Welcome!

Firmware Training
Week 3

RoboJackets

Competitive Robotics at Georgia Tech

www.robojackets.org

Last Week!

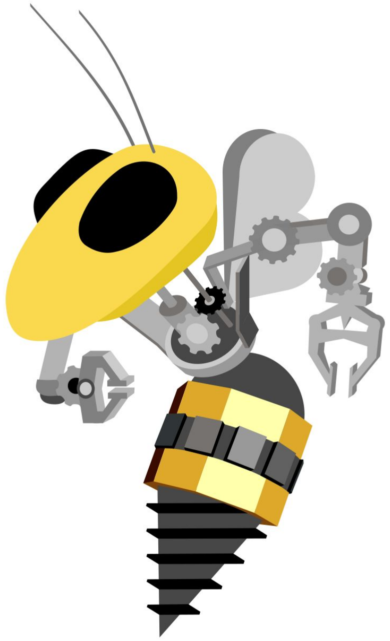
- C++ Continued
- Interrupts
- State Machines

This Week!

- Registers and Timers
- PWM
- Binary and Hexadecimal
- Bitwise Operations
- Masking
- Lab

Dues

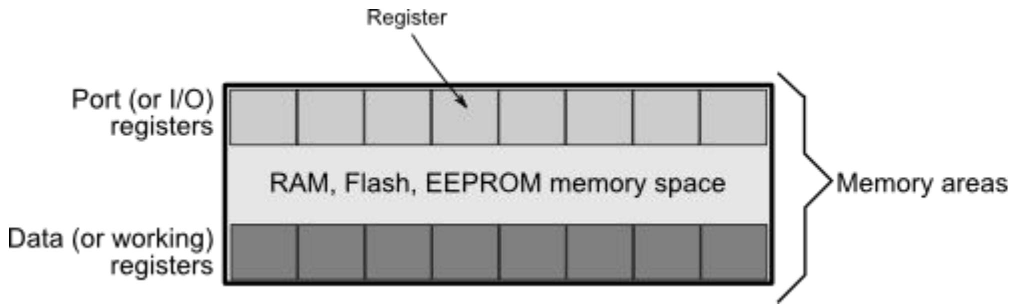
- Please pay dues by Saturday, October 10th
- Can do so at my.robojackets.org/dues



Registers and Timers

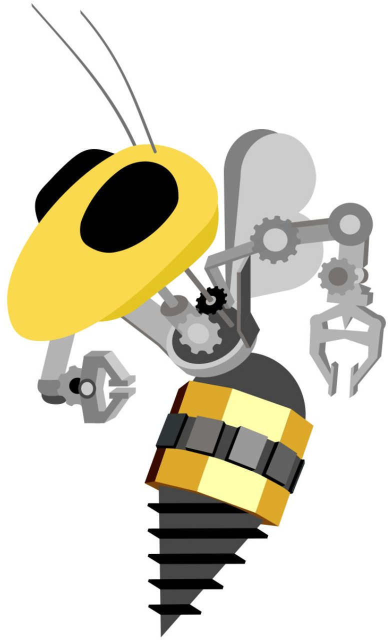
What is a register?

- Hardware used for storage - can read or write multiple bits
- Methods like Arduino’s digitalWrite modify the value of a register that controls whether a pin is high or low



Timers and Timer Registers

- Timers are a peripheral device used to count up to a certain value before resetting
- Timer registers can be used to trigger different actions at set intervals by checking the value of the timer register against a different register

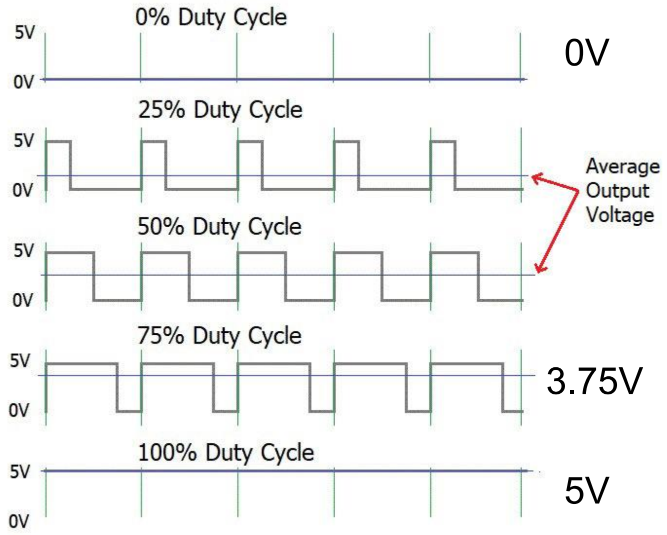


PWM

Pulses go brrrrr

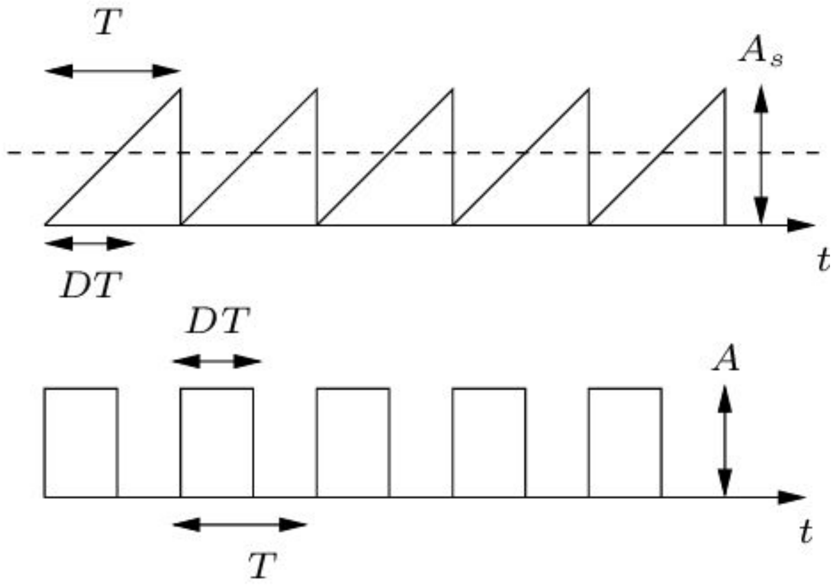
What is PWM?

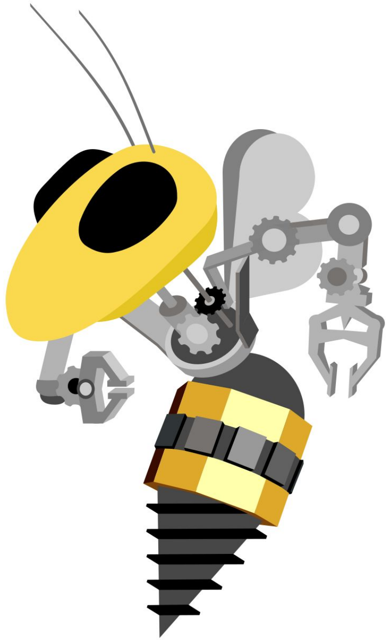
- Pulse-width modulation
- By alternating between a low and high voltage the effect of a middle voltage can be achieved
- We can get this voltage by varying the duty cycle (the effective voltage is the weighted average)



Relation to Timers

- Switching frequency is controlled by a timer register
- The time voltage is high compared to the total time tells us the % duty cycle which directly relates to the output voltage



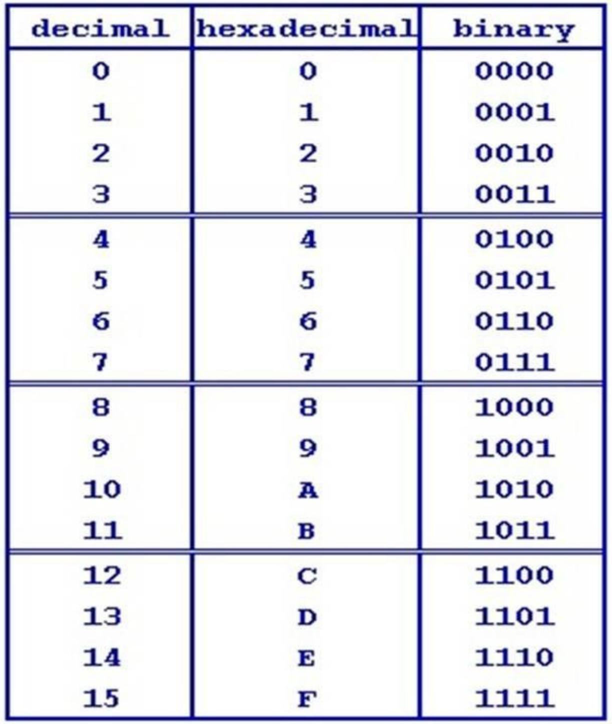


Binary and Hexadecimal

52 6f 62 6f 4a 61 63 6b 65 74 73

What are Binary and Hexadecimal?

- Binary and Hexadecimal are alternate number systems
- The number system that everyone is taught is called decimal and it is base 10
- Binary is base 2 : 0,1
- Hexadecimal is base 16 : 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F



decimal	hexadecimal	binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

Example Conversion Binary-Decimal

Decimal to Binary: 158 to 10011110

158 / 2 = 79 | r = 0
79 / 2 = 39 | r = 1
39 / 2 = 19 | r = 1
19 / 2 = 9 | r = 1
9 / 2 = 4 | r = 1
4 / 2 = 2 | r = 0
2 / 2 = 1 | r = 0
1 / 2 = 0 | r = 1

Binary to Decimal: 10011110 to 158

2^7 128	2^6 64	2^5 32	2^4 16	2^3 8	2^2 4	2^1 2	2^0 1
1	0	0	1	1	1	1	0

128*1 +16*1+8*1+4*1+2*1 = 158

Example Conversion Hexa-Decimal

Decimal to Hexadecimal:

158 to 9E

158 / 16 = 9 | r = 14 ↑
9 / 16 = 0 | r = 9

14 is E in Hexadecimal so the result is 9E !

Hexadecimal to Decimal: 9E to 158

16^1 16	16^0 1
9	E

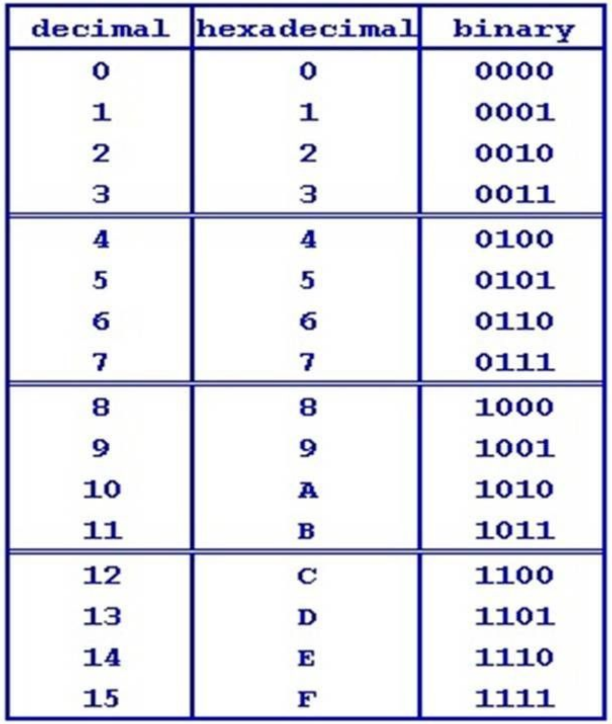
9*16 +14*1 = 144 + 14 = 158

Example Conversion Hexa-Binary

Hexa to Binary :

9E to 10011110

$$\begin{tikzcd} 9 \arrow[d] & E \arrow[d] \\ 1001 & 1110 \end{tikzcd}$$

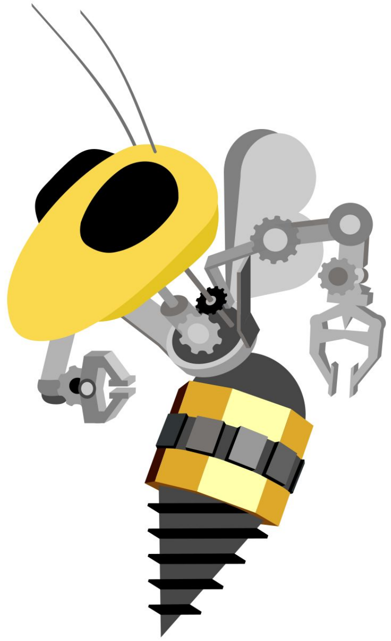


decimal	hexadecimal	binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

Binary to Hexa :

10011110 to 9E

$$\begin{tikzcd} 1001 \arrow[d] & 1110 \arrow[d] \\ 9 & E \end{tikzcd}$$



Bitwise Operations

Yes or no

What are Bitwise Operations?

- Bitwise operators:
  - AND $\longrightarrow$ &
  - OR $\longrightarrow$ |
  - NOT $\longrightarrow$!
  - XOR $\longrightarrow$ ^
    - (A & !B) | (!A & B)

BIT A	BIT B	AND	OR	XOR
0	0	0	0	0
0	1	0	1	1
1	0	0	1	1
1	1	1	1	0

Bitwise operations are Logical Operations but instead of comparing conditions, bits are compared

How does it work?

Example: 01000011(67) ; 00101010(42)

$$\begin{array}{r} 01000011 \\ \& \; \underline{00101010} \\ 00000010 \end{array} \qquad \begin{array}{r} 01000011 \\ | \; \underline{00101010} \\ 01101011 \end{array} \qquad \begin{array}{r} 01000011 \\ \wedge \; \underline{00101010} \\ 01101001 \end{array}$$

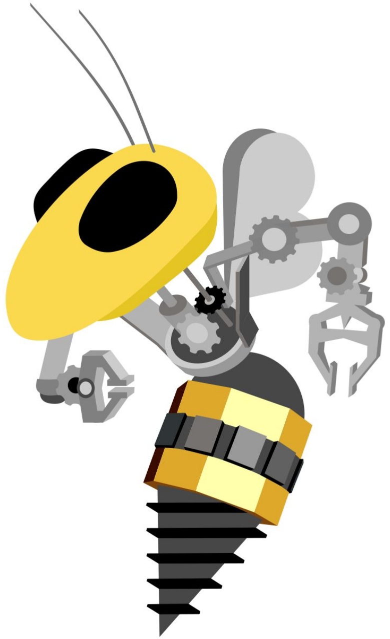
Logical Shift

Left Shift	Right Shift
<<	>>

- Left Shift
  - A single left shift multiplies a number by 2:
    - (2) 0010 << 1 → 0100 (4)
- Right Shift
  - A single right shift divides a number by 2 (discards the remainder)
    - (5) 0101 >> 1 → 0010 (2)

Why are they useful?

- Very efficient
- Small memory usage
- They are used in embedded devices, socket programming (network), cryptography etc...



Masking

Mask on (or off)

What is it?

- Using bitwise operations to access/set particular bits
- Read a value from a binary number
  - Masking with 0 to ignore subset of bits
  - Use a bitwise AND (&)
- Write certain bits of a binary number
  - Masking bits to 1 to change subset of bits
  - Use a bitwise OR (|)

How to mask?

Masking with &:

- Any number & 0 leaves a 0
- Any number & 1 leaves that number

Ex:

```
  1001010
 &0101001
  -------
  0001000
```

Masking with |:

- Any number | 0 leaves that number
- Any number | 1 leaves a 1

Ex:

```
  1001010
| 0101001
  -------
  1101011
```

Example

You have a color : #34EB98 (hexadecimal),
110100111010111000110000 (binary)

How do you get only the amount of blue of this color ?

Example

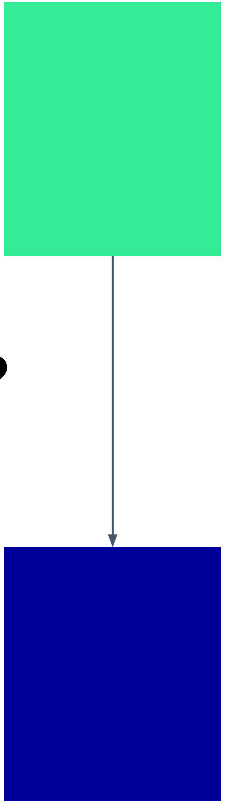
You have a color : #34EB98 (hexadecimal),

001101001110101110011000 (binary)

How do you get only the amount of blue of this color ?

Mask (&) :

```
      0011 0100 1110 1011 1001 1000
&     0000 0000 0000 0000 1111 1111
=>    0000 0000 0000 0000 1001 1000
```



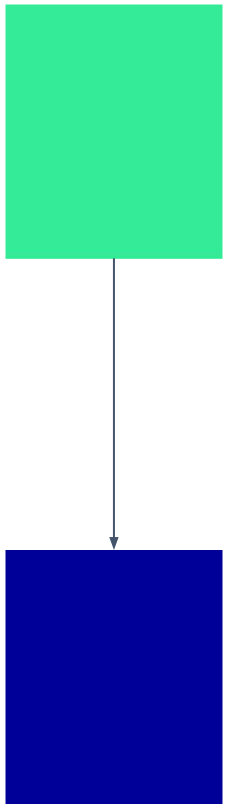
Example

You have a color : #34EB98 (hexadecimal),

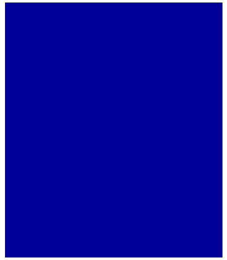
001101001110101110011000 (binary)

How about the amount of green ?

```
Mask (&) :           0011 0100 1110 1011 1001 1000
                   & 0000 0000 1111 1111 0000 0000
                  => 0000 0000 1110 1011 0000 0000
Shift right (>>8):   0000 0000 0000 0000 1110 1011
```



Example



Now we have : #000098 (hexadecimal),

000000000000000010011000 (binary)

How do you add red to this color ?

Example

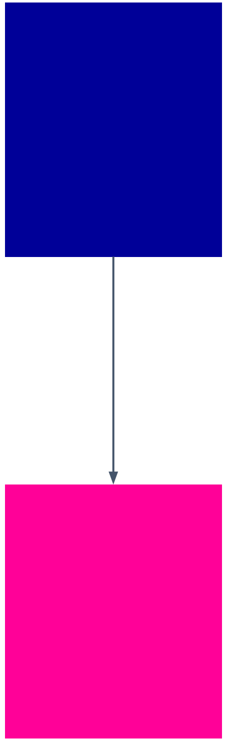
Now we have : #000098 (hexadecimal),

000000000000000010011000 (binary)

How do you add red to this color ?

Mask (|) :

```
      0000 0000 0000 0000 1001 1000
|     1111 1111 0000 0000 0000 0000
=>    1111 1111 0000 0000 1001 1000
```



Example

Now we have : #000098 (hexadecimal),

000000000000000010011000 (binary)

How do you add a specific amount of red ? (E.g. 129)

Shift, then mask!

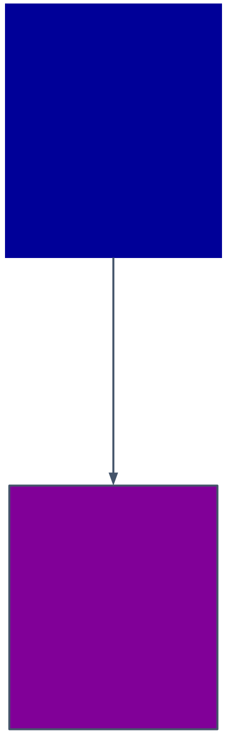
Get value (129): 0000 0000 0000 0000 1000 0001

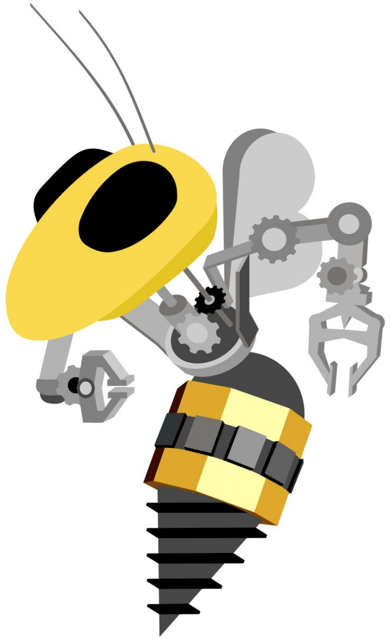
Shift right (<<16): 1001 0001 0000 0000 0000 0000

Mask (|) : 0000 0000 0000 0000 1001 1000

| 1000 0001 0000 0000 0000 0000

=> 1000 0001 0000 0000 1001 1000





Lab Time

Lab Info

- Read about ATmega microcontroller
- Read about the timer registers
    - Setup fast PWM mode using the register
- Write interrupt handler for button
- Display brightness using LED