ECE391
Computer System Engineering

Lecture 18

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Lecture Topics

- Scheduling
  - Philosophy
  - Algorithm
  - Data structures

Aministrivia

- **MP3 Checkpoint 2**
  - **Due by 6:00pm Monday, March 29**

ECE391 EXAM 2

- **EXAM 2 – Tuesday, April 6; 6:00pm - 8:00pm**
- **Topics covered by the EXAM 2**
  - Material covered in lectures (Lecture12 – Lecture15)
    - Virtual Memory and Paging
    - Interrupt support in Linux (IDT, hardware interrupts, exceptions)
  - MP2 (ModeX, Tux controller)
  - MP3.1
  - Material covered in discussions
- **NOTE: File System** and **Scheduling NOT** included in Exam 2
- **NO Lecture on Tuesday, April 6**

Scheduling Philosophy

- Several types of jobs exist
  - Interactive
    - examples: editors, GUIs Graphic Interface
    - driven by human interaction (e.g., keystrokes, mouse clicks)
    - little or no work to do after each event
    - but important to respond quickly
  - Batch 批量处理
    - examples: compilation, simulation
    - usually only time to completion matters
    - want a fair share of CPU computation

Scheduling Philosophy (cont.)

- Real-time
  - examples: music, video, teleconferencing
  - periodic deadlines (e.g., 30 frames per second of video)
  - work often only useful if finished on time

- alternative taxonomy: I/O-bound vs. compute-bound

- Goal of scheduling:
  efficient, fair, and responsive (all at once!)

Scheduling Philosophy (cont.)

- General strategy
  - break time into slices
  - allow interactive jobs to preempt the current job based on interrupts
    - typically, a job becomes runnable when an interrupt occurs (e.g., a key is pressed)
    - Linux checks for rescheduling after each interrupt, system call, and exception
  - Linux 2.4 does NOT preempt code running in kernel (code may yield)
  - Linux 2.6 DOES preempt code running in kernel to support real-time

中断当前执行的程序，
执行新的程序

General Scheduling Algorithm Used by Linux

- Time broken into epochs
  - each task given a quantum of time (in ticks of 10 milliseconds)
  - run until no runnable task has time left
  - then start a new epoch

- Real-time jobs Jobs that have deadline
  - always given priority over non-real-time jobs
  - prioritized amongst themselves

- Static and dynamic priorities used for non-real-time jobs

General Scheduling Algorithm Used by Linux (cont.)

- Interactive jobs handled with heuristics 启发法
  - heuristic estimates job interactiveness
  - an interactive job
    - can continue to run after running out of time
    - takes turns with other interactive jobs
  - philosophy is that they don't usually use up quantum
  - heuristic ensures that job can't use lots of CPU and still be "interactive"

Scheduler only run tasks who are ready to run

Task State (fields of task_struct)

- State field can be one of
  - TASK_RUNNING
    - task is executing currently or waiting to execute
    - task is in a run queue on some processor
  - TASK_INTERRUPTIBLE
    - task is sleeping on a semaphore/condition/signal
    - task is in a wait queue
    - can be made runnable by delivery of signal
  - TASK_UNINTERRUPTIBLE
    - task is busy with something that can't be stopped
    - e.g., a device that will stay in unrecoverable state without further task interaction 在某些情况下需要连续向device发送多条数据，如果中途断掉会失去对device的控制
    - cannot be made runnable by delivery of signal

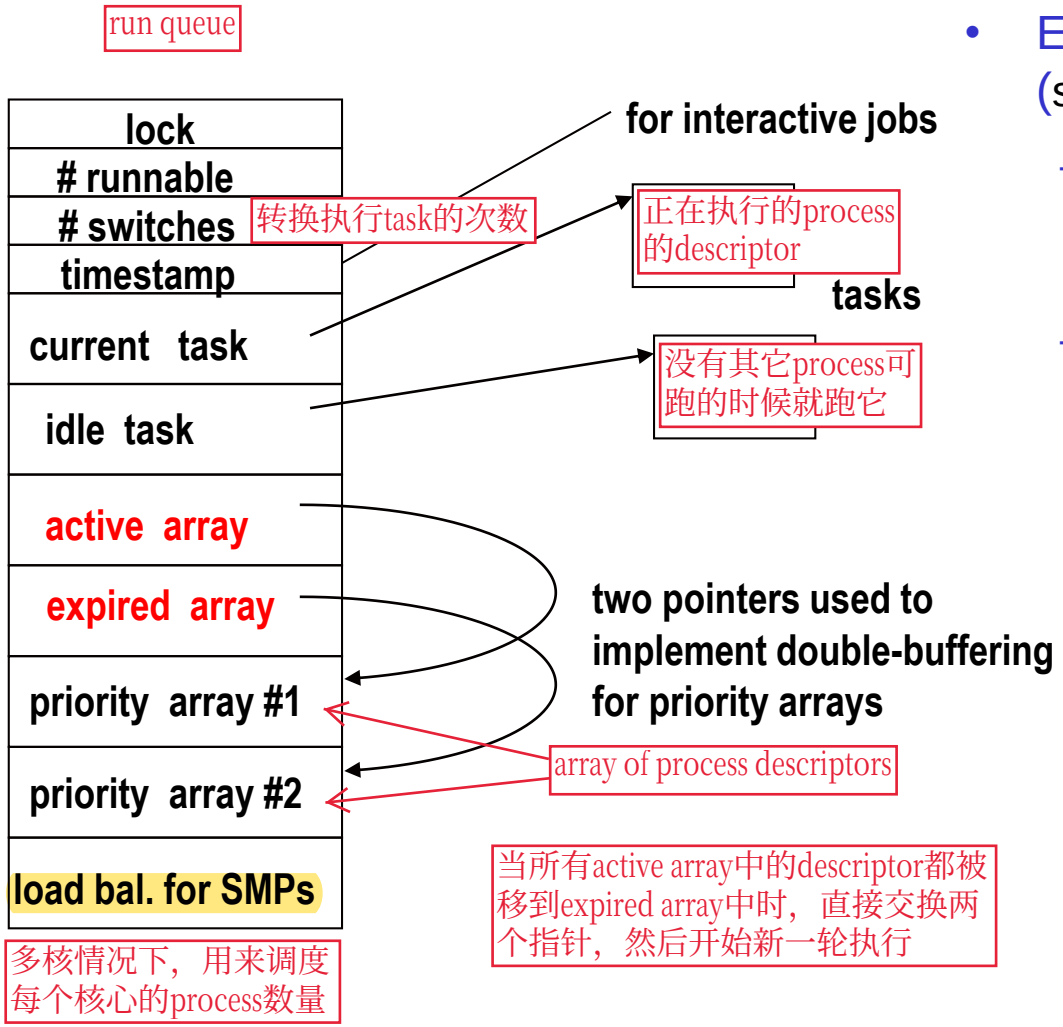
Task State (fields of task_t) (cont.)

- TASK_STOPPED
  - task is stopped
  - task is not in a queue; must be woken by signal
- TASK_ZOMBIE 其对应的descriptor没有被free，导致memory leak
  - task has terminated
  - task state retained until parent collects exit status information
    descriptor of task
  - task is not in a queue

- The swapper process is always runnable (it's an idle loop)

scheduler在没有其它task可跑的时候就会跑这个

Scheduling Data Structures



- Each processor has a run queue (struct runqueue in sched.c)
  - each run queue has two priority arrays, i.e., lists of tasks of each priority
  - they are double-buffered to implement epochs

Active processes: runnable processes that have not yet exhausted their time quantum/slice and hence, are allowed to run

Expired processes: runnable processes that have exhausted their time quantum/slice and hence, are not allowed to run until all active processes expire

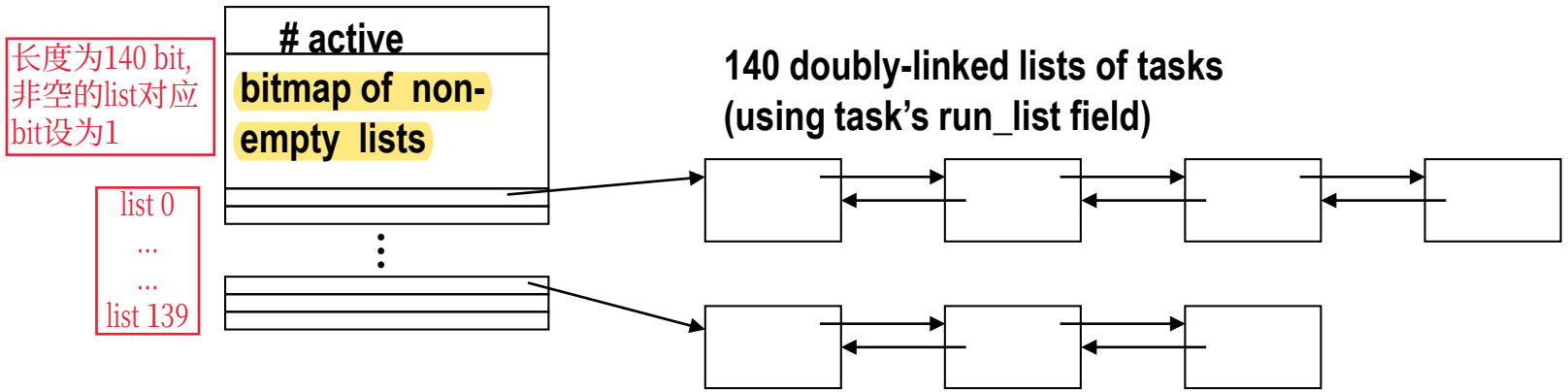
Priority Array Structure
(struct prio_array in sched.c)

这是单核的情况还是多核的情况？

- 100 real-time priorities
- 40 regular priorities

lower the number, higher the priority

- One list per priority and a bitmap to make finding non-empty list fast



找到bit map中第一个为1的bit的位置，执行对应编号的list里的process

Scheduler Policies: SCHED_FIFO

First-In, First-Out real-time process. When the scheduler assigns the CPU to the process, it leaves the process descriptor in its current position in the runqueue list. If no other higher-priority real time process is runnable, the process will continue to use the CPU as long as it wishes, even if other real-time processes having the same priority are runnable.

- Run until they relinquish the CPU voluntarily
- Priority levels maintained
- Not pre-empted !!

Scheduler Policies: SCHED_RR

Round Robin real-time process. When the scheduler assigns the CPU to the process, it puts the process descriptor at the end of the runqueue list. This policy ensures a fair assignment of CPU time to all SCHED_RR real-time processes that have the same priority.

优先级是根据在list中的位置来定的？

- Assigned a time slice and run till the time slice is exhausted.
- Once all RR tasks of a given priority level exhaust their time slices, their time slices are refilled and they continue running
- Priority levels are maintained

Scheduler Policies: SCHED_NORMAL

A conventional, time-shared process (used to be called SCHED_OTHER) for normal tasks. Task priority recalculated using a predefined formula. Tasks at the same priority are scheduled using round robin policy.

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Rescheduling and Yielding

- Task can change (called a context switch) when
  - current task yields by calling schedule (sched_yield at user level)
  - current task runs out of time
- Other places where a task may yield implicitly
  - semaphores
  - wake_up_process
  - copy_to/from_user
- At every timer tick (interrupt, generated every 10 milliseconds)
  - run a function (scheduler_tick) to reduce current task's time
  - executes with IF=0
  - interrupt is IRQ0

教授问起来，这就是为什么用tick而不是RTC的原因

PIT，不同于RTC的另一个计时设备，频率只能由kernel设置，其interrupt是最高优先级(IRQ0)
原因：
1. scheduling是很要紧的事情，所以要用优先级最高的时钟来控制
2. PIT的周期不必是2的次方，可以做到更快（？）更灵活
3. PIT不会受user影响

Linux Scheduler

heduler_tick and task_running_tick (kernel/sched.c)

```
void scheduler_tick (void)
{
    unsigned long long now = sched_clock ();
    struct task_struct* p  = current;
    int cpu                = smp_processor_id ();
    int idle_at_tick       = idle_cpu (cpu);
    struct rq* rq          = cpu_rq (cpu);

    update_cpu_clock (p, rq, now);

    if (!idle_at_tick)
        task_running_tick (rq, p);
}
```

Will not be tested

idle_cpu returns 1 if CPU is running the idle task

update_cpu_clock tracks nanoseconds since last tick/context switch

for all but idle task, call task_running_tick

```
static void task_running_tick (struct rq* rq, struct task_struct* p)
{
    if (p->array != rq->active) {
        set_tsk_need_resched (p);
        return;
    }
    spin_lock (&rq->lock);
    if (rt_task (p)) {
        if ((p->policy == SCHED_RR) && !--p->time_slice) {
            p->time_slice = task_timeslice (p);
            p->first_time_slice = 0;
            set_tsk_need_resched (p);
            requeue_task (p, rq->active);
        }
        goto out_unlock;
    }
    if (!--p->time_slice) {
        dequeue_task (p, rq->active);
        set_tsk_need_resched (p);
        p->prio = effective_prio (p);
        p->time_slice = task_timeslice (p);
        p->first_time_slice = 0;

        if (!rq->expired_timestamp)
            rq->expired_timestamp = jiffies;
        if (!TASK_INTERACTIVE (p) || expired_starving (rq)) {
            enqueue_task (p, rq->expired);
            if (p->static_prio < rq->best_expired_prio)
                rq->best_expired_prio = p->static_prio;
        } else
            enqueue_task (p, rq->active);
    } else {
        /* Prevent long timeslices that allow a task to monopolize the
         * CPU by splitting up the timeslice into smaller pieces.  We
         * requeue this task to the end of the list on this priority
         * level, which is a round-robin of tasks with equal priority. */
        if (TASK_INTERACTIVE (p) &&
            !((task_timeslice (p) - p->time_slice) % TIMESLICE_GRANULARITY (p)) &&
            (p->time_slice >= TIMESLICE_GRANULARITY (p)) && (p->array == rq->active)) {

            requeue_task (p, rq->active);
            set_tsk_need_resched (p);
        }
    }
out_unlock:
    spin_unlock (&rq->lock);
}
```

Take care of task which already expired

Critical section begins

Handle real-time tasks

real time

if a task's time slice expires

dequeue and reschedule the task

regular

breaks long time slices into pieces

Critical section ends

Comments on `scheduler_tick` *function*

- **`idle_cpu`** returns 1 if CPU is running the idle task
- **`update_cpu_clock`** tracks nanoseconds since last tick/context switch
- For all but idle task, call **`task_running_tick`**

Comments on `task_running_tick` *function*

- If the task has already expired
  - make sure that it gets rescheduled on return from interrupt
  - by setting **`TIF_NEED_RESCHED`**
- The remainder is a critical section for the run queue
- Next handle real-time tasks
  - real-time round-robin tasks take turns by placing themselves at the end of the list of their priority
  - otherwise real-time tasks just keep rescheduling (until yield or preemption by higher priority)

Comments on `task_running_tick` *function*

- If a task's time slice expires
  - take it out of the run queue
  - mark it as needing to be removed from processor
  - give it a new time slice
  - if it's an interactive job, and expired tasks are not being starved by interactive ones, put it back into run queue (at end)
  - normal tasks go into expired queue
- Last block
  - breaks long time slices into pieces
  - round-robin between tasks at same priority

Linux Scheduler (Part1)

schedule function (kernel/sched.c)

```
asmlinkage void schedule (void)
{
    task_t* prev    = current;
    task_t* next;
    runqueue_t* rq = this_rq ();
    prio_array_t* array;
    list_t* queue;
    int idx;

    if (in_interrupt ())
        BUG();
    release_kernel_lock (prev, smp_processor_id ());
    prev->sleep_timestamp = jiffies;
    spin_lock_irq (&rq->lock);

    switch (prev->state) {
        case TASK_INTERRUPTIBLE:
            if (signal_pending (prev)) {
                prev->state = TASK_RUNNING;
                break;
            }
        default:
            deactivate_task (prev, rq);
        case TASK_RUNNING:
            ;
    }
    if (!rq->nr_running) {
        next = rq->idle;
        rq->expired_timestamp = 0;
        goto switch_tasks;
    }

    array = rq->active;
    if (!array->nr_active) {
        /*
         * Switch the active and expired arrays.
         */
        rq->active = rq->expired;
        rq->expired = array;
        array = rq->active;
        rq->expired_timestamp = 0;
    }

    idx = sched_find_first_bit (array->bitmap);
    queue = array->queue + idx;
    next = list_entry (queue->next, task_t, run_list);
```

find task to run

Sleep timestamp records time at which task leaves CPU

Critical section begins

if the task is trying to go to sleep check for receipt of signal

default case removes task from run queue

no tasks are runnable

nothing is left in the active run queue

find the next task to run

- find first no-zero bit in the bitmask of the active set
- take the first task at the list indicataed by that bit

Comments on ***schedule*** *function*

- *Schedule()* function called when processor needs to change to new task
  - time has expired for current task, or
  - task has voluntarily yielded (by calling this function)
- Sleep timestamp records time at which task leaves CPU
- Remainder is run queue critical section
- If the task is trying to go to sleep
  - check for receipt of signal
  - handles race condition with sleeping in wait queue
- Default case removes task from run queue

Comments on schedule function (cont.)

- If no tasks are runnable
  - run the idle task
  - reset forced expiration of interactive tasks
- If nothing is left in the active run queue
  - the epoch is over
  - swap the priority arrays
  - and reset forced expiration of interactive tasks
- Find the next task to run
  - find first bit selects the priority
  - then take the first task at that priority (linked list)

Linux Scheduler (Part2)

*schedule function (**kernel/sched.c**)*

```
switch_tasks:
    prefetch (next);
    prev->need_resched = 0;

    if (prev != next) {
        rq->nr_switches++;
        rq->curr = next;
        context_switch (prev, next);
        /*
         * The runqueue pointer might be from another CPU
         * if the new task was last running on a different
         * CPU - thus re-load it.
         */
        barrier ();
        rq = this_rq ();
    }
    spin_unlock_irq (&rq->lock);

    reacquire_kernel_lock (current);
    return;
}
```

clear need_resched flag for next time current task is scheduled

Switch if newly selected task is not the current one

call architecture-dependent switch function

Critical section ends

Comments on ***schedule*** *function (cont.)*

- This portion of the code implements the actual switch
- First clears need_resched flag for next time current task is scheduled
- Switch only occurs if newly selected task is not the current one
- Switch does two things
  - does some accounting
  - calls architecture-dependent switch function (context_switch)