

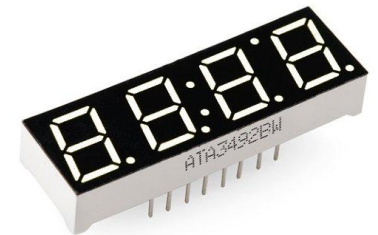
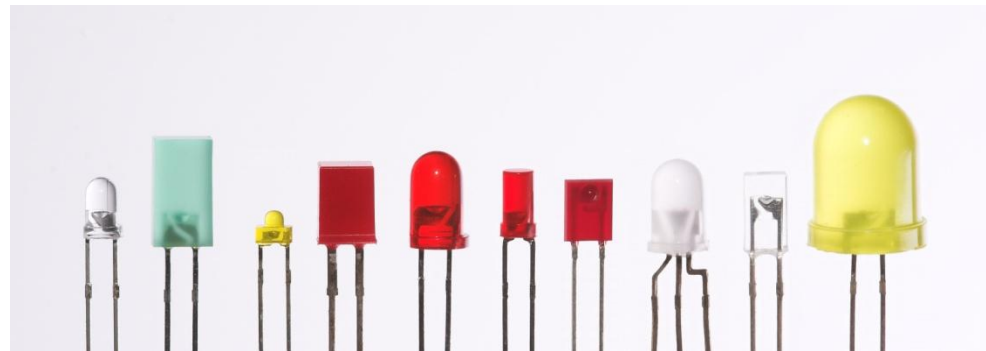
IMPLEMENTING IOE

Week 6

Assist. Prof. Rassim Suliyev - SDU 2017

Visual Output

- Lets the Arduino show off
- Arduino supports a broad range of LED devices
- Use digital and analog outputs for visualization
- Digital output
 - All pins that used for digital input can be used as output as well
 - Digital output causes the voltage on a pin to be either high (5 volts) or low (0 volts)
 - `digitalWrite(outputPin, value)`
 - `pinMode(outputPin, OUTPUT)`

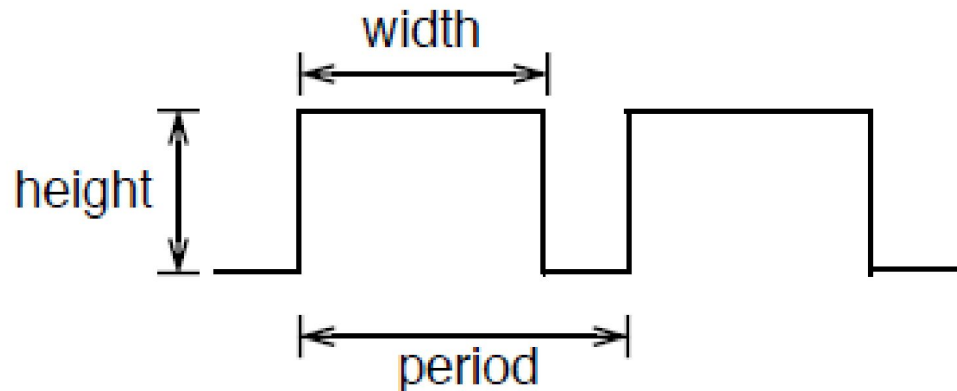


Analog Output

- Refers to levels that can be gradually varied up to their maximum level
- `analogWrite(pin, val)`
 - Used to control such things as the intensity of an LED
 - Is not truly analog, but behave like analog
 - Uses a technique called Pulse Width Modulation (PWM)
 - Emulates an analog signal using digital pulses
 - Works by varying the proportion of the pulses' on time to off time

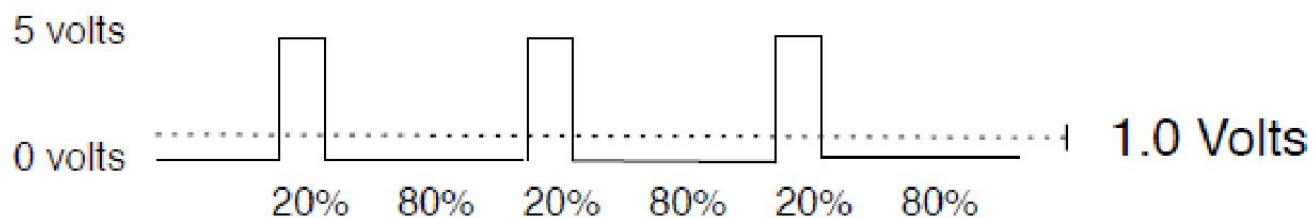
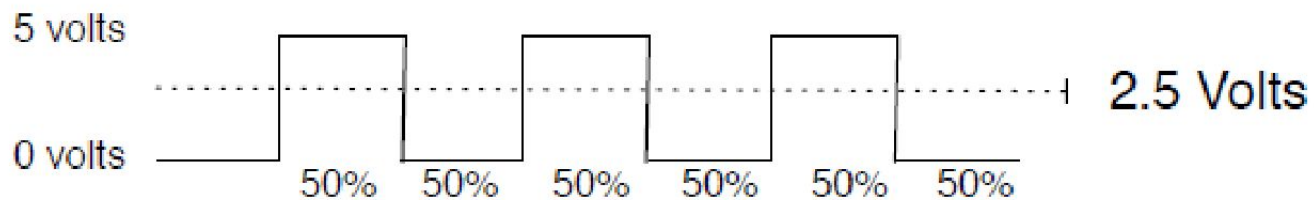
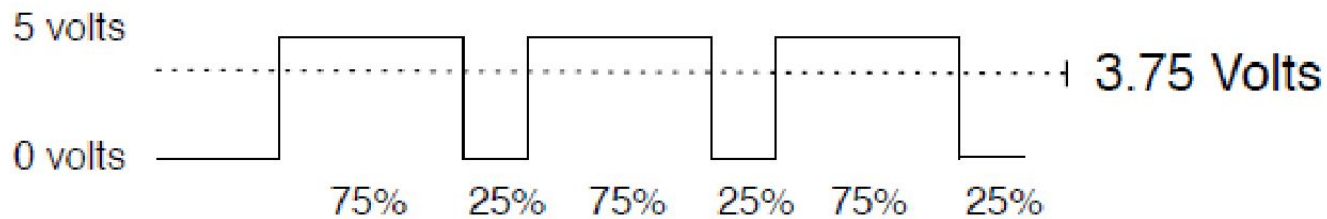
Pulse Width Modulation

- More commonly called “PWM”
- Computers can't output analog voltages
 - Only digital voltages (0 volts or 5 volts)
- But you can fake it
 - if you average a digital signal flipping between two voltages
- For example...



PWM

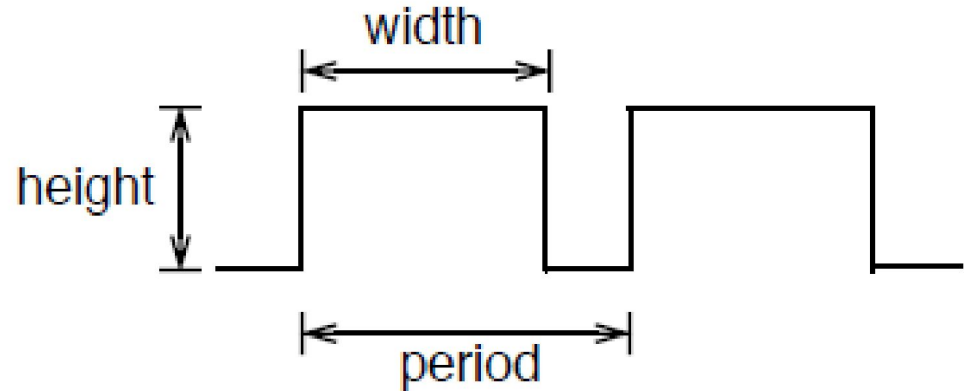
- Output voltage is averaged from on vs. off time
 - $\text{output_voltage} = (\text{on_time} / \text{off_time}) * \text{max_voltage}$



PWM

- Used everywhere

- Lamp dimmers
- Motor speed control
- Power supplies
- Noise making



- Three characteristics of PWM signals

- Pulse width range (min/max)
- Pulse period ($= 1 / \text{pulses per second}$)
- Voltage levels (0-5V, for instance)

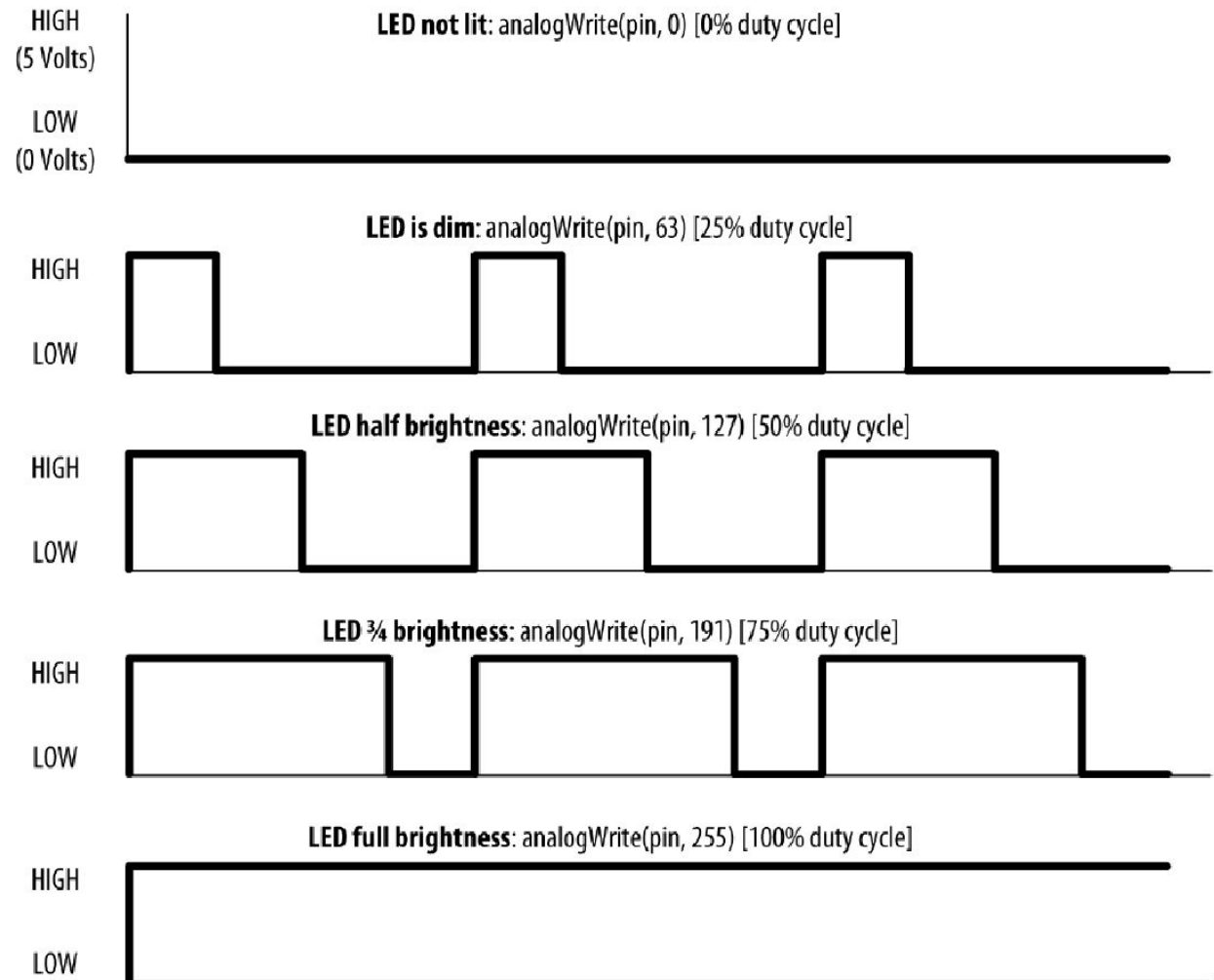
Arduino PWM

- Arduino has built-in PWM
 - On UNO they are pins 3, 5, 6, 9, 10, 11
- Use `analogWrite(pin,value)`
 - pin: the pin to write to.
 - value: the duty cycle: between 0 (always off) and 255 (always on).
- It operates at a high, fixed frequency
 - 490HZ for most pins (except pins 5 and 6 which run at 980HZ)
 - Great for LEDs and motors
- Uses built-in PWM circuits of the ATmega8 chip
 - No software needed



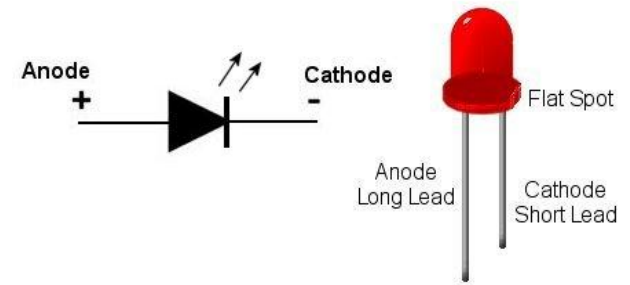
Arduino PWM

- Higher level output is emulated with pulses that are on more than they are off
- Pulses are repeated quickly enough
- almost 500 times per second on Arduino
- pulsing cannot be detected by human senses



LED specifications

- LED is a semiconductor device (diode)
 - Two leads, an anode and a cathode
- The device emits light (photons) when
 - $V_{\text{anode}} > V_{\text{cathode}} + \textit{forward voltage}$
- Anode is usually the longer lead and flat spot on the housing indicates the cathode
- LED color and forward voltage depend on the construction of the diode
- Typical red LED has a forward voltage of around 1.8 volts
- Limit the current with a resistor, or the LED will burn out



Consult an LED data sheet

Key data sheet specifications: absolute maximum ratings

Parameter	Symbol	Rating	Units	Comment
Forward current	I_f	25	mA	The maximum continuous current for this LED
Peak forward current (1/10 duty @ 1 kHz)	I_f	160	mA	The maximum pulsed current (given here for a pulse that is 1/10 on and 9/10 off)

Key data sheet specifications: electro-optical characteristics

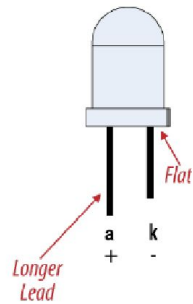
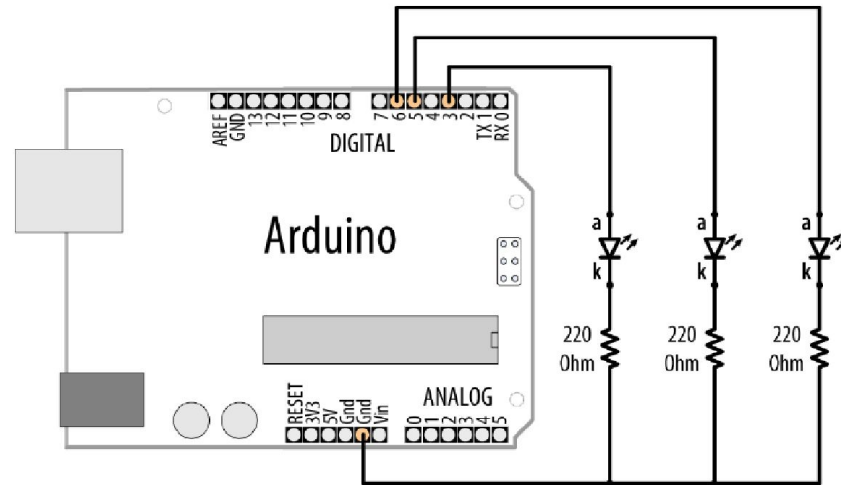
Parameter	Symbol	Rating	Units	Comment
Luminous intensity	I_v	2	mcd	$I_f = 2$ mA – brightness with 2 mA current
	I_v	40	mcd	$I_f = 20$ mA – brightness with 20 mA current
Viewing angle		120	degrees	The beam angle
Wavelength		620	nm	The dominant or peak wavelength (color)
Forward voltage	V_f	1.8	volts	The voltage across the LED when on

- Arduino pins can supply up to 40 mA of current
- This is plenty for a typical medium intensity LED, but not enough to drive the higher brightness LEDs or multiple LEDs connected to a single pin

Adjusting the Brightness of an LED

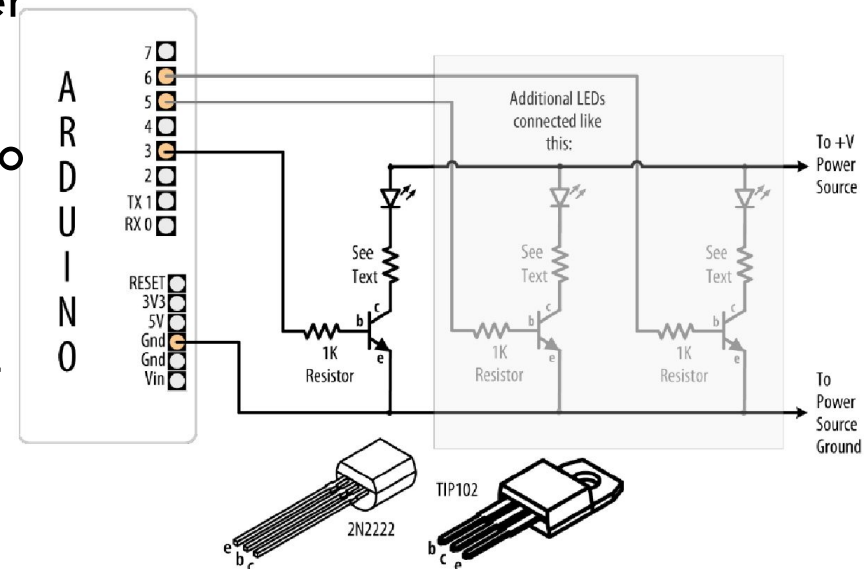
- Connect each LED to an analog (PWM) output

```
const int firstLed = 3;
const int secondLed = 5;
const int thirdLed = 6;
int brightness = 0;
int increment = 1;
void setup(){
  //for analogWrite no need
  //to declare as OUTPUT
}
void loop(){
  if(brightness > 254){
    increment = -1; // count down after reaching 254
  }else if(brightness < 1){
    increment = 1; // count up after dropping back down to 0
  }
  brightness = brightness + increment; // increment (or decrement sign is
  minus)
  // write the brightness value to the LEDs
  analogWrite(firstLed, brightness);
  analogWrite(secondLed, brightness);
  analogWrite(thirdLed, brightness );
  delay(10); // 10ms for each step change means 2.55 secs to fade up or down
}
```



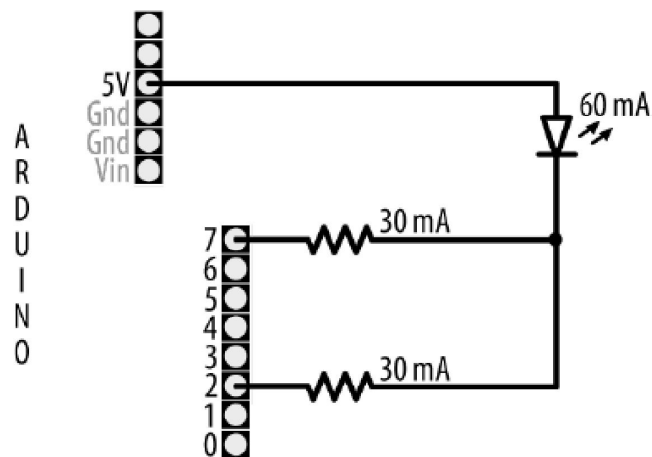
Driving High-Power LEDs

- Arduino can handle current up to 40 mA per pin
- Use a transistor to switch on and off the current
- Arrow indicates a +V power source
 - +5V power pin can supply up to 400 mA or so
- If an external power supply is used, remember to connect the ground of the external supply to the Arduino ground
- Current flows from collector to emitter when transistor is ON
- Turn ON transistor by writing HIGH to appropriate pin
- Resistor between the pin and the transistor base prevents huge current flow (1K-5mA)
- Voltage drop of transistor $\sim 0.7V$ (collector-emitter saturation voltage)



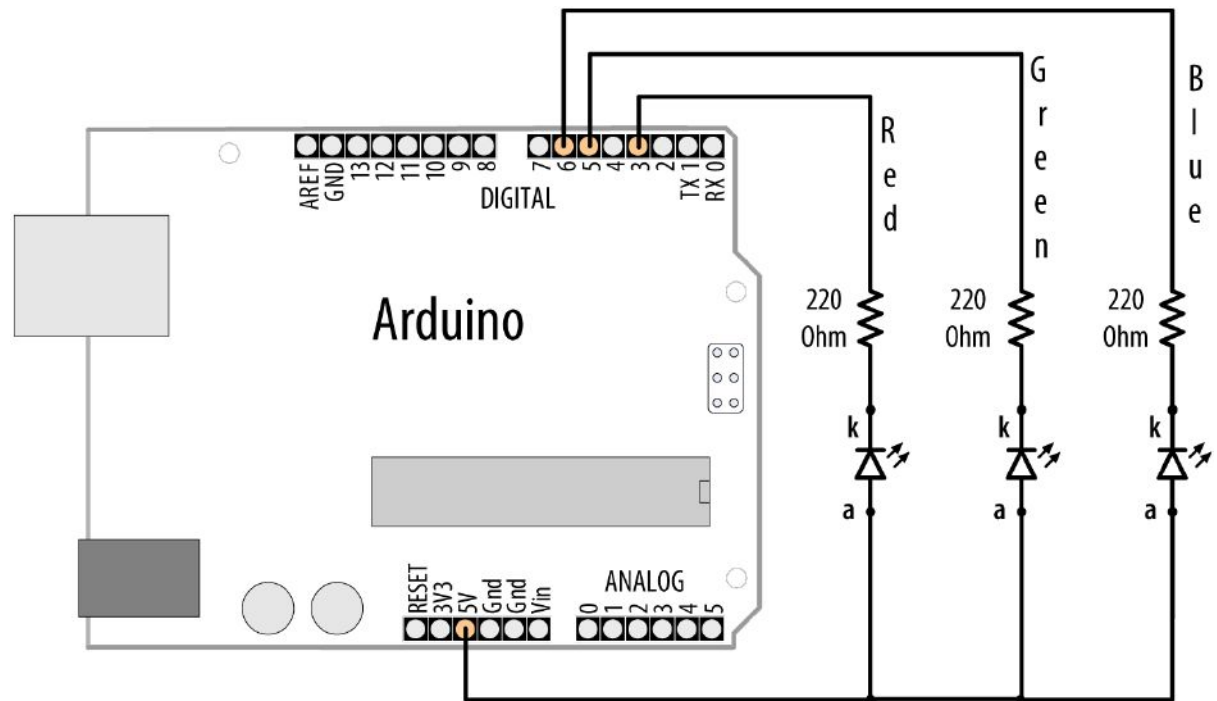
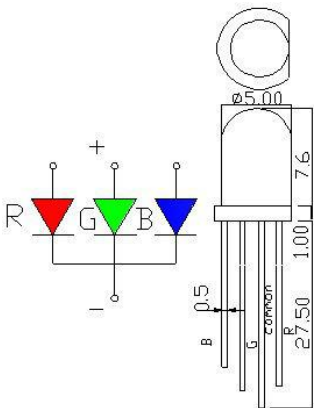
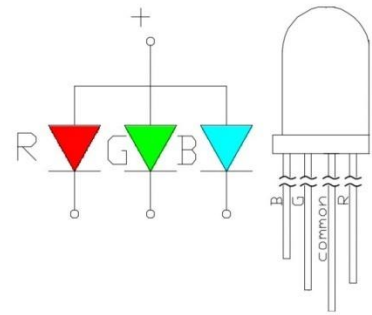
How to Exceed 40 mA per Pin

- Connect multiple pins in parallel to increase current beyond the 40 mA
- Don't try to use a single resistor to connect the two pins
- This technique can also be used to source current
- It does not work with analogWrite



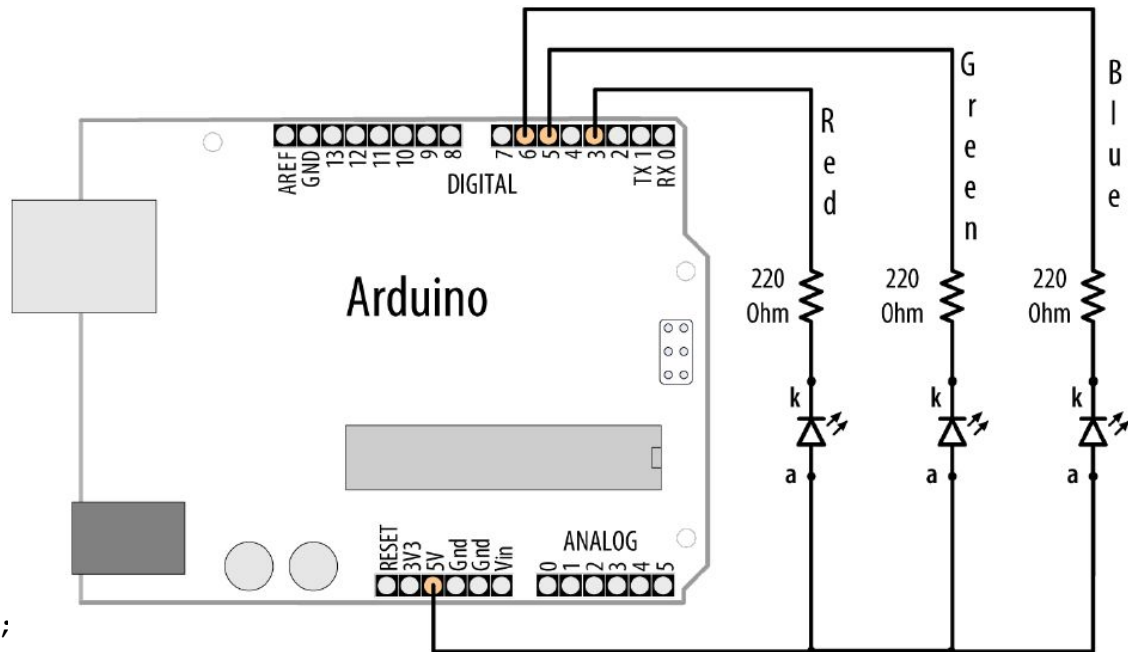
Adjusting the Color of an LED

- RGB LEDs have red, green, and blue elements in a single package
 - common anode or common cathode



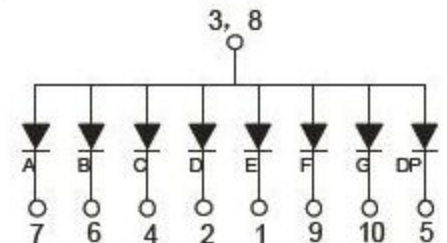
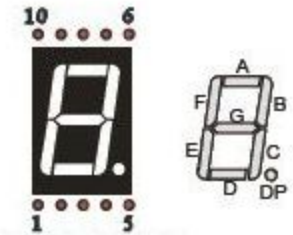
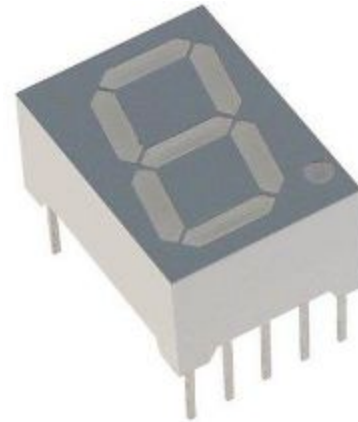
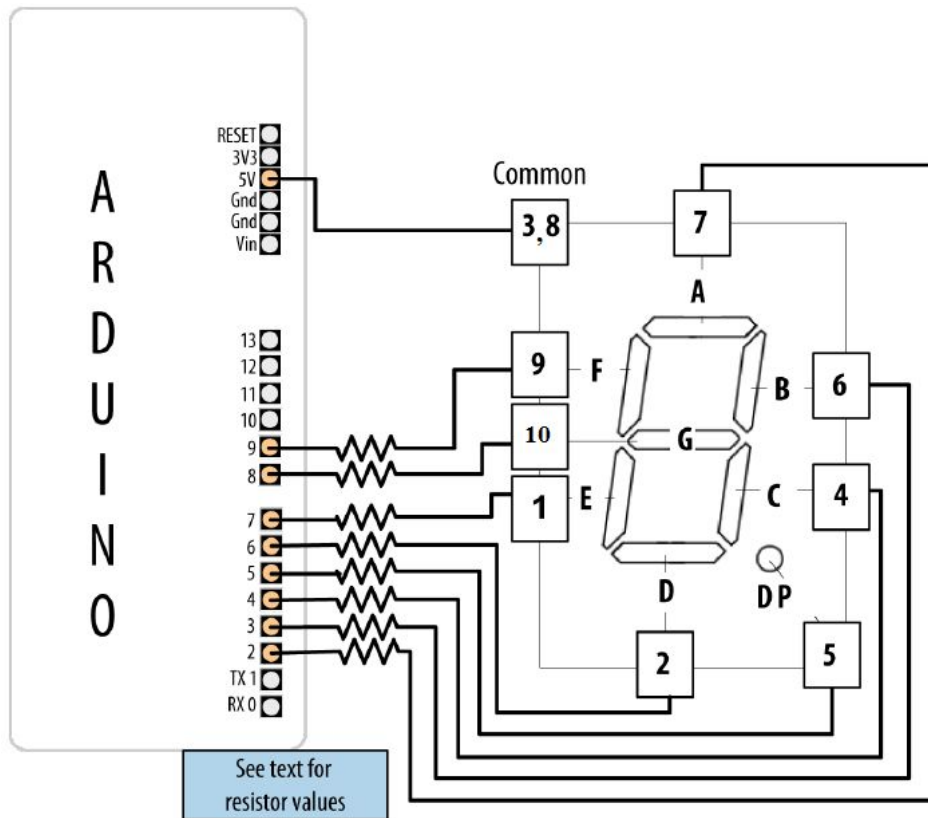
Adjusting the Color of an LED

```
const int redPin = 3; // choose the pin for each of the LEDs
const int greenPin = 5;
const int bluePin = 6;
int R, G, B, seg, i; // the Red Green and Blue color components
void setup(){
  R = G = B = seg = i = 0;
}
void loop(){
  if(i > (255 * 8 - 1)) i = 0;
  switch(i / 255){
    case 0: R++; break;
    case 1: G++; break;
    case 2: R--; break;
    case 3: B++; break;
    case 4: R++; break;
    case 5: G--; break;
    case 6: R--; break;
    case 7: B--; break;
  }
  analogWrite(redPin, 255 - R);
  analogWrite(greenPin, 255 - G);
  analogWrite(bluePin, 255 - B);
  delay(3);
  i++;
}
```



Driving a 7-Segment LED Display

- Contains 8 LEDs (including Decimal Point indicator)
- Common Anode & Common Cathode

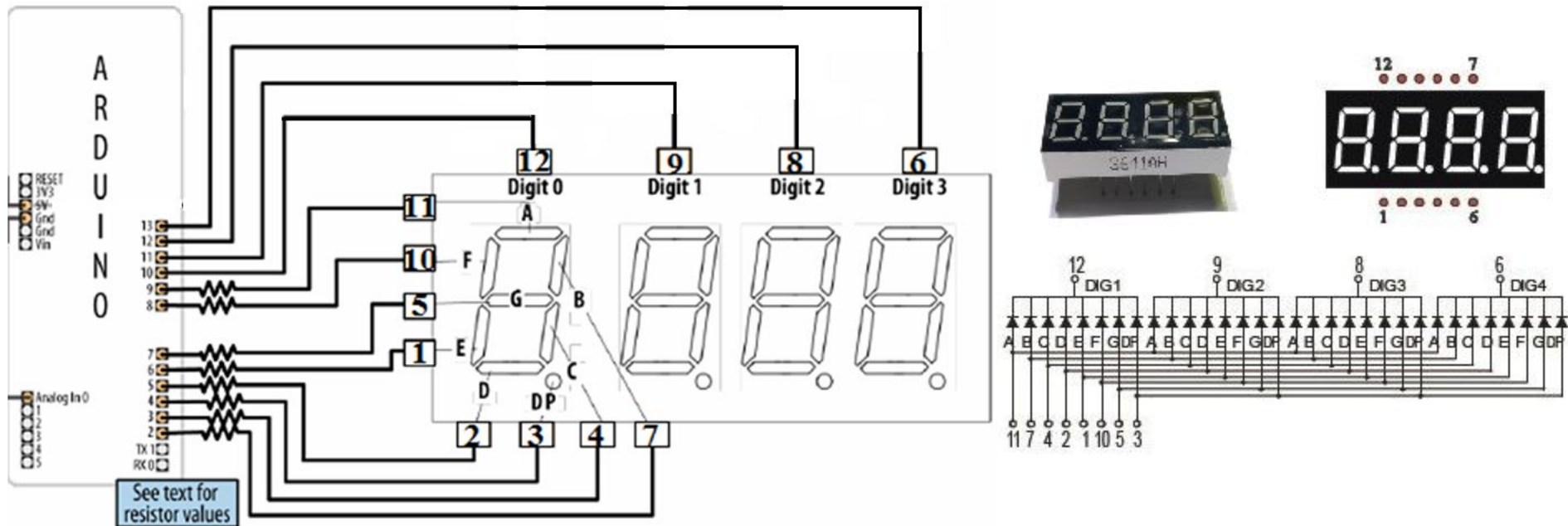


Driving a 7-Segment LED Display

```
const byte numeral[10][8] = {
    {1,1,1,1,1,1,0,0}, // 0
    {0,1,1,0,0,0,0,0}, // 1
    {1,1,0,1,1,0,1,0}, // 2
    {1,1,1,1,0,0,1,0}, // 3
    {0,1,1,0,0,1,1,0}, // 4
    {1,0,1,1,0,1,1,0}, // 5
    {0,0,1,1,1,1,1,0}, // 6
    {1,1,1,0,0,0,0,0}, // 7
    {1,1,1,1,1,1,1,0}, // 8
    {1,1,1,0,0,1,1,0}  // 9
}; //A,B,C,D,E,F,G,dp
const int segmentPins[8] = {2,3,4,6,7,8,9,5}; // A,B,C,D,E,F,G,dp
void setup(){
    for(int i=0; i < 8; i++){
        pinMode(segmentPins[i], OUTPUT); // set segment and DP pins to output
    }
}
void loop(){
    for(int i=0; i < 10; i++){
        showDigit(i); delay(1000);
    }
}
void showDigit(int number){
    if( number >= 0 && number <= 9){
        for(int segment = 0; segment < 8; segment++){
            int isBitSet = ! numeral[number][segment]; // remove ! sign if common cathode display
            digitalWrite(segmentPins[segment], isBitSet);
        }
    }
}
```

Multidigit, 7-Segment: Multiplexing

- Corresponding segments from each digit are connected together



Multidigit, 7-Segment: Multiplexing

```
const byte numeral[10][8] = {
  {1,1,1,1,1,1,0,0}, // 0
  {0,1,1,0,0,0,0,0}, // 1
  {1,1,0,1,1,0,1,0}, // 2
  {1,1,1,1,0,0,1,0}, // 3
  {0,1,1,0,0,1,1,0}, // 4
  {1,0,1,1,0,1,1,0}, // 5
  {0,0,1,1,1,1,1,0}, // 6
  {1,1,1,0,0,0,0,0}, // 7
  {1,1,1,1,1,1,1,0}, // 8
  {1,1,1,0,0,1,1,0} // 9
}; //A,B,C,D,E,F,G,dp
```

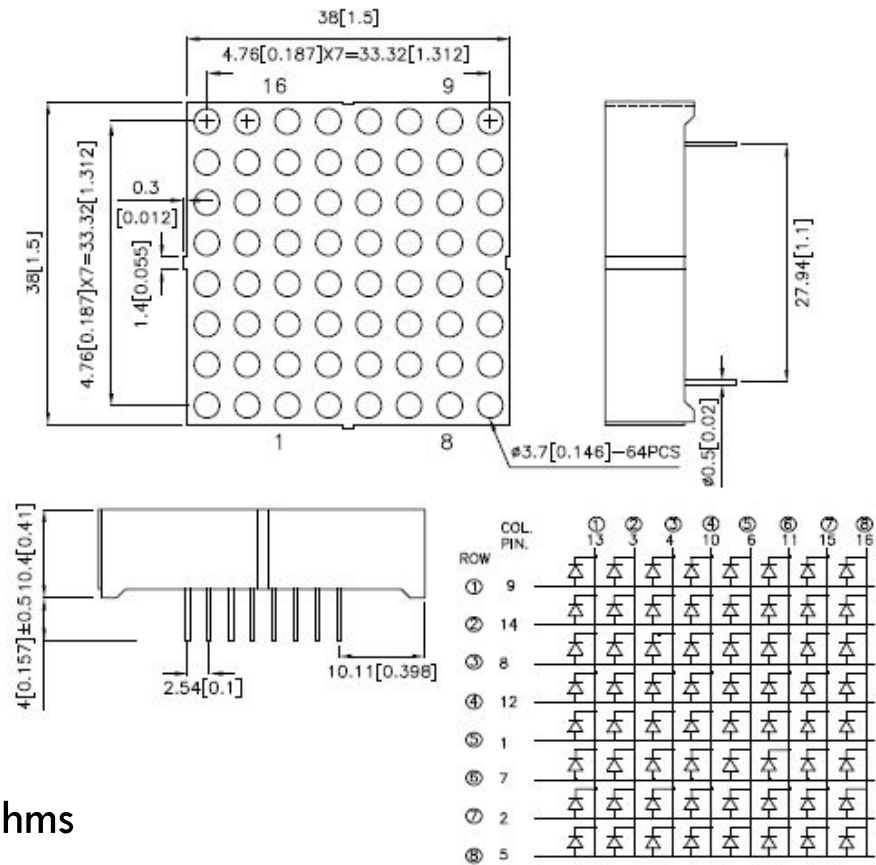
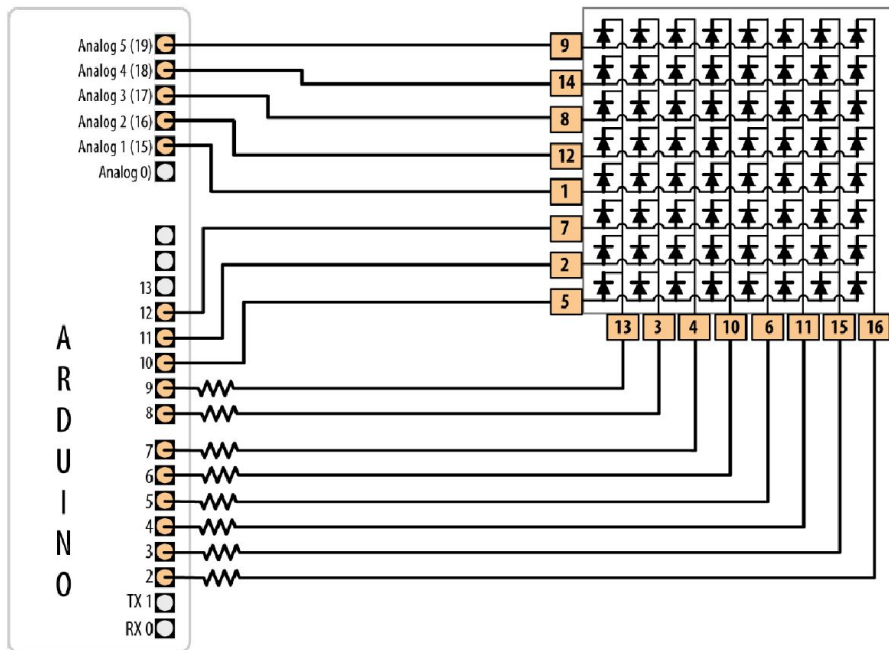
```
const int segmentPins[8] = {9,2,3,5,6,8,7,4};
// A-11,B-7,C-4,D-2,E-1,F-10,G-5,dp-3
const int digitPins[4] = {13,12,11,10};
// DIG4-6,DIG3-8,DIG2-9,DIG1-12
unsigned long count = 0;
void setup(){
  for(int i=0; i < 8; i++){
    pinMode(segmentPins[i], OUTPUT);
  }
  for(int i=0; i < 4; i++){
    pinMode(digitPins[i], OUTPUT);
  }
}
void loop(){
  if(millis()/1000 > count) count++;
  showNumber(count);
}
void showNumber(int num){
  for(int i = 0; i < 4; i++){
    showDigit(num % 10, i);
    num = num / 10;
  }
}
void showDigit(int digit, int pos){
  if( digit >= 0 && digit <= 9){
    for(int segment = 0; segment < 8; segment++){
      digitalWrite(segmentPins[segment], numeral[digit][segment]);
    }
    digitalWrite(digitPins[pos], LOW);
    delayMicroseconds(300);
    digitalWrite(digitPins[pos], HIGH);
  }
}
```

Multiplexing

- To control many LEDs use a technique called multiplexing
- Multiplexing is switching groups of LEDs in sequence
 - Usually arranged in rows or columns
- Scanning through the LEDs quickly enough
 - Creates the impression that the lights remain on
 - Through the phenomenon of persistence of vision
- Charlieplexing uses multiplexing along with the fact that LEDs have polarity
 - They only illuminate when the anode is more positive than the cathode
 - Switch between two LEDs by reversing the polarity

Controlling an LED Matrix

- 8X8 LED matrix contains 64 LEDs
- Anodes connected in rows and cathodes in columns



- Resistors must be chosen so that max. current through a pin does not exceed 40 mA
- 8 LEDs in column => 5mA for each => 680ohms

Lighting Each Pixel of LED Matrix

```
const int columnPins[] = { 2, 3, 4, 5, 6, 7, 8, 9};
const int rowPins[] = { 10,11,12,14,15,16,17,18};
int pixel = 0; // 0 to 63 LEDs in the matrix
int columnLevel = 0; // pixel value converted into LED column
int rowLevel = 0; // pixel value converted into LED row
void setup() {
  for (int i = 0; i < 8; i++){
    pinMode(columnPins[i], OUTPUT); // make all the LED pins outputs
    digitalWrite(columnPins[i], HIGH);
    pinMode(rowPins[i], OUTPUT);
    digitalWrite(rowPins[i], LOW);
  }
}
void loop() {
  pixel = pixel + 1;
  if(pixel > 63) pixel = 0;
  columnLevel = pixel / 8; // map to the number of columns
  rowLevel = pixel % 8; // get the fractional value
  digitalWrite(columnPins[columnLevel], LOW); // connect this column to Ground
  digitalWrite(rowPins[rowLevel], HIGH);
  delay(100);
  digitalWrite(rowPins[rowLevel], LOW); // turn off LED
  digitalWrite(columnPins[columnLevel], HIGH);
}
```

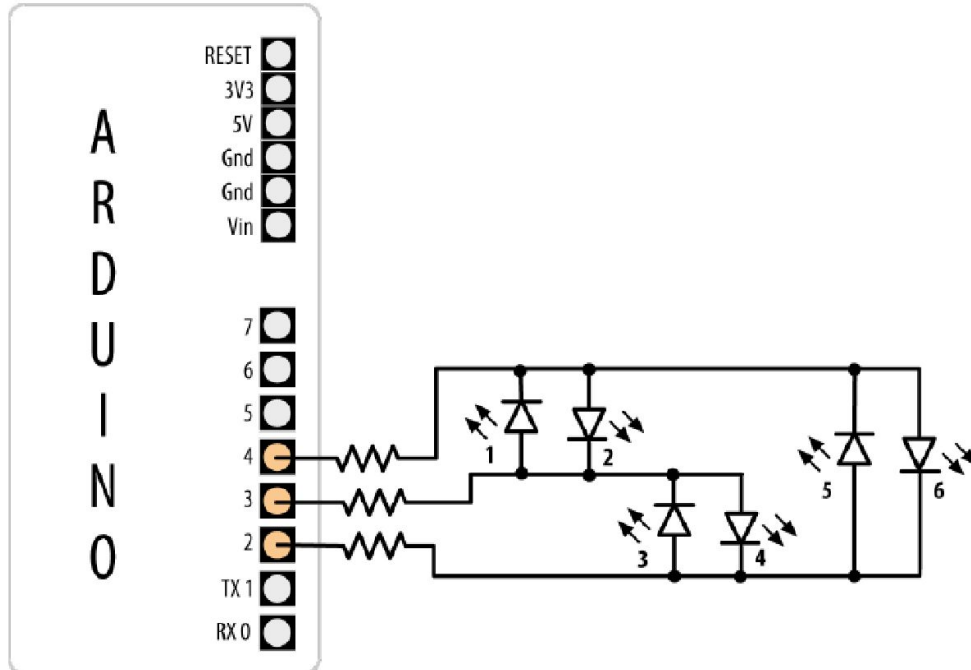
Displaying Images on an LED Matrix

```
byte bigHeart[] = {
B01100110,
B11111111,
B11111111,
B11111111,
B01111110,
B00111100,
B00011000,
B00000000};
byte smallHeart[] = {
B00000000,
B00000000,
B00010100,
B00111110,
B00111110,
B00011100,
B00001000,
B00000000};
```

```
const int columnPins[] = { 2, 3, 4, 5, 6, 7, 8, 9};
const int rowPins[] = { 10,11,12,14,15,16,17,18};
void setup() {
  for (int i = 0; i < 8; i++){
    pinMode(rowPins[i], OUTPUT); // make all the LED pins outputs
    pinMode(columnPins[i], OUTPUT);
    digitalWrite(columnPins[i], HIGH); // disconnect column pins
  }
}
void loop() {
  show(smallHeart, 800); // show the small heart image for 100 ms
  show(bigHeart, 800); // followed by the big heart for 200ms
  delay(400); // show nothing between beats
}
void show( byte * image, unsigned long duration){
  unsigned long start = millis(); // begin timing the animation
  while (start + duration > millis()){ // loop until duration passed
    for(int row = 0; row < 8; row++){
      digitalWrite(rowPins[row], HIGH); // connect row to +5 volts
      for(int column = 0; column < 8; column++){
        boolean pixel = bitRead(image[row],column);
        if(pixel == 1) digitalWrite(columnPins[column], LOW);
        delayMicroseconds(300); // a small delay for each LED
        digitalWrite(columnPins[column], HIGH);
      }
      digitalWrite(rowPins[row], LOW); // disconnect LEDs
    }
  }
}
```

Controlling LEDs: Charlieplexing

- Charlieplexing - increases the number of LEDs that can be driven by a group of pins
- Based on the fact that LEDs only turn on when anode more positive than the cathode



Pins			LEDs					
4	3	2	1	2	3	4	5	6
L	L	L	0	0	0	0	0	0
L	H	i	1	0	0	0	0	0
H	L	i	0	1	0	0	0	0
i	L	H	0	0	1	0	0	0
i	H	L	0	0	0	1	0	0
L	i	H	0	0	0	0	1	0
H	i	L	0	0	0	0	0	1

L is LOW, H is HIGH, and i is INPUT mode

Controlling LEDs: Charlieplexing

```
byte pins[] = {2,3,4}; // the pins that are connected to LEDs
const int NUMBER_OF_PINS = sizeof(pins)/ sizeof(pins[0]);
const int NUMBER_OF_LEDS = NUMBER_OF_PINS * (NUMBER_OF_PINS-1);
byte pairs[NUMBER_OF_LEDS/2][2] = { {0,1}, {1,2}, {0,2} }; // maps pins to LEDs
void setup(){
}
void loop(){
  for(int i=0; i < NUMBER_OF_LEDS; i++){
    lightLed(i); // light each LED in turn
    delay(1000);
  }
}
void lightLed(int led){
  int indexA = pairs[led/2][0];
  int indexB = pairs[led/2][1];
  int pinA = pins[indexA];
  int pinB = pins[indexB];
  for(int i=0; i < NUMBER_OF_PINS; i++)
    if( pins[i] != pinA && pins[i] != pinB){ // if this pin is not one of our pins
      pinMode(pins[i], INPUT); // set the mode to input
      digitalWrite(pins[i],LOW); // make sure pull-up is off
    }
  pinMode(pinA, OUTPUT); pinMode(pinB, OUTPUT);
  if( led % 2 == 0){
    digitalWrite(pinA,LOW); digitalWrite(pinB,HIGH);
  }else{
    digitalWrite(pinB,LOW); digitalWrite(pinA,HIGH);
  }
}
```