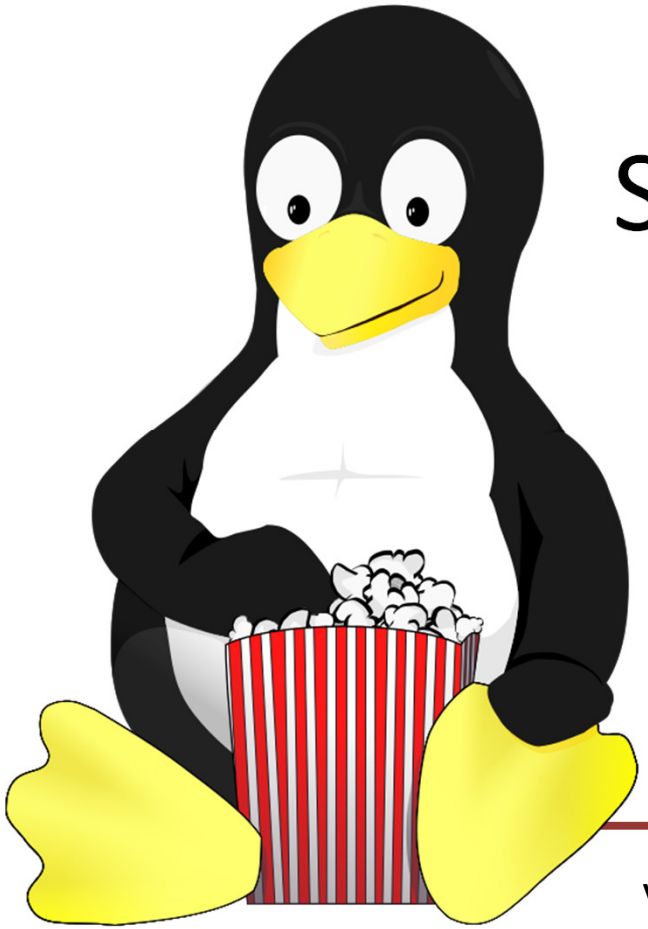
Systems Software Research Group



Popcorn Project: Starting with Popcorn OS

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VTLUUG meeting , May 2nd 2013

VirginiaTech Invent the Future

Patches 14th Dec 2012

- Popcorn Hacking Guide
  - Generic modifications (all archs)
    - linux-3.2.14-popcorn-build.patch
    - linux-3.2.14-popcorn-syscall.patch
    - linux-3.2.14-popcorn-generic.patch
  - Architecture dependent in `arch/x86`
    - linux-3.2.14-popcorn-x86-build.patch
    - linux-3.2.14-popcorn-x86-syscall.patch
    - linux-3.2.14-popcorn-x86-generic.patch
    - linux-3.2.14-popcorn-x86-apic.patch
    - **linux-3.2.14-popcorn-x86-boot.patch**
    - linux-3.2.14-popcorn-x86-vty.patch
  - Drivers modifications (all archs) in `drivers/`
    - linux-3.2.14-popcorn-drivers-vty.patch
    - linux-3.2.14-popcorn-drivers-acpi.patch
    - linux-3.2.14-popcorn-drivers-gpu.patch
    - linux-3.2.14-popcorn-drivers-pci.patch
- Goal
  - Release a first usable version of the project (alternative to virtual machines)
  - Document the project
  - Attract contributors and enthusiasts
  - Separate the architecture dependent code (initial porting guide)

Patches 25th Mar 2013

- Goal
  - Release a new usable version of the project (replicated-kernel)
  - Add new components
    - Inter-Kernel Messaging layer
    - Remote process creation and migration
    - Other improvements and fixes

GIT Repositories

- Hosted on TO BE ANNOUNCED
  - Publicly browseable, direct r/w access is protected (ssh key required)
- Kernel code
  - TO BE ANNOUNCED
  - many different branches
    - davek – process/thread remote creation, migration
    - net_msg_integration – fast software network switch
    - shmem_tuntap – software network switch using TUN/TAP
    - bshelton_messaging – inter-kernel messaging layer
    - andy_fd_aware – NUMA aware scheduling
    - andy_load_balance – again, NUMA aware scheduling
    - mklinux-readonly – one page table per NUMA-node
    - etc.
- Utils package
  - TO BE ANNOUNCED
- Kexec repository
  - TO BE ANNOUNCED

Before Booting Popcorn OS

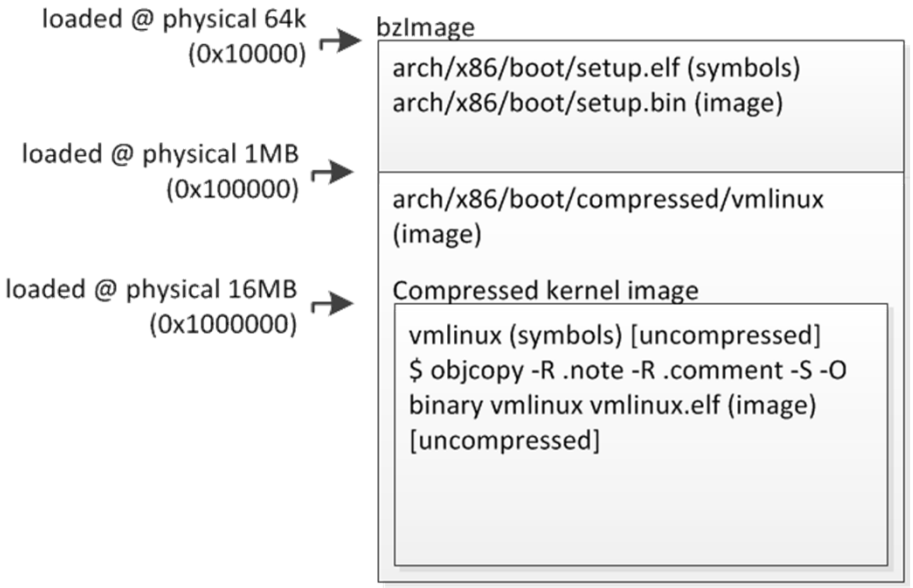
1. Start your machine with any Linux kernel with NUMA enabled
2. Download, compile and install a **Popcorn kernel**
3. Download, compile and install **Popcorn's kexec** utility
4. Download, compile and install the **Popcorn utils** package
5. Create a **ramdisk** image for the secondary kernels
6. Create the **resource** partition or cluster **configurations**
7. Copy and paste the primary kernel configuration to the boot loader (or take note of it)
8. Reboot!

Booting Popcorn OS

1. At the boot loader **select** the Popcorn kernel
2. Add the generated (slide 5 step 6) kernel **command line parameters** (if not added before)
3. When the Linux kernel is up and running, **login as root**
4. Use one of the scripts (in Popcorn utils) to **load other kernel instances** (secondary kernels)
5. The kernels will automatically and transparently form a **single OS** (this functionality can be disabled)

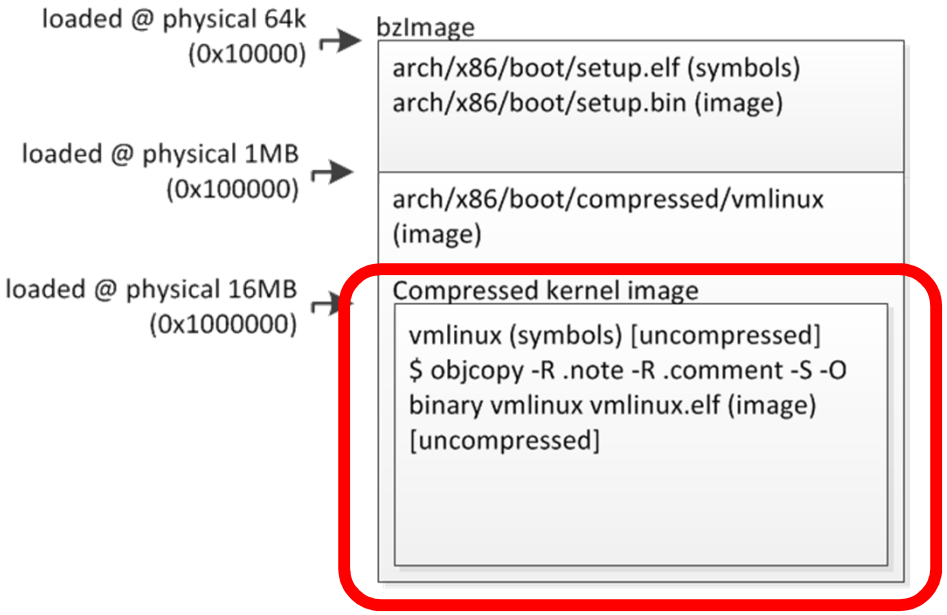
SMP Linux Boot Image (bzImage)

- x86_64 uses **bzImage** (default)
- the boot format is discussed in detail in `Documentation/x86/boot.txt`
- **bzImage** is made up of
  - a compressed and stripped version of **vmlinux**
  - that is accompanied by real-mode code for relocation and decompression



Popcorn Boot Images

- The primary Popcorn kernel boots from a conventional bzImage
- Secondary Popcorn kernels boot up from **vmlinux.elf**
  - decompression is not required, i.e. faster startup

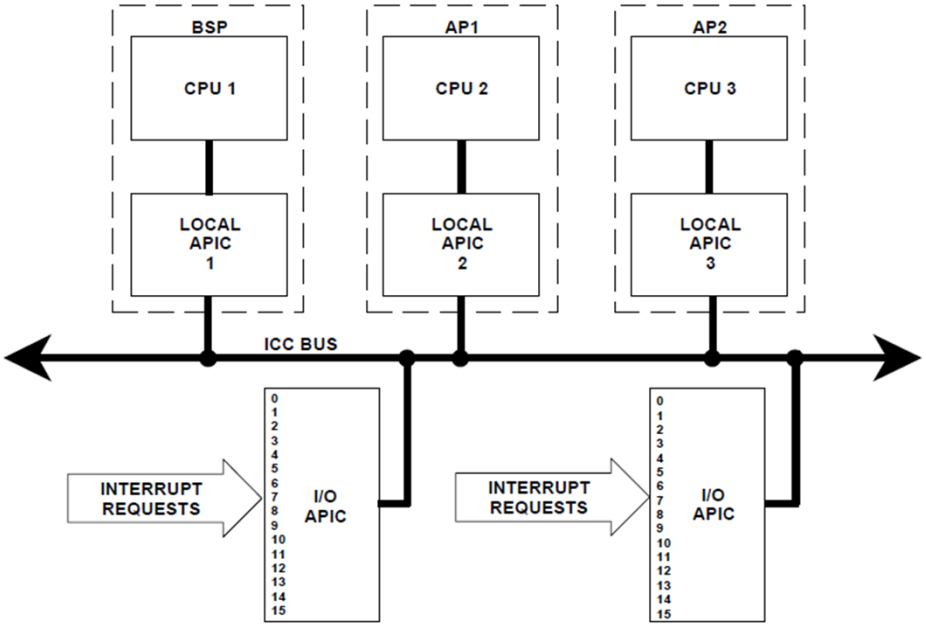


Secondary Kernels – Strategy Overview

- Use ***kexec*** to put the kernel image in the correct place in the physical memory (and start the boot process)
- Modify the Linux SMP boot trampoline to launch secondary kernels
- Adapt the existing Linux infrastructure to provide basic OS services in a replicated-kernel environment

SMP Linux Boot Process (x86)

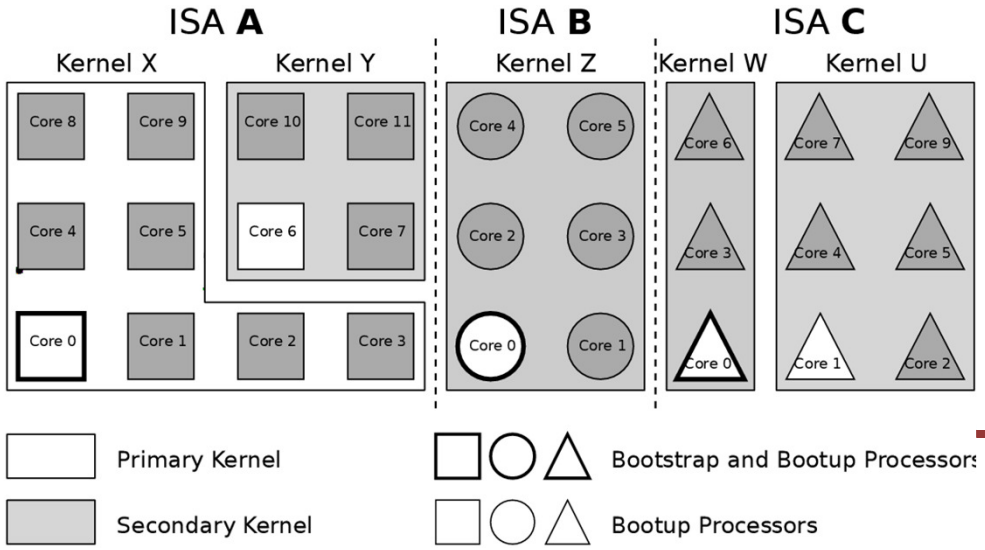
- In a multiprocessor (multi-core) x86 box there is
  - a Bootstrap Processor (**BSP**)
  - all other processors are Application Processors (**AP**)
- The BSP is the one that executes the BIOS code
- The BSP has to bring up all the APs



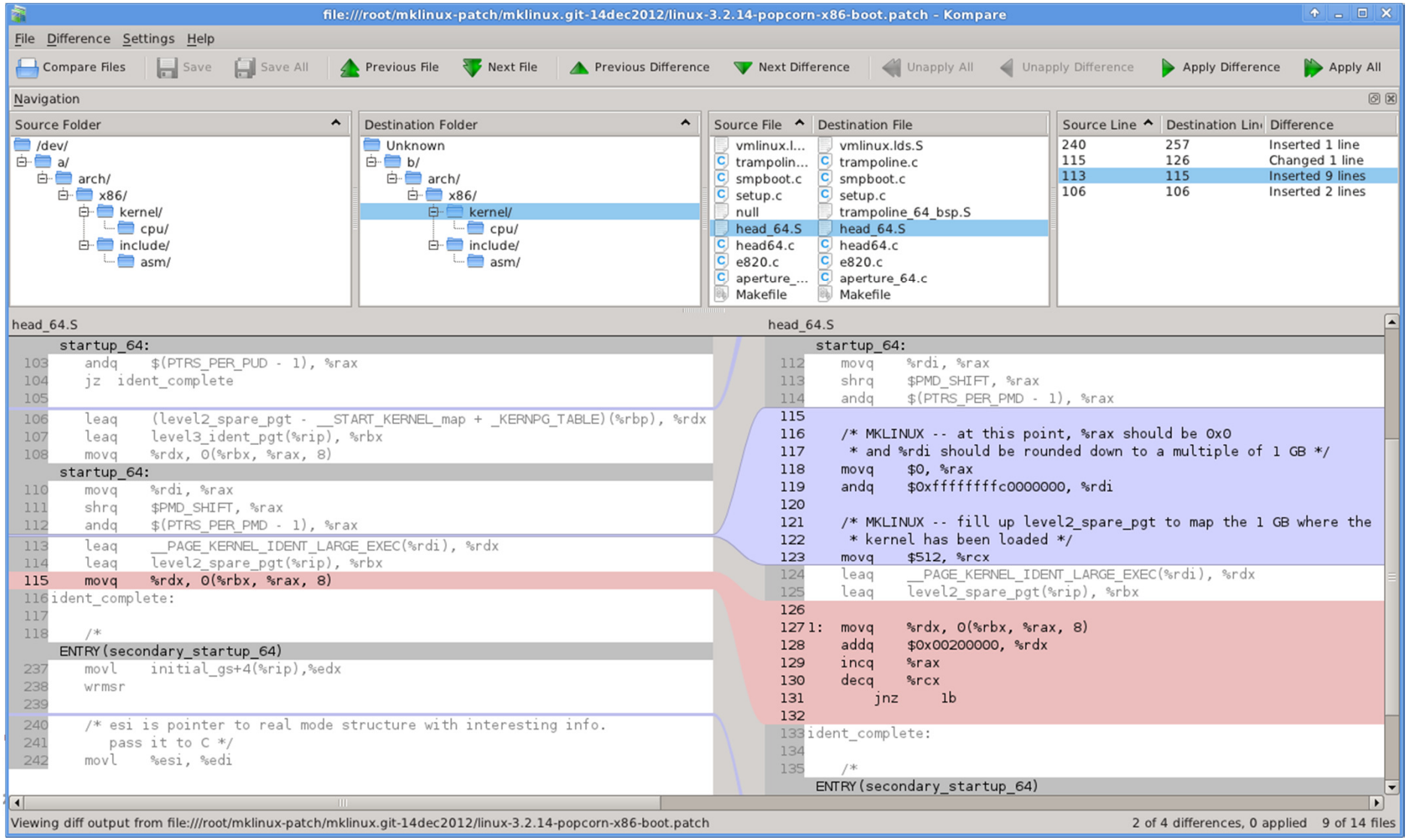
From Intel "MulitProcessor Specification", 1997

Primary and Secondary Kernels

- The Primary kernel is the kernel that boots on the bootstrap processor (i.e. the first kernel to boot)
- Any other kernel that boots is called a Secondary Kernel
- We redefine the names in order to extend the BSP/AP processors nomenclature from the Intel specifications to kernels in a heterogeneous ISA setting

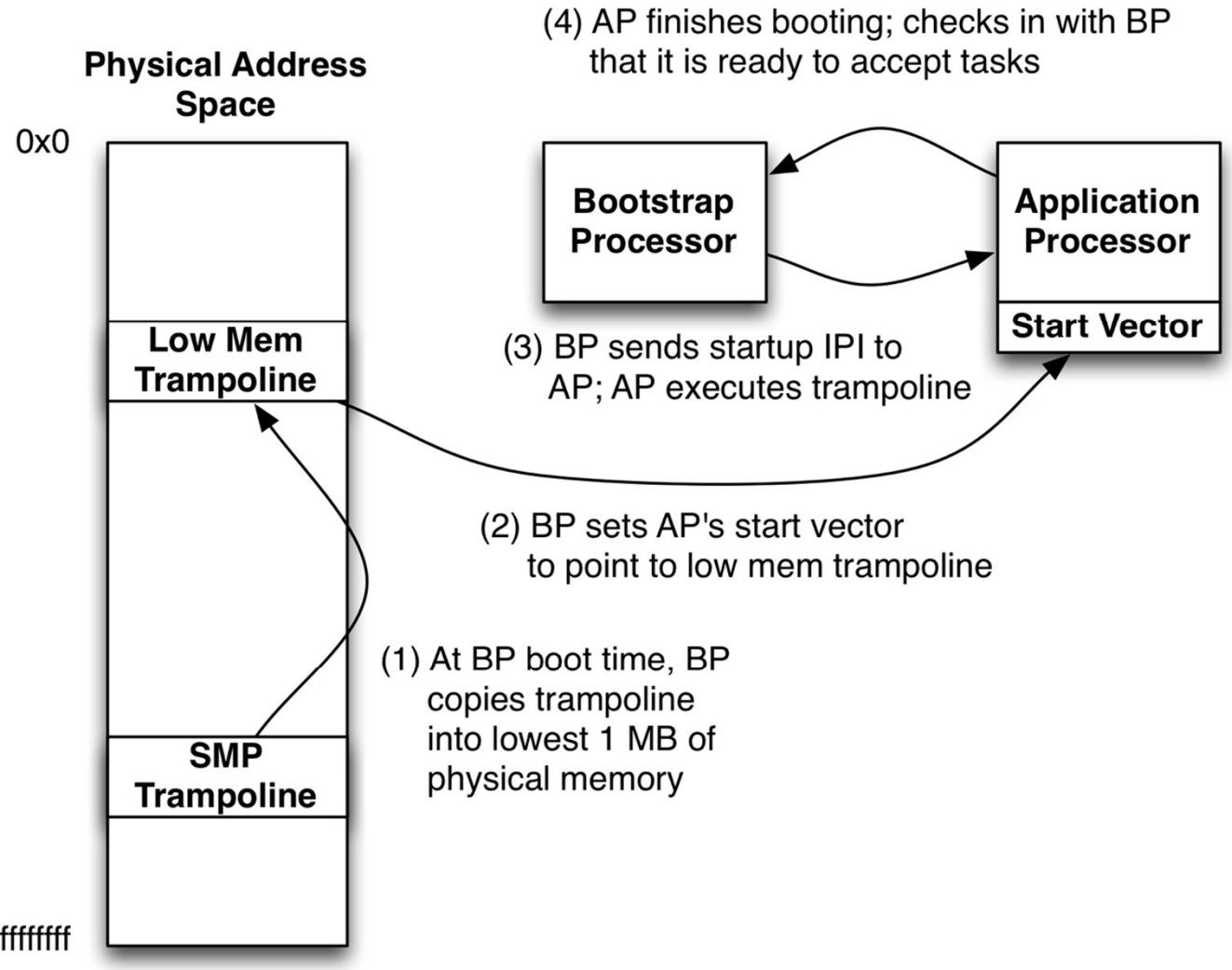


Fixes in arch/x86/kernel/head_64.S



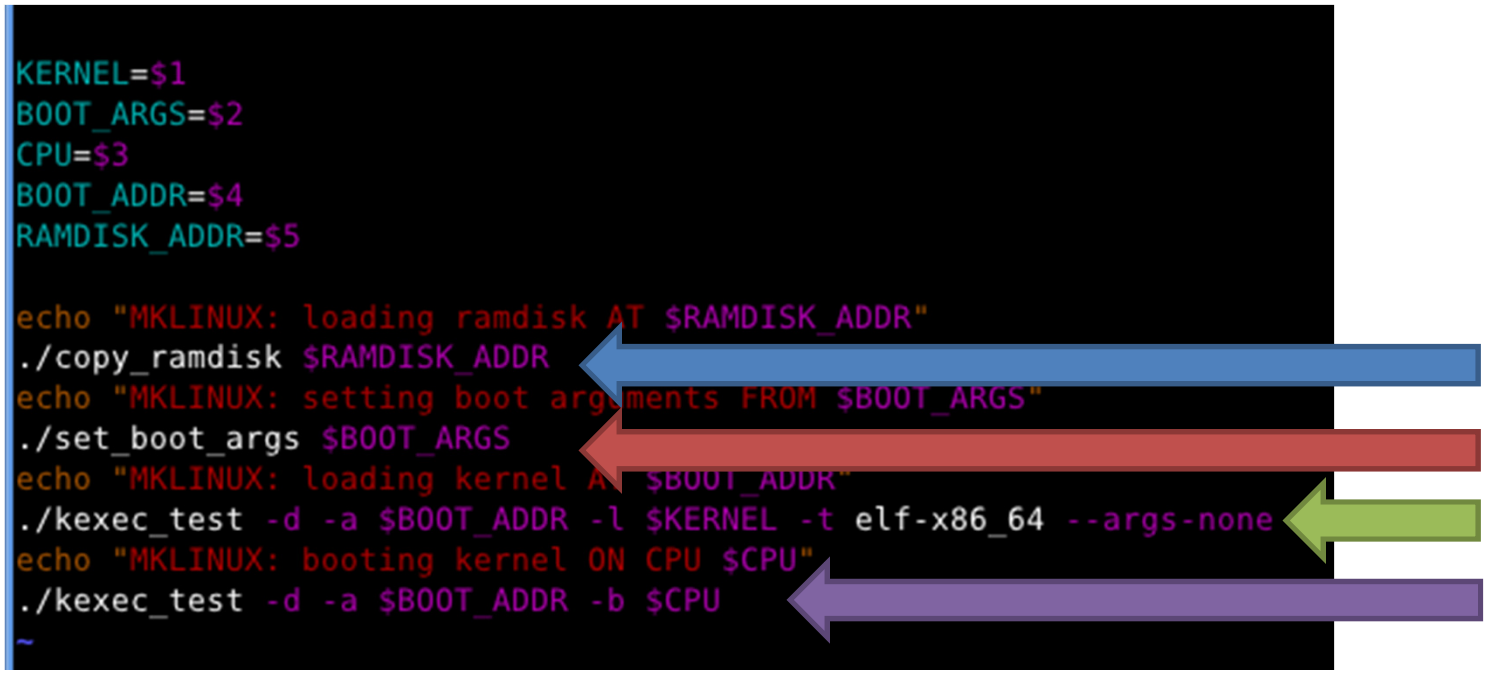
The content of this slide is taken from Ben Shelton's MS Thesis

SMP Linux AP Boot Process



Secondary Kernels Booting (script)

- Due to not being fully integrated with ***kexec***, the x86_64 version requires multiple loading steps



Secondary Kernels Booting (cmdline)

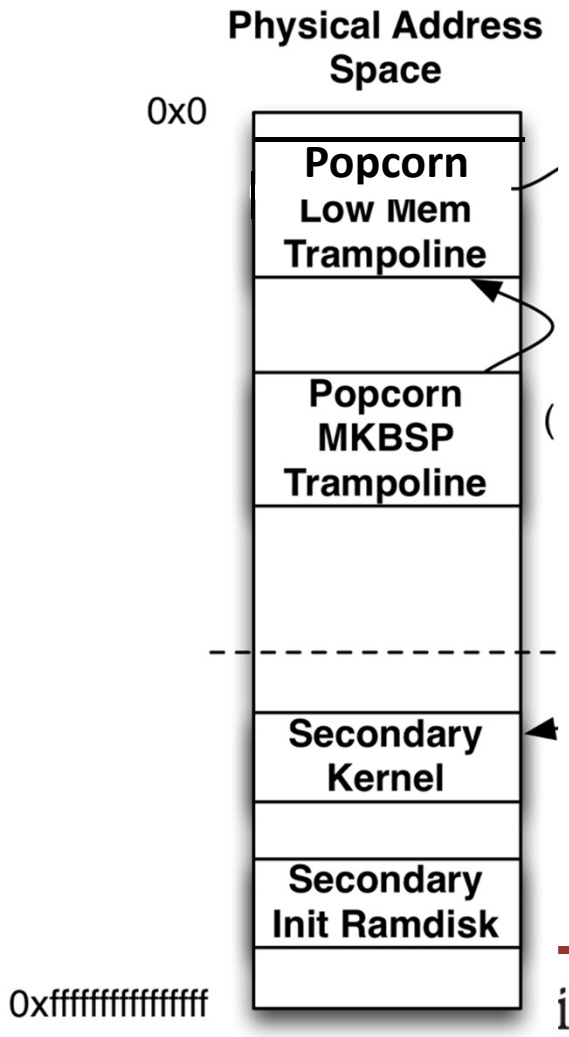
```
earlyprintk=ttyS0,115200 console=ttyS0,115200 acpi_irq_nobalance no_ipi_broadcas
t lapic_timer=1000000 pci_dev_flags=0x8086:0x10c9:b,0x102b:0x0532:b,0x1002:0x5a1
0:b,0x1002:0x4390:b,0x1002:0x4396:b,0x1002:0x4397:b,0x1002:0x4398:b,0x1002:0x439
9:b mklinux debug vty_offset=0x1fac000000 present_mask=2 memmap=1920M@4608M memm
ap=4592M$16M mem=6528M
~
```

- earlyprintk=ttyS0,115200
- console=ttyS0,115200
- acpi_irq_nobalance
- no_ipi_broadcast
- **lapic_timer=1000000**
- **pci_dev_flags=0x8086:0x10c9:b,0x102b:0x0532:b,0x1002:0x5a10:b,0x1002:0x4390:b,0x1002:0x4396:b,0x1002:0x4397:b,0x1002:0x4398:b,0x1002:0x4399:b**
- **mklinux**
- debug
- **vty_offset=0x1fac000000**
- **present_mask=2**
- memmap=1920M@4608M memmap=4592M$16M mem=6528M

In this example the kernel will be loaded on core 2

Secondary Kernels Boot Process

- The kernel binary is copied to the selected physical location
- The boot **ramdisk** is copied to the designated kernel's memory area
- The secondary kernel's *boot_params* are initialized with the appropriate kernel arguments and **ramdisk** location/size
- A syscall to boot the secondary kernel is made, this sets the CPU's initial instruction pointer to point to the multi-kernel trampoline and will send an inter-processor interrupt (IPI) to the CPU to wake it up

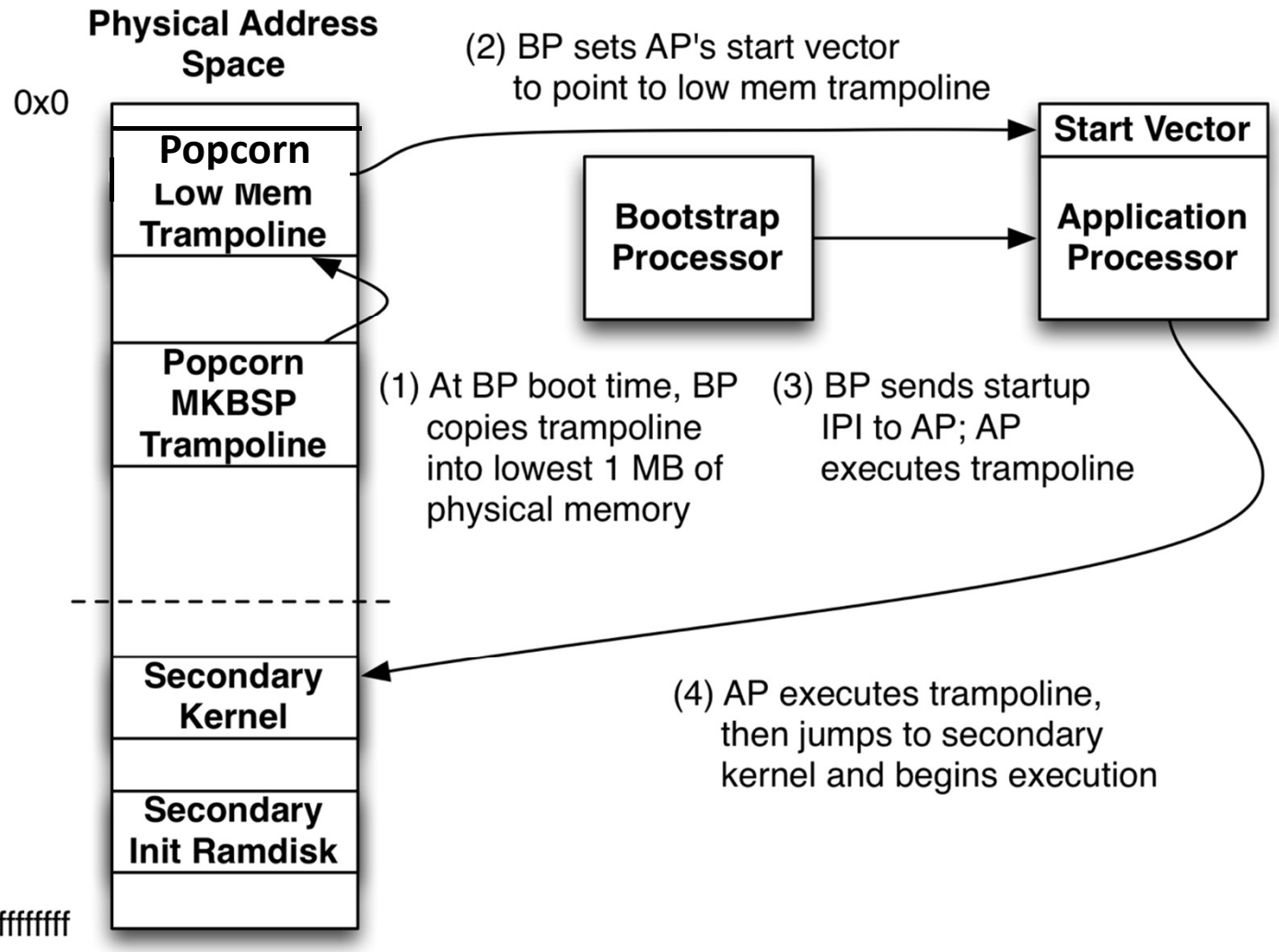


...from the trampoline

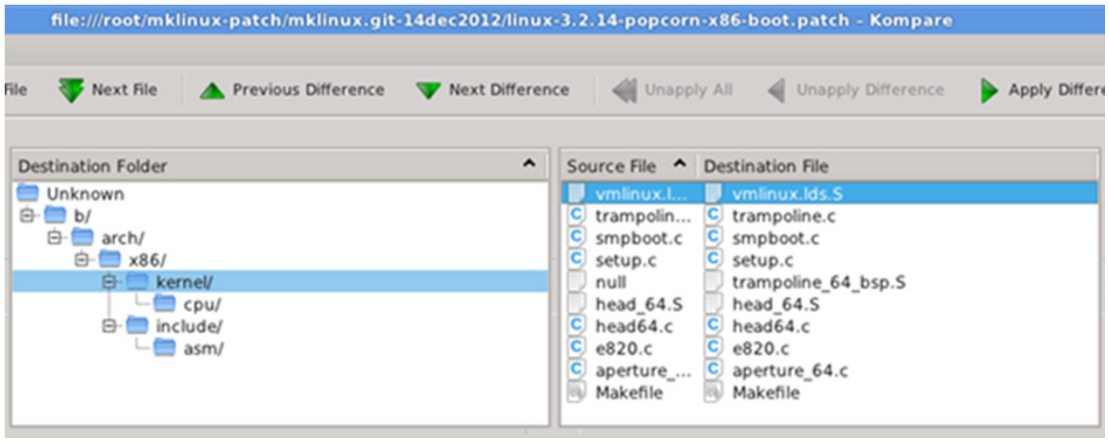
- Transition from real to protected mode, then jump to 64-bit long mode
- Load a 64-bit identity-mapped pagetable for the appropriate region
- Do a long jump to **`head_64`** of the guest kernel
- Fix up the kernel's pagetables, and setup the identity mappings for the 2 GB of physical address space where the kernel was loaded
- Continue to **`x86_64_start_kernel()`** to begin executing the kernel code itself

The content of this slide is taken from Ben Shelton's MS Thesis

Popcorn AP Boot Process



Popcorn Low Mem Trampoline

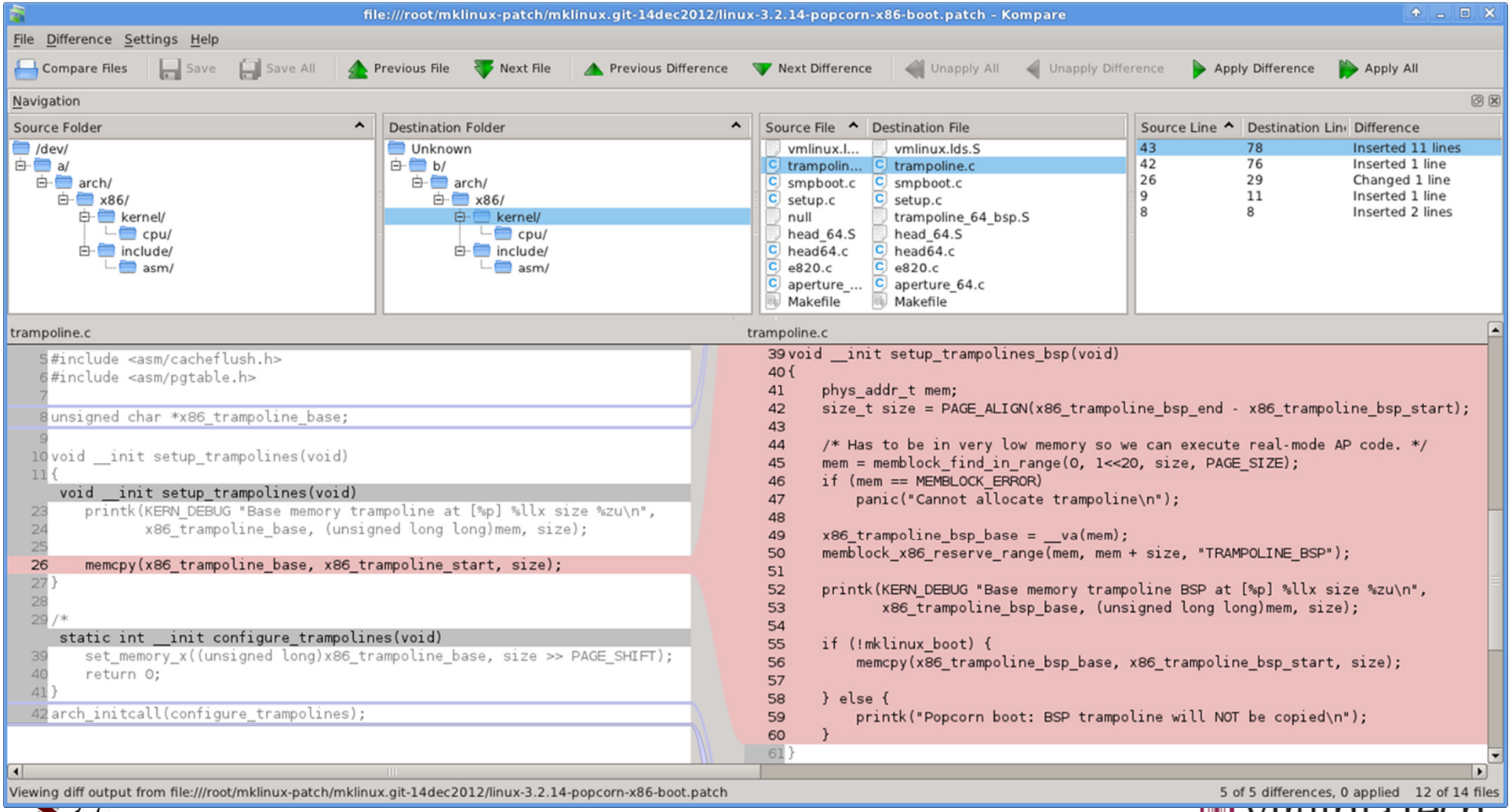


vmlinux.lds.S

```
    SECTIONS
209         x86_trampoline_end = .;
210     }
211
212 #ifdef CONFIG_POPCORN
213     .x86_trampoline_bsp : AT(ADDR(.x86_trampoline_bsp) - LOAD_OFFSET) {
214         x86_trampoline_bsp_start = .;
215         *(.x86_trampoline_bsp)
216         x86_trampoline_bsp_end = .;
217     }
218 #endif
219
220     .x86_cpu_dev.init : AT(ADDR(.x86_cpu_dev.init) - LOAD_OFFSET) {
221         __x86_cpu_dev_start = .;
222         *(.x86_cpu_dev.init)
```

- We added a new trampoline
- There are now **two trampolines**
  - One for APs, i.e. cores that belongs to the same kernel
  - And another for secondary kernels

Setup Popcorn trampoline..



Resource Configurations

- In the **Popcorn utils** package there are scripts and applications to automatically (statically) subdivide hardware resources in your machine amongst kernels (and assists with booting them)
  - `generate_all.sh` creates the configurations
  - `mklinux_boot.sh` boots a secondary configuration
- ***mpart*** is the main application to divide computational and memory resources into partitions, optionally in a NUMA-aware fashion

mpart

```
antoniob@gigi:~$ numactl --hardware
available: 8 nodes (0-7)
node 0 cpus: 0 1 2 3 4 5 6 7
node 0 size: 16381 MB
node 0 free: 15841 MB
node 1 cpus: 8 9 10 11 12 13 14 15
node 1 size: 16384 MB
node 1 free: 15893 MB
node 2 cpus: 16 17 18 19 20 21 22 23
node 2 size: 16384 MB
node 2 free: 15943 MB
node 3 cpus: 24 25 26 27 28 29 30 31
node 3 size: 16384 MB
node 3 free: 15940 MB
node 4 cpus: 32 33 34 35 36 37 38 39
node 4 size: 16384 MB
node 4 free: 15916 MB
node 5 cpus: 40 41 42 43 44 45 46 47
node 5 size: 16384 MB
node 5 free: 15895 MB
node 6 cpus: 48 49 50 51 52 53 54 55
node 6 size: 16384 MB
node 6 free: 15940 MB
node 7 cpus: 56 57 58 59 60 61 62 63
node 7 size: 16368 MB
node 7 free: 15921 MB
node distances:
node   0   1   2   3   4   5   6   7
  0:  10  16  16  22  16  22  16  22
  1:  16  10  22  16  22  16  22  16
  2:  16  22  10  16  16  22  16  22
  3:  22  16  16  10  22  16  22  16
  4:  16  22  16  22  10  16  16  22
  5:  22  16  22  16  16  10  22  16
  6:  16  22  16  22  16  22  10  16
  7:  22  16  22  16  22  16  16  10
```

- Gathers NUMA information from:
  - /sys/devices/system/node/
  - /proc/meminfo
- Outputs the kernel boot arguments for different configurations
  - Different alignments and resource reservations
  - Clustering (one kernel per NUMA-zone)
  - Partitioning (one kernel per core)

Masking Resources

- When Linux boots, it automatically discovers the PCI devices present in the system
- Each kernel assumes that it has access to all of the devices in the system unless a device is "blacklisted" using kernel arguments
- Example syntax (from slide 15)
  - **pci_dev_flags=0x8086:0x10c9:b,0x102b:0x0532:b,0x1002:0x5a10:b,0x1002:0x4390:b,0x1002:0x4396:b,0x1002:0x4397:b,0x1002:0x4398:b,0x1002:0x4399:b**

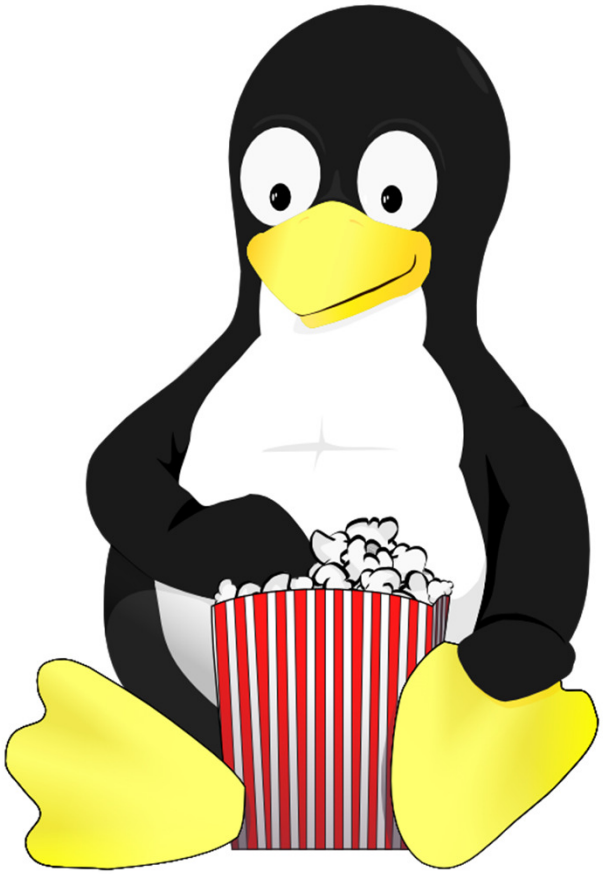
Partitioning and Clustering

- Logical to physical translation for CPU ID and APIC ID to provide a contiguous range
- I/O APIC is set up to direct device interrupts to the kernel that owns the device
- Local APICs are set up to allow inter-processor interrupts (IPI) between kernels for synchronization and communication

Interact with Secondary Kernels

- A user can interact with any of the kernels by using any of:
  - Virtual TTY
    - example: **`$ cu -l /dev/ttyX`**
    - X is the core ID on which the kernel is started
    - Virtual TTYs appear to applications as regular TTYs
  - Virtual Network Switch
    - example: **`$ ssh 10.1.2.X`**
    - X is the core ID plus one on which the kernel is started
    - Different versions are currently available depending on the performance and resilience needed
  - Inter-Kernel Shared Memory

Questions?



Team

www.popcornlinux.org