Programming with Android: System Architecture

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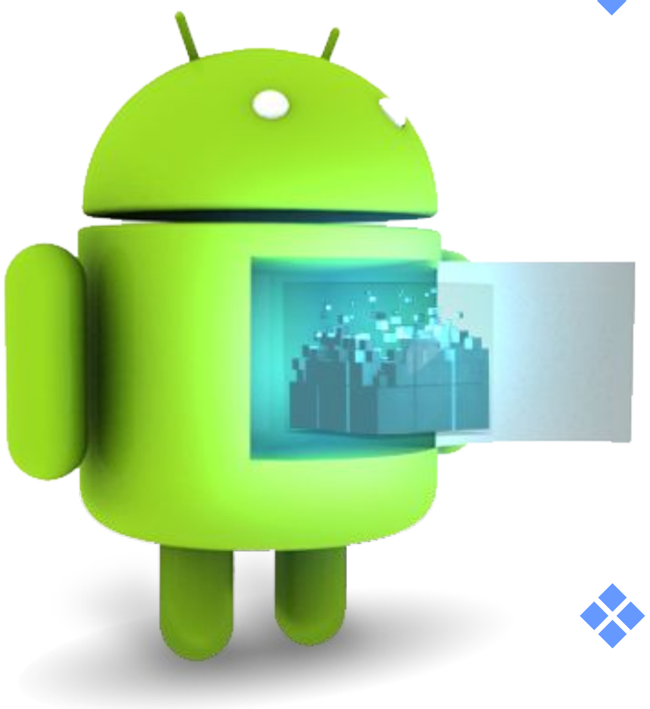
Outline

- Android Architecture: An **Overview**
- Android Java **Virtual Machine**
- Android Components: **Activities**
- Android Components: **Intents**
- Android Components: **Services**
- Android Components: **Content Providers**
- Android Application **Distribution** and **Markets**

Android ... What?



- **Android** is a *Linux-based* platform for *mobile touchscreen devices* …
  - *Operating System*
  - *Middleware*
  - *Applications*
  - *Software Development Kit* (**SDK**)
- Which kind of **mobile devices** … (examples)

SMARTPHONES

TABLETS

EREADERS

ANDROID TV

GOOGLE GLASSES

?

Android ... What?

ANDROID MICROWAVE

SMART FRIDGE

SMARTPHONES

TABLETS

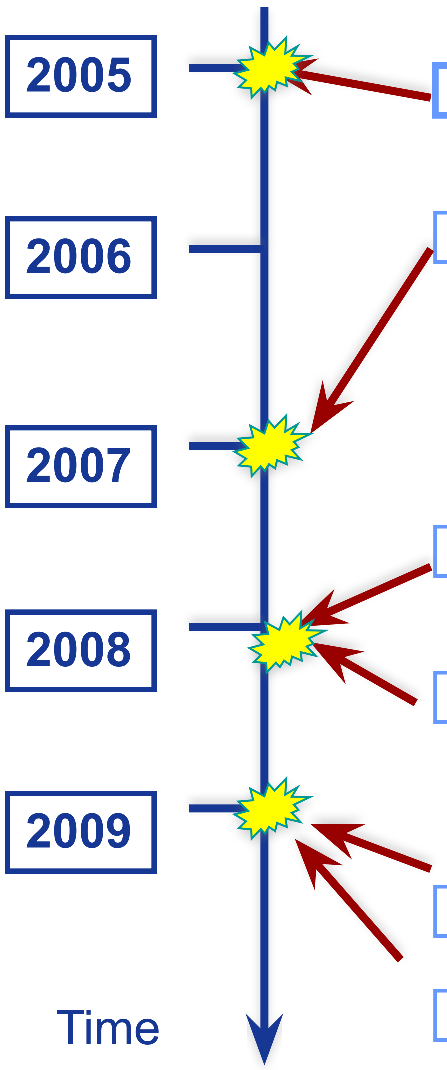
EREADERS

ANDROID TV

GOOGLE GLASSES

?

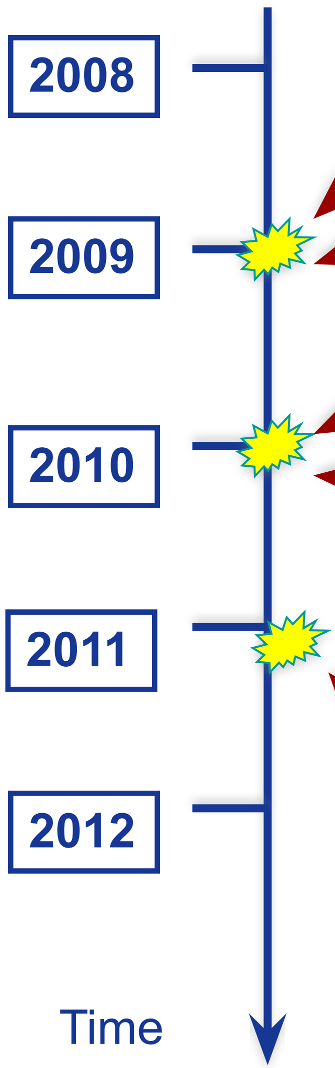
Android … When?



- **Google** buys Android from the **Android Inc.**
- Open Handset Alliance (**OHA**) created for open standards for mobile devices. Partners of OHA: Google, Motorola, Samsung, Vodafone, T-Mobile, etc.
- Android 1.0 Released
- The first Android smartphone: G1 HTC-Dream

  Few Google apps integrated directly with the OS
- Android **1.1** Released
- Android **1.5 (CupCake)** Released
  - External Apps
  - On- screen keyboard

Android … When?



- Android **1.6 (Donut)** Released
  - Different screen sizes
  - CDMA
- Android **2.0 (Eclair)** Released
  - speech-to-text
  - pinch-to-zoom

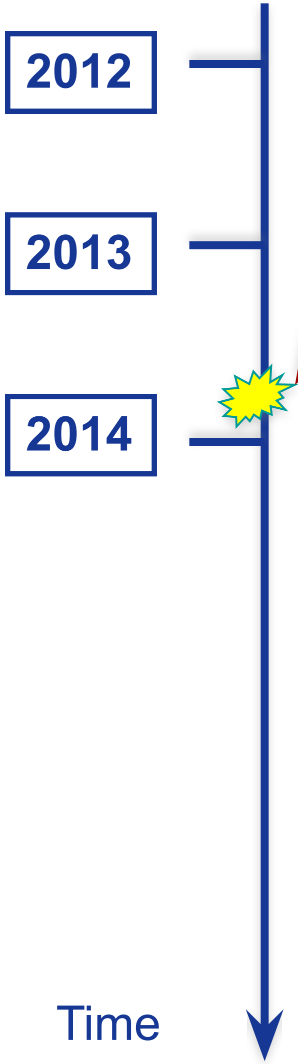
- Android **2.2 (Froyo)** Released
  - bottom dock
  - voice actions
- Android **2.3 (Gingerbread)** Released
  - The “design release”
- Android **3.0 (Honeycomb)** Released

(First version for devices with larger screens such as tablets)

- Android **4.0 (Ice-Cream Sandwich)** Released. (It merges the 3.x tab centric design and the v2.x phone based design into a single version.)

- swiping for dismissing
- card appearance

Android … When?



- Android **4.1** (**Jelly Bean**) Released
- Android **4.4** (**Kitkat**) Released

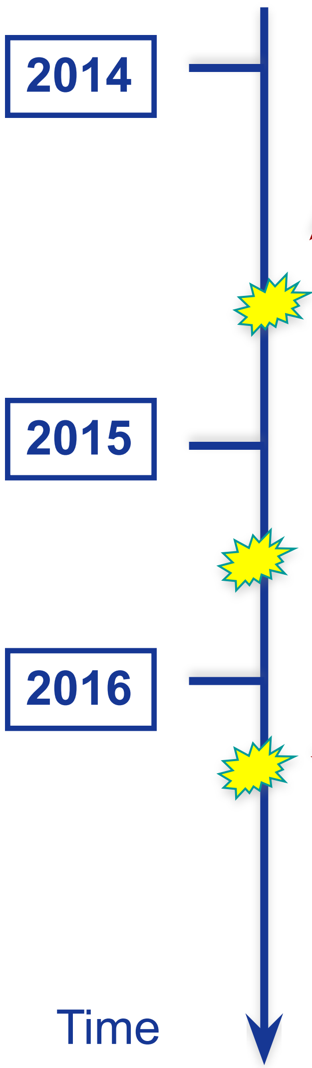
OK GOOGLE!
(but only when the screen is on…)

  - Wireless printing capability
  - Ability for applications to use "immersive mode”
  - Performance optimization
  - New experimental runtime virtual machine, ART…

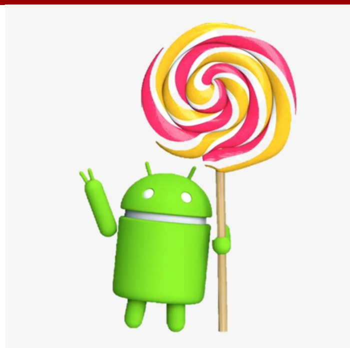
API Level 19 (Android 4.4):

- Support to new embedded sensors (e.g. STEP_DETECTOR)
- Adaptive video playback functionalities
- Read and write SMS and MMS messages (managing default text messaging client)

Android … When?



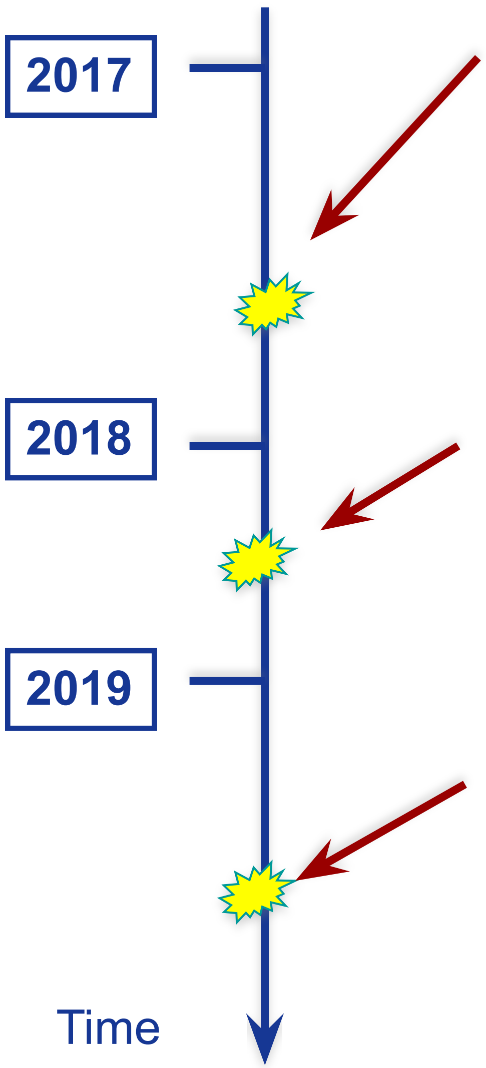
- Android **5.0** (**Lollipop**) Released
  - Material Design!
  - OK Google (the true one)
  - Lots of bugs...



- Android **6.0** (**Marshmallow**) Released
  - Fingerprint
  - USB-C
  - Runtime Permissions!!!

- Android **7.0** (**Nougat)** Released
  - Google Assistant
  - Split screen, data saver...
  - ...Pixel!!!

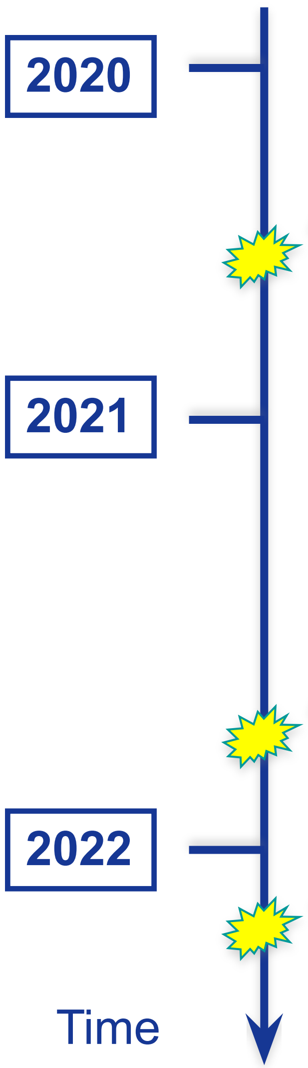
Android … When?



- Android **8.0** (**Oreo**) Released
  - Notification Channels and Snooze
  - picture-in-picture
  - Android Apps on Chromebooks
- Android **9.0** (**Pie**) Released
  - Brightness & Battery Management
  - Hybrid gestures system
  - Privacy & Security
- Android **10.0** (**Q**) Released
  - Expanded permission
  - swipe-driven
  - ...No more sweets!!!

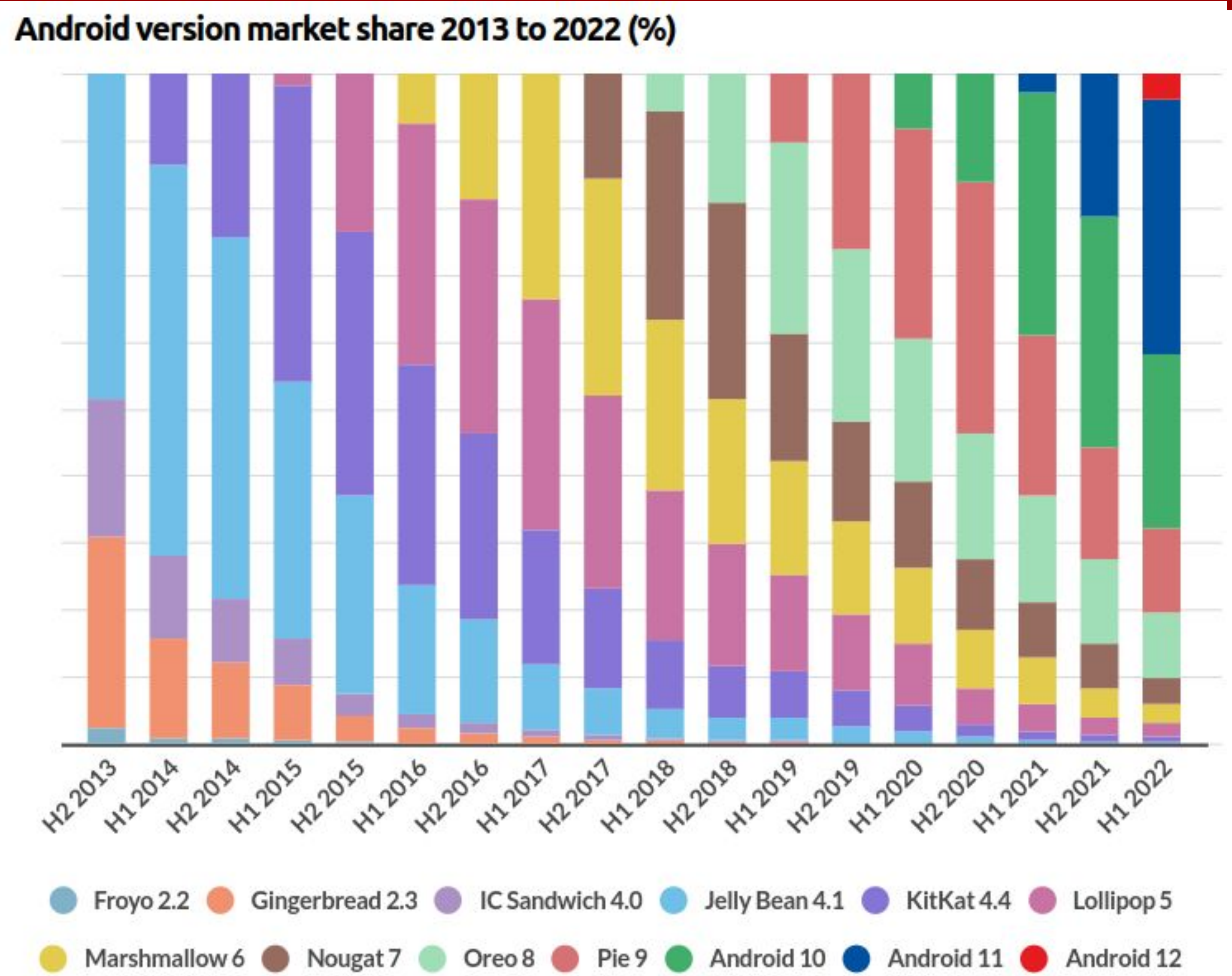
android

Android ... When?

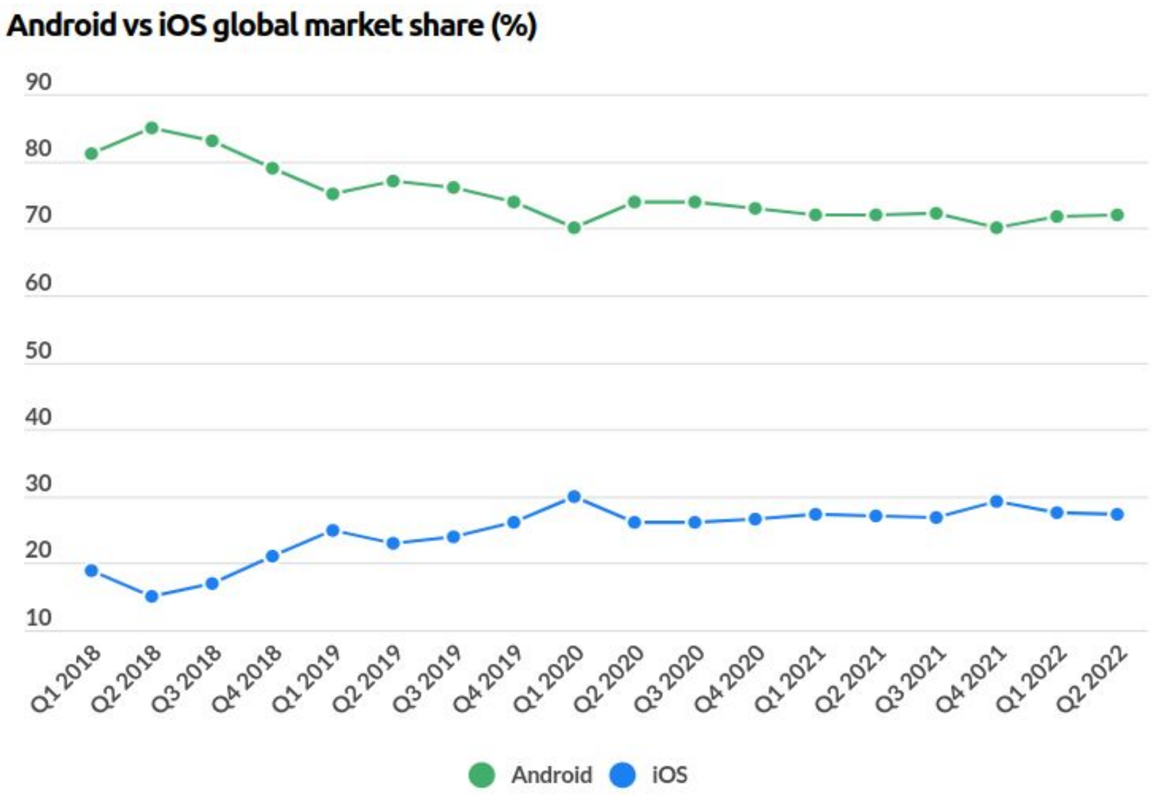


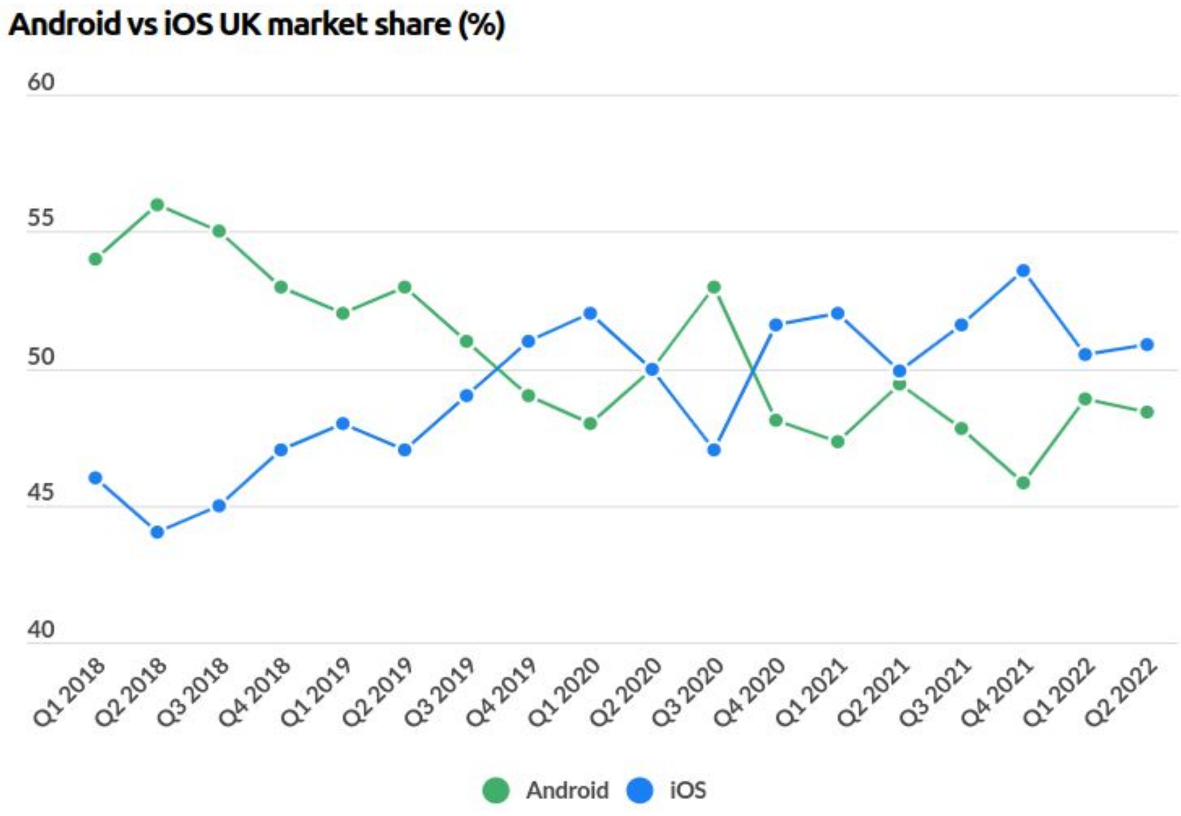
- In February Android **11.0** (**R**) Released
  - One-time permissions for temporary features (location, microphone and camera)
  - Exposure notification and privacy fixes
- In October Android **12.0** (**S**) Released
  - Location can be blurred even if required
  - Mostly optimizations and graphical improvements
- Android **13.0** (**Tiramisu**) Released
  - per-app language personalization
  - permission for notification
  - gallery restricted access to apps

Android … market share

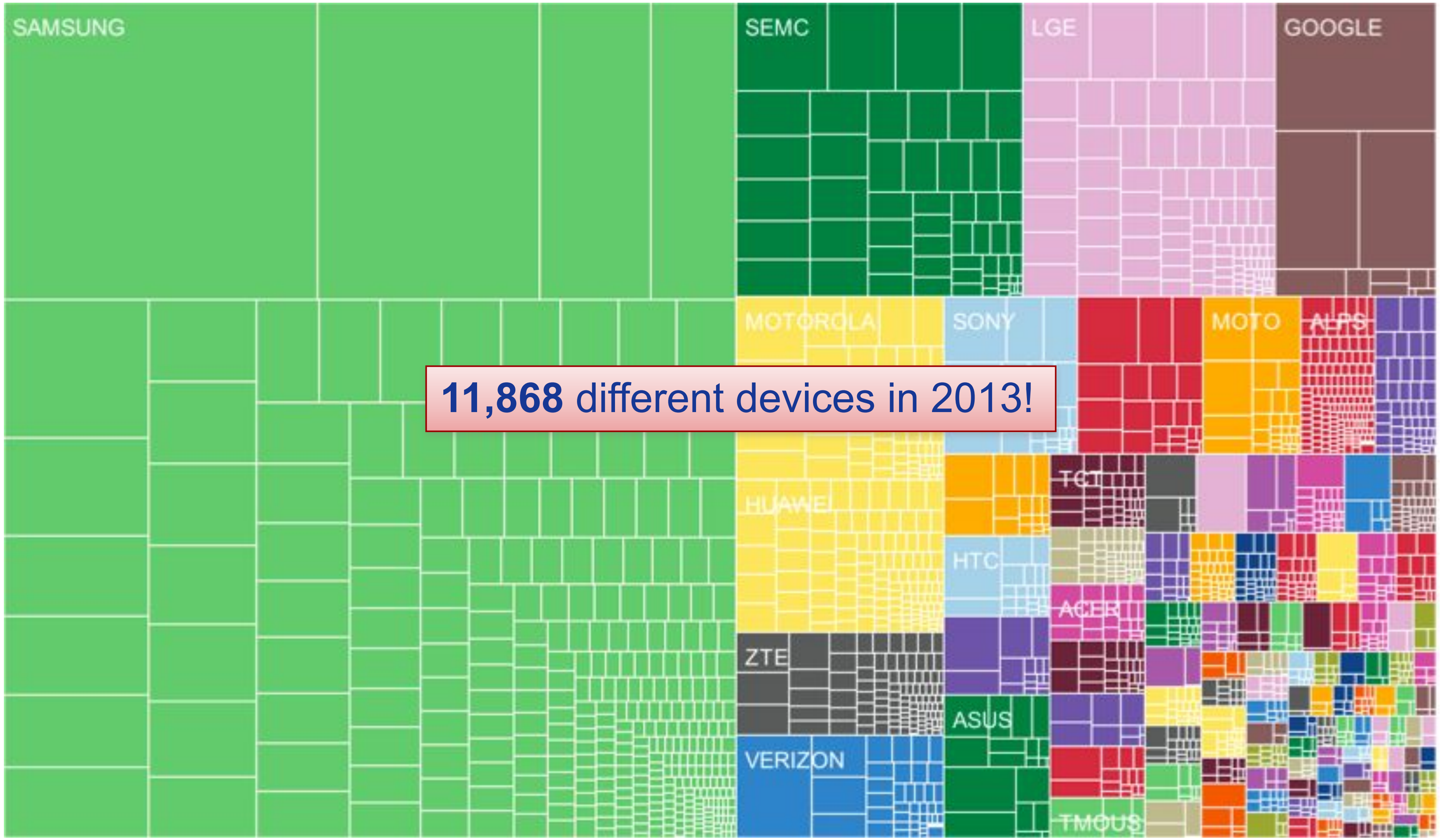


Android … heterogeneity





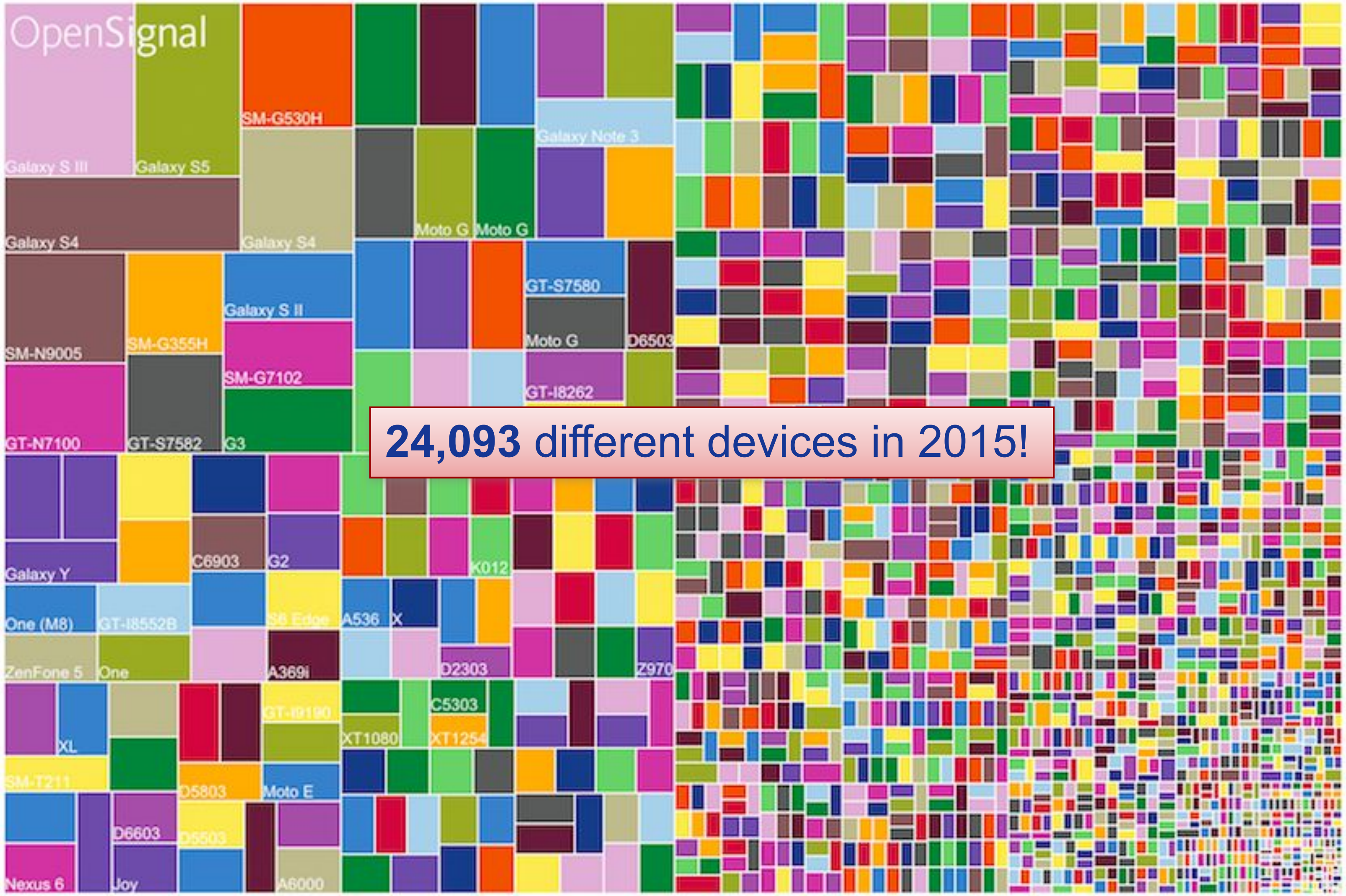
Android … heterogeneity



11,868 different devices in 2013!

http://opensignal.com/reports/fragmentation-2013/

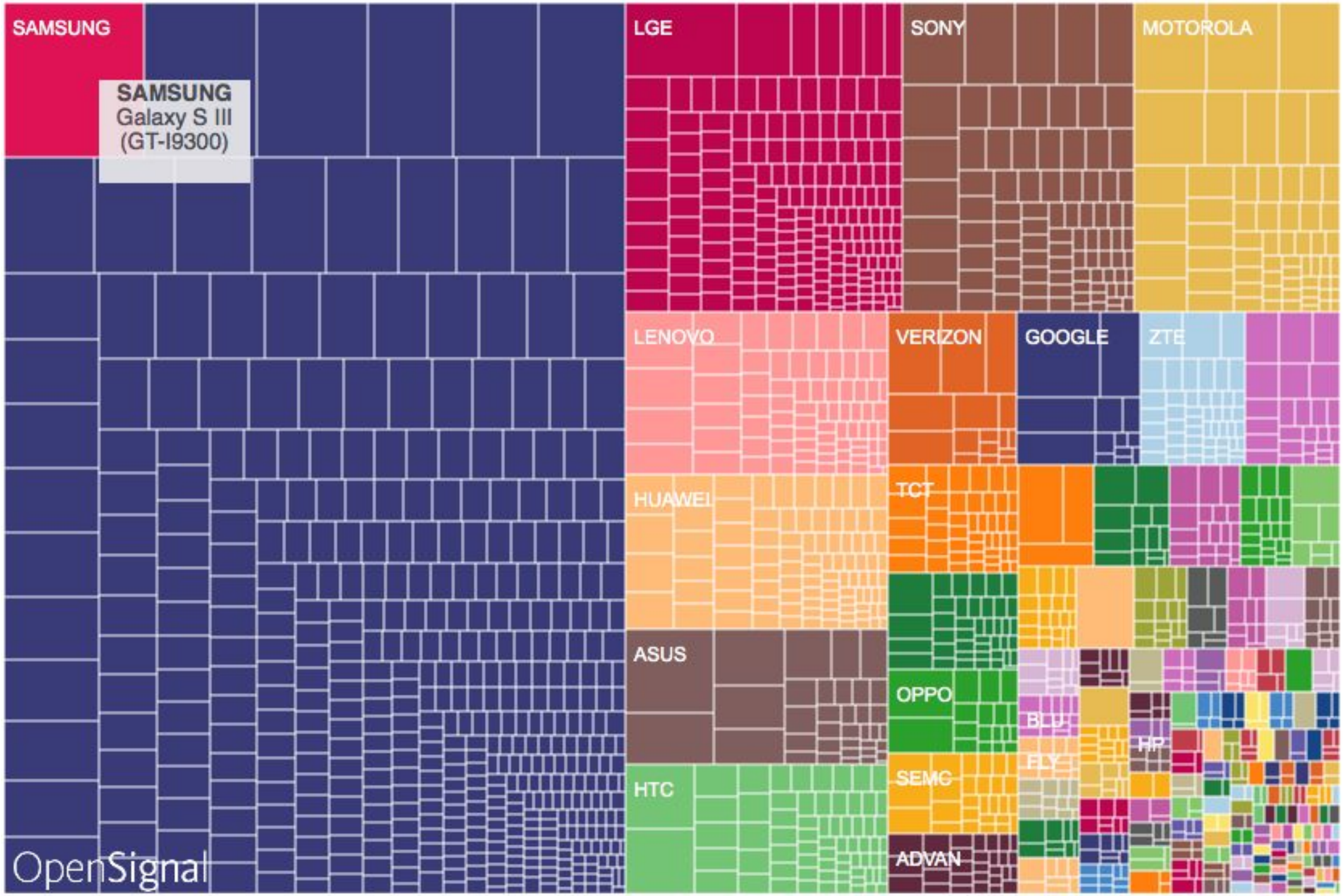
Android … heterogeneity



24,093 different devices in 2015!

http://opensignal.com/reports/2015/08/android-fragmentation/

Android ... heterogeneity



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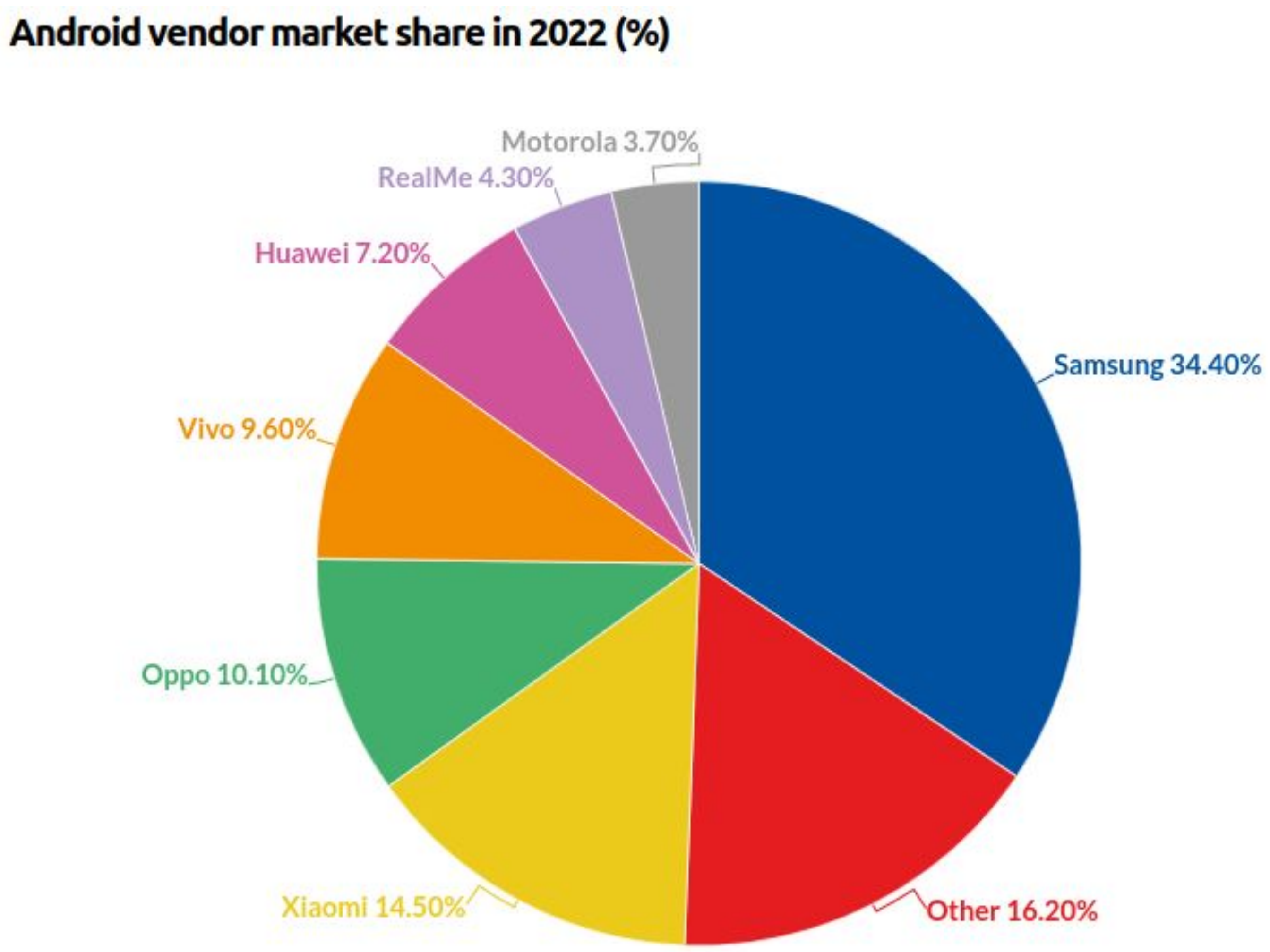
Android … heterogeneity



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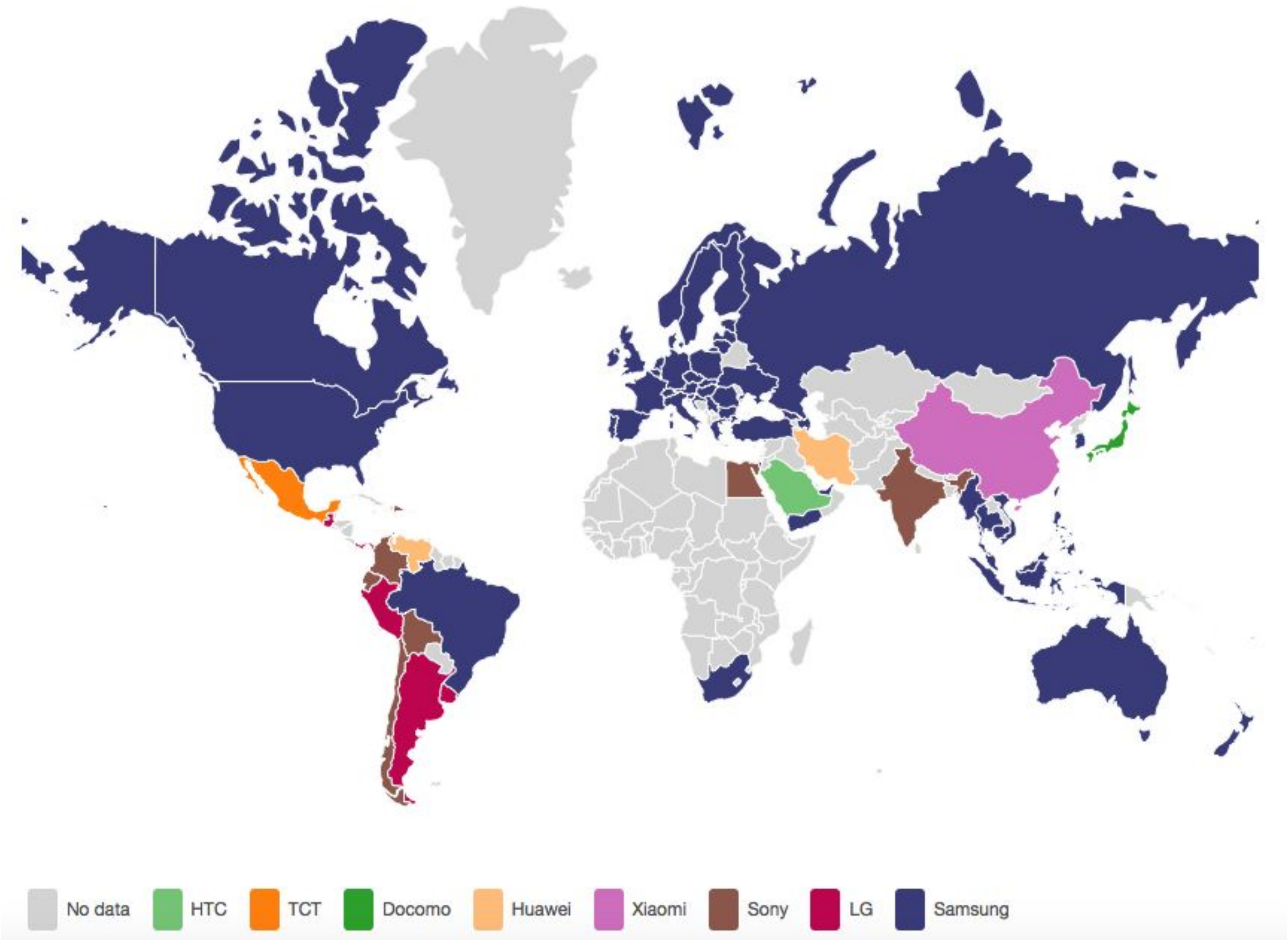
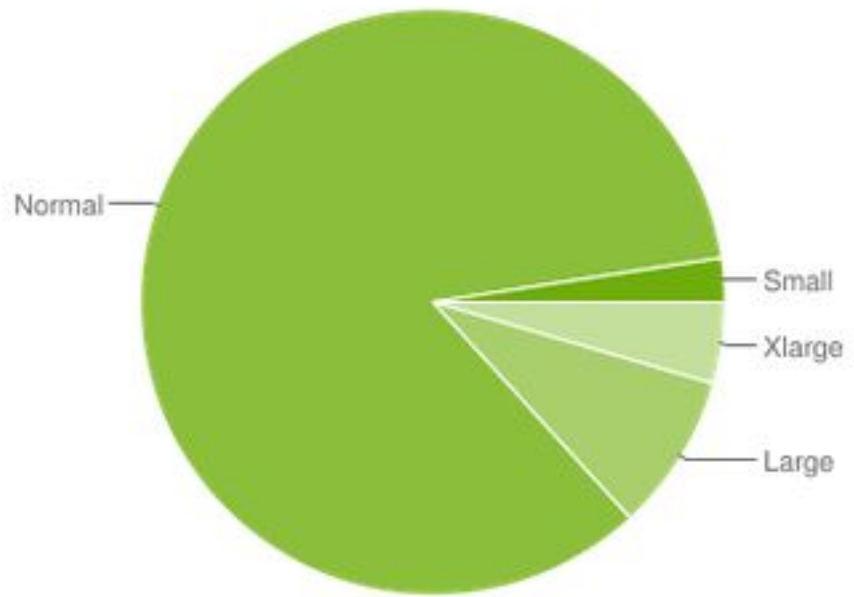
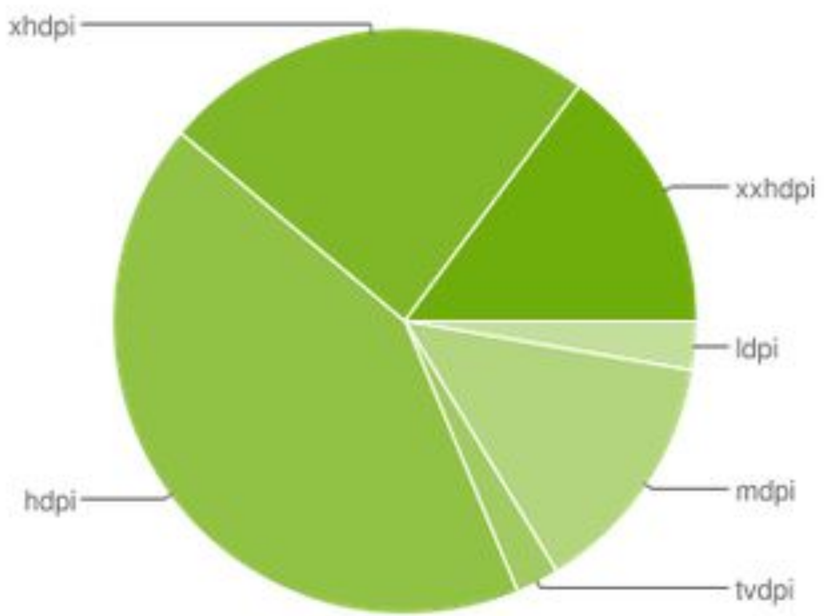


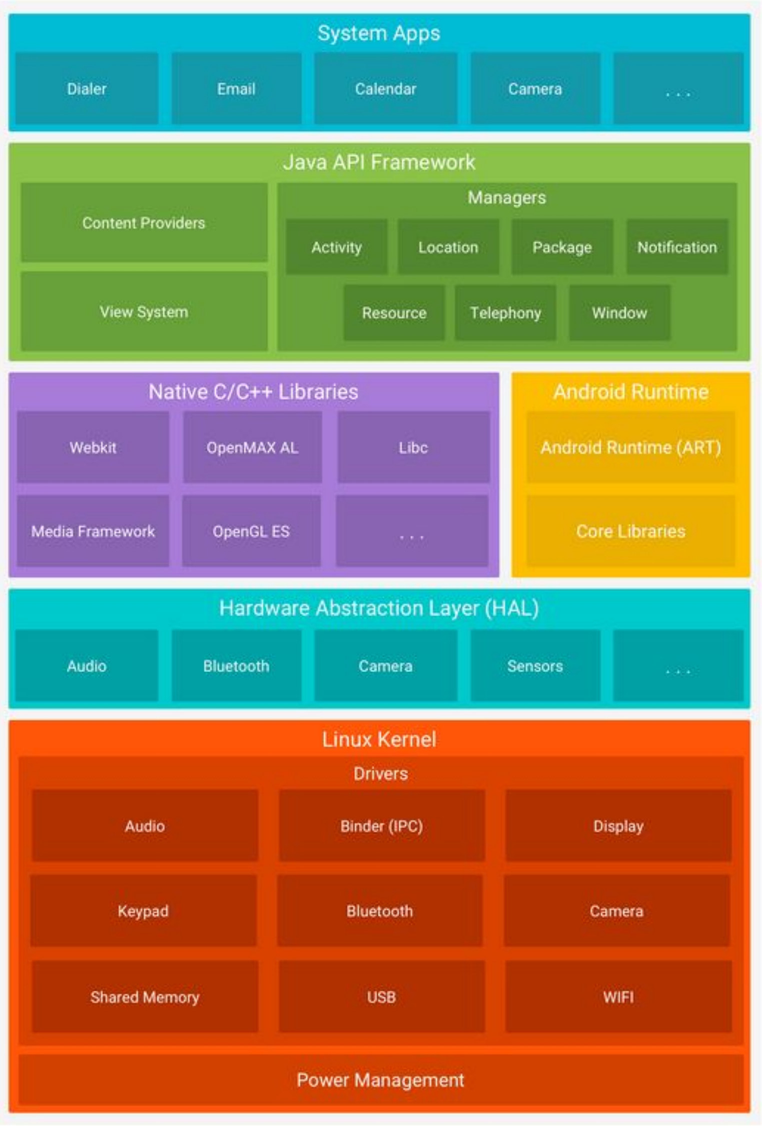
Android … heterogeneity

	ldpi	mdpi	tvdpi	hdpi	xhdpi	xxhdpi	Total
Small	2.4%						2.4%
Normal		5.1%	0.1%	41.5%	22.9%	14.8%	84.4%
Large	0.3%	5.0%	2.3%	0.6%	0.5%		8.7%
Xlarge		3.5%		0.3%	0.7%		4.5%
Total	2.7%	13.6%	2.4%	42.4%	24.1%	14.8%	

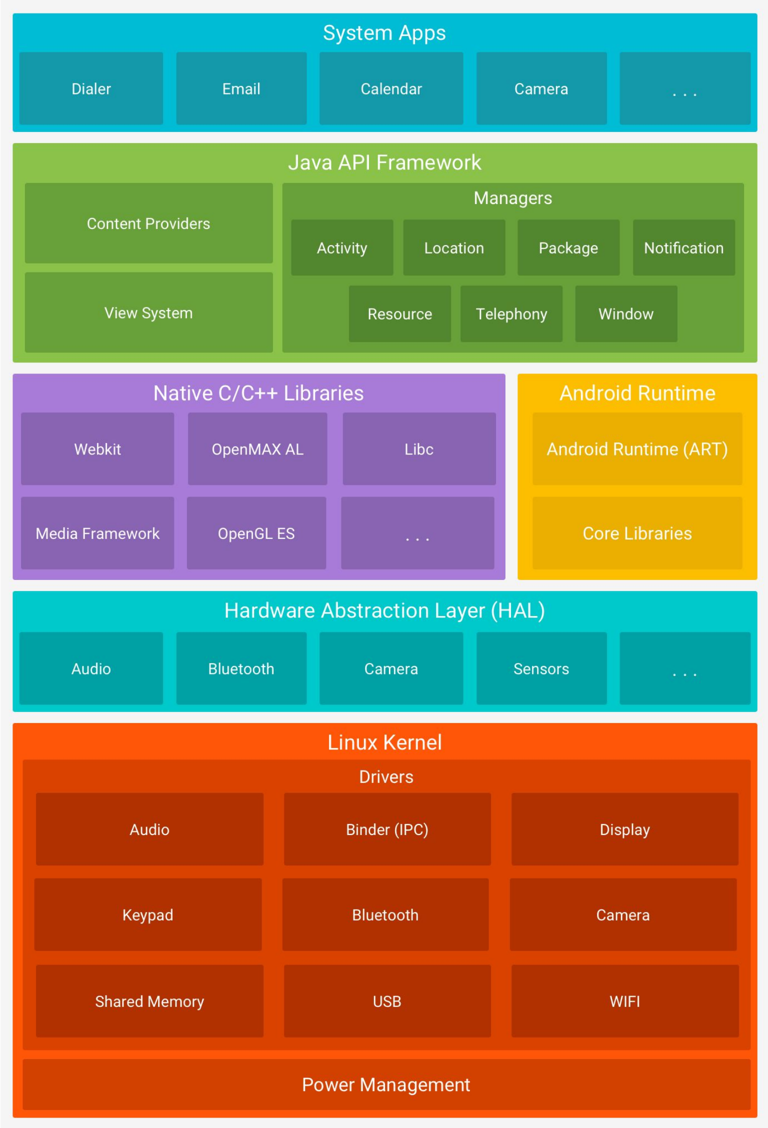




The Android Architecture



The Android **Architecture**



Built on top of **Linux kernel**

Advantages:

- **Portability** (i.e. easy to compile on different hardware architectures)
- **Security** (e.g. secure multi-process environment)
- **Power** Management
- **Android Runtime (ART)** relies on the kernel for threads and memory management
- **Manufacturers** build drivers on top of a reliable kernel

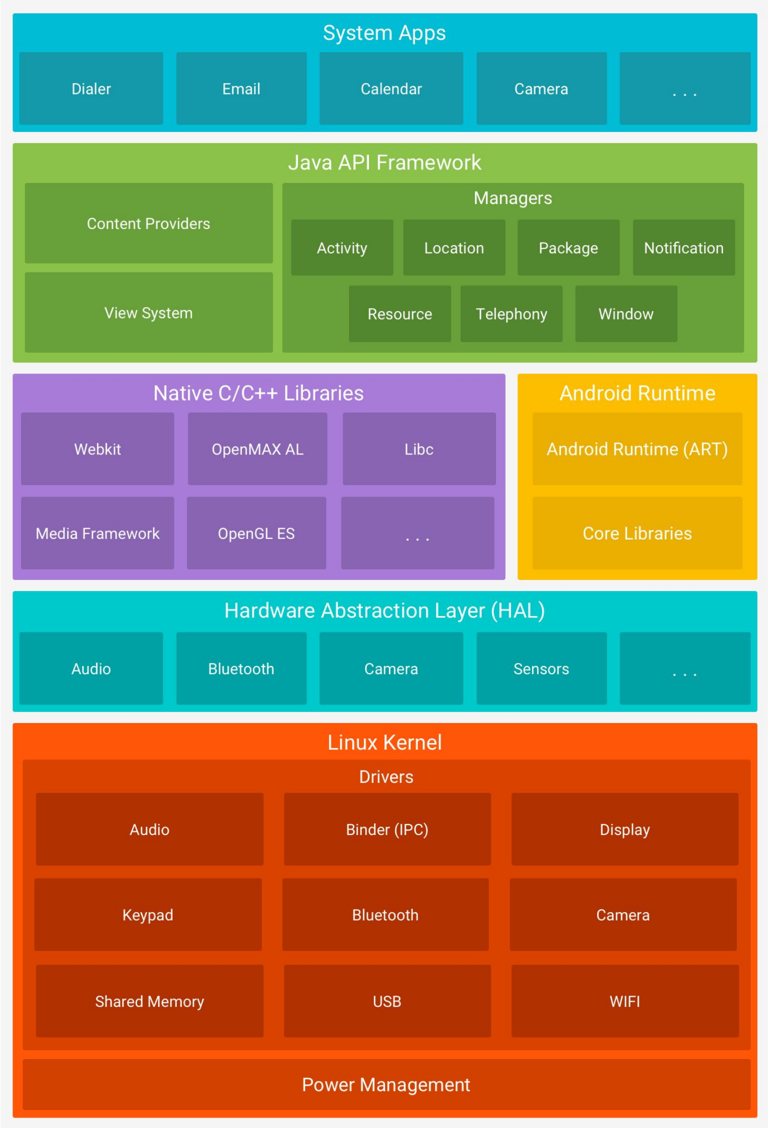
Kernel Security

- User based permission model
- Processes are isolated
- Inter-process communication (IPC)
- Resources are protected from other processes
- Each application has its own User ID (UID)
- Application Sandbox (process isolation)
- Verified boot

Kernel **Security**

- Android 5.0:
  - Mandatory Access Control (MAC) between system and apps, all third-party apps ran within the same SELinux context so inter-app isolation was primarily enforced by UID-based sandbox.
- Android 8.0:
  - limited system calls available to user-level apps
- Android 9.0:
  - all non-privileged apps with SDK version >= 28 must run in individual SELinux sandboxes, providing MAC on a per-app basis
- Android 10:
  - apps have a limited raw view of the filesystem, with no direct access to paths like /sdcard/DCIM. However, apps retain full raw access to their package-specific paths

The Android **Architecture**



HAL

Advantages:

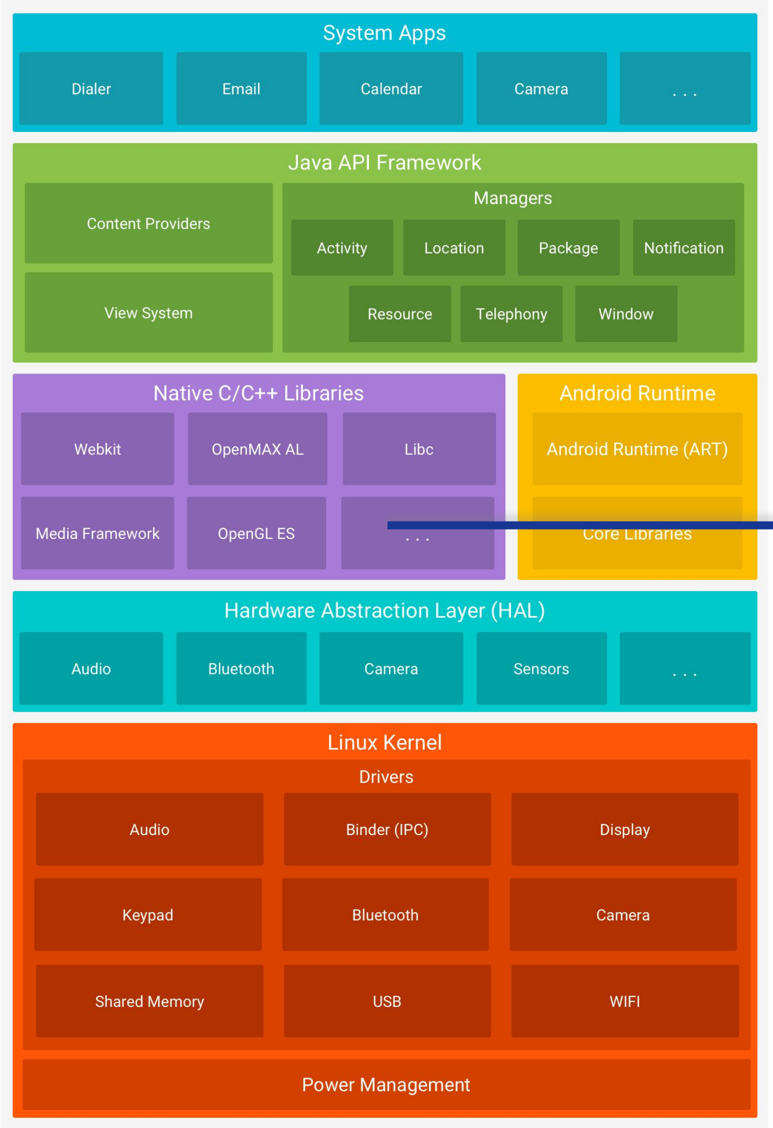
- **Shadows** the real device
- **Manages** different devices of the same type
- **Standard interfaces** to expose lower level capabilities to higher level APIs

HAL

- **Standard interface** that manufacturers have to implement – Android is **agnostic** about lower level driver implementations

- Application developers rely on **common APIs**
  - **Depending on the hardware**, **appropriate libraries** are loaded

The Android Architecture



Native **Libraries** (C/C++ code)

- **Graphics** (Surface Manager)
- **Multimedia** (Media Framework)
- **Database DBMS** (SQLite)
- **Font Management** (FreeType)
- **WebKit**
- **C libraries** (Bionic)
- **….**

Android NDK

- Enables **C/C++** coding

- Useful if you want to **interact/extend** with some native libraries
  - **Performance**
  - **Reuse** your C/C++ libraries

- **JAVA APIs** are provided for most used libraries

- NDK can be installed as an **Android Studio plugin**

```
public class myNDKActivity extends Activity {
        public native void doNothing():
}
```

Android NDK

the NDK can be useful for cases in which you need to do one or more of the following:

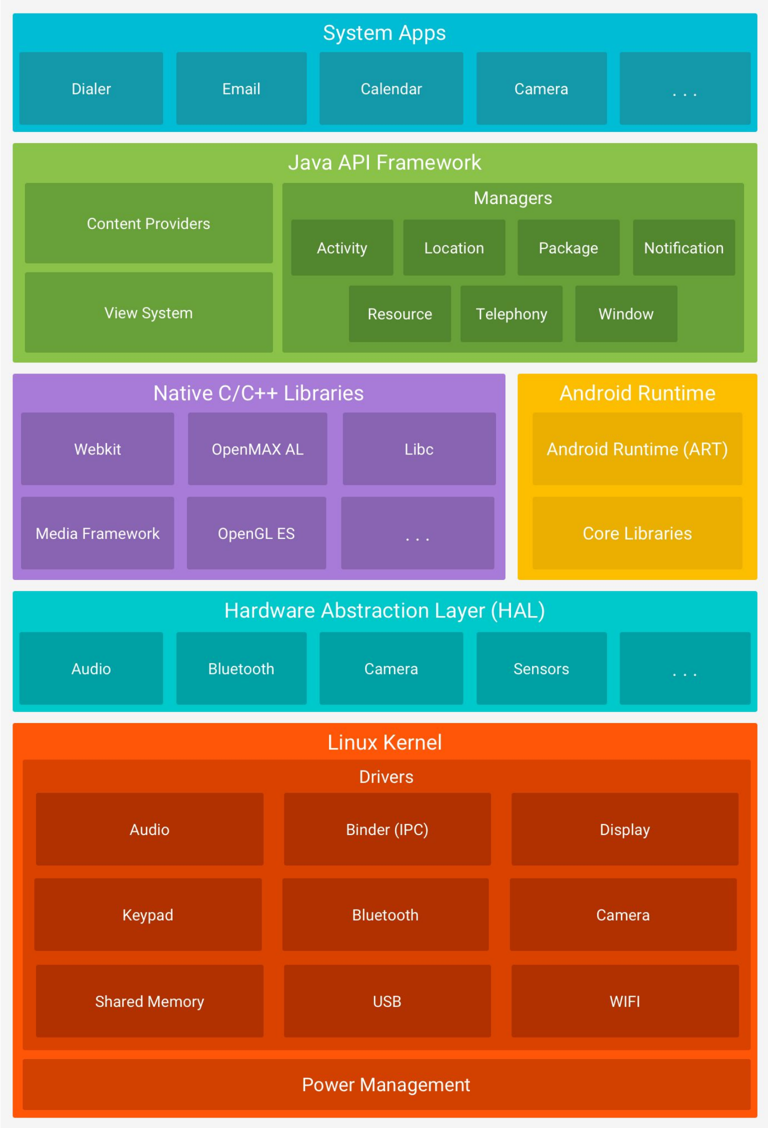
- Squeeze extra performance out of a device to achieve low latency or run computationally intensive applications, such as games or physics simulations.
- Reuse your own or other developers' C or C++ libraries.

Usage:

- Use the NDK to compile C and C++ code into a native library and package it into your APK using Gradle.
- Your Java code can then call functions in your native library through the Java Native Interface (JNI) framework.

https://developer.android.com/ndk/guides

The Android Architecture

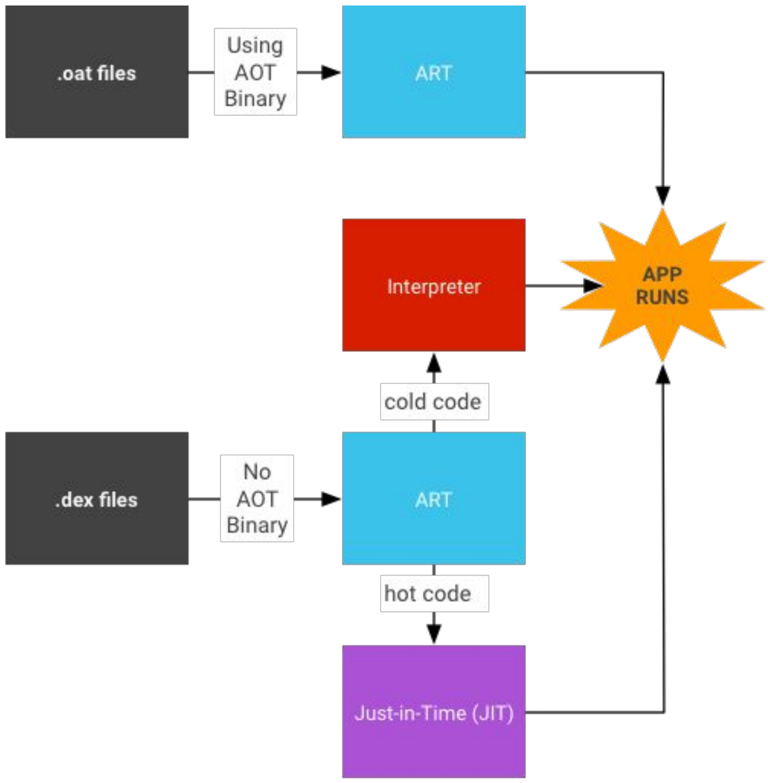


ART (VM)

- **Novel** Java Virtual Machine implementation (not using the Oracle JVM)
- **Optimized** for memory-constrained devices
- **Faster** than Oracle JVM
- **ART** optional from 4.4, mandatory from 5.0

ART

- Starting from Android 5.0, ART is used instead of Dalvik
  - Several enhancements such as stack size, error handling, AOT...
  - more at https://source.android.com/docs/core/runtime/jit-compiler?hl=en
- Designed to run multiple VM on low end devices
- Runs DEX bytecode
- Ahead-of-time (AOT) and Just-in-time (JIT) compilation
  - AOT: At install time, ART compiles APPs using an on-device tool called dex2oat
    →Code compiled at installation
  - JIT: code profiling
    →Code partially interpreted when compiled not available
- Optimized Garbage collection



ART

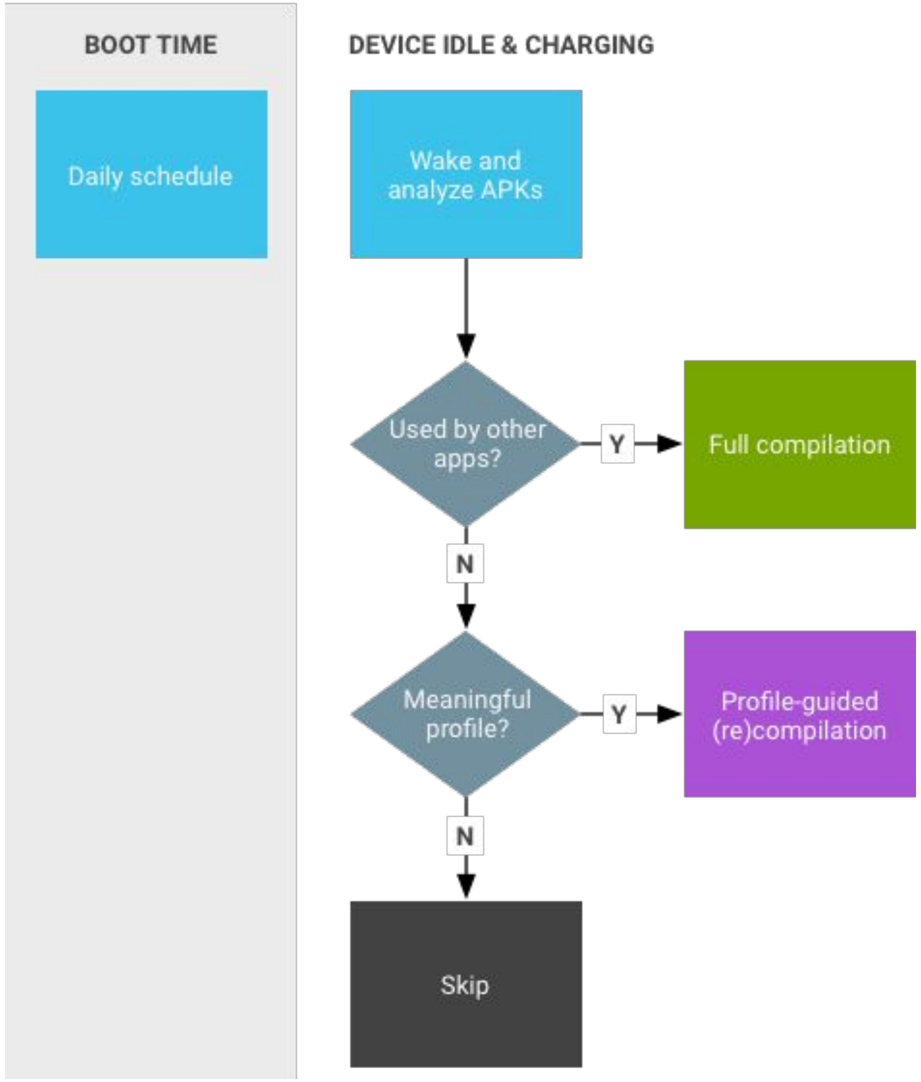
There is a lot more to it nowadays.

DEX files need to be interpreted by the VM (or JIT compiled).

OAT files are already “machine level” code, so more similar to pure compilation.

We have a daemon that looks for uncompiled apps when the device is idle and compiles them through.

Compiled apps may be recompiled sometimes by JIT if the conditions have changed…



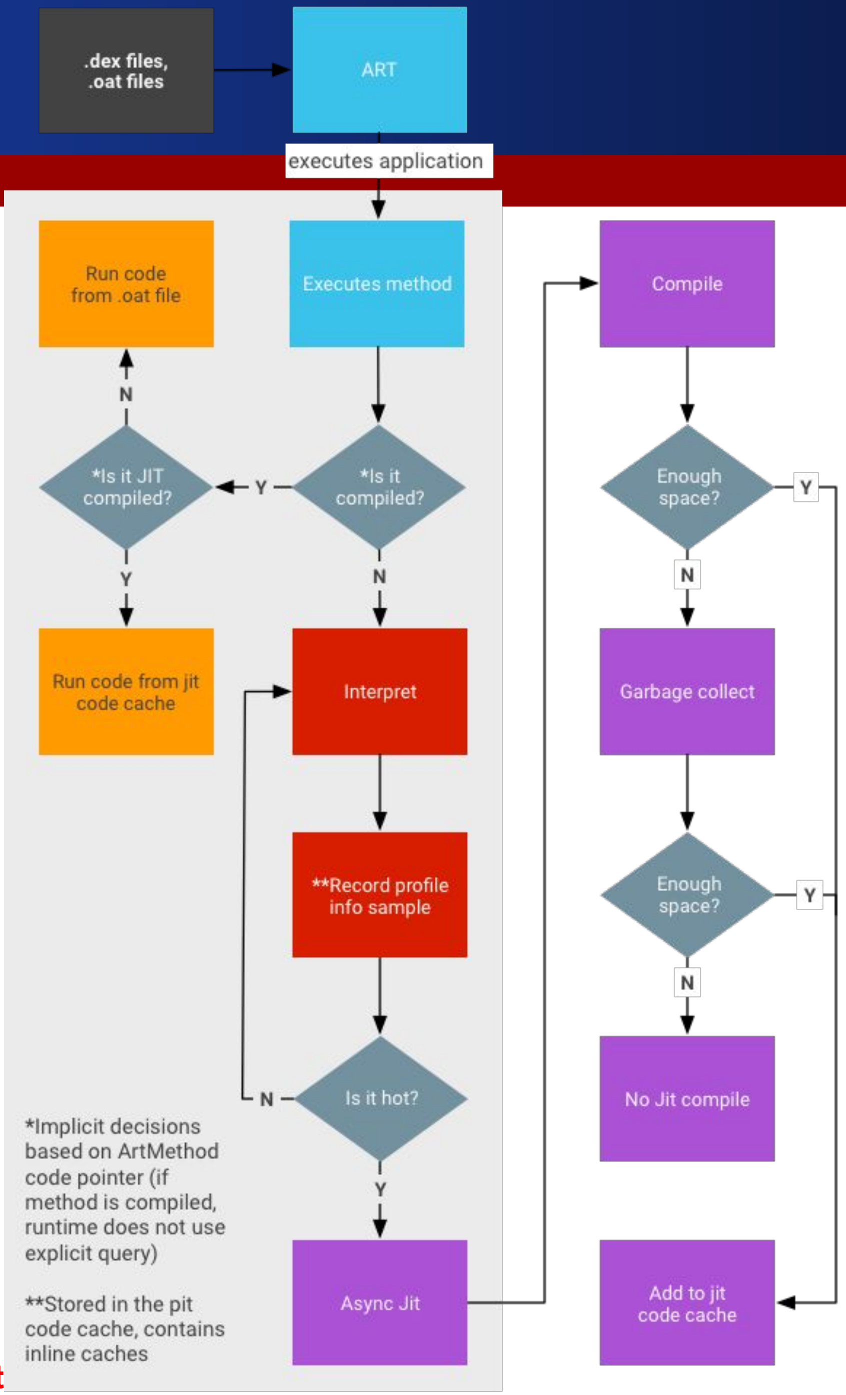
ART

AOT and JIT **replace** the code interpretation that was classic for Java.

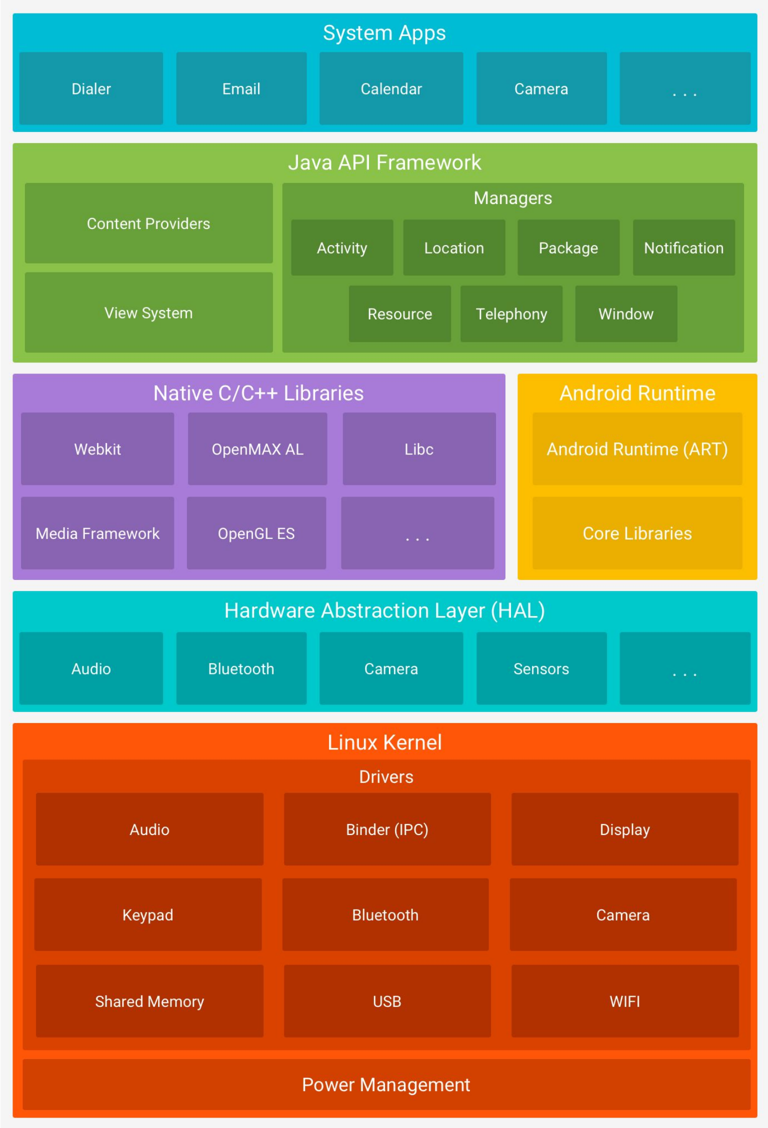
However, their management is complex (see aside).

Do not confuse AOT and JIT with the “compilation” that takes place when developing the app and outputs an APK…

The latter outputs <u>bytecode</u>, which still is <u>not</u> machine code.



The Android Architecture



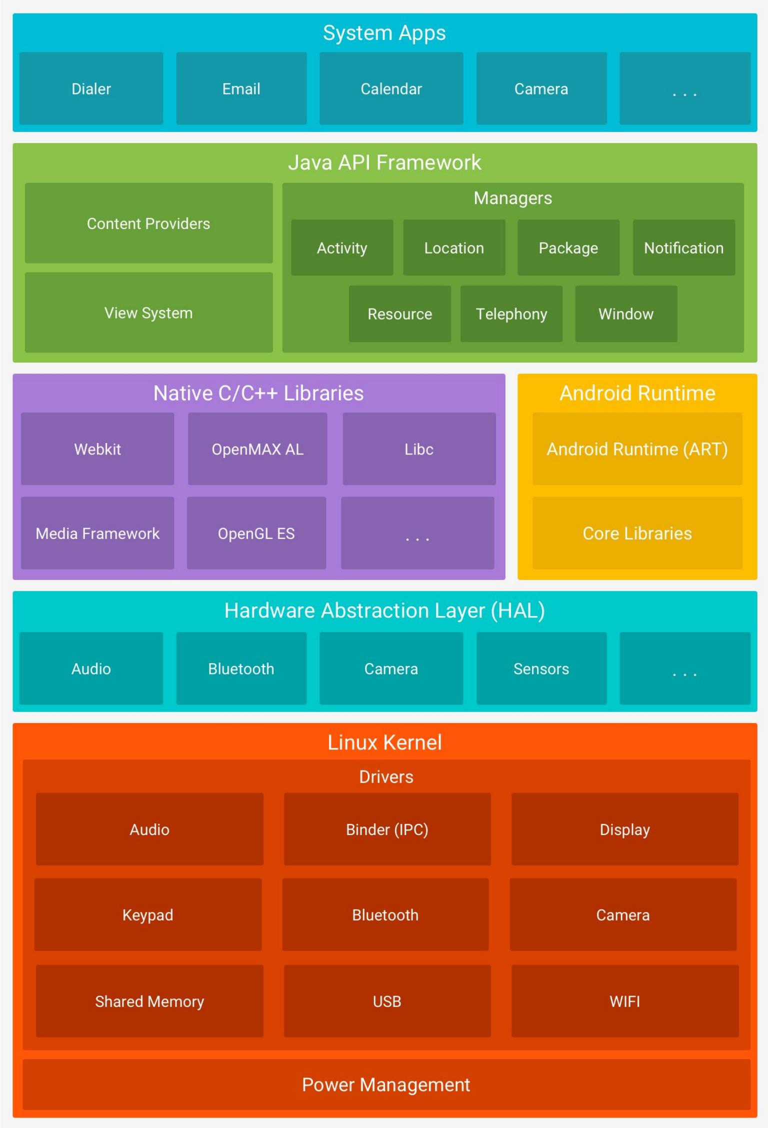
APIs (Core Components of Android)

- **Activity Manager**
- **Packet Manager**
- **Telephony Manager**
- **Location Manager**
- **Contents Provider**
- **Notification Manager**
- **….**

Java **APIs**

- **View System**
  - Through which you build the **APP UI**
- **Resource Manager**
  - Through which you handle **resources**
- **Notification Manager**
  - Through which you can access to different kind of **notifications**
- **Activity Manager**
  - Which handles the **Activity lifecycle** and provides a **back stack**
- **Content Providers**
  - To **share data** among APPs

The Android Architecture



Applications

(Written in **Java/Kotlin** code)

- **Android Play Store**
- **Entertainment**
- **Productivity**
- **Personalization**
- **Education**
- **Geo-communication**
- **....**

Android Applications Design

APPLICATION **DESIGN**:

- **GUI** Definition
- **Events** Management
- Application **Data** Management
- **Background** Operations
- **User** Notifications

APPLICATION COMPONENTS

- Activities & Fragments
- Intents
- Services
- Content Providers
- Broadcast Receivers

Android Components: Activities

- An **Activity** corresponds to a **single screen** of the **Application**.
- An Application can be composed of *multiples screens* (Activities).
- The **Home Activity** is shown when the user launches an application.
- Different activities can exchange information one with each other.

Android Components: Activities

- Each activity is composed by a list of *graphics components*.
- Some of these components (also called **Views**) can interact with the user by handling **events** (e.g. Buttons).
- Two ways to build the graphic interface:

PROGRAMMATIC APPROACH

Example:

```
Button button = new Button (this);
TextView text = new TextView();
text.setText("Hello world");
```

Android Components: Activities

- Each activity is composed by a list of *graphics components*.
- Some of these components (also called **Views**) can interact with the user by handling **events** (e.g. Buttons).
- Two ways to build the graphic interface:

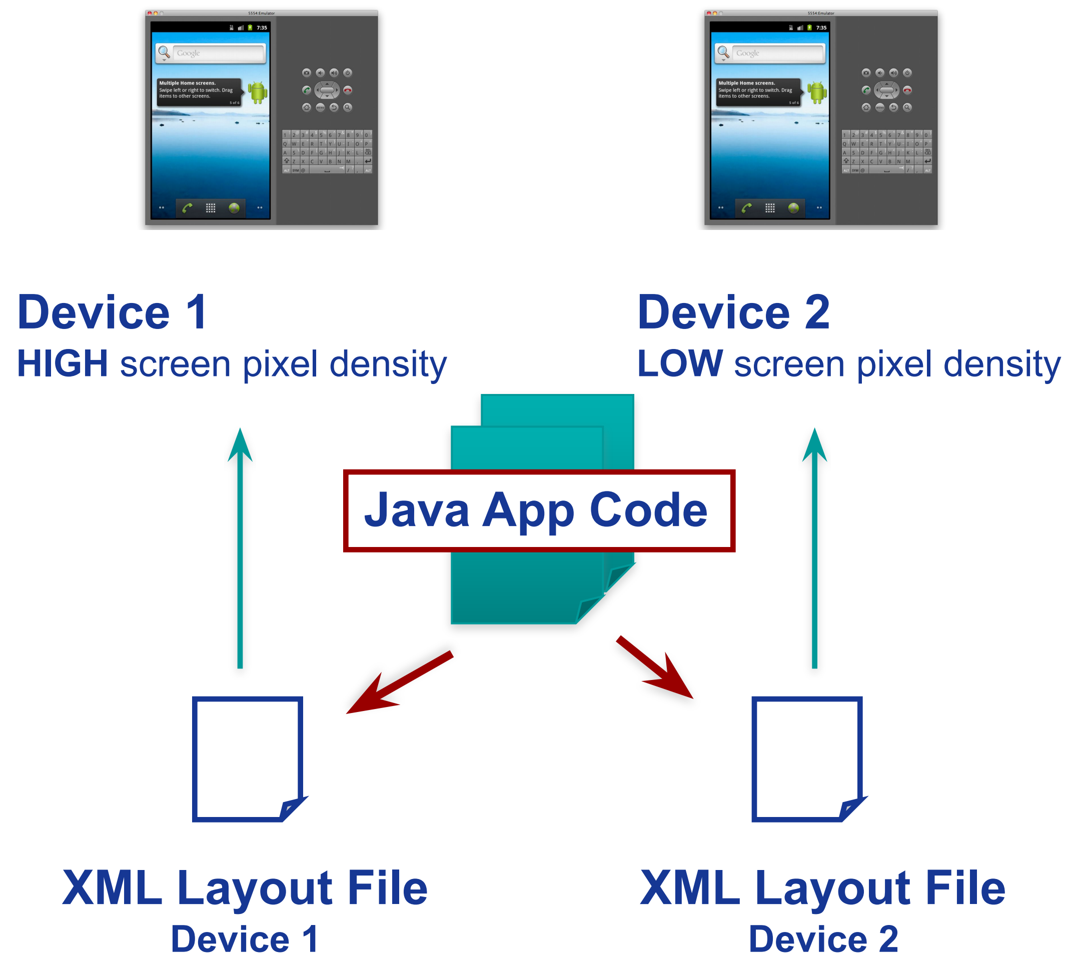
DECLARATIVE APPROACH

Example:

```
< TextView android.text=@string/hello" android:textcolor=@color/blue
android:layout_width="fill_parent" android:layout_height="wrap_content" />
< Button android.id="@+id/Button01" android:textcolor="@color/blue"
android:layout_width="fill_parent" android:layout_height="wrap_content" />
```

Android Components: Activities

EXAMPLE



- Build the **application layout** through XML files (like HTML)
- Define **two** different XML **layouts** for two different devices
- At **runtime**, Android detects the current device configuration and loads the appropriate resources for the application
- **No need to recompile**!
- Just add a new XML file if you need to support a new device

- *Android applications typically use both the approaches!*

DECLARATIVE APPROACH

↓

XML Code → Define the Application **layouts** and **resources** used by the Application (e.g. labels).

PROGRAMMATIC APPROACH

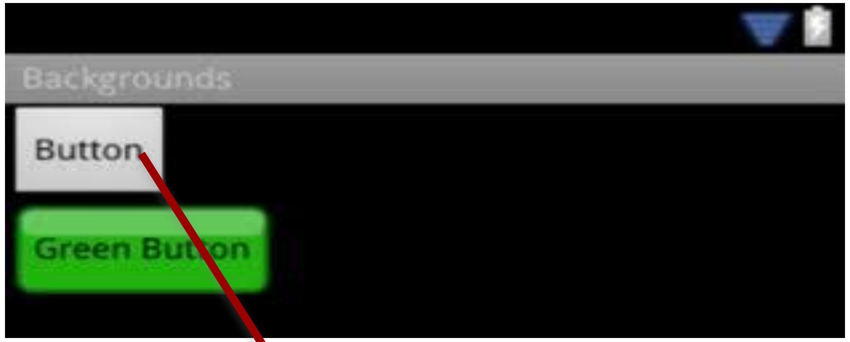
↓

Java Code → Manages the **events**, and handles the **interaction** with the user.

Android Components: Activities

- **Views** can generate **events** (caused by human interactions) that must be managed by the Android-developer through **CALLBACKS** (from now on you need to know what these are)

Button

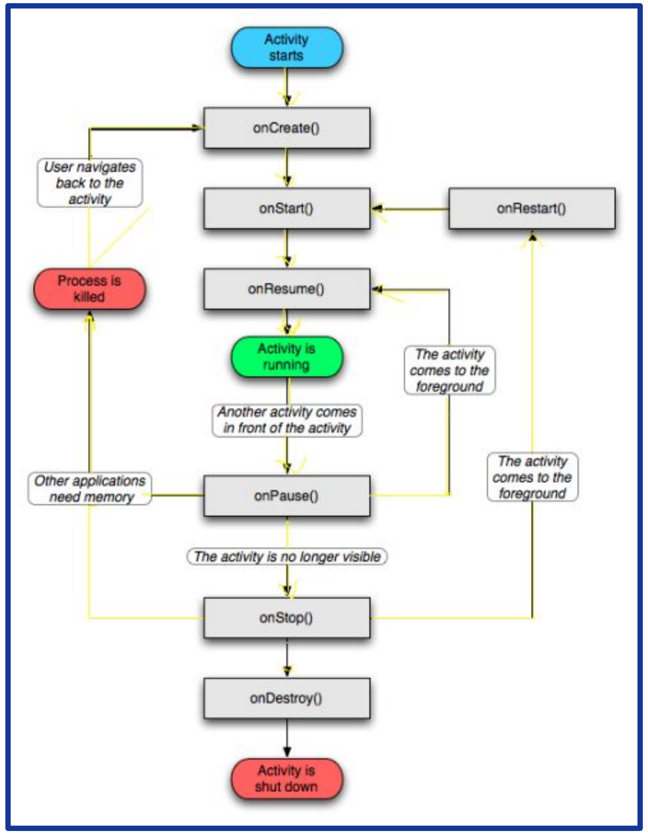


TextEdit

EXAMPLE

```
public void onClick(View arg0) {
    if (arg0 == Button) {
        // Manage Button events
    }
}
```

Android Components: **Activities**



- The **Activity Manager** is responsible for creating, destroying, managing activities.
- Activities can be on different **states**: *starting*, *running*, *stopped*, *destroyed*, *paused*.
- Only one activity can be on the **running** state at a time.
- Activities are organized on a **stack**, and have an event-driven life cycle (details later …)

Android Components: Activities

- Main difference between Android programming and Java (Oracle) programming:
  - **Mobile devices have constrained resource capabilities!**

- Activity lifetime depends on **users' choice** (i.e. change of visibility) as well as on **system constraints** (i.e. memory shortage).

- Developer must implement **lifecycle methods** to account for state changes of each Activity …
  - **This is a reactive programming style!**

Android Components: Activities

```
public class MyApp extends Activity {

   public void onCreate() { ... }
   public void onPause()  { ... }
   public void onStop()   { ... }
   public void onDestroy(){ ... }
   ....
}
```

Called when the Activity is **created** the first time.

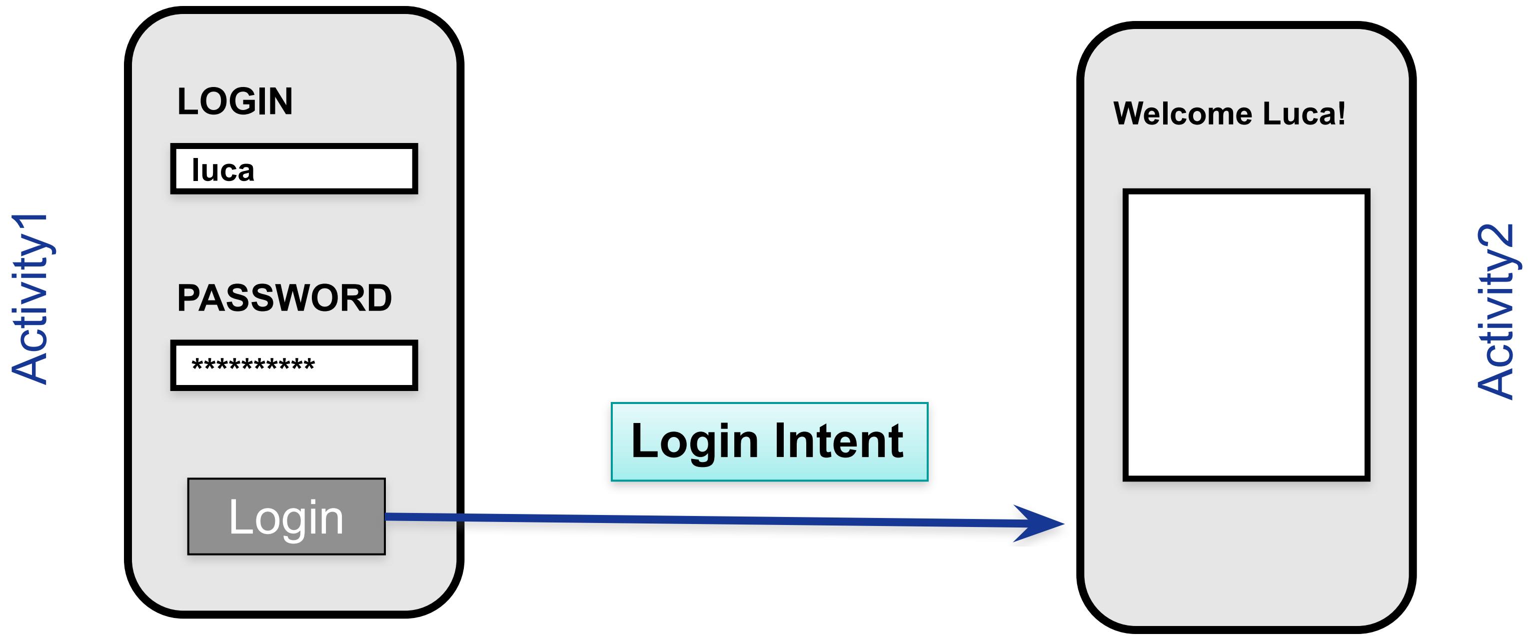
Called when the Activity is **partially visible**.

Called when the Activity is **no longer visible**.

Called when the Activity is **dismissed**.

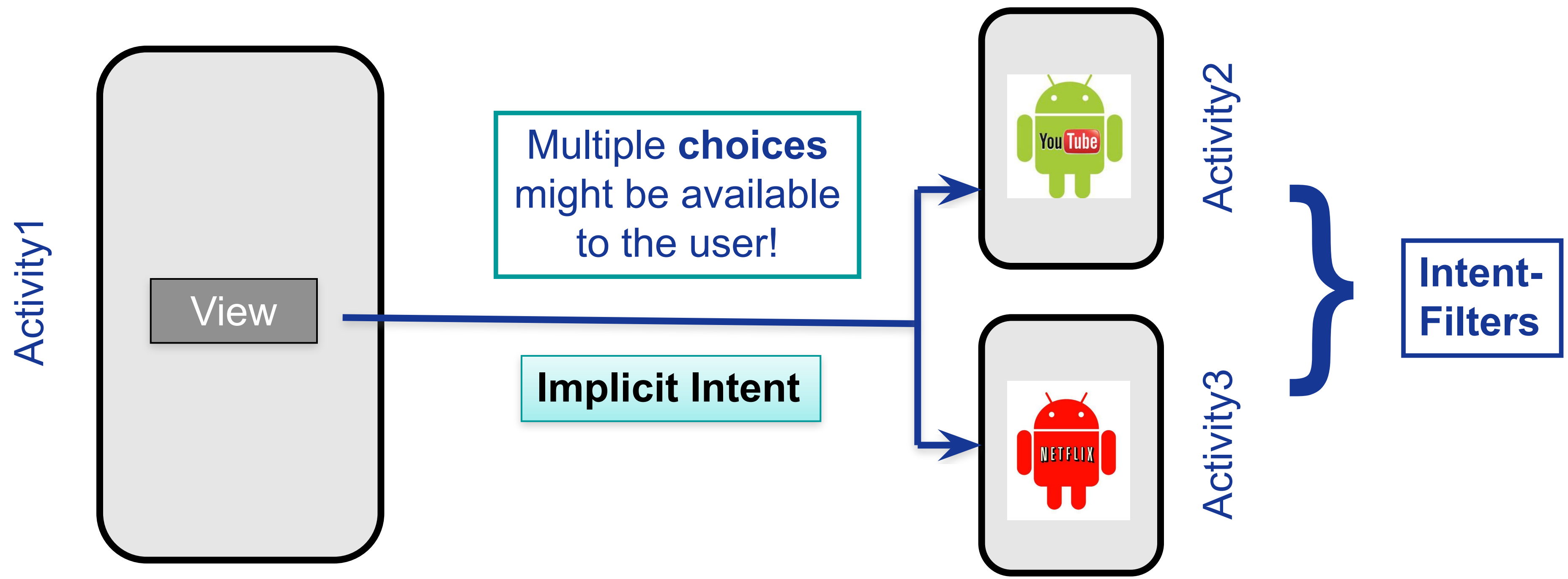
Android Components: **Intents**

- **Intents**: asynchronous **messages** to activate core Android components (e.g. Activities).
- **Explicit** Intent The component *(e.g. Activity1)* specifies the destination of the intent *(e.g. Activity2)*.



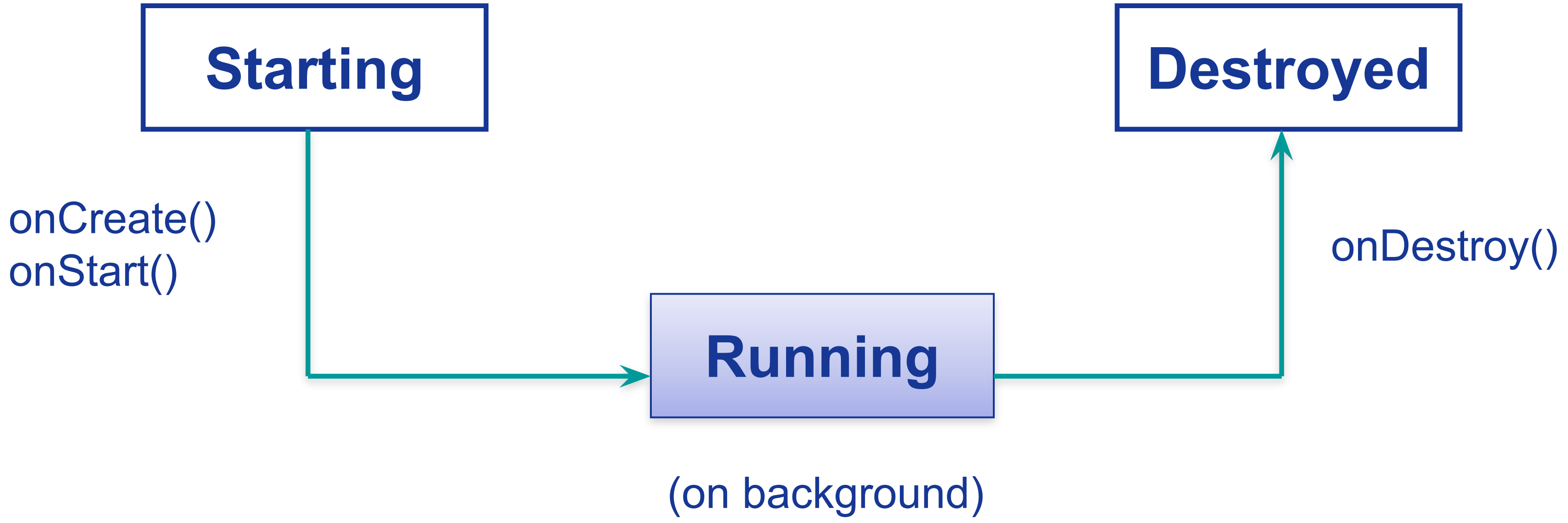
Android Components: Intents

- **Intents**: asynchronous **messages** to activate core Android components (e.g. Activities).
- **Implicit** Intent The component *(e.g. Activity1)* specifies the type of the intent *(e.g. "View a video")*.



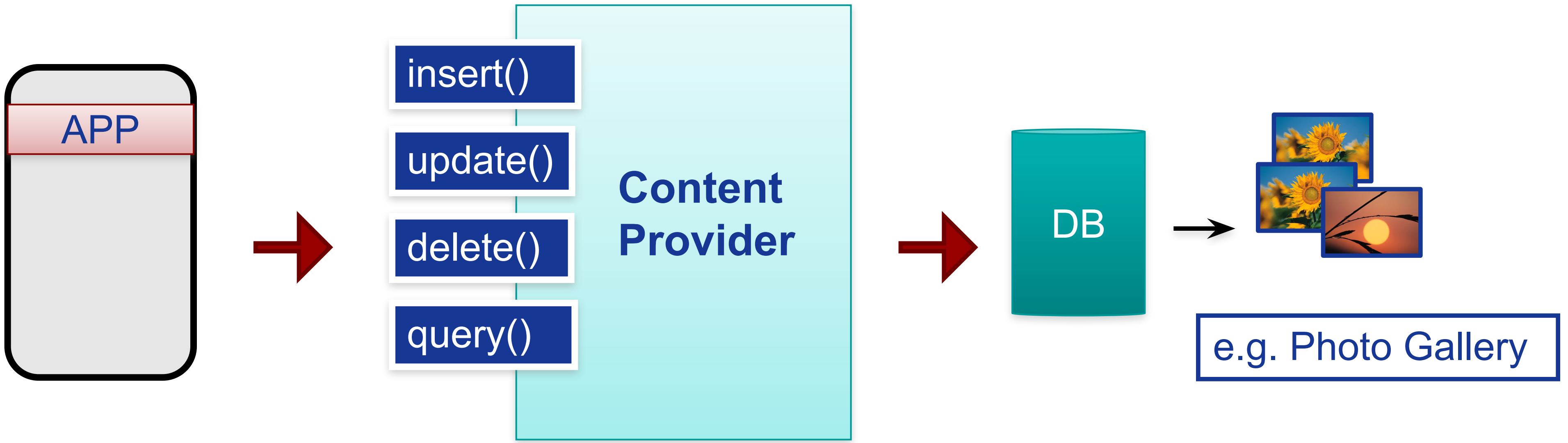
Android Components: Services

- **Services**: like Activities, but run in **background** and do not provide an user interface.
- Used for **non-interactive** tasks (e.g. networking).
- Service life-time composed of 3 states:

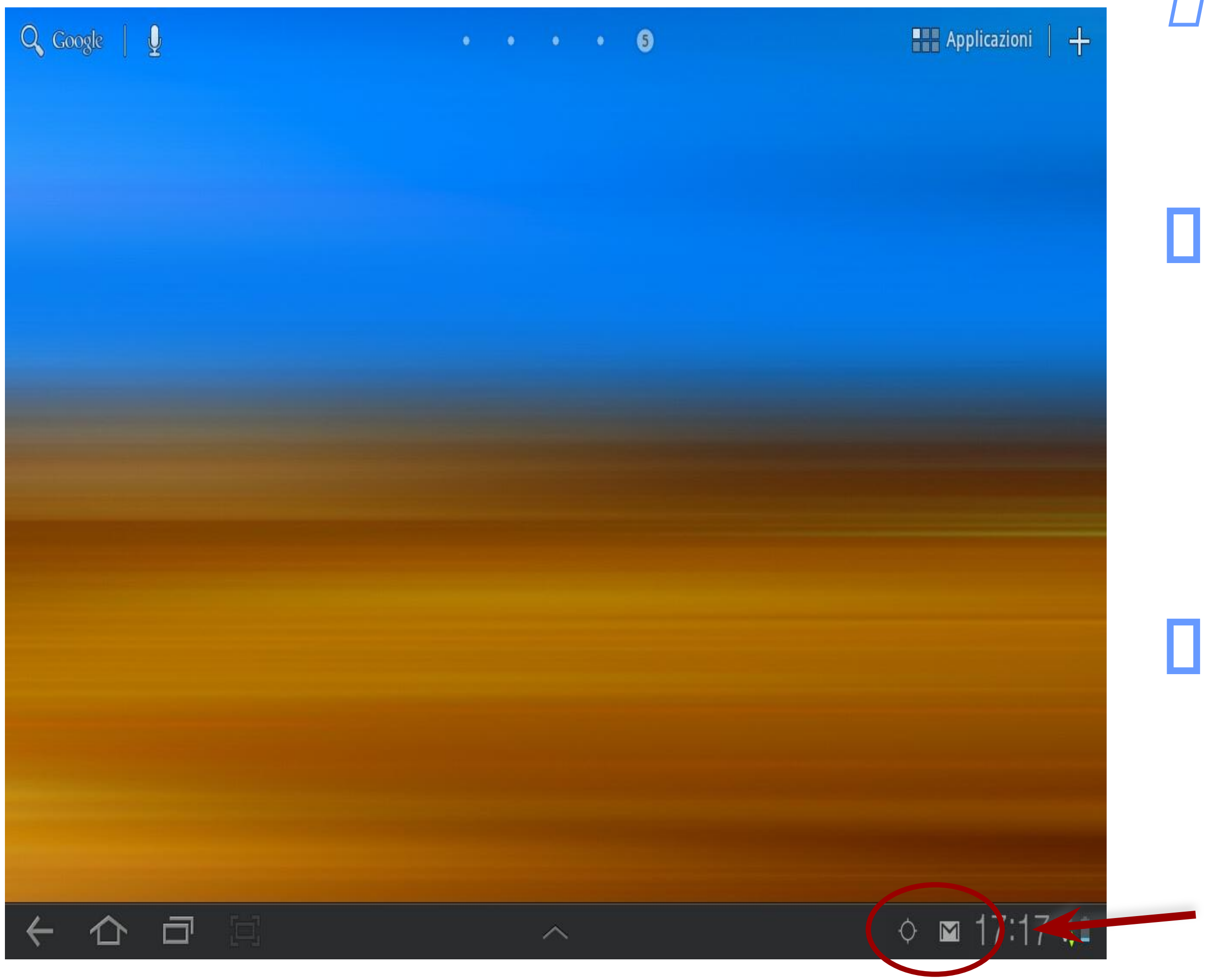


Android Components: Content Providers

- Each Android **application** has its own **private** set of data (managed through *files* or through *SQLite* database).
- **Content Providers**: Standard **interface** to *access and share data among different applications*.



Android Components: Broadcast Receivers



- *Publish/Subscribe* paradigm
- **Broadcast Receivers**: An application can be signaled of **external events**.
- **Notification** types: Call incoming, SMS delivery, Wifi network detected, etc

Android Components: Broadcast Receivers

BROADCAST RECEIVER example

```
class WifiReceiver extends BroadcastReceiver {
       public void onReceive(Context c, Intent intent) {
           String s = new StringBuilder();
           wifiList = mainWifi.getScanResults();
           for(int i = 0; i < wifiList.size(); i++){
               s.append(new Integer(i+1).toString() + ".");
               s.append((wifiList.get(i)).toString());
               s.append("\\n");
           }
           mainText.setText(s);
       }
   }
```

Android Components: System API

- Using the **components** described so far, Android applications can then leverage the system API …

SOME EXAMPLEs …

- *Telephony Manager* data access (call, SMS, etc)
- *Sensor* management (GPS, accelerometer, etc)
- Network *connectivity* (Wifi, bluetooth, NFC, etc)
- *Web* surfing (HTTP client, WebView, etc)
- *Storage* management (files, SQLite db, etc)
- ….

Android Components: Google API

- … or easily interface with other **Google services**:

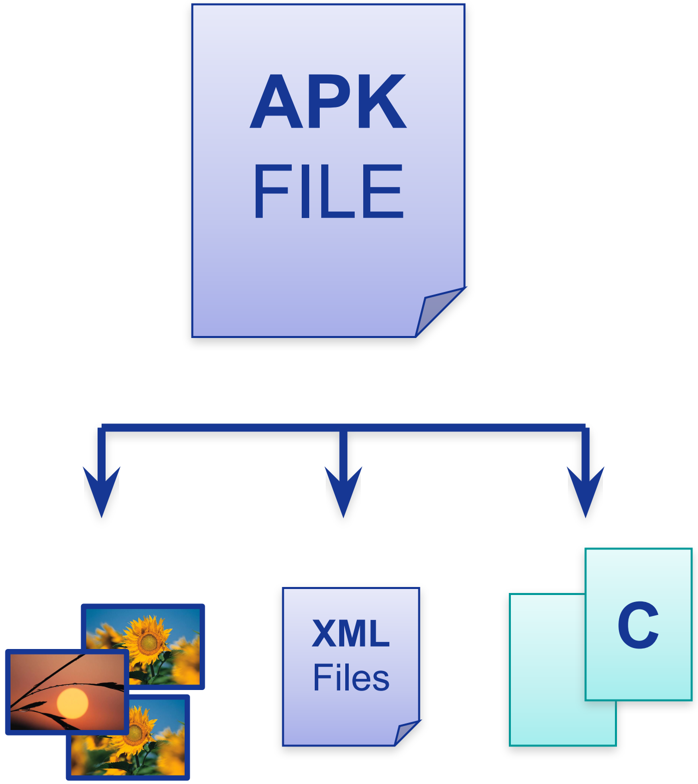
Google maps

Google places

Firebase

Android Application Distribution

- Each Android **application** is contained on a single **APK** file.
  - Java **Bytecode**
  - **Resources** (e.g. images. videos, XML layout files)
  - **Libraries** (optimal native C/C++ code)



Android Application Security

- Android applications run with a distinct system identity (Linux user ID and group ID), in an **isolated** way.
- Applications must explicitly share resources and data. They do this by declaring the ***permissions*** they need for additional capabilities.
  - Applications statically **declare** the permissions they require.
  - User must **give his/her consensus** during the installation.
  - Everything changes starting from 6.0

ANDROIDMANIFEST.XML

```
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION" />

<uses-permission android:name="android.permission.INTERNET" />
```

Permissions from 6.0

- Android Marshmallow (6.0) introduces runtime permissions
  - Permissions are not requested at install-time, but when they are used

- **Bad behavior**: request everything on the first screen of the first launch of the app

- **Good behavior**: request permission only when needed
  - APP should work (with limited functions) even if some permissions are not granted
- Things about permissions evolved further...