Timer Interrupts

ECE 476 Advanced Embedded Systems

Jake Glower - Lecture #17

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Introduction:

The previous lecture covered edge interrupts

- Subroutine called by hardware
- Triggered by a rising or falling edge

This lecture looks at timer interrupts

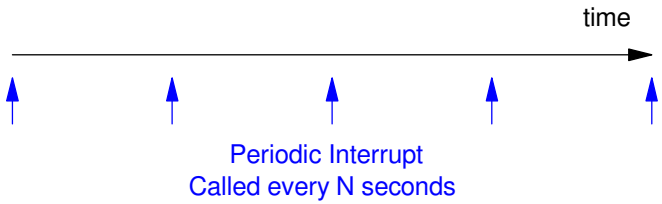
- Interrupts triggered every N seconds
- Interrupts triggeded N seconds from now

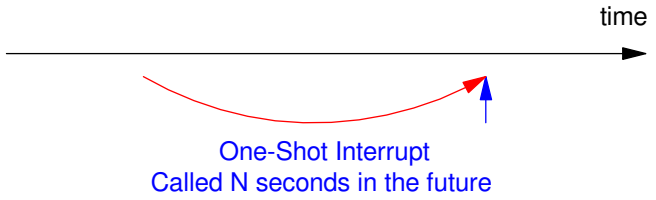
Timer interrupts are useful:

- More efficient & accurate version of sleep()
- More precise timing of the main loop
- Processor isn't shut down like sleep()

With timer interrupts, you can

- Build an automated stoplight
- Sample a voltage every N ms
- Implement a digital filter





In this lecture, we'll go over

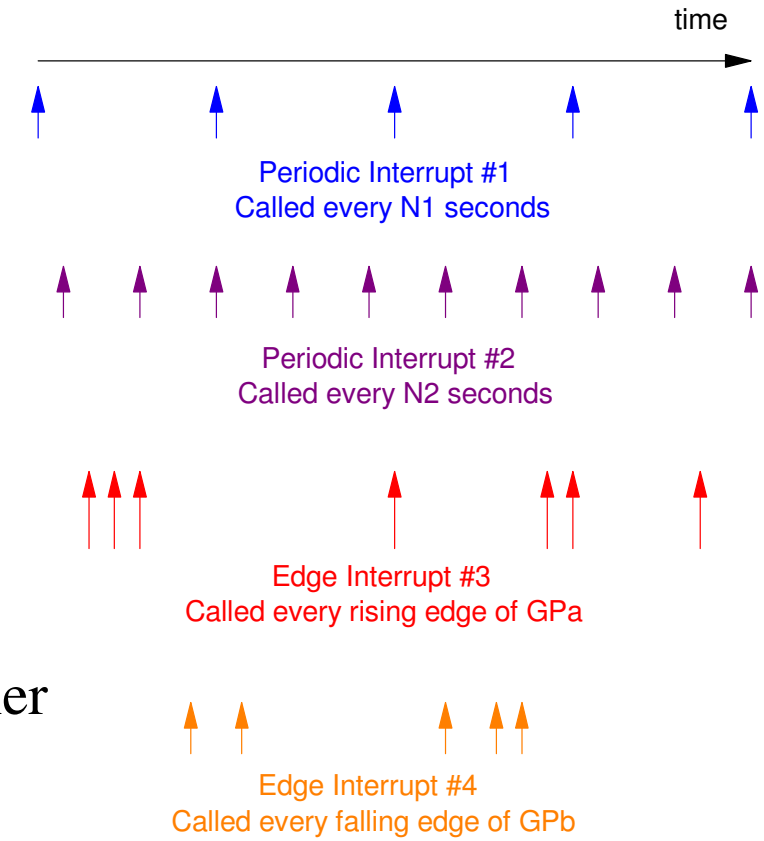
- What Timer interrupts are,
- How they're set up,

and some things you can do with them

- Implement a Ton() function:
  - A button has to be held down for T seconds
- Implement a Toff() function:
  - An output remains on for T seconds
- Set the timing for a stoplight
- Set the timing of a game
  - play *hungry hungry hippo* for 10.00 seconds

Note: Interrupts don't interfere with each other

- You can turn on multiple timer interrupts
- You can turn on multiple edge interrupts
- All at the same time



Turning On Periodic Timer Interrupts

Starting out, let's just turn on a timer interrupt

- Count once per second

Timer interrupts are similar to edge interrupts:

- Called by hardware
  - one second elapses
- Global variables are needed
  - pass data to the main routine
- Only called when needed
  - The main loop is free to do whatever between interrupts
  - Different from sleep(1)

```
from machine import Pin, Timer
from time import sleep_ms

led = Pin(17, Pin.OUT)
tim = Timer()
N = 0

def tic(timer):
    global N
    N += 1

tim.init(freq=1, mode=Timer.PERIODIC,
callback=tic)

while(1):
    print(N)
    sleep_ms(100)
```

Timer Interrupts

Program Desciption:

- Timer
  - timer interrupt function
  - low-level routine from machine
- N
  - Global variable
  - Passes the count to the main routine
- tick(time):
  - Interrupt service routine
- freq=1
  - interrupt is called every 1Hz
- mode=Timer.PERIODIC
  - called over an over again
- mode=Timer.ONE_SHOT
  - called just once

```
from machine import Pin, Timer

led = Pin(17, Pin.OUT)
tim = Timer()
N = flag = 0

def tick(timer):
    global N
    global flag
    N += 1
    flag = 1

tim.init(freq=1, mode=Timer.PERIODIC,
callback=tick)

while(1):
    if(flag):
        flag = 0
        print(N)
```

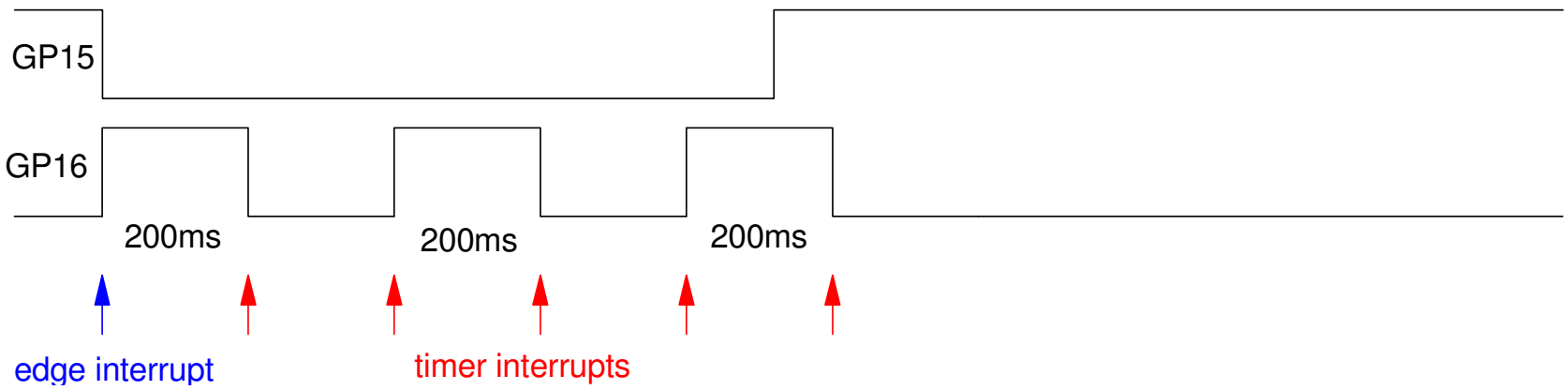
Program 2: Fire Cheat:

Both edge and timer interrupts can be used

- Interrupts do not conflict

Example: Fire-Button Cheat

- When GP15 is pressed, (falling edge interrupt)
- Three pulses are output of GP16 (three shots using a timer interrupt)
- Each shot should be on for 200ms and off for 200ms



Fire Cheat

Fire

- Falling Edge interrupt
- Initializes N = 5
  - five toggles coming up
- Initializes timer interrupts
  - 5Hz (200ms)
  - periodic

Tic

- Timer interrupt
- Decrements N down to zero
- If on last toggle (N==1)
  - Makes next interrupt a one-shot

Main Loop

- Doesn't do anything
- Interrupts do all the work
- The flag isn't needed
  - just prints on toggles

```
from machine import Pin, Timer
from time import sleep_ms

tim = Timer()
flag = N = 0
pin1 = Pin(15,Pin.IN,Pin.PULL_UP)
LED  = Pin(16,Pin.OUT)

def Fire(pin1):
    global N, flag
    LED.value(1)
    if(N == 0):
        N = 5
        flag = 1
        tim.init(freq=5, mode=Timer.PERIODIC,
callback=Tic)

def Tic(timer):
    global N, flag
    if(N):
        flag = 1
        N -= 1
        LED.toggle()
        if(N == 1):
            tim.init(freq=5,
mode=Timer.ONE_SHOT, callback=Tic)
    else:
        LED.value(0)

pin1.irq(trigger=Pin.IRQ_FALLING, handler=Fire)

while(1):
    if(flag):
        flag = 0
        print(LED.value(), N)
```

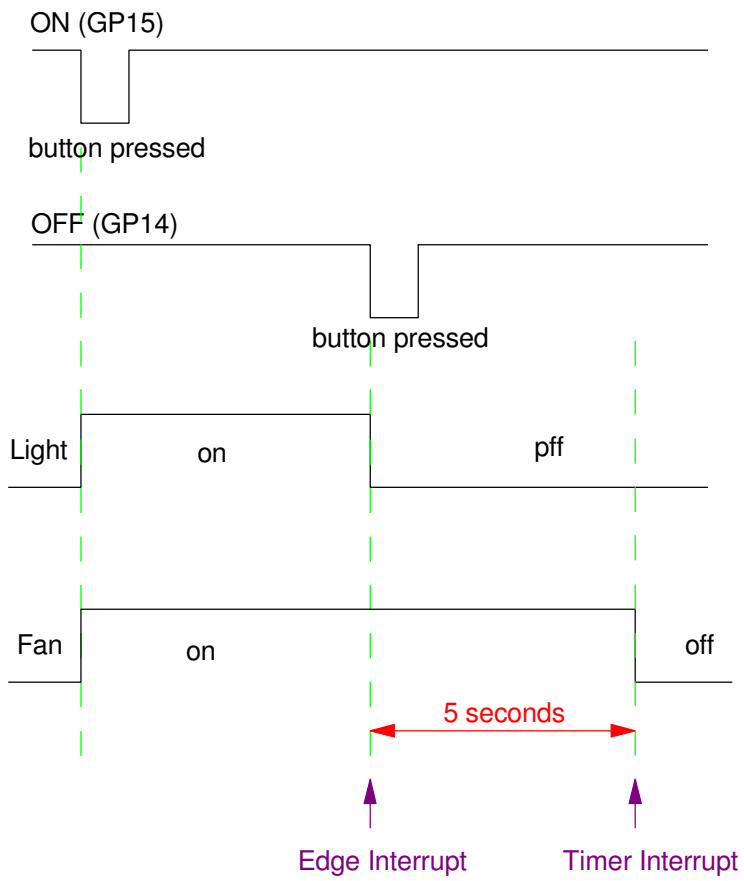
Toff: Bathroom Light & Fan:

The ONE_SHOT feature allows you to set up events N seconds ahead

Example: Bathroom light and fan

- When GP15 is pressed (on)
  - The bathroom light turns on, and
  - The bathroom fan turns on
- When GP14 is pressed (off)
  - The light turns off immediately
  - The fan turns off five seconds later

With ladder logic, this is called a Toff function



Python Code

Three interrupts are used

- On
  - Falling edge interrupt
  - Turn on the light and fan
- Off
  - Falling edge interrupt
  - Turn off the light
  - Set up a timer interrupt in 5 seconds
- Tick
  - Timer interrupt
  - Turn off the fan

Note

- This is a fairly simple program using interrupts

```
from machine import Pin, Timer
from time import sleep

tim = Timer()
N = 0
pin1 = Pin(15,Pin.IN,Pin.PULL_UP)
pin2 = Pin(14,Pin.IN,Pin.PULL_UP)
LED  = Pin(16,Pin.OUT)
Fan  = Pin(17,Pin.OUT)

def On(pin1):
    LED.value(1)
    Fan.value(1)

def Off(pin2):
    LED.value(0)

def Tick(timer):
    Fan.value(0)
    tim.init(freq=1/5, mode=Time.ONE_SHOT,
callback=Tick)
pin1.irq(trigger=Pin.IRQ_FALLING, handler=On)
pin2.irq(trigger=Pin.IRQ_FALLING, handler=Off)


while(1):
    print(LED.value(), Fan.value())
    sleep(1)
```

Ton Function

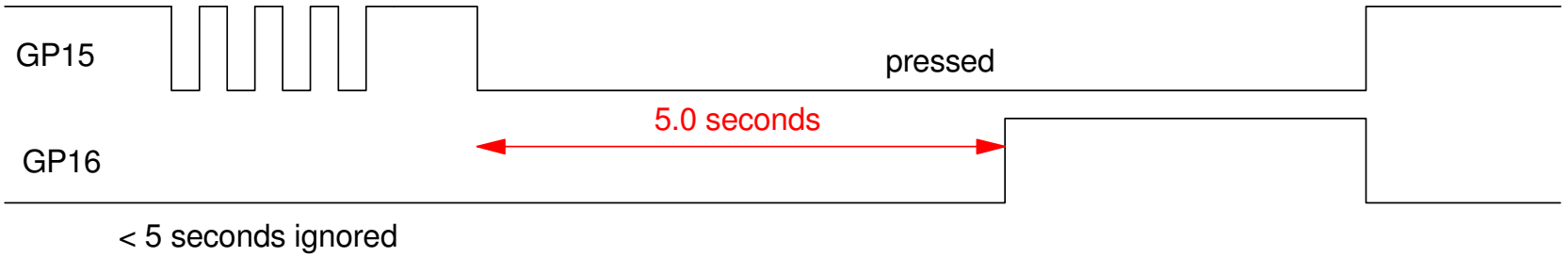
- Turn on a light if a button is held down for X seconds

Sometimes you want to require a button is held down for X seconds

- Inadvertent button presses are ignored
- In ladder logic, this is called a Ton function

For example

- Turn on a light (GP16) if a button is held down for 5.00 seconds
  - Ignore button presses shorter than 5.00 seconds
- Turn off a light as soon as the button is released



Ton Code (take 1)

There are several ways to do this.

Option #1:

- Set a timer for 10ms
- Set up a counter (TimeOn)
  - Clear the counter when button is released
  - Increment the counter when buttton is pressed
- If the counter exceeds 500 (5sec)
  - Turn on the light

- Note:
  - This code works, but it is inefficient (interupts are called every 10ms)
  - Timing is a little off (changes every 10ms)

```
from machine import Pin, Timer
import time

light = Pin(16, Pin.OUT)

tim = Timer()
TimeOn = 0

pin1 = Pin(15,Pin.IN,Pin.PULL_UP)

def Tick(timer):
    global TimeOn
    if(pin1.value() == 0):
        TimeOn += 1
    else:
        TimeOn = 0
        light.value(0)

    if(TimeOn >= 500):
        TimeOn = 500
        light.value(1)

tim.init(freq=100,
mode=Timer.PERIODIC, callback=Tick)

while (1):
    print(light.value(), TimeOn)
    time.sleep(0.1)
```

Ton Code (take 2)

- A better solution:
  - A little trickier
  - More precise

Use an edge interrupt (Light):

- If a rising edge (off)
  - turn off the light
  - Change the timer interrupt to call Light Off (light stays off)
- If a falling edge (on)
  - Turn on a timer interrupt in 5 seconds
  - Change the timer interupt to call LightOn
- Timer Interrupt
  - When timer interrupt kicks in, turn on or off the light
  - Only turns on if falling edge was detected 5.00 seconds ago

```
# Ton Function (ver 2)

from machine import Pin, Timer
import time

tim = Timer()
pin1 = Pin(15,Pin.IN,Pin.PULL_UP)
LED = Pin(16, Pin.OUT)

def Light(pin1):
    if(pin1.value() == 1):
        LED.value(0)
        tim.init(freq=5,
mode=Timer.ONE_SHOT, callback=LightOff)
    else:
        tim.init(freq=1/5,
mode=Timer.ONE_SHOT, callback=LightOn)

def LightOn(timer):
    LED.value(1)

def LightOff(timer):
    LED.value(0)

pin1.irq(trigger=Pin.IRQ_FALLING | Pin.IRQ_RISING,
handler=Light)

while (1):
    print(light.value(), TimeOn)
    time.sleep(0.1)
```

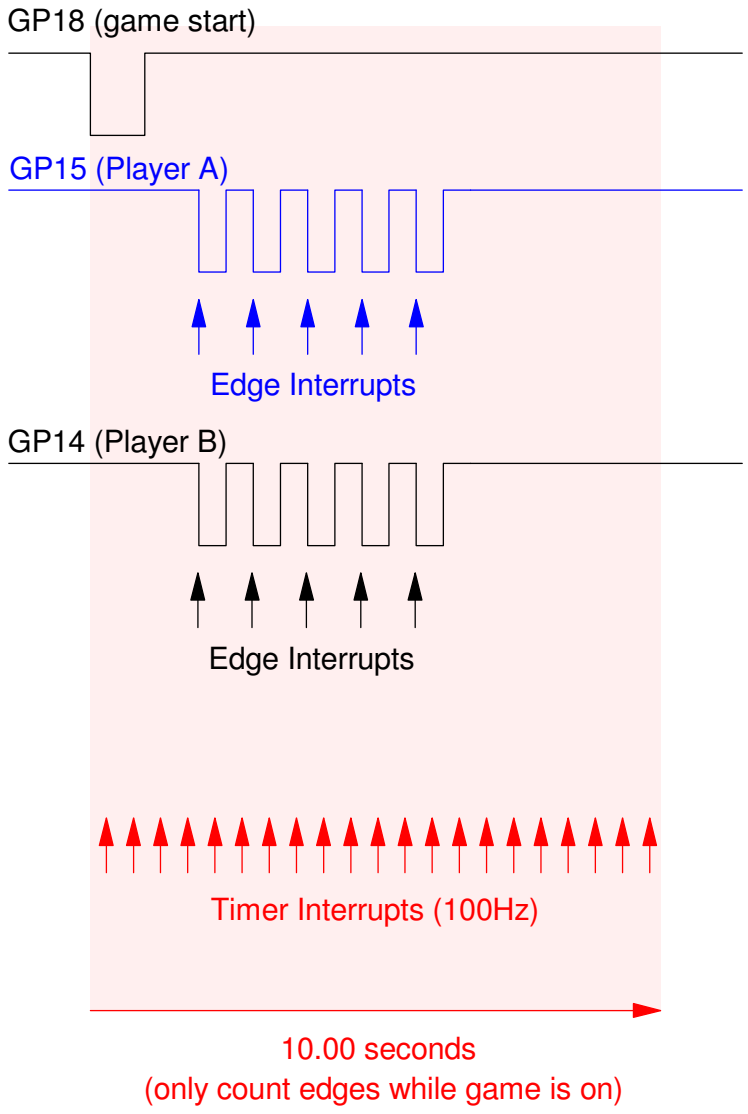
Hungry-Hungry Hippo (ver 3)

Use edge interrupts

- Start the game on GP18
  - Set the time to 10.00 seconds
- Count button presses for each player
  - Falling edges on GP15 and GP14

Use timer interrupts for game duration

- Timer interrupts every 10ms
  - Allows you to display the time remaining
  - Decrement time to 0.00, stopping at zero
- Score points while the game is ongoing
  - Stop counting edges once the game ends



Hungry-Hungry-Hippo v3

- Edge Interrupts

Start the game on reset

- Reset counters to zero
- Reset game time to 10.00 seconds

Player1

- Falling edge interrupt
  - GP15 is pressed
- If the game is ongoing
  - Count button presses for player 1

Player2

- Falling edge interrupt
  - GP14 is pressed
- If the game is ongoing
  - Count button presses for player 2

```
from machine import Pin, Timer
import time

pin0 = Pin(18,Pin.IN,Pin.PULL_UP)
pin1 = Pin(15,Pin.IN,Pin.PULL_UP)
pin2 = Pin(14,Pin.IN,Pin.PULL_UP)

N1 = N2 = 0
Game Time = 1000

def player1(pin1):
    global N1
    global GameTime
    if(GameTime > 0):
        N1 = N1 + 1

def player2(pin2):
    global N2
    global GameTime
    if(GameTime > 0):
        N2 = N2 + 1

pin0.irq(trigger=Pin.IRQ_FALLING, handler=GameStart)
pin1.irq(trigger=Pin.IRQ_FALLING, handler=player1)
pin2.irq(trigger=Pin.IRQ_FALLING, handler=player2)
```

Hungry-Hungry-Hippo v3

- Timer Interrupts

Tic

- If the game is ongoing
  - Decrement time to zero
  - Toggle the LED
- Once the game is over
- Turn off the LED

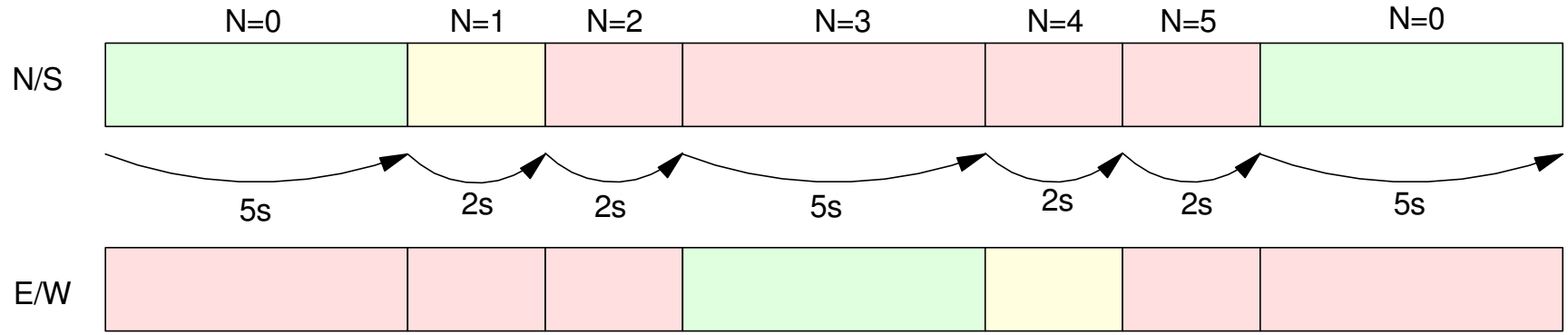
The main routine

- Displays the score every 100ms

```
:
LED = Pin(18,Pin.OUT)

def tic(timer):
    global led
    global GameTime
    if(GameTime > 0):
        GameTime -= 1
        led.toggle()
    else:
        led.off()

tim.init(freq=100, mode=Timer.PERIODIC, callback=tic)

while(1):
    while (GameTime > 0):
        print(GameTime*0.01, N1, N2)
        time.sleep(0.1)
    time.sleep(0.1)
```

StopLight (ver 3)

With timer interrupts, you can set up the time for each color. Building upon the previous stoplight program, write a program that counts from N=0 to 6 with timing being:



Interrupts can be used to set these times several ways:

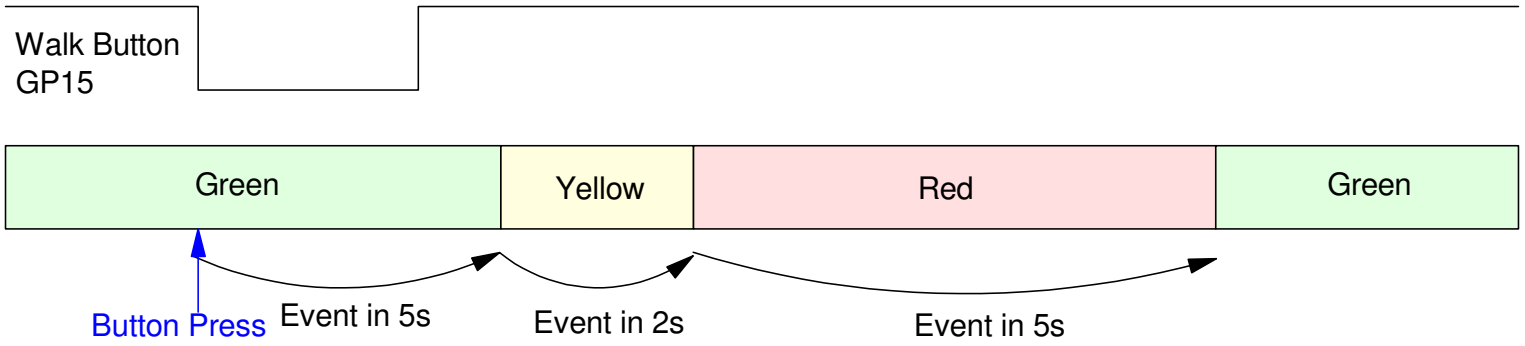
- A timer interrupt can be called every 100ms and keep track of time.
  - At certain times, the lights change (N increases), or
- Each time the light changes,
  - Set up the next interrupt X seconds in the future

Using the latter method:

```
# Stoplight (ver 3)

from machine import Pin, Timer
from time import sleep_ms

tim = Timer()
N = 0

def StopLight(pin1):
    global N
    N = (N + 1) % 6
    if(N == 0):
        tim.init(freq=1/5,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 1):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 2):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 3):
        tim.init(freq=1/5,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 4):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 5):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)

time.init(freq=1/5,mode=Timer.ONE_SHOT,callback=StopLight)

Time = 0
while(1):
   print(Time, N)
   Time += 1
   speep_ms(1000)
```

StopLight (ver 4): Adding a Walk button

A simple variation is to have the light always green E/W unless the walk button is pressed. Once that happens, go through the sequence of N=0..5 then stop again at 0 until the walk button is pressed again.



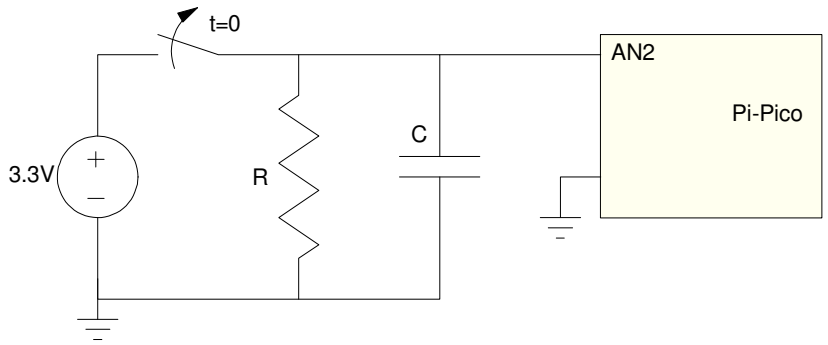
Walk Button: Trigger a light change using one-time events (one-shot interrupts)

```
from machine import Pin, Timer
from time import sleep_ms

tim = Timer()
N = 0

pin1 = Pin(15,Pin.IN,Pin.PULL_UP)

def Walk(pin1):
    tim.init(freq=1/5,mode=Timer.ONE_SHOT,callback=StopLight)

def StopLight(pin1):
    global N
    N = (N + 1) % 6
    if(N == 1):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 2):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 3):
        tim.init(freq=1/5,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 4):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)
    if(N == 5):
        tim.init(freq=1/2,mode=Timer.ONE_SHOT,callback=StopLight)

pin.irq(trigger=Pin.IRQ_FALLING,handler=Walk)

Time = 0
while(1):
   print(Time, N)
   Time += 1
   sleep_ms(1000)
```

Setting a Fixed Sampling Rate with Timer Interrupts

Timer interrupts are a more precise way of setting the sampling rate.

- Example: measure the discharge of a capacitor
- Sample the voltage every 1.00ms

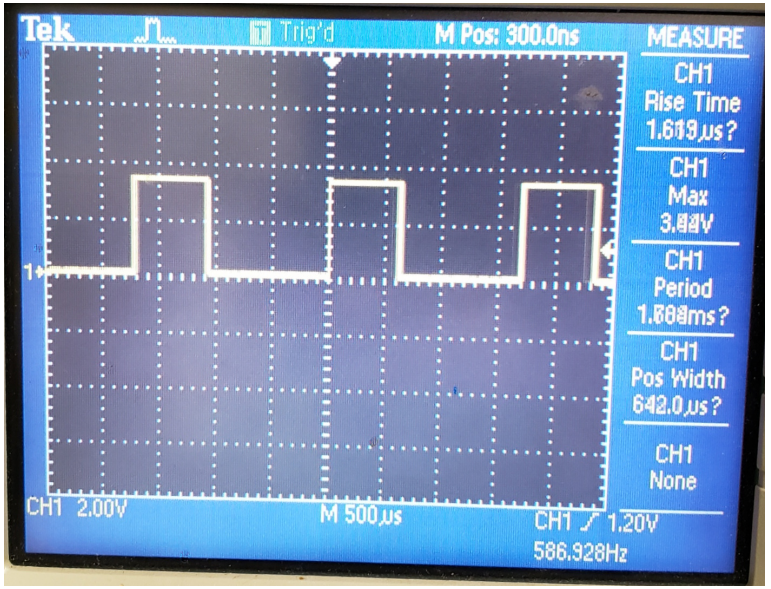


time.sleep() works, but

- The time isn't exact
  - the total loop includes additional code
- sleep() wasts a lot of processor time

Example (following page)

- The sampling rate is 586.928Hz
- The sampling time is 1.703ms
  - should be 1.000ms



Better Solution:

- Set up a timer interrupt for 1.00ms
- Set a flag every time you interrupt

The main routine waits for the flat to be set

- When detected, run through the main loop
- Clear the flag, then
- Wait for it to be set again
  - every 1.000 ms

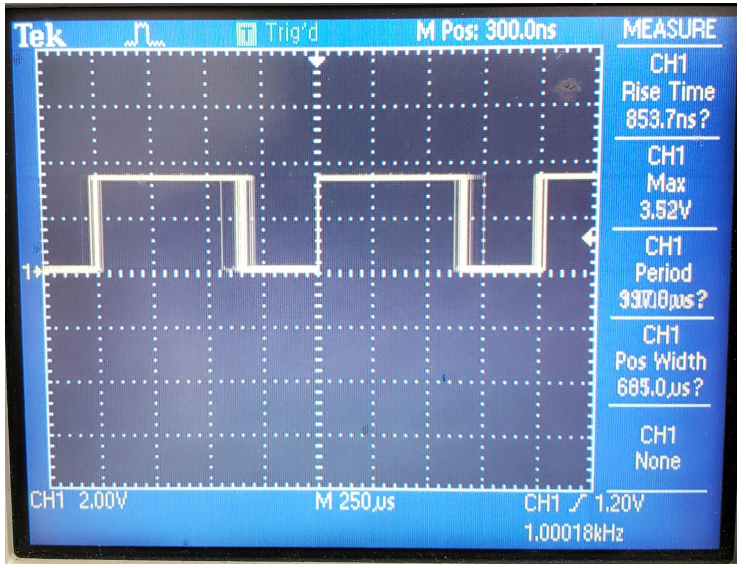
Note: The output square wave is 1.00018kHz

- The sampling rate is 1.00ms

Code:

- A flag is used
- Indicates 1ms has elapsed

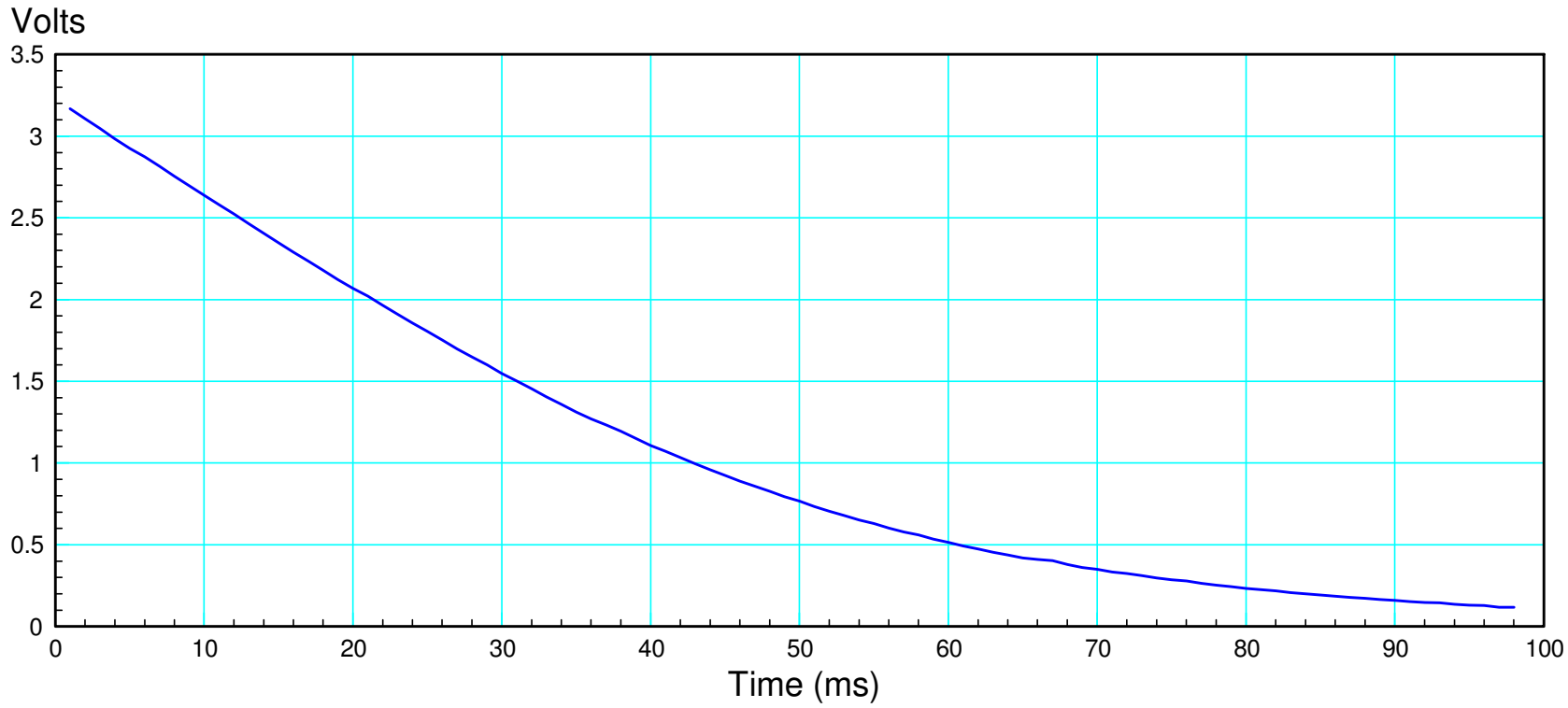
```
from machine import ADC, Pin, Timer
from time import sle

a2d2 = machine.ADC(2
tim = Timer()

flag = 0
k = 3.3 / 65520
dT = 0.001

def tick(timer):
    global flag
    flag = 1

tim.init(freq=1000, m

LED = Pin(16,Pin.OUT)

while(1):
    LED.value(0)
    while(flag == 0):
        pass
    LED.value(1)
    flag = 0

    a2 = a2d2.read_u16()
    V2 = k*a2

    print('{: 7.4f}'.format(V2))
```



Fixed Sampling Rate: Example

Measure the voltage across a capacitor as it discharges

- Sample the voltage every 1.00ms
- Result is a clean exponential decay



Digital Filters

Yet another application of timer interrupts is implementing digital filters. With a digital filter, you *have* to know the sampling rate, T: the conversion from the s-plane to the z-plane depends upon knowing T. If T changes, the filter is wrong.

For example, design a digital filter to implement

$$Y = \left(\frac{50}{(s+5+j5)(s+5-j5)}\right)X = \left(\frac{50}{s^2+10s+50}\right)X$$

One way to do this is to convert to the z-plane

$$z = e^{sT}$$

Assuming a sampling rate of 10ms (T = 0.01), the poles in the s-plane convert to the z-plane as

$$s = -5 + j5 \qquad z = e^{sT} = 0.9500 + j0.0475$$

$$s = -5 - j5 \qquad z = e^{sT} = 0.9500 - j0.0475$$

so a discrete-version of G(s) would be

$$Y = \left(\frac{k(z+1)^2}{(z-0.9500-j0.0475)(z-0.9500+j0.0475)} \right) X$$

where k is chosen to set the DC gain to 1.00 (same as G(s)). Multiplying out

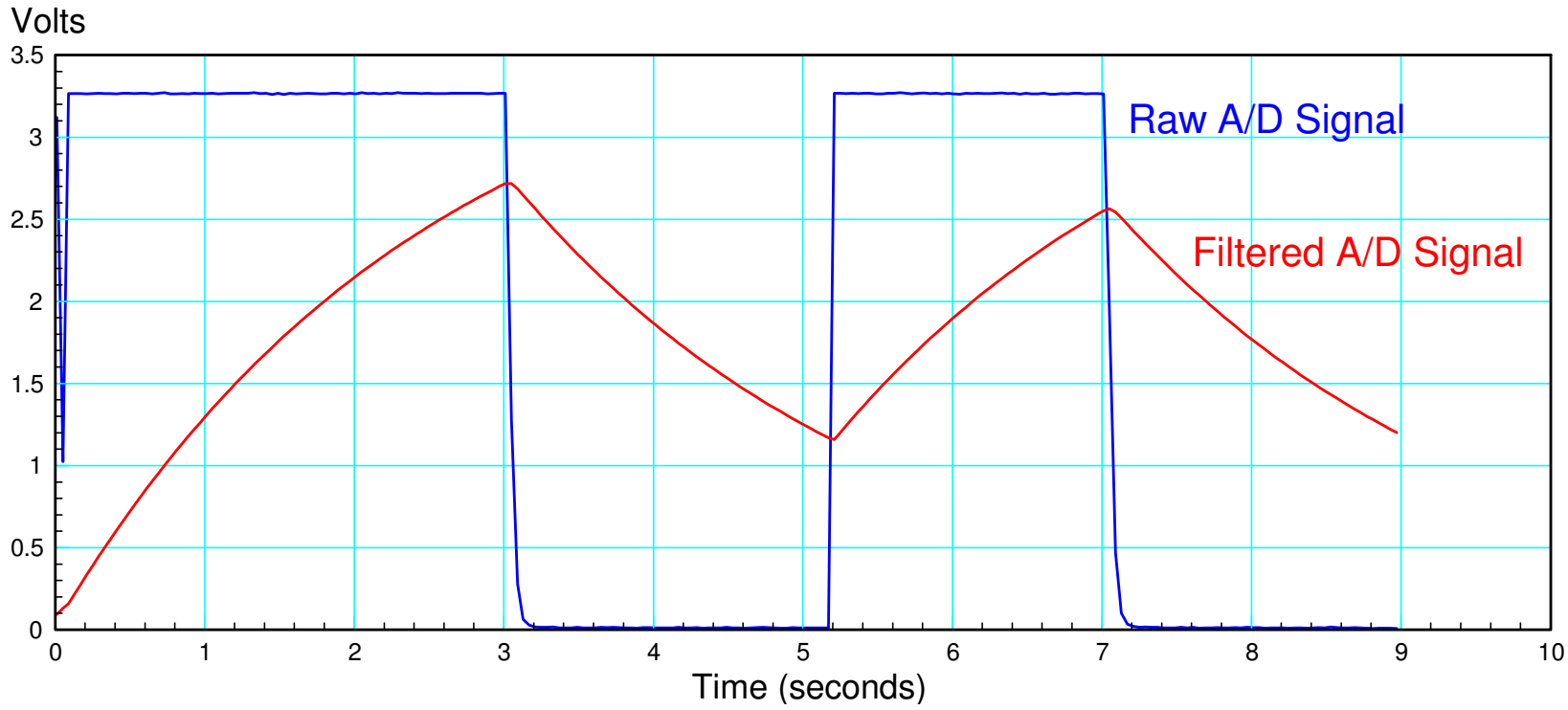
$$Y = \left(\frac{0.001209\left(z^2+2z+1\right)}{z^2-1.900z+0.904837} \right) X$$

In Code...

```
from machine import ADC, Pin, Timer

a2d2 = machine.ADC(2)
tim = Timer()

flag = 0
k = 3.3 / 65520
x0 = x1 = x2 = y0 = y1 = y2 = 0

def tick(timer):
    global flag
    flag = 1

tim.init(freq=100, mode=Timer.PERIODIC, callback=tick)
LED = Pin(16,Pin.OUT)
while(1):
    LCD.value(0)
    while(flag == 0):
        pass
    LED1.value(1)
    flag = 0

    a2 = a2d2.read_u16()
    V2 = k*a2

    x2 = x1
    x1 = x0
    x0 = k*a2

    y2 = y1
    y1 = y0
    y0 = 1.9008*y1 - 0.90483*y0 + 0.001209*(x0 + 2*x1 + x2);

    print('{: 7.4f}'.format(x0), '{: 7.4f}'.format(y0))
```

Result when filtering a square wave:

- Filter has poles at s = -5 + /- j5
- Shows up as exponential rise and fall



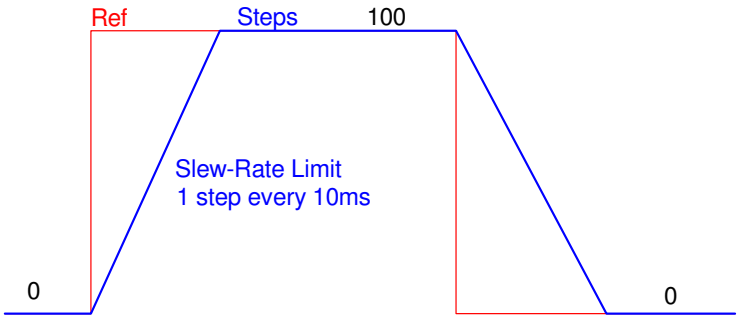
Result of filtering the A/D signal

Stepper Motor Controls

Finally, timer interrupts are also useful for stepper motors

Every 10ms (Timer interrupt):

- Step forward one step if Step < Ref
- Step back one step if Step > Ref
- No nothing if Step == Ref



By placing this inside the interrupt

- The main routine is free to do anything
- The timing for the stepper motor won't be affected

```
from machine import Pin, Timer
import time

tim = Timer()
Step = 0
Ref = 0

pin1 = Pin(15,Pin.IN,Pin.PULL_UP)
pin2 = Pin(14,Pin.IN,Pin.PULL_UP)

Sa = Pin(6,Pin.OUT)
Sb = Pin(7,Pin.OUT)
Sc = Pin(8,Pin.OUT)
Sd = Pin(9,Pin.OUT)

def Stepper(Step):
    X = Step % 4;
    if(X == 0):
        Sa.value(1)
        Sb.value(0)
        Sc.value(0)
        Sd.value(0)
    if(X == 1):
        Sa.value(0)
        Sb.value(1)
        Sc.value(0)
        Sd.value(0)
    if(X == 2):
        Sa.value(0)
        Sb.value(0)
        Sc.value(1)
        Sd.value(0)
    if(X == 3):
        Sa.value(0)
        Sb.value(0)
        Sc.value(0)
        Sd.value(1)

def tick(timer):
    global Step, Ref
    if(Step < Ref):
        Step += 1
    if(Step > Ref):
        Step -= 1
    Stepper(Step)

tim.init(freq=100,
mode=Timer.PERIODIC, callback=tick)

while (1):
    if(pin1.value() == 0):
        Ref = 0
    if(pin2.value() == 0):
        Ref = 100
    print(Ref, Step, )
    time.sleep(0.1)
```

Summary

The Pi-Pico is capable of timer interrupts as well

Timer interrupts

- Allow you to measue time
- Allow you to set a fixed sampling rate
- Allow you to trigger routines N seconds in the future

Again, interrupts are confusing

- If you can figure them out, some programs become much simpler to write