



Embedded Operating Systems

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Linux Environment

Advantages of Linux

- ▶ Linux is free— both in source code and cost, due to the GPL
- ▶ Linux is fully customizable in all its components
- ▶ Linux can runs on low-end, inexpensive hardware (HW) platforms, e.g., one with 4 MB RAM
- ▶ Most Linux systems are stable
- ▶ The Linux kernel can be very small and compact
- ▶ Linux is highly compatible with many common applications and functions
- ▶ Linux is well-supported

Different Type of Operating System Kernels

▶ Monolithic kernel

- The entire operating system is working in kernel space
- All parts of the kernel share the same kernel-level memory
- Kernel components might affect other components
- The Linux kernel is an example

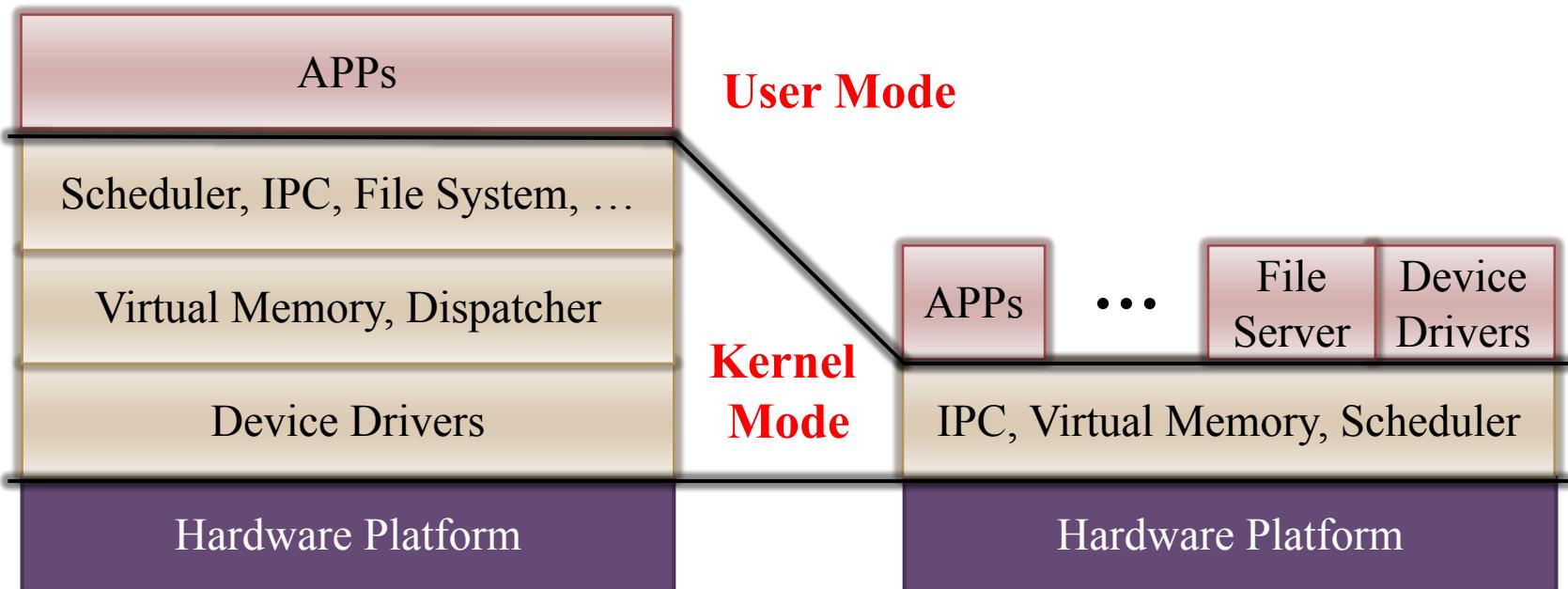
▶ Microkernel

- Kernel functions are partitioned into components
- Communications are via inter process communication (IPC) protocol
- The L4 microkernel is an example

Monolithic Kernel and Microkernel

Monolithic Kernel

Microkernel



Device Driver

▶ Character Devices

- Sequential access
- Examples might include printers, scanners, sound boards
- The same device may have both block and character oriented interfaces

▶ Block Devices

- Block devices can support filesystem
- The block size is from 512B to 4KB and is going to increase in advanced devices
- For example, disks are commonly implemented as block devices

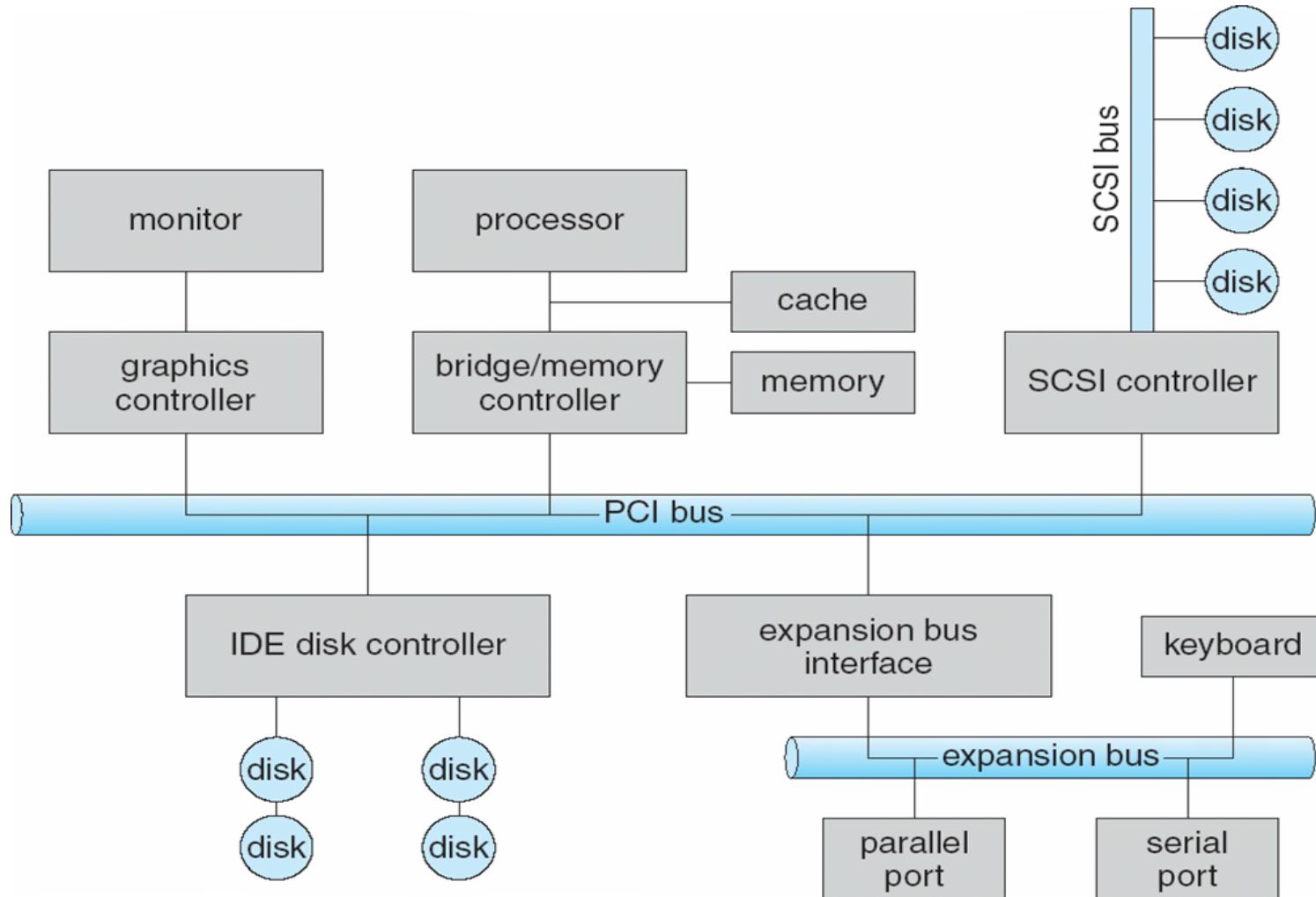
Major and Minor Numbers

- ▶ Major number
 - Each device driver is identified by a unique major number
 - This number is assigned by the Linux Device Registrar
- ▶ Minor number
 - The number uniquely identifies a particular instance of a device of the same device type
 - If there are three devices with the same device driver, they should have the same major number but different minor numbers
- ▶ Command: mknod [device name][bcp] [Major] [Minor]
 - b: block devices
 - c: character devices
 - p: a FIFO file

I/O Hardware

- ▶ Incredible Variety of I/O Devices
 - Storage
 - Transmission
 - Human-interface
 - ...
- ▶ Common Concepts
 - **Port**: a connection point for a device
 - **Bus**: can be daisy chain or shared direct access
 - **Controller** (host adapter): electronics that operate ports, buses, devices

Typical PC Bus Structure



Access to I/O Hardware

- ▶ Devices registers which can be accessed by the host
 - The **data-in register** is read by the host to get the **input**
 - The **data-out register** is written by the host to send the **output**
 - The **status register** contains bits which indicate device **states**
 - The **control register** is written by the host to send **commands**
- ▶ Methods to access devices with their addresses
 - **Direct I/O instructions**
 - **Memory-mapped I/O**
 - Device data and command registers mapped to processor address space
 - Especially for large address spaces (graphics)

Device I/O Port Locations on PCs (Partial)

I/O address range (hexadecimal)	device
000–00F	DMA controller
020–021	interrupt controller
040–043	timer
200–20F	game controller
2F8–2FF	serial port (secondary)
320–32F	hard-disk controller
378–37F	parallel port
3D0–3DF	graphics controller
3F0–3F7	diskette-drive controller
3F8–3FF	serial port (primary)

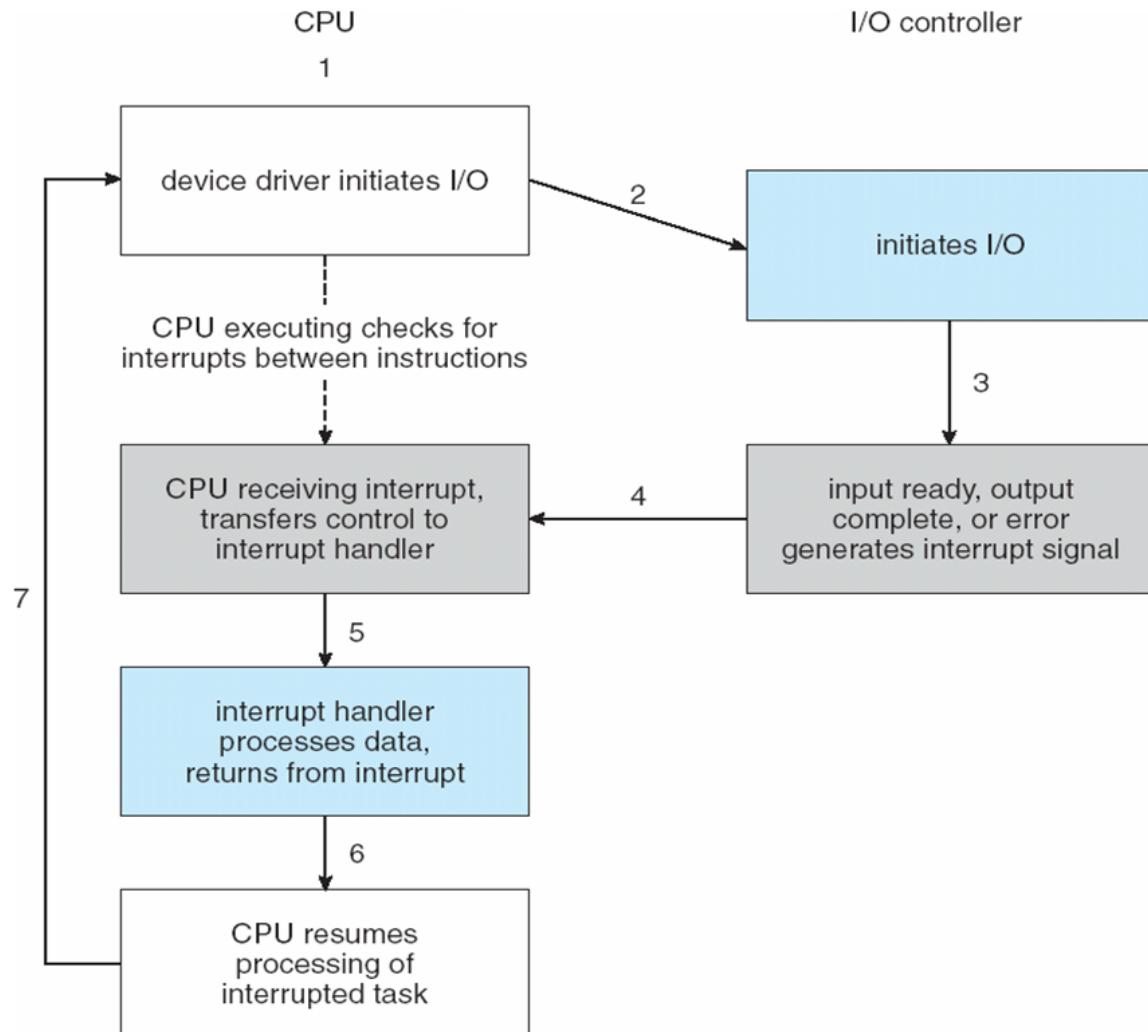
Polling

- ▶ An example of polling I/O
 1. Host reads the busy bit from the status register until 0
 2. Host sets read or write bit and copies data into data-out register if it is going to write data
 3. Host sets command-ready bit
 4. Controller sets busy bit, executes the transmission
 5. Controller clears busy bit, error bit, and command-ready bit when the transmission is done
- ▶ Step 1 is busy-waiting to wait for I/O from devices
 - Reasonable if device is fast
 - But inefficient if device is slow
 - CPU switches to other tasks?
 - Might miss some data

Interrupts

- ▶ CPU interrupt-request line triggered by I/O device
 - Checked by processors (hardware) after each instruction
- ▶ Interrupt handler receives interrupts
 - Masked to ignore or delay some interrupts
- ▶ Interrupt vector table is used to dispatch interrupt to correct handler
 - Context switches at start and end
 - Based on priority
 - Some nonmaskable
 - Interrupt chaining if more than one device at the same interrupt number

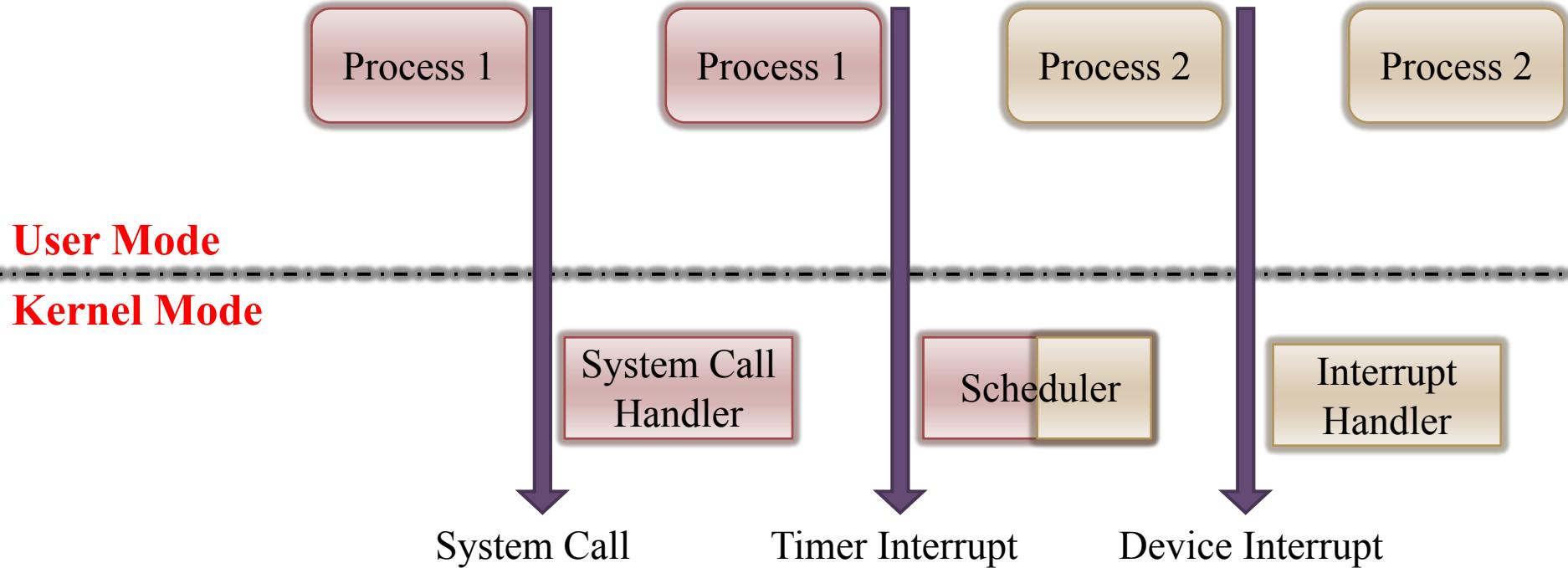
Interrupt-Driven I/O Cycle



Interrupt Usage

- ▶ Interrupt vector table is used to identify which device sent out the interrupt
 - When multiple devices share an interrupt number, the handlers are checked one by one
- ▶ Interrupt mechanism is also used for exceptions
 - Terminate process or crashed subsystem due to hardware error
 - Page fault executes when there is some memory access error
 - System call executes via a trap to trigger the kernel to execute some request
- ▶ Multi-CPU systems can process interrupts concurrently
 - If operating system designed to handle it

Transitions between User and Kernel Modes in Linux



Direct Memory Access

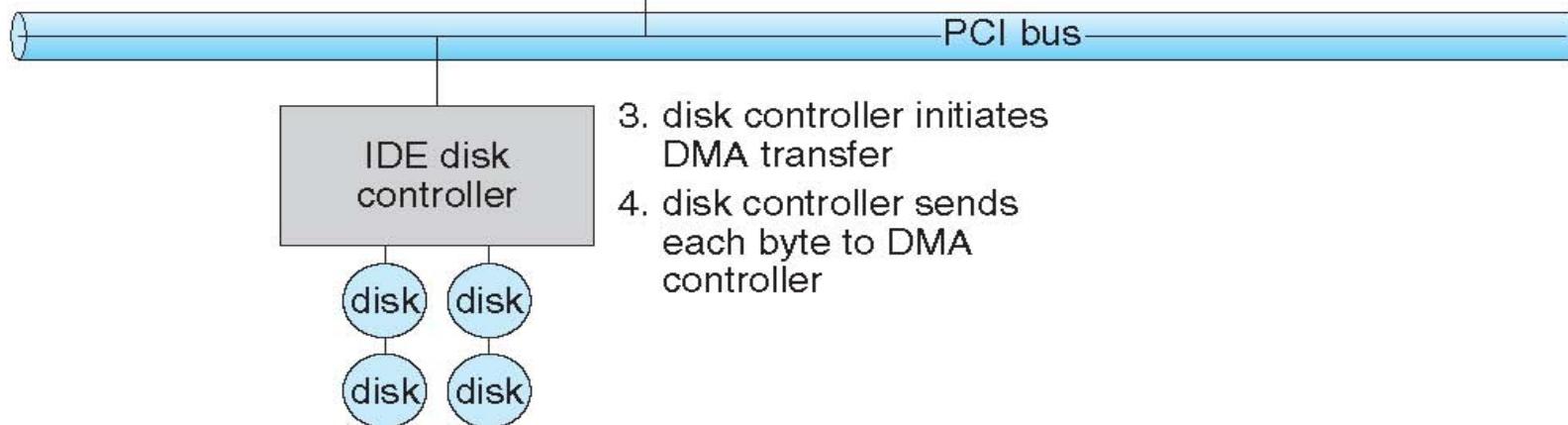
- ▶ Used to avoid programmed I/O (one byte at a time) for large data movement
- ▶ Requires a DMA controller
- ▶ Bypasses the CPU to transfer data directly between I/O devices and memory
- ▶ OS writes a DMA command block into memory
 - Source and destination addresses
 - Read or write mode
 - Number of bytes
- ▶ OS writes the location of the command block to the corresponding DMA controller
 - Bus mastered by the DMA controller – grabs bus from CPU
 - When transmission is done, the DMA controller sends an interrupt

DMA Transfer

5. DMA controller transfers bytes to buffer X, increasing memory address and decreasing C until $C = 0$
6. when $C = 0$, DMA interrupts CPU to signal transfer completion

1. device driver is told to transfer disk data to buffer at address X

2. device driver tells disk controller to transfer C bytes from disk to buffer at address X



Getting Started

- ▶ Installing Linux is now easier than installing MS Windows
- ▶ Doing it on a virtual machine can be harmless
- ▶ Many distributions are there for you



- ▶ Which Linux distribution is better?
 - If you ask this question, it means “it doesn't matter for you”
 - Just use the distribution with the most supports you can find



Android Environment

History of Android

- ▶ Android was founded in Palo Alto, California in October 2003
- ▶ Google acquired Android in August 2005
- ▶ The Open Handset Alliance started in November 2007
- ▶ The first commercially available smartphone running Android was the HTC Dream, released on October 22, 2008
- ▶ The latest released version is Android Oreo 8.0.0, which was released on August 21, 2017

Android Versions



Cupcake
Android 1.5



Donut
Android 1.6



Eclair
Android 2.0/2.1



Froyo
Android 2.2



Honeycomb
Android 3.0-3.2



Ice cream Sandwich
Android 4.0+



Jelly Bean
Android 4.1-4.3



KitKat
Android 4.4



Lollipop
Android 5.0-5.1



Marshmallow
Android 6.0-6.0.1

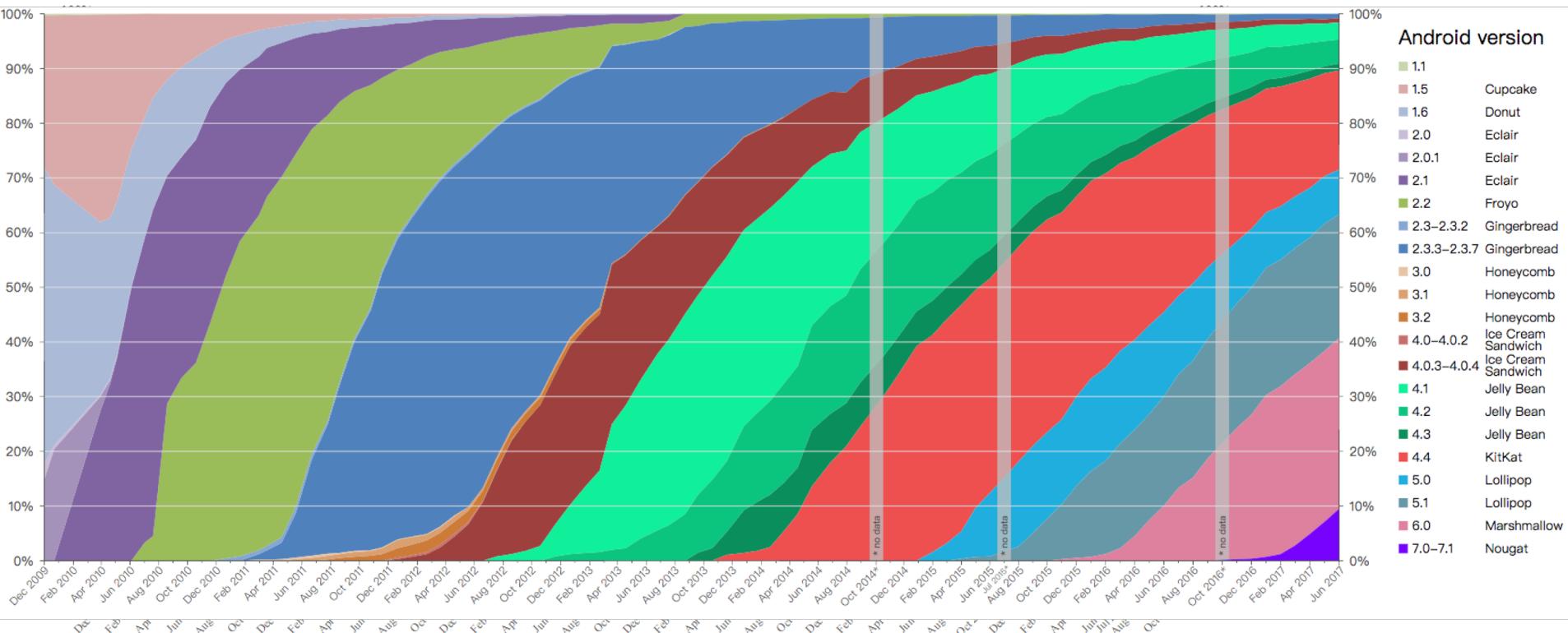


Nougat
Android 7.0 – 7.1.2



Oreo
Android 8.0-

Android Distribution



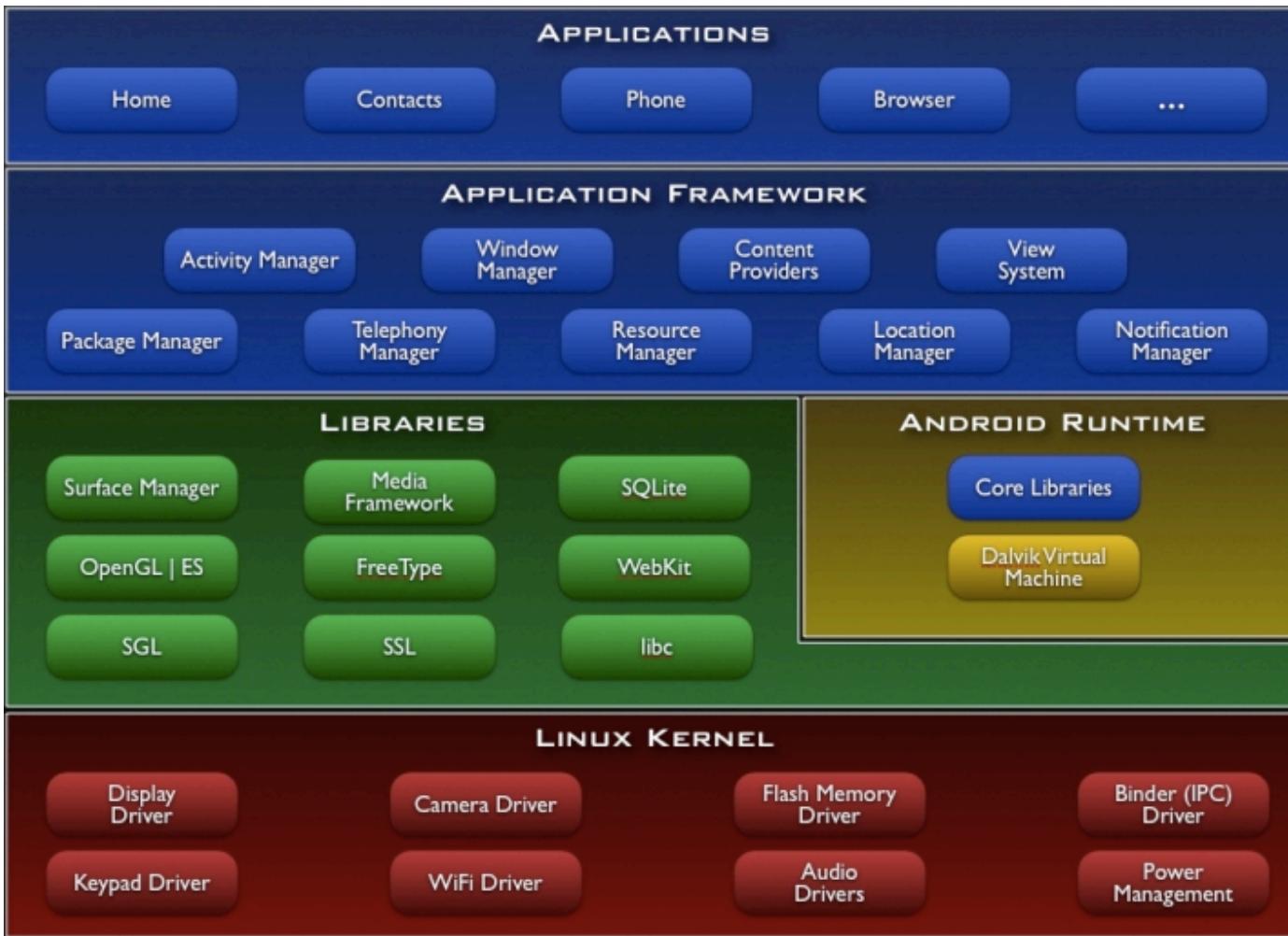
Source: http://en.wikipedia.org/wiki/File:Android_historical_version_distribution_-_vector.svg



Google Android

- ▶ A software stack for mobile devices
 - An operating system
 - Middleware
 - Key Applications
- ▶ Linux for core system services
 - Security
 - Memory management
 - Process management
 - Power management
 - Hardware drivers

Android Architecture



Mobile Devices

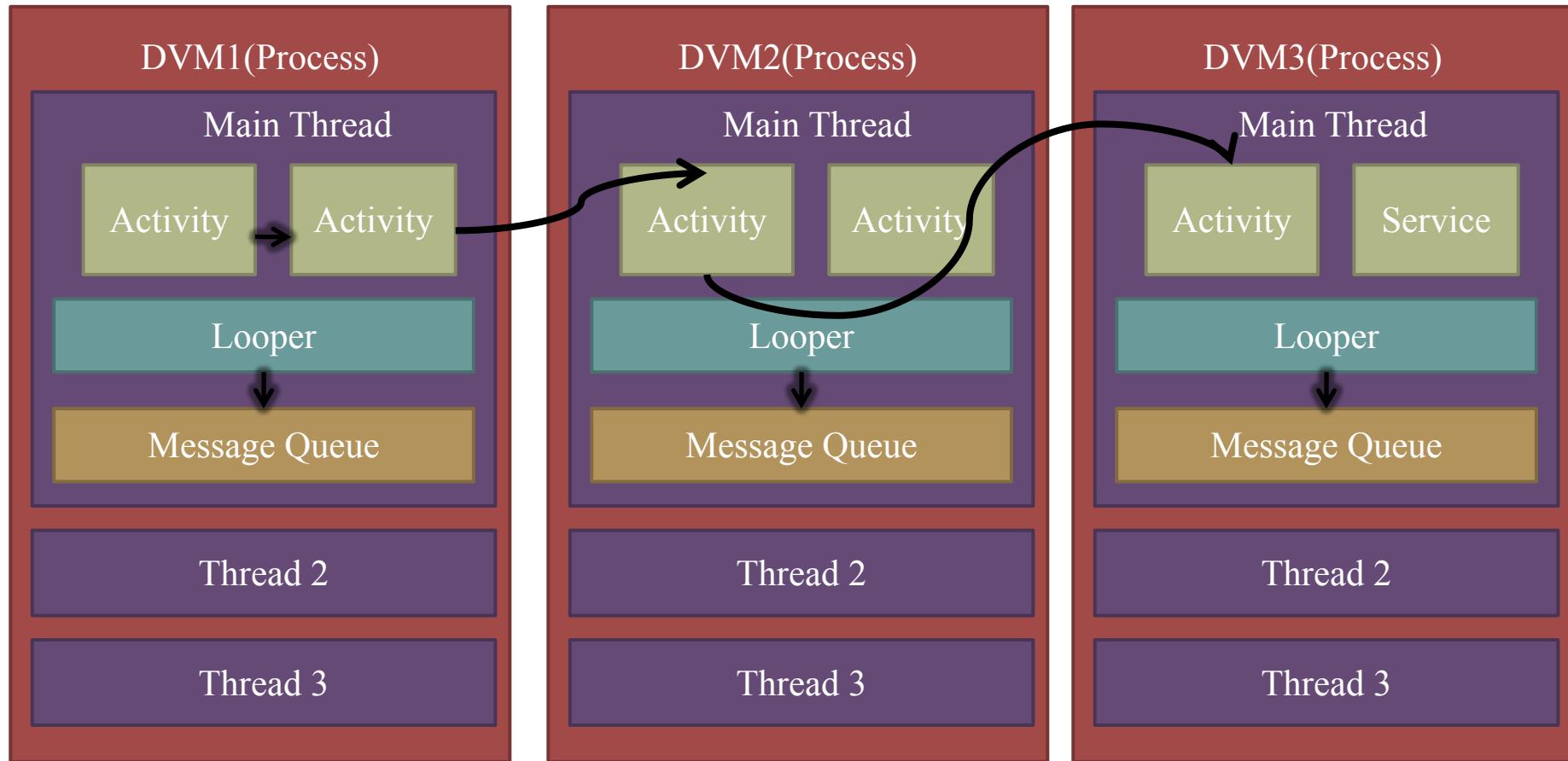
► Advantages

- Always with the user
- Typically have Internet access
- Typically GPS enabled
- Typically have accelerometer & compass
- Most have cameras & microphones

► Disadvantages

- Limited screen size
- Limited battery life
- Limited processor speed
- Limited web browser functionality

Android Applications



Android Market / Google Play

- ▶ Has various categories, allows ratings
- ▶ Have both free/paid apps
- ▶ Featured apps on web and on phone
- ▶ Initial release: October 23, 2008, as Android Market
- ▶ Development status:
 - 1+ million apps, as of July, 2013
 - 1.3+ million apps, as of July, 2014
 - 1.5+ million apps, as of Q1, 2015
 - 1.9+ million apps, as of Q1, 2016
 - 2.7+ million apps, as of Q1, 2017

Publish Your APP

▶ Link to an Account

- Developer Account: \$25 fee
- Link to your checking account
- Developer take 70% of app purchase price



Android Environment

- ▶ Eclipse + ADT (Android Developer Tools) Plugin
- ▶ Android SDK (System Development Kit) Tools
- ▶ Android Platform-Tools
- ▶ The Latest Android Platform Configuration
- ▶ The Latest Android System Image for the Emulator



Android Studio



Java Development Kit

The screenshot shows the Oracle Java Development Kit (JDK) download page. At the top, there's a navigation bar with links for Sign In/Register, Help, Country, Communities, I am a..., I want to..., Search, Products, Solutions, Downloads, Store, Support, Training, Partners, About, and OTN. Below the navigation is a breadcrumb trail: Oracle Technology Network > Java > Java SE > Downloads.

On the left, there's a sidebar with links for Java SE, Java EE, Java ME, Java SE Support, Java SE Advanced & Suite, Java Embedded, Java DB, Web Tier, and Java Card. Below this is a section titled "Java SE Downloads" with links for Java Platform (JDK) 8u65 / 8u66 and NetBeans with JDK 8.

The main content area has tabs for Overview, Downloads (which is selected), Documentation, Community, Technologies, and Training. A sub-section titled "Java SE Development Kit 7 Downloads" contains a message about the end of public updates for Oracle JDK 7. It also includes a thank you message for downloading the Java Platform, Standard Edition Development Kit (JDK). There are links for Java SE Downloads, Java SE Support, Java SE Advanced & Suite, Java Embedded, Java DB, Web Tier, Java Card, Java APIs, Technical Articles, Demos and Videos, and Forums.

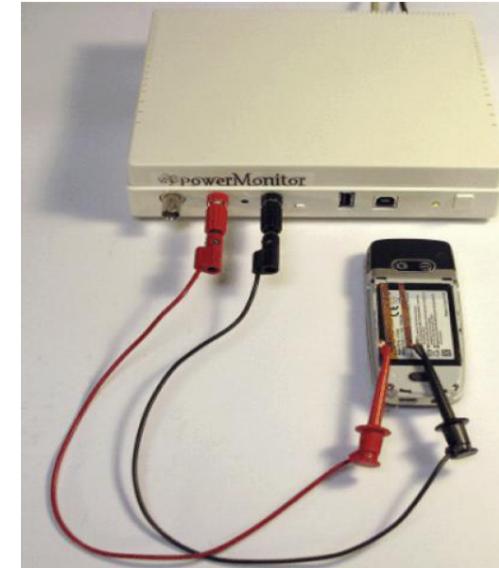
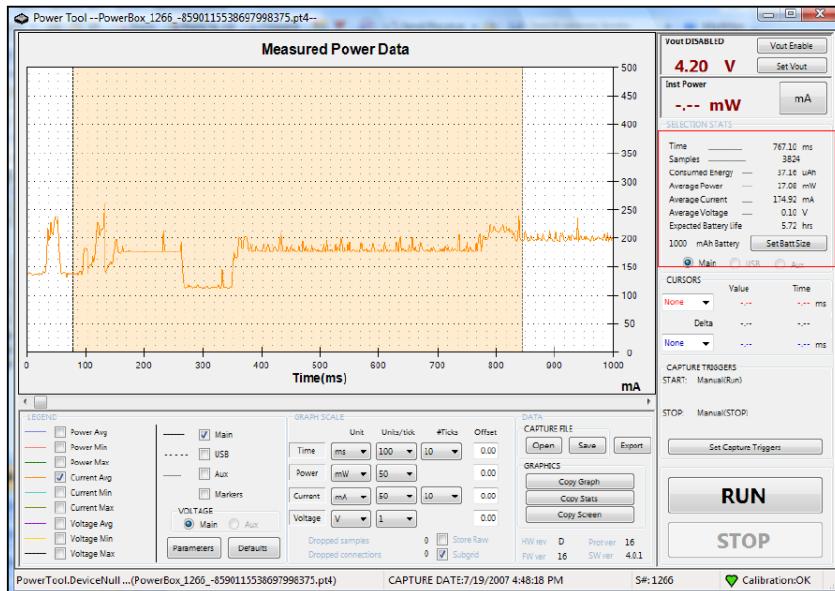
To the right, there's a sidebar titled "Java SDKs and Tools" with links for Java SE, Java EE and Glassfish, Java ME, Java Card, NetBeans IDE, and Java Mission Control. Another sidebar titled "Java Resources" includes links for Java APIs, Technical Articles, Demos and Videos, and Forums.

A large callout box for "Java SE Development Kit 8u66" asks the user to accept the Oracle Binary Code License Agreement. It provides two options: "Accept License Agreement" (selected) and "Decline License Agreement". Below this is a table of download links for various Java editions:

Product / File Description	File Size	Download
Linux x86	154.67 MB	jdk-8u66-linux-i586.rpm
Linux x86	174.83 MB	jdk-8u66-linux-i586.tar.gz
Linux x64	152.69 MB	jdk-8u66-linux-x64.rpm
Linux x64	172.89 MB	jdk-8u66-linux-x64.tar.gz
Mac OS X x64	227.12 MB	jdk-8u66-macosx-x64.dmg
Solaris SPARC 64-bit (SVR4 package)	139.65 MB	jdk-8u66-solaris-sparcv9.tar.Z
Solaris SPARC 64-bit	99.05 MB	jdk-8u66-solaris-sparcv9.tar.gz
Solaris x64 (SVR4 package)	140 MB	jdk-8u66-solaris-x64.tar.Z
Solaris x64	96.2 MB	jdk-8u66-solaris-x64.tar.gz
Windows x86	181.31 MB	jdk-8u66-windows-i586.exe
Windows x64	186.65 MB	jdk-8u66-windows-x64.exe

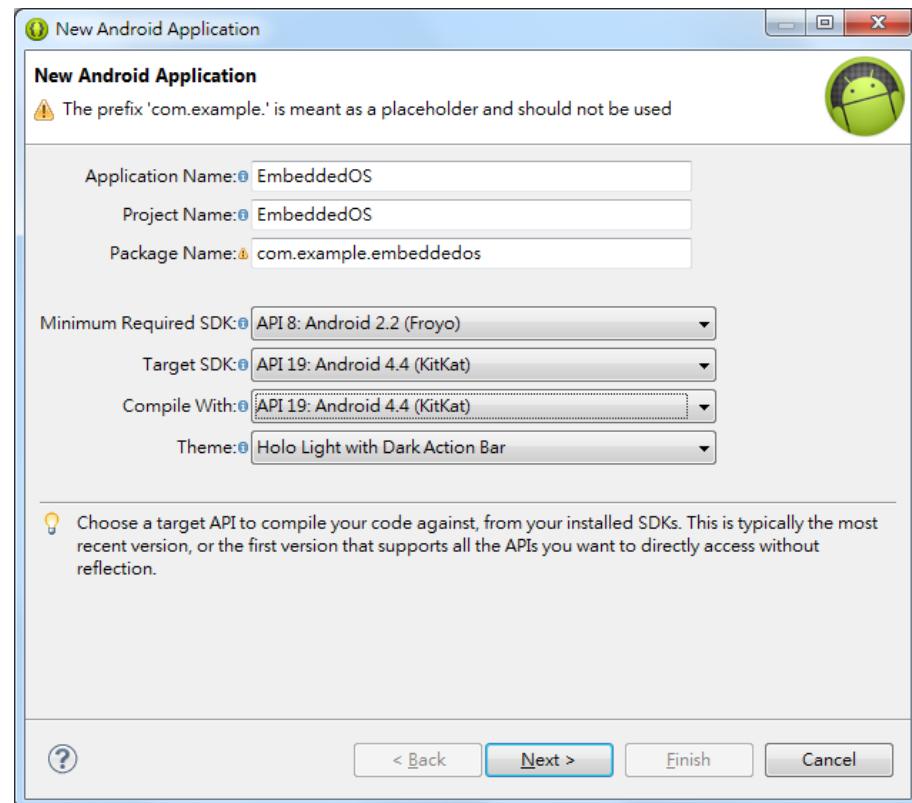
Power Monitor

- ▶ Power measurement for any device with a single lithium battery



Set Information of the Project

- ▶ **Application Name** is the app name that appears to users
- ▶ **Project Name** is the name of your project directory and the name visible in Eclipse
- ▶ **Package Name** is the package namespace for your app (following the same rules as packages in the Java programming language)

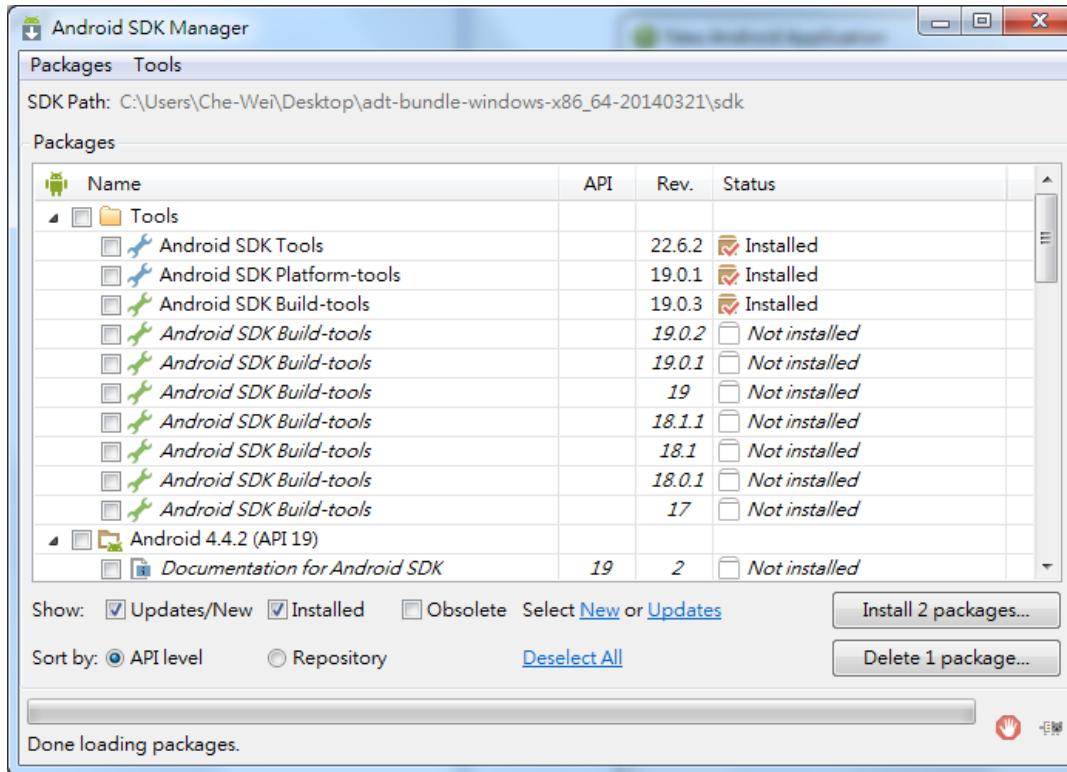


API Support

- ▶ **Minimum Required SDK** is the lowest version of Android that your app supports
- ▶ **Target SDK** indicates the highest version of Android
- ▶ **Compile With** is the platform version against which you will compile your app
 - By default, this is set to the latest version of Android available in your SDK
- ▶ **Theme** specifies the Android UI style to apply for your app

SDK Manager

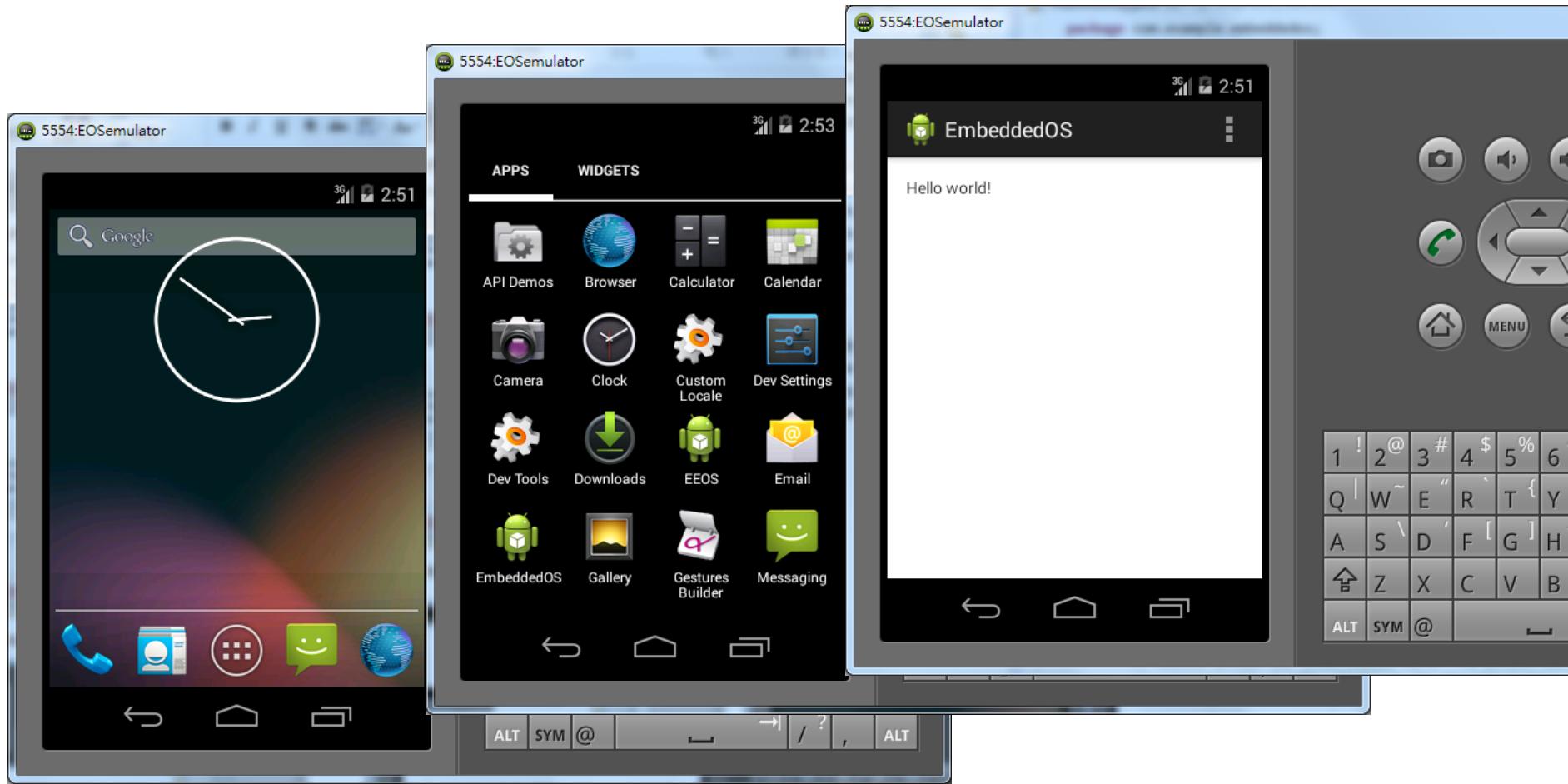
- ▶ If you want to install more libraries for different Android versions or different function supports



Execute APP on an Android Device

- ▶ Enable USB debugging on your device
 - On most devices running Android 3.2 or older, you can find the option under Settings → Applications → Development
 - On Android 4.0 and newer, it's in Settings → Developer options
 - On Android 4.2 and newer, Developer options is hidden by default
 - To make it available, go to Settings → About phone → tap Build number (版本號碼 or 軟體版本) seven times
 - It might be different for different Android devices
 - Return to the previous screen to find Developer options
- ▶ Developer Options → Enable USB debugging
- ▶ Down and install the USB driver and install it

Hello World



Dalvik Virtual Machine

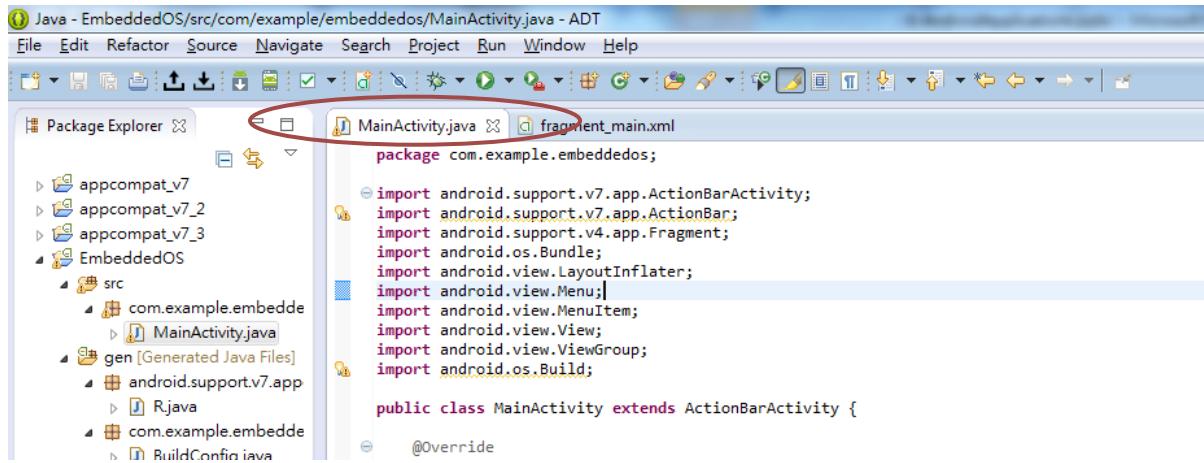
- ▶ Providing environment on which every Android application runs
 - Each Android application runs in its own process, with its own instance of the Dalvik Virtual Machine (DVM)
 - Register-based virtual machine
- ▶ Executing the Dalvik Executable (.dex) format
 - .dex format is optimized for minimal memory footprint
- ▶ Relying on the Linux Kernel
 - Multi-threading
 - Low-level memory management

Android Runtime (ART)

- ▶ Android Runtime (ART) is an application runtime environment
- ▶ ART is provided to replace Dalvik
- ▶ ART introduces the use of ahead-of-time (AOT) compilation
- ▶ AOT compiles entire applications into native machine code upon their installation
- ▶ Android 4.4 has alternatives to use ART or Dalvik
- ▶ After Android 5.0, Dalvik was entirely replaced by ART

Activities

- ▶ Activities are the basis of android applications
- ▶ An Activity defines a viewable screen
- ▶ Multiple Activities for an application are allowed
- ▶ Each activity is a separate entity
- ▶ They have a life cycle
 - Events happen either via touching buttons or programmatically



```
Java - EmbeddedOS/src/com/example/embeddedos/MainActivity.java - ADT
File Edit Refactor Source Navigate Project Run Window Help

Package Explorer X MainActivity.java fragment_main.xml

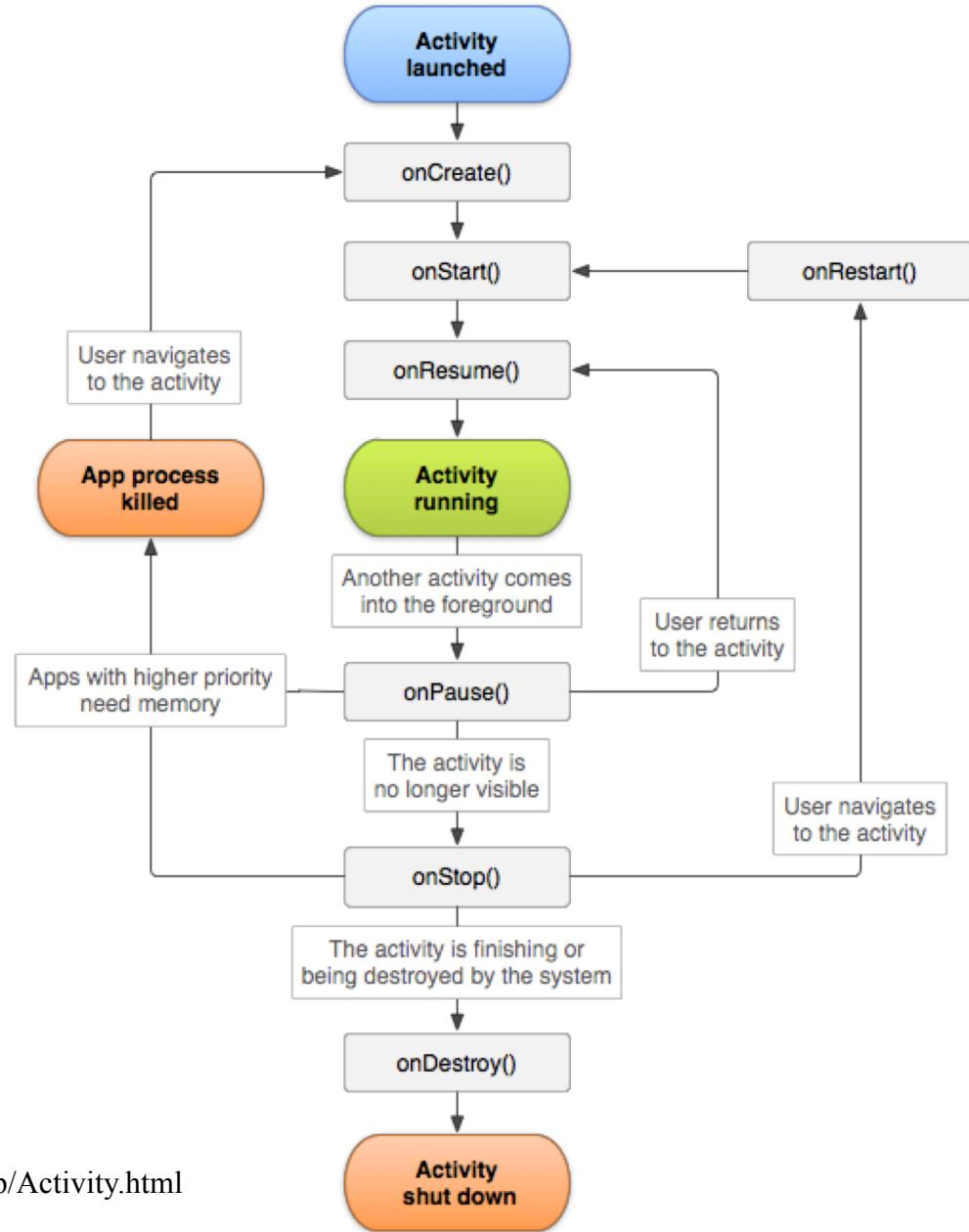
appcompat_v7 appcompat_v7_2 appcompat_v7_3 EmbeddedOS
src com.example.embedde
gen (Generated Java Files) android.support.v7.app
R.java com.example.embedde
BuildConfig.java

package com.example.embeddedos;
import android.support.v7.app.ActionBarActivity;
import android.support.v7.app.ActionBar;
import android.support.v4.app.Fragment;
import android.os.Bundle;
import android.view.LayoutInflater;
import android.view.Menu;
import android.view.MenuItem;
import android.view.View;
import android.view.ViewGroup;
import android.os.Build;

public class MainActivity extends ActionBarActivity {
    @Override
```



Activity Lifecycle

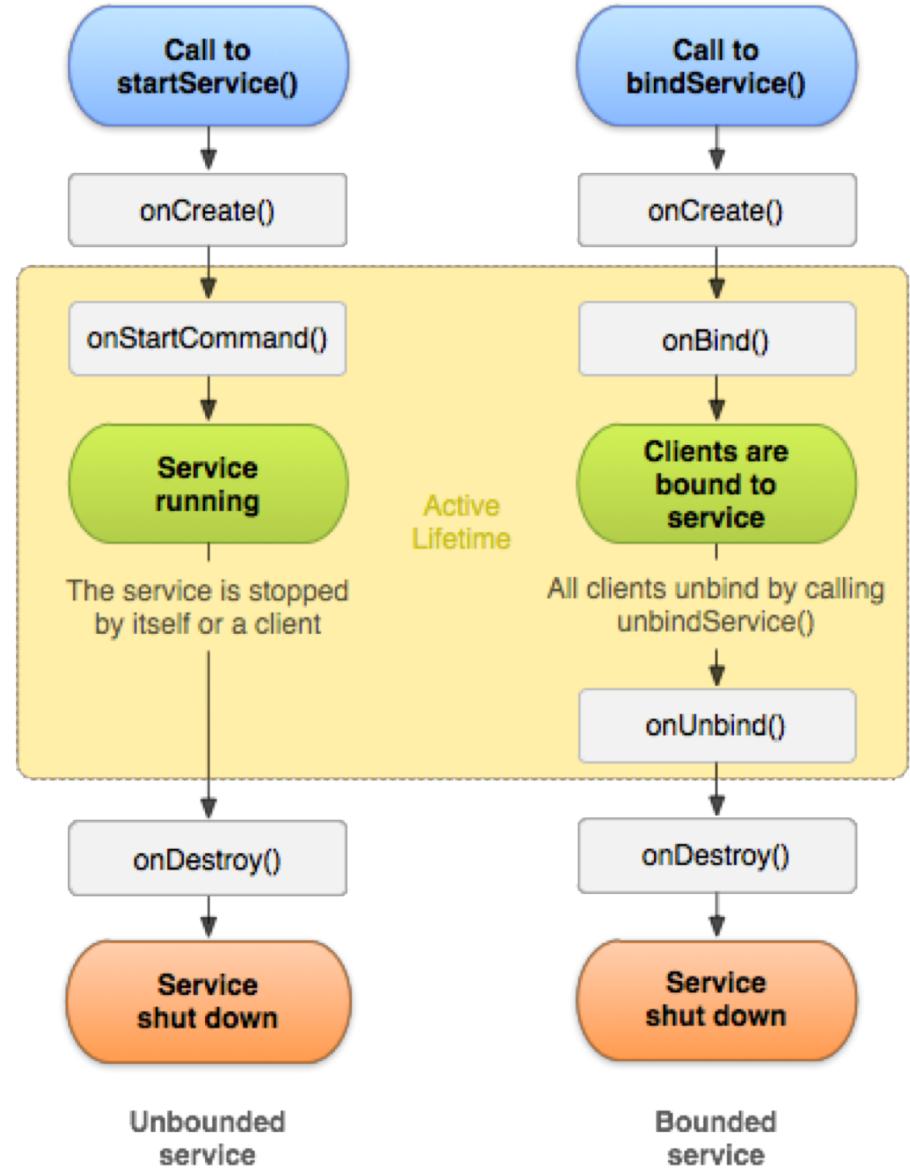


Source: <http://developer.android.com/reference/android/app/Activity.html>

Services

- ▶ Run in the background
 - Should be used if something needs to be done while the user is not interacting with application
 - Should create a new thread in the service to do work in
- ▶ Can be bound to an application
 - It will terminate when all applications bound to it have unbound
 - Multiple applications can communicate with each other via a service
- ▶ Needs to be declared in manifest file

Service Lifecycle



Source: <http://developer.android.com/guide/components/services.html>