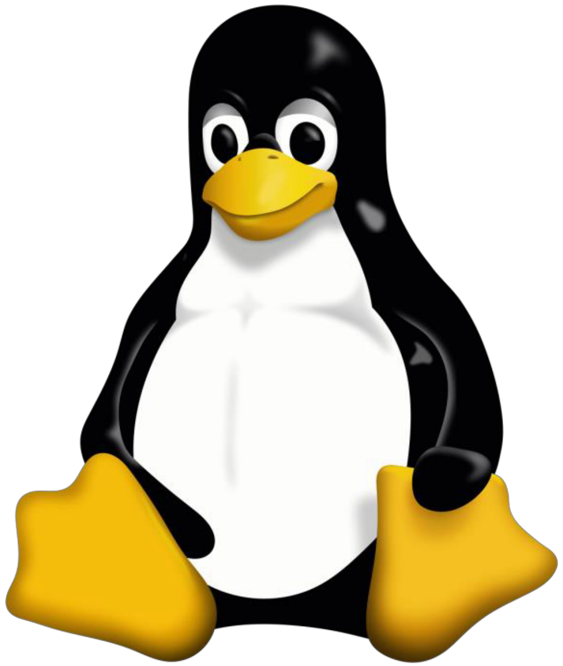
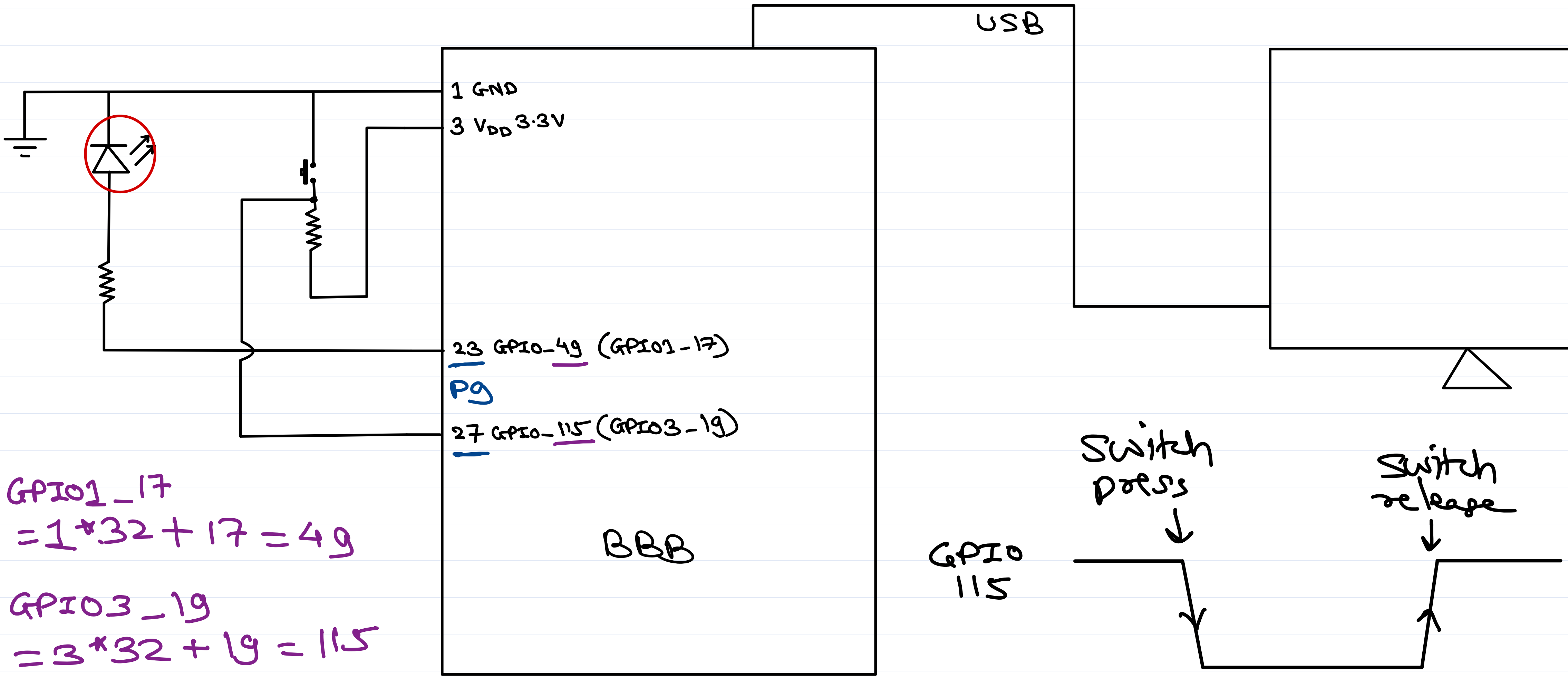


Linux Character Device Driver

Sunbeam Infotech

BBB Led & Switch



GPIO1_17

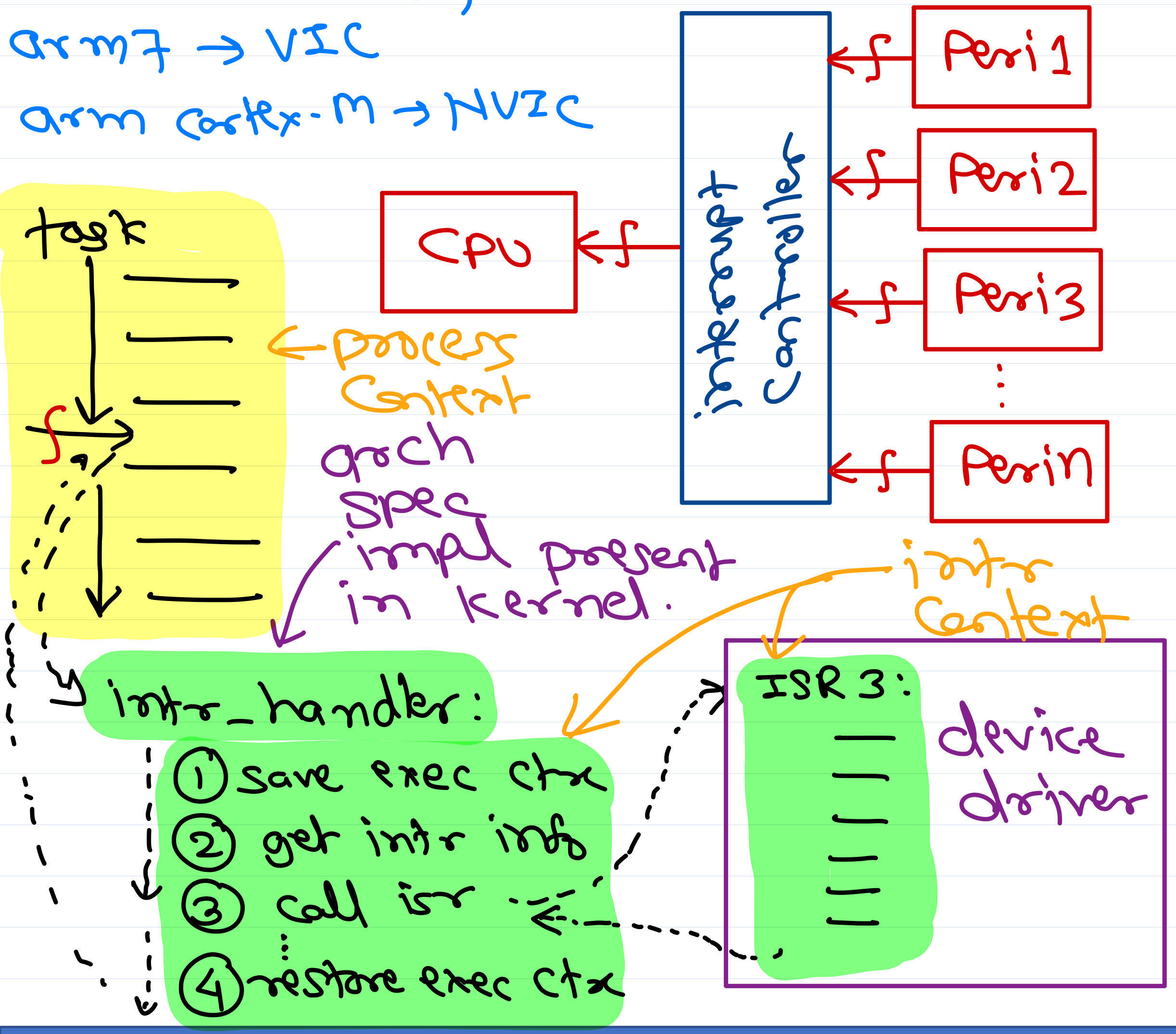
$= 1*32 + 17 = 49$

GPIO3_19

$= 3*32 + 19 = 115$

Interrupt Handling in Linux

x86 → PIC-8259
arm7 → VIC
arm cortex-m → NVIC



ISR impl:

irqreturn_t isr_fn(int irq, void *param);

- → IRQ_HANDLED → intr handled by this ISR.
- → IRQ_NONE → intr not handled by this ISR.
  - ↳ kernel calls next isr on same line.

Register ISR:

request_irq(irq, isr_fn, flags, name, param);

name ↓ cat /proc/interrupts

flags →
1. IRQF_DISABLED
2. IRQF_TIMER
3. IRQF_SAMPLE_RANDOM
4. IRQF_SHARED

true random nums
↳ /dev/random ↑ random entropy pool

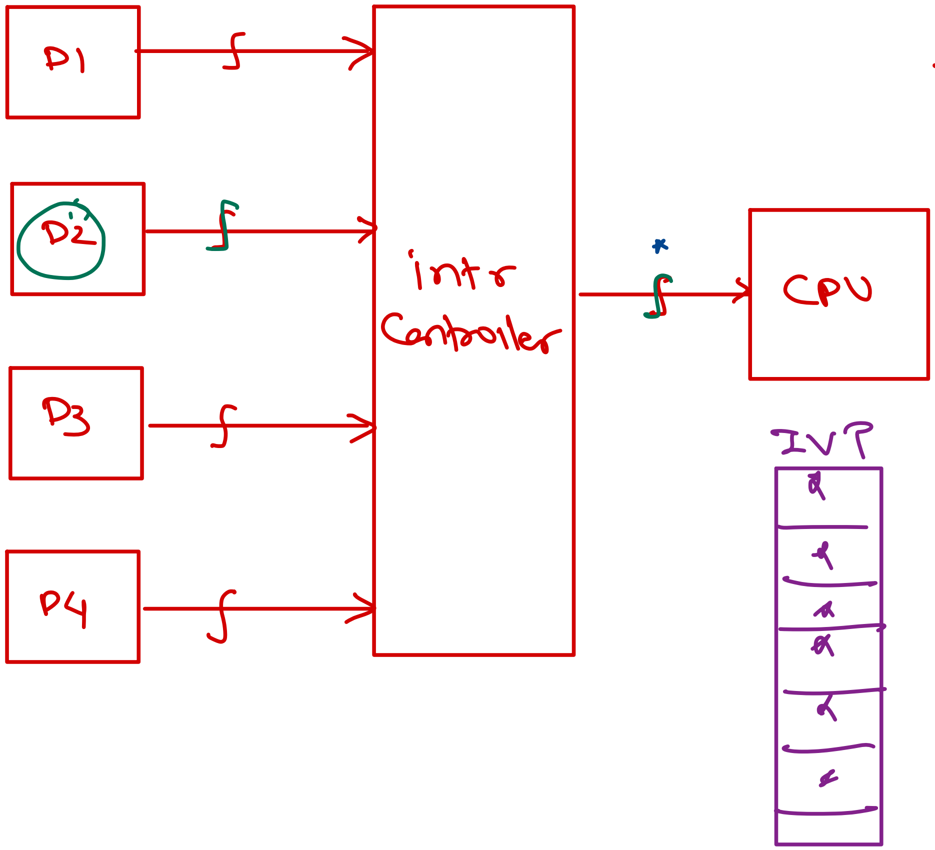
↳ Same irq line is shared for multiple hw devices.
e.g. com1, com2, com3, com4 ← Serial ports
↓ 4, 3, 4, 3

Unregister ISR:

free_irq(irq, param);

Interrupt

- Interrupts are special signals sent from device to CPU.
- Interrupt handling is architecture specific.



task:

intr_handler() {
1. Save ctx
2. get info which intr from IC.
3. invoke ISR
4. scheduler()
5. dispatcher() - restore ctx.
}

dev drv of dev2

isr1() {
}

isr2() {
}

isr3() {
}

isr4() {
}

Interrupt handling

- Interrupt is sent from the device to the PIC.
- PIC inform CPU about interrupt through interrupt line.
- CPU pause current task execution and execute interrupt handler.
- Interrupt handler does following
  - Save current task context on stack.
  - Get interrupt details from PIC.
  - Call ISR to handle the interrupt.
  - Invoke scheduler.
  - Restore the task context.
- In Linux there are two execution context.
  - Process context
    - User space process or kernel thread context. May block.
  - Interrupt context
    - Interrupt handler and ISR execution context.
    - Atomic context: cannot block.

uses user stack (in mb)
or kernel stack (8 KB)

uses interrupt stack (4 KB).
per CPU

Interrupt handling in Linux

- Since interrupt context cannot block, handler/ISR should return immediately.
- Heavy processing and/or blocking tasks should be deferred.
- Linux divides interrupt handling into two parts
  - Top half → ISR → Intr Context
    - Run immediately when interrupt arrives.
    - Do time critical and non-blocking task like interrupt acknowledgement.
    - Cannot be pre-empted by another interrupt from same device.
  - Bottom half → Soft IRQ, Tasklet, Work Queue
    - Variety of bottom half implementations in Linux kernel.
    - Execute later – in interrupt context or process context.
    - Do heavy processing and/or blocking tasks.
    - Can be pre-empted by interrupt (top-half).
- Interrupt handling must be done in corresponding device driver.
  - Driver should implement top-half and/or bottom-half as per requirement.
  - Linux kernel ensure uniform programming model irrespective of architecture.

Implementing top half

- Two step process
  - Implement ISR.

    irqreturn_t my_isr(int irq, void *param) {

  - Register ISR.

    3 request_irq()

- ISR registration
  - #include <linux/interrupt.h>
  - int request_irq(unsigned int irq, irq_handler_t handler, unsigned long flags, const char *name, void *dev);
    - irq: interrupt number
    - handler: typedef irqreturn_t (*irq_handler_t)(int, void *);
    - flags:
      - IRQF_DISABLED
      - IRQF_SAMPLE_RANDOM /dev/random
      - IRQF_TIMER
      - IRQF_SHARED
    - name: device name /proc/irq and /proc/interrupts
    - dev: extra information to be passed to handler.
    - Returns 0 on success or –EBUSY if interrupt line is already in use.
  - request_irq() may block and should not be called from interrupt context. Typically called when opening the device for processing or module initialization.

multiple device instances – private obj to keep each device info

e.g. struct serial_info {
    int irq;
    int ioaddr;
    mutex m;
    ...
};

struct private_struct devices[4];

irq=4 io=0x3F8 : com1	0
irq=3 io=0x2F8 : com2	1
irq=4 io=0x3E8 : com3	2
irq=3 io=0x2E8 : com4	3

com1
request_irq(4, my_isr, IRQF_SHARED, "com1", &devices[0]);

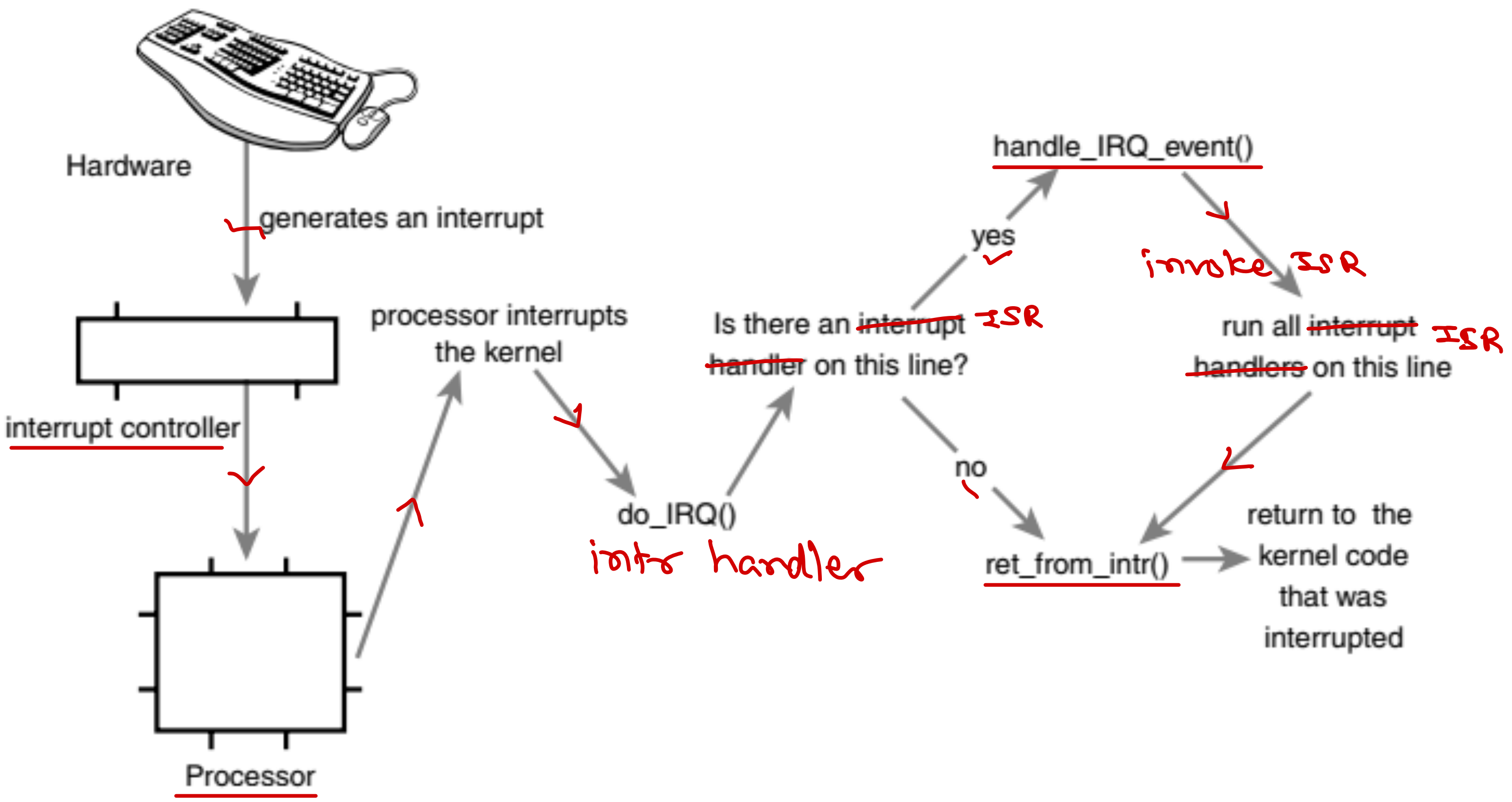
com3
request_irq(4, my_isr, IRQF_SHARED, "com3", &devices[2]);

Implementing top half

- ISR un-registration
  - Interrupt line must be released while unloading module or closing device.
  - void free_irq(unsigned int irq, void *dev);
- Implementing ISR
  - irqreturn_t my_intr_handler(int irq, void *dev);
    - irq: interrupt number
    - dev: extra param passed while request_irq()
    - returns IRQ_HANDLED or IRQ_NONE.
  - Should contain time-critical tasks and interrupt acknowledgement.
  - Also trigger bottom-half if required.
  - Should not sleep/block.
- Linux interrupt handlers are not re-entrant. Current interrupt line is disabled while execution of ISR.
- Shared interrupt handlers
  - Must pass unique dev param – typically device private struct.
  - ISR must check if interrupt is raised from the corresponding device before handling it.
  - Kernel execute all ISR registered on same interrupt line.

Interrupt handling

- Interrupt context
    - Atomic context.
    - One page kernel stack per processor.
- Interrupt execution



Interrupt control

- local_irq_disable(): Disables local interrupt delivery
- local_irq_enable(): Enables local interrupt delivery

current cpu

- local_irq_save(): Saves the current state of local interrupt delivery and then disables it
- local_irq_restore(): Restores local interrupt delivery to the given state
- disable_irq(): Disables the given interrupt line and ensures no handler on the line is executing
- enable_irq(): Enables the given interrupt line
- irqs_disabled(): Returns nonzero if local interrupt delivery is disabled; otherwise returns zero
- in_interrupt(): Returns nonzero if in interrupt context and zero if in process context
- in_irq(): Returns nonzero if currently executing an interrupt handler and zero otherwise

ISR

Bottom half

- If interrupt handling need to do heavy processing or blocking task, then driver must implement it in bottom half.
- General guideline for top and bottom half work division:
  - If the work is time sensitive, perform it in the interrupt handler. ISR
  - If the work is related to the hardware, perform it in the interrupt handler. ISR
  - If the work needs to ensure that another interrupt doesn't interrupt it, perform it in the interrupt handler. ISR
  - For everything else, consider performing the work in the bottom half.

top half

- Bottom half are executed after top half.
  - Immediately after top half in interrupt context.
  - In some specialized process context, when no other another high priority task is running.
- Types of bottom halves
  - BH - Removed in kernel 2.5
  - Task queue - Removed in kernel 2.5
  - Softirq - Added in kernel 2.3
  - Tasklet - Added in kernel 2.3
  - Work queue - Added in kernel 2.3

Softirq

- Softirqs are statically allocated at compile time.

```
struct softirq_action {
        void (*action)(struct softirq_action *);
};
static struct softirq_action softirq_vec[NR_SOFTIRQS];
```

32

- Softirqs are implemented for specialized sub-systems.
- Kernel 2.6.34 have 9 Softirqs implemented.

HI_SOFTIRQ	0	High-priority tasklets
TIMER_SOFTIRQ	1	Timers
NET_TX_SOFTIRQ	2	Send network packets
NET_RX_SOFTIRQ	3	Receive network packets
BLOCK_SOFTIRQ	4	Block devices
TASKLET_SOFTIRQ	5	Normal priority tasklets
SCHED_SOFTIRQ	6	Scheduler
HRTIMER_SOFTIRQ	7	High-resolution timers
RCU_SOFTIRQ	8	RCU locking

Softirqs

- Softirqs must be triggered for the execution. This is called as “raising Softirq”. Mostly done from ISR.
- Pending Softirq are checked and executed in one of the following place – do_softirq().
  - In the return from hardware interrupt code path ← interrupt context
  - In the ksoftirqd kernel thread (per processor) ← process context
  - In any code that explicitly checks for and executes pending softirqs, such as the networking subsystem
- Using Softirq
  - Currently only network and block subsystem is using Softirq directly.
  - It is not advised to use Softirqs directly.
  - Softirq can be registered using open_softirq() and can be triggered using raise_softirq().

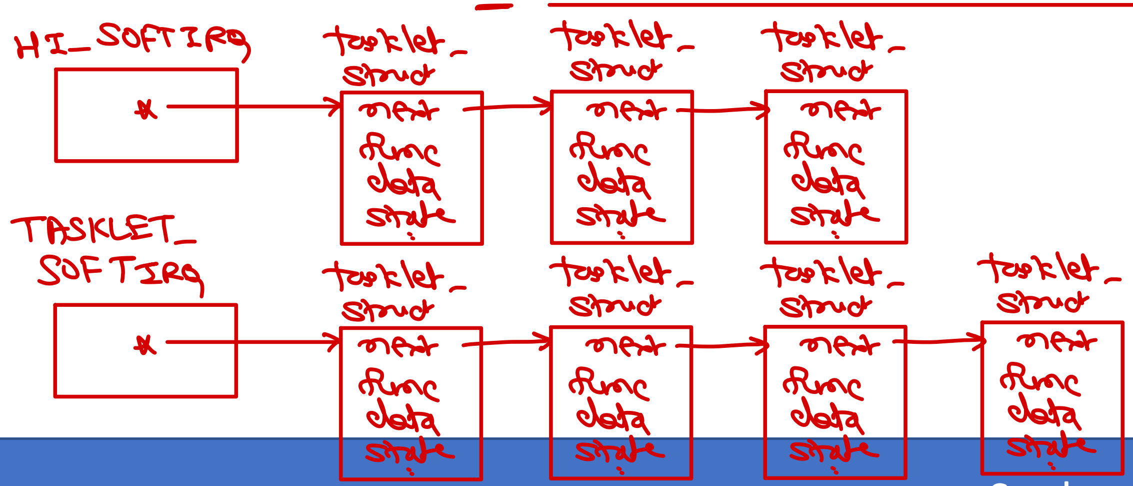
Tasklets

0 5

- Implemented on top of Softirqs i.e. HI_SOFTIRQ and TASKLET_SOFTIRQ.
- Tasklets are dynamic components and much easier to use.

```
struct tasklet_struct {
    struct tasklet_struct *next; /* next tasklet in the list */
    unsigned long state; /* state of the tasklet */
    atomic_t count; /* reference counter */
    void (*func)(unsigned long); /* tasklet handler function */
    unsigned long data; /* argument to the tasklet function */
};
```

- Tasklet state can be: 0, TASKLET_STATE_SCHED or TASKLET_STATE_RUN.



Tasklets

- Declare Tasklet statically.
  - DECLARE_TASKLET(my_tasklet, my_tasklet_handler, dev);
- Declare & initialize Tasklet dyanmically.
  - struct tasklet_struct my_tasklet;
  - tasklet_init(t, tasklet_handler, dev); arg to tasklet func.
- Tasklet handler implementation
  - void tasklet_handler(unsigned long data) { … }
  - Like softirq, tasklet cannot sleep/block.
  - While executing tasklet, interrupts are enabled.
  - Tasklet are not re-entrant or execute concurrently.
- Trigger Tasklet
  - tasklet_schedule(&my_tasklet); tasklet_hi_schedule(&my_tasklet);
  - Change tasklet state to TASKLET_STATE_SCHED.
- Tasklet can be enabled/disabled explicitly.
  - tasklet_enable(&my_tasklet);
  - tasklet_disable(&my_tasklet);

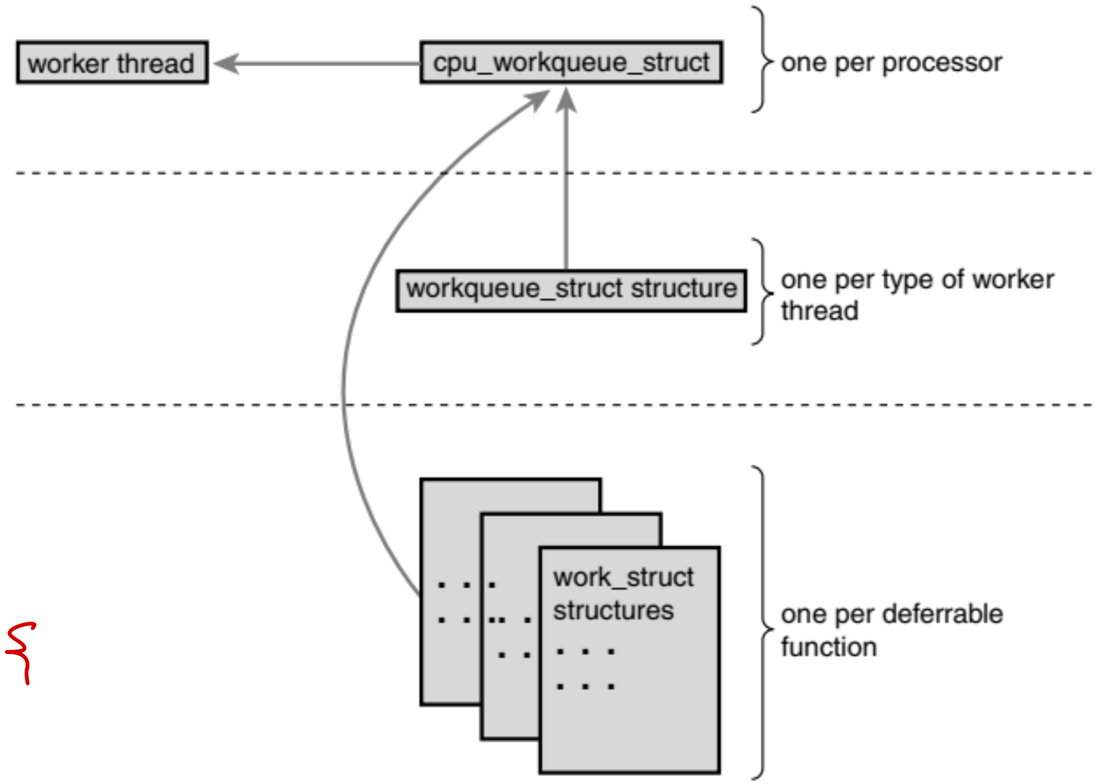
Work queue

- Work queues defer work into a kernel thread. → kworker
- Always runs in process context – worker threads (per processor).
- Work queues are schedulable and can sleep/block.
- Usual alternative to work queues is kernel threads. However creating new kernel threads isn't advised.

work queue → shared (by kernel)
→ dedicated (by driver).

```
struct cpu_workqueue_struct {
        spinlock_t lock; /* lock protecting this structure */
        struct list_head worklist; /* list of work */
        wait_queue_head_t more_work;
        struct work_struct *current_struct;
        struct workqueue_struct *wq; /* associated */
        task_t *thread; /* associated thread */
};
struct work_struct {
        atomic_long_t data;
        struct list_head entry;
        work_func_t func;
};
```

→ void func (data) {
}



Work queue (in shared work queue)

- Creating work
  - DECLARE_WORK(name, void (*func)(void *), void *data); // static
  - INIT_WORK(struct work_struct *work, void (*func)(void *), void *data); // dynamic
- Work handler
  - void work_handler(void *data) { … } → may sleep
- Scheduling work
  - schedule_work(&work);
  - schedule_delayed_work(&work, delay);

  } in shared work queue
- Ensure work completion
  - void flush_scheduled_work(void);
- Cancel scheduled work
  - int cancel_delayed_work(struct work_struct *work);

Control bottom half

- To enable/disable all bottom half (tasklet & work queue) processing
  - void local_bh_enable();
  - void local_bh_disable();
- Choosing bottom half
  - Softirq – static component
    - Concurrent execution and need synchronization
    - Good for fast execution and high frequency use → for special subsystem
    - Cannot sleep (may execute in process ctx - ksoftirq or may execute in intr ctx - return from intr)
  - Tasklet – dynamic component
    - Simplified programming
    - Not executed concurrently – no sync needed
    - Cannot sleep – internally depend on softirq.
  - Work queue – dynamic component
    - Can sleep – runs in process ctx - kworker.
    - Higher overheads due to kernel thread & context switching

kworker

Thank you!

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