jbox.dk

SANOS

Server Appliance Network Operating System

Technical Overview

SanOS Features 1

- Minimalistic application server operating system kernel.
- Open Source (BSD style license).
- Runs on standard PC hardware.
- 32-bit protected mode.
- Interrupt driven.
- Priority-based preemptive multitasking.
- Single address space.
- Kernel protection.
- Virtual memory.
- PE dynamically loadable modules (standard EXE/DLL format).
- Both kernel and user modules.
- Low memory footprint (less than 512 KB RAM)
- Lightweight
- Embedding support with PC104 and Flash devices

SanOS Features 2

- Self configuring (PCI,PnP & DHCP support)
- TCP/IP networking stack
- Very efficient multithreading
- High performance and stability through simplicity.
- Written in C (98%) and x86 assembler (2%)
- Development using Microsoft Visual C.
- Remote source level debugging support (windbg)

Hardware

- Standard PC architecture
- IA-32 processor (486, Pentium)
- RAM (min. 4 MB)
- IDE disk (UDMA)
- IDE cdrom
- Standard floppy
- Serial ports
- Keyboard
- Video controller

- NIC support:
  - Novell NE2000
  - AMD PCNET32
  - 3Com 3C905
  - SiS900
  - RealTek 8129/8139
  - Intel EtherExpress Pro100

Core Operating System Services

- System booting and application loading
- Memory Management
  - Virtual memory mapping
  - Physical memory allocation and paging
  - Heap allocation and module loading and linking
- Thread Control
  - Thread scheduling and trap handling
  - Thread context
  - Thread synchronization and timers
- I/O Management
  - I/O bus and unit enumeration
  - Block devices and filesystems
  - Stream devices
  - Packet devices (NIC) and networking (TCP/IP)

Overview

Part 1: Architecture

Part 2: Boot Process

Part 3: Memory Management

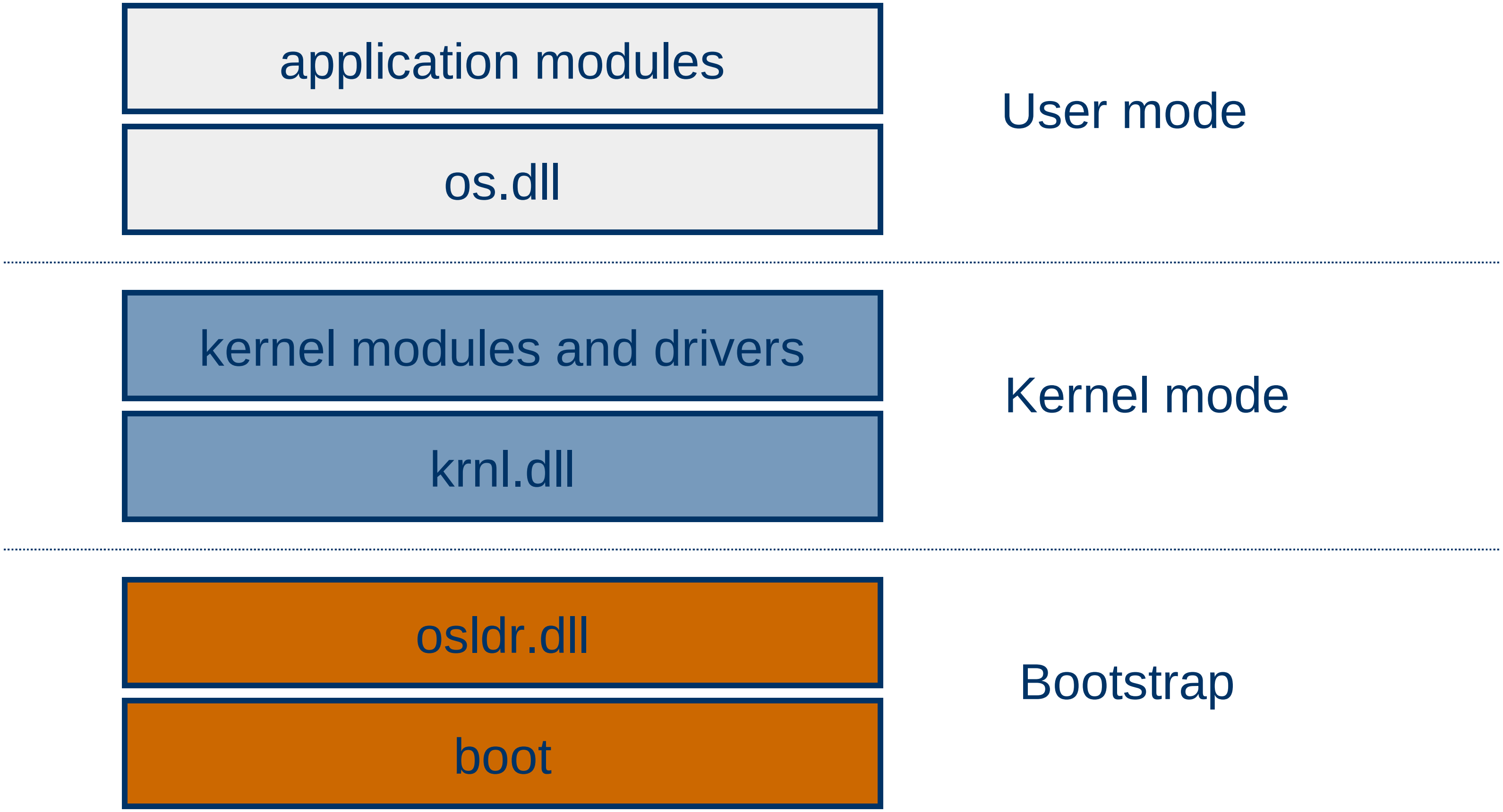
Part 4: Thread Control

Part 5: I/O Management

Part 1

Architecture

System Components



application modules

os.dll

User mode

kernel modules and drivers

krnl.dll

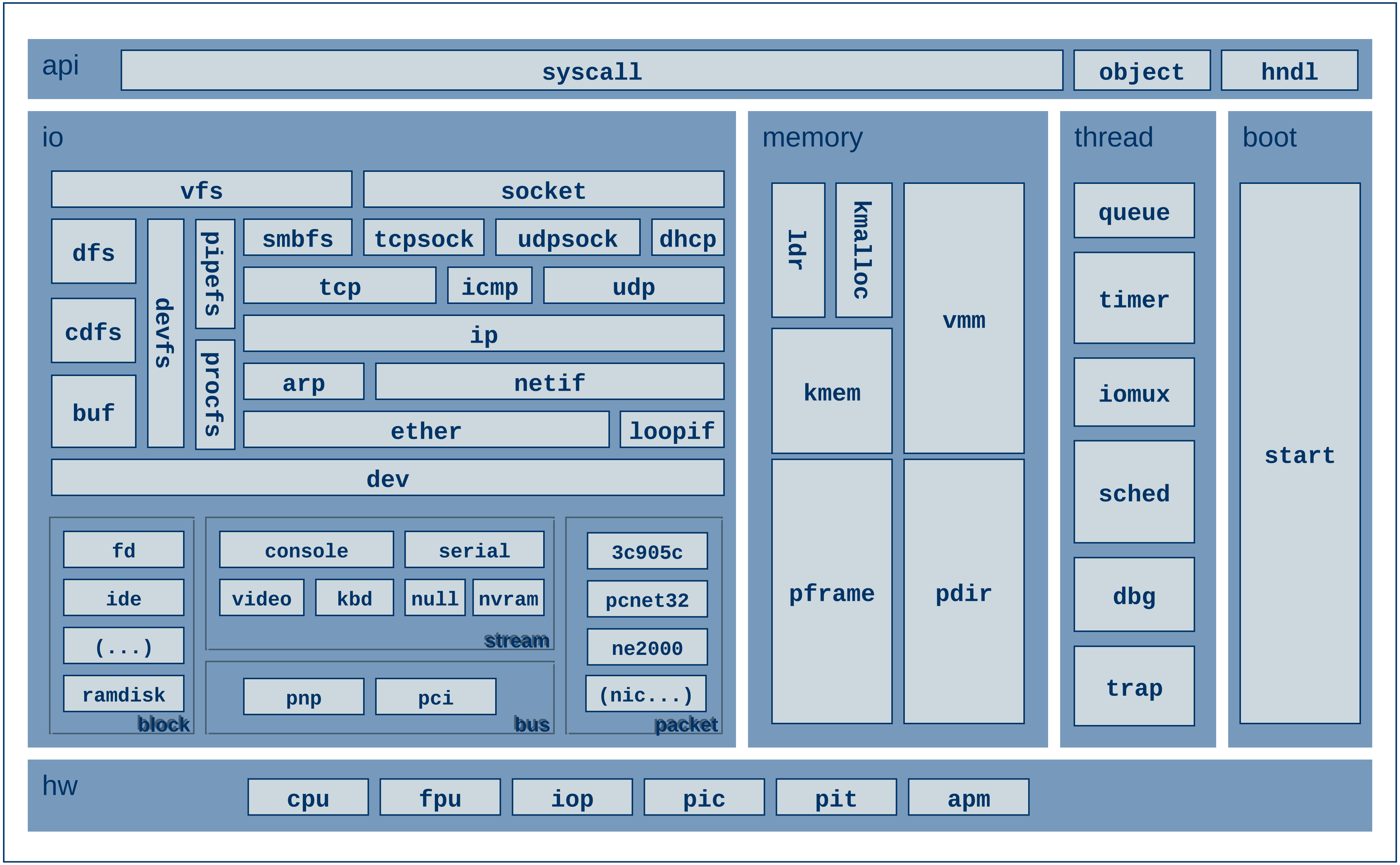
Kernel mode

osldr.dll

boot

Bootstrap

Kernel Architecture



api

syscall

object

hndl

io

vfs

socket

dfs

cdfs

buf

devfs

pipefs

procfs

smbfs

tcpsock

udpsock

dhcp

tcp

icmp

udp

ip

arp

netif

ether

loopif

dev

fd

ide

(...)

ramdisk

block

console

serial

video

kbd

null

nvram

stream

pnp

pci

bus

3c905c

pcnet32

ne2000

(nic...)

packet

memory

ldr

kmalloc

vmm

kmem

pframe

pdir

thread

queue

timer

iomux

sched

dbg

trap

boot

start

hw

cpu

fpu

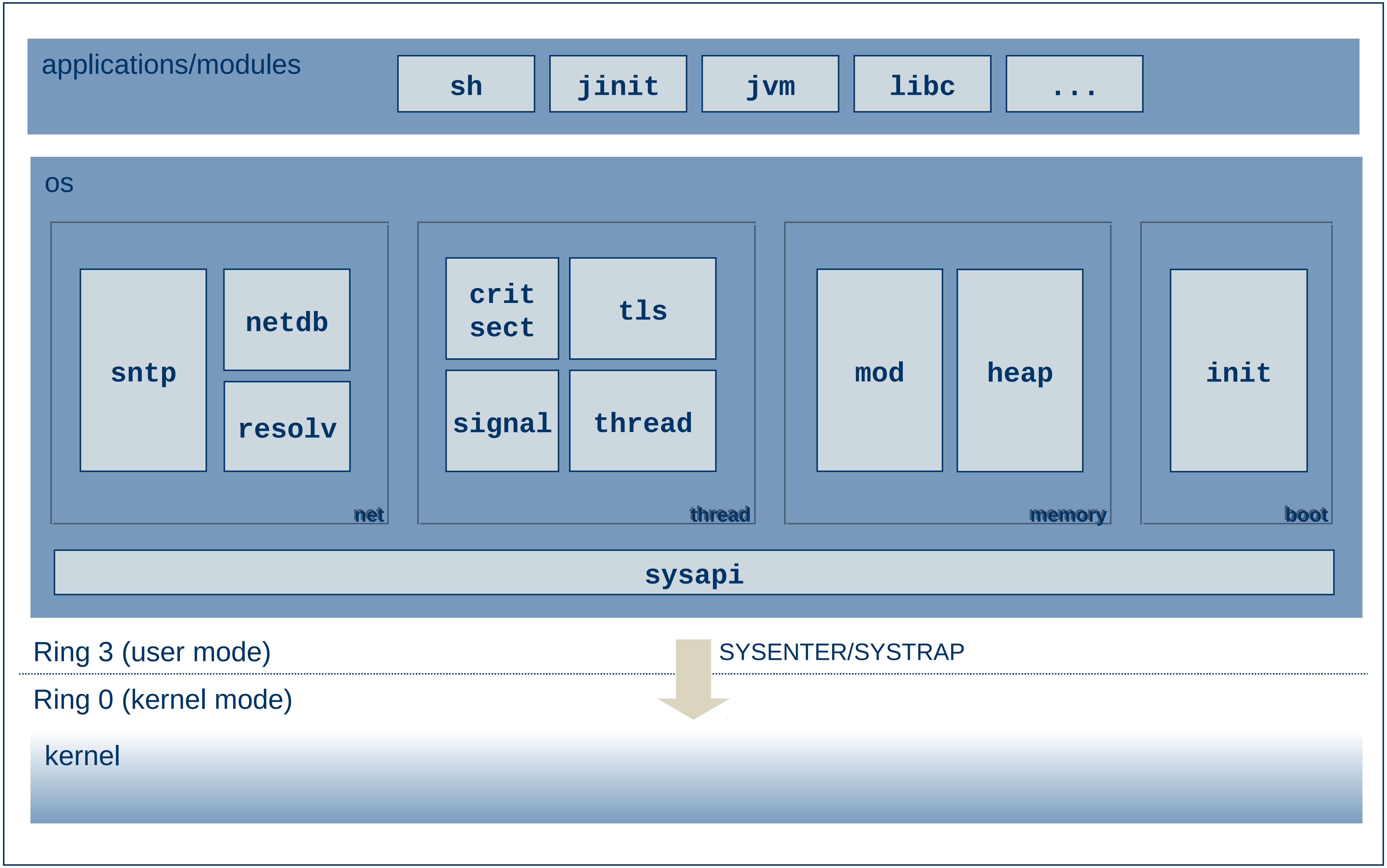
iop

pic

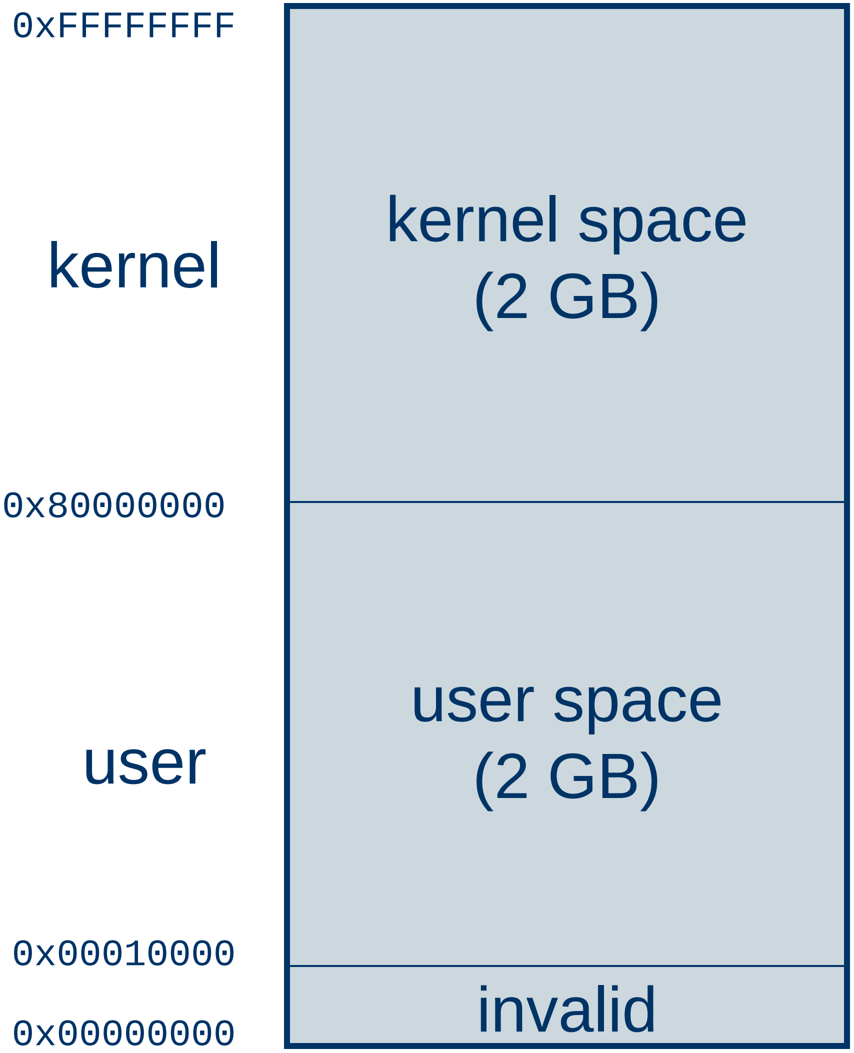
pit

apm

User Mode Components



Virtual Address Space Layout



0xFFFFFFFF

kernel

kernel space
(2 GB)

0x80000000

user

user space
(2 GB)

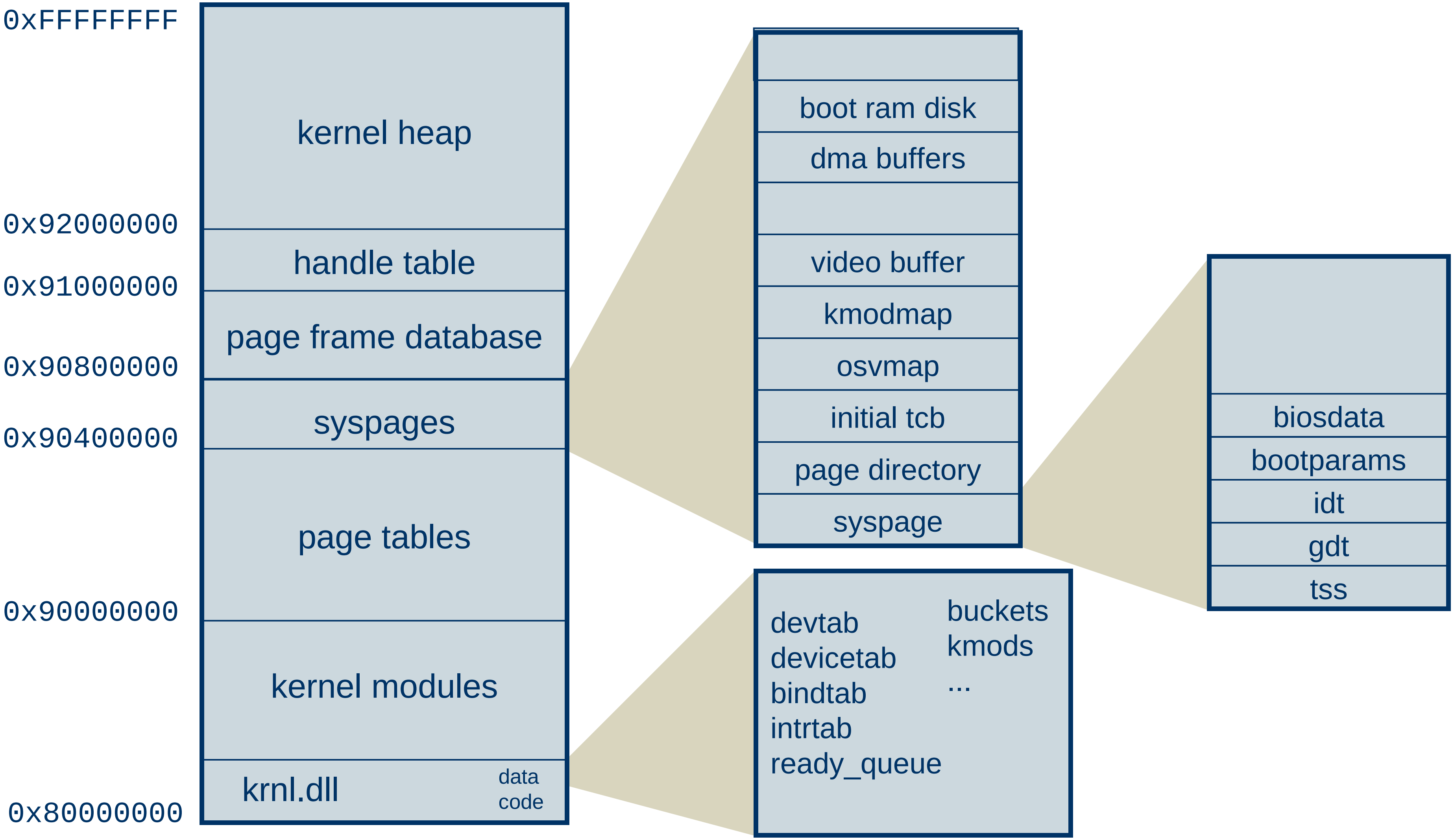
0x00010000

invalid

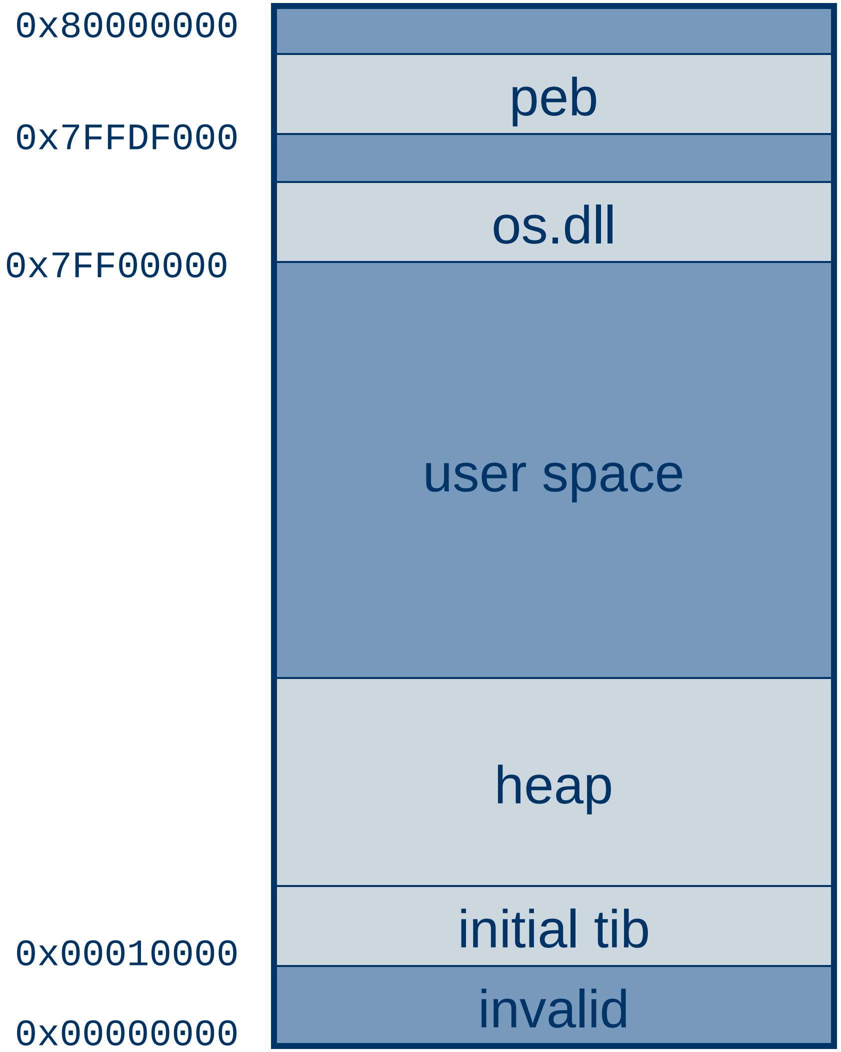
0x00000000

- Virtual address space divided into kernel region and user region.
- Ring 0 code (kernel) can access all 4 GB.
- Ring 3 code (user) can only access low 2 GB addess space.
- Kernel and user segment selectors controls access to address space.

Kernel Address Space Layout



User Address Space Layout



Segment selectors

Name	GDT index	Base	Limit	Access
NULL	0	0x00000000	0x00000000	None
KTEXT	1	0x00000000	0xFFFFFFFF	Ring 0 CODE
KDATA	2	0x00000000	0xFFFFFFFF	Ring 0 DATA
UTEXT	3	0x00000000	0x7FFFFFFF	Ring 3 CODE
UDATA	4	0x00000000	0x7FFFFFFF	Ring 3 DATA
TSS	5			Ring 0 TSS
TIB	6			Ring 3 DATA

Mode	CS	DS	ES	SS	FS
kernel	KTEXT	KDATA	KDATA	KDATA	TIB
user	UTEXT	UDATA	UDATA	UDATA	TIB

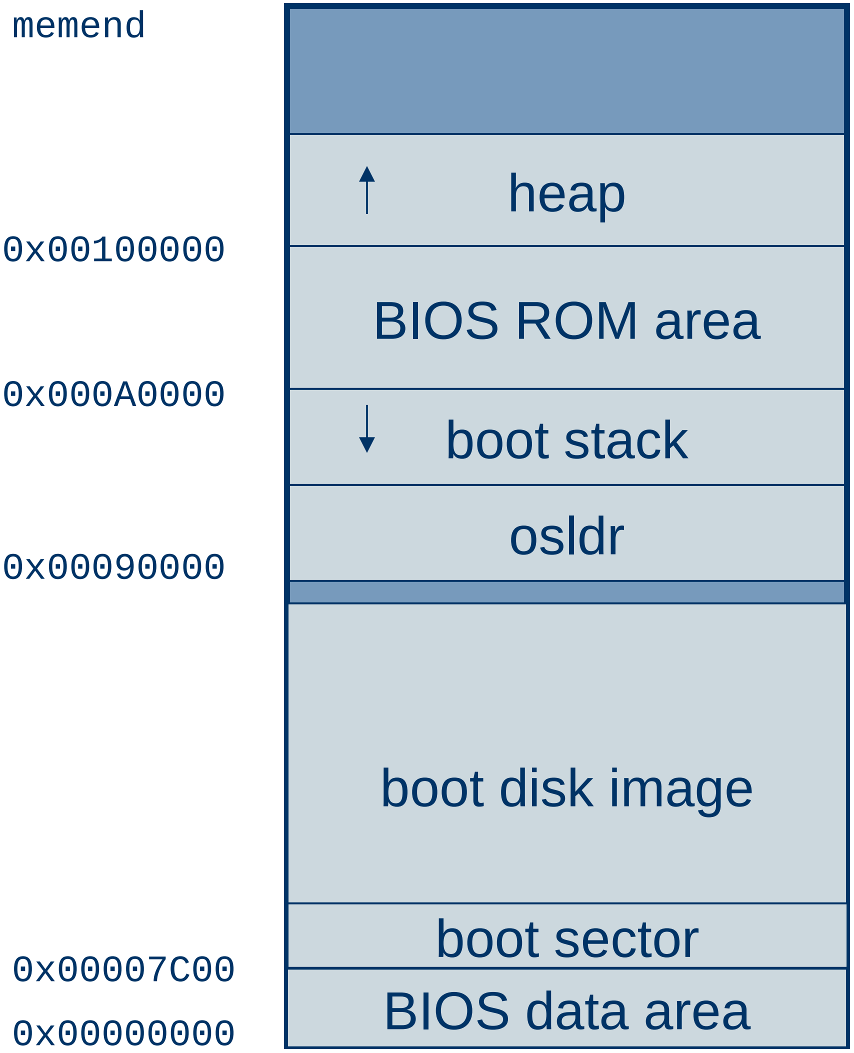
Part 2

Boot Process

Boot process

1. BIOS initialization and loading of boot sector.
2. Boot sector loads bootstrap loader (boot.asm).
3. Real-mode initialization (ldrinit)
4. Bootstrap loader sets up memory and loads kernel (osldr.dll).
5. Kernel initializes subsystems and starts main task (krnl.dll).
6. Main kernel task loads device drivers, mounts filesystems and loads os.dll into user space.
7. User mode component (os.dll) initializes user module database, memory heap, and loads and executes the init application (e.g. sh.exe or jinit.exe).
8. All systems are GO. We are up and running.

Step 1: BIOS



memend

heap

0x00100000

BIOS ROM area

0x000A0000

boot stack

osldr

0x00090000

boot disk image

boot sector

0x00007C00

BIOS data area

0x00000000

- CPU reset starts executing ROM BIOS.
- BIOS initializes and configures computer and devices.
- BIOS loads the boot sector from sector 0 of the boot device (512 bytes) at 0x7C00.
- The BIOS jumps to 0:7C00 in 16 bit real-mode.
- Partitioned boot devices first loads the master boot record (mbr), which then loads and starts the boot sector in the active boot partition.
- When booting from CD or network the whole initial boot disk image is loaded by BIOS at 7C00. Because the boot sector is the first sector of the boot disk the bootstrap is executed.

Step 2: Boot sector (boot)

- Depending on the boot device:
  - If booting from floppy or harddisk, loads the osldr from boot device using BIOS INT 13 services
  - If booting from CD or network, copies the osldr from the boot RAM disk image
- Calls real-mode entry point in osldr. The ”DOS-stub” in osldr.dll is used for real mode code in the loader.

Step 3: Real-mode initialization (ldrinit)

- Try to get system memory map from BIOS
- Check for APM BIOS
- Disables interrupts. Interrupts are reenabled when the kernel has been initialized.
- Enables A20.
- Loads boot descriptors (GDT, IDT).
- Initialize segment registers using boot descriptors.
- Switches the processor to protected mode and calls 32-bit entry point

Step 4: Bootstrap loader (osldr.dll)

- Determines memory size.
- Heap allocation starts at 1MB.
- Allocate page for page directory.
- Make recursive entry for access to page tables.
- Allocate system page.
- Allocate initial thread control block (TCB).
- Allocate system page directory page.
- Map system page, page directory, video buffer, and initial TCB.
- Temporarily map first 4MB to physical memory.
- If initial ram boot disk present copy it to high memory.
- Load kernel from boot disk.
- Set page directory (CR3) and enable paging (PG bit in CR0).
- Setup descriptors in syspage (GDT, LDT, IDT and TSS).
- Copy boot parameters to syspage.
- Reload segment registers.
- Switch to initial kernel stack and jump to kernel.

Step 5: Kernel startup (krnl.dll)

- Initialize memory management subsystem
  - Initialize page frame database.
  - Initialize page directory.
  - Initialize kernel heap.
  - Initialize kernel allocator.
  - Initialize virtual memory manager.
- Initialize thread control subsystem
  - Initialize interrupts, floating-point, and real-time clock.
  - Initialize scheduler.
  - Enable interrupts.
- Start main task
- Process idle tasks

Step 6: Main kernel task (krnl.dll)

- Enumerate root host buses and units
- Initialize boot devices (floppy and harddisk).
- Initialize built-in filesystems (dfs, devfs, procfs, and pipefs).
- Mount root device.
- Load kernel configuration (/etc/krnl.ini).
- Initialize kernel module loader.
- Load kernel modules.
- Bind, load and initialize device drivers.
- Initialize networking.
- Allocate handles for stdin, stdout and stderr.
- Allocate and initialize process environment block (PEB).
- Load /bin/os.dll into user space
- Initialize initial user thread (stack and tib)
- Call entry point in os.dll

Step 7: User mode startup (os.dll)

- Load user mode selectors into segment registers
- Load os configuration (/etc/os.ini).
- Initialize heap allocator.
- Initialize network interfaces, resolver and NTP daemon
- Initialize user module database.
- Mount additional filesystems.
- Load, bind and execute initial application.

Step 8: Execute application

- All systems are now up and running.
- The application uses the OS API, exported from os.dll to call system services.
- Examples: sh.exe and jinit.exe

OS API categories:

- system
- file
- network
- resolver
- virtual memory
- heap
- modules
- time
- threads
- synchronization
- critical sections
- thread local storage

OS API functions

file

- canonicalize
- chdir
- chsize
- close
- dup
- flush
- format
- fstat
- fstatfs
- futime
- getcwd
- getfsstat
- ioctl
- link
- lseek
- mkdir
- mount
- open
- opendir
- read
- readdir
- readv
- rename
- rmdir
- stat
- statfs
- tell
- umount
- unlink
- utime
- write
- writev

socket

- accept
- bind
- connect
- getpeername
- getsockname
- getsockopt
- listen
- recv
- recvfrom
- send
- sendto
- setsockopt
- shutdown
- socket

time

- clock
- gettimeofday
- settimeofday
- time

memory

- mlock
- mmap
- mprotect
- mremap
- munlock
- munmap

thread

- beginthread
- endthread
- epulse
- ereset
- eset
- getcontext
- getprio
- gettib
- gettid
- mkevent
- mksem
- raise
- resume
- self
- semrel
- setcontext
- setprio
- signal
- sleep
- suspend
- wait
- waitall
- waitany

critsect

- csfree
- enter
- leave
- mkcs

tls

- tlsalloc
- tlsfree
- tlsget
- tlsset

heap

- calloc
- free
- mallinfo
- malloc
- realloc

system

- config
- dbgbreak
- exit
- loglevel
- panic
- peb
- syscall
- syslog

resolver

- dn_comp
- dn_expand
- res_mkquery
- res_query
- res_querydomain
- res_search
- res_send

netdb

- gethostbyaddr
- gethostbyname
- gethostname
- getprotobyname
- getprotobynumber
- getservbyname
- getservbyport
- inet_addr
- inet_ntoa

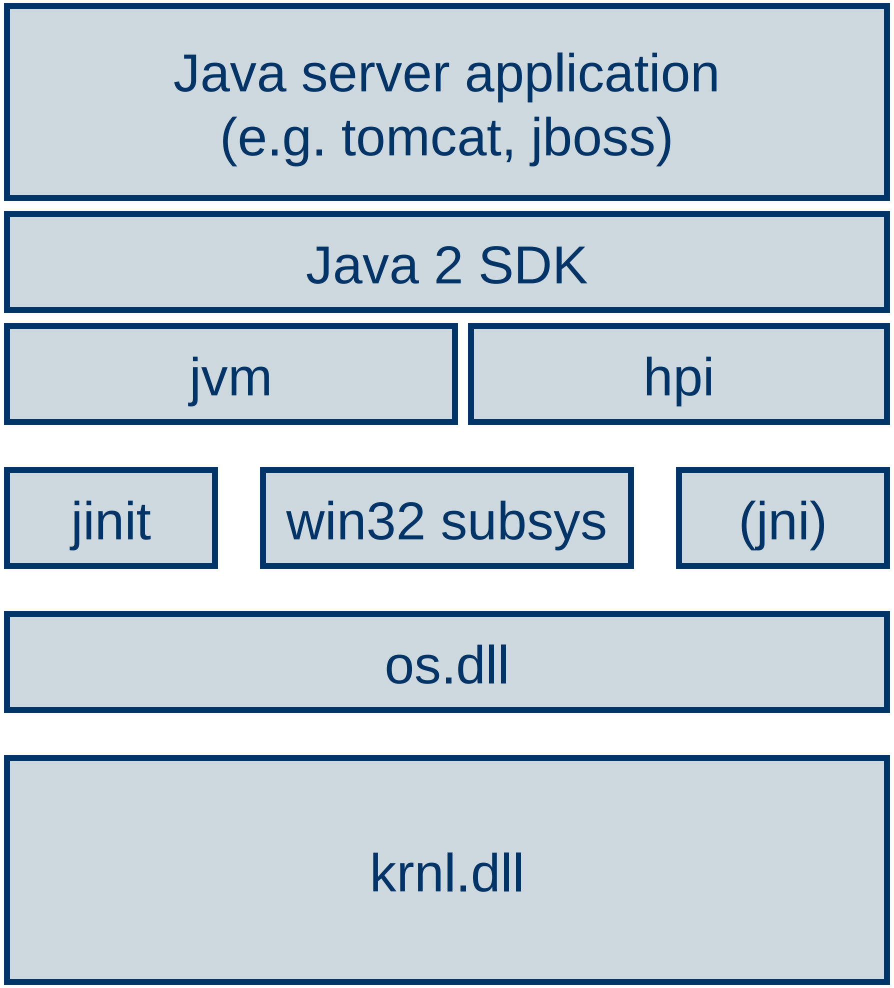
module

- exec
- getmodpath
- getmodule
- load
- resolve
- unload

Win32 subsystem

- Partial implementation of the following Win32 modules:
  - KERNEL32
  - USER32
  - ADVAPI32
  - MSVCRT
  - WINMM
  - WSOCK32

Java VM



Java server application (e.g. tomcat, jboss)

Java 2 SDK

jvm

hpi

jinit

win32 subsys

(jni)

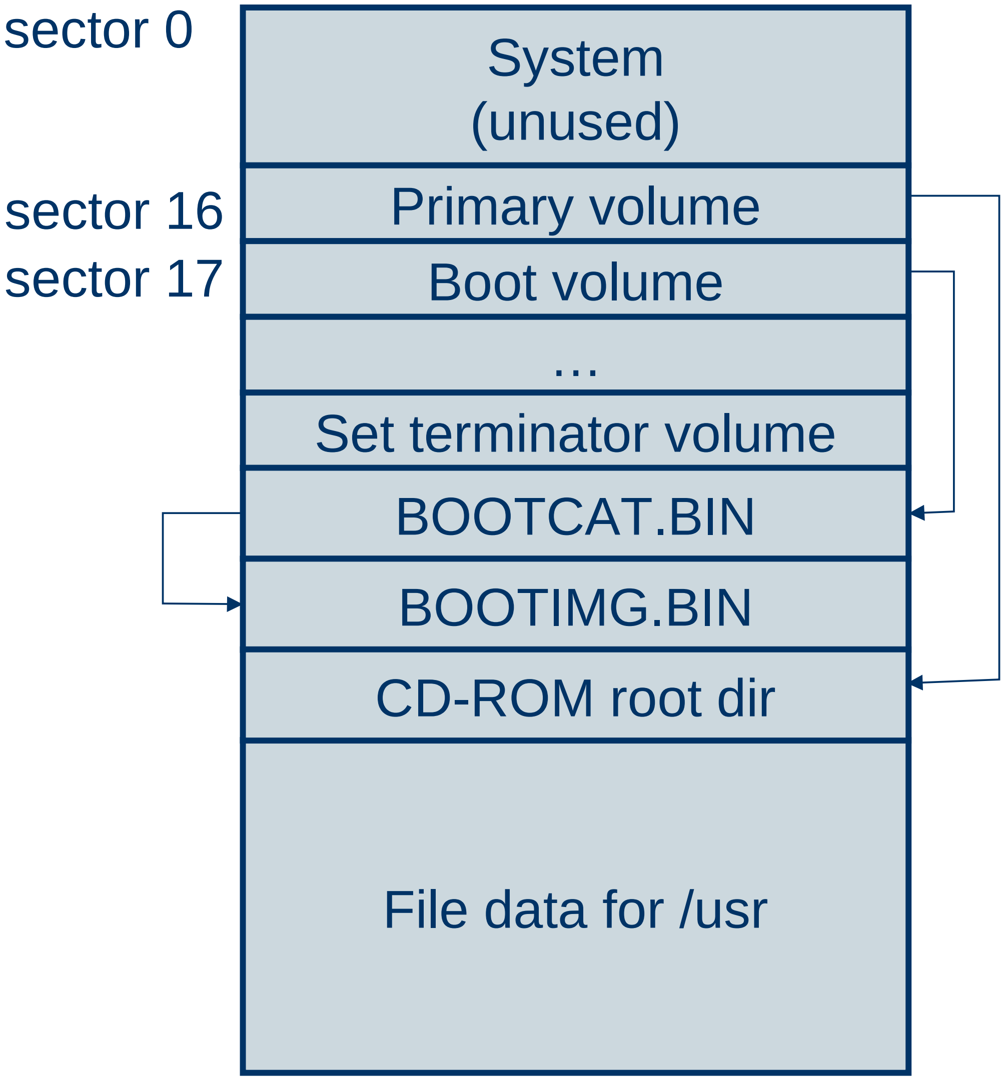
os.dll

krnl.dll

- SanOS supports any standard pure Java server applications.
- Uses Sun Microsystems HotSpot Java VM for Win32.
- Supports standard JNI for native interface.
- jinit.exe loads the Java VM and starts the main method of the startup class.

Booting from CD-ROM

Bootable CD-ROM image



sector 0

System (unused)

sector 16

Primary volume

sector 17

Boot volume

…

Set terminator volume

BOOTCAT.BIN

BOOTIMG.BIN

CD-ROM root dir

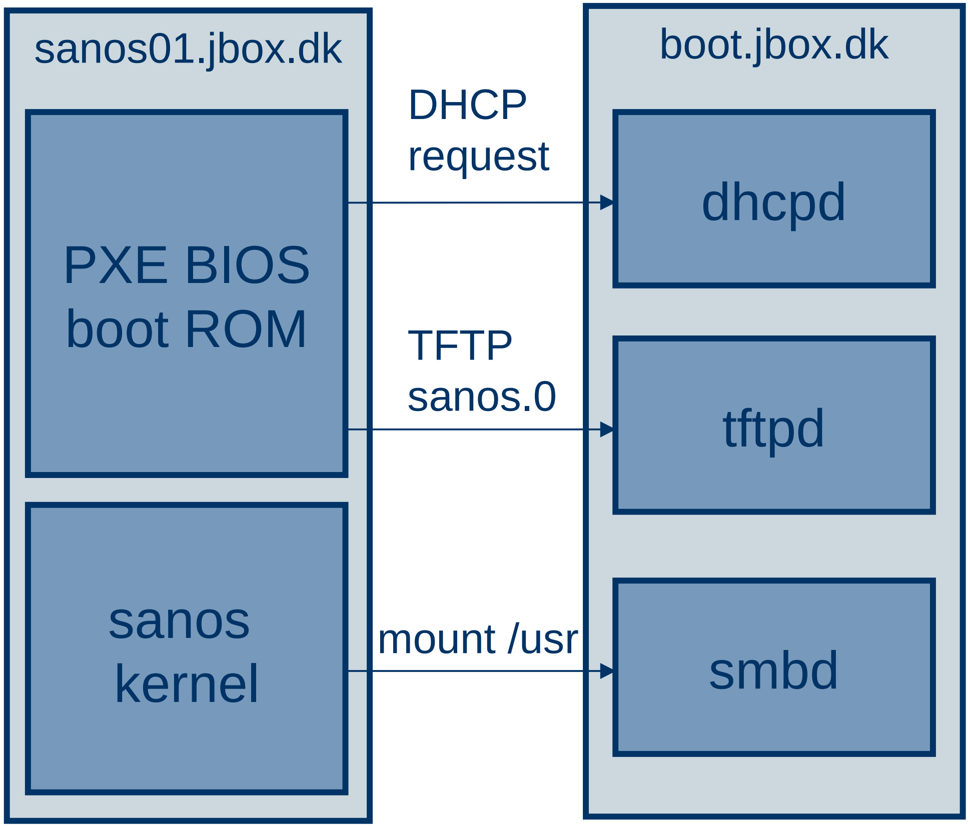
File data for /usr

- BOOTIMG.BIN contains a small (512K) dfs boot filesystem image with cdboot as boot sector.
- The CD-ROM boot loader in the BIOS loads the 512K boot image into memory at 0x7C00.
- The cdboot bootsector in the first sector of BOOTIMG.BIN copies the osldr to 0x90000 and executes it.
- The kernel is copied from the boot image to high memory. The boot image is also copied to high memory.
- When the kernel is started a RAM disk (initrd) is created from the boot image and mounted on root. The rest of the CD-ROM is mounted on /usr.

Booting from network

From /etc/dhcpd.conf on boot.jbox.dk:

```
host sanos01 {
  hardware ethernet 00:30:1b:ab:95:54;
  fixed-address sanos01.jbox.dk;
  filename "sanos/sanos.0";
  next-server boot.jbox.dk;
}
```

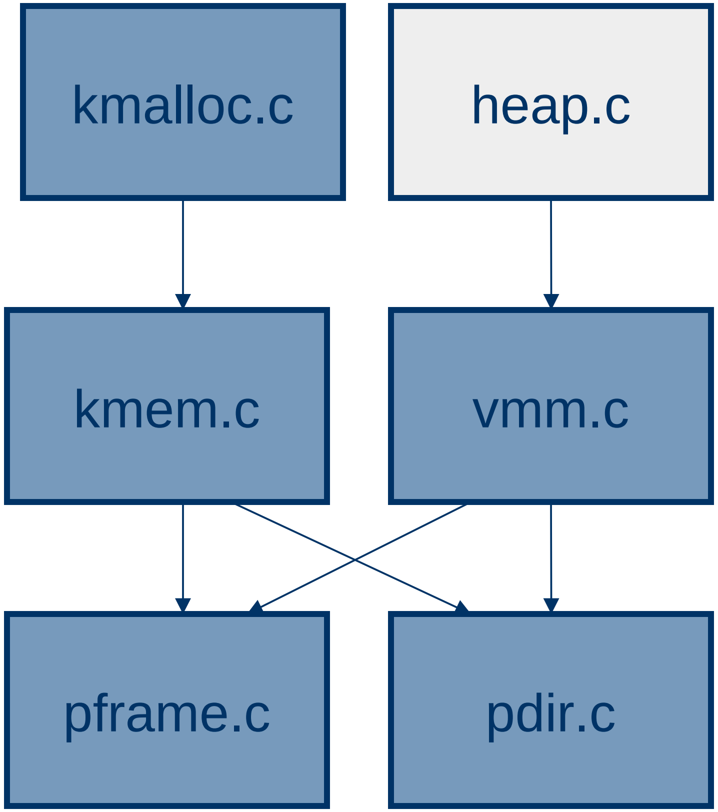


- PXE BIOS boot ROM sends DHCP request to obtain network and boot parameters.
- PXE BIOS retrieves 512K boot image (sanos.0) from TFTP server.
- The sanos.0 image is a boot image with a dfs filesystem. The first sector of the image contains the netboot boot sector.
- The netboot boot sector copies the osldr to 0x90000 and executes it.
- The kernel is copied from the boot image to high memory. The boot image is also copied to high memory.
- When the kernel is started a RAM disk (initrd) is created from the boot image and mounted on root. Then /usr is mounted on a remote SMB file share.

Part 3

Memory Management

Memory management



- **pdir.c** controls the virtual memory mapping (`pdir` and `ptab`).
- **pframe.c** controls the allocation of physical memory (`pfdb`).
- **kmem.c** tracks the use of the kernel module and heap areas and allocation and mapping of physical pages to virtual addresses (`osvmap` and `kmodmap`).
- **kmalloc.c** allocates and deallocates small blocks (<4K) from the kernel heap (`buckets`). Larger blocks are delegated to `kmem`.
- **vmm.c** reserves virtual addresses in user space and commits and maps these to physical memory (`vmap`).
- **heap.c** is a standard C heap allocator (`malloc`, `free`, `realloc`) (Doug Lea) on top of the `vmm`.

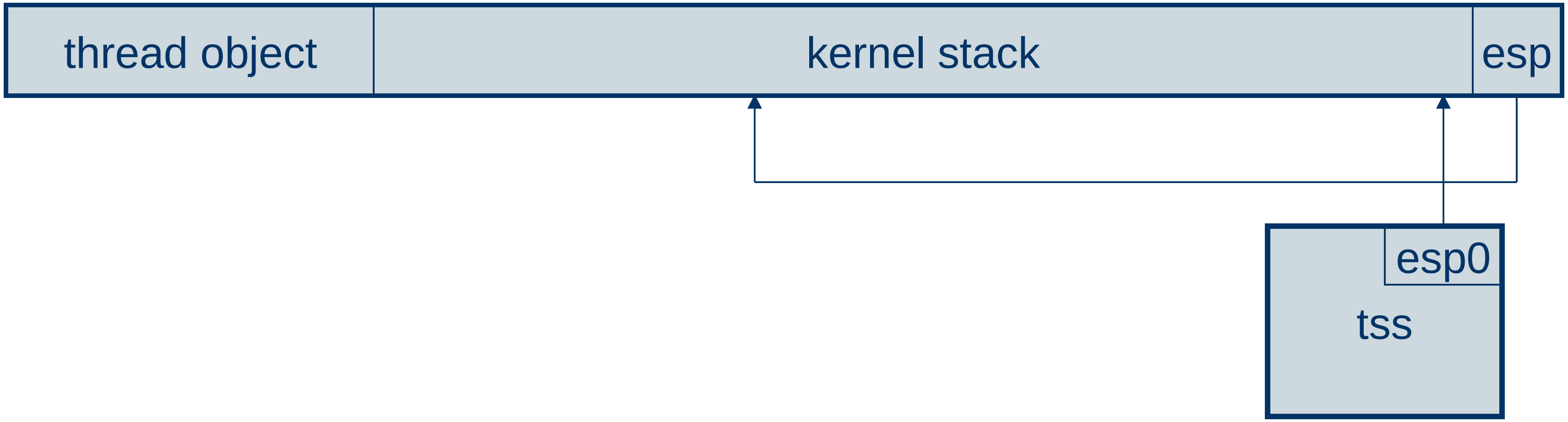
Module Loader

- Both kernel and user mode DLL modules
- Loading module
  - Allocate module memory and load image from file
  - Resolve dependencies
  - Relocate module(s)
  - Bind imports
  - Protect module(s)
  - Initialize module(s)
  - Notify debugger
  - Update reference counts

Part 4

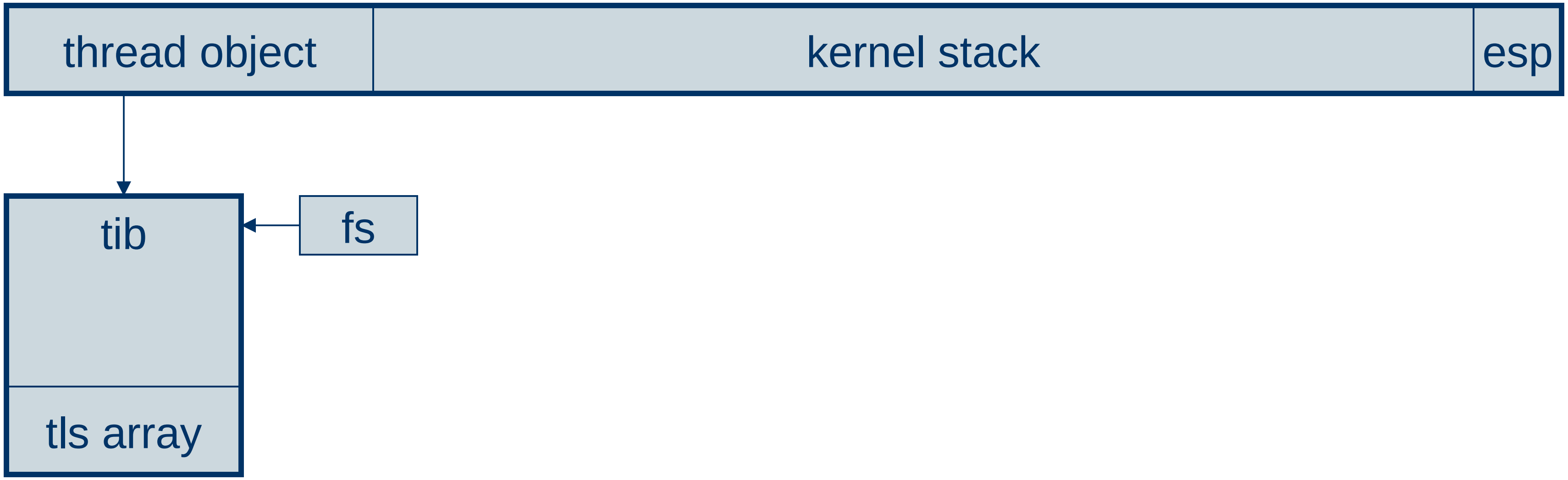
Thread Control

Thread control blocks



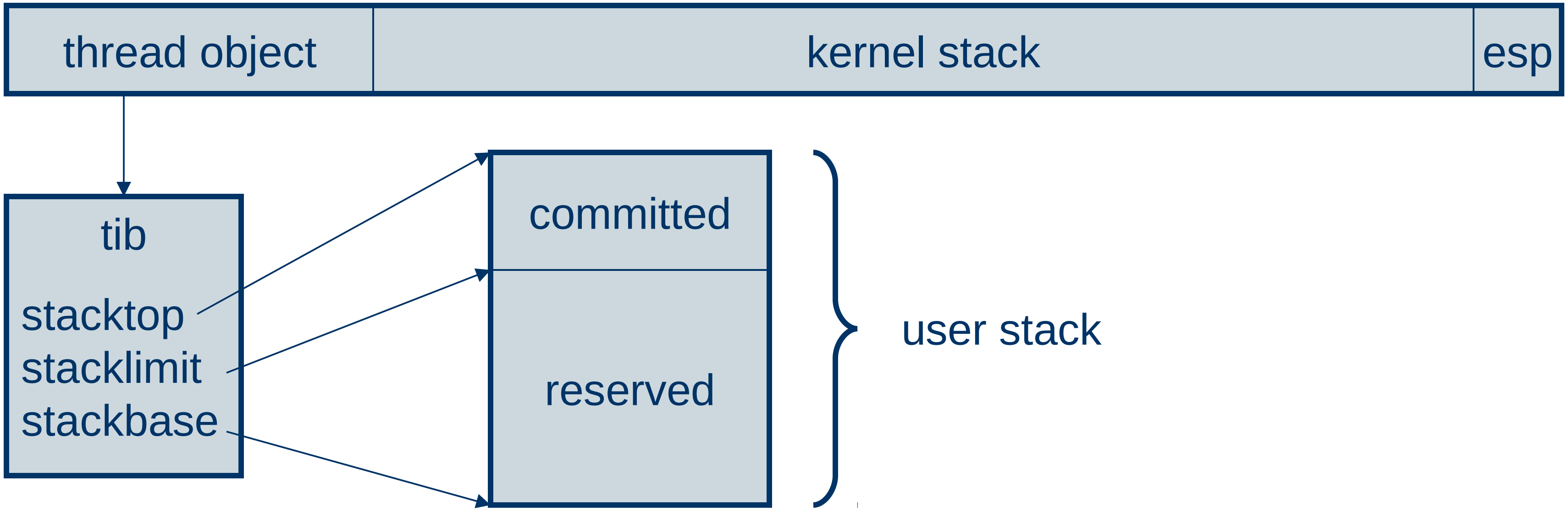
- Each thread has an 8K thread control block (tcb).
- Each tcb is aligned on 8K boundary
- tcbs are allocated on the kernel heap.
- Initial kernel thread is allocated in syspage block.
- esp0 in tss points to stack top in current tcb

Thread information block (tib)



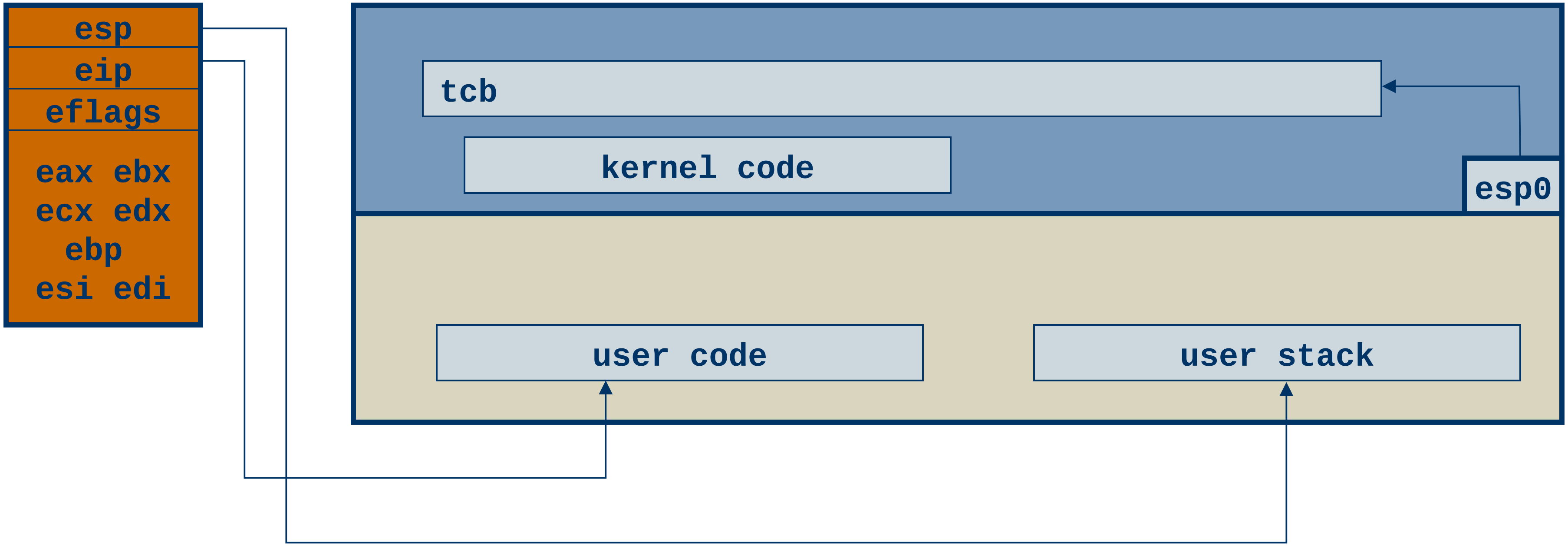
- Each user mode thread has a 4K thread information block (tib) allocated in user space.
- The format of the tib is compatible with win32.
- The fs segment register always references the tib for the current thread.
- The tib contains the thread local storage array for the thread.
- The tcb contains a reference to the tib for user mode threads.

User stacks



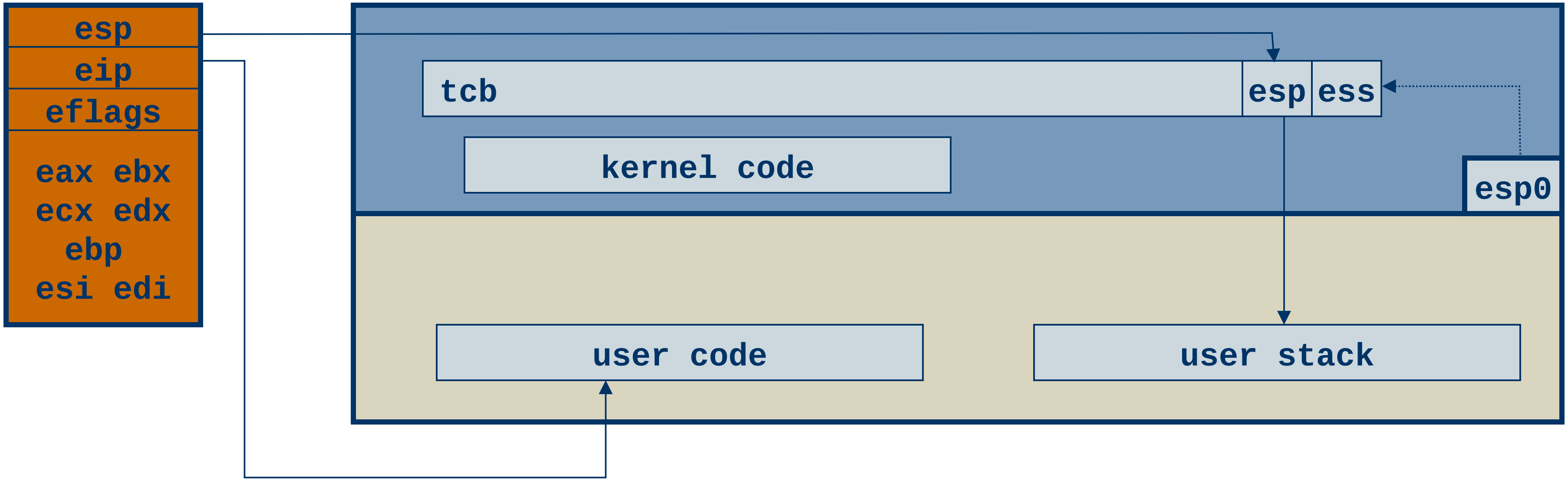
- Each user thread has a user mode stack
- The first page of the stack is committed when it is created.
- The rest of the pages in the stack are reserved with guard pages.
- When the stack grows the guard page handler expands down the stack and commits pages.

Enter kernel (1)



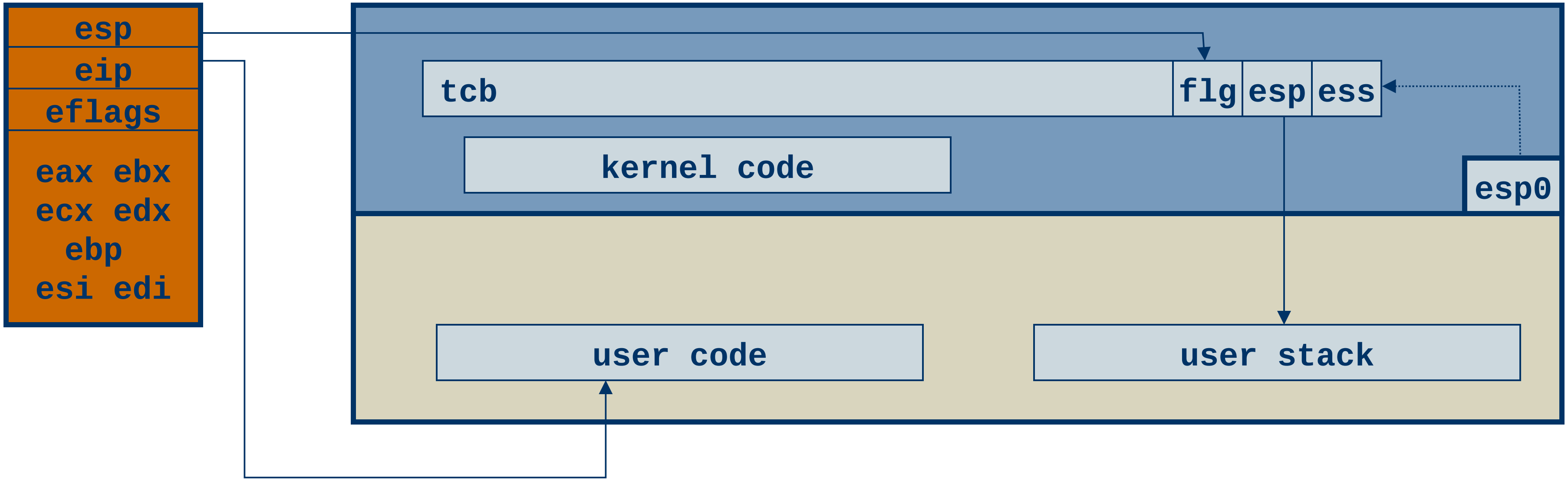
- trap/fault occurs (int, exception, interrupt)

Enter kernel (2)



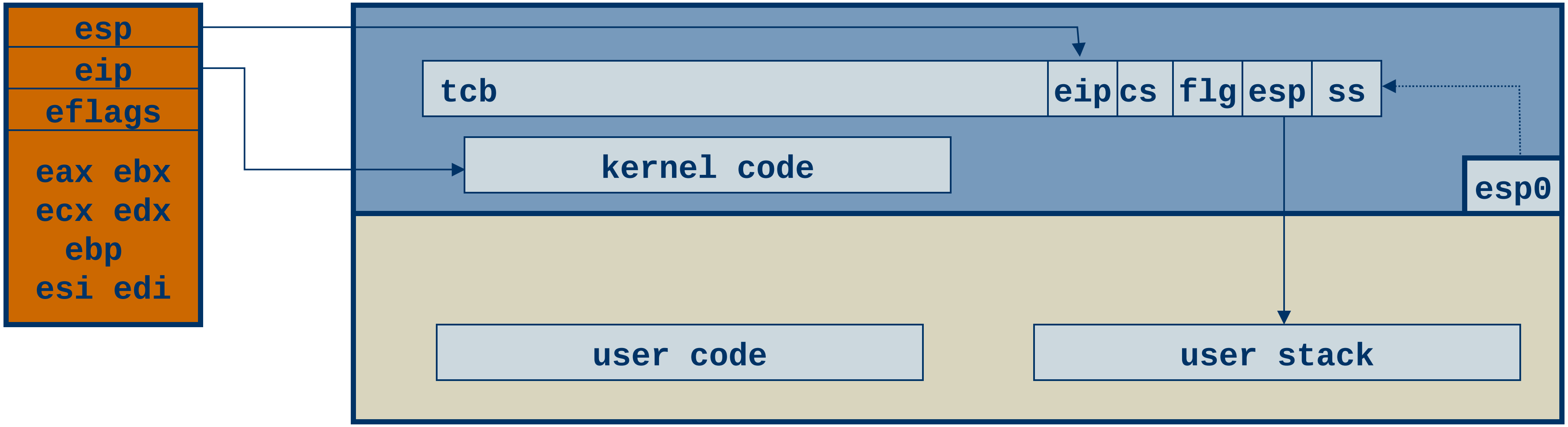
- trap/fault occurs (int, exception, interrupt)
  - push user esp on to kernel stack, load kernel esp

Enter kernel (3)



- trap/fault occurs (int, exception, interrupt)
  - push user esp on to kernel stack, load kernel esp
  - push user eflags, reset flags (IF=0, TF=0)

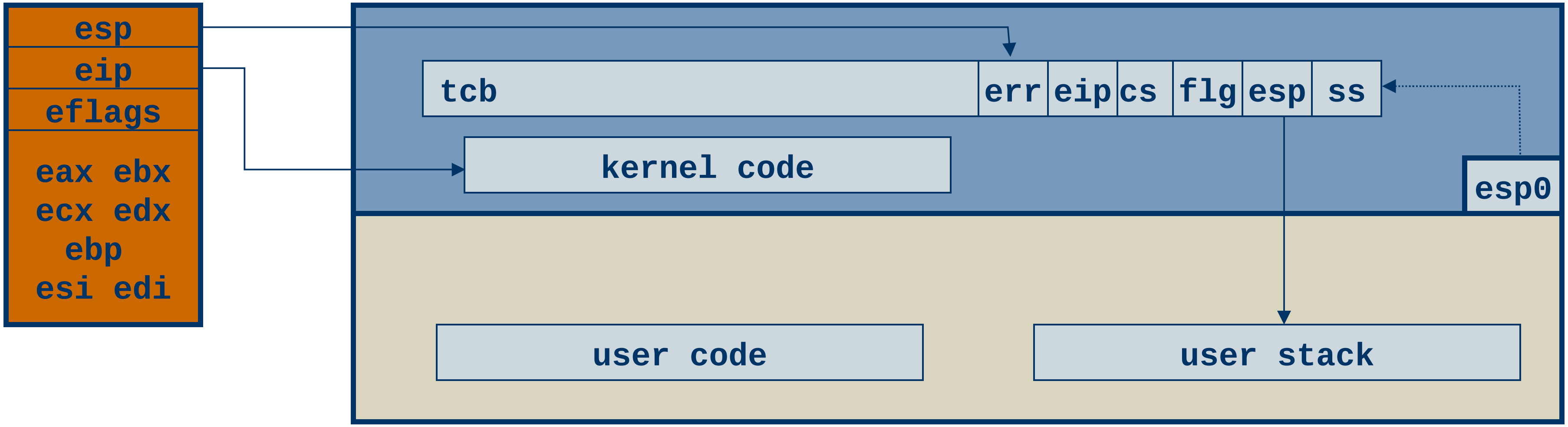
Enter kernel (4)



- trap/fault occurs (int, exception, interrupt)
  - push user esp on to kernel stack, load kernel esp
  - push user eflags, reset flags (IF=0, TF=0)
  - push user eip, load kernel entry eip

Hardware programmed single instrution

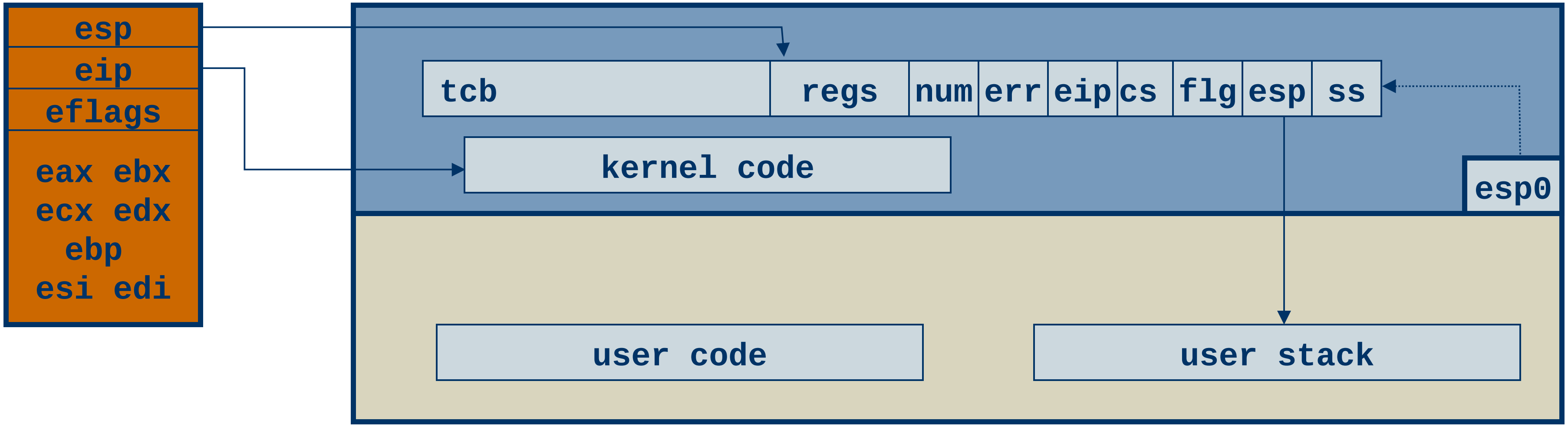
Enter kernel (5)



- trap/fault occurs (int, exception, interrupt)
  - push user esp on to kernel stack, load kernel esp
  - push user eflags, reset flags (IF=0, TF=0)
  - push user eip, load kernel entry eip
- push error code

Hardware programmed single instrution

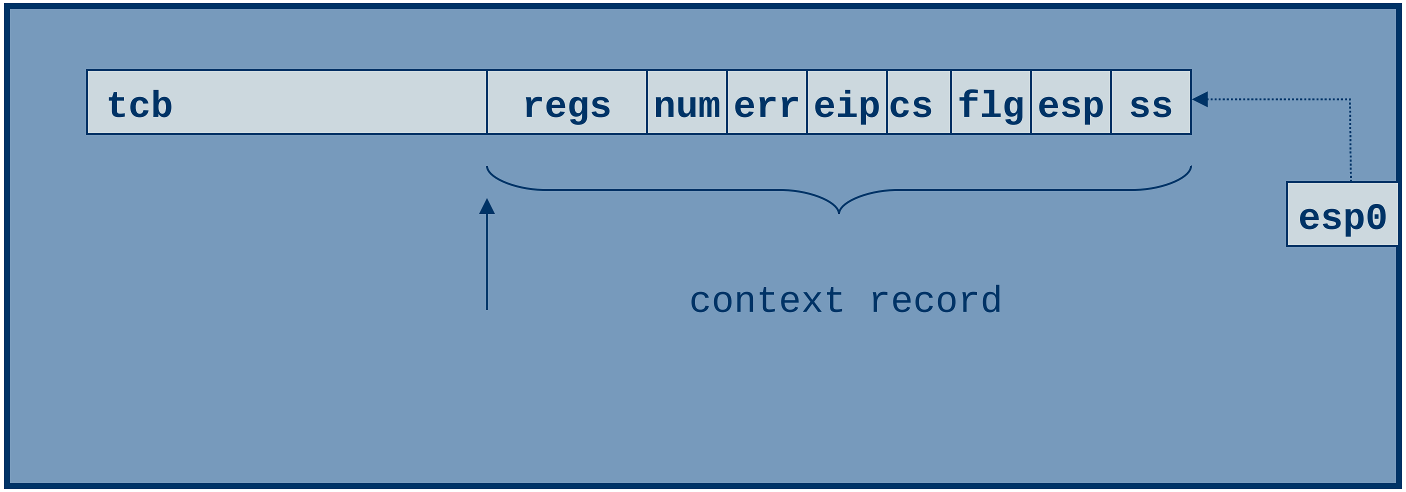
Enter kernel (6)



- trap/fault occurs (int, exception, interrupt)
  - push user esp on to kernel stack, load kernel esp
  - push user eflags, reset flags (IF=0, TF=0)
  - push user eip, load kernel entry eip
- push error code
- push trap number, registers and set thread context pointer

Hardware programmed single instrution

Context record

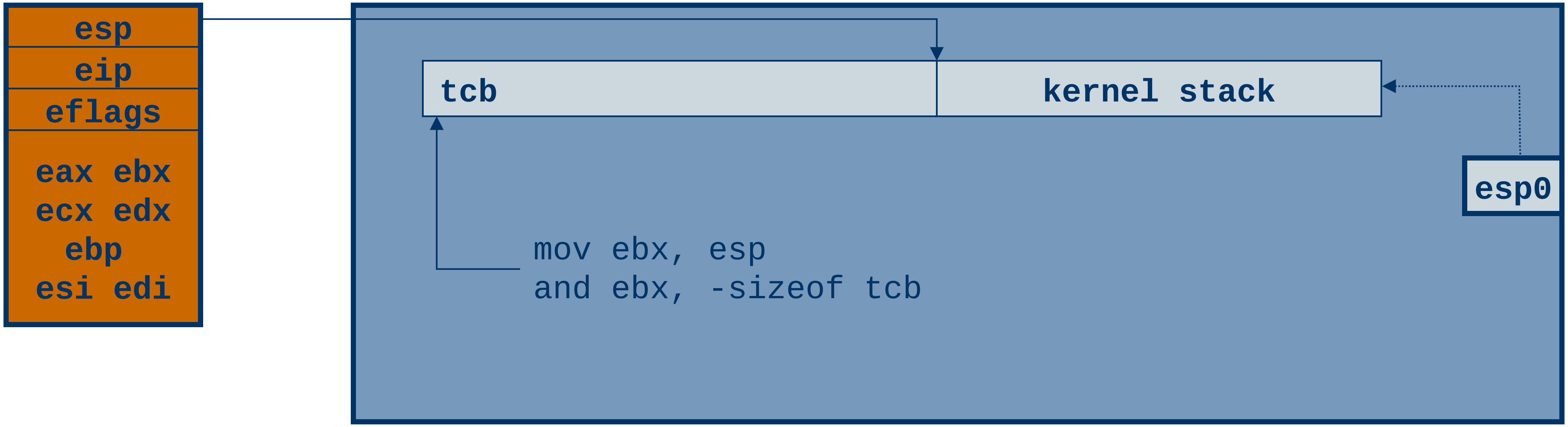


- Context record is a pointer into the kernel stack
- This record can be modified while in kernel mode
- Context record will be restored when the thread leaves the kernel

```
struct context
{
  unsigned long es, ds;
  unsigned long edi, esi, ebp, ebx, edx, ecx, eax;
  unsigned long traptype;
  unsigned long errcode;

  unsigned long eip, ecs;
  unsigned long eflags;
  unsigned long esp, ess;
};
```

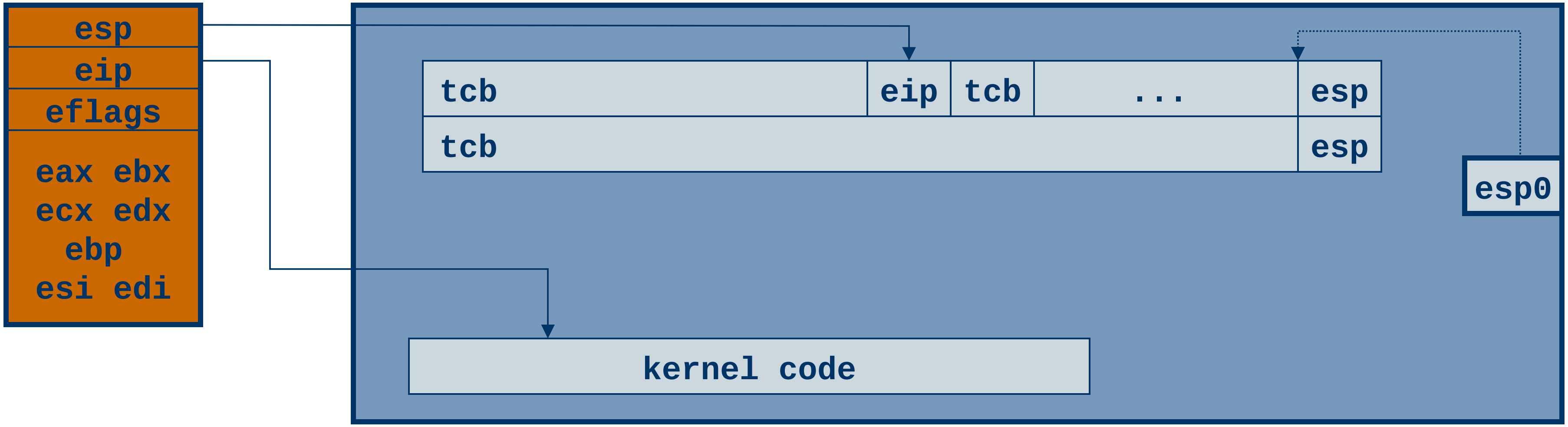
Current thread



```
mov ebx, esp
and ebx, -sizeof tcb
```

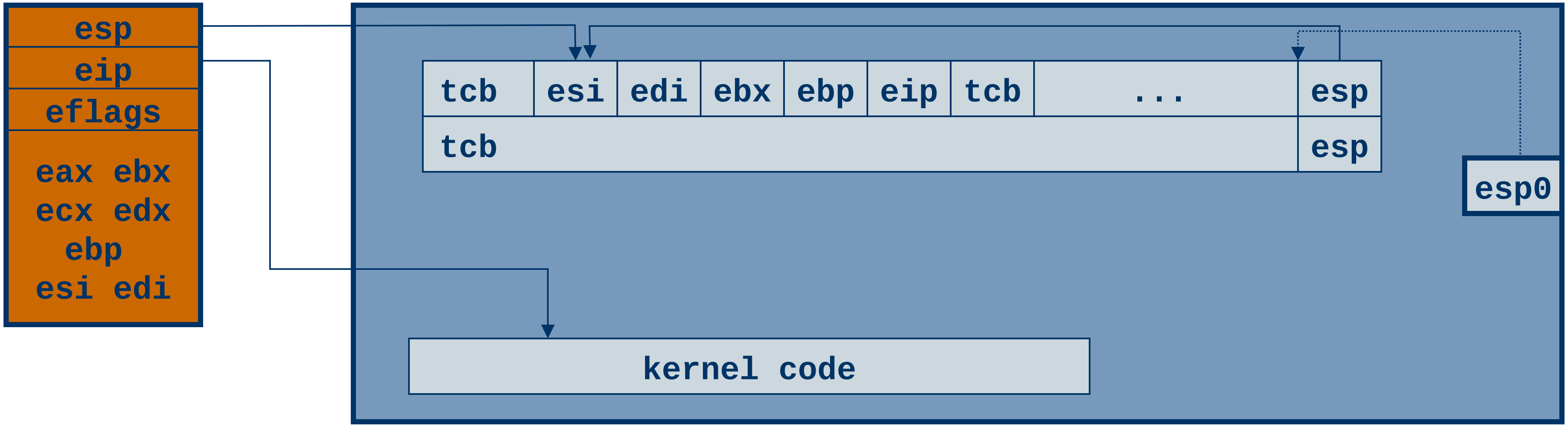
- tcbs are aligned on 8K boundary
- The current thread can be obtained from the value of the stack pointer in kernel mode.

Context switch (1)



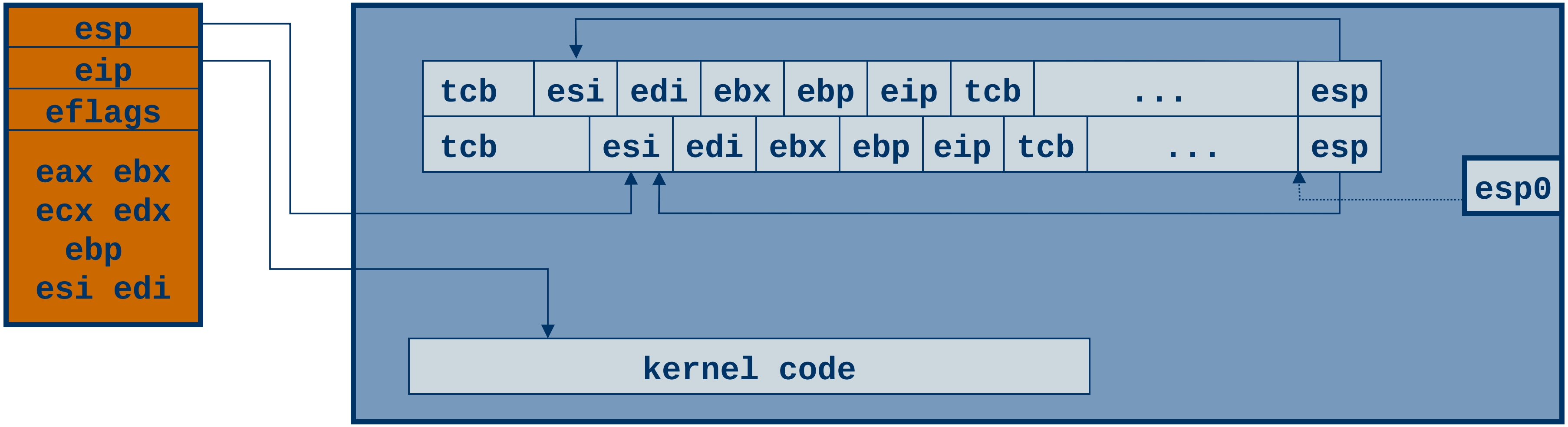
- Dispatcher calls context_switch to change context to another thread.
- Caller pushes new tcb and return address on stack.

Context switch (2)



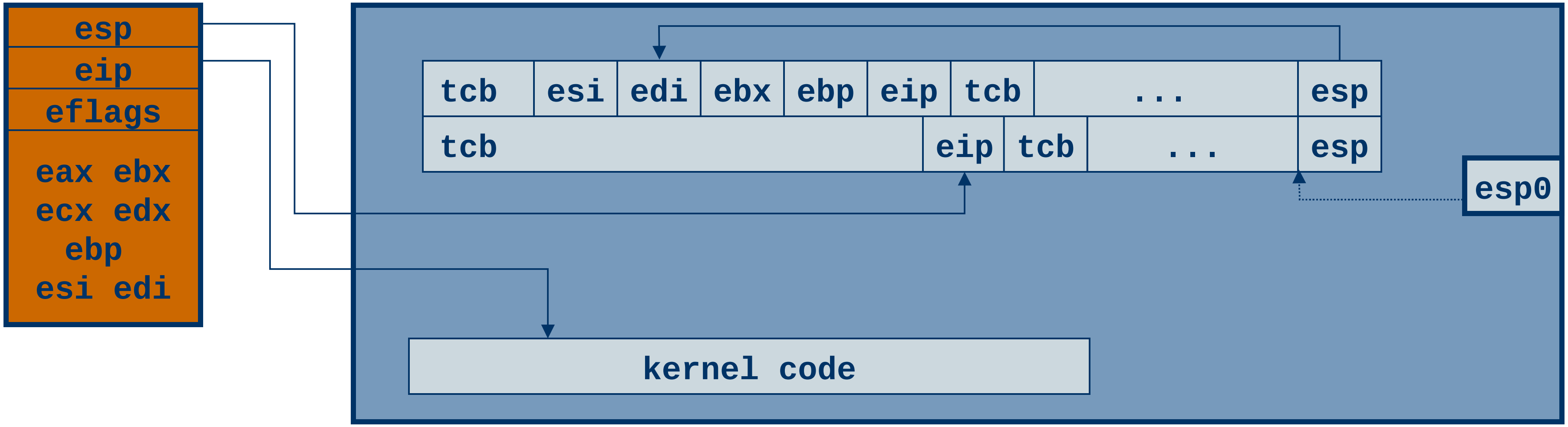
- Dispatcher calls context_switch to change context to another thread.
- Caller pushes new tcb and return address on stack.
- Registers are saved on current kernel stack.
- Store kernel stack pointer in tcb.

Context switch (3)



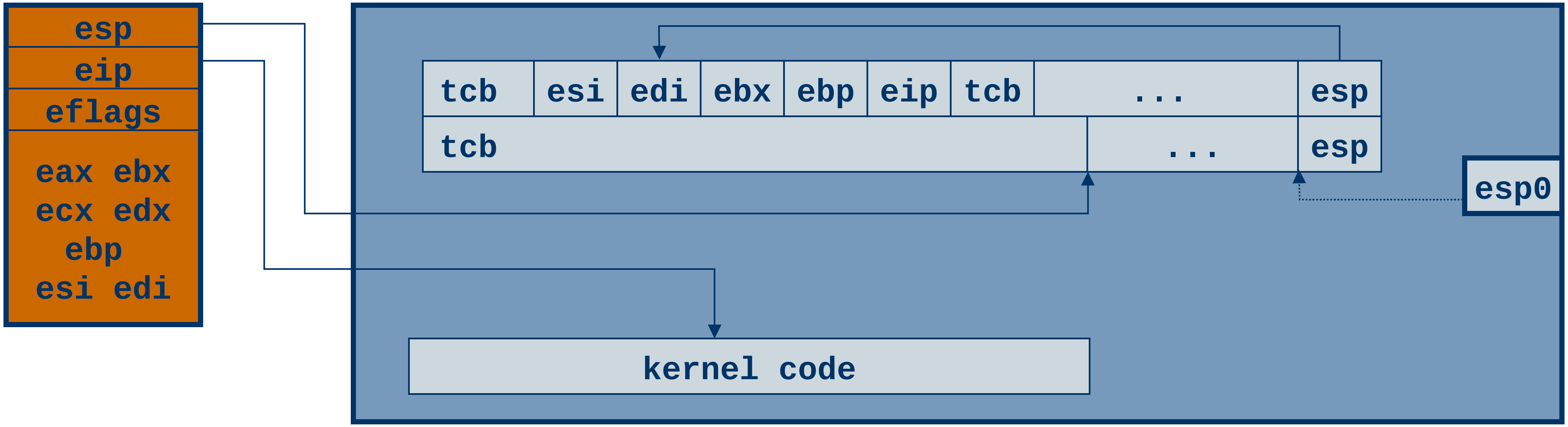
- Dispatcher calls context_switch to change context to another thread.
- Caller pushes new tcb and return address on stack.
- Registers are saved on current kernel stack.
- Store kernel stack pointer in tcb.
- Fetch stack pointer for new thread and store in esp0.

Context switch (4)



- Dispatcher calls context_switch to change context to another thread.
- Caller pushes new tcb and return address on stack.
- Registers are saved on current kernel stack.
- Store kernel stack pointer in tcb.
- Fetch stack pointer for new thread and store in esp0.
- Restore registers from new kernel stack.

Context switch (5)



- Dispatcher calls context_switch to change context to another thread.
- Caller pushes new tcb and return address on stack.
- Registers are saved on current kernel stack.
- Store kernel stack pointer in tcb.
- Fetch stack pointer for new thread and store in esp0.
- Restore registers from new kernel stack.
- Return from context_switch restores eip.

System calls (1)

- System calls are exported from os.dll.
- All kernel system calls are handled by the syscall() function.
- When a kernel system call is invoked a privilege transition from user mode to kernel mode takes place, and the stack is switched from user stack to kernel stack.
- When the function returns these actions are reversed, the thread switches back to the user stack and returns to user mode privileges.
- Consider the system call function(param1, param2). Prior to this function being called, two parameters are pushed onto the user stack in reverse order.
- When function() is invoked, the return address is first pushed onto the user stack and then the old base pointer for the previous stack frame is pushed. The call stack after the call looks like:

param2
param1
ret addr
ebp

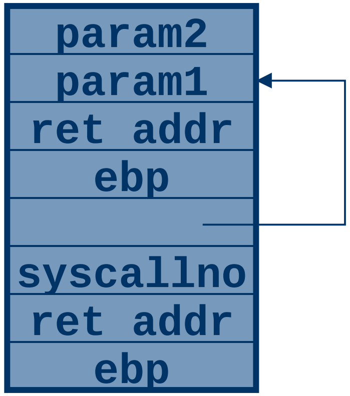
System calls (2)

- The implementation for function() is as follows:

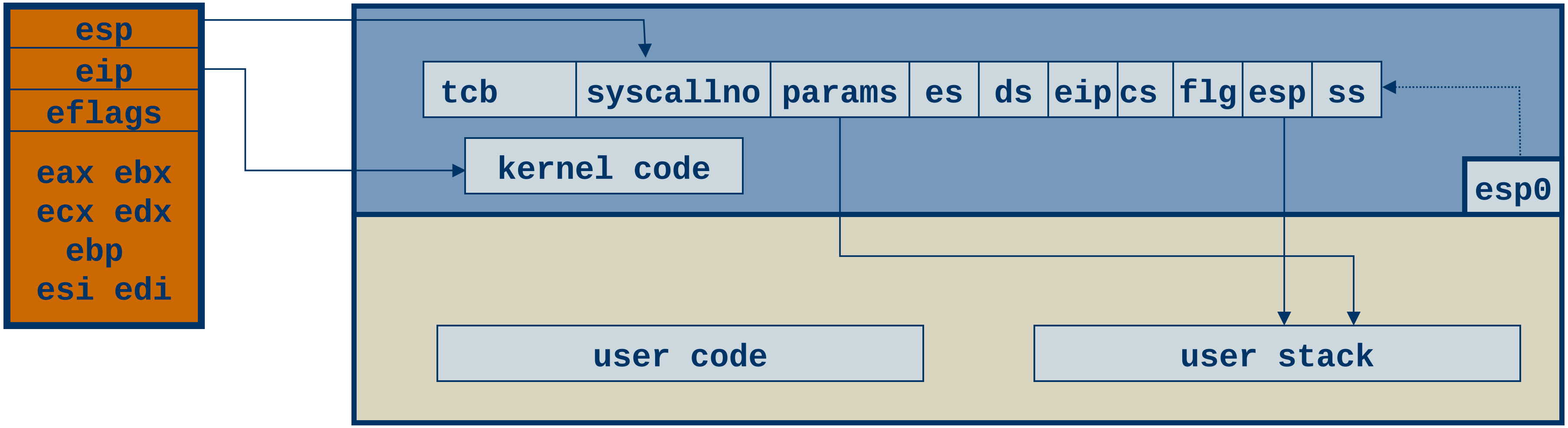
```
int function(param1, param2)
{
  return syscall(SYSCALL_FUNCTION, &param1);
}
```

```
syscall:
  push  ebp
  mov   ebp, esp
  mov   eax, 8[ebp]
  mov   edx, 12[ebp]
  int   48
  leave
  ret
```

- syscall() takes two parameters, a system call number, syscallno, and a pointer to the first parameter supplied to the function that calls syscall(). When syscall() is invoked, these two parameters are pushed onto the user stack in reverse order. The return address is pushed onto the stack when the call is made and the first action of the syscall() function is to push the base pointer onto the user stack.
- syscall() is an assembly language routine that causes a trap to the kernel through INT 48.
- Before doing this, it stores the system call number and pointer to the first parameter of the specific system call in the eax and edx registers, respectively.



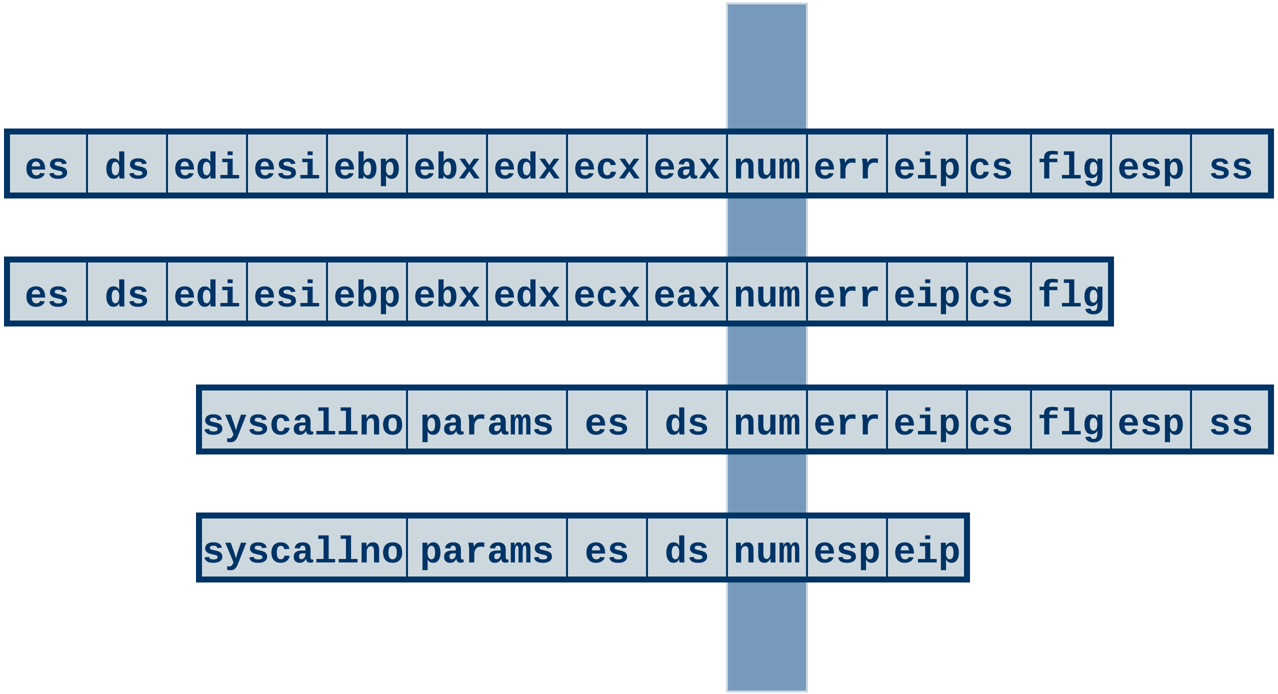
System calls (3)



- When the trap is executed the system switches to kernel mode and executes the systrap routine
- systrap saves the data segments and takes the two parameters in eax and edx and passes these to the kernel mode syscall routine.
- The system trap mechanism has been carefully designed to minimize the number of registers that must be preserved between system calls.
- Support for sysenter/sysexit for Pentium processors.

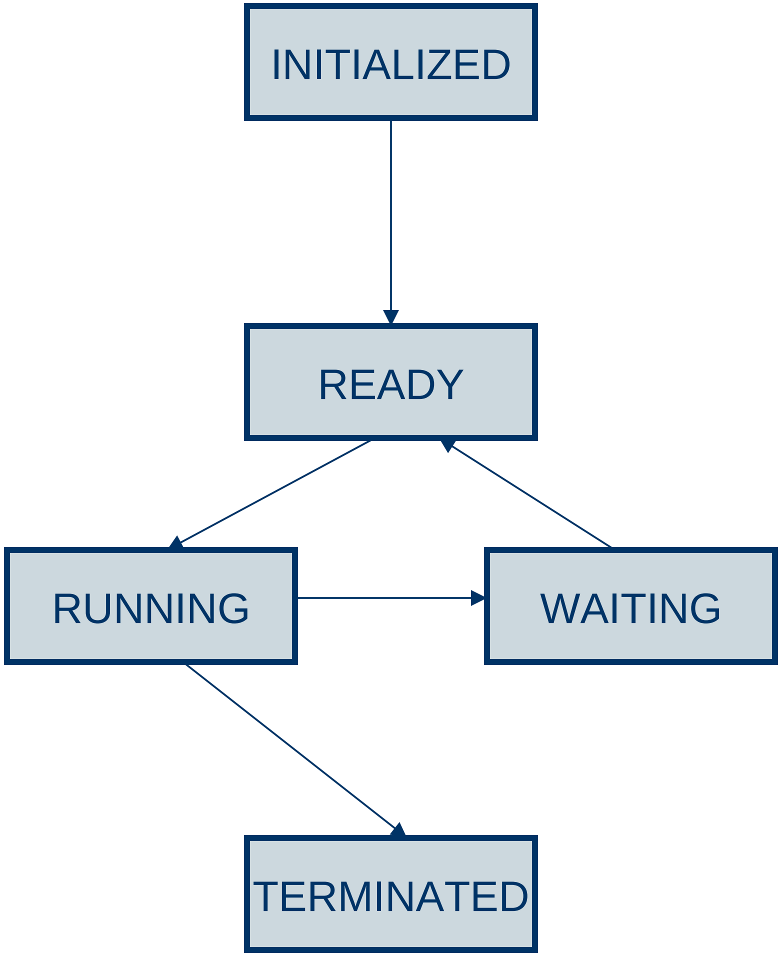
```
systrap:
  push   ds
  push   es
  push   edx
  push   eax
  mov    ax, SEL_KDATA
  mov    ds, ax
  mov    es, ax
  call   syscall
  add    esp, 8
  pop    es
  pop    ds
  iretd
```

Trap Frames



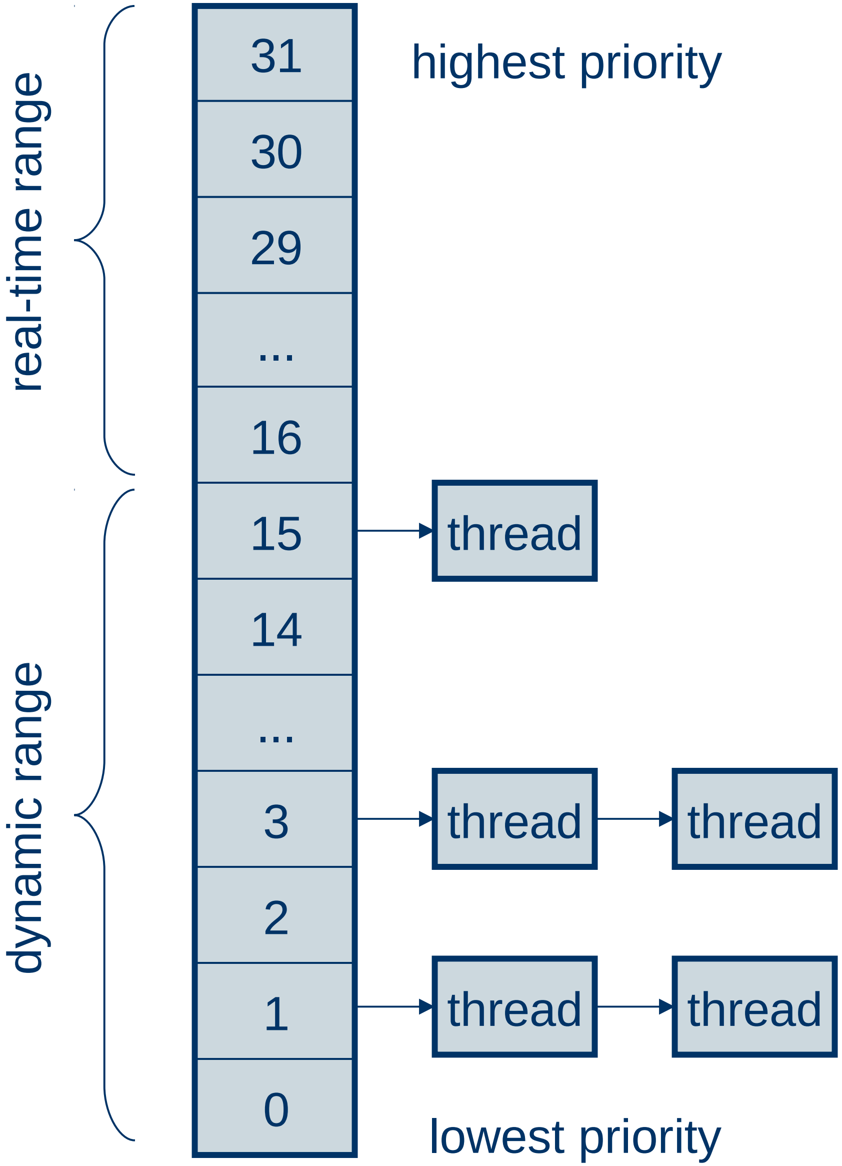
ring 3 interrupt	es	ds	edi	esi	ebp	ebx	edx	ecx	eax	num	err	eip	cs	flg	esp	ss
ring 0 interrupt	es	ds	edi	esi	ebp	ebx	edx	ecx	eax	num	err	eip	cs	flg		
int 48 syscall						syscallno	params	es	ds	num	err	eip	cs	flg	esp	ss
sysenter syscall						syscallno	params	es	ds	num	esp	eip				

Thread states



- Threads are created in INITIALIZED state.
- When mark_thread_ready() is called the thread moves to the READY state and is inserted into one of the wait queues.
- When the scheduler selects the thread for execution it moves to the RUNNING state and the dispatcher swicthes the processor to the threads context.
- The thread continues running until it must wait on an object to become signaled (blocked) or its quantum expires (preempted).
- If the quantum expires the thread is marked as READY and the next ready thread is moved to the RUNNING state.
- If the thread is blocked the thread is added to the waitlist for the object and enters the WAITING state.
- When the object is signaled the thread is scheduled for execution by inserting it into the ready queue for the threads priority. The thread enters the READY state.
- When the thread terminates it enters the TERMINATED state. The thread object is not removed until all handles to it has been closed.

Scheduling

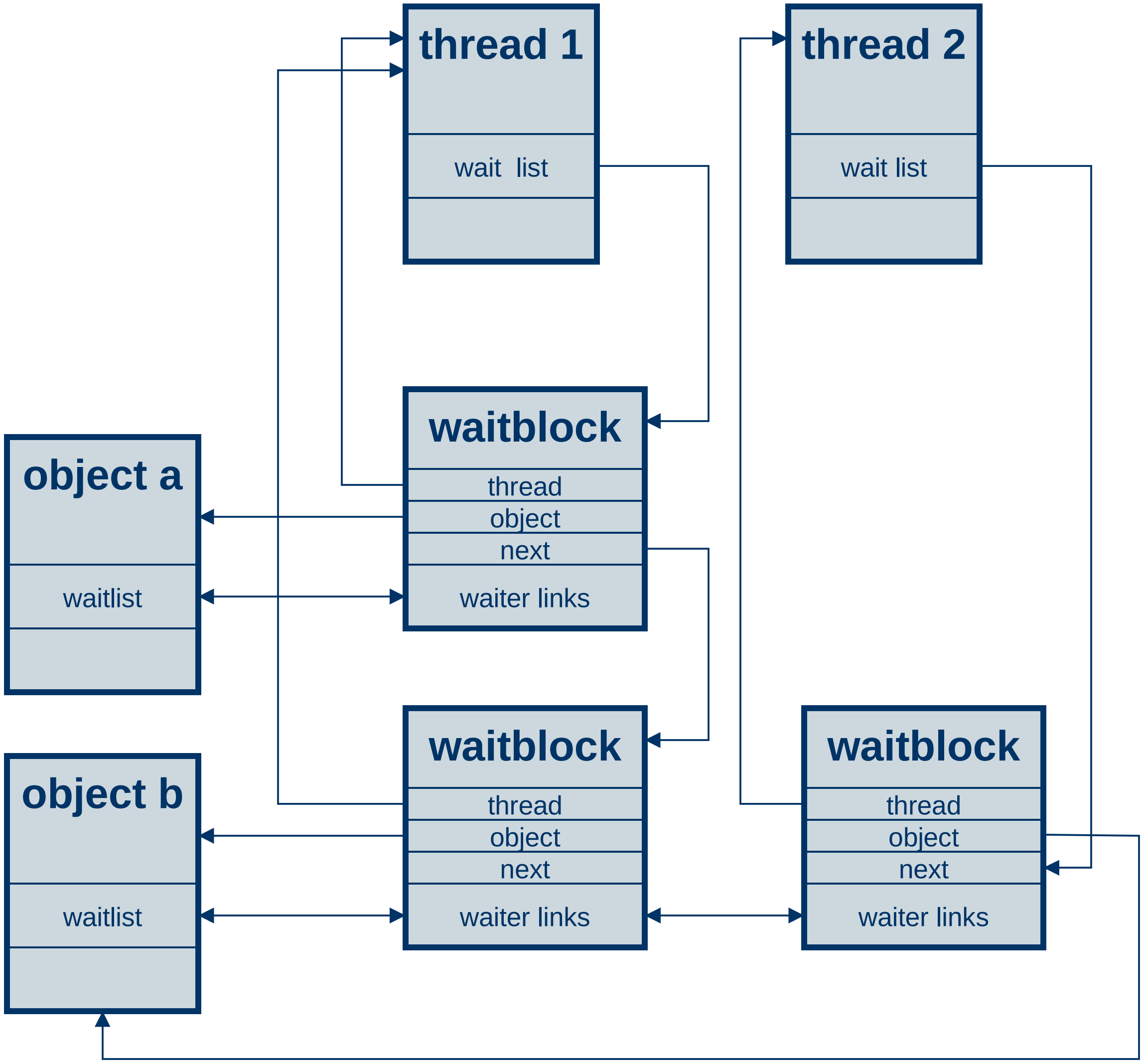


- Each thread has a dynamic and a base priority.
- Threads that are ready to run are scheduled in a round-robin manner based on priority.
- A thread is not scheduled until no higher priority threads are ready to run.
- The scheduler has one ready queue for each priority level.
- Time slice is 36 quantum units
- Three quantum units charged per tick (10 ms)
- One quantum unit charged each time a thread is restarted after a wait.
- Running thread preempted when higher priority thread gets ready to run.
- Priority boosting is applied to thread when started after an I/O wait.
- Boosting never moves threads to the real-time range.
- Boosting is applied to the base priority.
- Dynamic priority is decreased (decayed) at each quantum expiry until it reaches base priority.

Synchronization objects

- Object types
  - – THREAD
  - – EVENT
  - – TIMER
  - – MUTEX
  - – SEMAPHORE
  - – FILE
  - – SOCKET
  - – IOMUX

Thread synchronization



- The object header contains the object type, signaled state, and a list of the threads waiting on the object.
- The waitblock represents a thread waiting on an object.
- Each thread has a list of the objects it is waiting on.

Signal handling

- Signal handlers are registered with signal().
- When a trap occurs send_signal() is called by the kernel trap handler.
- The context record is pushed into the user stack.
- Parameters to global signal handler are pushed onto the stack.
- The EIP register in the context record is change to the address of the global signal handler.
- This causes the global signal handler in signal.c to be invoked when the thread leaves the kernel.
- The global signal handler uses the signal handler table to dispatch the signal to the signal handler.
- When the signal handler returns the global signal handler uses int 49 to call the sigexit handler in the kernel.
- The sigexit handler in the kernel restores the context and resumes execution of the thread.
- The signal handler can change the context record or use longjmp() to alter the execution of the thread.

Part 5

I/O Management

I/O Components

- Device Drivers
- Device Manager
- Virtual File System layer and filesystems
- Socket interface and networking
- I/O multiplexing

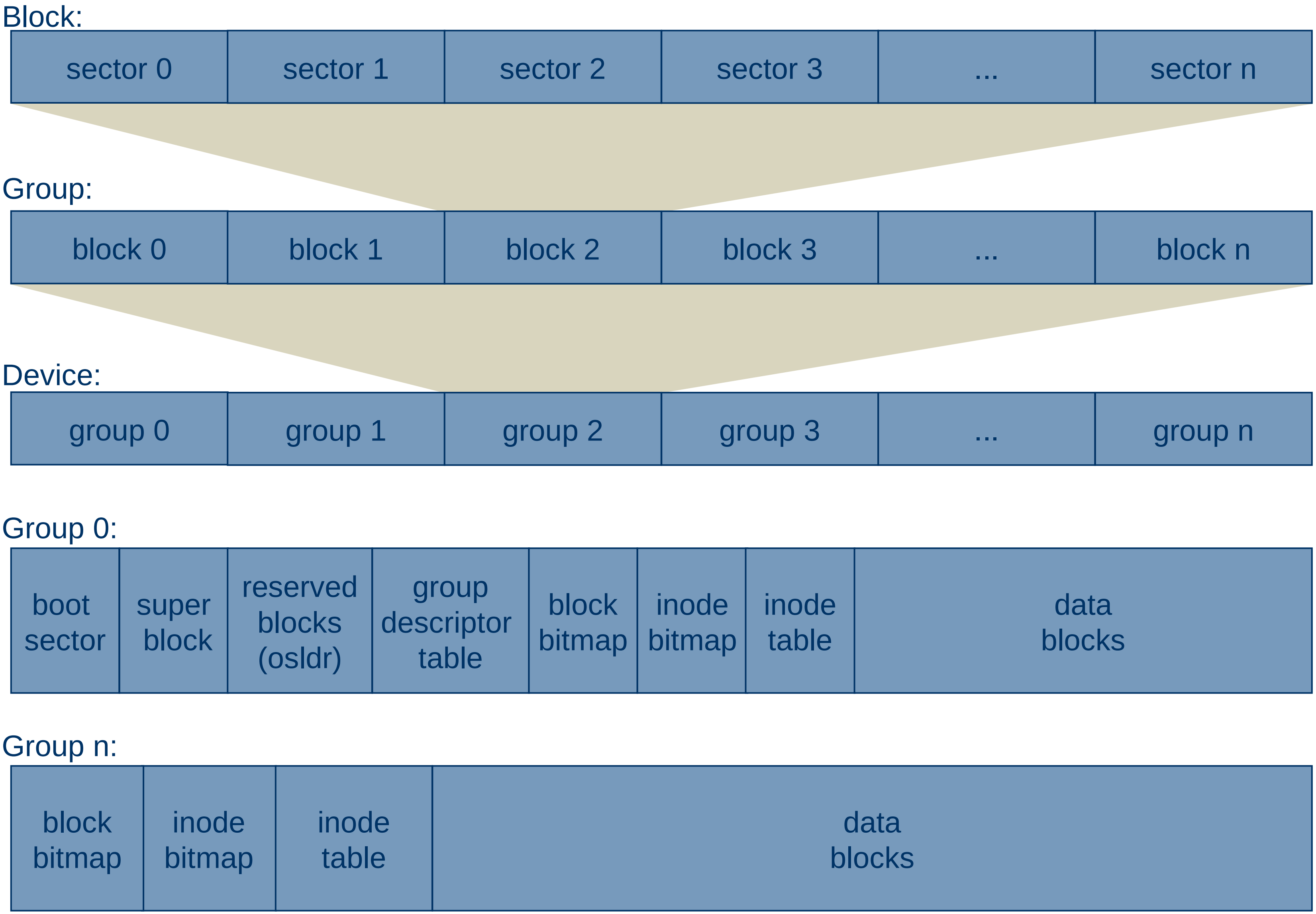
Device types

- Bus device (enumerate)
  - pci
  - isapnp
- Block device (read, write)
  - fd
  - hd
  - cd
- Stream device (read, write)
  - console
  - serial
- Packet device (receive, transmit)
  - 3c905c
  - ne2000
  - pcnet32
  - eepro100
  - sis900
  - rtl8139

File systems

- Virtual File System (vfs)
- File systems
  - *dfs*
    Native sanos disk file system
  - *devfs*
    Device file system (/dev)
  - *procfs*
    Kernel information file system (/proc)
  - *pipefs*
    Pipe file system (for pipe())
  - *smbfs*
    Remote SMB file system (Windows file shares)
  - *cdfs*
    CD-ROM file system (ISO-9660)
- Buffer Cache Manager

Disk file system layout



Block:

sector 0	sector 1	sector 2	sector 3	...	sector n

Group:

block 0	block 1	block 2	block 3	...	block n

Device:

group 0	group 1	group 2	group 3	...	group n

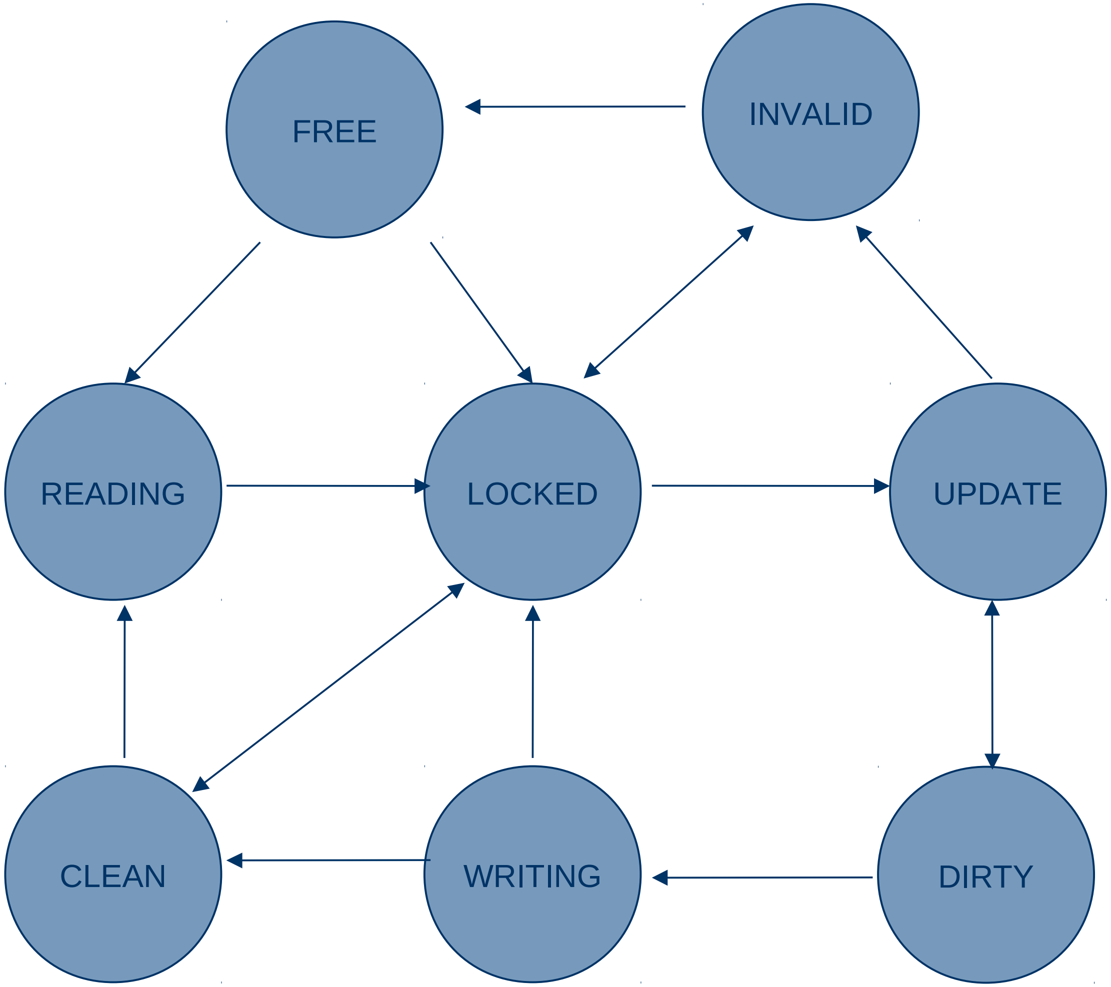
Group 0:

boot sector	super block	reserved blocks (osldr)	group descriptor table	block bitmap	inode bitmap	inode table	data blocks

Group n:

block bitmap	inode bitmap	inode table	data blocks

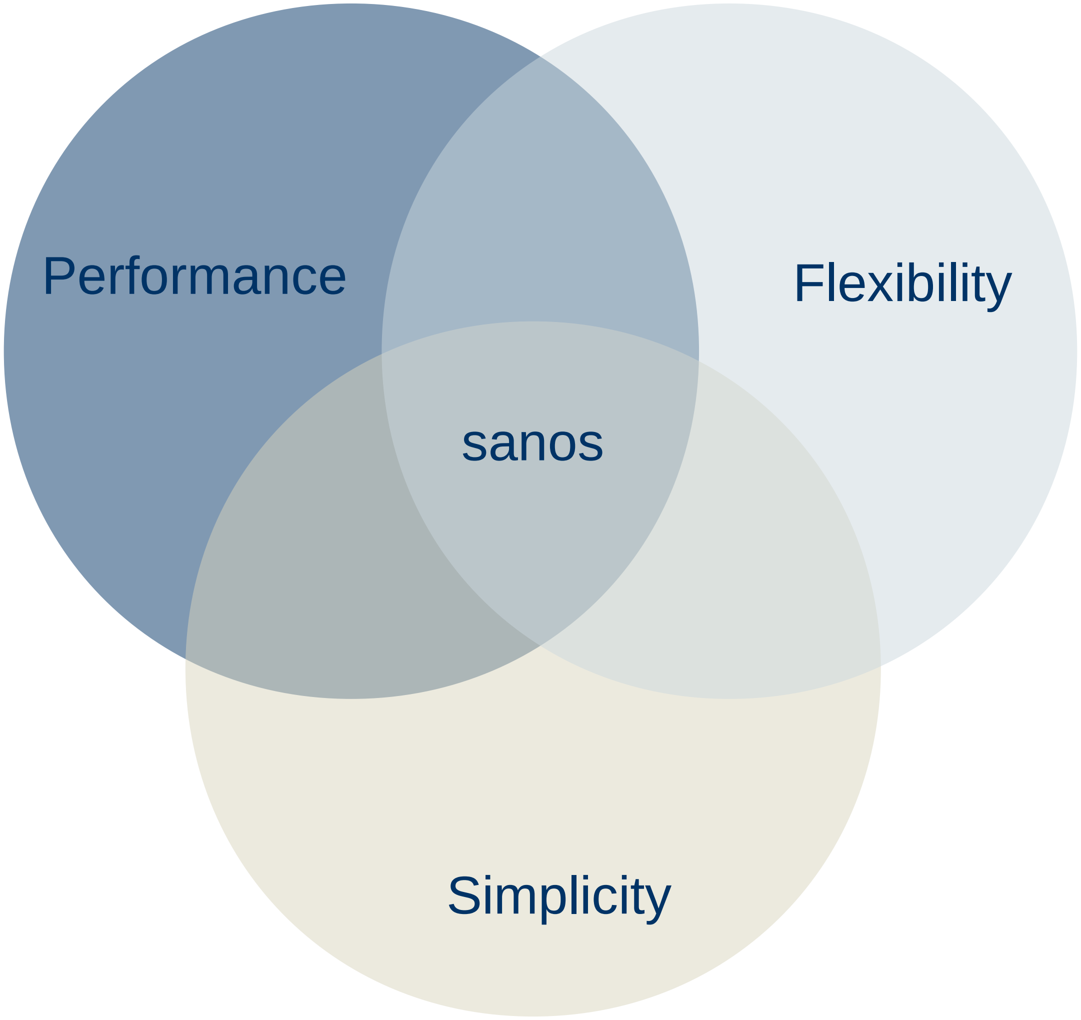
Cache buffer states



Networking

- Socket interface (tcp and udp sockets)
- Network interface (netif)
- Protocols
  - TCP
  - UDP
  - IP
  - ICMP
  - DHCP
  - DNS
  - ARP
  - IEEE 802.3 (Ethernet)

Design Principles



Logo