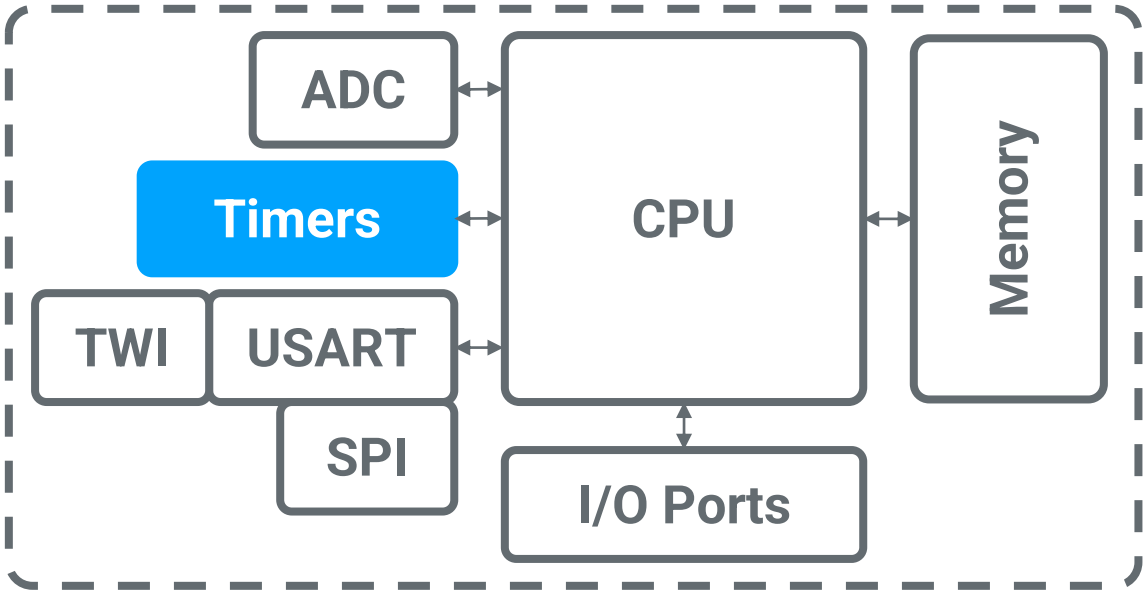
LECTURE VII

Timers and Interrupts

SECTION I

Timers

Timers



Timers are used by the microcontroller to **control the timing** of program execution or output signals and to **measure time**.

Types of Timers

- Timer types can be distinguished by when the **timeout** triggers
  - A **timeout** is an event that occurs after a preset period of time
- A **one-shot timer** has a single timeout
  - For the timer to be run again, it must be **reloaded manually**
  - Ex) A countdown timer runs just once, stopping when it reaches zero
- A **periodic** (or **auto-reload**) **timer** has *periodic* timeouts that occur at a fixed interval
  - The timer **reloads automatically**
  - Ex) An alarm clock rings once every morning

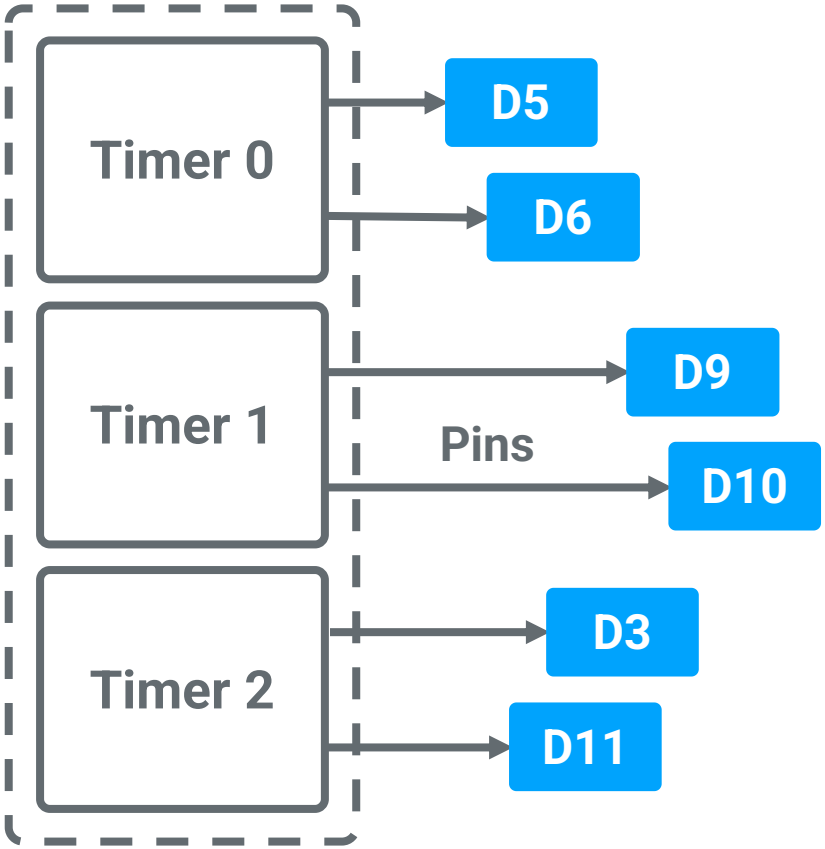
Timer Use Cases

- **Pausing/delaying the program**
  - `delay` uses a timer to suspend code execution for a specific period of time (Arduino)
  - This is considered a **blocking** timer function since it *blocks* program execution
- **Measuring time**
  - `millis` uses a timer to count the number of milliseconds since the program began (Arduino)
  - This is a **non-blocking** timer function since the program continues to execute as the timer runs

Timer Use Cases (Cont'd)

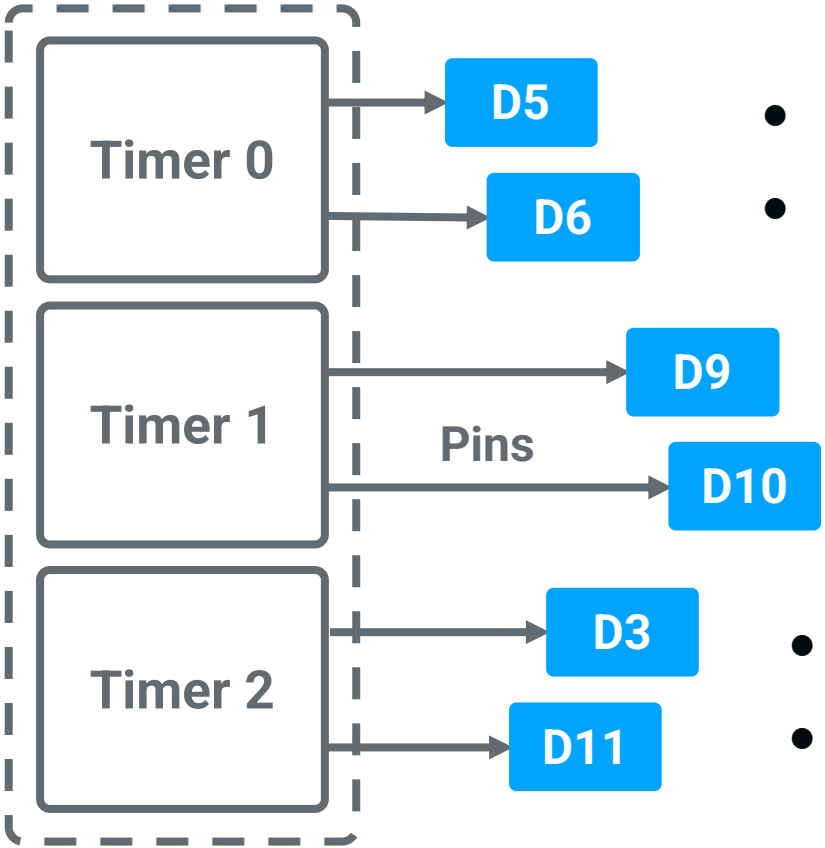
- **Calling a function upon timeout**
  - When the timer suspends, we may want specific instructions to occur. In which case, we call a function to *handle* the event
  - We'll discuss this use case in the **Interrupts** section…
- **Generating a PWM signal**
  - `analogWrite` uses a timer to time the rising and falling edges of the PWM waveform (Arduino)
  - See more in the Microcontroller Architecture and Arduino lecture…

Arduino Nano Timers



- The Arduino Nano has three **general purpose timers** (**GPTs**)
  - These timers are modules in the MCU used for various functions, PWM, and delays
  - Digital pins are capable of carrying the output of the timer to which they are connected
    - A pin used for timer output cannot also be used for a different purpose at the same time

Arduino Nano Timers (Cont'd)

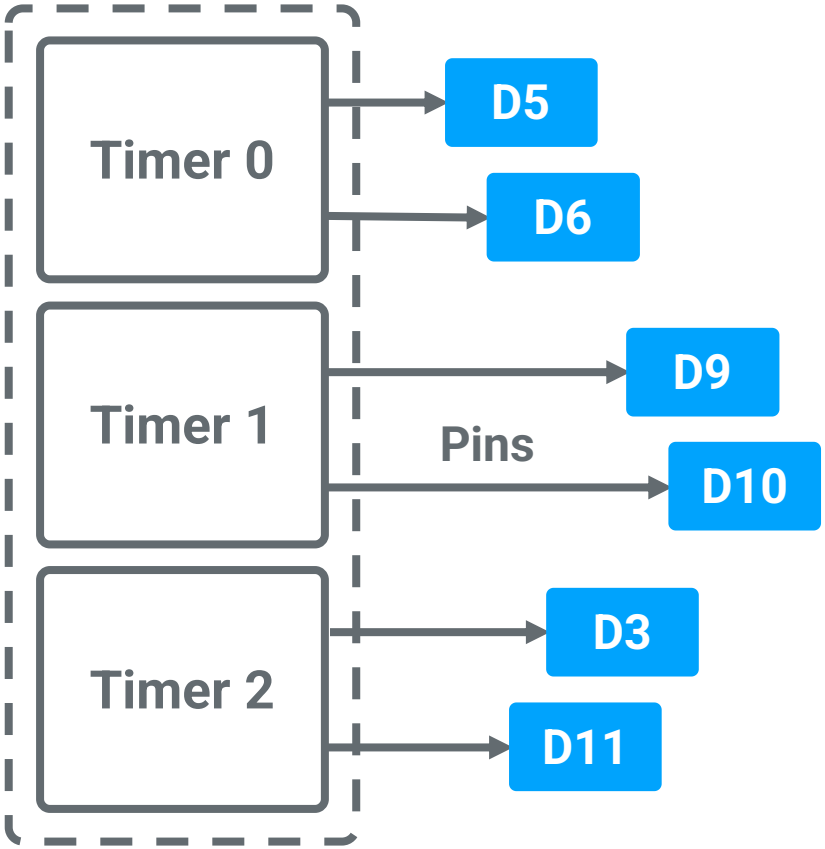


- 8-bit resolution
- Used by `delay` and `millis`

- **16-bit resolution**
- Used by Arduino Servo library

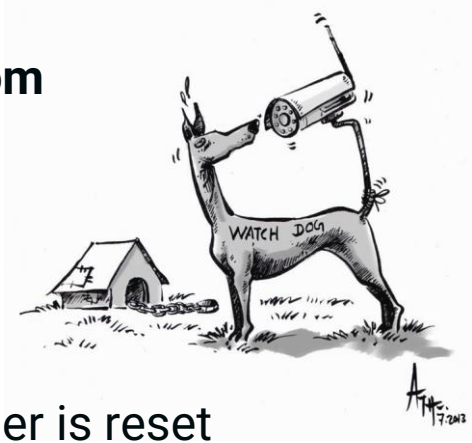
- 8-bit resolution
- Used by `tone`

Arduino Nano Timers (Cont'd)



- You only have three timers!
  Use them wisely
  - If two functions attempt to use the same timer for different purposes… unexpected behavior may occur

Arduino Nano Timers (Cont'd)



- A **watchdog timer** (**WDT**) is used to **detect and recover from** software or hardware **errors**
  - How it works:
    i. The WDT counts down to zero
    ii. Each time the program's main loop is run, the timer is reset
    iii. If the WDT reaches zero before its reset, then the WDT resets the entire processor
  - This is **not a perfect solution**! If a program loop takes a long time to execute, the WDT incorrectly assumes a fault, and the program is reset

SECTION II

Arduino Timer Library

Arduino Timer Library

- We will use one of the Arduino's internal timers to **measure time**
  - To do so, we will enlist the help of the Timer library, which will need to be downloaded and installed to the Arduino IDE
  - Make sure to use `#include <Timer.h>`
- If you would like to explore how timers can be used to call other functions, check out the TimerInterrupt library
  - We will not discuss it in this lecture

Arduino Timer Library (Cont'd)

- First, instantiate a `Timer` object as `Timer timer;`
  - Each of the following are member functions that can be called from this object
  - Time is **measured in milliseconds** by default
    - Alternatively, you can pass `MICROS` as a single argument to the constructor to measure in microseconds
- `timer.start()` starts the timer
  - The timer is in the `RUNNING` state

Arduino Timer Library (Cont'd)

- `timer.pause()` pauses the timer
  - The timer is in the `PAUSED` state
  - The time elapsed since `timer.start()` freezes
- `timer.resume()` resumes the timer from the `PAUSED` state
  - The timer is in the `RUNNING` state
  - The time elapsed since `timer.start()` resumes counting

Arduino Timer Library (Cont'd)

- `timer.stop()` stops the timer
  - The timer is in the `STOPPED` state
  - The time elapsed since `timer.start()` will be the reset the next time the `timer.start()` is called
- `timer.read()` returns the time elapsed since `timer.start()`
  - Measured in milliseconds
- `timer.state()` returns the state as one of three predefined constants
  - The state can be `RUNNING`, `PAUSED`, or `STOPPED`

SECTION III

Interrupts

Interrupts

- An **interrupt** is a request for the CPU to **halt the currently executing code** when an event occurs
  - The CPU suspends the current program to *handle* the event by executing a function called an **interrupt handler** or **interrupt service routine** (**ISR**)
  - When the interrupt handler finishes execution, the CPU returns to the old program

Types of Interrupts

- A **software interrupt** is triggered by an instruction
  - Also called a **trap** or **exception**
  - Often caused by an illegal operation
    - Ex) Dividing by zero, Accessing memory without permission
- A **hardware interrupt** is triggered by devices external to the CPU
  - Also called an **external interrupt**
  - Caused when a devices sends an **interrupt request** (**IRQ**) signal to the CPU
    - Ex) Timer timeout, button press, power failure

Polling

- **Polling** is a method of periodically checking the status of a device
  - Ex) A person checking their phone for new messages every 10 minutes
  - Polling loops cost additional CPU time
- Should we use interrupts instead of polling?
  - Interrupts signal *when* an event occurs whereas polling *checks* to see if an event occured
    - Ex) A person reading their phone upon receiving a push notification
  - **Use interrupts when an event is urgent and/or infrequent**

Interrupt Use Cases

- **Servicing timers**
  - When a timeout occurs, the programmer may want specific code to be run
    - This is when the timer sends an IRQ and an interrupt handler is called
- **Handling peripheral device events**
  - Ex) When a key is pressed, the keyboard sends an IRQ to the computer
    - An interrupt handler then responds to the event

SECTION IV

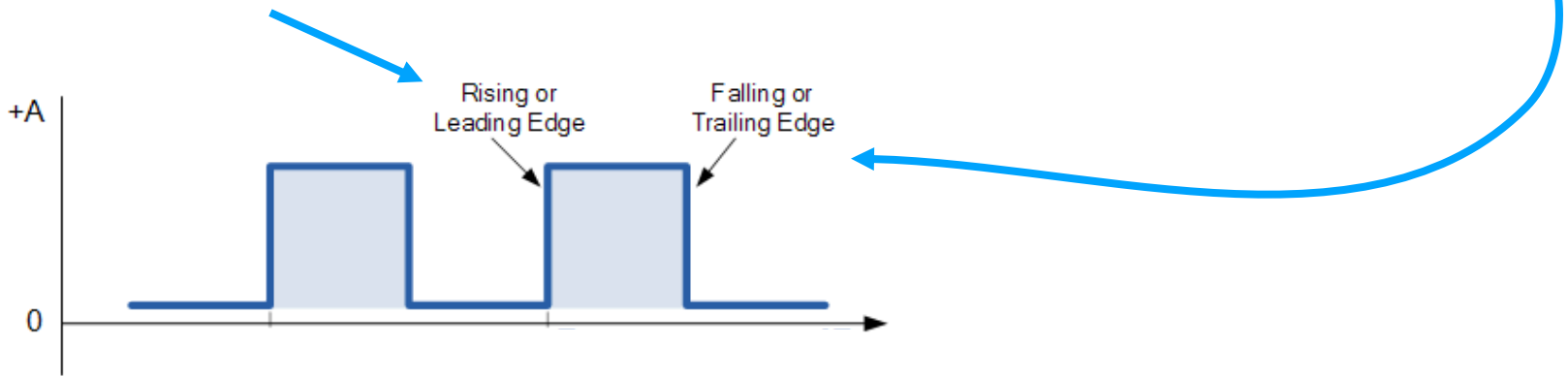
Interrupts with Arduino

attachInterrupt

- Only Arduino Nano **digital pins D2** and **D3** can be used for external interrupts
- `void attachInterrupt(interrupt, ISR, mode)`
  - This function initializes an interrupt
  - *`interrupt`* - the interrupt number (**not a pin number**); only one interrupt can be initialized per interrupt number
  - *`ISR`* - the name of the function to call as the interrupt handler
    - You need to define a function and pass its name as *`ISR`*
  - *`mode`* - configures the timing of the IRQ
    - You will set the mode to one of the following constants…

`attachInterrupt` (Cont'd)

- The options for ***`mode`*** are…
  - **`LOW`** - when the pin is a LOW voltage
  - **`CHANGE`** - when the pin changes value
  - **`FALLING`** - when the pin voltage changes from HIGH to LOW
  - **`RISING`** - when the pin voltage changes from LOW to HIGH



`attachInterrupt` (Cont'd)

- `void digitalPinToInterrupt(pin)`
  - This function converts a digital pin number to its corresponding interrupt number
- It is **recommended that you call `attachInterrupt` as follows:**
  - `attachInterrupt(digitalPinToInterrupt(pin), ISR, mode)`
  - This approach avoids confusion involving digital pin and interrupt numbers

SECTION V

Arduino Interrupt Exercise

Arduino LED Toggle Button

I/A

Write a program that satisfies the following requirements:

- You must write a program in which the **Arduino board toggles the state of its built-in LED (D13) when a button is pressed**
- The state of the LED must toggle only once for each button press
    - Meaning… The LED should not flicker ON and OFF if the button is held down
- This program must be implemented with `attachInterrupt`
- No loops may be used (that includes the main `loop`)
- No starter code!

“Ask not what your **interrupt** can do for you; ask what you can do when your **interrupt fires unexpectedly**.”

John F. Kennedy (circa 1961)

Famous Misquotes

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