# Linux Processes

COMS W4118

Prof. Kaustubh R. Joshi

krj@cs.columbia.edu

http://www.cs.columbia.edu/~krj/os

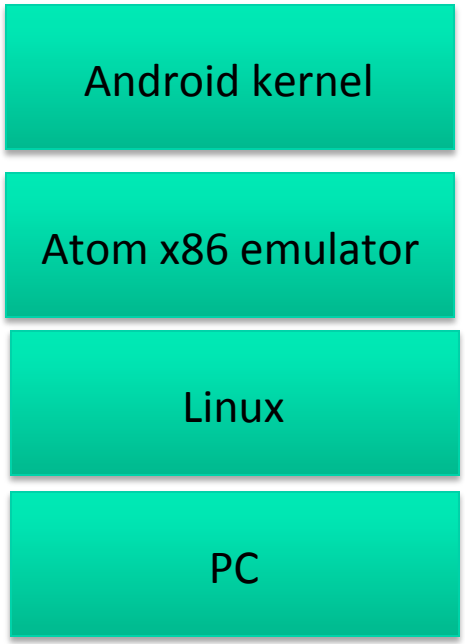
**References:** Operating Sys Concepts 9e, Understanding the Linux Kernel, previous W4118s

# Outline

- The Android Emulator
- Processes/tasks
  - The process descriptor: task_struct
  - Thread context
  - Task States
  - Process relationships
  - Wait queues
- Context switching
- Creating and destroying processes
- Kernel threads

# Development using Android emulator

- Based on QEMU emulator
  - Does what a real phone does
  - Except implemented in s/w!
  - Can emulate x86, arm,…
  - We'll use x86 Atom
  - Allows us to virtualize
- Run like a normal program on "host" OS



# Emulator of Registers

```
int32_t regs[8];
#define REG_EAX 1;
#define REG_EBX 2;
#define REG_ECX 3;
...
int32_t eip;
int16_t segregs[4];
...
```

# Emulator of CPU logic

```
for (;;) {
        read_instruction();
        switch (decode_instruction_opcode()) {
        case OPCODE_ADD:
                int src = decode_src_reg();
                int dst = decode_dst_reg();
                regs[dst] = regs[dst] + regs[src];
                break;
        case OPCODE_SUB:
                int src = decode_src_reg();
                int dst = decode_dst_reg();
                regs[dst] = regs[dst] - regs[src];
                break;
        ...
        }
        eip += instruction_length;
}
```

# Emulation of x86 memory

```
uint8_t read_byte(uint32_t phys_addr) {
        if (phys_addr < LOW_MEMORY)
                return low_mem[phys_addr];
        else if (phys_addr >= 960*KB && phys_addr < 1*MB)
                return rom_bios[phys_addr - 960*KB];
        else if (phys_addr >= 1*MB && phys_addr < 1*MB+EXT_MEMORY) {
                return ext_mem[phys_addr-1*MB];
        else ...
}

void write_byte(uint32_t phys_addr, uint8_t val) {
        if (phys_addr < LOW_MEMORY)
                low_mem[phys_addr] = val;
        else if (phys_addr >= 960*KB && phys_addr < 1*MB)
                ; /* ignore attempted write to ROM! */
        else if (phys_addr >= 1*MB && phys_addr < 1*MB+EXT_MEMORY) {
                ext_mem[phys_addr-1*MB] = val;
        else ...
}
```

# Emulating devices

- Hard disk: use file of the host
- VGA display: draw in a host window
- Keyboard: host's keyboard API
- Clock chip: host's clock
- Etc.

# VM Password

- Write it down! Not on web version of slides:
- andr01d_vm!

# Starting up the Emulator

- Create an Android Virtual Device (AVD)
  - tools/android avd
  - Choose Android 4.1.2, Atom x86 image
  - Image contains base kernel/OS/apps
  - We'll replace with our own kernel
- Start the emulator
  - tools/emulator –avd w4118
  - Wait a long time… (unless using virtualization)
- Interacting with the emulator
  - adb –s emulator-5555 shell|push|pull|…

# Getting the Android Source

- Custom per-group repository that will work with the emulator
  - Name is groupN (where N is your group number)
  - git clone krj@sp13-w4118-git.cs.columbia.edu:group0
- Learn about git!
  - Useful commands: checkout, commit –a, push, pull, format-patch
- Repository will not work with a Nexus 7
  - Need a different kernel branch (tegra)
  - See AOSP webpage on how to download

# Compiling the kernel

- To compile Android kernel, need NDK (native dev kit)
  - Provides cross compilers (same as native, we're on x86!)
  - Add the appropriate cross-compiler to your path
  - For Atom image, it's the <ndk>/toolchains/x86-4.4.3/prebuilt/linux-x86/bin compiler
- Configure and build the kernel
  - make CC="${CROSS_COMPILE}-gcc –mno-android" goldfish_defconfig
  - make CC="${CROSS_COMPILE}-gcc –mno-android" bzImage
  - Kernel in arch/x86/boot/bzImage directory of source tree
- To boot a custom kernel in the emulator
  - emulator –avd w4118 –kernel <path_to_kernel>

# Compiling command line programs

- Need to set path to right libraries and headers
  - Sample Makefile.ndk provided
  - Just change name of binary
  - make –f ~krj/android/Makefile.ndk
- To push binary to the emulator and run
  - adb –s dev_name shell mkdir –p /data/tmp
  - adb –s dev_name push <bin> /data/tmp
  - adb –s dev_name shell chmod 755 /data/tmp/bin
  - adb –s dev_name shell bin

# Android/Linux Kernel Source Tree

- include/linux/: architecture independent data structures
- kernel/: architecture independent code
  - Scheduler, synchronization, timers, syscalls
- mm/: memory management functions and syscalls
- arch/: architecture specific code
  - x86/, arm/
    - kernel/: arch specific code
    - include/asm/: arch specific includes
    - mach-goldfish/, …: platform specific directories (timer, APIC)
- drivers/: device drivers
- block/: arch independent block device scheduling
- fs/: filesystem functions and syscalls
- net/: network protocol stacks
- init/: kernel setup and init process

# The Linux kernel is big

- The bad news…
  - 11511 .c, 10256 .h files, 7.7 million LOC
- The good news…
  - More than half the code in device drivers
    - 5000 .c, 2216 .h, 4.5 million LOC
  - Still more to support different architectures
    - 20+ different architectures
    - 1.1 million LOC in architecture specific code
  - Modular structure
  - E.g., the kernel directory is "just" 127k LOC

# Documentation

- /Documentation directory
  - Lot of useful information here
  - Design information
  - Architecture specific info
- LXR: the Linux Cross Referencer
  - Browsable/searchable repository of the code (where structs are defined, where used)
  - 2.6.29 Linux: http://lxr.linux.no/linux+v2.6.29/
  - Android: http://sp13-w4118-dev.cs.columbia.edu/lxr/goldfish/source (currently only partially functional)

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# Header Files

- The major header files used for process management are:

`include/linux/sched.h` – declarations for most task data structures

`include/linux/threads.h` – some configuration constants (unrelated to threads)

`include/linux/times.h` – time structures

`include/linux/time.h` – time declarations

`include/linux/timex.h` – wall clock time declarations

# Source Code

- The source code for process and thread management is in the `kernel` directory:
  - `sched.c` – task scheduling routines
  - `signal.c` – signal handling routines
  - `fork.c` – process/thread creation routines
  - `exit.c` – process exit routines
  - `time.c` – time management routines
  - `timer.c` – timer management routines
- The source code for the program initiation routines is in `fs/exec.c`.

# Linux: Processes or Threads?

- Linux uses a neutral term: tasks
  - Tasks represent both processes and threads
- Linux view
  - Threads: processes that share address space
  - Linux "threads" (tasks) are really "kernel threads“
- Lighter-weight than traditional processes
  - File descriptors, VM mappings need not be copied
  - Implication: file table and VM table not part of process descriptor

# Stacks and task-descriptors

- To manage multitasking, the OS needs to use a data-structure which can keep track of every task's progress and usage of the computer's available resources (physical memory, open files, pending signals, etc.)
- Such a data-structure is called a 'process descriptor' – every active task needs one
- Every task needs its own 'private' stack
- So every task, in addition to having its own code and data, will also have a stack-area that is located in user-space, plus another stack-area that is located in kernel-space
- Each task also has a process-descriptor which is accessible only in kernel-space

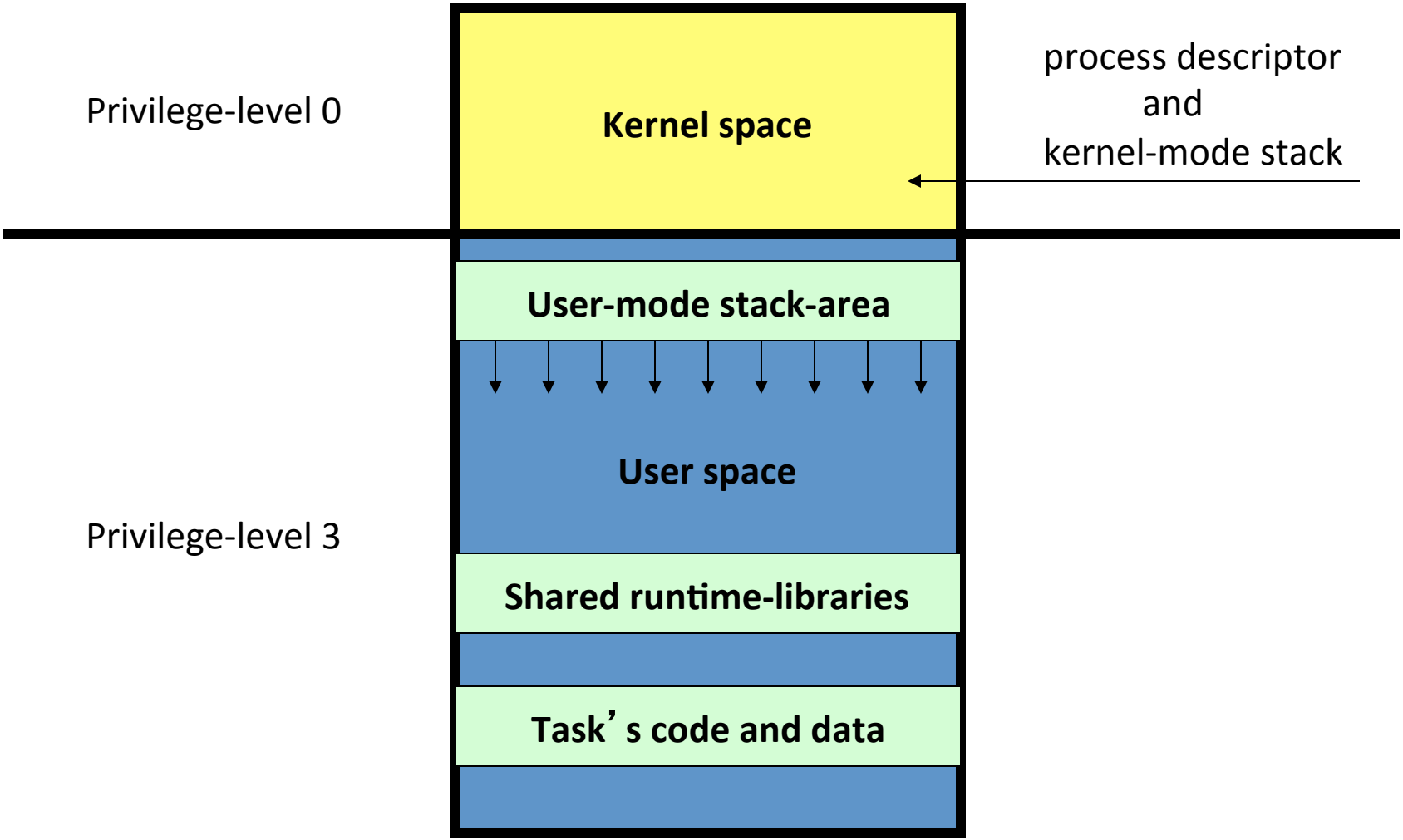
# Kernel Stacks

- Why need a special kernel stack?
  - Kernel can't trust addresses provided by user
  - Address may point to kernel memory
  - Address may not be mapped
  - Memory region may be swapped out from physical RAM
  - Leftover data from kernel ops could be read by process
- Why a different stack for every process?
  - What to do if a process sleeps while executing kernel code?
  - Wasn't a problem up to Linux 2.4
  - Kernel wasn't pre-emptive

# Pre-emptive Kernels

- Pre-emptive kernel different from process pre-emption
  - A non-preemptive kernel may not task switch while executing kernel code on behalf of a process
  - Up to Linux 2.4, implemented through BKL (big kernel lock)
  - Each syscall acquires BKL before execution
  - All other syscalls block. So, kernel code must run fast!
  - Inefficient on multicore architectures!
  - Finally removed in 2011
- Pre-emptive kernel: allow task switch while in kernel mode
  - What to do with kernel state?
  - Need per-process kernel stack!
  - What to do with interrupts?
  - Share process kernel stack (previously), or get their own (now)
  - All interrupts share single 4KB or 8KB kernel stack
- Which stack is being used determines kernel "context"

# A task's virtual-memory layout



# Process Descriptor

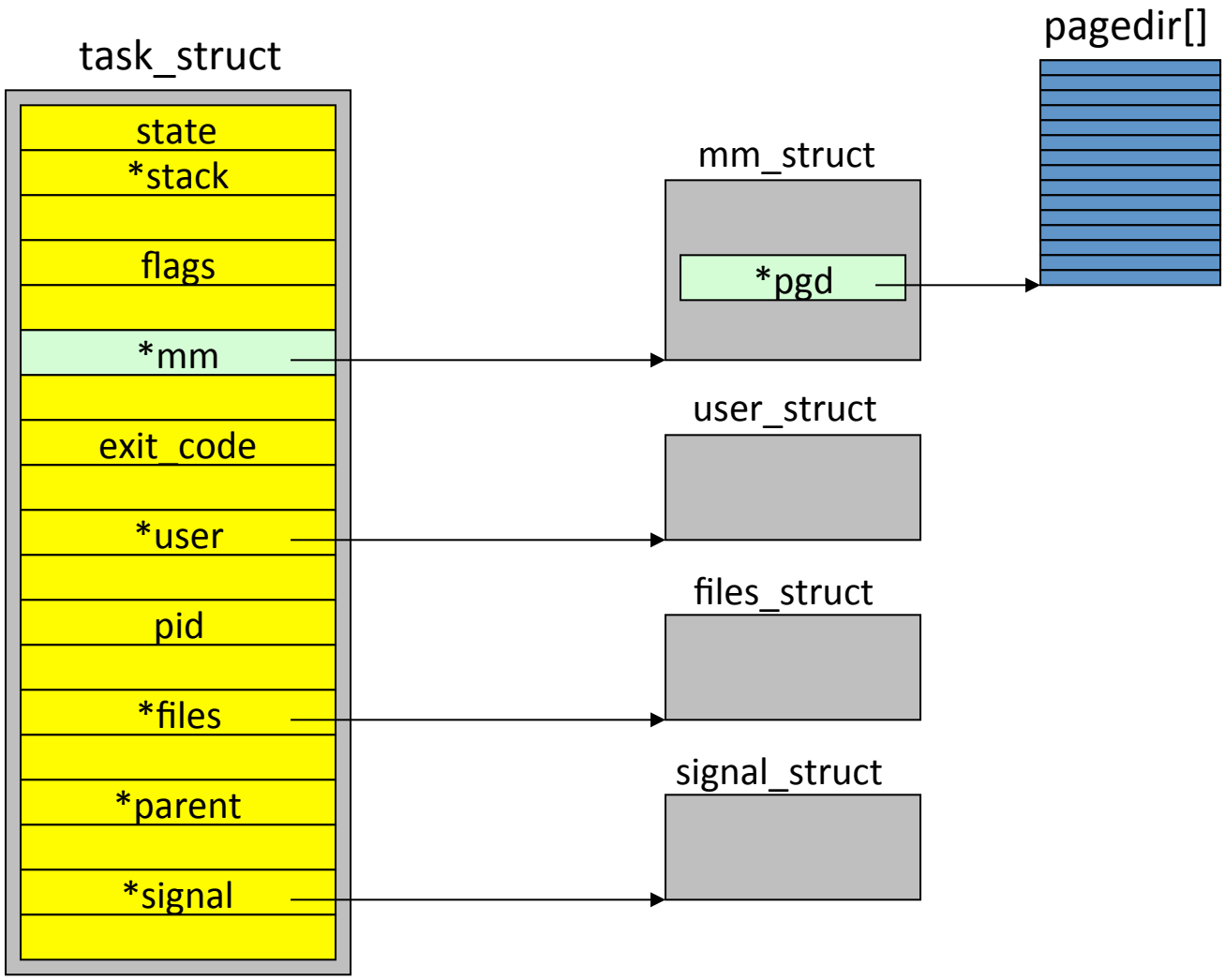
- Process – dynamic, program in motion
  - Kernel data structures to maintain "state"
  - Descriptor, PCB (control block), task_struct
  - Larger than you think! (about 1K)
  - 160+ fields
  - Complex struct with pointers to others
- Type of info in task_struct
  - state, id, priorities, locks, files, signals, memory maps, locks, queues, list pointers, …
- Some details
  - Address of first few fields hardcoded in asm
  - Careful attention to cache line layout

# The Linux process descriptor

Each process descriptor contains many fields

and some are pointers to other kernel structures

which may themselves include fields that point to structures

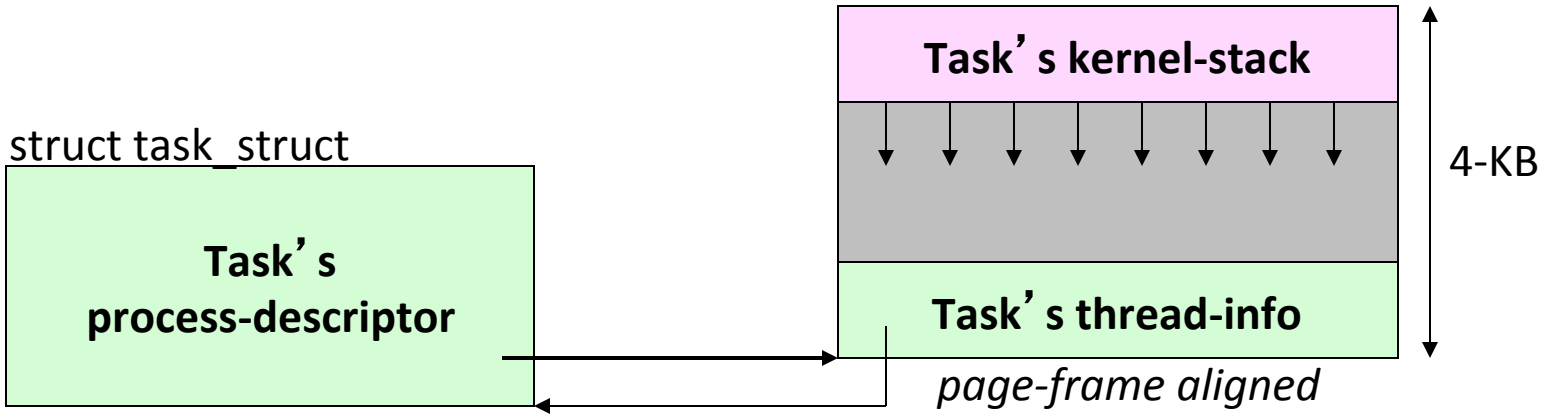


# The Task Structure

- The *task_struct* is used to represent a task.
- The *task_struct* has several sub-structures that it references:
  - *tty_struct* – TTY associated with the process
  - *fs_struct* – current and root directories associated with the process
  - *files_struct* – file descriptors for the process
  - *mm_struct* – memory areas for the process
  - *signal_struct* – signal structures associated with the process
  - *user_struct* – per-user information (for example, number of current processes)

# Process/Thread Context

- Linux uses part of a task's kernel-stack page-frame to store thread information
- The thread_info includes a pointer to the task's process-descriptor data-structure



# Finding a task's 'thread-info'

- During a task's execution in kernel-mode, it's very quick to find that task's *thread_info* object
- Just use two assembly-language instructions:

```
movl    $0xFFFFF000, %eax
andl    %esp, %eax
```

Ok, now %eax = the thread-info's base-address

- Masking off 13 bits of the stack yields *thread_info*
- Macro *current_thread_info* implements this computation
- *thread_info* points to *task_struct*
- *current* macro yields the *task_struct*
- *current* is not a static variable, useful for SMP

# Finding task-related kernel-data

- Use a macro '**task_thread_info**( task )' to get a pointer to the 'thread_info' structure:

```
struct thread_info  *info = task_thread_info( task );
```

- Then one more step gets you back to the address of the task's process-descriptor:

```
struct task_struct  *task = info->task;
```

# PID Hashes and Task Lookup

- PID: 16-bit process ID
- *task_struct*s are found by searching for *pid* structures, which point to the *task_struct*s. The *pid* structures are kept in several hash tables, hashed by different IDs:
  - process ID
  - thread group ID // pid of first thread in process
  - process group ID // job control
  - session ID // login sessions
  - (see `include/linux/pid.h`)
- Allocated process IDs are recorded in a bitmap representing around four million possible IDs.
- PIDs dynamically allocated, avoid immediate reuse

# Process Relationships

- Processes are related
  - Parent/child (fork()), siblings
  - Possible to "re-parent"
    - Parent vs. original parent
  - Parent can "wait" for child to terminate
- Process groups
  - Possible to send signals to all members
- Sessions
  - Processes related to login

# Task Relationships

- Several pointers exist between *task_struct*s:
  - *parent* – pointer to parent process
  - *children* – pointer to linked list of child processes
  - *sibling* – pointer to task of "next younger sibling" of current process
- *children* and *sibling* point to the *task_struct* for the first thread created in a process.
- The *task_struct* for every thread in a process has the same pointer values.

# Task States

From kernel-header: <linux/sched.h>

- #define TASK_RUNNING 0
- #define TASK_INTERRUPTIBLE 1
- #define TASK_UNINTERRUPTIBLE 2
- #define TASK_STOPPED 4
- #define TASK_TRACED 8
- #define EXIT_ZOMBIE 16
- #define EXIT_DEAD 32
- #define TASK_NONINTERACTIVE 64
- #define TASK_DEAD 128

# Task States

- TASK_RUNNING – the thread is running on the CPU or is waiting to run
- TASK_INTERRUPTIBLE – the thread is sleeping and can be awoken by a signal (EINTR)
- TASK_UNINTERRUPTIBLE – the thread is sleeping and cannot be awakened by a signal
- TASK_STOPPED – the process has been stopped by a signal or by a debugger
- TASK_TRACED – the process is being traced via the ptrace system call
- TASK_NONINTERACTIVE – the process has exited
- TASK_DEAD – the process is being cleaned up and the task is being deleted

# Exit States

```
135 * We have two separate sets of flags: task->state
136 * is about runnability, while task->exit_state are
137 * about the task exiting. Confusing, but this way
138 * modifying one set can't modify the other one by
139 * mistake.
```

- EXIT_ZOMBIE – the process is exiting but has not yet been waited for by its parent
- EXIT_DEAD – the process has exited and has been waited for

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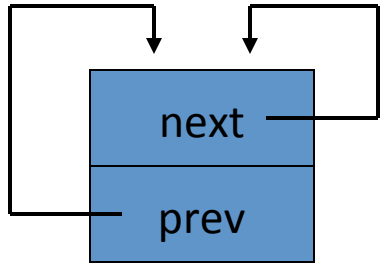
- Context switching
- Creating processes
- Destroying processes

# List Operations

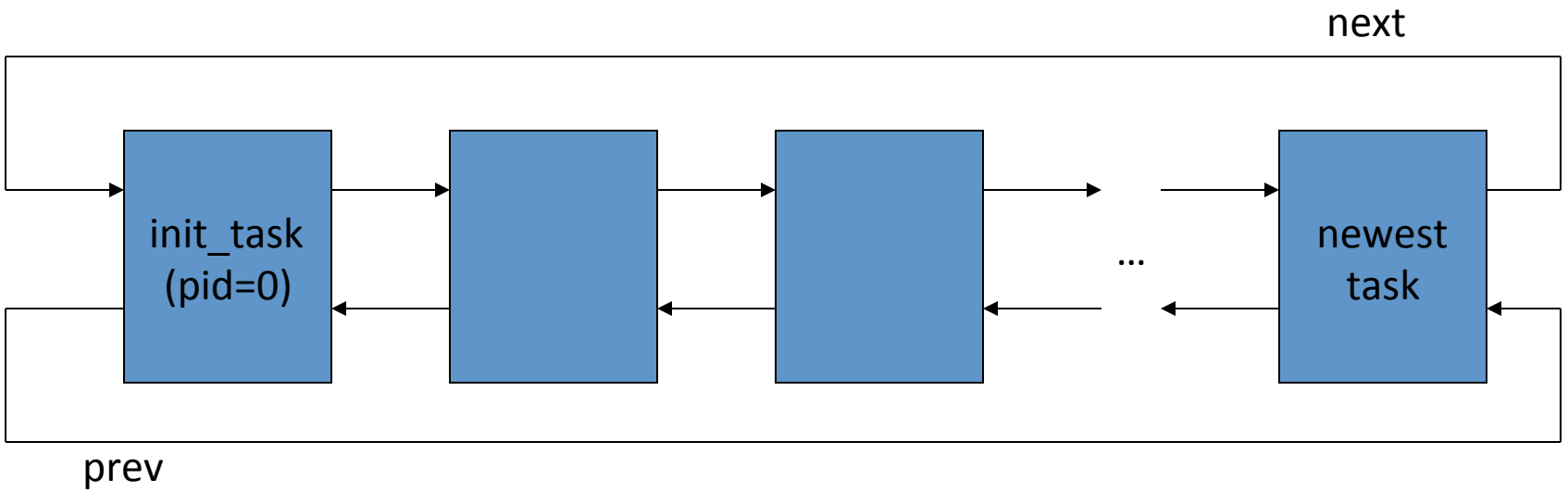
- The *list_head* is a generic list structure with a set of services:
  - *LIST_HEAD* – declare and initialize list head
  - *list_add* – add a *list_head* after item
  - *list_add_tail* – add a *list_head* before item
  - *list_del* – remove *list_head* from list
  - *list_del_init* – remove and initialize *list_head*
  - *list_empty* – is a list empty?
  - *list_for_each, list_for_each_entry, list_entry*



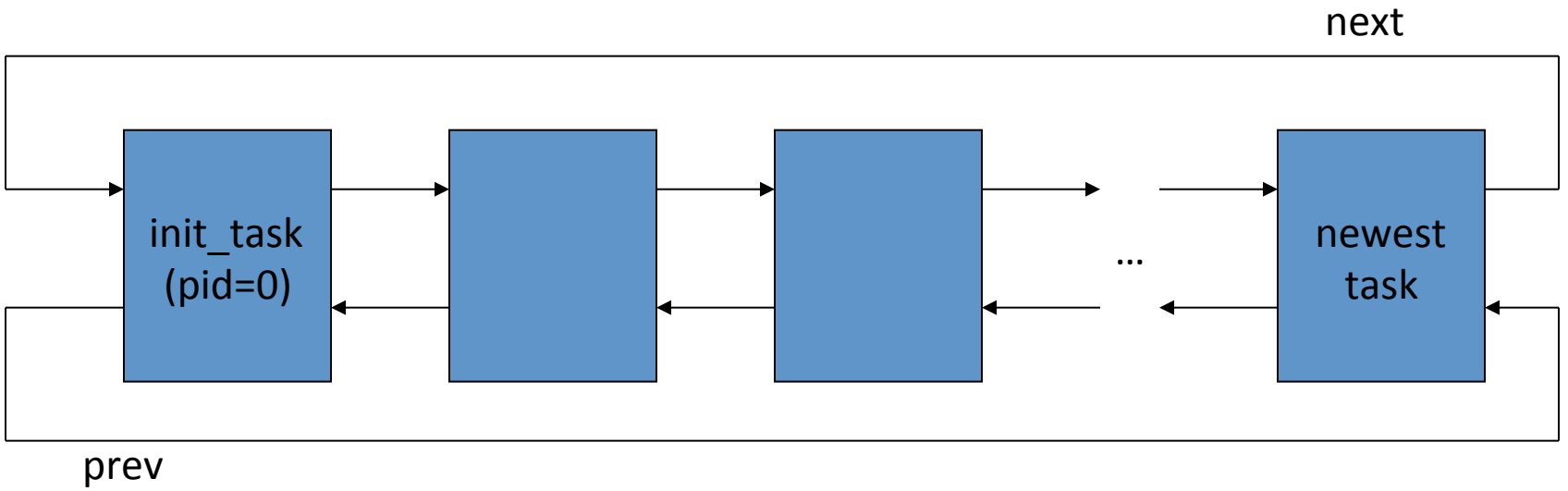
# The Kernel's 'task-list'

- Kernel keeps a list of process descriptors
- A 'doubly-linked' circular list is used
- The 'init_task' serves as a fixed header
- Other tasks inserted/deleted dynamically
- Tasks have forward & backward pointers, implemented as fields in the 'tasks' field
- To go forward: task = next_task( task );
- To go backward: task = prev_task( task );

# Doubly-linked Circular List



# Locking during Access

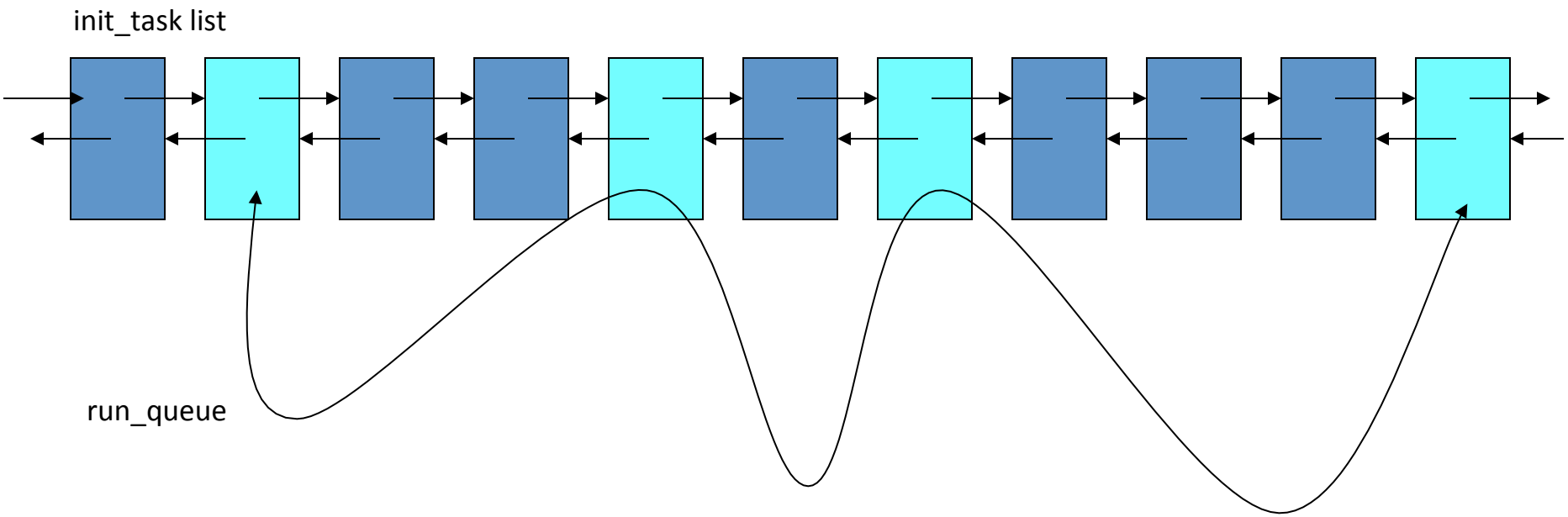



- When traversing the task list, must protect against concurrent accesses
  - read_lock_irq(&tasklist_lock), read_unlock_irq(&tasklist_lock)
- When modifying a task_struct
  - task_lock(task), task_unlock(task)
- Don't sleep when holding a lock on task list or structs!

# ‘run’ queues and ‘wait’ queues

- In order for Linux to efficiently manage the scheduling of its various ‘tasks’, separate queues are maintained for ‘running’ tasks and for tasks that temporarily are ‘blocked’ while waiting for a particular event to occur (such as the arrival of new data from the keyboard, or the exhaustion of prior data sent to the printer)

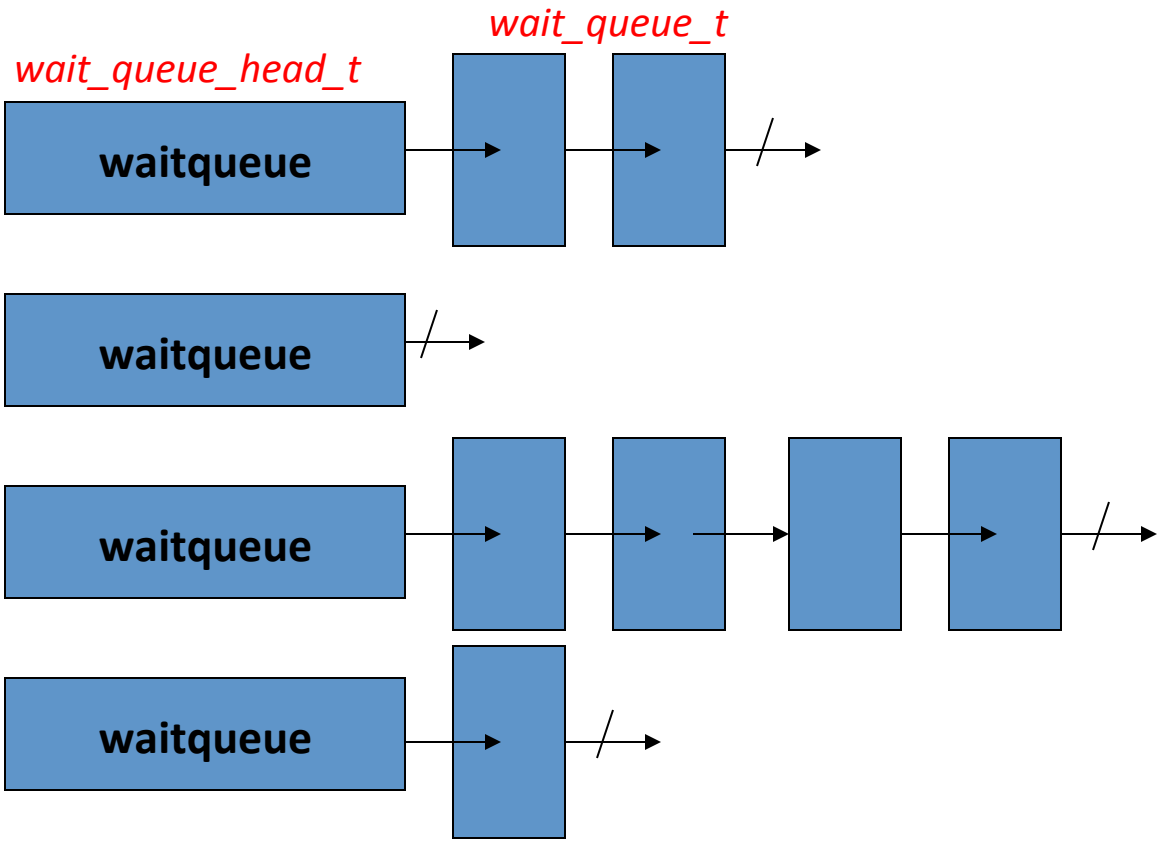
# Some tasks are ‘ready-to-run’




Those tasks that are ready-to-run comprise a sub-list of all the tasks, and they are arranged on a queue known as the ‘run-queue’

Those tasks that are blocked while awaiting a specific event to occur are put on alternative sub-lists, called ‘wait queues’, associated with the particular event(s) that will allow a blocked task to be unblocked

# Kernel Wait Queues




*wait_queue_head_t* can have 0 or more *wait_queue_t* chained onto them

However, usually just one element

Each *wait_queue_t* contains a *list_head* of tasks

All processes waiting for specific "event"

Used for timing, synch, device i/o, etc.

# How Do I Block?

- By calling one of the sleep_on functions:
  - *sleep_on, interruptible_sleep_on, sleep_on_timeout,* etc.
- These functions create a *wait_queue* and place the calling task on it
- Modify the value of its '*state*' variable:
  - TASK_UNINTERRUPTIBLE
  - TASK_INTERRUPTIBLE
- Then call *schedule* or *schedule_timeout*
- The next task to run calls *deactivate_task* to move us out of the run queue
- Only tasks with '*state == TASK_RUNNING*' are granted time on the CPU by the scheduler

# How Do I Wake Up?

- By someone calling one of the wake functions:
  - *wake_up, wake_up_all, wake_up_interruptible,* etc.
- These functions call the *curr->func* function to wake up the task
  - Defaults to *default_wake_function* which is *try_to_wake_up*
- *try_to_wake_up* calls *activate_task* to move us out of the run queue
- The '*state*' variable is set to *TASK_RUNNING*
- Sooner or later the scheduler will run us again
- We then return from *schedule* or *schedule_timeout*

# What are all these options?

- *INTERUPTIBLE* vs. *NON-INTERUPTIBLE*:
  - Can the task be woken up by a signal?
- *TIMEOUT* vs no timeout:
  - Wake up the task after some timeout interval
- *EXCLUSIVE* vs. *NON-EXCLUSIVE*:
  - Should only one task be woken up?
  - Only one *EXCLUSIVE* task is woken up
    - Kept at end of the list
  - All *NON-EXCLUSIVE* tasks are woken up
    - Kept at head of the list
  - Functions with _nr option wake up number of tasks

# Other Wait Queue Notes

- Process can wakeup with event not true
  - If multiple waiters, another may have resource
  - Always check availability after wakeup
  - Maybe wakeup was in response to signal
- 'Interruptible' functions are preferred
- *sleep_on* functions are deprecated
  - *sleep_on* functions suffer from race conditions
  - Want to atomically test and sleep
  - *prepare_to_wait* functions preferred

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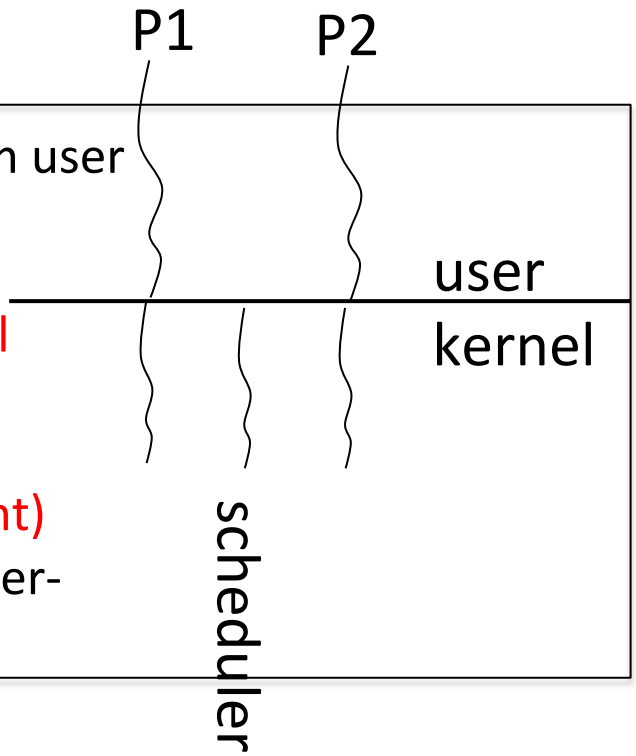
# Example: Linux Context Switch

Contains both arch dependent and independent pieces

- Arch independent code in kernel/sched.c, context_switch()
- Arch dependent in include/asm/system.h and arch/x86/kernel/process_32.c in switch_to macro

1. Save P1's user-mode CPU context and switch from user to kernel mode (need hw)
2. Scheduler selects another process P2
3. Switch to P2's address space (need hw, but kernel memory stays same)
4. Save P1's kernel CPU context (arch dependent)
5. Switch to P2's kernel CPU context (arch dependent)
6. Switch from kernel to user mode and load P2's user-mode CPU context (need hw)




- Change context by changing kernel stack
- When stack changes, all local variables change, including the identity of the previous and next PCB!
- Solution: maintain across process switch by storing in registers

Reference: Bovet and Cesati, Ch. 3.3

# Context Switch

- Context switching is the process of saving the state of the currently running task and loading the state of the next task to run.
- This involves saving the task's CPU state (registers), changing the *current* task value, and loading the CPU state of the new task into the registers.
- *schedule* determines the next task to run, calls *context_switch*, which calls *switch_mm* to change the process address space, then calls *switch_to* to context switch to the new task.

# Context Switch: switch_mm

- *switch_mm* is architecture specific. It generally loads any hardware state required to make the process' user address space addressible in user mode. If the address space is unchanged (task switching between threads in one process), very little is done.

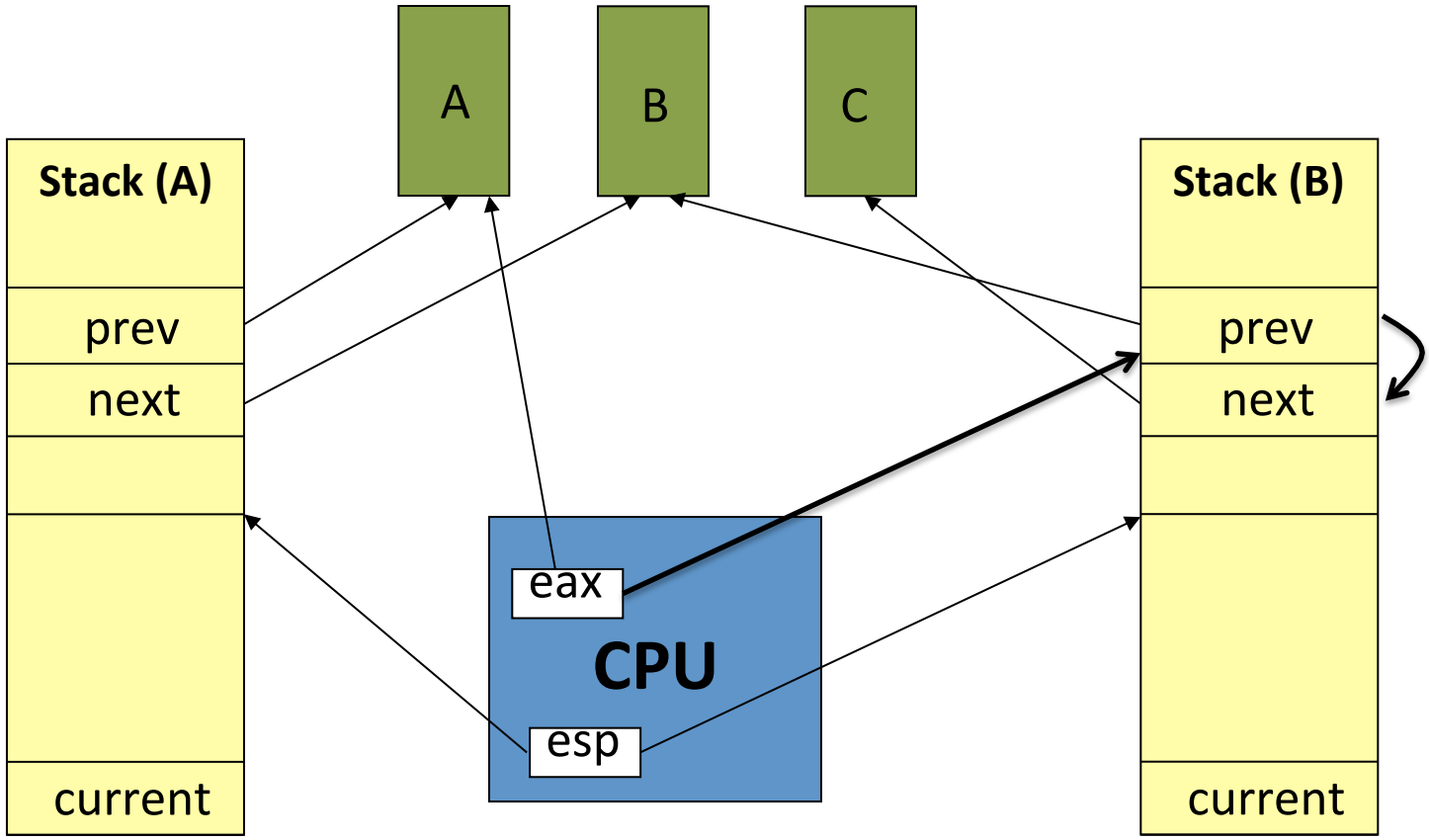
# Context Switch: switch_to

- *switch_to* is architecture specific.
- Generally, it saves the old task's hardware state of the CPU (registers) to one of three places:
  - The task's kernel stack
  - the *thread_struct*
  - *task_struct->thread*
- It then copies the new task's hardware state from the appropriate places
  - Stack is in *next->thread.esp*

# The Role of the Stack

- One process must save state where another can find it
- When the new state is loaded, the CPU *is* running another process -- the state *is* the process!
- The stack pointer determines most of the state
- Some of the registers are on the stack
- The stack pointer determines the location of *thread_info,* which also points to *task struct*
- *Changing the stack pointer changes the process!*

# Stack Switching




- switch_to: A -> B

# Floating Point Registers

- Floating point (FPU) and MMX instructions use a separate set of registers
- SSE and SSE2 instructions use yet another set of registers
- FPU/MMX and SSE/SSE2 registers are *not* automatically saved
- Legacy issue: floating point originally handled by outboard (expensive) chip
- Expense: it takes a fair number of cycles to save and restore these registers
- Rarity: most processes don't use floating point

# Context Switch: FP Registers

- Many CPU architectures support lazy saving of floating point state (registers) by allowing floating point capability to be disabled, resulting in an exception when a floating point operation is performed.
- With this capability, state save can detect when a thread first uses floating point and only save floating point state from then on. It can also only load floating point state after a floating point operation following a context switch.

# Context Switch: FP Registers

- On context switch:
  - Hardware flag set: *TS* in *cr0*
  - Software flag *TS_USEDFPU* is cleared in *task_struct*
- If task uses floating point instruction and hardware flag is set:
  - Hardware raises "device not available" exception (trap)
  - Kernel restores floating point registers
  - TS is cleared
  - *TS_USEDFPU* is set in the *task_struct* for this process
- Any time it's set, floating point registers are saved for that process at switch time (but not restored for the next)
- Bottom line: only done if needed; if only one process uses floating point, no save/restore needed

- Not needed on modern processors! More efficient FPU.

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  - Wait queues
- Context switching
- Creating and destroying processes
- Kernel threads

# Creating New Processes

- The *fork* system call is used to create a new process.
  - Identical to parent except …
  - execution state
  - process ID
  - parent process ID.
  - other data is either copied (like process state) or made copy on write (like process address space).
- Copy on write allows data to be shared as long as it is not modified, but each task gets its own copy when one task tries to modify the data.

# Creating New Processes

- The *fork* system call uses *do_fork* to create a new task. The flags passed to *do_fork* indicate which task attributes to copy and which to create anew.
- *do_fork* calls *copy_process* to create a new *task_struct* and initialize it appropriately.

# fork() Call Chain

```
1   libc fork()
2       system_call (arch/i386/kernel/entry.S)
3           sys_clone() (arch/i386/kernel/process.c)
4               do_fork() (kernel/fork.c)
5                   copy_process() (kernel/fork.c)
6                       p = dup_task_struct(current) // shallow copy
7                       copy_* // copy point-to structures
8                       copy_thread () // copy stack, regs, and eip
9                   wake_up_new_task() // set child runnable
```

# do_fork

- *do_fork* creates a new task and allows the new task to share resources with the calling task.
- The following options specify what should be shared with the calling task:
  - CLONE_VM - share address space
  - CLONE_FS - share root and current working directories
  - CLONE_FILES - share file descriptors
  - CLONE_SIGHAND - share signal handlers
  - CLONE_PARENT – share parent process ID
  - CLONE_THREAD – create thread for process

# Creating New Threads

- The *clone* system call also uses *do_fork* to create a new task.
- The *clone* system call takes flags which are passed to *do_fork* to indicate which task attributes to copy and which to create anew.
- This system call gives applications the ability to create new processes, new threads, or new tasks that have the attributes of both processes and threads.
- *clone* is used by threads libraries to create new kernel threads.

# vfork System Call

- What usually happens after a fork()?
  - execve() call to start new executable
  - Replace entire process address space
  - Then why bother duplicating?
- Enter vfork()
  - Create child with same page tables as as parent
  - Child only allowed to invoke execve()
  - Pause the parent until child invokes execve()
  - Then resume parent/child
  - Faster than fork+exec
- Implemented through clone() syscall
  - CLONE_VFORK flag needs to be set in the clone call
  - Tells clone to suspend parent until child calls execve or exit

# Destroying a Task

- Tasks stop executing when they call the *exit* system call, are killed by the kernel (due to an exception), or are killed by a fatal signal which was sent.
- *exit* calls *do_exit* which decrements usage counts on the sub-structures of the *task_struct*. Any substructure with a zero usage count has its memory freed.
- Lastly, the task is changed to the *EXIT_ZOMBIE* state.
- *task_struct*s are actually destroyed by *release_task*, which is called when the process' parent calls the *wait* system call.
  - extremely difficult for a task to delete its own task structure and kernel stack.
  - also provides an easy mechanism for parents to determine their children's *exit* status.
- *release_task* removes the task from the task list and frees its memory.
- The `init` process cleans up children.

# exit() Call Chain

```
1   libc exit (code)
2       system_call (arch/i386/kernel/entry.S)
3           sys_exit() (kernel/exit.c)
4               do_exit() (kernel/exit.c)
5                   exit_*() // free data structures
6                   exit_notify() // tell other processes we exit
7                       // reparent children to init
8                       // EXIT_ZOMBIE
9                       // EXIT_DEAD
```

# Outline

- The Android Emulator
- Processes/tasks
  - The process descriptor: task_struct
  - Thread context
  - Task States
  - Process relationships
  - Wait queues
- Context switching
- Creating and destroying processes
- Kernel threads

# Threads

- Threads in a process are represented by creating a *task_struct* for each thread in the process and keeping most of the data the same for each *task_struct*.
- ultimately done by using *do_fork*
- simplifies some algorithms because there is only one structure for both processes and threads.
- can improve performance for single threaded processes.
- Process data is generally in task sub-structures which can be shared by all tasks in the process.

# Thread Structures

- The thread state is represented by the *thread_info* structure.
- The *thread_info* structure has a reference to the *task_struct* for the thread as well as the execution domain for the program the thread is executing within.
- The *thread_info* structure and the thread's kernel stack are located together within a *thread_union* structure. size varies by architecture
- thread's stack thus also varies by architecture
  - just less than 4K in size on 32-bit architectures
  - just less than 8K in size on 64-bit architectures.

# Kernel Threads

- Linux has a small number of kernel threads that run continuously in the kernel (daemons)
  - No user address space
  - Only execute code and access data in kernel address space
- How to create: *kernel_thread*
- Scheduled in the same way as other threads/tasks
- Process 0: idle process
- Process 1: init process
  - Spawns several kernel threads before transitioning to user mode as /sbin/init
  - kflushd (bdflush) – Flush dirty buffers to disk under "memory pressure"
  - kupdate – Periodically flushes old buffers to disk
  - kswapd – Swapping daemon

# Task Zero

- The task with process ID zero is called the swapper or the idle task
- Its task structure is in *init_thread_union*, which also includes its kernel stack.
- The kernel builds this task piece by piece to use to boot the system. (All other tasks are copied from an existing task by *do_fork*.)
- All other tasks are maintained in a linked list off of this task.
- This task becomes the idle task that runs when no other task is runnable.
- This task forks the init task (task 1) and is the ancestor of all other tasks.

# Task Zero

- On SMP systems, this task uses *clone* to create duplicate tasks which run as the idle task on each of the other processors.
- All of these tasks have process ID zero.
- Each of these tasks is used only by its associated processor.