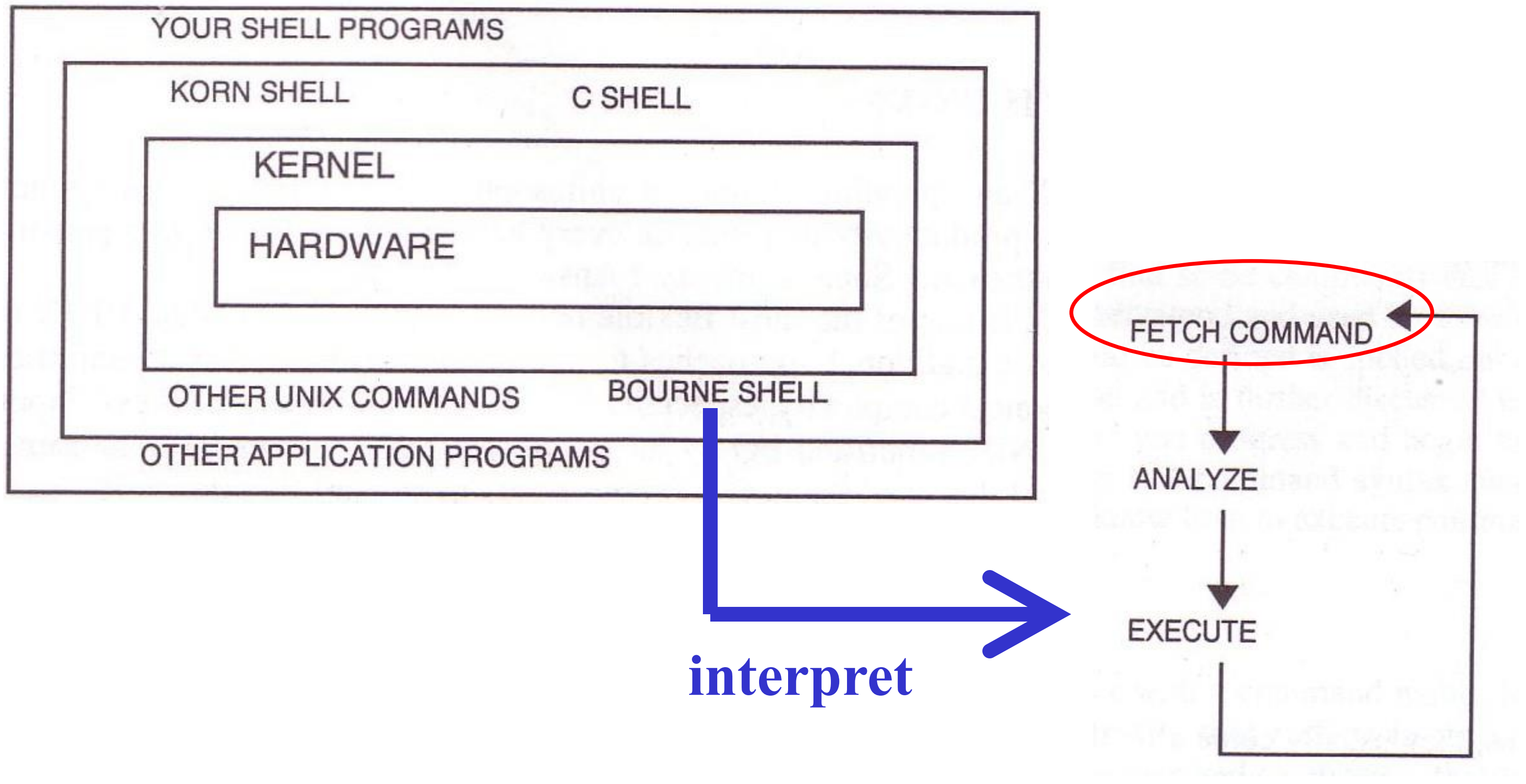
Drivers and the Kernel

lwhsu (2019, CC-BY)

? (?-2018)

Introduction – UNIX Kernel and Shell



Run-time structure of the kernel

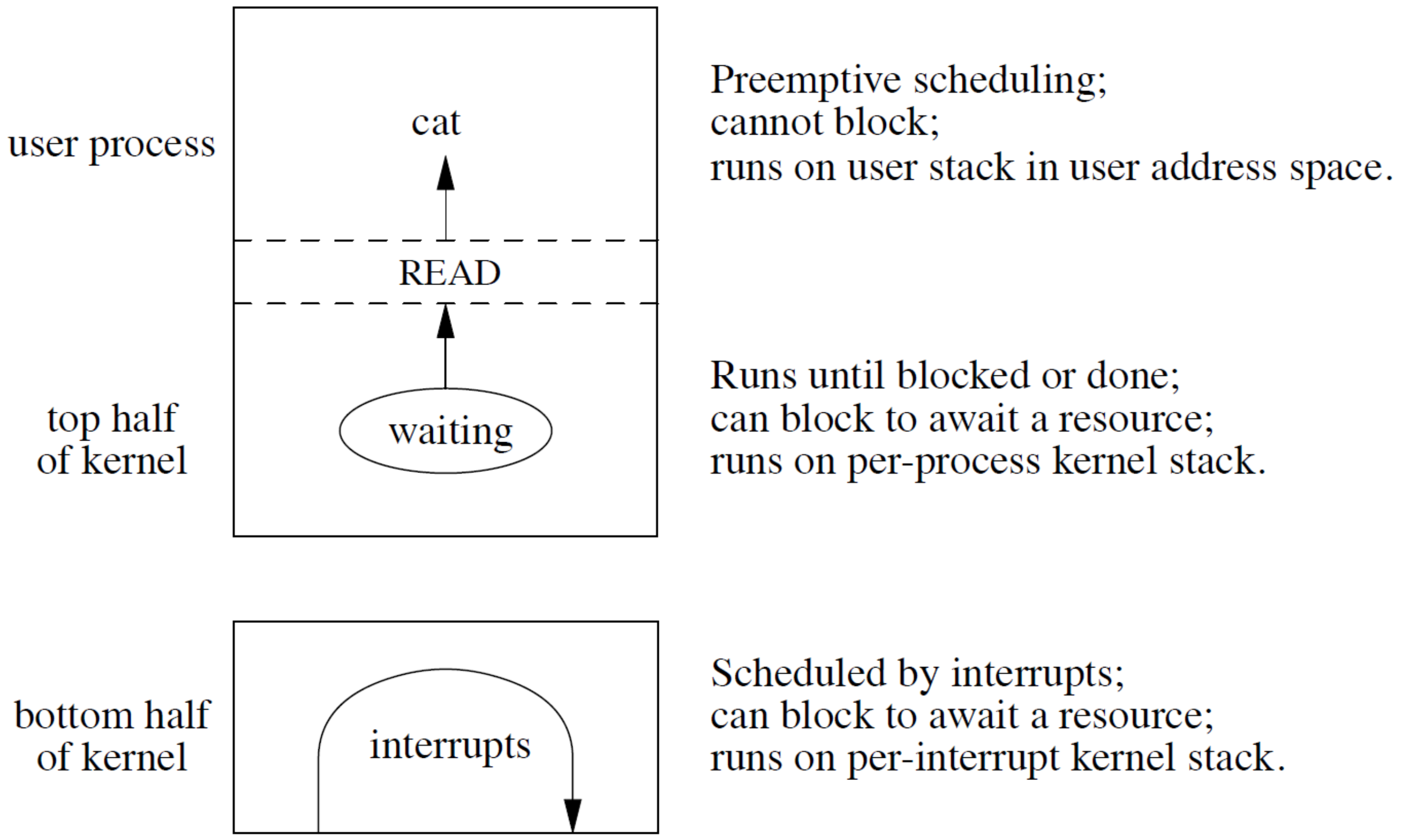
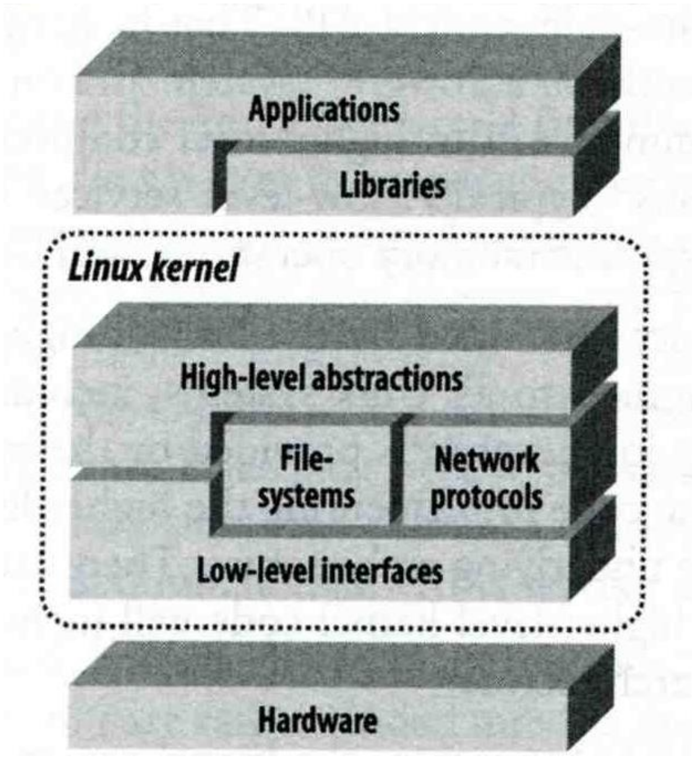

user process
cat
READ
top half of kernel
waiting
bottom half of kernel
interrupts
Preemptive scheduling; cannot block; runs on user stack in user address space.
Runs until blocked or done; can block to await a resource; runs on per-process kernel stack.
Scheduled by interrupts; can block to await a resource; runs on per-interrupt kernel stack.

Figure 3.1 - Design and Implementation of the FreeBSD Operating System, The, 2nd Edition

Roles of Kernel

- Components of a UNIX System
  - User-level programs
  - Kernel
  - Hardware
- Two roles of kernel (OS)
  - High-level abstractions
    - Process managements
      - Time sharing, memory protect
    - File system management
    - Memory management
    - I/O management
  - Low-level interface
    - drivers



Kernel I/O structure

-

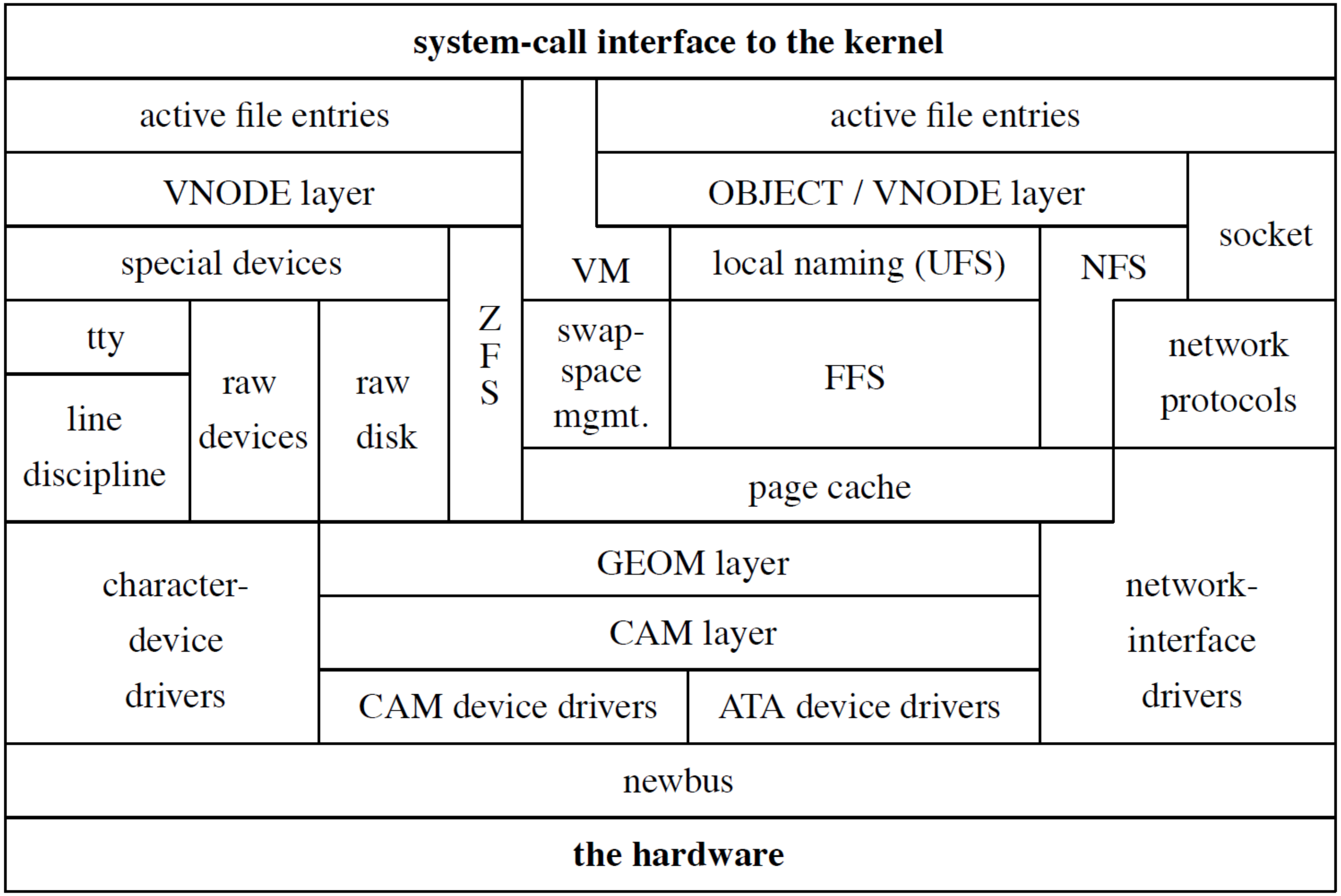
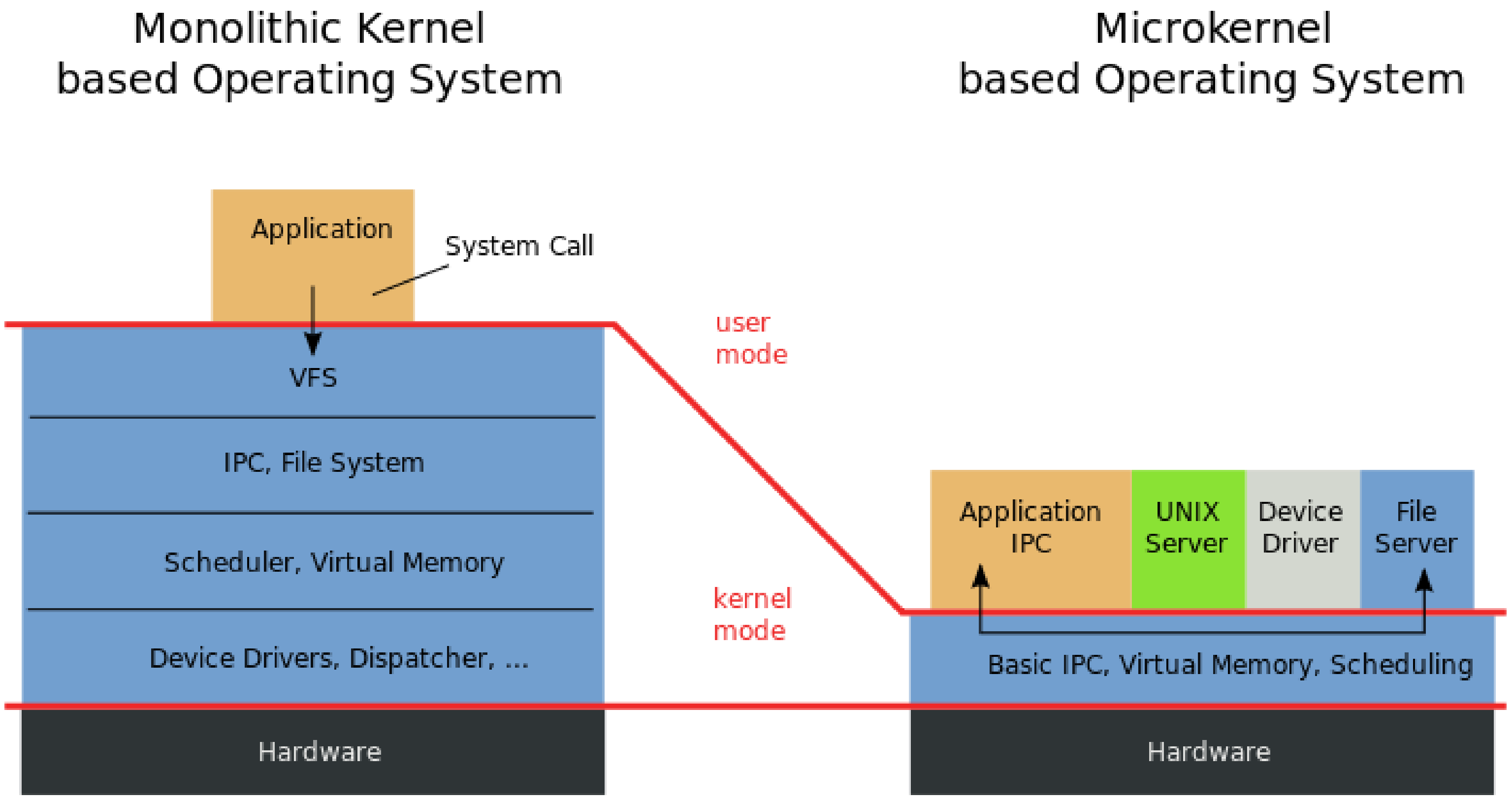


Figure 7.1 - Design and Implementation of the FreeBSD Operating System, The, 2nd Edition

Kernel Types



https://en.wikipedia.org/wiki/Microkernel

Kernel Types

Concept of being modulized …
only provides essential functionalities;
Put other sophisticated functions into user level
e.g., I/O management in the user level

- increase scalability and less difficult in maintenance
- How to communicate?
  → Message passing – less efficient

❑ Two extreme types

- **Microkernel**
  - ➢ **Provide only necessarily, compact and small functionalities**
  - ➢ **Other functions is added via well-defined interfaces**
- **Monolithic kernel (龐大的kernel – e.g., UNIX)**
  - ➢ **Whole functionalities in one kernel**

More integrated…

❑ Modern OS

- Solaris
  - ➢ **Completely modular kernel**
  - ➢ **Load necessary module when it is needed**
- BSD/Linux-derived system
  - ➢ **Much of the kernel's functionality is contained in modules**

Monolithic kernel developing towards micro kernel (being more modulized), but without IPC (message passing) problem

Kernel related directory

- Build directory and location

System	Build Directory	Kernel file
FreeBSD	/usr/src/sys	/kernel (< 4.x) /boot/kernel/kernel (>= 5.x)
Linux	/usr/src/linux	/vmlinuz or /boot/vmlinuz
Solaris	-	/kernel/unix
SunOS	/usr/kvm/sys	/vmunix

Why configure the kernel?

Generic: with various devices…, functions supported

- ❑ The native kernel is often big and common

kernel image → memory usage

- ❑ Tailoring kernel to match site situation
  - Purge unnecessary kernel devices and options
  - Add functionalities that you want
- ❑ OS patch
  - Remedy security hole of kernel implementation
- ❑ Fine-tune system performance
  - Such as adjusting important system parameters
- ❑ Adding device drivers
- ❑ Fast boot time
- ❑ Lower memory usage

Building a FreeBSD Kernel

<ARCH> represents one of amd64, arm, arm64, i386, riscv, mips, powerpc, sparc64

- ❑ Kernel source
  - /usr/src/sys
- ❑ Kernel configuration file
  - /usr/src/sys/<ARCH>/conf
    - ➢ GENERIC
    - ➢ LINT (generated by `make LINT` under this directory

LINT file: lists all options

- ❑ Steps to build a new kernel
  - Edit /usr/src/sys/<ARCH>/conf/<KERNCONF>
    - ➢ For example, save a configuration file named as SABSD
  - % cd /usr/src ;
  - % make buildkernel KERNCONF=SABSD
  - % make installkernel KERNCONF=SABSD

https://www.freebsd.org/doc/en/books/handbook/kernelconfig-building.html

To Build a FreeBSD Kernel…

- ❑ What to Choose?
- ❑ What to Load?
- ❑ Option Settings?
- ❑ Device Drivers?

Finding the system hardware (1)

Listing devices from M$ windows

- Before venturing into kernel configuration
  - Get an inventory of the machine’s hardware
  - Microsoft's **Device Manager**
- dmesg
  - dmesg(8) - display the system message buffer
  - cat /var/run/dmesg.boot

Listing devices from dmesg

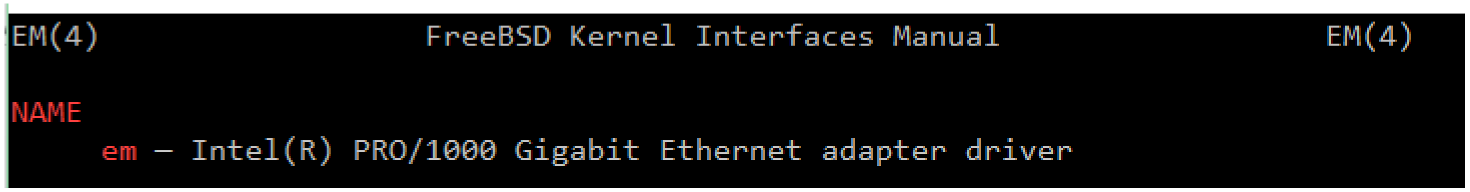
```
psm0: <PS/2 Mouse> irq 12 on atkbdc0
psm0: [GIANT-LOCKED]
psm0: [ITHREAD] psm0: model Generic PS/2 mouse, device ID 0
```

Finding the system hardware (2)

- pciconf & man page
  - man -k *Atheros*
    - Find drivers from company name
  - pciconf -l & man
    - List all attached devices

```
ehci1@pci0:0:29:7:      class=0x0c0320 card=0x3a3a8086 chip=0x3a3a8086 rev=0x00 hdr=0x00
pcib10@pci0:0:30:0:     class=0x060401 card=0x244e8086 chip=0x244e8086 rev=0x90 hdr=0x01
isab0@pci0:0:31:0:      class=0x060100 card=0x3a168086 chip=0x3a168086 rev=0x00 hdr=0x00
ahci0@pci0:0:31:2:      class=0x010601 card=0x3a228086 chip=0x3a228086 rev=0x00 hdr=0x00
none8@pci0:0:31:3:      class=0x0c0500 card=0x3a308086 chip=0x3a308086 rev=0x00 hdr=0x00
em0@pci0:3:0:0:         class=0x020000 card=0x00008086 chip=0x10d38086 rev=0x00 hdr=0x00
em1@pci0:2:0:0:         class=0x020000 card=0x00008086 chip=0x10d38086 rev=0x00 hdr=0x00
```

    - man *[device]*
      – man em



```
EM(4)                FreeBSD Kernel Interfaces Manual                EM(4)

NAME
     em – Intel(R) PRO/1000 Gigabit Ethernet adapter driver
```

Finding the system hardware (3)

- pciconf
  - pciconf -lv

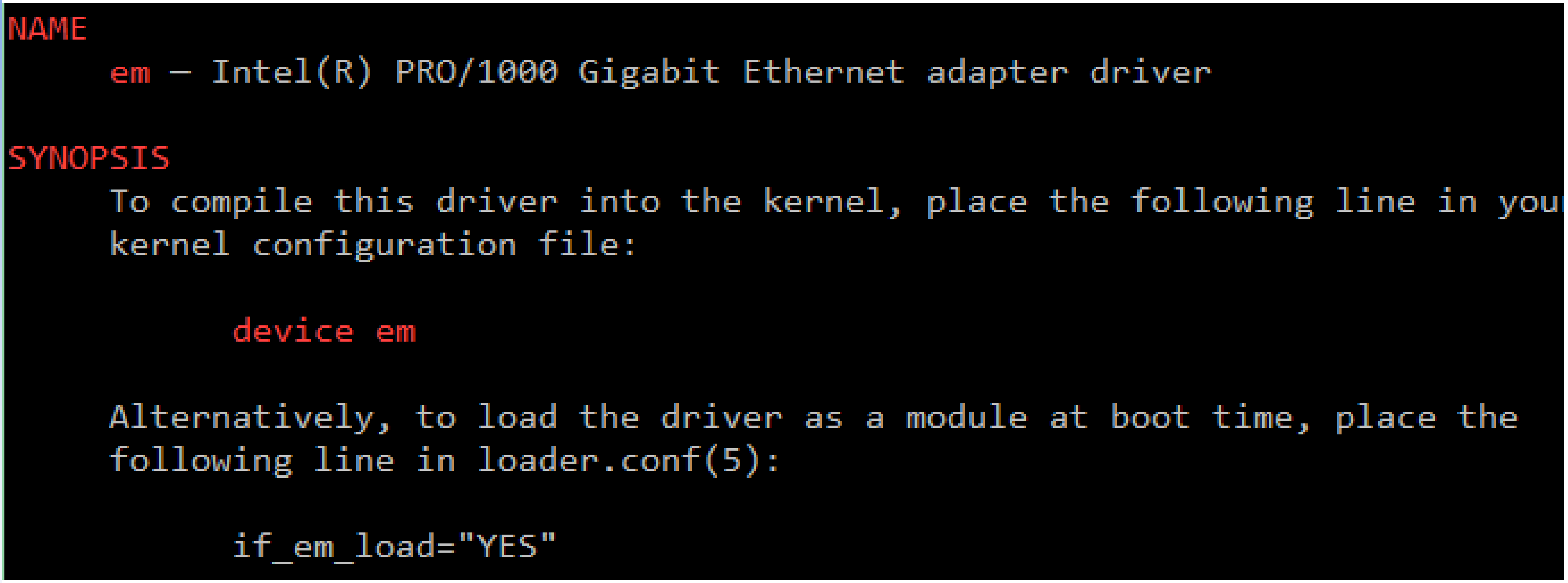
```
none3@pci0:0:20:3:      class=0x028000 card=0x00348086 chip=0x9df08086 rev=0x30 hdr=0x00
    vendor     = 'Intel Corporation'
    device     = 'Cannon Point-LP CNVi [Wireless-AC]'
    class      = network
```

```
em0@pci0:0:31:6:        class=0x020000 card=0x20748086 chip=0x15be8086 rev=0x30 hdr=0x00
    vendor     = 'Intel Corporation'
    device     = 'Ethernet Connection (6) I219-V'
    class      = network
    subclass   = ethernet
nvme0@pci0:109:0:0:     class=0x010802 card=0x2263c0a9 chip=0x2263c0a9 rev=0x03 hdr=0x00
    vendor     = 'Micron/Crucial Technology'
    device     = 'P1 NVMe PCIe SSD'
    class      = mass storage
    subclass   = NVM
```

May not support by GENERC because of size, license, or…

Finding the system hardware (4)

- ❑ Man page for devices
  - man *[device]*



```
NAME
     em — Intel(R) PRO/1000 Gigabit Ethernet adapter driver

SYNOPSIS
     To compile this driver into the kernel, place the following line in you
     kernel configuration file:

           device em

     Alternatively, to load the driver as a module at boot time, place the
     following line in loader.conf(5):

           if_em_load="YES"
```

Building a FreeBSD Kernel – Configuration file

The explanations on options and devices…

- Each line is a control phrase
  - Keyword + arguments

Keyword	Function	Example
machine	Sets the machine type	i386 or amd64
cpu	Sets the CPU type	I586_CPU or HAMMER
ident	Sets the name of the kernel	SABSD
maxusers	Sets the kernel's table sizes	0
(no)options	Sets various comiple-time options	INET, INET6
device	Declares devices	fxp, em

amd64/conf/GENERIC

```
cpu             HAMMER
ident           GENERIC
makeoptions     DEBUG=-g                # Build kernel with gdb(1) debug symbols
options         SCHED_ULE               # ULE scheduler
options         NUMA                    # Non-Uniform Memory Architecture support
options         PREEMPTION              # Enable kernel thread preemption
options         INET                    # InterNETworking
device          em
```

https://www.freebsd.org/doc/en/books/handbook/kernelconfig-config.html

Kernel backup

Your last chance to prevent module missing…to survive!!

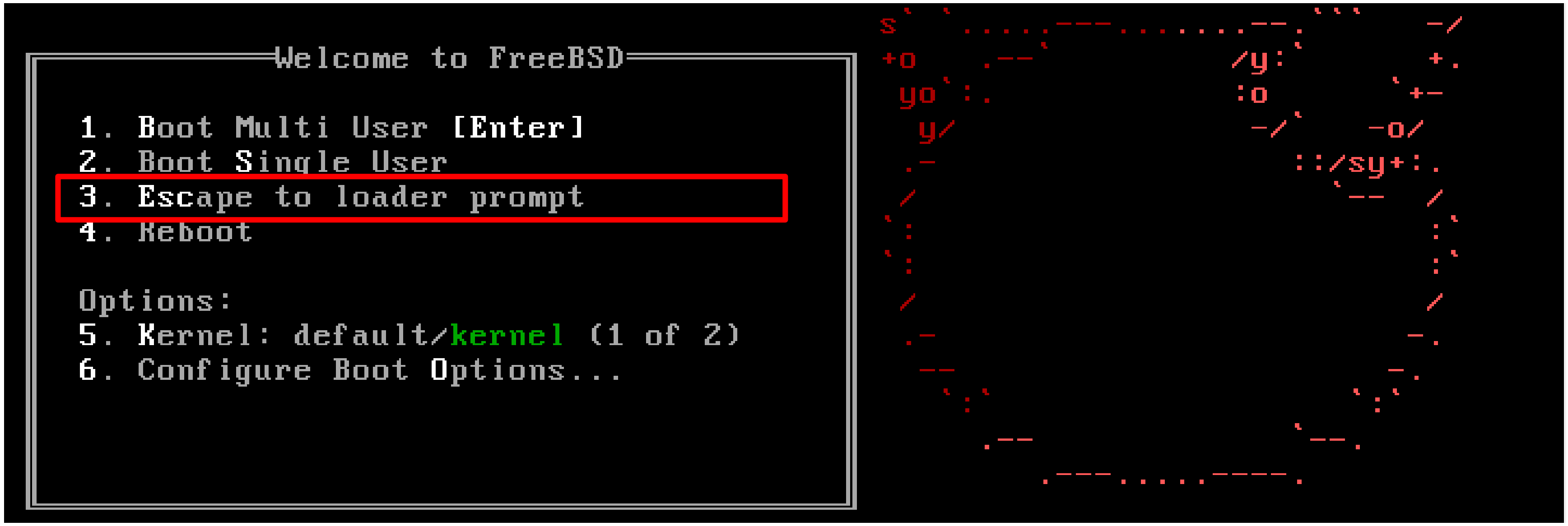
- Kernel file locations
  - Put in the /boot directory
  - /boot/GENERIC/kernel, /boot/kernel.old/kernel
  - /kernel.GENERIC, /kernel.old (Freebsd 4.x)

Old kernel is automatically moved to kernel.old when you're making the new kernel

Or just simply cp your GENERIC /boot/kernel first!

- If something goes wrong
  - ok mode !
    - unload kernel; load kernel.old/kernel
    - load kernel modules
  - mv /boot/kernel */boot/kernel.bad*

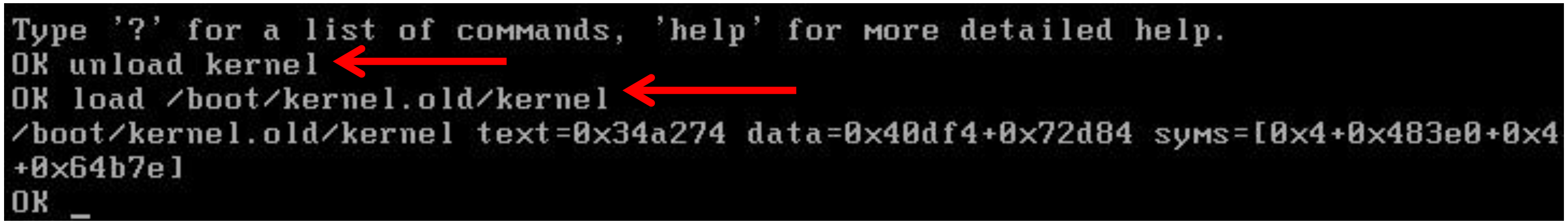
Ok mode



```
Welcome to FreeBSD

 1. Boot Multi User [Enter]
 2. Boot Single User
 3. Escape to loader prompt
 4. Reboot

 Options:
 5. Kernel: default/kernel (1 of 2)
 6. Configure Boot Options...
```



```
Type '?' for a list of commands, 'help' for more detailed help.
OK unload kernel
OK load /boot/kernel.old/kernel
/boot/kernel.old/kernel text=0x34a274 data=0x40df4+0x72d84 syms=[0x4+0x483e0+0x4
+0x64b7e]
OK _
```

Or “enable modules” in the ok mode..

Tuning the FreeBSD Kernel

- sysctl command
  - Dynamically set or get kernel parameters
  - All changes made by sysctl will be lost across reboot
  - Use sysctl to tune the kernel and test it, then recompile the kernel

    The other way is to write your settings into /etc/sysctl.conf…
  - Format:

    % sysctl [options] name[=value] …

  Ex:

```
% sysctl -a                  list all kernel variables
% sysctl -d kern.maxfiles    print the description of the variable
% sysctl kern.maxfiles       print the value of the variable
% sudo sysctl kern.maxfiles=2048
```

- tuning(7)

Kernel modules

- Kernel module location
  - /boot/kernel/*.ko
  - /modules (FreeBSD 4.x)
- kldstat

```
zfs[/boot/kernel] -chiahung- kldstat
Id Refs Address    Size     Name
 1   15 0xc0400000 4abd60   kernel
 2    1 0xc08ac000 13b0fc   zfs.ko
 3    2 0xc09e8000 3d5c     opensolaris.ko
 4    2 0xc09ec000 16b84    krpc.ko
 5    1 0xc0a03000 8c48     if_le.ko
```

- Load/unload kernel modules
  - kldload(8), kldunload(8)
    - E.g., kldload if_fxp
- Examples in share/examples/kld

Procedure of Loading a Device Module

- Loading a device module
  1. pciconf -l for a device
  2. man vendor name for module name in BSD
  3. grep the name in /boot/kernel/*.ko
  4. kldload [module name]
  5. Setup permanently by
     a) **Recompile the kernel** or
     b) **Add [module name]_enable="YES" in /boot/loader.conf**

Building Linux Kernel

- General procedure
  - Install kernel toolchain
  - Get source code from https://kernel.org
  - Extract to /usr/src/linux
  - make menuconfig
  - make –j*N*
  - make modules
  - make modules_install
  - make install
  - Check /boot/{initramfs.img,System.map,vmlinuz}
- Check the distribution specified method
  - Kernel package

Reference

- http://www.freebsd.org/doc/en/books/handbook/kernelconfig-config.html
- /usr/src/sys/<ARCH>/conf
  - NOTES → machine dependent kernel configuration notes.
  - LINT
  - GENERIC
- "building kernel" of Linux distributions documents
  - https://kernel-team.pages.debian.net/kernel-handbook/ch-common-tasks.html#s-common-official
  - https://wiki.ubuntu.com/Kernel/BuildYourOwnKernel
  - https://wiki.archlinux.org/index.php/Kernel/Arch_Build_System
  - https://wiki.centos.org/HowTos/Custom_Kernel