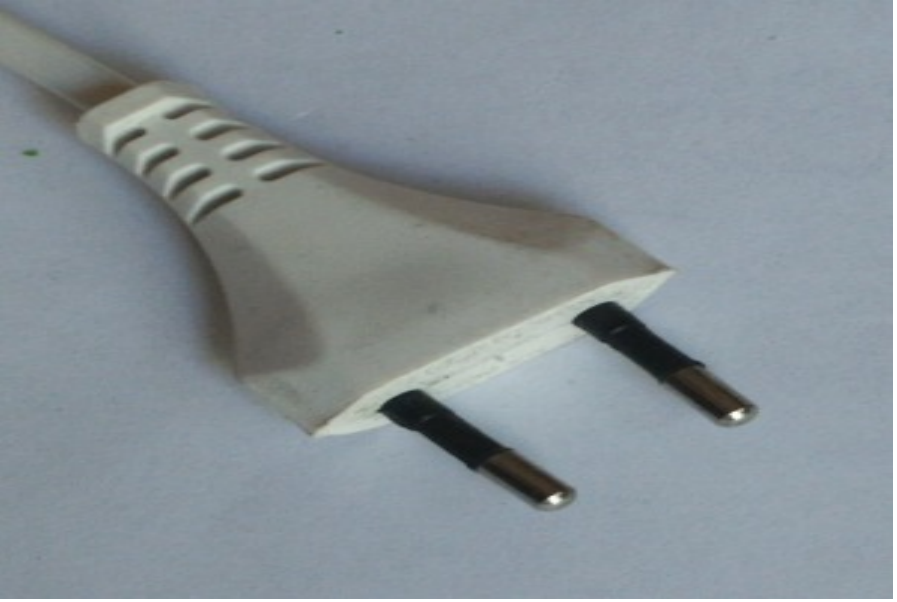


Power management from Linux kernel to Android

Liran Sinay
Yedidel Elhayany

Power Management from Linux Kernel to Android

Agenda

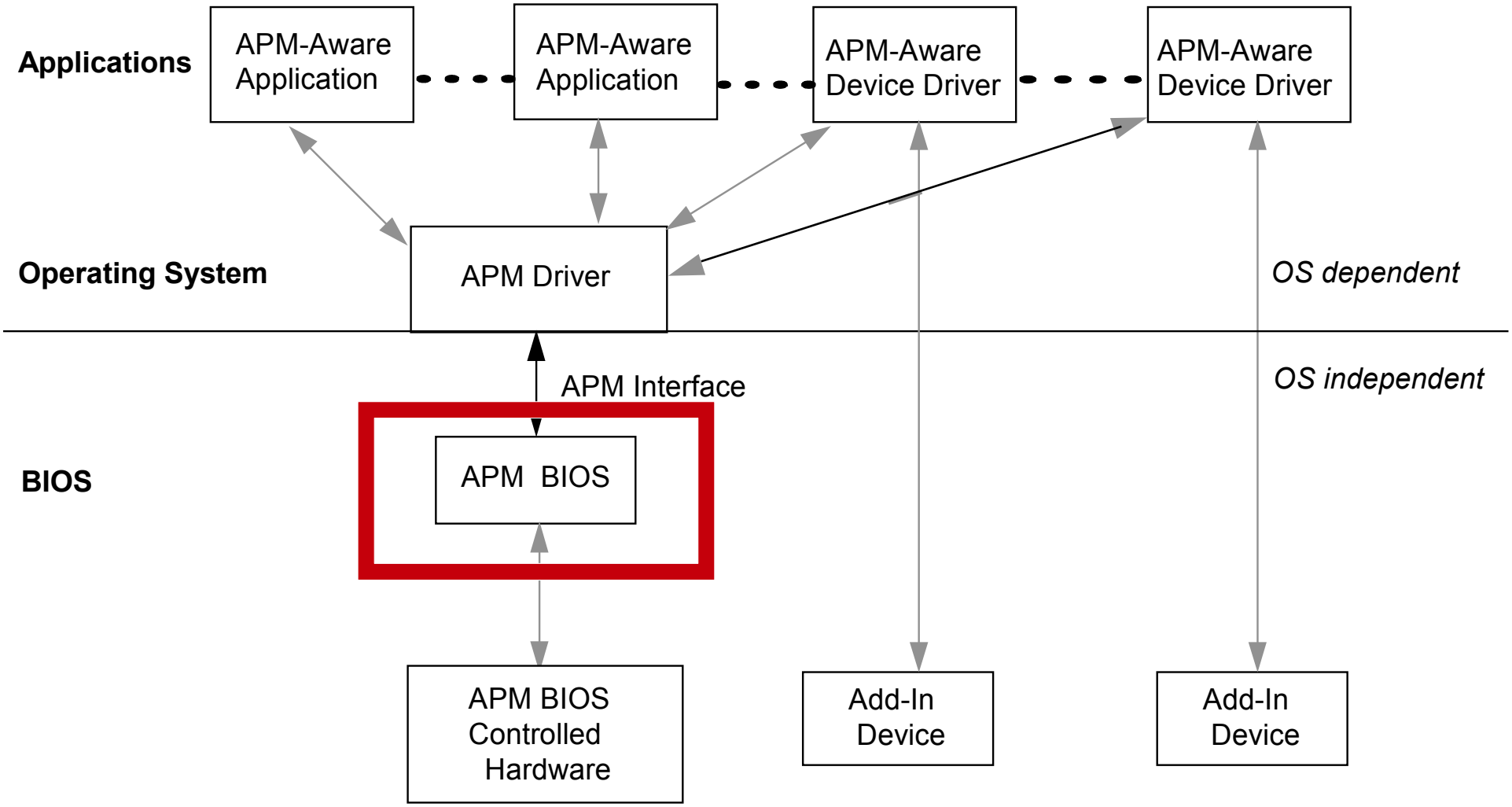
- Introduction to Linux Power Management
- Concepts behind Android Power Management
- Design and Implementation
- Room for Improvements

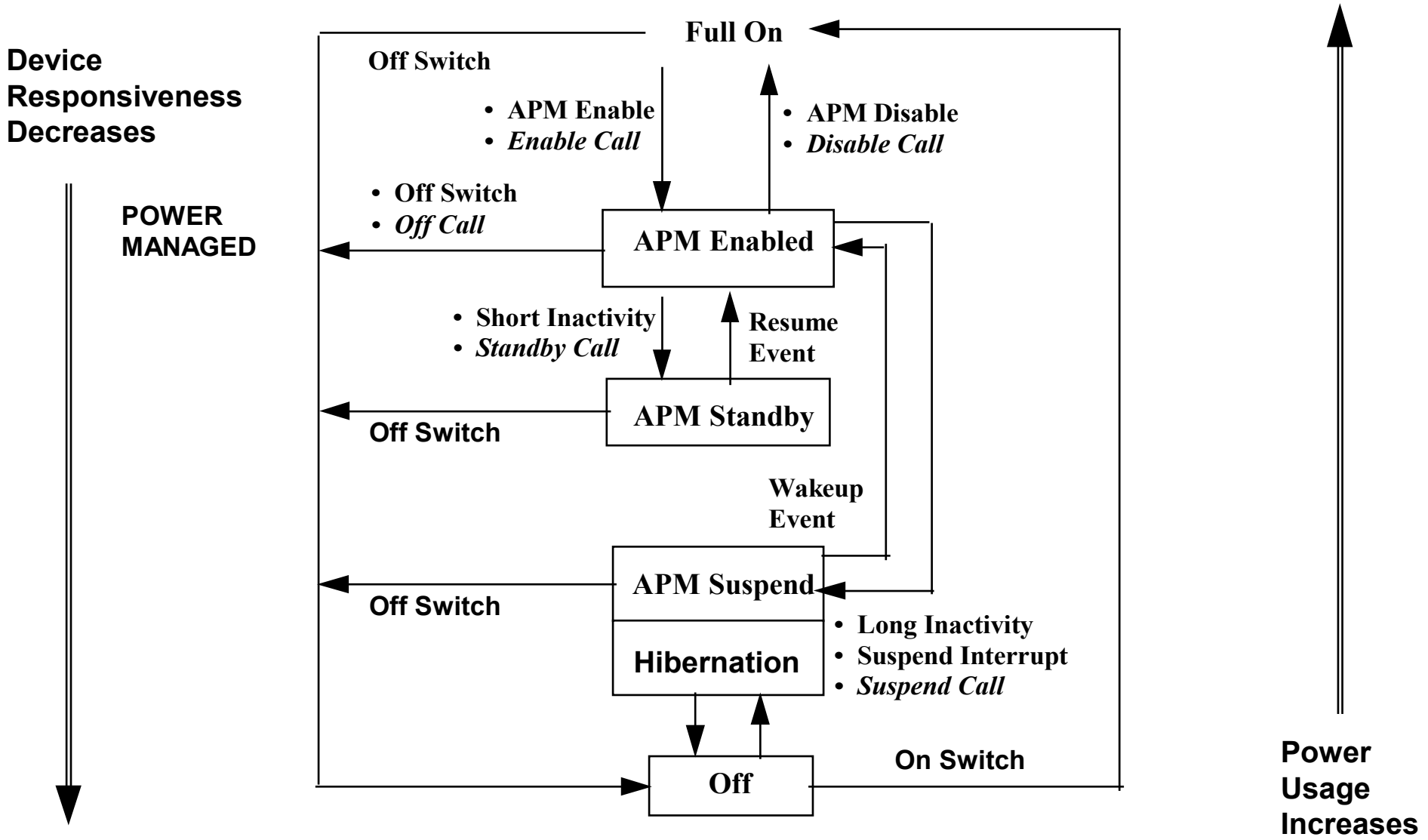
- **Introduction to Linux Power Management**
  - **Goal of Power Management**
  - **APM vs. ACPI**
  - **APM emulation**
  - **No silver bullet**
  - **Manage power in different power state**
  - **Lighthouse in the sea**
- Concepts behind Android Power Management
- Design and Implementation
- Room for Improvements

Power Management Basics

Prolong  Life

Advanced Power Management




Device
Responsiveness
Decreases
POWER
MANAGED
Full On
Off Switch
• APM Enable
• Enable Call
• APM Disable
• Disable Call
• Off Switch
• Off Call
APM Enabled
• Short Inactivity
• Standby Call
Resume
Event
APM Standby
Off Switch
Wakeup
Event
APM Suspend
Off Switch
Hibernation
• Long Inactivity
• Suspend Interrupt
• Suspend Call
Off
On Switch
Power
Usage
Increases

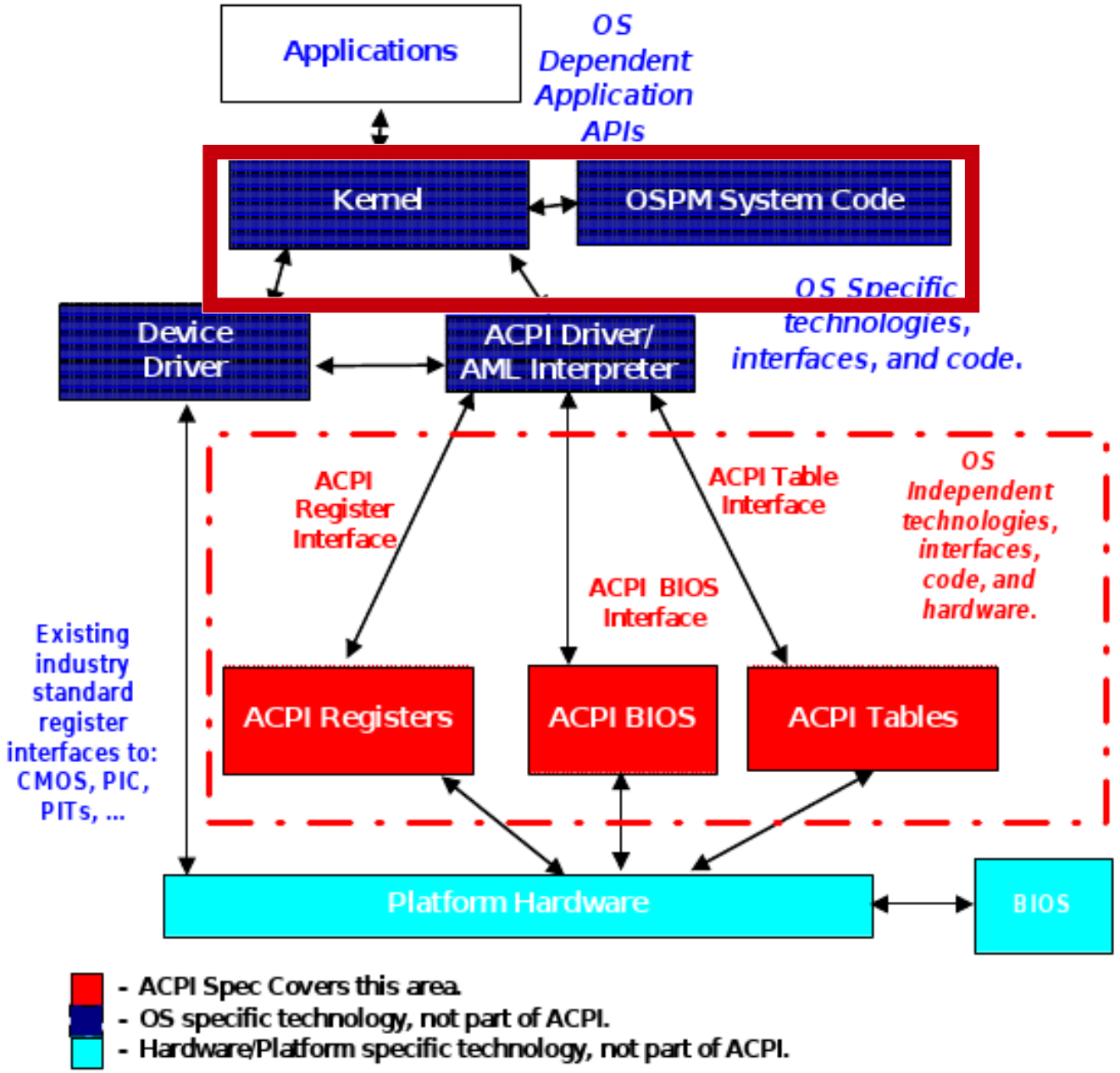
Power management events

Name	Code	Comment
System Standby Request Notification	0x0001	
System Suspend Request Notification	0x0002	
Normal Resume System Notification	0x0003	
Critical Resume System Notification	0x0004	
Battery Low Notification	0x0005	
Power Status Change Notification	0x0006	
Update Time Notification	0x0007	
Critical System Suspend Notification	0x0008	
User System Standby Request Notification	0x0009	
User System Suspend Request Notification	0x000A	
System Standby Resume Notification	0x000B	
Capabilities Change Notification	0x000C	Due to setup or device insertion/removal

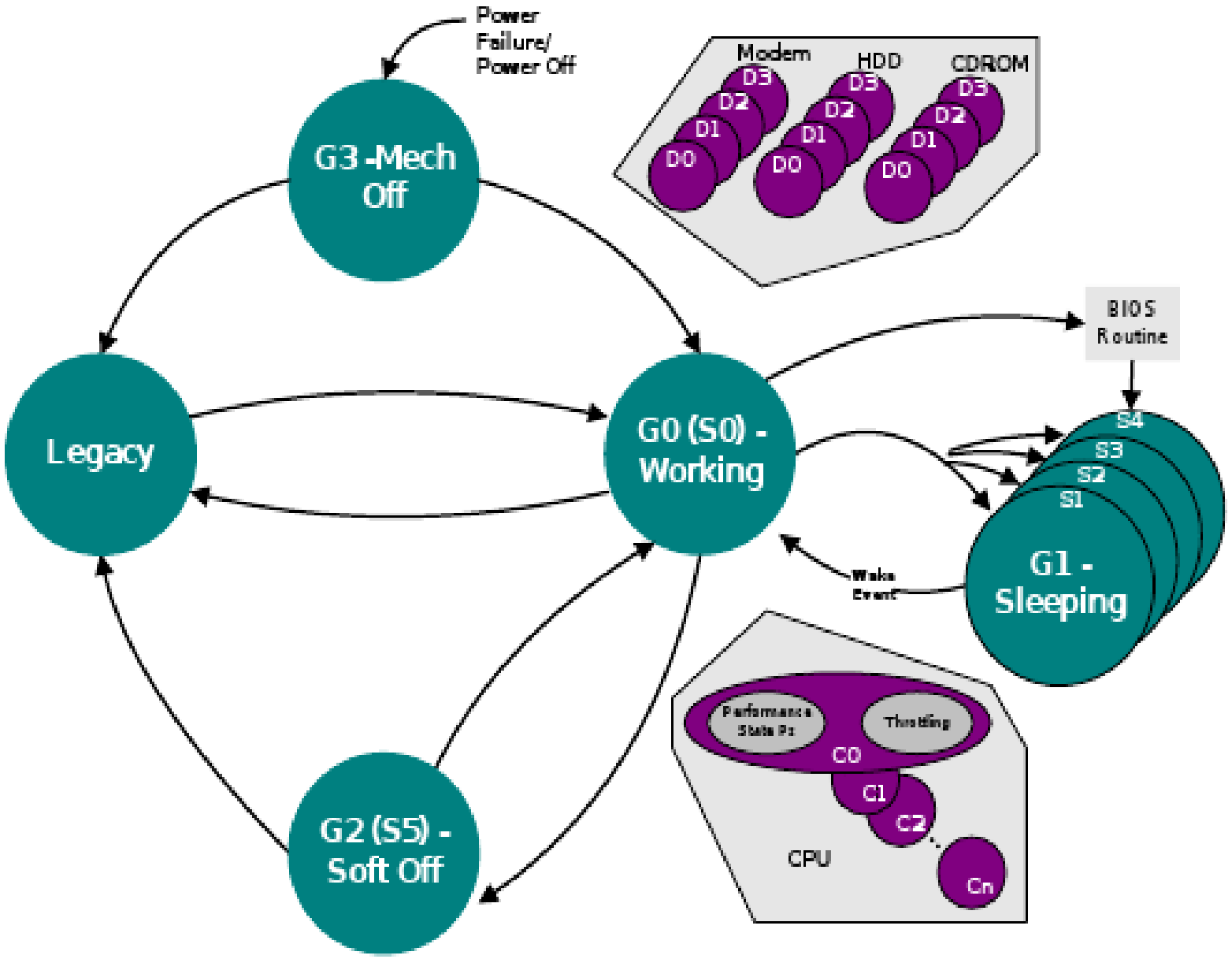
Power management functions

Name	Code	Comment
APM Installation Check	0x00	
APM Real Mode Interface Connect	0x01	
APM Protected Mode 16-bit Interface Connect	0x02	Avoids real or virtual86 mode.
APM Protected Mode 32-bit Interface Connect	0x03	Avoids real or virtual86 mode.
APM Interface Disconnect	0x04	
CPU Idle	0x05	Requests system suspend. 0) Clock halted until timer tick interrupt. 1) Slow clock[1]
CPU Busy	0x06	Driver tells system APM to restore clock speed of the CPU.
Set Power State	0x07	Set system or device into Suspend/Standby/Off state.
Enable/Disable Power Management	0x08	
Restore APM BIOS Power-On Defaults	0x09	
Get Power Status	0x0A	Supports AC status "On backup power". And battery status.
Get PM Event	0x0B	Checks for APM events. Shall be called once per second.
Get Power State	0x0C	
Enable/Disable Device Power Management	0x0D	
APM Driver Version	0x0E	
Engage/Disengage Power Management	0x0F	APM management for a specific device.
Get Capabilities	0x10	
Get/Set/Disable Resume Timer	0x11	
Enable/Disable Resume on Ring Indicator	0x12	
Enable/Disable Timer Based Requests	0x13	
OEM APM Installation Check	0x80	Tells if APM BIOS supports OEM hardware dependent functions.
OEM APM Function	0x80	Access to OEM specific functions.

Advanced Configuration and Power Interface



ACPI Power State Transition



Power states

State	Description
S0/Working	System is on. The CPU is fully up and running; power conservation operates on a per-device basis.
S1 Sleep	System appears off. The CPU is stopped; RAM is refreshed; the system runs in a low power mode.
S2 Sleep	System appears off. The CPU has no power; RAM is refreshed; the system uses a lower power mode than S1.
S3 Sleep (Standby)	System appears off. The CPU has no power; RAM is in slow refresh; the power supply is in a reduced power mode. This mode is also referred to[*by whom?*] as 'Save To RAM'.
S4 Hibernate	System appears off. The hardware is completely off, but system memory has been saved as a temporary file onto the harddisk. This mode is also referred to as 'Save To Disk'.
S5/Off	System is off. The hardware is completely off, the operating system has shut down; nothing has been saved. Requires a complete reboot to return to the Working state.
Source	http://www.lifsoft.com/power/faq.htm

APM vs. ACPI

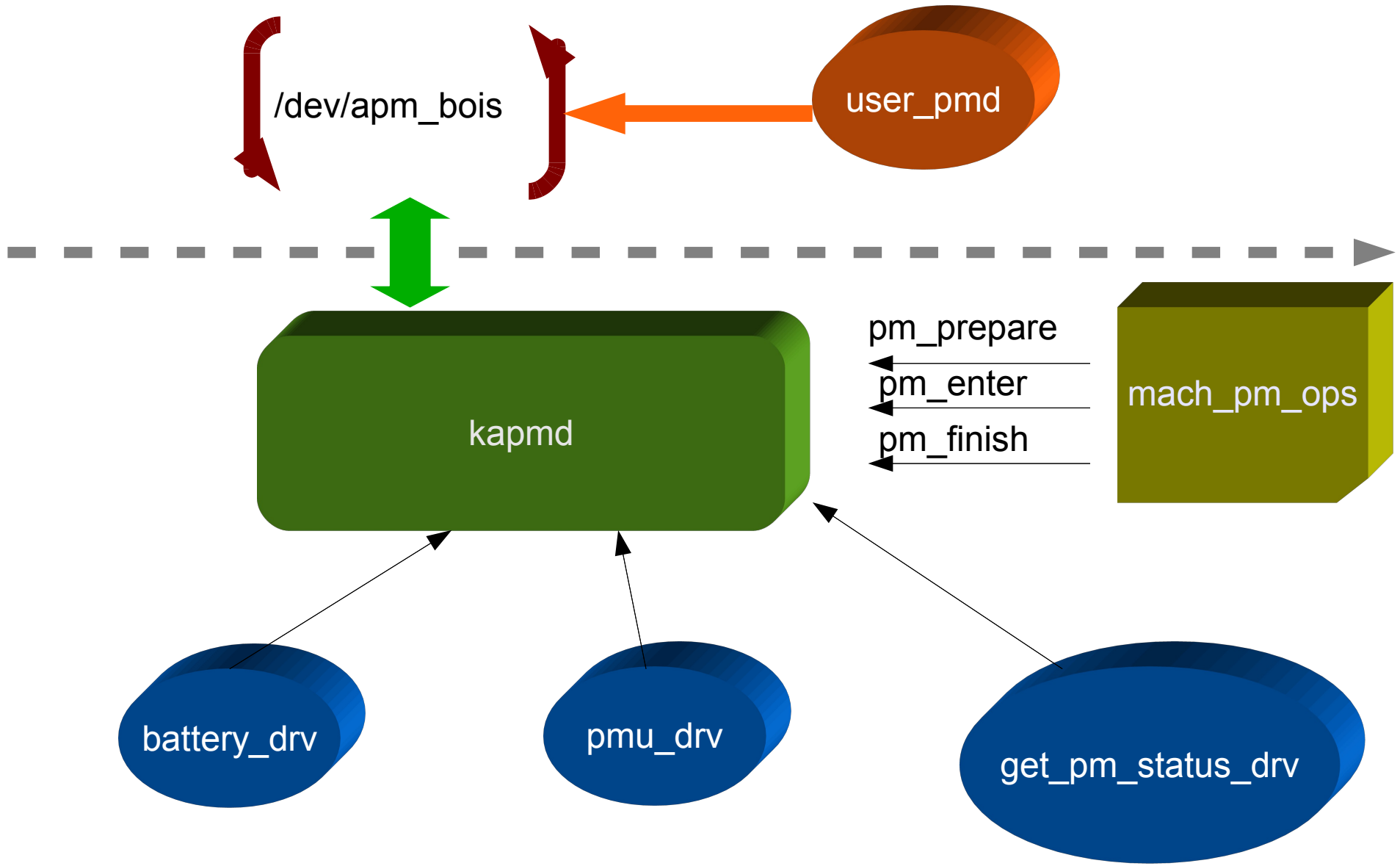
APM

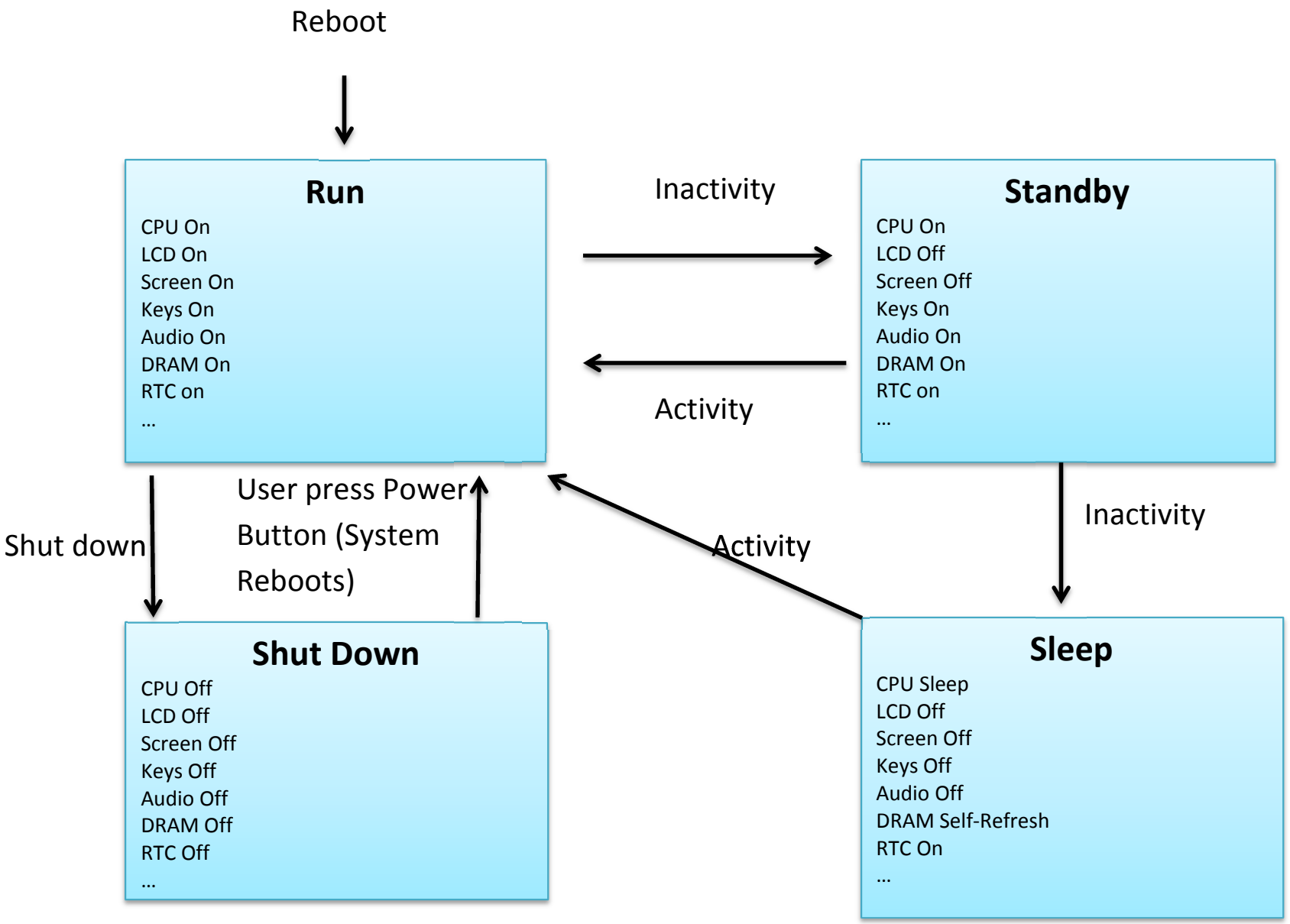
- Control resides in BIOS
- Uses activity timeouts to determine when to power down a device
- BIOS rarely used in embedded systems
- Makes power-management decisions without informing OS or individual applications
- No knowledge of add-in cards or new devices (e.g. USB, IEEE 1394)

ACPI

- Control divided between BIOS and OS
- Decisions managed through the OS
- Enables sophisticated power policies for general-purpose computers with standard usage patterns and hardware
- No knowledge of device-specific scenarios (e.g. need to provide predictable response times or to respond to critical events over extended period)

APM emulation




Reboot
Run
CPU On
LCD On
Screen On
Keys On
Audio On
DRAM On
RTC on
…
Inactivity
Activity
Standby
CPU On
LCD Off
Screen Off
Keys On
Audio On
DRAM On
RTC on
…
Shut down
User press Power Button (System Reboots)
Activity
Inactivity
Shut Down
CPU Off
LCD Off
Screen Off
Keys Off
Audio Off
DRAM Off
RTC Off
…
Sleep
CPU Sleep
LCD Off
Screen Off
Keys Off
Audio Off
DRAM Self-Refresh
RTC On
…

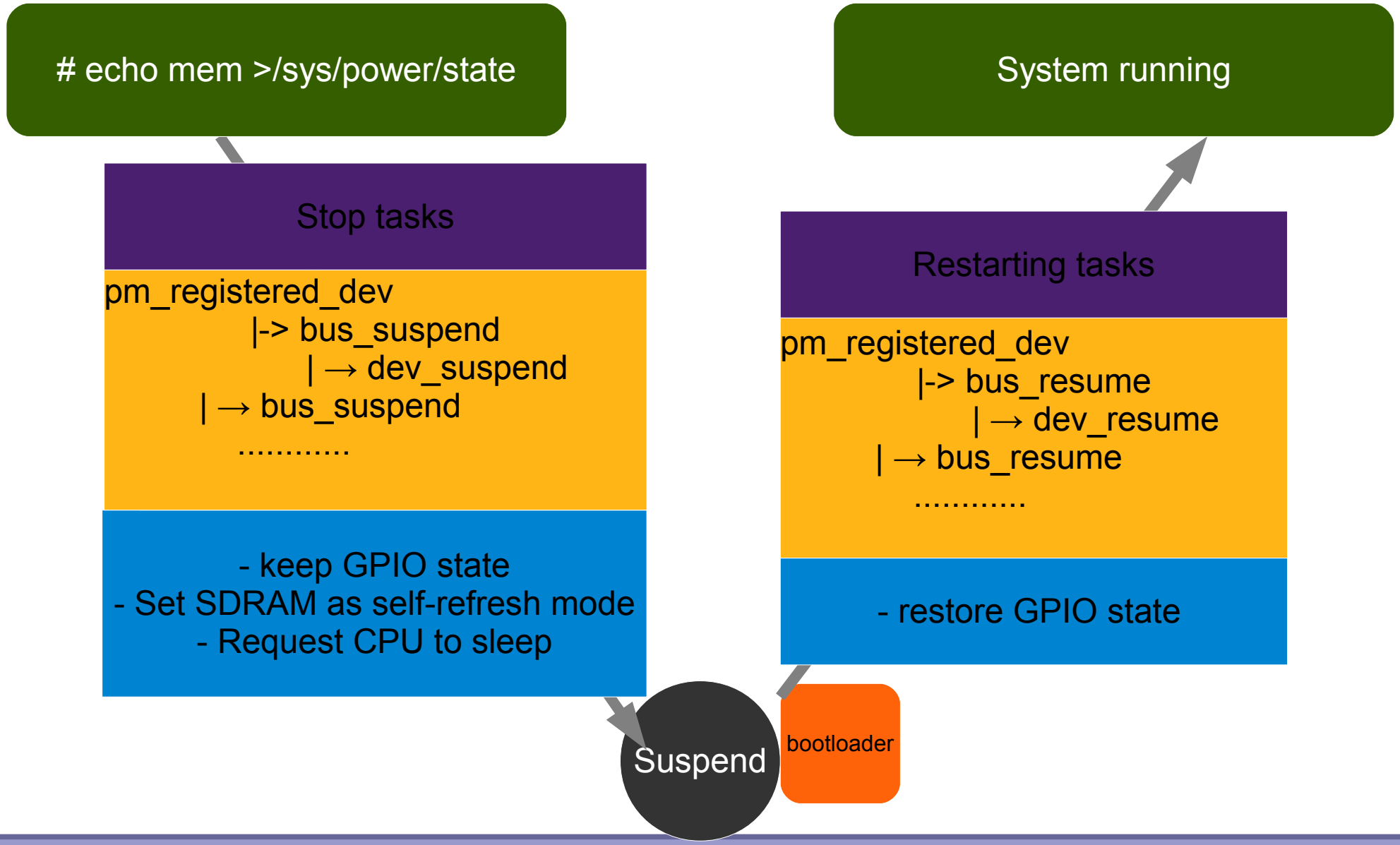
Runtime / Standby

- Application-driven power management
- Micro manage your device
  - WiFi -enable PS poll mode
  - Switch on/off device by demand (Android's concept)
  - Gating off unused device clock
- Keep the flexibility of CPU
  - Gating CPU freq dynamically
  - Tickless idle
  - Using DMA instead PIO

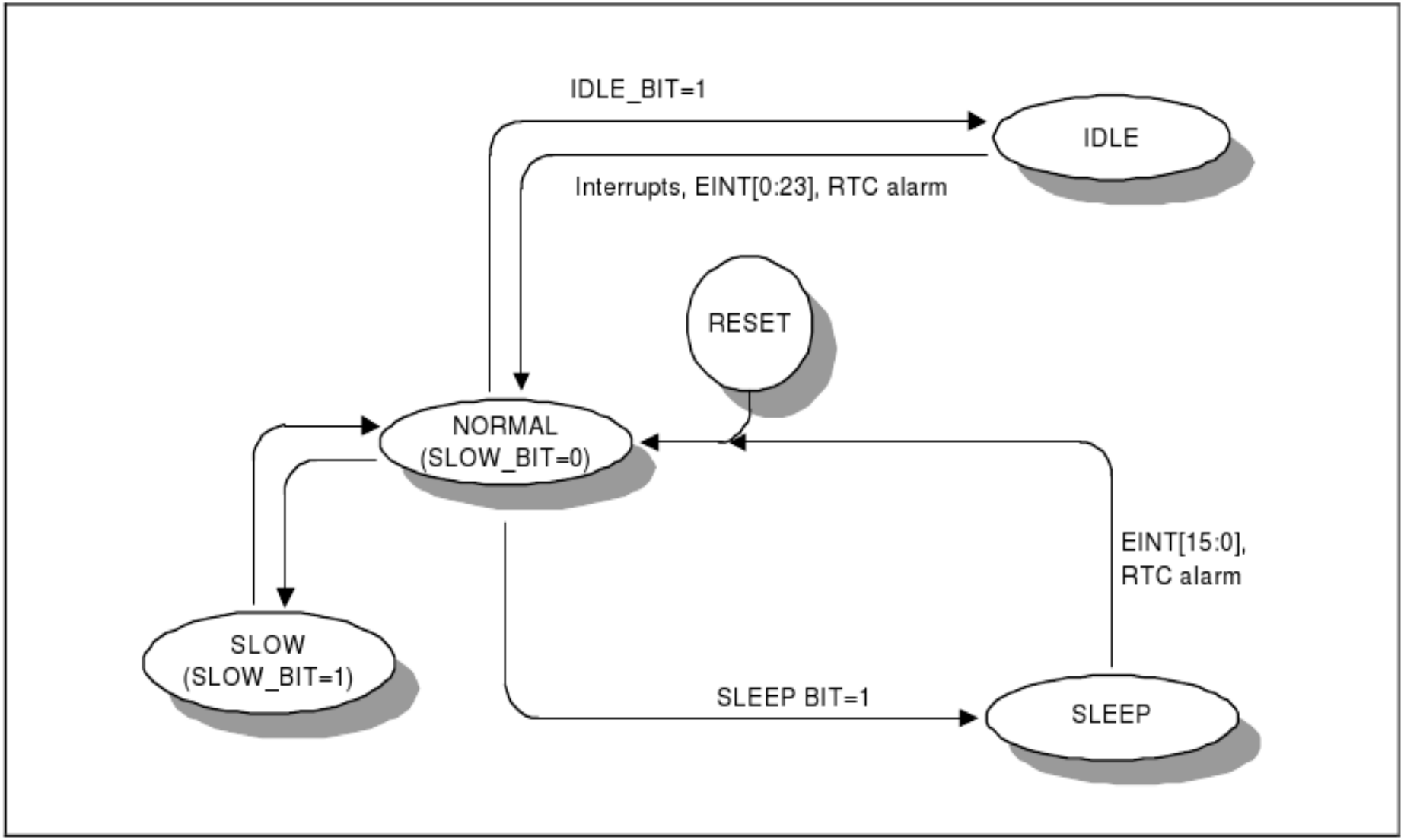
Suspend/Sleep Mode

- STR vs STD
  - Suspend to RAM
  - Suspend to Disk/Hibernate
- STR: A technique by which systems preserve state in RAM during suspend and restore system state from RAM upon resume
- STR is suitable for mobile device if hardware supports this function

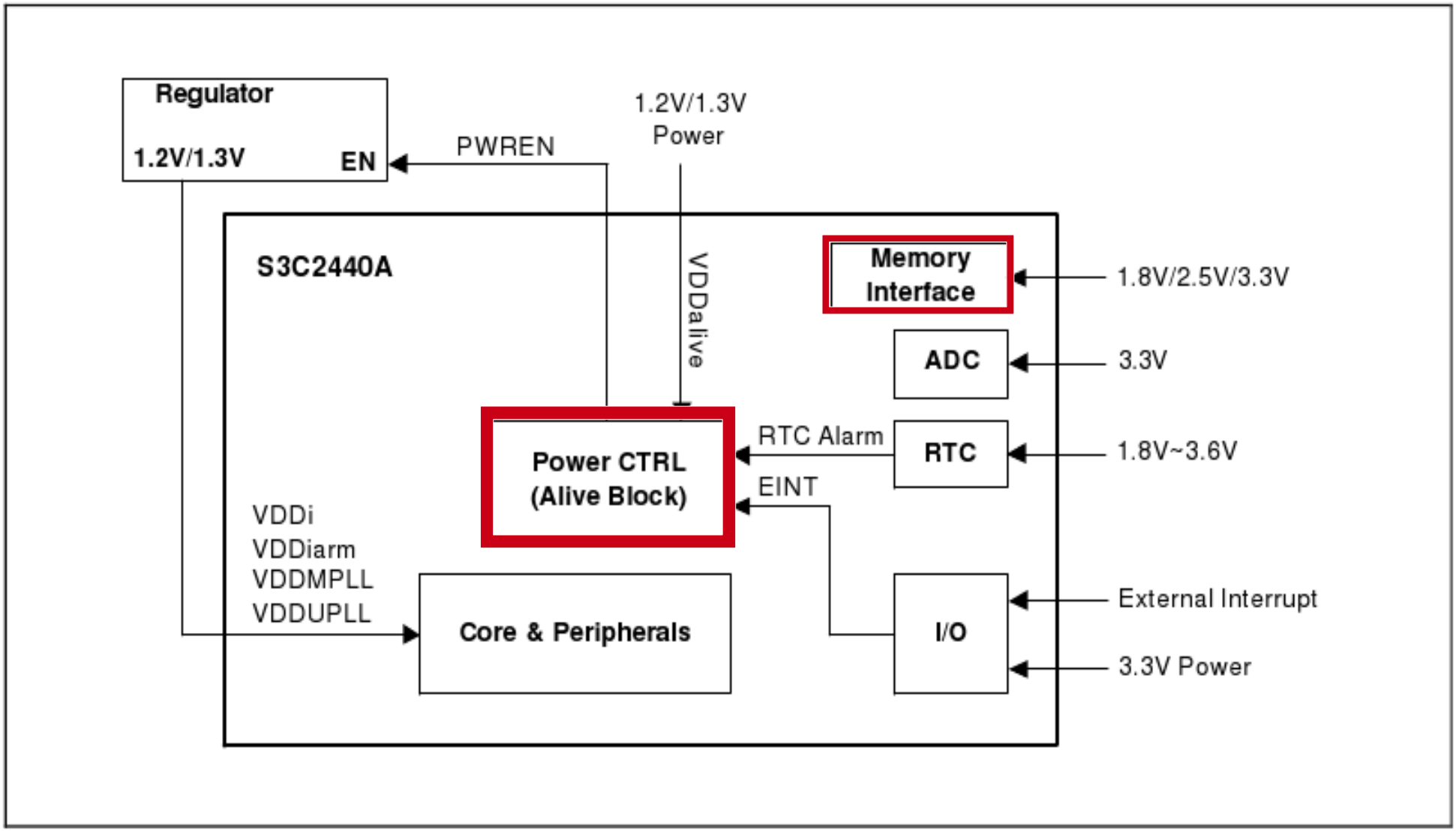
Suspend/Resume Control Path



Practical Example -S3C244x (1)



Practical Example -S3C244x (2)



A ship on the beach is a lighthouse to the sea

- Provide a kernel module to dump and check GPIOs
- Provide power source as independent as possible
- Don't ignore the poweroff state
- To most difficult part of debugging STR is resuming

- Introduction to Linux Power Management
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  - Basically, it is the slim wrapper for Linux Power Management
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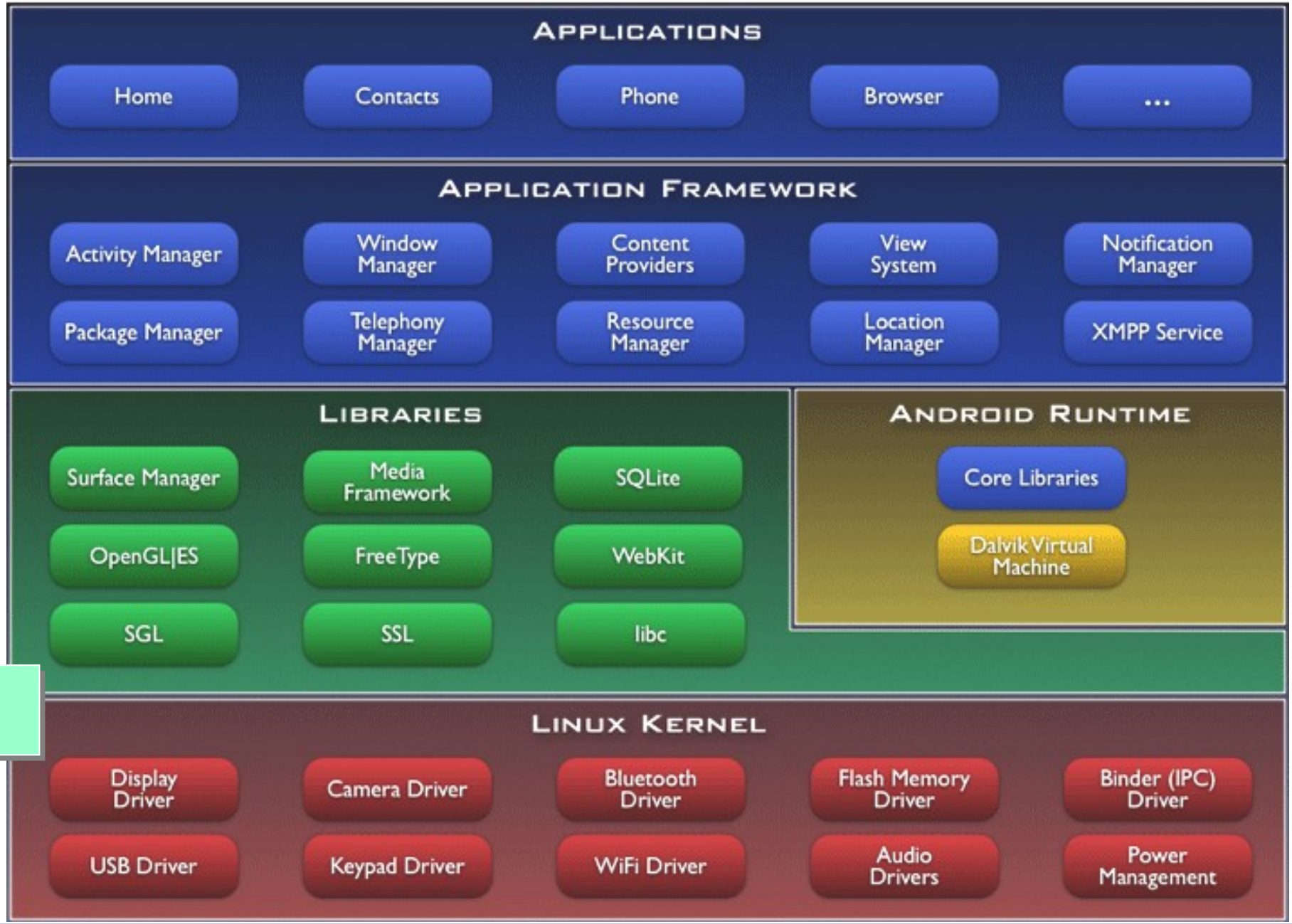
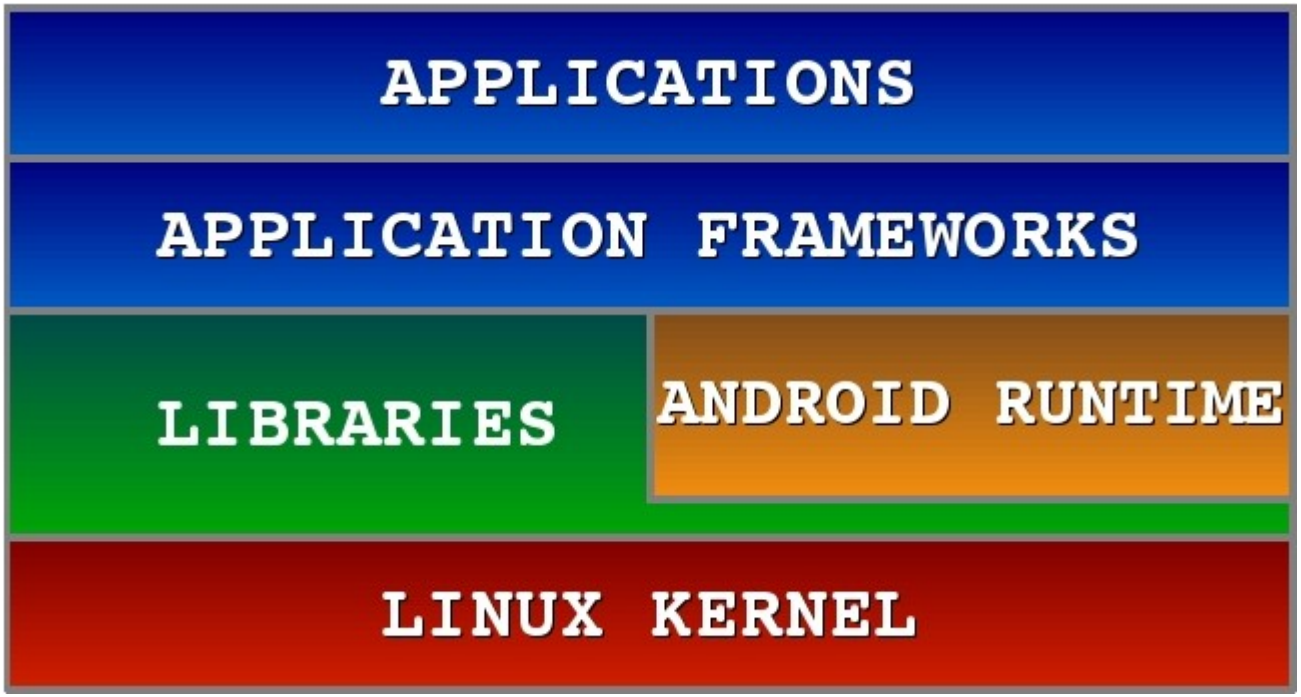
Where is Power Manager?



PM?

In fact, power ghost exists everywhere

- Let "**`grep -ri power`**" tell you about the details!
- It is layered into several components, but implementation involves in some hacks.
- Check: CONFIG_PM, sysfs, device drivers, libhardware_legacy, libril, init.rc, powerd, alarm, vold, JNI, PowerManager, BatteryManager, ...



Base: Linux Kernel

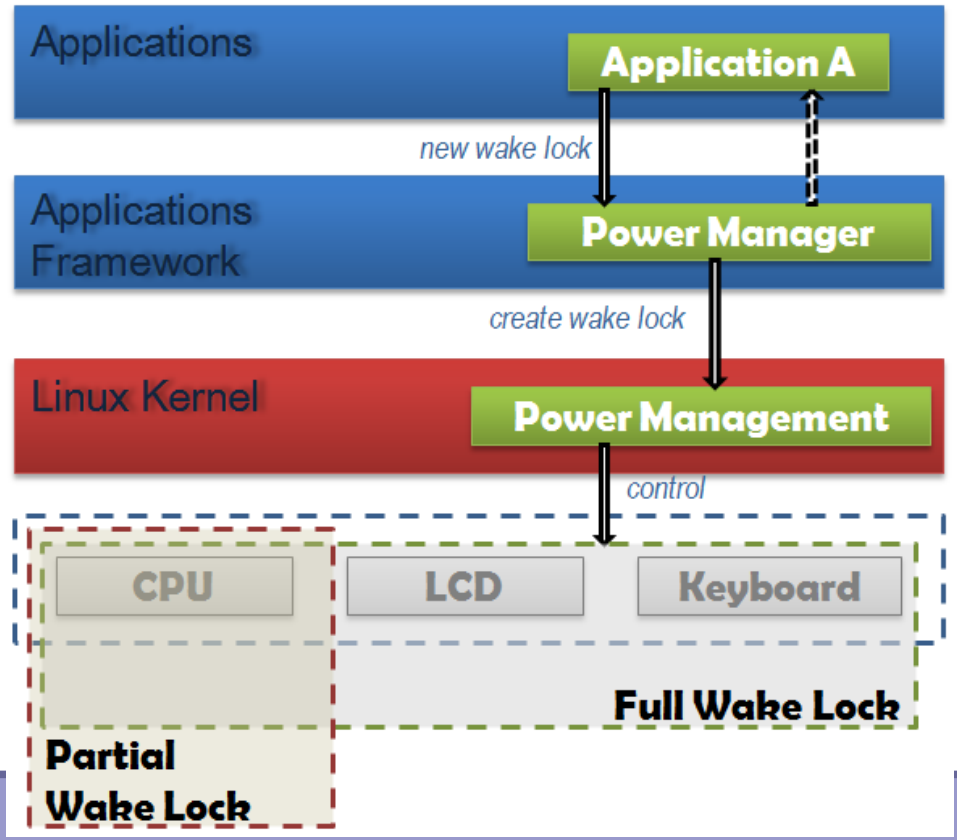
Directory: arch/arm/mach-omap2/
board-omap3beagle.c
gpmc.c
pm.[ch]

- Android does rely on Linux Kernel 2.6 for core system services
  - Memory/Process Management
  - Device Driver Model
  - sysfs, kobject/uevent, netlink
- Android Kernel extensions
  - Binder
  - android_power
    - /sys/android_power/, /sys/power/

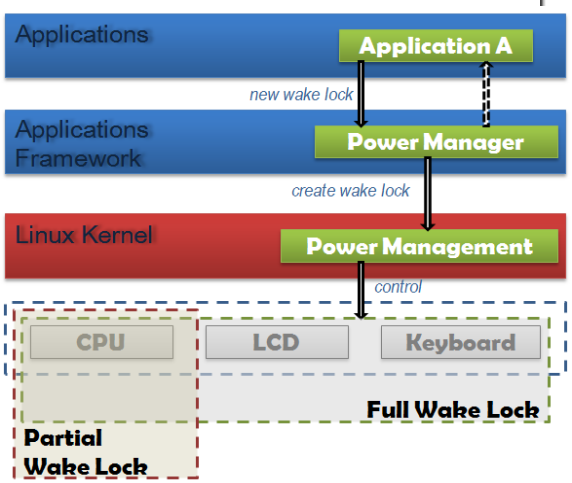
Key Idea: Android attempts to provide an abstraction layer between hardware and the related software stack.

Android's PM Concepts

- Android PM is built on top of standard Linux Power Management.
- It can support more aggressive PM, but looks fairly simple now.
- Components make requests to keep the power on through "**Wake Locks**".
  - PM does support several types of "Wake Locks".



- If there are no active wake locks, CPU will be turned off.
- If there is are partial wake locks, screen and keyboard will be turned off.



Applications

Application A

Application B

Application C

```
WI = newWakeLock(…);
WI.acquire();
WI.release();
```

Applications Framework

PowerManager
Android.os.PowerManager

Power
Android.os.Power

PowerManagerService
Andorid.server.PowerManagerService

JNI

Libraries (user space)

Core Libraries

X

Power
/lib/hardware/power.c

Linux Kernel

Linux Drivers

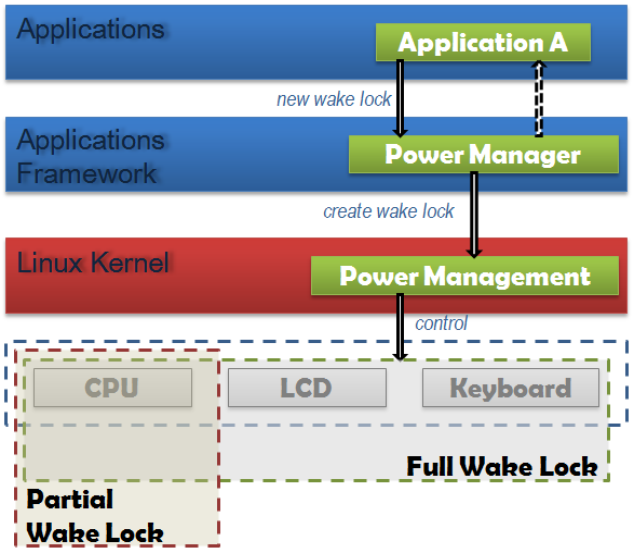
Android Power Management
/drivers/android/power.c

Android_register_early_suspend()
Android_register_early_resume()

Linux Power Management

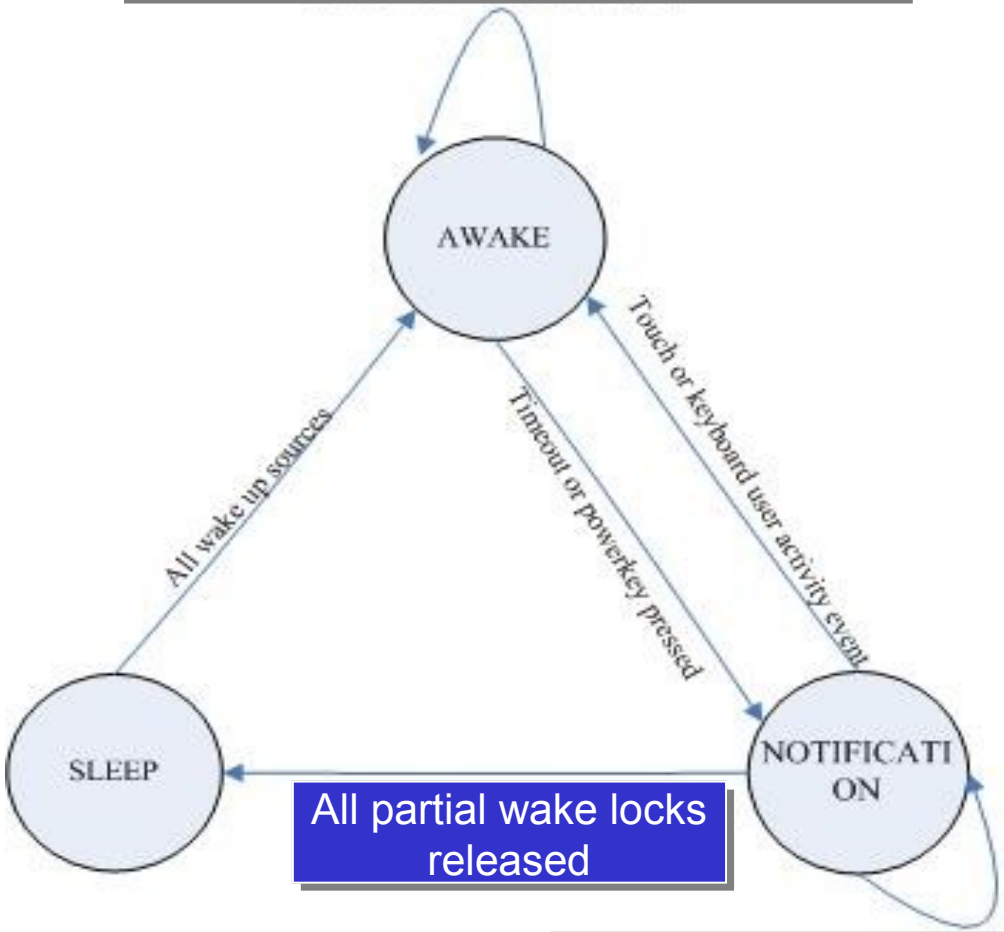
Types of Wake Locks

- ACQUIRE_CAUSES_WAKEUP
  - Normally wake locks don't actually wake the device, they just cause it to remain on once it's already on. Think of the video player app as the normal behavior.
- FULL_WAKE_LOCK
  - Wake lock that ensures that the screen and keyboard are on at full brightness.
- ON_AFTER_RELEASE
  - When this wake lock is released, poke the user activity timer so the screen stays on for a little longer.
- PARTIAL_WAKE_LOCK
  - Wake lock that ensures that the CPU is running. The screen might not be on.
- SCREEN_BRIGHT_WAKE_LOCK
  - Wake lock that ensures that the screen is on at full brightness; the keyboard backlight will be allowed to go off.
- SCREEN_DIM_WAKE_LOCK
  - Wake lock that ensures that the screen is on, but the keyboard backlight will be allowed to go off, and the screen backlight will be allowed to go dim.



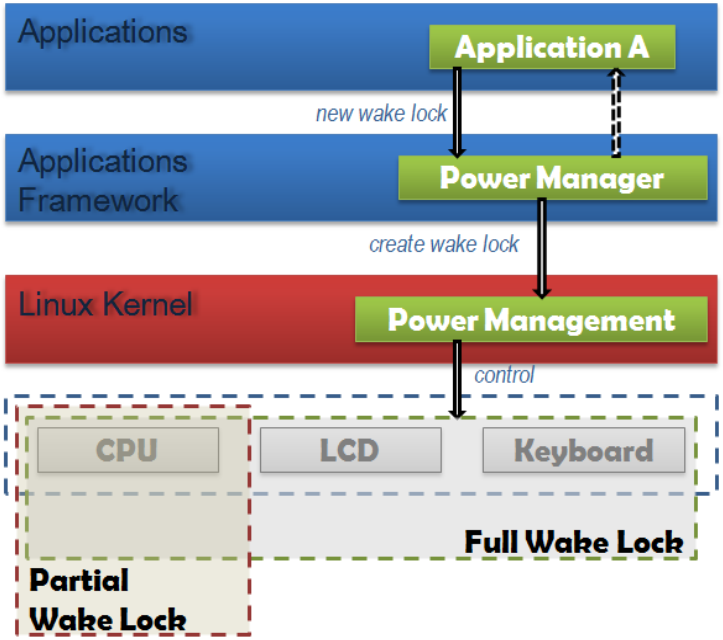
PM State Machine

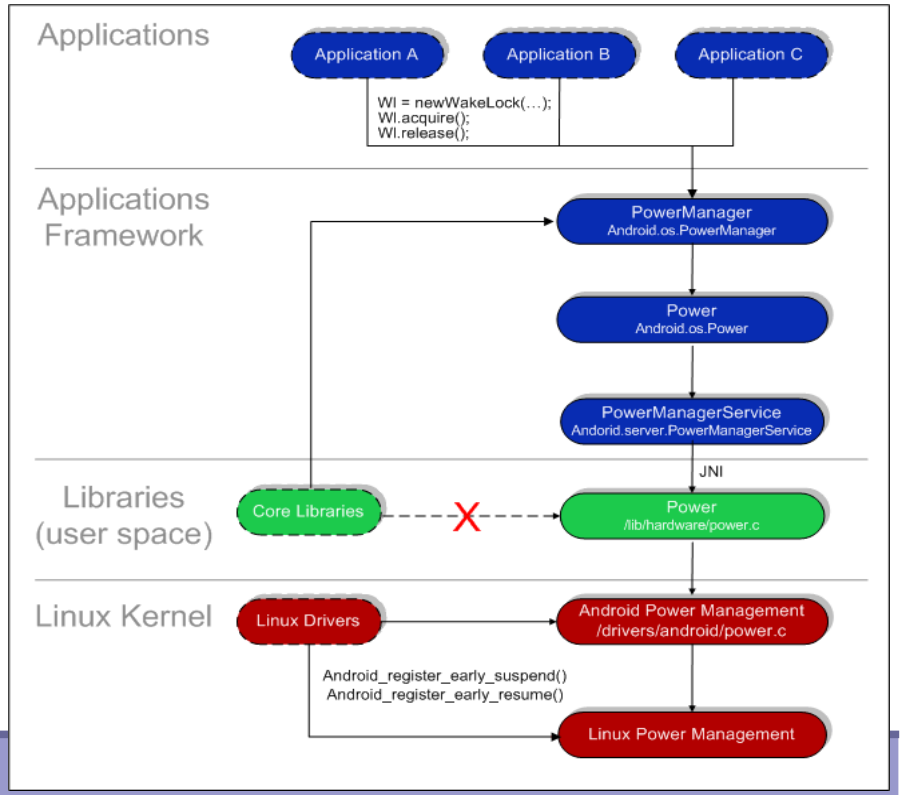
Touchscreen or keyboard user activity event or full wake locks acquired.



All partial wake locks released

Partial wake locks acquired





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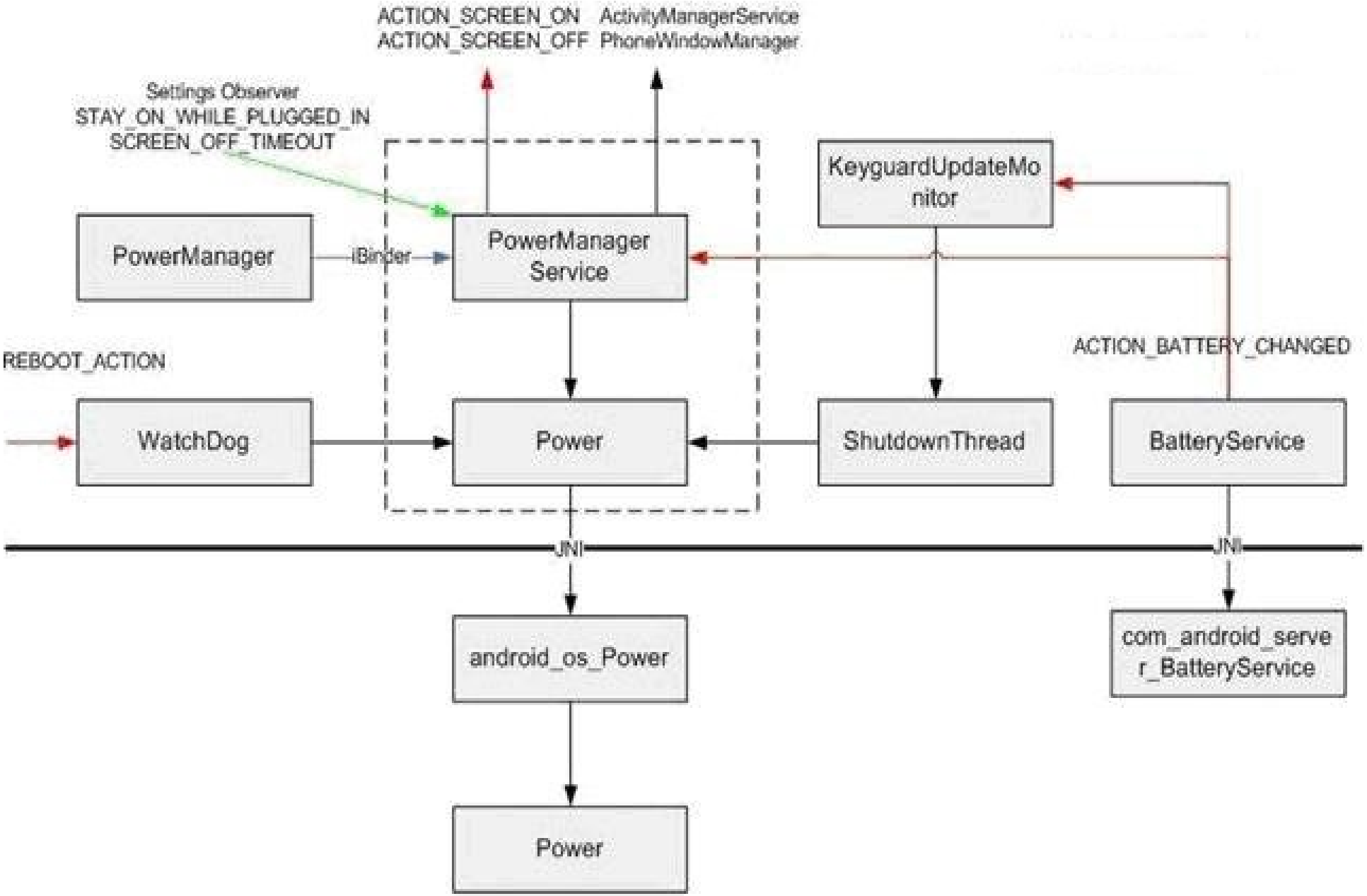
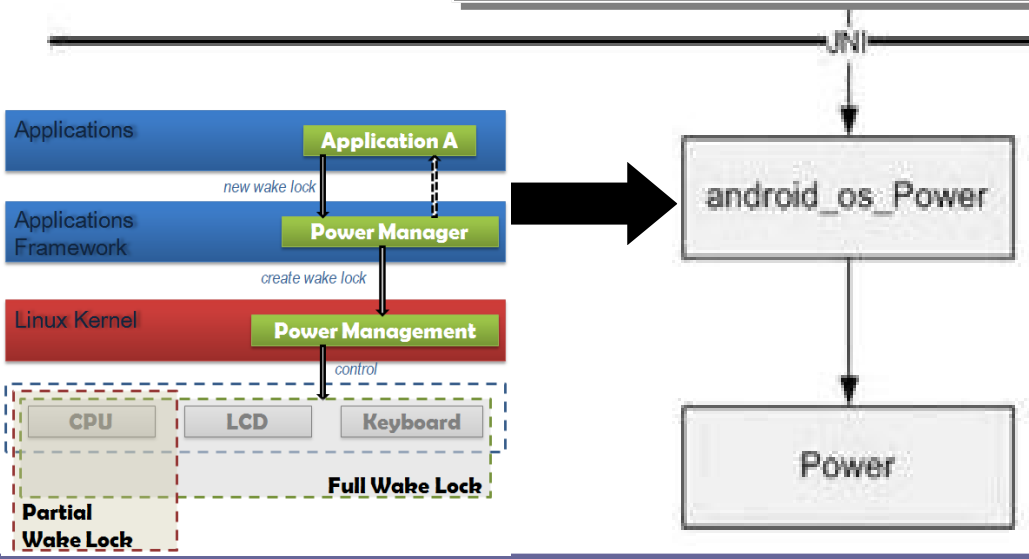
Design and Implementation



android_os_Power

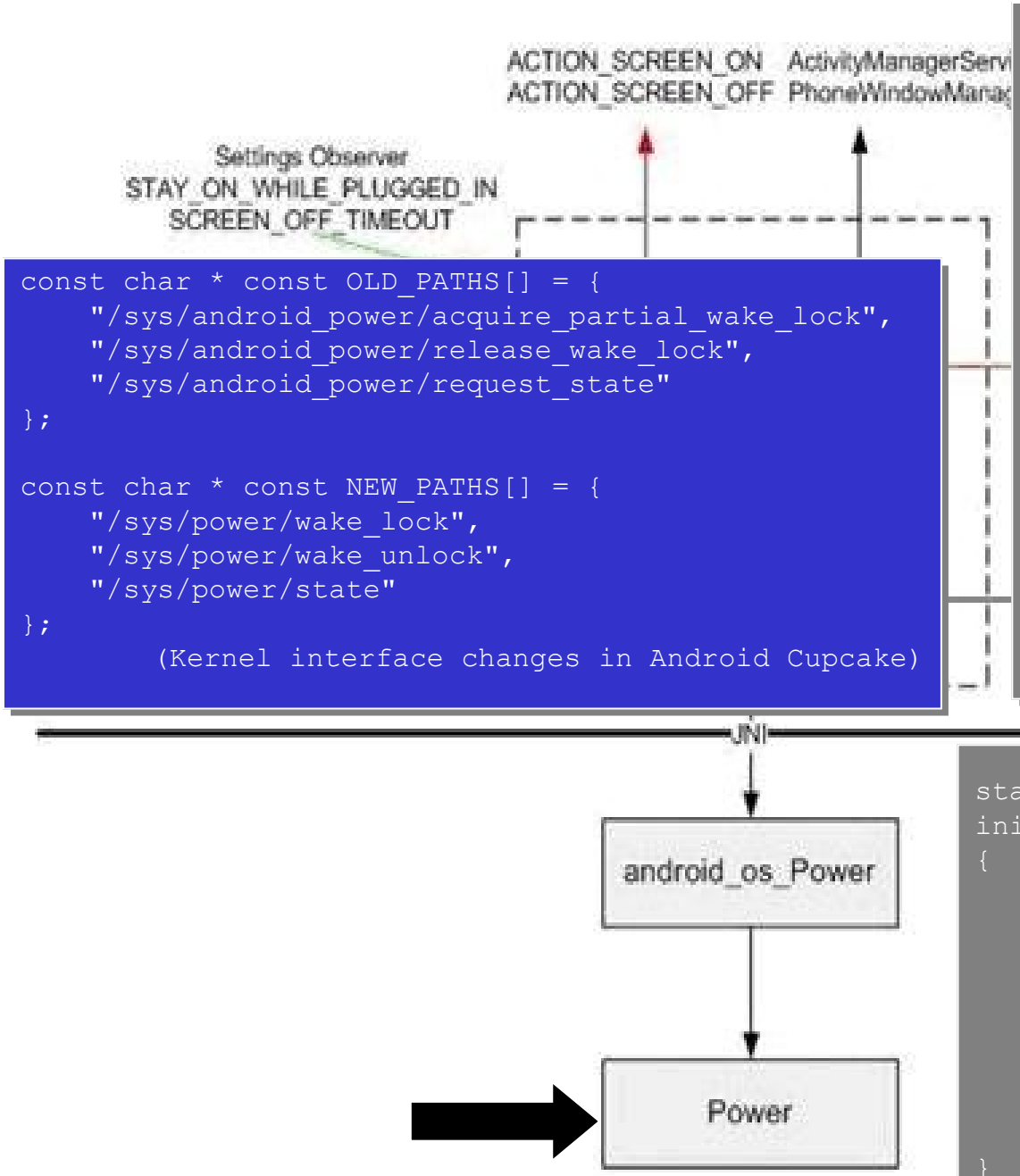
frameworks/base/core/jni/android_os_Power.cpp

```
...
static JNINativeMethod method_table[] = {
    { "acquireWakeLock", "(ILjava/lang/String;)V", (void*)acquireWakeLock },
    { "releaseWakeLock", "(Ljava/lang/String;)V", (void*)releaseWakeLock },
    { "setLastUserActivityTimeout", "(J)I", (void*)setLastUserActivityTimeout },
    { "setLightBrightness", "(II)I", (void*)setLightBrightness },
    { "setScreenState", "(Z)I", (void*)setScreenState },
    { "shutdown", "()V", (void*)android_os_Power_shutdown },
    { "reboot", "(Ljava/lang/String;)V", (void*)android_os_Power_reboot },
};

int register_android_os_Power(JNIEnv *env)
{
    return AndroidRuntime::registerNativeMethods(
        env, "android/os/Power",
        method_table, NELEM(method_table));
}
```




```
static void
acquireWakeLock(JNIEnv *env, jobject clazz,
                jint lock, jstring idObj)
{
    if (idObj == NULL) {
        throw_NullPointerException(env, "id is null");
        return ;
    }

    const char *id = env->GetStringUTFChars(idObj, NULL);

    acquire_wake_lock(lock, id);

    env->ReleaseStringUTFChars(idObj, id);
}
```

Power




```
const char * const OLD_PATHS[] = {
    "/sys/android_power/acquire_partial_wake_lock",
    "/sys/android_power/release_wake_lock",
    "/sys/android_power/request_state"
};

const char * const NEW_PATHS[] = {
    "/sys/power/wake_lock",
    "/sys/power/wake_unlock",
    "/sys/power/state"
};
```

(Kernel interface changes in Android Cupcake)

hardware/libhardware_legacy/power/power.c

```
...
int
acquire_wake_lock(int lock, const char* id)
{
    initialize_fds();
    if (g_error) return g_error;

    int fd;
    if (lock == PARTIAL_WAKE_LOCK) {
        fd = g_fds[ACQUIRE_PARTIAL_WAKE_LOCK];
    }
    else {
        return EINVAL;
    }
    return write(fd, id, strlen(id));
}
```

```
static inline void
initialize_fds(void)
{
    if (g_initialized == 0) {
        if(open_file_descriptors(NEW_PATHS) < 0) {
            open_file_descriptors(OLD_PATHS);
            on_state = "wake";
            off_state = "standby";
        }
        g_initialized = 1;
    }
}
```

Android PM Kernel APIs

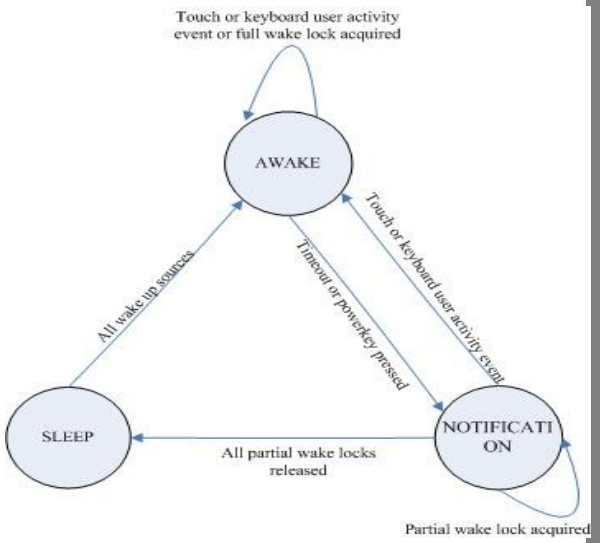
- Source code (Cupcake, linux-2.6.27)
  - kernel/kernel/power/userwake.c
  - kernel/kernel/power/wakelock.c

```
static int power_suspend_late(
     struct platform_device *pdev,
     pm_message_t state)
{
     int ret =
          has_wake_lock(WAKE_LOCK_SUSPEND) ?
          -EAGAIN : 0;
     return ret;
}

static struct platform_driver power_driver = {
     .driver.name = "power",
     .suspend_late = power_suspend_late,
};
static struct platform_device power_device = {
     .name = "power",
};
```

```
static long has_wake_lock_locked(int type)
{
     struct wake_lock *lock, *n;
     long max_timeout = 0;
     BUG_ON(type >= WAKE_LOCK_TYPE_COUNT);
     list_for_each_entry_safe(lock, n,
                &active_wake_locks[type], link) {
          if (lock->flags & WAKE_LOCK_AUTO_EXPIRE) {
                long timeout = lock->expires - jiffies;
                if (timeout <= 0)
                     expire_wake_lock(lock);
                else if (timeout > max_timeout)
                     max_timeout = timeout;
          } else
                return -1;
     }
     return max_timeout;
}

long has_wake_lock(int type)
{
     long ret;
     unsigned long irqflags;
     spin_lock_irqsave(&list_lock, irqflags);
     ret = has_wake_lock_locked(type);
     spin_unlock_irqrestore(&list_lock, irqflags);
     return ret;
}
```

Android PM Kernel APIs

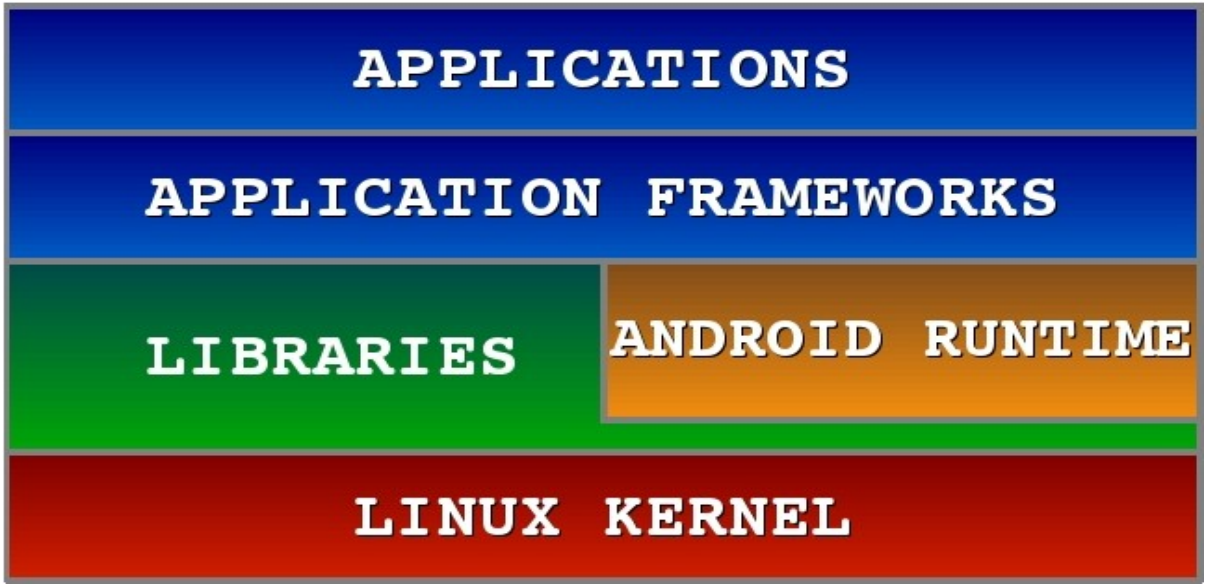
- kernel/kernel/power/wakelock.c




```
static int __init wakelocks_init(void)
{
	int ret;
	int i;

	for (i = 0; i < ARRAY_SIZE(active_wake_locks); i++)
		INIT_LIST_HEAD(&active_wake_locks[i]);


	wake_lock_init(&main_wake_lock, WAKE_LOCK_SUSPEND, "main");
	wake_lock(&main_wake_lock);
	wake_lock_init(&unknown_wakeup, WAKE_LOCK_SUSPEND, "unknown_wakeups");

	ret = platform_device_register(&power_device);
	if (ret) {
		pr_err("wakelocks_init: platform_device_register failed\n");
		goto err_platform_device_register;
	}
	ret = platform_driver_register(&power_driver);
	if (ret) {
		pr_err("wakelocks_init: platform_driver_register failed\n");
		goto err_platform_driver_register;
	}

	suspend_work_queue = create_singlethread_workqueue("suspend");
	if (suspend_work_queue == NULL) {
		ret = -ENOMEM;
		goto err_suspend_work_queue;
	}
```

Back to userspace

- Use "**`grep -r acquire_wake_lock`**" to discover.
  - frameworks/base/libs/ui/EventHub.cpp
    - EventHub::EventHub(), EventHub::~EventHub(), EventHub::getEvent()
  - hardware/ril/libril/ril.cpp
    - RIL_onUnsolicitedResponse(),
  - system/wlan/ti/sta_dk_4_0_4_32/CUDK/tiwlan_loader/tiwlan_loader.c
    - start_cli()



Back to userspace

- Use “**`grep -ri power`**” to discover.
  - base/core/jni/android_net_wifi_Wifi.cpp
    - android.net.wifi.WifiNative.setPowerModeCommand (android_net_wifi_setPowerModeCommand)
  - base/core/java/com/android/internal/os/BatteryStats.java
  - base/core/java/com/android/internal/os/BatteryStatsImpl.java
  - base/core/java/com/android/os/PowerManager.java
  - base/core/java/com/android/os/LocalPowerManager.java
  - base/core/java/com/android/os/Power.java
  - base/core/java/com/android/app/ApplicationContext.java
  - base/core/java/android/bluetooth/ScoSocket.java
  - base/core/java/android/bluetooth/HeadsetBase.java
  - base/core/media/java/android/media/MediaPlayer.java
  - base/core/media/java/android/media/AsyncPlayer.java

Back to userspace

- Use “**`grep -ri power`**” to discover.
  - base/telephony/java/com/android/internal/telephony/gsm/GSMConnection.java
  - base/telephony/java/com/android/internal/telephony/gsm/RIL.java
  - base/telephony/java/com/android/internal/telephony/gsm/GSMPhone.java
  - base/services/jni/com_android_server_BatteryService.cpp
  - base/services/java/com/android/server/am/ActivityManagerService.java
  - base/services/java/com/android/server/SystemServer.java
  - base/services/java/com/android/server/BatteryService.java
  - base/services/java/com/android/server/AlarmManagerService.java
  - base/services/java/com/android/server/LocationManagerService.java
  - base/services/java/com/android/server/HardwareService.java
  - base/services/java/com/android/server/PowerManagerService.java

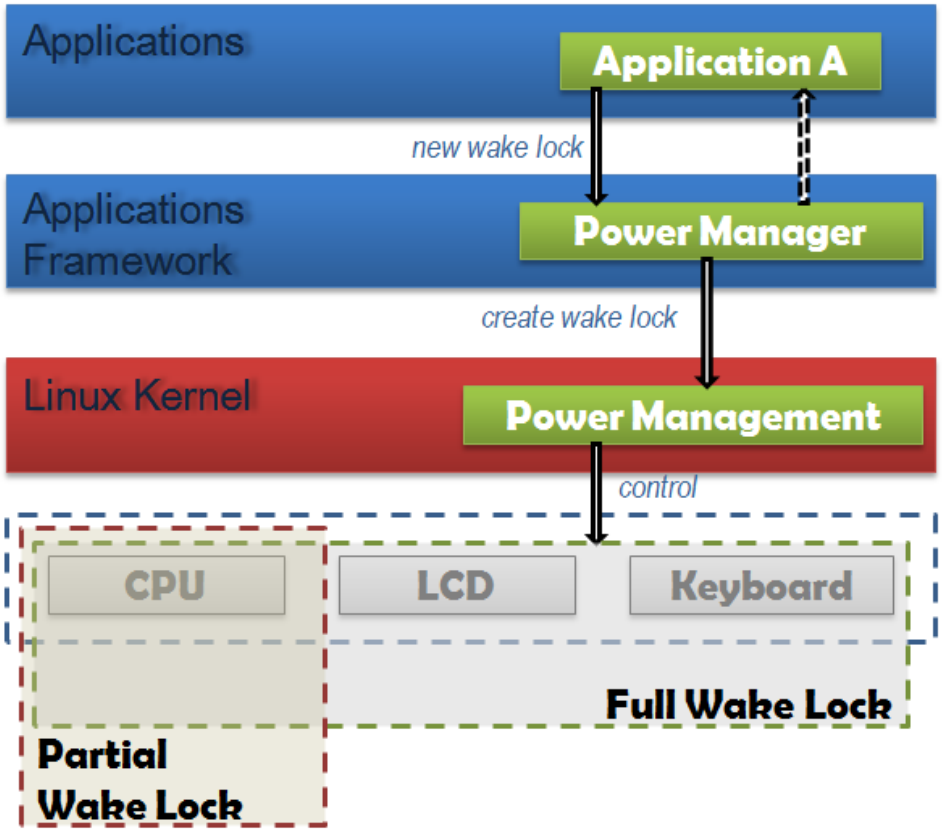
Back to userspace

- Use “**`grep -ri power`**” to discover.
  - system/core/toolbox/powerd.c
  - system/core/toolbox/alarm.c
  - system/core/vold/mmc.c
  - system/core/vold/uevent.c

- Introduction to Linux Power Management
- Concepts behind Android Power Management
  - Basically, it is the slim wrapper for Linux Power Management
- Design and Implementation
- Room for Improvements

So, Android PM is simple

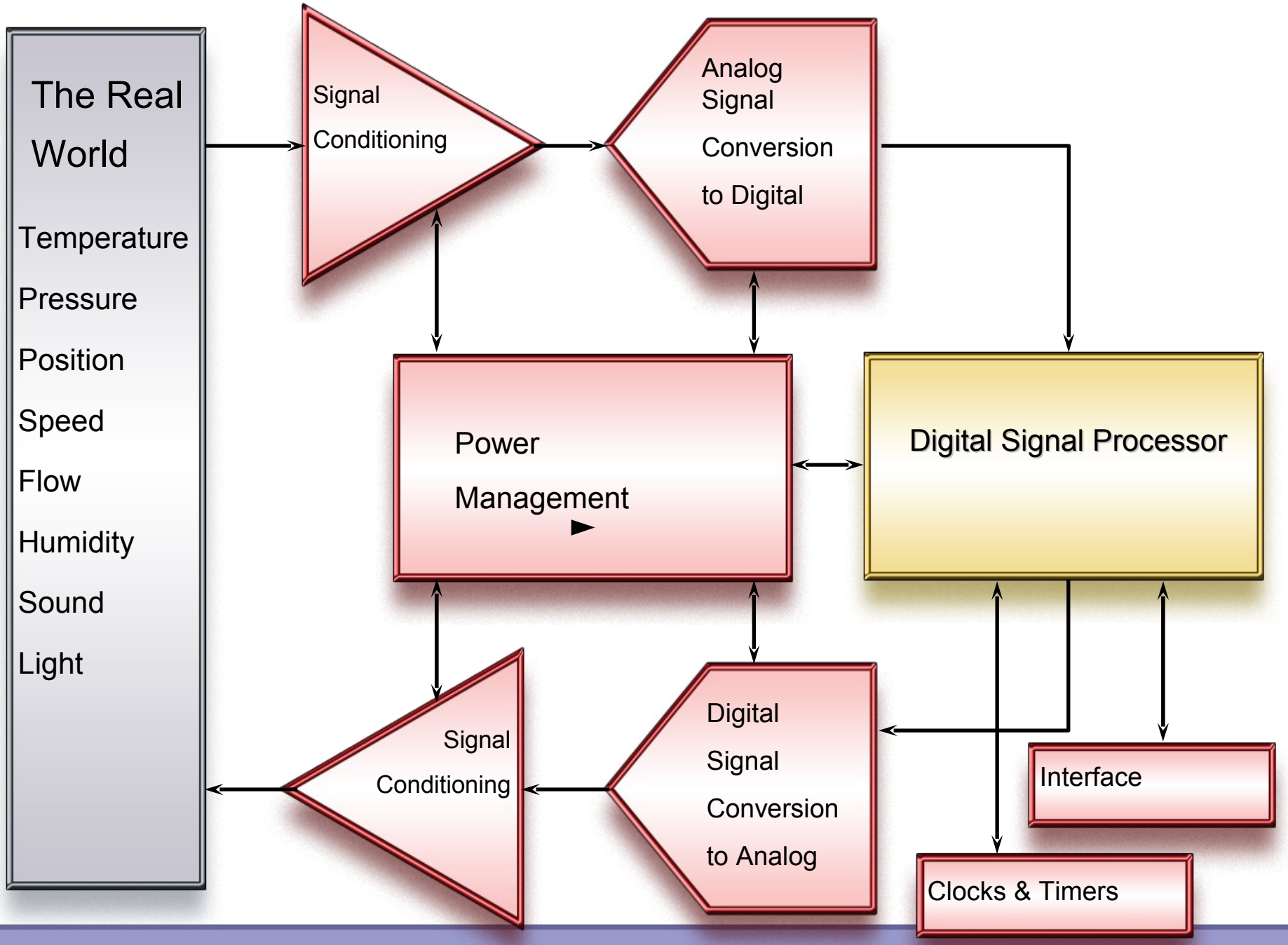
- Key concept is “Wake Locks”, which is simple and portable.
- The implementation should be introspected.



- If there are no active wake locks, CPU will be turned off.
- If there is are partial wake locks, screen and keyboard will be turned off.

- Nowadays, CPU can enter into more states for power saving and usability purpose! → applied in modern SoC

Interface to Physical World



Advanced Power Management

Power management aims to improve battery life of equipment by minimizing power consumption while guaranteeing expected system performance

Active power consumption occurs while some processing is on-going

- Dynamic power consumption (transistor switching) + Leakage consumption

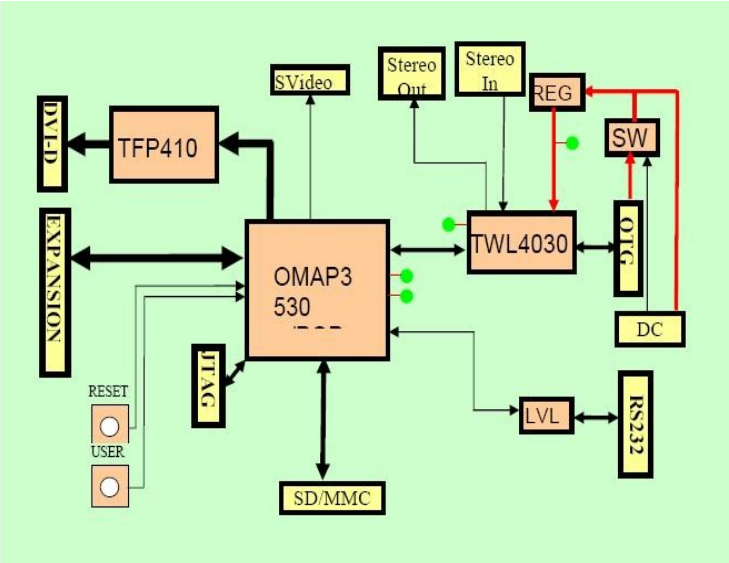
Static (also Standby or Idle) power consumption occurs when limited or no processing is on-going and the system is waiting for a wakeup event

- Very limited dynamic power consumption + Leakage consumption
- Managed by
  - Dynamic Voltage & Frequency Scaling (DVFS)
  - Adaptive Voltage Scaling (AVS)
  - Dynamic Power Switching (DPS)

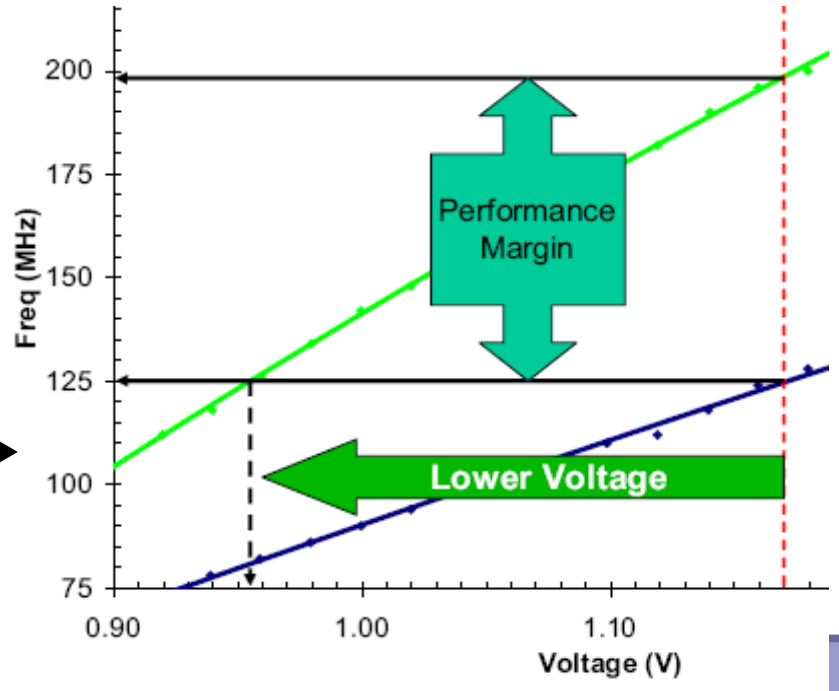
On OMAP35xx, power management is handled by the Power, Reset and Clock Management (PRCM) module

Adaptive Voltage Scaling

- Silicon manufacturing process yields a distribution of performance capability
- For a given frequency requirement:
  - Devices on hot/strong/fast end of distribution can meet this at a lower voltage
  - Devices on cold/weak/slow end of distribution need higher voltage
- Simple system will set the higher voltage for operating all devices
- Smarter system will adapt operating voltage per device.



hotter device



Linux PM Mechanisms

- cpuidle
  - Generic framework for supporting software-controlled idle processor power management
  - Hardware specific drivers
  - Various governing for the state transition decisions
- Latency and power management
  - Framework for expressing latency constraints, and make sure that they are taken into account for power management decisions
- Needs to be integrated into Android Partial Wake Locks

Summary

Integration is the key to the most power-saving system

Reference

- PDK :: Android – Power Management
  - http://www.netmite.com/android/mydroid/development/pdk/docs/power_management.html
- Android Cupcake source code
  - http://www.netmite.com/android/mydroid/cupcake/
- BeagleBoard and its Linux support
  - http://elinux.org/BeagleBoard
- class PowerManager
  - http://developer.android.com/reference/android/os/PowerManager.html
- Free-Electrons
  - http://free-electrons.com/training
- CELF's power management specification
  - http://elinux.org/Power_Management