Intro to Arduino I/O
~
Programming beyond the pins

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Squidwrench

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The Big Picture

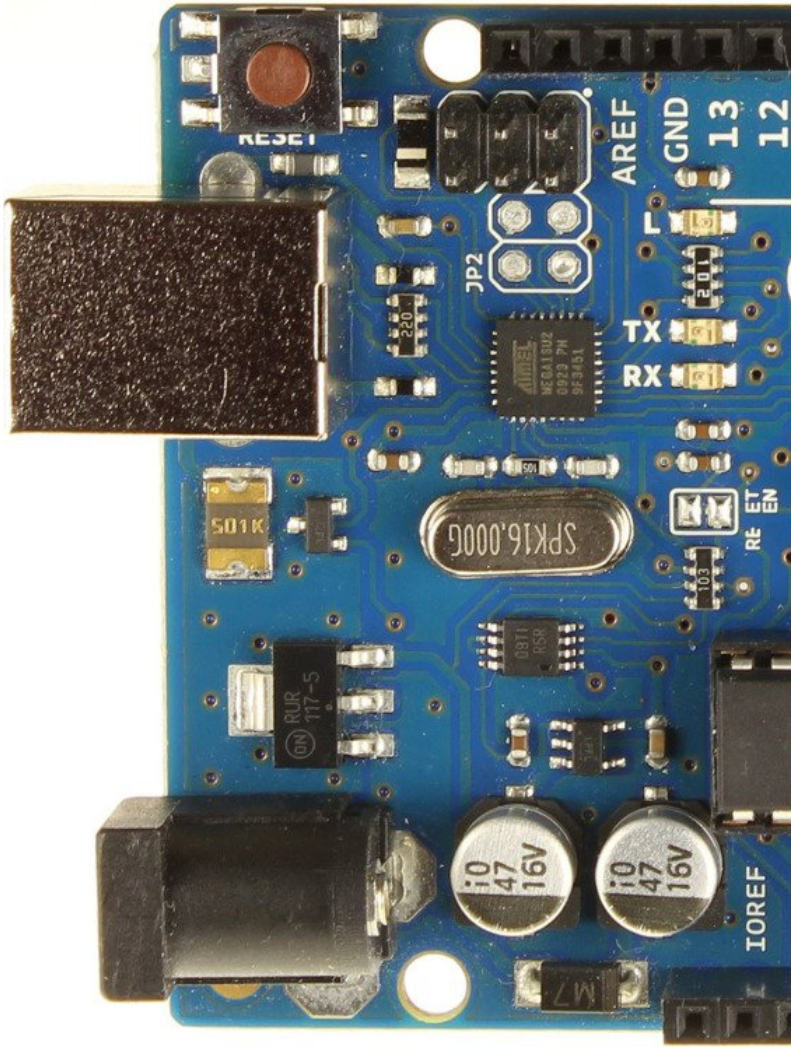
- Arduino stuff
  - PCB with known pin layout & spacing
  - Power Source: USB or DC wall wart
  - Atmel Atmega168 / 328 µC + USB Interface
  - Digital & analog I/O pins
- Your stuff
  - Draws power (ideally 5 V, maybe 12 V, or ...)
  - Connects to µC I/O pins (5 V only!)
  - Must play well with Arduino

Useful Background

- Dimensions & units
  - E = voltage: volt V, millivolt mV
  - I = current: ampere A, milliampere mA = A/1000
  - P = power: watt W, milliwatt mW = W/1000
  - R = resistance: ohm Ω, kilohm kΩ = Ω • 1000
  - L = inductance: henry H, millihenry mH = H/1000
- Ohm's Law: $E = I \cdot R$ (for resistors with known R)
- Power: $P = I^2 \cdot R = E^2/R = E \cdot I$ (for *anything*)
- You need a calculator and a multimeter ... *now*!

Power Supply

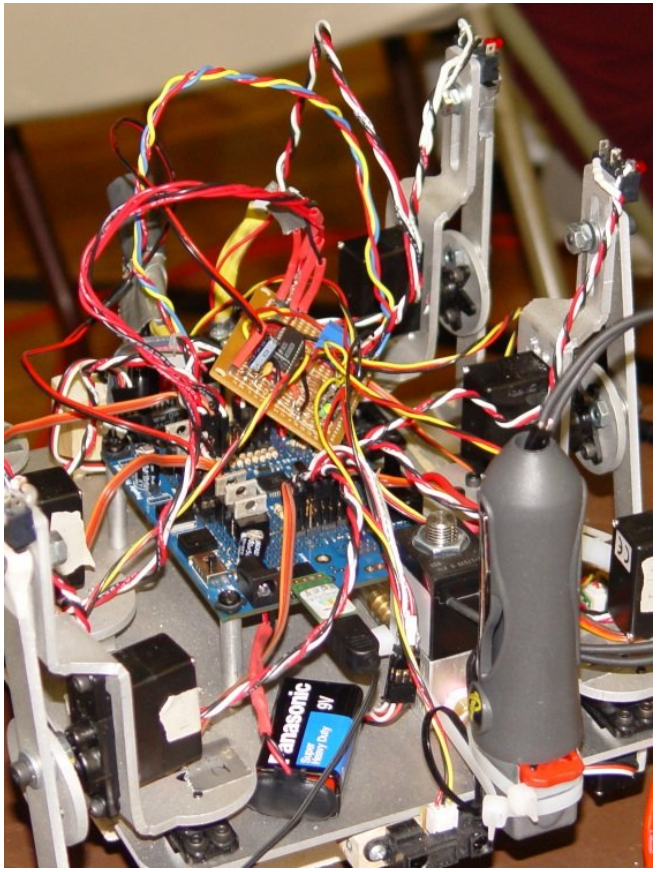
- USB Supply ≠ 5.0 V
  - Measure actual V & I
  - Draw < 200 mA from port
    - Max ≈ 500 mA, usually
- Wall Wart V_{EXT} ≤ 12 V
  - Loose wire? µC dies > 5 V!
  - Less heat @ V_{EXT} < 9 V
    - Keep regulator << 500 mW
    - Power P = (V_{EXT} - 5) * I



http://arduino.cc/en/Main/ArduinoBoardUno

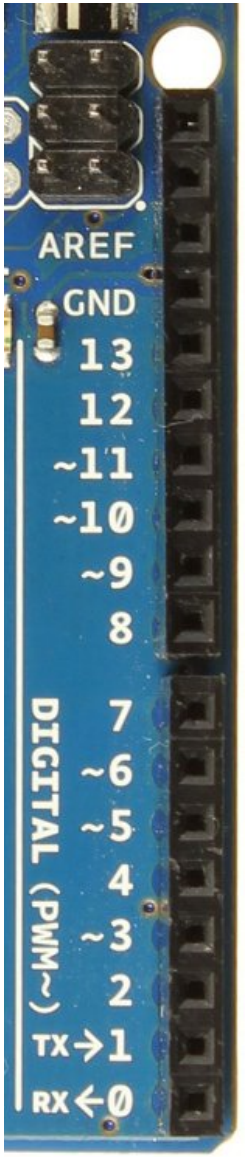
Plug It In, It Turns On

- Getting Started Instructions
- Fetch & Install Arduino 1.0.5 IDE
  - Windows / Linux / Mac
- Arduino ↔ USB Cable ↔ PC
  - Beware cheap cables!
- Select the right “serial” port
- Select proper microcontroller
- Load / run / change Blink sketch
- Install Libraries?
  - New in 1.0.5: Sketch → Import Library



Digital Output Pins

- Configure pins for output in `setup()`
  - `pinMode(2,OUTPUT)`
- Outputs `HIGH` = 5 V or `LOW` = 0 V
  - Depends on load: measure!
- Current ≤ 40 mA / pin = *absolute max*
  - Happiness ↑↑ for current ≤ 20 mA
  - Enough for one standard LED...
- Maximum total µC current = 200 mA
  - Draw much less than that: ≤ 100 mA max



http://arduino.cc/en/Tutorial/DigitalPins
http://arduino.cc/en/Reference/DigitalWrite

Simple Blink Sketch

```
int led = 13;                    ← always has an LED!

void setup() {
  pinMode(led, OUTPUT);          ← make pin an output
}

void loop() {
  digitalWrite(led, HIGH);       ← turn LED on
  delay(1000);                   ← wait for a while
  digitalWrite(led, LOW);        ← turn LED off
  delay(1000);                   ← try a different value!
}
```


http://arduino.cc/en/Tutorial/Blink

BlinkNoDelay: Definitions

```
const byte pinLED =  13;

byte ledState;

unsigned long MillisNow;
unsigned long MillisThen;
unsigned long interval = 100;
```


Adapted from http://arduino.cc/en/Tutorial/BlinkWithoutDelay

BlinkNoDelay: setup()

```
void setup() {
  pinMode(pinLED, OUTPUT);
}
```

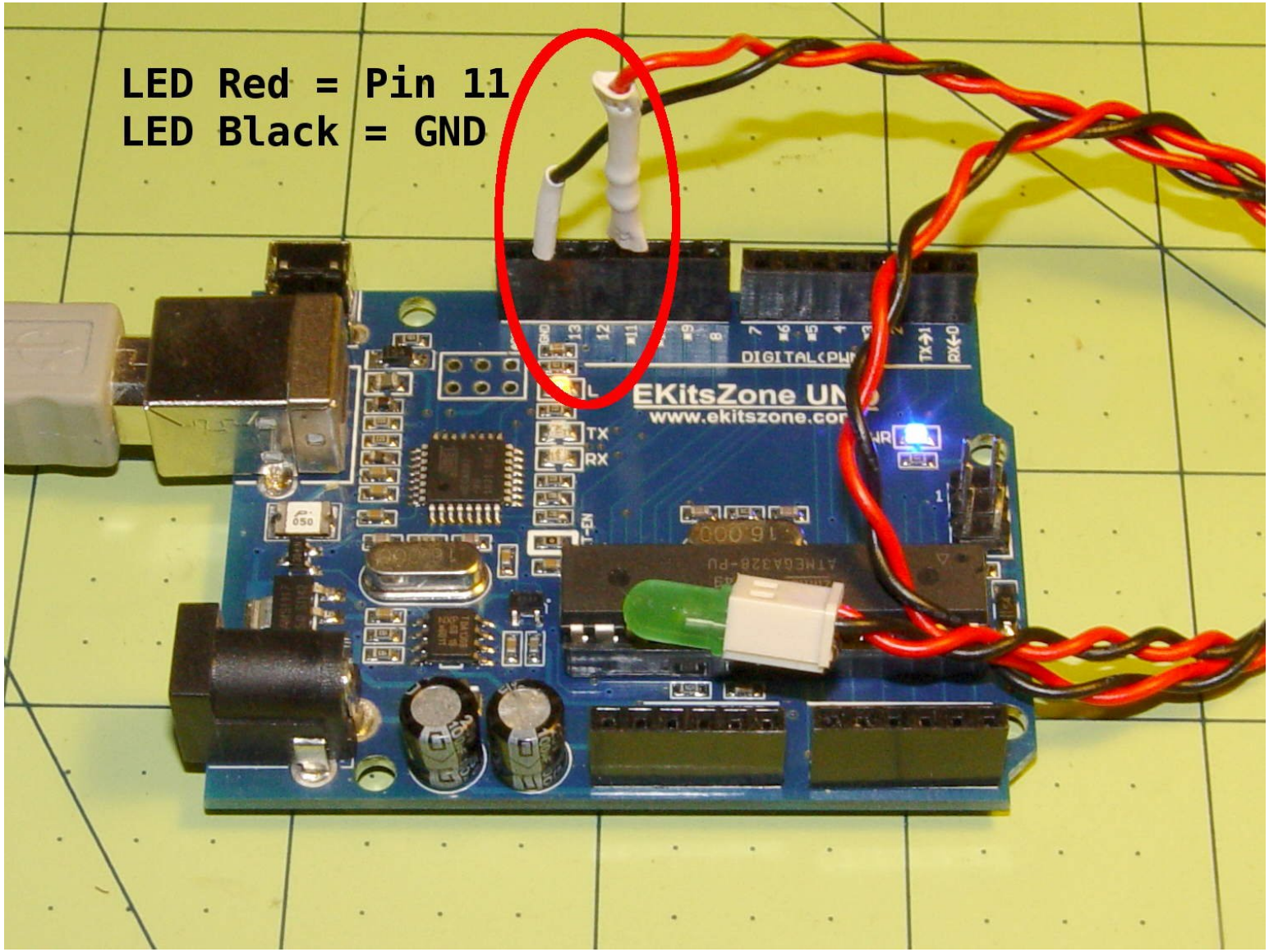

Adapted from http://arduino.cc/en/Tutorial/BlinkWithoutDelay

BlinkNoDelay: loop()

```
void loop() {
  MillisNow = millis();

  if ((MillisNow - MillisThen) > interval) {
    MillisThen = MillisNow;

    ledState = !ledState;

    digitalWrite(pinLED, ledState);
  }
}
```


Adapted from http://arduino.cc/en/Tutorial/BlinkWithoutDelay

Alternating LEDs



Blink2: Definitions

```
const byte pinLED =  13;
const byte pinLED2 = 11;

byte ledState = LOW;

unsigned long MillisNow;
unsigned long MillisThen;
unsigned long interval = 100;
```

Blink2: setup()

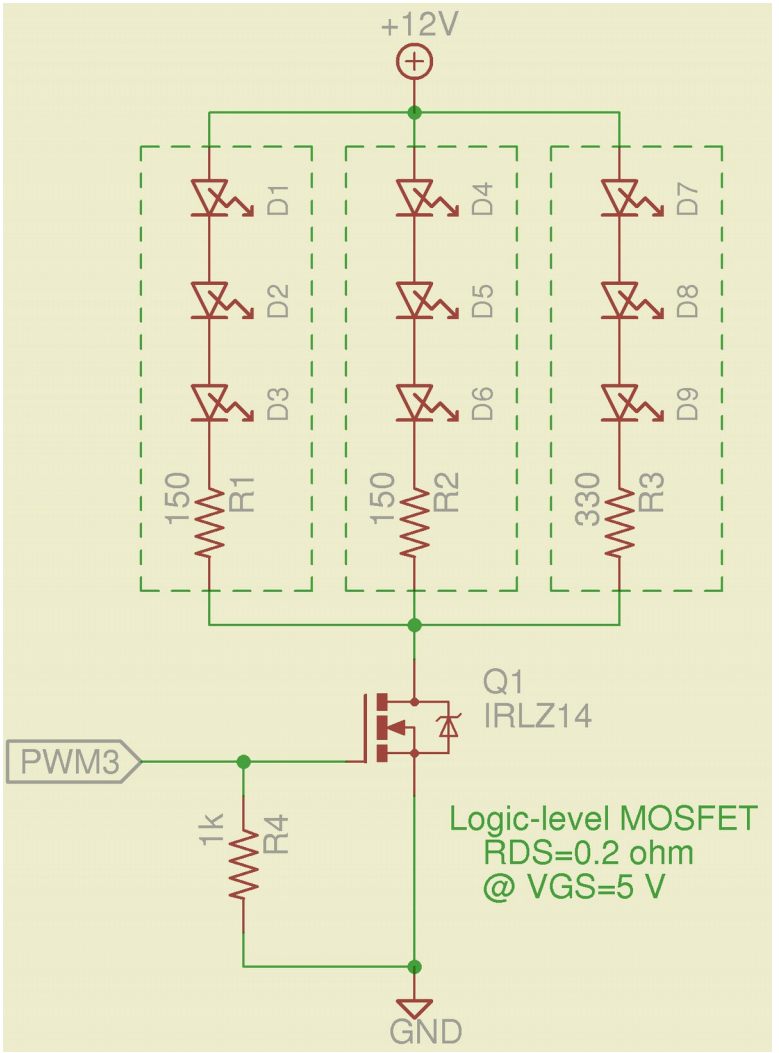
```
void setup() {
  pinMode(pinLED, OUTPUT);
  pinMode(pinLED2, OUTPUT);
}
```

Blink2: loop()

```
void loop() {
  MillisNow = millis();

  if ((MillisNow - MillisThen) > interval) {
    MillisThen = MillisNow;

    ledState = !ledState;

    digitalWrite(pinLED, ledState);
    digitalWrite(pinLED2, !ledState);
  }
}
```

LED Strip Driver

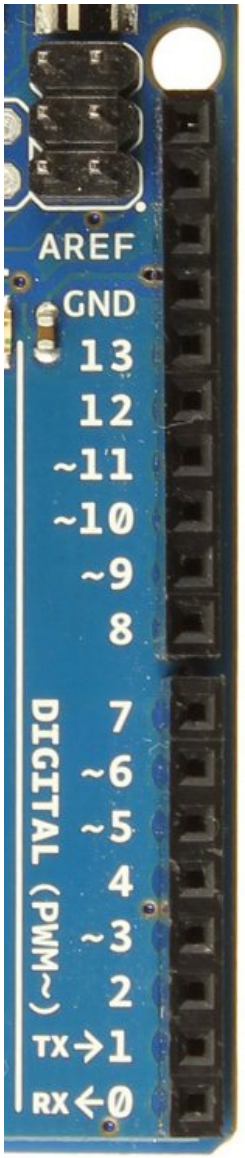
- 3 LED sections = 60 mA
- Logic-level MOSFET
- Must have gate pulldown R
  - Override µC input pullup
- More sections = heatsink!
  - MOSFET $P = I^2 \bullet R_{DS}$
- May need RC snubber
  - Stray inductance (!)



http://softsolder.com/2009/03/06/rc-snubber-resonant-design/

Digital Input Pins

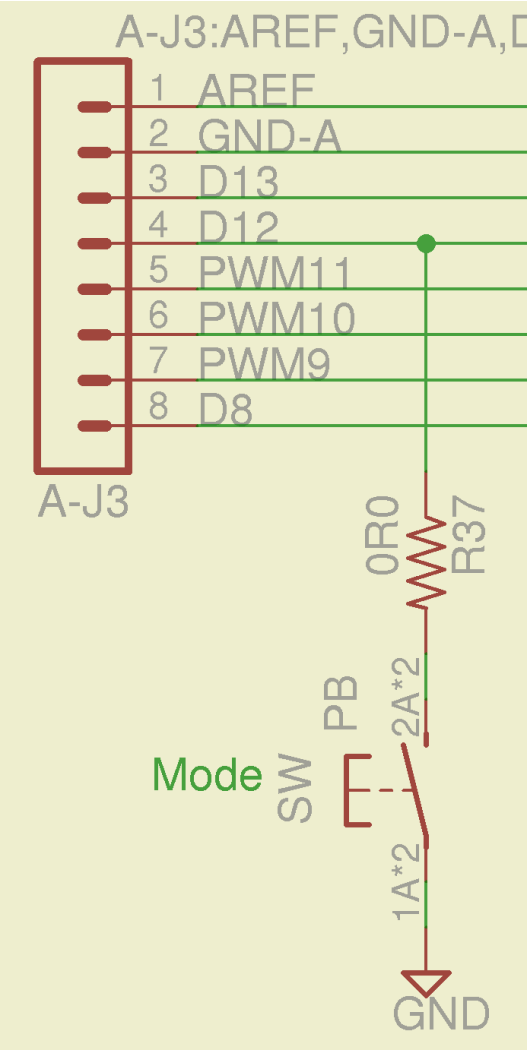
- All pins are inputs before `setup()`
  - `pinMode(2,INPUT)` ← comforting
- Enable internal pullup resistors (always?)
  - `pinMode(2,INPUT_PULLUP)` ← new
  - `digitalWrite(2,HIGH)` ← old
- *Do not* depend on pullup resistor value
  - Min 20 kΩ – what everyone assumes it is
  - Max 50 kΩ – what it might actually be
- `digitalRead(2)`



http://arduino.cc/en/Tutorial/DigitalPins
http://arduino.cc/en/Reference/DigitalRead

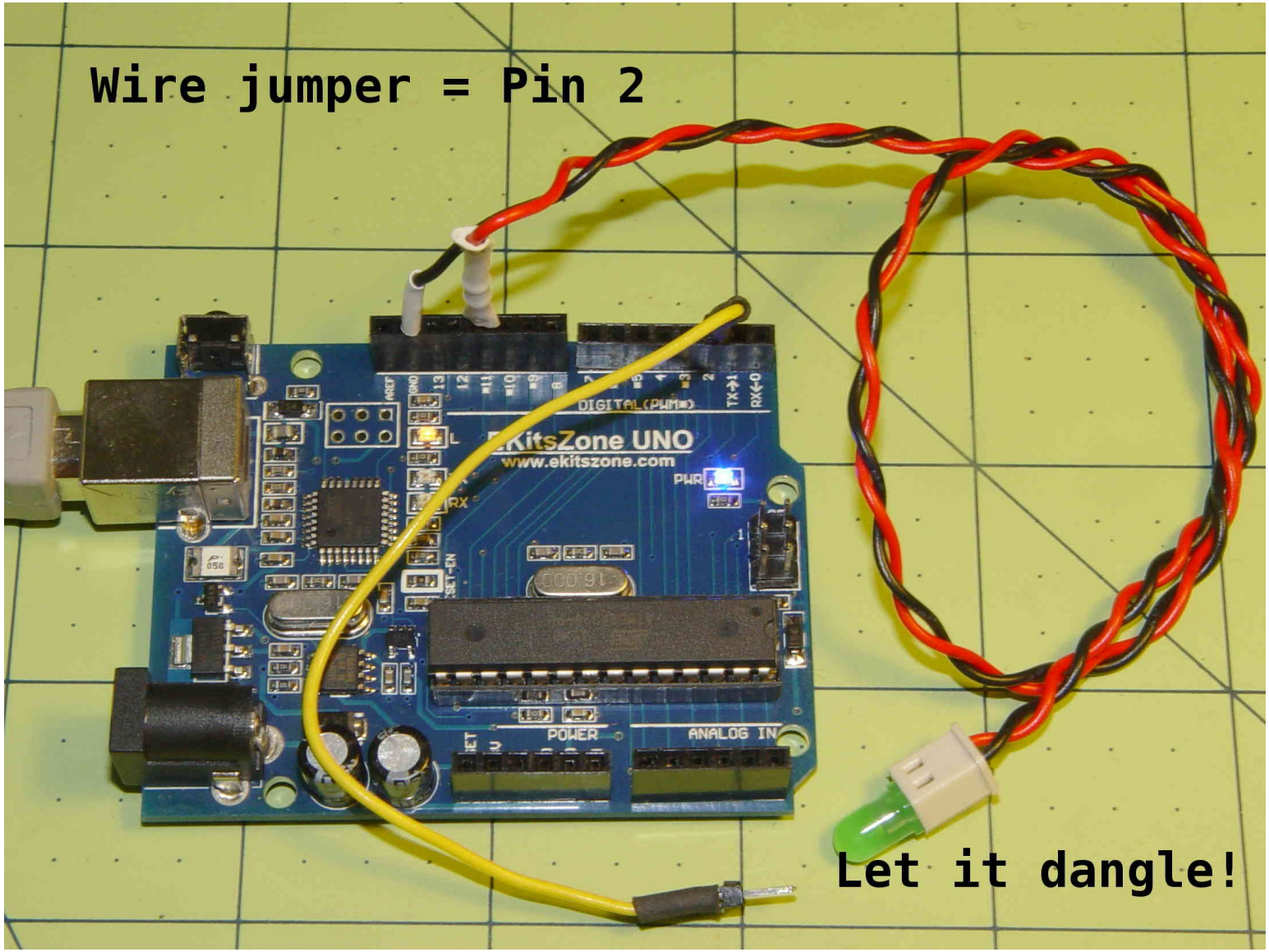
Switch Inputs

- Connect input pin to ground
  - This kills output pins = HIGH
  - Add 1 kΩ series R for protection?
- Enable internal pullup
  - `pinMode(12,INPUT_PULLUP)`
- Pin states track *voltages*
  - Closed = pushed = `LOW` = `false`
  - Open = released = `HIGH` = `true`



http://arduino.cc/en/Reference/DigitalRead

Digital Input



BitInFloat: Definitions

```
const byte pinLED =  13;
const byte pinLED2 = 11;
const byte pinSwitch = 2;

byte ledState;

unsigned long MillisNow;
unsigned long MillisThen;
unsigned long interval = 100;
```

BitInFloat: setup()

```
void setup() {
  pinMode(pinLED, OUTPUT);
  pinMode(pinLED2, OUTPUT);
  pinMode(pinSwitch, INPUT);
}
```

BitInFloat: loop()

```
void loop() {
  MillisNow = millis();

  if ((MillisNow - MillisThen) > interval) {
    MillisThen = MillisNow;

    ledState = !ledState;

    digitalWrite(pinLED, ledState);
  }

  digitalWrite(pinLED2,digitalRead(pinSwitch));

}
```

BitInFloat

- Is that floating wire LOW or HIGH?
- Why does waving your hand change it?
- How often will you make this mistake?

BitIO: setup()

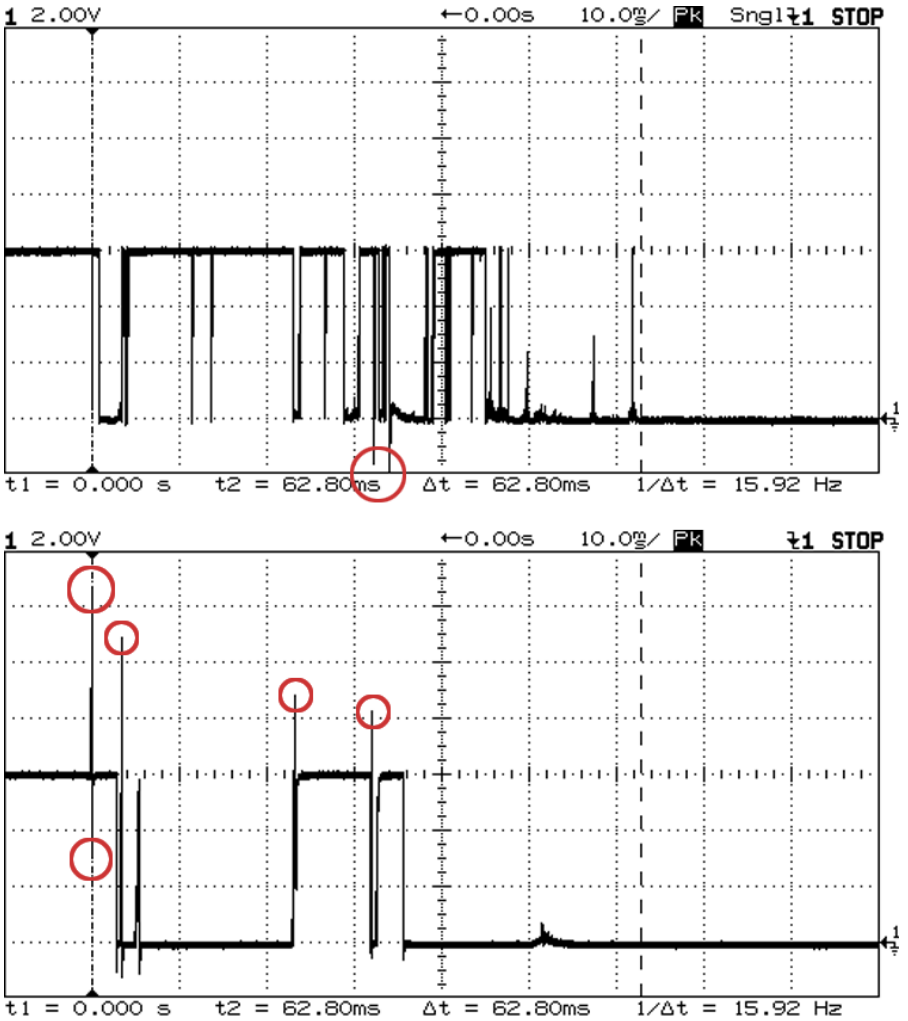
```
void setup() {
  pinMode(pinLED, OUTPUT);
  pinMode(pinLED2, OUTPUT);
  pinMode(pinSwitch, INPUT_PULLUP);
}
```

BitIO

- Now, is that floating input LOW or HIGH?
- What could possibly change it?

Switch Contact Bounce

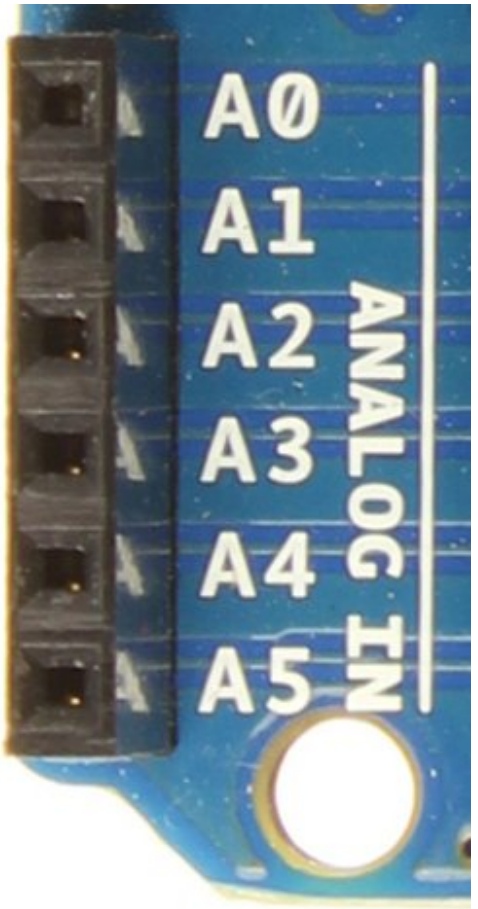
- Glitches galore!
  - Time scale = 10 ms/div
  - Unpredictable events
- Add parallel C = bad
  - Resonant with stray L
  - Voltage spikes!
- Use Bounce library
  - Don't roll your own
- Plan for the worst case



https://en.wikipedia.org/wiki/Switch#Contact_bounce
http://arduino.cc/playground/Code/Bounce

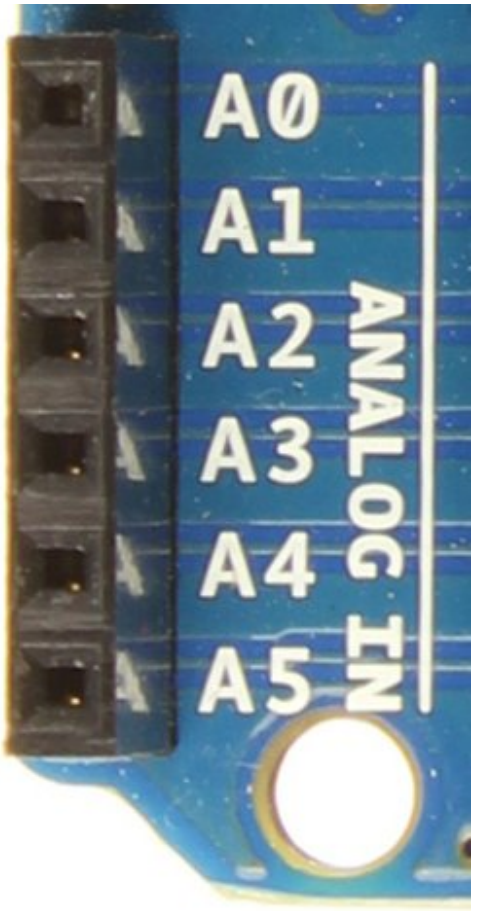
Additional Digital I/O Pins!

- Reconfigure Analog Input pins
  - `pinMode(A0,INPUT_PULLUP)`
  - `pinMode(A0,OUTPUT)`
- The usual digital functions
  - `digitalWrite(A0,LOW)`
  - `digitalRead(A0)`
- No analog *output*
  - ~~`analogWrite(A0,128)`~~



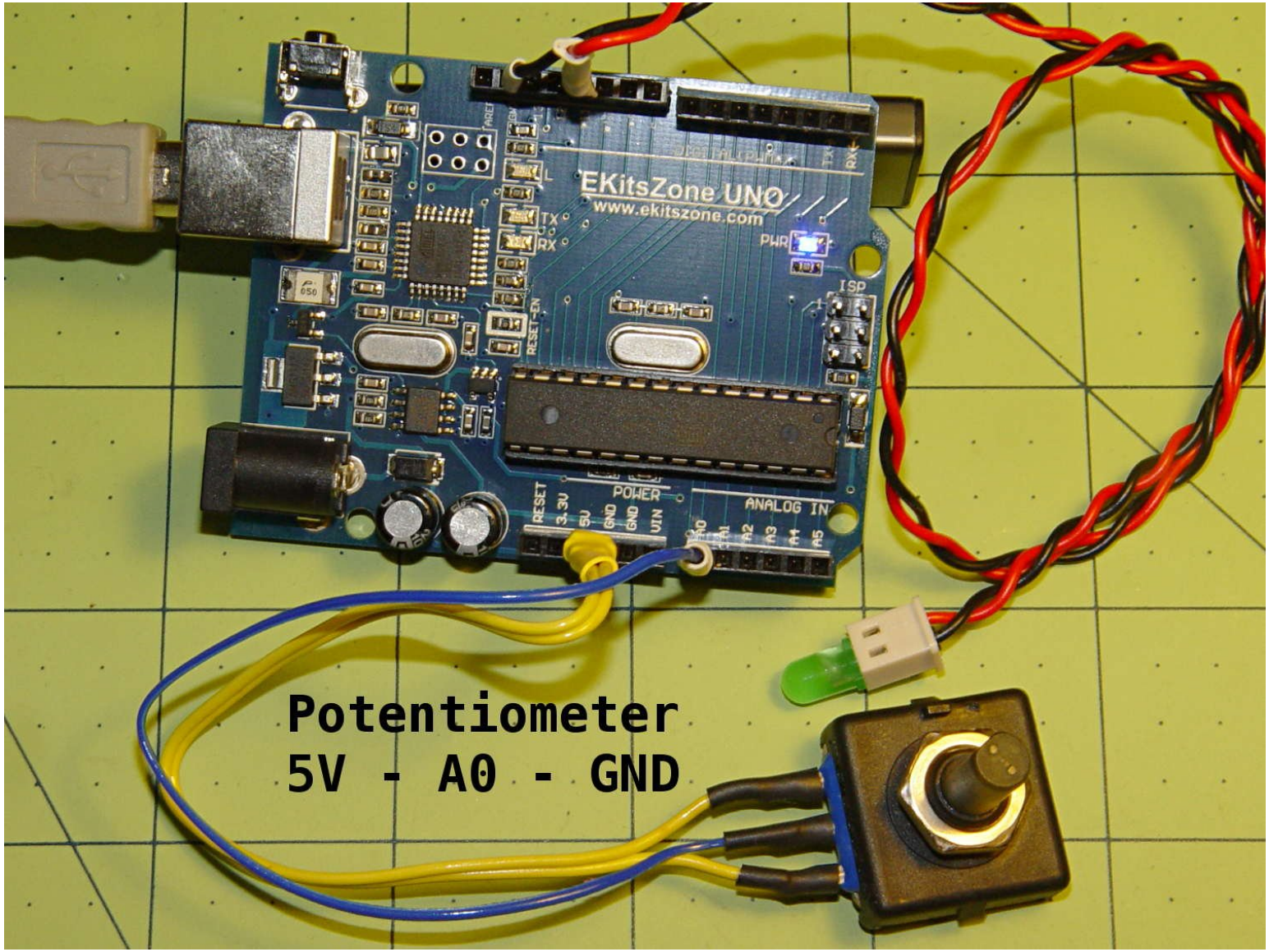
Analog Input

- analogRead(A0)
  - Minimum 0 = 0V
  - Maximum 1023 = 5 V (pretty close)
  - Depends on actual supply voltage!
    - Value = 1023 * (V / Vcc)
- Wall wart = stable V_{CC} = vital (*duh*)
- 0 V < [pin voltage] < 5 V
- Avoid digital pin output before AI
- Average several AI readings



http://arduino.cc/en/Tutorial/AnalogInputPins
http://arduino.cc/en/Reference/AnalogReference

Analog Input



AnalogIn: Definitions

```
const byte pinLED =  13;
const byte pinLED2 = 11;
const byte pinPot = A0;

byte ledState;
word AnalogValue, AnalogValueOld = 2000;

unsigned long MillisNow;
unsigned long MillisThen;
unsigned long interval = 100;
```

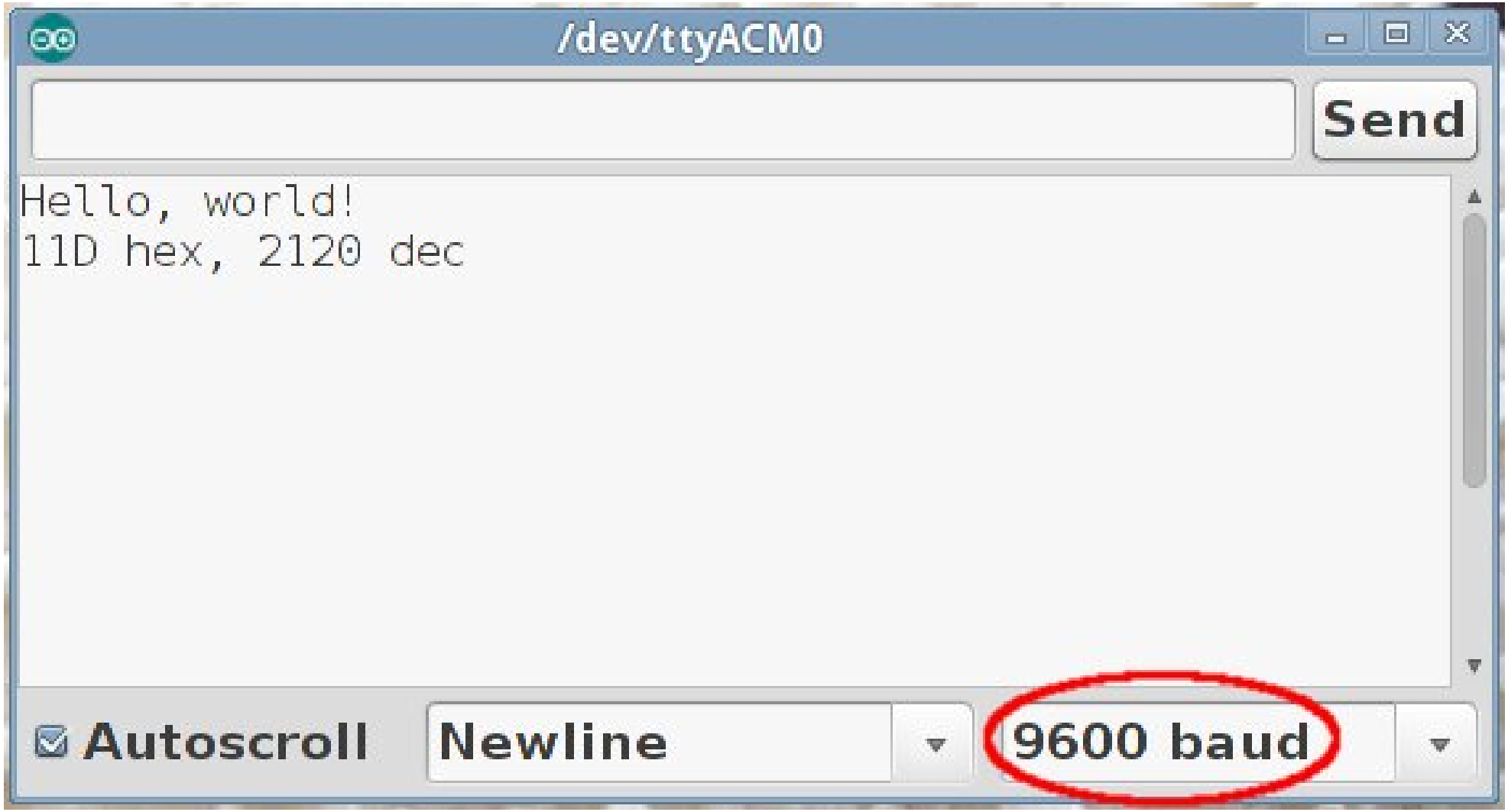
AnalogIn: setup()

```
void setup() {
  pinMode(pinLED, OUTPUT);
  pinMode(pinLED2, OUTPUT);

  Serial.begin(9600);
  Serial.println("Hello, world!");
}
```

AnalogIn: loop()

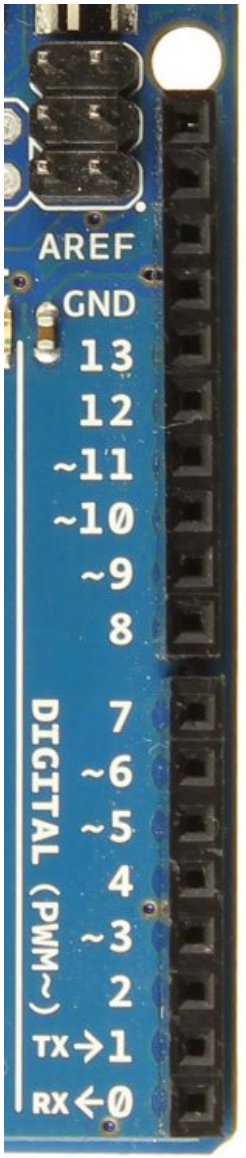
```
void loop() {
  MillisNow = millis();
  if ((MillisNow - MillisThen) > interval) {
    MillisThen = MillisNow;
    ledState = !ledState;
    digitalWrite(pinLED, ledState);
  }

  AnalogValue = analogRead(pinPot);
  if (abs(AnalogValue - AnalogValueOld) > 4) {
    AnalogValueOld = AnalogValue;
    Serial.print(AnalogValue,HEX);
    Serial.print(" hex, ");
    Serial.print(AnalogValue,5);
    Serial.println(" dec");
  }
}
```

Arduino Serial Monitor



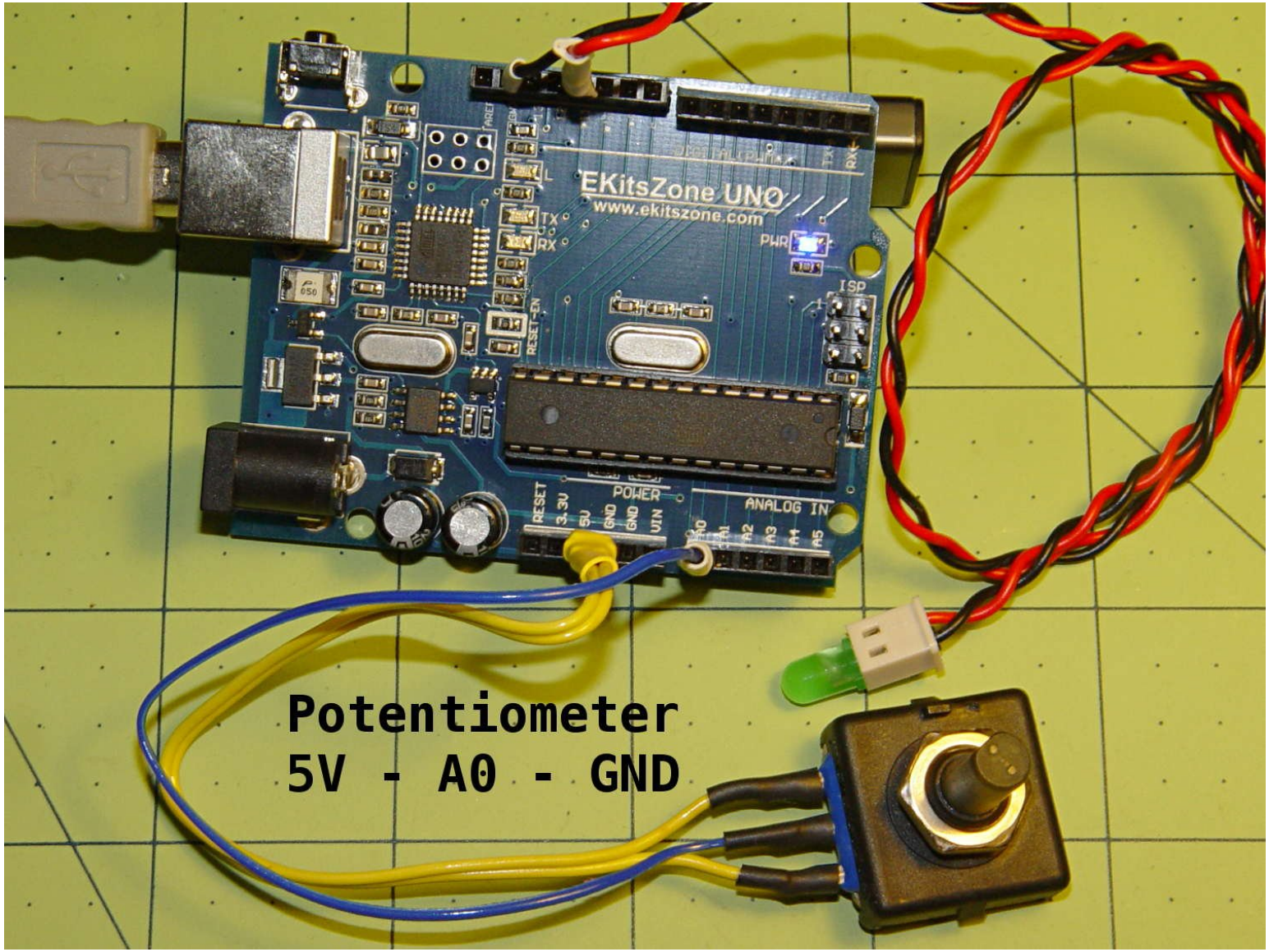
“Analog” Output

- It’s not *analog*, it’s *digital* ...
  - PWM = Pulse Width Modulation
  - Output pins 3, 5, 6, 9, 10, 11 *only*
- `analogWrite(3,100)`
  - Minimum = 0 → 0 V
  - Maximum = 255 → 5 V (depends on load)
  - 0 < “analog PWM” < 255 → pulses (*duh*)
- PWM frequency ≈ 488 & 976 Hz
  - Direct LED drive works fine



http://arduino.cc/en/Reference/AnalogWrite
http://arduino.cc/en/Tutorial/PWM

“Analog” Output

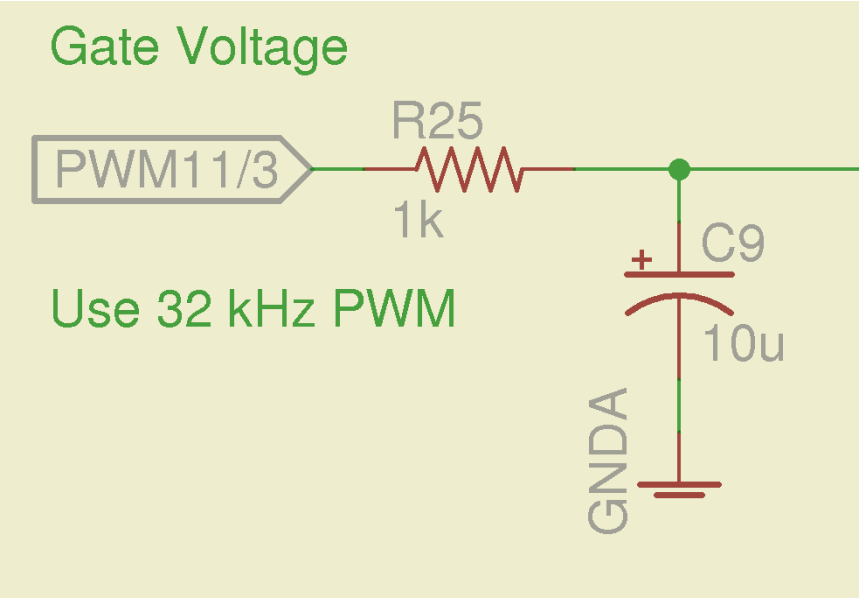


AnalogIO: loop()

```
… snippage …
  AnalogValue = analogRead(pinPot);
  if (abs(AnalogValue - AnalogValueOld) > 4) {
    AnalogValueOld = AnalogValue;
    Serial.print(AnalogValue,HEX);
    Serial.print(" hex, ");
    Serial.print(AnalogValue,5);
    Serial.println(" dec");
    analogWrite(pinLED2,AnalogValue/4);
  }
```

Real Analog Output

- Filter PWM → Analog
  - Simple RC filter OK
  - R•C >> 1/(2π•PWM freq)
  - C can be nasty big
  - ↑↑ PWM freq = ↓↓ C
- Analog buffer / op amp
  - Minimal load = good
  - Voltage scaling
- Wall wart = stable V (*duh)*



http://arduino.cc/en/Tutorial/PWM
http://softsolder.com/2009/02/21/changing-the-arduino-pwm-frequency/
http://softsolder.com/2009/03/04/arduino-fast-pwm-faster/

Other Gotchas

- Motors
  - DC – H-bridge driver
  - Steppers – microstep
  - Servo – PWM
- Noisemakers
  - Piezo
  - Speaker
- Keyboard / Keypads
- Thermistors
- SPI / I^2C / OWP chips
- LCD Panels
- LED Char / Dot Matrix
- EEPROM / SD Data
- Ethernet / WiFi
- Zigbee / XBee
- Accelerometers
- ...

Everything Else

Is

A Simple Matter of Software

More Info

arduino.cc/en/Reference/HomePage
www.ladyada.net/learn/arduino/index.html
todbot.com/blog/spookyarduino/
www.sparkfun.com/tutorials

and, of course ...
softsolder.com/tag/arduino/

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Ed Nisley

Say “NISS-lee”, although we're on the half-essed branch of the tree

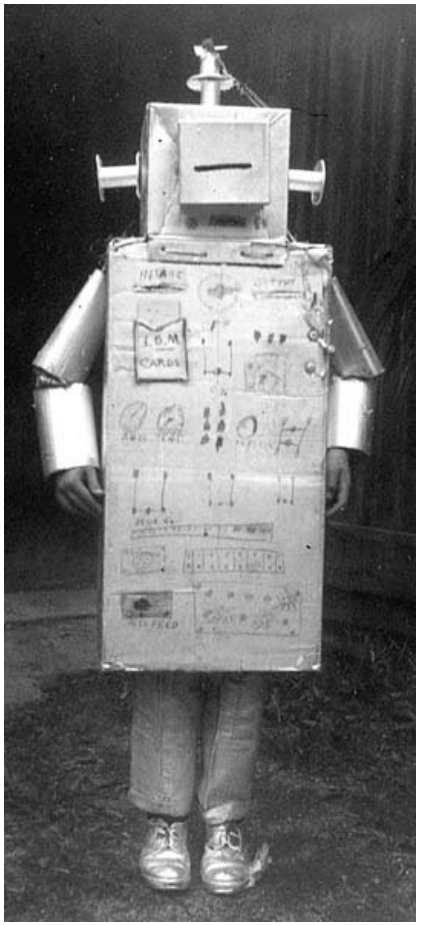
Engineer (ex PE), Hardware Hacker, Programmer, Author

The Embedded PC's ISAÂ Bus:Â Firmware, Gadgets, Practical Tricks

Circuit Cellar www.circuitcellar.com
- Firmware Furnace (1988-1996) - Nasty, grubby hardware bashing
- Above the Ground Plane (2001 ...) - Analog and RF stuff

Digital Machinist www.homeshopmachinist.net
- Along the G-Code Way (2008 ...) - G-Code, math, 3D printing

Dr. Dobb’s Journal www.ddj.com
- Embedded Space (2001-2006) - All things embedded
- Nisley’s Notebook (2006-2007) - Hardware & software collisions



The Smell of Molten Projects in the Morning
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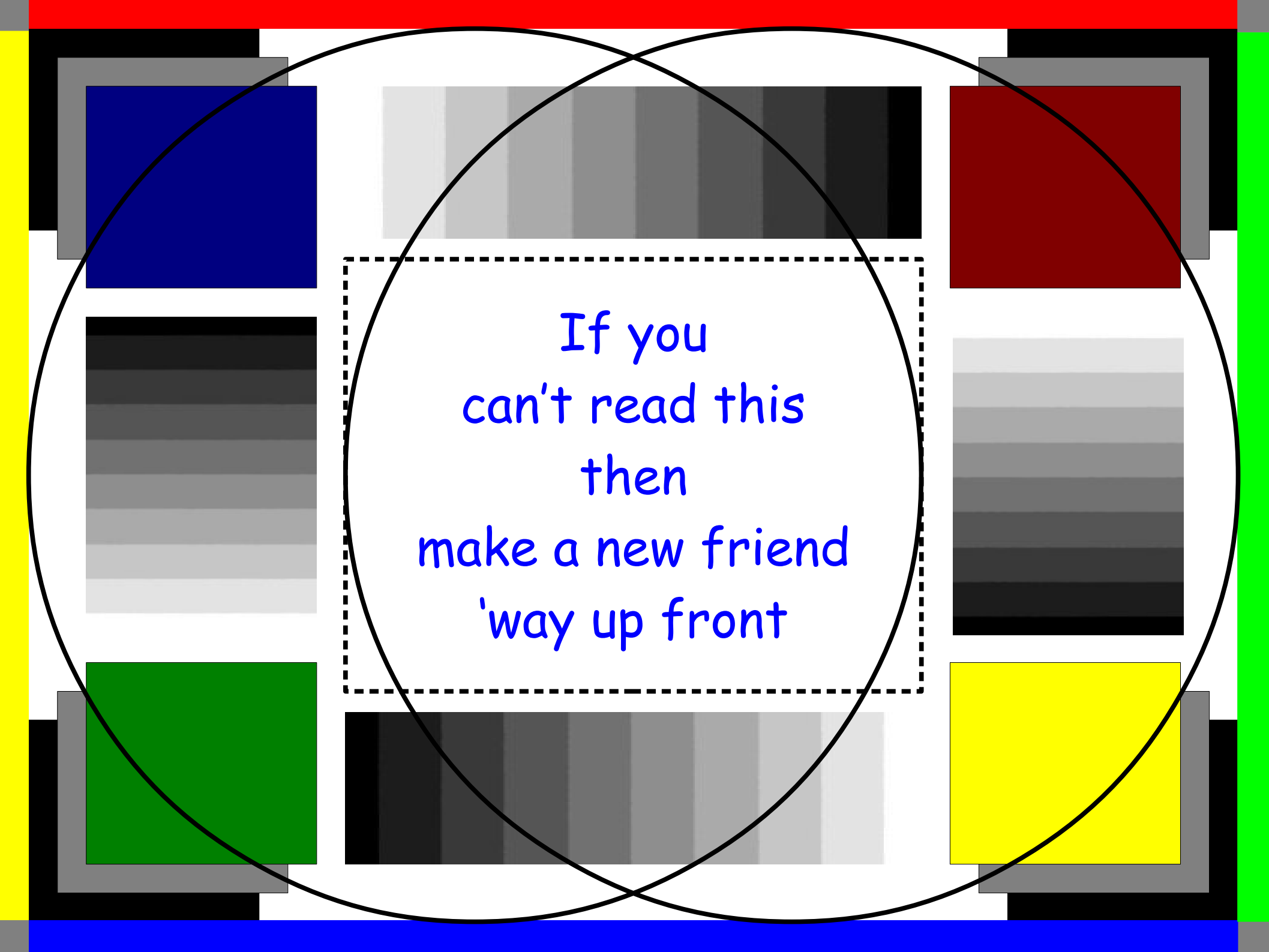
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