Scheduling in Linux – Part 3

Scheduler Related Code Walk Through

Disclaimer: *Codes shown have in many cases some unimportant/uninteresting lines deleted in the middle (sometimes marked with … and sometimes not).You are supposed to check the actual code from the sources, not just look at slides.*

CFS Implementation in Linux

- Outline of what we will see
  - What are some of the basic data structures involved?
  - Initialization of the scheduling parameters
  - Updating the runtimes
  - Updating the loads
  - Basic flow of the main scheduler
  - What happens on a timer tick?
  - Sleep and wakeup
  - When is the scheduler called?

Some Basic Data Structures

Some scheduling info in task_struct

```
struct task_struct {
    …
    int                          prio;
    int                          static_prio;
    int                          normal_prio;
    unsigned int                 rt_priority;
    const struct sched_class     *sched_class;
    struct sched_entity          se;
    struct sched_rt_entity       rt;
    struct sched_dl_entity       dl;
    …
```

- *static_prio* : the static priority of the process from the nice value
- *prio* : the actual priority of the process used by the scheduler
- *normal_prio* : the priority based on the static priority and the scheduling policy
- *rt_priority* : real time priority (a number between 0 and 99)
- *se, rt, dl* : different scheduling entity structures corresponding to *fair*, *rt*, and *deadline* class. The applicable structure is used depending on the scheduling class of the process

Computing the different priorities

- Suppose the *task_struct* is pointed to by *p*
- Compute *p->normal_prio* from *p->static_prio*
- Compute *p->prio* from *p->normal_prio* (via *effective_prio()*)

```
#define MAX_USER_RT_PRIO      100
#define MAX_RT_PRIO           MAX_USER_RT_PRIO
#define MAX_PRIO              (MAX_RT_PRIO + NICE_WIDTH)
#define DEFAULT_PRIO          (MAX_RT_PRIO + NICE_WIDTH / 2)
```

https://elixir.bootlin.com/linux/v5.10.188/source/include/linux/sched/prio.h#L22

https://elixir.bootlin.com/linux/v5.10.188/A/ident/effective_prio

```
static inline int normal_prio(struct task_struct *p)
{
        return __normal_prio(p->policy, p->rt_priority, PRIO_TO_NICE(p->static_prio));
}

static inline int __normal_prio(int policy, int rt_prio, int nice)
{
        int prio;
        if (dl_policy(policy))
                prio = MAX_DL_PRIO – 1;
        else if (rt_policy(policy))
                prio = MAX_RT_PRIO – 1 – rt_prio;
        else
                prio = NICE_TO_PRIO(nice);
        return prio;
}
```

```
static int effective_prio(struct task_struct *p)
{
        p->normal_prio = normal_prio(p);
        /*
         * If we are RT tasks or we were boosted to RT priority,
         * keep the priority unchanged. Otherwise, update priority
         * to the normal priority:
         */
        if (!rt_prio(p->prio))
                return p->normal_prio;
        return p->prio;
}
```

The sched_entity data structure

- https://elixir.bootlin.com/linux/v5.10.188/source/include/linux/sched.h#L459
- Defines the entity being scheduled in CFS
- Each node of the RB tree is a *sched_entity* structure
- This is a fair class specific structure, there are separate structures (*sched_entity_rt* etc.) for other classes

```
struct sched_entity {
        struct load_weight            load;
        struct rb_node                run_node;
        …
        unsigned int                  on_rq;
        u64                           exec_start;
        u64                           sum_exec_runtime;
        u64                           vruntime;
        …
        u64                           nr_migrations;
        struct sched_statistics       statistics;
        …
```

- *load* : the load of this process (the weight we used in CFS)
- *run_node* : the RB tree node for this process
- *on_rq* : task is on runqueue
- *exec_start* : starting time of the process in the last scheduling tick period
- *sum_exec_runtime* : total runtime of the process
- *vruntime* : virtual runtime
- *nr_migration* : number of times this process is migrated between CPUs
- *statistics* : a structure containing different scheduling stats field

The sched_class data structure

- https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/sched.h#L1783
- Defines generic functions (function pointers) for operations on the runqueue

```
struct sched_class {

    void (*enqueue_task) (struct rq *rq, struct task_struct *p, int flags);
    void (*dequeue_task) (struct rq *rq, struct task_struct *p, int flags);
    void (*yield_task)   (struct rq *rq);
    …
    void (*check_preempt_curr)(struct rq *rq, struct task_struct *p, int flags);
    struct task_struct *(*pick_next_task)(struct rq *rq);
    void (*task_fork)(struct task_struct *p);
    void (*task_dead)(struct task_struct *p);
    void (*task_tick)(struct rq *rq, struct task_struct *p, int queued);
    …
    void (*prio_changed) (struct rq *this_rq, struct task_struct *task, int oldprio);
    void (*update_curr)(struct rq *rq);
    ...
```

- *enqueue_task* : called when a task becomes runnable
- *dequeue_task* : called when a task is no longer runnable
- *yield_task* : called when a task wants to give up the CPU voluntarily (but is still runnable)
- *check_preempt_curr* : checks if a runnable task should preempt the currently running task or not
- *pick_next_task* : choose the next task to run
- *task_fork, task_dead* : called to inform the scheduler that a new task is spawned or dead
- *task_tick* : called on a timer interrupt
- *prio_changed*: called when the priority of a process is changed
- *update_curr* : updates the runtime statistics

- Pointed to from the *task_struct* structure, assigned the correct scheduler class variable on initialization based on scheduling class
  - The scheduler class variable has the actual functions
  - https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/fair.c#L11529

```
const struct sched_class fair_sched_class
    __section(" fair_sched_class") = {
   .enqueue_task          =      enqueue_task_fair,
   .dequeue_task          =      dequeue_task_fair,
   .yield_task            =      yield_task_fair,
   .check_preempt_curr    =      check_preempt_wakeup,
   .pick_next_task        =      __pick_next_task_fair,
   .task_tick             =      task_tick_fair,
   .task_fork             =      task_fork_fair,
   .prio_changed          =      prio_changed_fair
   .update_curr           =      update_curr_fair
     …
```

- The scheduler classes are themselves organized in an array by a linker script
  - The order is very important, used in code in many places to ascertain priority
  - https://elixir.bootlin.com/linux/v5.10.188/source/include/asm-generic/vmlinux.lds.h#L128

```
#define SCHED_DATA                              \
        STRUCT_ALIGN();                         \
        __begin_sched_classes = .;              \
        *(__idle_sched_class)                   \
        *(__fair_sched_class)                   \
        *(__rt_sched_class)                     \
        *(__dl_sched_class)                     \
        *(__stop_sched_class)                   \
        __end_sched_classes = .;
```

The runqueue

- Each CPU has its own runqueue
- The runqueue is a generic structure, has pointers to class-specific runqueues
  - https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/sched.h#L897

```
struct rq {
        raw_spinlock_t                  lock;
        unsigned int                    nr_running;
        …
        struct cfs_rq                   cfs;
        struct rt_rq                    rt;
        struct dl_rq                    dl;
        …
        struct task_struct __rcu        *curr;
        struct task_struct              *idle;
        int                             cpu;
        …
```

- *lock* : spinlock for locking the runqueue
- *nr_running*: number of processes on this queue, over all scheduling classes
- *cfs, rt, dl* : class specific queues for fair class, rt class, and deadline class
- *curr :* pointer to currently running process
- *idle :* pointer to the idle process
- *cpu :* cpu of this runqueue

Some of the fields in the CFS runqueue

```
struct cfs_rq {
        struct load_weight      load;
        unsigned int            nr_running;
        unsigned int            h_nr_running;
        …
        u64                     min_vruntime;
        struct sched_entity     *curr;
        …
```

- *load* : the load of all the processes in the runqueue
- *nr_running* : no. of processes in runqueue that will share the CPU
- *h_nr_running* : no. of processes in the runqueue
- *min_vruntime* : minimum vruntime in the queue
- *curr* : current running process

Initializations of scheduling parameters

Initializations

- *kernel_clone()* (in kernel/fork.c) calls *copy_process()* (in kernel/fork.c), which calls *sched_fork()* (in kernel/sched/core.c) that initializes most scheduling parameters
  - https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/core.c#L3244

```
static void __sched_fork(unsigned long clone_flags, struct task_struct *p)
{
    p->on_rq                          =    0;
    p->se.on_rq                       =    0;
    p->se.exec_start                  =    0;
    p->se.sum_exec_runtime            =    0;
    p->se.prev_sum_exec_runtime       =    0;
    p->se.nr_migrations               =    0;
    p->se.vruntime                    =    0;
    ...
```

```
int sched_fork(unsigned long clone_flags, struct task_struct *p)
{
    __sched_fork(clone_flags, p);
    …
    p->prio=current->normal_prio;
    …
    if (unlikely(p->sched_reset_on_fork)) {
            if (task_has_dl_policy(p) || task_has_rt_policy(p)) {
                p->policy=SCHED_NORMAL; p->static_prio=NICE_TO_PRIO(0);   p>rt_priority=0;
            } else if (PRIO_TO_NICE(p->static_prio) < 0) p->static_prio=NICE_TO_PRIO(0);
        p->prio=p->normal_prio=p->static_prio;
        set_load_weight(p);
        p->sched_reset_on_fork=0;
    }
    if (dl_prio(p->prio)) return -EAGAIN;
    else if (rt_prio(p->prio)) p->sched_class= &rt_sched_class;
    else p->sched_class=&fair_sched_class;
…
```

Updating runtimes

Updating the runtime

- Done by the *update_curr_fair()* function, which calls the *update_curr()* function
- https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/fair.c#L852
- Called periodically on scheduler tick or on sleep/wakeup

```
static void update_curr(struct cfs_rq *cfs_rq)
{
    struct sched_entity *curr = cfs_rq->curr;
    u64 now = rq_clock_task(rq_of(cfs_rq));
    u64 delta_exec;
    if (unlikely(!curr))
        return;
    delta_exec = now – curr->exec_start;
    curr->exec_start = now;
    curr->sum_exec_runtime += delta_exec;
    curr->vruntime += calc_delta_fair(delta_exec, curr);
    update_min_vruntime(cfs_rq);
    …
}
```

```
static inline u64 calc_delta_fair(u64 delta, struct sched_entity *se)
{
	if (unlikely(se->load.weight != NICE_0_LOAD))
		delta = __calc_delta(delta, NICE_0_LOAD, &se->load);
	return delta;
}
```

```
static void update_min_vruntime(struct cfs_rq *cfs_rq)
{
	struct sched_entity *curr = cfs_rq->curr;
	struct rb_node *leftmost = rb_first_cached(&cfs_rq->tasks_timeline);
	u64 vruntime = cfs_rq->min_vruntime;
	if (curr) {
		if (curr->on_rq)
			vruntime = curr->vruntime;
		else
			curr = NULL;
	}
```

```
if (leftmost) { /* non-empty tree */
		struct sched_entity *se;
		se = rb_entry(leftmost, struct sched_entity, run_node);
		if (!curr)
			vruntime = se->vruntime;
		else
			vruntime = min_vruntime(vruntime, se->vruntime);
	}
	/* ensure we never gain time by being placed backwards. */
	cfs_rq->min_vruntime = max_vruntime(cfs_rq->min_vruntime, vruntime);
```

Updating the load

Updating the load

- Needs to be done when
  - The priority changes
    - Done by the *set_load_weight()* function
    - *set_load_weight()* calls *reweight_task()* which computes the task's new weight and calls *reweight_entity()*
    - *reweight_entity()* assigns the task's weight to its *sched_entity* structure and updates the request queue's total load
    - Note that here both the task's and the runqueue's load changes
  - When a task is added or deleted from the queue
    - Only the runqueue's load changes (total load of all tasks in it)

On changing priority

```
static void set_load_weight(struct task_struct *p)
{
        bool update_load = !(READ_ONCE(p->state) & TASK_NEW);
        int prio = p->static_prio - MAX_RT_PRIO;
        struct load_weight *load = &p->se.load;
        …
        /* SCHED_OTHER tasks have to update their load when changing their weight */
        if (update_load && p->sched_class == &fair_sched_class) {
                reweight_task(p, prio);
        } else {
                load->weight = scale_load(sched_prio_to_weight[prio]);
                …
        }
}
```

```
static void reweight_entity(struct cfs_rq *cfs_rq, struct sched_entity *se,  unsigned long weight)
{
        if (se->on_rq) {
                if (cfs_rq->curr == se) update_curr(cfs_rq);
                update_load_sub(&cfs_rq->load, se->load.weight);
        }
        update_load_set(&se->load, weight);
        if (se->on_rq) update_load_add(&cfs_rq->load, se->load.weight);
}
```

On adding/deleting tasks

- *enqueue_task_fair()* calls *enqueue_entity()*
- *enqueue_entity()* calls *account_entity_enqueue()*
- *acccoun_entity_enqueue()* calls *update_load_add()* to actually add the weight to the runqueue's load

Scheduler Flow

Basic scheduler flow

- Entry point is the generic _*schedule()* function
- https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/core.c#L4430

- General Flow
  - Disable interrupts (*local_irq_disable()*)
  - Lock the runqueue (*rq_lock()*)
  - If current task is not in TASK_RUNNING state
    - If it has a signal pending (*signal_pending_state()*), change state to TASK_RUNNING
    - Else dequeue it
  - Choose the next task to run (*pick_next_task()*) and context switch if needed (if different from current task)
  - Unlock the run queue

Picking the next task

- Done by the *pick_next_task()* routine
- https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/core.c#L4351
- Simply goes through all scheduler classes in order to pick the highest priority task available
- Makes some interesting optimizations based on the fact that most often all tasks belong to the fair scheduling class
- Calls the scheduler class specific routine that actually picks the next task

```
static inline struct task_struct *
pick_next_task(struct rq *rq, struct task_struct *prev, struct rq_flags *rf)
{
    const struct sched_class *class; struct task_struct *p;
    if (likely(prev->sched_class <= &fair_sched_class &&
                        rq>nr_running == rq->cfs.h_nr_running)) {
        p = pick_next_task_fair(rq, prev, rf);
        if (unlikely(p == RETRY_TASK))
            goto restart;
        if (!p) {
            put_prev_task(rq, prev);
            p = pick_next_task_idle(rq);
        }
        return p;
    }
```

```
…
restart:
    put_prev_task_balance(rq, prev, rf);
    for_each_class(class) {
        p = class->pick_next_task(rq);
        if (p)
            return p;
```

- The CFS specific function *pick_next_task_fair()* actually picks the CFS task
- https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/fair.c#L7255

```c
struct task_struct *
pick_next_task_fair(struct rq *rq, struct task_struct *prev, struct rq_flags *rf)
{
	struct cfs_rq *cfs_rq = &rq->cfs;
	struct sched_entity *se;
	struct task_struct *p;
	int new_tasks;
again:
	if (!sched_fair_runnable(rq))
		goto idle;
	…
	if (prev)
		put_prev_task(rq, prev);
	do {
		se = pick_next_entity(cfs_rq, NULL);
		set_next_entity(cfs_rq, se);
		…
	} while (cfs_rq);

	p = task_of(se);
```

What happens on timer tick

Time management

- The timer periodically interrupts
  - called a *scheduler tick*
- The timer interrupt handler calls *update_process_times()*
- *update_process_times()* calls *scheduler_tick()*
- *scheduler_tick()* calls the current process's *task_tick()* function, which for fair class, is *task_tick_fair()*
- *task_tick_fair()* calls *entity_tick()*

```
static void entity_tick(struct cfs_rq *cfs_rq, struct sched_entity *curr, int queued)
{
        update_curr(cfs_rq);
        …
        if (cfs_rq->nr_running > 1)
                check_preempt_tick(cfs_rq, curr);
        …
```

- Already seen *update_curr()*
  - Updates *vruntime* and *min_vruntime*
- *check_preempt_tick()*
  - Checks if preemption is needed
  - Basically, compute the timeslice the current process should get
  - If the process has already run for longer than this, reschedule it
  - Otherwise, it the process should not run as per its new *vruntime*, reschedule it

```
static void check_preempt_tick(struct cfs_rq *cfs_rq, struct sched_entity *curr)
{
        unsigned long ideal_runtime, delta_exec;
        struct sched_entity *se;
        s64 delta;
        ideal_runtime = sched_slice(cfs_rq, curr);
        delta_exec = curr->sum_exec_runtime – curr->prev_sum_exec_runtime;
        if (delta_exec > ideal_runtime) {
                resched_curr(rq_of(cfs_rq));
                …
                return;
        }
```

```
…
se = __pick_first_entity(cfs_rq);
delta = curr->vruntime – se->vruntime;
if (delta < 0) return;
if (delta > ideal_runtime)
        resched_curr(rq_of(cfs_rq));
}
```

- *resched_curr()* actually does not preempt the current process (does not call the scheduler), it just sets a flag (TIF_NEED_RESCHED) indicating the task needs to be rescheduled
- *sched_slice()* calculates the timeslice

```
static u64 sched_slice(struct cfs_rq *cfs_rq, struct sched_entity *se)
{
        unsigned int nr_running = cfs_rq->nr_running;
        u64 slice;
        slice = __sched_period(nr_running + !se->on_rq);
        …
        load = &cfs_rq->load;
        …
        slice = __calc_delta(slice, se->load.weight, load);
        …
        return slice;
}
```

```
static u64 __sched_period(unsigned long nr_running)
{
        if (unlikely(nr_running > sched_nr_latency))
                return nr_running * sysctl_sched_min_granularity;
        else
                return sysctl_sched_latency;
}
```

Sleep and Wakeup

Sleep and Wakeup

- Processes wait on different wait queues
- Wait queues
  - Linked list of wait queue entries

Basic data structures for wait queues

```
struct wait_queue_entry {
        unsigned int          flags;
        void                  *private;
        wait_queue_func_t     func;
        struct list_head      entry;
};

struct wait_queue_head {
        spinlock_t            lock;
        struct list_head      head;
};
```

- *flags*: different values, the two of interest to us are
  - WQ_FLAG_EXCLUSIVE
  - WQ_FLAG_BOOKMARK
- *private*: points to the task that is waiting
- *func*: the function to be called on wake up
  - There is a *default_wake_function()* also, which through other functions, calls *activate_task()*), which enqueues the task back into the run queue

Creating a wait queue

```
#define __WAITQUEUE_INITIALIZER(name, tsk) {
        .private = tsk,
        .func           = default_wake_function,
        .entry          = { NULL, NULL } }

#define DECLARE_WAITQUEUE(name, tsk)
        struct wait_queue_entry name = __WAITQUEUE_INITIALIZER(name, tsk)
```

Initializing a wait queue and an entry

Head can be initialized by the *init_waitqueue_head()* function

Initializing an entry:

```
static inline void init_waitqueue_entry(struct wait_queue_entry *wq_entry, struct task_struct *p)
{
        wq_entry->flags         = 0;
        wq_entry->private       = p;
        wq_entry->func          = default_wake_function;
}
```

Adding/Deleting from wait queues

```
void add_wait_queue(struct wait_queue_head *wq_head, struct wait_queue_entry
*wq_entry)
{
        unsigned long flags;
        wq_entry->flags &= ~WQ_FLAG_EXCLUSIVE;
        spin_lock_irqsave(&wq_head->lock, flags);
        __add_wait_queue(wq_head, wq_entry);
        spin_unlock_irqrestore(&wq_head->lock, flags);
}
```

```
void add_wait_queue_exclusive(struct wait_queue_head *wq_head, struct
wait_queue_entry *wq_entry)
{
        unsigned long flags;
        wq_entry->flags |=WQ_FLAG_EXCLUSIVE;
        spin_lock_irqsave(&wq_head->lock, flags);
        __add_wait_queue_entry_tail(wq_head, wq_entry);
        spin_unlock_irqrestore(&wq_head->lock, flags);
}
void remove_wait_queue(struct wait_queue_head *wq_head, struct wait_queue_entry
*wq_entry);
```

- Entries with WQ_FLAG_EXCLUSIVE are always added to the end
- Thus the queue will always have a sequence of non-exclusive entries followed by a sequence of exclusive entries
- Matters in the way we wake up processes

- Basic steps
  - Declare a wait queue
  - On trying to sleep
    - Create a wait queue entry and initialize it properly
    - Add to wait queue and set state properly (*prepare_to_wait()*)
    - Call scheduler
    - After being woken, set task state to runnable again and remove entry from wait queue (*finish_wait()*)

```
void
prepare_to_wait(struct wait_queue_head *wq_head, struct wait_queue_entry *wq_entry, int state)
{
        unsigned long flags;

        …
        spin_lock_irqsave(&wq_head->lock, flags);
        if (list_empty(&wq_entry->entry))
                __add_wait_queue(wq_head, wq_entry);
        set_current_state(state);
        spin_unlock_irqrestore(&wq_head->lock, flags);
}
```

```
void finish_wait(struct wait_queue_head *wq_head, struct wait_queue_entry *wq_entry)
{
        unsigned long flags;
        __set_current_state(TASK_RUNNING);
                if (!list_empty_careful(&wq_entry->entry)) {
                spin_lock_irqsave(&wq_head->lock, flags);
                list_del_init(&wq_entry->entry);
                spin_unlock_irqrestore(&wq_head->lock, flags);
        }
}
```

An example: helper function for socket buffer allocation

```
static long sock_wait_for_wmem(struct sock *sk, long timeo)
{
        DEFINE_WAIT(wait); …
        for (;;) {
                if (!timeo) break;
                if (signal_pending(current)) break;
                …
                prepare_to_wait(sk_sleep(sk), &wait, TASK_INTERRUPTIBLE);
                …
                if (sk->sk_shutdown & SEND_SHUTDOWN) break;
                if (sk->sk_err) break;
                timeo = schedule_timeout(timeo);
        }
        finish_wait(sk_sleep(sk), &wait);
        return timeo;
}
```

https://elixir.bootlin.com/linux/v5.10.188/source/net/core/sock.c#L2300

Waking Up Tasks

- Main entry point: *wake_up()*
- Calls finally *__wake_up_common_lock()* which calls *__wake_up_common()*
- *__wake_up_common()*
  - Walks the queue to wake up the waiting processes, subject to a maximum
    - The exact number depends on wait flags and a count
  - For each process woken, calls the corresponding function in its *wait_queue_entry*
  - If a maximum number is reached and there are still entries to wake up, bookmark and return, *__wake_up_common_lock* will call it again immediately in a loop

```
static void __wake_up_common_lock(struct wait_queue_head *wq_head, unsigned int mode,
                        int nr_exclusive, int wake_flags, void *key)
{
        unsigned long flags;  wait_queue_entry_t bookmark;
        bookmark.flags = 0;  bookmark.private = NULL;  bookmark.func = NULL;
        INIT_LIST_HEAD(&bookmark.entry);
        do {
                spin_lock_irqsave(&wq_head->lock, flags);
                nr_exclusive = __wake_up_common(wq_head, mode, nr_exclusive,
wake_flags, key, &bookmark);
                spin_unlock_irqrestore(&wq_head->lock, flags);
        } while (bookmark.flags &WQ_FLAG_BOOKMARK);
}
```

```
static int __wake_up_common(struct wait_queue_head *wq_head, unsigned int mode,
                        int nr_exclusive, int wake_flags, void *key,
                        wait_queue_entry_t *bookmark)
{
        wait_queue_entry_t *curr, *next;
        int cnt = 0;
        lockdep_assert_held(&wq_head->lock);
        if (bookmark && (bookmark->flags &WQ_FLAG_BOOKMARK)) {
                curr = list_next_entry(bookmark, entry);
                list_del(&bookmark->entry);
                bookmark->flags = 0;
        } else
                curr = list_first_entry(&wq_head->head, wait_queue_entry_t, entry);
        if (&curr->entry == &wq_head->head)
                return nr_exclusive;
```

```
    list_for_each_entry_safe_from(curr, next, &wq_head->head, entry) {
            unsigned flags = curr->flags;    int ret;
            if (flags &WQ_FLAG_BOOKMARK)  continue;
            ret = curr->func(curr, mode, wake_flags, key);
            if (ret < 0)  break;
            if (ret && (flags &WQ_FLAG_EXCLUSIVE) && !--nr_exclusive) break;

            if (bookmark && (++cnt >WAITQUEUE_WALK_BREAK_CNT) && (&next->entry !=
&wq_head->head)) {
                    bookmark->flags =WQ_FLAG_BOOKMARK;
                    list_add_tail(&bookmark->entry, &next->entry);
                    break;
            }
    }

    return nr_exclusive;
}
```

Example: Releasing a socket

```
void release_sock(struct sock *sk)
{
        spin_lock_bh(&sk->sk_lock.slock);
        if (sk->sk_prot->release_cb)
                sk->sk_prot->release_cb(sk);
        sock_release_ownership(sk);
        if (waitqueue_active(&sk->sk_lock.wq))
                wake_up(&sk->sk_lock.wq);
        spin_unlock_bh(&sk->sk_lock.slock);
}
```

The idle process

- Function executed *do_idle()*
- Entry function at CPU startup (*cpu_startup_entry*)

```
void cpu_startup_entry(enum cpuhp_state state)
{
        arch_cpu_idle_prepare();
        cpuhp_online_idle(state);
        while (1)
                do_idle();
}
```

```
static void do_idle(void)
{
        …
        while (!need_resched()) {
                …
        }
        …
        schedule_idle();
        …
```

Where all is the scheduler called from

When is the scheduler called?

- On process exit
  - Called by the function *do_task_dead()* (called by *do_exit()*) when a process exits
  - https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/core.c#L4565
- For scheduling the idle process
  - Called by *schedule_idle()* (from *do_idle()*) for scheduling the idle task
  - https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/core.c#L4654
- Called from wait and wake up functions
  - Too many to list, from too many drivers, file systems, other places

- On process preemption, from *preempt_schedule()* and related functions
  - https://elixir.bootlin.com/linux/v5.10.188/source/kernel/sched/core.c#L4723
  - Checks the need-to-reschedule flag set earlier after a kernel task finishes

Scheduling Real Time Tasks

Scheduling Real Time Tasks

- Two policies
  - SCHED_FIFO
  - SCHED_RR
- *sched_fork()* initializes class based on priority value
- Runqueue are a set of priority arrays, 1 per real time priority
- Bitmap of size MAX_RT_PRIO, one per real time priority

```
struct rt_prio_array {
        DECLARE_BITMAP(bitmap, MAX_RT_PRIO+1); /*
include 1 bit for delimiter */
        struct list_head queue[MAX_RT_PRIO];
};
```

```
struct rt_prio_array {
        DECLARE_BITMAP(bitmap, MAX_RT_PRIO+1); /* include 1 bit for
delimiter */
        struct list_head queue[MAX_RT_PRIO];
};
```

- Scheduling is very similar to what we saw earlier
  - *pick_next_task_rt()* eventually calls *pick_next_task_rt_entity()* which finds the first non-empty priority queue (from highest to lowest priority) using the bitmap, then chooses the first task in it to run
  - SCHED_FIFO: no timeslice, a task runs till completion
  - SCHED_RR: fixed timeslice, round-robin within the same priority level

```
static struct sched_rt_entity *pick_next_rt_entity(struct rt_rq *rt_rq)
{
        struct rt_prio_array *array = &rt_rq->active;
        struct sched_rt_entity *next = NULL;
        struct list_head *queue;
        int idx;
        idx = sched_find_first_bit(array->bitmap);
        queue = array->queue + idx;
        if (SCHED_WARN_ON(list_empty(queue)))
                return NULL;
        next = list_entry(queue->next, struct sched_rt_entity, run_list);
        return next;
}
```

- On periodic scheduler tick
  - *scheduler_tick()* calls *task_tick()*, which calls *task_tick_rt()*
- task_tick_rt() action
  - If SCHED_FIFO, no effect, as they have no timeslice
  - If SCHED_RR and timeslice is not over, return
  - If SCHED_RR and timeslice over, recompute timeslice and add to end of queue, call resched_curr() to schedule next task
    - Timeslices are same for all priorities, given by RR_TIMESLICE

```
static void task_tick_rt(struct rq *rq, struct task_struct *p, int queued)
{
        struct sched_rt_entity *rt_se = &p->rt;

        update_curr_rt(rq);
        …
        if (p->policy != SCHED_RR) return;
        if (--p->rt.time_slice) return;
        p->rt.time_slice = sched_rr_timeslice;
        for_each_sched_rt_entity(rt_se) {
                if (rt_se->run_list.prev != rt_se->run_list.next) {
                        requeue_task_rt(rq, p, 0);
                        resched_curr(rq);
                        return;
                }
        }
}
```