ELEC 424/553
Mobile & Embedded Systems

Lecture 8 - Introduction to Device Drivers

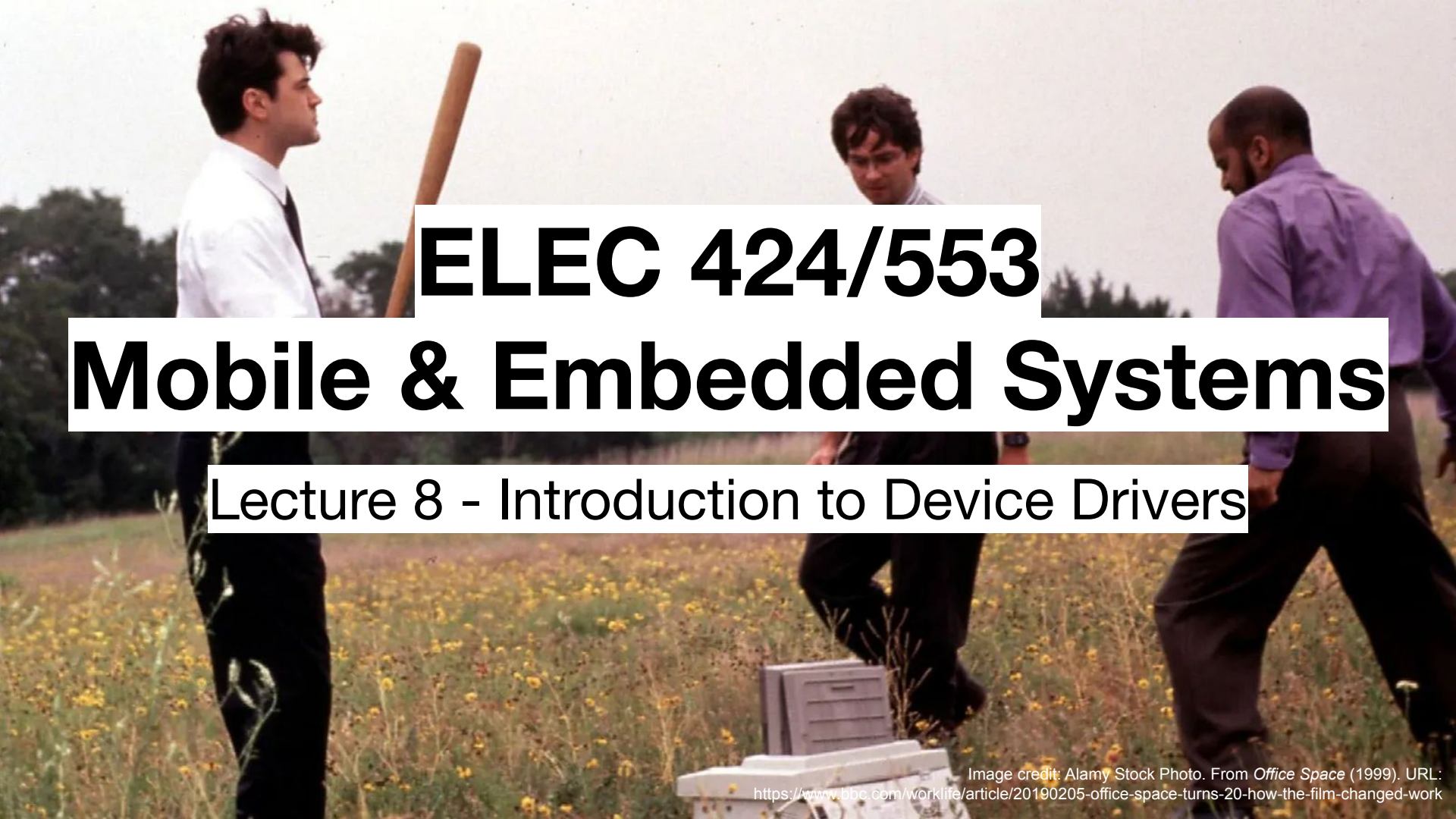

Image credit: Alamy Stock Photo. From *Office Space* (1999). URL: https://www.bbc.com/worklife/article/20190205-office-space-turns-20-how-the-film-changed-work

Questions From Last Class

- Can a process just decide to be on the deadline or realtime schedulers?
  - It depends :)
  - The quoted text below (with my bolding) from: Michael Kerrisk, “sched(7) — Linux manual page”, URL: https://man7.org/linux/man-pages/man7/sched.7.html
    - Look at “Privileges and resource limits”
    - **Deadline**: “A **thread must be privileged** (CAP_SYS_NICE) in order to set or modify a SCHED_DEADLINE policy.”
    - **Realtime**: “the RLIMIT_RTPRIO resource limit **defines a ceiling on an unprivileged thread's static priority** for the SCHED_RR and SCHED_FIFO policies.”
    - **CAP_SYS_NICE**: “Privileged (CAP_SYS_NICE) threads ignore the RLIMIT_RTPRIO limit; as with older kernels, they can make arbitrary changes to scheduling policy and priority.”

Questions From Last Class

CAP_SYS_NICE

* Lower the process nice value (nice(2), setpriority(2)) and change the nice value for arbitrary processes;
* set real-time scheduling policies for calling process, and set scheduling policies and priorities for arbitrary processes (sched_setscheduler(2), sched_setparam(2), sched_setattr(2));
* set CPU affinity for arbitrary processes (sched_setaffinity(2));
* set I/O scheduling class and priority for arbitrary processes (ioprio_set(2));
* apply migrate_pages(2) to arbitrary processes and allow processes to be migrated to arbitrary nodes;
* apply move_pages(2) to arbitrary processes;
* use the **MPOL_MF_MOVE_ALL** flag with mbind(2) and move_pages(2).

Text to the left copy and pasted from:

Michael Kerrisk, “capabilities(7) — Linux manual page”, URL: https://man7.org/linux/man-pages/man7/capabilities.7.html

Questions From Last Class

- What is the ABI? Does it relate to system calls?
  - Application binary interface (ABI)
  - How compiled code should access other compiled code
  - E.g., Compiled application accessing compiled library
- So, for your application to access a system call:
  - For your C source code, use the API (application programming interface) provided by glibc, which will be a function that causes a system call to get executed
  - Your source code gets compiled and will adhere to the ABI for your computer architecture and system configuration
    - In other words, your compiled code will be able to run
  - However, your compiled binary may not execute on another computer with the same architecture (e.g., x86-64) because of differences in system configuration
    - Windows vs. Linux
    - Even within Linux, could be a different distribution, etc.

Questions From Last Class

- Does each core get its own EAX register for system calls?
  - Yes (in x86-64 is it called RAX; EAX is 32-bit)
    - From ENOSUCHBLOG, URL: https://blog.yossarian.net/2020/11/30/How-many-registers-does-an-x86-64-cpu-have
- Pipelining & microkernel - doesn't seem to be much out there
  - https://core.ac.uk/download/pdf/36737603.pdf

Questions From Last Class

- Something I forgot? Let me know!

Housekeeping

- **Assignment 1**
  - Posted soon
- **Soldering Session - Today!**
  - 6:30-8:30 in FE&P 102
  - Last name K and lower in first hour, above K in second hour
  - Required to use safety glasses!!

Soldering Safety

Soldering: users may solder in the lab under the following conditions

- **Approved** soldering irons or desoldering equipment only.
- **Lead** – users should assume that any solder they handle contains lead and take personal precautions accordingly.
- **More than one person** must be present when soldering. No solo work.
- **Do not touch solder** except with hands
- **Wash hands** after handling solder
- **Clean** the work surface after soldering to prevent lead contamination.
- Use **safety glasses** when soldering or sitting next to someone soldering
- **Heat** – don’t touch tip or iron; always put tip in holster when not using
- **Filter** – use the fan + charcoal filters provided when soldering

Housekeeping

- **Office Hours**
  - **Joe**: Tues 3:00-4:00pm in Duncan Hall 2098 or by appointment
  - **Luxi Zhu & Xinbo Luo (TAs)**: Wed 5:30-6:30 in Ryon B10 or by appointment

Device Drivers

- **Software** that enables **interfacing** with **hardware**
- Drivers everywhere
  - Printers
  - Graphics cards
  - Solid state drives (SSDs)
  - Network cards
  - …

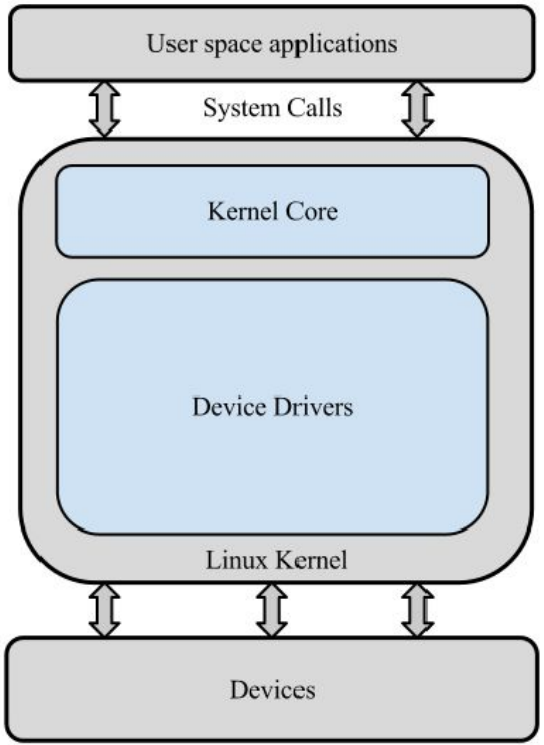

Figure from Zakharov et al, “Generating Environment Model for Linux Device Drivers”. 2013. Conference: 7th Spring/Summer Young Researchers' Colloquium on Software Engineering.
URL: https://www.researchgate.net/publication/301370659_Generating_Environment_Model_for_Linux_Device_Drivers

State of the Art: Linux Drivers

“Most of the code in Linux is device drivers,

Quote from “Device Power Management Basics”.
URL: https://www.kernel.org/doc/html/v5.0/driver-api/pm/devices.html

State of the Art: Linux Drivers

“Most of the code in Linux is device drivers, so most of the Linux power management (PM) code is also driver-specific.

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State of the Art: Linux Drivers

How much is “most”?

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“Talk is cheap. Show me the code.” - Linus Torvalds

“**Device drivers constitute 70% of the Linux code base** [32]

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“**Device drivers constitute 70% of the Linux code base** [32], and likely are a greater fraction of the code written for the Windows kernel, which supports many more devices. Several studies have shown that **drivers are the dominant cause of OS crashes** in desktop PCs [14, 28].”

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Let’s Hear From Linus Himself

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Let’s Hear From Linus Himself (Abridged)

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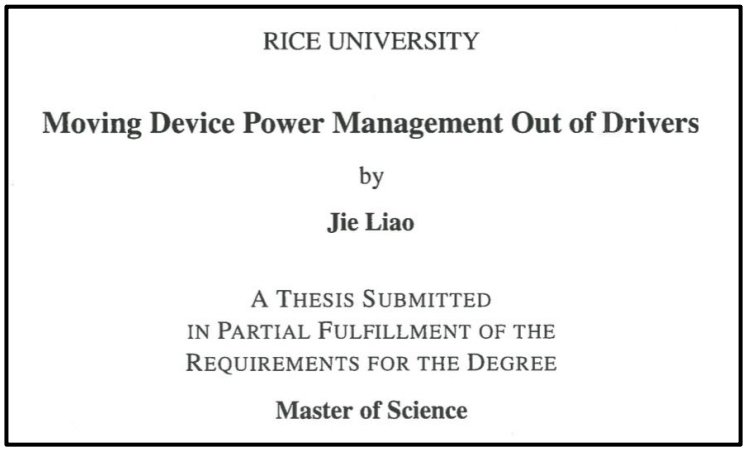
Can We Simplify Drivers?



RICE UNIVERSITY

Moving Device Power Management Out of Drivers

by

Jie Liao

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

Master of Science

Thesis URL: https://scholarship.rice.edu/handle/1911/95976

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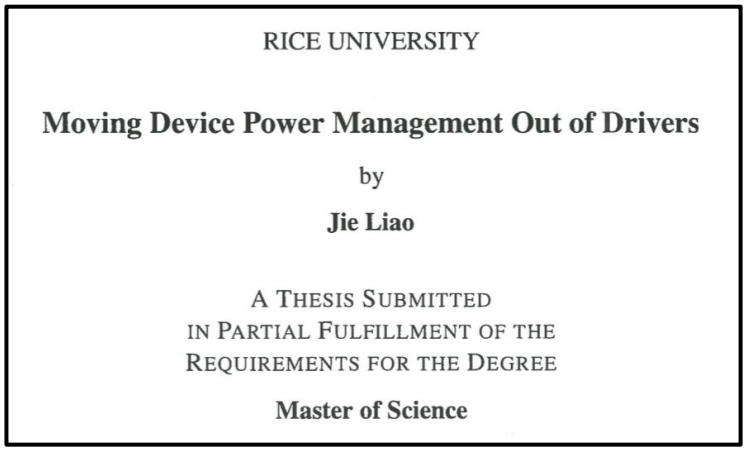

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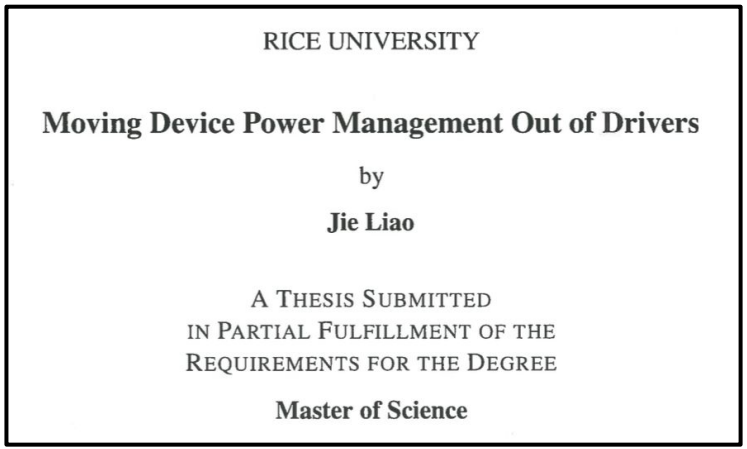

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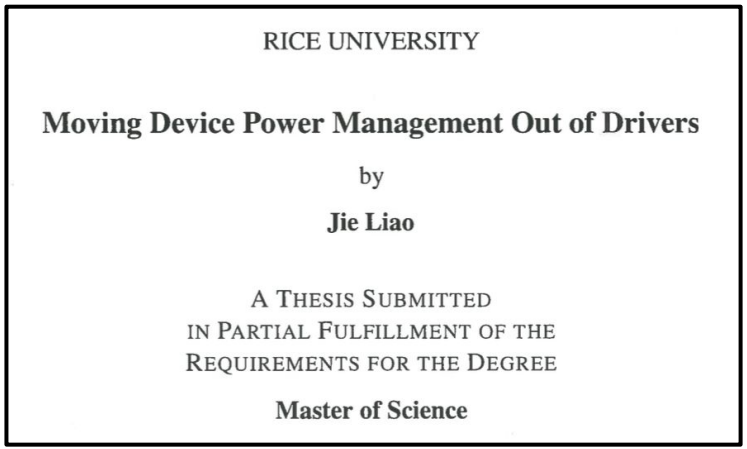

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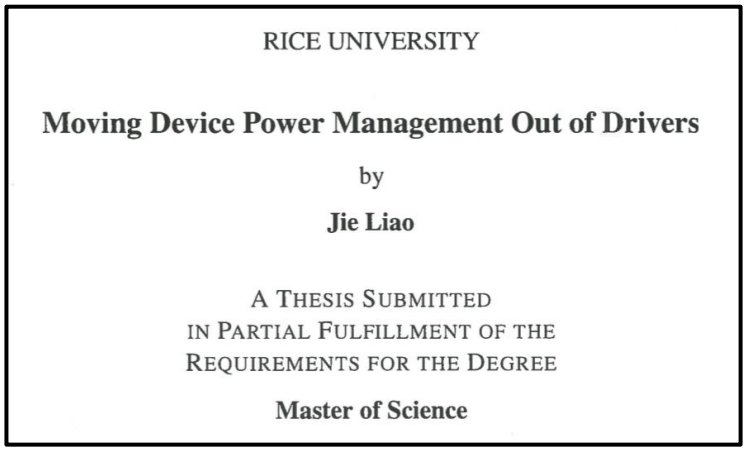

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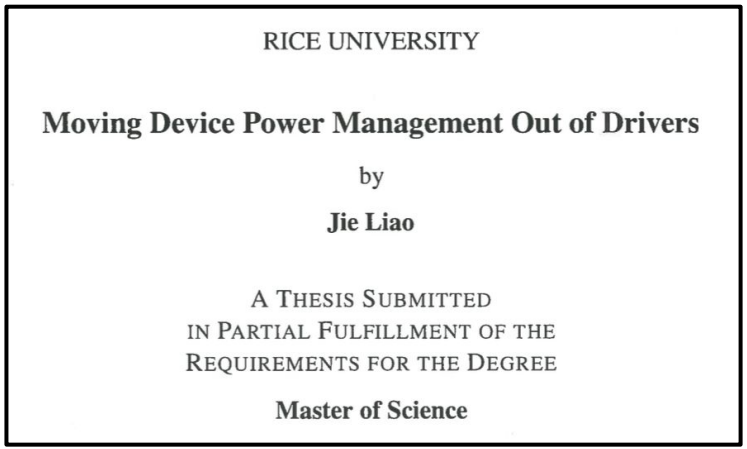

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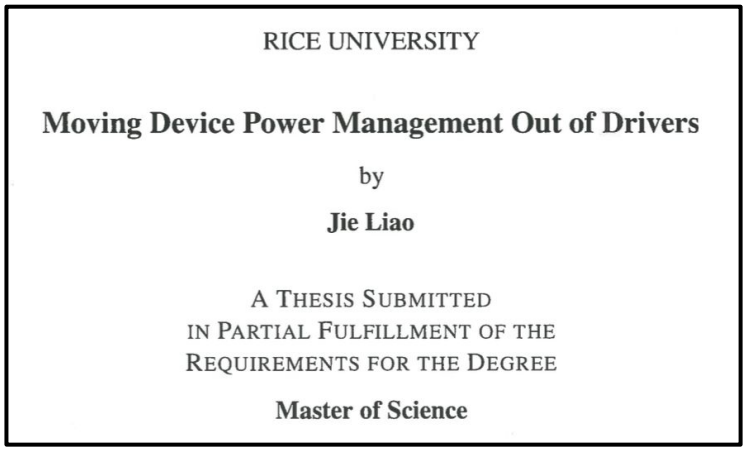

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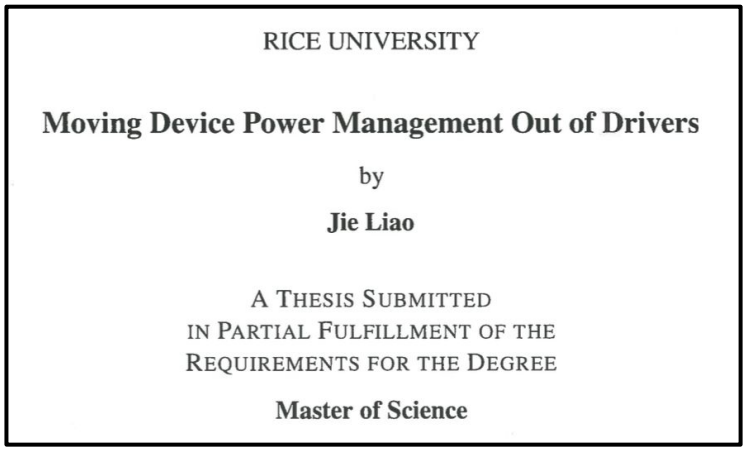

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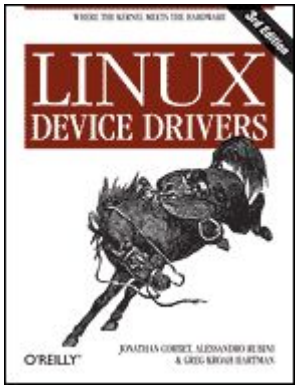
Short Stories

Power saving is everything (“electron is king”)
&
GPS+LED init
&
Hour-long discussions

Much of the Following Is Based on Chapter 1 of ...



Linux Device Drivers
Third Edition

Jonathan Corbet
Alessandro Rubini
Greg Kroah-Hartman

Available for free from here: https://lwn.net/Kernel/LDD3/

Kernel Overview

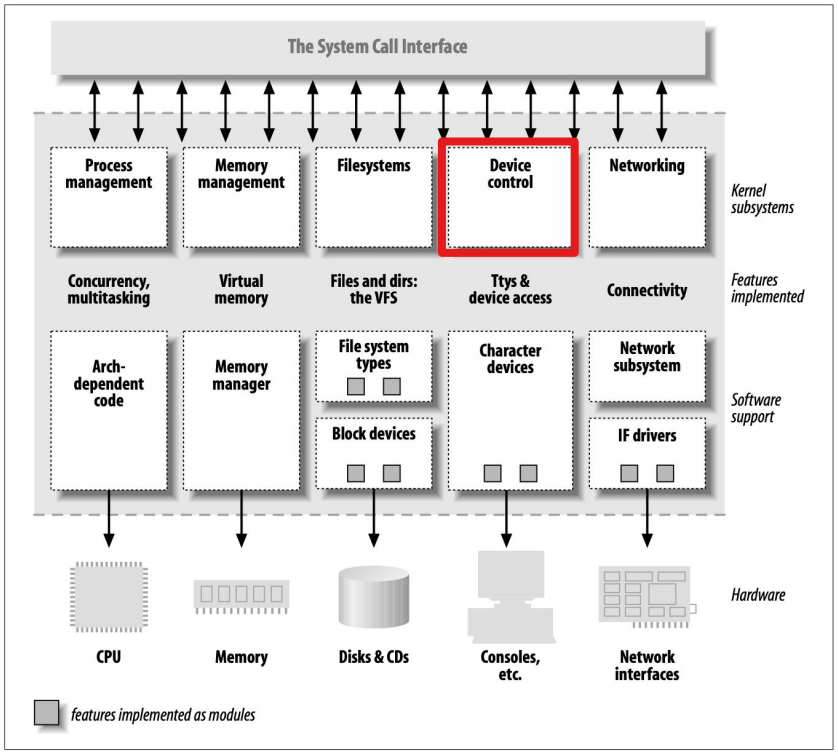
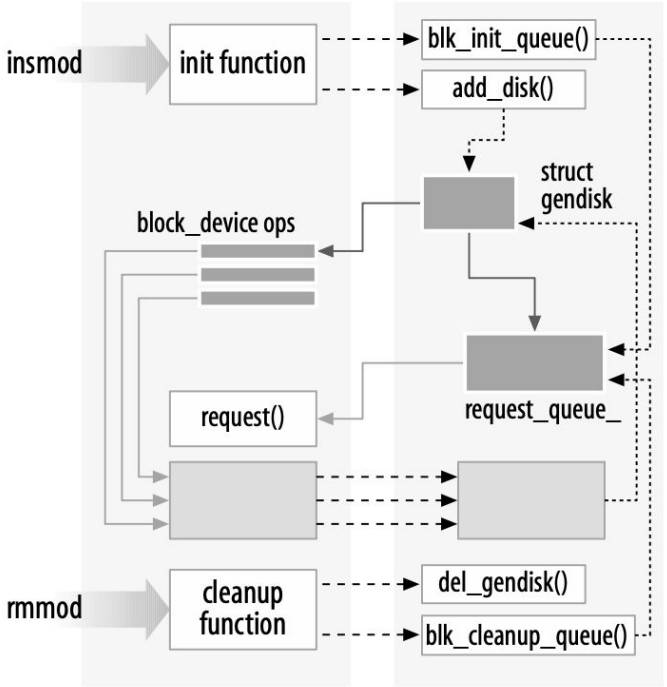


Figure 1-1. A split view of the kernel

Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed. Fig. from p. 6.

Linux Kernel Modules (LKMs)

- **Loadable** object code
- Enable kernel to do more (or less) on the fly
- Module **classes**
  - E.g. **device drivers**
- Dynamically linked to kernel via **`insmod`**
- Dynamically unlinked to kernel via **`rmmod`**



Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed. Fig. from p. 19 - full figure not shown.

Modules Used For Different Kernel Services

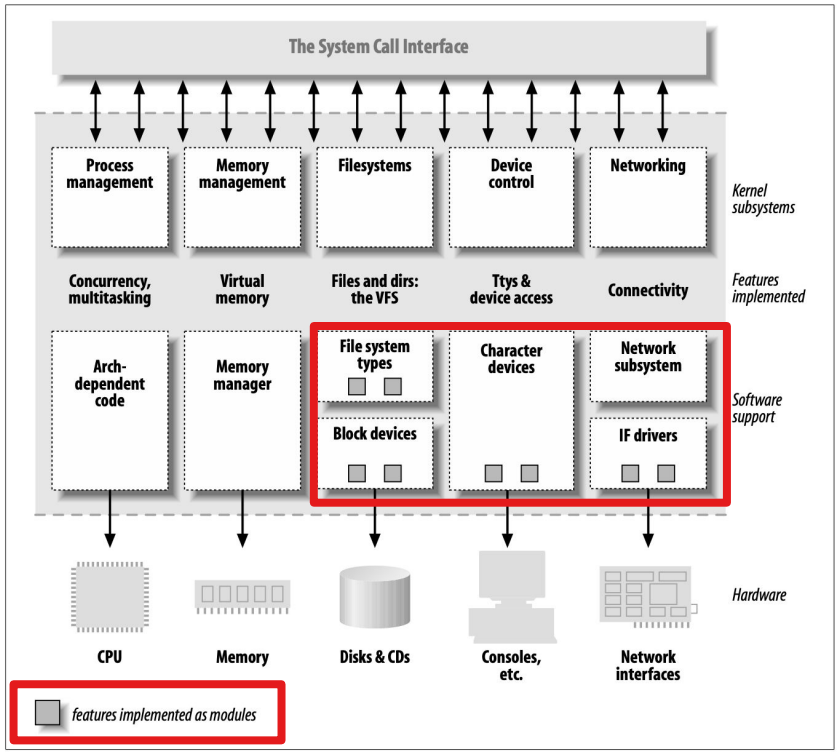


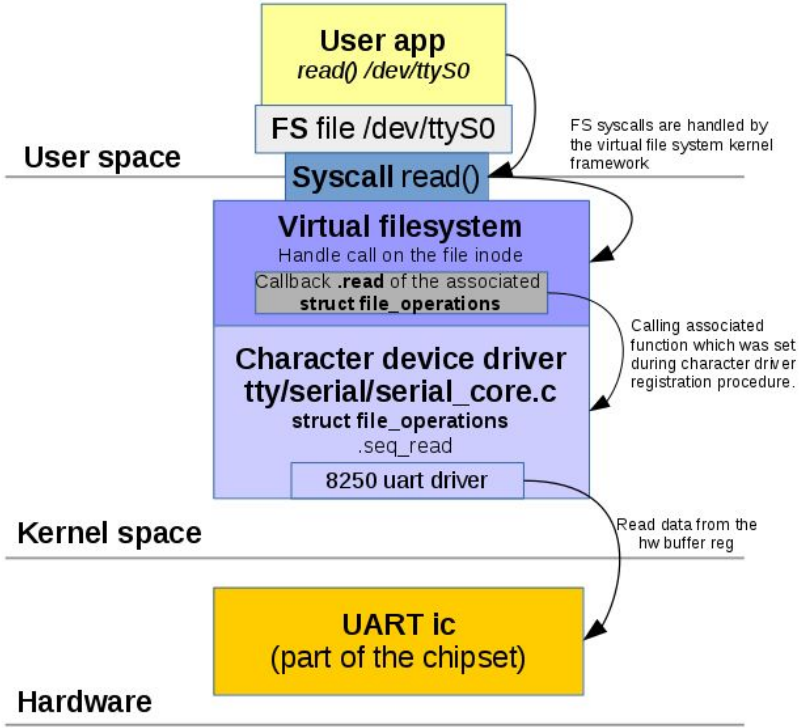
Figure 1-1. A split view of the kernel

- Module class defined by **functionality**
  - **char** module
  - **block** module
  - **network** module

Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed. Fig. from p. 6.

Character (char) Devices (*cdevs*)

- Interfaced through **stream of bytes**
- System calls commonly used include:
  - `open`
  - `close`
  - `read`
  - `write`
- Similar to **files**
  - But generally limited to sequential access
- Appear in **`/dev`**



Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed.
Figure: Oleg Kutkov, "Simple Linux character device driver". URL: https://olegkutkov.me/2018/03/14/simple-linux-character-device-driver/

Examples of Character Devices

- Keyboards
- Mice
- Printers

Block Devices (*blkdevs*)

- Device with **filesystem-hosting** capability
  - E.g. solid state drive (SSD)
- Also appear in `/dev`
- Unix flavors generally limited to whole block (~512 bytes) I/O
- Linux can perform arbitrary byte-level I/O
- Applications can access block & char devices the same way
  - Kernel has to figure out how to work with each

Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed.
Picture: Modified from https://me.me/i/i-missed-the-part-where-thats-my-problem-84a8acd93c234e08990d6d7769fc2a34

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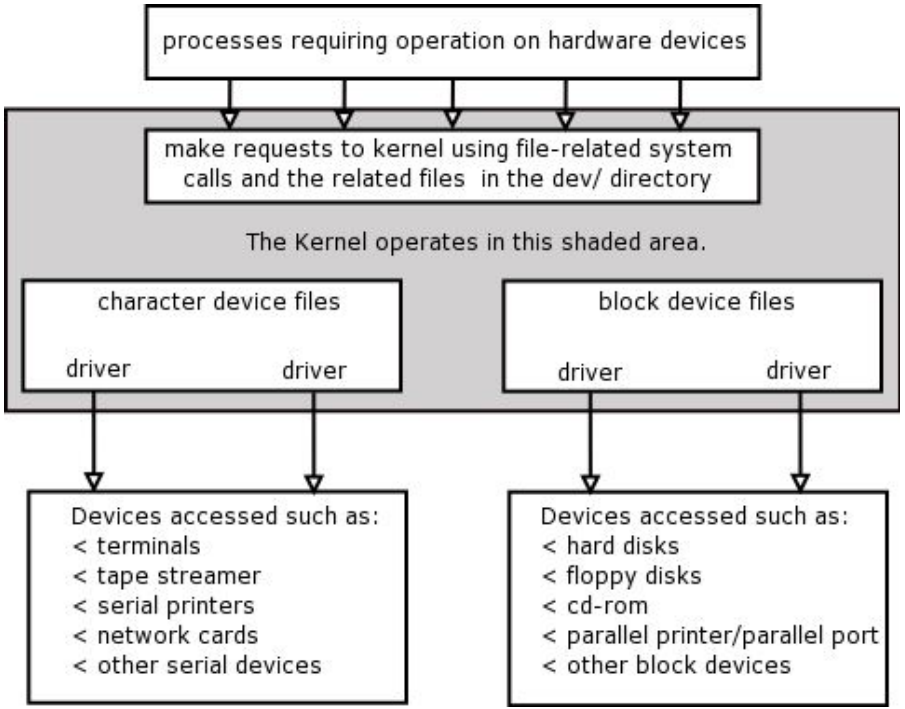

Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed.
Figure: EmbLogic's Blog, “Character Driver VS Block Driver”. URL: https://www.emblogic.com/blog/08/character-driver-vs-block-driver/

Examples of Block Devices

- Hard drives
- Solid state drives (SSDs)
- Blu-ray discs
- Flash memory devices

Network Interfaces

- HW/SW devices used to trade **data packets**
  - SW: Loopback interface
- No filesystem entry
- Unix/Linux: Use name like **`eth0`**
  - Remember **`wlan0`** in Project 1?
- **Functions** used by kernel rather than read/write for char & block
  - **Socket API**
  - “Everything is a file” motto of Unix violated

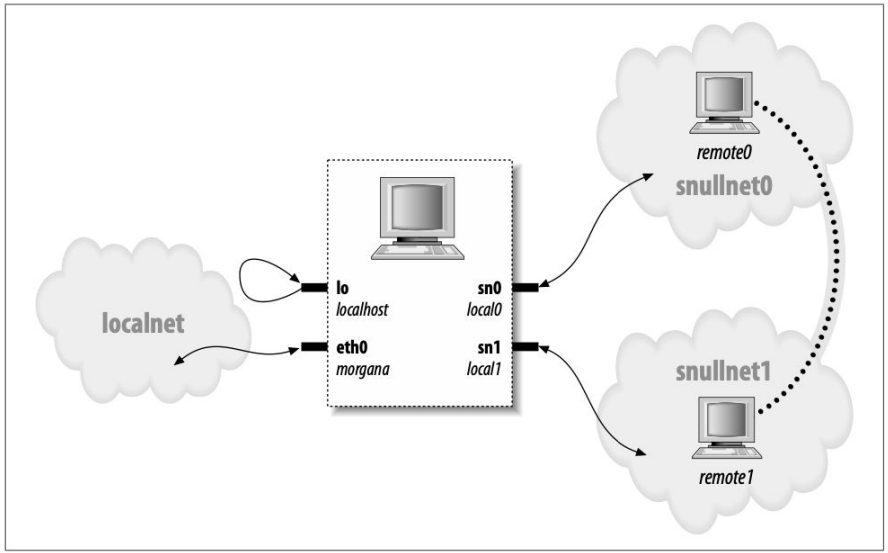

Figure 17-1. How a host sees its interfaces

Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed. Fig. from p. 500.

Where Do USB Devices Fit In All of This?

- USB devices will appear to Linux as one of the three aforementioned types
- USB serial port
  - Char device
- USB memory card reader
  - Block device
- USB Ethernet interface
  - Network device

Security Motivation

- Should anyone be able to load a module? Why or why not?
- With modules, we're in kernel space - so the answer is a strong "no"
- Verification of process permission to insert modules performed by system call **`init_module`**
  - Hacker goal: Gain permission
- Generally prefer to have higher-level security management
  - Similar to driver power management discussion
- But sometimes, driver writers have to care

Security Considerations

- C will not perfectly protect you
  - Buffer overrun
- Be paranoid about user process input
- Don’t let device receive arbitrary information from user
- Enforce user access levels

‘How to Solve a Buffer Overrun Detected Problem’. URL: https://www.tech-faq.com/how-to-solve-buffer-overrun-detected-problem.html

How Does GPL Relate to Drivers & Modules?

- Linux has GPLv2
- “The GPL allows anybody to redistribute, and even sell, a product covered by the GPL, as long as the recipient has access to the source and is able to exercise the same rights.” - LDD
- “Additionally, any software **product derived from a product covered by the GPL must**, if it is redistributed at all, **be released under the GPL**.” - LDD
- Are drivers a derived product?
- Can vendors give just binaries of their modules/drivers?

Slide based on and quotes from: Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed.

How Does GPL Relate to Drivers & Modules?

“1. **You may copy and distribute verbatim copies of the Program's source code** as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice and disclaimer of warranty; keep intact all the notices that refer to this License and to the absence of any warranty; and give any other recipients of the Program a copy of this License along with the Program.”

“GNU General Public License, version 2”. URL: https://www.gnu.org/licenses/old-licenses/gpl-2.0.en.html. Bolding is my own.

How Does GPL Relate to Drivers & Modules?

"3. **You may copy and distribute the Program** (or a work based on it, under Section 2) **in object code** or executable form under the terms of Sections 1 and 2 above **provided that you also do one of the following**:

a) **Accompany it with the complete corresponding machine-readable source code**, which must be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange; or,

b) Accompany it with a written offer, valid for at least three years, to give any third party, for a charge no more than your cost of physically performing source distribution, **a complete machine-readable copy of the corresponding source code**, to be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange; or,

c) **Accompany it with the information you received as to the offer to distribute corresponding source code**. (This alternative is allowed only for noncommercial distribution and only if you received the program in object code or executable form with such an offer, in accord with Subsection b above.)

The source code for a work means the preferred form of the work for making modifications to it."

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How Does GPL Relate to Drivers & Modules?

- Up to this point, it's been okay to only give module binaries
- Overall message - modules not considered derived products
- Tread cautiously - not uniform consensus among developers
- "Talk to legal"
- Of course, this is different for mainline kernel modules
    - Those require a GPL-compatible license
    - You must give out the source!

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Slide based on and quotes from: Corbet, Rubini, & Kroah-Hartman, *Linux Device Drivers*, 3rd Ed.
Image URL: https://www.hunts.com/tomato-sauce-and-paste/tomato-sauce

Next Time

Writing Your Very Own Kernel Module