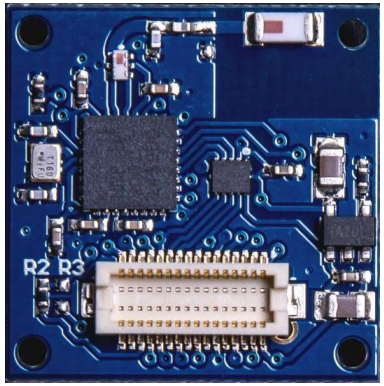
EE107 Spring 2019

Lecture 3

Time and Interrupts



Embedded Networked Systems

Sachin Katti

*slides adapted from Aaron Schulman's CSE190

What time is the Apple Watch tracking?

How often | *Granularity*

Clock (all the time | sec)
Alarm (all the time | sec)
Stopwatch (when open | msec)
Sync (all the time | sec)
UI (when open | msec)
Buzzer (when buzzing | msec)
WiFi (when communicating | usec)

Why do we need timers?

In this project, we need timers for

- Determining when to change the bits
  - 20 Hz means change bits every 50 milliseconds
  - How to measure 50 ms?
  - Option 1: Use the timer hardware to let you know when 50 ms has passed.
  - Option 2: Count how many processor cycles it would take to equal 50 ms.

Why do we need timers?

- In general, why do we need timers?
  - What time is it now?
  - How much time has elapsed since I last checked?
  - Let me know when this much time passes.
  - When did this external input occur?

What peripherals do we use to track time?

(all the time | sec) - [Alarm, Sync]

32-bit Real time clock (RTC) peripheral with interrupts

(when open/buzzing | msec) - [Stopwatch, UI, Buzzer]

Processor's *timer* peripheral with interrupts

(when communicating | usec) - [WiFi]

WiFi chip's internal timer peripheral with interrupts

What peripherals do we use to track time?

(all the time | sec) - [Alarm, Sync]

32-bit Real time clock (RTC) peripheral with interrupts

The term is used to avoid confusion with ordinary hardware clocks which are only signals that govern digital electronics, and do not count time in human units.

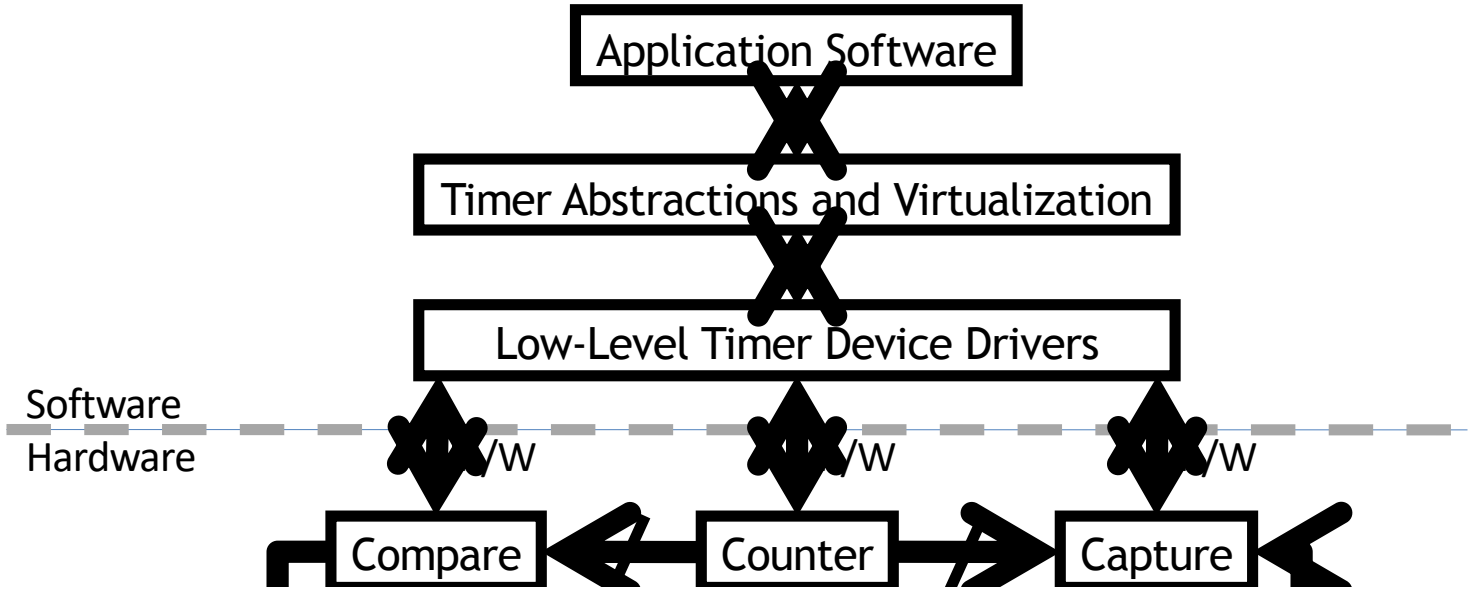
(when open/buzzing | msec) - [Stopwatch, UI, Buzzer]

Processor's *timer* peripheral with interrupts

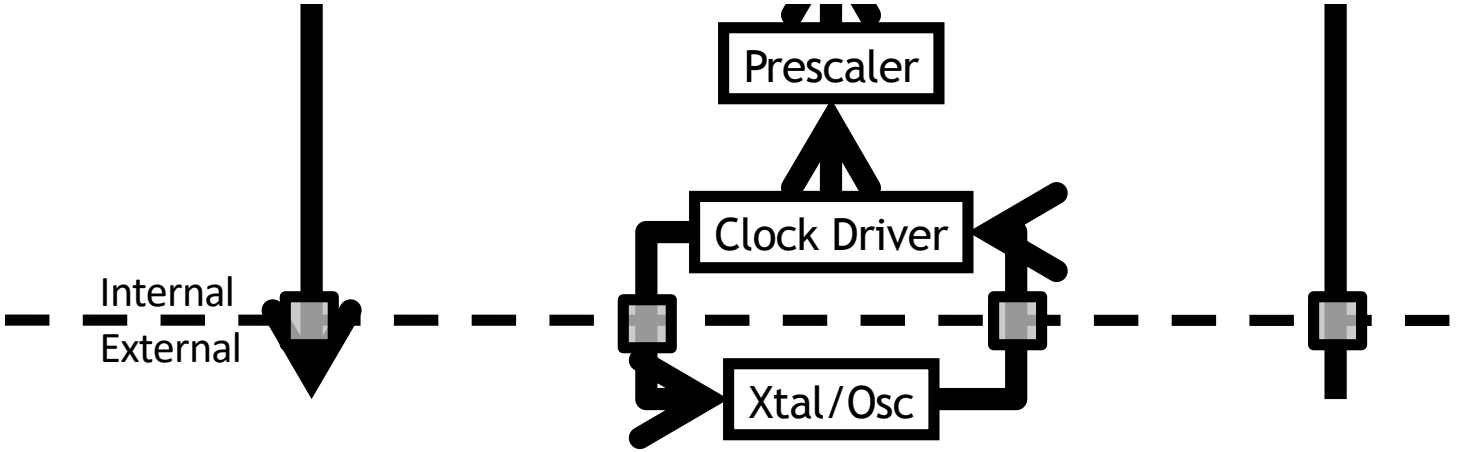
(when communicating | usec) - [WiFi]

WiFi chip's internal timer peripheral with interrupts

The internal structure of a timer peripheral



The purpose of the prescaler is to allow the timer to be clocked at the rate a user desires.



Frequency depends on the attached oscillator device

Figure adapted from Prabal Dutta's EE373 slides

How does the number in the counter register correspond to wall clock time?

Frequency (Hz) = Cycles / Second

1 / Frequency (Hz) = Seconds / Cycle

The counter is incremented once per cycle.

You read 100 from the counter register which is clocked by a 1 MHz oscillator. How much time has passed since the counter was reset?

How should we choose the OSC frequency?

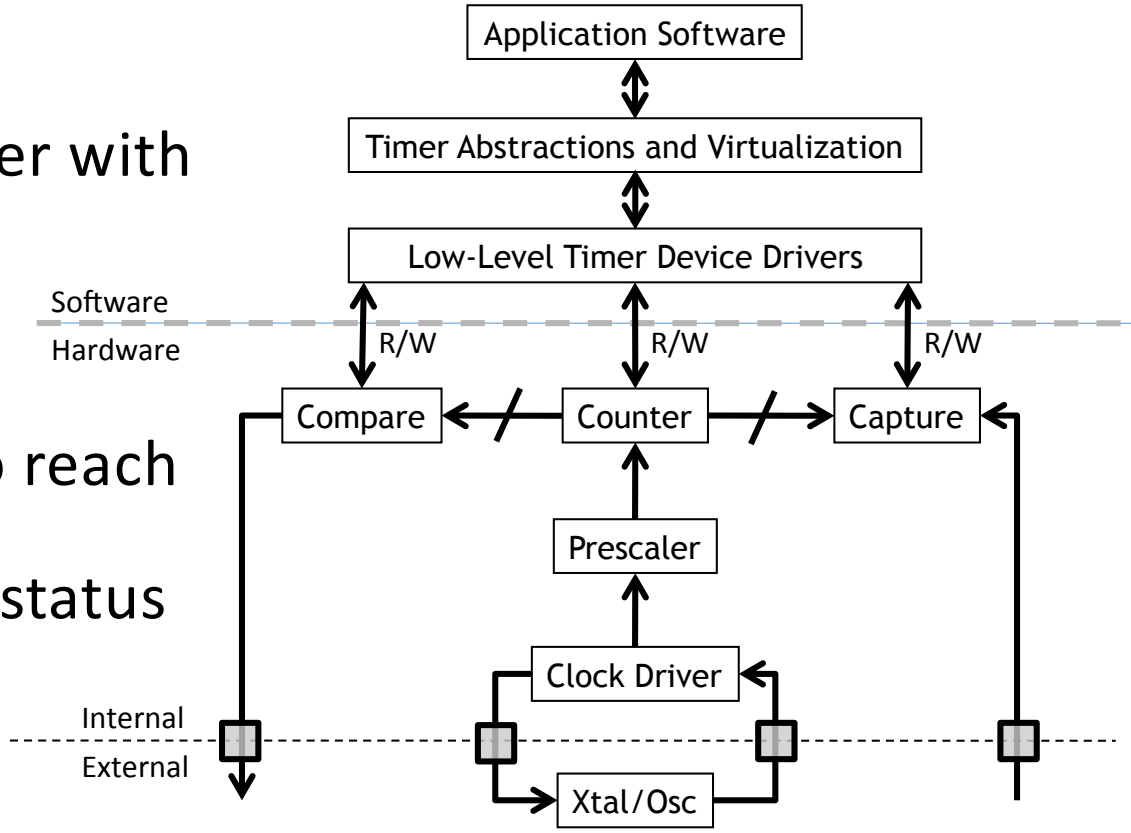
For timers, there will often be a tradeoff between resolution (high resolution requires a high clock rate) and range (high clock rates cause the timer to overflow more quickly).

1MHz OSC: resolution = 1 / 1e6 second = 1us
10MHz OSC: resolution = 1/10e6 second = 0.1us

16-bits timer:
1MHz OSC: max range = 1 / 1e6 * 2^16 = 65.536ms
10MHz OSC: max range = 1/10e6 * 2^16 = 6.5536ms

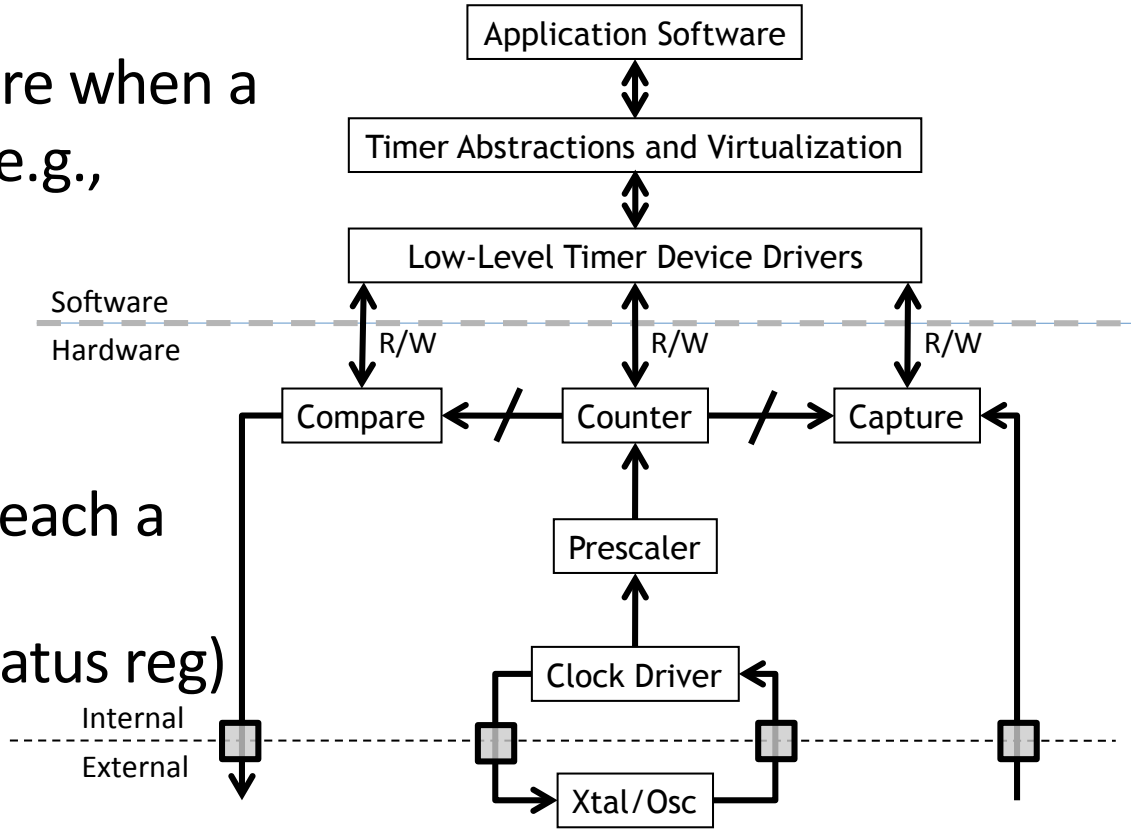
How does a firmware developer use the compare register?

1. Stop the timer
2. Set the compare register with the time it should fire
3. Reset the counter
4. Start the timer
5. Wait for the counter to reach the compare
   (via interrupt or check status reg)



How does a firmware developer use the capture register?

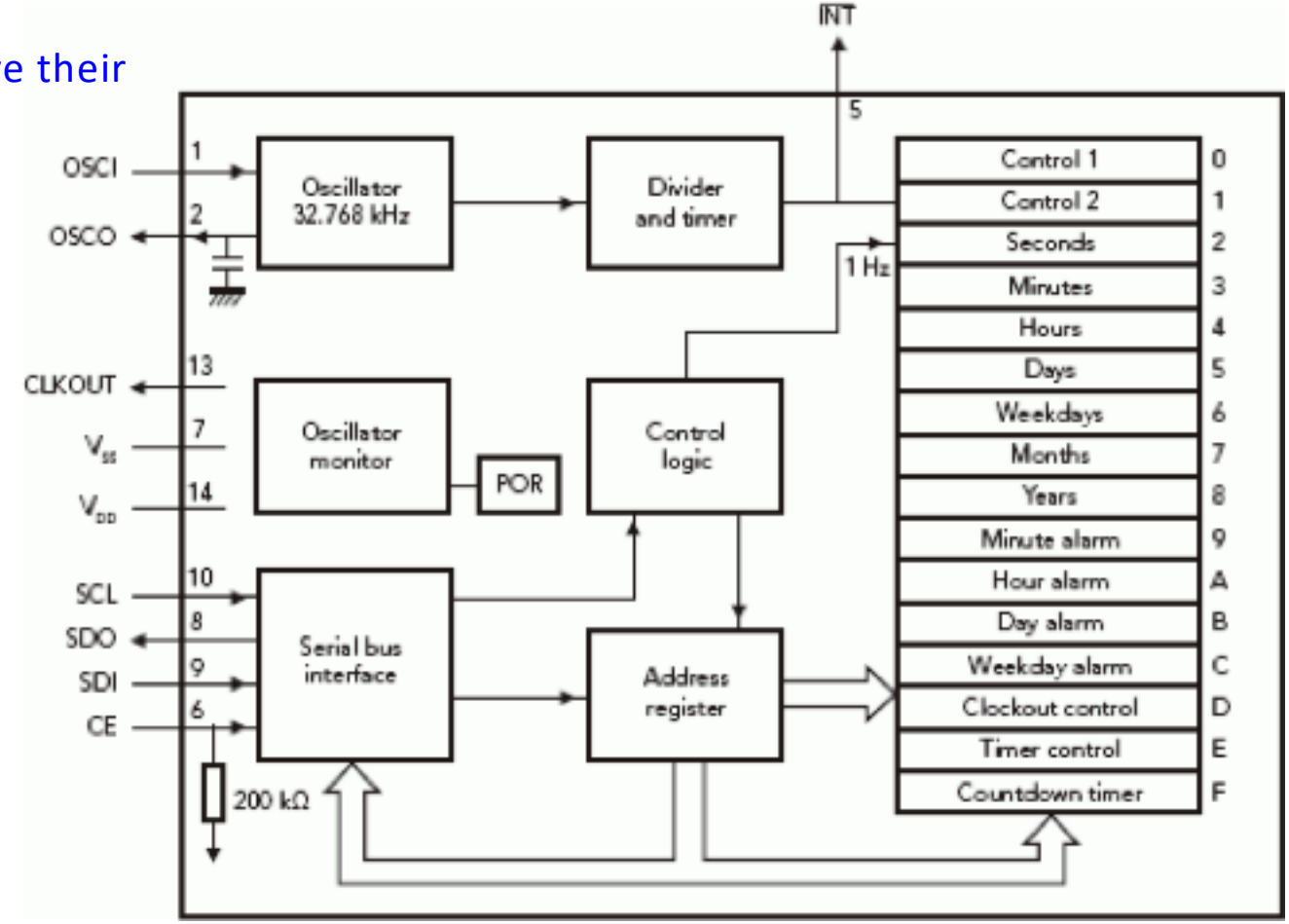
1. Stop the timer
2. Setup the timer to capture when a particular event occurs (e.g., change of GPIO pin)
3. Reset the counter
4. Start the timer
5. Wait for the counter to reach a capture event
   (via interrupt or check status reg)



The internal structure of a Real Time Clock (RTC)

Note: RTCs have their own oscillator.

Why is it 32,768 kHz?



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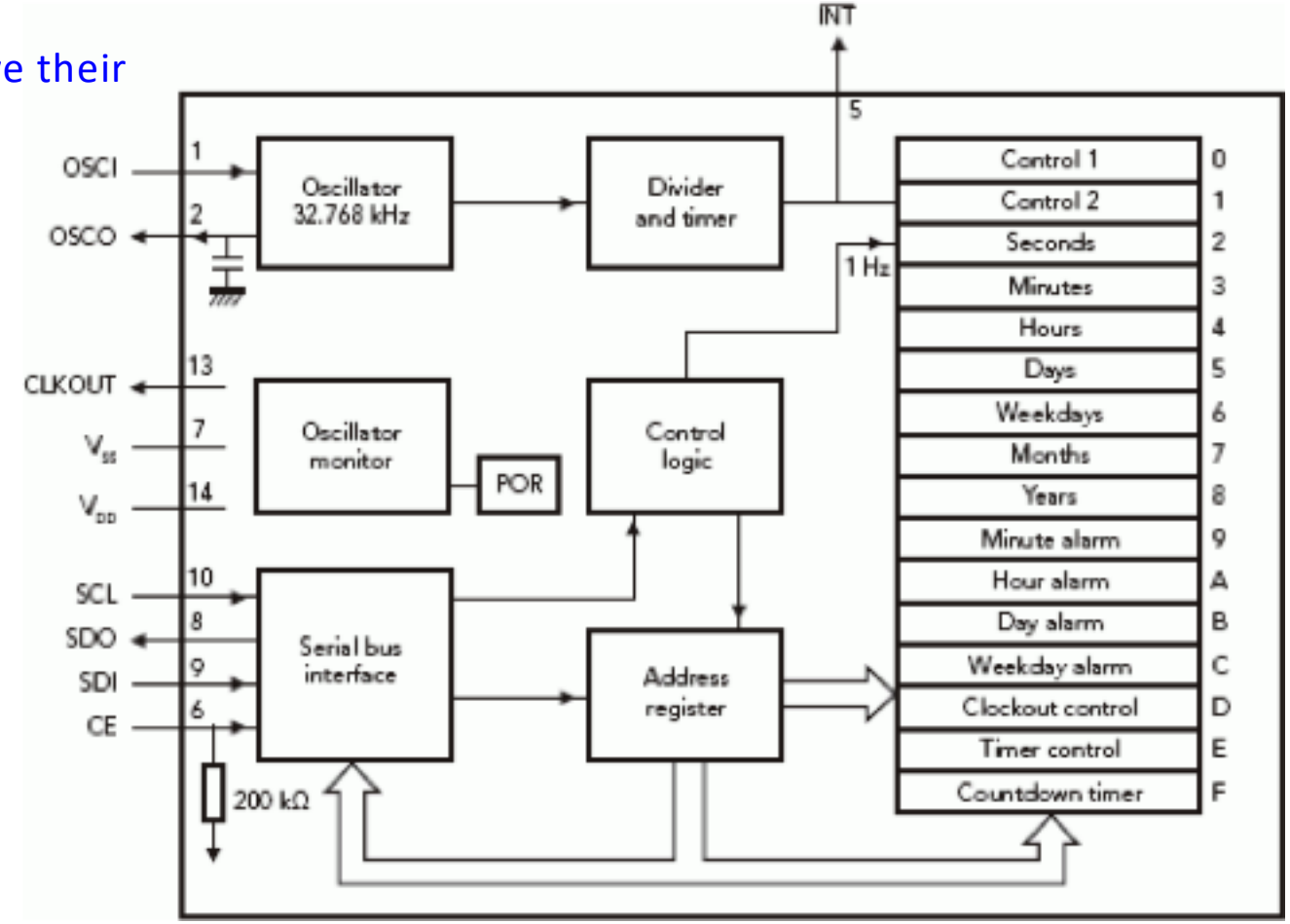


The reason the 32,768 Hz resonator has become so common is due to a compromise between the large physical size of low frequency crystals and the large current drain of high frequency crystals.

Figure adapted from Prabal Dutta's EE373 slides

Interrupts

How peripherals notify the CPU that their state just changed.

Example: A button just pressed

Interrupts

- Definition
  - An event external to the currently executing process that causes a change in the normal flow of instruction execution; usually generated by hardware devices external to the CPU.
  - Key point is that interrupts are asynchronous w.r.t. current process
  - Typically indicate that some device needs service

Why interrupts?

- MCUs have many external peripherals
  - Keyboard, mouse, screen, disk drives, scanner, printer, sound card, camera, etc.
  - These devices occasionally need CPU service
    - But we can't predict when
  - We want to keep the CPU busy (or asleep) between events
  - Need a way for CPU to find out devices need attention

Possible Solution: Polling

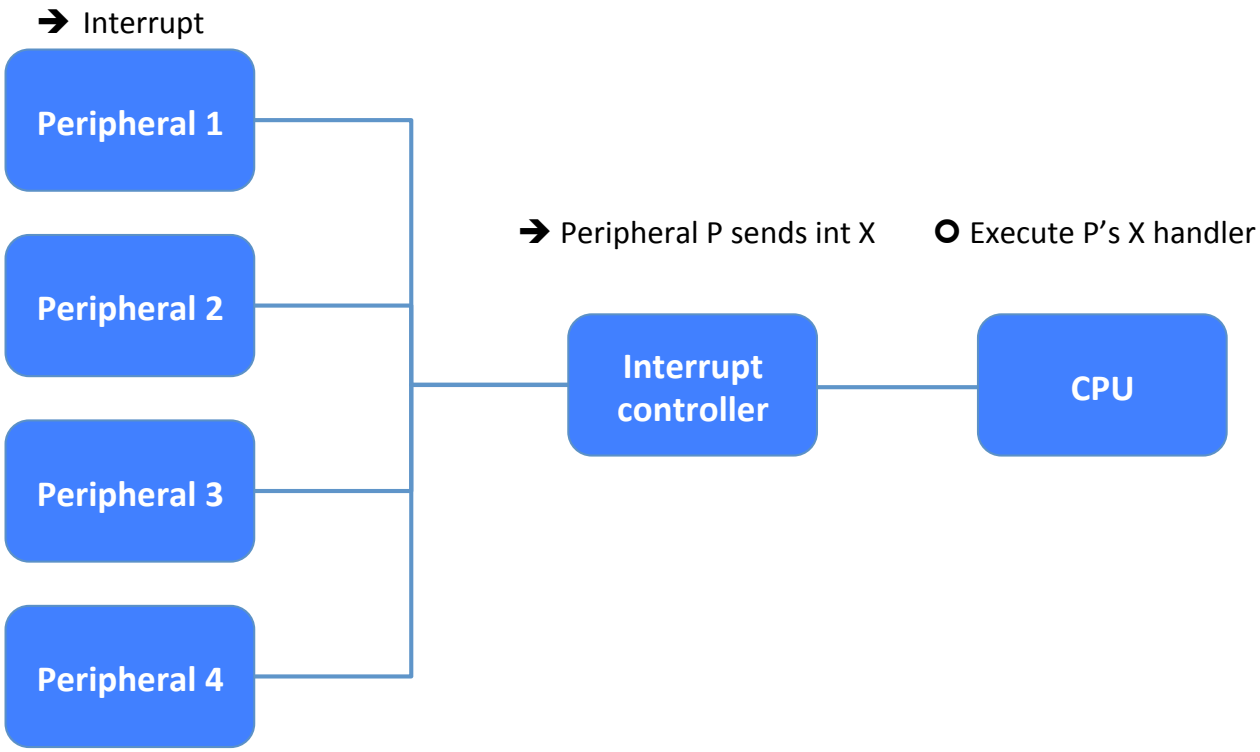
- CPU periodically checks each device to see if it needs service
  - "Polling is like picking up your phone every few seconds to see if you have a call. …"

Possible Solution: Polling

- CPU periodically checks each device to see if it needs service
  - "Polling is like picking up your phone every few seconds to see if you have a call. …"
  - Cons: takes CPU time even when no requests pending
  - Pros: can be efficient if events arrive rapidly

Alternative: Interrupts

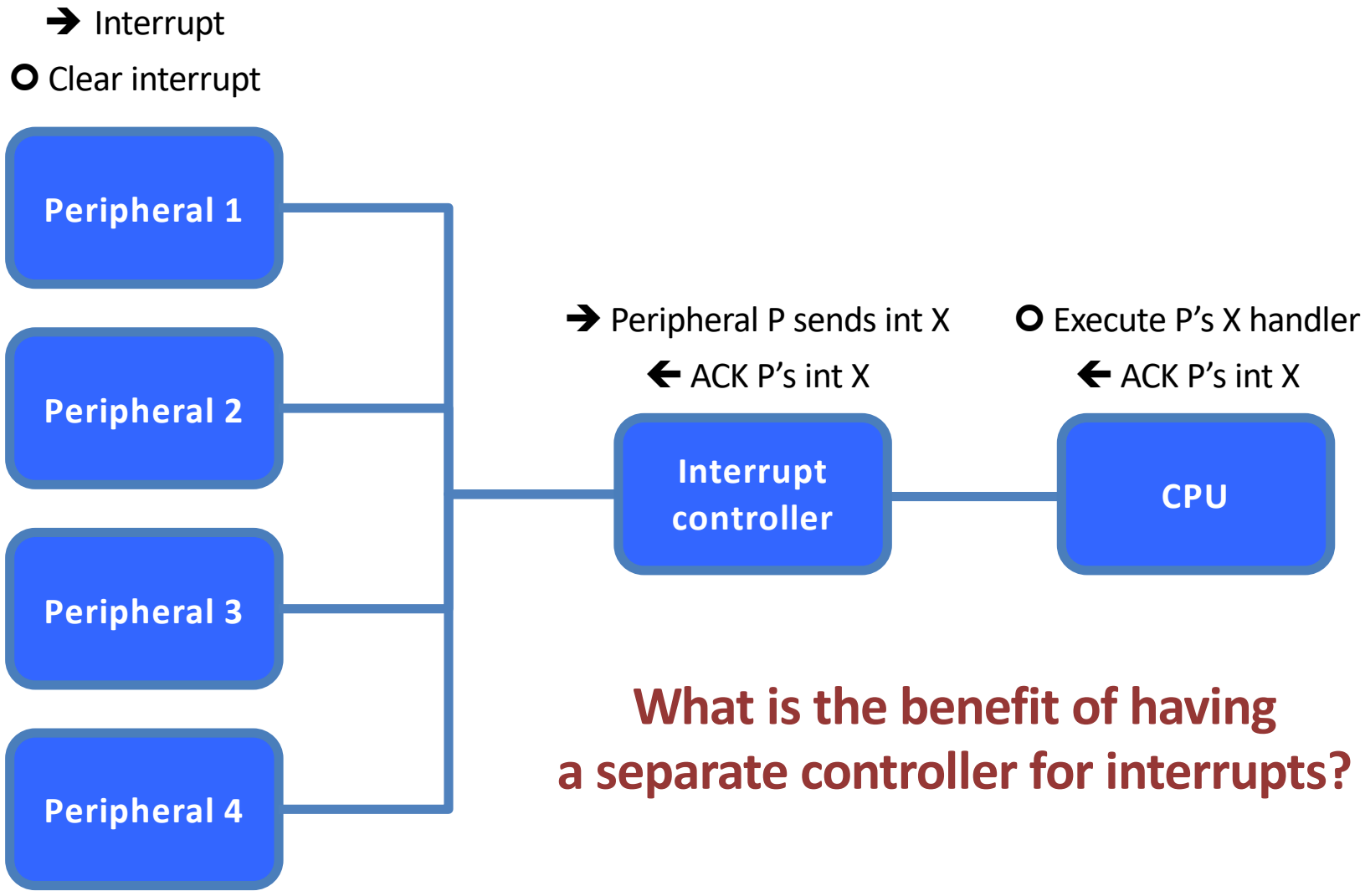
- Give each device a wire (interrupt line) that it can use to signal the processor



Alternative: Interrupts

- Give each device a wire (interrupt line) that it can use to signal the processor
  - When interrupt signaled, processor executes a routine called an interrupt handler to deal with the interrupt
  - No overhead when no requests pending

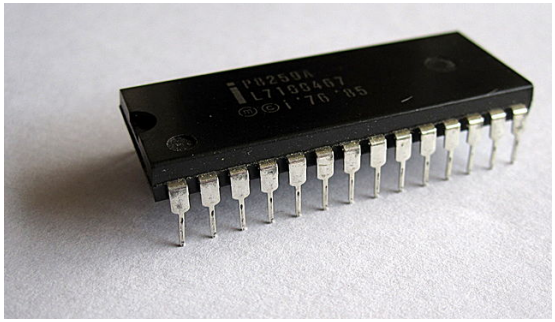
How do interrupts work?



The Interrupt controller

- **Handles simultaneous interrupts**
  - Receives interrupts while the CPU handles interrupts
- **Maintains interrupt flags**
  - CPU can poll interrupt flags instead of jumping to a interrupt handler
- **Multiplexes many wires to few wires**
  - CPU doesn't need a interrupt wire to each peripheral

Fun fact: Interrupt controllers used to be separate chips!



Intel 8259A IRQ chip

Image by Nixdorf - Own work

How to use interrupts

1. Tell the peripheral which interrupts you want it to output.
2. Tell the interrupt controller what your priority is for this interrupt.
3. Tell the processor where the interrupt handler is for that interrupt.
4. When the interrupt handler fires, do your business then clear the int.

CPU execution of interrupt handlers

INTERRUPT

1. Wait for instruction to end
2. Push the program counter to the stack
3. Push all active registers to the stack
4. Jump to the interrupt handler in the interrupt vector
5. Pop the program counter off of the stack