Introduction to Hardware Programming

NOTES:

Topics:

→ **Hardware I/O**

Programming PCI bus devices

Handling Interrupts

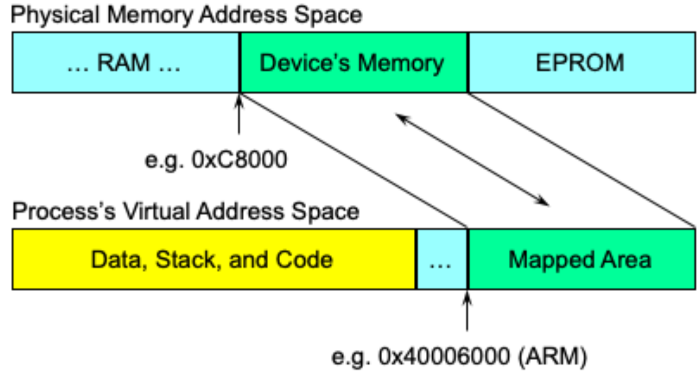
Conclusion

NOTES:

Memory Interface

To access memory on a hardware device:

- physical addresses must be mapped into your process's virtual address space:




```
// get a pointer to memory physically located at 0xc8000
vaddr = mmap_device_memory (0, 0x4000,
                    PROT_READ | PROT_WRITE | PROT_NOCACHE,
                    0, 0xc8000);
```


NOTES:

DMA Safe Memory

DMA operations usually require physically contiguous RAM:

```
// for DMA:
// allocate len bytes of physically contiguous
// system memory

vaddr = mmap (0, len,
              PROT_READ | PROT_WRITE | PROT_NOCACHE,
              MAP_PHYS | MAP_ANON | MAP_SHARED, NOFD, 0);

// get the physical address for passing to the controller
mem_offset64 (vaddr, NOFD, len, &paddr, NULL);
```


NOTES:

Control Registers

How you access control registers varies based on the platform:

- on ARM and AARCH64 platforms:
  - registers are mapped like memory
  - pointer dereferences are used for read/write operations
  - procnto knows based on system page that these are not RAM, sets CPU access flags differently
  - some x86_64 devices may, also, be accessed this way
- on x86_64 most devices continue to use “x86-style” I/O ports
  - a special address line must be active to change from memory to I/O addressing
  - requires a special set of assembly instructions for access

NOTES:

Interfacing to I/O ports (x86_64):

– QNX supplies cover functions for the inline assembly needed

```
#include <hw/inout.h> // header for in*() & out*() fns

// enable I/O privilege for this thread
ThreadCtl (_NTO_TCTL_IO, NULL);

val8  = in8  (ioport_addr); // read an 8 bit value
val16 = in16 (ioport_addr); // read a 16 bit value
val32 = in32 (ioport_addr); // read a 32 bit value

out8  (ioport_addr, val8 ); // write an 8 bit value
out16 (ioport_addr, val16); // write a 16 bit value
out32 (ioport_addr, val32); // write a 32 bit value
```


NOTES:

To see what the *in*()* and *out*()* functions actually do, look at **`${QNX_TARGET}/usr/include/x86_64/inout.h`**.

Intro to Hardware Programming

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NOTES:

PCI API

To find and configure a PCI device:

- you must run the PCI server:

```
pci-server
```


NOTES:

PCI - The calls

The PCI calls include:

`pci_device_find()`	find hardware by Device ID and Vendor ID
`pci_device_attach()`	find hardware and get basic configuration information
`pci_device_reset()`	reset device
`pci_device_detach()`	detach device
`pci_device_read_*()`	read configuration information
`pci_device_write_*()`	write to device command or status register
`pci_device_map_as()`	translate between CPU and PCI addresses

NOTES:

PCI – Device information

The *pci_device_find()* call:

- fills in a **`pci_bdf_t`** base data type
  - encodes the bus, device and function of the PCI device
- various calls can determine
  - interrupt number
  - address translations for bus master PCI devices
  - PCI configuration space registers
  - the base addresses of a device

NOTES:

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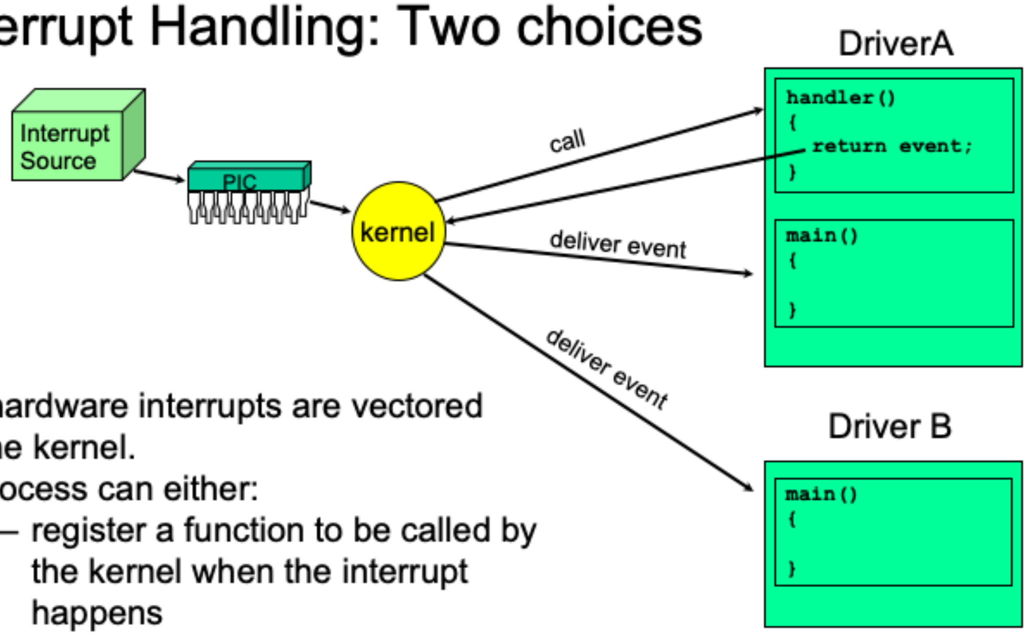
Interrupt Handling: Two choices



All hardware interrupts are vectored to the kernel.

A process can either:

- register a function to be called by the kernel when the interrupt happens
- request notification that the interrupt has happened

NOTES:

Interrupt calls:

```
id = InterruptAttach (int intr,
                      struct sigevent *(*handler)(void *, int),
                      void *area, int size, unsigned flags);
id = InterruptAttachEvent (int intr, struct sigevent *event,
                           unsigned flags);
InterruptDetach (int id);
InterruptWait (int flags, uint64_t *reserved);
InterruptMask (int intr, int id);
InterruptUnmask (int intr, int id);
InterruptLock (struct intrspin *spinlock);
InterruptUnlock (struct intrspin *spinlock);
```

☞ Permissions are complicated… see next slide.

NOTES:

There are also:

```
InterruptEnable (void);
InterruptDisable (void);
```

They are for non-SMP systems only and so are not good as a general solution. You should use *InterruptLock()* and *InterruptUnlock()* instead.

Interrupt Calls – System Privileges

The privileges required for interrupt calls are complex:

- *InterruptAttach()*
  - **PROCMGR_AID_INTERRUPT**
- *InterruptAttachEvent()*
  - **PROCMGR_AID_INTERRUPTEVENT** or **PROCMGR_AID_INTERRUPT**
- *InterruptMask()*, *InterruptUnmask()*
  - I/O privilege is required to mask an interrupt the process has not attached
- *InterruptLock()*, *InterruptUnlock()*, *InterruptDisable()*, *InterruptEnable()*
  - I/O privilege which is gotten by calling:
- *ThreadCtl(_NTO_TCTL_IO, 0)*:
  - **PROCMGR_AID_IO**

NOTES:

Handling an Interrupt

Driver A example: interrupt handler function

```
struct sigevent event;

const struct sigevent *
handler (void *not_used, int id)
{
  if (check_status_register())
    return (&event);
  else
    return (NULL);
}
main ()
{
  SIGEV_INTR_INIT (&event);
  id = InterruptAttach (INTNUM, handler, NULL, 0, ...);
  for (;;) {
    InterruptWait (0, NULL);
    // do some or all of the work here
  }
}
```


NOTES:

In this case, there is a user-supplied interrupt handler. This would be the case where there is work that must be done at interrupt priority for timing reasons. Notice that the handler and the thread can share the work. The handler can do the time-critical work (typically I/O) and the thread can be woken up every now and then for the non-time-critical work (number crunching, passing the data on to other threads.)

In the interrupt handler above, *check_status_register()* represents some code that checks some status register on the hardware to see if our hardware generated the interrupt and/or to clear the source of the interrupt. This is needed on level-sensitive architectures, since interrupts can be shared, and the kernel will issue an EOI at the end of the interrupt chain, so we must clear the interrupt before returning. This is also why, using the *InterruptAttachEvent()* method, the kernel must mask the interrupt before scheduling the thread.

In existing code, you may a *ThreadCtl(_NTO_TCTL_IO, 0)* call before attaching to interrupts – this was required in QNX versions before 7.0.4.

Driver B example: interrupt event loop

```
struct sigevent event;

main ()
{
  SIGEV_INTR_INIT (&event);
  id = InterruptAttachEvent (INTNUM, &event, ...);
  for (;;) {
    InterruptWait (0, NULL);
    // do the interrupt work here, at thread priority
    InterruptUnmask (intnum, id);
  }
}
```


NOTES:

When the kernel gets control, it will mask the interrupt, and use the event to do the appropriate scheduling. In this case, because you are using **SIGEV_INTR**, the *InterruptWait()* will unblock.

In existing code, you may a *ThreadCtl(_NTO_TCTL_IO, 0)* call before attaching to interrupts – this was required in QNX versions before 7.0.4.

InterruptAttachEvent

Telling kernel what code to run when an interrupt happens:

```
id = InterruptAttachEvent (intr, event, flags);
```

tell kernel what wakeup
event to give us

logical interrupt
vector number

additional
information
flags

handler function
to run on interrupt

mem passed
Into handler

```
id = InterruptAttach (intr, handler, area, size, flags);
```


NOTES:

InterruptAttach*() Flags

InterruptAttachEvent() and *InterruptAttach()*'s flags parameter can contain:

- **`_NTO_INTR_FLAGS_END`**: If multiple interrupt handlers, specify we should execute last
- **`_NTO_INTR_FLAGS_PROCESS`**: for events types that are directed at a process rather than a thread, e.g. pulses
- **`_NTO_INTR_FLAGS_TRK_MSK`**: request that the kernel adjust the interrupt mask when the attaching process terminates (ALWAYS set this flag)
- **`_NTO_INTR_FLAGS_NO_UNMASK`**: must explicitly unmask the interrupt to enable

NOTES:

Interrupt Handler Environment

An interrupt handler operates in the following environment:

- it is sharing the data area of the process that attached it
- the environment is very restricted:
  - cannot call kernel functions except *InterruptMask()*, *InterruptUnmask*() and *TraceEvent()* (see notes)
  - cannot call any function that might call a kernel function
    - the documentation for each function specifies whether or not that function is safe to call from an interrupt handler
    - there is also a section in the Library Reference manual called "Full Safety Information" that lists all safe functions
  - the interrupt handler is using the kernel's stack, so keep stack usage small (if you have a lot of data, use variables defined outside of the handler rather than variables defined local to the function, and don't call too many function levels deep)
  - shouldn't do floating point or equivalent operations

NOTES:

InterruptLock() and *InterrtuptUnlock()* may also be called in an interrupt handler as they are not kernel calls. They are implemented as inline assembly.

See the Library Reference for a caveat about *TraceEvent()*.

Should you attach a handler or an event?

- The kernel is the single point of failure for a QNX system; attaching a handler increases the size of the SPOF, an event does not
- debugging is far simpler with an event
  - ISR code can not be stepped/traced with the debugger
- full OS functionality when doing h/w handling in a thread
- events impose far less system overhead at interrupt time than handlers
  - no need for the MMU work to gain access to process address space if using an event
- scheduling a thread for every interrupt could be more overhead, if you could do some work at interrupt time and only need to schedule a thread some of the time
- handlers have lower latency than getting a thread scheduled
  - does your hardware have some sort of buffer or FIFO? If not, then you might not be able to wait until a thread is scheduled

NOTES:

Notification Methods

You have the following notification methods:

- SIGEV_INTR
  - unblocks *InterruptWait()*
  - simplest to use (least setup)
  - fastest (lowest overhead, latency)
  - not queued or counted
  - must dedicate a thread
- SIGEV_SEM
  - unblocks *sem_wait()* on a named semaphore
    - within driver, use an anonymous named semaphore
  - counted
  - only direct cross-process choice

continued...

NOTES:

Notification methods (continued):

- SIGEV_SIGNAL
  - unblocks *sigwaitinfo()*
    - Do not use a signal handler, the overhead and latency are awful
  - can be queued
  - can carry data
- SIGEV_PULSE
  - unblocks *MsgReceive*()*
  - queued
  - carries data
  - most flexible
    - single threaded driver can handle hardware and clients
    - pool of threads
  - highest overhead and latency

NOTES:

EXERCISE

Simple interrupt handler:

- in your **`interrupt`** project is a skeleton file called **`intsimple.c`**
- fill it in with the code for handling interrupts, the instructor will tell you which interrupt to attach to
- attach an interrupt handler that will return a **`SIGEV_INTR`** event
- in the loop, use *InterruptWait()* to wait for the interrupt notification

QNX

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Conclusion

You learned:

- That memory or port mappings have to be set up to access hardware devices
- that the kernel is the first handler for all interrupts
- that processes can register handlers or can register for notification of interrupts
- that interrupt handlers run in a very restricted environment

QNX

NOTES: