week
02
Digital Input and Output
RGB LEDs fade with PWM
Microcontrollers

Output Transducers
actuators (e.g., motors, buzzers)

Input Transducers
sensors (e.g., switches, levers, sliders, etc.)

Illustration adapted and modified from O’Sullivan and Igoe
Digital vs. Analog

Binary vs. continuous signals

- Binary / Digital = “whether or not”
- Continuous / Analog signal = “how much” or “faster,” “brighter,” etc.
Digital vs. Analog

Internally, all microprocessors compute binary: 0 or 1 (0V or 5V)
In general, most microprocessors output only binary (0V or 5V)
Specifically, Arduino output pins can only be LOW (0V) or HIGH (5V)
Digital vs. Analog

Two states (binary signal) vs. multiple states (continuous signal)
Digital Output

Blinking LED

```cpp
/*
 * Blink
 *
 * The basic Arduino example. Turns on an LED on for one second,
 * then off for one second, and so on... We use pin 13 because,
 * depending on your Arduino board, it has either a built-in LED
 * or a built-in resistor so that you need only an LED.
 *
 * http://www.arduino.cc/en/Tutorial/Blink
 */

int ledPin = 13;    // LED connected to digital pin 13

void setup()        // run once, when the sketch starts
{
    pinMode(ledPin, OUTPUT);  // sets the digital pin as output
}

void loop()         // run over and over again
{
    digitalWrite(ledPin, HIGH);  // sets the LED on
    delay(1000);                  // waits for a second
    digitalWrite(ledPin, LOW);   // sets the LED off
    delay(1000);                  // waits for a second
}
```
Can We Do Analog Out?

LED with 23% brightness?
Pulse Width Modulation (PWM)

Most microprocessors can only output binary: LOW (0V) or HIGH (5V)
So you fake it with PWM, Pulse Width Modulation
It gives you an illusion of analog values, in between LOW and HIGH
PWM

![PWM Waveforms](image)
PWM

75% brightness

50% brightness

25% brightness
Pulse Width Modulation (PWM)

Your Arduino board has built in PWM circuits, on pins 3, 5, 6, 9, 10, and 11
**analogWrite(pin, value)**

The duty cycle: between 0 and 255

- `analogWrite(11, 191)` 75% brightness
- `analogWrite(11, 127)` 50% brightness
- `analogWrite(11, 64)` 25% brightness
In Class Exercise

Make a color mixer with RGB LEDs

Exercise with digital input and output, and PWM
Color Mixer with RGB LEDs

Make any colors with Red, Green, and Blue LEDs, except black
In Class Exercise

1. LED Blink
2. LED Fade
3. Circuit with 3 LEDs
4. RGB LED Fade
5. Serial RGB LED
Blinking LED (c.f. homework)

```c
/*
 * Blink
 *
 * The basic Arduino example. Turns on an LED on for one second,
 * then off for one second, and so on... We use pin 13 because,
 * depending on your Arduino board, it has either a built-in LED
 * or a built-in resistor so that you need only an LED.
 *
 * http://www.arduino.cc/en/Tutorial/Blink
 */

int ledPin = 13;     // LED connected to digital pin 13

void setup()         // run once, when the sketch starts
{
    pinMode(ledPin, OUTPUT); // sets the digital pin as output
}

void loop()          // run over and over again
{
    digitalWrite(ledPin, HIGH); // sets the LED on
    delay(1000); // waits for a second
    digitalWrite(ledPin, LOW);  // sets the LED off
    delay(1000); // waits for a second
}
```
In Class Exercise

1. LED Blink
2. LED Fade
3. Circuit with 3 LEDs
4. RGB LED Fade
5. Serial RGB LED
LED Fade

```cpp
// Fading LED
// by BARRAGAN <https://people.interaction-lvse.it/b.barragan>
int value = 0; // variable to keep the actual value
int ledpin = 0; // light connected to digital pin 0

void setup()
{  
  // nothing for setup
}

void loop()
{
  for (value = 0; value <= 255; value += 5) // fade in (from min to max)
  {
    analogWrite(ledpin, value); // sets the value (range from 0 to 255)
    delay(30); // waits for 30 milliseconds to see the dimming effect
  }
  for (value = 255; value >= 0; value -= 5) // fade out (from max to min)
  {
    analogWrite(ledpin, value);
    delay(30);
  }
}
```
In Class Exercise

1. LED Blink
2. LED Fade
3. Circuit with 3 LEDs
4. RGB LED Fade
5. Serial RGB LED
Circuit with 3 LEDs

Plug three LEDs, red, green, and blue and make different colors
In Class Exercise

1. LED Blink
2. LED Fade
3. Circuit with 3 LEDs
4. RGB LED Fade
5. Serial RGB LED
RGB LED Fade

Slow color fading and mixing

```cpp
// The debugging code assumes Arduino 0004, as it uses the new Serial.begin(9600) style functions

/* Clay Shyhyk <clay.shyhyk@syu.edu>
*/

// Output
int redPin = 9; // Red LED, connected to digital pin 9
int greenPin = 10; // Green LED, connected to digital pin 10
int bluePin = 11; // Blue LED, connected to digital pin 11

// Program variables
int redVal = 255; // Variables to store the values to send to the pins
int greenVal = 1; // Initial values are Red full, Green and Blue off
int blueVal = 1;

int i = 0; // Loop counter
int wait = 50; // 50ms (.05 second) delay: shorten for faster fades
int DEBUG = 0; // DEBUG counter: if set to 1, will write values back via serial

void setup() {
    pinMode(redPin, OUTPUT); // sets the pins as output
    pinMode(greenPin, OUTPUT);
    pinMode(bluePin, OUTPUT);
    if (DEBUG) {
        // If we want to see the pin values for debugging...
        Serial.begin(9600); // ...set up the serial output on 0004 style
    }
}
```
Diffuser

Take a few packing peanuts to experiment
In Class Exercise

1. LED Blink
2. LED Fade
3. Circuit with 3 LEDs
4. RGB LED Fade
5. Serial RGB LED
Serial RGB

```c
void loop () {
  // read the serial port and create a string out of what you read
  readSerialString(serInString);

  colorCode = serInString[0];
  if (colorCode == 'r' || colorCode == 'g' || colorCode == 'b') {
    colorVal = atoi(serInString+1);
    Serial.print("setting color ");
    Serial.print(colorCode);
    Serial.print(" to ");
    Serial.print(colorVal);
    Serial.println();
    serInString[0] = 0;
    // indicates we've used this string
    if (colorCode == 'r')
      analogWrite(redPin, colorVal);
    else if (colorCode == 'g')
      analogWrite(greenPin, colorVal);
    else if (colorCode == 'b')
      analogWrite(bluePin, colorVal);
  }
}
```

Tell it to mix 50 red, 100 green, and 20 blue... Etc.
Arduino Board

• USB to serial
Serial Monitor

```javascript
{  redVal = 1; // Red low  
  greenVal = 1; // Green down  
  blueVal += 1; // Blue up  
}
else if (i < 763) // Third phase of fades  
{  redVal -= 1; // Red up  
  greenVal = 1; // Green low  
  blueVal -= 1; // Blue down  
}
else // Re-set the counter, and start the fades again  
{  i = 1;  
}

analogWrite(redPin, redVal); // Write current values to LED pins  
analogWrite(greenPin, greenVal);  
analogWrite(bluePin, blueVal);  
```
Serial Communication

Serial.begin()  e.g., Serial.begin(9600)
Serial.print()  e.g., Serial.print(colorVal)
Serial.read()
Serial RGB

Tell it to mix 50 red, 100 green, and 20 blue... etc.
char serInString[100];  // array that will hold the different bytes of the string. 100=100 characters
// -> you must state how long the array will be else it won't work properly.

char colorCode;
int colorVal;

int redPin = 9;  // Red LED, connected to digital pin 9
int greenPin = 10;  // Green LED, connected to digital pin 10
int bluePin = 11;  // Blue LED, connected to digital pin 11

void setup() {}  
  pinMode(redPin, OUTPUT);  // sets the pins as output
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
  Serial.begin(9600);
  analogWrite(redPin, 127);  // set them all to aid brightness
  analogWrite(greenPin, 127);
  analogWrite(bluePin, 127);  // set them all to aid brightness
  Serial.println("enter color command (e.g. 'r43');

void loop () {}  
//read the serial port and create a string out of what you read
readSerialString(serInString);

  colorCode = serInString[0];
  if (colorCode == 'r' || colorCode == 'g' || colorCode == 'b' ||
    colorVal = atoi(serInString+1);
    Serial.print("Setting color ");
    Serial.println(colorCode);
    Serial.println(" to ");
    Serial.println(colorVal);
    Serial.println();  // prints return
  serInString[0] = 0;  // indicates we've used this string
  if (colorCode == 'r')
    analogWrite(redPin, colorVal);
  else if (colorCode == 'g')
    analogWrite(greenPin, colorVal);
  else if (colorCode == 'b')
    analogWrite(bluePin, colorVal);

  delay(100);  // wait a bit, for serial data
}
```c
char serInString[100]; // array that will hold the different bytes of the string. 100=100characters
// -> you must state how long the array will be else it won't work properly!

char colorCode;
int colorVal;

int redPin = 9; // Red LED, connected to digital pin 9
int greenPin = 10; // Green LED, connected to digital pin 10
int bluePin = 11; // Blue LED, connected to digital pin 11

void setup() {
  pinMode(redPin, OUTPUT); // sets the pins as output
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
  Serial.begin(9600);
  analogWrite(redPin, 127); // set them all to aid brightness
  analogWrite(greenPin, 127);
  analogWrite(bluePin, 127); // set them all to aid brightness
  Serial.println("Enter color command (e.g. 'r43') :");
}

void loop() {
  //read the serial port and create a string out of what you read
  readSerialString(serInString);

  colorCode = serInString[0];
  if (colorCode == 'r' || colorCode == 'g' || colorCode == 'b') {
    colorVal = atoi(serInString+1);
    Serial.print("Setting color ");
    Serial.print(colorCode);
    Serial.print(" to ");
    Serial.print(colorVal);
    Serial.println(); // prints return
  }
  serInString[0] = 0; // indicates we've used this string
  if (colorCode == 'r')
    analogWrite(redPin, colorVal);
  else if (colorCode == 'g')
    analogWrite(greenPin, colorVal);
  else if (colorCode == 'b')
    analogWrite(bluePin, colorVal);
}

delay(100); // wait a bit, for serial data
```
char serInString[100]; // array that will hold the different bytes of the string. 100=100 characters
// -> you must state how long the array will be else it won't work properly

char colorCode;
int colorVal;

int redPin = 9; // Red LED, connected to digital pin 9
int greenPin = 10; // Green LED, connected to digital pin 10
int bluePin = 11; // Blue LED, connected to digital pin 11

void setup() {
  pinMode(redPin, OUTPUT); // sets the pins as output
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
  Serial.begin(9600);
  analogWrite(redPin, 127); // set them all to aid brightness
  analogWrite(greenPin, 127); // set them all to aid brightness
  analogWrite(bluePin, 127); // set them all to aid brightness
  Serial.println("Enter color command (e.g. 'r43'):");
}

void loop() {
  //read the serial port and create a string out of what you read
  readSerialString(serInString);

  colorCode = serInString[0];
  if(colorCode == 'r' || colorCode == 'g' || colorCode == 'b') {
    colorVal = atoi(serInString+1);
    Serial.print("Setting color ");
    Serial.print(colorCode);
    Serial.print(" to ");
    Serial.print(colorVal);
  }
  // prints return
  Serial.println(); // indicates we've used this string

delay(100); // wait a bit, for serial data
}
```c
char serInString[100]; // array that will hold the different bytes of the string. 100=100characters
// -> you must state how long the array will be else it won't work properly

char colorCode;
int colorVal;

int redPin = 9; // Red LED, connected to digital pin 9
int greenPin = 10; // Green LED, connected to digital pin 10
int bluePin = 11; // Blue LED, connected to digital pin 11

void setup() {
    pinMode(redPin, OUTPUT); // sets the pins as output
    pinMode(greenPin, OUTPUT);
    pinMode(bluePin, OUTPUT);
    Serial.begin(9600);
    analogWrite(redPin, 127); // set them all to aid brightness
    analogWrite(greenPin, 127); // set them all to aid brightness
    analogWrite(bluePin, 127); // set them all to aid brightness
    Serial.println("Enter color command (e.g. 'r43'): ");
}

void loop() {
    // Read the serial port and create a string out of what you read
    readSerialString(serInString);

    colorCode = serInString[0];
    if (colorCode == 'r' || colorCode == 'G' || colorCode == 'b') {
        colorVal = atoi(serInString+1);
        Serial.print("Setting color ");
        Serial.print(colorCode);
        Serial.println(" to ");
        Serial.println(colorVal);
        Serial.println(); // prints return
    } else if (serInString[0] == 0) { // indicates we've used this string
        if (colorCode == 'r')
            analogWrite(redPin, colorVal);
        else if (colorCode == 'G')
            analogWrite(greenPin, colorVal);
        else if (colorCode == 'b')
            analogWrite(bluePin, colorVal);
    }
}

delay(100); // wait a bit, for serial data
}```
In Class Exercise

1. LED Blink
2. LED Fade
3. Circuit with 3 LEDs
4. RGB LED Fade
5. Serial RGB LED
Homework (due next Thursday, Sep 13)

Part I: Design a good diffuser for your RGB LEDs
e.g., ping pong ball, styrofoam, mylar, cottons, icecream cone?

Part II: Modify the Serial RGB code for new keyboard input:

- **Basic**: Control the RGB values with multiple key presses (e.g., instead of typing “r127” to set the Red LED to 50% brightness, count how many times the characters “r” “g” “b” were pressed. E.g., press “r” 5 times to get it to 50%, 8 times for 80%, 10 times for 100%, 11 times to go back to 0%, etc.)

- **Advanced**: Find new ways of controlling the colors of LEDs using the keyboard

Post both parts on the course website (photo, descriptions, code)
Supplement Readings

More on PWM and LED fading: Chapter 6 (p. 112-114) of O’Sullivan and Igoe

More on microcontroller in general: Chapter 4 (p.49-63)
Next Thursday: Analog Input

Two states (binary signal) vs. multiple states (continuous signal)