {
        // show the result to the user
        FibonacciActivity.this.output.setText(result);
    }
}
}.execute(); // run our AsyncTask
}
```

- Our activity should already be registered in our `AndroidManifest.xml` file

FibonacciClient/AndroidManifest.xml

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    android:versionCode="1" android:versionName="1.0"
    package="com.marakana.android.fibonacciclient">
    <uses-sdk android:minSdkVersion="8" />
    <application android:icon="@drawable/icon" android:label="@string/app_name">
        <activity android:name="com.marakana.android.fibonacciclient.FibonacciActivity"
            android:label="@string/app_name">
            <intent-filter>
                <action android:name="android.intent.action.MAIN" />
                <category android:name="android.intent.category.LAUNCHER" />
            </intent-filter>
        </activity>
    </application>
</manifest>
```

- And the result should look like



4.10 Async-IPC via Binder

- Binder allows for the asynchronous communication between the client and its service via the oneway declaration on the AIDL interface
- Of course, we still care about the result, so generally async calls are used with call-backs - typically through listeners
- When clients provide a reference to themselves as call-back listeners, then the roles reverse at the time the listeners are called: clients' listeners become the services, and services become the clients to those listeners
- This is best explained via an example (based on Fibonacci)
- The code is available

- As a ZIP archive: <https://github.com/marakana/FibonacciAsyncBinderDemo/zipball/master>
- By Git: `git clone https://github.com/marakana/FibonacciAsyncBinderDemo.git`

4.10.1 FibonacciCommon - Defining a oneway AIDL Service

- First, we need a listener, which itself is a oneway AIDL-defined "service":

FibonacciCommon/src/com/marakana/android/fibonaccicommon/IFibonacciServiceResponseListener.aidl:

```
package com.marakana.android.fibonaccicommon;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;

oneway interface IFibonacciServiceResponseListener {
    void onResponse(in FibonacciResponse response);
}
```

- Now we can create a our oneway (i.e. asynchronous) interface:

FibonacciCommon/src/com/marakana/android/fibonaccicommon/IFibonacciService.aidl:

```
package com.marakana.android.fibonaccicommon;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciServiceResponseListener;

oneway interface IFibonacciService {
    void fib(in FibonacciRequest request, in IFibonacciServiceResponseListener listener);
}
```

4.10.2 FibonacciService - Implementing our async AIDL service

- The implementation of our service invokes the listener, as opposed to returning a result:

FibonacciService/src/com/marakana/android/fibonaccicommon/IFibonacciServiceImpl.java:

```
package com.marakana.android.fibonaccicommon;

import android.os.RemoteException;
import android.os.SystemClock;
import android.util.Log;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;
```

```

import com.marakana.android.fibonacci.common.IFibonacciServiceResponseListener;
import com.marakana.android.fibonacci.native.FibLib;

public class IFibonacciServiceImpl extends IFibonacciService.Stub {
    private static final String TAG = "IFibonacciServiceImpl";

    @Override
    public void fib(FibonacciRequest request,
        IFibonacciServiceResponseListener listener) throws RemoteException {
        long n = request.getN();
        Log.d(TAG, "fib(" + n + ")");
        long timeInMillis = SystemClock.uptimeMillis();
        long result;
        switch (request.getType()) {
            case ITERATIVE_JAVA:
                result = FibLib.fibJI(n);
                break;
            case RECURSIVE_JAVA:
                result = FibLib.fibJR(n);
                break;
            case ITERATIVE_NATIVE:
                result = FibLib.fibNI(n);
                break;
            case RECURSIVE_NATIVE:
                result = FibLib.fibNR(n);
                break;
            default:
                result = 0;
        }
        timeInMillis = SystemClock.uptimeMillis() - timeInMillis;
        Log.d(TAG, String.format("Got fib(%d) = %d in %d ms", n, result,
            timeInMillis));
        listener.onResponse(new FibonacciResponse(result, timeInMillis));
    }
}

```

Note

The service will not block waiting for the listener to return, because the listener itself is also oneway.

4.10.3 FibonacciClient - Implementing our async AIDL client

- Finally, we implement our client, which itself has to also implement a listener as a Binder service:

FibonacciClient/src/com/marakana/android/fibonacciclient/FibonacciActivity.java:

```

package com.marakana.android.fibonacciclient;

import android.app.Activity;
import android.app.Dialog;
import android.app.ProgressDialog;
import android.content.ComponentName;
import android.content.Intent;
import android.content.ServiceConnection;
import android.os.Bundle;
import android.os.Handler;
import android.os.IBinder;
import android.os.Message;
import android.os.RemoteException;
import android.os.SystemClock;

```

```
import android.text.TextUtils;
import android.util.Log;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.Button;
import android.widget.EditText;
import android.widget.RadioGroup;
import android.widget.TextView;

import com.marakana.android.fibonaccicommon.FibonacciRequest;
import com.marakana.android.fibonaccicommon.FibonacciResponse;
import com.marakana.android.fibonaccicommon.IFibonacciService;
import com.marakana.android.fibonaccicommon.IFibonacciServiceResponseListener;

public class FibonacciActivity extends Activity implements OnClickListener,
    ServiceConnection {

    private static final String TAG = "FibonacciActivity";

    // the id of a message to our response handler
    private static final int RESPONSE_MESSAGE_ID = 1;

    // the id of a progress dialog that we'll be creating
    private static final int PROGRESS_DIALOG_ID = 1;

    private EditText input; // our input n

    private Button button; // trigger for fibonacci calculation

    private RadioGroup type; // fibonacci implementation type

    private TextView output; // destination for fibonacci result

    private IFibonacciService service; // reference to our service

    // the responsibility of the responseHandler is to take messages
    // from the responseListener (defined below) and display their content
    // in the UI thread
    private final Handler responseHandler = new Handler() {
        @Override
        public void handleMessage(Message message) {
            switch (message.what) {
                case RESPONSE_MESSAGE_ID:
                    Log.d(TAG, "Handling response");
                    FibonacciActivity.this.output.setText((String) message.obj);
                    FibonacciActivity.this.removeDialog(PROGRESS_DIALOG_ID);
                    break;
            }
        }
    };

    // the responsibility of the responseListener is to receive call-backs
    // from the service when our FibonacciResponse is available
    private final IFibonacciServiceResponseListener responseListener = new ←
        IFibonacciServiceResponseListener.Stub() {

        // this method is executed on one of the pooled binder threads
        @Override
        public void onResponse(FibonacciResponse response)
            throws RemoteException {
            String result = String.format("%d in %d ms", response.getResult(),
                response.getTimeInMillis());
        }
    };
}
```

```
        Log.d(TAG, "Got response: " + result);
        // since we cannot update the UI from a non-UI thread,
        // we'll send the result to the responseHandler (defined above)
        Message message = FibonacciActivity.this.responseHandler
            .obtainMessage(RESPONSE_MESSAGE_ID, result);
        FibonacciActivity.this.responseHandler.sendMessage(message);
    }
};

@Override
public void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    super setContentView(R.layout.main);
    // connect to our UI elements
    this.input = (EditText) super.findViewById(R.id.input);
    this.button = (Button) super.findViewById(R.id.button);
    this.type = (RadioGroup) super.findViewById(R.id.type);
    this.output = (TextView) super.findViewById(R.id.output);
    // request button click call-backs via onClick(View) method
    this.button.setOnClickListener(this);
    // the button will be enabled once we connect to the service
    this.button.setEnabled(false);
}

@Override
protected void onStart() {
    Log.d(TAG, "onStart()'ed");
    super.onStart();
    // Bind to our FibonacciService service, by looking it up by its name
    // and passing ourselves as the ServiceConnection object
    // We'll get the actual IFibonacciService via a callback to
    // onServiceConnected() below
    if (!super.bindService(new Intent(IFibonacciService.class.getName()),
        this, BIND_AUTO_CREATE)) {
        Log.w(TAG, "Failed to bind to service");
    }
}

@Override
protected void onStop() {
    Log.d(TAG, "onStop()'ed");
    super.onStop();
    // No need to keep the service bound (and alive) any longer than
    // necessary
    super.unbindService(this);
}

public void onServiceConnected(ComponentName name, IBinder service) {
    Log.d(TAG, "onServiceConnected()'ed to " + name);
    // finally we can get to our IFibonacciService
    this.service = IFibonacciService.Stub.asInterface(service);
    // enable the button, because the IFibonacciService is initialized
    this.button.setEnabled(true);
}

public void onServiceDisconnected(ComponentName name) {
    Log.d(TAG, "onServiceDisconnected()'ed to " + name);
    // our IFibonacciService service is no longer connected
    this.service = null;
    // disabled the button, since we cannot use IFibonacciService
    this.button.setEnabled(false);
}
```

```
@Override
protected Dialog onCreateDialog(int id) {
    switch (id) {
        case PROGRESS_DIALOG_ID:
            // this dialog will be opened in onClick(...) and
            // dismissed/removed by responseHandler.handleMessage(...)
            ProgressDialog dialog = new ProgressDialog(this);
            dialog.setMessage(super.getText(R.string.progress_text));
            dialog.setIndeterminate(true);
            return dialog;
        default:
            return super.onCreateDialog(id);
    }
}

// handle button clicks
public void onClick(View view) {
    // parse n from input (or report errors)
    final long n;
    String s = this.input.getText().toString();
    if (TextUtils.isEmpty(s)) {
        return;
    }
    try {
        n = Long.parseLong(s);
    } catch (NumberFormatException e) {
        this.input.setError(super.getText(R.string.input_error));
        return;
    }

    // build the request object
    final FibonacciRequest.Type type;
    switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
        case R.id.type_fib_jr:
            type = FibonacciRequest.Type.RECURSIVE_JAVA;
            break;
        case R.id.type_fib_ji:
            type = FibonacciRequest.Type.ITERATIVE_JAVA;
            break;
        case R.id.type_fib_nr:
            type = FibonacciRequest.Type.RECURSIVE_NATIVE;
            break;
        case R.id.type_fib_ni:
            type = FibonacciRequest.Type.ITERATIVE_NATIVE;
            break;
        default:
            return;
    }

    final FibonacciRequest request = new FibonacciRequest(n, type);
    try {
        Log.d(TAG, "Submitting request...");
        long time = SystemClock.uptimeMillis();
        // submit the request; the response will come to responseListener
        this.service.fib(request, this.responseListener);
        time = SystemClock.uptimeMillis() - time;
        Log.d(TAG, "Submitted request in " + time + " ms");
        // this dialog will be dismissed/removed by responseHandler
        super.showDialog(PROGRESS_DIALOG_ID);
    } catch (RemoteException e) {
        Log.wtf(TAG, "Failed to communicate with the service", e);
    }
}
```

```
    }  
    }  
}
```

4.11 Lab: Binder-based Service with AIDL

Create an AIDL-described `ILogService` that provides the following functionality:

```
package com.marakana.android.logservice;  
public interface ILogService {  
    public void log(LogMessage logMessage);  
}
```

where `LogMessage` is defined as follows:

```
package com.marakana.android.logservice;  
public class LogMessage ... {  
    ...  
    public LogMessage(int priority, String tag, String msg) {  
        ...  
    }  
    ...  
}
```

Create a simple Android client that allows the user to submit a `LogMessage` request to the remote `ILogService` running in a separate process.

You can borrow code (UI) from the basic `LogNative` application, which you can get:

- As a ZIP archive: <https://github.com/marakana/LogNative/zipball/master>
- By **Git**: `git clone https://github.com/marakana/LogNative.git`

Tip

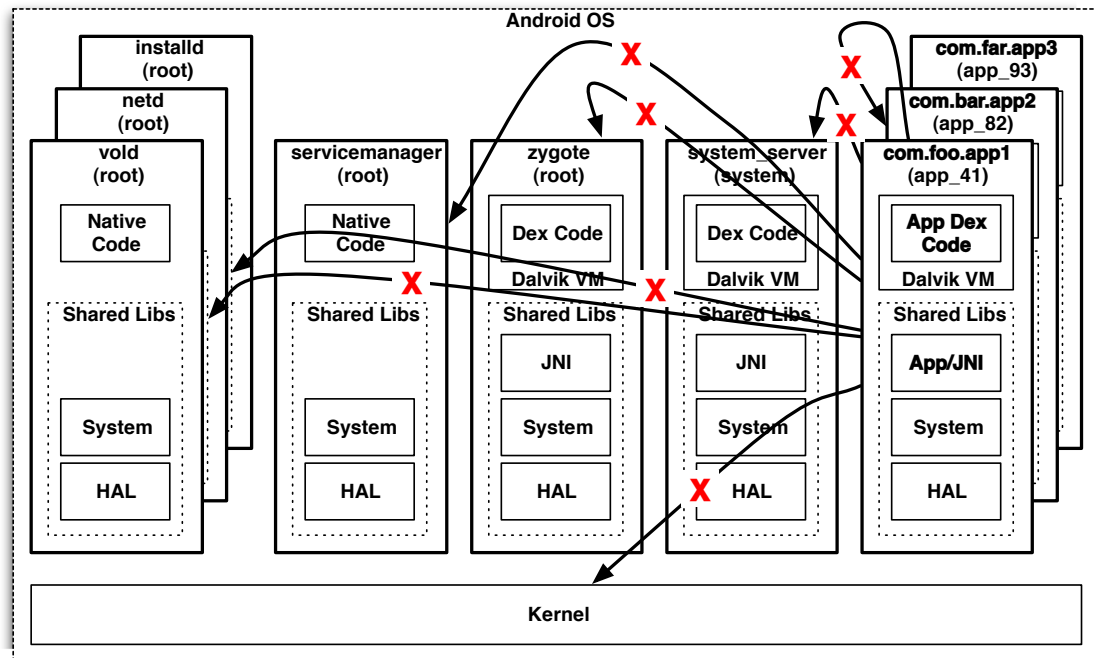
Your implementation could simply use `android.util.Log.println(int priority, String tag, String msg)` to do the logging.

The solution is provided:

- As a ZIP archive: <https://github.com/marakana/LogBinderDemo/zipball/master>
 - By **Git**: `git clone https://github.com/marakana/LogBinderDemo.git`
-

5 Android Security

5.1 Android Security Architecture



- Android is privilege-separated operating system
 - Each app runs with a separate process with a distinct system identity (user/group ID), as do parts of the system
 - OS (Linux) provides app isolation (sandboxing)
- By default, no app can do anything to adversely affect other apps, the system, or the user
 - E.g. reading/writing user data, modifying other apps’/system’ files and settings, accessing network, keeping the device awake, etc.
- Android provides fine-grained permission system that restricts what apps can do if they want to play outside the sandbox
 - Apps statically declare permissions they need (use)
 - The Android system prompts the user for consent at app installation-time (and on update if changed)
 - No support for dynamic (run-time) granting of permissions (complicates user experience)
 - The responsibility lies with the user to make educated decisions as to which apps to install based on the list of requested permissions
 - Prone **confused deputy attacks** where a non-privileged malicious app exploits a vulnerable interface of another privileged (but "confused") application
- Apps can explicitly share resources/data, via ContentProviders, Intents, Binder/IPC, local sockets, or the file system
 - This sharing goes un-checked by Android
 - The entire system prone to **collusion attacks** where malicious applications can collude to combine their permissions, allowing them to perform actions beyond their individual privileges

- Linux kernel is the sole mechanism of application (i.e. process) sandboxing
 - Dalvik VM is not a security boundary
 - Native code (via NDK) is subject to the same restrictions (i.e. no extra privileges)
- All apps are created equal
 - Sandboxed in the same way
 - Same level of security from each other

5.2 Application Signing

- All apps (.apk files) *must be* digitally signed prior to installation on a device with a certificate whose private key is kept confidential by the developer of the application
- Android uses the certificate as a means of:
 - Identifying the author of an application
 - * Used to ensure the authenticity of future application updates
 - Establishing trust relationships between applications
 - * Applications signed with the same certificate can share signature-level permissions, runtime process, user-id, and data
- The signing process is based on public-key cryptography, as defined by Java's JAR specification
 - The private/signing key is kept confidential by the developer of the application
 - The certificate (including the public key) is embedded in the application itself (META-INF/CERT.RSA), along with the signature generated with the private key (META-INF/CERT.SF)
 - * The certificate can be self-signed - **no trusted 3rd party (i.e. certification authority) is required**
 - * The certificate's validity period should be 25 years or longer
 - The certificate validity is only verified during the installation/update process (not at startup) - so apps with expired certificates would continue to function normally, but could not be updated
 - Key/certificate management, app signing, and key verification can be accomplished using a number of tools:
 - * Java's `keytool` - used to create/manage keys (in keystores)

```
$ keytool -genkey -v -keystore marakana.keystore -alias android -keyalg RSA -keysize 2048 -validity 10000 \
-dname "CN=Android Application Signer, OU=Android, O=Marakana Inc., L=San Francisco, ST=California, C=US"
```

- * Java's `jarsigner` - used to sign/verify .apk files (signing is done in-place, replacing any existing signatures)

```
$ jarsigner -keystore marakana.keystore MyApp.apk android
$ jarsigner -verify MyApp.apk
jar verified.
```

- * Android's ADT Export Wizard for Eclipse - offers a wizard UI over the whole signing process (wraps `keytool`/`jarsigner` functionality)
- During the development, Android allows the use of the debug key (~/.android/debug.keystore), but applications *must be* signed using a real key prior to publishing
- To print the information about the certificate embedded in an APK, we can do the following:

```
$ jar -xvf MyApp.apk META-INF/CERT.RSA
$ keytool -printcert -file META-INF/CERT.RSA
Owner: CN=Android Application Signer, OU=Android, O=Marakana Inc., L=San Francisco, ST= ←
California, C=US
Issuer: CN=Android Application Signer, OU=Android, O=Marakana Inc., L=San Francisco, ST= ←
California, C=US
Serial number: 4f4e6461
Valid from: Wed Feb 29 11:46:09 CST 2012 until: Sun Feb 22 11:46:09 CST 2037
Certificate fingerprints:
    MD5:  57:B8:23:06:09:CD:2A:C9:9C:02:6C:B4:5D:1C:34:BD
    SHA1: 2E:49:E4:20:81:9E:A3:E9:91:5D:99:57:2A:A6:88:0E:23:14:63:AA
    Signature algorithm name: SHA1withRSA
    Version: 3
$ rm META-INF/CERT.RSA && rmdir META-INF
```

- An APK could be signed using multiple keys (each with a different alias), though this is an uncommon use-case
- Since signatures are applied to the individual files, not the .apk itself, developers **should** use Android's zipalign tool to optimize the final .apk package

```
$ zipalign -v 4 UnalignedApp.apk AlignedApp.apk
```

- See <http://developer.android.com/guide/publishing/app-signing.html>

5.2.1 Platform Keys

- AOSP comes with four platform keys in build/target/product/security/
 - platform - used to sign core parts of the system (configured with LOCAL_CERTIFICATE := platform): framework core, BackupRestoreConfirmation, DefaultContainerService, SettingsProvider, SharedStorageBackup, SystemUI, VpnDialogs, Bluetooth, CertInstaller, KeyChain, Nfc, PackageInstaller, Phone, Provision, Settings, Stk, TelephonyProvider, etc.
 - shared - used to sign home/contacts part of AOSP (configured with LOCAL_CERTIFICATE := shared): Contacts, Launcher2, QuickSearchBox, LatinIME, PinyinIME, ApplicationsProvider, ContactsProvider, UserDictionaryProvider, and built-in live wall papers
 - media - used to sign media/download framework parts of AOSP (configured with LOCAL_CERTIFICATE := media): Gallery, DownloadProvider, DrmProvider, MediaProvider
 - testkey - used to sign everything else - i.e. this is the default key for packages that don't specify one of the keys above
- The keys provided by default cannot be used to ship an actual product (enforced by CTS)
- For example, to generate our own keys, we can use the supplied development/tools/make_key command for each platform, media, shared, and testkey:
 - a. \$ rm build/target/product/security/platform.p*
 - b. \$ SIGNER="/C=US/ST=California/L=San Francisco/O=Marakana Inc./OU=Android/CN=Android Platform Signer/emailAddress=android@marakana.com"
 - c. \$ echo | development/tools/make_key build/target/product/security/platform "\$SIGNER"
 - d. Repeat for media, shared, and testkey
- To sign our own app using the platform key:
 - If we are building it as part of the ROM, we can just add LOCAL_CERTIFICATE := platform to our app's Android.mk file
 - To sign our app outside the build process, assuming we have access to platform sources and keys, we could use the signapk.jar tool:

```
$ java -jar /path/to/aosp/out/host/linux-x86/framework/signapk.jar \
/path/to/aosp/build/target/product/security/platform.x509.pem \
/path/to/aosp/build/target/product/security/platform.pk8 \
MyApp.apk MySignedApp.apk
```

5.3 User IDs

- Each app (package) is assigned an arbitrary, but distinct, OS user ID at installation time
 - Typically something like app_XX (e.g. app_79), where the actual UID is offset from 10000
 - Does not change during app's life on a device
 - For example, the Browser app is assigned UID 10001 (though it could be different), which translates to app_1:

```
$ adb -e shell cat /data/system/packages.list |grep com.android.browser
com.android.browser 10001 0 /data/data/com.android.browser
```

- Each app process runs under its own UID:

```
$ adb -e shell ps |grep com.android.browser
app_1      682    37      192592 53144 ffffffff 40011384 S com.android.browser
```

- All app resources are owned by its UID

```
adb -e shell ls -l /data/data/com.android.browser
drwxrwx--x app_1      app_1      2012-02-06 12:47 app_appcache
drwxrwx--x app_1      app_1      2012-02-06 12:47 app_databases
drwxrwx--x app_1      app_1      2012-02-06 12:47 app_geolocation
drwxrwx--x app_1      app_1      2012-02-06 12:47 app_icons
drwxrwx--x app_1      app_1      2012-02-06 12:47 cache
drwxrwx--x app_1      app_1      2012-02-06 12:48 databases
drwxr-xr-x system     system     2012-01-17 15:42 lib
drwxrwx--x app_1      app_1      2012-02-06 12:47 shared_prefs
```

- Apps that are signed with the same certificate can share data, user ID, as well as run in a single process
 - They just need to specify the same `sharedUserId` and `process`

AndroidManifest.xml

```
<manifest package="com.marakana.android.myapp"
  android:sharedUserId="marakana.uid.myapp"
  android:sharedUserLabel="@string/myapp_uid" ... >
  <application android:process="myapp" ... >
    ...
  </application>
</manifest>
```

Note

From the security standpoint, packages with the same `sharedUserId` are treated as being parts of the same application, with the same UID and file permissions.

5.4 File Access

- Android has a number of different partitions:

```
$ adb shell mount
rootfs / rootfs ro 0 0
tmpfs /dev tmpfs rw,nosuid,mode=755 0 0
devpts /dev/pts devpts rw,mode=600 0 0
proc /proc proc rw 0 0
sysfs /sys sysfs rw 0 0
none /acct cgroup rw,cpuacct 0 0
tmpfs /mnt/asec tmpfs rw,mode=755,gid=1000 0 0
tmpfs /mnt/obb tmpfs rw,mode=755,gid=1000 0 0
none /dev/cpuctl cgroup rw,cpu 0 0
/dev/block/mtdblock0 /system yaffs2 ro 0 0
/dev/block/mtdblock1 /data yaffs2 rw,nosuid,nodev 0 0
/dev/block/mtdblock2 /cache yaffs2 rw,nosuid,nodev 0 0
/dev/block/vold/179:0 /mnt/sdcard vfat rw,dirsync,nosuid,nodev,noexec,uid=1000,gid=1015, ↵
    fmask=0702,dmask=0702,allow_utime=0020,codepage=cp437,iocharset=iso8859-1,shortname= ↵
    mixed,utf8,errors=remount-ro 0 0
/dev/block/vold/179:0 /mnt/secure/asec vfat rw,dirsync,nosuid,nodev,noexec,uid=1000,gid ↵
    =1015,fmask=0702,dmask=0702,allow_utime=0020,codepage=cp437,iocharset=iso8859-1, ↵
    shortname=mixed,utf8,errors=remount-ro 0 0
tmpfs /mnt/sdcard/.android_secure tmpfs ro,size=0k,mode=000 0 0
```

- The notable ones include:

- / - the read-only root file system, containing the `init` process plus some bootstrapping configuration files
- /system - the read-only home of the Android OS, containing the system libraries (including HAL and application framework), executables (daemons), fonts, media, and system apps
- /data - the read-write file system containing user apps as well as application data (e.g. settings, preferences, etc) and system state information
- /cache - the read-write file system containing transient user state (e.g. browser cache)

- Apps could be stored in several locations:

- /system/app/<App-Name>.apk (for system apps)
 - * The optimized dex code for this app would be stored as /system/app/<App-Name>.odex
 - * When booted into safe-mode (by holding pre-configured keys pressed on power-on), Android will only make system apps available to the user
- /data/app/<App-Name>.apk (for pre-loaded user apps)
 - * The optimized dex code for this app would be stored as /data/dalvik-cache/<App-Name>.odex
- /data/app/<app-package-name>-1.apk (for downloaded user apps)
 - * The optimized dex code for this app would be stored as /data/dalvik-cache/data@app@<app-package-name>-1.
- /mnt/secure/asec/<app-package-name>-1.apk (for apps moved to SD Card)
 - * The optimized dex code for this app would be stored as /data/dalvik-cache/mnt@asec@<app-package-name>-1@

- To find out where a particular application is stored, we can ask the package manager:

```
$ adb shell pm path com.android.browser
package:/system/app/Browser.apk
```

- Files created by apps are owned by apps' distinct user/group ID and are not world-accessible
 - Stored under /data/data/<app-package-name>/

- Native libraries (generated by NDK) are copied to `/data/data/<app-package-name>/lib/lib<library-name>.so`
- Exceptions
 - `/mnt/sdcard` is FAT32, so free-for-all (though it requires `android.permission.WRITE_TO_EXTERNAL_STORAGE` permission)
 - Apps can create files, preferences, database with `MODE_WORLD_READABLE` and/or `MODE_WORLD_WRITABLE`, which affect world access, but not file ownership

5.5 Using Permissions

- By default, apps cannot do much outside their sandbox
- Attempts to access restricted resources without holding the appropriate permission
 - Fail with `SecurityException` (explicit failures)
 - * For example, dialing a number (i.e. starting an activity with action `android.intent.action.CALL` for some data URI/phone-number) is restricted

```
$ adb shell run-as com.example.helloworld am start -a android.intent.action.CALL -d ↵
tel:4155551234
Starting: Intent { act=android.intent.action.CALL dat=tel:xxxxxxxxx }
java.lang.SecurityException: Permission Denial: starting Intent { act=android.intent. ↵
action.CALL dat=tel:xxxxxxxxx flg=0x10000000 cmp=com.android.phone/. ↵
OutgoingCallBroadcaster } from null (pid=1533, uid=10045) requires android. ↵
permission.CALL_PHONE
at android.os.Parcel.readException(Parcel.java:1327)
at android.os.Parcel.readException(Parcel.java:1281)
at android.app.ActivityManagerProxy.startActivity(ActivityManagerNative.java:1631)
at com.android.commands.am.Am.runStart (Am.java:433)
at com.android.commands.am.Am.run (Am.java:107)
at com.android.commands.am.Am.main (Am.java:80)
at com.android.internal.os.RuntimeInit.finishInit (Native Method)
at com.android.internal.os.RuntimeInit.main (RuntimeInit.java:238)
at dalvik.system.NativeStart.main (Native Method)
```

- * For example, trying to read a private system directory is restricted:

```
$ adb shell run-as com.example.helloworld ls /data/misc/keystore
opendir failed, Permission denied
```

- Ignored but logged by the system (implicit failures) - e.g. `BroadcastReceiver` listening on a protected intent
- To access restricted features of the system or other apps, apps developers are required to *use* permissions via explicit `<uses-permission>`s in `AndroidManifest.xml`
- Subject to one-time user-approval, permissions are granted at install time with no support for run-time per-use user approval
- For example, an app that wishes to track user by GPS and report location via network/SMS would require three permissions: access (fine) location, access the internet, and send SMS
- Its `AndroidManifest.xml` would look like this:

```
<manifest xmlns:android="http://schemas.android.com/apk/res/android" package="com.marakana ↵
.android.trackapp">
  <uses-permission android:name="android.permission.ACCESS_FINE_LOCATION" />
  <uses-permission android:name="android.permission.INTERNET" />
  <uses-permission android:name="android.permission.SEND_SMS" />
  ...
</manifest>
```

- For the list of built-in permissions:

- See <http://developer.android.com/reference/android/Manifest.permission.html>
- Or run:

```
adb shell pm list permissions
All Permissions:

permission:android.permission.CLEAR_APP_USER_DATA
permission:android.permission.SHUTDOWN
permission:android.permission.BIND_INPUT_METHOD
permission:android.permission.ACCESS_DRM
permission:android.permission.DOWNLOAD_CACHE_NON_PURGEABLE
permission:android.permission.INTERNAL_SYSTEM_WINDOW
permission:android.permission.SEND_DOWNLOAD_COMPLETED_INTENTS
permission:android.permission.MOVE_PACKAGE
permission:android.permission.ACCESS_CHECKIN_PROPERTIES
permission:android.permission.CRYPT_KEEPER
permission:android.permission.READ_INPUT_STATE
permission:android.permission.DEVICE_POWER
permission:android.permission.DELETE_PACKAGES
permission:android.permission.ACCESS_CACHE_FILESYSTEM
permission:android.permission.REBOOT
permission:android.permission.STATUS_BAR
permission:android.permission.ACCESS_DOWNLOAD_MANAGER_ADVANCED
permission:android.permission.ACCESS_ALL_DOWNLOADS
permission:android.permission.STOP_APP_SWITCHES
permission:android.permission.BIND_VPN_SERVICE
permission:android.permission.CONTROL_LOCATION_UPDATES
permission:android.permission.ACCESS_DOWNLOAD_MANAGER
permission:android.permission.MANAGE_APP_TOKENS
permission:android.permission.BIND_PACKAGE_VERIFIER
permission:android.permission.DELETE_CACHE_FILES
permission:android.permission.BATTERY_STATS
permission:android.permission.COPY_PROTECTED_DATA
permission:com.android.email.permission.ACCESS_PROVIDER
permission:android.permission.INSTALL_DRM
permission:android.permission.MASTER_CLEAR
permission:android.permission.SET_ACTIVITY_WATCHER
permission:android.permission.BRICK
permission:android.permission.MODIFY_NETWORK_ACCOUNTING
permission:android.permission.READ_NETWORK_USAGE_HISTORY
permission:android.permission.BACKUP
permission:android.permission.SET_TIME
permission:android.permission.STATUS_BAR_SERVICE
permission:android.permission.INSTALL_PACKAGES
permission:android.permission.PERFORM_CDMA_PROVISIONING
permission:android.permission.INJECT_EVENTS
permission:android.permission.SET_POINTER_SPEED
permission:com.android.browser.permission.PRELOAD
permission:android.permission.WRITE_SECURE_SETTINGS
permission:android.permission.INSTALL_LOCATION_PROVIDER
permission:android.permission.CONFIRM_FULL_BACKUP
permission:android.permission.PACKAGE_USAGE_STATS
permission:android.permission.ACCESS_SURFACE_FLINGER
permission:android.permission.CALL_PRIVILEGED
permission:android.permission.PACKAGE_VERIFICATION_AGENT
permission:android.permission.CHANGE_COMPONENT_ENABLED_STATE
permission:android.intent.category.MASTER_CLEAR.permission.C2D_MESSAGE
permission:android.permission.WRITE_GSERVICES
permission:android.permission.MANAGE_NETWORK_POLICY
permission:android.permission.ALLOW_ANY_CODEC_FOR_PLAYBACK
```

```

permission:android.permission.BIND_TEXT_SERVICE
permission:android.permission.READ_FRAME_BUFFER
permission:android.permission.FORCE_BACK
permission:android.permission.UPDATE_DEVICE_STATS
permission:android.permission.BIND_WALLPAPER
permission:android.permission.BIND_REMOTEVIEWS
permission:android.permission.SET_ORIENTATION
permission:android.permission.FACTORY_TEST
permission:android.permission.BIND_DEVICE_ADMIN

```

Note

Add `-f` for the full description of permissions - i.e. `adb shell pm list permissions -f`

- Or take a look at `frameworks/base/core/res/AndroidManifest.xml` in AOSP source tree

5.6 Permission Enforcement

There are a number of trigger points for security/permission checks:

5.6.1 Kernel / File-system Permission Enforcement

- Access to system resources (files/drivers/unix-sockets and net/BT-sockets) is restricted via a combination of
 - File-system permissions
 - Paranoid network security (Android-specific kernel-patches)
- File/driver/unix-socket ownership/permissions are set in:
 - `/init` process
 - `/init.rc` file(s)
 - `/ueventd.rc` file(s)
 - system ROM (via `system/core/include/private/android_filesystem_config.h` in AOSP)
- Application's logical permissions (i.e. ones defined via `<uses-permission>` in `AndroidManifest.xml`) are mapped to system groups via:

frameworks/base/data/etc/platform.xml (Android source code)

```

<permissions>
  ...
  <permission name="android.permission.INTERNET" >
    <group gid="inet" />
  </permission>

  <permission name="android.permission.CAMERA" >
    <group gid="camera" />
  </permission>

  <permission name="android.permission.READ_LOGS" >
    <group gid="log" />
  </permission>

  <permission name="android.permission.WRITE_EXTERNAL_STORAGE" >
    <group gid="sdcard_rw" />
  </permission>
  ...
</permissions>

```

Note

Run `adb shell cat /system/etc/permissions/platform.xml` to see all the mappings

- Permissions assigned to individual applications are stored in `/data/system/packages.xml`

5.6.2 UID-based Permission Enforcement

- Some system processes (daemons) explicitly check for the UID of the calling process (via IPC)
- For example, `servicemanager` explicitly limits registration of new services to processes running as root, system, radio, media, nfc, and drm (with some additional restrictions)

frameworks/base/cmds/servicemanager/service_manager.c:

```
...
static struct {
    unsigned uid;
    const char *name;
} allowed[] = {
#ifdef LVMX
    { AID_MEDIA, "com.lifevibes.mx.ipc" },
#endif
    { AID_MEDIA, "media.audio_flinger" },
    { AID_MEDIA, "media.player" },
    { AID_MEDIA, "media.camera" },
    { AID_MEDIA, "media.audio_policy" },
    { AID_DRM, "drm.drmManager" },
    { AID_NFC, "nfc" },
    { AID_RADIO, "radio.phone" },
    { AID_RADIO, "radio.sms" },
    { AID_RADIO, "radio.phonesubinfo" },
    { AID_RADIO, "radio.simphonebook" },
    /* TODO: remove after phone services are updated: */
    { AID_RADIO, "phone" },
    { AID_RADIO, "sip" },
    { AID_RADIO, "isms" },
    { AID_RADIO, "iphonesubinfo" },
    { AID_RADIO, "simphonebook" },
};
...
int svc_can_register(unsigned uid, uint16_t *name)
{
    unsigned n;

    if ((uid == 0) || (uid == AID_SYSTEM))
        return 1;

    for (n = 0; n < sizeof(allowed) / sizeof(allowed[0]); n++)
        if ((uid == allowed[n].uid) && str16eq(name, allowed[n].name))
            return 1;

    return 0;
}
...
```

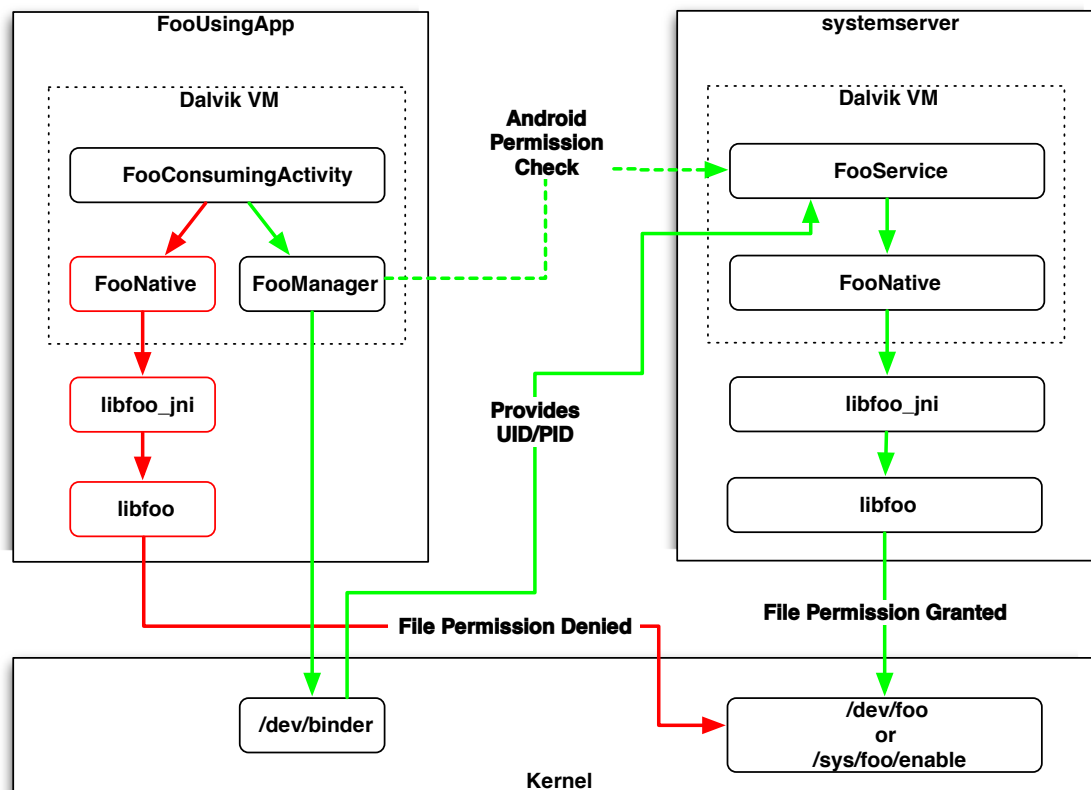
5.6.3 Static Permission Enforcement

- Automatically managed by `ActivityManagerService`

- In `AndroidManifest.xml` an application restricts access to its components via `android:permission` attribute
 - On `<activity>`, controls who can `Context.startActivity()` and `startActivityForResult()`
 - On `<service>`, controls who can `Context.startService()`, `stopService()`, and `bindService()`
 - On `<provider>`, controls who can access it via a `ContentResolver`
 - * `android:readPermission` specifically controls who can `ContentResolver.query()`;
 - * `android:writePermission` specifically controls who can `ContentResolver.insert()`, `ContentResolver.update()`, and `ContentResolver.delete()`
 - On `<receiver>`, controls who can send broadcasts to the receiver
 - * Receivers can also be registered programmatically, so the sender's permission requirement can be specified via `Context.registerReceiver()` method
 - * Senders can also programmatically require that the receivers hold the appropriate permission via `Context.sendBroadcast()` method
 - * Some broadcasts are declared as `<protected-broadcast android:name="..." />` in `frameworks/base/core` (AOSP source tree) - these can only be sent by the system
- For example:

```
<manifest ...>
...
<application ...>
...
  <activity android:name=".GetPasswordActivity"
    android:permission="com.marakana.android.permission.GET_PASSWORD_FROM_USER" ... >
    ...
  </activity>
  <service android:name=".UserAuthenticatorService"
    android:permission="com.marakana.android.permission.AUTHENTICATE_USER" ... >
    ...
  </service>
  <provider android:name=".EnterpriseDataProvider"
    android:readPermission="com.marakana.android.permission.READ_ENTERPRISE_DATA"
    android:writePermission="com.marakana.android.permission.WRITE_ENTERPRISE_DATA" ... <-
    >
    ...
  </provider>
  <receiver android:name=".UserAuthStatusReceiver"
    android:permission="com.marakana.android.permission.SEND_USER_AUTH_STATUS">
    ...
  </receiver>
</application>
</manifest>
```

5.6.4 Enforcing Permissions Dynamically



- Permissions can also be enforced programmatically

```

- android.content.Context.checkCallingPermission(String permission)
- android.content.Context.checkPermission(String permission, int pid, int uid)
- android.content.Context.enforceCallingOrSelfPermission (String permission, String message)
- ...
- android.content.pm.PackageManager.checkPermission(String permName, String pkgName)

```

- All these return `PackageManager.PERMISSION_GRANTED` or `PackageManager.PERMISSION_DENIED`

- This is how many of the application framework services enforce their permissions

frameworks/base/services/java/com/android/server/VibratorService.java

```

package com.android.server;
...
public class VibratorService extends IVibratorService.Stub {
    ...
    public void vibrate(long milliseconds, IBinder token) {
        if (mContext.checkCallingOrSelfPermission(android.Manifest.permission.VIBRATE)
            != PackageManager.PERMISSION_GRANTED) {
            throw new SecurityException("Requires VIBRATE permission");
        }
        ...
    }
    ...
}

```

frameworks/base/services/java/com/android/server/LocationManagerService.java

```

package com.android.server;
...
public class LocationManagerService extends ILocationManager.Stub implements Runnable {
    ...
    private static final String ACCESS_FINE_LOCATION =
        android.Manifest.permission.ACCESS_FINE_LOCATION;
    private static final String ACCESS_COARSE_LOCATION =
        android.Manifest.permission.ACCESS_COARSE_LOCATION;
    ...
    private void checkPermissionsSafe(String provider) {
        if ((LocationManager.GPS_PROVIDER.equals(provider)
            || LocationManager.PASSIVE_PROVIDER.equals(provider))
            && (mContext.checkCallingOrSelfPermission(ACCESS_FINE_LOCATION)
                != PackageManager.PERMISSION_GRANTED)) {
            throw new SecurityException("Provider " + provider
                + " requires ACCESS_FINE_LOCATION permission");
        }
        if (LocationManager.NETWORK_PROVIDER.equals(provider)
            && (mContext.checkCallingOrSelfPermission(ACCESS_FINE_LOCATION)
                != PackageManager.PERMISSION_GRANTED)
            && (mContext.checkCallingOrSelfPermission(ACCESS_COARSE_LOCATION)
                != PackageManager.PERMISSION_GRANTED)) {
            throw new SecurityException("Provider " + provider
                + " requires ACCESS_FINE_LOCATION or ACCESS_COARSE_LOCATION permission");
        }
    }
    ...
    private Location _getLastKnownLocationLocked(String provider) {
        checkPermissionsSafe(provider);
        ...
    }
    ...
    public Location getLastKnownLocation(String provider) {
        ...
        _getLastKnownLocationLocked(provider);
        ...
    }
}

```

- Not very common in application code
 - Can be used in bound services to differentiate access to specific methods (e.g. "administrative" operations)

5.7 Declaring Custom Permissions

Before we can enforce our own permissions, we have to declare them using one or more `<permission>` in

AndroidManifest.xml

```

<manifest xmlns:android="http://schemas.android.com/apk/res/android" package="com.marakana. ↵
    android.myapp" >
    <permission
        android:name="com.example.app.DO_X"
        android:label="@string/do_x_label"
        android:description="@string/do_x_desc"
        android:permissionGroup="android.permission-group.PERSONAL_INFO"
        android:protectionLevel="dangerous" />
    ...
</manifest>

```

5.7.1 Permission Components

- `name` - arbitrary but unique (name-spaced) identifier of this permission
- `protectionLevel` - specifies if/how will Android inform the user when another app uses this permission
 - `normal (0)` - A low-risk permission that is automatically granted (by default), though users have an option to review these before installing (users often just ignore)
 - `dangerous (1)` - A higher-risk permission that requires explicit user approval at install time (preferred)
 - `signature (2)` - A permission that will be granted automatically if the requesting app shares the signature of the declaring app (preferred for application "suites")
 - `signatureOrSystem (3)` - A permission that will be granted only to packages in `/system/app/` (i.e. burned to ROM) or that are signed with the same certificates.
 - * This is useful in special-cases where different vendors supply apps to be built into system image, and those apps need to work together
- `label` - a short description of the functionality protected by the permission (ignored when `protectionLevel=signature*`)
- `description` - a longer description (warning) of what can go wrong if the permission is abused (ignored when `protectionLevel=signature*`)
- `android:icon` - an drawable resource describing this permission
- `permissionGroup` - helps organize (group) permissions by some pre-determined categories (e.g. `...COST_MONEY`, `...PERSONAL_INFO`, `...SYSTEM_TOOLS`, etc.)
 - See http://d.android.com/reference/android/Manifest.permission_group.html for the existing Android categories
 - For example

```
$ adb shell pm list permission-groups
permission group:android.permission-group.DEVELOPMENT_TOOLS
permission group:android.permission-group.PERSONAL_INFO
permission group:android.permission-group.COST_MONEY
permission group:android.permission-group.LOCATION
permission group:android.permission-group.MESSAGES
permission group:android.permission-group.NETWORK
permission group:android.permission-group.ACCOUNTS
permission group:android.permission-group.STORAGE
permission group:android.permission-group.PHONE_CALLS
permission group:android.permission-group.HARDWARE_CONTROLS
permission group:android.permission-group.SYSTEM_TOOLS
```

Note

We can list permissions currently defined on an Android device/emulator: `$ adb shell pm list permissions -s`

5.7.2 Adding Custom Permissions Dynamically

- Android allows permissions to be defined programmatically via `PermissionManager.addPermission(PermissionInfo)` API
 - The new permission can only be added relative to a permission tree setup via `<permission-tree/>` in the `AndroidManifest.xml` file
 - Permissions added through this API are persisted (across device reboots)
 - Existing permissions (that already exist) are updated
-

- For example:

AndroidManifest.xml:

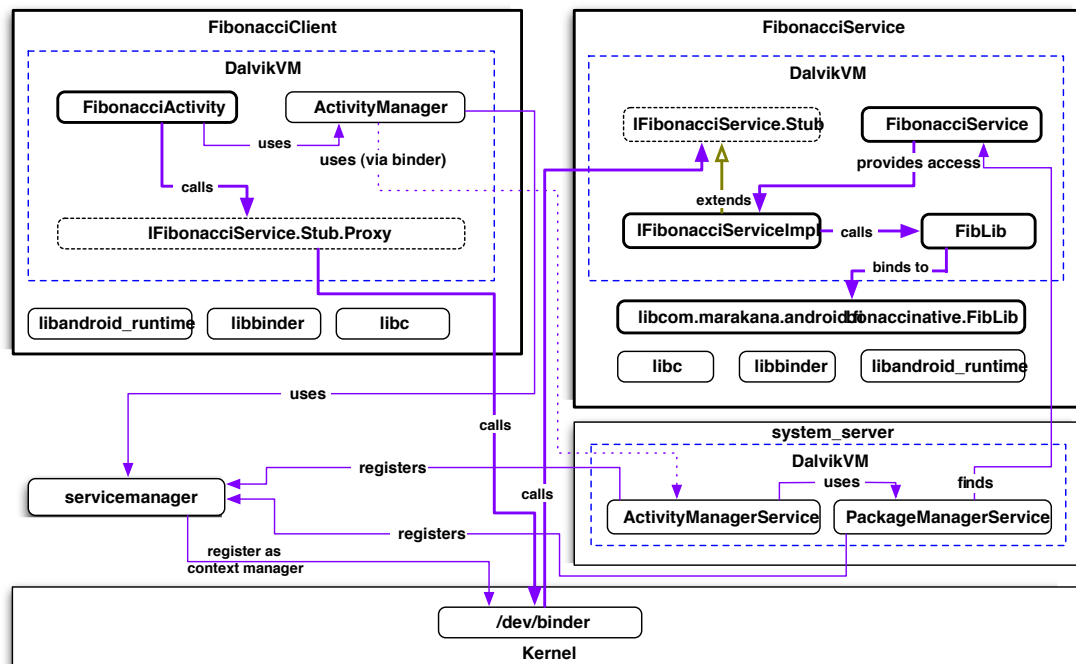
```
<manifest ...>
  ...
  <permission-tree android:name="com.marakana.android.foo" />
  ...
</manifest>
```

src/com/marakana/android/foo/FooActivity.java:

```
...
public class FooActivity extends Activity ... {
    public void onCreate() {
        super.onCreate();
        ...
        PermissionInfo permission = new PermissionInfo();
        permission.name = "com.marakana.android.foo.DO_X_WITH_FOO";
        permission.protectionLevel = PermissionInfo.PROTECTION_SIGNATURE;
        super.getPackageManager().addPermission(permission);
        ...
    }
}
```

5.8 Fibonacci Example: Custom Permissions

- In this example, we are given two applications, FibonacciClient and FibonacciService



- These two apps communicate via Binder/IPC
- Common files for these applications reside in a library project called **FibonacciCommon**
- The finished code for these applications (as Eclipse projects) is available:
 - As a ZIP archive: <https://github.com/marakana/FibonacciBinderDemo/zipball/secured>
 - By **Git**: `git clone https://github.com/marakana/FibonacciBinderDemo.git -b secured`

5.8.1 Static Permission Enforcement

Here, we want to restrict access to the `com.marakana.android.fibonacciservice.FibonacciService` to applications (i.e. clients) that hold `USE_FIBONACCI_SERVICE` custom permission

1. We start by creating a custom permission group (making sure that we name-space it):

FibonacciService/res/values/strings.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
    ...
    <string name="fibonacci_permissions_group_label">Fibonacci Permissions</string>
    ...
</resources>
```

FibonacciService/AndroidManifest.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ...>
    ...
    <permission-group
        android:name="com.marakana.android.fibonacciservice.FIBONACCI_PERMISSIONS"
        android:label="@string/fibonacci_permissions_group_label" />
    ...
</manifest>
```

Note

This permission group is optional - as we could instead use one of the already provided groups

2. Next, we create a custom permission (again, making sure that we name-space it), while taking advantage of our newly-created permission group:

FibonacciService/res/values/strings.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
    ...
    <string name="use_fibonacci_service_permission_label">use fibonacci service</string>
    <string name="use_fibonacci_service_permission_description">
        applications with this permissions get fibonacci results for free
    </string>
    ...
</resources>
```

FibonacciService/AndroidManifest.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ...>
    ...
    <permission-group .../>
    <permission
        android:name="com.marakana.android.fibonacciservice.USE_FIBONACCI_SERVICE"
        android:description="@string/use_fibonacci_service_permission_description"
        android:label="@string/use_fibonacci_service_permission_label"
        android:permissionGroup="com.marakana.android.fibonacciservice.FIBONACCI_PERMISSIONS"
        android:protectionLevel="dangerous" />
    ...
</manifest>
```

3. Now we can statically require the permission on our FibonacciService service:

FibonacciService/AndroidManifest.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ...>
    ...
    <permission-group .../>
    <permission .../>
    <application ...>
        <service
            android:name=".FibonacciService"
            android:permission="com.marakana.android.fibonacciservice. ↵
                USE_FIBONACCI_SERVICE" >
            ...
        </service>
    </application>
    ...
</manifest>
```

4. If we now re-run the FibonacciService and re-run the FibonacciClient, we will notice that the client will fail to launch and adb logcat will show something like:

```
...
W/ActivityManager( 85): Permission Denial: Accessing service ComponentInfo{com. ↵
    marakana.android.fibonacciservice/com.marakana.android.fibonacciservice. ↵
    FibonacciService} from pid=540, uid=10043 requires com.marakana.android. ↵
    fibonacciservice.USE_FIBONACCI_SERVICE
D/AndroidRuntime( 540): Shutting down VM
W/dalvikvm( 540): threadid=1: thread exiting with uncaught exception (group=0x409c01f8 ↵
    )
E/AndroidRuntime( 540): FATAL EXCEPTION: main
E/AndroidRuntime( 540): java.lang.RuntimeException: Unable to resume activity {com. ↵
    marakana.android.fibonacciclient/com.marakana.android.fibonacciclient. ↵
    FibonacciActivity}: java.lang.SecurityException: Not allowed to bind to service ↵
    Intent { act=com.marakana.android.fibonaccicommon.IFibonacciService }
E/AndroidRuntime( 540):    at android.app.ActivityThread.performResumeActivity( ↵
    ActivityThread.java:2444)
...
E/AndroidRuntime( 540):    at dalvik.system.NativeStart.main(Native Method)
E/AndroidRuntime( 540): Caused by: java.lang.SecurityException: Not allowed to bind to ↵
    service Intent { act=com.marakana.android.fibonaccicommon.IFibonacciService }
E/AndroidRuntime( 540):    at android.app.ContextImpl.bindService(ContextImpl.java ↵
    :1135)
E/AndroidRuntime( 540):    at android.content.ContextWrapper.bindService( ↵
    ContextWrapper.java:370)
E/AndroidRuntime( 540):    at com.marakana.android.fibonacciclient.FibonacciActivity. ↵
    onResume(FibonacciActivity.java:65)
...
W/ActivityManager( 85): Force finishing activity com.marakana.android. ↵
    fibonacciclient/.FibonacciActivity
...
```

5. Finally, we can give FibonacciClient a fighting chance by allowing it to *use* the USE_FIBONACCI_SERVICE permission:

FibonacciClient/AndroidManifest.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ...>
    ...
    <uses-permission android:name="com.marakana.android.fibonacciservice. ↵
        USE_FIBONACCI_SERVICE"/>
```



```
...
</manifest>
```

6. We can now observe that our client is again able to use the service
7. In the Emulator, if we go to *Home* → *Menu* → *Manage apps* → *Fibonacci Client* → *PERMISSIONS*, we should see the *Fibonacci Permissions* group and under it, *use fibonacci service* permission

5.8.2 Dynamic Permission Enforcement

Here, we want to restrict access to the `com.marakana.android.fibonacciservice.IFibonacciServiceImpl`'s recursive operations (`fibJR(long n)` and `fibNR(long n)`) for $n > 10$ to applications (i.e. clients) that hold *USE_SLOW_FIBONACCI_SERVICE* custom permission

1. Like before, we start off by creating a custom permission:

FibonacciService/res/values/strings.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
    ...
    <string name="use_slow_fibonacci_service_permission_label">
        use slow fibonacci service operations
    </string>
    <string name="use_slow_fibonacci_service_permission_description">
        applications with this permissions can melt the CPU and drain the battery
        by using slow fibonacci operations
    </string>
    ...
</resources>
```

FibonacciService/AndroidManifest.xml:

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ...>
    ...
    <permission-group .../>
    <permission .../>
    <permission
        android:name="com.marakana.android.fibonacciservice.USE_SLOW_FIBONACCI_SERVICE"
        android:description="@string/use_slow_fibonacci_service_permission_description"
        android:label="@string/use_slow_fibonacci_service_permission_label"
        android:permissionGroup="com.marakana.android.fibonacciservice. ←
            FIBONACCI_PERMISSIONS"
        android:protectionLevel="dangerous" />
    ...
</manifest>
```

2. Next, we update our `IFibonacciServiceImpl` to enforce this permission dynamically - via a `android.content.Context` that get expect to get through the constructor:

FibonacciService/src/com/marakana/android/fibonacciservice/IFibonacciServiceImpl.java:

```
package com.marakana.android.fibonacciservice;

import android.content.Context;
...
public class IFibonacciServiceImpl extends IFibonacciService.Stub {
    ...
    private final Context context;
```

```

public IFibonacciServiceImpl(Context context) {
    this.context = context;
}

private long checkN(long n) {
    if (n > 10) {
        this.context.enforceCallingOrSelfPermission(
            Manifest.permission.USE_SLOW_FIBONACCI_SERVICE, "Go away!");
    }
    return n;
}
...
public long fibJR(long n) {
    ...
    return FibLib.fibJR(this.checkN(n));
}
...
public long fibNR(long n) {
    ...
    return FibLib.fibNR(this.checkN(n));
}
...
}

```

3. We have to update `FibonacciService` to invoke the new `IFibonacciServiceImpl`'s constructor:

`FibonacciService/src/com/marakana/android/fibonacciservice/FibonacciService.java`:

```

...
public class FibonacciService extends Service {
    ...
    @Override
    public void onCreate() {
        ...
        this.service = new IFibonacciServiceImpl(super.getApplicationContext());
        ...
    }
    ...
}

```

4. If we now re-run the `FibonacciService` and re-run the `FibonacciClient` for a recursive operation with $n > 10$, we will notice that the client will fail and `adb logcat` will show something like:

```

...
D/IFibonacciServiceImpl( 617): fib(15, RECURSIVE_NATIVE)
D/IFibonacciServiceImpl( 617): fibNR(15)
W/dalvikvm( 604): threadid=11: thread exiting with uncaught exception (group=0 ↵
    x409c01f8)
E/AndroidRuntime( 604): FATAL EXCEPTION: AsyncTask #1
E/AndroidRuntime( 604): java.lang.RuntimeException: An error occurred while executing ↵
    doInBackground()
...
E/AndroidRuntime( 604):     at java.lang.Thread.run(Thread.java:856)
E/AndroidRuntime( 604): Caused by: java.lang.SecurityException: Go away!: Neither user ↵
    10043 nor current process has com.marakana.android.fibonacciservice. ↵
    USE_SLOW_FIBONACCI_SERVICE.
...

```

5. Finally, we can allow `FibonacciClient` to melt our CPU and drain our battery by allowing it to *use* the `USE_SLOW_FIBONACCI_SERVICE` permission:

`FibonacciClient/AndroidManifest.xml`:

```
<?xml version="1.0" encoding="utf-8"?>
<manifest ...>
    ...
    <uses-permission android:name="com.marakana.android.fibonacciservice. ↵
        USE_SLOW_FIBONACCI_SERVICE"/>
    ...
</manifest>
```

6. We can now observe that our client is again able to use recursive fibonacci operations even for $n > 10$
7. In the Emulator, if we go to *Home* → *Menu* → *Manage apps* → *Fibonacci Client* → *PERMISSIONS* → *Fibonacci Permissions*, we should see both *use fibonacci service* and *use slow fibonacci service operations* permissions

5.9 Lab: Custom Permissions

- For this lab, you are given two applications, LogClient and LogService
 - These two apps communicate via Binder/IPC, where the common files reside in a library project called LogCommon: **LogCommon/src/com/marakana/android/logcommon/ILogService.aidl:**

```
package com.marakana.android.logcommon;
import com.marakana.android.logcommon.LogMessage;

interface ILogService {
    void log(in LogMessage logMessage);
}
```

LogCommon/src/com/marakana/android/logcommon/LogMessage.java:

```
package com.marakana.android.logcommon;

import android.os.Parcel;
import android.os.Parcelable;

public class LogMessage implements Parcelable {
    private final int priority;
    private final String tag;
    private final String msg;

    public LogMessage(int priority, String tag, String msg) {
        this.priority = priority;
        this.tag = tag;
        this.msg = msg;
    }

    public int getPriority() {
        return priority;
    }

    public String getTag() {
        return tag;
    }

    public String getMsg() {
        return msg;
    }
    ...
}
```

- To get started:

- a. Get LogCommon, LogService, and LogClient Eclipse projects
 - As a ZIP archive: <https://github.com/marakana/LogBinderDemo/zipball/master>
 - By Git: `git clone https://github.com/marakana/LogBinderDemo.git`
- b. Unzip or `git clone` into your workspace directory
- c. Import LogCommon, LogClient, and LogService (as existing) projects into Eclipse

Tip

If you get errors on import, try to clean all projects (menubar → *Project* → *Clean...* → *Clean all projects* → *OK*), and/or close and reopen all projects, and/or restart Eclipse

- In the provided Log client-service applications:

1. Restrict access to the `com.marakana.android.logservice.LogService` to applications that hold *USE_LOG_SERVICE* custom permission
 - a. Create a custom permission group (make sure to name-space it)
 - b. Create a custom permission (make sure to name-space it)
 - c. Then require the permission on the service
 - d. Test that a client without the required permission cannot bind to the service
 - i. Look for an exception stack trace in `adb logcat` when you launch the client
 - e. Have the client use the required permission
 - f. Test again - the client should now be able to bind to the service as before
2. Restrict access to "long" log messages on `com.marakana.android.logservice.ILogService` to applications that hold *USE_LONG_LOG_SERVICE* permission (e.g. where `"long" == logMessage.getTag().length() > 10 || logMessage.getMsg().length() > 80`)
 - a. Create another custom permission (make sure to name-space it)
 - b. Dynamically enforce your permission

Tip

For you to do this, you'll need access to a `android.content.Context` object inside the provided `com.marakana.android.logservice.ILogServiceImpl`. Conveniently enough, `com.marakana.android.logservice.LogService` extends `android.app.Service`, which in turn implements `android.content.Context` and has access to *application context* via `getApplicationContext()` method.

- c. Test that a client without the required permission cannot log "long" messages
- d. Have the client use the required permission
- e. Test again - the client should now be able to use the service as before

- Solution

- As a ZIP archive: <https://github.com/marakana/LogBinderDemo/zipball/secured>
- By Git: `git clone https://github.com/marakana/LogBinderDemo.git -b secured`

5.10 ContentProvider URI Permissions

- Simple `ContentProvider` read/write permissions on are not always flexible enough
 - E.g. an image viewer app wants to get access to an email attachment for viewing – it would be an overkill to give it read-permission over all of email (assuming that email is exposed via a content provider)
 - E.g. a contact picker (selector) activity wants to select a contact
- Use per-URI permissions instead

- When starting another Activity, caller sets `Intent.FLAG_GRANT_READ_URI_PERMISSION` or `Intent.FLAG_GRANT_WRITE_URI_PERMISSION`
- This grants the receiving activity permission to access the specific URI regardless of whether it holds a permission over the `ContentProvider` managing the data behind the URI
- `ContentProviders` need to add explicit support for URI permissions via `android:grantUriPermission`

5.11 Public vs. Private Components

- Android is based on Inter-component communication (via Intents), but the components can span applications
- Components can be public or private
 - Private by default
 - Public if intent-filters are defined
 - Can be explicitly controlled via a simple boolean `android:exported="true|false"` attribute of individual components in `AndroidManifest.xml`
- Components may be unknowingly be leaked to other applications (assuming no permissions are used)
- Unless absolutely designed for external use, explicitly set the `android:exported="false"`

```
<manifest ...>
  ...
  <application ...>
    ...
    <activity android:name=".GetPasswordActivity" android:exported="false" ... >
      <intent-filter>
        ...
      </intent-filter>
    </activity>
  </application>
</manifest>
```

- Or use permissions and don't trust component inputs!

5.12 Intent Broadcast Permissions

- Broadcast senders can specify which permission the `BroadcastReceiver`s must hold to access the intent
- If they don't, the broadcast intent is leaked to all applications on the system
- Always specify read permission via `Context.sendBroadcast(Intent i, String receiverPermission)` unless we use an explicit destination

5.13 Pending Intents

- **PendingIntent** allows delayed triggering of an actual intent (to **start an activity**, **send a broadcast** or **start a service**) in another application
 - E.g. Notification
 - E.g. Alarms
- When the application given a pending intent triggers the actual intent, it does so with **the same permissions and the identity** as the application that created the pending intent
- The application given the pending intent can **fill-in** unspecified values of the actual intent (subject to the rules of `Intent.fillIn()`), which may influence destination and/or integrity of the actual intent's data
- Best to only use pending intents as triggers for our own private components - i.e. explicitly specify our own component's class in the actual Intent - so that it can go there and nowhere else

5.14 Encryption

5.14.1 Data encryption

- Privacy and integrity of data can be achieved using encryption
- Data being transported off device is usually encrypted via TLS/SSL, which Android supports
 - At the native level - via **OpenSSL** (/system/lib/libssl.so)
 - At the Java level - using Java Cryptography Extension (JCE), which on Android is implicitly provided by **BouncyCastle** provider
 - For example, for HTTPS with client-side authentication, we could use **HttpsURLConnection**:

```
KeyStore keyStore = ...;
KeyManagerFactory kmf = KeyManagerFactory.getInstance("X509");
kmf.init(keyStore);
SSLContext context = SSLContext.getInstance("TLS");
context.init(kmf.getKeyManagers(), null, null);
URL url = new URL("https://www.example.com/");
HttpsURLConnection urlConnection = (HttpsURLConnection) url.openConnection();
urlConnection.setSSLSocketFactory(context.getSocketFactory());
InputStream in = urlConnection.getInputStream();
...
```

- Android also comes with **android.net.SSLCertificateSocketFactory** (a more-specialized version of **javax.net.ssl.SSLContext**) with extra features:
 - Timeout specification for SSL handshake operations
 - SSL certificate and hostname verification checks
 - * Hostname verification requires that the socket is created with a hostname, as opposed to an IP address
 - * Can be disabled with `adb shell setprop socket.relaxsslcheck yes` on development devices (i.e. requires root)
 - Optional, persistent, and file-based SSL session caching with **SSLSessionCache**
 - * Saves time, power, and bandwidth by skipping the long SSL handshake when re-establishing a connection to the same server
 - For example:

```
int timeout = 10000;
String host = "www.fortify.net";
int port = 443;
SSLSessionCache cache = new SSLSessionCache((Context) this);
Socket socket = SSLCertificateSocketFactory.getDefault(timeout, cache).createSocket(host,
    port);
OutputStream out = socket.getOutputStream();
InputStream in = socket.getInputStream();
String request = "GET /sslcheck.html HTTP/1.1\r\nHost: 68.178.217.222\r\n\r\n";
out.write(request.getBytes());
byte[] response = new byte[1024];
int nRead = in.read(response);
```

- The key store of trusted root certs (CAs) is at
 - /system/etc/security/cacerts.bks and can only be changed by rebuilding the ROM (< ICS)
 - /system/etc/security/cacerts/*.0 and certificates can be individually disabled via the system settings (>= ICS)
- On-device data encryption is usually also done via JCE

- Use a basic infrastructure like **CryptUtil**:

```
package com.marakana.android.securenote;

import java.io.EOFException;
import java.io.IOException;
import java.io.InputStream;
import java.security.InvalidAlgorithmParameterException;
import java.security.InvalidKeyException;
import java.security.Key;
import java.security.NoSuchAlgorithmException;
import java.security.SecureRandom;
import java.security.spec.InvalidParameterSpecException;
import java.util.Arrays;

import javax.crypto.Cipher;
import javax.crypto.KeyGenerator;
import javax.crypto.NoSuchPaddingException;
import javax.crypto.spec.IvParameterSpec;
import javax.crypto.spec.SecretKeySpec;

public class CryptUtil {

    public static final int IV_LENGTH = 16;

    private static final String ENCRYPTION_ALGORITHM = "AES/CBC/PKCS5Padding";

    private static final String KEY_ALGORITHM = "AES";

    private static final int KEY_SIZE = 256;

    public static Key getKey(byte[] secret) throws NoSuchAlgorithmException {
        return getKey(secret, false);
    }

    public static Key getKey(byte[] secret, boolean wipeSecret) throws
        NoSuchAlgorithmException {
        // generate an encryption/decryption key from random data seeded with
        // our secret (i.e. password)
        SecureRandom secureRandom = SecureRandom.getInstance("SHA1PRNG");
        secureRandom.setSeed(secret);
        KeyGenerator keyGenerator = KeyGenerator.getInstance(KEY_ALGORITHM);
        keyGenerator.init(KEY_SIZE, secureRandom);
        Key key = new SecretKeySpec(keyGenerator.generateKey().getEncoded(),
            KEY_ALGORITHM);
        if (wipeSecret) {
            Arrays.fill(secret, (byte)0);
        }
        return key;
    }

    public static Cipher getEncryptCipher(Key key) throws NoSuchAlgorithmException,
        NoSuchPaddingException, InvalidKeyException {
        Cipher cipher = Cipher.getInstance(ENCRYPTION_ALGORITHM);
        cipher.init(Cipher.ENCRYPT_MODE, key);
        return cipher;
    }

    public static Cipher getDecryptCipher(Key key, byte[] iv) throws
        NoSuchAlgorithmException,
        NoSuchPaddingException, InvalidKeyException,
        InvalidAlgorithmParameterException {
```

```

        Cipher cipher = Cipher.getInstance(ENCIPHER_ALGORITHM);
        cipher.init(Cipher.DECRYPT_MODE, key, new IvParameterSpec(iv));
        return cipher;
    }

    public static byte[] getIv(Cipher cipher) throws InvalidParameterSpecException {
        return cipher.getParameters().getParameterSpec(IvParameterSpec.class).getIV();
    }

    public static byte[] getIv(InputStream in) throws IOException {
        byte[] iv = new byte[IV_LENGTH];
        for (int i = 0; i < iv.length; i) {
            int nRead = in.read(iv, i, iv.length - i);
            if (nRead == -1) {
                throw new EOFException("Unexpected EOF");
            } else {
                i += nRead;
            }
        }
        return iv;
    }
}

```

- To encrypt to a byte array, we could do:

```

byte[] secret = // some secret
byte[] plainText = // some plain text
Key key = CryptUtil.getKey(secret, true);
Cipher cipher = CryptUtil.getEncryptCipher(key);
byte[] iv = CryptUtil.getIv(cipher);
byte[] encrypted = cipher.doFinal(plainText);
// store iv and encrypted

```

- To decrypt from a byte array, we could do:

```

byte[] secret = // some secret
byte[] encrypted = // read encrypted buffer from somewhere
byte[] iv = // read iv from somewhere
Key key = CryptUtil.getKey(secret, true);
Cipher cipher = CryptUtil.getDecryptCipher(key, iv);
byte[] plainText = cipher.doFinal(encrypted);

```

- To encrypt to a file/stream, we could do:

```

byte[] secret = // some secret
byte[] plainText = // some plain text
Key key = CryptUtil.getKey(secret, true);
OutputStream out = new FileOutputStream("some-file"); // or = socket.getOutputStream()
try {
    Cipher cipher = CryptUtil.getEncryptCipher(key);
    byte[] iv = CryptUtil.getIv(cipher);
    out.write(iv);
    out = new CipherOutputStream(out, cipher);
    out.write(plainText);
    out.flush();
} finally {
    out.close();
}

```

- To decrypt a file/stream, we could do:

```

InputStream in = new FileInputStream("some-file"); // or = socket.getInputStream();
try {

```



```
byte[] iv = CryptUtil.getIv(in);
Cipher cipher = CryptUtil.getDecryptCipher(key, iv);
in = new CipherInputStream(in, cipher);
in.read(plainText); // do properly
} finally {
    in.close();
}
```

Note

In May 2011, Google was caught with their pants down. They passed authentication tokens from their Android client applications to their backend services, including contacts, calendars, and photos (picassa) over a plain-text (i.e. unencrypted) channel. This enabled potential attackers to get access and modify private content of users whose auth tokens were captured.

See http://money.cnn.com/2011/05/18/technology/android_security/?section=money_latest

5.14.2 Whole Disk Encryption

- Android 3.0 (Honeycomb) release introduced a new feature, Settings → Location & Security → Encryption → Encrypt tablet, which enables transparent encryption of the /data partition using Linux kernel's dm-crypt functionality (<http://www.saout.de/misc/dm-crypt/>)
- dm-crypt, which presents itself as a block-device, wraps another block device such as eMMC and similar flash devices (but not raw flash chips, so no yaffs2) and offers on-the-fly encryption/decryption of the underlying data
 - Note that at the moment encryption is done "in software", rather than by an optimized set of hardware instructors on the SoC
- To avoid issues with GPL, Android does not use dm-crypt's cryptsetup command and libdevmapper shared library, but rather moves that functionality to the volume daemon (vold), which directly ioctl-calls on the dm-crypt's kernel device
- Additionally, Android's init process had to be extended to support password-entry at boot
 - With encryption enabled, init gets the password and then restarts into the normal boot process with /data properly initialized as a real filesystem
 - See http://source.android.com/tech/encryption/android_crypto_implementation.html for details
- The rest of the Android OS as well as all the apps are unaware of any encryption of the underlying /data partition
- At present, the Android uses 128 AES with CBC and ESSIV:SHA256 for /data, and 128 bit AES for the master key (stored in the last 16KB of the encrypted partition)
- On an unencrypted tablet:
 - The /data partition is mounted as a memory block device:

```
$ adb shell mount |grep /data
/dev/block/mmcblk0p8 /data ext4 rw,nosuid,nodev,noatime,barrier=1,data=ordered 0 0
```

- Writing a 1GB file takes on average 103.919 seconds (10,333,296 bytes/sec)

```
cd /data/local/tmp/
time dd if=/dev/zero of=out bs=4096 count=262144
262144+0 records in
262144+0 records out
1073741824 bytes transferred in 104.006 secs (10,323,845 bytes/sec)
    1m44.02s real    0m0.45s user    0m8.42s system
rm out
time dd if=/dev/zero of=out bs=4096 count=262144
...
rm out
time dd if=/dev/zero of=out bs=4096 count=262144
...
```

- Reading a 1GB file takes on average 45.99 seconds (23,348,197 bytes/sec)

```
time dd if=out of=/dev/null bs=4096 count=262144
262144+0 records in
262144+0 records out
1073741824 bytes transferred in 45.692 secs (23499558 bytes/sec)
    0m45.70s real    0m0.54s user    0m8.84s system
time dd if=out of=/dev/null bs=4096 count=262144
...
time dd if=out of=/dev/null bs=4096 count=262144
...
rm out
```

- After encryption

- The /data partition is mounted as a dm-crypt device-mapper target, which wraps the original memory block device:

```
$ adb shell mount |grep /data
/dev/block/dm-0 /data ext4 rw,nosuid,nodev,noatime,barrier=1,data=ordered 0 0
```

- Writing a 1GB file takes on average 107.288 seconds (10,014,686 bytes/sec), a mere 3.2% degradation in performance, mostly because writing to NAND is slow
- Reading a 1GB file takes on average of 70.616 seconds (15,209,002 bytes/sec), a significant **54% degradation** in performance
 - * Note, that at some point dm-crypt could be optimized to take advantage of any special encryption facilities offered in the hardware (on the SoC)

- Android's whole-disk encryption is still vulnerable to various attacks:

- "Evil maid attack"
 - * Only the /data is encrypted, so we don't know if we can trust the bootloader and /system not to contain any "keyloggers"
 - * Everything along the boot path would have to be encrypted, which it is not at the moment
- Cold-boot attack (<http://citp.princeton.edu/memory/>)
 - * Since dm-crypt stores the encryption keys in RAM, it would theoretically be possible to reboot the device with something like msramp (McGrew Security RAM Dumper) or ram2usb to dump the contents of RAM (containing the encryption key) to a USB drive
 - The device has to be running in order for this to work
 - Even if the host device itself does not support booting from an alternative device (or USB), the RAM could be cooled (so that it retains its state), and then transferred to a device that would support alternative boot methods
 - This is a problem for almost all disk-encryption "solutions" in popular OSs, like Windows, Mac OS X, and Linux
 - * To protect against this, we would need encryption key to be stored somewhere other than RAM, like the CPU (debug) registers, which may be hardware-dependent (e.g. AES-NI on new Intel chips works well), requires changes to the Linux kernel (see TRESOR patch), and is not supported by dm-crypt/Android at the moment



Caution

Breaks during 3.0 to 3.1 OS upgrade. A 3.0-encrypted device had to be master-reset (i.e. all data on /data had to be wiped) on upgrading to 3.1.



Caution

While Honeycomb's whole-disk encryption based on dm-crypt is clearly a step in the right direction, it is far from being a NIST FIPS 140-2-certified solution, which requires two-factor encryption and is mandated for most of DOD applications.

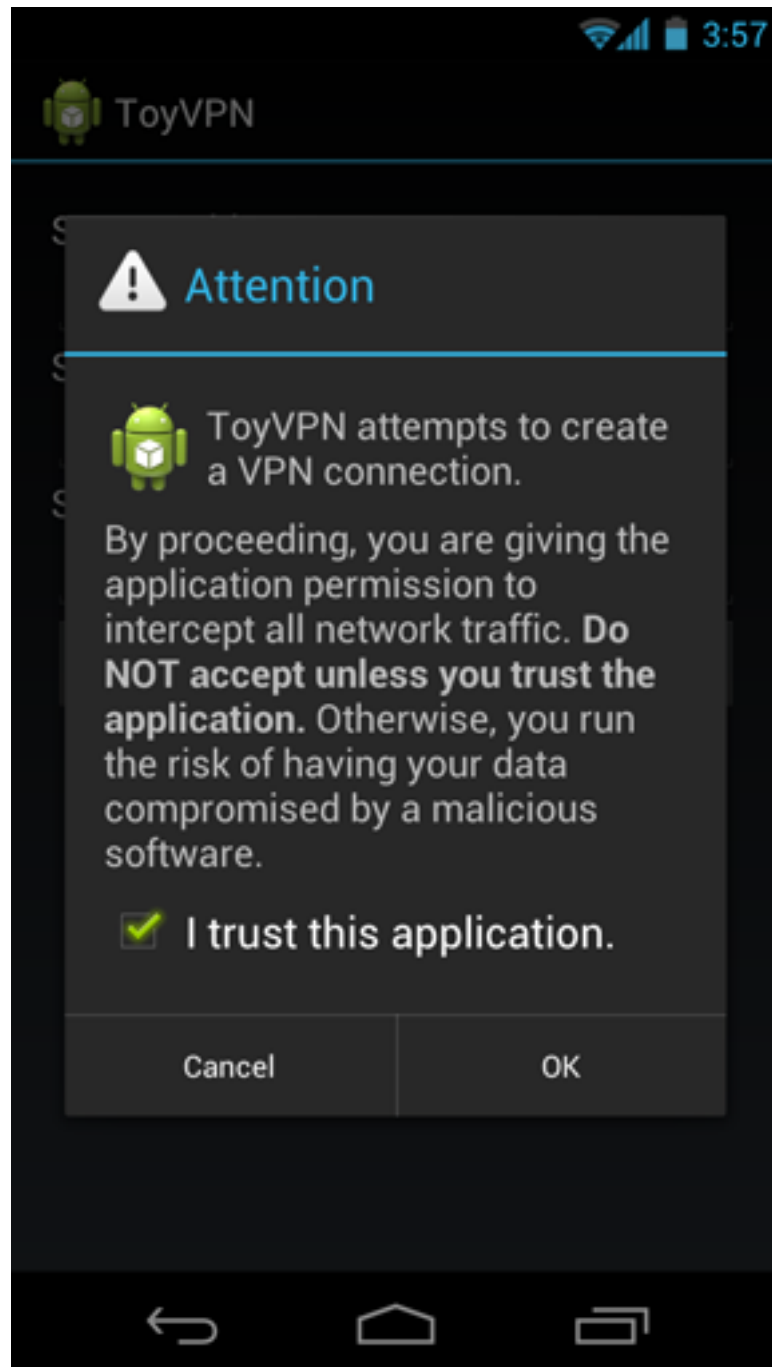
Note

Apple's iOS 4 256-bit hardware encryption was cracked in May 2011 by ElcomSoft through a "simple" brute-force attack in as little as 30 mins using CPU and GPUs of modern host machines. See <http://www.geek.com/articles/chips/apples-ios-4-hardware-encryption-has-been-cracked-20110525/> for more info.

Also, according to Nguyen from Symantec, iOS encryption key is stored on the device, but itself is not encrypted by the user's master key. This means that if a potential attackers successfully jailbreak the device, they would be able to access the data without knowing the passcode.

5.14.3 VPN

- Pre ICS/4.0, Android supported L2TP, L2TP/IPSec PSK, L2TP/IPSec RSA, and PPTP VPNs
 - ICS/4.0 adds support for pure IPSec VPNs - for better compatibility with commonly deployed VPN endpoints/routers
 - Also new in ICS/4.0 is the new VPN API that enables SSL VPN clients to be deployed as apps
 - Via `android.net.VpnService.Builder`, an app can configure addresses, routing rules, DNS/search domains, and even MTUs
 - Via `android.net.VpnService`, the app can then create a virtual network interface tunnel, which is exposed to it as a file descriptor
 - * Outgoing packets are *read* from the FD and sent to the VPN tunnel
 - * Incoming packets are received from the VPN tunnel and *written* to the FD
 - * Each FD read/write operation retrieves/injects one IP packet at a time (so the packets start with IP headers)
 - To address security/exclusivity issues:
 - * User has to approve the creation of a new VPN connection
 - * There can be only one VPN connection running at the same time (any existing one is deactivated)
 - * A system-managed notification is shown during the lifetime of a VPN connection and provides information on the current connection as well as a way to disconnect
 - * The network is restored automatically when the file descriptor is closed (in the event that the app process is terminated)
 - Example app provided by *ToyVpn* sample application:
-



5.14.4 Keystore and Keychain API

- Since Donut/1.6, Android has had a system-wide `keystore` for storage of VPN and (later) WiFi authentication keys
 - See [Working with secure certificates](#)
 - Pre ICS/4.0, applications were not able to access it, so those needing to authenticate via client certificates ended up maintaining their own key store (hard to manage across apps)
- In ICS/4.0, Android adds support for `android.security.KeyChain`, which provides apps with
 - Access to private keys in the system key store and their corresponding certificate chains (subject to one-time user approval)
 - Ability to initiate installation of credentials from X.509 certificates and PKCS#12 key stores (e.g. for installation of organization CA certs)

- Also, in ICS/4.0, Android uses the screen lock password to protect the system credential storage, which works well with device administration APIs and prevents the user from disabling the password as long as they use the secured credentials
- See [Unifying Key Store Access in ICS](#)

5.15 Rooting an Android device

- Why root?
 - Use applications that require root (e.g. backup, tethering, overclocking, etc.)
 - Customize the existing ROM (e.g. remove bloatware, themes, etc.)
 - Install (e.g. upgrade) new custom ROMs
 - Understand how it works
 - Malware rootkits!
- To obtain "root" on an Android device usually involves a number of steps:

1. Exploit a vulnerability of the system to give us root once (see below)
2. Remount the `/system` partition read-write:

```
$ mount -o remount,rw -t ext4 /dev/block/mmcblk0p1 /system
```

3. Create a setuid version of `/system/bin/sh`

```
$ cat /system/bin/sh > /system/bin/su
$ chmod 06755 /system/bin/su
```

4. Remount the `/system` partition read-only

```
$ mount -o remount,ro -t ext4 /dev/block/mmcblk0p1 /system
```

5. Use `/system/bin/su` to become root at any time afterwards

5.15.1 Controlling access to `/system/bin/su` with *Superuser*

- In the real world, most people would not leave `su` wide open to anyone (or any application) - for obvious security implications
- Instead they use something like *Superuser* (<http://code.google.com/p/superuser/>)
 - Superuser is a combination of a custom `/system/bin/su` binary, as well as a `Superuser.apk` (application).
 - When a 3rd-party application wants super-user access, it runs `/system/bin/su` (possibly with parameters of what it wishes to execute)
- 1. The `su` binary first checks whether the calling process is white-listed
 - a. First, it checks in the SQLite database owned by the Superuser application: `/data/data/com.koushikdutta.superuser`
 - * Its `whitelist` table stores three values: the calling process UID, process name (usually just the package name), and a flag (-1=not allowed, 1=temporary allowed, 10000=always allowed)
 - b. If the calling process is already not-approved `su` exits
 - c. If the calling process is not already approved,
 - i. `su` launches a simple activity dialog of the Superuser application by passing the calling process' UID and PID as extra intent parameters:

```
...
char sysCmd[1024];
sprintf(sysCmd, "am start -a android.intent.action.MAIN -n com.koushikdutta. ↵
    superuser/com.koushikdutta.superuser.SuperuserRequestActivity --ei uid %d -- ↵
    ei pid %d > /dev/null", g_puid, ppid);
if (system(sysCmd))
    ...
```

- d. Now `com.koushikdutta.superuser` application starts and `SuperuserRequestActivity` prompts the user to make their selection
 - i. The user's selection is saved into the database and `SuperuserRequestActivity` terminates
 - ii. `su` now checks the database again, and if the process is not approved, it exits
 - e. `su` then `setuid(uid)-s` and `setgid(gid)-s` the calling process
 - f. `su` finally executes `/system/bin/sh` with the same parameters that the original `su` was invoked with
2. The 3rd party application can now use `sh` to pass any commands that it wishes to run as `root`

Now, let take a look at some of the past Android exploits (Getting root the first time):

5.15.2 UDEV exploit (CVE-2009-1185)

- On a standard Linux OS, `udev` enables dynamic management of devices - specifically ones that can be hot-plugged while the system is running (like USB)
 - When a new device is detected, Linux kernel passes a message (containing executable code) to the `udev` daemon, which runs as `root` and acts on this event
 - Prior to version 1.4.1, `udev` did not verify that the message came from the kernel, which made it possible for a rouge application to fake a device and have `udev` execute arbitrary code
 - Newer kernels sent authenticated messages, but `udev` needs to be smart to verify them
- On Android, `udev` functionality is rolled into Android's `init` process (actually `ueventd`), which still runs as `root`
 - This "exploid2" (a.k.a "Exploit") roughly works as follows:
 1. The user copies to the device (e.g. `adb push exploit2 /data/local/tmp/exploit2`)
 2. The user then runs the "exploid2" process (e.g. `adb shell /data/local/tmp/exploit2`)
 3. On the first run, the "exploid2" copies itself to `/sqlite_stmt_journals/exploit2`
 4. The "exploid2" then sends a `NETLINK_KOBJECT_UEVENT` message (via a local unix socket) to `init` (i.e., `udev` code within `init`) to tell it to run a copy of itself next time a device is plugged in (basically it presents itself as `FIRMWARE` update for this device)
 5. The user then "hot-plugs" a device by clicking Settings → Wireless → Airplane, WiFi, etc. or plugs in a USB device (if USB host port is available)
 6. The "exploid2" runs again, this time as `root` (as part of `init`) and it then
 - a. Remounts the `/system` in read-write mode
 - b. Copies itself to `/system/bin/rootshell` and sets its permission as `04711` (i.e. `setuid-bit` enabled)
 7. If the user now wants root, the user simply runs `/system/bin/rootshell`, which then
 - a. Switches to `root` via a simple `setuid(0); setgid(0);`
 - b. Executes `/system/bin/sh` (now as `root`) with the parameters passed to `/system/bin/rootshell`

5.15.3 ADB setuid exhaustion attack (CVE-2010-EASY)

- Android Debug Bridge Daemon (`adbd`) starts as `root`, but calls `setuid(shell)` when forking itself to execute remote requests (i.e. to run `/system/bin/sh`)
- In this case, a program called `rageagainstthecage` exploits a **known condition** where a call to `setuid()` fails once we reach `RLIMIT_NPROC`, preventing `adbd` from dropping its privileges, and since it does not check for this failure, it remains running as `root`
- The program "fork-bombs" `adbd` by creating client requests to it (which causes it to fork) until the system reaches the maximum number of processes (`RLIMIT_NPROC`) - typically around 2-5K
- At this point, `rageagainstthecage` tries to fill the last slot with its connection to `adbd` while it is still running as `root` before `adbd` has a chance to `setuid()` itself
- The problem is that `adbd` does not check whether its call to `setuid()` succeeded, which leaves `rageagainstthecage` running with `root` access

5.15.4 Zimperlich attack against Zygote

- Similar to `adbd`, `zygote` (Android app spawner, which also runs as root) did not check for `setuid()` failures, so it too was prone to this sort of attack
- Fork self repeatedly to reach the process limit (`RLIMIT_NPROC`)
- The call to `setuid()` fails
- The app that was spawned runs as root

5.15.5 Ashmem memory protection attack (CVE-2011-1149)

- "Android before 2.3 does not properly restrict access to the system property space, which allows local applications to bypass the application sandbox and gain privileges, as demonstrated by `psneuter` and `KillingInTheNameOf`, related to the use of Android shared memory (`ashmem`) and `ASHMEM_SET_PROT_MASK`."
- `KillingInTheNameOf` exploit:
 - a. Changes protections of shared (`ashmem`) memory space where system properties are stored to allow writing
 - b. Sets `ro.secure` to 0
 - c. User restarts `adbd`
 - d. User get root via `adb shell`
- `psneuter` exploit:
 - a. Disables access to shared (`ashmem`) memory space where system properties are stored (sets protection mask to 0)
 - b. User restarts `adbd`, but since `adbd` cannot read `ro.secure` it assumes `ro.secure=0`
 - c. User get root via `adb shell`

5.15.6 Buffer Overrun on `vold` exploit (CVE-2011-1823)

- "The `vold` volume manager daemon on Android 3.0 and 2.x before 2.3.4 trusts messages that are received from a `PF_NETLINK` socket, which allows local users to execute arbitrary code and gain root privileges via a negative index that bypasses a maximum-only signed integer check in the `DirectVolume::handlePartitionAdded` method, which triggers memory corruption, as demonstrated by `Gingerbreak`"
 - On Android, `vold` (volume daemon running as root) is used for operations such as SD-Card mounting/unmounting, as well as encryption of `/data` partition
 - Here, an application called **Gingerbreak** (a.k.a. *Softbreak*) is first uploaded to the device (e.g. to `/data/local/tmp/softbreak`)
 - When executed (e.g. via `adb shell`) it tries to exploit an out of bounds array access in `vold` and thus inject code to be executed by root
 - Because `vold` is configurable by the OEMs (and its memory state changes), this attack is not guaranteed to work every time - in fact, it often causes `vold` to segfault
 - A **malicious application** on the device can exploit the same vulnerability to **gain root access**
 - While this exploit initially targeted `Gingerbread`, it also works on `Froyo` and `Honeycomb` (≤ 3.1) releases
-

5.15.7 Linux Local Privilege Escalation via SUID `/proc/pid/mem` Write (CVE-2012-0056)

- In Linux-based systems, `/proc/pid/mem` provides an interface for reading and writing directly to a process's virtual memory
 - Seeking on `/proc/pid/mem` is the same as seeking on the memory of that process
- In v2.6.39, the kernel was simplified to do permission checks on `/proc/pid/mem` at the time it is opened, instead of tracking the process that's using it
 - If we hold the file descriptor to `/proc/pid/mem` open over an `execve()` system call, we'll continue to read from the virtual memory of the original *old* process
 - This vulnerability can be exploited (CVE-2012-0056) by local users to gain root privileges by modifying process memory (assuming no ASLR) of a setuid-enabled executable that writes something deterministic to a file descriptor (like `su`), as demonstrated by [Mempodipper](#)
 - Fixed by [Linus on Tue, 17 Jan 2012](#)
- Most Android devices running Android 4.0.0 - 4.0.3 (like Galaxy Nexus) are based on kernels $\geq 2.6.39$ (e.g. 3.0.8) and are **vulnerable** (via setuid-enabled `run-as`) so can be easily **rooted**
 - Fortunately, `run-as` does an early check to verify that it is running as the `root` or `shell` user so this particular exploit requires ADB-based shell access
 - Since `run-as` is **statically linked**, the mempodroid exploit needs to be given the exact offsets to `exit()` and `setresuid()` (which happen to be `0xd7f4` and `0xad4b` on Galaxy Nexus)

```
$ adb push mempodroid /data/local/tmp/.
$ adb shell chmod 755 /data/local/tmp/mempodroid
$ adb shell
shell@android:/ # id
uid=2000(shell) gid=2000(shell) groups=1003(graphics),1004(input),1007(log),1009(mount) ↵
,1011(adb),1015(sdcard_rw),3001(net_bt_admin),3002(net_bt),3003(inet)
127|shell@android:/ /data/local/tmp/mempodroid 0xd7f4 0xad4b sh
shell@android:/ # id
uid=0(root) gid=0(root) groups=1003(graphics),1004(input),1007(log),1009(mount),1011(adb ↵
),1015(sdcard_rw),3001(net_bt_admin),3002(net_bt),3003(inet)
```

- Patched in Android 4.0.4

5.15.8 WebKit exploit

- Initially discovered on iOS, which also uses WebKit
- Based on buffer-overruns
- Enables the browser (or any app using a WebKit via Android's `WebView` or directly via `libwebcore`) to execute arbitrary code
- A proof of concept creates a remote shell
- But, not a root exploit, because the application is sandboxed
 - Still, access to bookmarks, SSL sessions, stored passwords, etc.
- Patched in 2.2

5.15.9 To Root or Not To Root?

- Dangers on already rooted devices
- A malicious app can gain root access and inject a loadable kernel module into the kernel
- Very hard to detect
- Can open network-channels to leak information from the device

5.15.10 Malware Rootkits

- If we can root our own phone, so can malicious applications (e.g. trojans)
- But they have to be installed first
 - Easy, when they are repackaged versions of legit apps, so they look and feel "official"
 - Users are often confused into installing applications from Market that are not authentic, since they have no easy way to verify
 - Google has ability to both pull apps from Market as well as remotely uninstall them from users' devices (via C2DM) but this process is reactive - not proactive
- OEMs/Carriers are often too slow to patch the devices out in the field - so users remain vulnerable to these root exploits

5.16 Security of Memory

- **Address Space Layout Randomization (ASLR)** to randomize key locations in memory: stack, heap, libs and mmap, exec, linker (and Virtual Dynamically-linked Shared Objects, which are typically not used on Android)
 - Standard in ICS (Android 4.0)
 - Possible, because shared libraries are no longer **pre-linked** in ICS
 - But, **Android's ALSR implementation** does *not* randomize:
 - * The heap (\Leftarrow 4.0.2) - as `/proc/sys/kernel/randomize_va_space` is set to 1 (enabling randomization for mmap, stack, VDSO, and executable mapping), but not the heap, which requires the setting of 2
 - * The location of the executables - as they are not compiled as **position-independent code (PIC)**, probably due to PIC's performance penalty on architectures with limited GPRs (like x86)
 - * The location of Android's custom dynamic linker
 - * Locations of **dynamic libraries for child processes of zygote** (until the next reboot)
 - Pre ICS, there was a **proposal** (by Hristo Bojinov and Dan Boneh from Stanford University and Rich Cannings and Iliyan Malchev from Google) to apply ASLR statically at the time of system recovery (by *retouching* all executable code) and support undoing randomization to support future diff-based OTA updates
 - * Designed to help against remote exploits from network attacks and network-facing services
 - A website with malicious content
 - Any remote network service that exploits a vulnerability of a local [network] protocol parser (e.g. DHCP, HTTP, NTP, or even app "protocols" like iCal, vCard, etc)
 - A rogue access point
 - A rogue SMS packet
 - A malicious audio/video file that targets a flow in a codec decoder
 - Does not help against local code that has access to the actual memory locations of binary code (even if randomized)
- Hardware-based **executable space protection**, a.k.a. **No eXecute (NX)**
 - Known as XN on ARM, XD bit on Intel, and Enhanced Virus Protection on AMD processors

- Enables us to mark certain memory pages as non-executable (i.e. data vs. instruction memory) such that an attempt to execute code in those pages will cause a hardware exception
- Prevents code execution on the stack and the heap
- ProPolice to **prevent stack buffer overruns** or specifically, **stack-smashing attacks** through the use of overrun detection canaries - generated by the compiler
- **safe_iop** to help reduce integer overflows
- Extensions to OpenBSD dlmalloc to prevent double free() vulnerabilities and to prevent chunk consolidation attacks, which are a common way to exploit heap corruption.
- OpenBSD calloc to prevent integer overflows during memory allocation
- Linux mmap_min_addr() to mitigate null pointer dereference privilege escalation
- **Valgrind** (versions **>= 3.7.0+ support Android**) to detect incorrect use of heap memory: accessing uninitialized or already freed memory, accessing memory out of bounds, memory leaks, etc.
- A proposal to prevent brute-force attacks (trying to guess random offsets)
 - Part of the same **research paper** as on pre-ICS ASLR proposal
 - Given the millions of deployed devices, a successful exploit on one device can potentially work on a large enough subset of other devices
 - For example, with a 8-bit randomization offset, for any one device, there are 1 in 256 devices just like it
 - Use cloud-based analysis of crash reports to reliably detect attempts to bypass ASLR by guessing random offset used on each device
 - Attack on a single device is hard to detect, but an attack across a range of devices tends to have a well-known signature
 - Once detected, issue patches, or isolate vulnerable code that lead to the attack in the first place

5.17 Tap-Jacking on Android

- Similar to "click-jacking" in web browsers
 - Example scenario
 - a. A malicious application starts a "sensitive" activity from another application (e.g. system settings)
 - b. The malicious application then overlays a customized notification dialog on top of the legitimate activity (say something that looks like a game)
 - c. User interacts with the custom notification dialog, but user touch events are passed down to the legitimate activity (say to inadvertently enable some "insecure" settings mode: like side-loading)
 - Proof of concept: <http://www.youtube.com/watch?v=gCLU7YUXUAY>
 - To prevent, set `android:filterTouchesWhenObscured="true"` on views which are deemed "secure" (e.g. EditText used for password entry)
 - When set to `true` the view system discards touch events that are received whenever the view's window is obscured by another visible window
 - The view will not receive touches whenever a toast, dialog, or other window appears above the view's window
 - For custom views, consider overriding `View.onFilterTouchEventForSecurity(MotionEvent)` to implement your own security policy
 - See <http://developer.android.com/reference/android/view/View.html#Security> for more info.
 - Only available as for Android API 9 (Gingerbread)
 - Another scenario
-

- a. A malicious application starts a background service
- b. User launches a legitimate "secure" application (say a banking app)
- c. This service launches another activity, masquerading as the original
- d. User enters password/pin/gesture to access the "secure" application
- e. The malicious activity captures user input, records it, and simulates a failure - leading the user to re-enter the info into the legitimate activity
- f. The secure app has no knowledge of the fact that the user taps were recorded

5.18 Android Device Administration

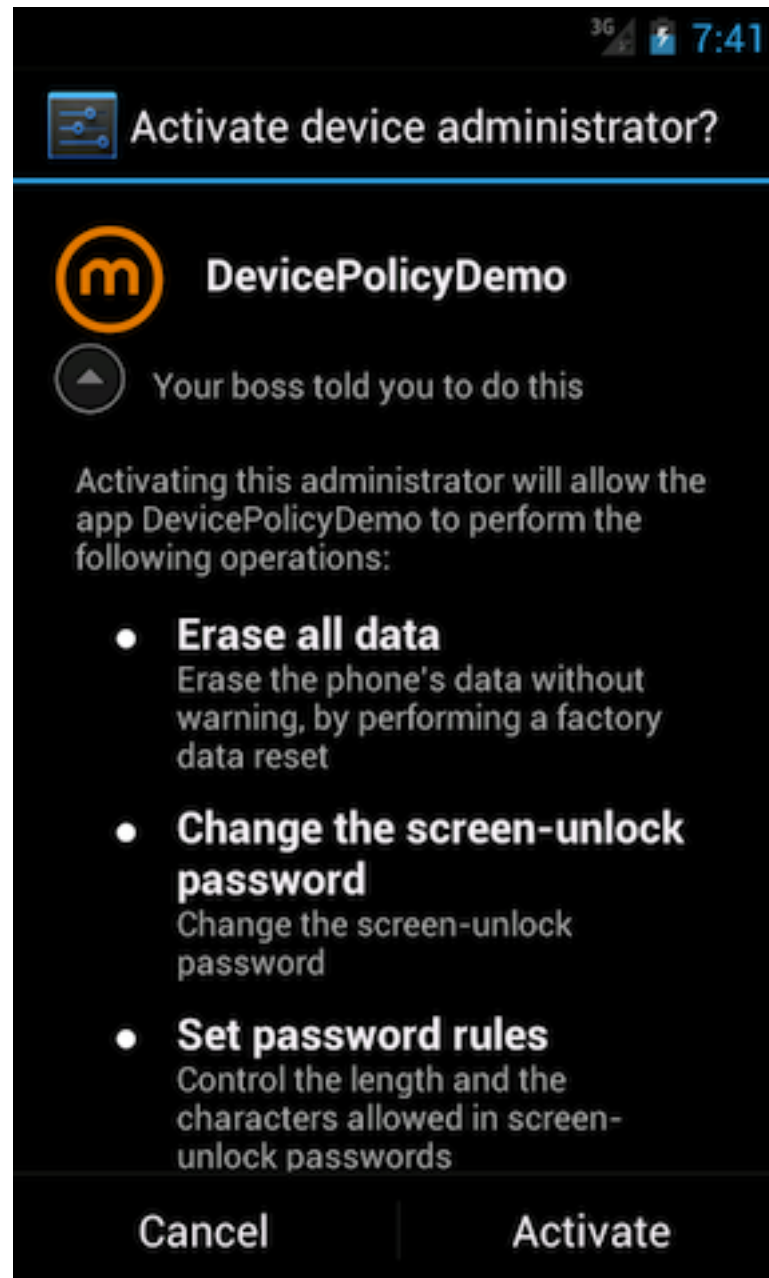
5.18.1 Device Administration Overview

The Android Device Administration API, introduced in Android 2.2, allows you to create security-aware applications that are useful in enterprise settings, such as:

- Email clients
- Security applications that do remote wipe
- Device management services and applications

You use the Device Administration API to write device admin applications that users install on their devices. The device admin application enforces desired *security policies*. Here's how it works:

- A system administrator writes a device admin application that enforces remote/local device security policies.
 - The application is installed on a user's device.
 - The system prompts the user to enable the device admin application.
-



- Once the users enable the device admin application, they are subject to its policies.

When enabled, in addition to enforcing security policies, the admin application can:

- Prompt the user to set a new password
- Lock the device immediately
- Perform a factory reset on the device, wiping the user data (if it has permission)

5.18.2 Device Administration Overview (cont.)

If a device contains multiple enabled admin applications, the strictest policy is enforced.

If users do not enable the device admin app, it remains on the device, but in an inactive state.

- Users will not be subject to its policies, but the application may disable some or all of its functionality.

If a user fails to comply with the policies (for example, if a user sets a password that violates the guidelines), it is up to the application to decide how to handle this.

- For example, the application may prompt the user to set a new password or disable some or all of its functionality.

To uninstall an existing device admin application, users need to first deactivate the application as a device administrator.

- Upon deactivation, the application may disable some or all of its functionality, delete its data, and/or perform a factory reset (if it has permission).

5.18.3 Security Policies

An admin application may enforce security policies regarding the device's screen lock PIN/password, including:

- The maximum inactivity time to trigger the screen lock
- The minimum number of PIN/password characters
- The maximum number of failed password attempts
- The minimum number of uppercase letters, lowercase letters, digits, and/or special password characters (Android 3.0)
- The password expiration period (Android 3.0)
- A password history restriction, preventing users from reusing the last n unique passwords (Android 3.0)

Additionally, a security policy can require device storage encryption as of Android 3.0 and disabling of camera as for Android 4.0.

5.18.4 The Device Administration Classes

The Device Administration API includes the following classes:

DeviceAdminReceiver

Base class for implementing a device administration component. This class provides a convenience for interpreting the raw intent actions that are sent by the system. Your Device Administration application must include a `DeviceAdminReceiver` subclass.

DevicePolicyManager

A class for managing policies enforced on a device. Most clients of this class must have published a `DeviceAdminReceiver` that the user has currently enabled. The `DevicePolicyManager` manages policies for one or more `DeviceAdminReceiver` instances.

DeviceAdminInfo

This class is used to specify metadata for a device administrator component.

5.18.5 Creating the Manifest

The manifest of your admin application must register your `DeviceAdminReceiver` as a `<receiver>`.

The `<receiver>` should set `android:permission="android.permission.BIND_DEVICE_ADMIN"` to ensure that only the system is allowed to interact with the broadcast receiver.

The `<receiver>` must have an `<intent-filter>` child element including one or more of the following `<action>`s, as defined in the `DeviceAdminReceiver` class:

ACTION_DEVICE_ADMIN_ENABLED

(Required) This is the primary action that a device administrator must implement to be allowed to manage a device. This is sent to a device administrator when the user enables it for administration.

ACTION_DEVICE_ADMIN_DISABLE_REQUESTED

Action sent to a device administrator when the user has requested to disable it, but before this has actually been done.

ACTION_DEVICE_ADMIN_DISABLED

Action sent to a device administrator when the user has disabled it.

ACTION_PASSWORD_CHANGED

Action sent to a device administrator when the user has changed the password of their device.

ACTION_PASSWORD_EXPIRING

Action periodically sent to a device administrator when the device password is expiring.

ACTION_PASSWORD_FAILED

Action sent to a device administrator when the user has failed at attempted to enter the password.

ACTION_PASSWORD_SUCCEEDED

Action sent to a device administrator when the user has successfully entered their password, after failing one or more times.

```
<receiver android:name="MyDeviceAdminReceiver"
  android:permission="android.permission.BIND_DEVICE_ADMIN">
  <intent-filter>
    <action android:name="android.app.action.DEVICE_ADMIN_ENABLED" />
    <action android:name="android.app.action.ACTION_DEVICE_ADMIN_DISABLE_REQUESTED" />
    <action android:name="android.app.action.ACTION_DEVICE_ADMIN_DISABLED" />
  </intent-filter>
  <!-- ... -->
</receiver>
```

5.18.6 Creating the Manifest (cont.)

Your `<receiver>` element must also include a `<meta-data>` child element specifying an XML resource declaring the policies used by your admin application.

- The `android:name` attribute must be `android.app.device_admin`.
- The `android:resource` must reference an XML resource in your application.
- For example:

```
<meta-data android:name="android.app.device_admin"
  android:resource="@xml/device_admin_sample" />
```

An example XML resource requesting all policies would be:

```
<device-admin xmlns:android="http://schemas.android.com/apk/res/android">
  <uses-policies>
    <limit-password />
    <watch-login />
    <reset-password />
    <force-lock />
    <wipe-data />
    <expire-password />
    <encrypted-storage />
    <disable-camera />
  </uses-policies>
</device-admin>
```

Your application needs to list only those policies it actually uses.

5.18.7 The DeviceAdminReceiver Class

The `DeviceAdminReceiver` class defines a set of methods that you can override to handle the device administration events broadcast by the system:

`void onEnabled(Context context, Intent intent)`

Called after the administrator is first enabled, as a result of receiving `ACTION_DEVICE_ADMIN_ENABLED`. At this point you can use `DevicePolicyManager` to set your desired policies.

`CharSequence onDisableRequested(Context context, Intent intent)`

Called when the user has asked to disable the administrator, as a result of receiving `ACTION_DEVICE_ADMIN_DISABLE_REQUESTED`. You may return a warning message to display to the user before being disabled, or `null` for no message.

`void onDisabled(Context context, Intent intent)`

Called prior to the administrator being disabled, as a result of receiving `ACTION_DEVICE_ADMIN_DISABLED`. Upon return, you can no longer use the protected parts of the `DevicePolicyManager` API.

`void onPasswordChanged(Context context, Intent intent)`

Called after the user has changed their password, as a result of receiving `ACTION_PASSWORD_CHANGED`.

`void onPasswordExpiring(Context context, Intent intent)`

Called periodically when the password is about to expire or has expired, as a result of receiving `ACTION_PASSWORD_EXPIRING` (API 11)

`void onPasswordFailed(Context context, Intent intent)`

Called after the user has failed at entering their current password, as a result of receiving `ACTION_PASSWORD_FAILED`.

`void onPasswordSucceeded(Context context, Intent intent)`

Called after the user has succeeded at entering their current password, as a result of receiving `ACTION_PASSWORD_SUCCEEDED`.

5.18.8 Testing Whether the Admin Application is Enabled

You can query the `DevicePolicyManager` to test if your admin application is enabled:

```
DevicePolicyManager devicePolicyManager
    = (DevicePolicyManager) getSystemService(Context.DEVICE_POLICY_SERVICE);
ComponentName deviceAdminComponentName
    = new ComponentName(this, MyDeviceAdminReceiver.class);
boolean isActive = devicePolicyManager.isAdminActive(deviceAdminComponentName);
```

You could then enable or disable features of your application depending on whether it is an active device administrator.

5.18.9 Enabling the Application

Your application must explicitly request the user to enable it for device administration. To do so:

1. Create an implicit Intent with the `DevicePolicyManager.ACTION_ADD_DEVICE_ADMIN` action:

```
Intent intent = new Intent(DevicePolicyManager.ACTION_ADD_DEVICE_ADMIN);
```

2. Add an extra identifying your `DeviceAdminReceiver` component:

```
ComponentName deviceAdminComponentName
    = new ComponentName(this, MyDeviceAdminReceiver.class);
intent.putExtra(DevicePolicyManager.EXTRA_DEVICE_ADMIN, deviceAdminComponentName);
```

3. Optionally, provide an explanation as to why the user should activate the admin application:

```
intent.putExtra(DevicePolicyManager.EXTRA_ADD_EXPLANATION, "Your boss told you to do ↵
    this");
```

4. Use the Intent with `startActivityForResult()` to display the activation dialog:

```
startActivityForResult(intent, ACTIVATION_REQUEST);
```

5. You can test for successful activation in your Activity's `onActivityResult()` method:

```
@Override
protected void onActivityResult(int requestCode, int resultCode, Intent data) {
    switch (requestCode) {
        case ACTIVATION_REQUEST:
            if (resultCode == Activity.RESULT_OK) {
                Log.i("DeviceAdminSample", "Administration enabled!");
            } else {
                Log.i("DeviceAdminSample", "Administration enable FAILED!");
            }
            return;
    }
    super.onActivityResult(requestCode, resultCode, data);
}
```

5.18.10 Setting Password Quality Policies

`DevicePolicyManager` includes APIs for setting and enforcing the device screen lock password policy.

- The `setPasswordQuality()` lets you set basic password requirements for your admin application, using these constants:

PASSWORD_QUALITY_ALPHABETIC

The user must enter a password containing at least alphabetic (or other symbol) characters.

PASSWORD_QUALITY_ALPHANUMERIC

The user must enter a password containing at least both numeric and alphabetic (or other symbol) characters.

PASSWORD_QUALITY_NUMERIC

The user must enter a password containing at least numeric characters.

PASSWORD_QUALITY_SOMETHING

The policy requires some kind of password, but doesn't care what it is.

PASSWORD_QUALITY_UNSPECIFIED

The policy has no requirements for the password.

PASSWORD_QUALITY_COMPLEX

(API 11) The user must have entered a password containing at least a letter, a numerical digit and a special symbol.

- Once you have set the password quality, you may also specify a minimum length (except with `PASSWORD_QUALITY_SOMETHING` and `PASSWORD_QUALITY_UNSPECIFIED`) using the `setPasswordMinimumLength()` method.
- For example:

```
devicePolicyManager.setPasswordQuality(deviceAdminComponentName, ↵
    PASSWORD_QUALITY_ALPHANUMERIC);
devicePolicyManager.setPasswordMinimumLength(deviceAdminComponentName, 6);
```

Your application's policy metadata resource must request the `<limit-password />` policy to control password quality; otherwise these methods throw a security exception.

5.18.11 Setting Password Quality Policies, API 11

Beginning with Android 3.0, the `DevicePolicyManager` class includes methods that give you greater control over the contents of the password. Here are the methods for fine-tuning a password's contents:

- `setPasswordMinimumLetters()`
- `setPasswordMinimumLowerCase()`
- `setPasswordMinimumUpperCase()`
- `setPasswordMinimumNonLetter()`
- `setPasswordMinimumNumeric()`
- `setPasswordMinimumSymbols()`

You can also set the password expiration timeout, and prevent users from reusing the last n unique passwords:

- `setPasswordExpirationTimeout()`
- `setPasswordHistoryLength()`

Additionally, Android 3.0 introduced support for a policy requiring the user to encrypt the device, which you can set with:

- `setStorageEncryption()`

Your application's policy metadata resource must request the `<limit-password />` policy to control password quality; otherwise these methods throw a security exception.

Similarly, it must request the `<expire-password />` and `<encrypted-storage />` policies to control those features without throwing a security exception.

5.18.12 Setting the Device Password

You can test if the current device password meets the quality requirements by calling `DevicePolicyManager.isActivePassword` which returns a boolean result.

If necessary, you can start an activity prompting the user to set a password as follows:

```
Intent intent = new Intent(DevicePolicyManager.ACTION_SET_NEW_PASSWORD);
startActivity(intent);
```

Your application can also perform a password reset on the device using `DevicePolicyManager.resetPassword()`. This can be useful if your application is designed to support remote administration, with a new password being provided from a central administration system.

Your application's policy metadata resource must request the `<reset-password />` policy to reset the password; otherwise `resetPassword()` throws a security exception.

5.18.13 Locking and Wiping the Device

Your application can lock the device programmatically using `DevicePolicyManager.lockNow()`.

You can wipe the user data of the device, performing a factory reset, using `DevicePolicyManager.wipeData()`.

Additionally, you can set the maximum number of allowed failed password attempts before the device is wiped automatically by calling `DevicePolicyManager.setMaximumFailedPasswordsForWipe()`

Your application's policy metadata resource must request the `<wipe-data />` policy to wipe the data either explicitly or set the maximum failed passwords for wipe; otherwise a security exception is thrown. `setMaximumFailedPasswordsForWipe()` also requires the `<watch-login />` policy.

The `lockNow()` method requires your application to request the `<force-lock />` policy to avoid throwing a security exception.

5.18.14 Device Administration Demo

In this example app, you will see how to write an application that requests to device administration privileges, and once it gets them, allows user to lock or reset the device.

We are going to look at the following files:

- Android Manifest File
- XML Resource File
- Device Admin Receiver Component
- Activity

The source code for this project is available at <https://marakana.com/static/courseware/android/DevicePolicyDemo.zip>

5.18.15 Android Manifest File

This is where we register our device administration receiver component. It appears as another receiver declaration.

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.marakana.android.devicepolicydemo"
    android:versionCode="1"
    android:versionName="1.0" >

    <uses-sdk android:minSdkVersion="10" />

    <application
        android:icon="@drawable/ic_launcher"
        android:label="@string/app_name" >
        <activity
            android:name=".DevicePolicyDemoActivity"
            android:label="@string/app_name" >
            <intent-filter>
                <action android:name="android.intent.action.MAIN" />

                <category android:name="android.intent.category.LAUNCHER" />
            </intent-filter>
        </activity>
```

```

<!-- This is where we register our receiver -->
<receiver
    android:name=".DemoDeviceAdminReceiver"
    android:permission="android.permission.BIND_DEVICE_ADMIN" >
    <intent-filter>

        <!-- This action is required -->
        <action android:name="android.app.action.DEVICE_ADMIN_ENABLED" />
    </intent-filter>

    <!-- This is required this receiver to become device admin component. -->
    <meta-data
        android:name="android.app.device_admin"
        android:resource="@xml/device_admin_sample" />
    </receiver>
</application>

</manifest>

```

Notice that `<receiver>` element now includes required `android:permission="android.permission.BIND_DEVICE_ADMIN"` permission declaration.

We also must include the appropriate intent action filter `android.app.action.DEVICE_ADMIN_ENABLED` as well as the `<meta-data/>` element that specifies that this receiver uses `@xml/device_admin_sample` resource, which we'll look at next.

5.18.16 XML Resource File

This XML resource file, referenced from `AndroidManifest.xml` specifies what policies we are interested in.

```

<device-admin xmlns:android="http://schemas.android.com/apk/res/android">
    <uses-policies>
        <limit-password />
        <watch-login />
        <reset-password />
        <force-lock />
        <wipe-data />
        <expire-password />
        <encrypted-storage />
    </uses-policies>
</device-admin>

```

In this example, we ask for most of the available policies merely to illustrate what is available. In a real-world example, you should only ask for policies that you really require.

5.18.17 Device Admin Receiver Component

This is the main device administration component. It is basically a specialized `BroadcastReceiver` class that implements some callbacks specific to device administration.

```

package com.marakana.android.devicepolicydemo;

import android.app.admin.DeviceAdminReceiver;
import android.content.Context;
import android.content.Intent;
import android.util.Log;
import android.widget.Toast;

/**
 * This is the component that is responsible for actual device administration.

```

```

* It becomes the receiver when a policy is applied. It is important that we
* subclass DeviceAdminReceiver class here and to implement its only required
* method onEnabled().
*/
public class DemoDeviceAdminReceiver extends DeviceAdminReceiver {
    static final String TAG = "DemoDeviceAdminReceiver";

    /** Called when this application is approved to be a device administrator. */
    @Override
    public void onEnabled(Context context, Intent intent) {
        super.onEnabled(context, intent);
        Toast.makeText(context, R.string.device_admin_enabled,
            Toast.LENGTH_LONG).show();
        Log.d(TAG, "onEnabled");
    }

    /** Called when this application is no longer the device administrator. */
    @Override
    public void onDisabled(Context context, Intent intent) {
        super.onDisabled(context, intent);
        Toast.makeText(context, R.string.device_admin_disabled,
            Toast.LENGTH_LONG).show();
        Log.d(TAG, "onDisabled");
    }

    @Override
    public void onPasswordChanged(Context context, Intent intent) {
        super.onPasswordChanged(context, intent);
        Log.d(TAG, "onPasswordChanged");
    }

    @Override
    public void onPasswordFailed(Context context, Intent intent) {
        super.onPasswordFailed(context, intent);
        Log.d(TAG, "onPasswordFailed");
    }

    @Override
    public void onPasswordSucceeded(Context context, Intent intent) {
        super.onPasswordSucceeded(context, intent);
        Log.d(TAG, "onPasswordSucceeded");
    }
}

```

Notice that we subclass `DeviceAdminReceiver` class. This is the required for this component to be able to receive policy notifications.

We also must implement the required `onEnabled()` method that is called when the policy administration is first enabled.

We don't really do much here other than log what happened to visually illustrate the execution of this code.

5.18.18 Activity

The activity acts as our demo client in this case. The significant methods are `onClick()`, `onCheckedChanged()` and `onActivityResult()`.

```

package com.marakana.android.devicepolicydemo;

import android.app.Activity;
import android.app.admin.DevicePolicyManager;

```

```

import android.content.ComponentName;
import android.content.Context;
import android.content.Intent;
import android.os.Bundle;
import android.util.Log;
import android.view.View;
import android.widget.CompoundButton;
import android.widget.CompoundButton.OnCheckedChangeListener;
import android.widget.Toast;
import android.widget.ToggleButton;

public class DevicePolicyDemoActivity extends Activity implements
    OnCheckedChangeListener {
    static final String TAG = "DevicePolicyDemoActivity";
    static final int ACTIVATION_REQUEST = 47; // identifies our request id
    DevicePolicyManager devicePolicyManager;
    ComponentName demoDeviceAdmin;
    ToggleButton toggleButton;

    /** Called when the activity is first created. */
    @Override
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.main);

        toggleButton = (ToggleButton) super
            .findViewById(R.id.toggle_device_admin);
        toggleButton.setOnCheckedChangeListener(this);

        // Initialize Device Policy Manager service and our receiver class
        devicePolicyManager = (DevicePolicyManager) getSystemService(Context. ↵
            DEVICE_POLICY_SERVICE);
        demoDeviceAdmin = new ComponentName(this, DemoDeviceAdminReceiver.class);
    }

    /**
     * Called when a button is clicked on. We have Lock Device and Reset Device
     * buttons that could invoke this method.
     */
    public void onClick(View v) {
        switch (v.getId()) {
            case R.id.button_lock_device:
                // We lock the screen
                Toast.makeText(this, "Locking device...", Toast.LENGTH_LONG).show();
                Log.d(TAG, "Locking device now");
                devicePolicyManager.lockNow();
                break;
            case R.id.button_reset_device:
                // We reset the device - this will erase entire /data partition!
                Toast.makeText(this, "Locking device...", Toast.LENGTH_LONG).show();
                Log.d(TAG,
                    "RESETEing device now - all user data will be ERASED to factory settings ↵
                    ");
                devicePolicyManager.wipeData(ACTIVATION_REQUEST);
                break;
        }
    }

    /**
     * Called when the state of toggle button changes. In this case, we send an
     * intent to activate the device policy administration.
     */

```

```

@Override
public void onCheckedChanged(CompoundButton button, boolean isChecked) {
    if (isChecked) {
        // Activate device administration
        Intent intent = new Intent(
            DevicePolicyManager.ACTION_ADD_DEVICE_ADMIN);
        intent.putExtra(DevicePolicyManager.EXTRA_DEVICE_ADMIN,
            demoDeviceAdmin);
        intent.putExtra(DevicePolicyManager.EXTRA_ADD_EXPLANATION,
            "Your boss told you to do this");
        startActivityForResult(intent, ACTIVATION_REQUEST);
    }
    Log.d(TAG, "onCheckedChanged to: " + isChecked);
}

/**
 * Called when startActivityForResult() call is completed. The result of
 * activation could be success or failure, mostly depending on user okaying
 * this app's request to administer the device.
 */
@Override
protected void onActivityResult(int requestCode, int resultCode, Intent data) {
    switch (requestCode) {
        case ACTIVATION_REQUEST:
            if (resultCode == Activity.RESULT_OK) {
                Log.i(TAG, "Administration enabled!");
                toggleButton.setChecked(true);
            } else {
                Log.i(TAG, "Administration enable FAILED!");
                toggleButton.setChecked(false);
            }
            return;
    }
    super.onActivityResult(requestCode, resultCode, data);
}
}

```

`onCheckedChanged()` is invoked when the toggle button changes state. It sends an intent requesting that this application be granted device administration permissions on this device. User has to allow this request. The result of user's action is then passed to `onActivityResult()` method.

`onClick()` method processes button clicks for lock and reset buttons. Note that its calls to `DevicePolicyManager` will lock and wipe out the device user data partition, respectively.

5.18.19 Lab (Device Administration)

Device-admin-enable an existing Android app:

1. Download <http://marakana.com/static/courseware/android/SecureNote.zip>
2. Expand into your (Eclipse) workspace
3. Import into Eclipse
4. Using Device Admin APIs
 - a. Require that the screen-lock password be set (of at least 6 characters with at least one digit)
 - b. Automatically wipe the device after 5 invalid login attempts
5. Check against the solution available at <http://marakana.com/static/courseware/android/DeviceAdministeredSecureNote.zip>

5.19 Malware

5.19.1 Lessons From The Field

- [Dissecting Android Malware: Characterization and Evolution](#) paper by Yajin Zhou and Xuxian Jiang from North Carolina State University
- Collected and analyzed over 1200 malware samples from August 2010 to October 2011 for the [Android Malware Genome Project](#)
- From these 1200+ samples, they found that:
 - 86% are repackaged versions of existing apps with malicious payloads
 - * These include paid apps, popular games, utilities (including security), as well as porn-related apps
 - * The malicious payload often "hidden" with class-file names that look legitimate (e.g. `com.sec.android.provider.drm`, `com.google.ssearch`, or `com.google.update`)
 - * Some take advantage of compromised platform-level keys (for some popular custom ROMs)
 - 7% look benign because they don't *contain* the malicious code, but instead offer the user an option to install the *updated* version of itself, which does contain the malicious code
 - * This is done to avoid detection
 - * The update may be downloaded or packaged as an asset or a resource
 - Some take advantage of Dalvik's run-time class-loading capabilities via `dalvik.system.DexClassLoader`
 - * Avoid updating the whole app (which requires user confirmation)
 - * Download (encrypted) DEX code, load it into the Dalvik VM, and execute it

```
DexClassLoader classLoader = new DexClassLoader(
    new File(context.getFilesDir(), "bad.jar").getAbsolutePath(), // contains classes. ↵
    dex
    context.getDir("dex", 0).getAbsolutePath(), // create a directory for optimized DEX ↵
    code
    null, // we could also specify a path for native libraries!
    context.getClassLoader());
Class<?> badClass = classLoader.loadClass("com.malicious.app.Bad");
Bad bad = (Bad) badClass.newInstance();
bad.run();
```

- Some use *drive-by-download* to send the user to a site, which "analyzes" the user's device, finds a problem, and attempts to trick the user into installing a malware app that claims to address the problem
- 13.8% are straight-out spyware/malware that hide their malicious behavior behind some seemingly useful functionality
- 83.3% are activated by `BOOT_COMPLETED` broadcast intent (among other events, like `SMS_RECEIVED`)
- Compared to normal apps, malware apps request more (~ 20) permissions than popular non-malware apps (~ 4)
 - * `INTERNET`: 98% vs 89%
 - * `RECEIVE_BOOT_COMPLETED`: 53.7% vs 10.9%
 - * `READ_SMS`: 62.7% vs 2.6%
 - * `WRITE_SMS`: 52.2% vs ?% (not in the top 20)
 - * `RECEIVE_SMS`: 39.6% vs ?% (not in the top 20)
 - * `SEND_SMS`: 43.9% vs 3.4%
 - * `READ_CONTACTS`: 36.3% vs 5.6%
 - * `RESTART_PACKAGES`: 26.4% vs 2.6%
- 36.7% leverage root-level exploits
 - * Common payloads include exploit, `RageAgainstTheCage`, `Zimperlich`, `GingerBreak`, and `asroot`
 - * 29.5% come with multiple root exploits
 - * Some encrypt the root-exploit code and store it as asset/resource files to avoid detection

- 93% turn the compromised phones into a botnet controlled over the network via C&C servers
 - * The names of C&C servers are often obfuscated (or encrypted) to avoid detection
 - * Some store the names of C&C servers in obfuscated posts/comments on public blog/forum sites
 - * Some use SMS for control
- 45.3% have the built-in support of sending out SMS messages to premium-rate numbers or making phone calls without user awareness
 - * The numbers to SMS/call often come from C&C servers
 - * Some subscribe users to premium services via outbound SMS, trap incoming SMS replies, and send out confirmation SMS messages to "complete the transaction"
- 51.1% harvest user's information (e.g. user accounts, SMS messages, and dialed numbers)
- Some come with "shadow payloads" that get installed (via root), so that the payload remains even if the original app gets discovered and removed
- Some use obfuscation/"encryption" or native/JNI code to make it harder to detect and analyze
- The also tested major anti-virus/anti-malware applications with the following rates of detection:
 - AVG Antivirus Free - 54.7%
 - Lookout Security & Antivirus - 79.6%
 - Norton Mobile Security Lite - 20.2%
 - Trend Micro Mobile Security Personal Edition - 76.7%

5.19.2 Detection

- Use `android.content.pm.PackageManager.getInstalledPackages(int flags)` for the full app scan
 - By package-name (e.g. check against a black/white-list):

```
for (PackageInfo packageInfo : getPackageManager().getInstalledPackages(0)) {
    if (packageInfo.packageName.startsWith("com.malware")) {
        // found malware!
    }
}
```

- By permission (e.g. check against a black-list of inappropriate permissions):

```
for (PackageInfo packageInfo : getPackageManager().getInstalledPackages(PackageManager. ↵
    GET_PERMISSIONS)) {
    if ((packageInfo.applicationInfo.flags & ApplicationInfo.FLAG_SYSTEM) == 0) {
        continue; // skip system apps
    }
    if (packageInfo.requestedPermissions != null) {
        for (String requestedPermission : packageInfo.requestedPermissions) {
            if (requestedPermission.equals(android.Manifest.permission.SEND_SMS)) {
                // found malware!
            }
        }
    }
}
```

- By signature (e.g., check against a black/white-list of issuers):

```
CertificateFactory certificateFactory = CertificateFactory.getInstance("X509");
PublicKey trustedIssuerPublicKey = // get some trusted key
for (PackageInfo packageInfo : getPackageManager().getInstalledPackages(PackageManager. ↵
    GET_SIGNATURES)) {
    if ((packageInfo.applicationInfo.flags & ApplicationInfo.FLAG_SYSTEM) == 0) {
```



```

        continue; // skip system apps
    }
    if (packageInfo.signatures != null) {
        for (Signature signature : packageInfo.signatures) {
            InputStream input = new ByteArrayInputStream(signature.toByteArray());
            try {
                X509Certificate cert = (X509Certificate) certificateFactory.generateCertificate( ←
                    input);
                cert.checkValidity();
                cert.verify(trustedIssuerPublicKey);
                if (cert.getIssuerDN().getName().equals("CN=Some One,O=Bad,C=US")) {
                    // found malware!
                }
            } catch (CertificateException e) {
                // found malware!
            }
        }
    }
}

```

– By code:

```

for (PackageInfo packageInfo : getPackageManager().getInstalledPackages(0)) {
    if ((packageInfo.applicationInfo.flags & ApplicationInfo.FLAG_SYSTEM) == 0) {
        continue; // skip system apps
    }
    String apk = packageInfo.applicationInfo.sourceDir;
    FileInputStream in = new FileInputStream(apk); // this is legal!
    try {
        // scan for malicious code (unzip first) or upload to remote server for analysis
    } finally {
        in.close();
    }
    String nativeDir = packageInfo.applicationInfo.nativeLibraryDir; // these are readable ←
        by all!
    // scan native libraries for malicious code or upload to remote server for analysis
}

```

- Listen for `android.intent.action.PACKAGE_ADDED` broadcasts and verify new/updated apps:

AndroidManifest.xml:

```

<manifest ... >
    ...
    <application ... >
        ...
        <receiver android:name=".ApplicationInstallReceiver" >
            <intent-filter>
                <action android:name="android.intent.action.PACKAGE_ADDED" />
                <action android:name="android.intent.action.PACKAGE_REPLACED" />
                <data android:scheme="package" />
            </intent-filter>
        </receiver>
    </application>
</manifest>

```

ApplicationInstallReceiver.java:

```

...
public class ApplicationInstallReceiver extends BroadcastReceiver {
    @Override
    public void onReceive(Context context, Intent intent) {

```

```

Uri packageUri = intent.getData();
String packageName = packageUri.getEncodedSchemeSpecificPart();
int flags = PackageManager.GET_PERMISSIONS | PackageManager.GET_SIGNATURES;
try {
    PackageInfo packageInfo =
        context.getPackageManager().getPackageInfo(packageName, flags);
    // verify packageInfo
} catch (NameNotFoundException e) {
    // handle
}
}
}

```

5.19.3 Removal

- Once a malicious app is found, offer the user a chance to delete it

```

Uri packageURI = Uri.parse("package:com.malicious.app");
Intent uninstallIntent = new Intent(Intent.ACTION_DELETE, packageURI);
startActivity(uninstallIntent);

```

- Cannot use `PackageManager.deletePackage(String packageName, IPackageDeleteObserver observer, int flags)`
 - Requires `signatureOrSystem` permission
 - The API call is hidden (unless we use the framework APIs or reflection)
- Sample source-code available
 - As a ZIP archive: <https://github.com/marakana/AntiMalware/zipball/master>
 - By Git: `git clone https://github.com/marakana/AntiMalware.git`

5.20 SE Android (SE-Linux on Android)

- Discretionary Access Control (DAC) vs. Mandatory Access Control (MAC)
- DAC on Android
 - Default form of access control (also true for most Linux systems)
 - Access to data is controlled by the app developers
 - * Except for root
 - Based on user/group identity associated with each app and its data
 - Coarse-grained decentralized control
 - * No easy way to establish a system-wide policy
- MAC with SE-Linux
 - System-wide security policy applies to all processes, data, and system operations
 - Based on security labels
 - Confines flawed/malicious apps as well as system processes (including those that run as root!)
 - * Prevent privilege escalation
 - Centralized/manageable device-wide policy
- See [SEAndroid website](#) on how to build it

- From Stephen Smalley's "**The Case for Security Enhanced (SE) Android**":

- SE Android brings MAC to Android and has the following goals:

- Prevent privilege escalation by apps
- Prevent data leakage by apps
- Prevent bypass of security features
- Enforce legal restrictions on data
- Protect integrity of apps and data
- Targeted at consumers, businesses, and government

- What SE Android *can* help with:

- Confine privileged daemons
 - * Protect from misuse
 - * Limit the damage that can be done via them
- Sandbox and isolate apps
 - * Strongly separate apps from one another
 - * Prevent privilege escalation by apps
- Provide centralized, analyzable policy

- What SE Android *can no* help with:

- Kernel vulnerabilities (in general)
 - * May block exploitation of specific vulnerabilities
- Anything allowed by security policy
 - * Good policy is important
 - * Architecture of system applications matters
 - Decomposition, least privilege

- Challenges

- Kernel
 - * No support for per-file security labeling (yaffs2)
 - * Unique kernel subsystems lack SELinux support
- Userspace
 - * No existing SELinux support
 - * Sharing through framework services
- Policy
 - * Existing policies unsuited to Android

5.21 Other Security Concerns

- Unintentional app vulnerabilities

- For example (CVE-2011-1717) "Skype for Android stored sensitive user data without encryption in sqlite3 databases that have weak permissions, which allows local applications to read user IDs, contacts, phone numbers, date of birth, instant message logs, and other private information."

- Push-based installation of apps from Market (based on the Google account)
-

- If the Google account associated with the device is compromised, malicious applications could be pushed directly to affected owner's devices
 - Social-engineering vectors of attack
 - Lack of the developer-user trust model
 - Reactive vs preventative security of Market-installed apps
 - Firewall
 - Android uses all-or-nothing access to networking
 - * Requested via the INTERNET permission, mapped to `inet` group, enforced via `ANDROID_PARANOID_NETWORK` kernel extension
 - * `iptables` is available, but not exposed to the user
 - * No easy way to setup a firewall policy controlling/limiting access to network resources
 - WhisperMonitor is a 3rd party custom ROM that tries to address this shortcoming, providing a full-fledged application firewall manageable by the end user
 - Encryption of communication
 - Whisper Systems' RedPhone application uses ZRTP-encrypted SMS messages to establish calls over a VOIP connection (hidden behind an alternative dialer)
 - * ZRTP was designed by PGP inventor Phillip Zimmerman
 - Rogue applications signed using platform keys (targeting custom ROMs): jSMShider
 - <http://blog.mylookout.com/2011/06/security-alert-malware-found-targeting-custom-roms-jsmshider/>
 - App obfuscation
 - Proguard
 - Recovery mode
 - State of the device while in the recovery mode
 - Controlling access to private content with a privacy manager
 - North Carolina State University's TISSA (Taming Information-Stealing Smartphone Applications) privacy manager controls access to user's private data (Location, Phone Identity, Contacts, and Call Log)
 - * On an app-by-app basis, users decide how their data is shared: Trusted (unlimited), Bogus (false), Anonymized (filtered), or Empty (pretend that there is no data)
 - * <http://mobile.engadget.com/2011/04/19/ncsu-teases-tissa-for-android-a-security-manager-that-keeps-per/>
 - Security issues with device skins (e.g. HTC Sense): "Security hole in HTC phones gives up e-mail addresses, location"
 - <http://arstechnica.com/gadgets/news/2011/10/security-hole-in-htc-phones-gives-up-e-mail-addresses-location.ars>
 - Dual-mode phones (work and pleasure) - e.g. AT&T Toggle (a.k.a. Enterpoid Divide)
 - <http://www.technologyreview.com/communications/38865/?p1=A1>
 - Non-market installations
 - Server-side polymorphism to generate unique variants and avoid detection by anti-malware
 - <http://www.infoworld.com/d/security/symantec-warns-of-android-trojans-mutate-every-download-185664?source=fssr>
 - Google Bouncer
-

- Upon application upload to Market, Google Bouncer scans it for known malware, spyware and trojans
- Application is then run in a simulated environment (inside Google's cloud) and tested for hidden and malicious behavior (comparing it to previously analyzed apps)
- New developer accounts are checked against previously known offenders
- Already-installed malicious apps can be automatically removed (remote kill-switch)
- <http://googlemobile.blogspot.com/2012/02/android-and-security.html>

6 Building Android From Source

6.1 Why Build Android From Source?

- To understand how Android works
- Build custom ROMs
 - Enable custom services - beyond what's possible with APKs along
 - Support custom hardware

6.2 Setting up the Build Environment

- Before we can download and build Android from source, we need to setup our build environment
- Requirements:
 - Linux (specifically Ubuntu 10.04 or later) and Mac OS X are officially supported
 - * Windows is explicitly not supported
 - Approximately 30GB of disk space (11GB for sources and 20GB for a complete build)
 - A case-sensitive file-system
 - * Most Unix/Linux-based file systems are already case-sensitive
 - * Mac OS Extended (HFS+) file system is case-insensitive by default - we need to create "case sensitive, journaled" volume (e.g. via "Disk Utility")
 - Python 2.4 — 2.7
 - Java Development Kit (official Sun/Oracle release is recommended)
 - * JDK 5 for \leq Froyo
 - * JDK 6 for \geq Gingerbread
 - Git 1.5.4 or newer
 - Build tools and libraries: flex, bison, gcc, make, zlib, libc-dev, ncurses, 32-bit dev libs, etc.
 - See <http://source.android.com/source/initializing.html> for the easy copy+paste installation instructions for the required binaries and how to configure USB access (on Linux)
- We also need to increase our open file limits (`ulimit -n` on Ubuntu defaults to 1024) to 8192:

- a. Add the following to:
/etc/security/limits.conf:

```
...
*      soft    nofile   8192
*      hard    nofile   8192
```

- b. Reboot

6.3 Downloading the Source Tree

- First we need to get `repo`, a simple tool that makes it easier to work with Git in the context of Android

```
$ mkdir ~/bin
$ export PATH=~/.bin:$PATH
$ curl https://dl-ssl.google.com/dl/googlesource/git-repo/repo > ~/bin/repo
$ chmod a+x ~/bin/repo
```

- For more info on `repo`, see <http://source.android.com/source/version-control.html>

- The next step is to set up a local working directory (on a case-sensitive file-system)

```
$ mkdir android-src
$ cd android-src
```

- Next, we `repo init` to update `repo` itself as well as specify where we are going to download the sources from (including the particular version/branch)

```
$ repo init -u https://android.googlesource.com/platform/manifest.git -b gingerbread
```

- Here, `gingerbread` points to a particular branch - i.e. Android 2.3.7
- For the complete list of available branches (e.g. "donut", "eclair", "froyo", "gingerbread", etc.), see "heads" under <http://android.googlesource.com/platform/manifest.git;a=summary>
- For more info on codenames, tags, and build numbers see <http://source.android.com/source/build-numbers.html>
- To understand Android Branches and Releases (i.e. code-lines), see <http://source.android.com/source/code-lines.html>

Note

Official Android repository `android.googlesource.com` is not the only game in town.

For example, to get Android sources for TI's SOC's, we would:

```
repo init -u git://gitorious.org/rowboat/manifest.git -m TI-Android-FroYo-DevKit-V2.2.0
for OMAP3 and
```

```
repo init -u git://gitorious.org/rowboat/manifest.git -m TI-Android-FroYo-DSP-DevKit-V2.2.0
for DM37x EVM
```

(the `.xml` files come from TI) to check out Froyo build optimized for their hardware.

- The final step is to pull the actual files from the repository (11.7GB download for ICS)

```
$ repo sync
```

- See <http://source.android.com/source/downloading.html> for more details on getting Android sources

6.4 Android Source Code Structure

- `bionic/` - the home of the Bionic (libc) library
 - `bootable/` - the home of Android's bootloader, diskinstaller, and recovery image support
 - `build/` - the home of the Android build system
 - `cts/` - Android's Compatibility Test Suite
 - See <http://source.android.com/compatibility/cts-intro.html> for more info.
 - `dalvik/` - the home of the Dalvik VM
 - `development/` - development tools, configuration files and sample apps
-

- `device/` - device-specific binaries (like kernel and device drivers) and source
 - Gingerbread tree supports HTC Nexus One and Samsung Nexus S
- `external/` - 3rd party libraries (mostly native, but also Java), which are synced from their own repositories
- `frameworks/` - Android-specific native utilities (e.g. `app_process`, `bootanimation`, etc.), daemons (e.g. `installd`, `servicemanager`, `system_server`), and libraries (including JNI wrappers and HAL support), as well as Java APIs (i.e. all of `android.*`) and services (all all Application Framework support)
- `hardware/` - hardware-abstraction-layer (HAL) definitions (`libhardware` and `libhardware_legacy`) and some device-specific implementations (e.g. `msm7k`'s `libaudio.so` and TI OMAP3's `libstagefrighthw.so`) both in source code and binaries
- `libcore/` - Apache Harmony (see `libcore/luni/src/main/java/`) as well as test/support libraries
- `ndk/` - the home of NDK
- `out/` - the location where binaries built by `make go`
- `packages/` - the home of the built-in applications (e.g. Phone, Browser, Gallery, etc), content providers (e.g. Contact Provider, Media Provider, etc.), wall papers (including live wall papers), input methods (e.g. LatinIME), etc.
- `prebuilt/` - pre-built kernels (mostly for QEMU) as well as other binaries (mostly 3rd party development tools)
- `sdk/` - the home of Android SDK tools (`ddms`, `traceview`, `ninepatch`, etc.)
- `system/` - the home of the Android root file system, configuration files, `init` and `init.rc`, as well as some of the native daemons

6.5 Android Build System

- Android's build system is based on *make*
- Android OS is a collection of modules (executables, libraries, applications, etc.) - each with its own unique makefile (`Android.mk`)
- The build system was designed around some specific objectives:
 - Allows building for multiple targets (emulator, various devices) and on multiple hosts (Linux and MacOS X)
 - Uses `make` non-recursively - helps avoid slow/unpredictable build times
 - * The build system still allows makefiles from sub-directories (one level) to be included via `include $(call all-subdir-m`
 - Allows selective (individual component) builds - to speed up compile-test cycles
 - Enables configuration via environment settings as well as configuration files - makes the build system more flexible
 - Separates built binaries from the source files - enables fast cleans
 - Enables automatic dependency resolution - so no need for explicit dependancies in makefiles
 - Enables hiding of command lines - so the output of the build is not too verbose
 - Enables multiple targets in one directory - allows for modules to be more compact
- Porting existing autoconf-based (libtool-ized) projects to Android's build system can be simplified by <http://cgkit.collabora.com/-git/user/derek/androgonizer.git>

6.6 Initializing the Build Environment

- Before we can run the actual build, we need to initialize the build environment by sourcing `build/envsetup.sh` into our shell
- Running this command adds special functions to our shell: `help`, `croot`, `m`, `mm`, `mmm`, `cgrep`, `jgrep`, `resgrep`, `godir`, `lunch`, etc. - as these are used later for the actual build
- Finally, this script also includes vendor/device-specific functions as well (which are used to register targets to build)

```
$ source build/envsetup.sh
$ help
Invoke ". build/envsetup.sh" from your shell to add the following functions to your ↵
environment:
- croot:    Changes directory to the top of the tree.
- m:        Makes from the top of the tree.
- mm:       Builds all of the modules in the current directory.
- mmm:      Builds all of the modules in the supplied directories.
- cgrep:    Greps on all local C/C++ files.
- jgrep:    Greps on all local Java files.
- resgrep:  Greps on all local res/*.xml files.
- godir:    Go to the directory containing a file.

Look at the source to view more functions. The complete list is:
add_lunch_combo cgrep check_product check_variant choosecombo chooseproduct choosetype ↵
choosevariant cproj croot
findmakefile gdbclient get_abs_build_var get_build_var getbugreports getprebuilt gettop ↵
godir help isviewserverstarted
jgrep lunch m mm mmm pid print_lunch_menu printconfig resgrep runhat runtest set_java_home ↵
set_sequence_number
set_stuff_for_environment setpaths setttitle smoketest startviewserver stopviewserver ↵
systemstack tapas tracedmdump
```

6.7 Choosing the Build Target

- Next, we choose our *target* using the `lunch` command (actually, it's one of the functions added by `build/envsetup.sh` to our shell)

```
$ lunch

You're building on linux

Lunch menu... pick a combo:
  1. generic-eng
  2. full_passion-userdebug
  3. full_crespo-userdebug
  4. full_crespo4g-userdebug

Which would you like? [generic-eng]

=====
PLATFORM_VERSION_CODENAME=REL
PLATFORM_VERSION=2.3.4
TARGET_PRODUCT=generic
TARGET_BUILD_VARIANT=eng
TARGET_SIMULATOR=false
TARGET_BUILD_TYPE=release
TARGET_BUILD_APPS=
TARGET_ARCH=arm
HOST_ARCH=x86
HOST_OS=linux
```



```
HOST_BUILD_TYPE=release
BUILD_ID=GINGERBREAD
=====
```

- We could also run `lunch 1` to choose the first target or we can explicitly specify a particular target as `lunch generic-eng`
- We could also use `choosecombo` command, which internally uses `chooseproduct`, `choosetype`, and, `choosevariant` to prompt us for product, type, and variant separately

```
$ choosecombo
Only device builds are supported for linux
  Forcing TARGET_SIMULATOR=false

Press enter:

Build type choices are:
  1. release
  2. debug

Which would you like? [1]

Which product would you like? [generic]

Variant choices are:
  1. user
  2. userdebug
  3. eng
Which would you like? [eng]

=====
PLATFORM_VERSION_CODENAME=REL
PLATFORM_VERSION=2.3.4
TARGET_PRODUCT=generic
TARGET_BUILD_VARIANT=eng
TARGET_SIMULATOR=false
TARGET_BUILD_TYPE=release
TARGET_BUILD_APPS=
TARGET_ARCH=arm
HOST_ARCH=x86
HOST_OS=linux
HOST_BUILD_TYPE=release
BUILD_ID=GINGERBREAD
=====
```

- Either way, the result of `lunch` or `choosecombo` sets up the environmental variables which the build system reads to know what to build
 - These environmental variables can also be printed using `printconfig` command
- Targets take the form of *CodeName-BuildType*
 - *CodeName* is mapped to a specific device as follows
 - * `passion` - HTC Nexus One
 - * `crespo` - Samsung Nexus S
 - * `crespo4g` - Samsung Nexus S 4G
 - * `generic` - QEMU Emulator

Note

Building AOSP on Linux-x86 also supported a `simulator` target, which was a partial build of Android, compiled as a single Linux x86 binary, meant to run as a stand-alone process. It would enable testing Dalvik, OpenCORE/Stagefright, or WebKit under Valgrind (instrumentation/debugging framework). But `simulator` has been dropped as a valid lunch target since it's no longer actively maintained by the AOSP team.

-
- *BuildType* specifies the intended use (security restrictions)

- * `user`

- Intended to be the final release
- Installs modules tagged as `user`
- Installs non-APK modules that have no tags specified
- Installs APKs according to the product definition files (tags are ignored for APK modules)
- Sets `ro.secure=1`
- Sets `ro.debuggable=0`
- `adbd` is disabled by default (i.e. has to be enabled via Settings → Applications → Development → USB Debugging)

- * `userdebug` - the same as `user`, except:

- Intended for limited debugging
- Installs modules tagged with `debug`
- Sets `ro.debuggable=1`
- `adbd` is enabled by default

- * `eng`

- Intended for platform-level debugging
 - Installs modules tagged with: `eng`, `debug`, `user`, and/or `development`
 - Installs non-APK modules that have no tags specified
 - Installs APKs according to the product definition files, in addition to tagged APKs
 - Sets `ro.secure=0`
 - Sets `ro.debuggable=1`
 - Sets `ro.kernel.android.checkjni=1`
 - `adbd` is enabled by default
-

Note

Additional *CodeName-BuildType* combinations may be available based on what `build/envsetup.sh` finds (usually in the `device/` folder)

Note

Building for real hardware usually requires that we get proprietary binaries (mostly user-space HAL). For Nexus and other Google-supported devices, we can go to <http://code.google.com/android/nexus/drivers.html>, which allows us to download scripts, which in turn extract binaries from the connected devices (via `adb pull`) into `vendor/` directory tree structure.

6.8 Compiling Android

- Before the actual compile, it is useful to setup `ccache` - a compiler cache that can be used to speed-up rebuilds

- Add the following to your shell's startup-script (e.g. `.bashrc`) and/or run from the command line:

```
$ export USE_CCACHE=1
```

- The max-disk usage for `ccache` defaults to about 1GB, so to change it (assuming you have enough space) run the following from command line (assuming `linux-x86` as your host):
-

```
$ prebuilt/linux-x86/ccache/ccache -M 50G
```

- We can build the entire code-base with GNU's `make` command (note that this can take 20-120 mins)

```
$ make -j4
```

Note

GNU Make supports `-jN` argument, which allows us to parallelize compilation across multiple hardware threads. Typically, `N` should be set to the number of hardware threads available on the host machine plus two. For example, use `make -j10` to build on a quad-core i7 with two hardware threads per core (i.e. hyperthreaded).

**Caution**

Use `-jN` with caution, because you may run into memory, disk I/O, or max open-file limits.

6.8.1 Makefile targets

- In addition to the default `all` target, Android's Makefile (actually `build/core/main.mk`) supports additional targets
- `make sdk` - build the tools that are part of Android SDK (adb, fastboot, etc.)
- `make snod` - build the system image from the current software binaries
- `make services`
- `make runtime`
- `make droid` - make droid is the normal build
- `make all` - make everything, whether it is included in the product definition or not
- `make clean` - remove all built files (prepare for a new build). Same as `rm -rf out/<configuration>/`
- `make clobber`
- `make dataclean`
- `make installclean`
- `make modules` - shows a list of submodules that can be built (List of all `LOCAL_MODULE` definitions)
- `make <local_module>` - make a specific module (note that this is not the same as directory name. It is the `LOCAL_MODULE` * definition in the `Android.mk` file)
- `make clean-<local_module>` - clean a specific module

6.9 Examining the Built Images

- Upon successful generic (emulator) build, the `make` command will create the following images
 - `out/target/product/generic/ramdisk.img` - the temporary root file system used during the booting process to setup our mount points and support the `init` process
 - `out/target/product/generic/system.img` - this /system image with
 - * `/system/bin` - system binaries (including various daemons started by `init` via `init.rc`)
 - * `/system/xbin` - debugging/profiling binaries
-

- * /system/usr - mostly configuration/mapping files (e.g. keylayouts)
- * /system/etc - configuration files (e.g. permissions, library mappings, networking/DHCP, etc.)
- * /system/lib - system/framework native libraries (including support for user-space HAL)
- * /system/framework - system/framework Dalvik libraries (in dex bytecode format but in .jar files)
- * /system/app - built-in system apps (including content providers, input providers, etc.)
- * /system/fonts - built-in system fonts
- out/target/product/generic/userdata.img - the contents of the /data partition (empty)
- Since the emulator is based on QEMU, it uses its own built-in /boot partition with a pre-compiled kernel on it
- Upon successful full_crespo-userdebug build (i.e. device-specific), the make command will create the following images
 - out/target/product/crespo/boot.img - a custom Android "filesystem" consisting of a 2KB header, followed by a gzipped kernel, followed by a ramdisk, followed by an optional second stage loader (not typically used)
 - * This image (as well as recovery.img) is created using Android's out/host/<arch>/bin/mkbootimg command, and produces a file of the following structure:
<http://android.git.kernel.org/?p=platform/system/core.git;a=blob;f=mkbootimg/bootimg.h>

```

52 /*
53 ** +-----+
54 ** | boot header      | 1 page
55 ** +-----+
56 ** | kernel           | n pages
57 ** +-----+
58 ** | ramdisk          | m pages
59 ** +-----+
60 ** | second stage     | o pages
61 ** +-----+
62 **
63 ** n = (kernel_size + page_size - 1) / page_size
64 ** m = (ramdisk_size + page_size - 1) / page_size
65 ** o = (second_size + page_size - 1) / page_size
66 **
67 ** 0. all entities are page_size aligned in flash
68 ** 1. kernel and ramdisk are required (size != 0)
69 ** 2. second is optional (second_size == 0 -> no second)
70 ** 3. load each element (kernel, ramdisk, second) at
71 **    the specified physical address (kernel_addr, etc)
72 ** 4. prepare tags at tag_addr. kernel_args[] is
73 **    appended to the kernel commandline in the tags.
74 ** 5. r0 = 0, r1 = MACHINE_TYPE, r2 = tags_addr
75 ** 6. if second_size != 0: jump to second_addr
76 **    else: jump to kernel_addr
77 */

```

- out/target/product/crespo/ramdisk.img - see above (included in boot.img)
 - * For more info on ramdisk, see <http://android.git.kernel.org/?p=kernel/common.git;a=blob;f=Documentation/filesystems/ramfs-rootfs-initramfs.txt>
- out/target/product/crespo/system.img - similar to generic system.img, but with additional content
 - * /system/modules - custom kernel modules (i.e. mostly drivers)
 - * /system/media/audio - custom audio ringtones, notifications, etc.
- out/target/product/crespo/userdata.img - the initial contents of the /data partition
- out/target/product/crespo/recovery.img - like boot.img, it has its own boot header, kernel, and ramdisk, but it also includes a custom /sbin/recovery program used during system recovery
 - * While Android system can reboot itself into recovery mode, we can usually also boot into recovery through special key combination - usually by holding down volume up or home key on power-up

- out/target/product/crespo/ramdisk-recovery.img - see above (included in recovery.img)
- See <http://source.android.com/source/building.html> for more info on building Android

6.10 Running Custom Android Build on Emulator

- Run emulator right from the source directory (requires lunch to be run first)

```
$ source build/envsetup.sh
$ lunch ...
$ make ...
$ out/host/linux-x86/bin/emulator &
```

Note

Replace linux-x86 with darwin-x86 for Mac OS X.

- Alternatively, we can run our image in one of our Android Virtual Devices (AVD)
 - Create an AVD - unless we already have one from before
 - * We could use "Android SDK and AVD Manager" GUI to create an AVD (based on the same "target" as the image we compiled)
 - * Or, we could create an AVD from the command line (assuming we are in the source directory and SDK's android is in our PATH):

```
$ android create avd --sdcard 16M --target android-10 --name custom-avd --path custom- ↵
  avd
Android 2.3.3 is a basic Android platform.
Do you wish to create a custom hardware profile [no]
Created AVD 'custom-avd' based on Android 2.3.3,
with the following hardware config:
hw.lcd.density=240
vm.heapSize=24
hw.ramSize=256
```

- We are now ready to run it (assuming we are in the source directory and SDK's emulator is in our PATH):

```
$ emulator -avd custom-avd -system out/target/product/generic/system.img -ramdisk out/ ↵
  target/product/generic/ramdisk.img &
```

- And the result is
-



6.11 Running Custom Android Build on Real Hardware

- First we reboot our device into fastboot mode (assuming SDK's adb is in our PATH)

```
$ adb reboot bootloader
```

- We could also reboot using the special key combination on power-up, but that's often device-specific (as mentioned above)
 - * Nexus S and Nexus S 4G: Press and hold Volume Up, then press and hold Power
 - * Nexus One: Press and hold the trackball, then press Power
 - * G1 and MyTouch 3G: Press and hold Back, then press Power
- Android requires that every device support "fastboot" protocol - a mechanism for communicating with bootloaders over USB
- For more info on Fastboot, see `bootable/bootloader/legacy/fastboot_protocol.txt` (relative to the source directory)

- We may need to unlock our bootloader (which may not be permitted on many devices)

```
$ out/host/linux-x86/bin/fastboot oem unlock
```

Note

Nexus One (passion) does not allow the bootloader to be locked again with `fastboot oem lock`

- We are now ready to flash our device

```
$ out/host/linux-x86/bin/fastboot flashall -w
```



Caution

Running this command will **wipe** our device! The `-w` switch is used to also wipe the `/data` partition, which is sometimes necessary (on first-flash, or on major updates), but is otherwise not required.

Note

Nexus One (passion) does not support the `-w` switch, so instead we can `fastboot erase cache` and `fastboot erase userdata` before flashing.

- Finally, we reboot the device to run our custom build

6.12 Building the Linux Kernel

- As of 2009, Linux kernel is no longer cloned as part of the standard `repo sync`
 - The kernel's build system is separate from the one Android uses for the rest of the platform
 - Most system integrators get the pre-built kernel from their SoC provider

Note

It is easiest to build the Linux kernel on a Linux OS. While other host OSs can also be used, they are not trivial to setup.

6.13 Getting the Kernel

```
$ git clone https://android.googlesource.com/kernel/common.git
$ git clone https://android.googlesource.com/kernel/goldfish.git
$ git clone https://android.googlesource.com/kernel/msm.git
$ git clone https://android.googlesource.com/kernel/omap.git
$ git clone https://android.googlesource.com/kernel/samsung.git
$ git clone https://android.googlesource.com/kernel/tegra.git
```

6.13.1 Building Kernel for the Emulator (Goldfish)

1. Start the emulator
2. Get the existing kernel version from `/proc/version` (since `uname` does not exist on Android)

```
$ adb shell cat /proc/version
Linux version 2.6.29-g46b05b2 (vchtchetkine@vc-irv.irv.corp.google.com) (gcc version ↩
4.4.3 (GCC) ) #28 Thu Nov 17 06:39:36 PST 2011
```

3. Get the corresponding kernel version (here, we are getting the kernel for goldfish, the emulator)

```
$ git clone https://android.googlesource.com/kernel/goldfish.git
$ cd goldfish/
$ git branch -a
$ git checkout -t remotes/origin/android-goldfish-2.6.29
```

Note

Alternatively, we could directly clone the goldfish 2.6.29 branch

```
$ git clone https://android.googlesource.com/kernel/goldfish.git -b
android-goldfish-2.6.29
```

4. Specify the target architecture and cross compiler

```
$ export ARCH=arm
$ export CROSS_COMPILE=/path/to/android-src/prebuilt/linux-x86/toolchain/arm-eabi-
-4.4.3/bin/arm-eabi-
```



Caution

Android's own build system uses `ARCH` and `CROSS_COMPILE` env vars, so these need to be cleared before building AOSP.

As an alternative, these can be also passed directly to the make commands: `$ make ... ARCH=... CROSS_COMPILE=...`

5. Get the existing kernel configuration file (with all of the Android/emulator specific options) by pulling it from the running emulator:

```
$ adb pull /proc/config.gz .
$ gunzip config.gz
$ mv config .config
```

Note

As an alternative, we could generate the Goldfish `.config` file (even without the emulator) by running:

```
$ make goldfish_armv7_defconfig ARCH=arm
```

6. You can optionally take a look at the existing configuration options and make changes as desired

```
$ make menuconfig ARCH=arm
```

- For example, you could set your *General setup* → *Local version - append to kernel release* to something like `-marakana-exa`

7. Now we are ready to compile

```
$ make
```

8. The resulting kernel will be compressed to `arch/arm/boot/zImage`

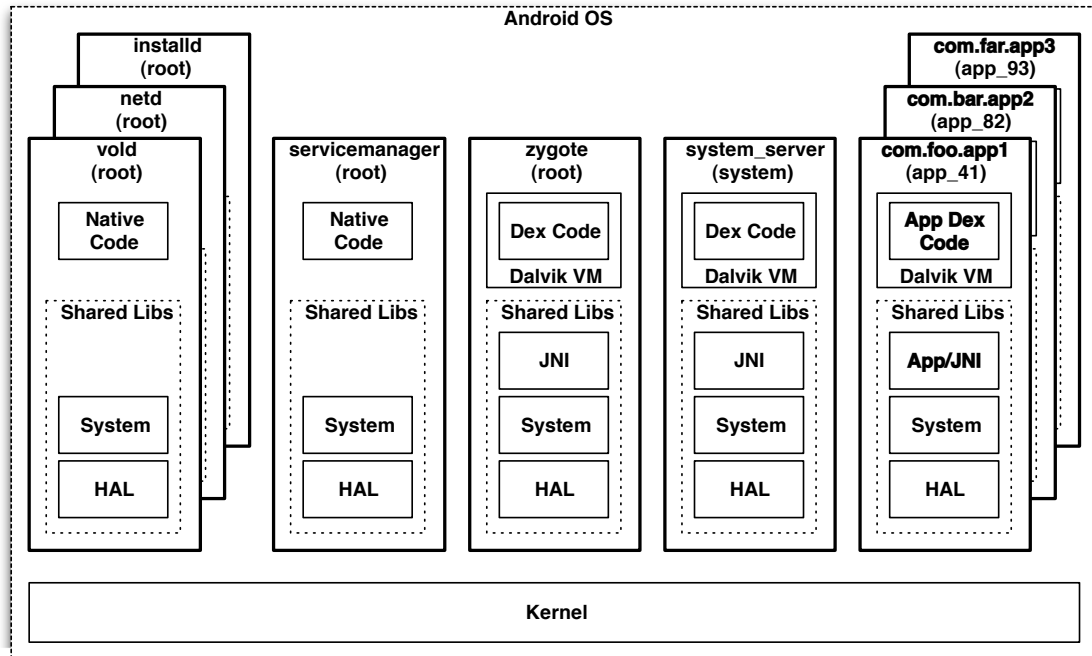
9. Run the emulator with our new kernel

```
$ out/host/linux-x86/bin/emulator -kernel /path/to/common/arch/arm/boot/zImage
```

10. And the result is



7 Android Startup



7.1 Bootloading the Kernel

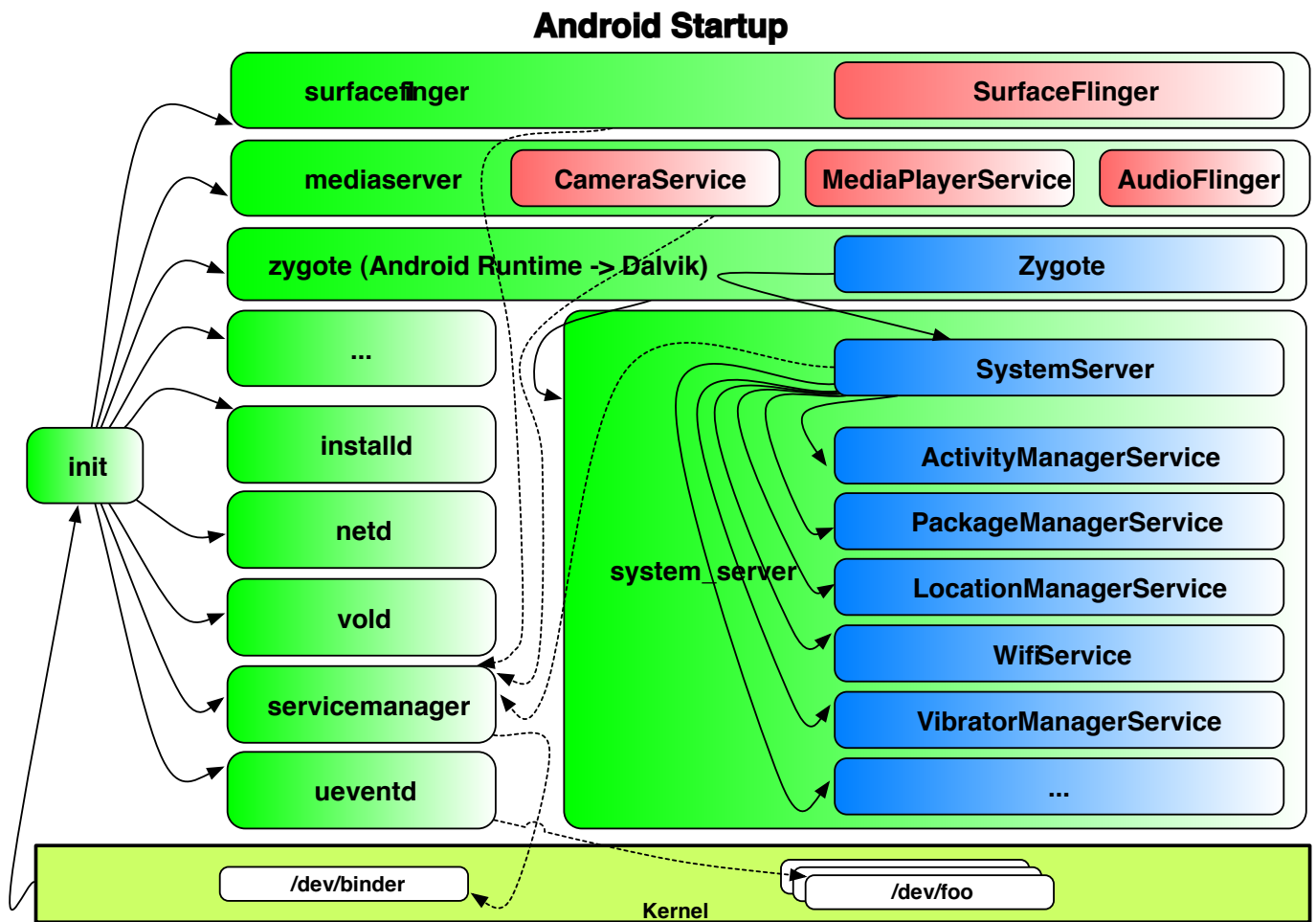
1. On power-up, CPU is uninitialized - wait for stable power
2. Execute Boot ROM (hardwired into CPU)
 - a. Locate the first-stage boot loader
 - b. Load the first-stage boot loader into internal RAM
 - c. Jump to first-stage boot loader's memory location to execute it
3. First-stage boot loader runs
 - a. Detect and initialize external RAM
 - b. Locate the second-stage boot loader
 - c. Load the second-stage boot loader into external RAM
 - d. Jump to the second-stage boot loader's memory location to execute it
4. Second-stage boot loader runs
 - a. Setup file systems (typically on Flash media)
 - b. Optionally setup display, network, additional memory, and other devices
 - c. Enable additional CPU features
 - d. Enable low-level memory protection
 - e. Optionally load security protections (e.g. ROM validation code)
 - f. Locate Linux Kernel

- g. Load Linux Kernel into RAM
- h. Place Linux Kernel boot parameters into memory so that kernel knows what to run upon startup
- i. Jump to Linux Kernel memory address to run it

5. Linux Kernel runs

- a. Build a table in RAM describing the layout of the physical memory
 - b. Initialize and setup input devices
 - c. Initialize and setup disk (typically MTD) controllers and map available block devices in RAM
 - d. Initialize Advanced Power Management (APM) support
 - e. Initialize interrupt handlers: Interrupt Descriptor Table (IDT), Global Descriptor Table (GDT), and Programmable Interrupt Controllers (PIC)
 - f. Reset the floating-point unit (FPU)
 - g. Switch from real to protected mode (i.e. enable memory protection)
 - h. Initialize segmentation registers and a provisional stack
 - i. Zero uninitialized memory
 - j. Decompress the kernel image
 - k. Initialize provisional kernel page tables and enable paging
 - l. Setup kernel mode stack for process 0
 - m. Fill the IDT with null interrupt handlers
 - n. Initialize the first page frame with system parameters
 - o. Identify the CPU model
 - p. Initialize registers with the addresses of the GDT and IDT
 - q. Initialize and start the kernel
 - i. Scheduler
 - ii. Memory zones
 - iii. Buddy system allocator
 - iv. IDT
 - v. SoftIRQs
 - vi. Date and Time
 - vii. Slab allocator
 - viii. ...
 - r. Create process 1 (`/init`) and run it
-

7.2 Android's init Startup



- The granddaddy of all other processes on the system (PID=1)
- Custom initialization script (with its own language)
 - Different than more traditional `/etc/inittab` and SysV-init-levels initialization options
- When started by the kernel, `init` parses and executes commands from two files:
 - `/init.rc` - provides generic initialization instructions (see `system/core/rootdir/init.rc`)
 - `/init.<board-name>.rc` - provides machine-specific initialization instructions - sometimes overriding `/init.rc`
 - * `/init.goldfish.rc` for the emulator
 - * `/init.trout.rc` for HTC's ADPI
 - * `/init.herring.rc` for Samsung's Nexus S (see `device/samsung/crespo/init.herring.rc`)
- The `init` program never exists (if it were, the kernel would panic), so it continues to monitor started services
- The `init`'s language consists of four broad classes of statements (see `system/core/init/readme.txt`)
 - Actions - named sequences of commands queued to be executed on a unique trigger

```
on <trigger>
  <command>
  <command>
  <command>
```

– Triggers - named events that trigger actions

- * early-init, init, early-fs, fs, post-fs, early-boot, boot - built-in stages of init
- * <name>=<value> - fires when a system property is set to <name>=<value>
- * device-added-<path> - fires when a device node at <path> is added
- * device-removed-<path> - fires when a device node at <path> is removed
- * service-exited-<name> - fires when a service by <name> exists

– Commands - a command to be queued and run

- * chdir <directory> - change working directory
- * chmod <octal-mode> <path> - change file access permissions
- * chown <owner> <group> <path> - change file user and group ownership
- * chroot <directory> - change process root directory
- * class_start <serviceclass> - start all non-running services of the specified class
- * class_stop <serviceclass> - stop all running services of the specified class
- * domainname <name> - set the domain name.
- * exec <path> [<argument>]* - fork and execute <path> <argument> ... (blocks init until exec returns)
- * export <name> <value> - set globally visible environment variable <name> =<value>
- * hostname <name> - set the host name
- * ifup <interface> - bring the network interface <interface> online
- * import <filename> - parse and process <filename> init configuration file (extends the current script)
- * insmod <path> - install the kernel module at <path>
- * loglevel <level> - initialize the logger to <level>
- * mkdir <path> [mode] [owner] [group] - create a directory at <path> and optionally change its default permissions (755) and user (root) / group (root) ownership
- * mount <type> <device> <dir> [<mountoption>]* - attempt to mount named <device> at <dir> with the optional `<mountoption>`s
- * setprop <name> <value> - set system property <name>=<value>
- * setrlimit <resource> <cur> <max> - set the rlimit for a <resource>
- * start <service> - start named <service> if it is not already running
- * stop <service> - stop name <service> if it is currently running
- * symlink <target> <path> - symbolically link <path> to <target>
- * sysclktz <mins_west_of_gmt> - set the system clock base (0 for GMT)
- * trigger <event> - trigger an event - i.e. call one action from another
- * write <path> <string> [<string>]* - write arbitrary <string>`s to file by specified `<path>

– Services - persistent daemon programs to be launched (optionally) restarted if they exit

```
service <name> <pathname> [ <argument> ]*
    <option>
    <option>
    ...
```

– Options - modifiers to services, modifying how/when they are run re/launched

- * critical - a device-critical service - devices goes into recovery if the service exits more than 4 times in 4 minutes
- * disabled - not started by default - i.e. it has to be started explicitly by name
- * setenv <name> <value> - set the environment variable <name>=<value> in the service
- * socket <name> <dgram|stream|seqpacket> <perm> [<user> [<group>]] - create a unix domain socket named /dev/socket/<name> and pass its fd to the service
- * user <username> - change service's effective user ID to <username>
- * group <groupname> [<groupname>]* - change service's effective group ID to <groupname> (additional groups are supplemented via setgroups())

- * oneshot - ignore service exist (default is to auto-restart)
- * class <name> - set the class name of the service (defaults to default) so that all services of a particular class can be started/stopped together
- * onrestart - execute a command on restart

- The default `init.rc` script

1. Starts `ueventd`
2. Initializes the system clock and logger
3. Sets up global environment
4. Sets up the file system (mount points and symbolic links)
5. Configures kernel timeouts and scheduler
6. Configures process groups
7. Mounts the file systems
8. Creates a basic directory structure on `/data` and applies permissions
9. Applies permissions on `/cache`
10. Applies permissions on certain `/proc` points
11. Initializes local network (i.e. `localhost`)
12. Configures the parameters for the low memory killer [Section 2.1.8](#)
13. Applies permissions for `systemserver` and daemons
14. Defines TCP buffer sizes for various networks
15. Configures and (optionally) loads various daemons (i.e. services): `ueventd`, `console`, `adbd`, `servicemanager`, `vold`, `netd`, `debuggerd`, `rild`, `zygote` (which in turn starts `system_server`), `mediaserver`, `bootanimation` (one time), and various Bluetooth daemons (like `dbus-daemon`, `bluetoothd`, etc.), `installd`, `racoond`, `mtpd`, `keystore`

- Nexus S' `init.herring.rc` additionally

1. Sets up product info
2. Initializes device-driver-specific info, file system structures, and permissions: `battery`, `wifi`, `phone`, `uart_switch`, `GPS`, `radio`, `bluetooth`, `NFC`, `lights`
3. Initializes and (re)mounts file systems
4. Loads additional device-specific daemons

7.3 Zygote Startup

1. Zygote starts from `/init.rc`

```
service zygote /system/bin/app_process -Xzygote /system/bin --zygote --start-system- ↵
server
socket zygote stream 666
onrestart write /sys/android_power/request_state wake
onrestart write /sys/power/state on
onrestart restart media
onrestart restart netd
```

2. This translates to `frameworks/base/cmds/app_process/app_main.cpp:main()`
3. The command `app_process` then launches `frameworks/base/core/java/com/android/internal/os/Zygote` in a Dalvik VM via `frameworks/base/core/jni/AndroidRuntime.cpp:start()`
4. `ZygoteInit.main()` then

- a. Registers for zygote socket
- b. Pre-loads classes defined in `frameworks/base/preloaded-classes` (1800+)
- c. Pre-loads resources `preloaded_drawables` and `preloaded_color_state_lists` from `frameworks/base/`
- d. Runs garbage collector (to clean the memory as much as possible)
- e. Forks itself to start `systemserver`
- f. Starts listening for requests to fork itself for other apps

7.4 System Server Startup

1. When Zygote forks itself to launch the `systemserver` process (in `ZygoteInit.java:startSystemServer()`), it executes `frameworks/base/services/java/com/android/server/SystemServer.java:main()`
2. The `SystemServer.java:main()` method loads `android_servers` JNI lib from `frameworks/base/services/jni/` and invokes `init1()` native method
3. Before `init1()` runs, the JNI loader first runs `frameworks/base/services/jni/onload.cpp:JNI_OnLoad()`, which registers native services - to be used as JNI counterparts to Java-based service manager loaded later
4. Now `frameworks/base/services/jni/com_android_server_SystemServer.cpp:init1()` is invoked, which simply wraps a call to `frameworks/base/cmds/system_server/library/system_init.cpp:system_init()`
5. The `system_init.cpp:system_init()` function
 - a. First starts native services (some optionally):
 - i. `frameworks/base/services/surfaceflinger/SurfaceFlinger.cpp`
 - ii. `frameworks/base/services/sensor/service/SensorService.cpp`
 - iii. `frameworks/base/services/audioflinger/AudioFlinger.cpp`
 - iv. `frameworks/base/media/libmediaplayerservice/MediaPlayerService.cpp`
 - v. `frameworks/base/camera/libcameraservice/CameraService.cpp`
 - vi. `frameworks/base/services/audioflinger/AudioPolicyService.cpp`
 - b. Then goes back to `frameworks/base/services/java/com/android/server/SystemServer.java:init1()` again via `frameworks/base/core/jni/AndroidRuntime.cpp:start()` JNI call
6. The `SystemServer.java:init2()` method then starts Java service managers in a separate thread (`ServerThread`), readies them, and registers each one with `frameworks/base/core/java/android/os/ServiceManager:addService()` (which in turn delegates to `ServiceManagerNative.java`, which effectively talks to `servicemanager` daemon previously started by `init`)
 - a. `frameworks/base/services/java/com/android/server/PowerManagerService.java`
 - b. `frameworks/base/services/java/com/android/server/am/ActivityManagerService.java`
 - c. `frameworks/base/services/java/com/android/server/TelephonyRegistry.java`
 - d. `frameworks/base/services/java/com/android/server/PackageManagerService.java`
 - e. `frameworks/base/services/java/com/android/server/BatteryService.java`
 - f. `frameworks/base/services/java/com/android/server/VibratorService.java`
 - g. etc
7. Finally `frameworks/base/services/java/com/android/server/am/ActivityManagerService.java:finishBoot()` sets `sys.boot_completed=1` and sends out
 - a. a broadcast intent with `android.intent.action.PRE_BOOT_COMPLETED` action (to give apps a chance to reach to boot upgrades)
 - b. an activity intent with `android.intent.category.HOME` category to launch the *Home* (or *Launcher*) application
 - c. a broadcast intent with `android.intent.action.BOOT_COMPLETED` action, which launches applications subscribed to this intent (while using `android.permission.RECEIVE_BOOT_COMPLETED`)

8 Android Services

The objective of this module is to explain the inter-workings of various Android services. There are close to sixty various services in ICS release. In this module, we've hand-picked some of the more common ones. By the end of the module, you should start to understand some common traits of Android service architecture, such as use of the Binder for inter-process communication, and use of JNI for Java-C interaction.

Android services are the key to exposing lower level functionality of the hardware and the Linux kernel to the high level Android apps. Understanding how they work creates the opportunity to customize and extend their behavior, or add another service altogether.

```
$ adb shell service list
Found 56 services:
0  phone: [com.android.internal.telephony.ITelephony]
1  iphonesubinfo: [com.android.internal.telephony.IPhoneSubInfo]
2  simphonebook: [com.android.internal.telephony.IIccPhoneBook]
3  isms: [com.android.internal.telephony.ISms]
4  samplingprofiler: []
5  diskstats: []
6  appwidget: [com.android.internal.appwidget.IAppWidgetService]
7  backup: [android.app.backup.IBackupManager]
8  uimode: [android.app.IUiModeManager]
9  usb: [android.hardware.usb.IUsbManager]
10 audio: [android.media.IAudioService]
11 wallpaper: [android.app.IWallpaperManager]
12 dropbox: [com.android.internal.os.IDropBoxManagerService]
13 search: [android.app.ISearchManager]
14 country_detector: [android.location.ICountryDetector]
15 location: [android.location.ILocationManager]
16 devicestoragemonitor: []
17 notification: [android.app.INotificationManager]
18 mount: [IMountService]
19 throttle: [android.net.IThrottleManager]
20 connectivity: [android.net.IConnectivityManager]
21 wifi: [android.net.wifi.IWifiManager]
22 wifip2p: [android.net.wifi.p2p.IWifiP2pManager]
23 netpolicy: [android.net.INetworkPolicyManager]
24 netstats: [android.net.INetworkStatsService]
25 textservices: [com.android.internal.textservice.ITextServicesManager]
26 network_management: [android.os.INetworkManagementService]
27 clipboard: [android.content.IClipboard]
28 statusbar: [com.android.internal.statusbar.IStatusBarService]
29 device_policy: [android.app.admin.IDevicePolicyManager]
30 accessibility: [android.view.accessibility.IAccessibilityManager]
31 input_method: [com.android.internal.view.IInputMethodManager]
32 window: [android.view.IWindowManager]
33 alarm: [android.app.IAlarmManager]
34 vibrator: [android.os.IVibratorService]
35 battery: []
36 hardware: [android.os.IHardwareService]
37 content: [android.content.IContentService]
38 account: [android.accounts.IAccountManager]
39 permission: [android.os.IPermissionController]
40 cpuinfo: []
41 gfxinfo: []
42 meminfo: []
43 activity: [android.app.IActivityManager]
44 package: [android.content.pm.IPackageManager]
45 telephony.registry: [com.android.internal.telephony.ITelephonyRegistry]
46 usagestats: [com.android.internal.app.IUsageStats]
47 batteryinfo: [com.android.internal.app.IBatteryStats]
48 power: [android.os.IPowerManager]
```



```

49 entropy: []
50 sensorService: [android.gui.SensorServer]
51 media.audio_policy: [android.media.IAudioPolicyService]
52 media.camera: [android.hardware.IAudioPolicyServiceService]
53 media.player: [android.media.IMediaPlayerService]
54 media.audio_flinger: [android.media.IAudioFlinger]
55 SurfaceFlinger: [android.ui.ISurfaceComposer]

```

8.1 Vibrator

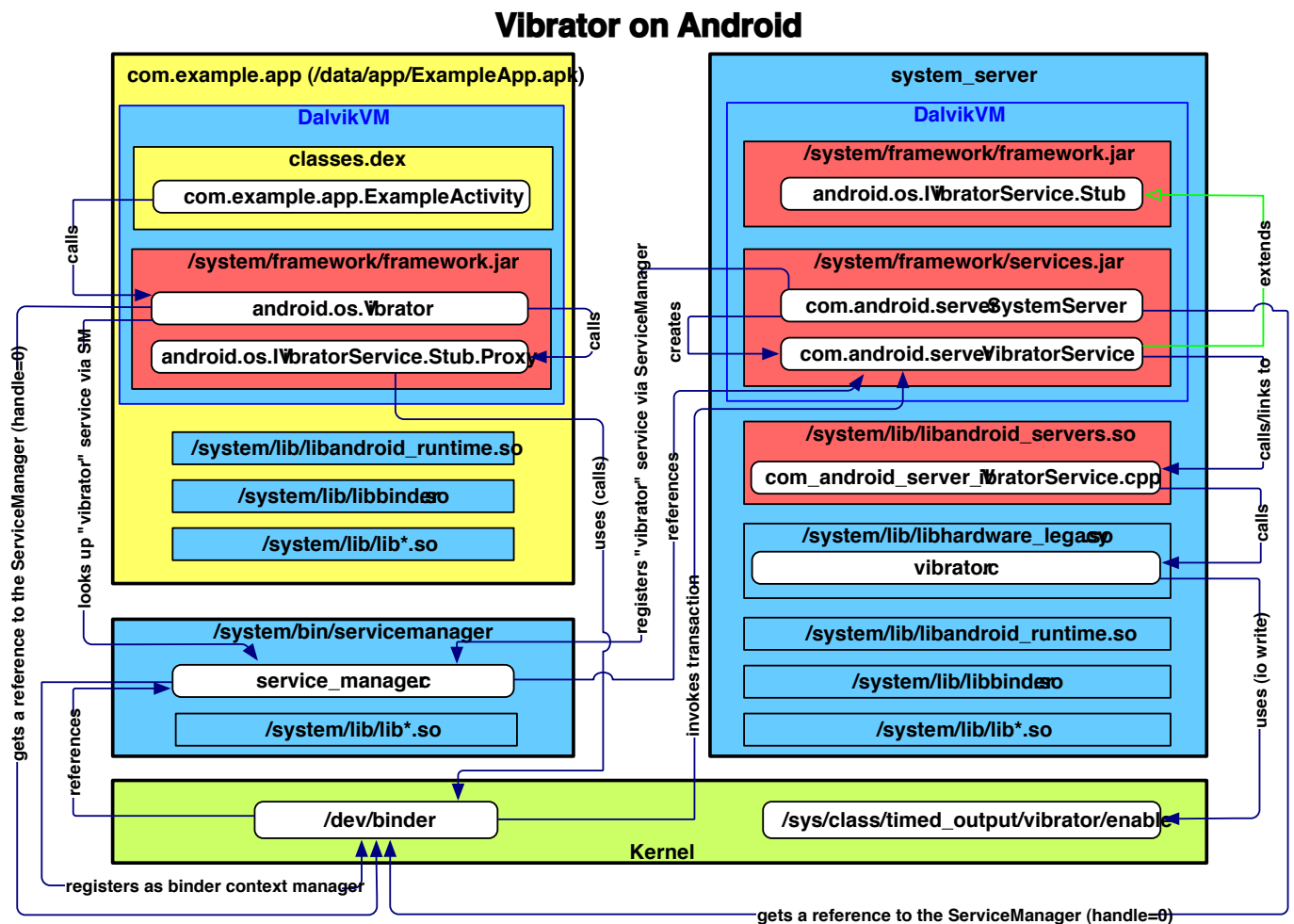


Figure 5: Vibrator Service Architecture

- /system/framework/framework.jar** is built by `frameworks/base/Android.mk`
 - `android.os.Vibrator` is defined by `frameworks/base/core/java/android/os/Vibrator.java`
 - `android.os.IVibratorService` is defined by `frameworks/base/core/java/android/os/IVibratorService.java`
- /system/bin/servicemanager** is built by `frameworks/base/cmds/servicemanager.Android.mk` and started from `system/core/rootdir/init.rc`
 - `service_manager.c` comes from `frameworks/base/cmds/servicemanager/service_manager.c`
- system_server** is forked from `zygote` via `frameworks/base/core/java/com/android/internal/os/ZygoteInit.java` which in turn calls `libcore/dalvik/src/main/java/dalvik/system/Zygote.java:forkSystemServer(...)`

- **zygote is a daemon started by** frameworks/base/cmds/app_process/app_main.cpp **from** system/core/rootdir/init
- /system/framework/services.jar **is built by** frameworks/base/services/java/Android.mk
 - com.android.server.SystemServer **is defined by** frameworks/base/services/java/com/android/server/SystemServer.java
 - com.android.server.VibratorService **is defined by** frameworks/base/services/java/com/android/server/VibratorService.java
- /system/lib/libandroid_servers.so **is built by** frameworks/base/services/jni/Android.mk
 - com_android_server_VibratorService.cpp **comes from** frameworks/base/services/jni/com_android_server_VibratorService.cpp
- /system/lib/libhardware_legacy.so **is built by** hardware/libhardware_legacy/Android.mk
 - vibrator.c **comes from** hardware/libhardware_legacy/vibrator/vibrator.c

8.2 Power Service

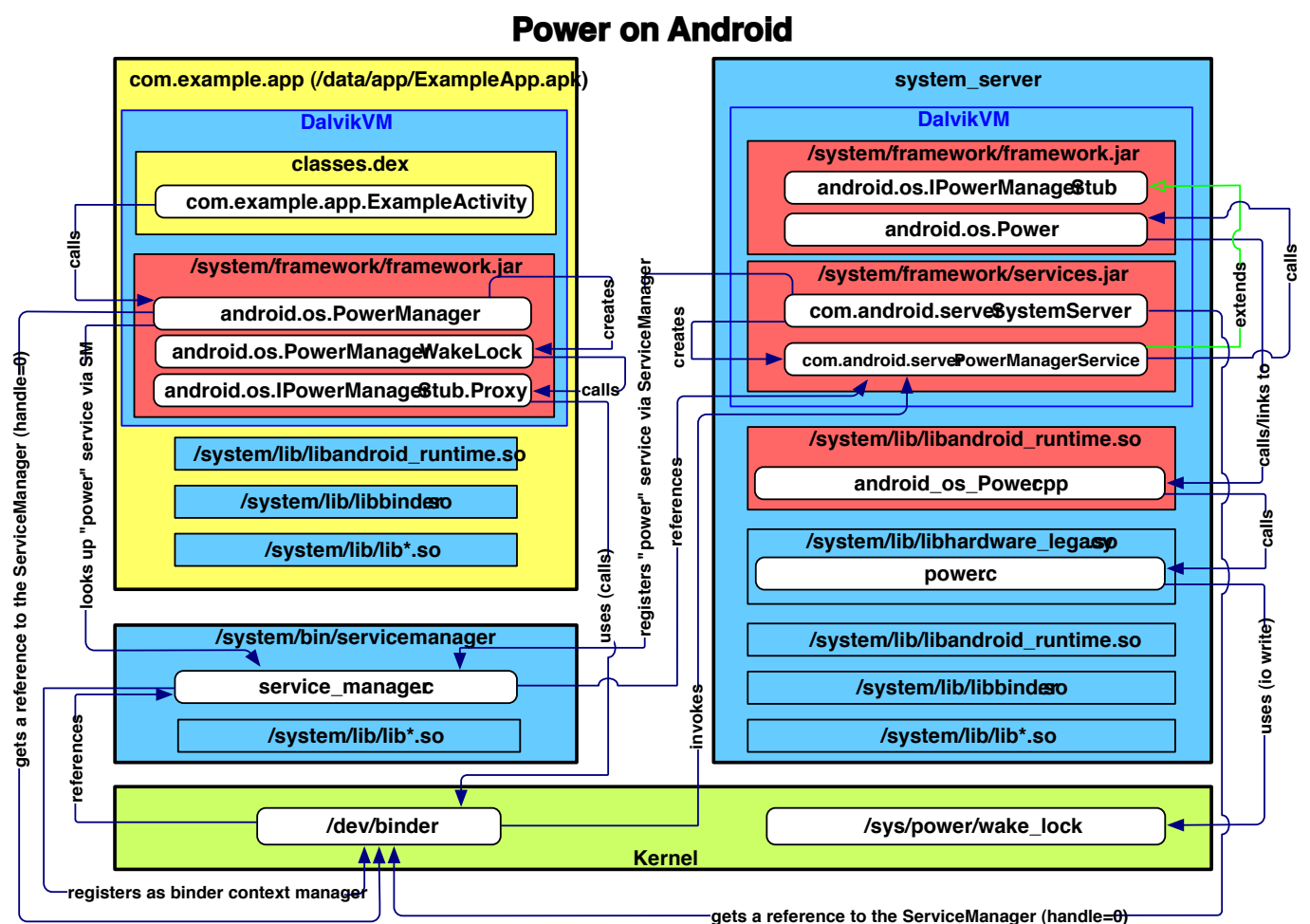


Figure 6: Power Service Architecture

8.2.1 Links

- <https://gitorious.org/android/powertop>

8.3 Alarm Service

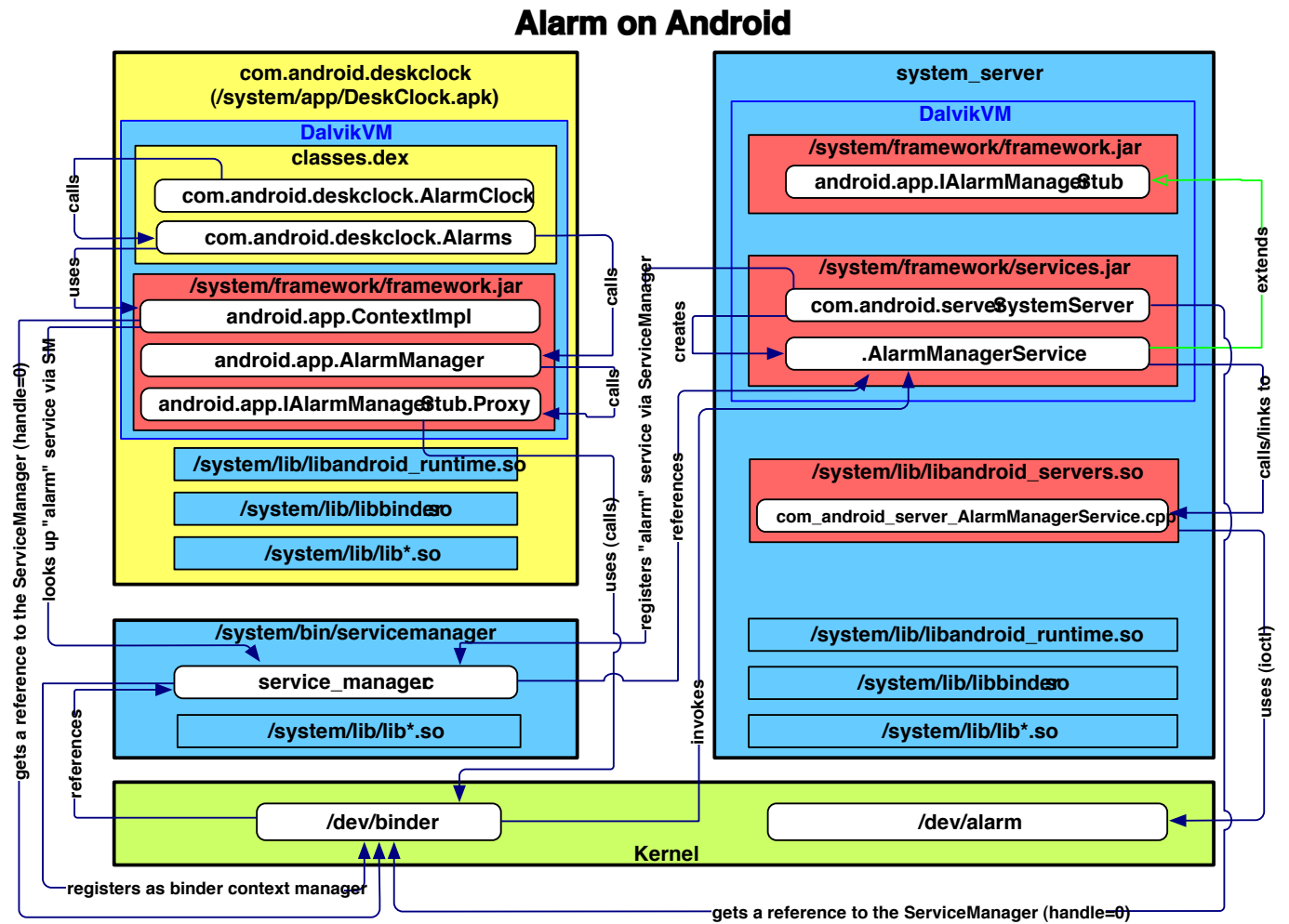


Figure 7: Alarm Service Architecture

8.4 Package Service

Package Manager on Android

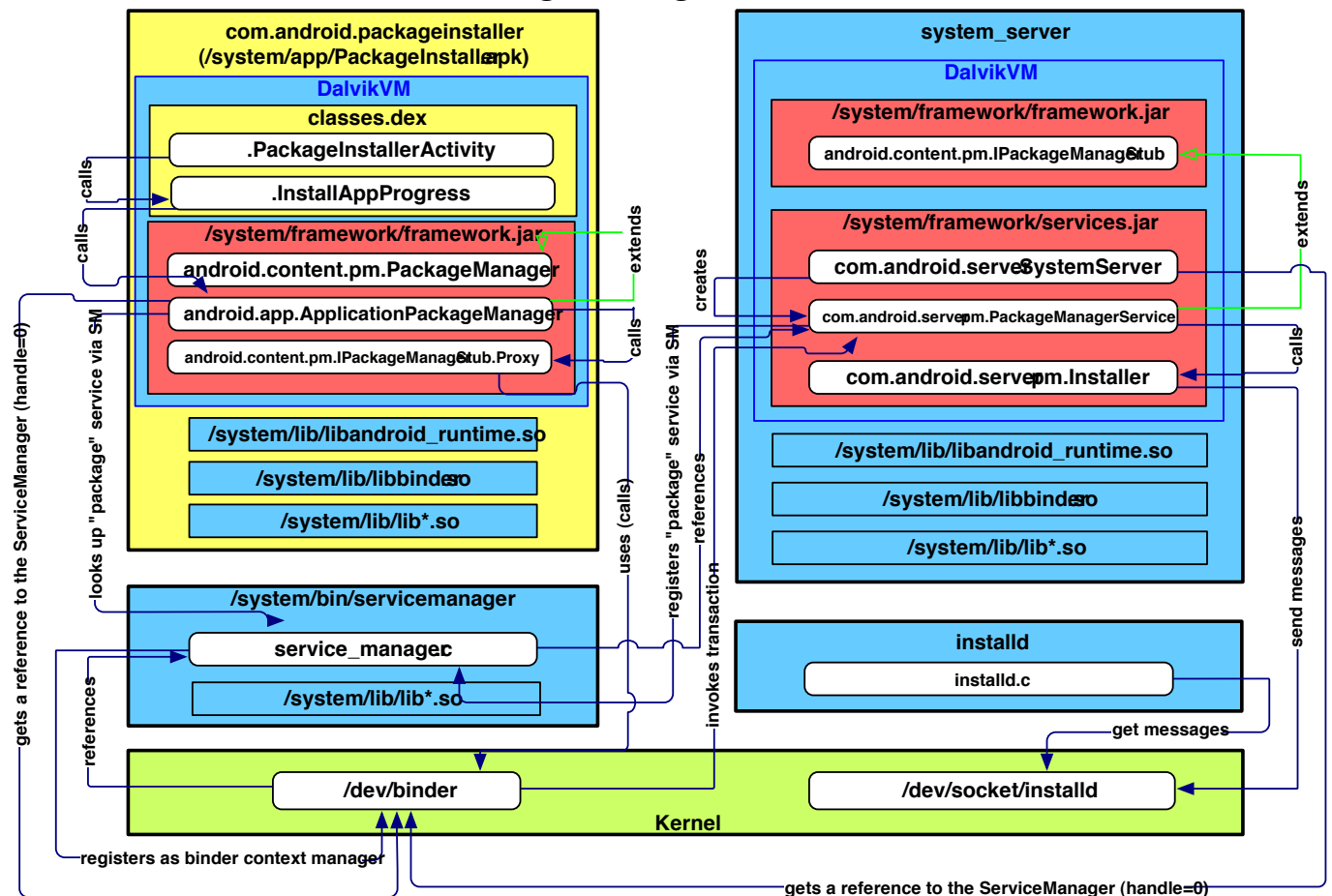


Figure 8: Package Service Architecture

8.5 WiFi Service

Wifi Service exposes wifi functionality of the underlying system to the application layer via `WifiManager` class. The key differentiation between wifi stack and some other ones is that the wifi stack primarily uses the `wpa_supplicant` to manage the Wifi driver.

WiFi Management on Android

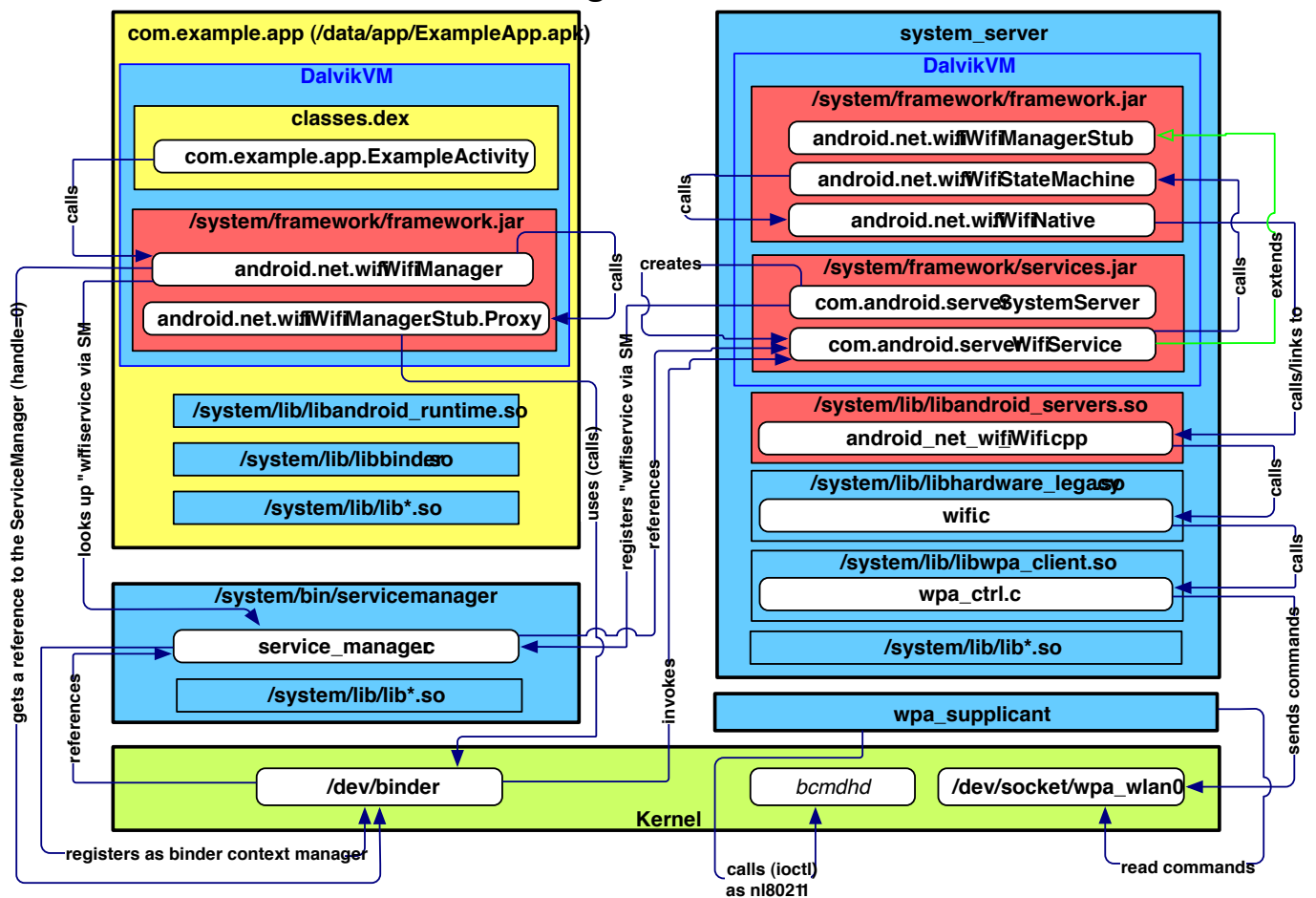


Figure 9: Wifi Service Architecture

8.5.1 Links

- <http://developer.android.com/reference/android/net/wifi/package-summary.html>
- <http://linuxwireless.org/>
- <http://www.youtube.com/playlist?p=PLA12950D8456F1818>
- http://www.au-kbc.org/comm/Docs/papers/Vipin_Analysis_of_open_source_WLAN_driver_paper.pdf
- http://en.wikipedia.org/wiki/Wpa_supplicant

8.6 Location Service

Location on Android

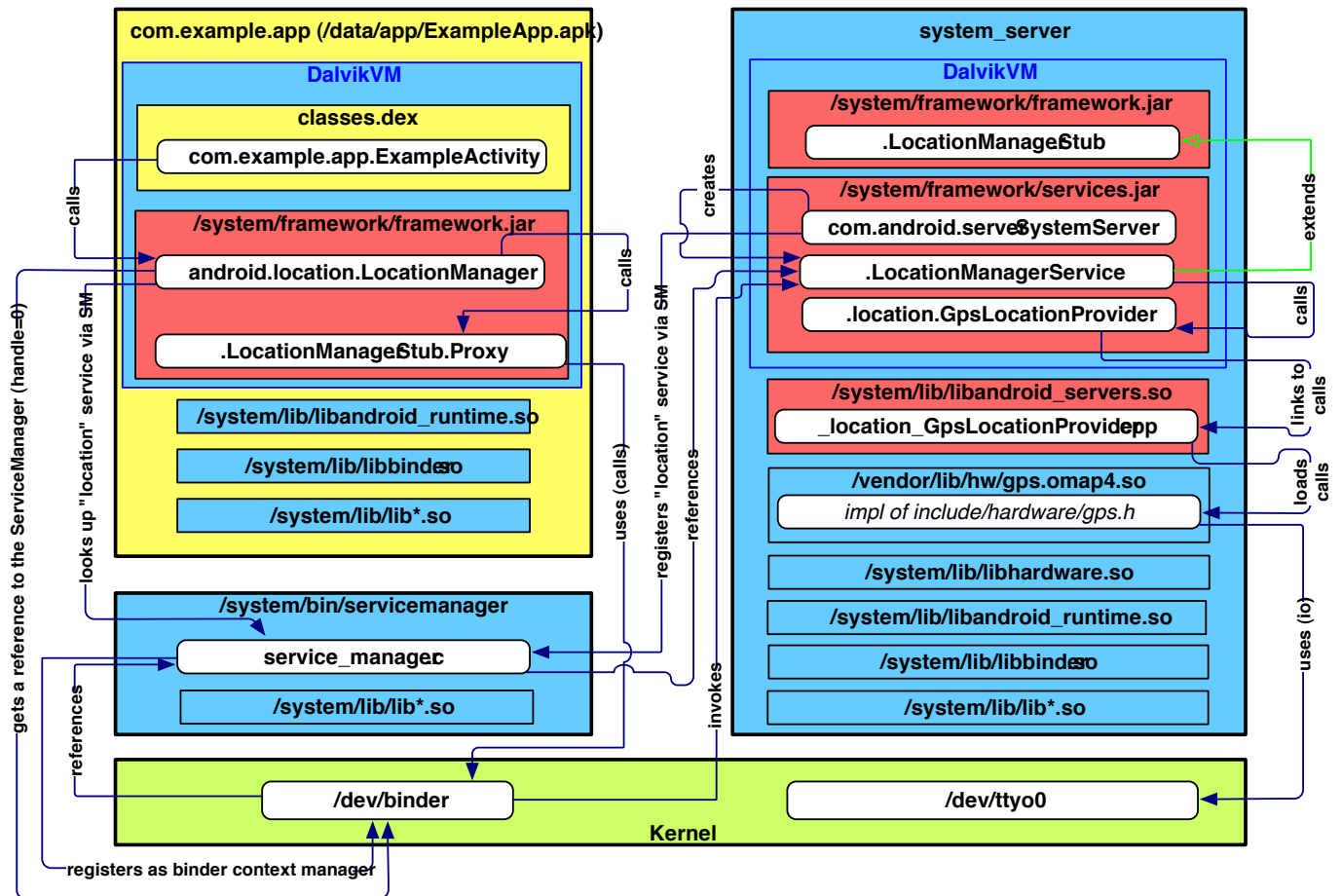


Figure 10: Location Service Architecture

8.7 Audio Service

Audio Playback on Android

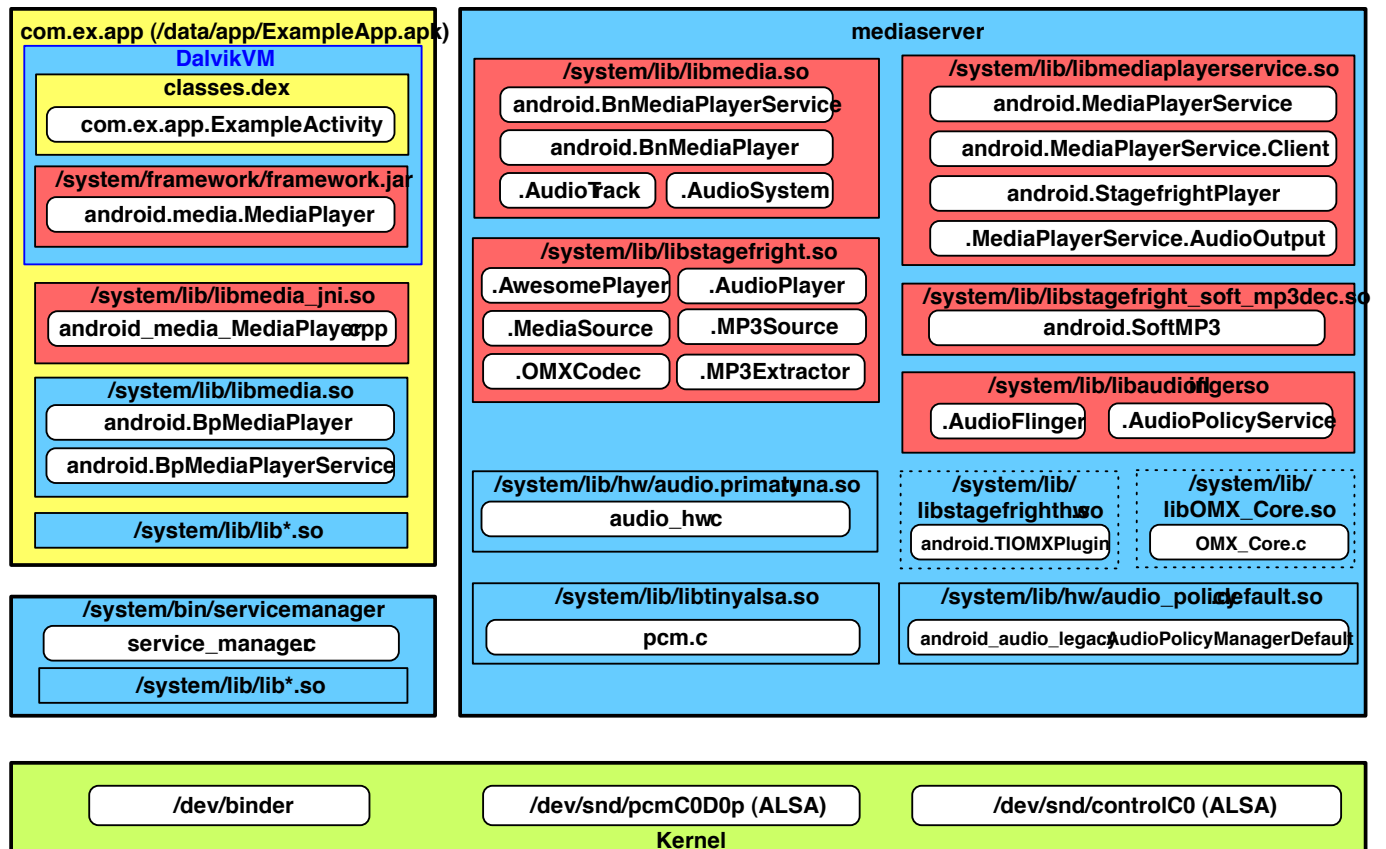
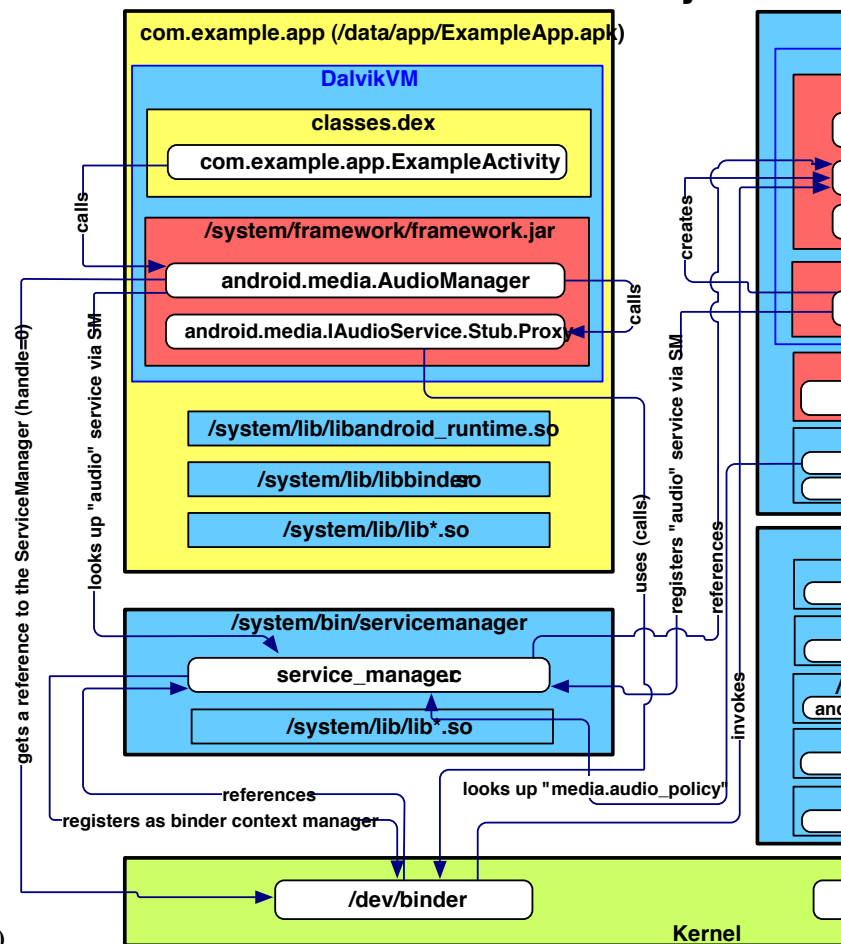


Figure 11: Audio Architecture (playing audio)

Audio Policy on Android



Audio Manager-Service Architecture (setting volume)

- AudioFlinger - Android native audio system
- Hosted in /system/bin/mediaserver daemon (started from /init)
 - Written from scratch for Android
 - Similar to PulseAudio,
 - * A Linux standard sound system (POSIX-compliant)
 - * Licensed under LGPL
- AudioFlinger provides:
 - APIs for PCM media playback and recording
 - * Applications generally play/record audio via higher-level APIs
 - * Even OpenSL ES goes to AudioFlinger
 - Control mechanism for implementing audio policy
 - Effects
- Playing audio usually involves
 - a. Parsing and decoding of audio data by Section 8.8 (Stagefright) via the mediaplayer service
 - b. Writing decoded (PCM) data to an AudioTrack (AudioSink)
 - c. Mixing AudioTracks in AudioFlinger's mixer thread (AudioFlinger::MixerThread::threadLoop())
 - d. Applying effects

- e. Buffering stream data
 - f. Writing buffers to a PCM output device (e.g. ALSA driver) via `android_audio_legacy.AudioHardware` (audio legacy HAL) or "audio" hardware module HAL
- For example, on Galaxy Nexus:
 - a. `/system/lib/audioflinger.so`
 - b. `/system/lib/libhardware.so`
 - c. `/system/lib/hw/audio.primary.tuna.so`
 - d. `/system/lib/libtinyalsa.so`
 - e. `/dev/snd/pcmC0D0p`

8.7.1 Links

- http://www.alsa-project.org/main/index.php/Main_Page (ALSA Project)
 - <http://www.alsa-project.org/~tiwai/writing-an-alsa-driver/> (ALSA Driver Documentation)
 - <http://www.alsa-project.org/~tiwai/writing-an-alsa-driver.pdf> (ALSA Driver Documentation, PDF)
 - <http://www.alsa-project.org/~tiwai/alsa-driver-api/> (ALSA Driver API Reference)
 - <http://www.alsa-project.org/~tiwai/alsa-driver-api.pdf> (ALSA Driver API Reference, PDF)
 - <http://www.alsa-project.org/main/index.php/Matrix:Vendor-Intel> (Intel ICH southbridge AC97 audio support)
- <https://github.com/tinyalsa> (Tiny library to interface with ALSA in the Linux kernel)
- <http://www.alsa-project.org/main/index.php/SALSA-Library> (Small ALSA Library)
- <http://www.kandroid.org/online-pdk/guide/audio.html> (Outdated architecture of the audio stack in Android)
- <http://code.google.com/p/andraudio/wiki/GingerbreadMP3Diagrams> (Gingerbread-specific sequence diagrams)
- <http://www.pulseaudio.org/> (PulseAudio, an alternative to AudioFlinger)
 - <http://arunraghavan.net/2012/01/pulseaudio-vs-audioflinger-fight/> (PulseAudio vs. AudioFlinger comparison)
- <http://code.google.com/p/android/issues/detail?id=3434> (AudioFlinger latency issues)

8.8 Android Media Framework

8.8.1 Introduction

The media framework are the APIs and libraries used for controlling playback and recording of video/audio. Since everything involving video and audio require a lot of computing power, mobile devices usually use a lot of special-purpose hardware for this, compared to desktop computers where there normally is enough raw power to run most/everything in software. Full-software solutions normally are more flexible and portable, but obviously require more processor power (which also might give a higher power consumption).

Normally only the highest level APIs are public, to allow for flexibility in the implementation internally.

8.8.2 Typical stack of function calls

1. **java:** `android.media.MediaPlayer`
`frameworks/base/media/java/android/media/MediaPlayer.java`
2. **JNI:** `frameworks/base/media/jni/android_media_MediaPlayer.cpp`
 Quite straight mapping of java native functions to the C++ `MediaPlayer` class
3. **C++:** `MediaPlayer`
`frameworks/base/media/libmedia/mediaplayer.cpp`
4. `IMediaPlayer, IMediaPlayerService`
`frameworks/base/include/media/IMediaPlayer.h`
`frameworks/base/include/media/IMediaPlayerService.h`
5. **BpMediaPlayer: Binder client/proxy interface**
`frameworks/base/media/libmedia/IMediaPlayer.cpp`
6. **BnMediaPlayer: Binder implementation interface (running in the media server)**
7. **BnMediaPlayer implemented by `MediaPlayerService::Client`**
`frameworks/base/libmediaplayervice/MediaPlayerService.cpp`
8. **MediaPlayerService backed by different implementations:**
 - **PVPlayer (old OpenCORE based player, phased out in gingerbread, removed later)**
 - **StagefrightPlayer**
`frameworks/base/media/libmediaplayerservice/StagefrightPlayer.cpp`
 - **AwesomePlayer**
`frameworks/base/media/libstagefright/AwesomePlayer.cpp`
 - **OMXCodec**
`frameworks/base/media/libstagefright/OMXCodec.cpp`
Pull based stagefright element, wrapping IOMX
 - **AudioPlayer**
`frameworks/base/media/libstagefright/AudioPlayer.cpp`
 - **NuPlayer (new in ICS/Honeycomb only for HTTP Live Streaming)**
`frameworks/base/media/libmediaplayerservice/nuplayer/NuPlayerDriver.cpp`
 - **ACodec**
`frameworks/base/media/libstagefright/ACodec.cpp` **message passing based frontend on top of IOMX**
9. **MediaPlayerService::AudioOutput**
`frameworks/base/libmediaplayervice/MediaPlayerService.cpp`
10. **AudioTrack**
`frameworks/base/media/libmedia/AudioTrack.cpp`
11. **IAudioTrack**
 - **BpAudioTrack, BnAudioTrack**
12. **AudioFlinger::TrackHandle**
`frameworks/base/services/audioflinger/AudioFlinger.cpp`

The actual decoding/encoding in the `OMXCodec` and `ACodec` class is implemented via the IOMX interface:

- **IOMX**
 - **BpOMX, BnOMX**
 - **OMX** `frameworks/base/media/libstagefright/omx/OMX.cpp`

- OMXMaster frameworks/base/media/libstagefright/omx/OMXMaster.cpp
- OMXNodeInstance frameworks/base/media/libstagefright/omx/OMXNodeInstance.cpp
- Normal OpenMAX IL

The applications may also use OpenSL ES for playing back audio this internally uses OMXCodec from stagefright for decoding of the audio. (Code for this is in system/media/opensles/libopensles/android SfPlayer.cpp in gingerbread, in system/media/wilhelm/src/android/android AudioSfDecoder.cpp in ICS.) In ICS, there's also an OpenMAX AL API that can play back video, using the IMediaPlayerService interface.

8.8.3 The media server process

- restricting direct access to hardware devices to this single process normal processes cannot access the hardware directly.
 - a number of different entry points at both high and low API levels – BnMediaPlayer, BnOMX, BnAudioTrack
 - encapsulating most of the media handling – calling process only provides the input url/file descriptor, the surface to render into and calls start/stop

Most of the APIs above in section 2 can either run in the calling application processes, or in the media server. Each of the Binder APIs (IAPI/BpAPI/BnAPI, such as IOMX, BpOMX, BnOMX) can proxy calls into the media server. The caller only gets an instance of the generic interface, e.g. IMediaPlayer and does not know whether this is a proxy for calling the same interface in another process (BpOMX) or the actual implementation running within the same process (BnOMX).

Thanks to this, the whole concept of some parts of the API running within a separate process is mostly transparent when working with the APIs.

8.8.4 Stagefright

Intro

Stagefright is the library containing most of the implementation of the media framework.

Stagefright is a relatively recent development within android, replacing OpenCORE. It first appeared in Eclair, was made default player for all video (except for RTSP streaming which was still handled by OpenCORE) in Froyo, and in Gingerbread it had gained RTSP streaming support and was mature enough to be used for video recording, too, so OpenCORE was removed in Gingerbread. Since then, it has still evolved a bit.

Stagefright is mainly a generic pipeline kind of framework, similar to GStreamer, but much smaller and simpler. (It is purpose-written from scratch to fill the exact needs of Android, while OpenCORE was an already existing framework that PacketVideo provided at the time. Stagefright is a few orders of magnitude smaller than OpenCORE while still fulfilling all the needs Android has.)

Example

Being a pipeline framework means that it consists of individual elements that form a pipeline, where each element either can produce data itself, or take input data from another element. By chaining such elements together, one can produce a pipeline that does the intended thing. E.g., for playing back video from a mp4 file on the phone, the following elements are hooked up together:

- FileSource`
- MPEG4Extractor
 - One MPEG4Source for each track (audio/video) in the file
- OMXCodec (one for each track, connected to the MPEG4Source)
- AudioPlayer

The `AwesomePlayer` creates the right `MediaExtractor` in `finishSetDataSource_1`, setting up the tracks in `setDataSource_1`, and later creates the `OMXCodec` object for each of the tracks. The audio `OMXCodec` object is given as source object to `AudioPlayer`, which then reads data from it.

`GStreamer` has the same element/pipeline design, but is much more flexible supporting a number of modes of operation and a lot more elements, while `Stagefright` is simpler and smaller, since it only does exactly what is needed in Android.

Pipeline

The pipeline in `Stagefright` is pull-based, meaning that each element deriving from the base class `MediaSource` implements a method `read()`, which when called will block until the `MediaSource` element has produced one `MediaBuffer` which is returned. When the `MediaSource` subclass object is created, it is normally given an upstream `MediaSource` object to read from, e.g. for `OMXCodec`, the `MediaSource` is given as parameter to `OMXCodec::Create()`.

For `OMXCodec`, the `read()` method internally reads a packet of compressed data from the source (which might e.g. be `MPEG4Source` within `MPEG4Extractor` in the case above), passes the packet to the actual OpenMAX codec for decoding, and when the decoded raw audio data is available, it is returned by the `read()` method.

Similarly, the `MPEG4Source` object will block in the `read()` method until it has read one packet from the source file, which is then returned to the caller. With this design, elements can be more or less arbitrarily connected, as long as one element can handle the data type that the input element produces.

For pipelines, `Stagefright` contains these kinds of element implementations:

- Sources for reading data from a file, or reading raw data from capture devices (e.g. `CameraSource`)
- Extractors, for interpreting different file formats (e.g. `AACExtractor`, `AMRExtractor`, `AVIExtractor`, `MP3Extractor`, `MPEG4Extractor`, `OggExtractor`, `WAVExtractor`)
- `OMXCodec`, for decoding/encoding data • Writers, for producing files of different formats (e.g. `AACWriter`, `AMR-Writer`, `MPEG2TSWriter`, `MPEG4Writer`)

Other components

In Honeycomb/Ice Cream Sandwich, `Stagefright` has evolved further, with a second mode of operation in addition to the plain pipeline based system. Now, the `ACodec` class encapsulates an OpenMAX codec with a different kind of abstraction. This class isn't to be used as a strict pipeline element, thus, it doesn't implement the `MediaSource` interface. Instead, messages are passed to `ACodec` (which implements `AHandler`, for receiving messages) with buffers to pass to the OpenMAX codec. This is more similar to the behavior model of the actual OpenMAX codecs themselves.

In addition to the elements, `Stagefright` contains higher level classes such as `AwesomePlayer` that coordinates playback of a video file, other utility classes such as color converters, wrapping of OpenMAX codecs (providing a Binder C++ interface around OpenMAX, giving it the possibility to use the codecs from a different process even if the codecs themselves run within the media server), and a number of software implementations of codecs.

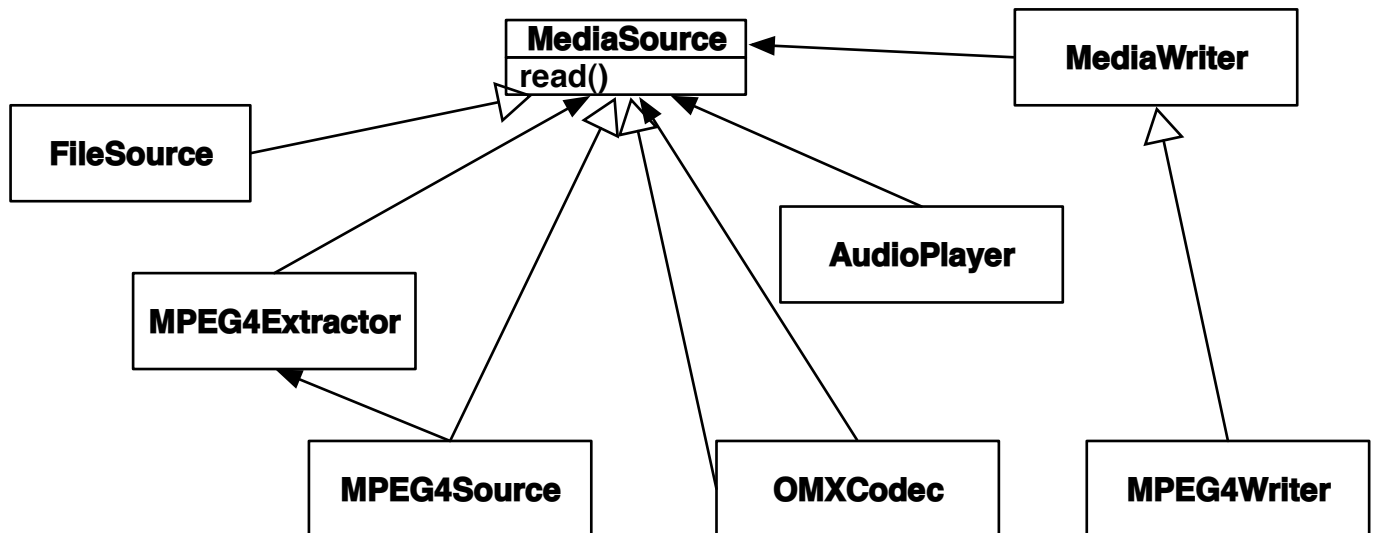


Figure 12: An illustration of the general pipeline structure.

Note

FileSource, MPEG4Source and OMXCodec all implement the MediaSource interface. MPEG4Extractor, OMXCodec, MediaPlayer, MediaWriter all use the MediaSource interface for reading their input from the preceding element, of which they don't need to know anything else than what's in MediaSource.

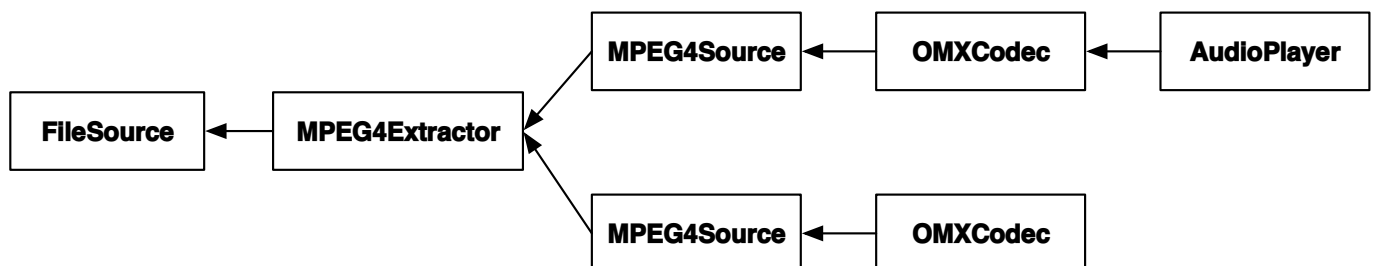


Figure 13: An example of a pipeline decoding audio and video from an MP4 file.

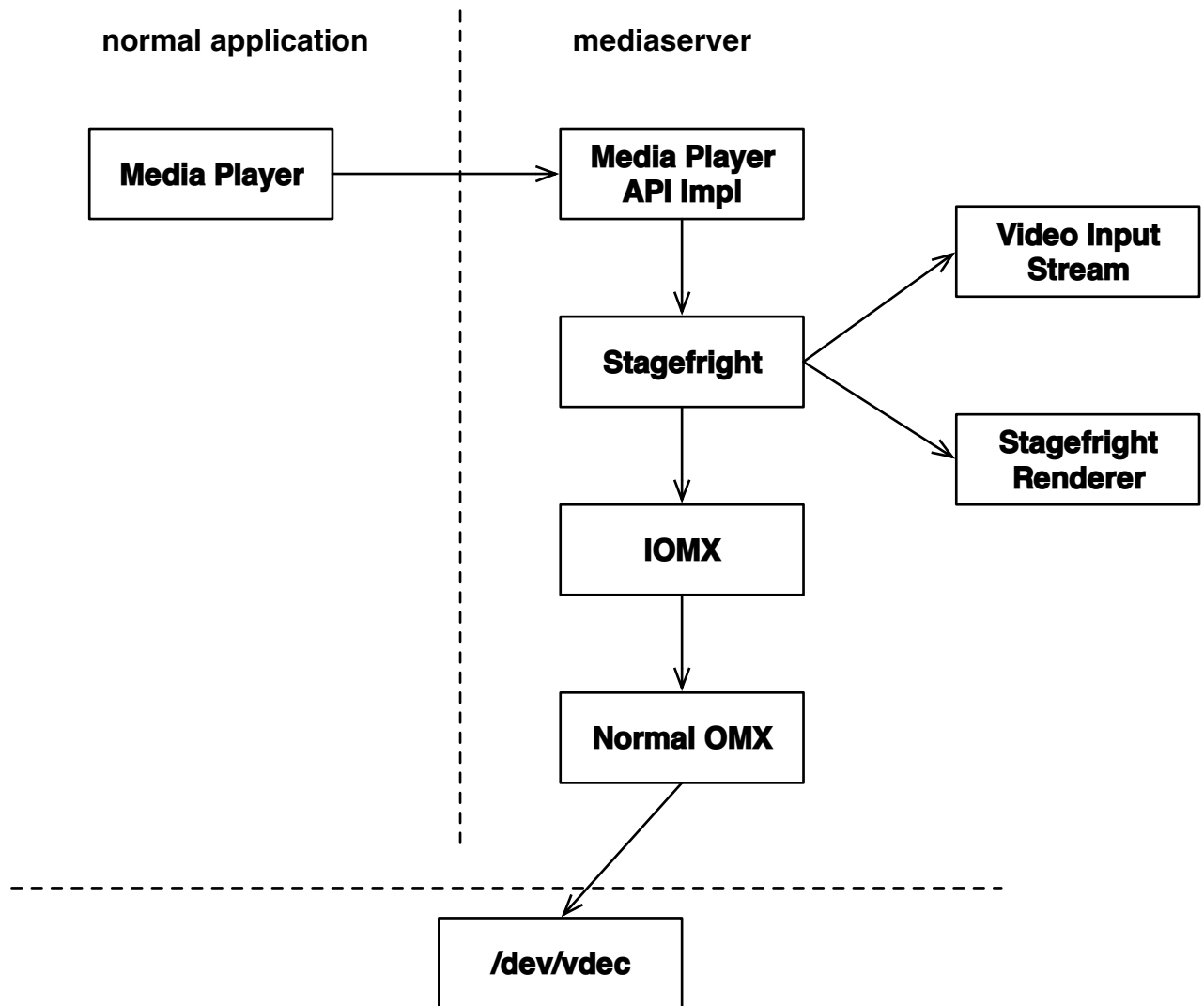


Figure 14: A rough visualization of the split between the application process and media server.

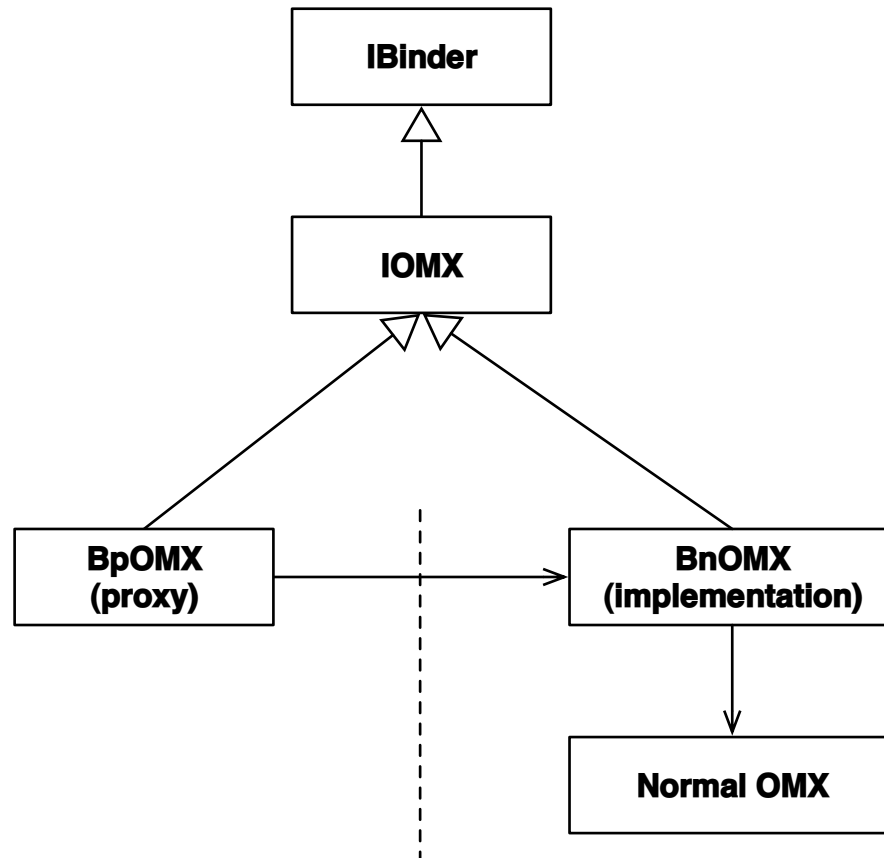


Figure 15: Details of the IOMX interface.

8.8.5 OpenMAX IL 5.1 Overview

- OpenMAX IL is a Khronos specified vendor-independent API for, among other things, providing access to codecs, both audio and video.
- An OpenMAX IL implementation consists of two separate parts a core and a number of components. The core acts as a registry for querying and instantiating the components.
- The component names are usually vendor specific, but each component implements one or more roles that are common among different implementations, e.g. "audio decoder.aac".
- OpenMAX IL components are state machines with a few different states (loaded, idle, executing). The input and output from the component happens via asynchronous buffer passing filled buffers with input data and empty data to fill with decoded/encoded data are passed to the component, and the component asynchronously calls back when an input buffer can be reused, or when an output buffer is filled and can be consumed.
- In general, each vendor provides a core of their own with different library name (e.g. `libOMX Core.so`, `libOmxCore.so`, `libomxil-bellagio.so`) that export the OMX core functions (OMX Init, OMX Deinit, OMX GetHandle and so on)

OpenMAX IL in Stagefright

Stagefright provides wrapping around OMX core implementations. The main client api is called IOMX (`frameworks/base/include`), which is a Binder interface with a proxy (BpOMX) and backend (BnOMX), allowing the caller and implementation to reside in separate processes. BnOMX is implemented by the OMX class in `frameworks/base/media/libstagefright/omx/OMX.cpp`, which uses the OMXMaster class in `frameworks/base/media/libstagefright/omx/OMXMaster.cpp` for querying and instantiating components from a number of different implementation sources. OMXMaster loads one or more plugins

(OMXPluginBase, defined in `frameworks/base/include/media/libstagefright/OMXPluginBase.h`) that are analogous to normal OMX IL cores.

OMXMaster loads a shared library named `libstagefrighthw.so`, which should have a function named `ZN7android15createOMXPlugin` (since ICS, both are tried, earlier, only the former was tried), that returns an `OMXPluginBase` pointer when called.

This library, `libstagefrighthw.so`, is vendor specific. Examples of implementations of this library, wrapping a normal OMX IL core, are available in:

- `hardware/qcom/media/libstagefrighthw/QComOMXPlugin.cpp`
- `hardware/ti/omap3/libstagefrighthw/TIOMXPlugin.cpp`
- `hardware/ti/omap4xxx/libstagefrighthw/TIOMXPlugin.cpp` (ICS only)

All of these are very similar they simply load an OMX core from a shared library, load the OMX core function pointers from the library, and map the `OMXPluginBase` methods to the OMX core.

For software codecs, there's no full proper OMX IL core in ICS, all decoders are mapped straight from the `OMXPluginBase`, implemented in `frameworks/base/media/libstagefright/omx/SoftOMXPlugin.cpp`. All software encoders (and in gingerbread, all software decoders too) are hooked up directly from the `OMXCodec` class, where the direct constructors of the software encoder classes are called, without any indirection via OMX like interfaces these software codecs implement the `MediaSource` interface directly. Due to this, these codecs cannot be accessed via the IOMX layer.

The development seems to be moving towards the OMX interfaces namely, in ICS, the software decoders have been converted to use OMX. The new `ACodec` class in ICS only uses codecs via the OMX interfaces.

8.8.6 Adding a custom OpenMAX IL plugin

Implement an OMX core for the codecs

Examples:

- `hardware/qcom/media/mm-core/omxcore`
- `hardware/ti/omap3/omx/system/src/openmax_il`
- `hardware/ti/omap4xxx/domx/omx_core` (ICS only)
- `device/samsung/crespo/sec_mm/sec_omx/sec_omx_core` (Gingerbread only)

The OMX core acts as a registry for the available codecs. If the build configuration already contains a vendor specific OMX core, the new OMX components can either be added to this OMX core, or a new separate OMX core can be added.

Build libstagefrighthw

Build `libstagefright`, containing an `OMXPluginBase` implementation that loads the OMX core. Examples:

- `hardware/qcom/media/libstagefrighthw/QComOMXPlugin.cpp`
- `hardware/ti/omap3/libstagefrighthw/TIOMXPlugin.cpp`
- `hardware/ti/omap4xxx/libstagefrighthw/TIOMXPlugin.cpp` (ICS only)
- `device/samsung/crespo/libstagefrighthw/SEC OMX Plugin.cpp` (Gingerbread only)

If one chooses to add a second OMX core, a second `libstagefrighthw` (with a slightly different name) has to be created, and this also requires modifications to `frameworks/base/media/libstagefright/omx/OMXMaster.cpp`, in order to be able to handle two different vendor libraries at the same time. Therefore, it's probably best to integrate new components within the current vendor OMX core if one already exists.

Implement OMX components for the codecs

This is the actual wrapping of the codecs. Simple examples (which don't use the proper real OMX API but only stagefright's own internal API) are available in

1. `frameworks/base/media/libstagefright/omx/SoftOMXComponent.cpp`
2. `frameworks/base/media/libstagefright/omx/SimpleSoftOMXComponent.cpp`
3. `frameworks/base/media/libstagefright/codecs/aacdec/SoftAAC.cpp`

These contain all the logic any OMX component needs to have, but the external API isn't the proper public OMX version, but only stagefright-internal ones. Real implementations with the proper public OMX API are available in e.g.:

- `hardware/ti/omap3/omx/audio/src/openmax_il/aac_dec`
- `hardware/qcom/media/mm-video/vidc/vdec`
- `device/samsung/crespo/sec_mm/sec_omx/sec_omx-component/video/dec/h264dec` (Gingerbread only)
- <http://omxil.sourceforge.net/> a full software OMX IL implementation

Register the new OMX components

Register the new OMX components in `frameworks/base/media/libstagefright/OMXCodec.cpp`. Simply add the component names and the mime types it handles in the `kDecoderInfo/kEncoderInfo` tables. (OMXCodec in stagefright doesn't query for which components implement certain roles, but blindly checks for all the components listed to support a certain mime type, and uses the first one that actually exists.)

8.9 Telephony

In this section, we'll explore the inter-workings of the telephony stack. We'll start with the standard Android Phone app, and trace the execution of placing a call all the way down to RIL daemon.

8.9.1 Telephony Manager

Android Framework provides the Telephony Manager class in `android.telephony` package. The Telephony Manager allows you to monitor the state of the mobile network connection. However, Telephony Manager does not allow you to place or manage any calls. Only the Phone app can initiate and answer phone calls.

8.9.2 Phone App

Note

Some of this content comes from the actual AOSP source code, licensed under [Apache 2 License](#).

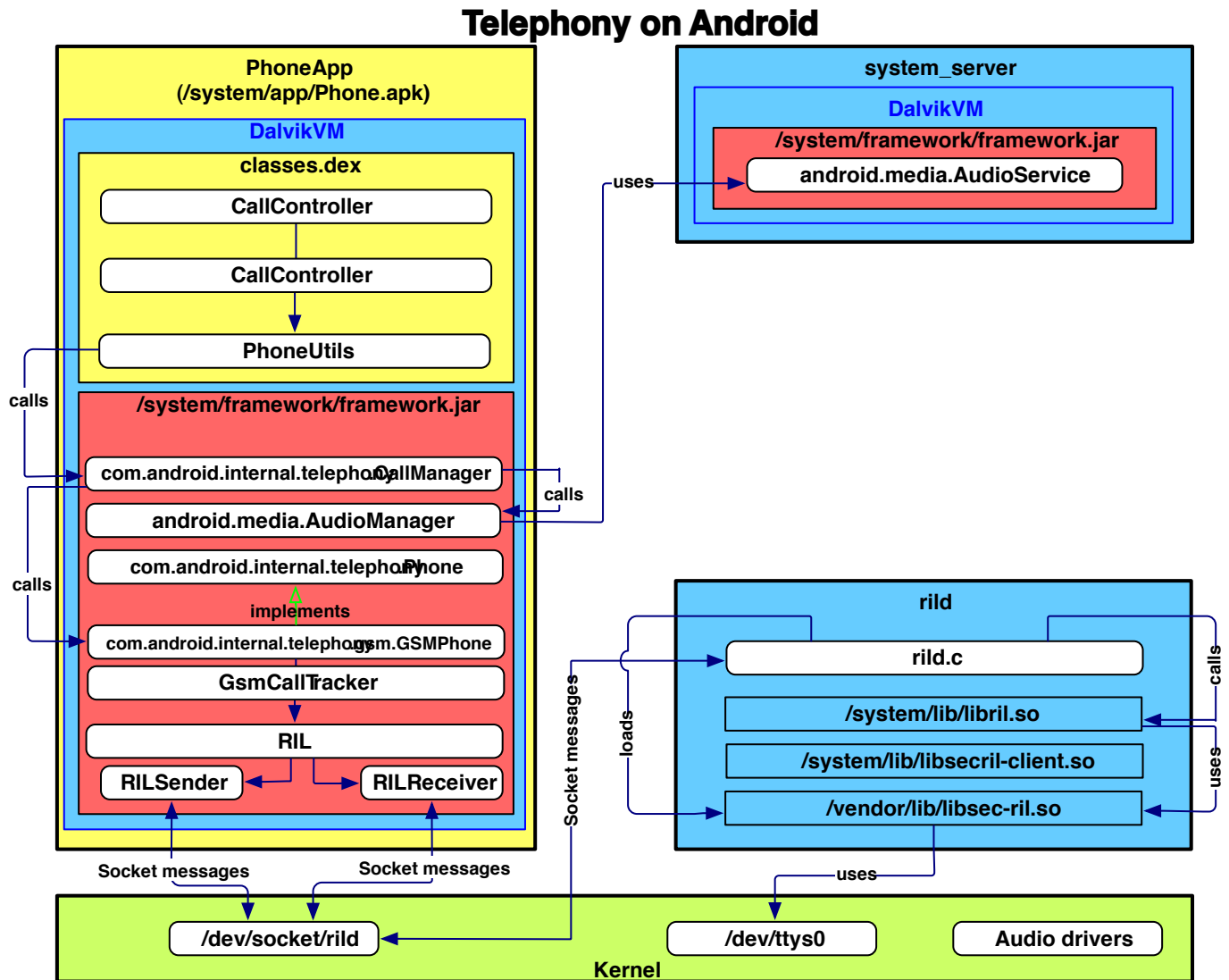


Figure 16: Android Telephony Architecture Diagram

Overview

Phone app does come with some UI components, such as the dialer, but the most significant part is its handling of `CALL` and `CALL_PRIVILEGED` intents to do the actual dialing of a number.

OutgoingCallBroadcaster

`OutgoingCallBroadcaster` activity receives `CALL` and `CALL_PRIVILEGED` Intents, and broadcasts the `ACTION_NEW_OUTGOING_CALL` intent which allows other applications to monitor, redirect, or prevent the outgoing call. After the other applications have had a chance to see the `ACTION_NEW_OUTGOING_CALL` intent, it finally reaches the `OutgoingCallReceiver`, which passes the (possibly modified) intent on to the `SipCallOptionHandler`, which will ultimately start the call using the `CallController.placeCall()` API.

CallController

`CallController` handler is the phone app module in charge of *call control*. This is a singleton object which acts as the interface to the telephony layer (and other parts of the Android framework) for all user-initiated telephony functionality, like making outgoing calls.

This functionality includes things like:

- actually running the `placeCall()` method and handling errors or retries
- running the whole "emergency call in airplane mode" sequence
- running the state machine of MMI sequences
- restoring/resetting mute and speaker state when a new call starts
- updating the proximity sensor wake lock state
- resolving what the voicemail: intent should mean (and making the call)

The single `CallController` instance stays around forever; it's not tied to the lifecycle of any particular Activity (like the `InCallScreen`). There's also no implementation of onscreen UI here (that's all in `InCallScreen`).

Note that this class does not handle asynchronous events from the telephony layer, like reacting to an incoming call; see `CallNotifier` for that. This class purely handles actions initiated by the user, like outgoing calls.

`placeCall(Intent intent)` initiates an outgoing call.

Here's the most typical outgoing call sequence:

1. `OutgoingCallBroadcaster` receives a `CALL` intent and sends the `NEW_OUTGOING_CALL` broadcast.
2. The broadcast finally reaches `OutgoingCallReceiver`, which stashes away a copy of the original `CALL` intent and launches `SipCallOptionHandler`.
3. `SipCallOptionHandler` decides whether this is a PSTN or SIP call (and in some cases brings up a dialog to let the user choose), and ultimately calls `CallController.placeCall()` (from the `setResultAndFinish()` method) with the stashed-away intent from step (2) as the "intent" parameter.
4. Here in `CallController.placeCall()` we read the phone number or SIP address out of the intent and actually initiate the call, and simultaneously launch the `InCallScreen` to display the in-call UI.
5. We handle various errors by directing the `InCallScreen` to display error messages or dialogs (via the `InCallUiState` "pending call status code" flag), and in some cases we also sometimes continue working in the background to resolve the problem (like in the case of an emergency call while in airplane mode). Any time that some onscreen indication to the user needs to change, we update the "status dialog" info in the `inCallUiState` and (re)launch the `InCallScreen` to make sure it's visible.

PhoneUtils

`PhoneUtils.placeCall(Context context, Phone phone, String number, Uri contactRef, boolean isEmergencyCall, Uri gatewayUri)` dials the number using the phone passed in.

CallManager

`CallManager`, defined in `PhoneApp` class.

`CallManager` class provides an abstract layer for `PhoneApp` to access and control calls. It implements `Phone` interface.

`CallManager` provides call and connection control as well as channel capability.

There are three categories of APIs `CallManager` provided

1. Call control and operation, such as `dial()` and `hangup()`
2. Channel capabilities, such as `CanConference()`
3. Register notification

`public Connection dial(Phone phone, String dialString)` in `CallManager` initiate a new voice connection. This happens asynchronously, so you cannot assume the audio path is connected (or a call index has been assigned) until `PhoneStateChanged` notification has occurred.

`dial()` uses `PhoneProxy` to implement `Phone` interface to make the call.

Phone Interface

Phone interface specifies the capabilities of the underlying phone system, whether GSM, CDMA, or SIP. We'll assume GMS from here on.

GSMPhone

GSMPhone extends PhoneBase which in turn implements the Phone interface.

It uses GSMCallTracker to dial via CommandsInterface. This interface is implemented by RIL class.

RIL in turn uses RILRequest to send the requests to rild daemon.

Tip

You can use `adb logcat -b radio` to see the radio-specific log messages.

RIL (Java)

RIL class is the implementation of the CommandsInterface that GSMPhone uses to dial out. This Java implementation writes out the commands to RIL daemon, the native code.

RIL uses RILSender and RILReceiver to send and receive messages from rild - the RIL Daemon. Unlike most of the other Android system services, RIL uses sockets for this inter-process communication, and not the Binder.

RIL Daemon

The RIL consists of two primary components:

- RIL Daemon: The RIL daemon initializes the Vendor RIL, processes all communication from Android telephony services, and dispatches calls to the Vendor RIL as solicited commands.
- Vendor RIL: The radio-specific Vendor RIL of ril.h that processes all communication with radio hardware and dispatches calls to the RIL Daemon (rild) through unsolicited commands.

Note

Some of the following documentation comes from once available *Android Platform Development Kit: Radio Layer Interface* documentation. This documentation is no longer readily available from Google (deemed outdated) but is licensed under [Apache 2.0 license](#). We've updated the references as originally provided.

RIL Initialization

Android initializes the telephony stack and the Vendor RIL at startup as described in the sequence below:

1. RIL daemon reads `rild.lib` path and `rild.libargs` system properties to determine the Vendor RIL library to use and any initialization arguments to provide to the Vendor RIL.
2. RIL daemon loads the Vendor RIL library and calls `RIL_Init` to initialize the RIL and obtain a reference to RIL functions.
3. RIL daemon calls `RIL_register` on the Android telephony stack, providing a reference to the Vendor RIL functions

Details of this implementation are available in `AOSP/hardware/ril/rild/rild.c`.

RIL Interaction

There are two forms of communication that the RIL handles:

- Solicited commands: Solicited commands originated by RIL lib, such as `DIAL` and `HANGUP`.
- Unsolicited responses: Unsolicited responses that originate from the baseband, such as `CALL_STATE_CHANGED` and `NEW_SMS`.

Solicited RIL Commands

The following snippet illustrates the interface for solicited commands:

- `void OnRequest (int request_id, void *data, size_t datalen, RIL_Token t);`
- `void OnRequestComplete (RIL_Token t, RIL_Error e, void *response, size_t responselen);`

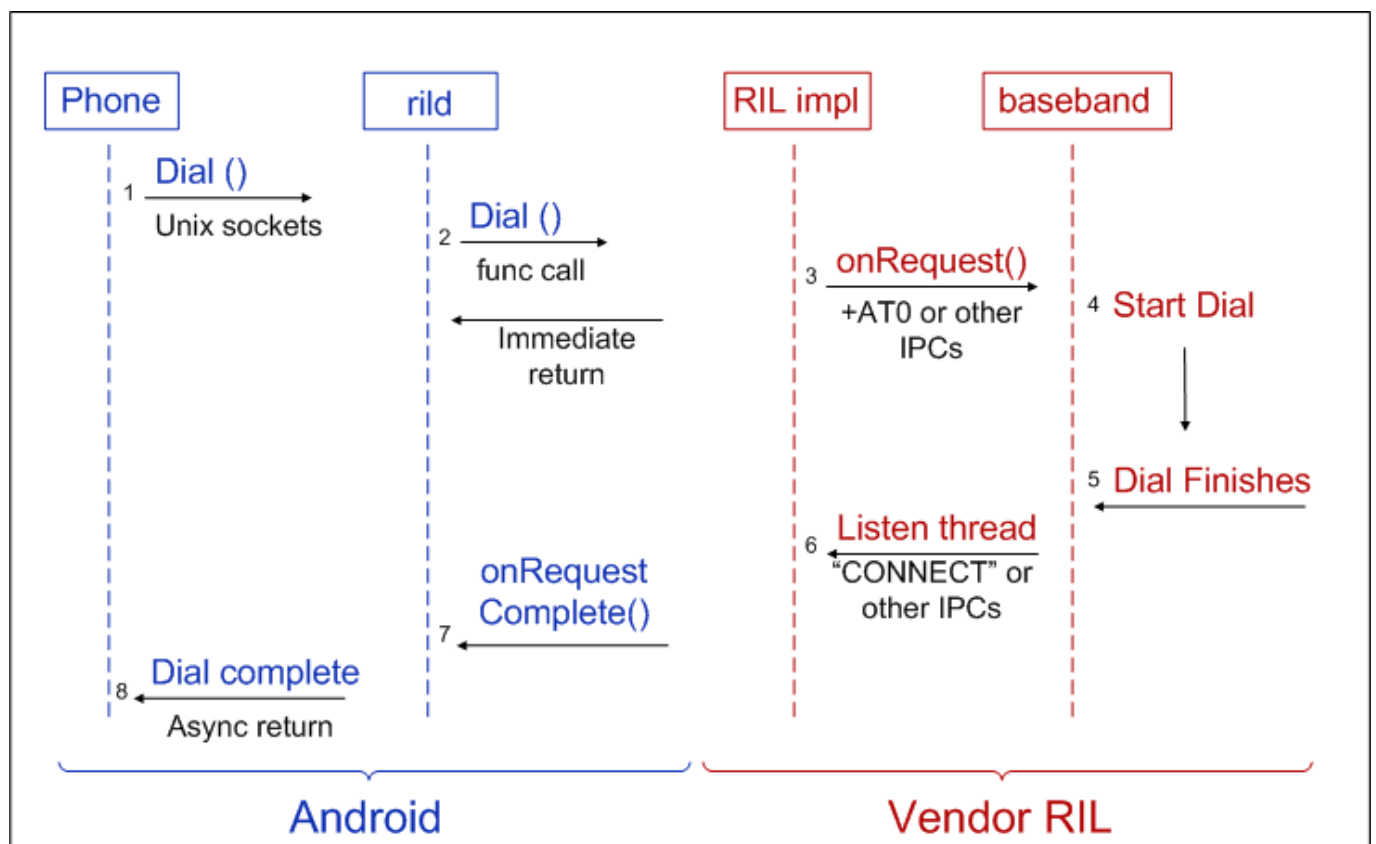


Figure 17: Example of solicited RIL commands

There are over sixty solicited commands grouped by the following families:

- SIM PIN, IO, and IMSI/IMEI (11)
- Call status and handling (dial, answer, mute...) (16)
- Network status query (4)
- Network setting (barring, forwarding, selection...) (12)
- SMS (3)

- PDP connection (4)
- Power and reset (2)
- Supplementary Services (5)
- Vendor defined and support (4)

Unsolicited RIL Commands

The following snippet illustrates the interface for unsolicited commands:

- `void OnUnsolicitedResponse (int unsolResponse, void *data, size_t datalen);`

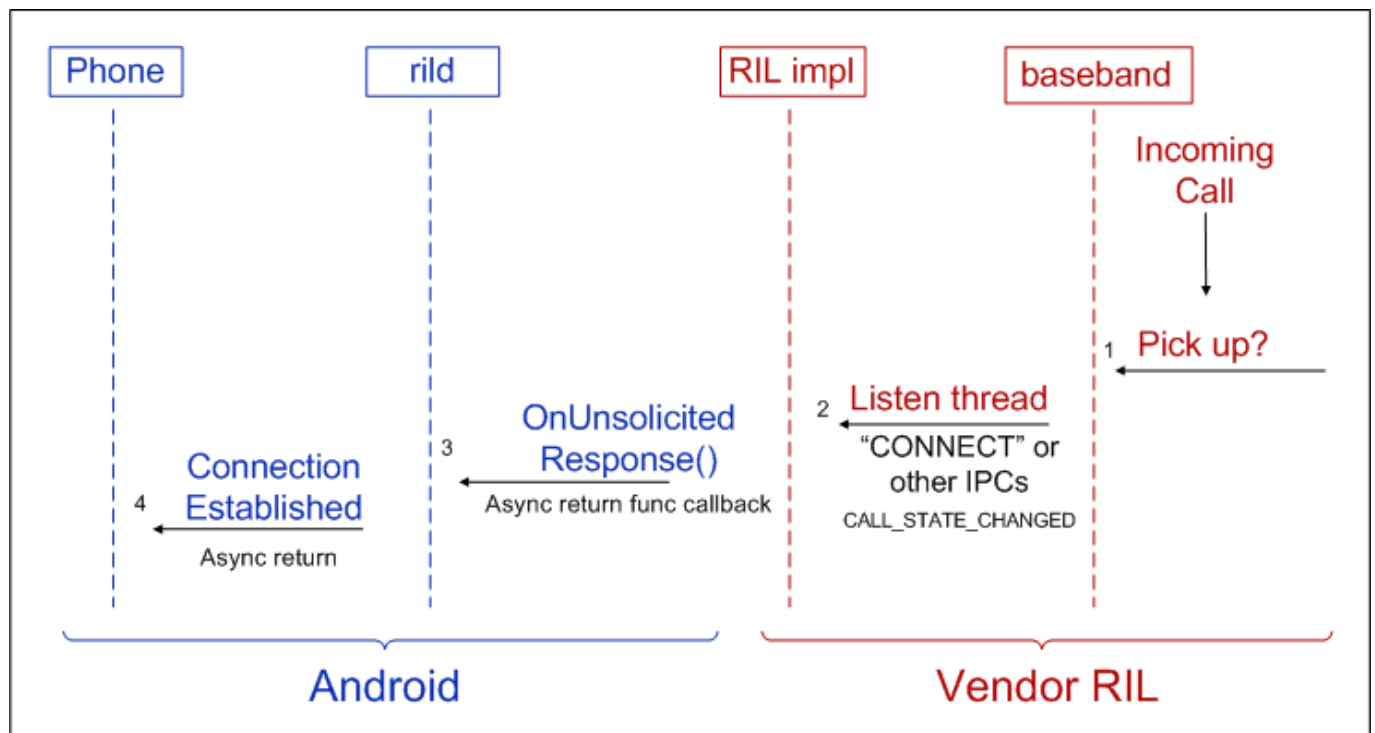


Figure 18: Example of unsolicited RIL commands

There are over ten unsolicited commands grouped by the following families:

- Network status changed (4)
- New SMS notify (3)
- New USSD notify (2)
- Signal strength or time changed (2)

Implementing the RIL

To implement a radio-specific RIL, create a shared library that implements a set of functions required by Android to process radio requests. The required functions are defined in the RIL header (`AOSP/hardware/ril/include/telephony/ril.h`).

The Android radio interface is radio-agnostic and the Vendor RIL can use any protocol to communicate with the radio. Android provides a reference Vendor RIL, using the Hayes AT command set, that you can use as a quick start for telephony testing and a guide for commercial vendor RILs. The source code for the reference RIL is found at `AOSP/hardware/ril/reference-ril`.

Compile your Vendor RIL as a shared library using the convention `libril-<companyname>-<RIL version>.so`, for example, `libril-acme-124.so`, where:

- `libril`: all vendor RIL implementations start with `libril`
- `<companyname>`: a company-specific abbreviation
- `<RIL version>`: RIL version number
- `so`: standard file extension for shared objects in Linux

For reference implementation of RIL, see `AOSP/hardware/ril/libril`.

8.9.3 Links

- [Linux Journal: The Java API to Android's Telephony Stack](#)
- [Android Application Development](#), by Rick Rogers and John Lombardo
- [The old official documentation of RIL no longer officially available](#)
- [Hayes command set](#)

8.10 Device Policy Service

DevicePolicy on Android

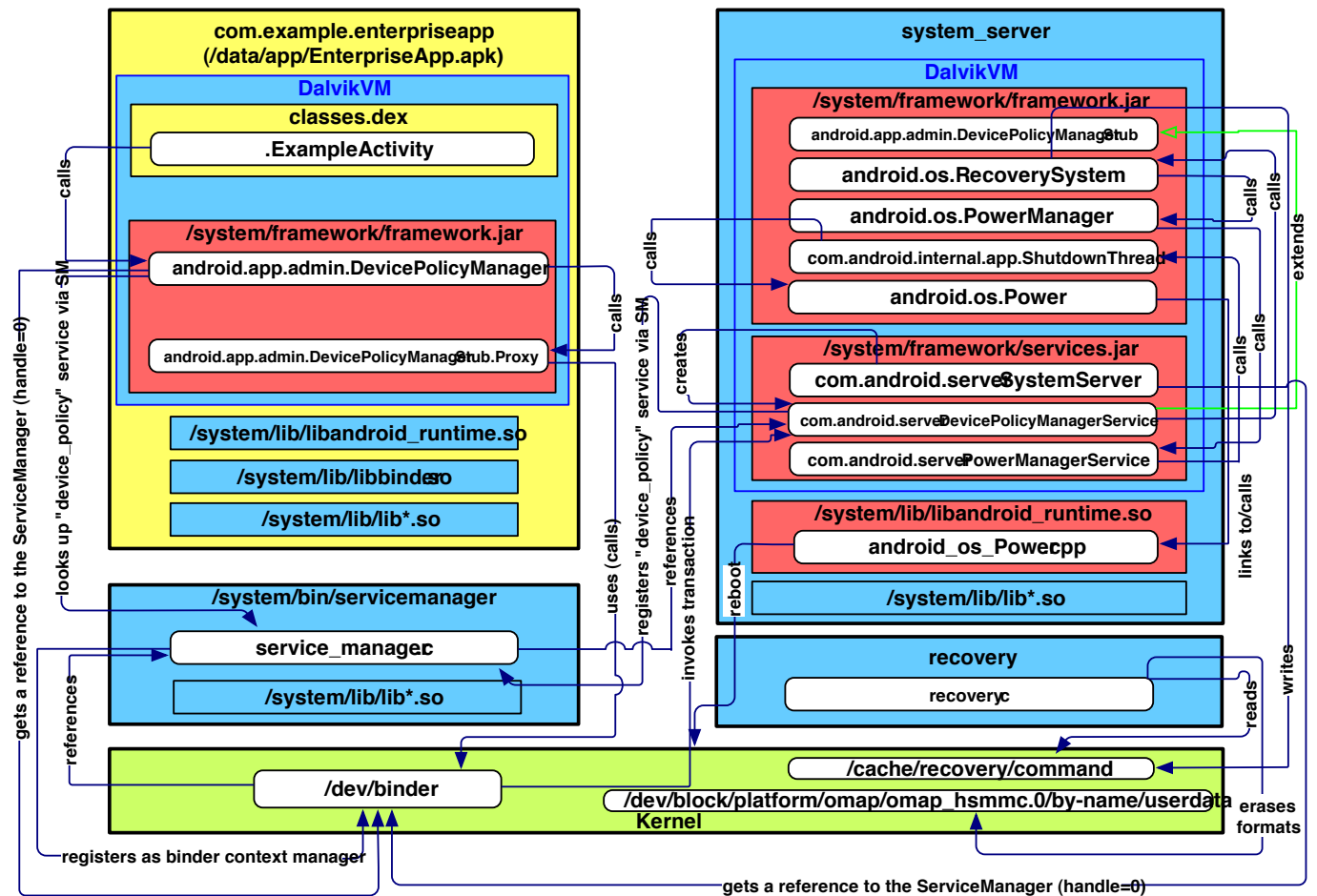


Figure 19: Device Policy Service Architecture

8.11 Surface Flinger

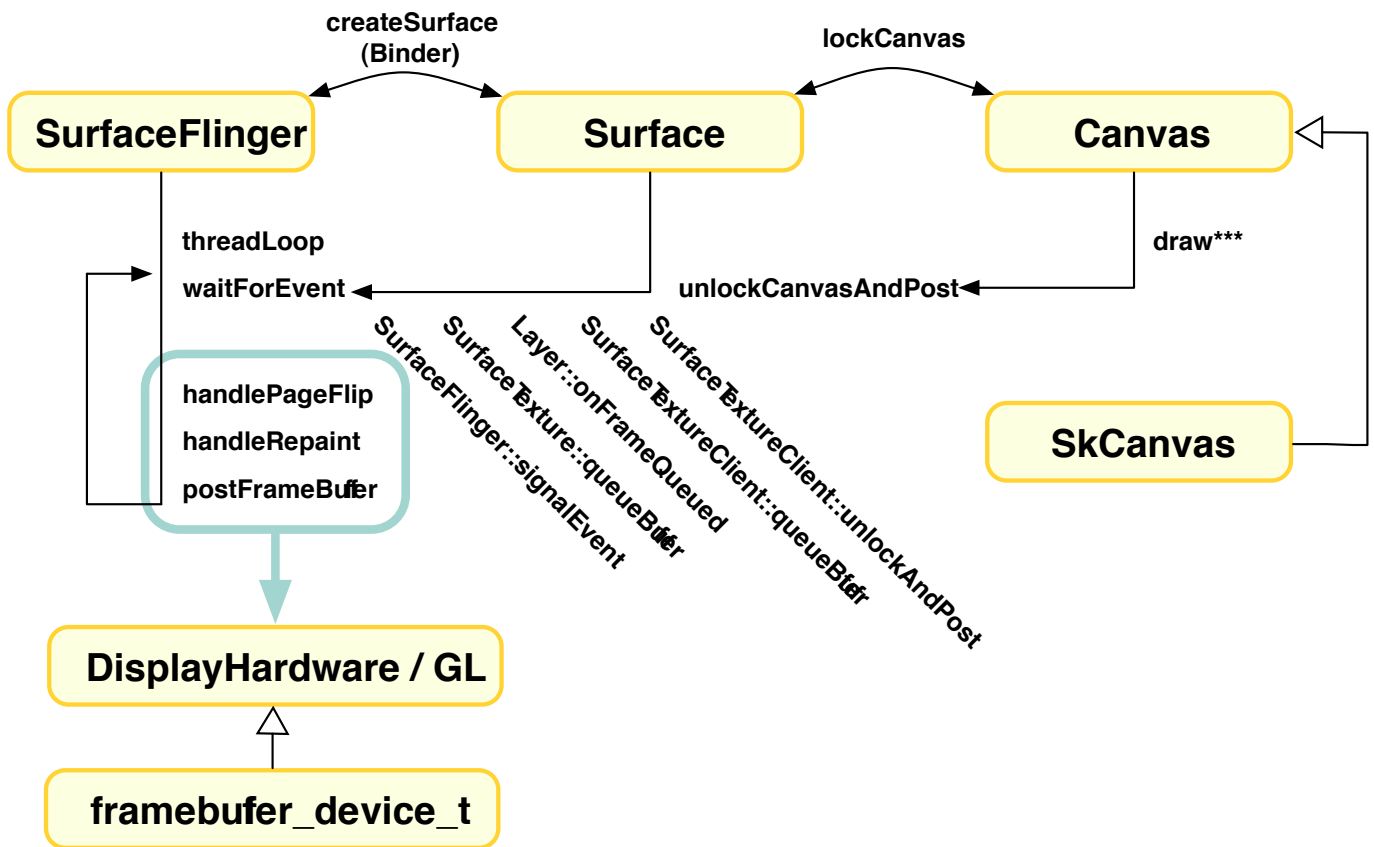


Figure 20: SurfaceFlinger Architecture

- SurfaceFlinger - Android low-level graphics compositor
 - Started from `frameworks/base/cmds/surfaceflinger/main_surfaceflinger.cpp`
 - Registers with Binder as `android.ui.ISurfaceComposer` under "SurfaceFlinger" name
 - Provides direct write access to framebuffer (`/dev/graphics/fb0`) memory
 - Surfaces are Z-Ordered into layers, and alpha blended via OpenGL ES
- 3D via EGL/OpenGL ES 1.0/2.0
 - 1.0 is can be rendered by the CPU by a software renderer though it can be accelerated by *Copybit*
 - 2.0 is GPU-only
 - OpenGL from Java is provided by JSR 239 plus a JNI wrapper to the native OpenGL
- Gralloc module - used by SurfaceFlinger to allocate and map graphics memory to processes (for 2D and 3D rendering)
 - Memory is allocated from the Unified Memory Provider (UMP) device driver and accessed through a secure ID
 - Memory can be shared (via Binder) across applications, drivers, and hardware components to enable zero-copy operations
 - Gralloc provides physical address info required to set up MMU/MPU table
 - Gralloc enables mapping of UMP memory into CPU address space to fascinate reading and writing
 - Definition at `hardware/libhardware/include/hardware/gralloc.h`
 - Implementation is typically proprietary (co-owned by SoC/GPU vendors)
- Refresh rate depends on VSYNC
 - Missing a VSYNC halves the refresh rate

8.11.1 Initialization

```
frameworks/base/cmds/surfaceflinger/main_surfaceflinger.cpp:
    SurfaceFlinger::publishAndJoinThreadPool();
```

8.11.2 Getting something to draw on

```
Surface()
    native Surface.init() ==> android_view_Surface.c Surface_init()
    SurfaceComposerClient::onFirstRef()
    ComposerService::getComposerService() -- singleton

    SurfaceComposerClient::createSurface()
    ISurfaceComposerClient::createSurface() -> SurfaceControl

Surface.lockCanvas()
    native Surface.lockCanvasNative ==> android_view_Surface.c Surface_lockCanvas() -> Canvas ←
    (SkCanvas)
```

8.11.3 Drawing

```
Canvas.drawLine()
    native Canvas.native_drawLine() ==> Canvas.cpp SkCanvasGlue::drawLine__FFFFPaint()
    SkCanvas::drawLine
    SkCanvas::drawPoints
    SkDevice::drawPoints
    SkDraw::drawPoints
```

8.11.4 Displaying what we drew on

```
native Surface.unlockCanvasAndPost() ==> android_view_Surface.c Surface_unlockCanvasAndPost ←
()
    Surface::unlockAndPost
    SurfaceTextureClient::unlockAndPost
    SurfaceTextureClient::queueBuffer
    SurfaceTexture::queueBuffer
    FrameAvailableListener::onFrameAvailable (interface)
    Layer::onFrameQueued
    SurfaceFlinger::signalEvent
    MessageQueue::invalidate
    ...
    SurfaceFlinger::waitForEvent returns
    SurfaceFlinger::threadLoop unblocks
    SurfaceFlinger::handlePageFlip
    SurfaceFlinger::handleRepaint
    DisplayHardware::compositionComplete
    FramebufferNativeWindow::compositionComplete

    SurfaceFlinger::postFramebuffer
    DisplayHardware::flip
```

8.11.5 Other

`ANativeWindow` (`core/include/system/window.h`) can be either:

```
FramebufferNativeWindow
SurfaceTextureClient
Surface
```

```
FramebufferNativeWindow::queueBuffer
framebuffer_device_t::post
```

8.11.6 Links

- <http://people.debian.org.tw/~olv/surfaceflinger/surfaceflinger.pdf> (outdated)
- <http://www.khronos.org/opengles/> (OpenGL ES)
 - <http://en.wikipedia.org/wiki/OpenGL>
 - [http://en.wikipedia.org/wiki/EGL_\(EGL\)](http://en.wikipedia.org/wiki/EGL_(EGL))
- <http://www.vivantecorp.com/Khronos.pdf> ("High Performance Graphics on Android")
- <http://jcp.org/en/jsr/detail?id=239> (JSR 239)
- <http://jsharkey.org/blog/2010/07/01/android-surfaceflinger-tricks-for-fun-and-profit/>
- <http://www.malideveloper.com/developer-resources/drivers/open-source-mali-gpus-android-gralloc-module.php>

8.12 Camera Service

See <http://marakana.com/static/courseware/android/Aptina-Android-Camera-Internals.pdf>

8.12.1 Links

- <http://www.kandroid.org/online-pdk/guide/camera.html> (outdated)

8.13 NFC Service

NFC on Android

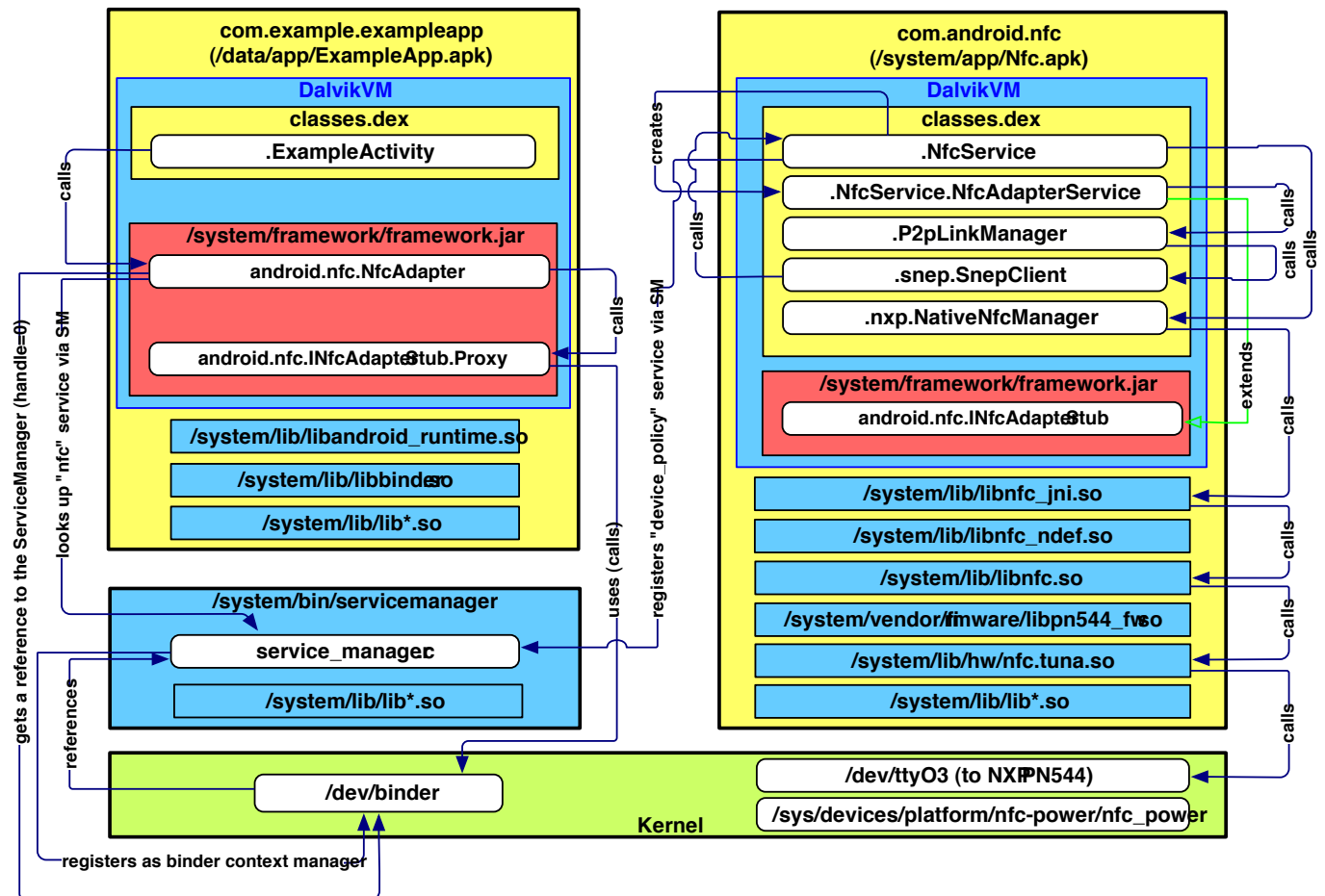


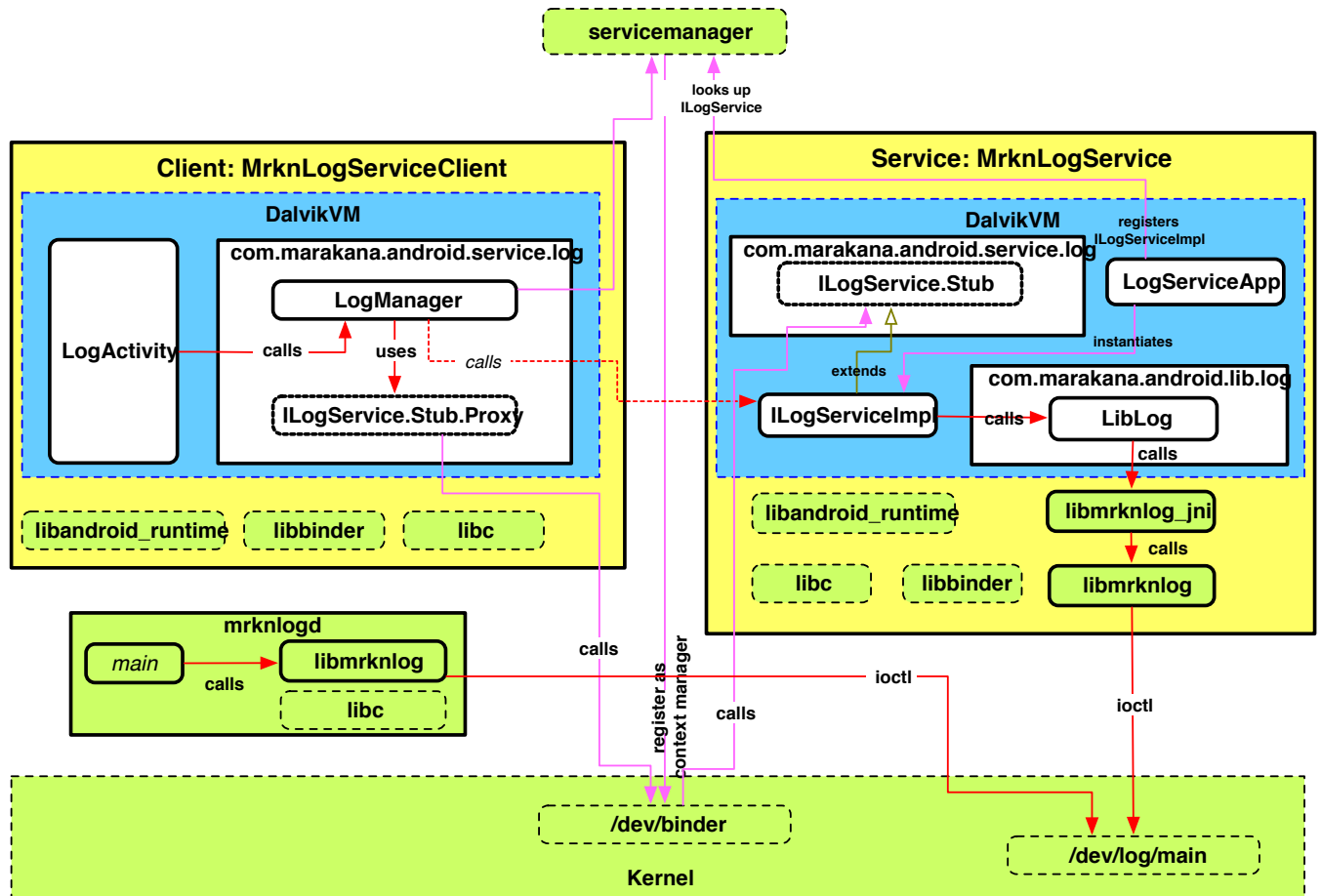
Figure 21: NFC Service Architecture

Note

This *service* is deployed as an *application*!

9 Customizing Android

- In this section, we will create:
 - a custom Android device (ROM), we'll call it *Marakana Alpha*
 - and a custom Android SDK add-on, that will enable 3rd party developers to develop for our custom device
- The following diagrams includes some of the custom components we'll be creating for *Marakana Alpha*:

**Note**

The following steps assume building Android ICS 4.0.3/4 for ARMv7 on Ubuntu 10.04 x86_64 and that the Android sources are available under `~/ics/` directory (for the current user).

Note

The complete code (which we'll develop in this section) for Marakana Alpha is available at <https://github.com/marakana/alpha>. The code for Marakana Alpha SDK add-on is available https://github.com/marakana/alpha_sdk_addon.

9.1 Setting up Custom Device Directory Structure

While we could overlay our device's custom components over the existing AOSP source tree, that makes it harder to deal with future OS upgrades. Instead, we will create a **self-contained** directory structure to host our device.

1. Create our vendor (e.g. *mararkana*) directory

```
$ mkdir device/marakana/
```

2. Now create our device (e.g. *alpha*) sub-directory:

```
$ mkdir device/marakana/alpha
```

9.2 Registering our Device with Android's Build System

We now want to add our device to the Android's *lunch* list

Note

Remember that `$ source build/envsetup.sh` registers lunch combos that we can later build

1. Create `vendorsetup.sh` file for our device (the name of this file is fixed):

device/marakana/alpha/vendorsetup.sh

```
add_lunch_combo full_marakana_alpha-eng
```

2. Re-build the lunch list:

```
$ source build/envsetup.sh
including device/marakana/alpha/vendorsetup.sh
including device/moto/stingray/vendorsetup.sh
including device/moto/wingray/vendorsetup.sh
including device/samsung/crespo4g/vendorsetup.sh
including device/samsung/crespo/vendorsetup.sh
including device/samsung/maguro/vendorsetup.sh
including device/samsung/torospr/vendorsetup.sh
including device/samsung/toro/vendorsetup.sh
including device/samsung/tuna/vendorsetup.sh
including device/ti/panda/vendorsetup.sh
including sdk/bash_completion/adb.bash
```

3. Finally, we can check to see that our device now appear in the lunch menu:

```
$ lunch

You're building on Linux

Lunch menu... pick a combo:
 1. full-eng
 2. full_x86-eng
 3. vbox_x86-eng
 4. full_marakana_alpha-eng
 5. full_stingray-userdebug
 6. full_wingray-userdebug
 7. full_crespo4g-userdebug
 8. full_crespo-userdebug
 9. full_maguro-userdebug
10. full_torospr-userdebug
11. full_toro-userdebug
12. full_tuna-userdebug
13. full_panda-eng

Which would you like? [full-eng]
```

- We are **not yet ready** to select it here, because we have not yet provided the necessary makefiles for `full_marakana_alpha`. If we do, we'll get:

```
$ lunch full_marakana_alpha-eng
build/core/product_config.mk:203: *** No matches for product "full_marakana_alpha".  ↵
Stop.

** Don't have a product spec for: 'full_marakana_alpha'
** Do you have the right repo manifest?
```

9.3 Adding the Makefile Plumbing for our Device

We now need to add basic support for building our device.

1. Start by creating a our own `AndroidProducts.mk` file, which simply defines the actual makefiles to be used when building our device:

device/marakana/alpha/AndroidProducts.mk

```
PRODUCT_MAKEFILES := $(LOCAL_DIR)/full_alpha.mk
```

Note

The only purpose of `AndroidProducts.mk` file (whose name is fixed) is to set `PRODUCT_MAKEFILES` to a list of product makefiles to expose to the build system. The only external variable it can use is `LOCAL_DIR`, whose value will be automatically set to the directory containing this file.

2. Create the main build-file for our device (we call it `full_alpha` following the example from `device/samsung/crespo/full_alpha.mk`)

device/marakana/alpha/full_alpha.mk

```
# Defines a list of languages to be supported by our device
$(call inherit-product, $(SRC_TARGET_DIR)/product/languages_small.mk)

# Defines the rules for building the base Android platform,
# but itself is not specialized for any particular device
$(call inherit-product, $(SRC_TARGET_DIR)/product/generic.mk)

# Discard inherited values and use our own instead.
PRODUCT_NAME := full_marakana_alpha
PRODUCT_DEVICE := alpha
PRODUCT_MODEL := Full Marakana Alpha Image for Emulator
```

A note inheriting from an existing product

Our device inherits from the `generic` product:

```
$(call inherit-product, $(SRC_TARGET_DIR)/product/generic.mk)
```

which resolves to `build/target/product/generic.mk` file.

This *generic* product (file) in turn inherits from:

- `build/target/product/generic_no_telephony.mk`
 - `frameworks/base/data/fonts/fonts.mk`
 - `external/lohit-fonts/fonts.mk`
 - `frameworks/base/data/keyboards/keyboards.mk`
 - `build/target/product/core.mk`
- `build/target/product/telephony.mk`

The combination of these files set up compilation rules that define what gets included in the final product.

3. Next, we'll import some boiler-plate make/support files from the "generic" board - since our device will run on the emulator:

```
$ cp build/target/board/generic/BoardConfig.mk device/marakana/alpha/.
$ cp build/target/board/generic/AndroidBoard.mk device/marakana/alpha/.
$ cp build/target/board/generic/device.mk device/marakana/alpha/.
$ cp build/target/board/generic/system.prop device/marakana/alpha/.
```

- `AndroidBoard.mk` - is essentially empty
- `device.mk` - sets up basic emulator-specific configuration files
- `system.prop` - used to set system-wide properties (here, just RIL settings for the emulator)
- `BoardConfig.mk` - defines our device board's kernel/hardware capabilities:

device/marakana/alpha/BoardConfig.mk

```
# config.mk
#
# Product-specific compile-time definitions.
#

# The generic product target doesn't have any hardware-specific pieces.
TARGET_NO_BOOTLOADER := true
TARGET_NO_KERNEL := true

# Note: we build the platform images for ARMv7-A _without_ NEON.
#
# Technically, the emulator supports ARMv7-A _and_ NEON instructions, but
# emulated NEON code paths typically ends up 2x slower than the normal C code
# it is supposed to replace (unlike on real devices where it is 2x to 3x
# faster).
#
# What this means is that the platform image will not use NEON code paths
# that are slower to emulate. On the other hand, it is possible to emulate
# application code generated with the NDK that uses NEON in the emulator.
#
TARGET_ARCH_VARIANT := armv7-a
TARGET_CPU_ABI := armeabi-v7a
TARGET_CPU_ABI2 := armeabi

HAVE_HTC_AUDIO_DRIVER := true
BOARD_USES_GENERIC_AUDIO := true

# no hardware camera
USE_CAMERA_STUB := true

# Set /system/bin/sh to ash, not mksh, to make sure we can switch back.
TARGET_SHELL := ash

# Enable dex-preoptimization to speed up the first boot sequence
# of an SDK AVD. Note that this operation only works on Linux for now
ifeq ($(HOST_OS),linux)
WITH_DEXPREOPT := true
endif

# Build OpenGL ES emulation guest and host libraries
BUILD_EMULATOR_OPENGL := true

# Build and enable the OpenGL ES View renderer. When running on the emulator,
# the GLES renderer disables itself if host GL acceleration isn't available.
USE_OPENGL_RENDERER := true
```


A note about CPU Architecture

Because we copied `build/target/board/generic/BoardConfig.mk` we inherited the following:

```
TARGET_ARCH_VARIANT := armv7-a
TARGET_CPU_ABI := armeabi-v7a
TARGET_CPU_ABI2 := armeabi
```

Alternatively, we could have built our image for x86, either by copying `build/target/board/generic_x86/BoardConfig.mk` or by changing our own `device/marakana/alpha/BoardConfig.mk` to say the following:

```
TARGET_ARCH := x86
TARGET_ARCH_VARIANT := x86-atom
TARGET_CPU_ABI := x86
```

9.4 Generating Our Own Platform Signing Keys (Optional)

Before we compile our device, we *should* generate our own platform signing keys Section 5.2.1, otherwise our device will not pass CTS.

1. Define our subject/issuer info:

```
$ SIGNER="/C=US/ST=California/L=San Francisco/O=Marakana Inc./OU=Android/CN=Android ↔
Platform Signer/emailAddress=android@marakana.com"
```

2. Remove the existing keys (it does not hurt to back them up first!):

```
$ rm build/target/product/security/*.p*
```

3. Generate the platform key:

```
$ echo | development/tools/make_key build/target/product/security/platform "$SIGNER"
creating build/target/product/security/platform.pk8 with no password
Generating RSA private key, 2048 bit long modulus
.....+++
.....+++
e is 3 (0x3)
```

4. Generate the shared key:

```
$ echo | development/tools/make_key build/target/product/security/shared "$SIGNER"
creating build/target/product/security/shared.pk8 with no password
Generating RSA private key, 2048 bit long modulus
.....
.....+++
e is 3 (0x3)
```

5. Generate the media key:

```
$ echo | development/tools/make_key build/target/product/security/media "$SIGNER"
creating build/target/product/security/media.pk8 with no password
Generating RSA private key, 2048 bit long modulus
.....+++
.....+++
e is 3 (0x3)
```

6. Generate the testkey key:

```
$ echo | development/tools/make_key build/target/product/security/testkey "$SIGNER"
creating build/target/product/security/testkey.pk8 with no password
Generating RSA private key, 2048 bit long modulus
.....+++
.....+++
e is 3 (0x3)
```

7. Verify that our keys have been created:

```
$ ls -l build/target/product/security/*.p*
build/target/product/security/media.pk8
build/target/product/security/media.x509.pem
build/target/product/security/platform.pk8
build/target/product/security/platform.x509.pem
build/target/product/security/shared.pk8
build/target/product/security/shared.x509.pem
build/target/product/security/testkey.pk8
build/target/product/security/testkey.x509.pem
```

8. Check that our specific subject/issuer has been used:

```
$ openssl x509 -noout -subject -issuer -in build/target/product/security/platform.x509 ←
.pem
subject= /C=US/ST=California/L=San Francisco/O=Marakana Inc./OU=Android/CN=Android ←
Platform Signer/emailAddress=android@marakana.com
issuer= /C=US/ST=California/L=San Francisco/O=Marakana Inc./OU=Android/CN=Android ←
Platform Signer/emailAddress=android@marakana.com
```



Caution

The build/target/product/security/.pk8 files are the private keys (.x509.pem are the certificates), and we need to make sure to keep them safe and secure - especially since we did not encrypt them!

9.5 Building our Device For The First Time

We are now ready to try out our "custom" device - though there is nothing truly custom yet, except for the PRODUCT_* settings and our own product keys.

1. For good measure, re-register our device:

```
$ source build/envsetup.sh
including device/marakana/alpha/vendorsetup.sh
...
```

2. Now we can lunch of our device:

```
$ lunch full_marakana_alpha-eng

=====
PLATFORM_VERSION_CODENAME=REL
PLATFORM_VERSION=4.0.3
TARGET_PRODUCT=full_marakana_alpha
TARGET_BUILD_VARIANT=eng
TARGET_BUILD_TYPE=release
TARGET_BUILD_APPS=
TARGET_ARCH=arm
TARGET_ARCH_VARIANT=armv7-a
```

```
HOST_ARCH=x86
HOST_OS=linux
HOST_BUILD_TYPE=release
BUILD_ID=IML74K
=====
```

3. We can now compile our device:

```
$ export USE_CCACHE=1
$ make -j10
...
Installed file list: out/target/product/alpha/installed-files.txt
Target system fs image: out/target/product/alpha/obj/PACKAGING/ ↵
    systemimage_intermediates/system.img
Install system fs image: out/target/product/alpha/system.img
```

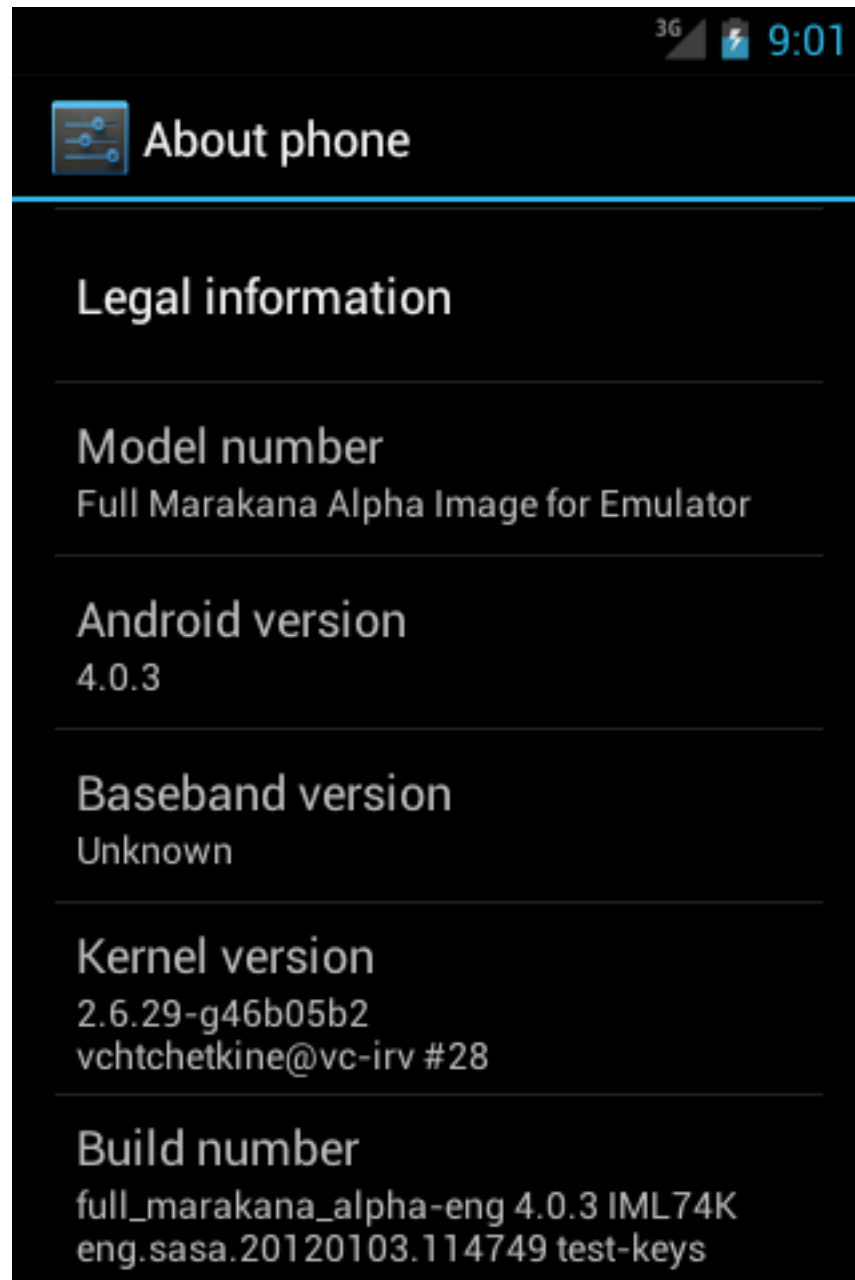
4. Finally, we can run it

```
$ out/host/linux-x86/bin/emulator &
```

Note

Replace `linux` with `darwin` for Mac OS X

5. And we should see



9.6 Adding a Custom Kernel to our Device

Our device would work fine with the provided QEMU-based (i.e. emulator-specific) kernel:

- `prebuilt/android-arm/kernel/kernel-qemu-armv7` for ARMv7
- `prebuilt/android-arm/kernel/kernel-qemu` for ARMv5
- `prebuilt/android-x86/kernel/kernel-qemu` for x86)

In this section, we will configure a custom kernel (???TITLE???) so that we can:

- Change the *Hardware* name of our device from *Goldfish* to *Alpha Marakana Board* - allowing us to have custom system (init/ueventd) configuration files
- To enable loadable module support - in case we decide to add new drivers as modules later on

The steps outlined here are similar to [???TITLE???](#):

1. Create a directory to host our kernel sources:

```
$ mkdir ~/kernel/
$ cd ~/kernel/
```

2. Clone the Goldfish kernel sources:

```
$ git clone https://android.googlesource.com/kernel/goldfish.git
$ cd goldfish/
```

3. Check out android-goldfish-2.6.29 branch of the kernel we wish to build:

```
$ git checkout -t remotes/origin/android-goldfish-2.6.29
```

4. Create the default kernel configuration file (.config):

```
$ make goldfish_armv7_defconfig ARCH=arm
```

Tip

Depending on `TARGET_ARCH_VARIANT` that we specified in `device/marakana/alpha/BoardConfig.mk`: to compile for ARMv5, we would run `make goldfish_defconfig ARCH=arm` instead. to compile for x86, we would run `make goldfish_defconfig ARCH=x86` instead.

5. Change the *Hardware* name from "Goldfish" to "Marakana Alpha Board":

arch/arm/mach-goldfish/board-goldfish.c:

```
...
MACHINE_START(GOLDFISH, "Marakana Alpha Board")
...
```

A note about the hardware (board) name

As we already know, when the Android kernel loads, it runs `init`, which configures itself from `init.rc` and `init.hardware.rc` configuration files.

The *hardware* name is extracted from `/proc/cpuinfo`:

```
$ adb shell cat /proc/cpuinfo |grep Hardware
Hardware      : Goldfish
```

Basically, `system/core/init/init.c:main()` uses `system/core/init/util.c:get_hardware_name(..)` to parse `/proc/cpuinfo` and extract the hardware name. This name is converted to lower-case and all the space characters are trimmed.

Android's `ueventd` process (started by `init`) also configures itself in a similar way, by loading `ueventd.rc` and `ueventd.hardware.rc` configuration files.

Since in our case we changed the name of our hardware to "Marakana Alpha Board", we will also need to create the corresponding: `init.marakanaalphaboard.rc` and `ueventd.marakanaalphaboard.rc` files.

6. Configure the kernel

```
$ make menuconfig ARCH=arm
```

Tip

For x86, run `$ make menuconfig ARCH=x86` instead.

- a. Set *General setup* → *Local version* to `-marakana-alpha-release`
- b. Select *Enable loadable module support* and within it also select *Module unloading* and within that *Forced module unloading*
- c. Customize the rest as desired

7. Compile the kernel

```
$ make -j10 ARCH=arm CROSS_COMPILE=~/.ics/prebuilt/linux-x86/toolchain/arm-eabi-4.4.3/ ↩
    bin/arm-eabi-
```

Tip

For x86, run `make -j10 ARCH=x86 CROSS_COMPILE=~/.ics/prebuilt/linux-x86/toolchain/i686-unk` instead.



Warning

We ran into issues (clobbered PIC register) last time we tried compiling for x86 (January 2012) with alternative i686 toolchains.

Note

Remember that `~/.ics/` is the root of the Android Open Source Project (AOSP) source tree

Tip

AOSP comes with a convenient script to compile the Linux kernel for QEMU-based emulator: `~/.ics/external/qemu/distrib/build-kernel.sh`, but this picked the wrong toolchain for x86.

8. Copy the compiled kernel to our device's alpha/ directory:

```
$ cp arch/arm/boot/zImage ~/.ics/device/marakana/alpha/kernel
```

Tip

For x86, copy `arch/x86/boot/bzImage` instead.

Note

In case you were not able to compile the kernel, you could also download a pre-built one from <https://github.com/-marakana/alpha/raw/master/kernel>

9. Now we can go back to the AOSP source

```
$ cd ~/.ics/
```

10. Enable our custom kernel in BoardConfig.mk (double-negation, nice!):

device/marakana/alpha/BoardConfig.mk

```
...
TARGET_NO_KERNEL := false
...
```

Note

This will cause the build system to rebuild the `boot.img` file, but because we are still working with the emulator, we'll have to explicitly reference our kernel on startup.

11. Now we are ready to create *our own* `init` and `ueventd` configuration files by copying the ones from Goldfish:

```
$ cp system/core/rootdir/etc/init.goldfish.rc device/marakana/alpha/init. ↵
   marakanaalphaboard.rc
$ cp system/core/rootdir/etc/ueventd.goldfish.rc device/marakana/alpha/ueventd. ↵
   marakanaalphaboard.rc
```

Note

Remember, `marakanaalphaboard` is our device's new hardware name (lowercased and stripped of spaces).

12. Create a `common.mk` makefile for our common components, where we'll configure our kernel and copy the `init` and `ueventd` configuration files:

device/marakana/alpha/common.mk

```
# Since this file can also be referenced by alpha-sdk_addon
# we cannot assume LOCAL_PATH points to the directory where
# this file is located. Instead, we create another variable
# to capture this directory.
MY_PATH := $(LOCAL_PATH)/../alpha

# Include all makefiles in sub-directories (one level deep)
include $(call all-subdir-makefiles)

# Enable our custom kernel
LOCAL_KERNEL := $(MY_PATH)/kernel
PRODUCT_COPY_FILES += $(LOCAL_KERNEL):kernel

# Copy our init and ueventd configuration files to the root
# file system (ramdisk.img -> boot.img)
PRODUCT_COPY_FILES += $(MY_PATH)/init.marakanaalphaboard.rc:root/init. ↵
   marakanaalphaboard.rc
PRODUCT_COPY_FILES += $(MY_PATH)/ueventd.marakanaalphaboard.rc:root/ueventd. ↵
   marakanaalphaboard.rc
```

13. Now, we need to include our common `common.mk` file in our device's main makefile (`full_alpha.mk`):

device/marakana/alpha/full_alpha.mk

```
...
# Include the common definitions and packages
include $(LOCAL_PATH)/common.mk
```

14. Re-build our ROM, which, in this case just creates a new `out/target/product/alpha/boot.img` (that we won't actually use):

```
$ make -j10
...
```

15. Restart the emulator (with our new kernel)

```
$ out/host/linux-x86/bin/emulator -kernel out/target/product/alpha/kernel &
```

Note

We have to run our emulator with `-kernel`, because otherwise it would ignore the kernel in our newly built `boot.img` and instead use the default one (`prebuilt/android-arm/kernel/kernel-qemu-armv7`). This applies just to the emulator.

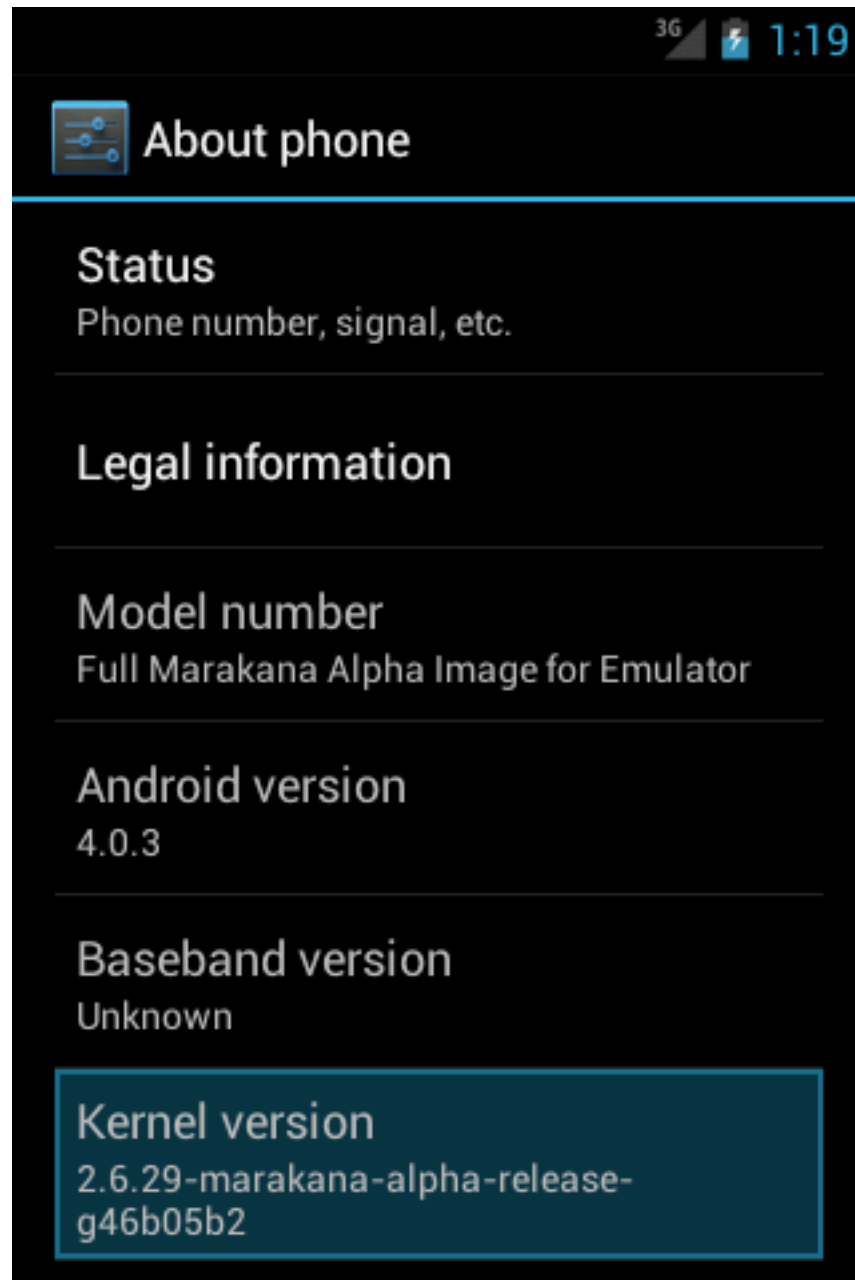
16. Test

```
$ adb shell cat /proc/version
Linux version 2.6.29-marakana-alpha-release-g46b05b2 (sasa@thermal) (gcc version 4.4.3 ↵
(GCC) ) #3 Tue Jan 3 13:25:44 PST 2012
```

Note

The path to `adb` was added to our `PATH` when we `$ source build/envsetup.sh` (on a Linux host, it comes from `out/host/linux-x86/bin/adb`)

17. We could also take a look at the updated *About* screen:



9.7 Adding a Custom Native Library and Executable to our Device

- In this section, we'll create a simple native shared library (like a HAL), which will directly interact with a kernel driver (the Android logger driver at `/dev/log/main`) and allow us to
 - Flush the log buffer
 - Get the max size of the log buffer
 - Get the used size of the log buffer
- We'll also create a simple executable that will use our shared library
- Let's get started:
 1. We start by creating a home for our shared libraries:

```
$ mkdir device/marakana/alpha/lib/
```

2. Since our actual libraries will be in their own sub-directories, we need to include them in our build system, via a simple makefile:

device/marakana/alpha/lib/Android.mk

```
include $(call all-subdir-makefiles)
```

3. Now we can create an actual directory for our libmrknlog library:

```
$ mkdir device/marakana/alpha/lib/libmrknlog
```

4. Now we can create a simple header file (libmrknlog.h) for our library:

device/marakana/alpha/lib/libmrknlog/libmrknlog.h

```
#ifndef _MRKNLOG_H_
#define _MRKNLOG_H_

#ifdef __cplusplus
extern "C" {
#endif

extern int mrkn_flush_log();
extern int mrkn_get_total_log_size();
extern int mrkn_get_used_log_size();

#ifdef __cplusplus
} /* End of the 'extern "C"' block */
#endif
#endif /* End of the _MRKNLOG_H_ block */
```

5. Next, we implement our shared library (libmrknlog.c) - using ioctl() to talk to the kernel driver:

device/marakana/alpha/lib/libmrknlog/libmrknlog.c

```
#define LOG_FILE "/dev/log/main"
#define LOG_TAG "MrknLog"

#include <cutils/logger.h>
#include <cutils/log.h>
#include <string.h>
#include <fcntl.h>
#include <errno.h>
#include <sys/ioctl.h>
#include <sys/stat.h>
#include <sys/types.h>

#include "libmrknlog.h"

static int ioctl_log(int mode, int request) {
    int logfd = open(LOG_FILE, mode);
    if (logfd < 0) {
        LOGE("Failed to open %s: %s", LOG_FILE, strerror(errno));
        return -1;
    } else {
        int ret = ioctl(logfd, request);
        close(logfd);
        return ret;
    }
}

extern int mrkn_flush_log() {
    return ioctl_log(O_WRONLY, LOGGER_FLUSH_LOG);
}
```

```
extern int mrkn_get_total_log_size() {
    return ioctl_log(O_RDONLY, LOGGER_GET_LOG_BUF_SIZE);
}

extern int mrkn_get_used_log_size() {
    return ioctl_log(O_RDONLY, LOGGER_GET_LOG_LEN);
}
```

6. We are now ready for the makefile (Android.mk):

device/marakana/alpha/lib/libmrknlog/Android.mk

```
LOCAL_PATH:= $(call my-dir)
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := libmrknlog.c
LOCAL_SHARED_LIBRARIES := libcutils
LOCAL_MODULE := libmrknlog
include $(BUILD_SHARED_LIBRARY)
```

Note

Here, we need `LOCAL_SHARED_LIBRARIES := libcutils` in order to link to `__android_log_print` (used by the `LOGE` macro)

Note

In previous versions of Android (pre 4.0), we would've also needed to add `LOCAL_PRELINK_MODULE := false` in order to prevent pre-linking of our library. Pre-linked libraries were registered to be loaded at fixed memory addresses in order to speed up linking and allow for faster booting (at the expense of ASLR). If we did not disable it, we would've had to register our library `build/core/prelink-linux-arm.map` (now deprecated).

7. Optionally, we can compile our library to test that it builds:

```
$ make libmrknlog
...
target thumb C: libmrknlog <= device/marakana/alpha/lib/libmrknlog/libmrknlog.c
target SharedLib: libmrknlog (out/target/product/alpha/obj/SHARED_LIBRARIES/ ↵
    libmrknlog_intermediates/LINKED/libmrknlog.so)
target Symbolic: libmrknlog (out/target/product/alpha/symbols/system/lib/libmrknlog.so ↵
    )
target Strip: libmrknlog (out/target/product/alpha/obj/lib/libmrknlog.so)
Install: out/target/product/alpha/system/lib/libmrknlog.so
```

A note about compiling individual modules

Android's build system allows us to compile individual modules via a simple `$ make <module-name>` where `<module-name>` is defined by `LOCAL_MODULE` (or `LOCAL_PACKAGE_NAME` for apps) in the module's `Android.mk` file. To clean just this one module, we can do `$ make clean-<module-name>`.

This works, but it still takes a long time (about 21.2s on 3.4GHz i7 with SSD) because the build system has to scan the entire source tree to find our module.

Alternatively, we can use the `mm` function right from the module's directory (takes about 1.6s):

```
$ godir libmrknlog
device/marakana/alpha/lib/libmrknlog$ mm
...
make: Entering directory ++/flash/ics-4.0.3'
target thumb C: libmrknlog <= device/marakana/alpha/lib/libmrknlog/libmrknlog.c
target SharedLib: libmrknlog (out/target/product/alpha/obj/SHARED_LIBRARIES/ ↵
    libmrknlog_intermediates/LINKED/libmrknlog.so)
target Symbolic: libmrknlog (out/target/product/alpha/symbols/system/lib/libmrknlog. ↵
    so)
target Strip: libmrknlog (out/target/product/alpha/obj/lib/libmrknlog.so)
Install: out/target/product/alpha/system/lib/libmrknlog.so
make: Leaving directory ++/flash/ics-4.0.3'
device/marakana/alpha/lib/libmrknlog$ cd -
$
```

The function `godir` builds a `filelist` index of all of the source-files, searches for the file that matches the argument name in that list, and then jumps to the directory containing that file. In this case, it's equivalent to `cd device/marakana/alpha/lib/libmrknlog` command.

Both `godir` and `mm` are defined by `build/envsetup.sh`, which we sourced into our shell.

8. Since our library's `Android.mk` states `LOCAL_MODULE_TAGS := optional`, we need to register it with Alpha's `PRODUCT_PACKAGES`, otherwise it will not be included in the final ROM:

device/marakana/alpha/common.mk

```
...
PRODUCT_PACKAGES += libmrknlog
```

9. Before we can create our executable to test our library, let's create a directory for all binaries:

```
$ mkdir device/marakana/alpha/bin
```

10. Like with our libraries, we need to "recursively" include makefiles in sub-directories of `.../bin/`, which is where our executables will live:

device/marakana/alpha/bin/Android.mk

```
include $(call all-subdir-makefiles)
```

11. Now we can create a directory for our `mrknlog` executable:

```
$ mkdir device/marakana/alpha/bin/mrknlog
```

12. Next we provide the implementation (`mrknlog.c`), which will use our shared library (`libmrknlog`):

device/marakana/alpha/bin/mrknlog/mrknlog.c

```
#include <stdio.h>
#include <string.h>
#include <errno.h>

#include <libmrknlog.h>

int main (int argc, char* argv[]) {
    int usedSize = mrkn_get_used_log_size();
```

```

int totalSize = mrkn_get_total_log_size();
if (totalSize >= 0 && usedSize >= 0) {
    if (mrkn_flush_log() == 0) {
        printf("Flushed log. Previously it was consuming %d of %d bytes\n",
            usedSize, totalSize);
        return 0;
    } else {
        fprintf(stderr, "Failed to flush log: %s", strerror(errno));
    }
} else {
    fprintf(stderr, "Failed to get log size: %s", strerror(errno));
}
return -1;
}

```

13. As with everything else, we need a makefile (Android.mk) to build our executable:

device/marakana/alpha/bin/mrknlog/Android.mk

```

LOCAL_PATH:= $(call my-dir)

include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := mrknlog.c
LOCAL_C_INCLUDES := $(LOCAL_PATH)/../../lib/libmrknlog/
LOCAL_SHARED_LIBRARIES := libmrknlog
LOCAL_MODULE := mrknlog
include $(BUILD_EXECUTABLE)

```

Note

Here, we need to tell the compiler where to find our library's header file:

```
LOCAL_C_INCLUDES := $(LOCAL_PATH)/../../lib/libmrknlog/
```

and tell the linker to link against our library:

```
LOCAL_SHARED_LIBRARIES := libmrknlog
```

Finally, unlike last time when we include \$(BUILD_SHARED_LIBRARY), this time we:

```
include $(BUILD_EXECUTABLE)
```

which will produce system/bin/mrknlog

14. We can compile our executable to test that it builds:

```

$ rm filelist
$ godir mrknlog.c
  [1] ./device/marakana/alpha/bin/mrknlog
  [2] ./device/marakana/alpha/lib/libmrknlog

Select one: 1
device/marakana/alpha/bin/mrknlog$ mm
...
target thumb C: mrknlog <= device/marakana/alpha/bin/mrknlog/mrknlog.c
target Executable: mrknlog (out/target/product/alpha/obj/EXECUTABLES/ ↵
    mrknlog_intermediates/LINKED/mrknlog)
target Symbolic: mrknlog (out/target/product/alpha/symbols/system/bin/mrknlog)
target Strip: mrknlog (out/target/product/alpha/obj/EXECUTABLES/mrknlog_intermediates/ ↵
    mrknlog)
Install: out/target/product/alpha/system/bin/mrknlog
...
device/marakana/alpha/bin/mrknlog$ croot
$

```

15. Just like with our library, since our executable's Android.mk states LOCAL_MODULE_TAGS := optional, we need to register it with Alpha's PRODUCT_PACKAGES, or otherwise it will not be included in the final ROM:

device/marakana/alpha/common.mk

```
...
PRODUCT_PACKAGES += mrknlog
```

16. Now we can rebuild our entire device:

```
$ make -j10
...
Install system fs image: out/target/product/alpha/system.img
```

17. Finally, we are ready to test our library/executable:

```
# (re)start the emulator
$ out/host/linux-x86/bin/emulator -kernel out/target/product/alpha/kernel &
# wait for the emulator to finish
# check out our library
$ adb shell ls -l /system/lib/libmrknlog.so
-rw-r--r-- root    root          5468 2012-01-04 10:02 libmrknlog.so
# check out our utility
$ adb shell ls -l /system/bin/mrknlog
-rwxr-xr-x root    shell         5612 2012-01-04 10:20 mrknlog
# check if our utility is doing what it is supposed to
$ adb logcat -g
/dev/log/main: ring buffer is 64Kb (54Kb consumed), max entry is 4096b, max payload is ←
4076b
$ adb shell /system/bin/mrknlog
Flushed log. Previously it was consuming 55981 of 65536 bytes
$ adb logcat -g
/dev/log/main: ring buffer is 64Kb (0Kb consumed), max entry is 4096b, max payload is ←
4076b
# check again
$ adb shell /system/bin/mrknlog
Flushed log. Previously it was consuming 0 of 65536 bytes
# good :-)
```

9.8 Using our Native Library via a Custom Daemon

- Having a custom utility `mrknlog` is fine, but what if we wanted to have it run periodically, to flush the log buffers at a regular interval - we'd need a daemon
- As we discussed before, daemons are executables (e.g. `mrknlogd`) generally started by `init` (from `init.rc`) as `services`
- Let's get started:
 1. As before, we need to create a home for our daemon source:

```
$ mkdir device/marakana/alpha/bin/mrknlogd
```

2. Next, we create our daemon source (`mrknlogd.c`), by utilizing our `libmrknlog` library:

device/marakana/alpha/bin/mrknlogd/mrknlogd.c

```
#define LOG_TAG "MRKN Log Daemon"

#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <utils/Log.h>
#include <libmrknlog.h>
```

```

int main (int argc, char* argv[]) {
    if (argc != 2) {
        fprintf(stderr, "Usage: %s <flush-frequency-in-seconds>\n", argv[0]);
        exit(2);
    } else {
        int frequency = atoi(argv[1]);
        int totalSize = mrkn_get_total_log_size();
        int usedSize;
        int count = 1;
        while(1) {
            usedSize = mrkn_get_used_log_size();
            if (mrkn_flush_log() == 0) {
                LOGI("Flushed log (%d, %d of %d bytes). Waiting %d seconds before the next flush.",
                    count, usedSize, totalSize, frequency);
                count++;
            } else {
                LOGE("Failed to flush log. Waiting %d seconds before the next attempt",
                    frequency);
            }
            sleep(frequency);
        }
    }
}

```

Note

This program is designed to run as a "daemon" simply by running infinitely in a `while(1) { ... }` block.

Tip

We can use `LOGI()`, `LOGE()`, and other such macros, which simplify logging:

```

#define LOGI(...) __android_log_print(ANDROID_LOG_INFO, LOG_TAG, __VA_ARGS__)
#define LOGE(...) __android_log_print(ANDROID_LOG_ERROR, LOG_TAG, __VA_ARGS__)

```

- Next, we create our makefile (`Android.mk`), which defines links from our source to our library:

device/marakana/alpha/bin/mrknlogd/Android.mk

```

LOCAL_PATH:= $(call my-dir)

include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := mrknlogd.c
LOCAL_C_INCLUDES := $(LOCAL_PATH)/../../lib/libmrknlog/
LOCAL_SHARED_LIBRARIES := libmrknlog libcutils
LOCAL_MODULE := mrknlogd
include $(BUILD_EXECUTABLE)

```

- Now we can compile our daemon to test that it builds:

```

$ make -j10 mrknlogd
...
target Executable: mrknlogd (out/target/product/alpha/obj/EXECUTABLES/ ↵
    mrknlogd_intermediates/LINKED/mrknlogd)
target Non-prelinked: mrknlogd (out/target/product/alpha/symbols/system/bin/mrknlogd)
target Strip: mrknlogd (out/target/product/alpha/obj/EXECUTABLES/ ↵
    mrknlogd_intermediates/mrknlogd)
Install: out/target/product/alpha/system/bin/mrknlogd

```

- Just like with our previous executable/library, we need to register our daemon with Alpha's `PRODUCT_PACKAGES`, or otherwise it will not be included in the final ROM:

device/marakana/alpha/common.mk

```
...
PRODUCT_PACKAGES += mrknlogd
```

6. Before we can rebuild our ROM, we need to configure `init` to start our `mrknlogd` daemon as a service, and to do that, we need to register this in our `init.marakanaalphaboard.rc` file:

device/marakana/alpha/init.marakanaalphaboard.rc:

```
...
on boot
    ...
    start mrknlogd
...
# Marakana's custom log-flushing daemon
service mrknlogd /system/bin/mrknlogd 60
    user system
    group log
    oneshot
```

A note about security

In order to get the size of the log buffer `/dev/log/main`, we need to be able to read from this "file", and for that, we need to be either `root` or belong to group `log` (we chose the latter):

```
$ adb shell ls -l /dev/log/main
crw-rw--w- root      log          10,  57 2012-01-05 00:02 main
```

7. Now we can rebuild our entire device:

```
$ make -j10
...
build/core/Makefile:25: warning: overriding commands for target ++out/target/product/ ↵
alpha/root/init.goldfish.rc'
system/core/rootdir/Android.mk:58: warning: ignoring old commands for target ++out/ ↵
target/product/alpha/root/init.goldfish.rc'
...
Install system fs image: out/target/product/alpha/system.img
Installed file list: out/target/product/alpha/installed-files.txt
```

Note

There warnings are (unfortunately) expected because our rule to copy `init.goldfish.rc` (implemented by `build/core/Makefile`) conflicts with what Android wants to do already (in `system/core/rootdir/Android.mk`).

8. Finally, we are ready to test our daemon:

```
# (re)start the emulator
$ out/host/linux-x86/bin/emulator -kernel out/target/product/alpha/kernel &
# wait for the emulator to finish
# check out our daemon
$ adb shell ls -l /system/bin/mrknlogd
-rwxr-xr-x root      shell          5636 2012-01-04 20:52 mrknlogd
# check that it runs
$ adb shell ps | grep mrknlogd
system    44      1      772    300    c0051854 40012c74 S /system/bin/mrknlogd
$ adb logcat | grep MRKN
I/MRKN Log Daemon(  37): Flushed log (1, 60 of 65536 bytes). Waiting 60 seconds ↵
before the next flush.
```



```
I/MRKN Log Daemon( 37): Flushed log (2, 34406 of 65536 bytes). Waiting 60 seconds ↵
    before the next flush.
I/MRKN Log Daemon( 37): Flushed log (3, 232 of 65536 bytes). Waiting 60 seconds ↵
    before the next flush.
^C
$ adb logcat -g
/dev/log/main: ring buffer is 64Kb (0Kb consumed), max entry is 4096b, max payload is ↵
    4076b
# good :-)
```

9.9 Exposing our Native Library via Java (i.e. JNI)

- Our shared native library (`libmrknlog.so`) is fine if we just develop in C/C++, but to utilize its functionality in the Java layers, we need to wrap it with some JNI love
- As we discussed in Section 3 section, here we will:
 - Create a Java "library" (`com.marakana.android.lib.log.LibLog`)
 - Declare some of its methods as native (e.g. `public static native void flushLog();`)
 - Extract the C header file (`com_marakana_android_lib_log_LibLog.h`) using `javah -jniLibLog`
 - Provide the implementation (`com_marakana_android_lib_log_LibLog.c`) - where we will finally get to utilize our shared library (`libmrknlog.so`)
 - Compile our Java/JNI library as `/system/frameworks/com.marakana.android.lib.log.jar` and `/system/lib/`
 - Create a simple Java program and test that our library works

- Let's get started:

1. Since our Java/JNI library will primarily service the *Application Framework* layer, let's create a home for our framework components:

```
$ mkdir device/marakana/alpha/framework
```

2. Like with our libraries and executables, we need to "recursively" include makefiles in sub-directories of `.../framework/`, which is where our Java/JNI library will live:

device/marakana/alpha/framework/Android.mk

```
include $(call all-subdir-makefiles)
```

3. Now, let's create the home for our Java/JNI library and two sub-directories for its Java and JNI parts:

```
$ mkdir device/marakana/alpha/framework/libmrknlog_jni
$ mkdir device/marakana/alpha/framework/libmrknlog_jni/java
$ mkdir device/marakana/alpha/framework/libmrknlog_jni/jni
```

4. To include these sub-directories in the compilation (`java/` and `jni/`), we again need one of those "recursive" makefiles: **device/marakana/alpha/framework/libmrknlog_jni/Android.mk**

```
include $(call all-subdir-makefiles)
```

5. Now, let's create the directory structure that reflects our Java library's package name (`com.marakana.android.lib.log`):

```
$ mkdir -p device/marakana/alpha/framework/libmrknlog_jni/java/com/marakana/android/ ↵
    lib/log
```

6. Now let's create our Java "library" class (`LibLog.java`) and its accompanying exception (`LibLogException.java`): **device/marakana/alpha/framework/libmrknlog_jni/java/com/marakana/android/lib/log/LibLog.java**

```
package com.marakana.android.lib.log;

public class LibLog {
    public native static void flushLog() throws LibLogException;
    public native static int getTotalLogSize() throws LibLogException;
    public native static int getUsedLogSize() throws LibLogException;

    static {
        System.loadLibrary("mrknlog_jni");
    }
}
```

device/marakana/alpha/framework/libmrknlog_jni/java/com/marakana/android/lib/log/LibLogException.java

```
package com.marakana.android.lib.log;

public class LibLogException extends RuntimeException {
    public LibLogException(String msg) {
        super(msg);
    }
}
```

7. While we are at it, we might as well create a simple `Main.java` class to test our Java/JNI library:

device/marakana/alpha/framework/libmrknlog_jni/java/com/marakana/android/lib/log/Main.java

```
package com.marakana.android.lib.log;

/** @hide */
public class Main {
    public static void main (String[] args) {
        try {
            int usedSize = LibLog.getUsedLogSize();
            int totalSize = LibLog.getTotalLogSize();
            LibLog.flushLog();
            System.out.printf("Flushed log. Previously it was consuming %d of %d bytes\n",
                usedSize, totalSize);
        } catch (LibLogException e) {
            System.err.println("Failed to flush the log");
            e.printStackTrace();
        }
    }
}
```

8. For our Java/JNI library (deployed as `/system/framework/com.marakana.android.lib.log.jar`) to be accessible to the running applications, we need to explicitly expose its logical name (`com.marakana.android.lib.log`) via a simple XML mapping file (`com.marakana.android.lib.log.xml`):

device/marakana/alpha/framework/libmrknlog_jni/java/com.marakana.android.lib.log.xml

```
<?xml version="1.0" encoding="utf-8"?>
<permissions>
    <library name="com.marakana.android.lib.log"
        file="/system/framework/com.marakana.android.lib.log.jar"/>
</permissions>
```

Note

This file will be deployed as `/system/etc/permissions/com.marakana.android.lib.log.xml` in the target image and applications that wish to use our library will have to reference it in their `AndroidManifest.xml` with:

```
<uses-library android:name="com.marakana.android.lib.log" android:required="true"/>
```

9. Now we are ready for the makefile (Android.mk):

device/marakana/alpha/framework/libmrknlog_jni/java/Android.mk

```
LOCAL_PATH := $(call my-dir)

# Build the library
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_MODULE := com.marakana.android.lib.log
LOCAL_SRC_FILES := $(call all-java-files-under,.)
include $(BUILD_JAVA_LIBRARY)

# Build the documentation
include $(CLEAR_VARS)
LOCAL_SRC_FILES := $(call all-subdir-java-files) $(call all-subdir-html-files)
LOCAL_MODULE := com.marakana.android.lib.log_doc
LOCAL_DROIDDOC_OPTIONS := com.marakana.android.lib.log
LOCAL_MODULE_CLASS := JAVA_LIBRARIES
LOCAL_DROIDDOC_USE_STANDARD_DOCLET := true
include $(BUILD_DROIDDOC)

# Copy com.marakana.android.lib.log.xml to /system/etc/permissions/
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_MODULE := com.marakana.android.lib.log.xml
LOCAL_MODULE_CLASS := ETC
LOCAL_MODULE_PATH := $(TARGET_OUT_ETC)/permissions
LOCAL_SRC_FILES := $(LOCAL_MODULE)
include $(BUILD_PREBUILT)
```

Note

In this one file, we have three separate targets: to compile the code, to build the documentation (used by the SDK addon), and to copy the `com.marakana.android.lib.log.xml` file to `/system/etc/permissions/` (though this last one seems a too fancy for a simple copy command). Notice that we separate these three targets using the `include $(CLEAR_VARS)` macro.

10. Compile:

```
$ cd device/marakana/alpha/framework/libmrknlog_jni/java
device/marakana/alpha/framework/libmrknlog_jni/java$ mm com.marakana.android.lib.log ↵
com.marakana.android.lib.log.xml
...
target Java: com.marakana.android.lib.log
...
Copying: out/target/common/obj/JAVA_LIBRARIES/com.marakana.android.lib. ↵
log_intermediates/classes.jar
...
Install: out/target/product/alpha/system/framework/com.marakana.android.lib.log.jar
target Prebuilt: com.marakana.android.lib.log.xml (out/target/product/alpha/obj/ETC/ ↵
com.marakana.android.lib.log.xml_intermediates/com.marakana.android.lib.log.xml)
Install: out/target/product/alpha/system/etc/permissions/com.marakana.android.lib.log. ↵
xml
...
device/marakana/alpha/framework/libmrknlog_jni/java$ croot
$
```

11. Next, we need create the C header file for our library (using the `javah -jni` command), and fortunately we can re-use the compiled classes left for us in the `out/` directory by the previous step:

```
$ javah -jni \
```

```
-d device/marakana/alpha/framework/libmrknlog_jni/jni/ \
-classpath out/target/common/obj/JAVA_LIBRARIES/com.marakana.android.lib. ↵
    log_intermediates/classes.jar \
    com.marakana.android.lib.log.LibLog
```

12. To check that it worked, we can take a look at the generated C header file (`..._LibLog.h`):

device/marakana/alpha/framework/libmrknlog_jni/jni/com_marakana_android_lib_log_LibLog.h

```
...
JNIEXPORT void JNICALL Java_com_marakana_android_lib_log_LibLog_flushLog
    (JNIEnv *, jclass);
...
JNIEXPORT jint JNICALL Java_com_marakana_android_lib_log_LibLog_getTotalLogSize
    (JNIEnv *, jclass);
...
JNIEXPORT jint JNICALL Java_com_marakana_android_lib_log_LibLog_getUsedLogSize
    (JNIEnv *, jclass);
...
```

13. Now we can provide our implementation (`...LibLog.c`), which simply wraps calls to functions from `libmrknlog` and provides some basic error handling:

device/marakana/alpha/framework/libmrknlog_jni/jni/com_marakana_android_lib_log_LibLog.c

```
#include <libmrknlog.h>
#include "com_marakana_android_lib_log_LibLog.h"

static void ThrowLibLogException(JNIEnv *env, const char *message) {
    jclass class = (*env)->FindClass(env, "com/marakana/android/lib/log/LibLogException" ↵
    );
    if (class) {
        (*env)->ThrowNew(env, class, message);
        (*env)->DeleteLocalRef(env, class);
    }
}

JNIEXPORT void JNICALL Java_com_marakana_android_lib_log_LibLog_flushLog
    (JNIEnv *env, jclass clazz) {
    if (mrkn_flush_log() != 0) {
        ThrowLibLogException(env, "Failed to flush log");
    }
}

JNIEXPORT jint JNICALL Java_com_marakana_android_lib_log_LibLog_getTotalLogSize
    (JNIEnv *env, jclass clazz) {
    jint result = mrkn_get_total_log_size();
    if (result < 0) {
        ThrowLibLogException(env, "Failed to get total log size");
    }
    return result;
}

JNIEXPORT jint JNICALL Java_com_marakana_android_lib_log_LibLog_getUsedLogSize
    (JNIEnv *env, jclass clazz) {
    jint result = mrkn_get_used_log_size();
    if (result < 0) {
        ThrowLibLogException(env, "Failed to get used log size");
    }
    return result;
}
```

14. Next, we create a makefile (`Android.mk`) to compile our JNI code into a shared library (`libmrknlog_jni.so`):

device/marakana/alpha/framework/libmrknlog_jni/jni/Android.mk

```

LOCAL_PATH:= $(call my-dir)
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := com_marakana_android_lib_log_LibLog.c
LOCAL_C_INCLUDES += $(JNI_H_INCLUDE) $(LOCAL_PATH)/../../../../lib/libmrknlog
LOCAL_SHARED_LIBRARIES := libmrknlog
LOCAL_MODULE := libmrknlog_jni
include $(BUILD_SHARED_LIBRARY)

```

Note

As with `libmrknlog.so`, in previous versions of Android (pre-4.0) we would have had to also specify `LOCAL_PRELINK_MODULE := false` to disable pre-linking of our shared library.

15. Now we have all the pieces to compile our JNI library (into `/system/lib/libmrknlog_jni.so`):

```

$ cd device/marakana/alpha/framework/libmrknlog_jni/jni
device/marakana/alpha/framework/libmrknlog_jni/jni$ mm
...
Install: out/target/product/alpha/system/lib/libmrknlog_jni.so
device/marakana/alpha/framework/libmrknlog_jni/jni$ croot
$

```

16. As before, since our Java/JNI library's components are marked as `LOCAL_MODULE_TAGS := optional`, in order to get them into the final ROM, we need to register them with Alpha's `PRODUCT_PACKAGES`:

device/marakana/alpha/common.mk

```

...
PRODUCT_PACKAGES += \
    com.marakana.android.lib.log \
    com.marakana.android.lib.log.xml \
    libmrknlog_jni

```

17. Now we can rebuild our entire device:

```

$ make -j10
...
Install system fs image: out/target/product/alpha/system.img

```

18. Finally, we are ready to test our Java/JNI library via the `Main.main()` method:

```

# (re)start the emulator
$ out/host/linux-x86/bin/emulator -kernel out/target/product/alpha/kernel &
# wait for the emulator to finish
# check out our Java library
$ adb shell ls -l /system/framework/com.marakana.android.lib.log.jar
-rw-r--r-- root    root          313 2012-01-05 00:47 com.marakana.android.lib.log. ↵
    jar
# check out our Java library registry file
$ adb shell ls -l /system/etc/permissions/com.marakana.android.lib.log.xml
-rw-r--r-- root    root          180 2012-01-05 00:47 com.marakana.android.lib.log. ↵
    xml
# check out our JNI shared library
$ adb shell ls -l /system/lib/libmrknlog_jni.so
-rw-r--r-- root    root        5452 2012-01-05 00:54 libmrknlog_jni.so
# check if our utility is doing what it is supposed to
$ adb logcat -g
/dev/log/main: ring buffer is 64Kb (33Kb consumed), max entry is 4096b, max payload is ↵
    4076b
# now run our Java library's Main.main() by directly invoking the Dalvik VM

```

```
$ adb shell dalvikvm -cp /system/framework/com.marakana.android.lib.log.jar com. ↵
marakana.android.lib.log.Main
Flushed log. Previously it was consuming 34346 of 65536 bytes
# check again
$ adb logcat -g
/dev/log/main: ring buffer is 64Kb (0Kb consumed), max entry is 4096b, max payload is ↵
4076b
$ adb shell dalvikvm -cp /system/framework/com.marakana.android.lib.log.jar com. ↵
marakana.android.lib.log.Main
Flushed log. Previously it was consuming 318 of 65536 bytes
# good :-)
```

9.10 Consuming our a Custom Java/JNI→Native Library via a Custom App (Optional)

- Now that we have a native library, and a JNI wrapper around it, we could create a custom application to take advantage of its services
- Note that we will later wrap the JNI library with a client-service Binder library/solution, so the app we are creating now is just for demonstration purposes - not the final "solution"
- Let's get started:

1. Create a home directory for our Alpha apps:

```
$ mkdir -p device/marakana/alpha/app/
```

Note

This app will not be shared with the SDK add-on.

2. As we should know by now, we need a makefile (Android.mk) to include app/'s the sub-directories:

device/marakana/alpha/app/Android.mk

```
include $(call all-subdir-makefiles)
```

3. Now we can create a sub-directory for our app (MrknLogLibClient), its basic directory structure (res/, and src/), and the source package (com.marakana.android.loglibclient) directory structure:

```
$ mkdir -p device/marakana/alpha/app/MrknLogLibClient/res/values
$ mkdir -p device/marakana/alpha/app/MrknLogLibClient/res/layout
$ mkdir -p device/marakana/alpha/app/MrknLogLibClient/src/com/marakana/android/ ↵
loglibclient
```

4. We need some basic string resources (used in the UI):

device/marakana/alpha/app/MrknLogLibClient/res/values/strings.xml

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
  <string name="app_name">Marakana Log Lib Client</string>
  <string name="log_utilization_message">Using %1$d of %2$d bytes of the log buffer< ↵
    /string>
  <string name="flush_log_button">Flush Log Buffer</string>
</resources>
```

5. And we also need a simple layout (log.xml), with a text view, to show the current log utilization, and a button, to allow us to clear the log:

device/marakana/alpha/app/MrknLogLibClient/res/layout/log.xml

```
<?xml version="1.0" encoding="utf-8"?>
<LinearLayout xmlns:android="http://schemas.android.com/apk/res/android"
    android:orientation="vertical" android:layout_width="fill_parent"
    android:layout_height="fill_parent">
    <TextView android:layout_width="fill_parent" android:layout_height="wrap_content"
        android:gravity="center" android:id="@+id/output" />
    <Button android:layout_width="fill_parent" android:layout_height="wrap_content"
        android:id="@+id/button" android:text="@string/flush_log_button"/>
</LinearLayout>
```

6. Now, we are ready to write our one-and only activity (LogActivity) utilizing `com.marakana.android.lib.log` Java/JNI library:

device/marakana/alpha/app/MrknLogLibClient/src/com/marakana/android/loglibclient/LogActivity.java

```
package com.marakana.android.loglibclient;

import android.app.Activity;
import android.os.Bundle;
import android.os.Handler;
import android.view.View;
import android.widget.Button;
import android.widget.TextView;
import com.marakana.android.lib.log.LibLog;

public class LogActivity extends Activity
    implements View.OnClickListener, Runnable {

    private TextView output;
    private Handler handler;

    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        super setContentView(R.layout.log);
        this.output = (TextView) super.findViewById(R.id.output);
        Button button = (Button) super.findViewById(R.id.button);
        button.setOnClickListener(this);
        this.handler = new Handler();
    }

    private void updateOutput() {
        this.output.setText(
            super.getString(R.string.log_utilization_message,
                LibLog.getUsedLogSize(), LibLog.getTotalLogSize()));
    }

    @Override
    public void onResume() {
        super.onResume();
        this.handler.post(this);
    }

    @Override
    public void onPause() {
        super.onPause();
        this.handler.removeCallbacks(this);
    }

    public void onClick(View view) {
        LibLog.flushLog();
        this.updateOutput();
    }
}
```

```

public void run() {
    this.updateOutput();
    this.handler.postDelayed(this, 1000);
}
}

```

Note

Our activity uses a handler in order to request periodic (1 Hz) call-backs to the `run()` method, via which we simply update our UI with the log utilization data.

7. And, like any other app, we need to provide our own `AndroidManifest.xml` configuration file:

device/marakana/alpha/app/MrknLogLibClient/AndroidManifest.xml

```

<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.marakana.android.loglibclient"
    android:versionCode="1"
    android:versionName="1.0">
    <uses-sdk android:minSdkVersion="8" />
    <uses-permission android:name="android.permission.READ_LOGS"/>
    <application android:label="@string/app_name">
        <uses-library android:name="com.marakana.android.lib.log" android:required="true"/>
        <activity android:name=".LogActivity" android:label="@string/app_name">
            <intent-filter>
                <action android:name="android.intent.action.MAIN" />
                <category android:name="android.intent.category.LAUNCHER" />
            </intent-filter>
        </activity>
    </application>
</manifest>

```

Note

We need `<uses-permission android:name="android.permission.READ_LOGS"/>` so that our app's user ID gets added to the log group membership, or otherwise we won't be able to read from `/dev/log/main` (as discussed earlier).

Additionally, we added `<uses-library android:name="com.marakana.android.lib.log" android:required="true"/>` so that we get run-time access to the `com.marakana.android.lib.log` library.

8. And, like any other component, our app also needs its own makefile (`Android.mk`):

device/marakana/alpha/app/MrknLogLibClient/Android.mk

```

LOCAL_PATH:= $(call my-dir)
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := $(call all-java-files-under,src)
LOCAL_JAVA_LIBRARIES := com.marakana.android.lib.log
LOCAL_PACKAGE_NAME := MrknLogLibClient
LOCAL_SDK_VERSION := current
LOCAL_PROGUARD_ENABLED := disabled
include $(BUILD_PACKAGE)

```

Note

We are referencing our `com.marakana.android.lib.log` library here as well, for the sake of the compiler. Also, notice that we are using `include $(BUILD_PACKAGE)` in order to build our code as an app.

9. And, also like any other component that we wish to include in our ROM, we need to register `MrknLogLibClient` with the device's main makefile (`full_alpha.xml`):

device/marakana/alpha/full_alpha.mk

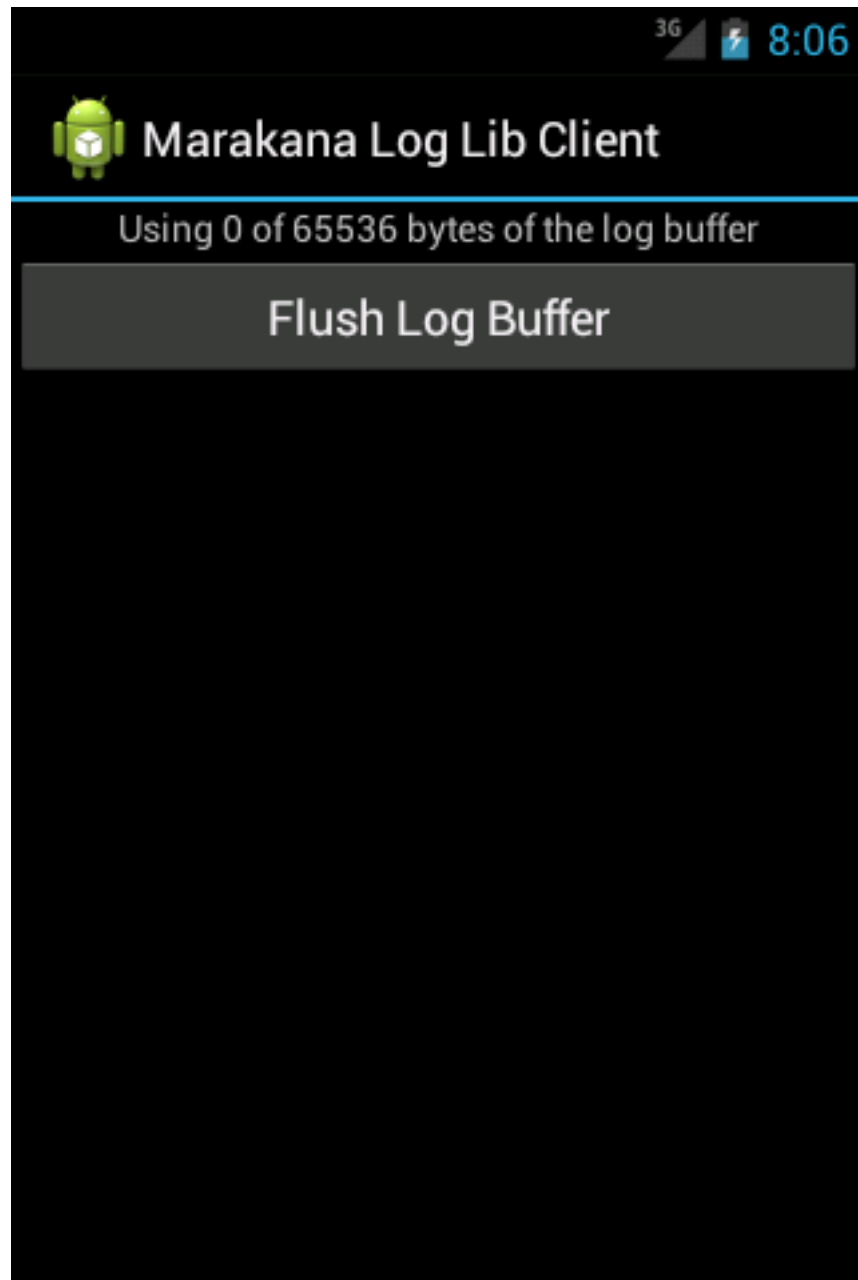
```
...  
PRODUCT_PACKAGES += MrknLogLibClient
```

10. Now we can compile it:

```
$ make -j10  
...  
Install: out/target/product/alpha/system/app/MrknLogLibClient.apk  
...  
Install system fs image: out/target/product/alpha/system.img
```

11. And finally, we can test everything:

- a. Restart the emulator
- b. Launch the Marakana Log Lib Client app
- c. Test that you can flush the log buffer



9.11 Exposing our Custom Library via a Custom IPC/Binder Service

- Let's suppose that we were able to control access to our "driver" (even though it is not really ours), such that:
 - The "read" operations (getting the used/total sizes of the log buffer) are implicitly permitted
 - The "write" operation (flushing the log buffer) requires an explicit permission check
- We can do this by wrapping "our driver" (and the custom library that enables these operations) with:
 - A custom Binder-based service where we control access to the driver
 - A custom Java-based manager (library) where we enable transparent access to our service
- Let's get started:
 1. We'll start off by creating a directory structure for the custom manager library, since that's where our service descriptor (`ILogService.aidl`) is going to live:

```
$ mkdir device/marakana/alpha/framework/mrknlogservice
$ mkdir -p device/marakana/alpha/framework/mrknlogservice/com/marakana/android/service ↔
/log
```

2. Let's create a simple AIDL description of our service (LibLogService.aidl):

device/marakana/alpha/framework/mrknlogservice/com/marakana/android/service/log/ILogService.aidl

```
package com.marakana.android.service.log;

/**
 * System-private API for talking to the LogService.
 *
 * {@hide}
 */
interface ILogService {
    void flushLog();
    int getTotalLogSize();
    int getUsedLogSize();
}
```

Note

Notice that the methods described by ILogService.aidl closely match what our LibLog JNI-bridge provides. Also, we are using {@hide} to *hide* our AIDL interface from the documentation we'll be producing later for our SDK addon. Why hide it? Because the clients will use our service via a manager proxy that we'll be creating next.

3. We don't want to force the "complexity" of Binder upon our clients, so we provide them with a convenience LogManager proxy to our (yet-to-be-created) service:

device/marakana/alpha/framework/mrknlogservice/com/marakana/android/service/log/LogManager.java

```
package com.marakana.android.service.log;

import android.os.IBinder;
import android.os.RemoteException;
import android.os.ServiceManager;
import android.util.Log;

public class LogManager {
    private static final String TAG = "LogManager";
    private static final String REMOTE_SERVICE_NAME = ILogService.class.getName();
    private final ILogService service;

    public static LogManager getInstance() {
        return new LogManager();
    }

    private LogManager() {
        Log.d(TAG, "Connecting to ILogService by name [" + REMOTE_SERVICE_NAME + "]");
        this.service = ILogService.Stub.asInterface(ServiceManager.getService(↔
            REMOTE_SERVICE_NAME));
        if (this.service == null) {
            throw new IllegalStateException("Failed to find ILogService by name [" + ↔
                REMOTE_SERVICE_NAME + "]");
        }
    }

    public void flushLog() {
        try {
            Log.d(TAG, "Flushing logs. If it works, you won't see this message.");
            this.service.flushLog();
        }
    }
}
```

```

    } catch (RemoteException e) {
        throw new RuntimeException("Failed to flush log", e);
    }
}

public int getTotalLogSize() {
    try {
        return this.service.getTotalLogSize();
    } catch (RemoteException e) {
        throw new RuntimeException("Failed to get total log size", e);
    }
}

public int getUsedLogSize() {
    try {
        return this.service.getUsedLogSize();
    } catch (Exception e) {
        throw new RuntimeException("Failed to get used log size", e);
    }
}
}

```

Note

We are using `android.os.ServiceManager` to lookup an object providing `ILogService` implementation. This is going to be our service, which we yet have to create and register with the service-manager.

4. For our clients to access `LogManager`, we need to expose it as a Java library - so we create an XML descriptor for it: **device/marakana/alpha/framework/mrknlogservice/com.marakana.android.service.log.xml**

```

<?xml version="1.0" encoding="utf-8"?>
<permissions>
  <library name="com.marakana.android.service.log"
    file="/system/framework/com.marakana.android.service.log.jar"/>
</permissions>

```

5. Now we are ready ready to create a makefile (`Android.mk`) with rules to compile our library, build its documentation, and copy its `com.marakana.android.service.log.xml` descriptor to `/system/etc/permissions/`: **device/marakana/alpha/framework/mrknlogservice/Android.mk**

```

LOCAL_PATH := $(call my-dir)

# Build the library
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_MODULE := com.marakana.android.service.log
LOCAL_SRC_FILES := $(call all-java-files-under,.)
LOCAL_SRC_FILES += com/marakana/android/service/log/ILogService.aidl
include $(BUILD_JAVA_LIBRARY)

# Build the documentation
include $(CLEAR_VARS)
LOCAL_SRC_FILES := $(call all-subdir-java-files) $(call all-subdir-html-files)
LOCAL_MODULE:= com.marakana.android.service.log_doc
LOCAL_DROIDDOC_OPTIONS := com.marakana.android.service.log
LOCAL_MODULE_CLASS := JAVA_LIBRARIES
LOCAL_DROIDDOC_USE_STANDARD_DOCLET := true
include $(BUILD_DROIDDOC)

# Copy com.marakana.android.service.log.xml to /system/etc/permissions/
include $(CLEAR_VARS)

```

```
LOCAL_MODULE_TAGS := optional
LOCAL_MODULE := com.marakana.android.service.log.xml
LOCAL_MODULE_CLASS := ETC
LOCAL_MODULE_PATH := $(TARGET_OUT_ETC)/permissions
LOCAL_SRC_FILES := $(LOCAL_MODULE)
include $(BUILD_PREBUILT)
```

6. To test that we did everything correctly, we can compile our library:

```
$ cd device/marakana/alpha/framework/mrknlogservice
device/marakana/alpha/framework/mrknlogservice$ mm -j10 com.marakana.android.service. ↵
log com.marakana.android.service.log.xml
...
Aidl: com.marakana.android.service.log <= device/marakana/alpha/framework/ ↵
mrknlogservice/com/marakana/android/service/log/ILogService.aidl
...
Install: out/target/product/alpha/system/framework/com.marakana.android.service.log. ↵
jar
...
Install: out/target/product/alpha/system/etc/permissions/com.marakana.android.service. ↵
log.xml
...
device/marakana/alpha/framework/mrknlogservice$ croot
$
```

7. For our `com.marakana.android.service.log` library to be included in the final ROM, we need to add it to the `common.mk` makefile:

device/marakana/alpha/common.mk

```
...
PRODUCT_PACKAGES += \
    com.marakana.android.service.log \
    com.marakana.android.service.log.xml
```

8. Now we can create our `MrknLogService`, which will implement `ILogService`, but since we'll define our service as an *application*, we need first to create a directory for alpha apps:

```
$ mkdir -p device/marakana/alpha/app/
```

Note

This directory may already exist if we created `MrknLogLibClient` app before (this was optional).

9. And, as we know by now, we need a makefile to include `app/`'s sub-directories into the build:

device/marakana/alpha/app/Android.mk

```
include $(call all-subdir-makefiles)
```

Note

This file may already exist if we created `MrknLogLibClient` app before (this was optional).

10. Next, we create a directory for our service (`MrknLogService`), its basic directory structure (`res/`, and `src/`), and the source package (`com.marakana.android.loglibclient`) directory structure:

```
$ mkdir -p device/marakana/alpha/app/MrknLogService/res/values
$ mkdir -p device/marakana/alpha/app/MrknLogService/src/com/marakana/android/ ↵
logservice
```

11. We need some basic string resources:

device/marakana/alpha/app/MrknLogService/res/values/strings.xml

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
  <string name="flush_log_permission_label">Flush Log</string>
  <string name="flush_log_permission_description">Applications with this permission ↵
    will be able
    to clear the logs, potentially covering their own tracks of malicious behavior.</ ↵
    string>
</resources>
```

Note

These strings are used for our custom permission that we'll be creating next.

12. Next, let's define our app's `AndroidManifest.xml` file:

device/marakana/alpha/app/MrknLogService/AndroidManifest.xml

```
<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
  package="com.marakana.android.logservice"
  android:versionCode="1"
  android:versionName="1.0"
  android:sharedUserId="android.uid.system">
  <uses-sdk android:minSdkVersion="8" />
  <uses-permission android:name="android.permission.READ_LOGS"/>
  <application android:name=".LogServiceApp" android:persistent="true">
    <uses-library android:name="com.marakana.android.service.log" android:required=" ↵
      true"/>
    <uses-library android:name="com.marakana.android.lib.log" android:required="true"/ ↵
    >
  </application>
  <permission android:name="com.marakana.android.logservice.FLUSH_LOG"
    android:protectionLevel="dangerous"
    android:permissionGroup="android.permission-group.SYSTEM_TOOLS"
    android:label="@string/flush_log_permission_label"
    android:description="@string/flush_log_permission_description"/>
</manifest>
```

Note

In this manifest file, there are a few items of interest:

We required that our app run with the system user (so that we can access the `ServiceManager` ⇒ `/system/bin/service_manager`) by adding `android:sharedUserId="android.uid.system"` attribute to the manifest. This is enforced by `frameworks/base/cmds/service_manager/service_manager.c:svc_can_register(...)`.

We gave ourselves access to the log group (so that we can read from `/dev/log/main`) with the `<uses-permission android:name="android.permission.READ_LOGS"/>` entry.

We defined a custom `LogServiceApp` application class, which once loaded, will in turn load our service (`ILogServiceImpl`) and register it with the `ServiceManager`. We defined our application as `android:persistent="true"`, which means that the `ActivityManager` will automatically launch it on boot, and it will never demote its importance (`/proc/<our-service-app-pid>/oom_adj=-12`), so `ActivityManagerService` and the low memory killer will never kill it. Additionally, gave our application access to `com.marakana.android.service.log` library to get access to `ILogService` interface and `com.marakana.android.lib.log` library to get access to `LibLog` JNI bridge.

Finally, we defined our custom permission (`...FLUSH_LOG`), which we'll later enforce in our service class implementation (`ILogServiceImpl`).

13. Now we can provide the implementation `ILogServiceImpl` for our AIDL-defined interface (`ILogService`) we created earlier:

device/marakana/alpha/app/MrknLogService/src/com/marakana/android/logservice/ILogServiceImpl.java

```
package com.marakana.android.logservice;

import android.content.Context;
import android.content.pm.PackageManager;
import android.os.RemoteException;
import android.util.Log;
import com.marakana.android.service.log.ILogService;
import com.marakana.android.lib.log.LibLog;

class ILogServiceImpl extends ILogService.Stub {
    private static final String TAG = "ILogServiceImpl";
    private final Context context;

    ILogServiceImpl(Context context) {
        this.context = context;
    }

    public void flushLog() throws RemoteException {
        if (this.context.checkCallingOrSelfPermission(Manifest.permission.FLUSH_LOG) !=
            PackageManager.PERMISSION_GRANTED) {
            throw new SecurityException("Requires FLUSH_LOG permission");
        }
        Log.d(TAG, "Flushing logs. If it works, you won't see this message.");
        LibLog.flushLog();
    }

    public int getUsedLogSize() throws RemoteException {
        return LibLog.getUsedLogSize();
    }

    public int getTotalLogSize() throws RemoteException {
        return LibLog.getTotalLogSize();
    }
}
```

Note

For the most part, our service simply wraps our JNI library, except that it requires that the caller be granted our custom `Manifest.permission.FLUSH_LOG` permission before calling the `LibLog.flushLog()` method.

14. For our `ILogServiceImpl` to be accessible to our `LogManager`, we need to instantiate it and register it with the `ServiceManager` - we do this in our custom `LogServiceApp` application class loaded from the manifest file:

device/marakana/alpha/app/MrknLogService/src/com/marakana/android/logservice/LogServiceApp.java

```
package com.marakana.android.logservice;

import android.app.Application;
import android.os.ServiceManager;
import android.util.Log;
import com.marakana.android.service.log.ILogService;

public class LogServiceApp extends Application {
    private static final String TAG = "LogServiceApp";
    private static final String REMOTE_SERVICE_NAME = ILogService.class.getName();
    private ILogServiceImpl serviceImpl;

    public void onCreate() {
```

```

    super.onCreate();
    this.serviceImpl = new ILogServiceImpl(this);
    ServiceManager.addService(REMOTE_SERVICE_NAME, this.serviceImpl);
    Log.d(TAG, "Registered [" + serviceImpl.getClass().getName() + "] as [" + ↵
        REMOTE_SERVICE_NAME + "]);
}

public void onTerminate() {
    super.onTerminate();
    Log.d(TAG, "Terminated");
}
}

```

Note

Normally, regular applications cannot get access to `ServiceManager` class (because it is hidden) nor to the `servicemanager` daemon (because it enforces UID-based restrictions). To work around these limitations, we'll compile our app with the framework classes (where `ServiceManager` is *not* hidden), and run it with the system user (which *does* have access to `servicemanager` daemon).

15. We are now ready for our makefile (Android.mk):

device/marakana/alpha/app/MrknLogService/Android.mk

```

LOCAL_PATH:= $(call my-dir)
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := $(call all-java-files-under,src)
LOCAL_REQUIRED_MODULES := \
    com.marakana.android.service.log \
    com.marakana.android.lib.log
LOCAL_JAVA_LIBRARIES := \
    com.marakana.android.service.log \
    com.marakana.android.lib.log \
    core \
    framework
LOCAL_PACKAGE_NAME := MrknLogService
LOCAL_SDK_VERSION := current
LOCAL_PROGUARD_ENABLED := disabled
LOCAL_CERTIFICATE := platform
include $(BUILD_PACKAGE)

```

Note

The setting `LOCAL_JAVA_LIBRARIES := ... framework` allows us to reference `ServiceManager` and `LOCAL_CERTIFICATE := platform` makes it possible for us to run with the system user and thereby access the `servicemanager` daemon.

16. Let's compile our code:

```

$ cd device/marakana/alpha/app/MrknLogService
device/marakana/alpha/app/MrknLogService$ mm
...
Install: out/target/product/alpha/system/app/MrknLogService.apk
device/marakana/alpha/app/MrknLogService$ croot
$

```

17. We want our `MrknLogService` to be included in the final ROM, so we add it to `common.mk`:

device/marakana/alpha/common.mk

```

...
PRODUCT_PACKAGES += MrknLogService

```


18. Compile the entire device:

```
$ make -j10
...
Install system fs image: out/target/product/alpha/system.img
```

19. It's best to test our new manager→service→library→driver proxy via a real application, so that's what we'll be creating next.

9.12 Building a Custom App Using a Custom Service Manager

- Similar to how we implemented `MrknLogLibClient` app, we are now going to create a new app (`MrknLogServiceClient`), that will take advantage of our IPC/Binder-based APIs
- Since most of the steps are going to be very similar, we'll focus only on the parts that are different:

1. Create a new directory for our new app (`MrknLogServiceClient`), its basic directory structure (`res/`, and `src/`), and the source package (`com.marakana.android.logserviceclient`) directory structure:

```
$ mkdir -p device/marakana/alpha/app/MrknLogServiceClient/res/values
$ mkdir -p device/marakana/alpha/app/MrknLogServiceClient/res/layout
$ mkdir -p device/marakana/alpha/app/MrknLogServiceClient/src/com/marakana/android/ ↵
logserviceclient
```

2. Just like before, we need some basic string resources (used in the UI):

device/marakana/alpha/app/MrknLogServiceClient/res/values/strings.xml

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
  <string name="app_name">Marakana Log Service Client</string>
  <string name="log_utilization_message">Using %1$d of %2$d bytes of the log buffer</ ↵
  string>
  <string name="flush_log_button">Flush Log Buffer</string>
</resources>
```

3. And we also need a simple layout (`log.xml`), which is exactly the same as the one we created for `MrknLogLibClient` before:

device/marakana/alpha/app/MrknLogServiceClient/res/layout/log.xml

```
<?xml version="1.0" encoding="utf-8"?>
<LinearLayout xmlns:android="http://schemas.android.com/apk/res/android"
  android:orientation="vertical" android:layout_width="fill_parent"
  android:layout_height="fill_parent">
  <TextView android:layout_width="fill_parent" android:layout_height="wrap_content"
    android:gravity="center" android:id="@+id/output" />
  <Button android:layout_width="fill_parent" android:layout_height="wrap_content"
    android:id="@+id/button" android:text="@string/flush_log_button"/>
</LinearLayout>
```

4. Our activity (`LogActivity`) will be similar to the one we wrote before, except that in this case will be using `com.marakana . Java (Binder) library` and its `LogManager` APIs:

device/marakana/alpha/app/MrknLogServiceClient/src/com/marakana/android/logserviceclient/LogActivity.java

```
package com.marakana.android.logserviceclient;

import android.app.Activity;
import android.os.Bundle;
import android.os.Handler;
import android.view.View;
import android.view.View.OnClickListener;
import android.widget.Button;
```

```

import android.widget.TextView;

import com.marakana.android.service.log.LogManager;

public class LogActivity extends Activity implements Runnable, OnClickListener {

    private TextView output;

    private Handler handler;

    private LogManager logManager;

    public void onCreate(Bundle savedInstanceState) {
        this.logManager = LogManager.getInstance();
        super.onCreate(savedInstanceState);
        super setContentView(R.layout.log);
        this.output = (TextView) super.findViewById(R.id.output);
        Button button = (Button) super.findViewById(R.id.button);
        button.setOnClickListener(this);
        this.handler = new Handler();
    }

    private void updateOutput() {
        this.output.setText(super.getString(R.string.log_utilization_message,
            this.logManager.getUsedLogSize(), this.logManager.getTotalLogSize()));
    }

    @Override
    public void onResume() {
        super.onResume();
        this.handler.post(this);
    }

    @Override
    public void onPause() {
        super.onPause();
        this.handler.removeCallbacks(this);
    }

    public void onClick(View view) {
        this.logManager.flushLog();
        this.updateOutput();
    }

    public void run() {
        this.updateOutput();
        this.handler.postDelayed(this, 1000);
    }
}

```

5. Like before, we need a `AndroidManifest.xml` file, but this time around we are using the `...FLUSH_LOG` permission, and `com.marakana.android.service.log` library:

device/marakana/alpha/app/MrknLogServiceClient/AndroidManifest.xml

```

<?xml version="1.0" encoding="utf-8"?>
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.marakana.android.logserviceclient"
    android:versionCode="1" android:versionName="1.0">
    <uses-sdk android:minSdkVersion="8" />
    <uses-permission android:name="com.marakana.android.logservice.FLUSH_LOG" />
    <application android:label="@string/app_name">
        <uses-library android:name="com.marakana.android.service.log"

```

```

        android:required="true" />
    <activity android:name=".LogActivity"
        android:label="@string/app_name">
        <intent-filter>
            <action android:name="android.intent.action.MAIN" />
            <category android:name="android.intent.category.LAUNCHER" />
        </intent-filter>
    </activity>
</application>
</manifest>

```

6. And, also like before, our app needs its own makefile (Android.mk):

device/marakana/alpha/app/MrknLogServiceClient/Android.mk

```

LOCAL_PATH:= $(call my-dir)
include $(CLEAR_VARS)
LOCAL_MODULE_TAGS := optional
LOCAL_SRC_FILES := $(call all-java-files-under,src)
LOCAL_JAVA_LIBRARIES := com.marakana.android.service.log
LOCAL_PACKAGE_NAME := MrknLogServiceClient
LOCAL_SDK_VERSION := current
LOCAL_PROGUARD_ENABLED := disabled
include $(BUILD_PACKAGE)

```

Note

We are referencing our `com.marakana.android.service.log` library here as well, for the sake of the compiler.

7. And, as before, we need to register `MrknLogServiceClient` with the device's main makefile (`full_alpha.xml`) in order to get it included in the ROM:

device/marakana/alpha/full_alpha.mk

```

...
PRODUCT_PACKAGES += MrknLogServiceClient

```

8. Now we can compile our entire device:

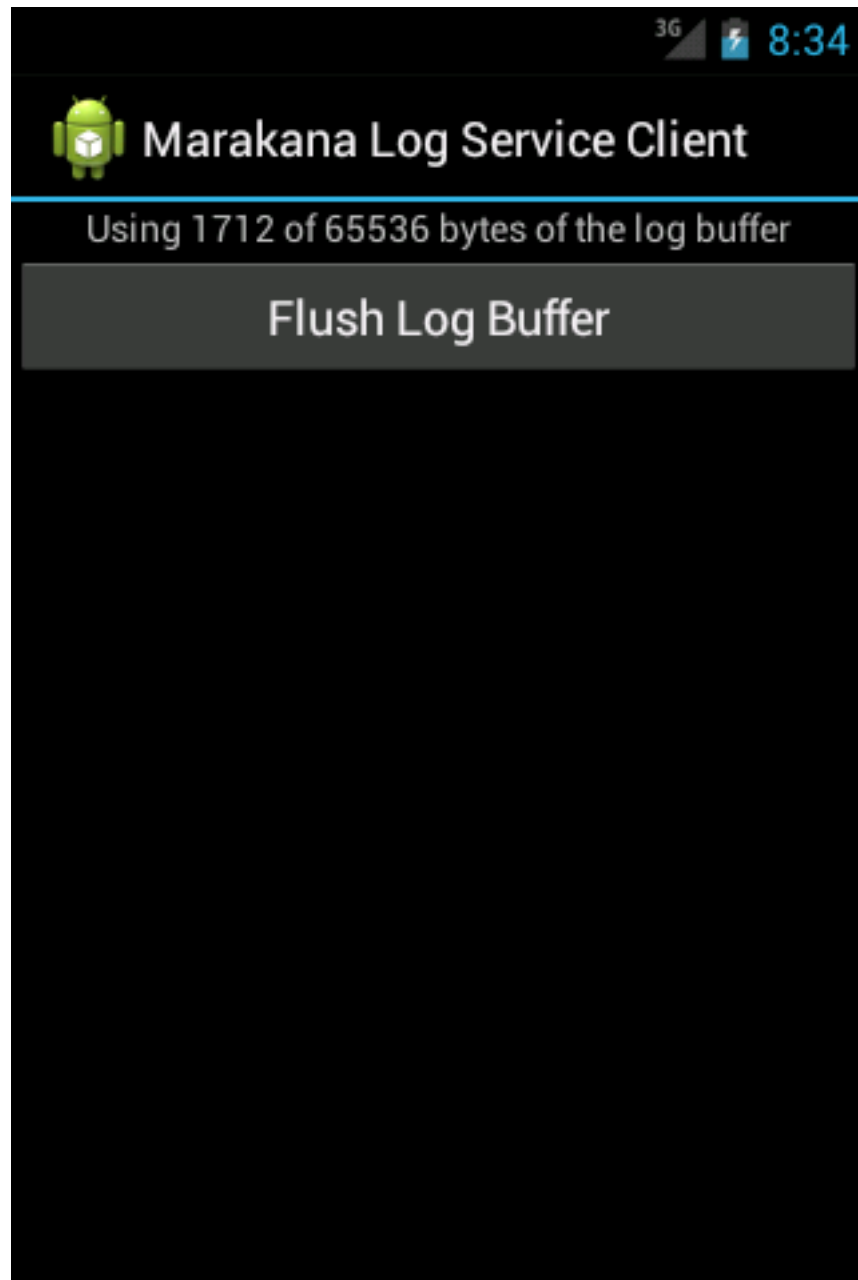
```

$ make -j10
...
Install: out/target/product/alpha/system/app/MrknLogServiceClient.apk
...
Install system fs image: out/target/product/alpha/system.img

```

9. And finally, we can test everything:

- a. Restart the emulator
- b. Launch the Marakana Log Service Client app
- c. Test that you can flush the log buffer



9.13 Creating a Custom SDK Add-on (Optional)

- We can create apps for our own custom device (utilizing our custom libraries), but what if we wanted to expose those APIs to 3rd party developers? We'd need an SDK Addon
- Android SDK addons allow 3rd party developers to get access to our custom system images (including our custom libraries), compile their apps against our APIs, and test them on an emulator
- Note that custom hardware would have to be simulated (e.g. the way GPS is simulated on the emulator)
- Fortunately, our SDK addon will be able to utilize most of what we provided in `alpha/` so we'll focus only on the differences
- Let's get started:

1. Create a directory for our addon:

```
$ mkdir device/marakana/alpha_sdk_addon
```

2. Though this is purely optional, let's create a custom emulator skin for our add-on, by copying an existing one:

```
$ mkdir device/marakana/alpha_sdk_addon/skins
$ cp -r sdk/emulator/skins/HVGA device/marakana/alpha_sdk_addon/skins/MrknHvgaMdpi
```

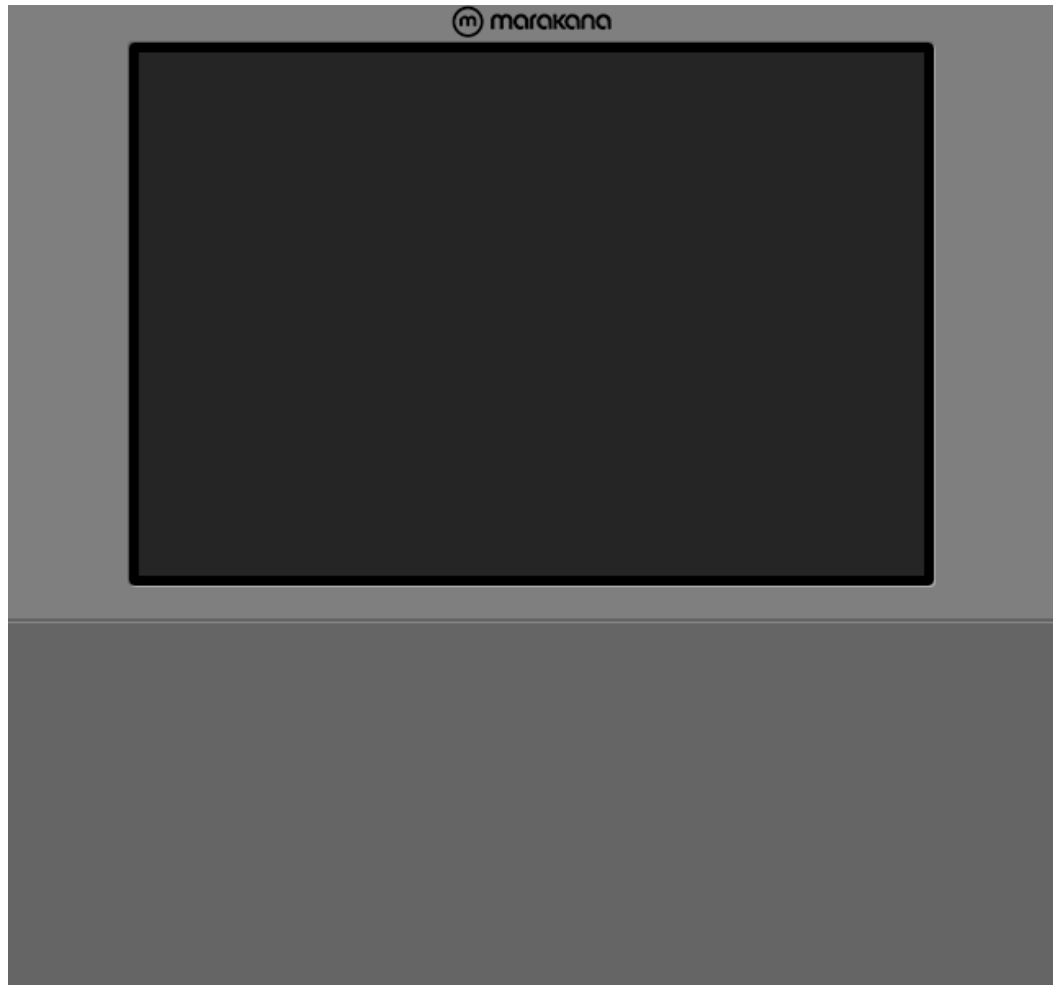
- a. We could now customize the portrait background of our skin (device/marakana/alpha_sdk_addon/skins/MrknHvgaMdpi) - say by adding our custom logo to it



Note

For example, we could use this one: https://github.com/marakana/alpha_sdk_addon/raw/master/skins/MrknHvgaMdpi/background_land.png

- b. We could also customize the landscape background of our skin (device/marakana/alpha_sdk_addon/skins/MrknHvgaMdpi) - also by adding our custom logo to it
-



Note

For example, we could use this one: https://github.com/marakana/alpha_sdk_addon/raw/master/skins/-MrknHvgaMdpi/background_port.png

- c. We could also customize other images, layout controls (`layout`), and hardware-specific values (`hardware.ini`)
3. To simulate that our devices supports NFC, we would:

- a. Create a directory (`nxp`):

```
$ mkdir device/marakana/alpha_sdk_addon/nxp
```

- b. Add a configuration file (`com.nxp.mifare.xml`) declaring NFC-feature support:

device/marakana/alpha_sdk_addon/nxp/com.nxp.mifare.xml

```
<?xml version="1.0" encoding="utf-8"?>
<!-- Devices that support MIFARE need to declare NXP's feature constant -->
<permissions>
  <feature name="com.nxp.mifare" />
</permissions>
```

Note

NFC-support is not really required for our particular product (*Alpha*), but this is an example of how some hardware-specific features are defined.

4. While on the subject of hardware, let's define skin-independent set of hardware properties (`hardware.ini`) for our emulated device:

device/marakana/alpha_sdk_addon/hardware.ini

```
# Custom hardware options for the add-on.
# Properties defined here impact all AVD targeting this add-on.
# Each skin can also override those values with its own hardware.ini file.
vm.heapSize = 24
```

5. Next, we define the properties of our SDK add-on (`manifest.ini`) - name, description, API version, revision, libraries, and skin - as these properties are required by development tools (such as SDK Manager and Eclipse) using our add-on: **device/marakana/alpha_sdk_addon/manifest.ini**

```
name=Alpha Add-On
vendor=Marakana
description=Marakana Alpha Add-on
api=15
revision=1
libraries=com.marakana.android.lib.log;com.marakana.android.service.log
com.marakana.android.lib.log=com.marakana.android.lib.log.jar;Marakana Log Library
com.marakana.android.service.log=com.marakana.android.service.log.jar;Marakana Log Service
skin=MrknHvgaMdpi
```

6. Next, we define a list of classes to be included (`+<package-name>. (*|<class-name>)`) or excluded (`-<package-name>`) from the generated SDK add-on's libraries:

device/marakana/alpha_sdk_addon/alpha_sdk_addon_stub_defs.txt

```
+com.marakana.android.lib.log.*
-com.marakana.android.lib.log.Main
+com.marakana.android.service.log.*
```

Note

These classes are known as SDK Addon Stub Definitions, and this file is processed by `development/tools/mkstubs` during the build time. The Java tool `mkstubs` loads this file via `PRODUCT_SDK_ADDON_STUB_DEFS` makefile property.

7. Now we are ready for our add-on's main makefile (`alpha_sdk_addon.mk`), which will be loaded later by `AndroidProduct.mk`: **device/marakana/alpha_sdk_addon/alpha_sdk_addon.mk**

```
# Include the common stuff
include $(LOCAL_PATH)/../alpha/common.mk

# List of modules to include in the the add-on system image
#PRODUCT_PACKAGES +=

# The name of this add-on (for the SDK)
PRODUCT_SDK_ADDON_NAME := marakana_alpha_addon

# Copy the following files for this add-on's SDK
PRODUCT_SDK_ADDON_COPY_FILES := \
    $(LOCAL_PATH)/manifest.ini:manifest.ini \
    $(LOCAL_PATH)/hardware.ini:hardware.ini \
    $(call find-copy-subdir-files,*, $(LOCAL_PATH)/skins/MrknHvgaMdpi, skins/ \
        MrknHvgaMdpi)

# Copy the jar files for the libraries (APIs) exposed in this add-on's SDK
PRODUCT_SDK_ADDON_COPY_MODULES := \
    com.marakana.android.lib.log:libs/com.marakana.android.lib.log.jar \
    com.marakana.android.service.log:libs/com.marakana.android.service.log.jar

PRODUCT_SDK_ADDON_STUB_DEFS := $(LOCAL_PATH)/alpha_sdk_addon_stub_defs.txt
```

```
# Define the name of the documentation to generate for this add-on's SDK
PRODUCT_SDK_ADDON_DOC_MODULES := \
    com.marakana.android.service.log_doc

# Since the add-on is an emulator, we also need to explicitly copy the kernel to ↵
    images
PRODUCT_SDK_ADDON_COPY_FILES += $(LOCAL_KERNEL):images/armeabi-v7a/kernel-gemu

# This add-on extends the default sdk product.
$(call inherit-product, $(SRC_TARGET_DIR)/product/sdk.mk)

# The name of this add-on (for the build system)
# Use 'make PRODUCT-<PRODUCT_NAME>-sdk_addon' to build the an add-on,
# so in this case, we would run 'make PRODUCT-marakana_alpha_addon-sdk_addon'
PRODUCT_NAME := marakana_alpha_addon
PRODUCT_DEVICE := alpha
PRODUCT_MODEL := Marakana Alpha SDK Addon Image for Emulator
```

Note

As we can see from the comments, this file extends from `build/target/product/sdk.mk`, includes everything from `alpha-common`, adds support for library documentation, defines the add-on's name (`PRODUCT_SDK_ADDON_NAME`), specifies the files/modules to be copied (`manifest.ini`, `hardware.ini`, `skin`, `libraries`, and `kernel`) into the add-on (`PRODUCT_SDK_ADDON_COPY_FILES`), loads stub defs, and defines the add-on's product info (like `PRODUCT_NAME`).

8. Just like with our alpha product, we need to create `AndroidProducts.mk` file, which the build system looks for to get a list of the actual make files (in this just `alpha_sdk_addon.mk`) to process for this "product" (i.e. SDK add-on):
device/marakana/alpha_sdk_addon/AndroidProducts.mk

```
PRODUCT_MAKEFILES := $(LOCAL_DIR)/alpha_sdk_addon.mk
```

9. Just to be on the safe side, let's make sure that make files from all sub-directories also get included:
device/marakana/alpha_sdk_addon/Android.mk

```
include $(call all-subdir-makefiles)
```

Note

This file is unnecessary in this particular case, but it does not hurt to have it in case we add more add-on-specific components down the road, which will most likely be stored in their own sub-directories.

10. Now we are ready to compile our add-on:

```
$ make -j10 PRODUCT-marakana_alpha_addon-sdk_addon
...
Copy: out/host/linux-x86/obj/SDK_ADDON/marakana_alpha_addon_intermediates/ ↵
    marakana_alpha_addon-eng.sasa-linux-x86/images/armeabi-v7a/system.img
Packaging SDK Addon: out/host/linux-x86/sdk_addon/marakana_alpha_addon-eng.sasa-linux- ↵
    x86.zip
```

Note

Notice that the directory/file-name encodes the name of the user who built this add-on (in this case "sasa"). Adjust the following steps as necessary.

11. Next, to test that it works, we first install our SDK to our Android SDK's `add-ons/` directory:


```
$ unzip out/host/linux-x86/sdk_addon/marakana_alpha_addon-eng.sasa-linux-x86.zip -d / ↔
  home/sasa/android/sdk/add-ons/
Archive:  out/host/linux-x86/sdk_addon/marakana_alpha_addon-eng.sasa-linux-x86.zip
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/select.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/arrow_left.png
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/background_land.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/arrow_right.png
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/layout
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/background_port.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/hardware.ini
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/spacebar.png
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/controls.png
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/key.png
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/keyboard.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/button.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/arrow_down.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  skins/MrknHvgaMdpi/arrow_up.png
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/package-list
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/help-doc.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/com/marakana/android/service/log/ ↔
  package-summary.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/com/marakana/android/service/log/ ↔
  package-frame.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/com/marakana/android/service/log/ ↔
  package-tree.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/com/marakana/android/service/log/ ↔
  LogManager.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/allclasses-noframe.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/constant-values.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/stylesheet.css
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/deprecated-list.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/index.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/allclasses-frame.html
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↔
  docs/com.marakana.android.service.log_doc/index-all.html
```

```
extracting: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
docs/com.marakana.android.service.log_doc/resources/inherit.gif  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
docs/com.marakana.android.service.log_doc/overview-tree.html  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
images/armeabi-v7a/build.prop  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
images/armeabi-v7a/ramdisk.img  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
images/armeabi-v7a/kernel-gemu  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
images/armeabi-v7a/NOTICE.txt  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
images/armeabi-v7a/userdata.img  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
images/armeabi-v7a/system.img  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
hardware.ini  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
manifest.ini  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
libs/com.marakana.android.lib.log.jar  
inflating: /home/sasa/android/sdk/add-ons/marakana_alpha_addon-eng.sasa-linux-x86/ ↵  
libs/com.marakana.android.service.log.jar
```

Tip

Adjust the path to Android SDK directory as necessary.

12. Let's test that it shows up in our *Android SDK and ADV Manager*:

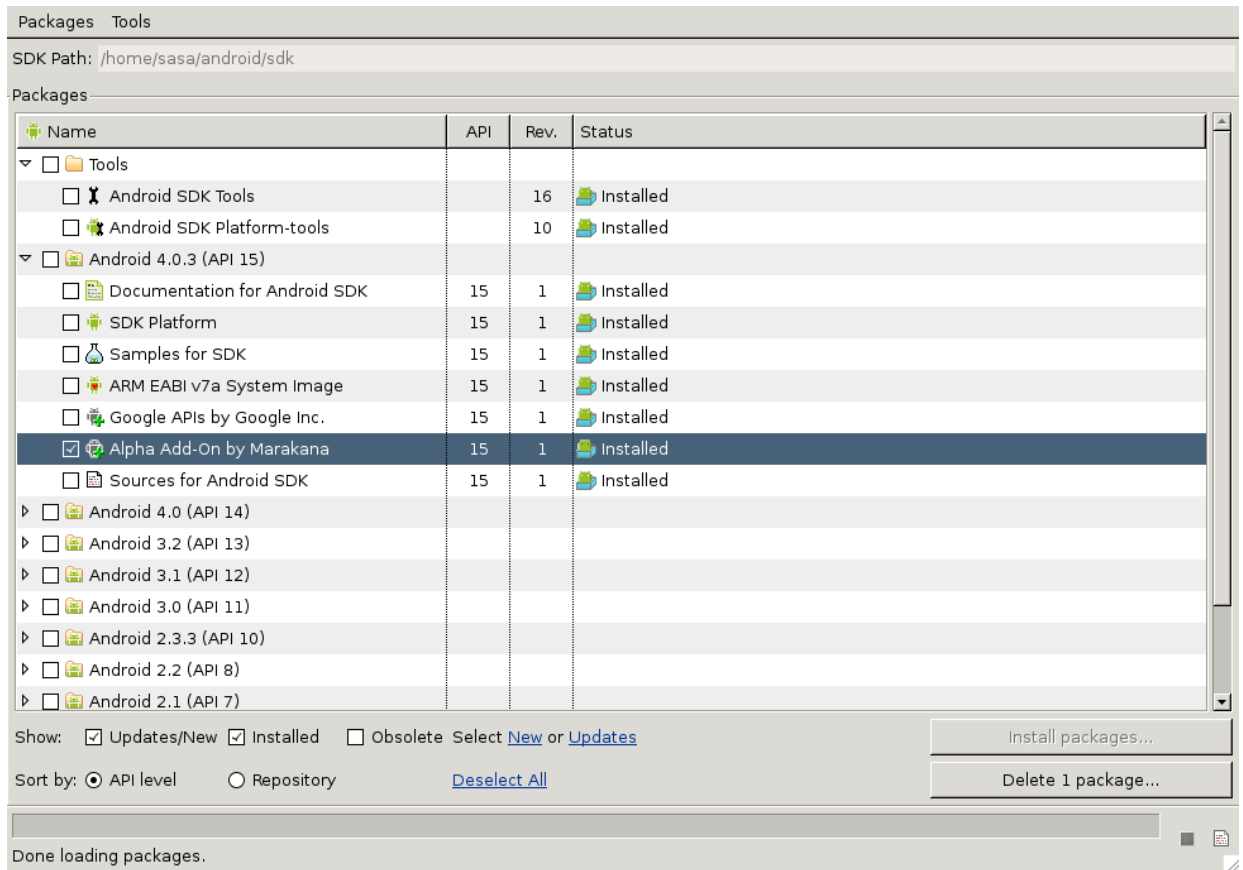
a. Run

```
$ /path/to/android/sdk/tools/android $
```

Note

Adjust the path to Android SDK directory as necessary.

b. And we should now see "Alpha Add-On by Marakana, Android API 15, revision 1, Installed" show up under *Packages*:

**Note**

For this to work, we need to have our add-on's `api` setting (in `manifest.ini` file) match an available *SDK Platform Android* of the same API version.

- Now we can create a new emulator image (AVD) based on our add-on (from the *Android SDK and AVD Manager*):

Name:

Target:

CPU/ABI:

SD Card:

☒ Size:

☐ File:

Snapshot: ☐ Enabled

Skin:

☒ Built-in:

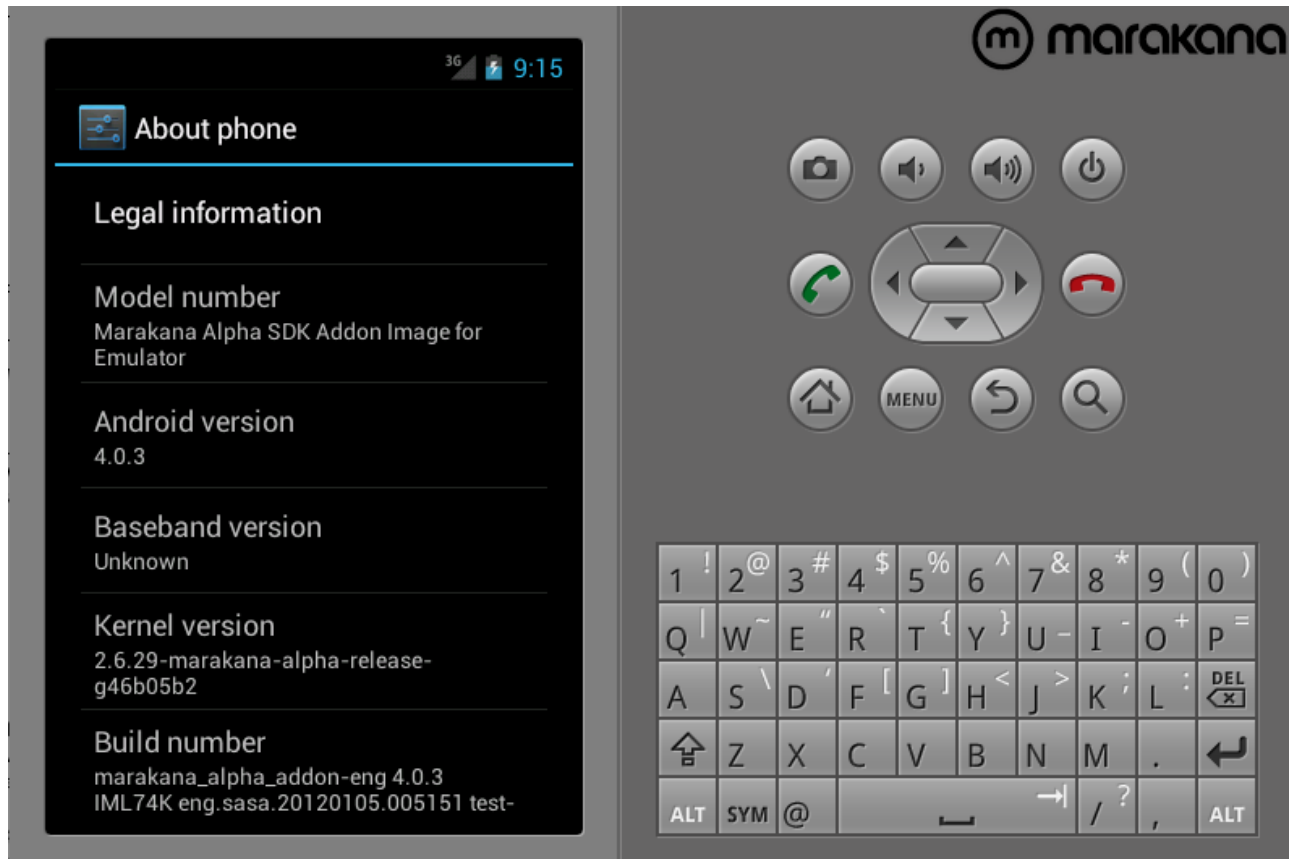
☐ Resolution: x

Hardware:

Property	Value	New...
Abstracted LCD density	160	<input type="button" value="Delete"/>
Max VM application heap size	24	
<input type="text"/>		

☐ Override the existing AVD with the same name

14. To see that it works, we can now launch our newly created "marakana-alpha" AVD:



15. Our marakana-alpha AVD will not have any of the *Mrkn*ClientApp* apps we previously created for the "Marakana Alpha" device, but since our APIs are available to us via the libraries, we can re-create these applications in Eclipse and deploy them to our AVD - this is left as an exercise for the reader :-)

9.13.1 Distributing our Custom SDK Add-on (Optional)

1. First, we need to create a `repository.xml` file to describe our add-on and publish it to our server:

<https://marakana.com/external/android/sdk-addon/repository.xml>

```
<?xml version="1.0" encoding="UTF-8"?>

<sdk:sdk-addon
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:sdk="http://schemas.android.com/sdk/android/addon/1">

  <sdk:add-on>
    <sdk:name>Alpha Add-On</sdk:name>
    <sdk:api-level>15</sdk:api-level>
    <sdk:vendor>Marakana</sdk:vendor>
    <sdk:revision>1</sdk:revision>
    <sdk:description>Android + Marakana Alpha Add-on, API 15, revision 1 </ ↔
      sdk:description>
    <sdk:desc-url>http://marakana.com/external/android/sdk-addon/</sdk:desc-url>
    <sdk:uses-license ref="marakana-android-addon-license" />
    <sdk:archives>
      <sdk:archive os="any">
        <sdk:size>96382546</sdk:size>
        <sdk:checksum type="sha1">5cec8cc3f3064441cb96a50e2b8aa528681ffc78</ ↔
          sdk:checksum>
        <sdk:url>marakana_alpha_sdk_addon_api-15_r1.zip</sdk:url>
      </sdk:archive>
    </sdk:archives>
  </sdk:add-on>
</sdk:sdk-addon>
```

```

        </sdk:archives>
        <sdk:libs>
        </sdk:libs>
    </sdk:add-on>

    <sdk:license type="text" id="marakana-android-addon-license">
Licensed under the Apache License, Version 2.0 (the "License");
you may not use this SDK addon except in compliance with the License.
You may obtain a copy of the License at: http://www.apache.org/licenses/LICENSE-2.0

Unless required by applicable law or agreed to in writing, software
distributed under the License is distributed on an "AS IS" BASIS,
WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied.
See the License for the specific language governing permissions and
limitations under the License.
    </sdk:license>
</sdk:sdk-addon>

```

Note

We have to make sure that we adjust the info as necessary to reflect our particular site/addon.

2. Next, we need to upload our addon to our site, relative to `<sdk:sdk-addon>` → `<sdk:add-on>` → `<sdk:desc-url>` URL (e.g. https://marakana.com/external/android/sdk-addon/marakana_alpha_sdk_addon_api-15)
3. We are now ready to test it out in our *Android SDK Manager*
 - a. Go to *Tools* → *Manage Add-on Sites...* in the menu bar
 - b. Click on *New...*
 - c. Enter the base URL in the URL field (e.g. <https://marakana.com/external/android/sdk-addon/>) and click on *OK*
 - d. Click on *Close* to dismiss the *Add-on Sites* window
 - e. Under *Packages* we should now see *Alpha Add-On by Marakana*, with a status *Not installed*
 - f. Click on the checkbox next to our package
 - g. Click on *Install 1 package...* button
 - h. Accept the license terms and click on *Install*
4. Test that it works by creating an AVD based on our add-on and/or using it in Eclipse

10 Android USB Support (Appendix)

10.1 Overview of Android USB Support

10.1.1 Android USB Host and Accessory Modes

Android supports a variety of USB peripherals and Android USB *accessories* (hardware that implements the Android accessory protocol) through two modes: *USB host* and *USB accessory*.

In USB host mode, the Android-powered device acts as the host.

- When the Android-powered device is in host mode, it acts as the USB host, powers the bus, and enumerates connected USB devices.
- Most existing USB peripherals are designed to connected to a USB host.

In USB accessory mode, the external USB hardware act as the USB hosts.

- When the Android-powered device is in USB accessory mode, the connected USB hardware (an Android USB accessory in this case) acts as the host and powers the bus.
- This design gives Android-powered devices that do not have host capabilities the ability to interact with USB hardware.
- Android USB accessories must be designed to work with Android-powered devices and adhere to the Android accessory protocol outlined in the *Android Accessory Development Kit* documentation.

10.1.2 Android USB Support

USB accessory and host modes are directly supported in Android 3.1 (API level 12) or newer platforms.

- USB accessory mode is also backported to Android 2.3.4 (API level 10) as an add-on library to support a broader range of devices.
- Device manufacturers can choose whether or not to include the add-on library on the device's system image.

Note

Support for USB host and accessory modes are ultimately dependent on the device's hardware, regardless of platform level. You can filter for devices that support USB host and accessory through a `<uses-feature>` element, as discussed later.

10.2 Android USB Host Mode

- API Overview
- Android Manifest Requirements
- Working with devices
- Discovering a device
- Obtaining permission to communicate with a device
- Communicating with a device
- Terminating communication with a device

10.2.1 API Overview

The `android.hardware.usb` package contains the following classes supporting USB host mode:

UsbManager

Allows you to enumerate and communicate with connected USB devices.

UsbDevice

Represents a connected USB device and contains methods to access its identifying information, interfaces, and endpoints.

UsbInterface

Represents an interface of a USB device, which defines a set of functionality for the device. A device can have one or more interfaces on which to communicate on.

UsbEndpoint

Represents an interface endpoint, which is a communication channel for this interface. An interface can have one or more endpoints, and usually has input and output endpoints for two-way communication with the device.

UsbDeviceConnection

Represents a connection to the device, which transfers data on endpoints. This class allows you to send data back and forth synchronously or asynchronously.

UsbRequest

Represents an asynchronous request to communicate with a device through a `UsbDeviceConnection`.

UsbConstants

Defines USB constants that correspond to definitions in `linux/usb/ch9.h` of the Linux kernel.

In general, you:

1. Obtain a `UsbManager` to retrieve the desired `UsbDevice`
 2. Find the appropriate `UsbInterface` and the `UsbEndpoint` of that interface to communicate on
 3. Open a `UsbDeviceConnection` to communicate with the USB device
-

In most situations, you need to use all of these classes (`UsbRequest` is only required if you are doing asynchronous communication) when communicating with a USB device.

10.2.2 Using the Manifest to Require USB Support

Not all Android-powered devices are guaranteed to support the USB host APIs.

To indicate that your application requires USB host support, add the following elements to your application's manifest:

- Include a `<uses-feature>` element that declares that your application uses the `android.hardware.usb.host` feature:

```
<uses-feature android:name="android.hardware.usb.host" />
```

- Set the minimum SDK of the application to API Level 12 or higher. The USB host APIs are not present on earlier API levels.

```
<uses-sdk android:minSdkVersion="12" />
```

10.2.3 Working with Devices

When users connect USB devices to an Android-powered device, the Android system can determine whether your application is interested in the connected device. If so, you can set up communication with the device if desired.

To do this, your application has to:

1. Discover connected USB devices either by:
 - Using an intent filter to be notified when the user connects a USB device, or
 - Enumerating USB devices that are already connected.
 2. Ask the user for permission to connect to the USB device, if not already obtained.
 3. Communicate with the USB device by reading and writing data on the appropriate interface endpoints.
-

10.2.4 Discovering a Device Using an Intent Filter, The Manifest

To have your application discover a particular USB device, you can specify an intent filter to filter for the `android.hardware.usb.action.USB_DEVICE_ATTACHED` intent.

- Along with this intent filter, you need to specify a resource file that specifies properties of the USB device, such as product and vendor ID.
- When users connect a device that matches your device filter, the system presents them with a dialog that asks if they want to start your application.
- If users accept, your application automatically has permission to access the device until the device is disconnected.

In your activity, you can obtain the `UsbDevice` that represents the attached device from the intent like this:

```
UsbDevice device = (UsbDevice) intent.getParcelableExtra(UsbManager.EXTRA_DEVICE);
```

The following example shows how to declare the intent filter in your application's manifest:

```
<activity ...>
    ...
    <intent-filter>
        <action android:name="android.hardware.usb.action.USB_DEVICE_ATTACHED" />
    </intent-filter>

    <meta-data android:name="android.hardware.usb.action.USB_DEVICE_ATTACHED"
        android:resource="@xml/device_filter" />
</activity>
```

The `<meta-data>` element points to an external XML resource file that declares identifying information about the device that you want to detect.

10.2.5 Discovering a Device Using an Intent Filter, The Resource File

In the XML resource file, declare `<usb-device>` elements for the USB devices that you want to filter.

- The `<usb-device>` element supports the following optional attributes:
 - `vendor-id`
 - `product-id`
 - `class`
 - `subclass`
 - `protocol` (device or interface)
- In general, use vendor and product ID if you want to filter for a specific device; use class, subclass, and protocol if you want to filter for a group of USB devices, such as mass storage devices or digital cameras.
- For example, the following resource file specifies that any USB device with the corresponding vendor ID and product ID should be filtered. These IDs are specific to the device and are specified by the device's manufacturer:

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
    <usb-device vendor-id="1234" product-id="5678" />
</resources>
```

Save the resource file in your application's `res/xml/` directory.

- The resource file name (without the `.xml` extension) must be the same as the one you specified in the `<meta-data>` element.
- For example, the resource file for the manifest shown previously should be saved in `res/xml/device_filter.xml`.

10.2.6 Enumerating USB Devices

If your application is interested in inspecting all of the USB devices currently connected while your application is running, it can enumerate devices on the bus.

- Use the `UsbManager.getDeviceList()` method to get a hash map of all the USB devices that are connected.
- The hash map is keyed by the USB device's name if you want to obtain a device from the map.

```
UsbManager manager = (UsbManager) getSystemService(Context.USB_SERVICE);  
// ...  
HashMap<String, UsbDevice> deviceList = manager.getDeviceList();  
UsbDevice device = deviceList.get("deviceName");
```

If desired, you can also just obtain an iterator from the hash map and process each device one by one:

```
UsbManager manager = (UsbManager) getSystemService(Context.USB_SERVICE);  
// ...  
HashMap<String, UsbDevice> deviceList = manager.getDeviceList();  
Iterator<UsbDevice> deviceIterator = deviceList.values().iterator();  
while (deviceIterator.hasNext()) {  
    UsbDevice device = deviceIterator.next();  
    // ...  
}
```

10.2.7 Obtaining Permission to Communicate With a Device

Before communicating with the USB device, your application must have permission from your users.

Note

If your application uses an intent filter to discover USB devices as they're connected, it automatically receives permission if the user allows your application to handle the intent. If not, you must request permission explicitly in your application before connecting to the device.

Explicitly asking for permission might be necessary in some situations such as when your application enumerates USB devices that are already connected and then wants to communicate with one.

- You must check for permission to access a device before trying to communicate with it.
- If not, you will receive a runtime error if the user denied permission to access the device.

To explicitly obtain permission:

1. Call `UsbManager.requestPermission()`.
2. The call to `requestPermission()` displays a dialog to the user asking for permission to connect to the device.
3. The system generates a broadcast intent with a boolean `EXTRA_PERMISSION_GRANTED` extra indicating the user's response.

The following sample code shows how to create a broadcast receiver to process the response:

```
private static final String ACTION_USB_PERMISSION = "com.android.example.USB_PERMISSION";

private final BroadcastReceiver mUsbReceiver = new BroadcastReceiver() {

    public void onReceive(Context context, Intent intent) {
        String action = intent.getAction();
        if (ACTION_USB_PERMISSION.equals(action)) {
            synchronized (this) {
                UsbDevice device = (UsbDevice)intent.getParcelableExtra(UsbManager.EXTRA_DEVICE);

                if (intent.getBooleanExtra(UsbManager.EXTRA_PERMISSION_GRANTED, false)) {
                    if (device != null) {
                        // Call method to set up device communication
                    }
                } else {
                    Log.d(TAG, "permission denied for device " + device);
                }
            }
        }
    }
};
```

To register the broadcast receiver, add this in your `onCreate()` method in your activity:

```
IntentFilter filter = new IntentFilter(ACTION_USB_PERMISSION);
registerReceiver(mUsbReceiver, filter);
```

To display the dialog that asks users for permission to connect to the device, call the `UsbManager.requestPermission()` method:

```
UsbManager mUsbManager = (UsbManager) getSystemService(Context.USB_SERVICE);
UsbDevice device;
// ...
mPermissionIntent = PendingIntent.getBroadcast(this, 0, new Intent(ACTION_USB_PERMISSION), 0);
mUsbManager.requestPermission(device, mPermissionIntent);
```

10.2.8 Communicating With a Device

Communication with a USB device can be either synchronous or asynchronous.

- In either case, you should create a new thread on which to carry out all data transmissions, so you don't block the UI thread.

To properly set up communication with a device, you need to obtain the appropriate `UsbInterface` and `UsbEndpoint` of the device that you want to communicate on and send requests on this endpoint with a `UsbDeviceConnection`. In general, your code should:

- Check a `UsbDevice` object's attributes, such as product ID, vendor ID, or device class to figure out whether or not you want to communicate with the device.
- When you are certain that you want to communicate with the device, find the appropriate `UsbInterface` that you want to use to communicate along with the appropriate `UsbEndpoint` of that interface.
 - Interfaces can have one or more endpoints, and commonly will have an input and output endpoint for two-way communication.

- When you find the correct endpoint, open a `UsbDeviceConnection` on that endpoint.
- Supply the data that you want to transmit on the endpoint with the `bulkTransfer()` or `controlTransfer()` method.
 - You should carry out this step in another thread to prevent blocking the main UI thread.

The following code snippet is a trivial way to do a synchronous data transfer. Your code should have more logic to correctly find the correct interface and endpoints to communicate on and also should do any transferring of data in a different thread than the main UI thread:

```
private byte[] bytes = "hello usb".getBytes();
private static int TIMEOUT = 0;
private boolean forceClaim = true;

...

UsbInterface intf = device.getInterface(0);
UsbEndpoint endpoint = intf.getEndpoint(0);
UsbDeviceConnection connection = mUsbManager.openDevice(device);
connection.claimInterface(intf, forceClaim);
connection.bulkTransfer(endpoint, bytes, bytes.length, TIMEOUT); // Do in another thread
```

To send data asynchronously, use the `UsbRequest` class to initialize and queue an asynchronous request, then wait for the result with `requestWait()`.

10.2.9 Terminating Communication With a Device

When you are done communicating with a device or if the device was detached, close the `UsbInterface` and `UsbDeviceConnection` by calling `releaseInterface()` and `close()`.

To listen for detached events, create a broadcast receiver like below:

```
BroadcastReceiver mUsbReceiver = new BroadcastReceiver() {
    public void onReceive(Context context, Intent intent) {
        String action = intent.getAction();

        if (UsbManager.ACTION_USB_DEVICE_DETACHED.equals(action)) {
            UsbDevice device = (UsbDevice)intent.getParcelableExtra(UsbManager.EXTRA_DEVICE ←
            );
            if (device != null) {
                // call your method that cleans up and closes communication with the device
            }
        }
    }
};
```

Creating the broadcast receiver within the application, and not the manifest, allows your application to handle detached events only while it is running.

- This way, detached events are sent only to the application that is currently running and not broadcast to all applications.

10.3 Android USB Accessory Mode

- Choosing the Right USB Accessory APIs
- Installing the Google APIs add-on library
- API Overview
- Usage differences between the add-on library and the platform APIs

- Android Manifest Requirements
- Working with accessories
- Discovering an accessory
- Obtaining permission to communicate with an accessory
- Communicating with an accessory
- Terminating communication with an accessory

10.3.1 Choosing the Right USB Accessory APIs

The USB accessory APIs were introduced to the platform in Android 3.1. They are also available in Android 2.3.4 using the Google APIs add-on library.

- Because these APIs were backported using an external library, there are two packages that you can import to support USB accessory mode.
- Depending on what Android-powered devices you want to support, you might have to use one over the other.

com.android.future.usb

To support USB accessory mode in Android 2.3.4, the Google APIs add-on library includes the backported USB accessory APIs and they are contained in this namespace.

- Android 3.1 also supports importing and calling the classes within this namespace to support applications written with the add-on library.
- This add-on library is a thin wrapper around the `android.hardware.usb` accessory APIs and does not support USB host mode.
- If you want to support the widest range of devices that support USB accessory mode, use the add-on library and import this package.

android.hardware.usb

This namespace contains the classes that support USB accessory mode in Android 3.1.

- This package is included as part of the framework APIs, so Android 3.1 supports USB accessory mode without the use of an add-on library.
- Use this package if you only care about Android 3.1 or newer devices that have hardware support for USB accessory mode, which you can declare in your manifest file.

10.3.2 API Overview

The following classes support the USB accessory APIs:

UsbManager

Allows you to enumerate and communicate with connected USB accessories.

- If you are using the add-on library, you must obtain the `UsbManager` object in the following manner:

```
UsbManager manager = UsbManager.getInstance(this);
```

- If you are not using the add-on library, you must obtain the `UsbManager` object in the following manner:

```
UsbManager manager = (UsbManager) getSystemService(Context.USB_SERVICE);
```

UsbAccessory

Represents a USB accessory and contains methods to access its identifying information.

- When you filter for a connected accessory with an intent filter, the `UsbAccessory` object is contained inside the intent that is passed to your application. If you are using the add-on library, you must obtain the `UsbAccessory` object in the following manner:

```
UsbAccessory accessory = UsbManager.getAccessory(intent);
```

- If you are not using the add-on library, you must obtain the `UsbAccessory` object in the following manner:

```
UsbAccessory accessory = (UsbAccessory) intent.getParcelableExtra(UsbManager.EXTRA_ACCESSORY);
```

Because the add-on library is a wrapper for the framework APIs, the classes that support the USB accessory feature are similar. You can use the reference documentation for the `android.hardware.usb` even if you are using the add-on library.

10.3.3 Android Manifest Requirements

Not all Android-powered devices are guaranteed to support the USB accessory APIs.

To indicate that your application requires USB accessory support, add the following elements to your application's manifest:

- Include a `<uses-feature>` element that declares that your application uses the `android.hardware.usb.accessory` feature:

```
<uses-feature android:name="android.hardware.usb.accessory" />
```

- Set the minimum SDK of the application to API Level 10 if you are using the add-on library or 12 if you are using the `android.hardware.usb` package.

```
<uses-sdk android:minSdkVersion="12" />
```

- If you are using the add-on library, add the `<uses-library>` element specifying `com.android.future.usb.accessory` for the library.

```
<uses-library android:name="com.android.future.usb.accessory" />
```

10.3.4 Working with Accessories

When users connect USB accessories to an Android-powered device, the Android system can determine whether your application is interested in the connected accessory. If so, you can set up communication with the accessory if desired.

To do this, your application has to:

1. Discover connected accessories by using an intent filter that filters for accessory attached events or by enumerating connected accessories and finding the appropriate one.
 2. Ask the user for permission to communicate with the accessory, if not already obtained.
 3. Communicate with the accessory by reading and writing data on the appropriate interface endpoints.
-

10.3.5 Discovering a Device Using an Intent Filter, The Manifest

To have your application discover a particular USB device, you can specify an intent filter to filter for the `android.hardware.usb.action.USB_ACCESSORY_ATTACHED` intent.

- Along with this intent filter, you need to specify a resource file that specifies properties of the USB accessory, such as manufacturer, model, and version.
- When users connect a device that matches your device filter, the system presents them with a dialog that asks if they want to start your application.
- If users accept, your application automatically has permission to access the device until the device is disconnected.

In your activity, you can obtain the `UsbAccessory` that represents the attached device from the intent.

- If you are using the add-on library, obtain the `UsbAccessory` object in the following manner:

```
UsbAccessory accessory = UsbManager.getAccessory(intent);
```

- If you are not using the add-on library, obtain the `UsbAccessory` object in the following manner:

```
UsbAccessory accessory = (UsbAccessory) intent.getParcelableExtra(UsbManager.EXTRA_ACCESSORY);
```

The following example shows how to declare the intent filter in your application's manifest:

```
<activity ...>
    ...
    <intent-filter>
        <action android:name="android.hardware.usb.action.USB_ACCESSORY_ATTACHED" />
    </intent-filter>

    <meta-data android:name="android.hardware.usb.action.USB_ACCESSORY_ATTACHED"
        android:resource="@xml/accessory_filter" />
</activity>
```

The `<meta-data>` element points to an external XML resource file that declares identifying information about the device that you want to detect.

10.3.6 Discovering a Device Using an Intent Filter, The Resource File

In the XML resource file, declare `<usb-accessory>` elements for the accessories that you want to filter.

- Each `<usb-accessory>` can have the following attributes:
 - manufacturer
 - model
 - version
- For example, the following resource file specifies that any USB accessory that has the corresponding model, manufacturer, and version should be filtered. These IDs are specific to the device and are specified by the device's manufacturer:

```
<?xml version="1.0" encoding="utf-8"?>
<resources>
    <usb-accessory model="DemoKit" manufacturer="Google" version="1.0"/>
</resources>
```

Save the resource file in your application's `res/xml/` directory.

- The resource file name (without the `.xml` extension) must be the same as the one you specified in the `<meta-data>` element.
- For example, the resource file for the manifest shown previously should be saved in `res/xml/accessory_filter.xml`.

10.3.7 Enumerating Accessories

You can have your application enumerate accessories that have identified themselves while your application is running.

Use the `UsbManager.getAccessoryList()` method to get an array all the USB accessories that are connected:

```
UsbManager manager = (UsbManager) getSystemService(Context.USB_SERVICE);
UsbAccessory[] accessoryList = manager.getAccessoryList();
```

Note

Currently, only one connected accessory is supported at one time, but the API is designed to support multiple accessories in the future.

10.3.8 Obtaining Permission to Communicate With an Accessory

Before communicating with the USB accessory, your application must have permission from your users.

Note

If your application uses an intent filter to discover USB devices as they're connected, it automatically receives permission if the user allows your application to handle the intent. If not, you must request permission explicitly in your application before connecting to the device.

Explicitly asking for permission might be necessary in some situations such as when your application enumerates USB devices that are already connected and then wants to communicate with one.

- You must check for permission to access a device before trying to communicate with it.
- If not, you will receive a runtime error if the user denied permission to access the device.

To explicitly obtain permission:

1. Call `UsbManager.requestPermission()`.
2. The call to `requestPermission()` displays a dialog to the user asking for permission to connect to the accessory.
3. The system generates a broadcast intent with a boolean `EXTRA_PERMISSION_GRANTED` extra indicating the user's response.

The following sample code shows how to create a broadcast receiver to process the response:

```
private static final String ACTION_USB_PERMISSION = "com.android.example.USB_PERMISSION";

private final BroadcastReceiver mUsbReceiver = new BroadcastReceiver() {

    public void onReceive(Context context, Intent intent) {
        String action = intent.getAction();
        if (ACTION_USB_PERMISSION.equals(action)) {
            synchronized (this) {
                UsbAccessory accessory = (UsbAccessory) intent.getParcelableExtra(UsbManager.EXTRA_ACCESSORY);

                if (intent.getBooleanExtra(UsbManager.EXTRA_PERMISSION_GRANTED, false)) {
                    if (accessory != null) {
                        // Call method to set up accessory communication
                    }
                }
            }
        }
    }
}
```



```

        else {
            Log.d(TAG, "permission denied for accessory " + accessory);
        }
    }
}
};

```

To register the broadcast receiver, add this in your `onCreate()` method in your activity:

```

IntentFilter filter = new IntentFilter(ACTION_USB_PERMISSION);
registerReceiver(mUsbReceiver, filter);

```

To display the dialog that asks users for permission to connect to the device, call the `UsbManager.requestPermission()` method:

```

UsbManager mUsbManager = (UsbManager) getSystemService(Context.USB_SERVICE);
UsbAccessory accessory;
// ...
mPermissionIntent = PendingIntent.getBroadcast(this, 0, new Intent(ACTION_USB_PERMISSION), 0);
mUsbManager.requestPermission(accessory, mPermissionIntent);

```

10.3.9 Communicating With an Accessory

You can communicate with the accessory by using the `UsbManager` to obtain a file descriptor that you can set up input and output streams to read and write data to descriptor.

- The streams represent the accessory's input and output bulk endpoints.
- You should set up the communication between the device and accessory in another thread, so you don't lock the main UI thread.
- The following example shows how to open an accessory to communicate with:

```

UsbAccessory mAccessory;
ParcelFileDescriptor mFileDescriptor;
FileInputStream mInputStream;
FileOutputStream mOutputStream;

// ...

private void openAccessory() {
    Log.d(TAG, "openAccessory: " + accessory);
    mFileDescriptor = mUsbManager.openAccessory(mAccessory);
    if (mFileDescriptor != null) {
        FileDescriptor fd = mFileDescriptor.getFileDescriptor();
        mInputStream = new FileInputStream(fd);
        mOutputStream = new FileOutputStream(fd);
        Thread thread = new Thread(null, this, "AccessoryThread");
        thread.start();
    }
}

```

In the thread's `run()` method, you can read and write to the accessory by using the `FileInputStream` or `FileOutputStream` objects.

When reading data from an accessory with a `FileInputStream` object, ensure that the buffer that you use is big enough to store the USB packet data.

- The Android accessory protocol supports packet buffers up to 16384 bytes, so you can choose to always declare your buffer to be of this size for simplicity.

Note

At a lower level, the packets are 64 bytes for USB full-speed accessories and 512 bytes for USB high-speed accessories. The Android accessory protocol bundles the packets together for both speeds into one logical packet for simplicity.

10.3.10 Terminating Communication With an Accessory

When you are done communicating with an accessory or if the accessory was detached, close the file descriptor that you opened by calling `close()`.

To listen for detached events, create a broadcast receiver like below:

```
BroadcastReceiver mUsbReceiver = new BroadcastReceiver() {
    public void onReceive(Context context, Intent intent) {
        String action = intent.getAction();

        if (UsbManager.ACTION_USB_ACCESSORY_DETACHED.equals(action)) {
            UsbAccessory accessory = (UsbAccessory)intent.getParcelableExtra(UsbManager.EXTRA_ACCESSORY);
            if (accessory != null) {
                // call your method that cleans up and closes communication with the accessory
            }
        }
    }
};
```

Creating the broadcast receiver within the application, and not the manifest, allows your application to handle detached events only while it is running.

- This way, detached events are sent only to the application that is currently running and not broadcast to all applications.

10.3.11 The Android Open Accessory Development Kit

The Android Open Accessory Development Kit (ADK) provides an implementation of an Android USB accessory that is based on the Arduino open source electronics prototyping platform.

The main hardware and software components of the ADK include:

- A USB micro-controller board that is based on the Arduino Mega2560 and [Circuits@Home](#) USB Host Shield designs ("the ADK board").
 - The ADK board provides input and output pins that you can implement through the use of attachments called "shields."
 - Custom firmware, written in C++, is installed on the board to define the board's functionality and interaction with the attached shield and Android-powered device.
- An Android Demo Shield (ADK shield) that affixes atop the ADK board implements the input and output points on the board.
 - These implementations include a joystick, LED outputs, and temperature and light sensors.
 - You can create or buy your own shields or wire your own features to the ADK board to implement custom functionality.
- A library based on the Arduino USB Host Shield library provides the logic for the USB micro-controller board to act as a USB Host.
 - This allows the board to initiate transactions with USB devices.

- An Arduino sketch defines the firmware that runs on the ADK board and is written in C++.
 - The sketch calls the Android accessory protocol library to interact with the Android-powered device.
 - It also sends data from the ADK board and shield to the Android application and receives data from the Android application and outputs it to the ADK board and shield.
- The Android accessory protocol library.
 - This library defines how to enumerate the bus, find a connected Android-powered device that supports accessory mode, and how to setup communication with the device.
- Other third party libraries to support the ADK board's functionality:
 - CapSense library
 - I2C / TWI (Two-Wire Interface) library
 - Servo library
 - Spi library
 - Wire library
- An Android application, DemoKit, that communicates with the ADK board and shield.

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