

## LECTURE VII

# Timers and Interrupts

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## **SECTION I**

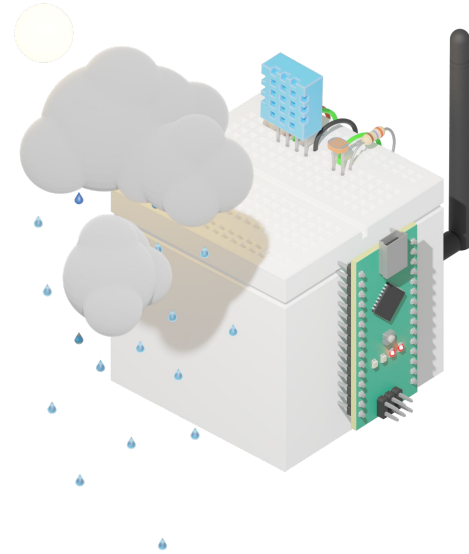
# **Project VI Review**

# Project 6 Review

- Build a **weather station** that wirelessly transmits **temperature** and **humidity data** to an indoor display.
- Due date: 2/14/2025 at 11:59PM

## Learning Concepts:

- Communication Protocols Pt. 2
- I<sup>2</sup>C Protocol
- SPI Protocol
- Arduino IDE Libraries (Continued)

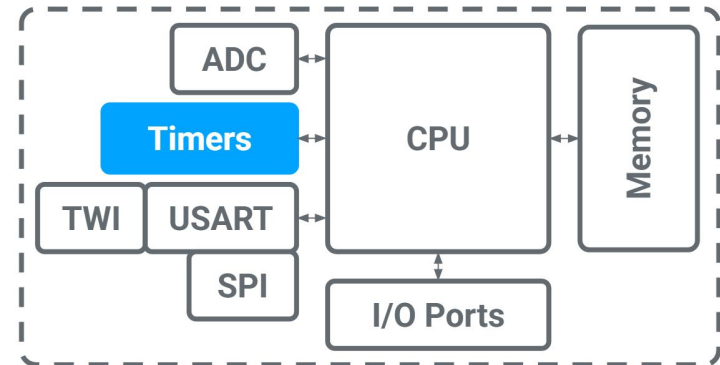
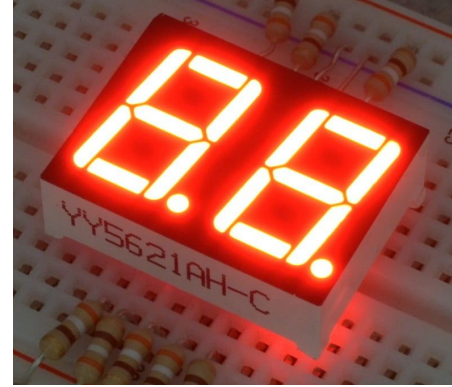


# Project 7

- Create a **digital stopwatch** using interrupts, timers, and a 7-segment display
- Due date: 2/28/2025 at 11:59PM

## Learning Concepts:

- Interrupts
- Timers
- Arduino IDE Libraries (Continued)



# IEEE Board Applications

- IEEE board applications are now open!
- If you have enjoyed OPS or are interested in gaining leadership experience in a teaching role, look no further!
- We urge those of you with a passion for learning to apply for either **OPS Lab Supervisor** or **OPS Lab Instructor**
- Applications are due **February 19th at 11:59PM**



The poster features a dark, textured background with a blue IEEE logo in the top left corner. The main text, '2025-2026 IEEE BOARD APPLICATIONS ARE OPEN !!', is written in large, bold, blue letters with a slight 3D effect. Below the text is a photograph of four students in blue IEEE shirts sitting at a long table with laptops. To the right of the photo is a list of positions under the heading 'WE ARE LOOKING FOR:'. At the bottom, the deadline 'DUE BY: FEBRUARY 19TH @ 11:59 PM' and the application link 'APPLICATION LINK: https://bit.ly/ieeeboardapp25' are provided, along with a note to check Discord announcements.

**2025-2026  
IEEE  
BOARD  
APPLICATIONS  
ARE OPEN !!**

**WE ARE LOOKING FOR:**

- MICROMOUSE STAFF
- OUTREACH COORDINATOR
- OPS LAB INSTRUCTOR
- OPS LAB SUPERVISOR
- SECRETARY
- iFamIEEE Coordinator
- EVENT COORDINATOR
- MEDIA COORDINATOR
- WEBMASTER
- PROJECT COORDINATOR
- LAB MANAGER

**DUE BY: FEBRUARY 19TH @ 11:59 PM**

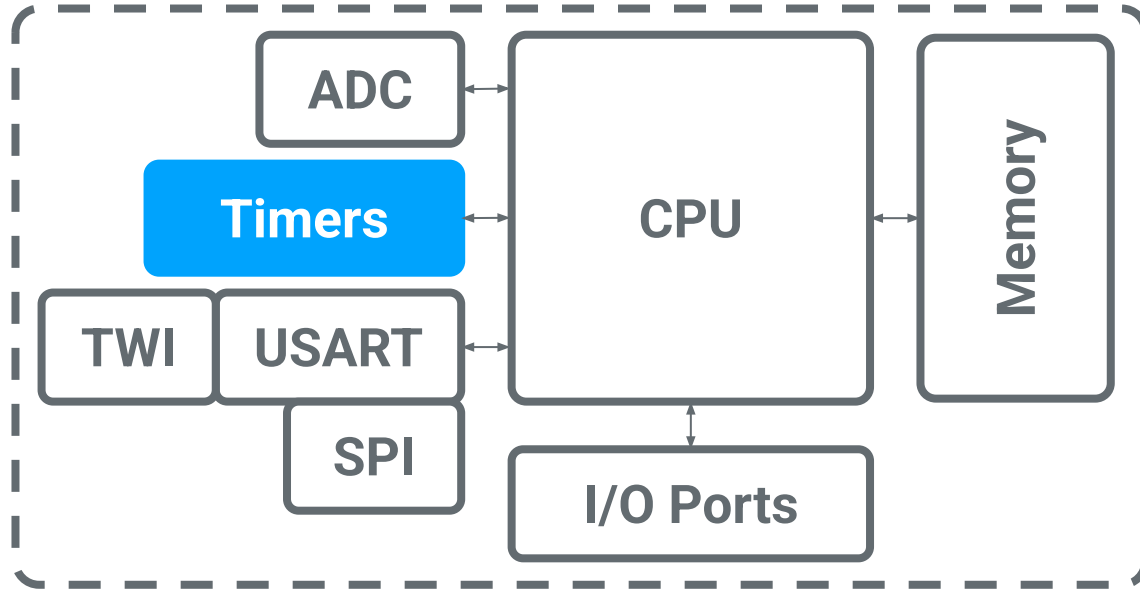
**APPLICATION LINK:** <https://bit.ly/ieeeboardapp25>

For more info, check out our Discord announcements!

## SECTION II

# Timers

# Timers



**Timers** are used by the microcontroller to **control the timing** of program execution or output signals and to **measure time**. Based on microcontroller's clock cycle

# 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...

# ESP32c3 Timers

## Timer Group 0

Timer 0  
(T0)

Watchdog  
Timer  
(WDT)

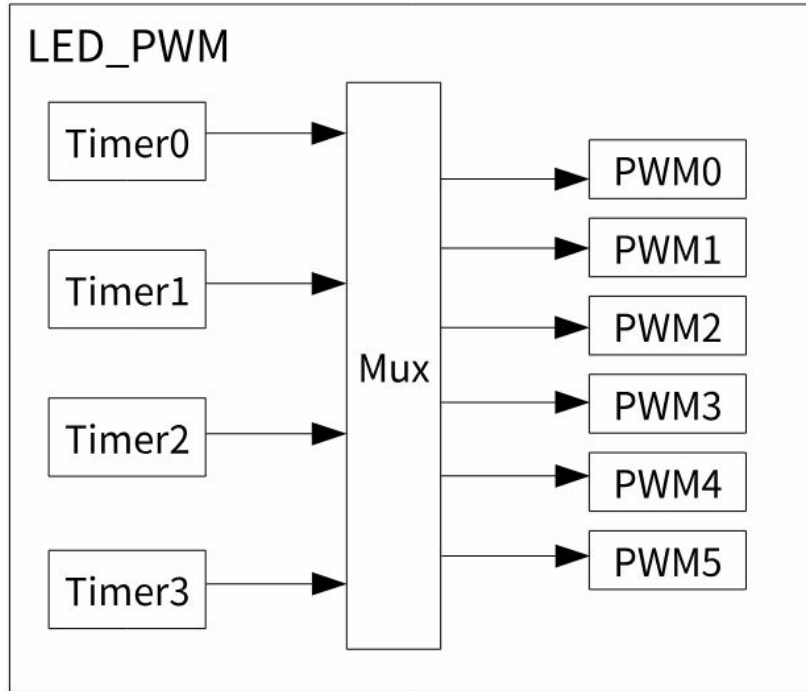
## Timer Group 1

Timer 0  
(T0)

Watchdog  
Timer  
(WDT)

- The ESP32c3 has two **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
  - There are more timers than this for other functions!

# Arduino Nano Timers (Cont'd)

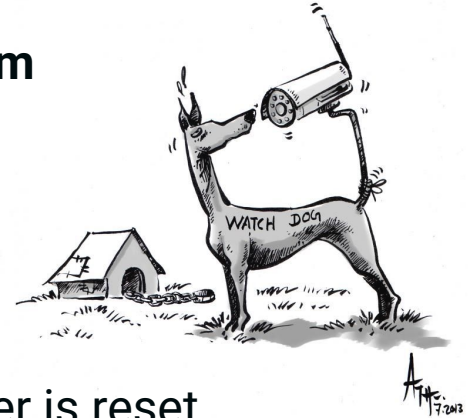


## Some other timers

- System timer
  - 52 bit timer
  - Used for interrupts
  - Used by **delay** and **millis**
- LED\_PWM
  - For duty cycle and frequency
  - 16-bit resolution

# 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 III**

# **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 IV

# 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 an interrupt halts the current code, a separate program / function can be called and run.
  - When the interrupt handler finishes execution, the CPU returns to the old program

# 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
    - We have been using polling in the `void loop()`
  - 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 occurred
    - Ex) A person reading their phone upon receiving a push notification
  - **Use interrupts when an event is urgent and/or infrequent**

# 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 device sends an **interrupt request (IRQ)** signal to the CPU
    - Ex) Timer timeout, button press, power failure

# 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 V**

# **Interrupts with Arduino**

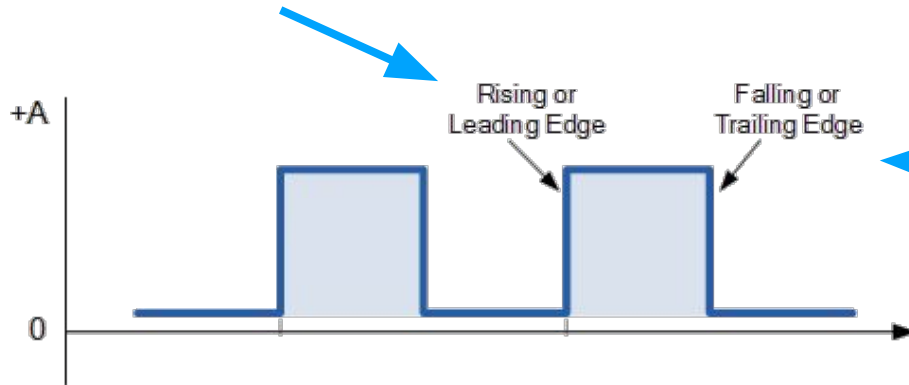


# attachInterrupt

- Any GPIO pin on the ESP32 can be an interrupt pin
- `void attachInterrupt(interrupt, ISR, mode)`
  - This function initializes an interrupt
  - *interrupt* - the interrupt number); only one interrupt can be initialized per interrupt number
    - The interrupt # should be the same for ESP32, but this is not always true.
  - *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 VI

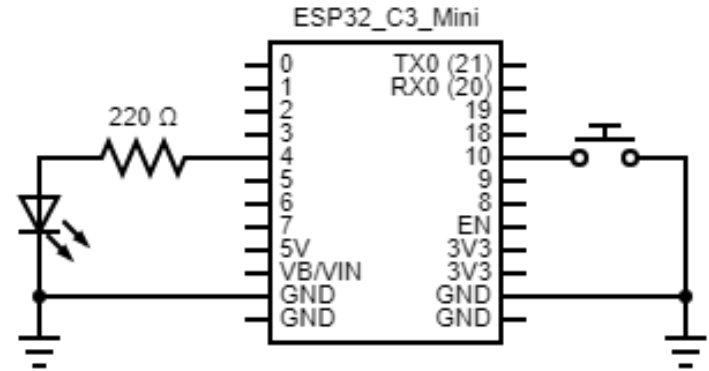
# ESP32 Interrupt Exercise

# ESP32 LED Toggle Button

I/A

Write a program that satisfies the following requirements:

- You must write a program in which the **ESP32 board toggles the state of its LED (on pin 4) 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!



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