Marakana Android Internals

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Aleksandar (Saša) Gargenta, Kan Jones, Marko Gargenta
Marakana.com

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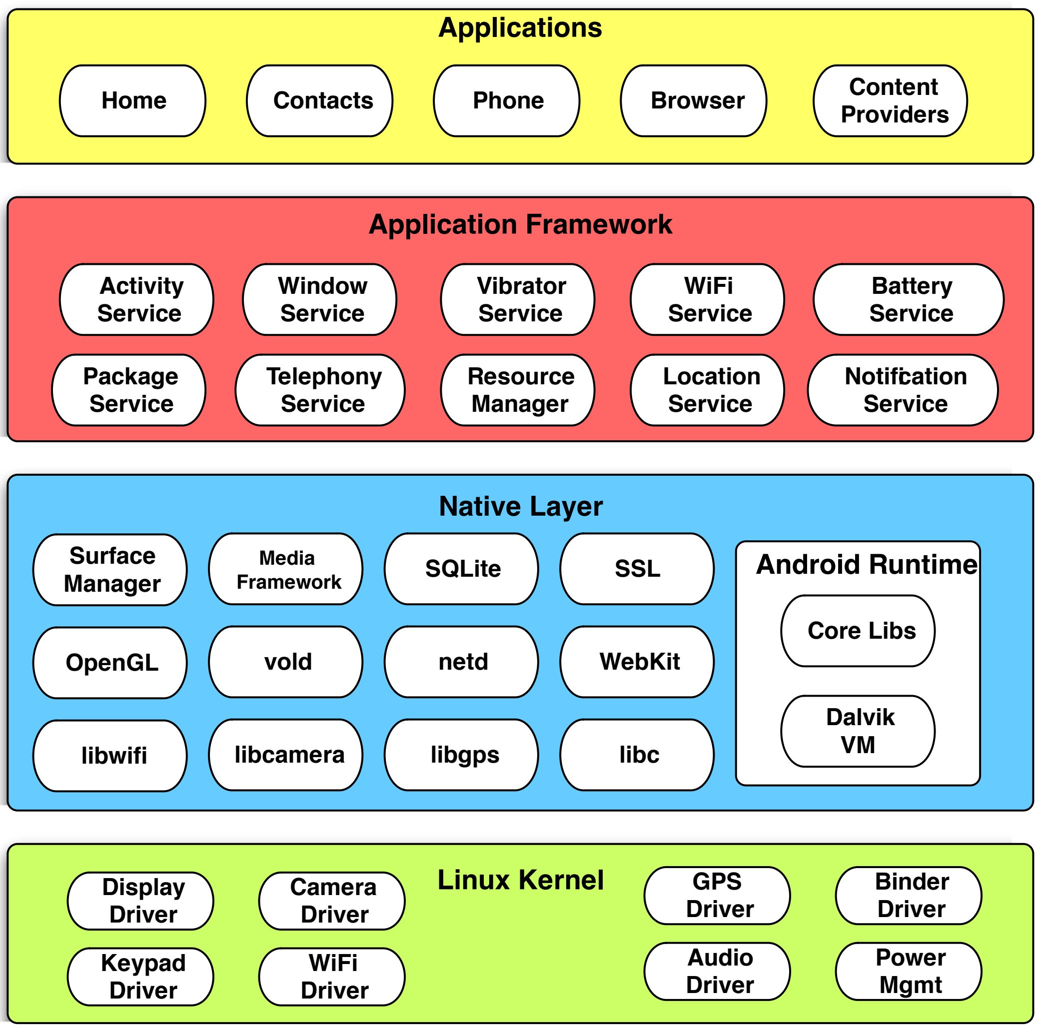
Chapter 2

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

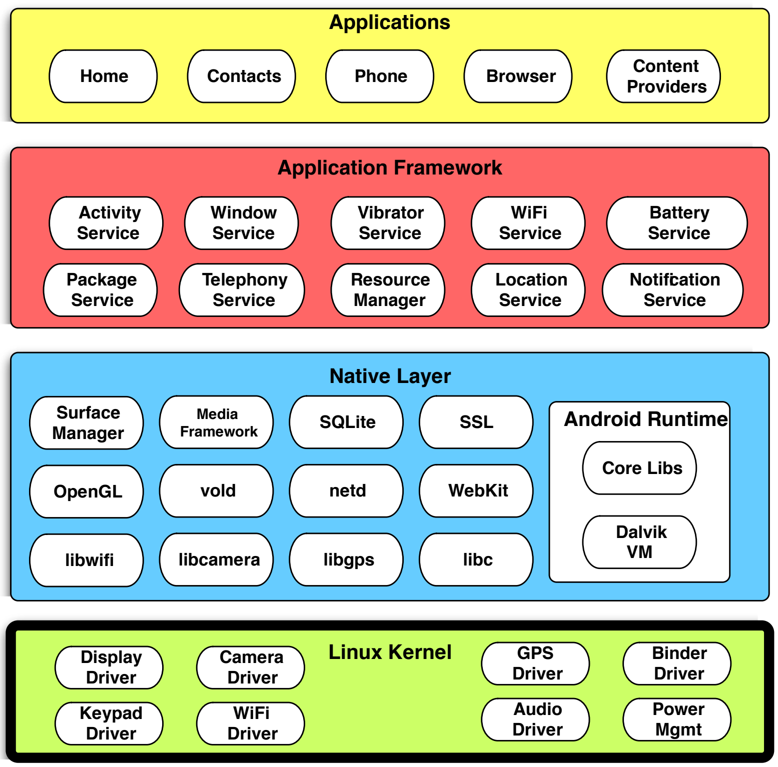


Figure 2.1: Android Kernel Layer

2.1.1 Overview

- Android runs on a modified Linux kernel

Table 2.1: 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

Table 2.1: (continued)

Android Version	**Kernel Version**
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 2.2: 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 wake_lock *lock);
void wake_unlock(struct wake_lock *lock);
void wake_lock_timeout(struct wake_lock *lock, long timeout);
void wake_lock_destroy(struct wake_lock *lock);
int wake_lock_active(struct wake_lock *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_INP`
- 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_SET_AND_WAIT`, `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_LEN`, `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 `ANDROID_PARANOID_NETWORK` kernel build option, which defines Kernel group IDs that have special network access

  /include/linux/android_aids.h (Kernel source-tree)

```
/* AIDs that the kernel treats differently */
...
#define AID_NET_BT_ADMIN 3001
#define AID_NET_BT       3002
#define AID_INET         3003
...
```

- 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

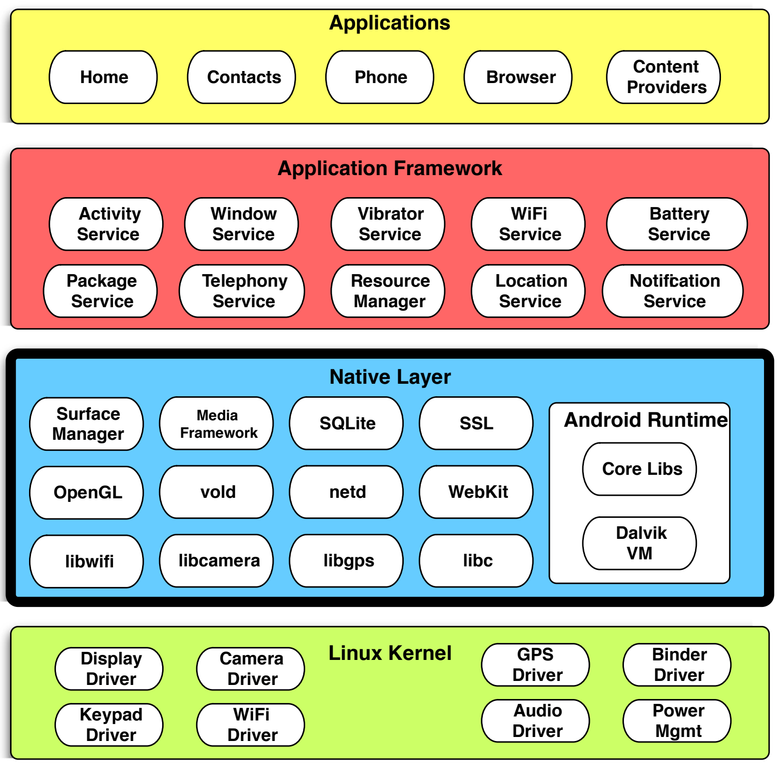


Figure 2.2: Android User-Space Native Layer

- 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 event 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="`
  - The Sensors "driver" is loaded from `/system/lib/hw/sensors.herring.so` (where `SENSORS_HARDWARE_MODULE_I`
- `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_lega` 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/uevent d`
  - 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_pffd         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 fasciliate 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

2.2.5.1 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

2.2.5.2 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.accessibiliy`, `javax.activity`, `javax.imageio`, `javax.naming` (JNDI), `javax.print`, `javax.security.auth.kerberos`, `javax.security.auth.spi`, `javax.security.spi`, `javax.security.sasl`, `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

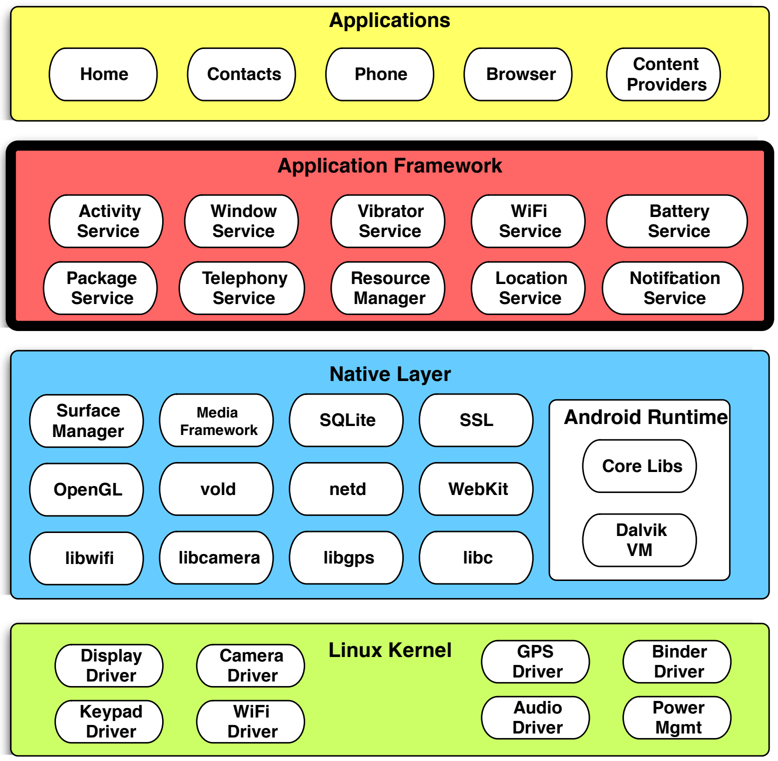
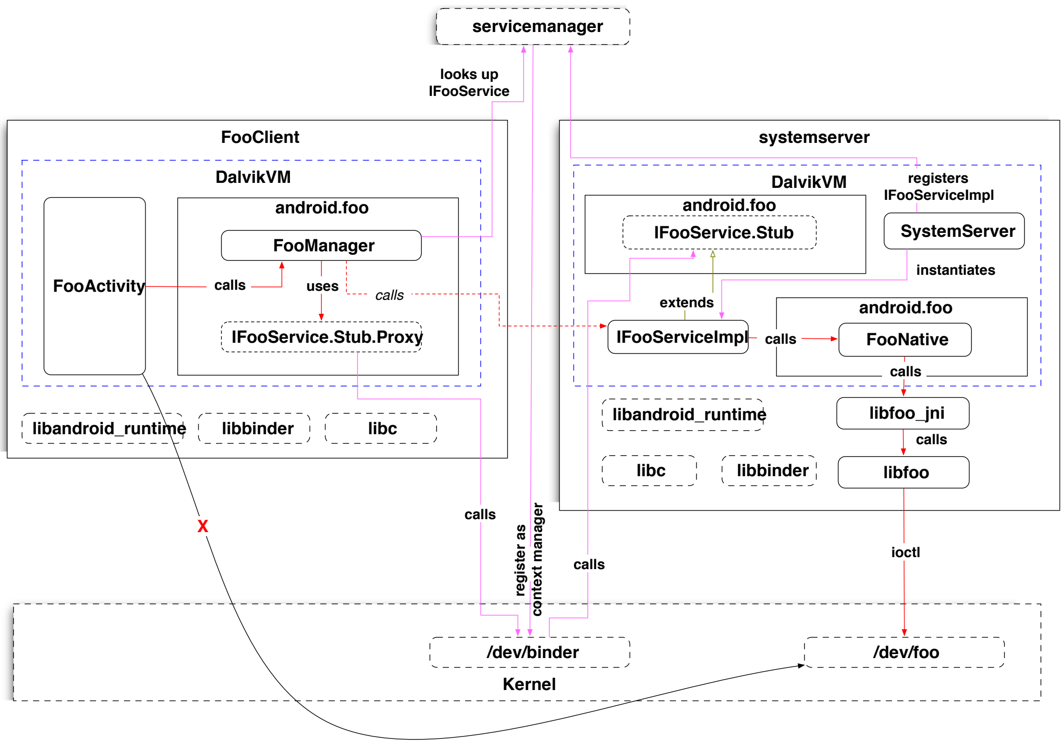


Figure 2.3: Android Application Framework Layer

2.3.1 Overview

- The rich set of system services wrapped in intuitive Java APIs
  - Most managed by the `systemserver` process and accessible via Binder/AIDL
- Abstraction of hardware services
  - Location, telephony, WiFi, Bluetooth, sensors, camera, etc.
- Java-language bindings for the native libraries (e.g. OpenGL, SQLite)
- Core platform services (like life-cycle management)
  - Essential to the apps, even if most are not used directly



2.3.2 Activity Manager Service

- Manages lifecycle of applications and their components
  - Sets up `oom_ajd` setting read by Low Memory Killer ([?]) Android extension to the Linux kernel
- Handles application requests to `startActivity()`, `sendBroadcast()`, `startService()`, `bindService()`, etc.
  - Enforces security permissions on those requests
- Maintains user task state - i.e. the back-stack

2.3.3 Package Manager Service

- Along with `installd` responsible for installation of `.apk`-s on the Android system
- Maintains internal data structures representing installed packages as well as their individual components
  - Used by Activity Manager when handling intents (i.e. intent resolution is handled here)
  - Provides this info on demand to other services and apps
- Very central to the platform's security

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

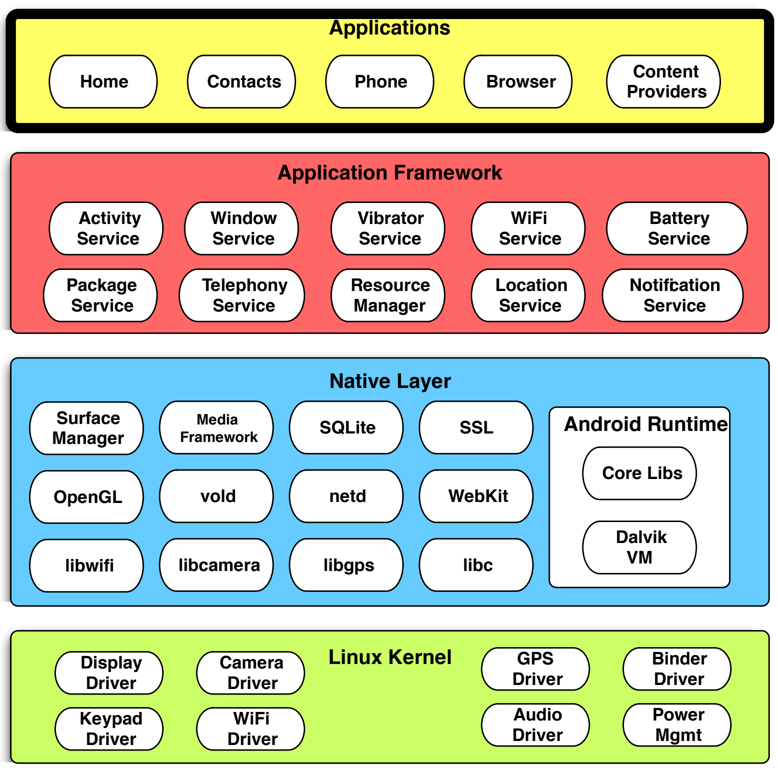


Figure 2.4: Android Application Layer

- 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 to 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*

Chapter 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`, `libjnigrahics`, 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) 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 Development (Java)

- Create a Java class with native method(s): `public native void sayHi(String who, int times);`
- Load the library which implements the method: `System.loadLibrary("HelloImpl");`
- Invoke the native method from Java

For example, our Java code could look like this:

```
package com.marakana.jniexamples;

public class Hello {
  public native void sayHi(String who, int times); //❶

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

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

❶, ❸ The method `sayHi` will be implemented in C/C++ in separate file(s), which will be compiled into a library.

❷ The library filename will be called `libHelloImpl.so` (on Unix), `HelloImpl.dll` (on Windows) and `libHelloImpl.jnil` (Mac OSX), but when loaded in Java, the library has to be loaded as `HelloImpl`.

3.3.4 JNI Development (C)

- We use the JDK `javah` utility to generate the header file `package_name_classname.h` with a function prototype for the `sayHi` method:
  `javac -d ./classes/ ./src/com/marakana/jniexamples/Hello.java`
  Then in the classes directory run: `javah -jni com.marakana.jniexamples.Hello` to generate the header file `com_marakana_jniexamples_Hello.h`
- We then create `com_marakana_jniexamples_Hello.c` to implement the `Java_com_marakana_jniexamples_Hello_sa` function

The file `com_marakana_jniexamples_Hello.h` looks like:

```
...
#include <jni.h>
...
JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Hello_sayHi
  (JNIEnv *, jobject, jstring, jint);
...
```

The file Hello.c looks like:

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

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_Hello_sayHi(JNIEnv *env, jobject ↩
    obj, jstring who, jint times) {
  jint i;
  jboolean iscopy;
  const char *name;
  name = (*env)->GetStringUTFChars(env, who, &iscopy);
  for (i = 0; i < times; i++) {
    printf("Hello %s\n", name);
  }
}
```

3.3.5 JNI Development (Compile)

- We are now ready to compile our program and run it
  - The compilation is system-dependent
- This will create `libHelloImpl.so`, `HelloImpl.dll`, `libHelloImpl.jnilib` (depending on the O/S)
- Set `LD_LIBRARY_PATH` to point to the directory where the compiled library is stored
- Run your Java application

For example, to compile `com_marakana_jniexamples_Hello.c` in the "classes" directory (if your `.h` file and `.c` file are there) on Linux do:

```
gcc -o libHelloImpl.so -lc -shared \
    -I/usr/local/jdk1.6.0_03/include \
    -I/usr/local/jdk1.6.0_03/include/linux com_marakana_jniexamples_Hello.c
```

On Mac OSX :

```
gcc -o libHelloImpl.jnilib -lc -shared \
    -I/System/Library/Frameworks/JavaVM.framework/Headers ↩
        com_marakana_jniexamples_Hello.c
```

Then set the `LD_LIBRARY_PATH` to the current working directory:

```
export LD_LIBRARY_PATH=.
```

Finally, run your application in the directory where your compiled classes are stored ("classes" for example):

```
java com.marakana.jniexamples.Hello Student 5
Hello Student
Hello Student
Hello Student
Hello Student
Hello Student
```

Note
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.

3.3.6 Type Conversion

- In many cases, programmers need to pass arguments to native methods and they do also want to receive results from native method calls
- Two kind of types in Java:
  - Primitive types such as `int`, `float`, `char`, etc
  - Reference types such as classes, instances, arrays and strings (instances of `java.lang.String` class)
- However, primitive and reference types are treated differently in JNI
  - Mapping for primitive types in JNI is simple

Table 3.1: JNI data type mapping in variables:

Java Language Type	Native Type	Description
boolean	jboolean	8 bits, unsigned
byte	jbyte	8 bits, signed
char	jchar	16 bits, unsigned
double	jdouble	64 bits
float	jfloat	32 bits
int	jint	32 bits, signed
long	jlong	64 bits, signed
short	jshort	16 bits, signed
void	void	N/A

  - Mapping for objects is more complex. Here we will focus only on strings and arrays but before we dig into that let us talk about the native methods arguments

---

- JNI passes objects to native methods as opaque references
- Opaque references are C pointer types that refer to internal data structures in the JVM
- Let us consider the following Java class:

```
package com.marakana.jniexamples;

public class HelloName {
  public static native void sayHelloName(String name);

  static { System.loadLibrary("helloname"); }
```

```
  public static void main (String[] args) {
    HelloName hello = new HelloName();
    String name = "John";
    hello.sayHelloName(name);
  }
}
```

- The `.h` file would look like this:

```
...
#include <jni.h>
...
JNIEXPORT void JNICALL Java_com_marakana_jniexamples_HelloName_sayHelloName
  (JNIEnv *, jclass, jstring);
...
```

- A `.c` file like this one would not produce the expected result:

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


JNIEXPORT void JNICALL Java_com_marakana_jniexamples_HelloName_sayHelloName(JNIEnv * ↩
    env, jclass class, jstring name){
    printf("Hello %s", name);
}
```

3.3.7 Native Method Arguments

- All native method implementation accepts two standard parameters:
  - `JNIEnv *env`: Is a pointer that points to another pointer pointing to a function table (array of pointer). Each entry in this function table points to a JNI function. These are the functions we are going to use for type conversion
  - The second argument is different depending on whether the native method is a static method or an instance method
    - Instance method: It will be a `jobject` argument which is a reference to the object on which the method is invoked
    - Static method: It will be a `jclass` argument which is a reference to the class in which the method is define

3.3.8 String Conversion

- We just talked about the `JNIEnv *env` that will be the argument to use where we will find the type conversion methods
- There are a lot of methods related to strings:
  - Some are to convert `java.lang.String` to `C` string: `GetStringChars` (Unicode format), `GetStringUTFChars` (UTF-8 format)
  - Some are to convert `java.lang.String` to `C` string: `NewString` (Unicode format), `NewStringUTF` (UTF-8 format)
  - Some are to release memory on C string: `ReleaseStringChars`, `ReleaseStringUTFChars`

Note
Details about these methods can be found at http://download.oracle.com/javase/6/docs/technotes/guides/jni/spec/functions.html

- If you remember the previous example, we had a native method where we wanted to display "Hello *name*":

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

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

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

- Here is what you would do, using UTF-8 string for instance:

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

JNIEXPORT void JNICALL Java_com_marakana_jniexamples_HelloName_sayHelloName(JNIEnv * ↩
    env, jclass class, jstring name){
    const jbyte *str;
    str = (*env)->GetStringUTFChars(env, name, NULL); //❶
    printf("Hello %s\n", str);
    (*env)->ReleaseStringUTFChars(env, name, str); //❷
}
```

❶ This returns a pointer to an array of bytes representing the string in UTF-8 encoding (without making a copy)

❷ When we are not making a copy of the string, calling `ReleaseStringUTFChars` prevents the memory area used by the string to stay "pinned". If the data was copied, we need to call `ReleaseStringUTFChars` to free the memory which is not used anymore

- Here is another example where we would construct and return a `java.lang.String` instance:

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

JNIEXPORT jstring JNICALL Java_com_marakana_jniexamples_ReturnName_GetName(JNIEnv * ↩
    env, jclass class) {
    char buffer[20];
    scanf("%s", buffer);
    return (*env)->NewStringUTF(env, buffer);
}
```

3.3.9 Array Conversion

- Here we are going to focus on primitive arrays only since they are different from objects arrays in JNI
- Arrays are represented in JNI by the `jarray` reference type and its "subtypes" such as `jintArray` ⇒ A `jarray` is not a C array!
- Again we will use the `JNIEnv *env` parameter to access the type conversion methods
  - `Get<Type>ArrayRegion`: Copies the contents of primitive arrays to a preallocated C buffer. Good to use when the size of the array is known
  - `Get<Type>ArrayElements`: Gets a pointer to the content of the primitive array
  - `New<Type>Array`: To create an array specifying a length

- We are going to see an example of how to read a Java primitive array in the native world
- First, this would be your Java program:

```
package com.marakana.jniexamples;

public class ArrayReader {
    private static native int sumArray(int[] arr); //❶
    public static void main(String[] args) {
        //Array declaration
        int arr[] = new int[10];
        //Fill the array
        for (int i = 0; i < 10; i++) {
            arr[i] = i;
        }
        ArrayReader reader = new ArrayReader();
        //Call native method
        int result = reader.sumArray(arr); //❷
        System.out.println("The sum of every element in the array is " + Integer. ↩
            toString(result));
    }
    static {
        System.loadLibrary("arrayreader");
    }
}
```

❶, ❷ This method will return the sum of each element in the array

- After running `javah`, create your `.c` file that would look like this:

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

JNIEXPORT jint JNICALL Java_com_marakana_jniexamples_ArrayReader_sumArray(JNIEnv *env ↩
    , jclass class, jintArray array) {
    jint *native_array;
    jint i, result = 0;
    native_array = (*env)->GetIntArrayElements(env, array, NULL); /* ❶ */
    if (native_array == NULL) {
```

```
        return 0;
    }
    for (i=0; i<10; i++) {
        result += native_array[i];
    }
    (*env)->ReleaseIntArrayElements(env, array, native_array, 0);
    return result;
}
```

1. We could also have used `GetIntArrayRegion` since we exactly know the size of the array

3.3.10 Throwing Exceptions In The Native World

- We are about to see how to throw an exception from the native world
- Throwing an exception from the native world involves the following steps:
  - Find the exception class that you want to throw
  - Throw the exception
  - Delete the local reference to the exception class
- We could imagine a utility function like this one:

```
void ThrowExceptionByClassName(JNIEnv *env, const char *name, const char *message) {
  jclass class = (*env)->FindClass(env, name); //❶
  if (class != NULL) {
      (*env)->ThrowNew(env, class, message); //❷
  }
  (*env)->DeleteLocalRef(env, class); //❸
}
```

1. Find exception class by its name
2. Throw the exception using the class reference we got before and the message for the exception
3. Delete local reference to the exception class

- Here would be how to use this utility method:

```
ThrowExceptionByClassName(env,"java/lang/IllegalArgumentException","This exception is ↩
     thrown from C code");
```

3.3.11 Access Properties And Methods From Native Code

- You might want to modify some properties or call methods of the instance calling the native code
- It always starts with this operation: Getting a reference to the object class by calling the `GetObjectClass` method
- We are then going to get instance field id or an instance method id from the class reference using `GetFieldID` or `GetMethodID` methods
- For the rest, it differs depending on whether we are accessing a field or a method

- From this Java class, we will see how to call its methods or access its properties in the native code:

```
package com.marakana.jniexamples;

public class InstanceAccess {
    public String name; //❶

    public void setName(String name) { //❷
        this.name = name;
    }

    //Native method
    public native void propertyAccess(); //❸
    public native void methodAccess(); //❹

    public static void main(String args[]) {
        InstanceAccess instanceAccessor = new InstanceAccess();
        //Set the initial value of the name property
        instanceAccessor.setName("Jack");
        System.out.println("Java: value of name = \""+ instanceAccessor.name +"\"");
        //Call the propetyAccess() method
        System.out.println("Java: calling propertyAccess() method...");
        instanceAccessor.propertyAccess(); //❺
        //Value of name after calling the propertyAccess() method
        System.out.println("Java: value of name after calling propertyAccess() = \""+ ↩
             instanceAccessor.name +"\"");
        //Call the methodAccess() method
        System.out.println("Java: calling methodAccess() method...");
        instanceAccessor.methodAccess(); //❻
        System.out.println("Java: value of name after calling methodAccess() = \""+  ↩
            instanceAccessor.name +"\"");
    }

    //Load library
    static {
        System.loadLibrary("instanceaccess");
    }
}
```

❶ Name property that we are going to modify along this code execution

❷ This method will be called by the native code to modify the name property

❸, ❺ This native method modifies the name property by directly accessing the property

❹, ❻ This native method modifies the name property by calling the Java method `setName()`

- This would be our C code for native execution:

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


JNIEXPORT void JNICALL Java_com_marakana_jniexamples_InstanceAccess_propertyAccess( ↩
    JNIEnv *env, jobject object){
    jfieldID fieldId;
    jstring jstr;
    const char *cString;
```

```
    /* Getting a reference to object class */
    jclass class = (*env)->GetObjectClass(env, object); /* ❶ */

    /* Getting the field id in the class */
    fieldId = (*env)->GetFieldID(env, class, "name", "Ljava/lang/String;"); /* ❷ */
    if (fieldId == NULL) {
        return; /* Error while getting field id */
    }

    /* Getting a jstring */
    jstr = (*env)->GetObjectField(env, object, fieldId); /* ❸ */

    /* From that jstring we are getting a C string: char* */
    cString = (*env)->GetStringUTFChars(env, jstr, NULL); /* ❹ */
    if (cString == NULL) {
        return; /* Out of memory */
    }
    printf("C: value of name before property modification = \"%s\"\n", cString);
    (*env)->ReleaseStringUTFChars(env, jstr, cString);

    /* Creating a new string containing the new name */
    jstr = (*env)->NewStringUTF(env, "Brian"); /* ❺ */
    if (jstr == NULL) {
        return; /* Out of memory */
    }
    /* Overwrite the value of the name property */
    (*env)->SetObjectField(env, object, fieldId, jstr); /* ❻ */
}


JNIEXPORT void JNICALL Java_com_marakana_jniexamples_InstanceAccess_methodAccess( ↩
    JNIEnv *env, jobject object){
    jclass class = (*env)->GetObjectClass(env, object); /* ❼ */
    jmethodID methodId = (*env)->GetMethodID(env, class, "setName", "(Ljava/lang/ ↩
        String;)V"); /* ❽ */
    jstring jstr;
    if (methodId == NULL) {
        return; /* method not found */
    }
    /* Creating a new string containing the new name */
    jstr = (*env)->NewStringUTF(env, "Nick"); /* ❾ */
    (*env)->CallVoidMethod(env, object, methodId, jstr); /* ❿ */
}
```

❶, ❼ This is getting a reference to the object class

❷ Gets a field Id from the object class, specifying the property to get and the internal type. you can find information on the jni type there: http://download.oracle.com/javase/6/docs/technotes/guides/jni/spec/types.html

❸ This will return the value of the property in the native type: here a jstring

❹ We need to convert the jstring to a C string

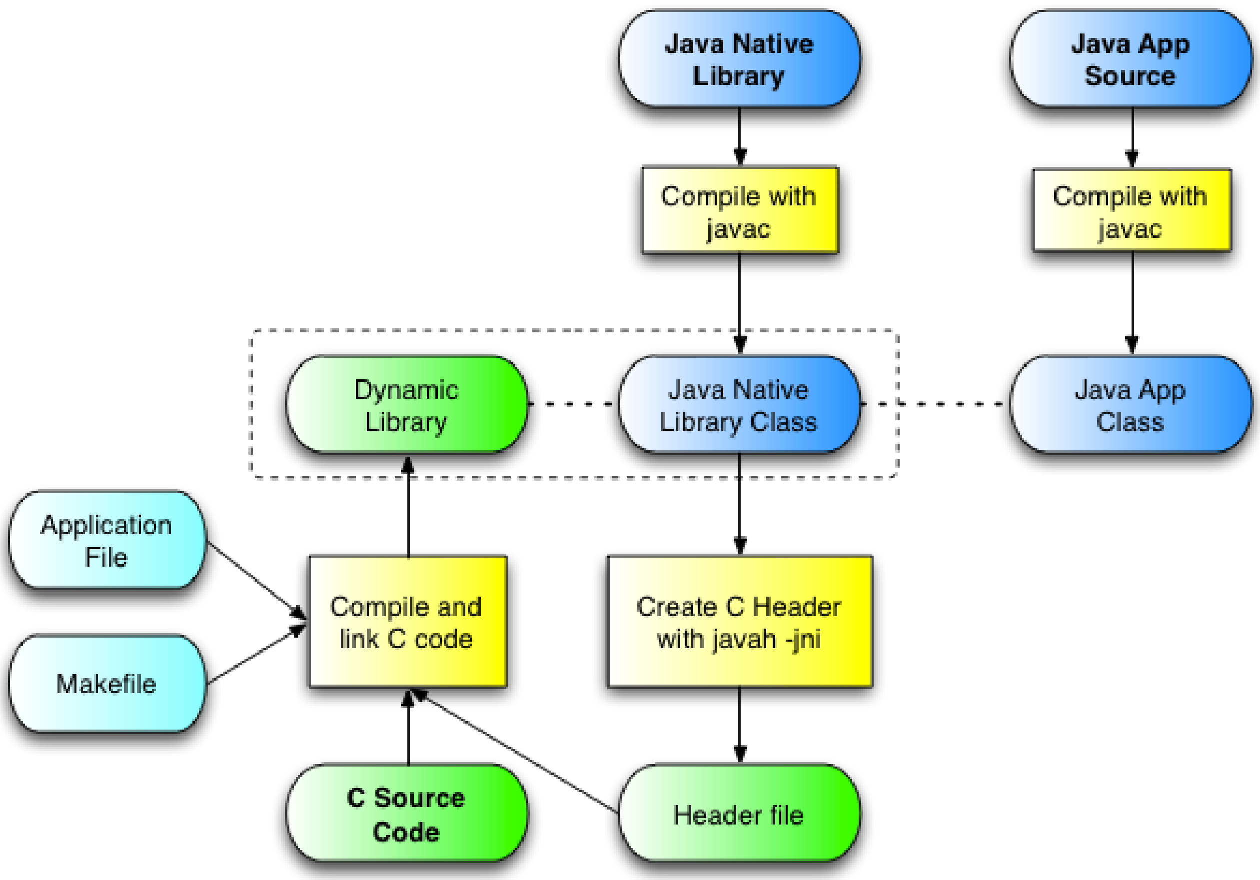
❺ This creates a new java.lang.String that is going be use to change the value of the property

❻ This sets the property to its new value

❽ Gets a method id from the object class previously obtained, specifying the name of the method along with its signature. There is a very useful java tool that you can use to get the signature of a method: `javap -s -p ClassName` for instance `javap -s -p InstanceAccess`

- ❾ This creates a new java.lang.String that we are going to use as an argument when calling the java method from native code
- ❿ Calling `CallVoidMethod` since the Java method return type is `void` and we are passing the previously created `jstring` as a parameter

3.4 Using NDK



3.5 Fibonacci Example Overview

- Start by creating a new Android Project
  - Project Name: FibonacciNative
  - Build Target: Android 2.2 (API 8)
  - 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;

public class FibLib {

    public static long fibJR(long n) { // ❶
        return n <= 0 ? 0 : n == 1 ? 1 : fibJR(n - 1) + fibJR(n - 2);
    }

    public static long fibJI(long n) { // ❷
        long previous = -1;
        long result = 1;
        for (long i = 0; i <= n; i++) {
            long sum = result + previous;
            previous = result;
            result = sum;
        }
        return result;
    }

    public native static long fibNR(long n); // ❸

    public native static long fibNI(long n); // ❹

    static {
        System.loadLibrary("com_marakana_android_fibonaccinative_FibLib"); // ❺
    }
}
```

❶ Recursive Java implementation of the Fibonacci algorithm (included for comparison only)

❷ Iterative Java implementation of the Fibonacci algorithm (included for comparison only)

❸ Function prototype for future native recursive implementation of the Fibonacci algorithm

❹ Function prototype for future iterative recursive implementation of the Fibonacci algorithm

❺ Use `System.loadLibrary()` to load the native module (to be compiled)

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 "com_marakana_android_fibonaccinative_FibLib.h" /* ❶ */

jlong fib(jlong n) { /* ❷ */
    return n <= 0 ? 0 : n == 1 ? 1 : fib(n - 1) + fib(n - 2);
}

JNIEXPORT jlong JNICALL Java_com_marakana_android_fibonaccinative_FibLib_fibNR
  (JNIEnv *env, jclass clazz, jlong n) { /* ❸ */
    return fib(n);
}

JNIEXPORT jlong JNICALL Java_com_marakana_android_fibonaccinative_FibLib_fibNI
  (JNIEnv *env, jclass clazz, jlong n) { /* ❹ */
    jlong previous = -1;
    jlong result = 1;
    jlong i;
    for (i = 0; i <= n; i++) {
        jlong sum = result + previous;
        previous = result;
        result = sum;
    }
    return result;
}
```

1. Include the header file that was created via `javah -jni` command.
2. Recursive implementation of the fibonacci algorithm (in a helper function)
3. Actual implementation of JNI-defined `fibNR` (recursive) function
4. Actual implementation of JNI-defined `fibNI` (iterative) function

3.5.4 Fibonacci - An Alternative Implementation (CPP)

We could also use an alternative mechanism of linking native-code to managed code by pre-registering our functions. This may lead to 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"

/*************************************************************
 * This is an alternative implementation that demonstrates *
 * how to pre-link native funcitons to the managed JNI     *
 * environment.                                            *
 * To test, switch to this file in Android.mk              *
 *************************************************************/

#ifndef NELEM
# define NELEM(x) ((int) (sizeof(x) / sizeof((x)[0])))
#endif
```

```
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) {
        return fib(n);
    }

    static jlong fibNI(JNIEnv *env, jclass clazz, jlong n) {
        jlong previous = -1;
        jlong result = 1;
        jlong i;
        for (i = 0; i <= n; i++) {
            jlong sum = result + previous;
            previous = result;
            result = sum;
        }
        return result;
    }

    // see http://docs.oracle.com/javase/6/docs/technotes/guides/jni/spec/types.html
    static JNINativeMethod method_table[] = {
        { "fibNR", "(J)J", (void*)fibNR },
        { "fibNI", "(J)J", (void*)fibNI }
    };
}

using namespace com_marakana_android_fibonaccinative;

// See dalvik/libnativehelper/JNIHelp.cpp
static int jniRegisterNativeMethods(JNIEnv* env, const char* className,
        const JNINativeMethod* gMethods, int numMethods) {
    jclass clazz = env->FindClass(className);
    if (clazz) {
        env->RegisterNatives(clazz, gMethods, numMethods);
        env->DeleteLocalRef(clazz);
        return 0;
    } else {
        return -1;
    }
}

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 -1;
    } else {
        // see http://java.sun.com/docs/books/jni/html/other.html#29535
        if (jniRegisterNativeMethods(env, "com/marakana/android/fibonaccinative/FibLib ↩
            ",
                method_table, NELEM(method_table)) != 0) {
            return -2;
        }
```

```
    }
    return JNI_VERSION_1_6;
}
```

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

```
# ❶
LOCAL_PATH := $(call my-dir)

# ❷
include $(CLEAR_VARS)

# ❸
LOCAL_SRC_FILES := com_marakana_android_fibonaccinative_FibLib.c

# ❹
LOCAL_MODULE    := com_marakana_android_fibonaccinative_FibLib

# ❺
include $(BUILD_SHARED_LIBRARY)
```

❶ `LOCAL_PATH` is used to locate source files in the development tree. An `Android.mk` file must begin with the definition of this variable. 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).

❷ `include $(CLEAR_VARS)` clears many `LOCAL_XXX` variables with the exception of `LOCAL_PATH` (this is needed because all variables are global)

❸ `LOCAL_SRC_FILES` lists all of our C files to be compiled (header file dependencies are automatically computed)

❹ `LOCAL_MODULE` defines the name of our shared module (this name will be prepended by `lib` and postfixed by `.so`)

❺ `include $(BUILD_SHARED_LIBRARY)` collects all `LOCAL_XXX` variables since `include $(CLEAR_VARS)` and determines what to build (in this case a 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.

3.5.6.1 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>` 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.

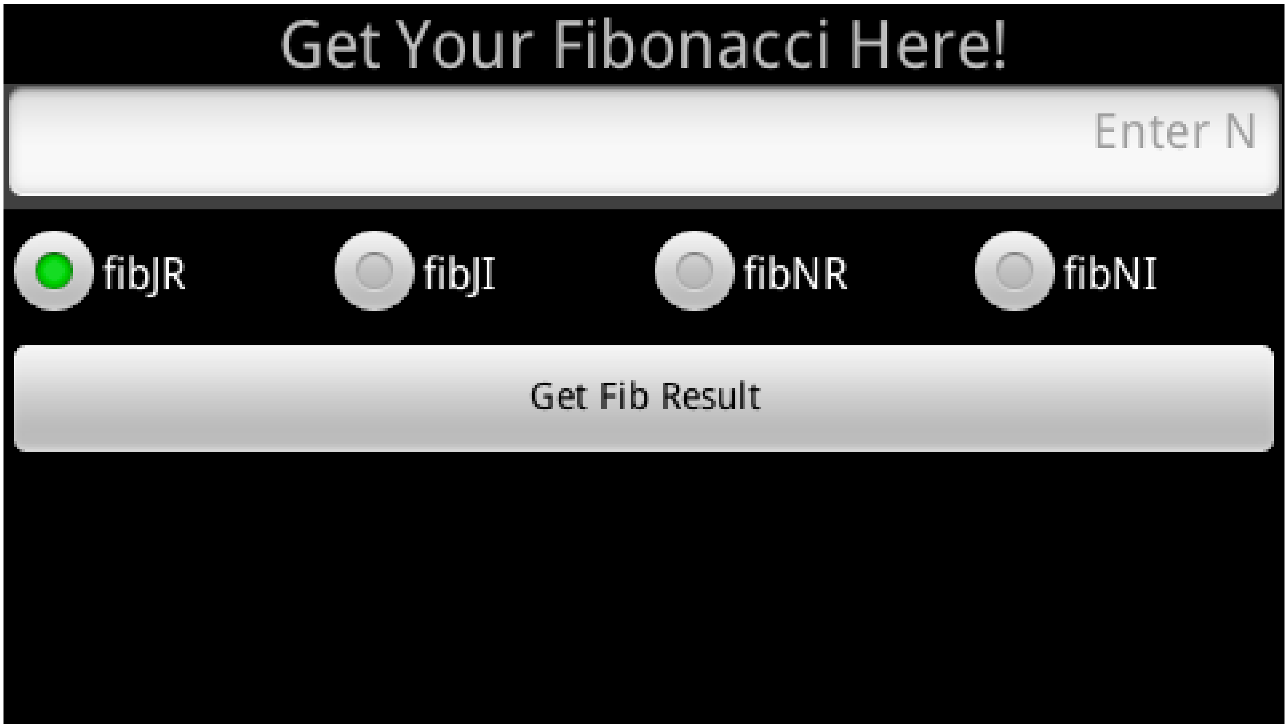
3.5.7.1 Fibonacci - String Resources

FibonacciNative/res/values/strings.xml

```xml
<?xml version="1.0" encoding="utf-8"?>
<resources>
    <string name="hello">Get Your Fibonacci Here!</string>
    <string name="app_name">Fibonacci Native</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="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>
```

3.5.7.2 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: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" /> <!-- ❶ -->
    <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" />  <!-- ❷ -->
    <RadioGroup android:orientation="horizontal"
        android:layout_width="match_parent" android:id="@+id/type"
        android:layout_height="wrap_content">  <!-- ❸ -->
        <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" />  < ↩
            !-- ❹ -->
    <TextView android:id="@+id/output" android:layout_width="match_parent"
        android:layout_height="match_parent" android:textSize="20sp"
        android:gravity="center" />  <!-- ❺ -->
</LinearLayout>
```

1. This is just a simple title ("Get Your Fibonacci Here!")
2. This is the entry box for our number *n*
3. This radio group allows the user to select the fibonacci implementation type
4. This button allows the user to trigger fibonacci calculation
5. This is the output area for the fibonacci result

3.5.7.3 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.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; // our input n

    private RadioGroup type; // fibonacci implementation type

    private TextView output; // destination for fibonacci result

    @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.type = (RadioGroup)super.findViewById(R.id.type);
        this.output = (TextView)super.findViewById(R.id.output);
        Button button = (Button)super.findViewById(R.id.button);
        // request button click call-backs via onClick(View) method
        button.setOnClickListener(this);
```

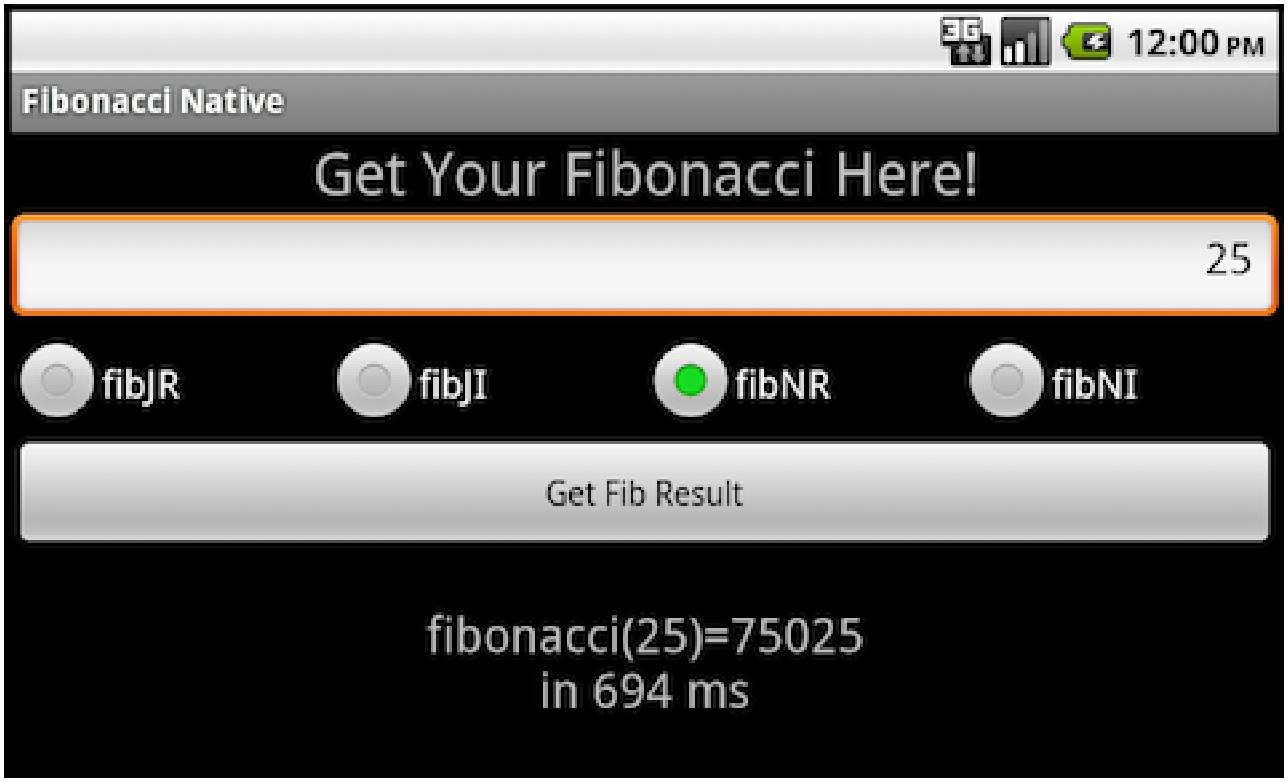
```
    }

    // 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;
        }
        // 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
                long result = 0;
                long t = System.currentTimeMillis(); // measure the time
                // call into our library (based on the type selection)
                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;
                }
                // measure the time difference
                t = System.currentTimeMillis() - t;
                // generate the result
                return String.format("fibonacci(%d)=%d\nin %d ms", n, result, t);
            }

            @Override
            protected void onPostExecute(String result) {
                // get rid of the dialog
                dialog.dismiss();
                // show the result to the user
                FibonacciActivity.this.output.setText(result);
            }
        }.execute(); // run our AsyncTask
```

```
    }
}
```

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>/usr/`

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/libGLESv1_CM.so with LOCAL_LDLIBS += -lGLESv1_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/libGLESv2.so with LOCAL_LDLIBS += -lGLESv2.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_ 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/inc

---

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 message);
    /* You'll need to load your library here */
}
```

It is up to you to design the UI, but it could be as simple as three `TextView` widgets (one for `priority`, one for `tag`, and one for `message`) and one `Button` widget to submit the message to the log, or even simpler - call `LibLog.log(3, "MyTag", "MyMessage");` from activity's `onCreate(Bundle)` method.

Tip
Don't forget to convert `tag` and `message` 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.

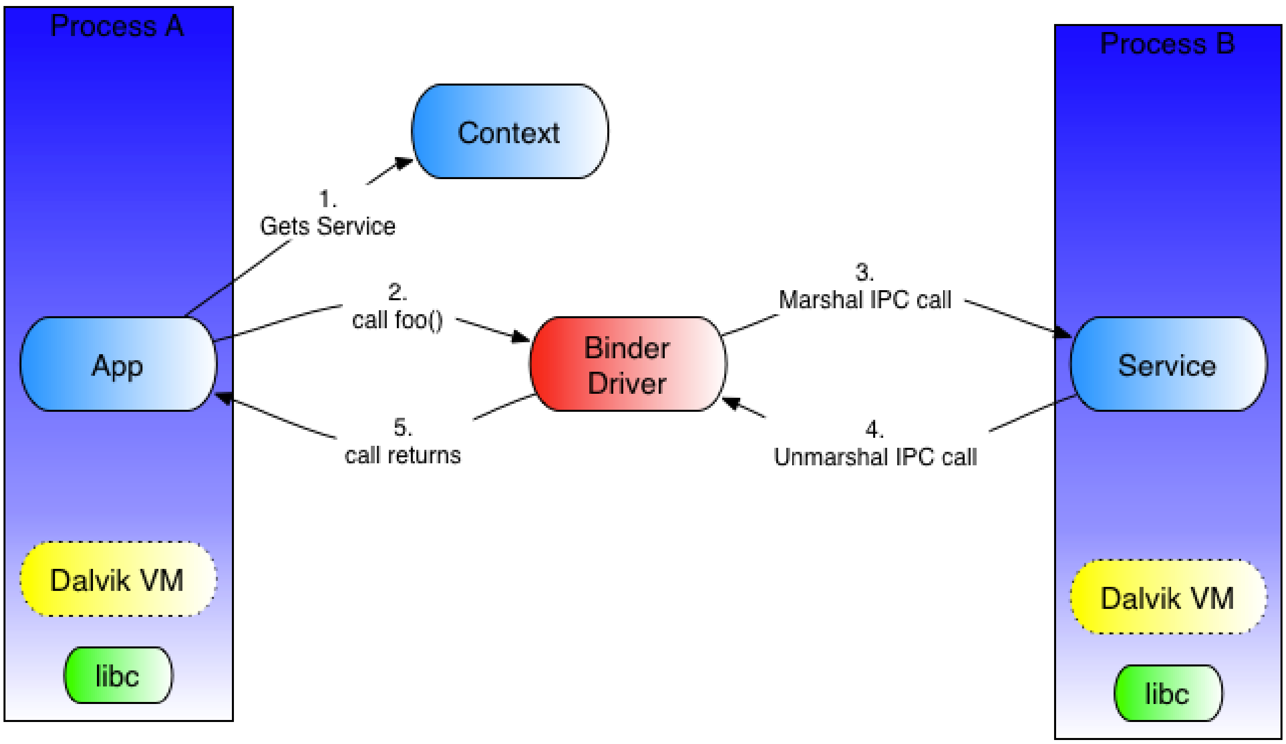
Chapter 4

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 interafaces
- 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(Parcel parcel) {
        this.id = parcel.readInt();
        this.data = parcel.readString();
    }

    // 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 in) {
            return new Bar(in);
        }
        public Bar[] newArray(int size) {
            return new Bar[size];
        }
    };
}
```

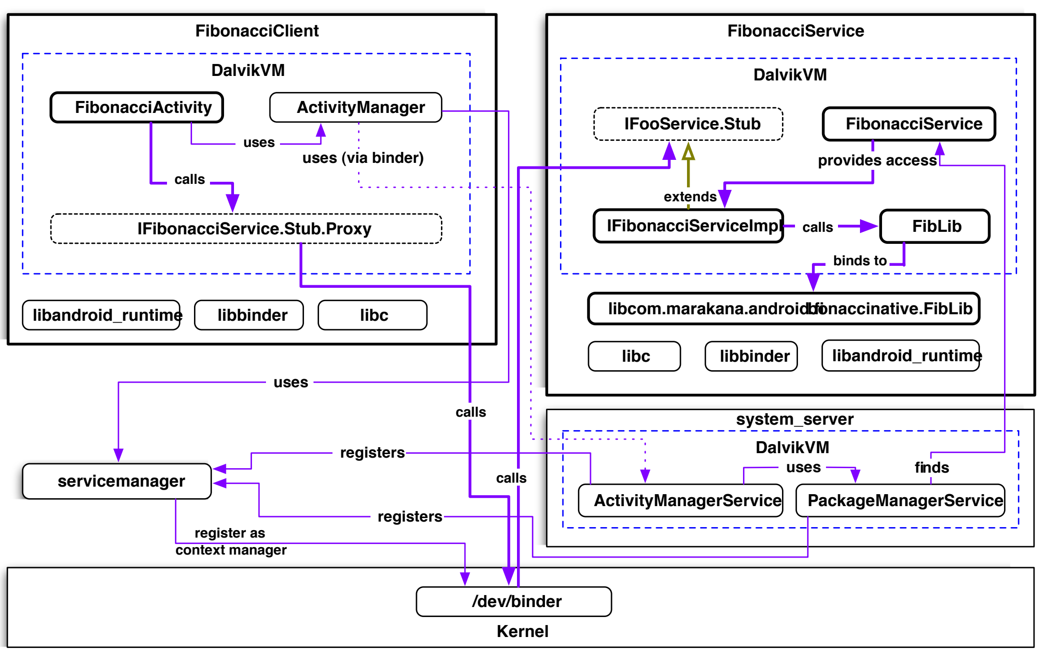
* These custom classes have to be declared in their own (simplified) `.aidl` files
src/com/example/app/Bar.aidl

```
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 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

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)
  - 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 refresh 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 final int RECURSIVE_JAVA_TYPE = 1;

    public static final int ITERATIVE_JAVA_TYPE = 2;

    public static final int RECURSIVE_NATIVE_TYPE = 3;

    public static final int ITERATIVE_NATIVE_TYPE = 4;

    private final long n;

    private final int type;

    public FibonacciRequest(long n, int type) {
        this.n = n;
        if (type < RECURSIVE_JAVA_TYPE || type > ITERATIVE_NATIVE_TYPE) {
            throw new IllegalArgumentException("Invalid type: " + type);
        }
        this.type = type;
    }

    private FibonacciRequest(Parcel parcel) {
        this(parcel.readLong(), parcel.readInt());
    }

    public long getN() {
        return n;
    }

    public int getType() {
        return type;
    }

    public int describeContents() {
        return 0;
    }

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

```
    public static final Parcelable.Creator<FibonacciRequest> CREATOR = new Parcelable ↩
        .Creator<FibonacciRequest>() {
        public FibonacciRequest createFromParcel(Parcel in) {
            return new FibonacciRequest(in);
        }

        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 FibonacciResponse(Parcel parcel) {
        this(parcel.readLong(), parcel.readLong());
    }

    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);
        }

        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)
  – 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=../Fibonacci` 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.fibona` (which in turn extends from `android.os.Binder`)

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

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

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.fibonaccinative.FibLib;

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

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

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

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

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

    public FibonacciResponse fib(FibonacciRequest request) {
        Log.d(TAG, "fib()");
```

```
        long timeInMillis = System.currentTimeMillis();
        long result;
        switch (request.getType()) {
            case FibonacciRequest.ITERATIVE_JAVA_TYPE:
                result = this.fibJI(request.getN());
                break;
            case FibonacciRequest.RECURSIVE_JAVA_TYPE:
                result = this.fibJR(request.getN());
                break;
            case FibonacciRequest.ITERATIVE_NATIVE_TYPE:
                result = this.fibNI(request.getN());
                break;
            case FibonacciRequest.RECURSIVE_NATIVE_TYPE:
                result = this.fibNR(request.getN());
                break;
            default:
                return null;
        }
        timeInMillis = System.currentTimeMillis() - 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"); // ❺
```

```
        return this.service; // ❻
    }

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

❻ 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`.

❹, ❺, 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.fibonaccicommon. ↩
                    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)
  - 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=../FibonacciC` 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.j`
    * 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.ProgressDialog;
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.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 calcualtion

    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
        int type;
        switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
            case R.id.type_fib_jr:
                type = FibonacciRequest.RECURSIVE_JAVA_TYPE;
                break;
            case R.id.type_fib_ji:
                type = FibonacciRequest.ITERATIVE_JAVA_TYPE;
                break;
            case R.id.type_fib_nr:
                type = FibonacciRequest.RECURSIVE_NATIVE_TYPE;
                break;
            case R.id.type_fib_ni:
                type = FibonacciRequest.ITERATIVE_NATIVE_TYPE;
                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 {
```

```
                    FibonacciResponse response = FibonacciActivity.this.service.fib( ↩
                        request);
                    // generate the result
                    return String.format("fibonacci(%d)=%d\nin %d ms", n, response. ↩
                        getResult(),
                            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)

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/fibonacciservice/IFibonacciServiceImpl.java:

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

import android.os.RemoteException;
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.fibonaccicommon.IFibonacciServiceResponseListener;
import com.marakana.android.fibonaccinative.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 = System.currentTimeMillis();
        long result;
        switch (request.getType()) {
            case FibonacciRequest.ITERATIVE_JAVA_TYPE:
                result = FibLib.fibJI(n);
                break;
            case FibonacciRequest.RECURSIVE_JAVA_TYPE:
                result = FibLib.fibJR(n);
                break;
            case FibonacciRequest.ITERATIVE_NATIVE_TYPE:
                result = FibLib.fibNI(n);
                break;
            case FibonacciRequest.RECURSIVE_NATIVE_TYPE:
                result = FibLib.fibNR(n);
                break;
            default:
```

```
                result = 0;
        }
        timeInMillis = System.currentTimeMillis() - 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.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 calcualtion

    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
        int type;
        switch (FibonacciActivity.this.type.getCheckedRadioButtonId()) {
            case R.id.type_fib_jr:
                type = FibonacciRequest.RECURSIVE_JAVA_TYPE;
                break;
            case R.id.type_fib_ji:
                type = FibonacciRequest.ITERATIVE_JAVA_TYPE;
                break;
            case R.id.type_fib_nr:
                type = FibonacciRequest.RECURSIVE_NATIVE_TYPE;
                break;
            case R.id.type_fib_ni:
                type = FibonacciRequest.ITERATIVE_NATIVE_TYPE;
                break;
            default:
                return;
        }

        FibonacciRequest request = new FibonacciRequest(n, type);
        try {
            Log.d(TAG, "Submitting request...");
            // submit the request; the response will come to responseListener
            this.service.fib(request, this.responseListener);
            Log.d(TAG, "Submited request");
            // 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 message) {
        ...
    }
    ...
}
```

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

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

Chapter 5

Android Security

5.1 Overview

- Android Security Architecture
- Android Application Signing
- Understanding Android User IDs
- File Access Permissions on Android
- Using Permissions in Android Applications
- Android Permission Enforcement
  - Permissions enforced by the Linux kernel
  - Permissions enforced by the Application Framework Services
- Custom Android Permissions
  - Declaring Custom Permissions
  - Requiring Custom Permissions
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- ContentProvider URI Permissions
- Developer DOs and DON'Ts
  - Public vs. Private Components
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- Encryption on Android
  - Application Data Encryption: OpenSSL, JCE/BouncyCastle
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- Rooting Android Devices
  - Controlling access to `/system/bin/sh`
  - Understanding Android Exploits
    - UDEV exploit (exploid)
    - ADB setuid exhaustion attack (rageagainstthecage)
    - Buffer-overrun of vold (softbreak/gingerbreak)
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    - Others
  - To root or not to root
  - Malware rootkits
- Memory protection on Android (ASLR, etc.)
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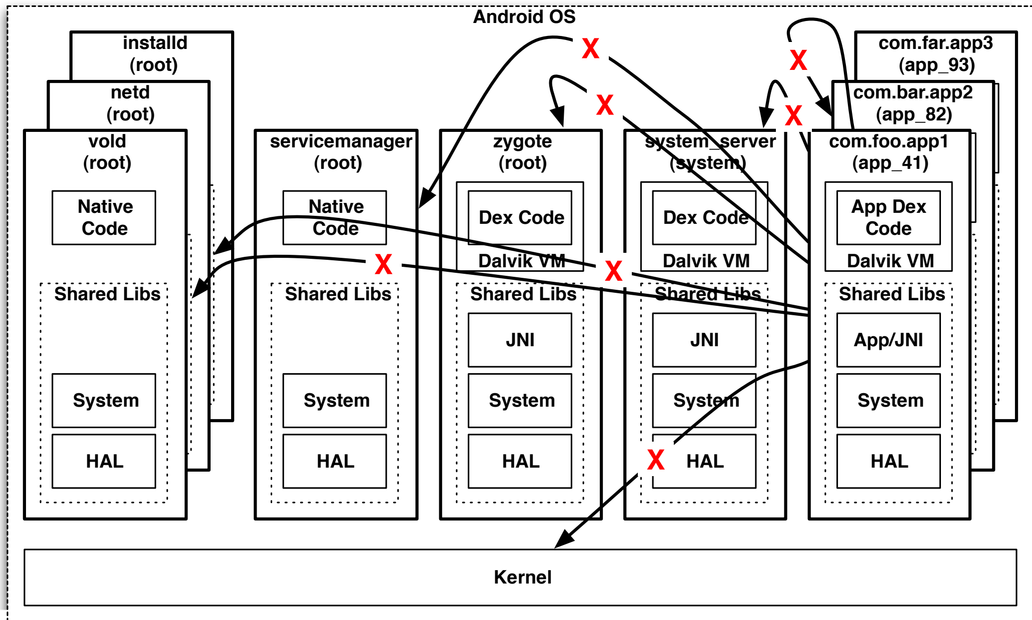
- Device Administration (management) on Android
- Building Anti-malware Applications for Android
- Other Security Concerns
  - Bootloaders
  - Security of GMail accounts affecting security of Android devices
  - Social-engineering vectors of attack
  - Encryption of communication
  - Firewall
  - SE-Linux
  - Recovery mode

5.2 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)
- Apps can explicitly share resources/data (usually via ContentProviders), and even "logic" (via AIDL)
- 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

5.3 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
  - 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

5.4 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="myapp"
          android:sharedUserLabel="@string/myapp_uid" ... >
  <application android:process="myapp" ... >
    ...
  </application>
</manifest>
```

5.5 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.apk
  - /mnt/secure/asec/<app-package-name>-1.asec (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@pkg
- 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

5.6 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:xxxxxxxxxx }
java.lang.SecurityException: Permission Denial: starting Intent { act=android. ↩
    intent.action.CALL dat=tel:xxxxxxxxxx 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 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

5.7 Permission Enforcement

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

5.7.1 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`

5.7.2 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_RADIO))
        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;
}
...
```

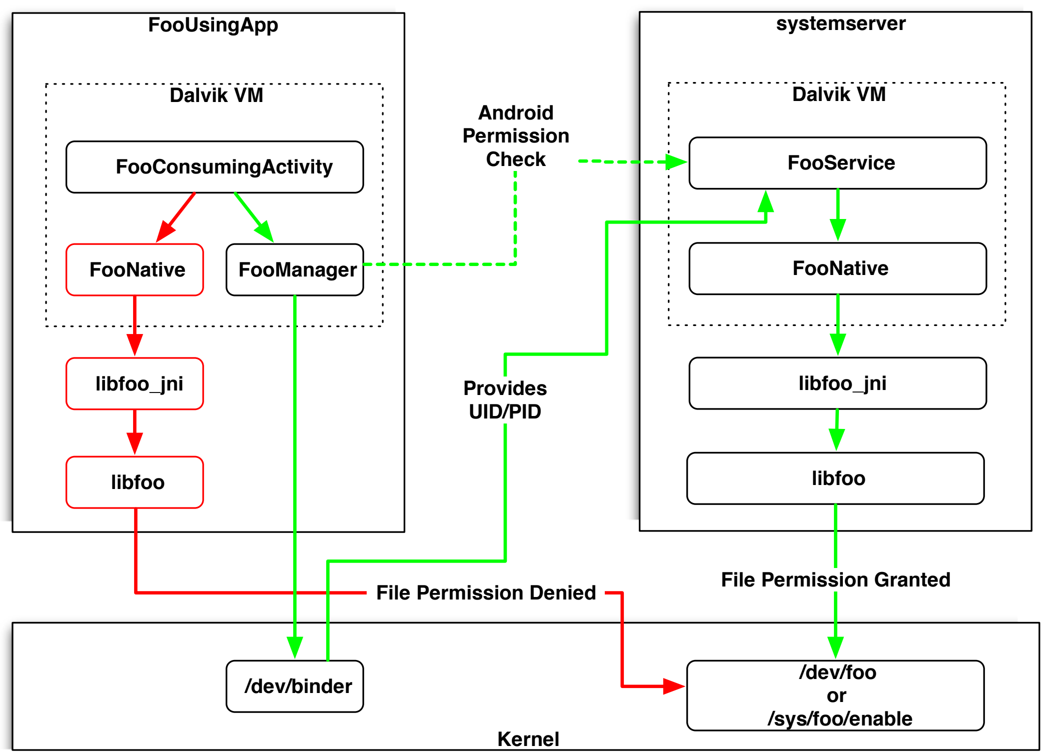
5.7.3 Static Permission Enforcement

- Automatically managed by ActivityManagerService
- In AndroidManifest.xml an application restricts access to its components via andriod: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.updat 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(BroadcastReceiver receiver, IntentFilter filter, String broadcastPermission, Handler scheduler) method
    * Senders can also programmatically require that the receivers hold the appropriate permission via Context.sendBroadcast(Int intent, String receiverPermission)
    * Some broadcasts are declared as <protected-broadcast android:name="..." /> in frameworks/base/core/re (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>
```

5.8 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)

5.9 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>
```

5.9.1 Permission Components

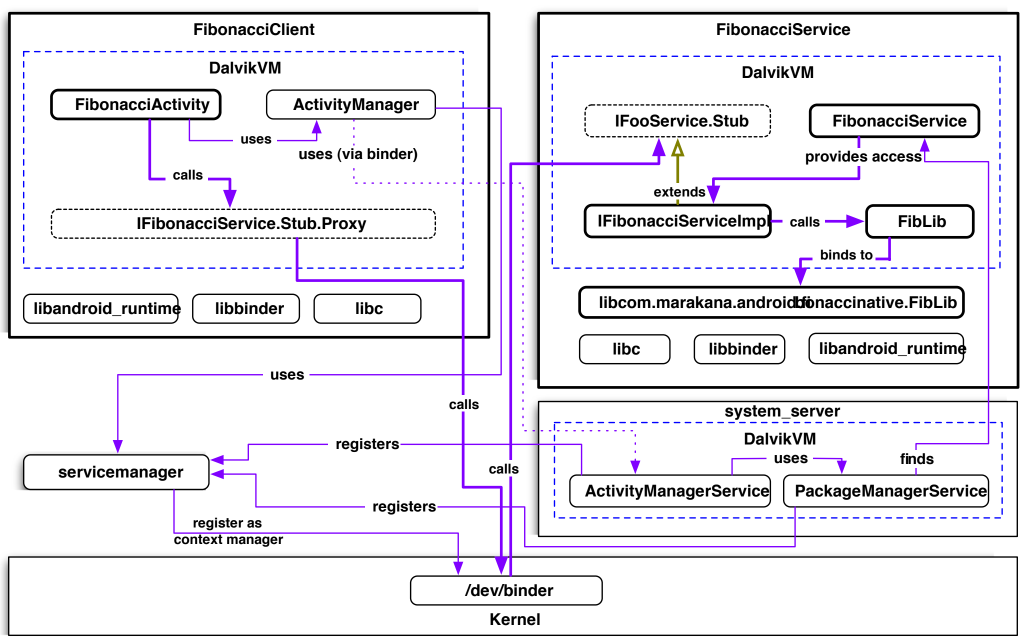
- `name` - arbitrary but unique (name-spaced) identifier of this permission
- `protectionLevel` - specifies if/how will Android inform the user when another app uses this permission
  - `normal` (0) - A low-risk permission that is automatically granted (by default), though users have an option to review 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 an an Android device/emulator: `$ adb shell pm list permissions -s`

5.10 Lab (Custom Permissions)

- For this lab, you 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`

- To get started:

  a. Download http://marakana.com/static/courseware/android/FibonacciLab.zip

b. Unzip into your workspace directory
c. Import `FibonacciCommon`, `FibonacciClient`, and `FibonacciService` (as existing) projects into Eclipse

- In the provided Fibonacci client-service applications:

1. Restrict access to the `com.marakana.android.fibonacciservice.FibonacciService` to applications that hold *USE_FIBONACCI_SERVICE* custom permission
   a. Start by creating a custom permission (make sure to name-space it)
   b. Then require the permission on the service
   c. 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
   d. Have the client use the required permission
   e. Test again - the client should now be able to bind to the service as before
2. Restrict access to "slow" operations of `com.marakana.android.fibonaccicommon.IFibonacciService` (e.g. recursive operations when `n > 10`) to applications that hold *USE_SLOW_FIBONACCI_SERVICE* permission
   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.fibonacciservice.IFibonacciServiceImpl`. Conveniently enough, `com.marakana.android.fibonacciservice.FibonacciService` extends `android.app.Service`, which in turn implements `android.content.Context`.

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

5.11 `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`
  - 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`

5.12 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!

5.13 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

5.14 Pending Intents

- PendingIntent allows delayed triggering of our intent in another application
  - E.g. Notification
  - E.g. Alarms
- The other application can fill-in unspecified values of our intent, which may influence destination and/or integrity of our intent's data
- Best to only use PendingIntents as triggers for private components (i.e. explicitly specify your component's class in the Intent)

5.15 Encryption

5.15.1 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
  - In Java using Java Cryptography Extension (JCE), which on Android is implicitly provided via BouncyCastle (http://www.bouncycastle.c)
    - Key store (of trusted root certs) is at `/system/etc/security/cacerts.bks` and can only be changed by rebuilding the ROM
- On-device data encryption is usually also done via JCE:

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

import java.io.InputStream;
import java.io.OutputStream;
import java.io.UnsupportedEncodingException;
import java.security.InvalidKeyException;
import java.security.Key;
import java.security.NoSuchAlgorithmException;
import java.security.SecureRandom;

import javax.crypto.BadPaddingException;
import javax.crypto.Cipher;
import javax.crypto.CipherInputStream;
import javax.crypto.CipherOutputStream;
import javax.crypto.IllegalBlockSizeException;
import javax.crypto.KeyGenerator;
import javax.crypto.NoSuchPaddingException;
import javax.crypto.spec.SecretKeySpec;

import android.util.Base64;

public class CryptUtil {
    private static final String ENCRYPTION_ALGORITHM = "AES";

    private static final int KEY_SIZE = 256;

    private static final String RANDOM_ALGORITHM = "SHA1PRNG";

    private static final String CHARSET = "UTF-8";

    public static Cipher getCipher(int mode, byte[] secret) throws  ←
        NoSuchAlgorithmException,
            NoSuchPaddingException, InvalidKeyException, UnsupportedEncodingException ←
                {
        // generate an encryption/decryption key from random data seeded with
        // our secret (i.e. password)
        SecureRandom secureRandom = SecureRandom.getInstance(RANDOM_ALGORITHM);
        secureRandom.setSeed(secret);
        KeyGenerator keyGenerator = KeyGenerator.getInstance(ENCRYPTION_ALGORITHM);
```

```
        keyGenerator.init(KEY_SIZE, secureRandom);
        Key key = new SecretKeySpec(keyGenerator.generateKey().getEncoded(),  ↩
            ENCRYPTION_ALGORITHM);
        // get a cipher based on the specified encryption algorithm
        Cipher cipher = Cipher.getInstance(ENCRYPTION_ALGORITHM);
        // tell the cipher if it will be used for encryption or decryption
        // (i.e. cipher mode) and give it our key
        cipher.init(mode, key);
        return cipher;
    }

    public static byte[] encrypt(byte[] input, byte[] secret) throws  ↩
        InvalidKeyException,
            IllegalBlockSizeException, BadPaddingException, NoSuchAlgorithmException,
            NoSuchPaddingException, UnsupportedEncodingException {
        return getCipher(Cipher.ENCRYPT_MODE, secret).doFinal(input);
    }

    public static byte[] decrypt(byte[] input, byte[] secret) throws  ↩
        InvalidKeyException,
            IllegalBlockSizeException, BadPaddingException, NoSuchAlgorithmException,
            NoSuchPaddingException, UnsupportedEncodingException {
        return getCipher(Cipher.DECRYPT_MODE, secret).doFinal(input);
    }

    public static String encrypt(String input, String secret) throws  ↩
        InvalidKeyException,
            IllegalBlockSizeException, BadPaddingException, NoSuchAlgorithmException,
            NoSuchPaddingException, UnsupportedEncodingException {
        return Base64.encodeToString(encrypt(input.getBytes(CHARSET), secret.getBytes ↩
            (CHARSET)),
                Base64.DEFAULT);
    }

    public static String decrypt(String input, String secret) throws  ↩
        InvalidKeyException,
            IllegalBlockSizeException, BadPaddingException, NoSuchAlgorithmException,
            NoSuchPaddingException, UnsupportedEncodingException {
        return new String(decrypt(Base64.decode(input.getBytes(), Base64.DEFAULT),  ↩
            secret
                .getBytes(CHARSET)), CHARSET);
    }

    public static OutputStream encrypt(OutputStream out, byte[] secret) throws  ↩
        InvalidKeyException,
            NoSuchAlgorithmException, NoSuchPaddingException,  ↩
                UnsupportedEncodingException {
        return new CipherOutputStream(out, getCipher(Cipher.ENCRYPT_MODE, secret));
    }

    public static InputStream decrypt(InputStream in, byte[] secret) throws  ↩
        InvalidKeyException,
            NoSuchAlgorithmException, NoSuchPaddingException,  ↩
                UnsupportedEncodingException {
        return new CipherInputStream(in, CryptUtil.getCipher(Cipher.DECRYPT_MODE,  ↩
            secret));
```

```
    }
}
```

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

5.15.2 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
- 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 byes/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 mare 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 byes/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 `msramdmp` (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.

5.15.3 VPN and WiFi Certificates

- See http://www.google.com/support/mobile/bin/answer.py?hl=en&answer=168466

5.15.4 Keychain API

- New in ICS/4.0
- Provides secure management of credentials
- Enables applications to manage authentication and secure sessions
  - Store and retrieve private keys and their corresponding certificate chains
  - Install and store user certificates and CAs securely
- See `android.security.KeyChain`

5.15.5 VPN client API

- New in ICS/4.0
- Enables applications to add custom VPN solutions
  - Configure addresses and routing rules
  - Process outgoing and incoming packets
  - Establish secure tunnels to a remote server
  - Manages credentials storage
- See `android.net.VpnService`
- Or, use the existing built-in VPN client that provides access to L2TP and IPSec protocols

5.16 Rooting an Android device

To obtain "root" on an Android device usually involves a number of steps:

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

  ```
  $ mount -o remount,rw -t yaffs2 /dev/block/mtdblock3 /system
  ```

- Create a setuid version of `/system/bin/sh`

  ```
  $ cat /system/bin/sh > /system/bin/su
  $ chmod 4755 /system/bin/su
  ```

- Remount the `/system` partition read-only

  ```
  $ mount -o remount,ro -t yaffs2 /dev/block/mtdblock4 /system
  ```

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

5.16.1 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)
    i. 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.superus`
          * 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: `am start -a android.intent.action.MAIN -n com.koushikdutta.sup --ei uid %d --ei pid %d > /dev/null`
          II. Now `com.koushikdutta.superuser` application starts and `SuperuserRequestActivity` prompts the user to make their selection
          III. The user's selection is saved into the database and `SuperuserRequestActivity` terminates
          IV. `su` now checks the database again, and if the process is not approved, it exits
       D. `su` then `setuid(uid)`-s and `setgid(gid)`-s the calling process
       E. `su` finally executes `/system/bin/sh` with the same parameters that the original `su` was invoked with
    ii. 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):

5.16.2 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 int Android's `init` process (i.e. it is not as a stand-alone executable), which still runs as root
  - This "exploid2" (a.k.a "Exploid") roughly works as follows:
    i. The user `copies` to the device (e.g. `adb push exploid2 /data/local/tmp/exploid2`)
    ii. The user then runs the "exploid2" process (e.g. adb shell `/data/local/tmp/exploid2`)
    iii. On the first run, the "exploid2" copies itself to `/sqlite_stmt_journals/exploid2`
    iv. 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)
    v. 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)
    vi. 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)
    vii. 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`

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

- Android Debug Bridge Daemon (`adbd`) starts as root, but `setuid` to the `shell` when forking itself to execute remote requests (i.e. to run `/system/bin/shell`)
- In this case, a program called `rageagainstthecage` tries to exploit a race condition such that it can preempt `adbd`-s call to `setuid`
- 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

5.16.4 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

5.16.5 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`

5.16.6 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 Softbreak/Gingerbreak 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

5.16.7 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

5.16.8 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

5.16.9 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

5.17 Security of Memory

- Address Space Layout Randomization (ASLR) to randomize key locations in memory
  - Standard in ICS (Android 4.0) - based on Linux PaX
  - No more pre-linking of libraries
- Hardware-based No eXecute (NX) to prevent code execution on the stack and heap
- ProPolice to prevent stack buffer overruns
- safe_iop to reduce integer overflows

- Extensions to OpenBSD dlmalloc to prevent double free() vulnerabilities and to prevent chunk consolidation attacks. Chunk consolidation attacks 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

5.17.1 ASLR on Android before ICS/4.0 - A Proposal

- Research by Hristo Bojinov and Dan Boneh from Stanford University and Rich Cannings and Iliyan Malchev from Google
  - http://bojinov.org/professional/wisec2011-mobileaslr-paper.pdf
- When employed, ASLR randomizes base addresses of shared libraries, base executables, and process stack and heap
- ASLR's goal is to make certain types of control-hijacking attacks (e.g. buffer/stack-overflow to return to libc) more difficult to execute reliably as the executable code location is unknown (or at least hard to guess)
  - 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)
- But, on Android, pre-linking, limited processing power, and restrictive update processes make ASLR hard to use
  - The Android OS prelinks shared libraries to speed up the boot process (by ~ 5%)
    * Prelinking (hard-coding memory addresses in library code) at OS build time
    * Prelinked libraries cannot be relocated (i.e randomized) in process memory - their location is well-known to potential attackers
  - Android's `/system` partition is mounted read-only (for security reasons), but this prevents post-build modifications of the system image (e.g. randomization of library offsets in binary code)
- ASLR on Android
  - Randomize all executable code (including libraries, base executables, and the linker) via *retouching*
    * Random offsets are applied by modifying existing binaries (i.e. "every" device looks different to potential attackers) at system upgrade time (i.e. in the recovery mode) when the `/system` is read-write
    * Requires "undo" capability, in order to roll-back to virgin state (prior to randomization), to support diff-based OTA updates, which depend on known system images
    * Minimal additional storage requirements (2%) to store "undo" info at the end of executables
    * Requires no kernel changes
  - Prevent brute-forcing
    * 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
    - Non pre-linked libraries already use standard Linux ASLR PaX approach: by randomizing the mmap base
    - Android kernel already performs stack randomization for each process
    - Android's use of `dlmalloc` already offers some overflow (randomization) protection for heap allocated chunks

5.18 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
- 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 a transparent custom notification dialog
    d. User enters password/pin/gesture to access the secure application
    e. The custom notification dialog captures user taps, records them, and passes them down to the secure app
    f. The secure app has no knowledge of the fact that the user taps were recorded
- How 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)

5.19 Android Device Administration

5.19.1 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)

5.19.2 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).

5.19.3 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.

5.19.4 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.

5.19.5 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>
```

5.19.6 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.

5.19.7 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_REQUEST` 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`.

5.19.8 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.

5.19.9 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);
}
```

5.19.10 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.

5.19.11 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.

5.19.12 Setting the Device Password

You can test if the current device password meets the quality requirements by calling DevicePolicyManager.isActivePasswordSu 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.

5.19.13 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.

5.19.14 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

5.19.15 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_ADMI` 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 users `@xml/device_admin_sample` resource, which we'll look at next.

5.19.16 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.

5.19.17 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.

5.19.18 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,
                    "RESETing 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 of 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.

5.19.19 Lab (Device Administration)

Device-admin-enable an existing Android app:

1. Download https://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 https://marakana.com/static/courseware/android/DeviceAdministeredSecureNote.zip

5.20 Anti-malware

- 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.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.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!
      }
    }
  }
}
```

- 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
    }
  }
}
```

- Once a malicious app is found, offer the user a chance to delete it

```
Uri packageURI = Uri.parse("package:com.malicous.app");
Intent uninstallIntent = new Intent(Intent.ACTION_DELETE, packageURI);
startActivity(uninstallIntent);
```

- Sample source-code available at https://marakana.com/static/courseware/android/AntiMalware.zip
- Some of the popular apps include
  - Norton Mobile Security
  - Lookout Mobile Security

5.21 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 http://selinuxproject.org/~jmorris/lss2011_slides/caseforseandroid.pdf
- Enable SE-Linux (Security Enhanced Linux) access rights controls at the Android kernel level
  - Experimental work by Hitachi (http://www.youtube.com/watch?v=e2yWDvcWu6I)
  - Challenges
    * Extended file attributes (`xattr`) not available on yaffs2, yet required by SE-Linux. Use ext3 or ext4 instead.
    * Only two domains can be used: processes started directly off `init` and those run from `app_process`, but we should be able to set up different policies for individual apps.
    * Default SE-Linux policy files are way too big. Optimize for Android.
  - http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5342408

5.22 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. Enterproid 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

Chapter 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 ⇐ Froyo
    * JDK 6 for >= 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/?p=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 SOCs, we would:
`repo init -u git://gitorious.org/rowboat/manifest.git -m TI-Android-FroYo-DevKit-V2.2.xml`
for OMAP3 and
`repo init -u git://gitorious.org/rowboat/manifest.git -m TI-Android-FroYo-DSP-DevKit-V2.`
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-makefiles)`
  - 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://cgit.collabora.com/-git/user/derek/androgenizer.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 settitle 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 Darwin

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=darwin
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 Darwin
     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=darwin
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=1`
- Sets `ro.debuggable=0`
- 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**

```
/*
** +-----------------+
** | boot header     | 1 page
** +-----------------+
** | kernel          | n pages
** +-----------------+
** | ramdisk         | m pages
** +-----------------+
** | second stage    | o pages
** +-----------------+
**
** n = (kernel_size + page_size - 1) / page_size
** m = (ramdisk_size + page_size - 1) / page_size
** o = (second_size + page_size - 1) / page_size
**
** 0. all entities are page_size aligned in flash
** 1. kernel and ramdisk are required (size != 0)
** 2. second is optional (second_size == 0 -> no second)
** 3. load each element (kernel, ramdisk, second) at
**    the specified physical address (kernel_addr, etc)
** 4. prepare tags at tag_addr.  kernel_args[] is
**    appended to the kernel commandline in the tags.
** 5. r0 = 0, r1 = MACHINE_TYPE, r2 = tags_addr
** 6. if second_size != 0: jump to second_addr
**    else: jump to kernel_addr
*/
```

- 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 ...
$ emulator
```

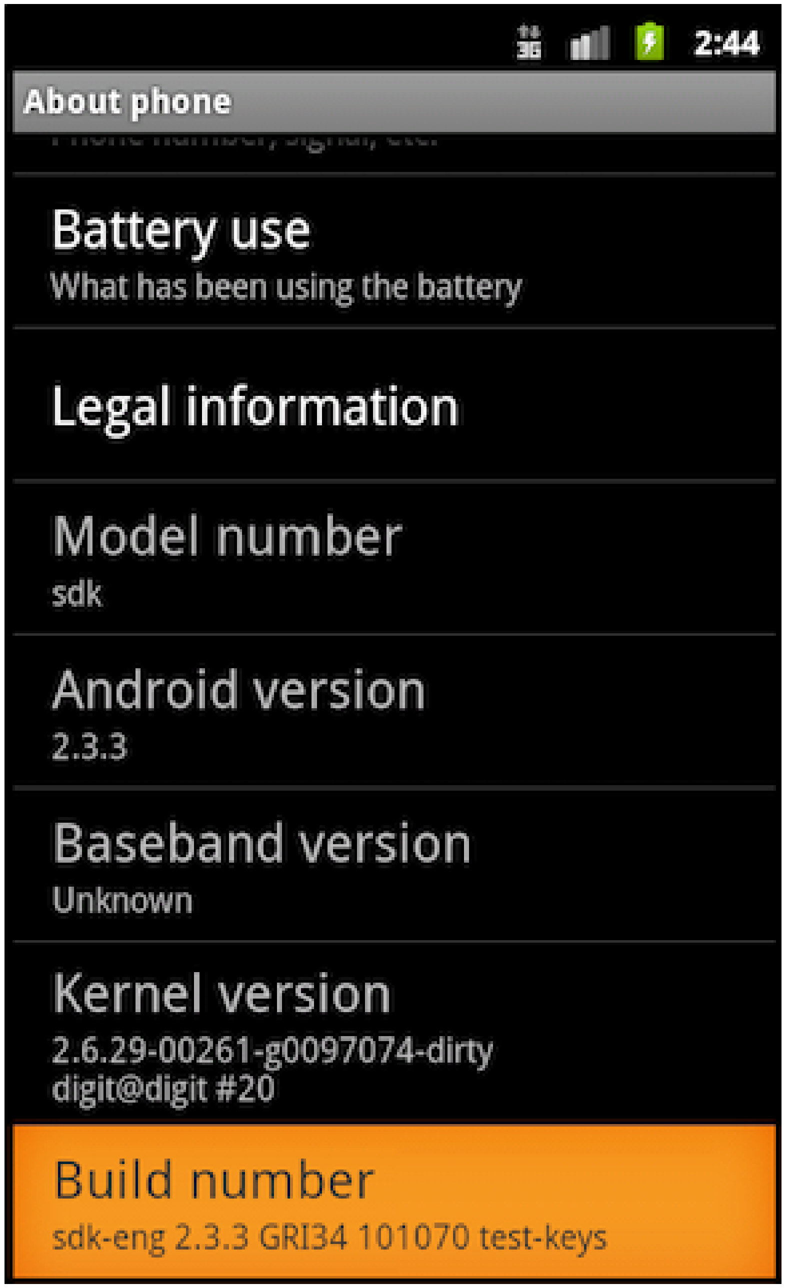
- Alternatively, we can run our image in one of our Android Virtual Devices (AVD)
  - Create an AVD - unless we already have one from before
    - We could use "Android SDK and AVD Manager" GUI to create an AVD (based on the same "target" as the image we compiled)
    - Or, we could create an AVD from 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/darwin-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/darwin-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_defconfig`

6. You can optionally take a look at the existing configuration options and make changes as desired

```
$ make menuconfig
```

   - For example, you could set your *General setup* → *Local version - append to kernel release* to something like `-marakana-example`

7. Now we are ready to compile

```
$ make
```

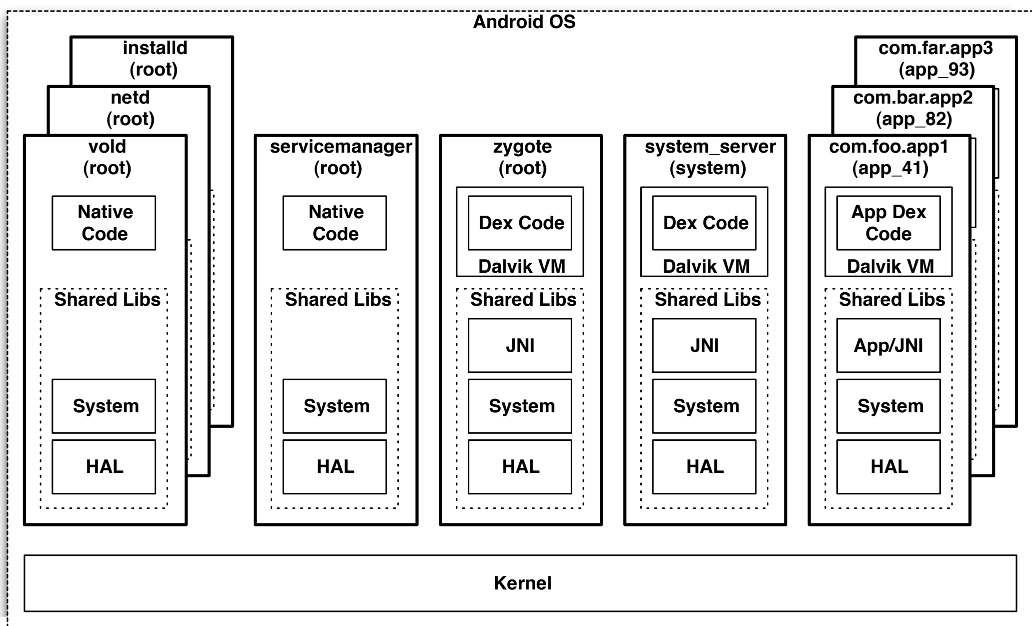
8. The resulting kernel will be compressed to `arch/arm/boot/zImage`
9. Run the emulator with our new kernel

```
$ emulator -kernel /path/to/common/arch/arm/boot/zImage
```

10. And the result is

Chapter 7

Android Startup

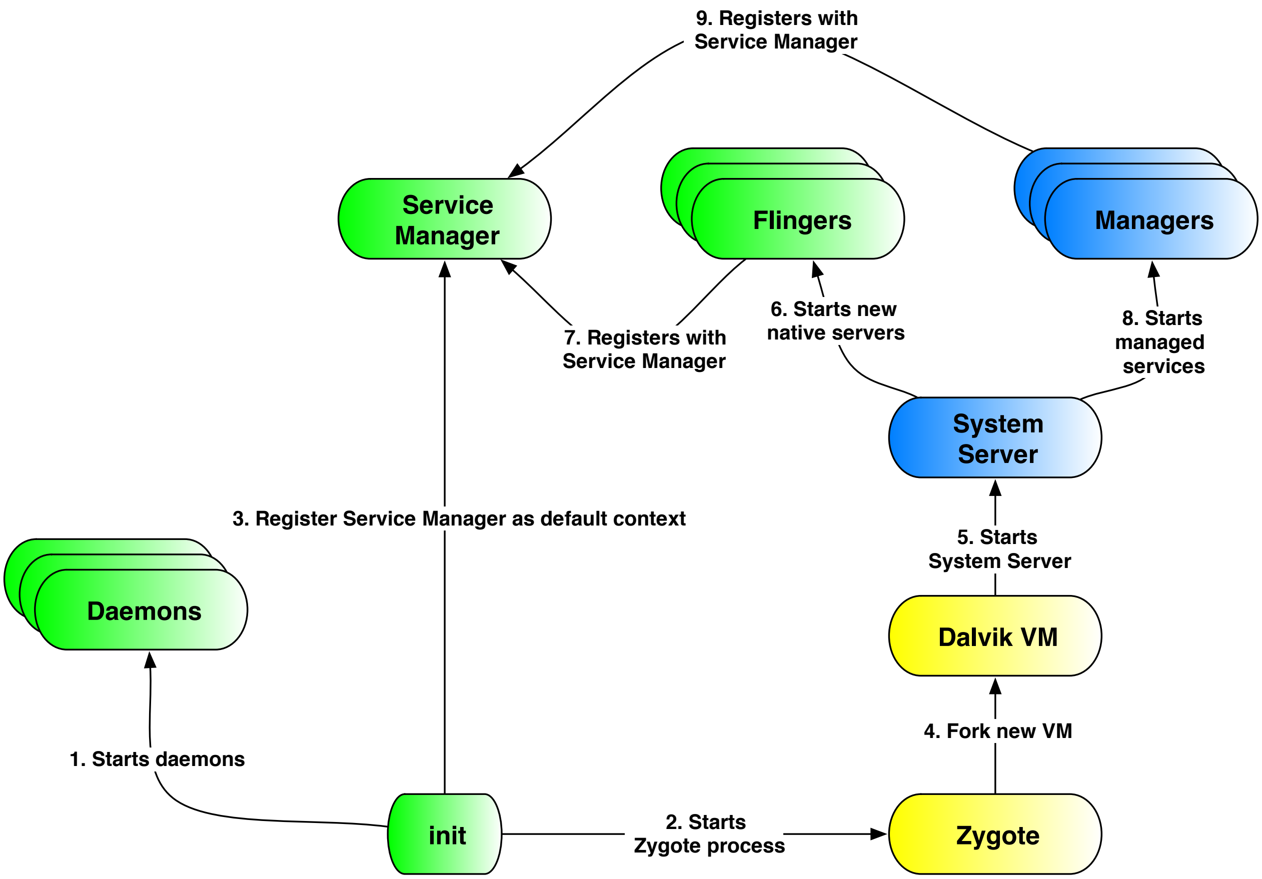


7.1 Bootloading the Kernel

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 ADP1
    * `/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 [?]
  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, racoon, 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/ZygoteIn` 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/cor`
   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:syste`
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/sensorservice/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:init2(` 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 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:fini` 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`)

Chapter 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]
```

```
statusbar: [com.android.internal.statusbar.IStatusBarService]
device_policy: [android.app.admin.IDevicePolicyManager]
accessibility: [android.view.accessibility.IAccessibilityManager]
input_method: [com.android.internal.view.IInputMethodManager]
window: [android.view.IWindowManager]
alarm: [android.app.IAlarmManager]
vibrator: [android.os.IVibratorService]
battery: []
hardware: [android.os.IHardwareService]
content: [android.content.IContentService]
account: [android.accounts.IAccountManager]
permission: [android.os.IPermissionController]
cpuinfo: []
gfxinfo: []
meminfo: []
activity: [android.app.IActivityManager]
package: [android.content.pm.IPackageManager]
telephony.registry: [com.android.internal.telephony.ITelephonyRegistry]
usagestats: [com.android.internal.app.IUsageStats]
batteryinfo: [com.android.internal.app.IBatteryStats]
power: [android.os.IPowerManager]
entropy: []
sensorservice: [android.gui.SensorServer]
media.audio_policy: [android.media.IAudioPolicyService]
media.camera: [android.hardware.IAudioPolicyServiceService]
media.player: [android.media.IMediaPlayerService]
media.audio_flinger: [android.media.IAudioFlinger]
SurfaceFlinger: [android.ui.ISurfaceComposer]
```

8.1 Vibrator

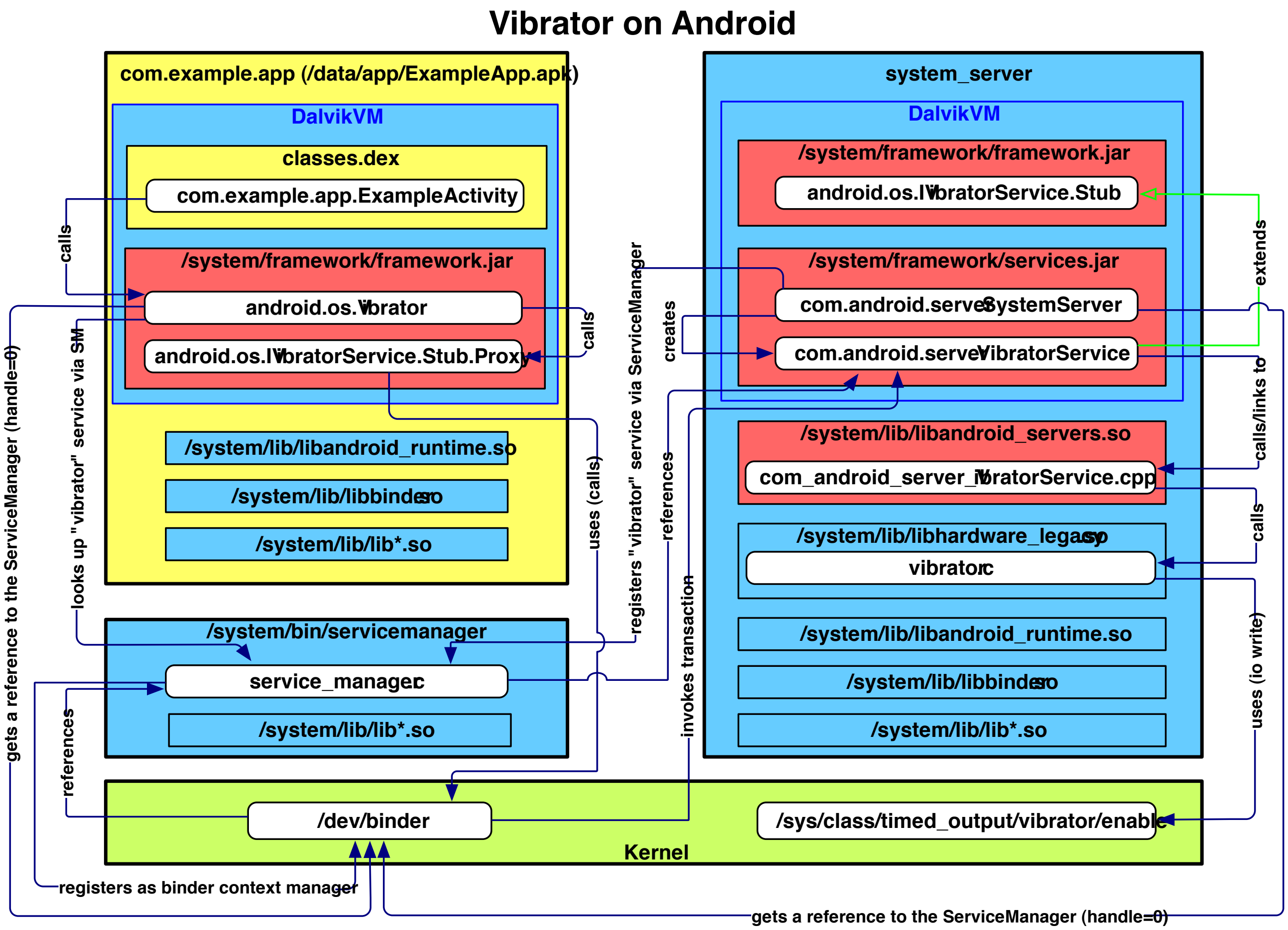


Figure 8.1: Vibrator Service Architecture

- `/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.`
- `/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` 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/`
- `/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/S`

  - com.android.server.VibratorService is defined by frameworks/base/services/java/com/android/serve
- /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_se
- /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

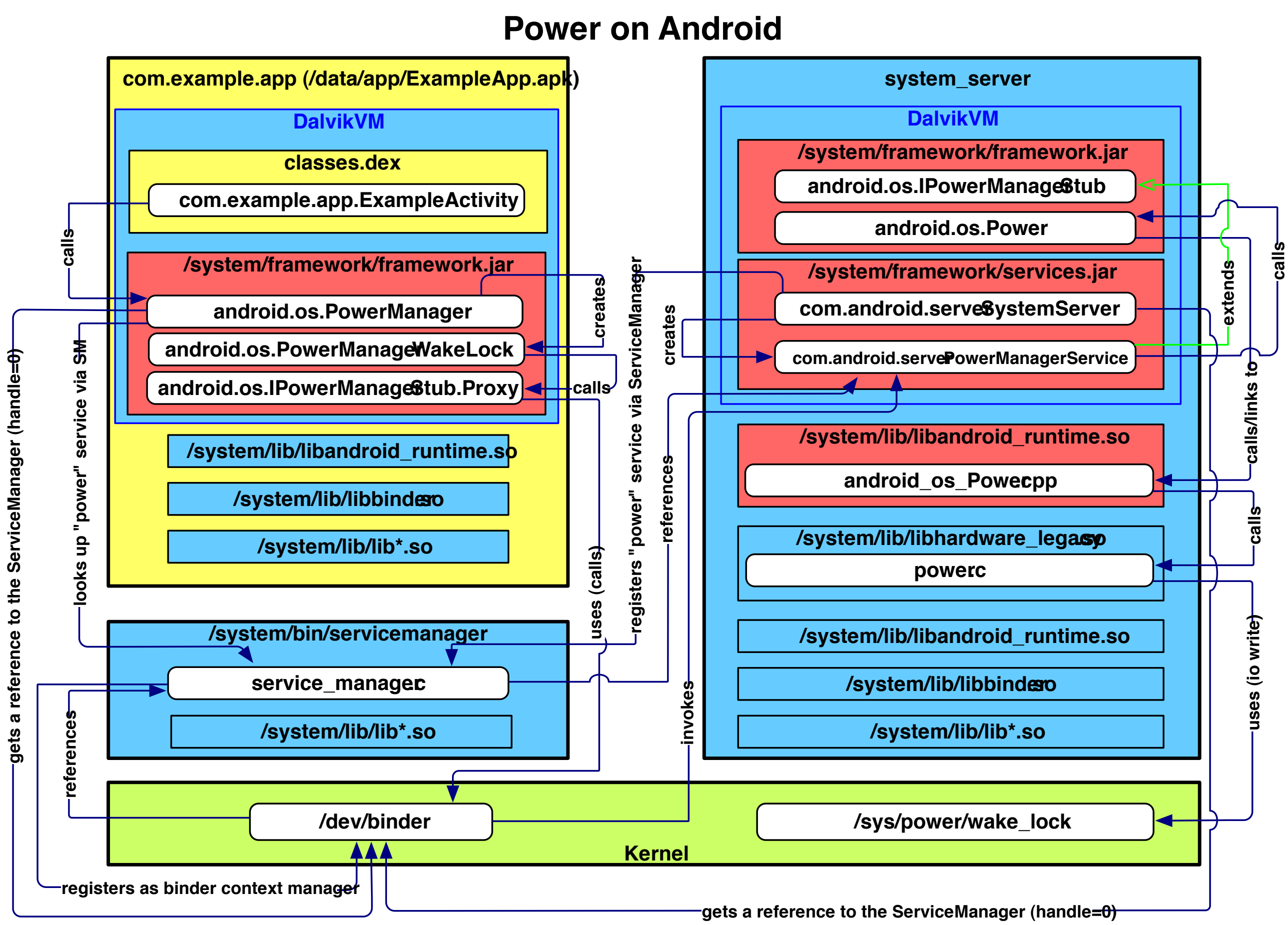


Figure 8.2: Power Service Architecture

8.2.1 Links

- https://gitorious.org/android/powertop

8.3 Alarm Service

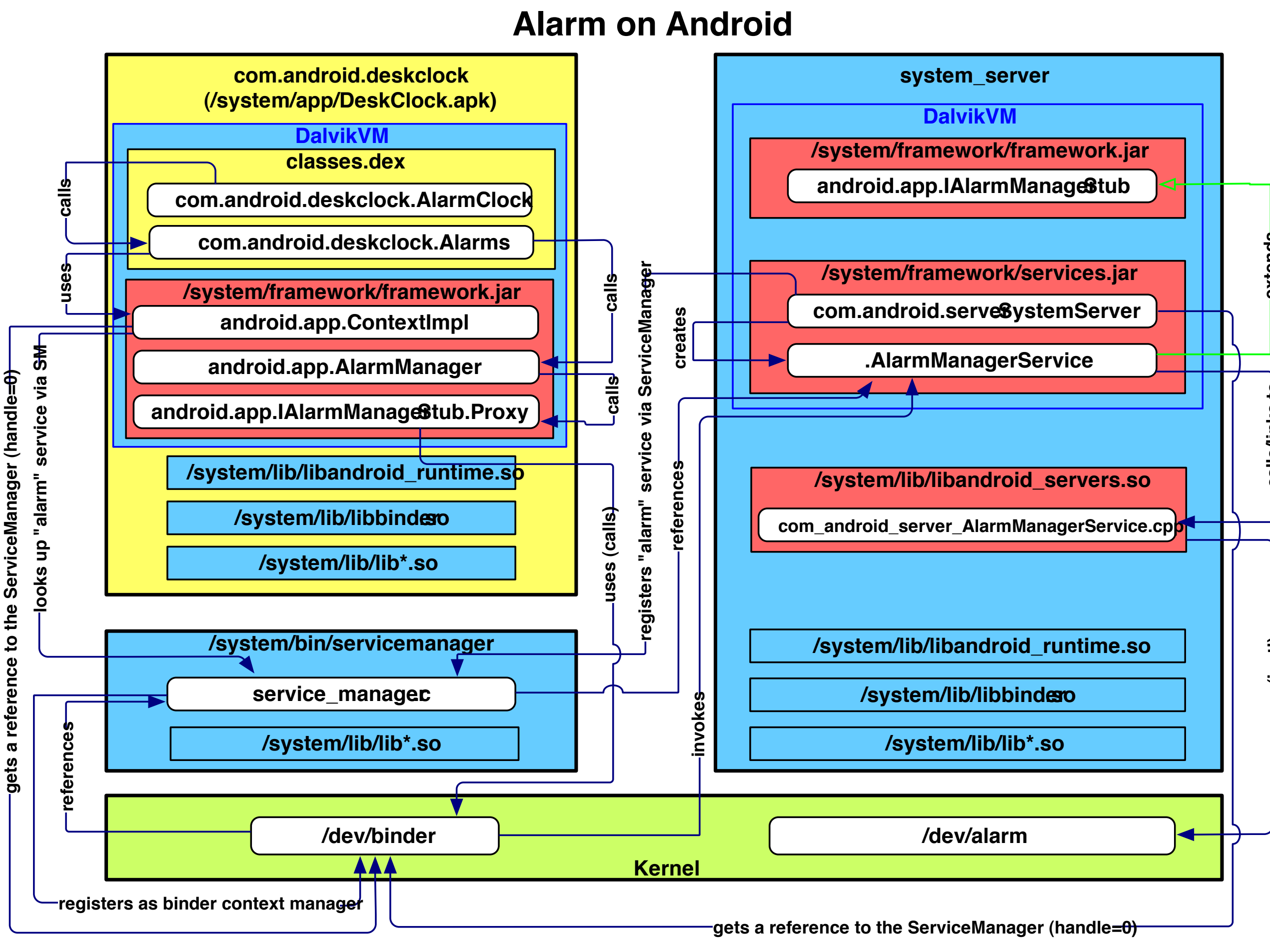


Figure 8.3: Alarm Service Architecture

8.4 Package Service

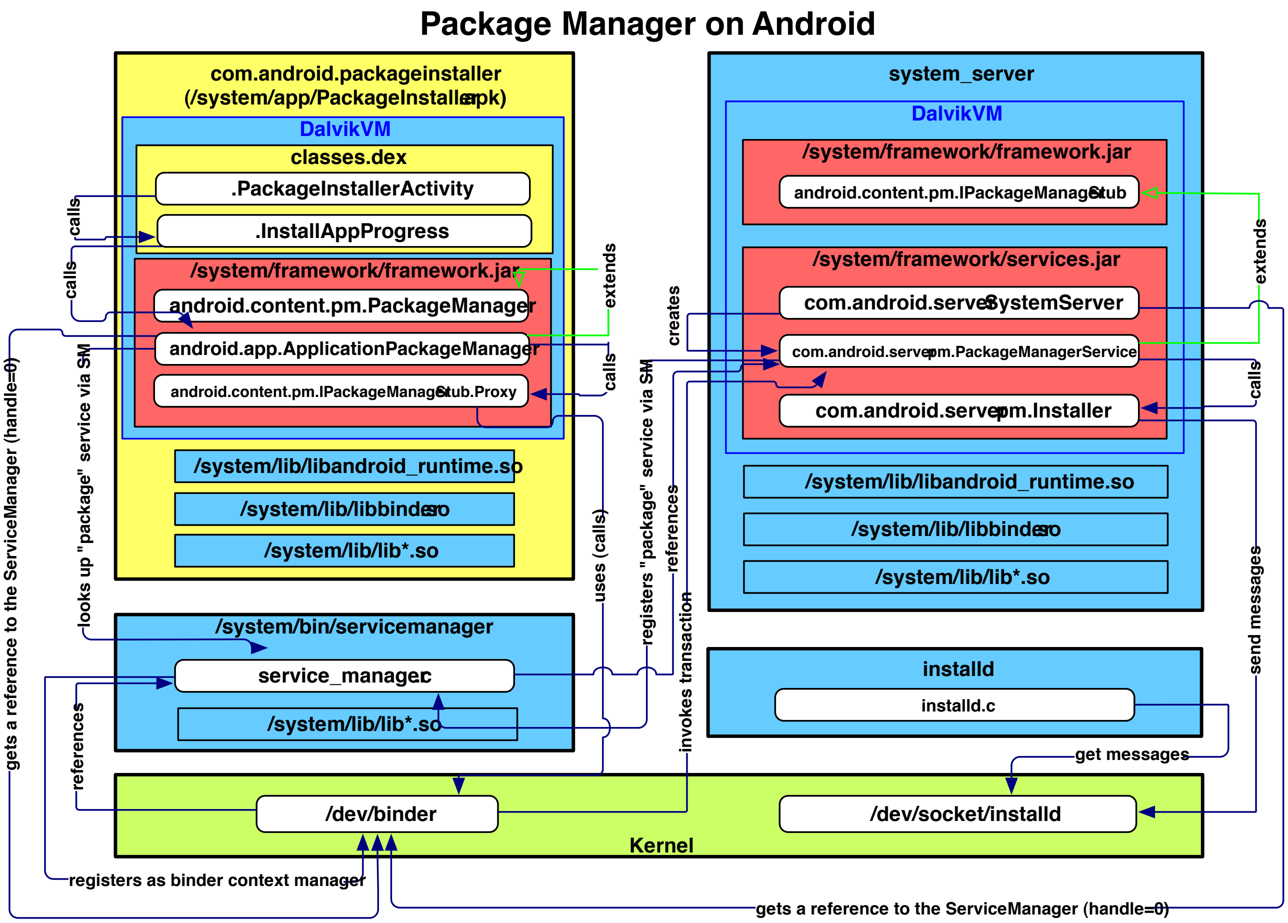


Figure 8.4: Package Service Architecture

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.

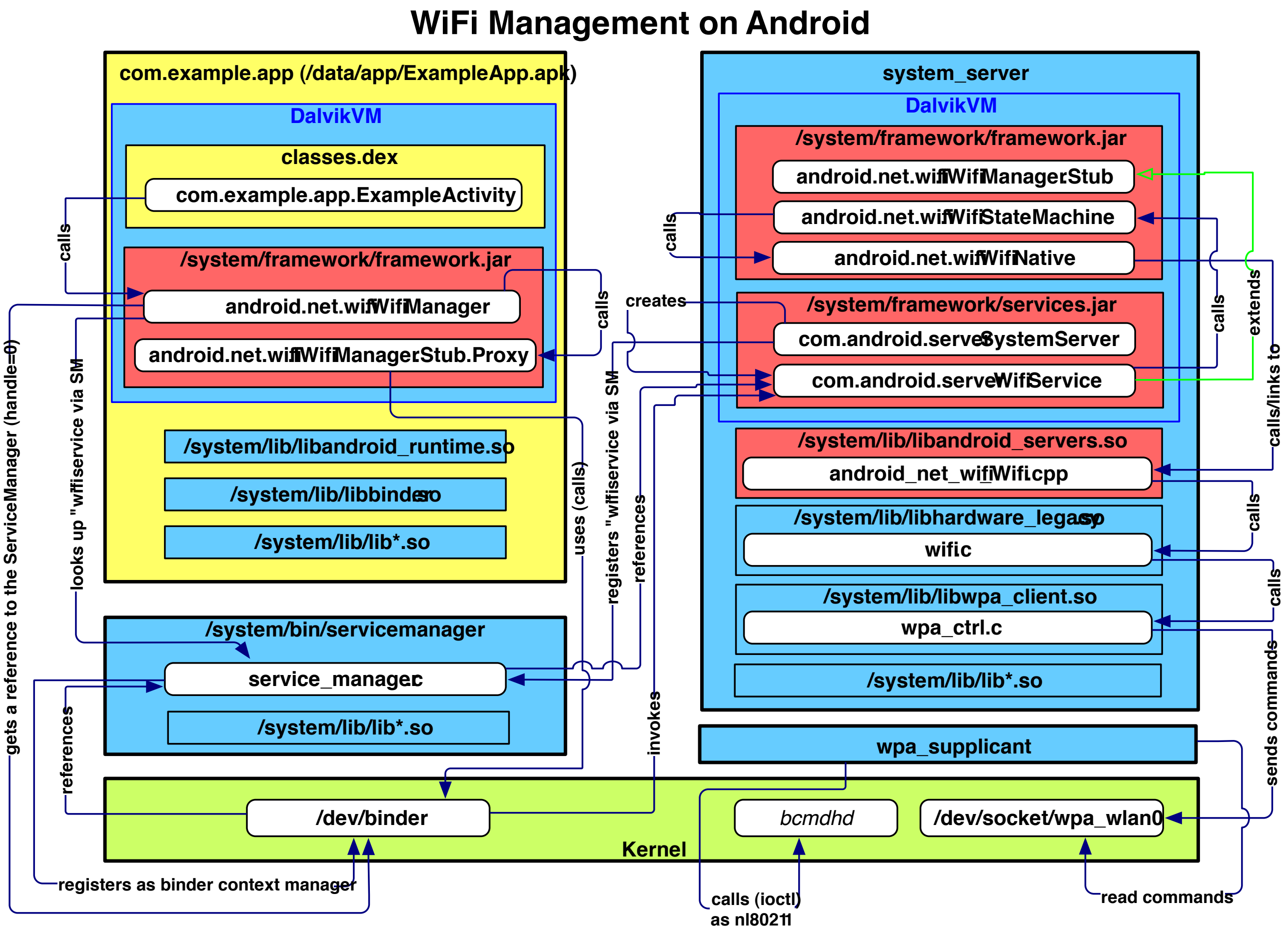


Figure 8.5: Wifi Service Architecture

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

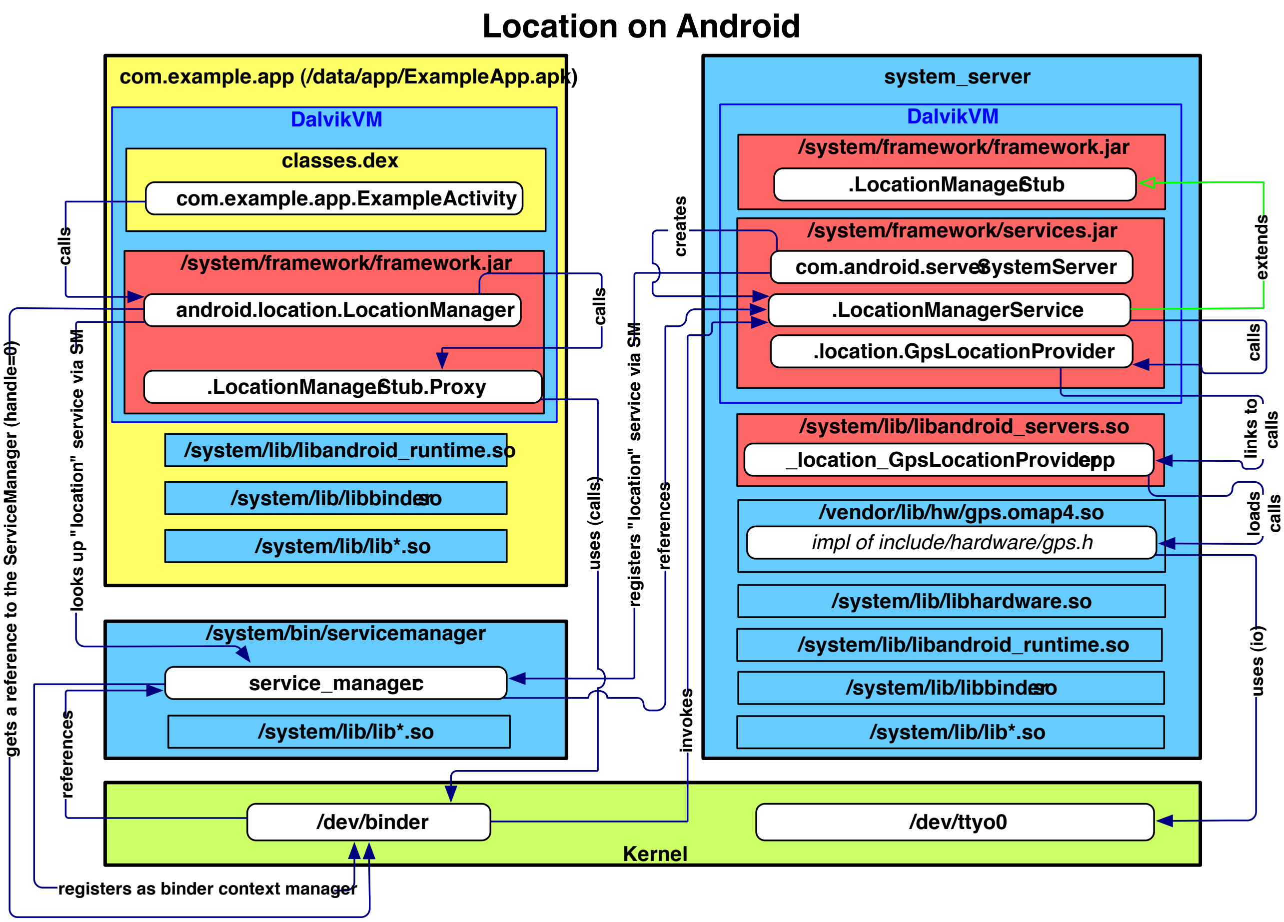


Figure 8.6: Location Service Architecture

8.7 Audio Service

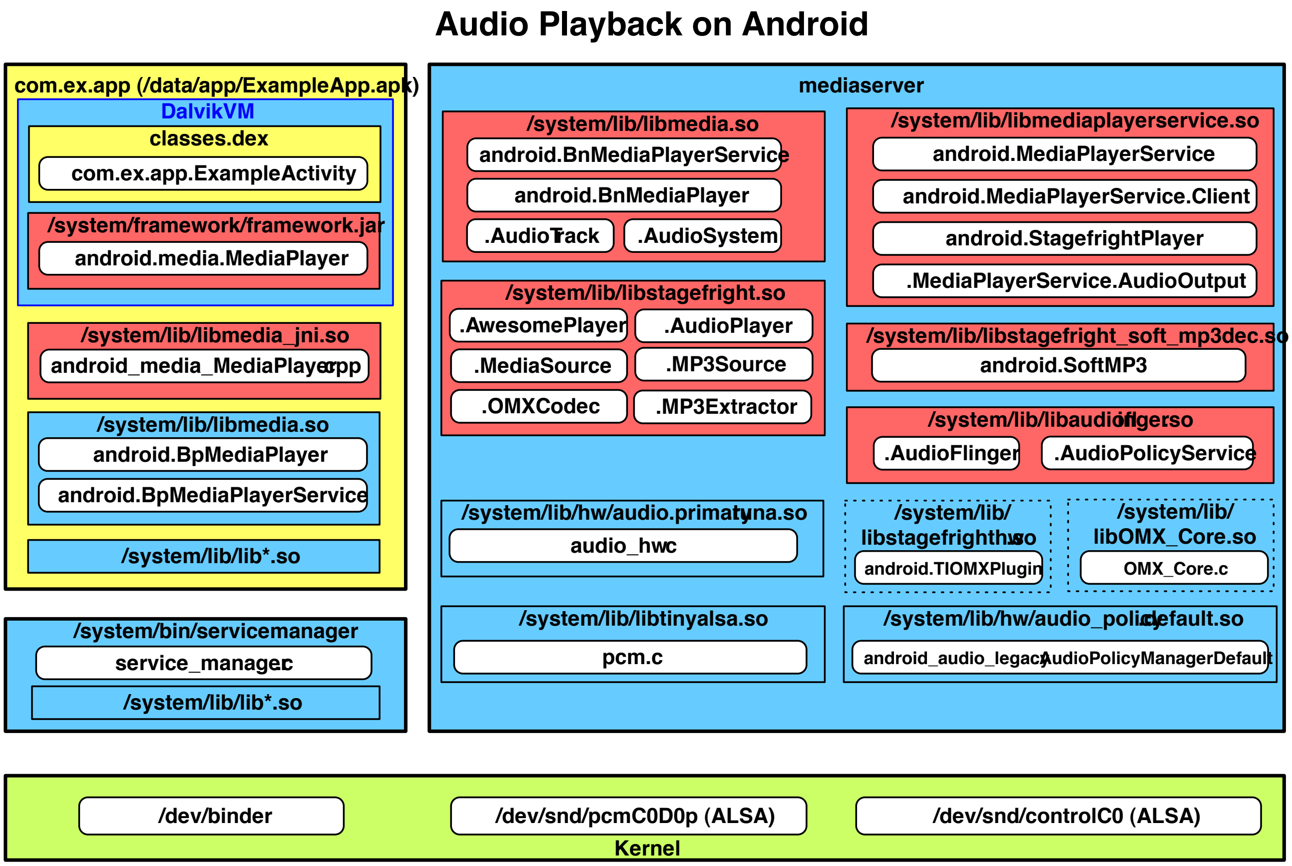
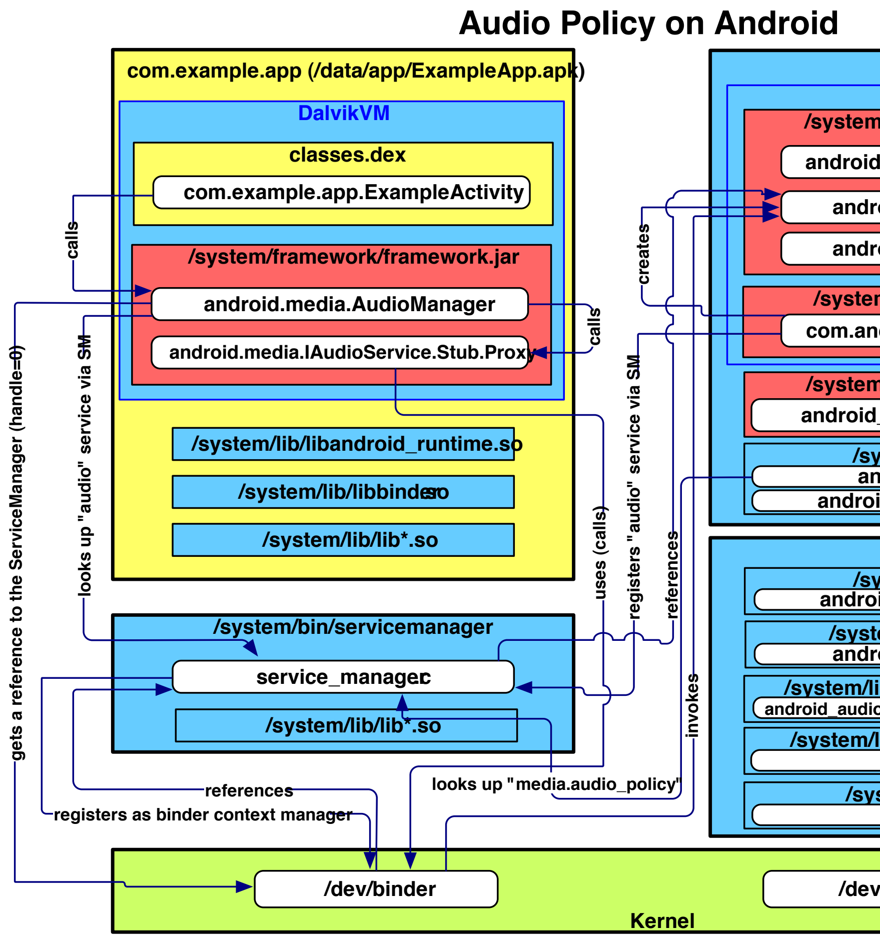


Figure 8.7: Audio Architecture (playing audio)



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/ (PusleAudio, an alternative to AudioFlinger)
  - http://arunraghavan.net/2012/01/pulseaudio-vs-audioflinger-fight/ (PusleAudio 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/libmediaplayservice/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/libmediaplayservice/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 a 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. `IMediaPlayerm` 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

8.8.4.1 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.)

8.8.4.2 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 l`, 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.

8.8.4.3 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`)

8.8.4.4 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.

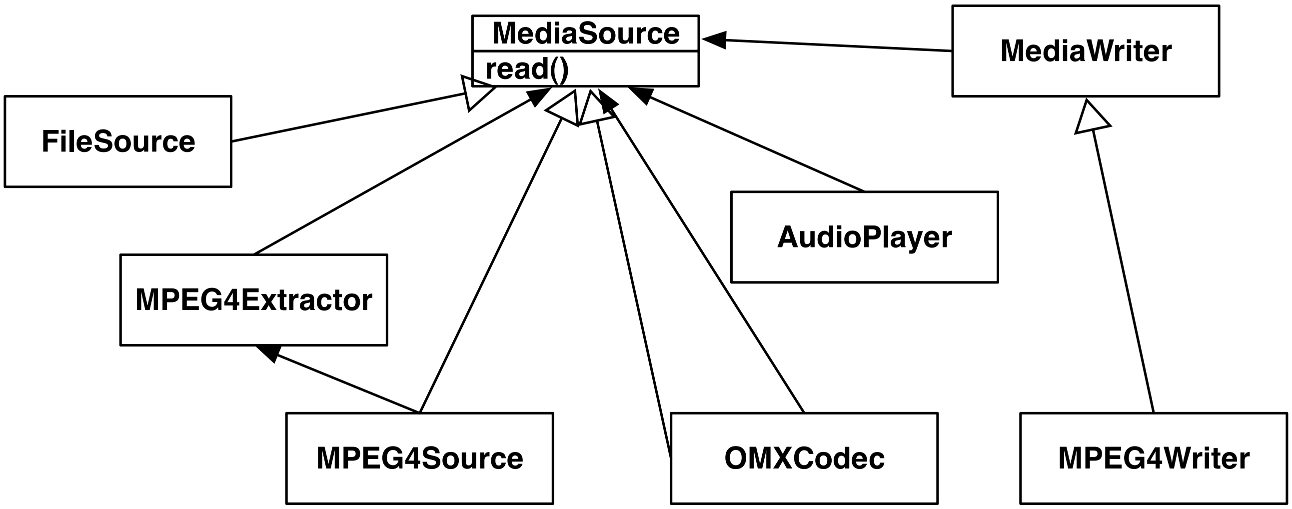


Figure 8.8: An illustration of the general pipeline structure.

Note

`FileSource`, `MPEG4Source` and `OMXCodec` all implement the `MediaSource` interface. `MPEG4Extractor`, `OMXCodec`, `AudioPlayer`, `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.

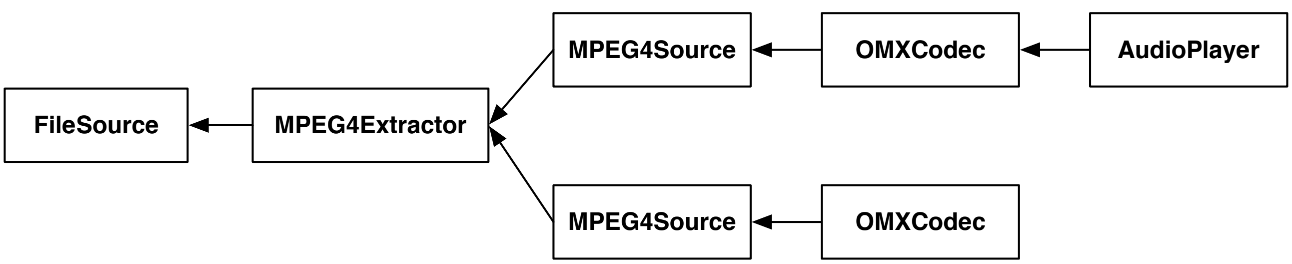


Figure 8.9: An example of a pipeline decoding audio and video from an MP4 file.

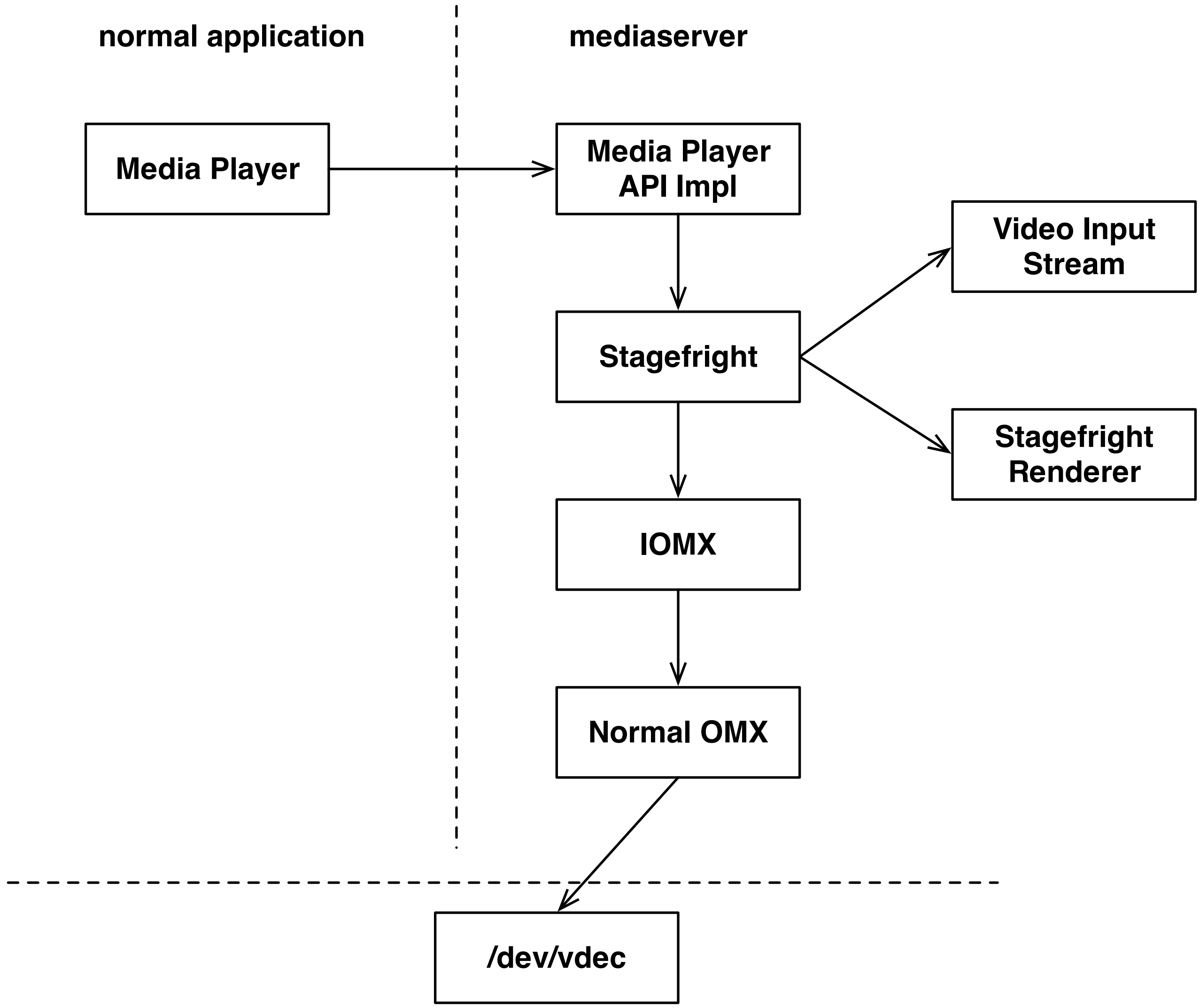


Figure 8.10: A rough visualization of the split between the application process and media server.

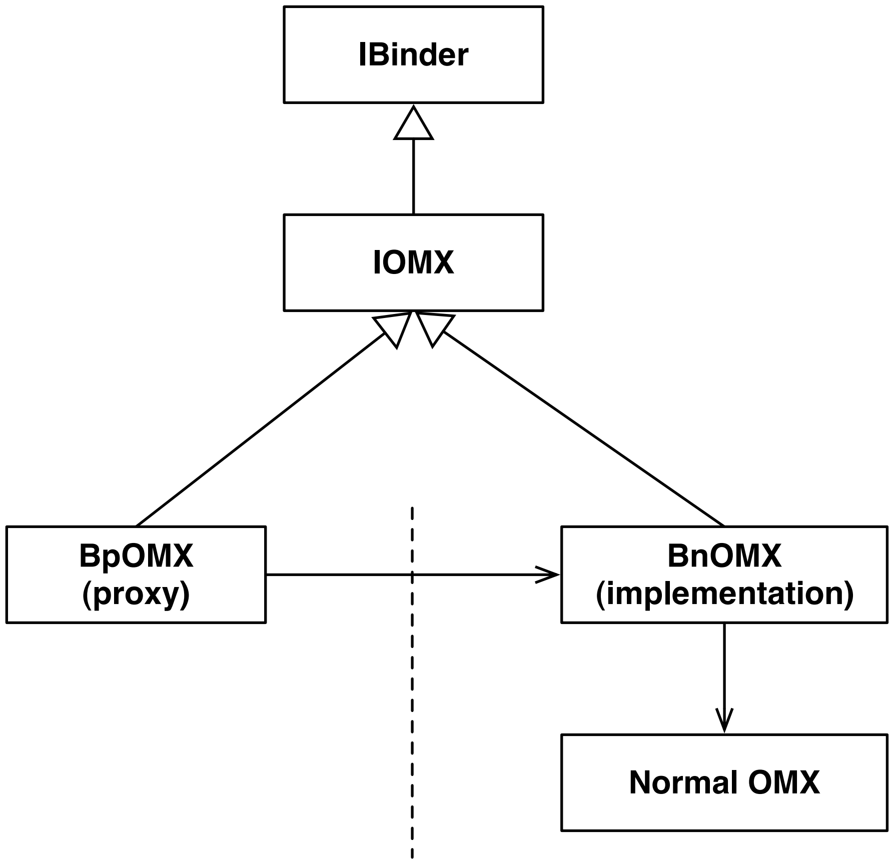


Figure 8.11: Details of the IOMX interface.

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 asynchronous 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)

8.8.5.1 OpenMAX IL in Stagefright

Stagefright provides wrapping around OMX core implementations. The main client api is called IOMX (frameworks/base/include/r 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 ZN7android15createOMX or createOMXPlugin (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

8.8.6.1 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.

8.8.6.2 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.

8.8.6.3 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

8.8.6.4 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.

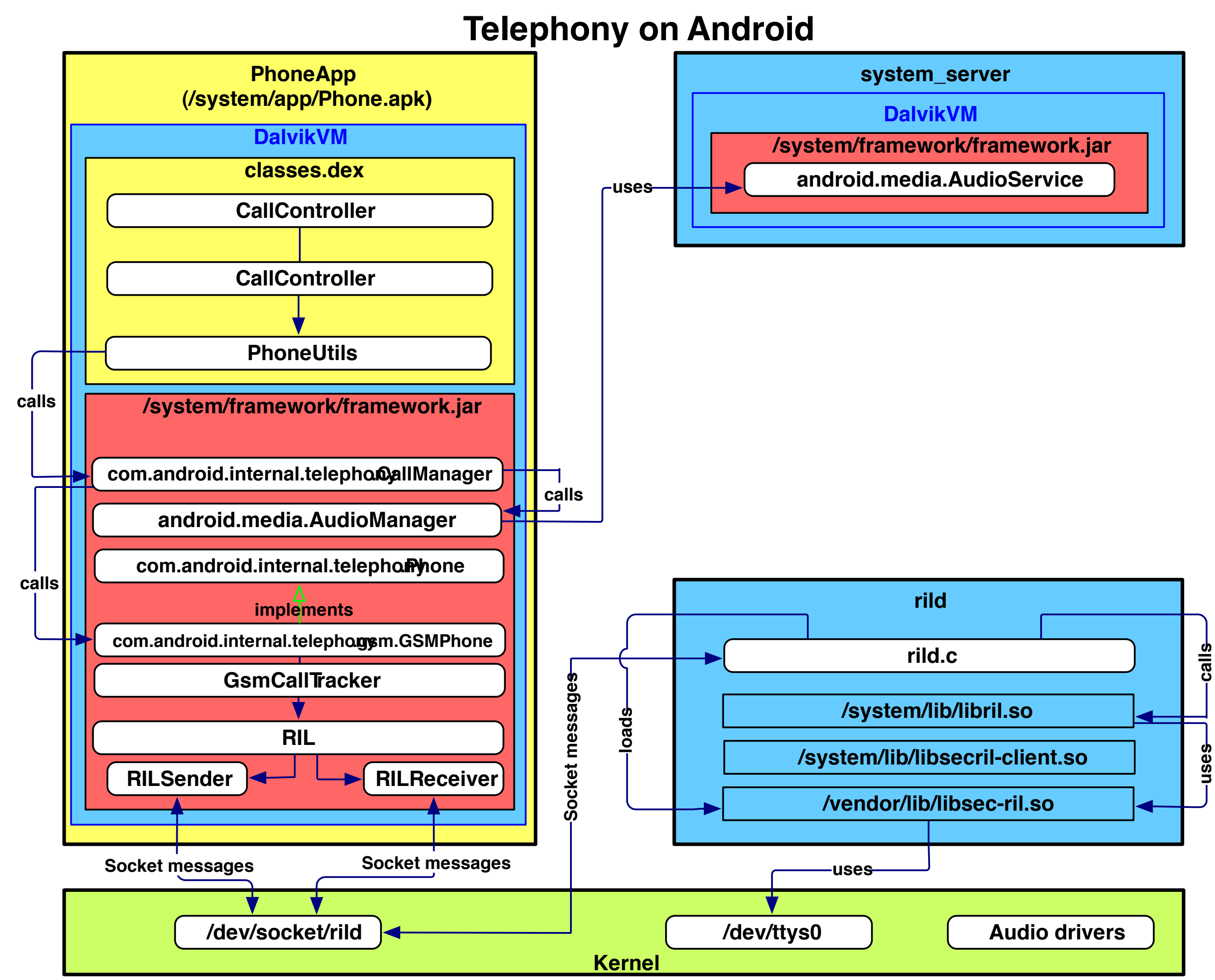


Figure 8.12: Android Telephony Architecture Diagram

8.9.2.1 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.

8.9.2.2 OutgoingCallBroadcaster

`OutgoingCallBroadcaster` activity receives `CALL` and `CALL_PRIVILEGED` Intents, and broadcasts the `ACTION_NEW_OUTGOING` 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.

8.9.2.3 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.

8.9.2.4 PhoneUtils

`PhoneUtils.placeCall(Context context, Phone phone, String number, Uri contactRef, boolean isEmergencyCall, Uri gatewayUri)` dials the number using the `phone` passed in.

8.9.2.5 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.

8.9.2.6 Phone Interface

`Phone` interface specifies the capabilities of the underlying phone system, weather GSM, CDMA, or SIP. We'll assume GMS from here on.

8.9.2.7 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.

8.9.2.8 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.

8.9.2.9 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.

8.9.2.10 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`.

8.9.2.11 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`.

8.9.2.12 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);`

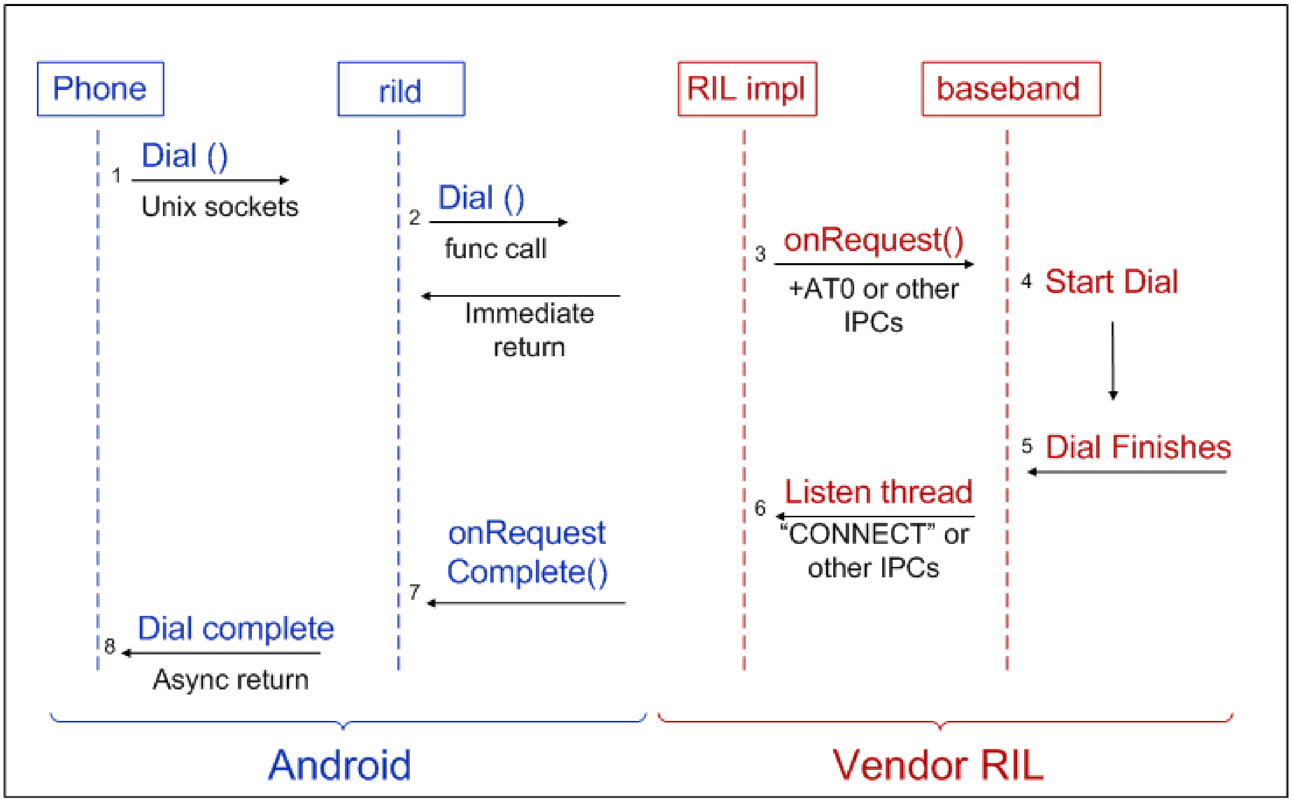


Figure 8.13: Example of solicited RIL commands

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)

8.9.2.13 Unsolicited RIL Commands

The following snippet illustrates the interface for unsolicited commands:

- `void OnUnsolicitedResponse (int unsolResponse, void *data, size_t datalen);`

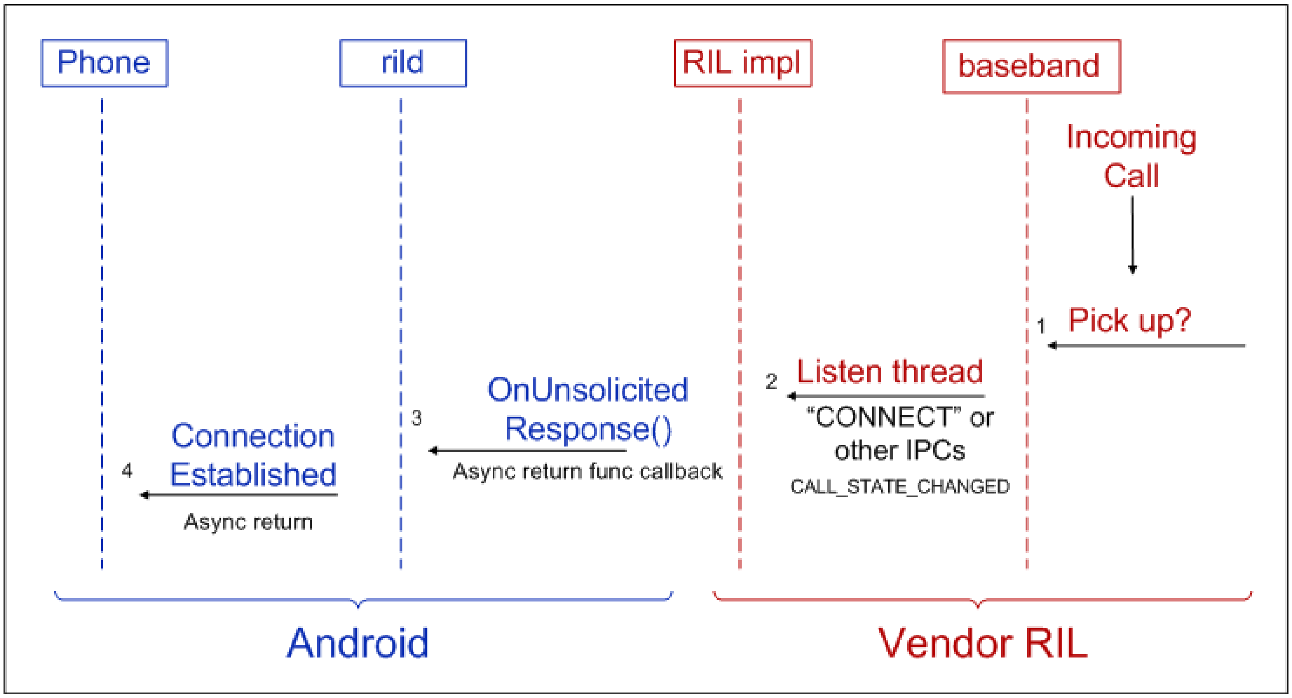


Figure 8.14: Example of unsolicited RIL commands

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)

8.9.2.14 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

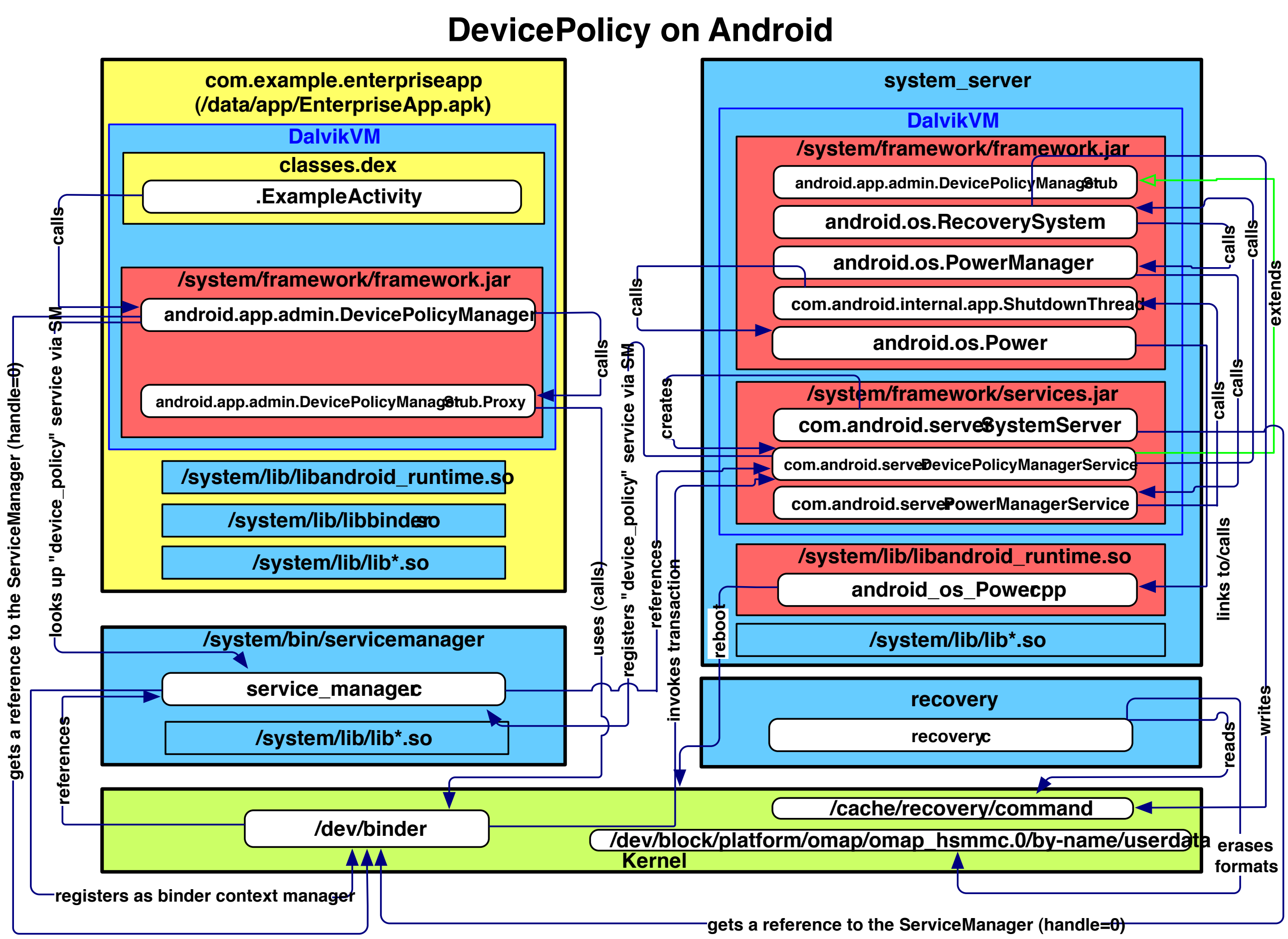


Figure 8.15: Device Policy Service Architecture

8.11 Surface Flinger

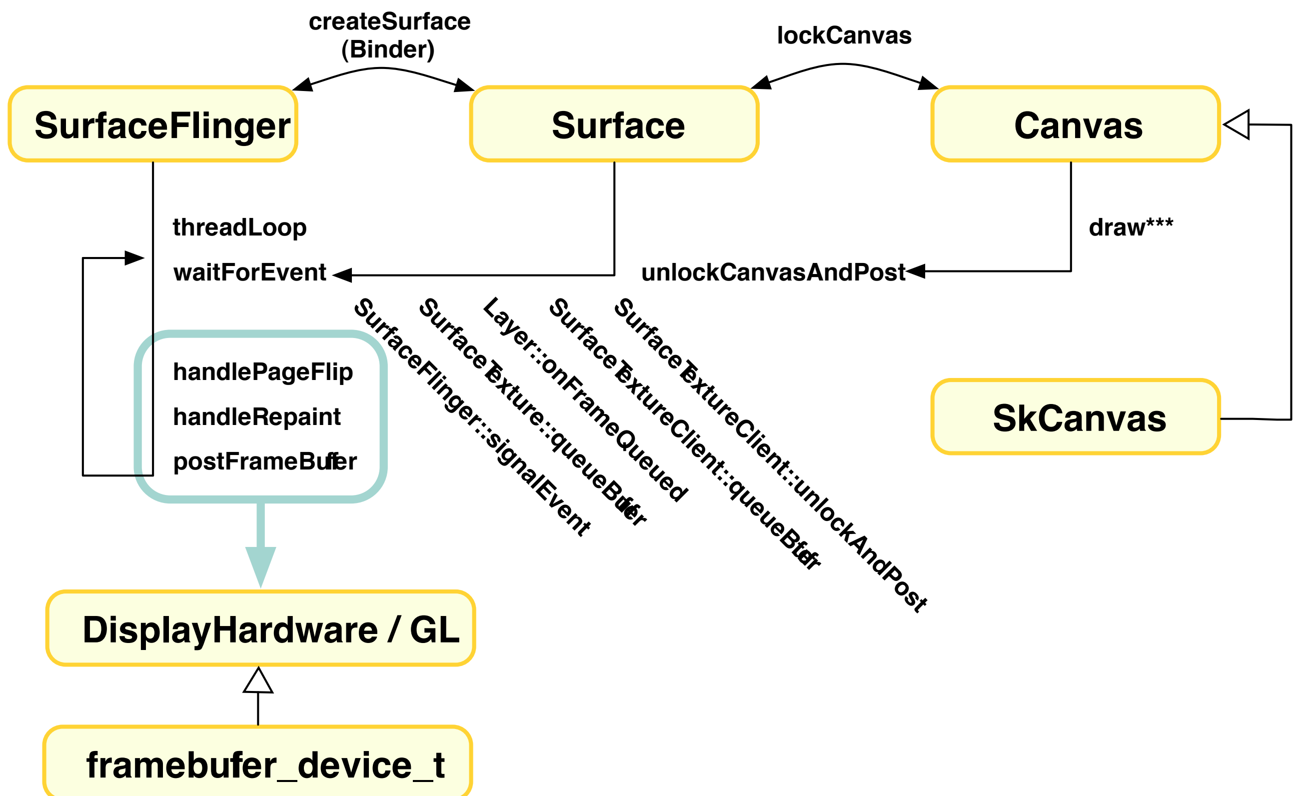


Figure 8.16: SurfaceFlinger Architecture

- 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://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

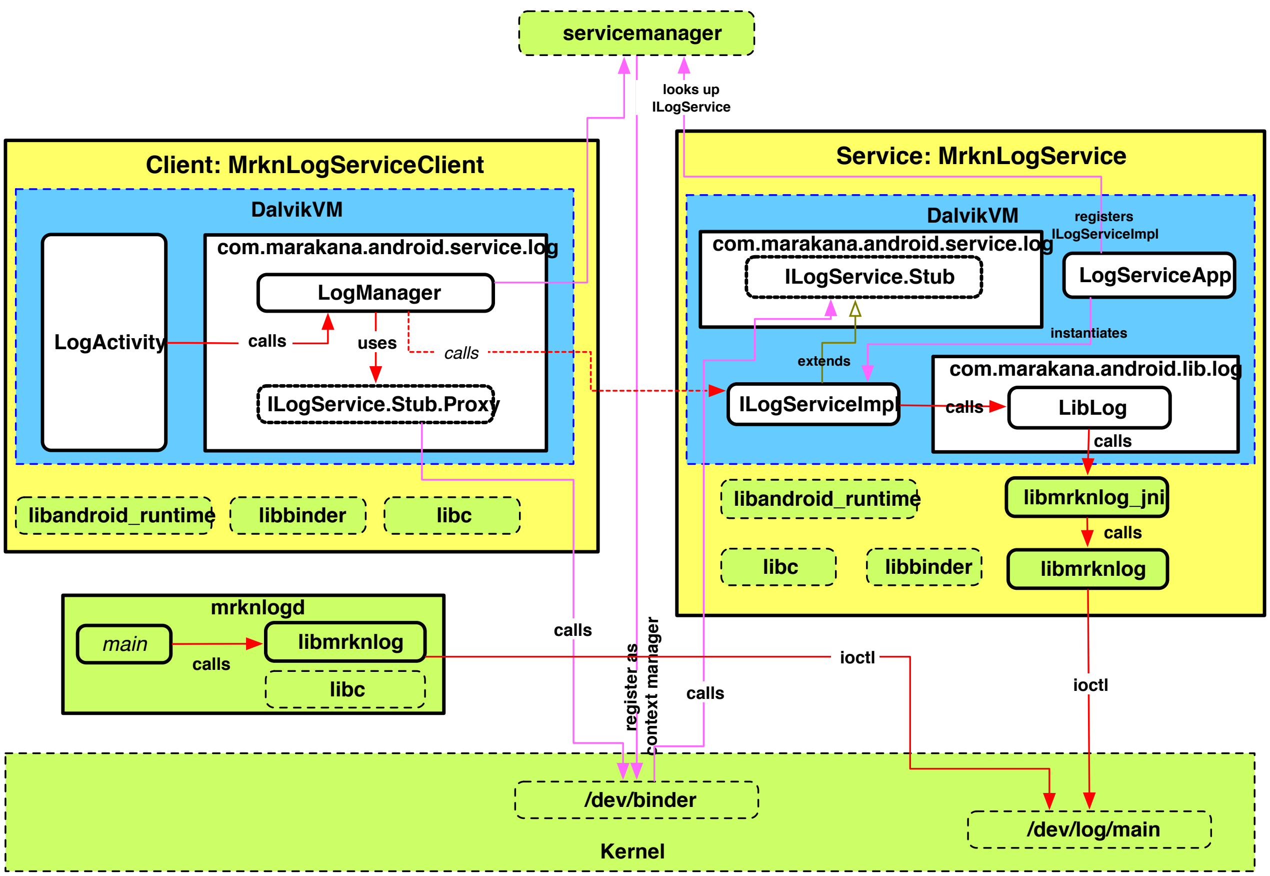
8.12.1 Links

- http://www.kandroid.org/online-pdk/guide/camera.html (outdated)

Chapter 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 for ARMv7 on Ubuntu 10.04 x86_64.

9.1 Setting up the 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`
  3. Also create our SDK addon (e.g. *alpha-sdk_addon*) sub-directory: `mkdir device/marakana/alpha-sdk_addon`
  4. Finally, create a sub-directory for common components, shared between the device and the addon: `mkdir device/marakana/alpha-common`

9.2 Registering our Device with Android's Build System

- Remember that `$ source build/envsetup.sh` registers lunch combos that we can later build
- We now want to add our device to that "lunch" list
  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/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_toro-userdebug
    11. full_tuna-userdebug
    12. 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 3
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`
device/marakana/alpha/full_alpha.mk

```
$(call inherit-product, $(SRC_TARGET_DIR)/product/languages_small.mk)
$(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

include $(call all-makefiles-under,$(LOCAL_PATH))
```

– Notice that this file:

  * Includes `build/target/product/languages_small.mk`, which defines a list of languages to be supported by our device
  * Includes `build/target/product/generic.mk`, which defines the rules for building the base Android platform, but itself is not specialized for any particular device
  * Includes all make files in the current directory (see below)
  * Defines our custom `PRODUCT_NAME`, `PRODUCT_DEVICE`, and `PRODUCT_MODEL`, which are arbitrarily chosen for our device (and which we override in our own makefile)

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 OpenGLES 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
```

---

4. We are now ready to try out our "custom" device (true, nothing truly custom yet, except for the `PRODUCT_*` settings):

   a. For good measure, re-register our device:

   ```
   $ source build/envsetup.sh
   including device/marakana/alpha/vendorsetup.sh
   ...
   ```

5. 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
============================================
```

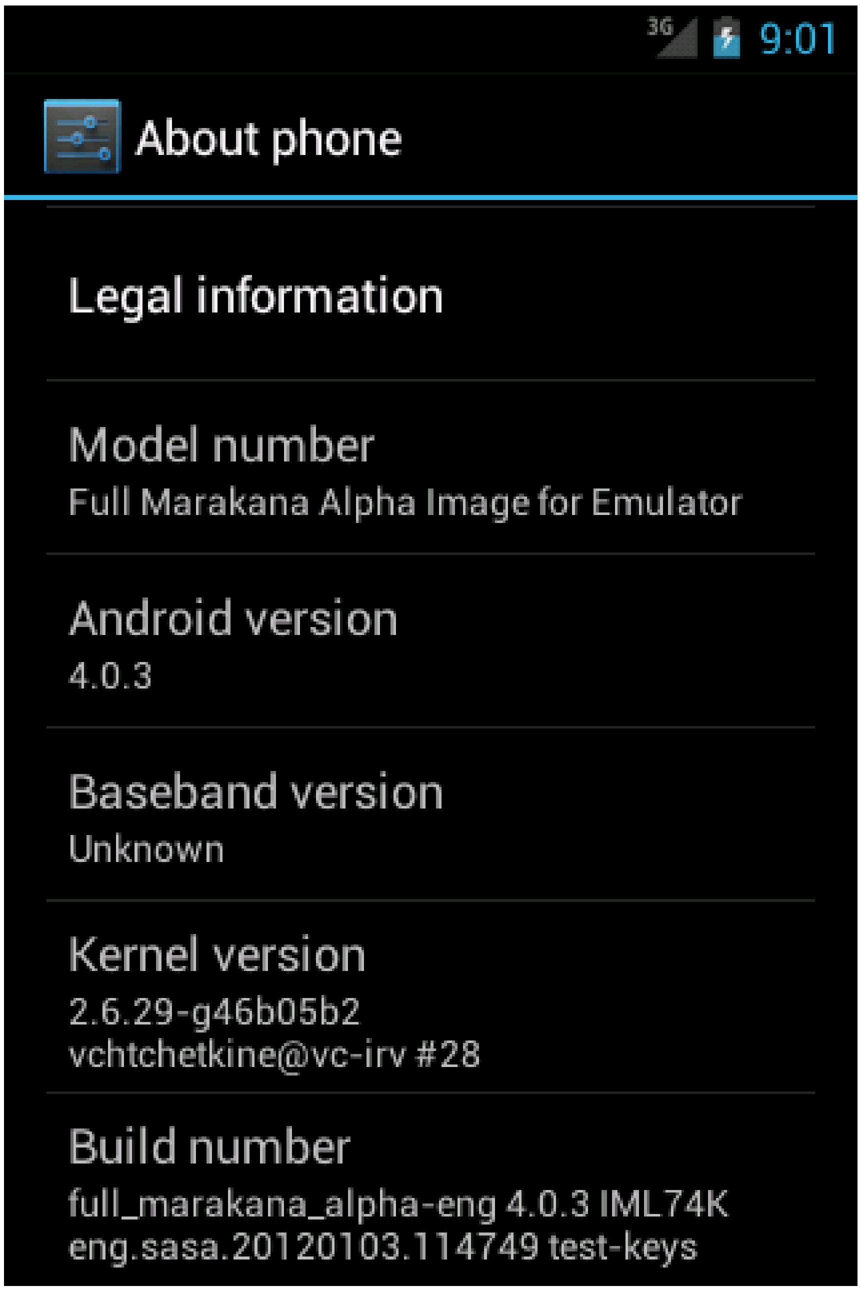
6. We can now compile our device:

```
$ 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
```

7. Finally, we can run it

```
$ emulator &
```

8. And we should see



9.4 Adding a Custom Kernel to our Device

- Our device works perfectly fine with the provided QEMU-based (i.e. emulator-specific) kernel: `prebuilt/android-arm/kernel/k` (or just `kernel-qemu` for ARMv5), but we could also configure it to use our custom one, say if we needed to add support for a particular driver or kernel feature

1. Build a custom kernel as desired, as outlined in ???TITLE??? section (or specifically ???TITLE???)

   > **Caution**
   > Make sure to select the correct `ARCH` when building the kernel - that is, the architecture has to match `TARGET_ARCH_VARIANT` in `device/marakana/alpha/BoardConfig.mk`.

   a. `$ mkdir ~/kernel/`
   b. `$ cd ~/kernel/`
   c. `$ git clone https://android.googlesource.com/kernel/goldfish.git`
   d. `$ cd goldfish/`
   e. `$ git branch -a`
   f. `$ git checkout -t remotes/origin/android-goldfish-2.6.29`
   g. `$ make goldfish_armv7_defconfig ARCH=arm`

      > **Note**
      > For x86, run `make goldfish_defconfig ARCH=x86` instead

   h. `$ make menuconfig`
      i. Customize as desired
      ii. For example, set *General setup* → *Local version* to "-marakana-alpha-release"
   i. `$ make -j10 ARCH=arm CROSS_COMPILE=/path/to/android-source/prebuilt/linux-x86/toolcha` (adjust `/path/to/android-source/` as necessary)

      > **Note**
      > For x86, run `make -j10 ARCH=x86 CROSS_COMPILE=/path/to/android-source/prebuilt/linux-x86` instead. Unfortunately, we run into issues (clobbered PIC register) when compiling for x86 last time (January 2012).

      > **Note**
      > Android also provides a convenient script to compile the Linux kernel for QEMU-based emulator: `/path/to/android-source/external/qemu/distrib/build-kernel.sh`.

   j. `$ ls -l arch/arm/boot/zImage`

      > **Note**
      > For x86, run `ls -l arch/x86/boot/zImage` instead

2. Copy the compiled kernel file (`zImage`) to our device's `common/` directory (since we'll use it in our SDK addon as well):

```
$ cp /path/to/kernel/arch/arm/boot/zImage device/marakana/alpha-common/kernel
```

Note
In our case, `/path/to/kernel/` is `~/kernel/goldfish`. For x86, copy `arch/x86/boot/zImage` 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/android-code/raw/master/CustomRom/device/marakana/alpha-common/kernel

3. Enable our custom kernel in `BoardConfig.mk` (double-negation, nice!):
   device/marakana/alpha/BoardConfig.mk

```
...
TARGET_NO_KERNEL := false
...
```

4. Create a `alpha.mk` makefile for our common components, where we'll configure our kernel:
   device/marakana/alpha-common/alpha.mk

```
MY_PATH := $(LOCAL_PATH)/../alpha-common

include $(call all-subdir-makefiles)

# Enable our custom kernel
LOCAL_KERNEL := $(MY_PATH)/kernel
PRODUCT_COPY_FILES += $(LOCAL_KERNEL):kernel
```

5. Now, we need to include our common `alpha.mk` file in our device's main makefile (`full_alpha.mk`):
   device/marakana/alpha/full_alpha.mk

```
...
include device/marakana/alpha-common/alpha.mk
```

6. 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
...
```

7. Restart the emulator (with our new kernel)

```
$ emulator -kernel out/target/product/alpha/kernel &
```

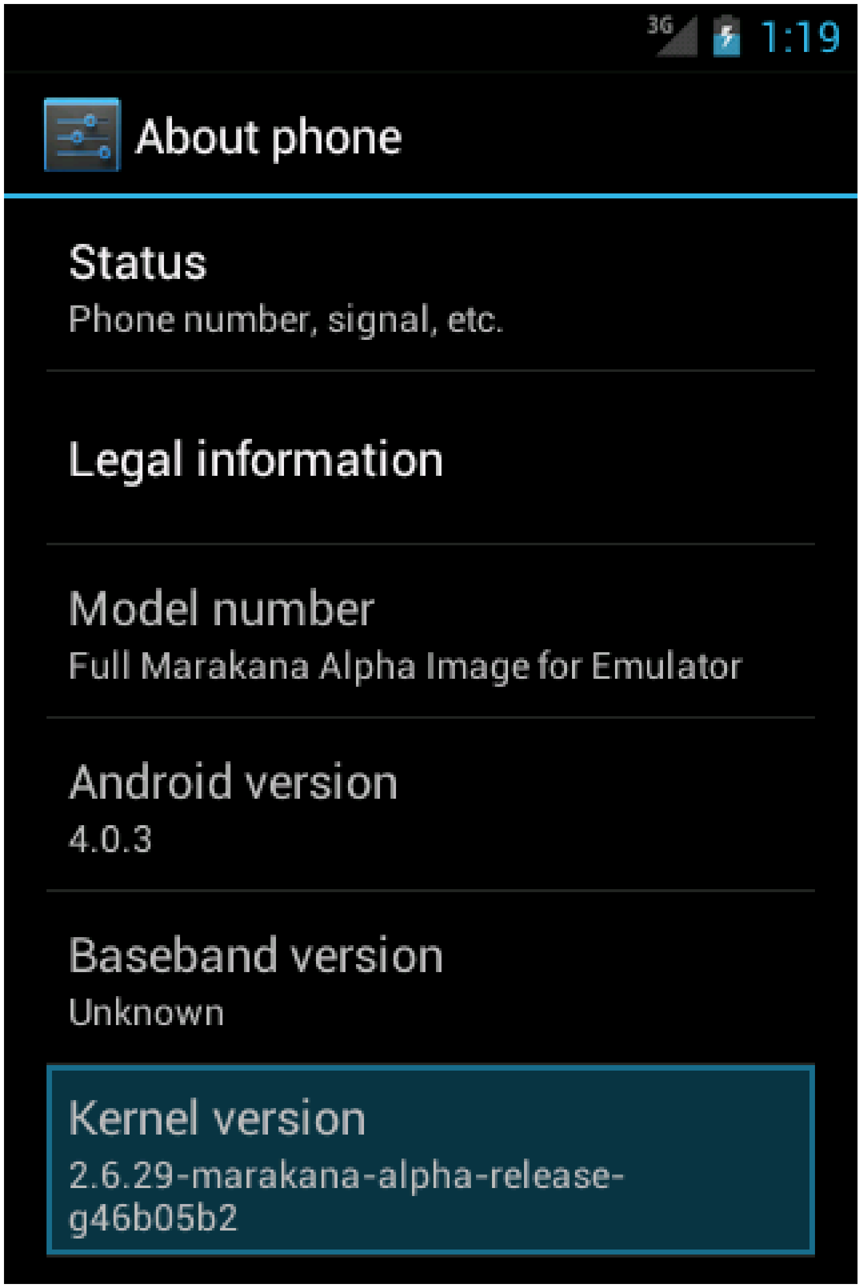
Note
We have to run our emulator with `-kernel`, because otherwise it would ignore the kernel in our newly built `boot.img` and instead use the default one (`prebuilt/android-arm/kernel/kernel-qemu-armv7`). This applies just to the emulator.

8. 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`)

9. We could also take a look at the updated *About* screen:



9.5 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-common/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-common/lib/Android.mk

```
include $(call all-subdir-makefiles)
```

3. Now we can create an actual directory for our `libmrknlog` library:

```
$ mkdir device/marakana/alpha-common/lib/libmrknlog
```

4. Now we can create a simple header file (`libmrknlog.h`) for our library:
device/marakana/alpha-common/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-common/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-common/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-common/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-common/lib/libmrknlog$ mm
...
make: Entering directory '/flash/ics-4.0.3'
target thumb C: libmrknlog <= device/marakana/alpha-common/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-common/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-common/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/alpha.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-common/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-common/bin/Android.mk

```
include $(call all-subdir-makefiles)
```

11. Now we can create a directory for our `mrknlog` executable:

```
$ mkdir device/marakana/alpha-common/bin/mrknlog
```

12. Next we provide the implementation (`mrknlog.c`), which will use our shared library (`libmrknlog`):
device/marakana/alpha-common/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-common/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-common/bin/mrknlog
   [2] ./device/marakana/alpha-common/lib/libmrknlog

Select one: 1
device/marakana/alpha-common/bin/mrknlog$ mm
...
target thumb C: mrknlog <= device/marakana/alpha-common/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-common/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/alpha.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
$ 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 :-)
```

9.6 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 `service`-es
- Let's get started:

1. As before, we need to create a home for our daemon source:

```
$ mkdir device/marakana/alpha-common/bin/mrknlogd
```

2. Next, we create or daemon source (`mrknlogd.c`), by utilizing our `libmrknlog` library:
device/marakana/alpha-common/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__)
```

---

3. Next, we create our makefile (`Android.mk`), which defines links from our source to our library:
   device/marakana/alpha-common/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)
```

4. 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
```

5. 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/alpha.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 a `init*.rc` file:

   a. Since we don't want to modify the existing `init.rc` file, we'll copy the one from goldfish into our own directory:

   ```
   $ cp system/core/rootdir/etc/init.goldfish.rc device/marakana/alpha-common/.
   ```

A note about board name ("goldfish")
Why did we use "goldfish"? Because that's the name of our board - since we inherited from the emulator, which is known as "goldfish":

```
$ 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 (and lower-case) the board name. It then loads the file `/init.<board-name>.rc`.
The actual name "Goldfish" is defined in `goldfish/arch/arm/mach-goldfish/board-goldfish.c` (i.e. goldfish kernel) as `MACHINE_START(GOLDFISH, "Goldfish")`.
We could change all of this of course, but that requires more significant effort if we want to continue using the emulator, since other files are also based on this name (e.g. `ueventd.goldfish.rc`).
If we do decide to make this change, we also should update our `BoardConfig.mk` to say:

```
TARGET_BOOTLOADER_BOARD_NAME := <our-custom-board-name>
TARGET_PROVIDES_INIT_TARGET_RC := true
```

b. Now we can define and start our service:
device/marakana/alpha-common/init.goldfish.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
```

c. Finally, we need to tell Android to use our custom `init.goldfish.rc` file (by copying it over the existing one during the build):
device/marakana/alpha-common/alpha.mk

```
...
# Copy our init.rc file over the existing one (since ours contains extra ↩
    changes)
PRODUCT_COPY_FILES += $(MY_PATH)/init.goldfish.rc:root/init.goldfish.rc
```

Note
Why not just update the existing `system/core/rootdir/etc/init.goldfish.rc` file? Well, we wanted to keep our changes self-contained - at the expense of some maintenance overhead (down the road).

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
$ 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 :-)
```

9.7 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 Chapter 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 -jni ....LibLog`

- 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/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-common/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-common/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-common/framework/libmrknlog_jni
$ mkdir device/marakana/alpha-common/framework/libmrknlog_jni/java
$ mkdir device/marakana/alpha-common/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-common/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-common/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-common/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-common/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-common/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-common/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 via `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-common/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,.)
LOCAL_JAVA_LIBRARIES := core
LOCAL_NO_STANDARD_LIBRARIES := true
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-common/framework/libmrknlog_jni/java
device/marakana/alpha-common/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-common/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-common/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-common/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-common/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-common/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-common/framework/libmrknlog_jni/jni
device/marakana/alpha-common/framework/libmrknlog_jni/jni$ mm
...
Install: out/target/product/alpha/system/lib/libmrknlog_jni.so
device/marakana/alpha-common/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/alpha.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
$ 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 :-)
```

9.8 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 device/marakana/alpha/app
   ```

   > **Note**
   > We created this directory under `alpha/` (and not `alpha-common/`) since we do not need to share this app with the SDK addon (which we'll be creating later).

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

9.9 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-common/framework/mrknlogservice
$ mkdir -p device/marakana/alpha-common/framework/mrknlogservice/com/marakana/ ↩
    android/service/log
```

2. Let's create a simple AIDL description of our service (`LibLogService.aidl`):

device/marakana/alpha-common/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-common/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-common/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-common/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
LOCAL_JAVA_STATIC_LIBRARIES := android-common
LOCAL_JAVA_LIBRARIES := core
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-common/framework/mrknlogservice
device/marakana/alpha-common/framework/mrknlogservice$ mm -j10 com.marakana. ↩
    android.service.log com.marakana.android.service.log.xml
...
Aidl: com.marakana.android.service.log <= device/marakana/alpha-common/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-common/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 `alpha.mk` makefile:

device/marakana/alpha-common/alpha.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-common` apps:

```
$ mkdir device/marakana/alpha-common/app
```

9. And, as we know by now, we need a makefile to include `app/`'s sub-directories into the build:
device/marakana/alpha-common/app/Android.mk

```
include $(call all-subdir-makefiles)
```

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-common/app/MrknLogService/res/values
$ mkdir -p device/marakana/alpha-common/app/MrknLogService/src/com/marakana/ ↩
    android/logservice
```

11. We need some basic string resources:
device/marakana/alpha-common/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-common/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/servicemanager`) by adding `android:sharedUserId="android.uid.system"` attribute to the manifest. This is enforced by `frameworks/base/cmds/servicemanager/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-common/app/MrknLogService/src/com/marakana/android/logservice/ILogServiceImpl.java

```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-common/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-common/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-common/app/MrknLogService
device/marakana/alpha-common/app/MrknLogService$ mm
...
Install: out/target/product/alpha/system/app/MrknLogService.apk
device/marakana/alpha-common/app/MrknLogService$ croot
$
```

17. We want our `MrknLogService` to be included in the final ROM, so we add it to `alpha.mk`:
device/marakana/alpha-common/alpha.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.

9.10 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. In case we skipped building `MrknLogLibClient`, we will also need `device/marakana/alpha/app/Android.mk` to include makefiles from sub-directories - though it's probably easiest to just copy this file:

```
$ cp device/marakana/alpha-common/app/Android.mk device/marakana/alpha/app/
```

3. 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>
```

4. 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>
```

5. Our activity (`LogActivity`) will be similar to the one we wrote before, except that in this case will be using `com.marakana.android.service.log` 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);
  }
}
```

6. 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>
```

7. 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.

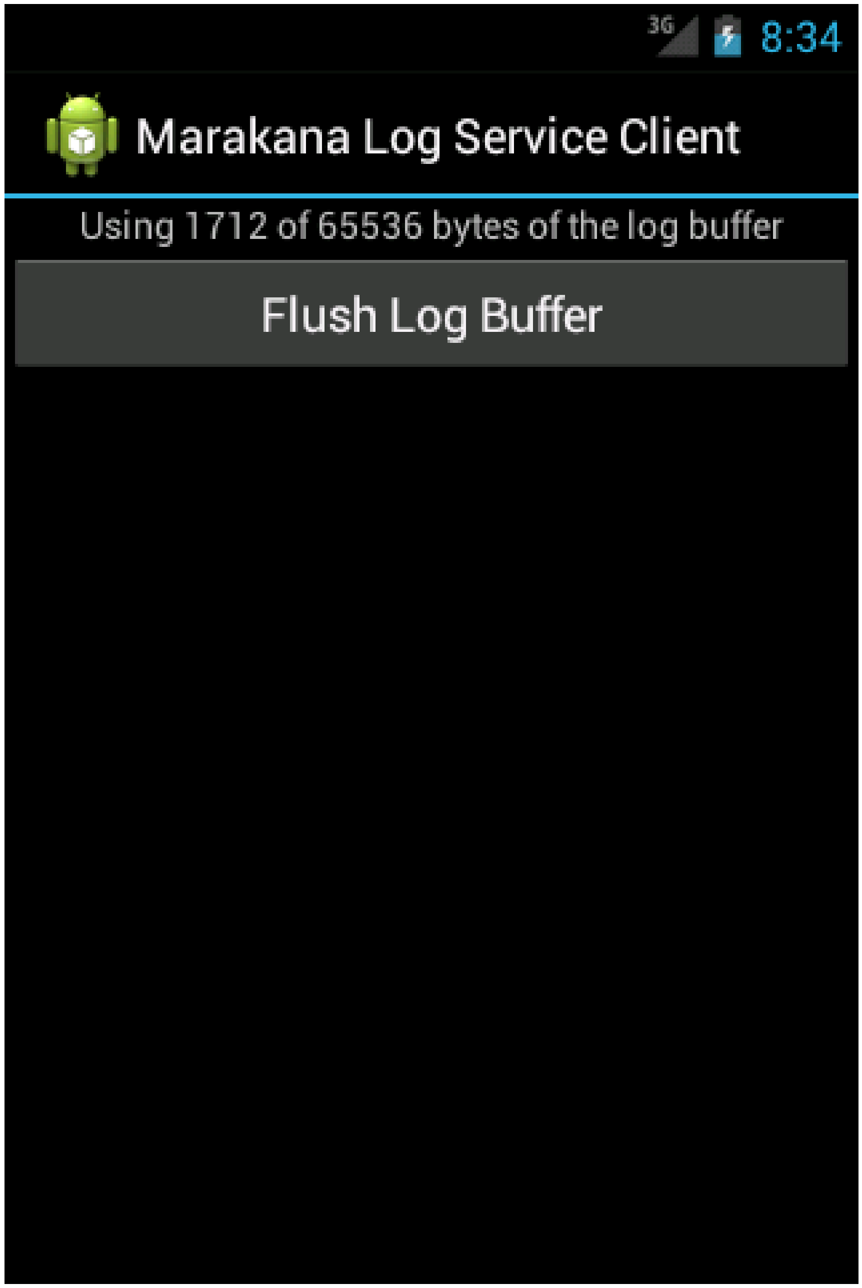
8. And, as before, we need to register `MrknLogServiceClient` with the device's main makefile (`full_alpha.xml`) in order to get it included in the ROM:
   device/marakana/alpha/full_alpha.mk

```
...
PRODUCT_PACKAGES += MrknLogServiceClient
```

9. 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
```

10. 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



9.11 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 part 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-common/` so we'll focus only on the differences
- Let's get started:

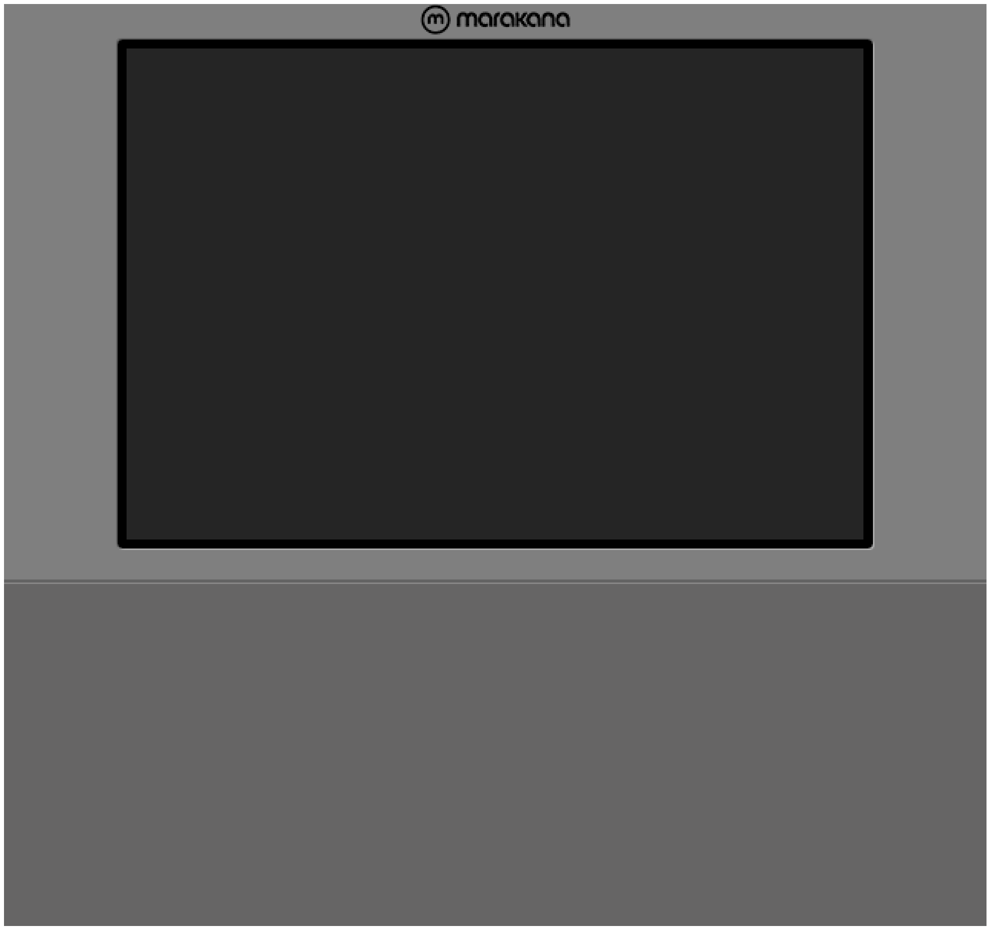
1. We need a directory for our addon, but we've already created it before: `device/marakana/alpha-sdk_addon`
2. Though this is purely optional, let's create a custom emulator for our add-on, by copying one of the existing ones:

```
$ 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/MrknHv`
   - say by adding our custom logo to it

> **Note**
> For example, we could use this one: https://github.com/marakana/android-code/raw/master/CustomRom/-device/marakana/alpha-sdk_addon/skins/MrknHvgaMdpi/background_land.png

   b. We could also customize the landscape background of our skin (`device/marakana/alpha-sdk_addon/skins/MrknH`
   - also by adding our custom logo to it



Note
For example, we could use this one: https://github.com/marakana/android-code/raw/master/CustomRom/-device/marakana/alpha-sdk_addon/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 addon (`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 addon:

   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>.(*|<class-name>)`) from the generated SDK addon'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 addon's main makefile (`alpha_sdk_addon.mk`), which will be loaded later by `AndroidProducts.mk`:

   device/marakana/alpha-sdk_addon/alpha_sdk_addon.mk

```
# Include the common stuff
include device/marakana/alpha-common/alpha.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-qemu

# 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-commmon`, adds support for library documentation, defines the addon's name (`PRODUCT_SDK_ADDON_NAME`), specifies the files/modules to be copied (`manifest.ini`, `hardware.ini`, skin, libraries, and kernel) into the addon (`PRODUCT_SDK_ADDON_COPY_FILES`), loads stub defs, and defines the addon'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 addon):
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 addon-specific components down the road, which will most likely be stored in their own sub-directories.

10. Now we are ready to compile our addon:

```
$ 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 addon (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-qemu
  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.

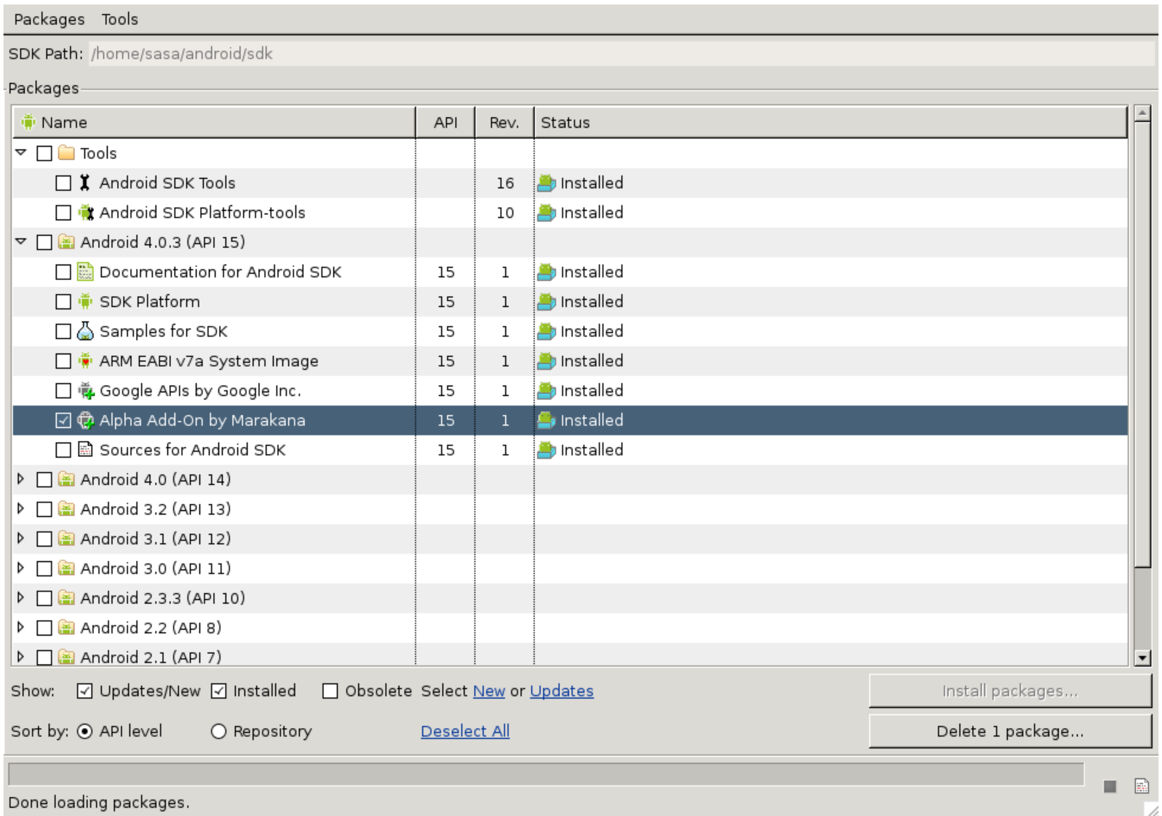
12. Let’s test that it shows up in our *Android SDK and ADV Manager*:
    a. Run

    ```
    $ /path/to/android/sdk/tools/android $
    ```

Note
Adjust the path to Android SDK directory as necessary.

---

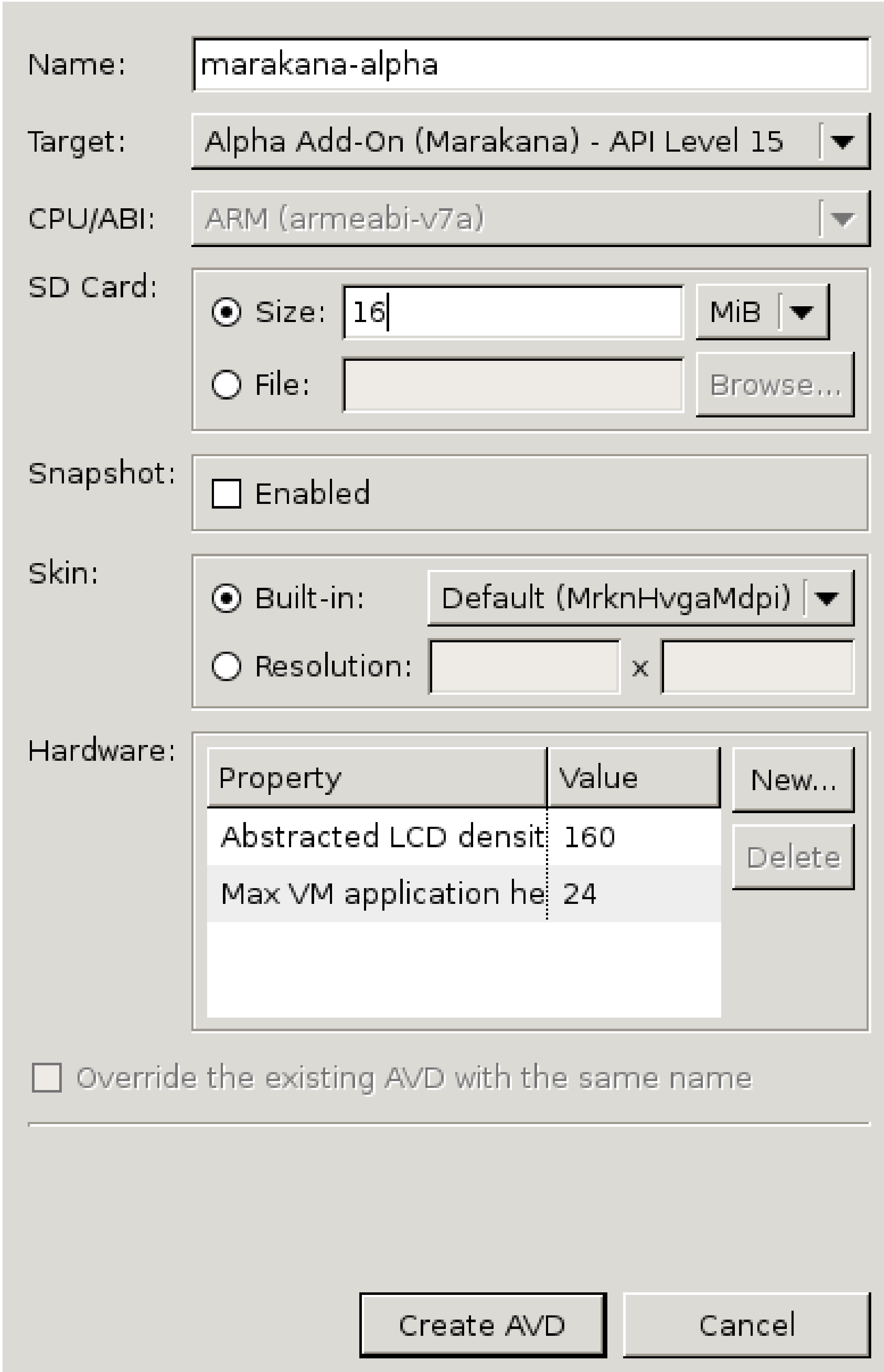
b. And we should now see "Alpha Add-On by Marakana, Android API 15, revision 1, Installed" show up under *Packages*:



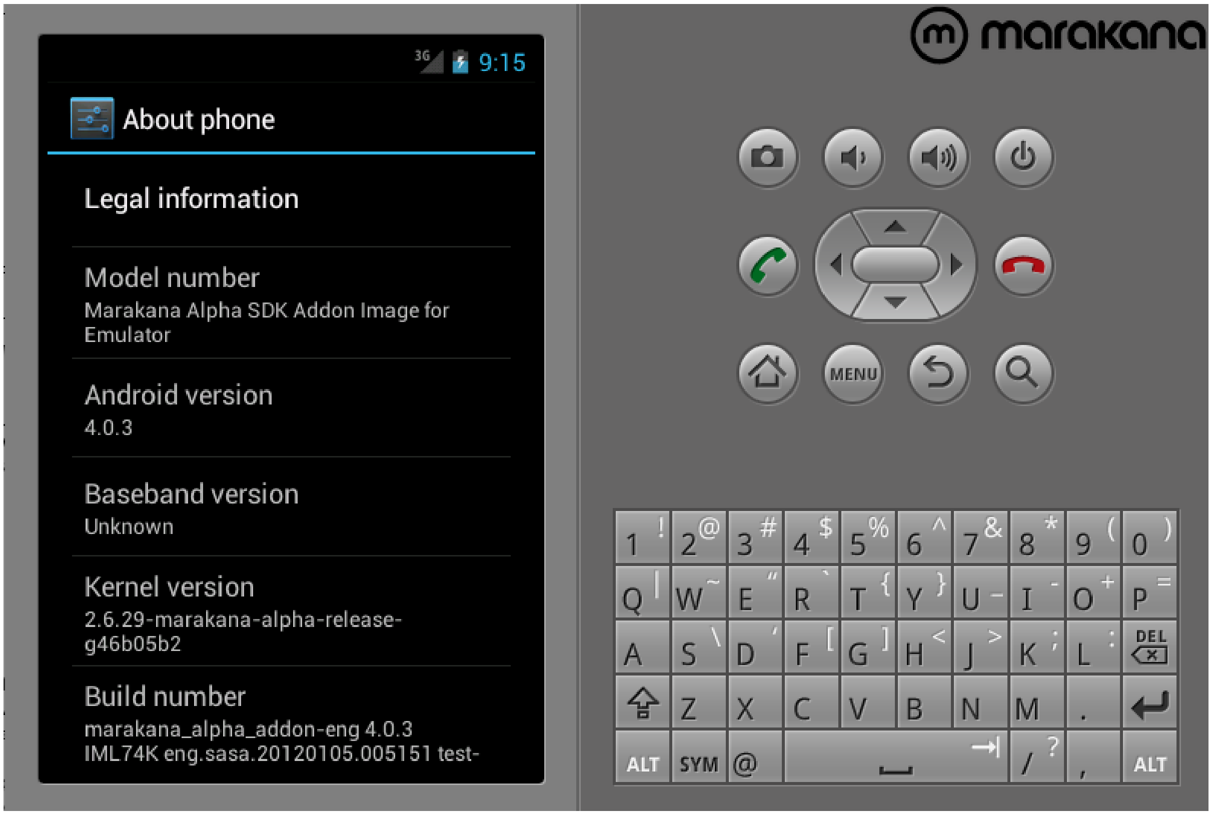
Note
For this to work, we need to have our addon's `api` setting (in `manifest.ini` file) match an available *SDK Platform Android* of the same API version.

---

13. Now we can create a new emulator image (AVD) based on our add-on (from the *Android SDK and AVD Manager*):



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 :-)

9.11.1 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: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_r1`
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

9.12 Android USB Support

9.12.1 Overview of Android USB Support

9.12.1.1 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.

9.12.1.2 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.

9.12.2 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

9.12.2.1 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 sychronously 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.

9.12.2.2 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" />
  ```

9.12.2.3 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.

9.12.2.4 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.acti` 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.

9.12.2.5 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`.

9.12.2.6 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()
    // ...
}
```

9.12.2.7 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);
```

9.12.2.8 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()`.

9.12.2.9 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.

9.12.3 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

9.12.3.1 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.

9.12.3.2 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_ACCES
    ```

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.

9.12.3.3 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" />
  ```

9.12.3.4 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.

9.12.3.5 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.acti` 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.

9.12.3.6 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`.

9.12.3.7 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.getAcccessoryList();
```

Note
Currently, only one connected accessory is supported at one time, but the API is designed to support multiple accessories in the future.

9.12.3.8 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);
```

9.12.3.9 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.

9.12.3.10 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.

9.12.3.11 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.