Linux Kernel Training.

Timers, Delays, Deferred Works

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Linux Kernel Time Sources

- Real-time clock (RTC)
  - Battery-backed HW clock;
  - Used to set and keep current date and time even when system is off;
- System Timers (Low Resolution): kernel/time/timer.c ;
  - Generate System ticks (100,250,1000 Hz);
  - Support System Time;
  - Tasks and Events scheduling;
- High Resolution Timers: kernel/time/hrtimer.c ;
  - Integrated into kernel mainline from 2.6.21;
  - Can support resolutions higher than 1 ms.
  - While S/W supports 1 ns resolution, normally rounded to the clock resolution of the specific platform.

Jiffies and HZ

- Jiffies
  - Until 2.6.21, jiffies was just a counter that was incremented every clock interrupt
  - Jiffies can wrap around depending on platform
    - 32 bits, 1000 HZ: about 50 days
    - 64 bits, 1000 HZ: about 600 million years
  - Jiffies_64:
    - On 64 bit machines, jiffies == jiffies_64;
    - On 32 bits, jiffies points to low-order 32 bits, jiffies_64 to high-order bits (be careful about atomicity!) =>

```
u64 get_jiffies_64(void);
```

- HZ
  - Determines how frequently the clock interrupt fires
  - Default is 1000 on x86, or 1 millisecond
  - Configurable at compile time or boot time Other typical values are 100 (10 ms) or 250 (4 ms)

- What's a good value for HZ?
  - Low values: less overhead
  - High values: better responsiveness

Kernel time structures

From include/uapi/linux/time(64).h (old type)

```
struct timespec(64) {
     __kernel_time_t     tv_sec;    /* seconds */
     long       tv_nsec;       /* nanoseconds */
};

struct timeval {
     __kernel_time_t      tv_sec;  /* seconds */
     __kernel_suseconds_t tv_usec; /* microseconds */
};
```

From include/uapi/linux/rtc.h

```
struct rtc_time {
    int tm_sec;
    int tm_min;
    int tm_hour;
    int tm_mday;
    int tm_mon;
    int tm_year;
    int tm_wday;     /* unused */
    int tm_yday;     /* unused */
    int tm_isdst;    /* unused */
};
```

Conversion functions (`jiffies.h`)

```
unsigned long timespec_to_jiffies(struct timespec *value);
void          jiffies_to_timespec(unsigned long jiffies, struct timespec *value);
unsigned long timeval_to_jiffies(struct timeval *value);
void          jiffies_to_timeval(unsigned long jiffies, struct timeval *value);
unsigned int  jiffies_to_msecs(const unsigned long j);        /* the same for _usecs */
unsigned long msecs_to_jiffies(const unsigned int m);
```

Measuring Time Lapses

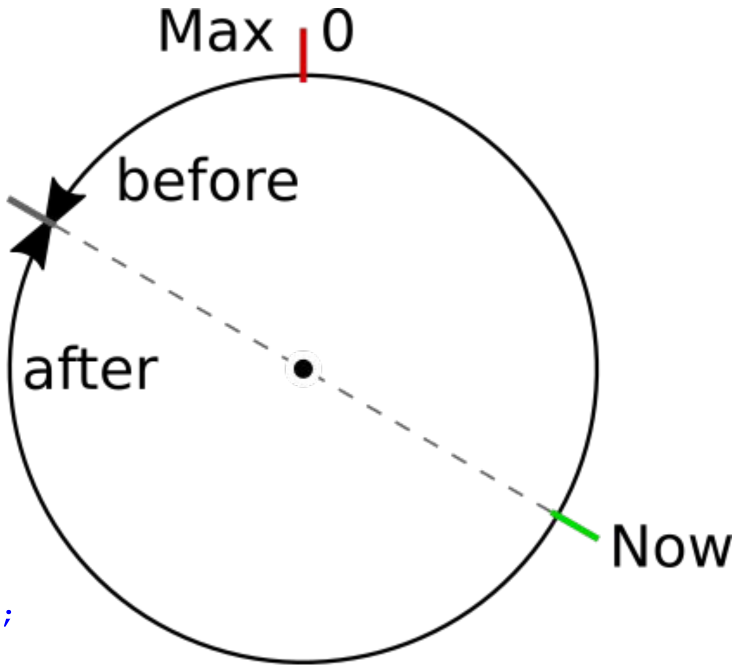
- Using jiffies

```
#include <linux/jiffies.h>
j = jiffies; /* read the current value */
stamp_1 = j + HZ; /* 1 second in the future */
stamp_half = j + HZ/2; /* half a second */
stamp_n = j + n*HZ/1000; /* n milliseconds */

bool time_after(unsigned long a, unsigned long b);
bool time_before(unsigned long a, unsigned long b);
bool time_after_eq(unsigned long a, unsigned long b);
bool time_before_eq(unsigned long a, unsigned long b);
```

- Similar for 64-bit

```
bool time_after64(u64 a, u64 b);
bool time_before64(u64 a, u64 b);
bool time_after_eq64(u64 a, u64 b);
bool time_before_eq64(u64 a, u64 b);
```



Processor Specific Registers

- x86:

  To access the timecounter, include <asm/msr.h> and use the following marcos

```
/* read into two 32-bit variables */
rdtsc(low32,high32);
/* read low half into a 32-bit variable */
rdtscl(low32);
/* read into a 64-bit long long variable */
rdtscll(var64);
```

  1-GHz CPU overflows the low half of the counter every 4.2 seconds

- Linux offers an architecture-independent function to access the architecture-specific cycle counter

```
#include <linux/timex.h>
cycles_t get_cycles(void);
```

  Returns 0 on platforms that have no cycle-counter register

Time Delays

- Busy-waiting

```
while (time_before(jiffies, j1))
        cpu_relax();

while (time_before(jiffies, j1))
        schedule();
```

```
#include <linux/delay.h>
void ndelay(unsigned long nsecs);
void udelay(unsigned long usecs);
void mdelay(unsigned long msecs);
```

- Non-busy waiting

```
void msleep(unsigned int millisecs);
unsigned long msleep_interruptible(unsigned int millisecs);
void ssleep(unsigned int seconds);
void __sched usleep_range(unsigned long min, unsigned long max);
signed long __sched schedule_timeout(signed long timeout);
     signed long __sched schedule_timeout_interruptible(signed long timeout);
     signed long __sched schedule_timeout_uninterruptible(signed long timeout);
     signed long __sched schedule_timeout_killable(signed long timeout);
```

Delays using WQ

See `linux/wait.h` (really they are macros):

```
DECLARE_WAIT_QUEUE_HEAD(name);
void wait_event(queue, condition);
long wait_event_timeout(wait_queue_head_t q, condition, long timeout);
long wait_event_interruptible_timeout(wait_queue_head_t q, condition, long timeout);
void wake_up(wait_queue_head_t *queue);
void wake_up_interruptible(wait_queue_head_t *queue);
```

Example:

```
    #include <linux/wait.h>

    wait_queue_head_t wait;

    init_waitqueue_head(&wait);
    wait_event_interruptible_timeout(wait, 0, delay);
```

Condition = 0 (no condition to wait for). Execution resumes when someone calls wake_up() or timeout expires;

Which function is best for me ?

- Documentation/timers/timers-howto.txt
  - "Is my code in an atomic context?"
  - This should be followed closely by "Does it really need to delay in atomic context?"

```
BUG: scheduling while atomic: swapper/1/0/0xffff0000
Modules linked in: tun libcomposite ipv6
[<c0014e4c>] (unwind_backtrace+0x0/0x11c) from [<c03a0720>] (__schedule_bug+0x48/0x5c)
[<c03a0720>] (__schedule_bug+0x48/0x5c) from [<c03a536c>] (__schedule+0x68/0x6e0)
[<c03a536c>] (__schedule+0x68/0x6e0) from [<c000ef08>] (cpu_idle+0xe4/0xfc)
```

- Are we doing bottom half or hardware interrupt processing? Are we in a softirq context? Interrupt context? See linux/preempt.h

```
#define in_irq()        (hardirq_count())
#define in_softirq()    (softirq_count())
#define in_interrupt()  (irq_count())
...
#define in_atomic()     ((preempt_count() != 0)
```

Contexts

- ATOMIC CONTEXT:

  You **must** use the *delay family of functions.

- NON-ATOMIC CONTEXT:

  You should use the *sleep[_range] family of functions.

  - SLEEPING FOR "A FEW" USECS (< ~10us?):

    Use udelay

  - SLEEPING FOR ~USECS OR SMALL MSECS (10us - 20ms):

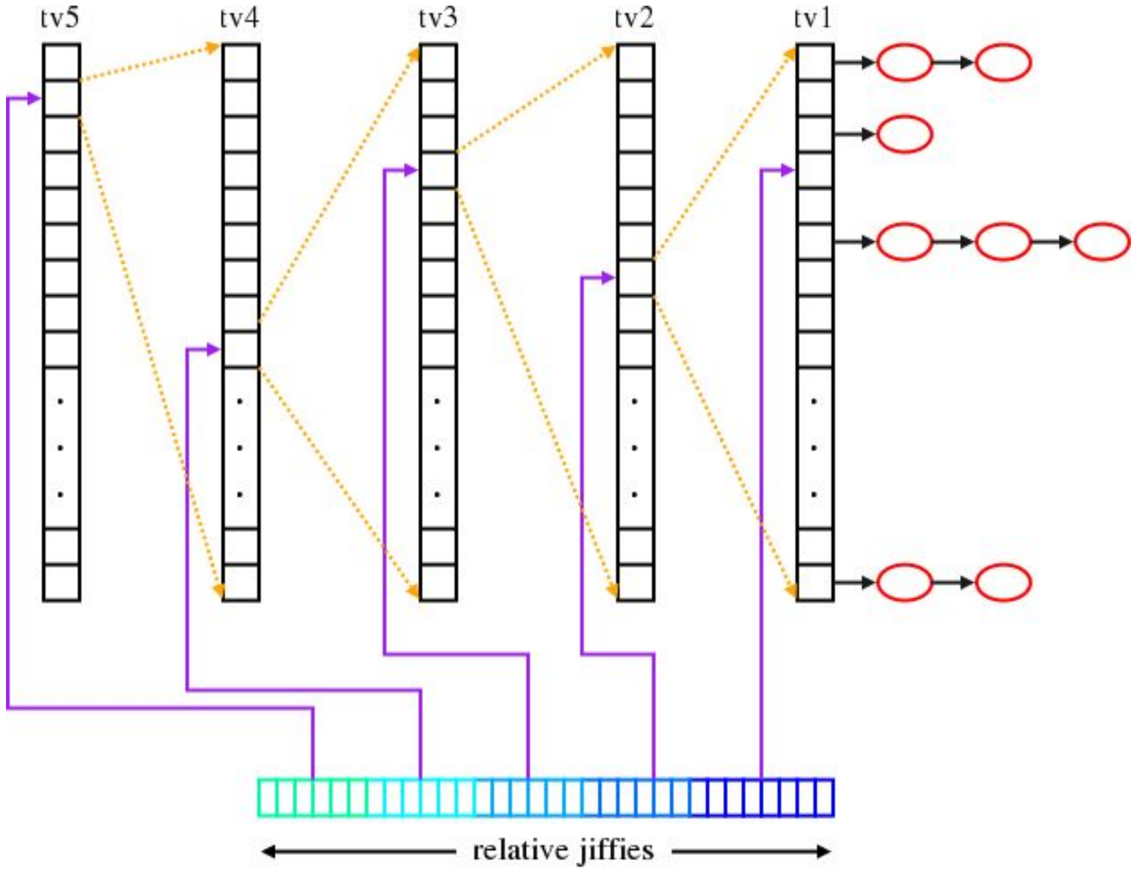
    Use usleep_range

  - SLEEPING FOR LARGER MSECS (10ms+)

    Use msleep or possibly msleep_interruptible

Kernel Timers

Cascaded Timer Wheel



tv1 - containing a set of 256 (in most configurations) linked lists of upcoming timer events;

tv2 - set of 64 next level timers;

Cascading initiated after all timers of the given level expired;

Timer add and Timer delay complexity O(1)

Timer cascading complexity O(n)

Timer list structure

Up to kernel 4.14

`data` is a pointer to related structure (may be timer itself)

```
struct timer_list {
        struct hlist_node   entry;
        unsigned long       expires;
        void                (*function)(unsigned long);
        unsigned long       data;
        u32                 flags;
};

setup_timer(&mydev.timer, timer_callback, &mydev)

struct mydev *md = t->data;     /* in callback */
```

Since kernel 4.15

Use `container_of`-based macro `from_timer()`

```
struct timer_list {
        struct hlist_node   entry;
        unsigned long       expires;
        void                (*function)(struct timer_list *);
        u32                 flags;
};

timer_setup(&mydev.mytimer, timer_callback, TIMER_FLAGS);

struct mydev *md = from_timer(md, t, mytimer); /* in callback */
```

Kernel Timer API

- **Creation and manipulation**

```
void init_timer(struct timer_list *timer);
void init_timer_deferrable(struct timer_list *timer);
void add_timer(struct timer_list * timer);
int del_timer(struct timer_list * timer);
int del_timer_sync(struct timer_list *timer);
int mod_timer(struct timer_list *timer, unsigned long expires);
```

- **Example (drivers/pci/hotplug/cpqphp_ctrl.c, pre-4.15 style)**

```
init_timer(&p_slot->task_event);
p_slot->task_event.expires = jiffies + 5 * HZ;   /* 5 second delay */
p_slot->task_event.function = pushbutton_helper_thread;
p_slot->task_event.data = (u32) p_slot;
add_timer(&p_slot->task_event);
//
mod_timer(&my_timer, next_timeout);
// ----
del_timer(&p_slot->task_event);
```

High Resolution Timers

- Motivated by the observation of 2 types of timers:
  - Timeout functions, which we don't expect to actually happen (e.g., retransmission timer for packet loss). Have low resolution and are usually removed before expiration.
  - Timer functions, which we do expect to run. Have high resolution requirements and usually expire
- Original timer implementation is based on jiffies and thus depends on HZ.
  - Works well for timeouts, less so for timers.
  - Resolution no better than HZ (e.g., 1 millisecond)
- High resolution timers, introduced in 2.6.16, allow 1 nanosecond resolution

  Implemented in an red-black tree (rbtree)
- Insert, delete, search in O(log n) time

High Resolution Timers API

- #include <linux/ktime.h>

```
union ktime {
        s64 tv64;       // in nanoseconds
};
```

- Initialization of time variable (defined in include/linux/ktime.h)

```
ktime_t kt;
kt = ktime_set(long secs, long nanosecs);

ktime_t ktime_add(ktime_t kt1, ktime_t kt2);
ktime_t ktime_sub(ktime_t kt1, ktime_t kt2);  /* kt1 - kt2 */
ktime_t ktime_add_ns(ktime_t kt, u64 nanoseconds);
ktime_t timespec_to_ktime(struct timespec tspec);
ktime_t timeval_to_ktime(struct timeval tval);
struct timespec ktime_to_timespec(ktime_t kt);
struct timeval ktime_to_timeval(ktime_t kt);
clock_t ktime_to_clock_t(ktime_t kt);
u64 ktime_to_ns(ktime_t kt);
```

High Resolution Timers API

void hrtimer_init(struct hrtimer *timer, clockid_t which_clock);

1. CLOCK_MONOTONIC: a clock which is guaranteed always to move forward in time, but which does not reflect "wall clock time"
2. CLOCK_REALTIME which matches the current real-world time.

void hrtimer_rebase(struct hrtimer *timer, clockid_t new_clock);

- Callback function :
  ```
  int  (*function)(void *);
  ```
  - HRTIMER_NORESTART
  - HRTIMER_RESTART
- Setting restart time:
  ```
  u64 hrtimer_forward(struct hrtimer *timer, ktime_t now, ktime_t interval);
  u64 hrtimer_forward_now(struct hrtimer *timer,ktime_t interval);
  static inline u64 hrtimer_forward_now(struct hrtimer *timer, ktime_t interval)
  {
      return hrtimer_forward(timer, timer->base->get_time(), interval);
  }
  ```

High Resolution Timers API

- **int hrtimer_start(struct hrtimer *timer, ktime_t time, enum hrtimer_mode mode);**
    - HRTIMER_ABS
    - HRTIMER_REL
- **int hrtimer_cancel(struct hrtimer *timer);**
    - The return value will be zero if the timer was not active (meaning it had already expired, normally), or one if the timer was successfully canceled;
- **int hrtimer_try_to_cancel(struct hrtimer *timer);**
    - Returns -1 if the timer function is running;
- **void hrtimer_restart(struct hrtimer *timer)** - can restart cancelled timer;
- **ktime_t hrtimer_get_remaining(const struct hrtimer *timer);**
- **bool hrtimer_active(const struct hrtimer *timer);**
- **int hrtimer_get_res(clockid_t which_clock, struct timespec *tp);**

HRT Example

```
int init_module(void)
{
     ktime_t ktime;

     ktime = ktime_set(0, MS_TO_NS(delay_in_ms));
     hrtimer_init(&hr_timer, CLOCK_MONOTONIC, HRTIMER_MODE_REL);
     hr_timer.function = &my_hrtimer_callback;
     hrtimer_start( &hr_timer, ktime, HRTIMER_MODE_REL );
     return 0;
}

enum hrtimer_restart my_hrtimer_callback( struct hrtimer *timer)
{
     if (restart--) {
          hrtimer_forward_now(timer, ns_to_ktime(MS_TO_NS(delay_in_ms)));
          return HRTIMER_RESTART;
     }
     return HRTIMER_NORESTART;
}
```

Summary

- Timer sources: System and RTC
- Jiffies - time measurement quant
- HZ - divider value
- Small resolution timer and high resolution timer are stored in different way in kernel

Thanks!

DS1307 reg map

ADDRESS	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0	FUNCTION	RANGE
00H	CH	10 Seconds			Seconds				Seconds	00–59
01H	0	10 Minutes			Minutes				Minutes	00–59
02H	0	12 24	10 Hour PM/AM	10 Hour	Hours				Hours	1–12 +AM/PM 00–23
03H	0	0	0	0	0	DAY			Day	01–07
04H	0	0	10 Date		Date				Date	01–31
05H	0	0	0	10 Month	Month				Month	01–12
06H	10 Year				Year				Year	00–99
07H	OUT	0	0	SQWE	0	0	RS1	RS0	Control	—
08H-3FH									RAM 56 x 8	00H–FFH

Bonus track: RTC

```
# ls /dev/i2c-1

# i2cdetect -y 1

# echo ds1307 0x68 > /sys/class/i2c-adapter/i2c-1/new_device

# modprobe ds1307

# hwclock -r

# hwclock -s
```