

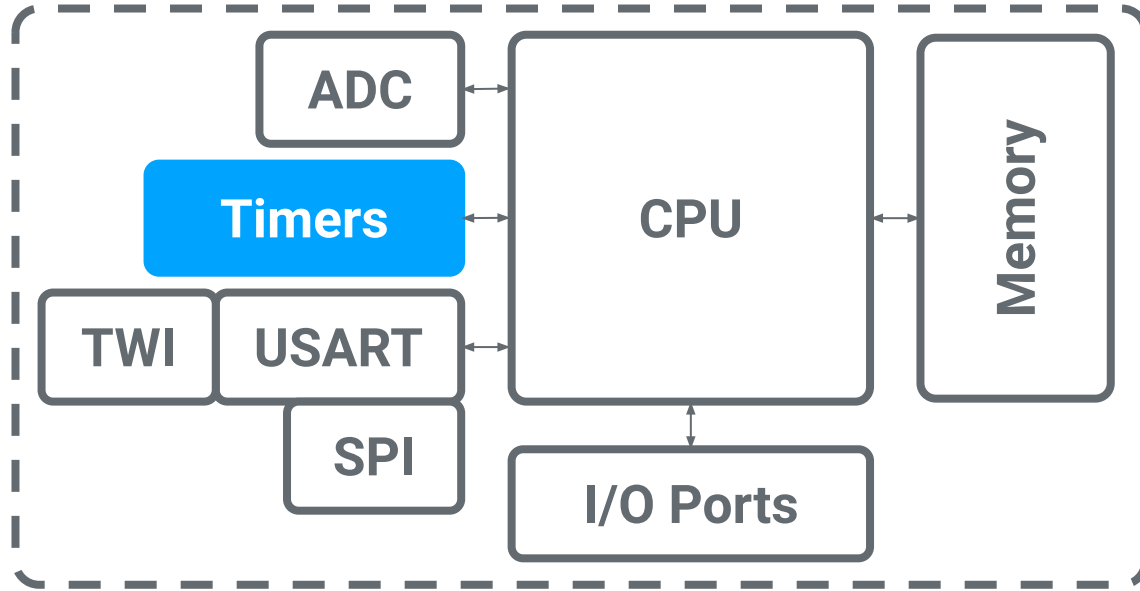
LECTURE VII

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

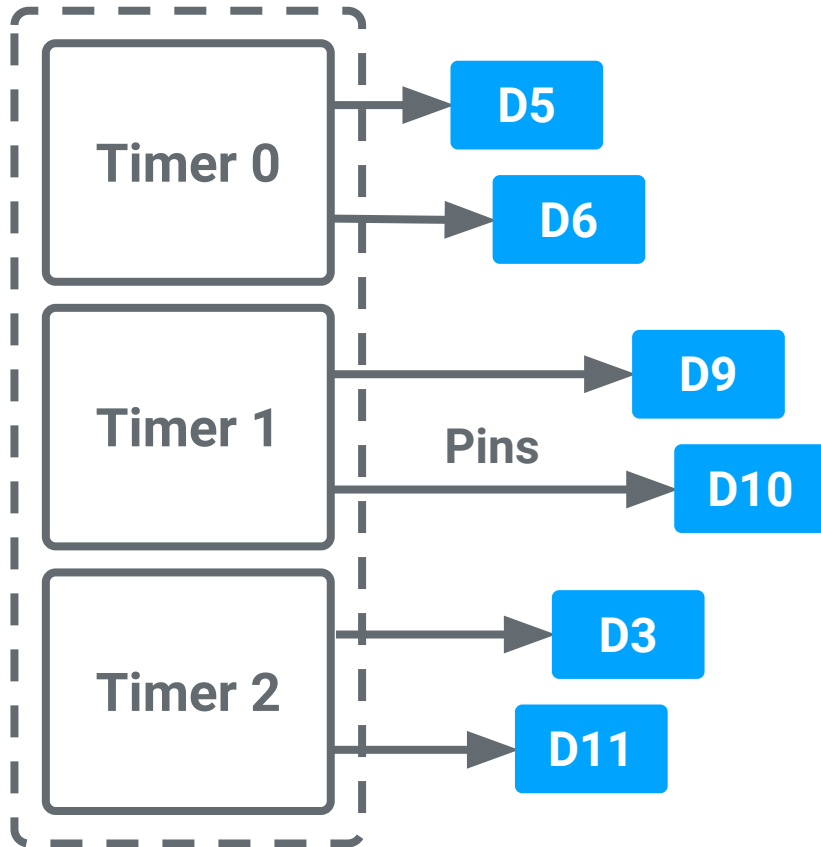
- **Measuring time**

- **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)

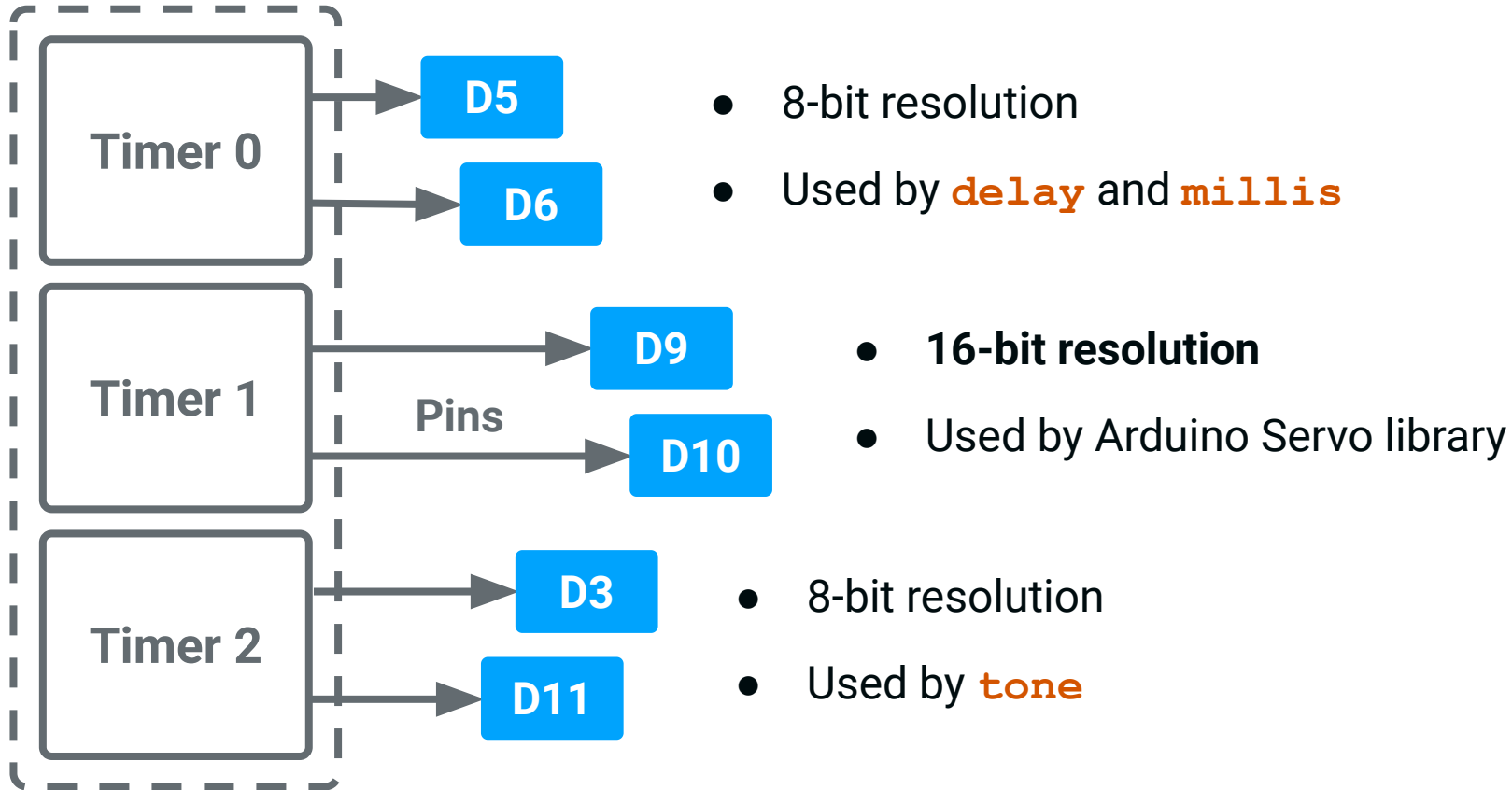
- **Calling a function upon timeout**
 - When the timer suspends, we may want specific instructions to occur. In which case, we call a function to *handle* the event
 - We'll discuss this use case in the **Interrupts** section...
- **Generating a PWM signal**
 - **analogWrite** uses a timer to time the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

Arduino Nano Timers

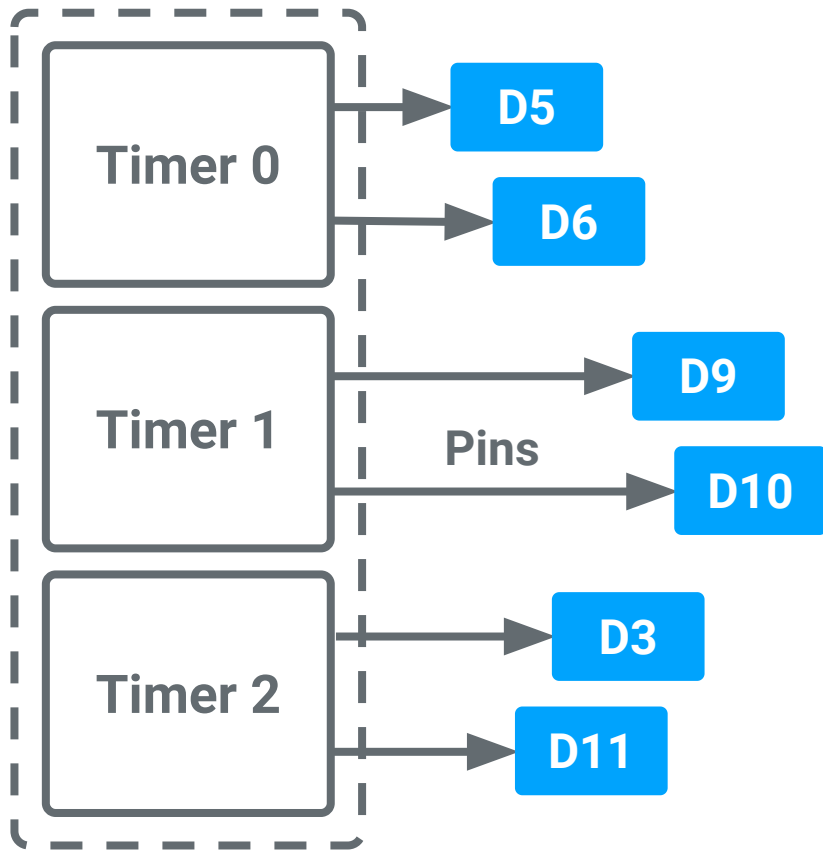


- The Arduino Nano has three **general purpose timers (GPTs)**
 - These timers are modules in the MCU used for various functions, PWM, and delays
 - Digital pins are capable of carrying the output of the timer to which they are connected
- A pin used for timer output cannot also be used for a different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

Arduino Nano Timers (Cont'd)



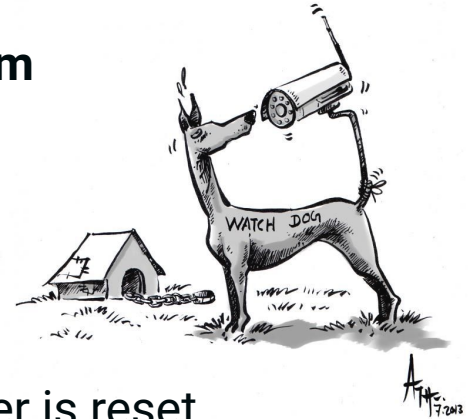
Arduino Nano Timers (Cont'd)



- 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 device 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 occurred
 - 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

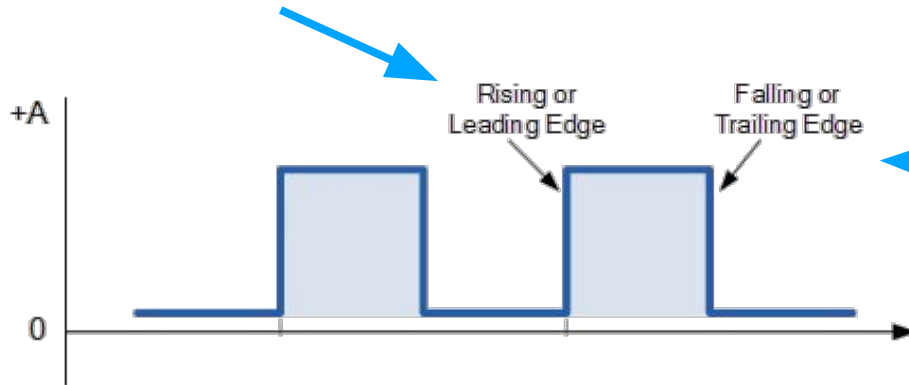
Interrupts with Arduino

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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