Facilitating Android Custom ROM Development with Kexec

Mike Kasick

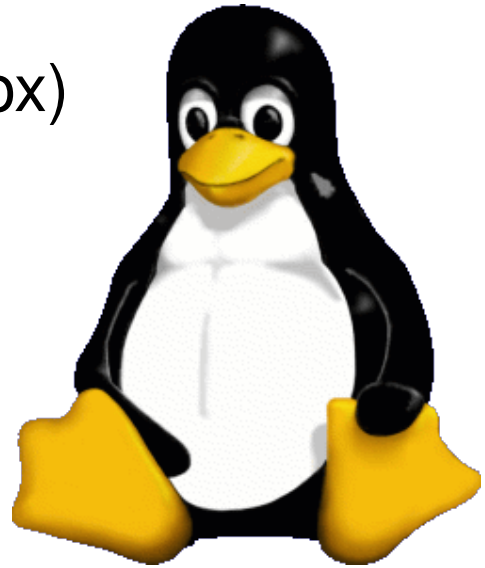
Outline

What is Android?

- “Google’s” open-source mobile operating system
- Developed by the Open Handset Alliance (OHA)
  - Google, HTC, Motorola, Qualcomm, TI, Samsung, 78 others
- Very popular: 68% smartphone OS market share (2012 Q2)
- Runs on phones (smart & feature), tablets, ereaders, etc.

Android is Linux (but not GNU)

- Uses a modified Linux kernel
- Features a highly-customized user space
- **Bionic** (libc): BSD-based with Linux support
- **Toolbox**: shell tools, omnibus binary (BusyBox)
- **Dalvik**: register-based VM, “runs apps”
- **Framework**: user interface layer, middleware



Android is “Open Source”

- Components released under various licenses
  - Kernel (Linux) and associated utilities are GPLv2
  - Certain libraries (e.g., WebKit) are GPL or LGPL
  - Bionic & Toolbox are (three-clause) BSD
  - Everything else (Dalvik, framework) is Apache v2
- Full platform sources are available (only) for Nexus devices
- Third-party manufacturers:
  - Use proprietary kernel modules, HAL libraries, custom UIs
  - Obligated to release kernel source code
  - Generally do not release non-GPL platform sources

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- CyanogenMod: Community-developed Android distribution
  - Supports Nexus and third-party devices (137 officially)
  - Significant reverse engineering and reimplementation effort
  - CM9 supports 69 devices from a single source tree
  - Basis for many source-based offshoot ROMs

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- Unencumbered development platform
  - Most devices support testing/debugging out of the box
  - Distribute apps through Google Play for one-time $25 fee
  - Open ecosystem: third-party stores, publish independently

Android Debug Bridge (adb)

- Tool and protocol to communicate with devices over USB
  - No need for serial console, setting up Ethernet and ssh, etc.
- Supports a variety of useful commands
  - `adb backup` / `restore`: backup or restore device contents
  - `adb forward`: forward host network sockets
  - `adb install`: upload and install an app
  - `adb logcat`: dump application log messages
  - `adb push` / `pull`: send files to, or receive files from device
  - `adb shell`: open a shell, or invoke a shell command
- Powerful development tool, kudos for making available

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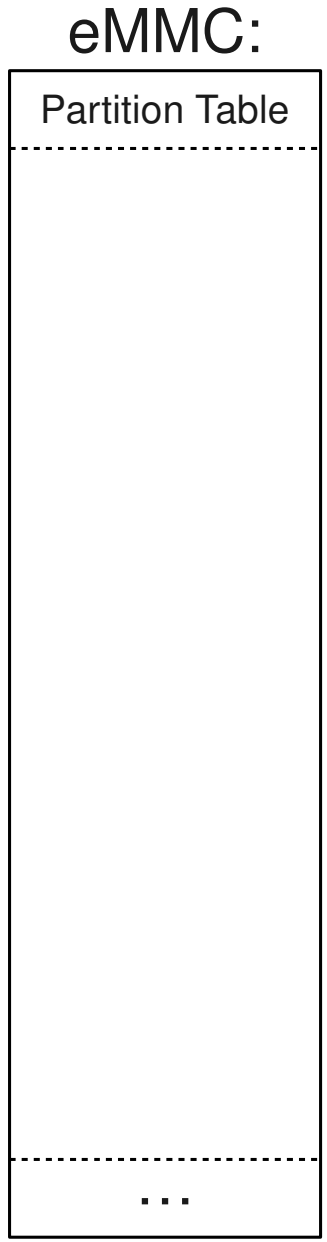
Typical Storage Setup (I)

- eMMC (flash) storage divided into partitions



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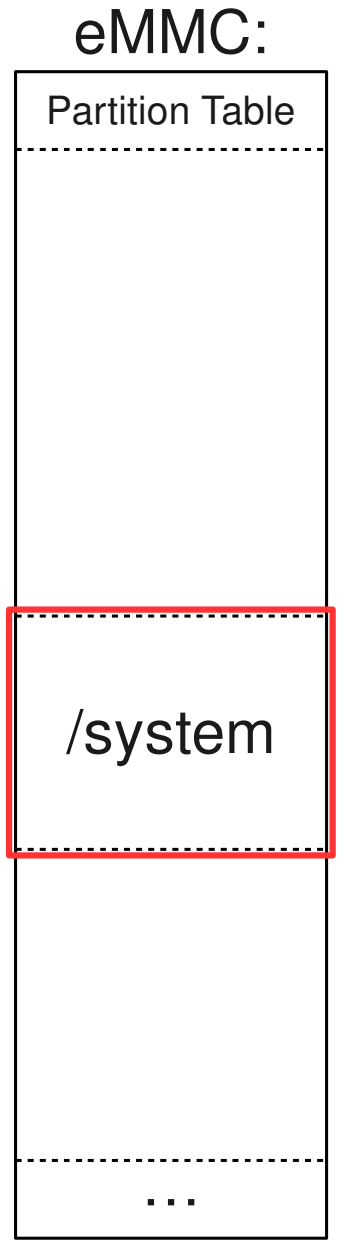

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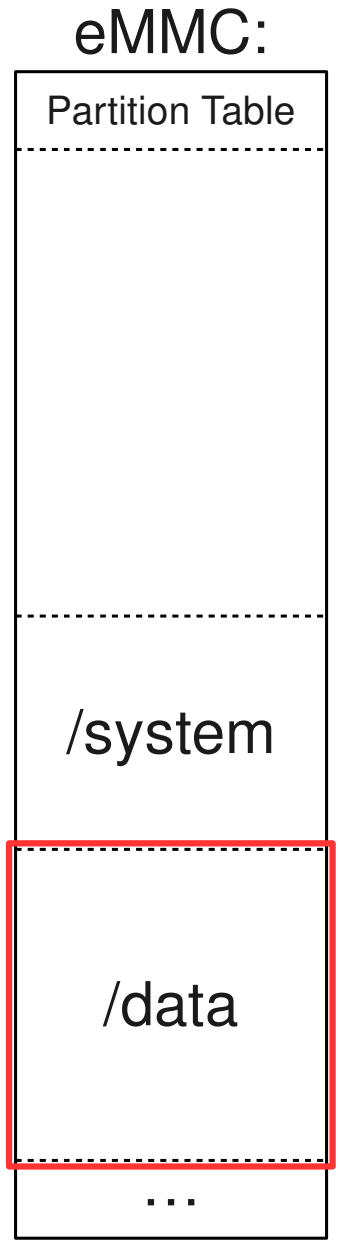
- eMMC (flash) storage divided into partitions
- /**system** partition
  - Read-only, contains OS and preinstalled apps
- /**data** partition
  - Writable, contains user-installed apps, media
  - “Factory data reset” wipes entire partition, restores device to factory state



Typical Storage Setup (II)

- **boot** partition
  - Contains boot kernel and initrd
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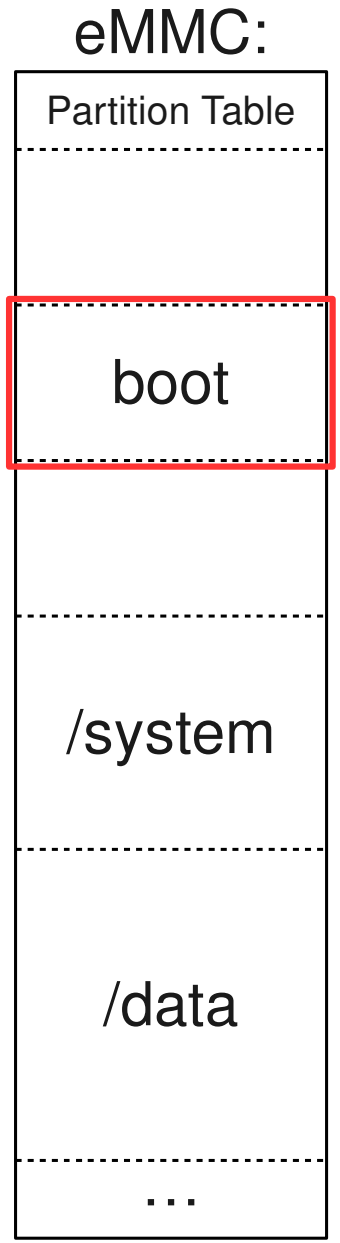

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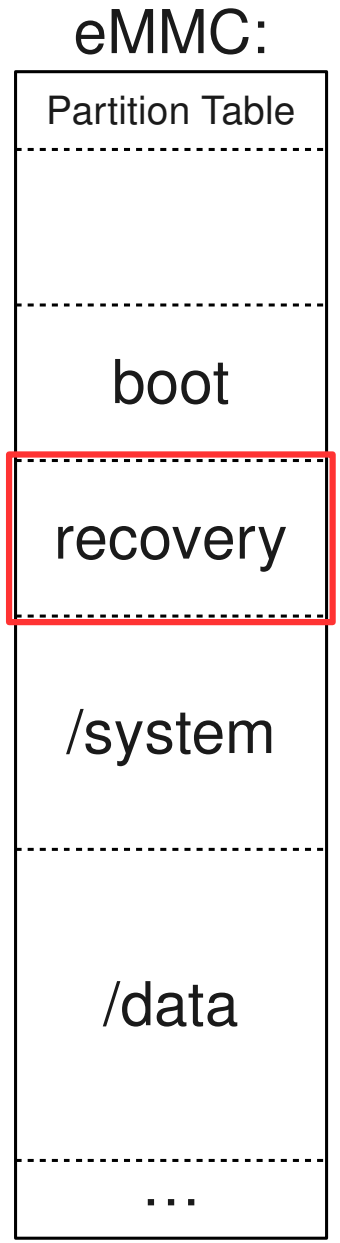
- **recovery** partition
  - Contains recovery kernel and initrd
  - Minimal boot environment (“Safe Mode”)
  - For applying system updates (update.zips)
  - Can wipe /data, `adb shell`, etc.



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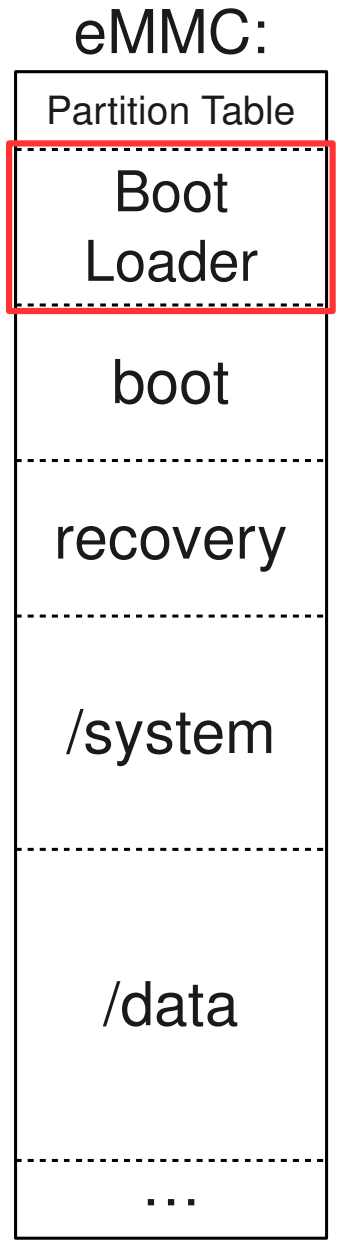
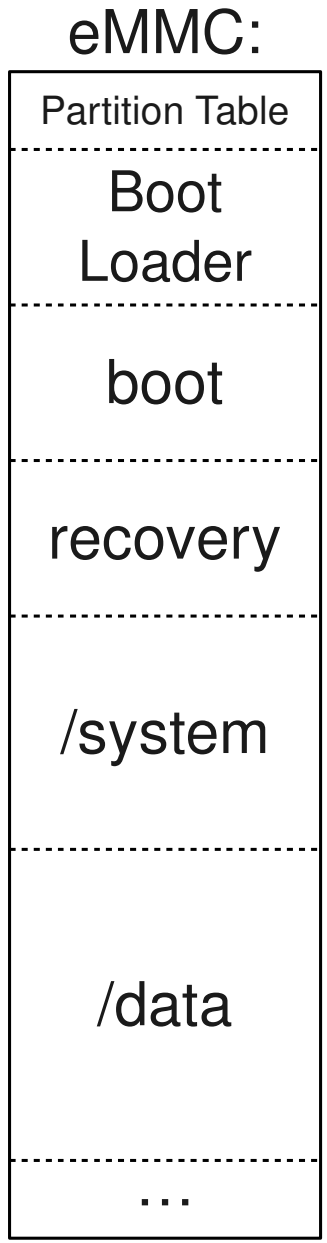


Typical Storage Setup (III)

- Boot loader partitions
  - Contain the device's boot loader
- Boot loader
  - Loads **boot** or **recovery** kernels, jumps to them
  - Special mode to flash partitions over USB
  - No single "Android boot loader", varies by OEM



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- Alternative: proprietary flashing protocols
  - Implemented by most boot loaders, even non-fastboot ones
  - Used to field reflash devices with broken partitions
  - Ex: Odin (Samsung), RSD (Motorola), nvflash (Nvidia)

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- "`fastboot boot`" great for kernel testing
  - Has limited device support
  - Subtle bugs on some devices (broken USB)
- Development & testing is inefficient
  - Lots of time spent reflashing device
  - Many erase cycles, wear on eMMC
  - **Dangerous!** If no way to recover from bad flash

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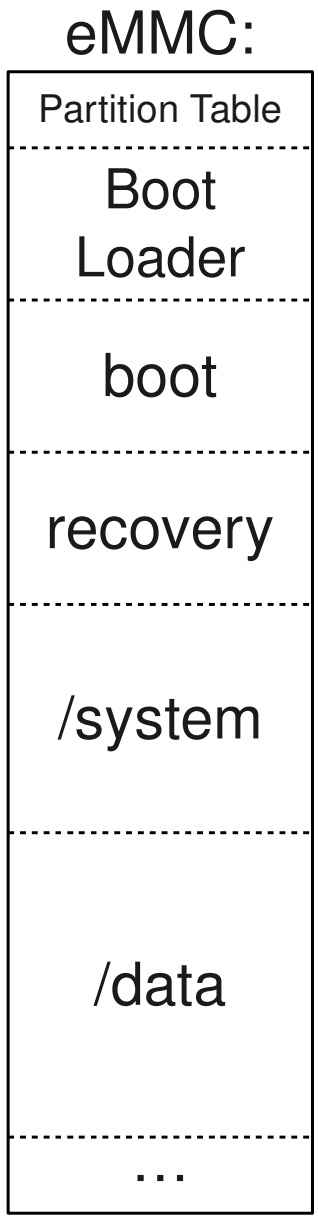

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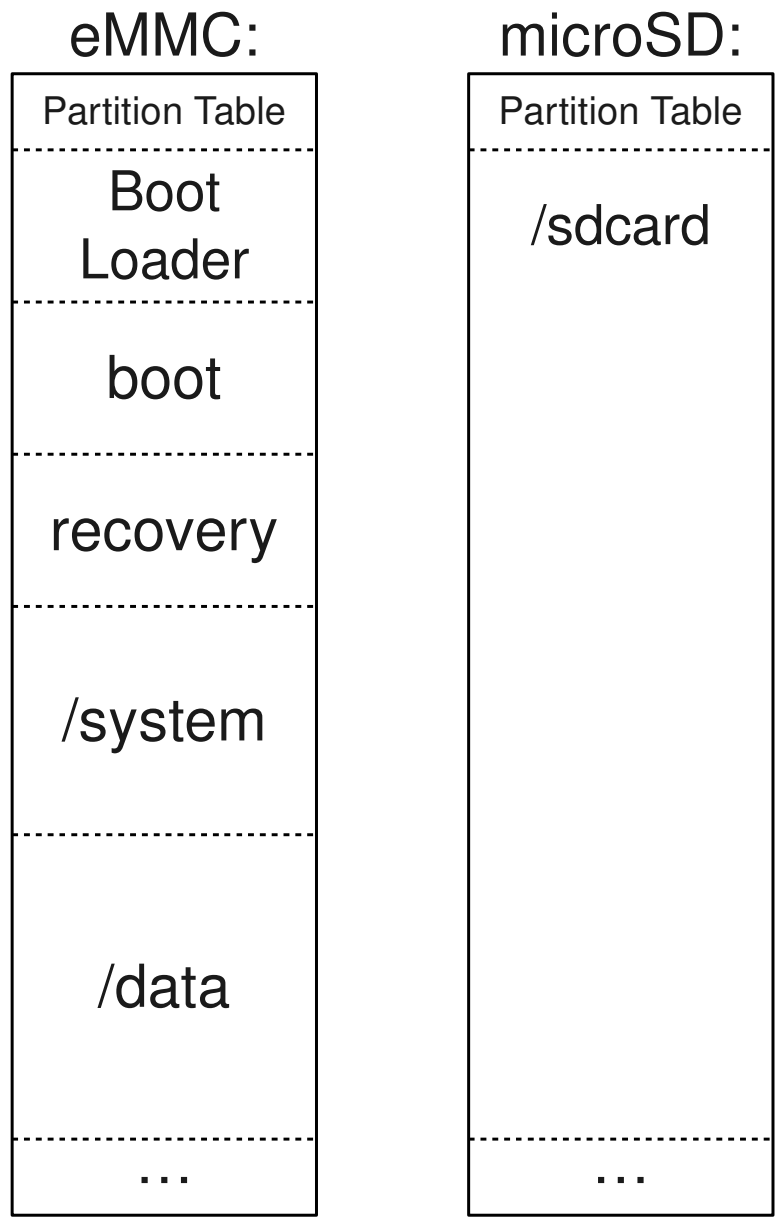

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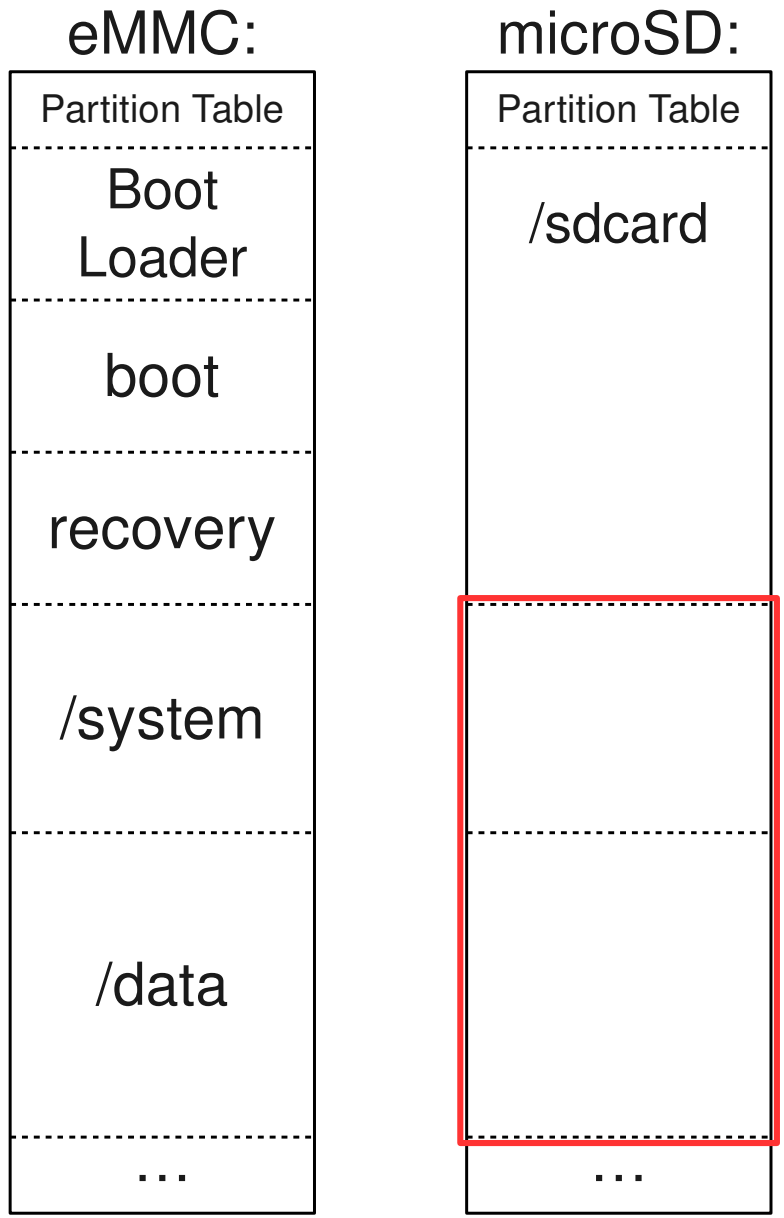

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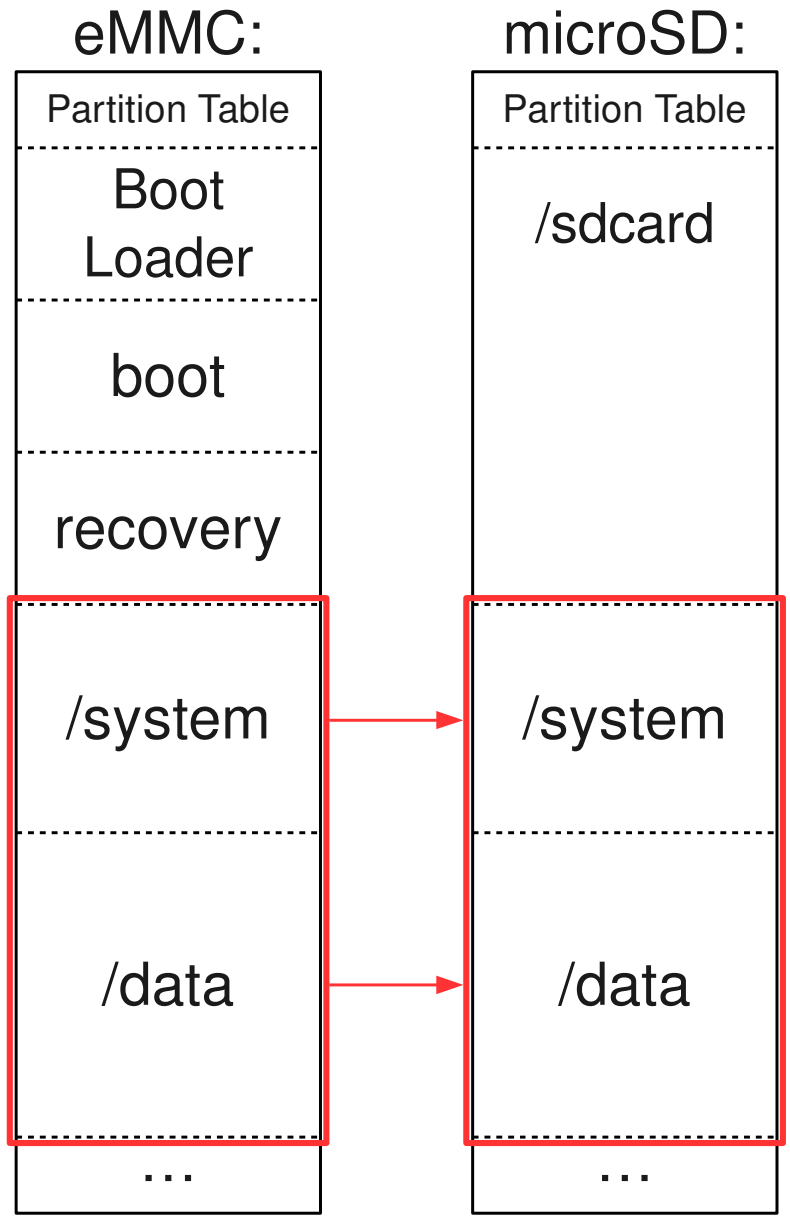

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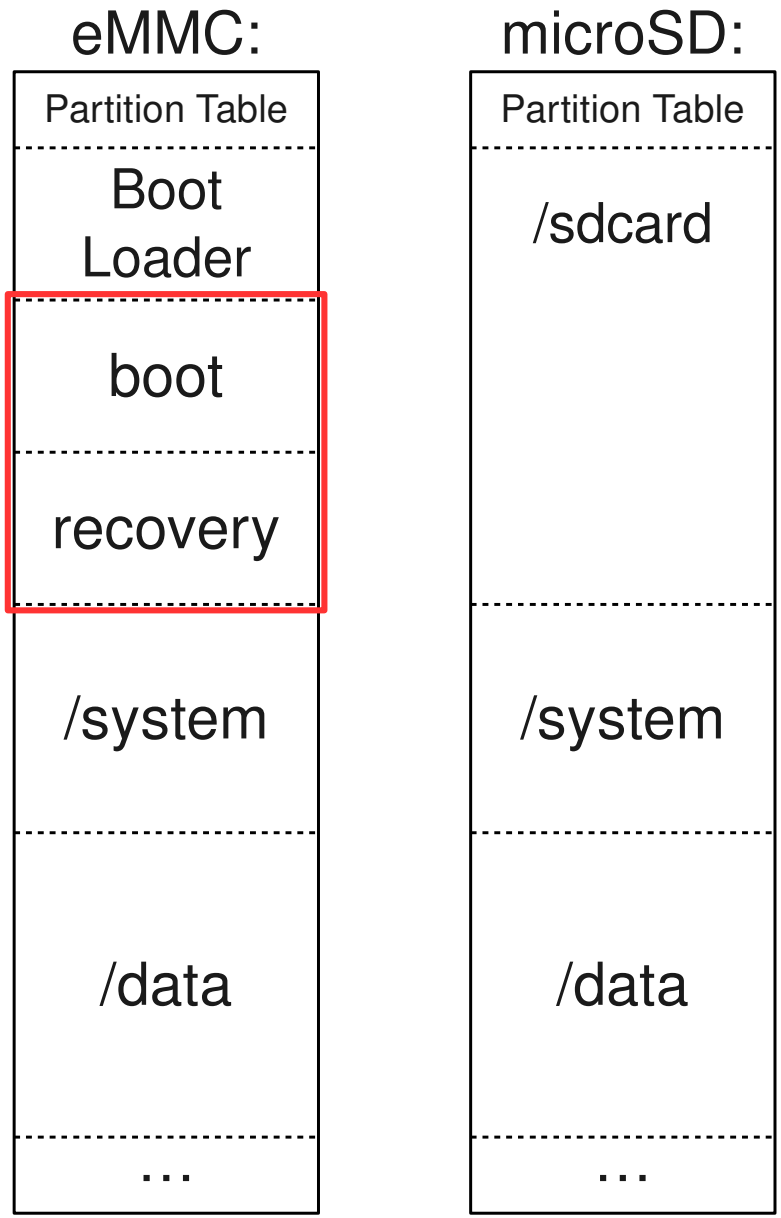

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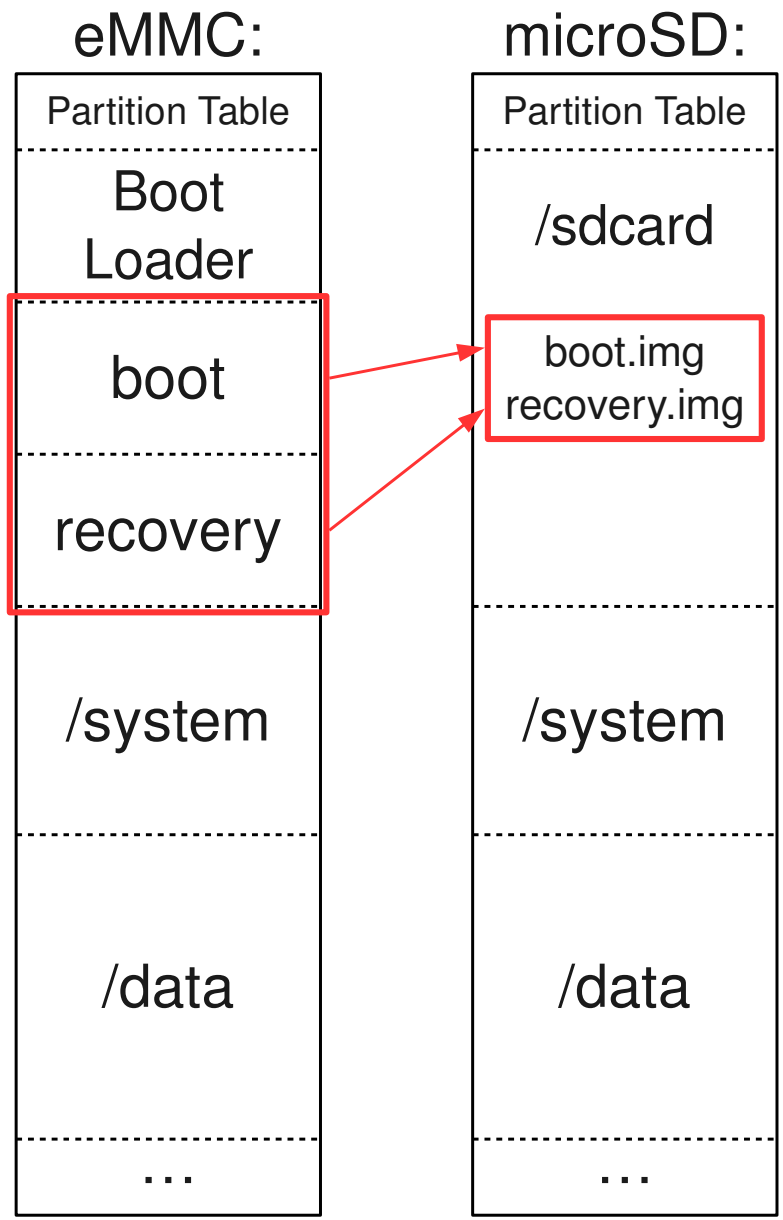

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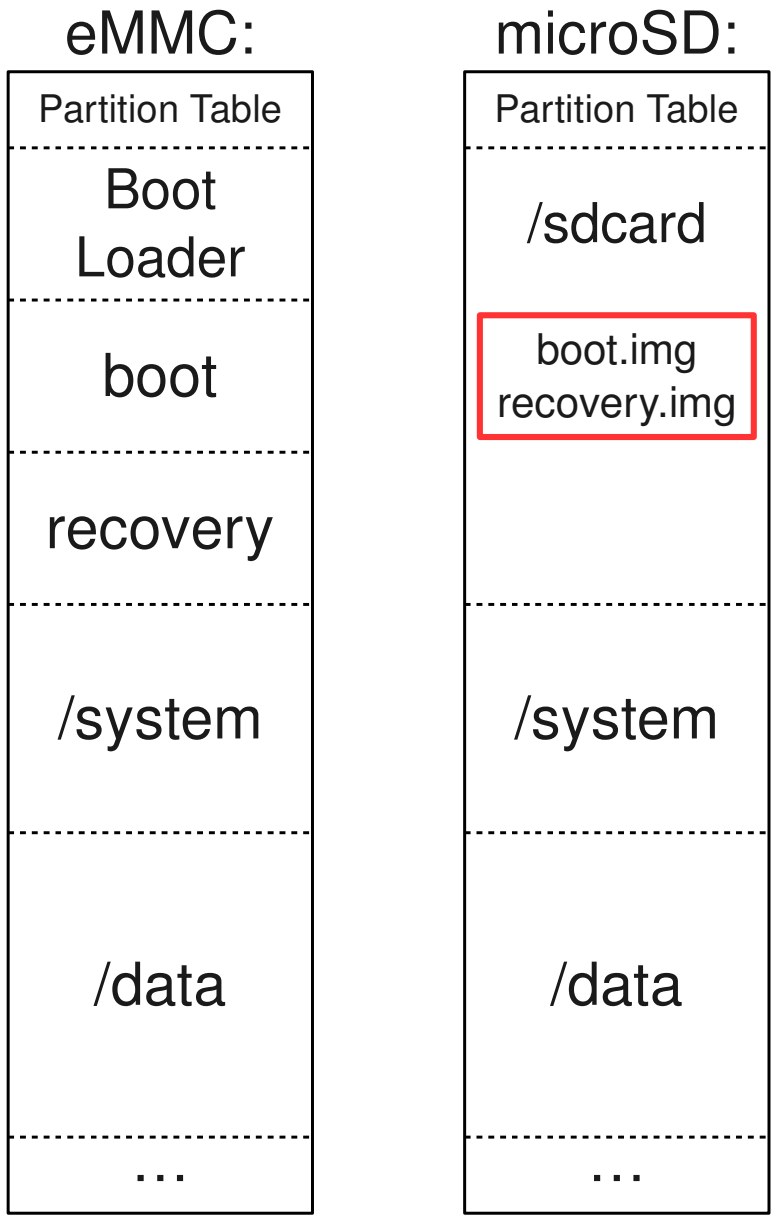
- How to boot /**sdcard/boot.img**?



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- `kexec -e`
  - Boots into the loaded kernel
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Kexec procedure

- Prepares for a typical reboot
  - Calls `.shutdown` method for each device
  - Stops all other CPUs
  - Disables IRQs, caches, MMU, etc.
- But, instead of performing a hardware reboot
  - Stages kernel at load address
  - Jumps to kernel entry point
  - New kernel begins to boot

The Kexec Problem

- Driver `.shutdown` methods must be `.probe` compatible
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- Secondary CPUs may not be recoverable
- Problems can be fixed, requires deep hardware knowledge

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Kexec Hardboot

- Modification, uses hardware reboot to fix “kexec problem”
- Basic idea
  - Use existing kexec to stage new kernel in memory
  - Perform hardware reboot to reinitialize devices
  - Hook into Linux boot process, jump to new kernel
- Requirement: “Some” RAM must preserve across reboot
  - DRAM controller must provide refresh cycles
  - Bootloader must leave some part of memory untouched

RAM Console

- Linux logs panic messages to kmsg buffer
  - Prints to VGA console on desktops and servers
  - Serial consoles used for embedded devices
  - No way to retrieve when phone panics in pocket
- Android RAM Console
  - Logs to circular buffer outside normal system RAM
  - Device automatically reboots on panic, preserves buffer
  - Old logs made available on reboot, `/proc/lastkmsg`
- Immensely useful for debugging, kudos for making available
- Serves as precedent for preserving RAM across reboot

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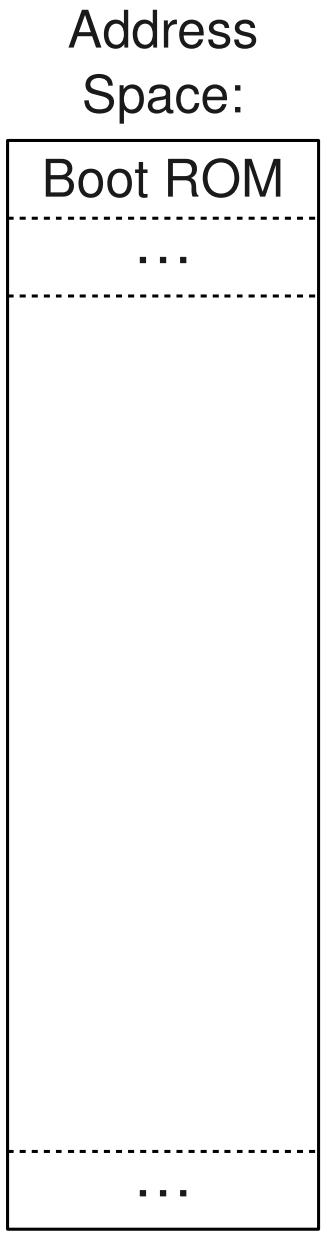

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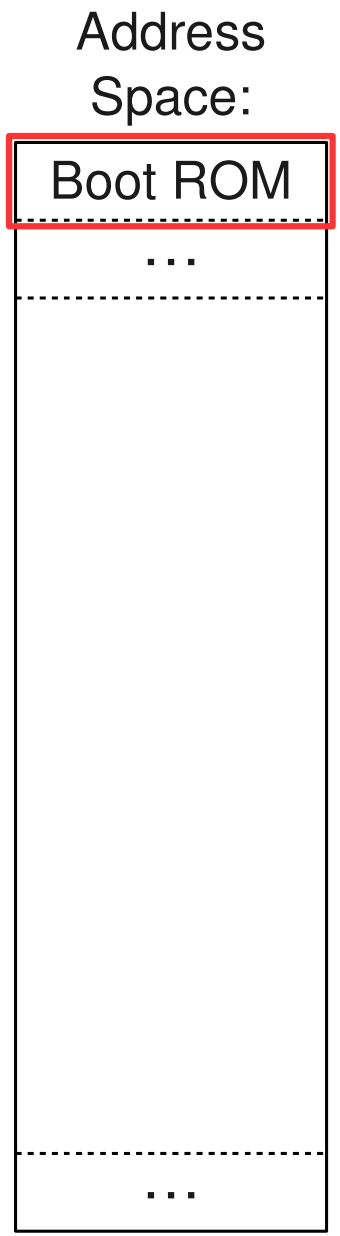

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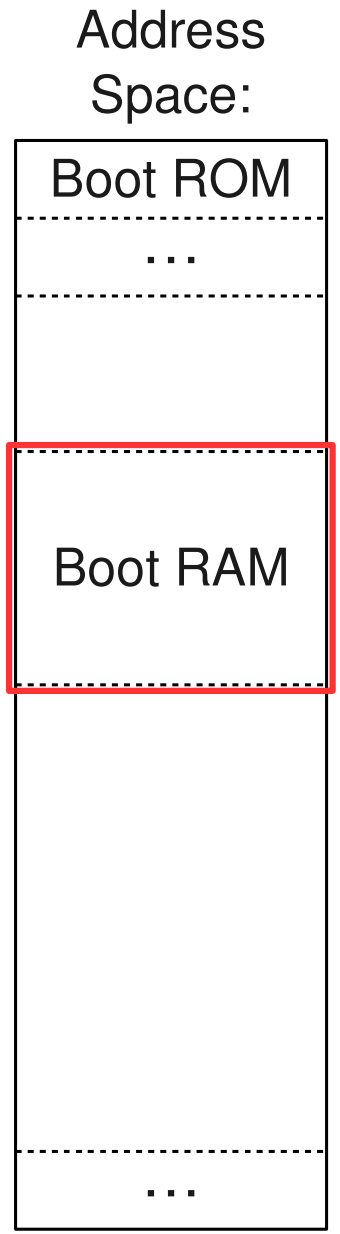

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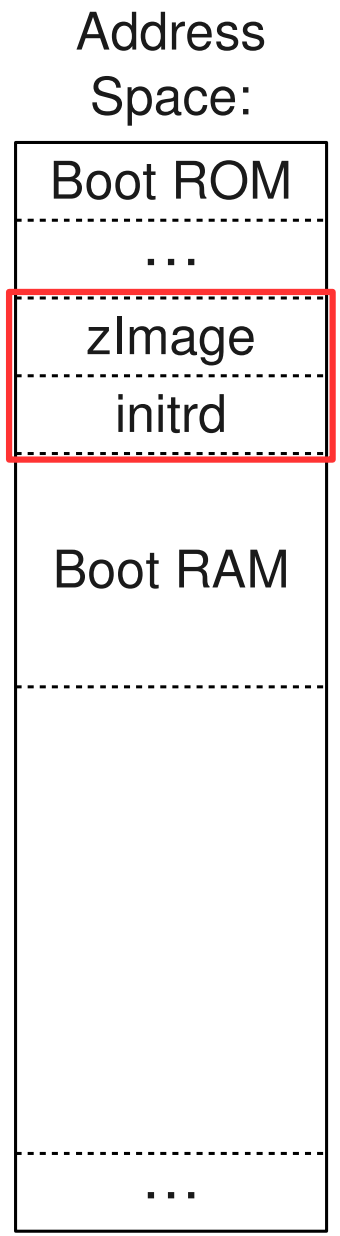

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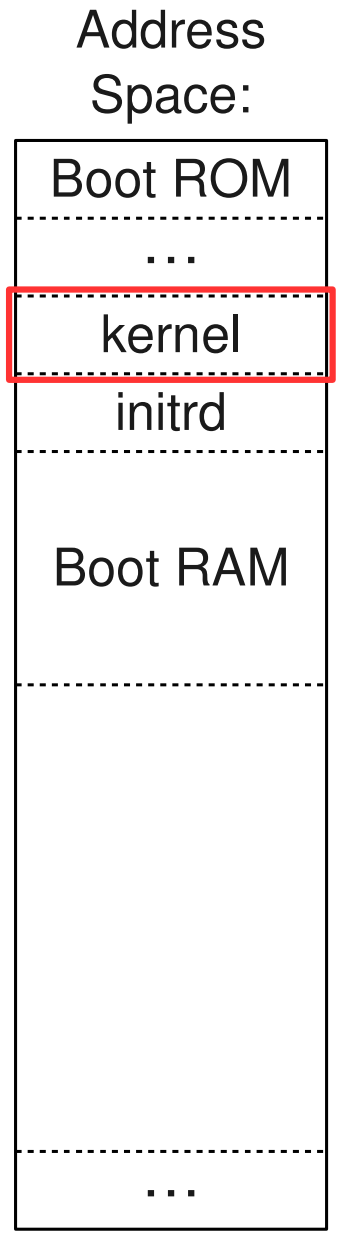

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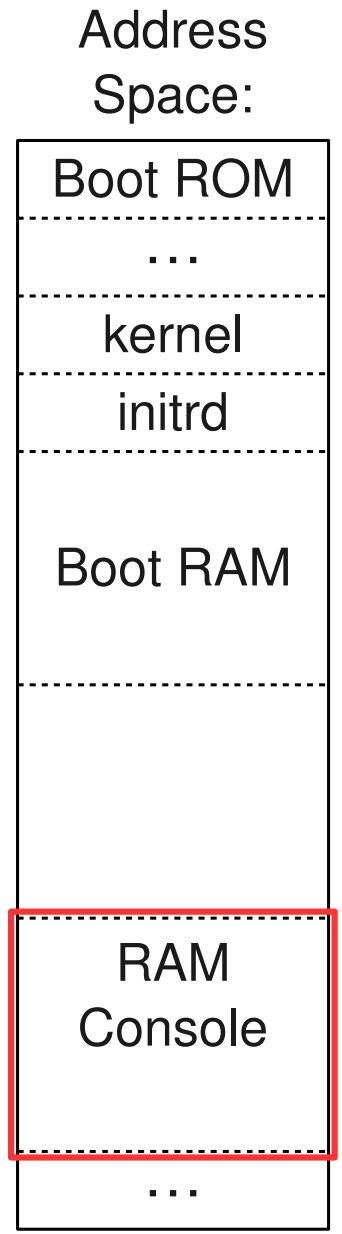

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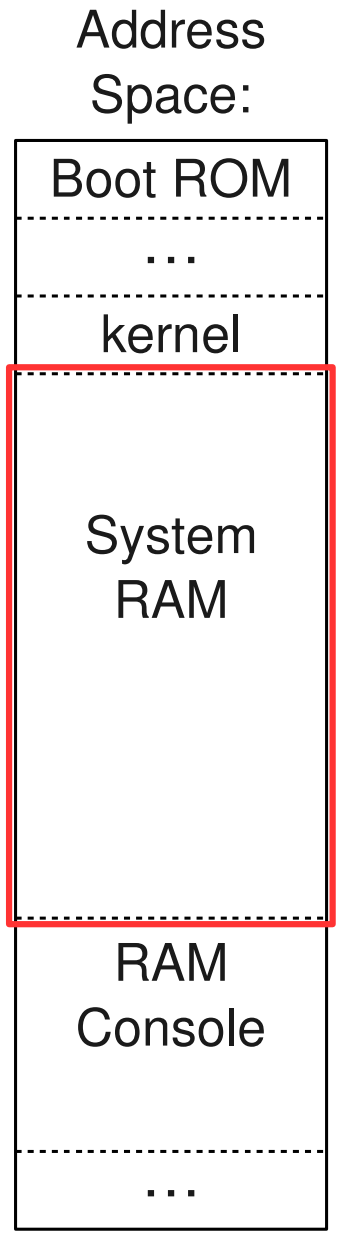
- Uses remaining memory as System RAM



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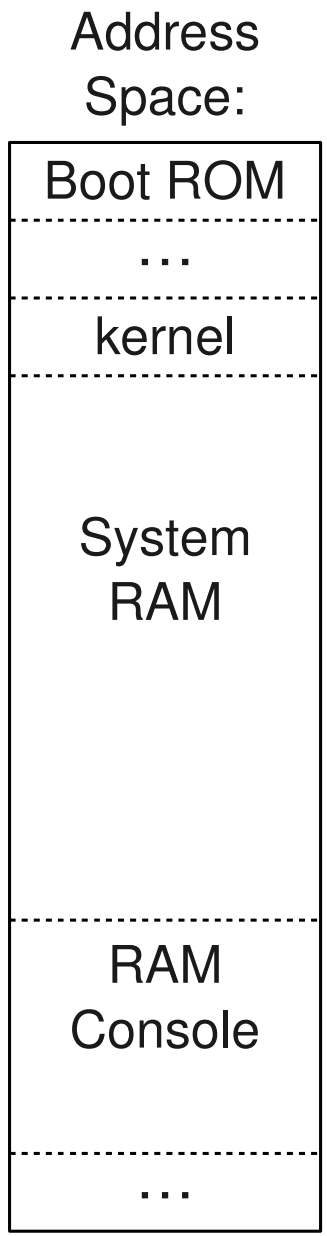

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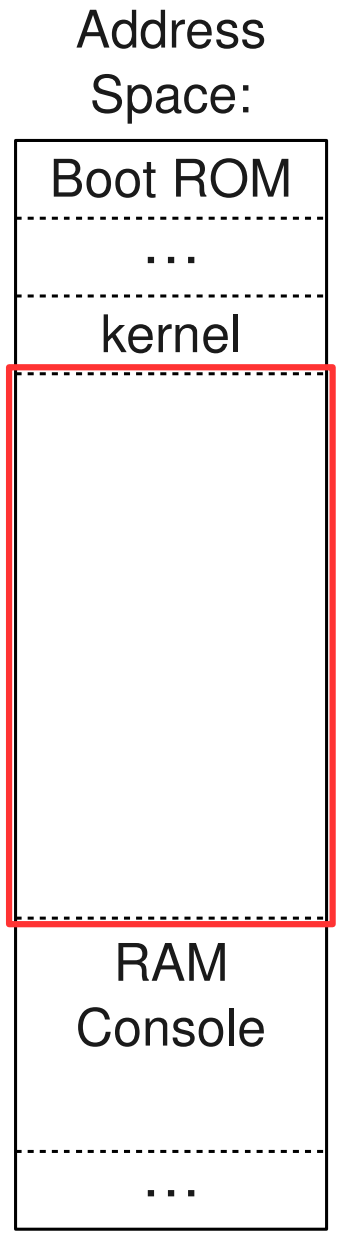

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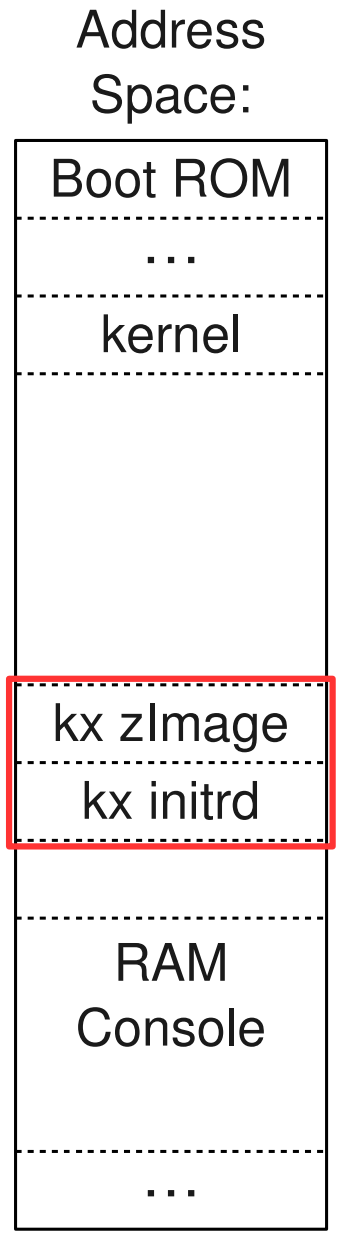

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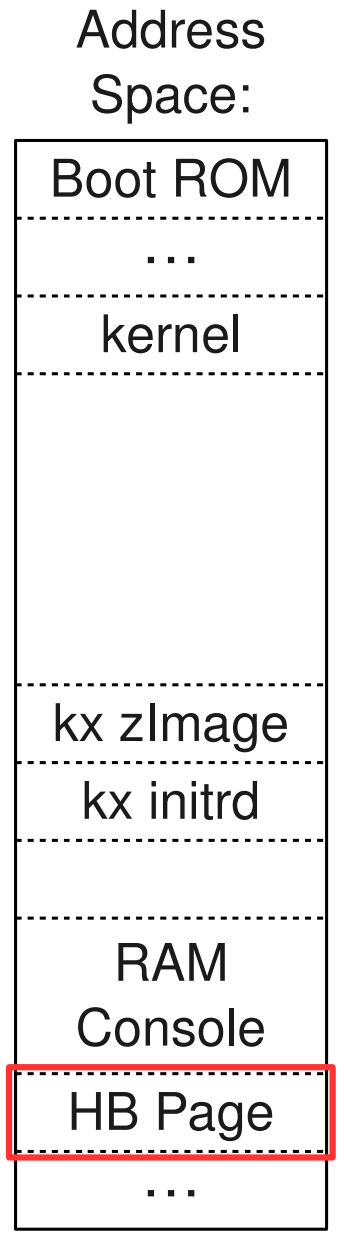

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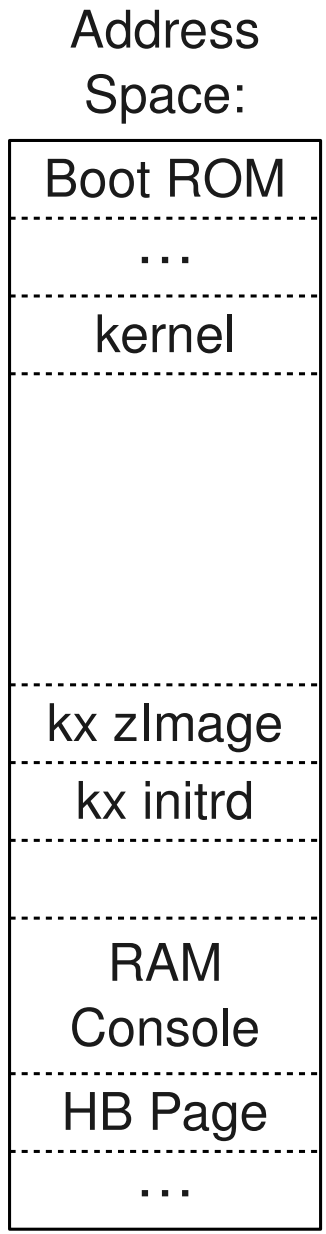

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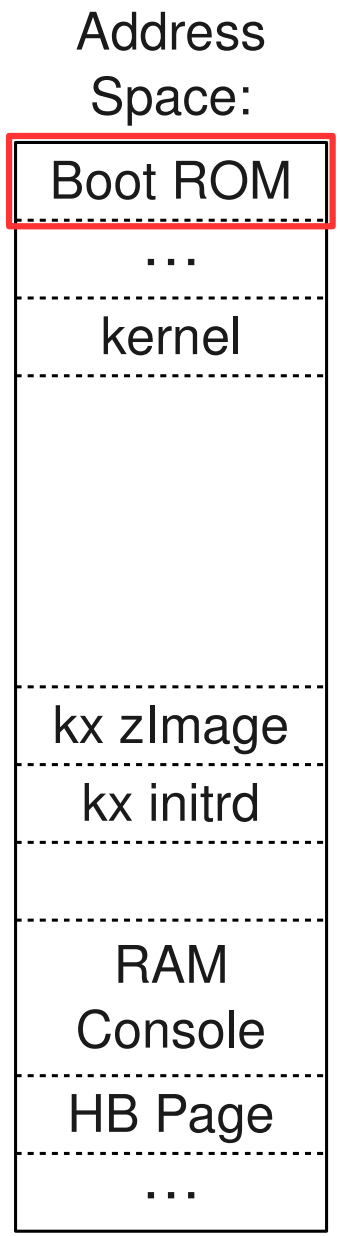

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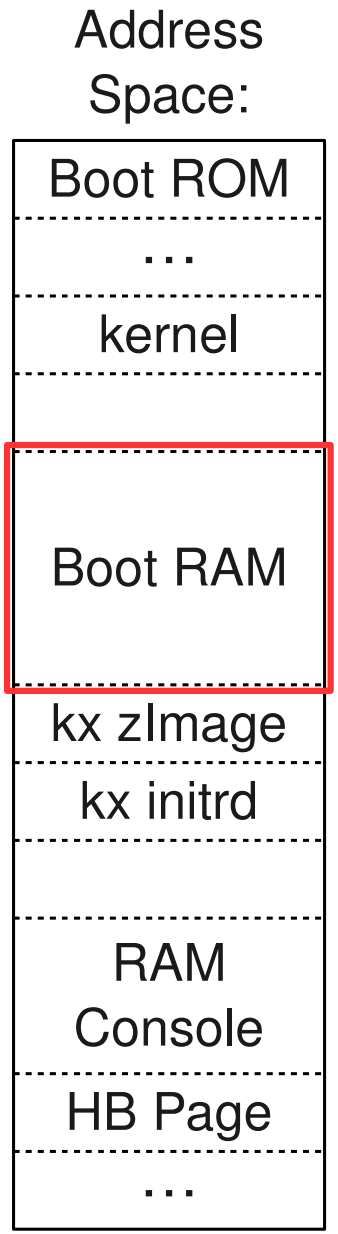

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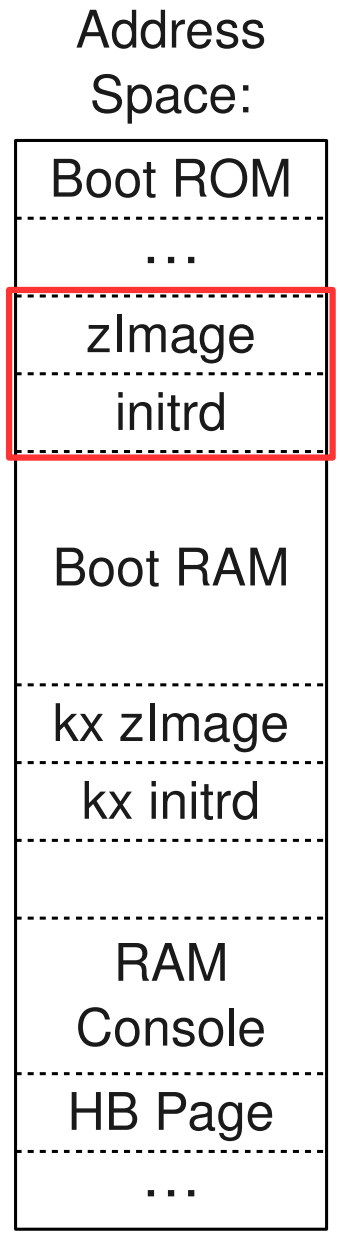
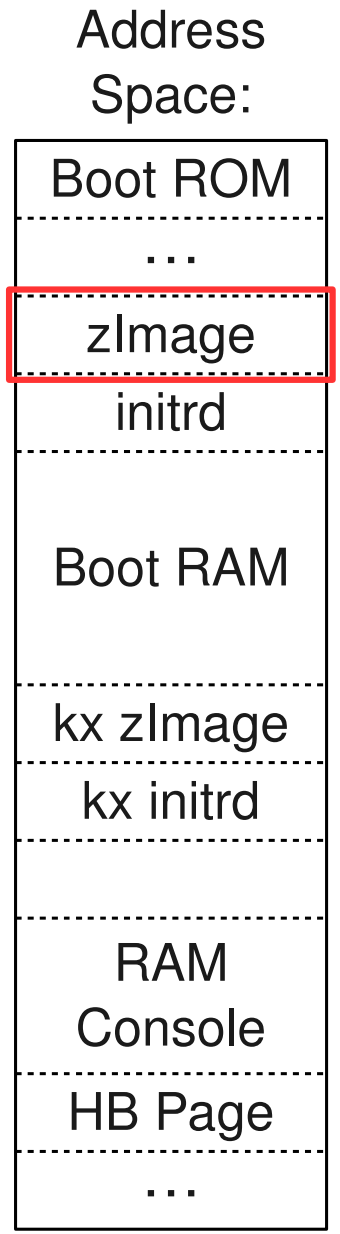


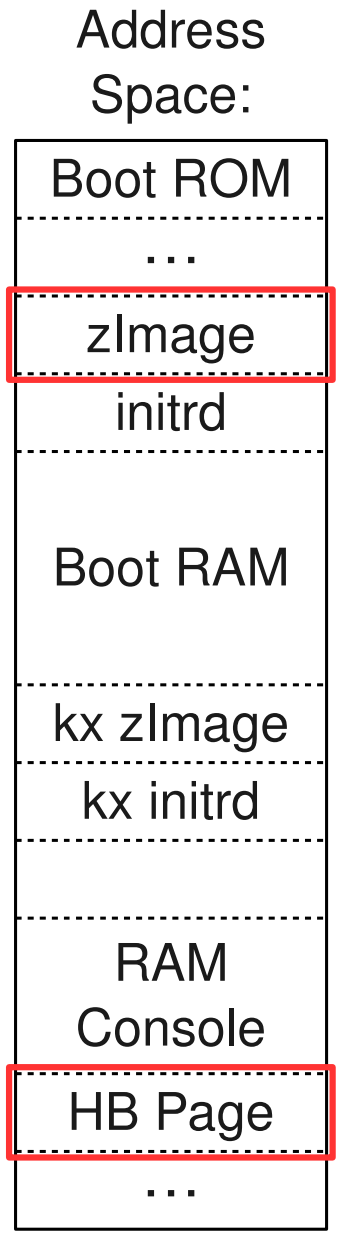
Kexec Hardboot Example (II)

- Restarts execution in boot ROM
- Initializes memory, sets up boot loader in RAM
- Loads compressed kernel (zImage) and initrd
- Jumps to zImage



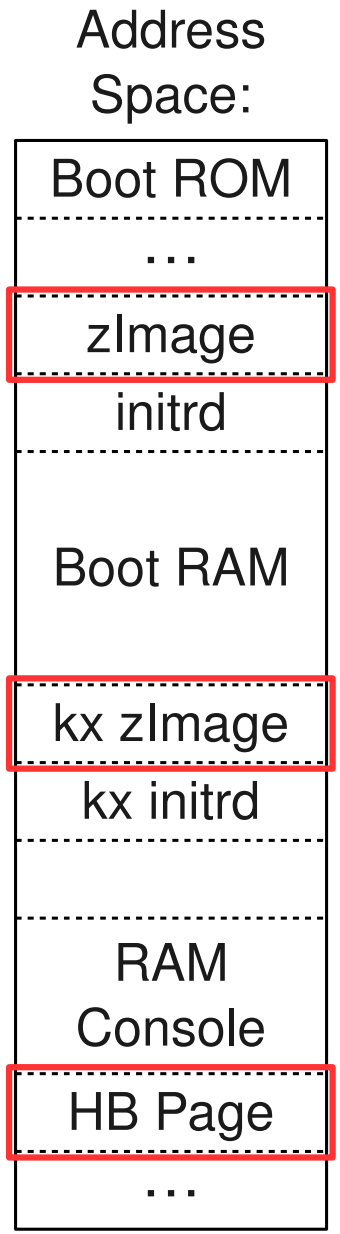
Kexec Hardboot Example (II)

- Restarts execution in boot ROM
- Initializes memory, sets up boot loader in RAM
- Loads compressed kernel (zImage) and initrd
- Jumps to zImage
- Decompressor checks for hardboot page



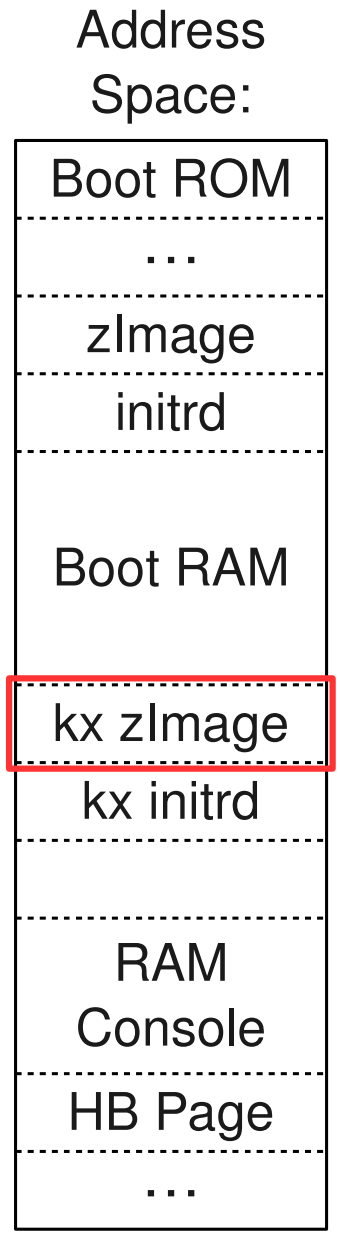
Kexec Hardboot Example (II)

- Restarts execution in boot ROM
- Initializes memory, sets up boot loader in RAM
- Loads compressed kernel (zImage) and initrd
- Jumps to zImage
- Decompressor checks for hardboot page
- Finds compressed kexec kernel in high RAM



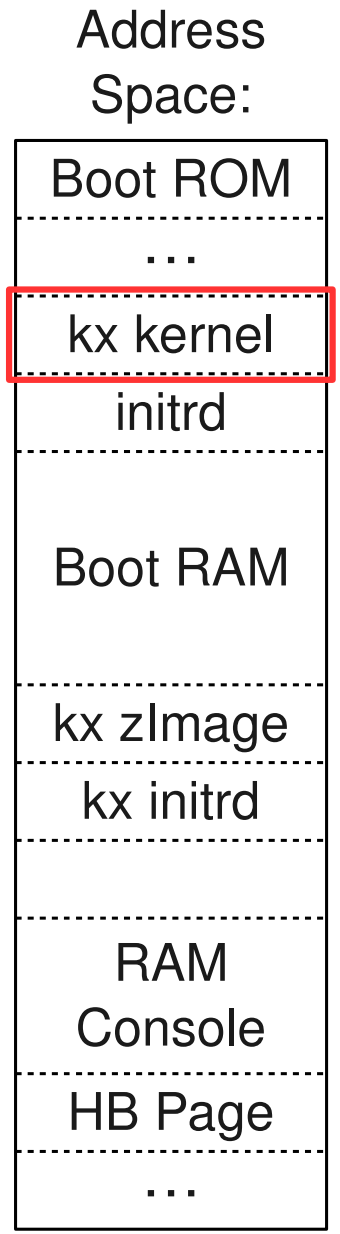
Kexec Hardboot Example (III)

- Jumps to kexec zImage



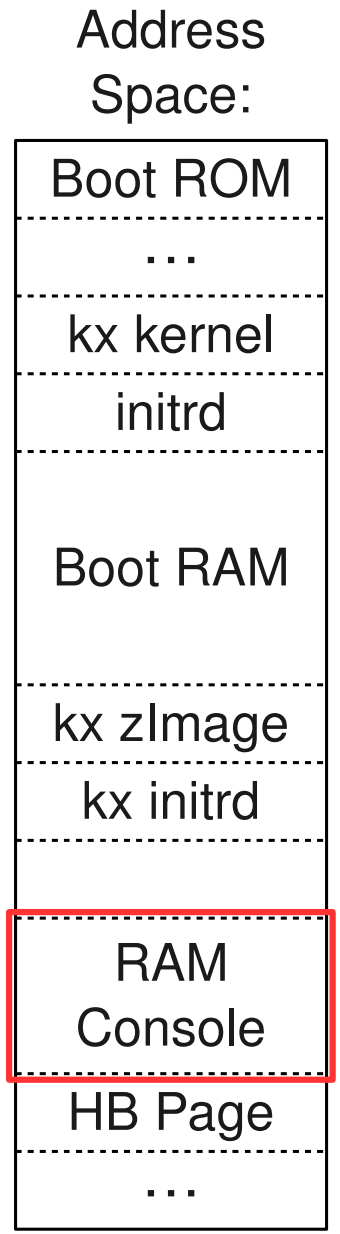
Kexec Hardboot Example (III)

- Jumps to kexec zImage
- Decompresses to regular load address, boots



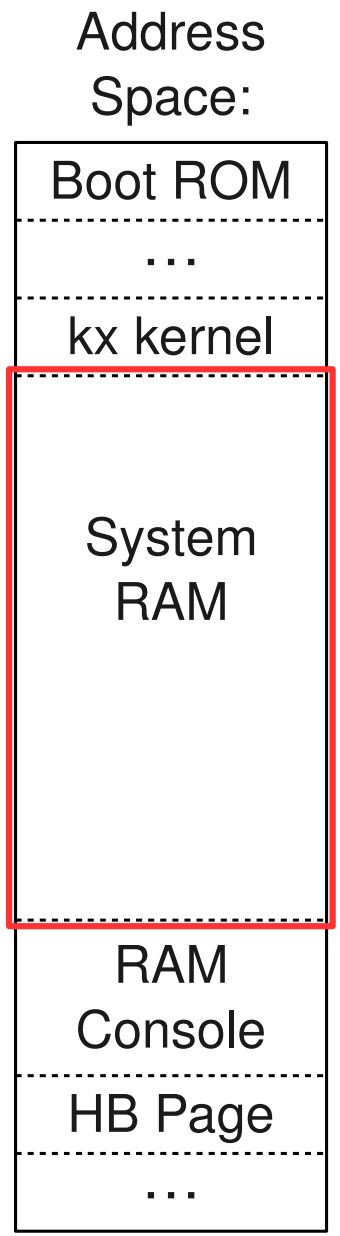
Kexec Hardboot Example (III)

- Jumps to kexec zImage
- Decompresses to regular load address, boots
- Saves old RAM Console buffer



Kexec Hardboot Example (III)

- Jumps to kexec zImage
- Decompresses to regular load address, boots
- Saves old RAM Console buffer
- Reuses remaining memory as System RAM



Code Components (I)

- Backports of recent ARM kexec patches to vendor kernels
  - Traditionally machines “soft reboot”, jump to reset vector
  - Soft reboot (MMU disable) broken as of ARMv6
  - Every vendor implements own hardware-based reboot code
  - Parts of soft reboot and kexec pathway left unimplemented
- Hardboot path for `relocate_new_kernel`
  - Scribble kernel location and boot params to hardboot page
  - Machine-specific code to force hardware reboot (port from C)
  - Tricky ARM assembly, no other kernel facilities available

Code Components (II)

- Aside: The zImage Decompressor
  - Very first Linux code to execute on boot
  - Self-contained program, essentially a third-stage boot loader
  - Flexible, can be located anywhere, relocates itself if needed
- Decompressor trampoline
  - Checks hardboot page for kexec kernel, jumps to its zImage
- Fixes to speed-up boot, relocate kernel parameters (atags)

Outline

Kexec Applications

- Kernel testing & debugging
  - `adb push` kernel to /**tmp**, run `kexec` from shell
- Repurpose Android Recovery as a boot menu
  - Usually accessed with a power-on key combination
  - Intended for applying system updates (update.zips)
  - Apply an “update.zip” that kexecs /**sdcard/boot.img**
- Dual-boot & multi-boot support
  - Keep stock ROM on device, custom ROM on microSD
  - SD-based “temp boot” stock ROMs for provisioning updates
  - NFS root: Boot ROMs from NFS shares, no flashing!

Device Support

- Currently supported devices
  - Samsung Epic 4G (epicmtd)
  - Samsung Epic 4G Touch
  - Samsung Galaxy S III (US variants: d2spr, d2vzw)
- Proof-of-concept ports
  - Samsung Nexus S (crespo, crespo4g)
  - Samsung Galaxy Tab (p1)
  - ASUS Transformer Prime TF201
- Working platforms: Exynos, Snapdragon (MSM), Tegra
- Little platform-specific code, relatively easy to port

Summary

- Android is a fun hacking platform, some neat tools
- Consumer-oriented devices are inflexible, difficult to hack
- Kexec makes devices far more flexible
- Hardboot approach makes kexec work on buggy devices