The Android System

A Bottom-Up Approach

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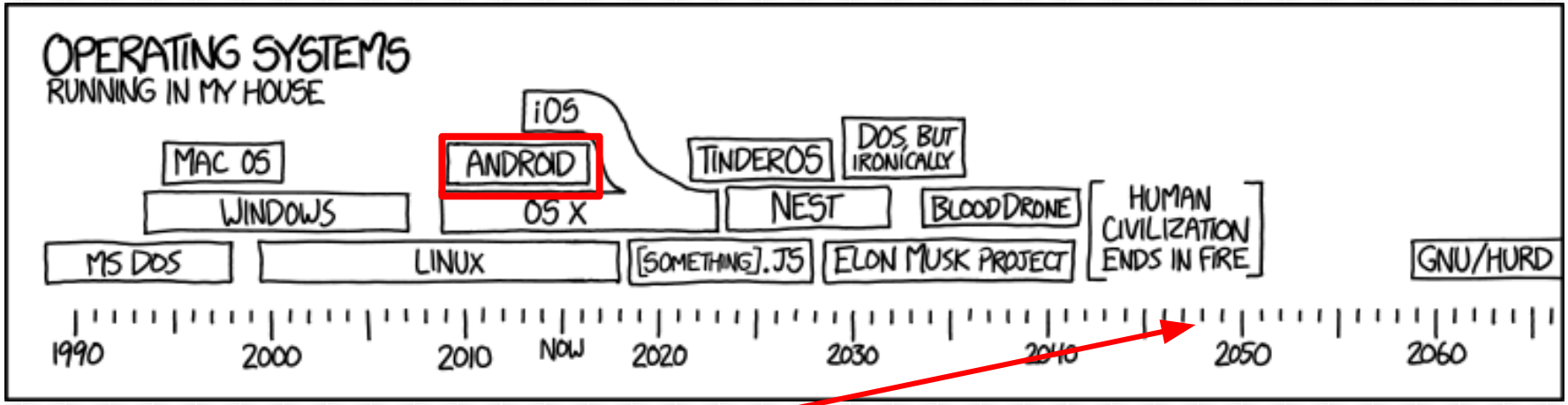
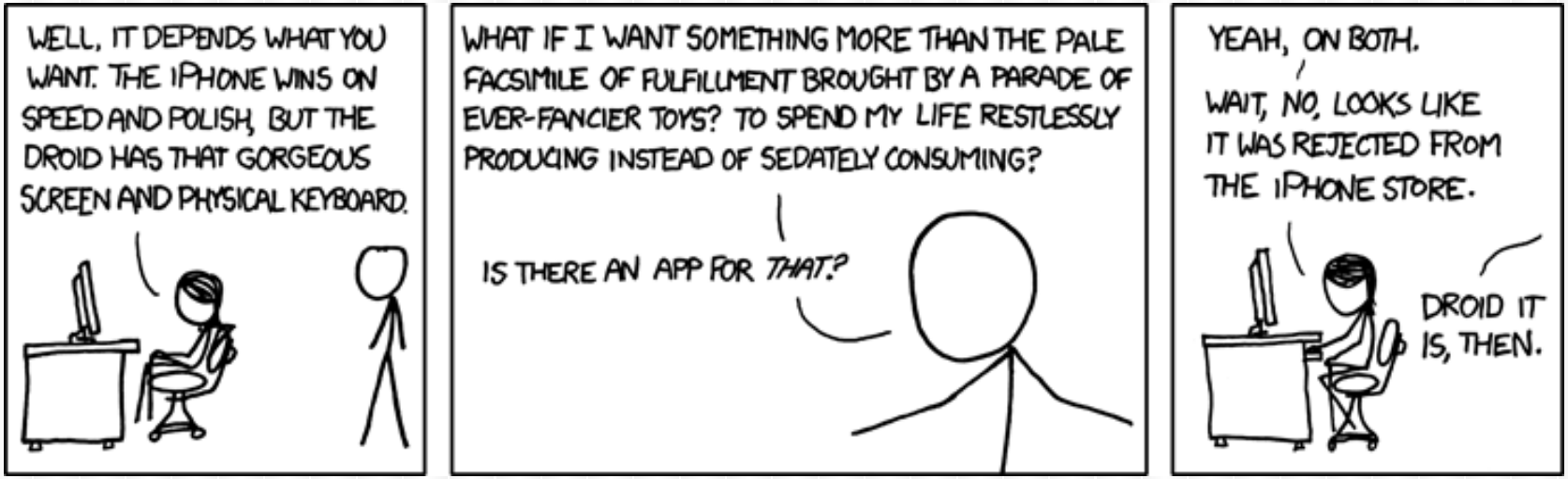
16 September 2015

Some Context



One of the survivors, poking around in the ruins with the point of a spear, uncovers a signed photo of Richard Stallman. They stare in silence. "This," one of them finally says, "This is a man who BELIEVED in something."

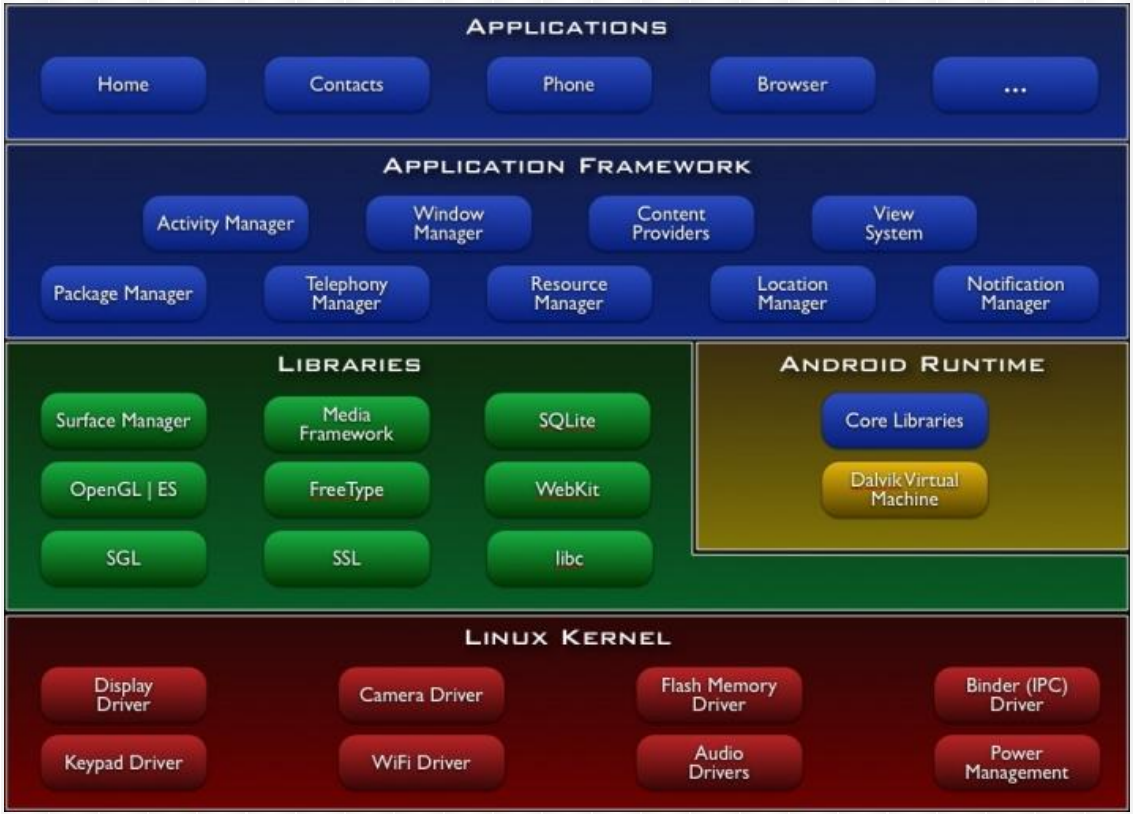
Some More Context



Android is complicated and supports a wide variety of devices and apps.

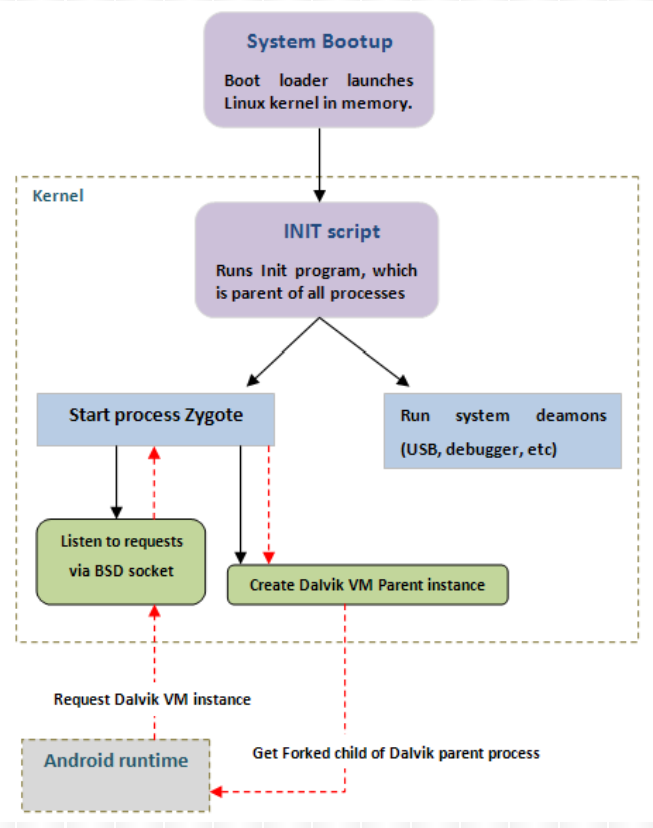
HOW DO YOU BUILD SUCH A SYSTEM?

Android System Architecture



Device Bootup

- The *Zygote* is a process started at boot (think *init*), which preloads a Dalvik instance and some shared libraries
- Every app runs in its own VM instance, so instances need minimal startup time and memory costs
  - New apps open a socket to the Zygote, which *forks* a new VM for it
  - Core libraries are shared across VMs
  - Each VM is garbage collected independently



Just… How?

https://github.com/android/platform_frameworks_base/blob/lollipop-release/

- core/java/com/android/internal/os/Zygote.java

```
/**
 * Forks a new VM instance.  The current VM must have been started
 * with the -Xzygote flag. <b>NOTE: new instance keeps all
 * root capabilities. The new process is expected to call capset()</b>.
public static int forkAndSpecialize(int uid, int gid, int[] gids, int debugFlags,
      int[][] rlimits, int mountExternal, String seInfo, String niceName, int[] fdsToClose,
      String instructionSet, String appDataDir) {
    long startTime = SystemClock.elapsedRealtime();
    VM_HOOKS.preFork();
    checkTime(startTime, "Zygote.preFork");
    int pid = nativeForkAndSpecialize(
              uid, gid, gids, debugFlags, rlimits, mountExternal, seInfo, niceName, fdsToClose,
              instructionSet, appDataDir);
    checkTime(startTime, "Zygote.nativeForkAndSpecialize");
    VM_HOOKS.postForkCommon();
    checkTime(startTime, "Zygote.postForkCommon");
    return pid;
}
```

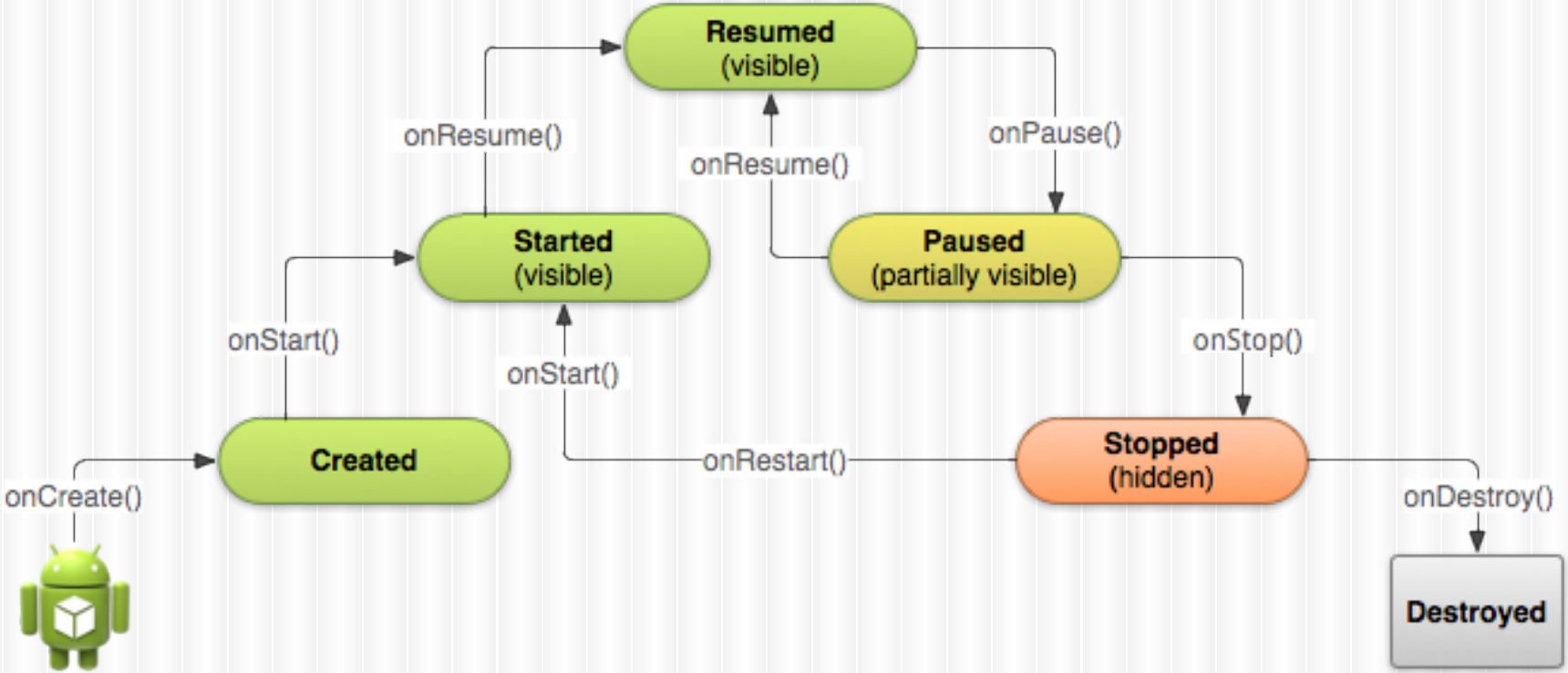
Just… How?

https://github.com/android/platform_frameworks_base/blob/lollipop-release/

- core/jni/com_android_internal_os_Zygote.cpp

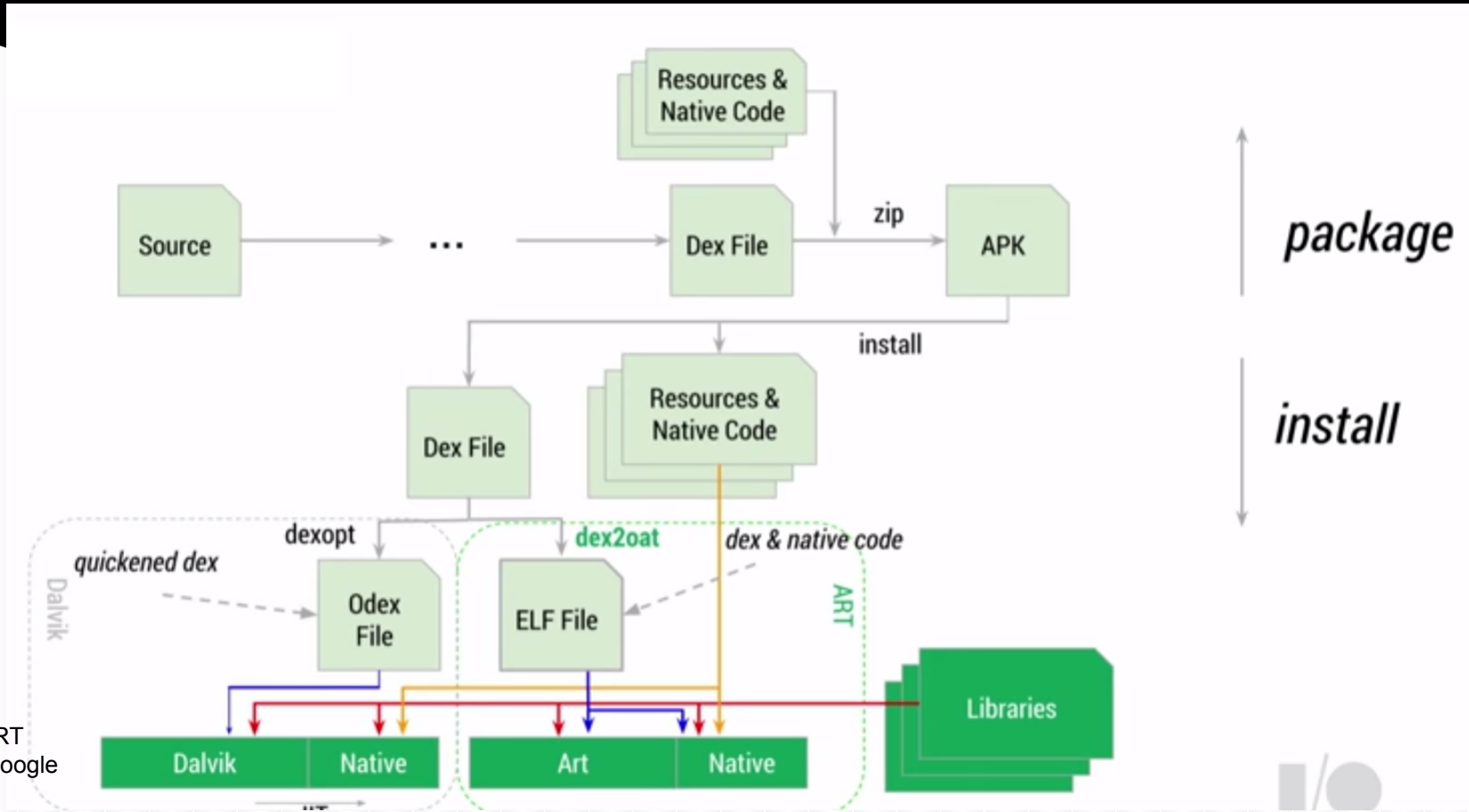
```
// Utility routine to fork zygote and specialize the child process.
static pid_t ForkAndSpecializeCommon(JNIEnv* env, uid_t uid, gid_t gid, jintArray javaGids,
                                     jint debug_flags, jobjectArray javaRlimits,
                                     jlong permittedCapabilities, jlong effectiveCapabilities,
                                     jint mount_external,
                                     jstring java_se_info, jstring java_se_name,
                                     bool is_system_server, jintArray fdsToClose,
                                     jstring instructionSet, jstring dataDir) {
  uint64_t start = MsTime();
  SetSigChldHandler();
  ckTime(start, "ForkAndSpecializeCommon:SetSigChldHandler");

  pid_t pid = fork();
```

The Activity Lifecycle



See: http://developer.android.com/training/basics/activity-lifecycle/starting.html

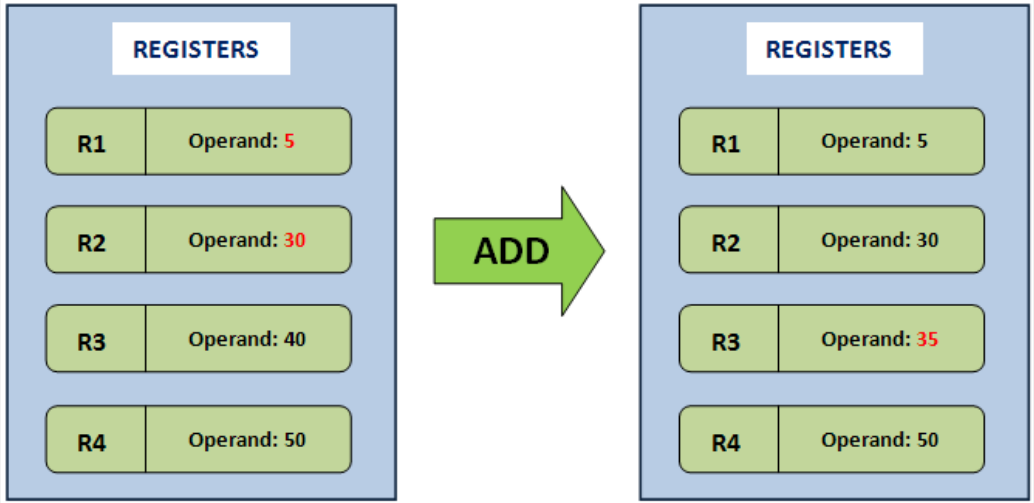
Life of an APK



See “The ART Runtime”, Google I/O 2014

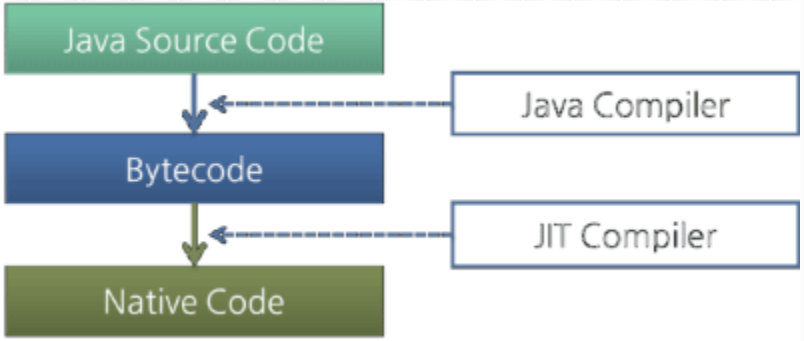
Dalvik Virtual Machine

- Is basically a JVM - allows “write once, run anywhere” code
- Executes “Dalvik Executable” files (.dex)
  - Optimized for low memory footprint
- Is a *register-based* VM - instruction operands are stored in registers



JIT All The Things

- DEX bytecode is compiled to Dalvik bytecode “Just In Time” for use
- Only “hot” (soon to be used) code is compiled
- Trace length of 100 opcodes
- Threads in the same process share a trace cache
- Consecutive traces can be chained together to increase performance
- JIT generates Dalvik bytecode, usually



Disadvantages of Dalvik

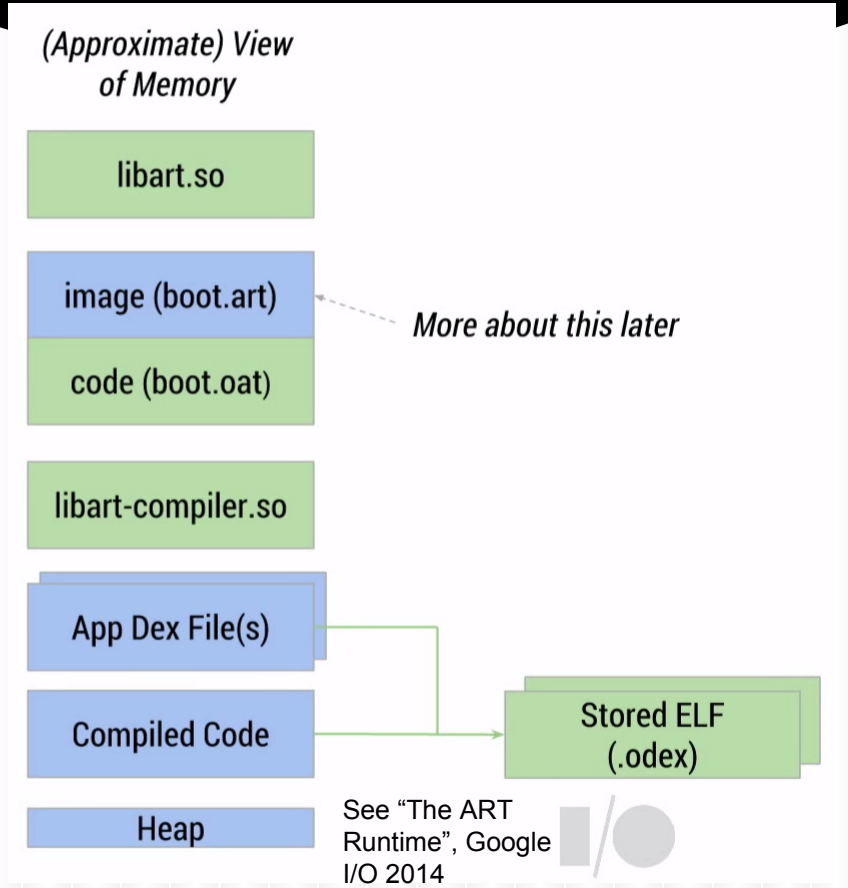
- Whenever a new application launches…
  - It needs to be JIT compiled and loaded into RAM
  - Sometimes cached (less effective as app sizes grew)

- These compilations happen while the user is engaged
  - Waiting for app to load
  - Can cause stutters if the system is low on memory

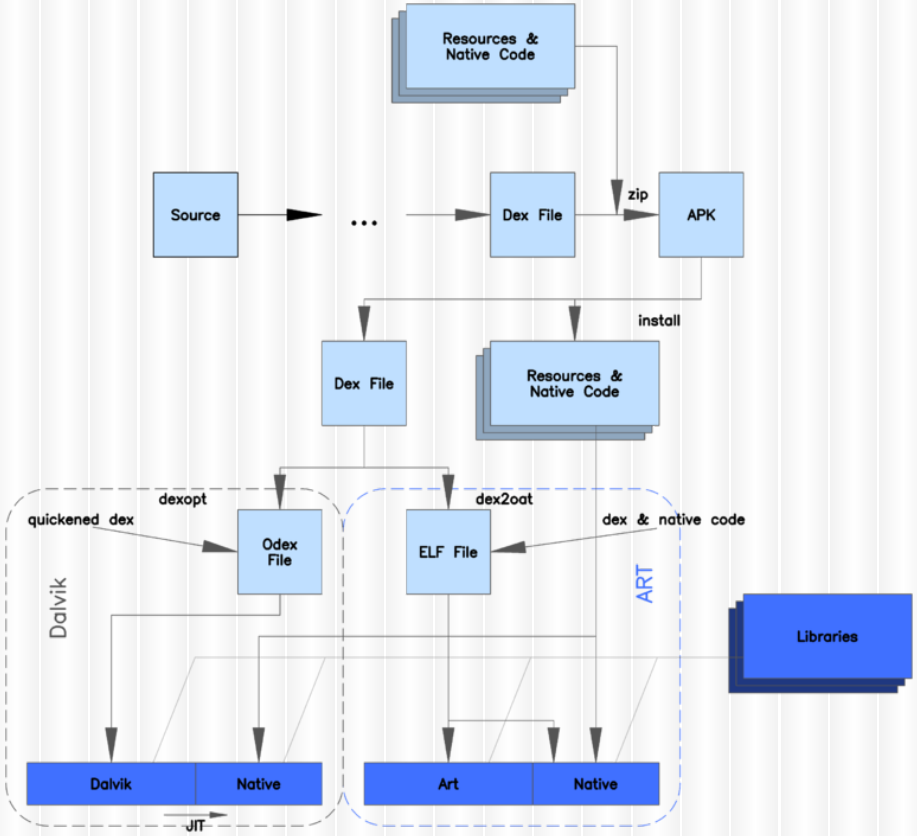
Why was this the original design choice, then?

Android Runtime (ART)

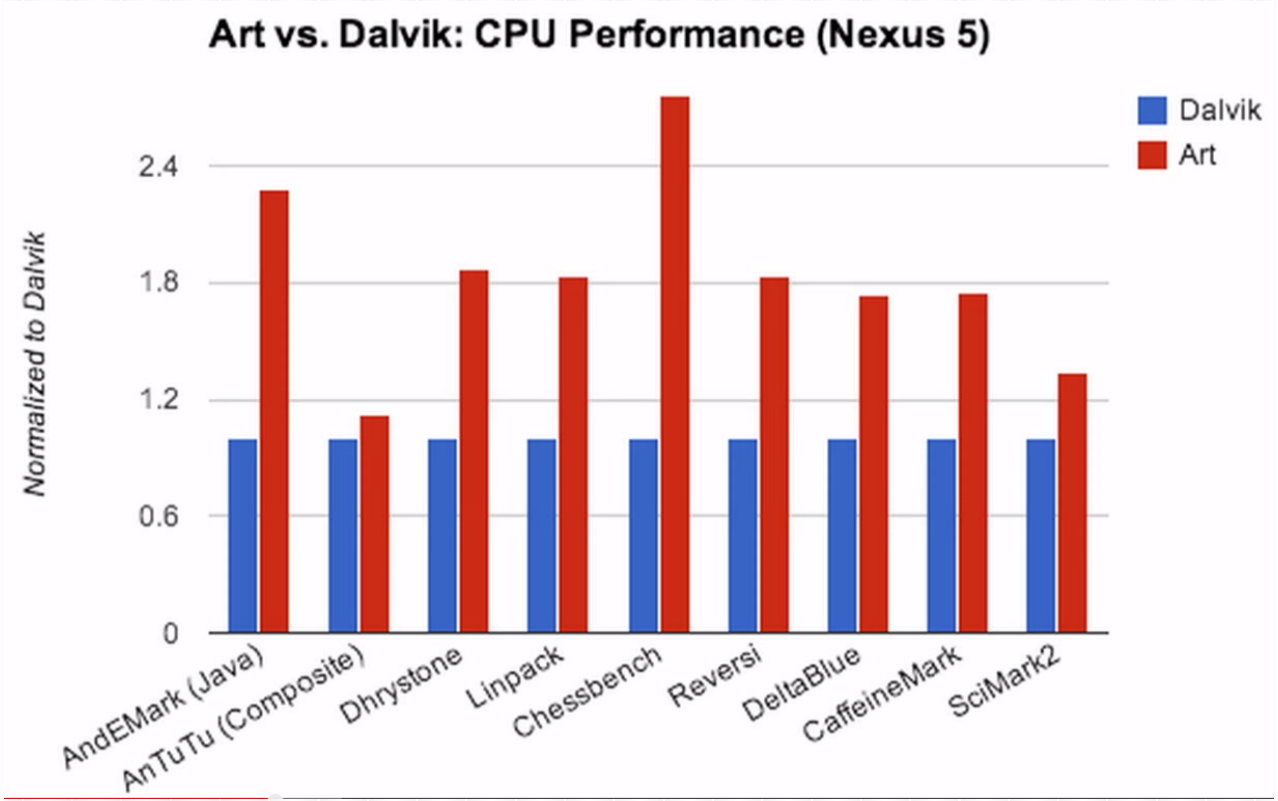
- Acts as Ahead of Time (AOT) compiler
  - Apps are compiled to *native code* **before** they're being used
    - At app install time
- Improves garbage collection (one pause instead of two)
  - Lower GC time - shouldn't be noticeable by user
- Optimize for Object Oriented Programs
- System performance improvements
  - Better battery life
  - Better memory footprint



What's the Difference?



Performance Boosting Thing



See “The ART Runtime”, Google I/O 2014

ART Can Be Smarter

```
setprop dalvik.vm.profiler 1
```

- ART can profile which methods are called most often
  - Therefore, which *need* to be compiled AOT
  - Profile data collected while app runs, used to determine if/when AOT compilation occurs

Do We Need To Run dex2oat?

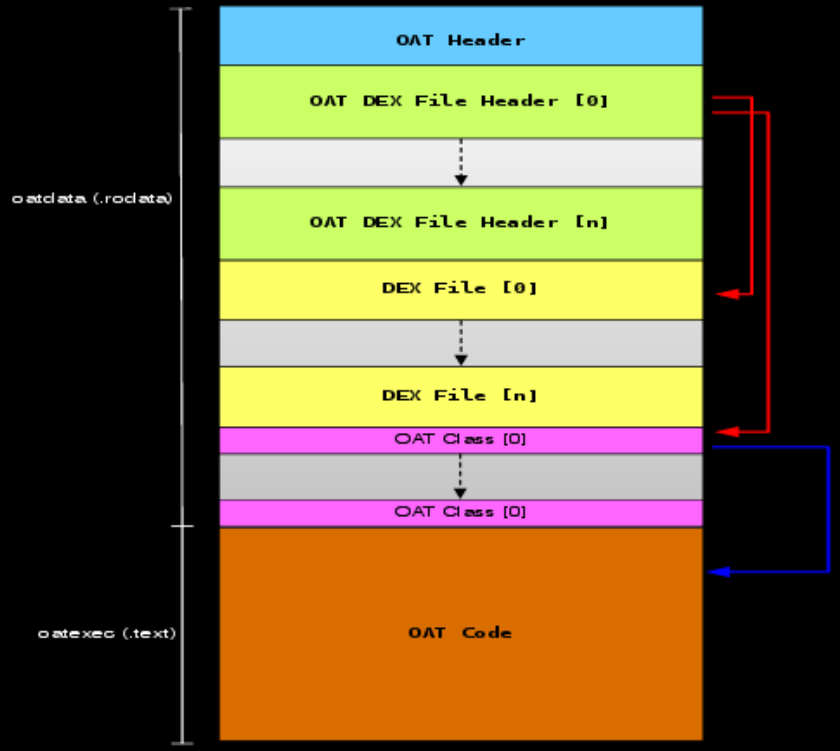
- Have methods comprising 90% of calls changed by >10%

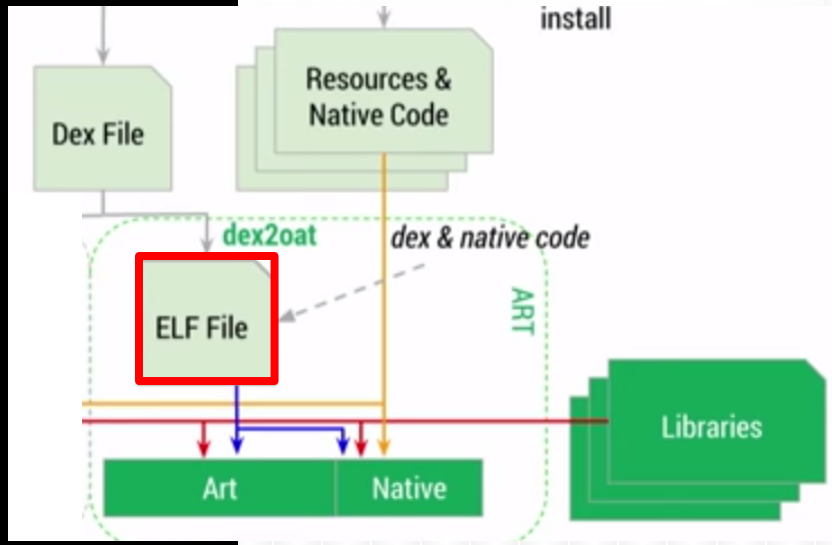
Then What Gets Compiled?

- Methods that get called 90% of the time

What's An oat?

OAT File





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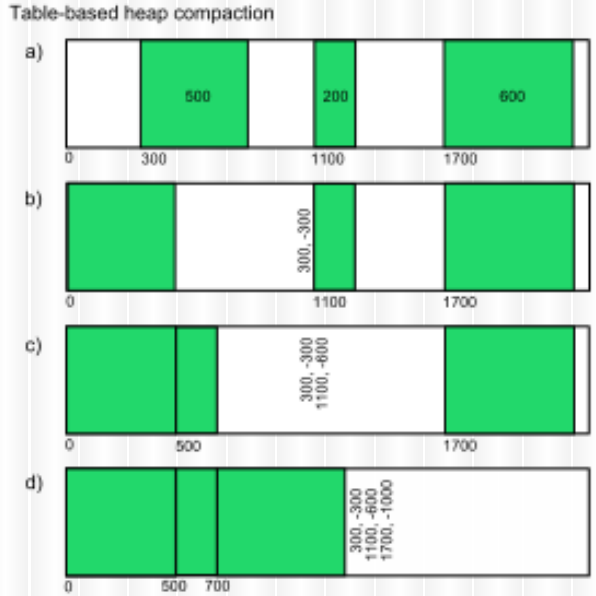
How About Garbage?

- GC has been improved in ART
  - One GC Pause (instead of two)
  - Parallel processing during second pause
  - Collector with shorter pause times specifically for short-lived objects
- Compacting GC is under development in AOSP



So that's it?

“Linux” Kernel

- Android runs a modified Linux kernel, currently based on v3.4
  - Contains some additional modules:
    - *Alarm, Ashmem, Binder,* Power Management, *Low Memory Killer,* Kernel Debugger, Logger
  - Open source because GPL

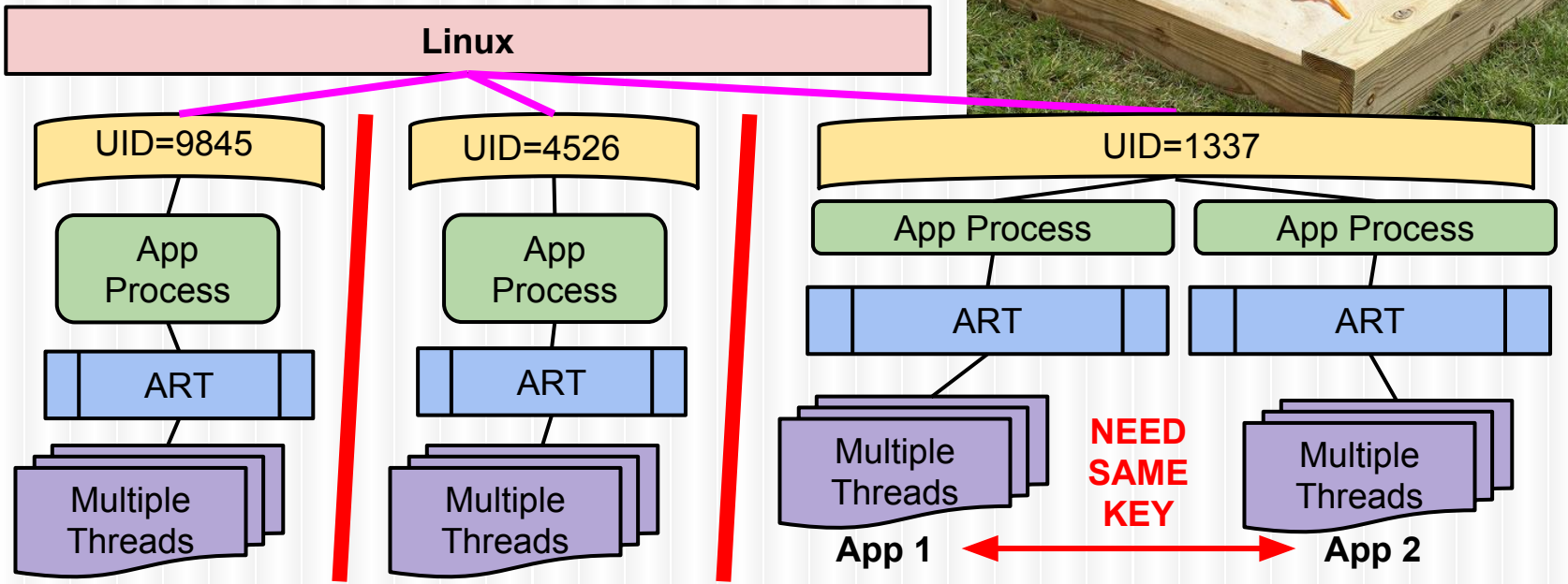
Android v. Linux Kernel

Some Differences (Not Exhaustive)

- Wake Locks & PowerManager
  - Applications can prevent the system from sleeping
  - Adds syscalls for creating, destroying, using wakelocks
- Improved memory management
  - Tailored for systems with small amounts of RAM
  - ASHMEM: named memory block, shared across processes
  - PMEM: allocate named physically contiguous memory
  - Low Memory Killer
    - Terminate unused processes when system has low memory

An App's Sandbox

- Each app on the system lives in its own sandbox



Bionic C Library

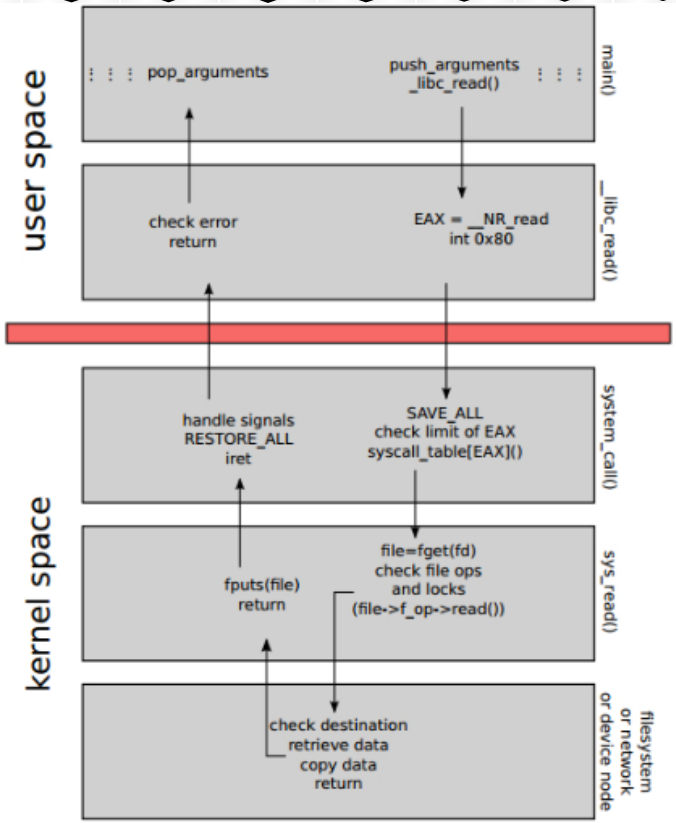
- Android does not use *glibc*
  - Uses *bionic*, an adaption of the BSD C Library optimized for embedded usage
  - Keep GPL out of userspace
- *bionic* is about half the size of *glibc* (at 200 kb)
- Fast *pthread* implementation
- Has some special Android parts built in

https://github.com/android/platform_bionic

Syscall List

Some C Sources

What Does A Syscall Look Like



How Is It Secure?

... Watch Out For Hackers

Security

- Android security is heavily dependent on Linux's multi-user features
- Because applications run in VMs, Dalvik controls code execution and resource accesses
  - Provides a security benefit, since the VM acts as a "gatekeeper" to the full system
  - All external requests are denied, unless the app requests the proper permission (enforced at runtime)
  - With new systems running ART, SELinux picks up the slack
- All app files are private to its assigned UID (at install time)
- Individual *components* can also be restricted
  - Only certain sources can start Activity, Service, or send broadcast to a receiver

Three Layers of Security

Divide Persistent Memory

- System partition is mounted as Read-Only
- Applications store data on its own R/W partition

Linux Discretionary Access Control (DAC)

- Each app's UID and GID can only access their files
- Only apps signed by the same author can run under the same UID
  - System sets up and enforces this

Android Permissions

- More granular access rights
- Mandatory Access Control (MAC) policy
- Requested at application install time, enforced at runtime
- Apps whitelist *Intents* they're allowed to receive

SELinux

- Linux Kernel security module, enforces Mandatory Access Control (MAC)
- Kernel enforces a set of “rules” on object accesses

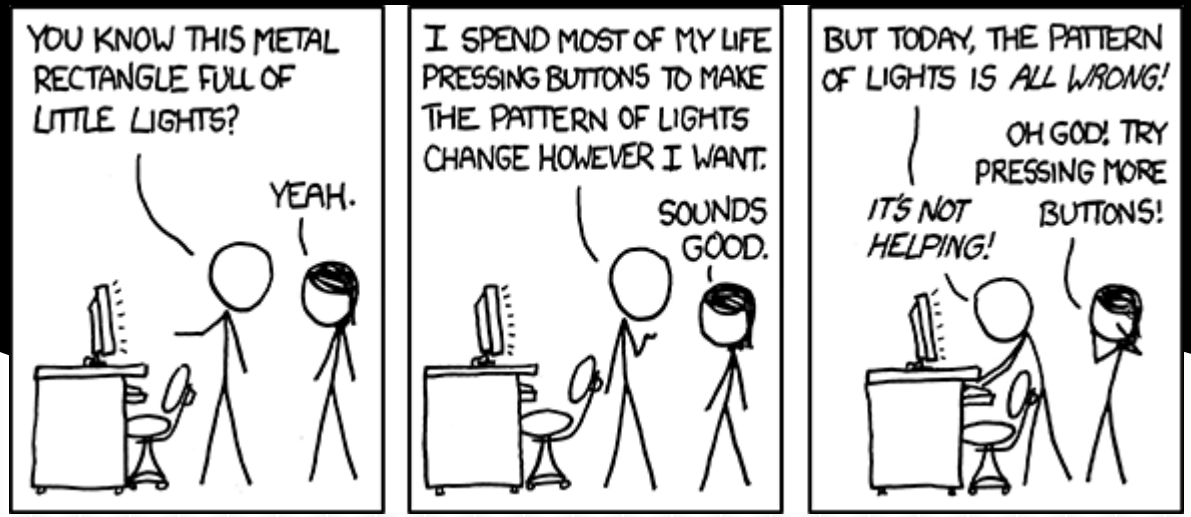
Benefits to Android:

SELinux can confine the privileged system daemons, limiting the damage they can cause

SELinux can monitor and control interactions between apps and the kernel & system resources

SELinux provides a centralized, system-wide security policy configuration

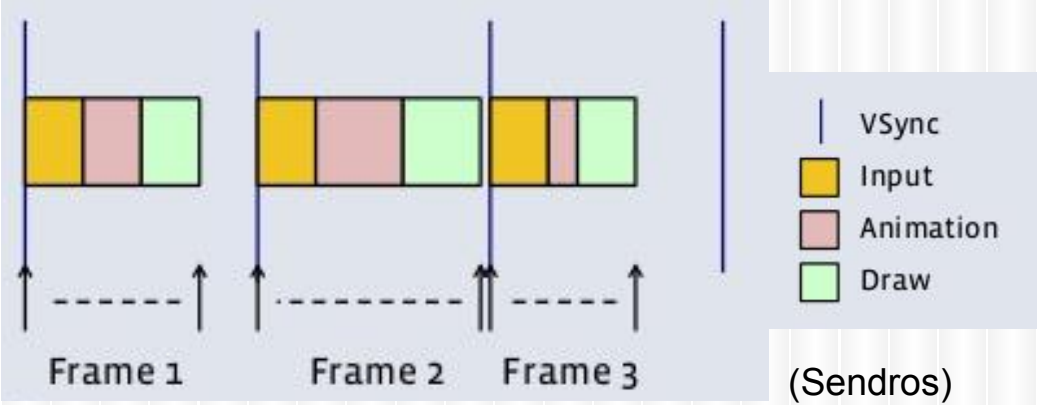
How Do I Get Pixels?



Layout Traversals

- Requirements: **notion of time** for *input*, and *rendering*

> "The choreographer receives timing pulses (such as vertical synchronization) from the display subsystem then schedules work to occur as part of rendering the next display frame."



(Sendros)

How It Works

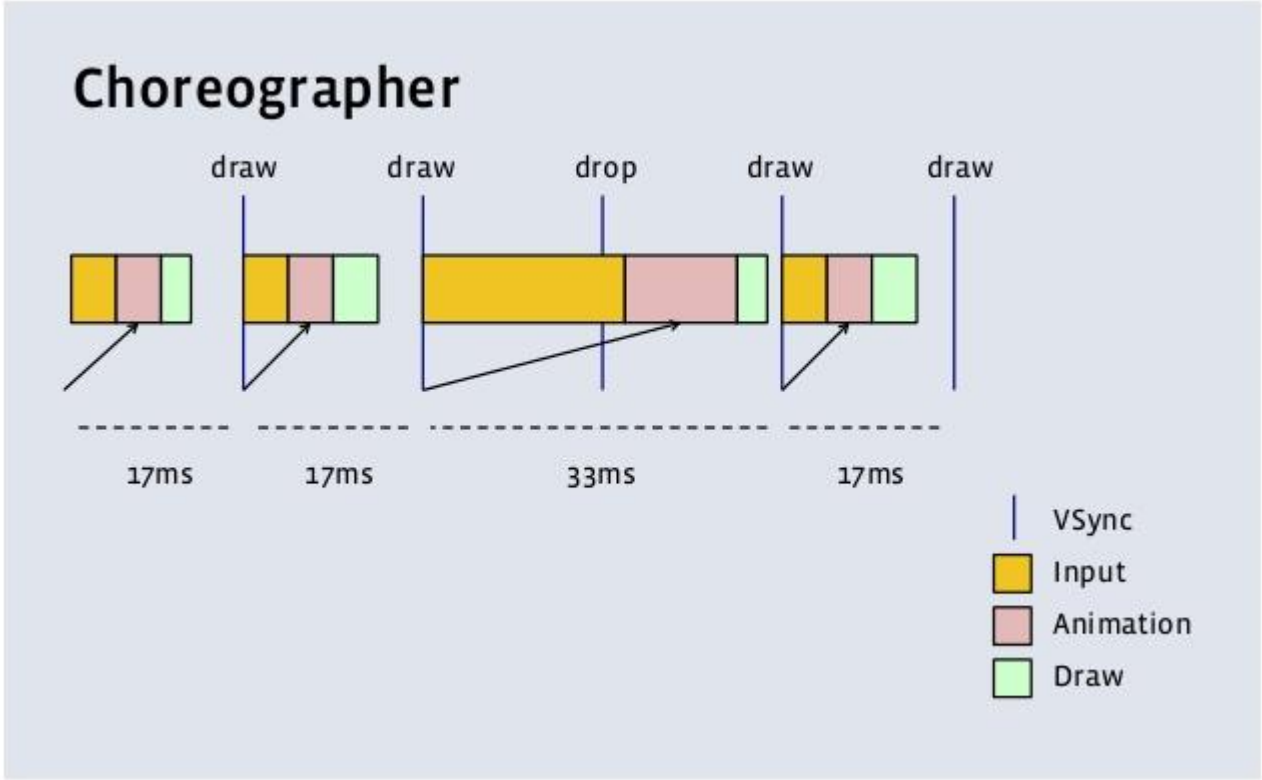
Choreographer.java

```
void doFrame(long frameTimeNanos, int frame) {
    final long startNanos;
    synchronized (mLock) {
        if (!mFrameScheduled) {
            return; // no work to do
        }

        startNanos = System.nanoTime();
        final long jitterNanos = startNanos - frameTimeNanos;
        if (jitterNanos >= mFrameIntervalNanos) {
            final long skippedFrames = jitterNanos / mFrameIntervalNanos;
            if (skippedFrames >= SKIPPED_FRAME_WARNING_LIMIT) {
                Log.i(TAG, "Skipped " + skippedFrames + " frames!  "
                        + "The application may be doing too much work on its main thread.");
            }
```

```
doCallbacks(Choreographer.CALLBACK_INPUT, frameTimeNanos);
doCallbacks(Choreographer.CALLBACK_ANIMATION, frameTimeNanos);
doCallbacks(Choreographer.CALLBACK_TRAVERSAL, frameTimeNanos);
```

When It All Goes Wrong



(Sendros)

So how can apps do IPC (Inter-Process Communication)?

IPC: Binders

Binders

- Binders provide access to functions and data between execution environments
- Android uses a custom implementation of *OpenBinder*, which extends the traditional IPC mechanisms
- Allow an app developer to call methods on *remote objects* as if they existed within *local objects*
- Binders are managed by an Android system service
  - Processes can *link-to-death* (get informed when a Binder is terminated)
- Each Binder is uniquely identifiable (can be used as security token)

Binder Kernel Driver

- Kernel Driver is written in C
- Has operations: *open*, *mmap*, *release*, *poll*, *ioctl*
- *ioctl* syscall is the main point of interface with higher layers
  - Takes a series of flags to define operations

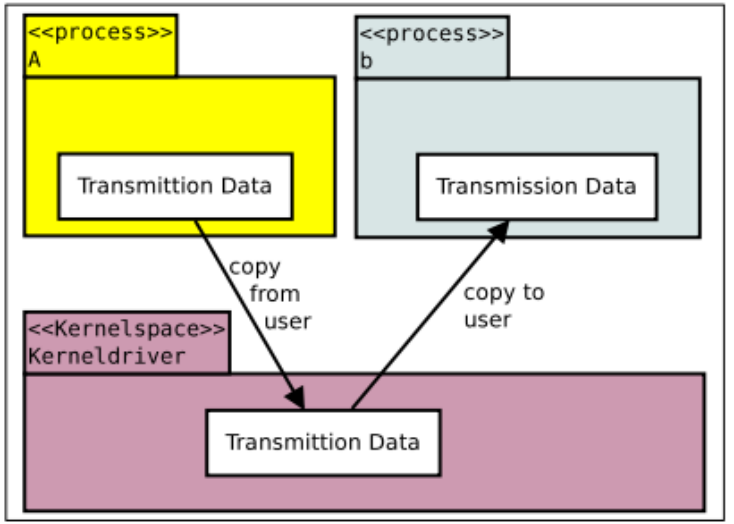
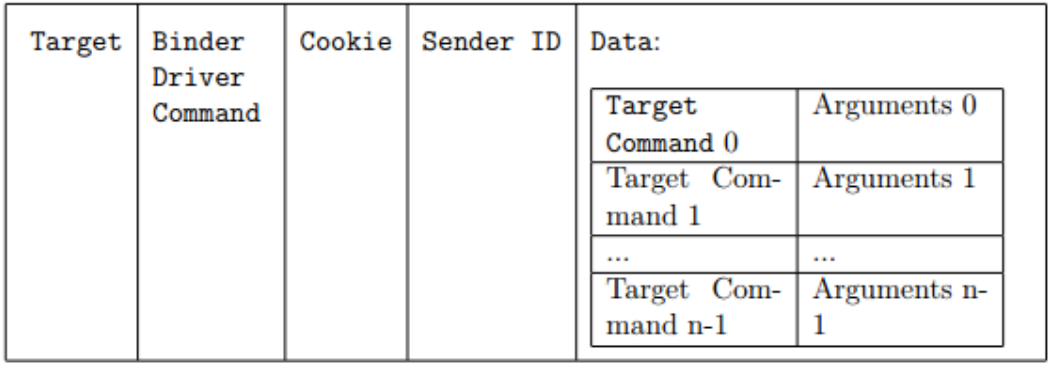


Figure 5.4.: Data Transaciton

Figure from Schreiber's paper

Binder Middleware

- Middleware written in C++
- Implements user space functionality for Binder framework
- Allow transformation of object for transmission
- Contains a JNI Wrapper so Java classes can use it



Target	Binder Driver Command	Cookie	Sender ID	Data:

Target Command 0	Arguments 0
Target Command 1	Arguments 1
...	...
Target Command n-1	Arguments n-1

Figure 4.3.: Transmission Data

Figure from Schreiber's paper

Binder API

- Android system provides a Java API for interacting with Binders
- Wraps the functionality of the middleware layer so that apps can communicate with Binders
- Introduces some additional abilities into the Binder framework
  - Namely intents

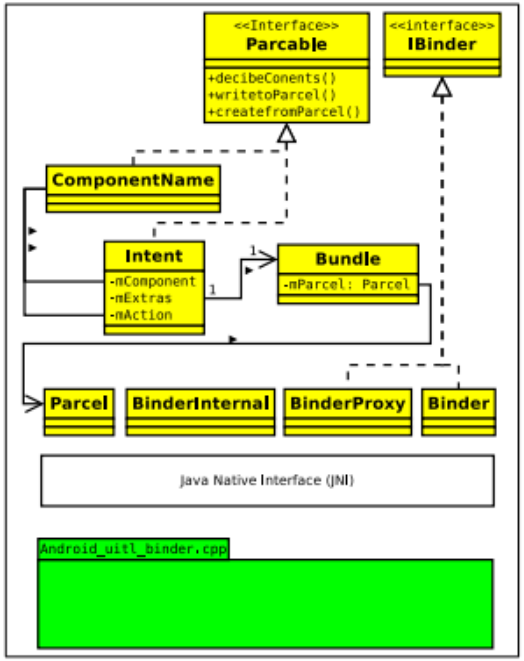


Figure 5.2.: Java System

Figure from Schreiber's paper

Questions

This presentation can be found at
http://phil-lopreiato.github.io/droidsys/

References

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