PHYSICAL PROTOTYPING

Sketching in Hardware

ABOUT ME

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Nokia Research Center
Palo Alto, USA

PHYSICAL PROTOTYPING IN INDUSTRIAL RESEARCH

Family Story Play
Pop goes the cell phone

FAMILY STORY PLAY

POP GOES THE CELL-PHONE

OUTLINE

- Why is prototyping important?
- Arduino
- Digital I/O
- Analog Sensors
- Actuators
- State of the art research

WHAT IS A PROTOTYPE?

- Prototyping structures innovation, collaboration, and creativity in the most successful design studios (Kelley and Littman, 2001)

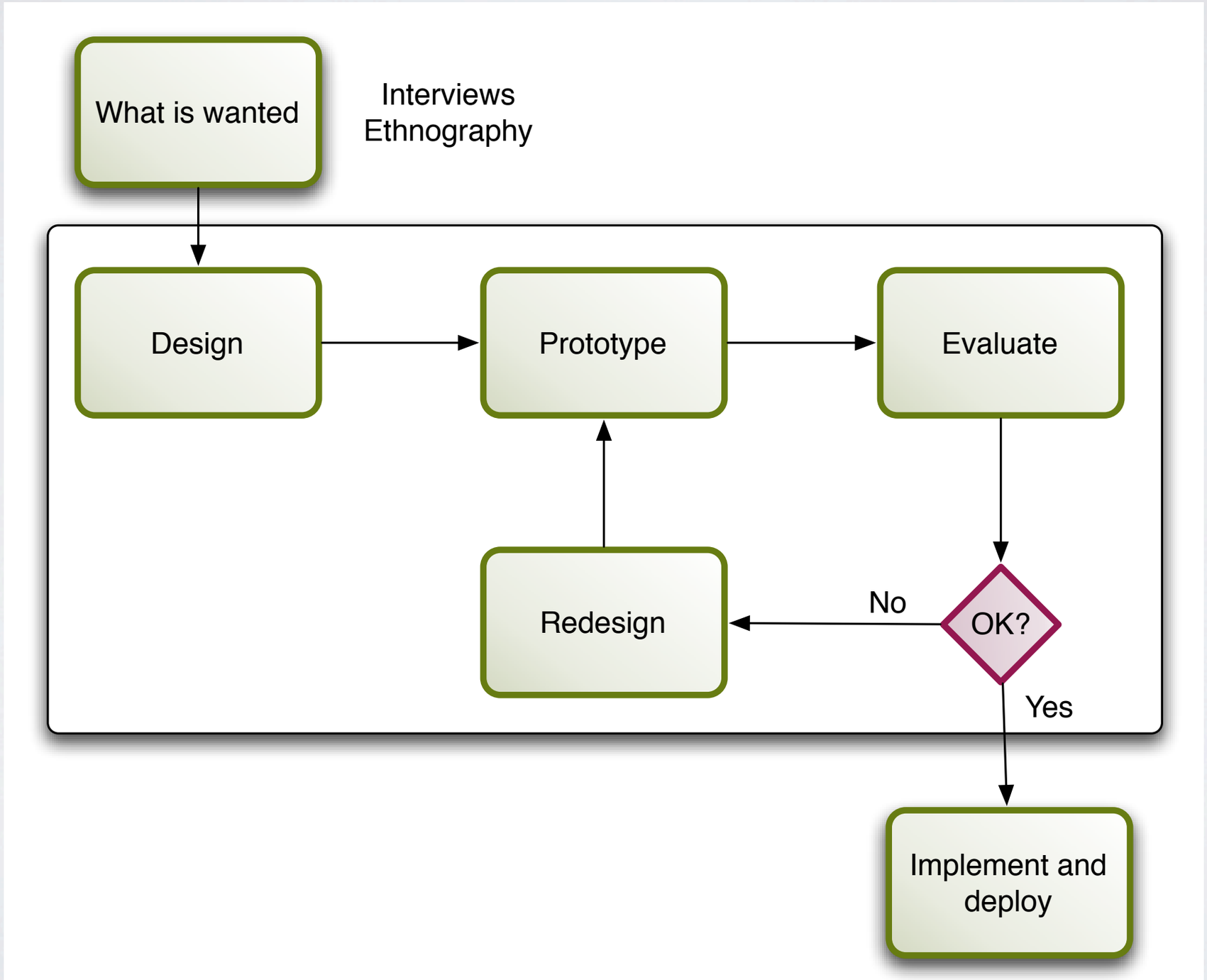
- Designers use prototypes as physical representations of ideas, effectively externalizing cognition and facilitating a "conversation with materials" to uncover surprising problems or generate suggestions for new designs (Schön and Bennett, 1996).

- Prototypes also serve as artifacts that represent tacit knowledge of developers as a communication tool to clients or other members of a design team (Schrage, 1999).

THE NATURE OF PROTOTYPING

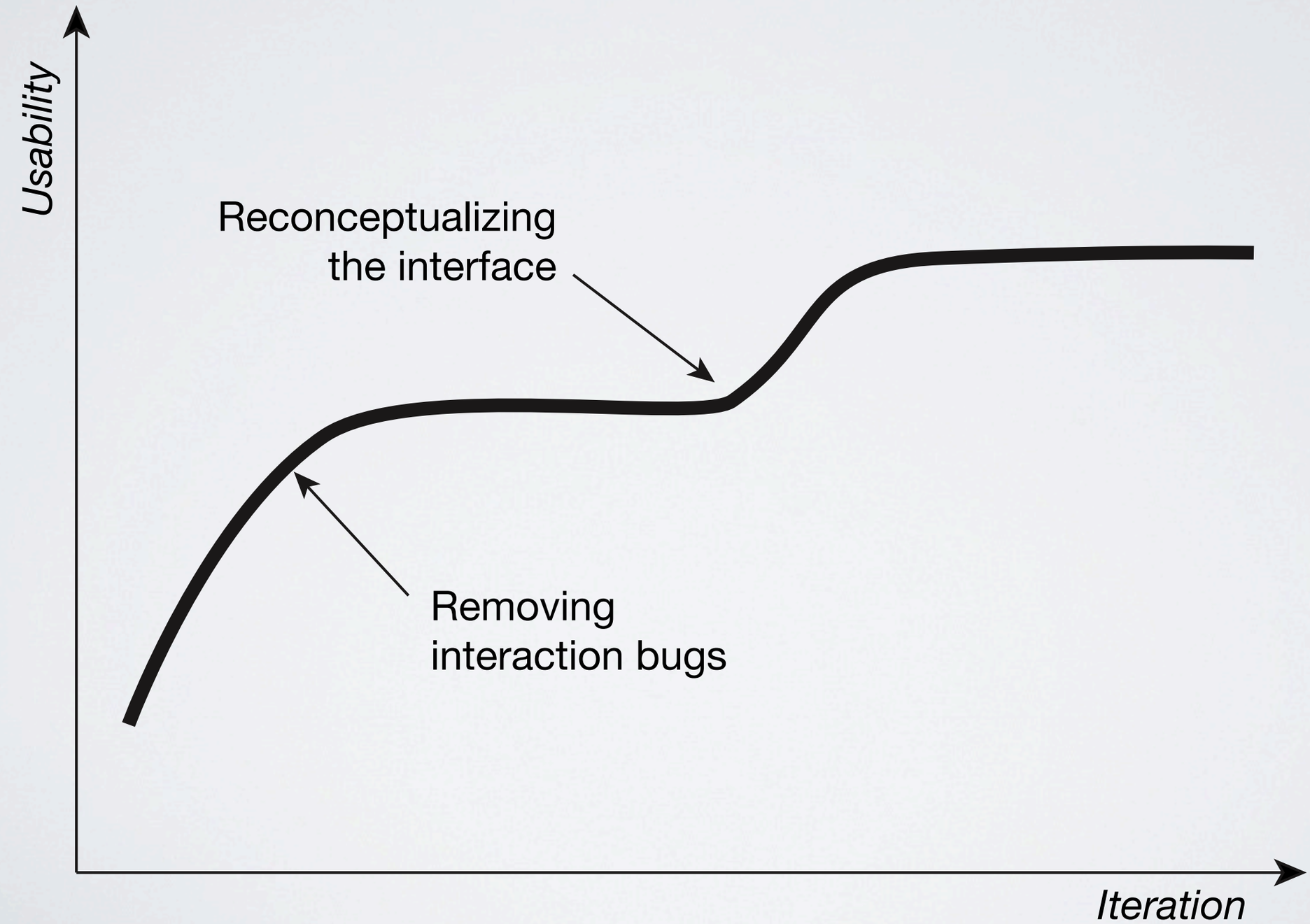
- Problems and solutions co-evolve (Dorst & Cross 2011)
- Subproblems are interconnected (Goel and Pirolli 1992)
- Constraints are often negotiable (Schön 1995)
- Solutions are not right or wrong, only better or worse (Rittle and Webber 1973)

ITERATIVE DESIGN



(Nielsen, 1993)

MORE ITERATIONS = BETTER DESIGNS



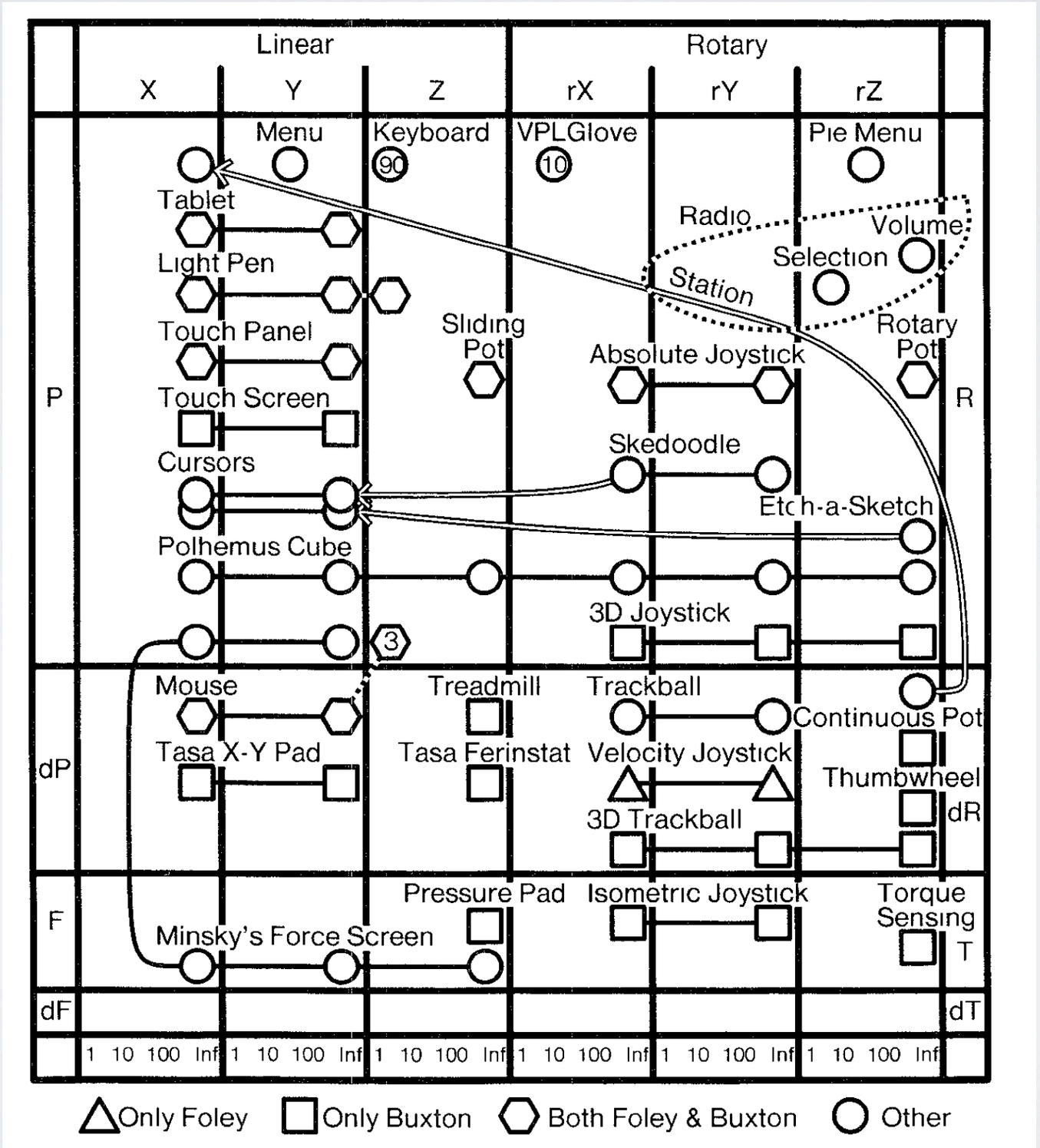
PARALLEL PROTOTYPING LEADS TO BETTER DESIGN

[Dow, 2010]

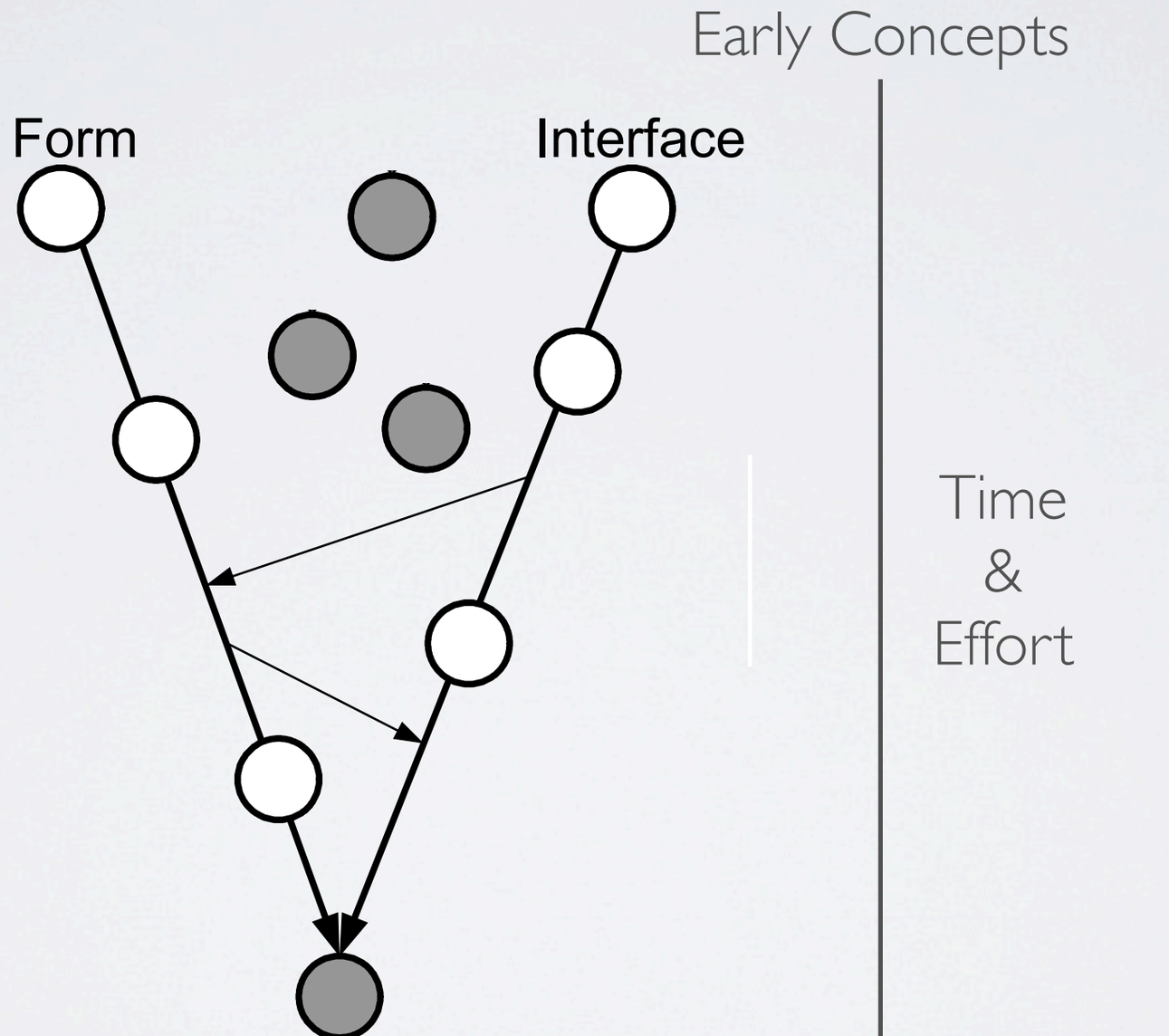
- Study comparing parallel to serial prototyping
- Parallel prototyping outperformed Serial by all objective performance measures
- Parallel prototypers had more divergent ideas
- Parallel prototypers react more positively toward critique

DESIGN SPACE OF INPUT DEVICES

[Card, 1991]



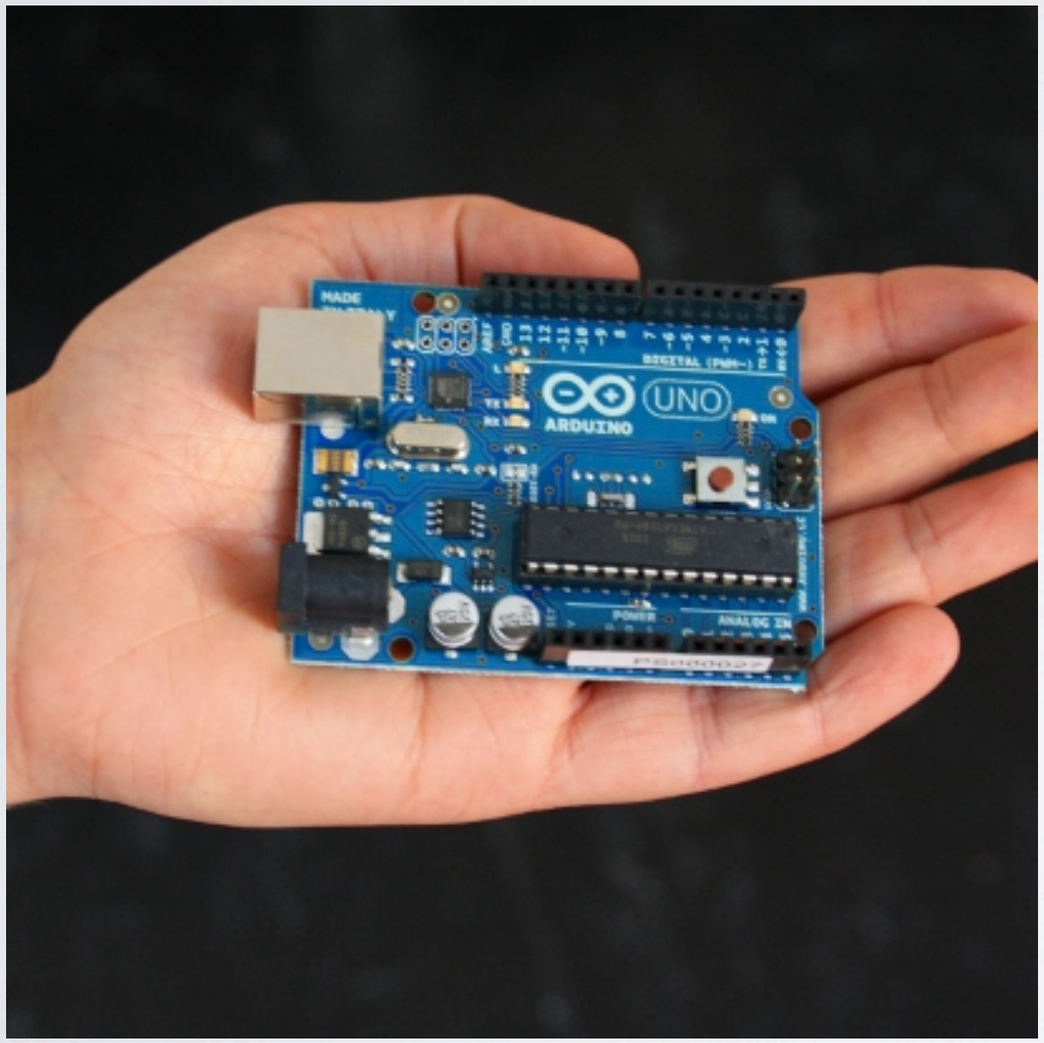
TRADITIONAL PROTOTYPING



PROTOTYPING KITS

ARDUINO UNO BOARD

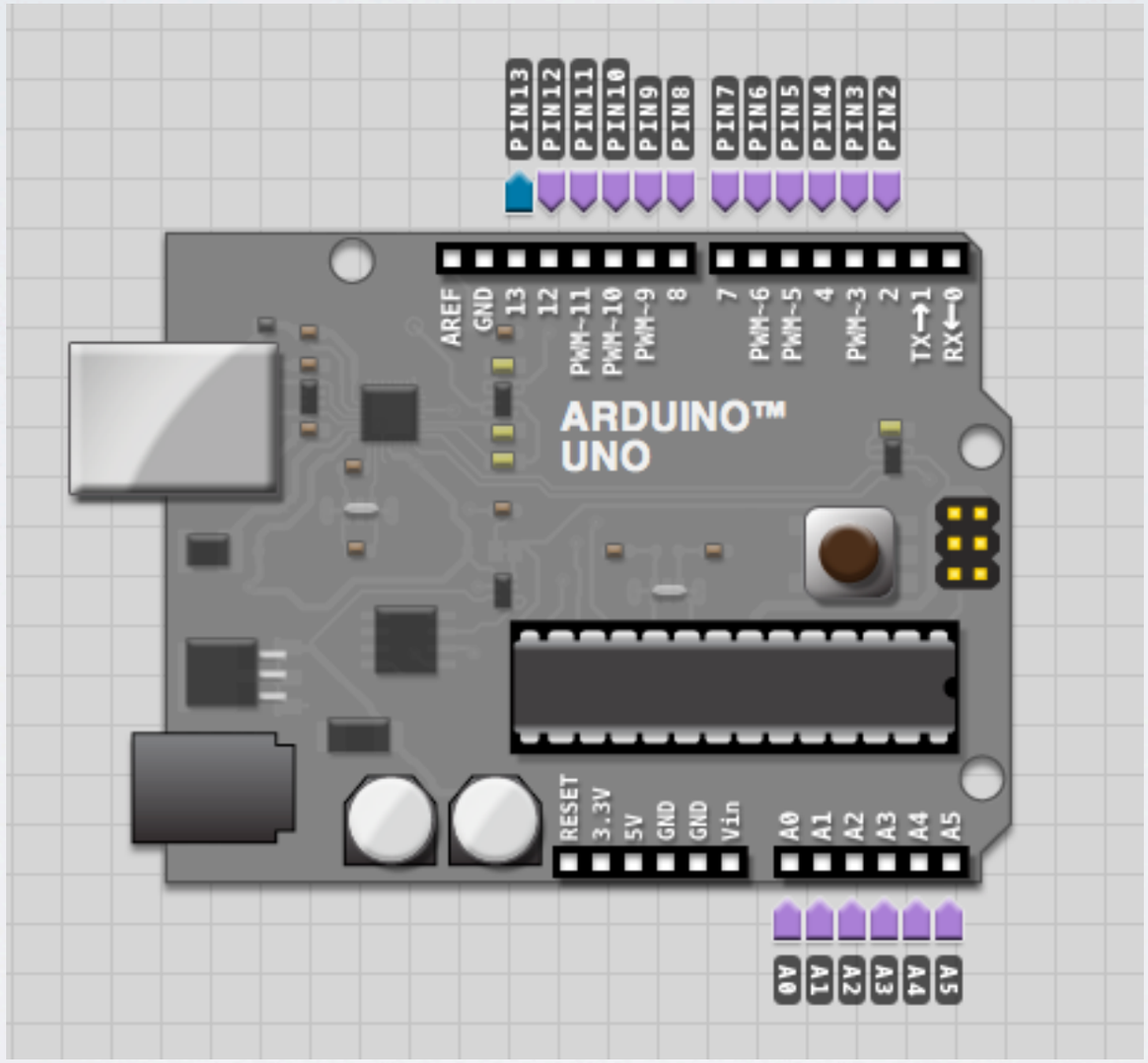
http://www.arduino.cc



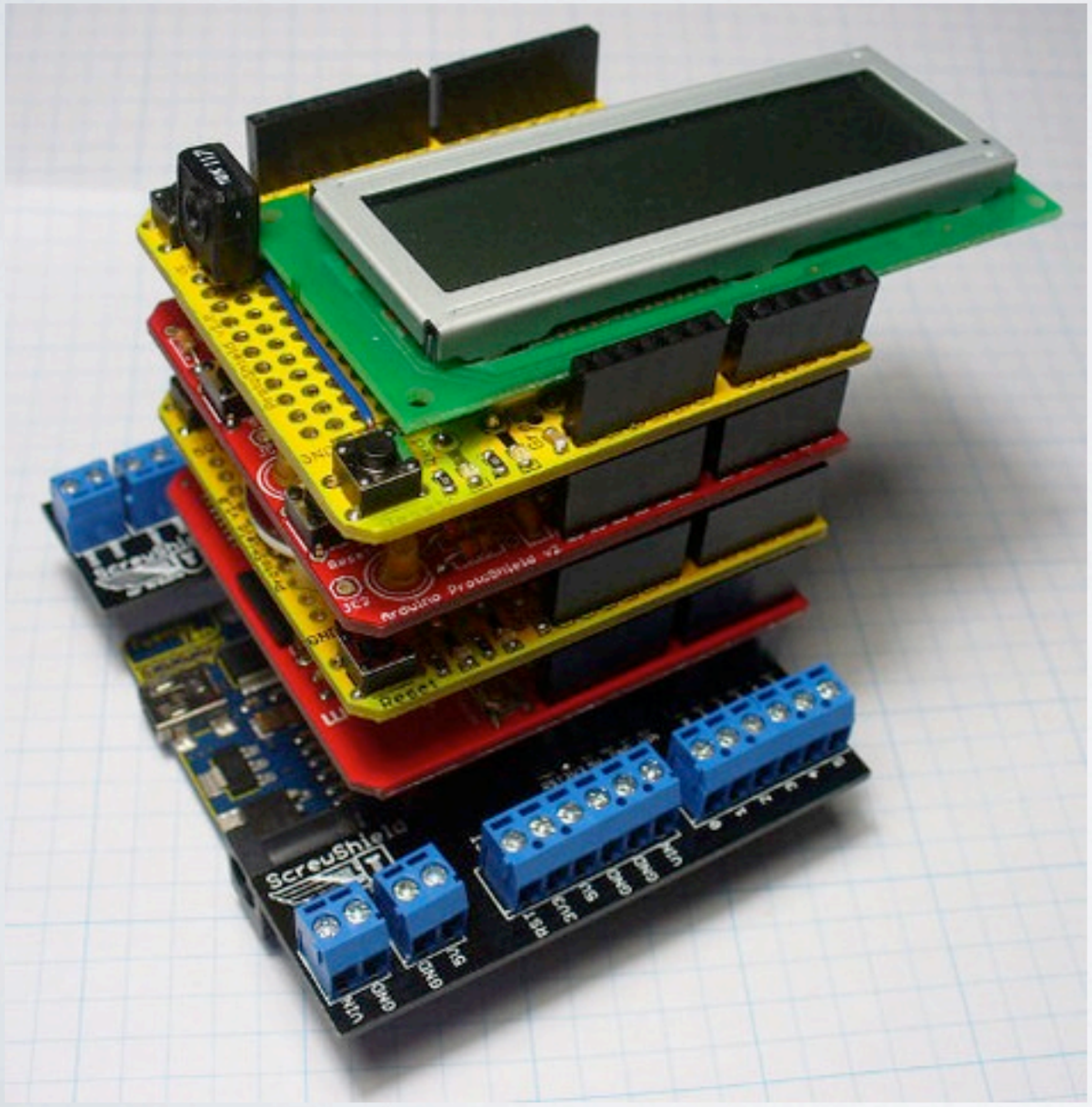
Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

ARDUINO I/O


PIN13
PIN12
PIN11
PIN10
PIN9
PIN8
PIN7
PIN6
PIN5
PIN4
PIN3
PIN2
AREF
GND
13
12
PWM~11
PWM~10
PWM~9
8
7
PWM~6
PWM~5
4
PWM~3
2
TX→1
RX←0
ARDUINO™
UNO
RESET
3.3V
5V
GND
GND
Vin
A0
A1
A2
A3
A4
A5
A0
A1
A2
A3
A4
A5

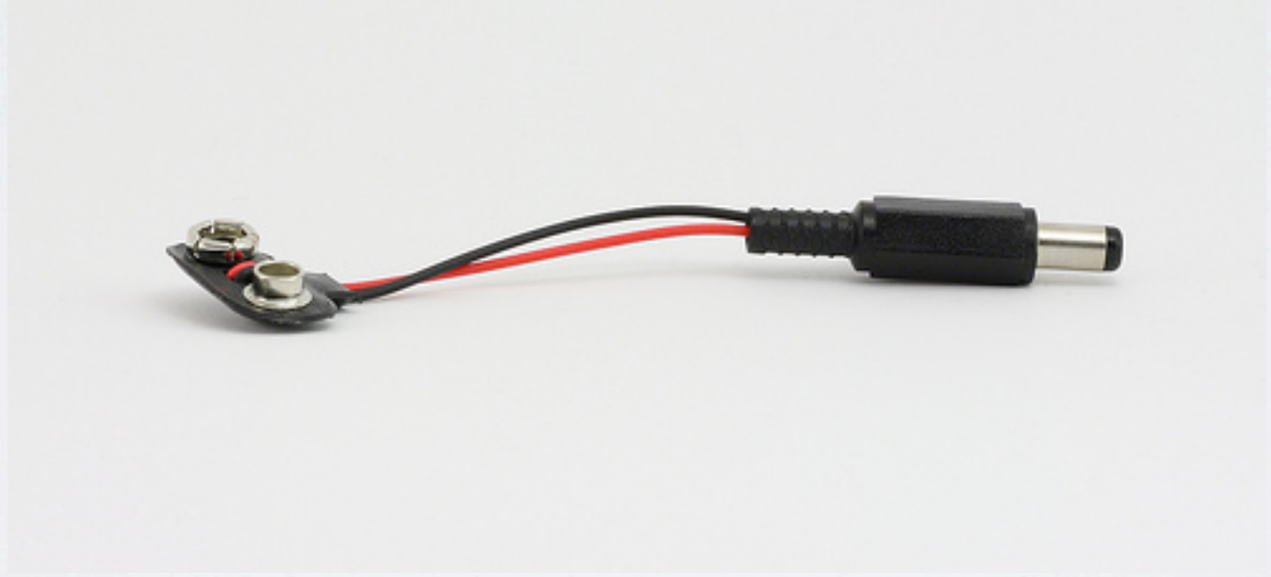
EXTENDING ARDUINO



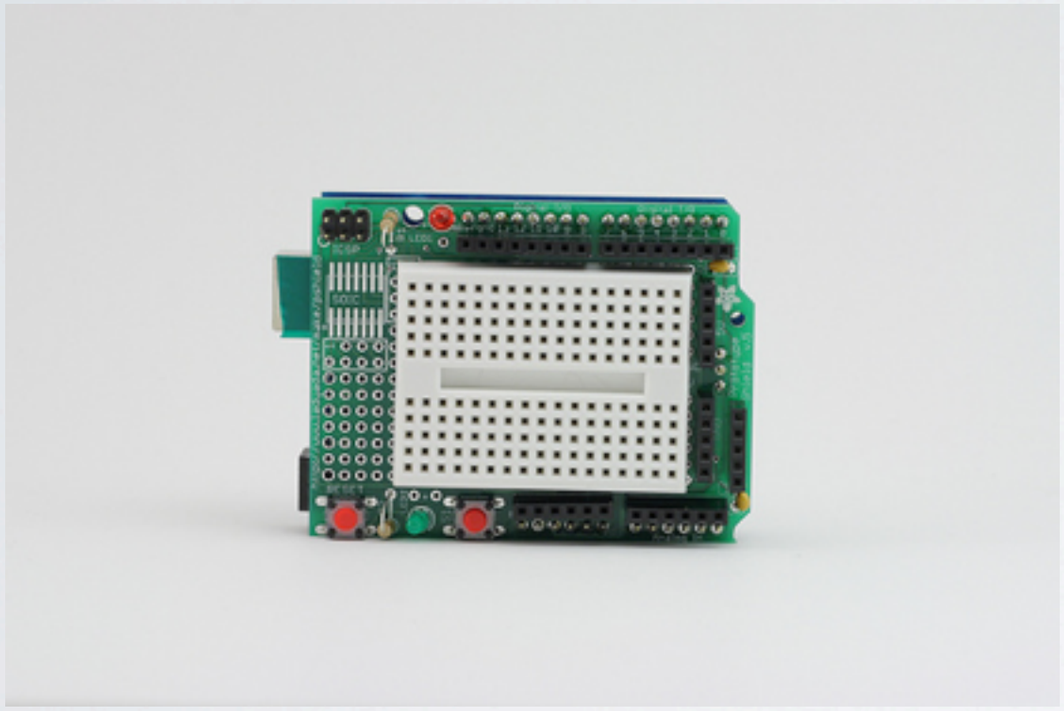
- Ethernet shield
- XBee shield
- Motor shield

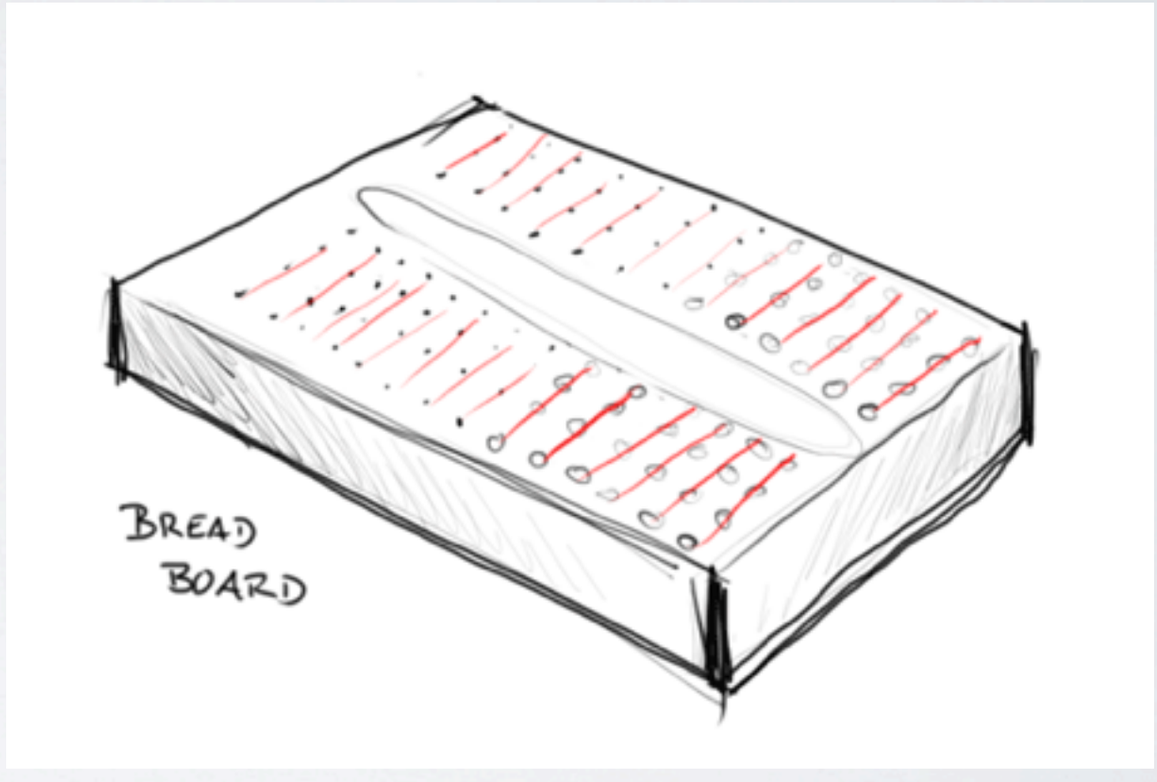
USB CABLE

9V BATTERY CONNECTOR

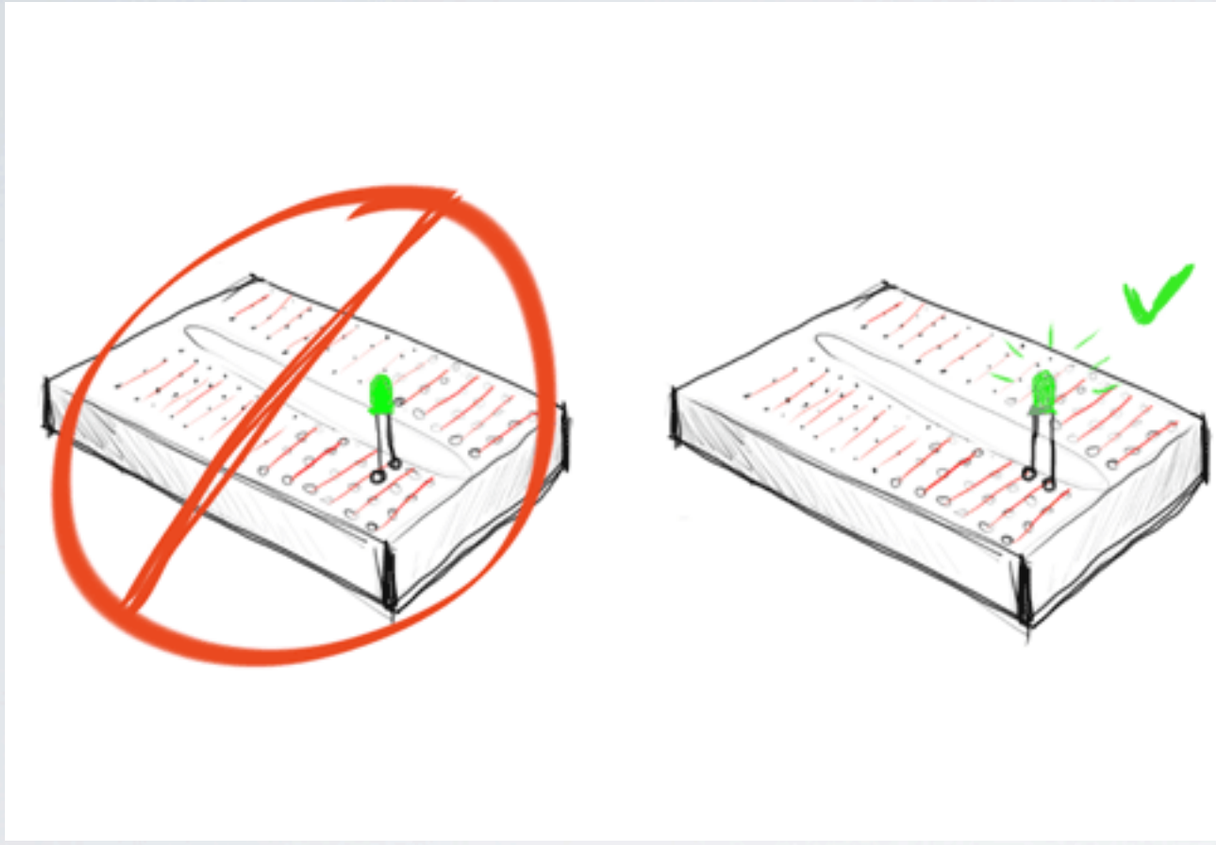


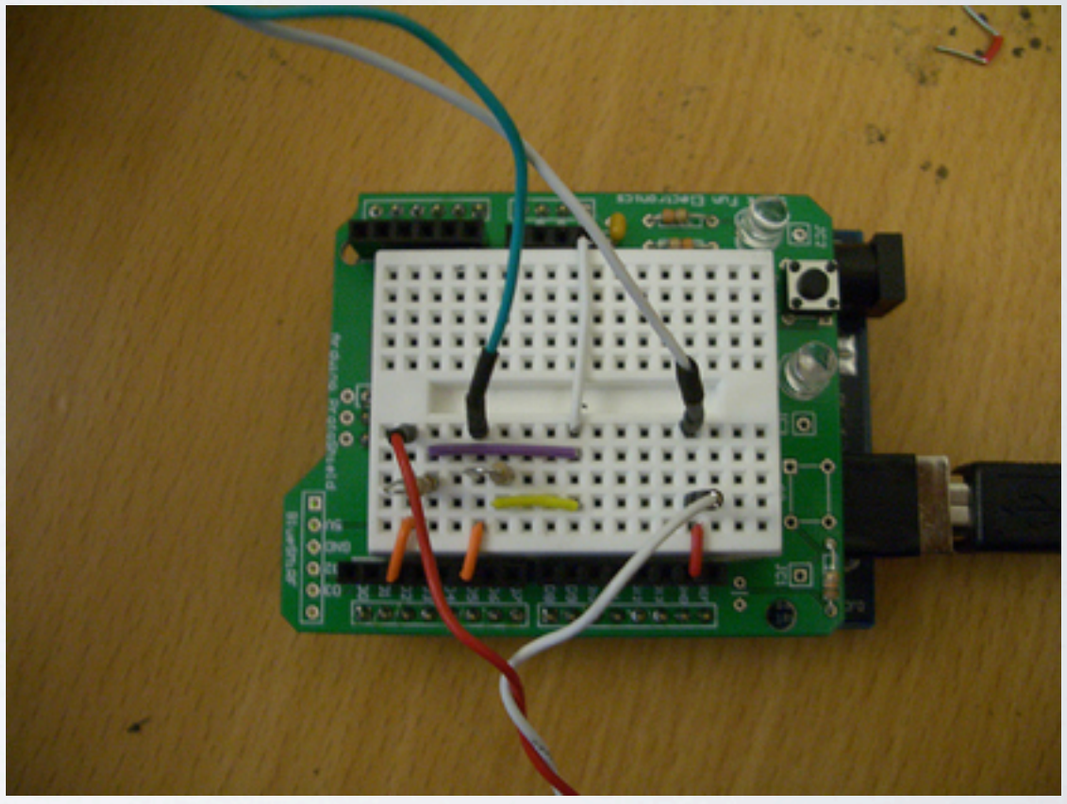
BREADBOARDS





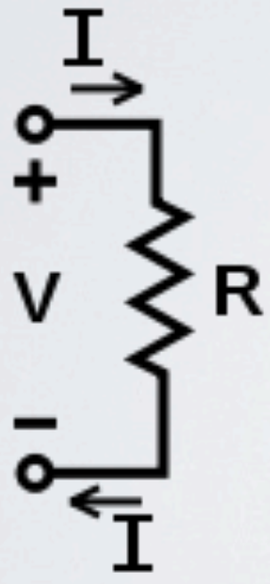
BREADBOARDS IN USE





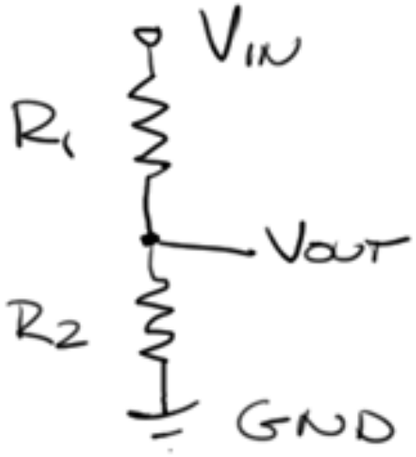
VOLTAGE, CURRENT, RESISTANCE

Ohm's law



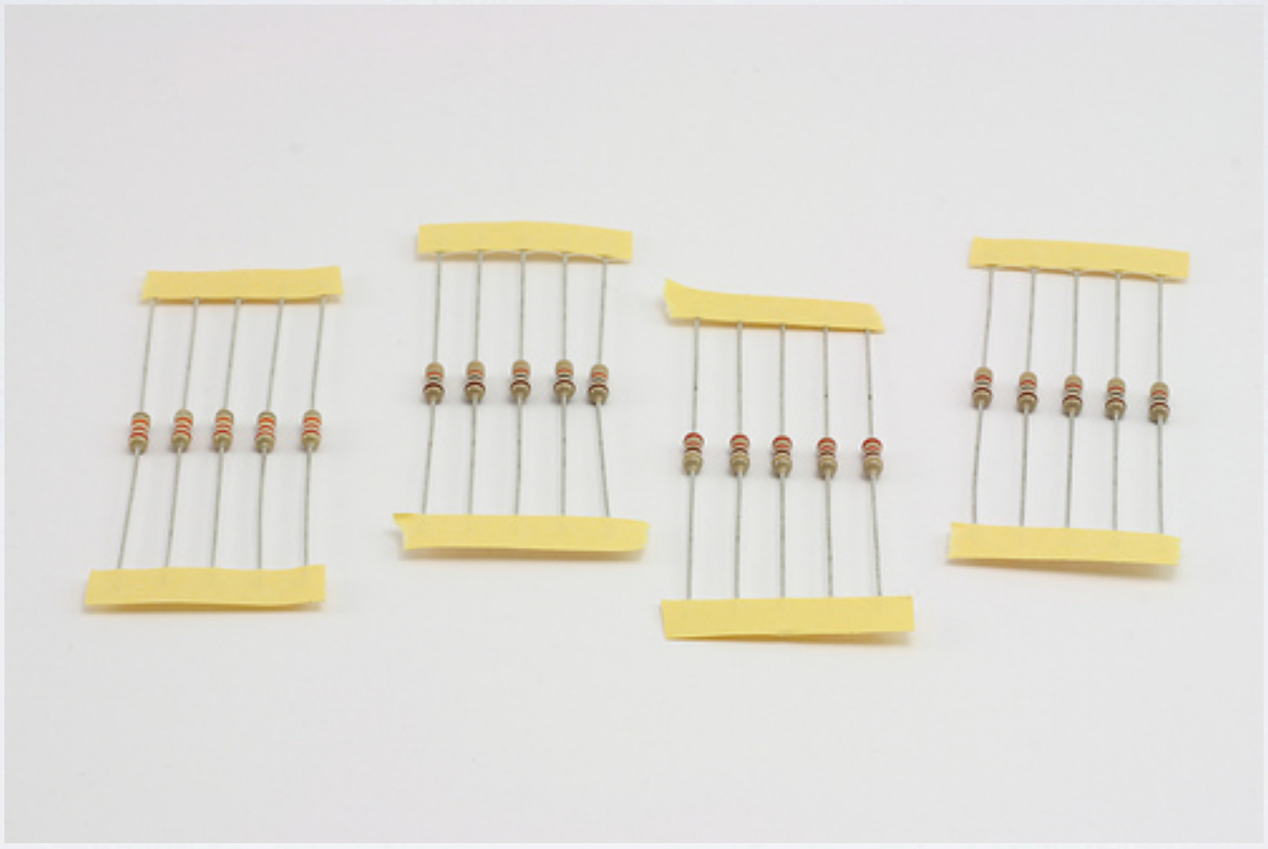
$V=IR$

Voltage Divider



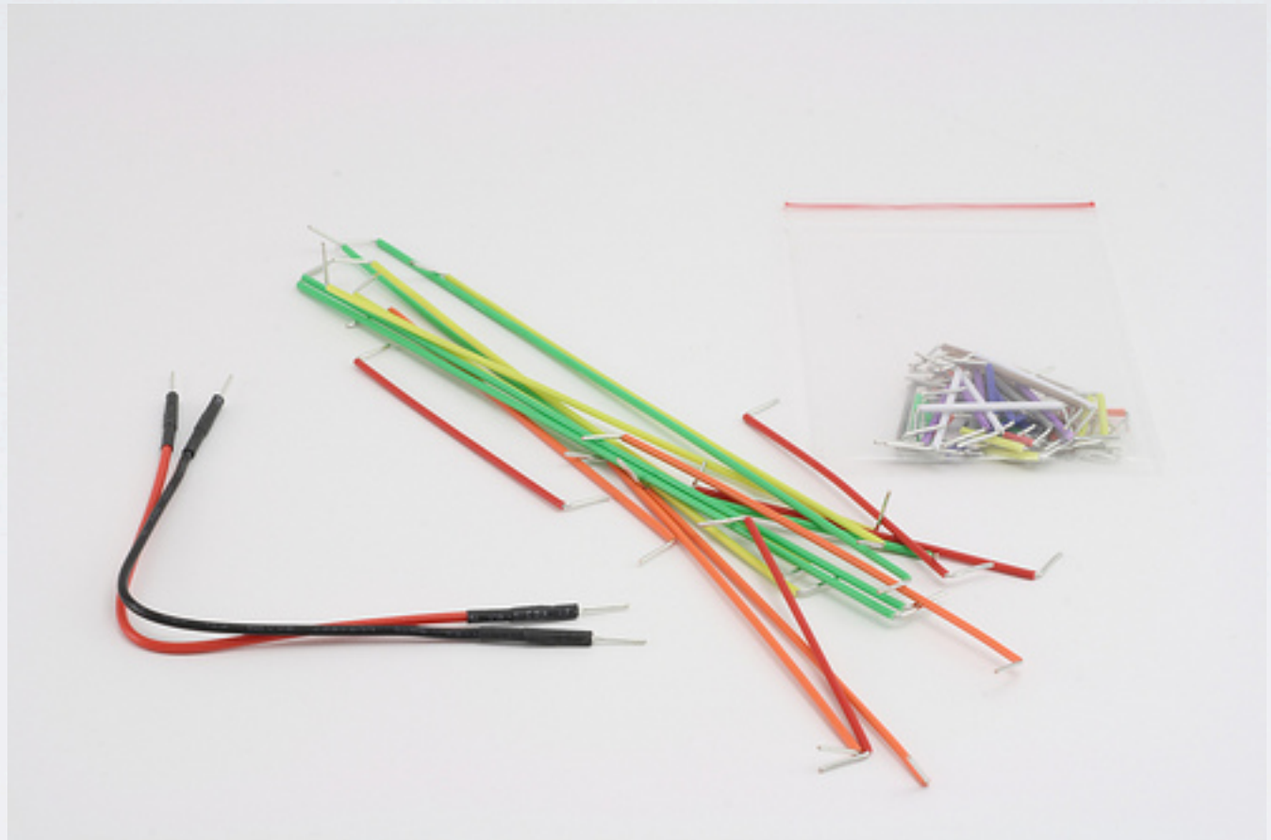
$$V_{out} = \frac{R_2}{R_1 + R_2} \cdot V_{IN}$$

RESISTORS



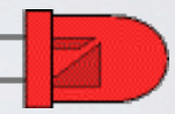
Resistor Color Codes: http://www.kpsec.freeuk.com/components/resist.htm
Resistor Calculator: http://www.dannyg.com/examples/res2/resistor.htm

JUMPERS

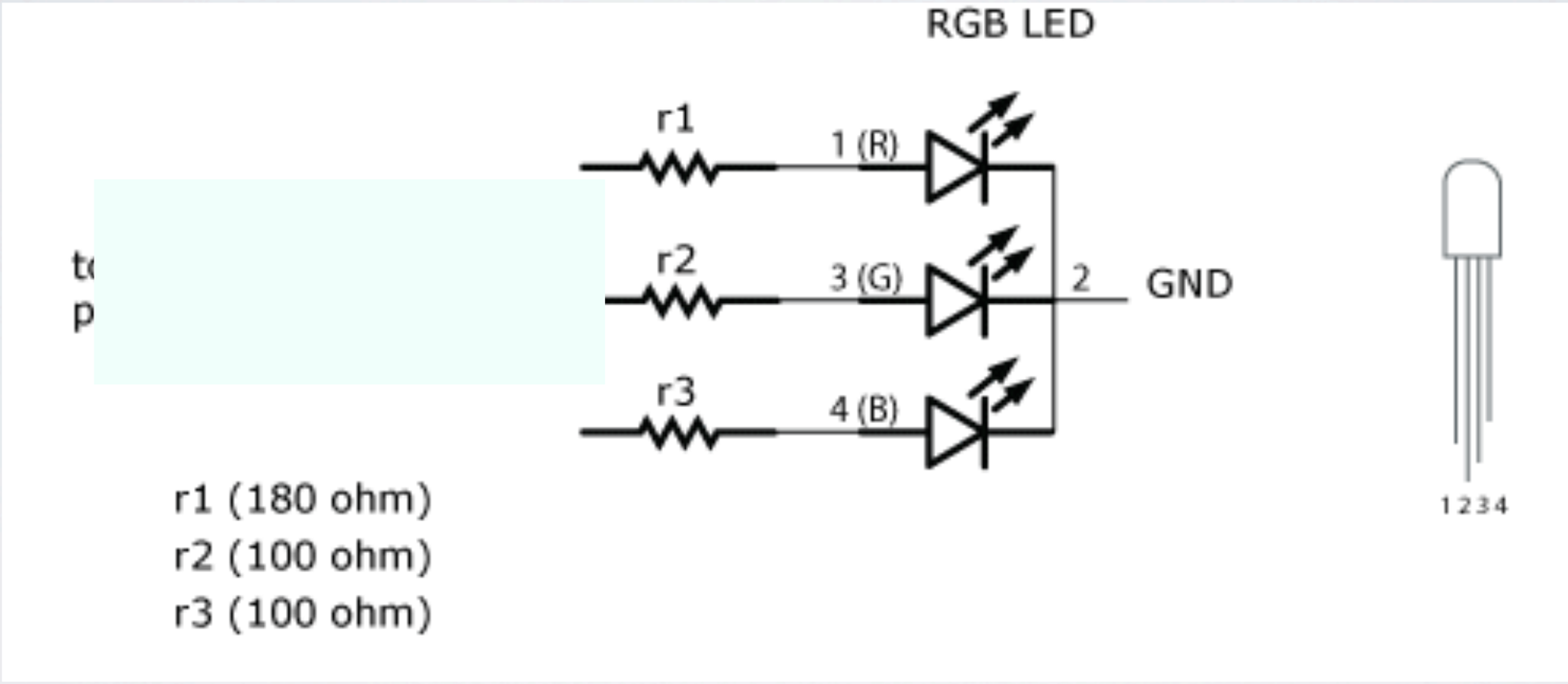


LIGHT EMITTING DIODE (LED)

anode (+)
cathode (-)



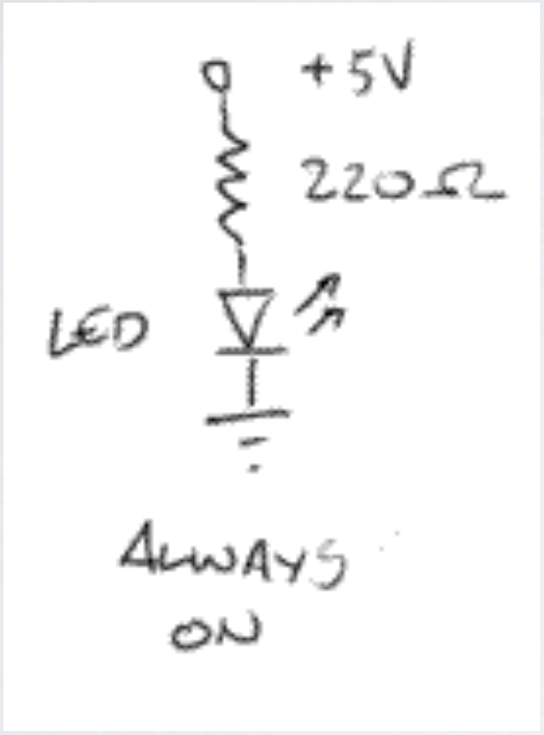
RGB LEDS

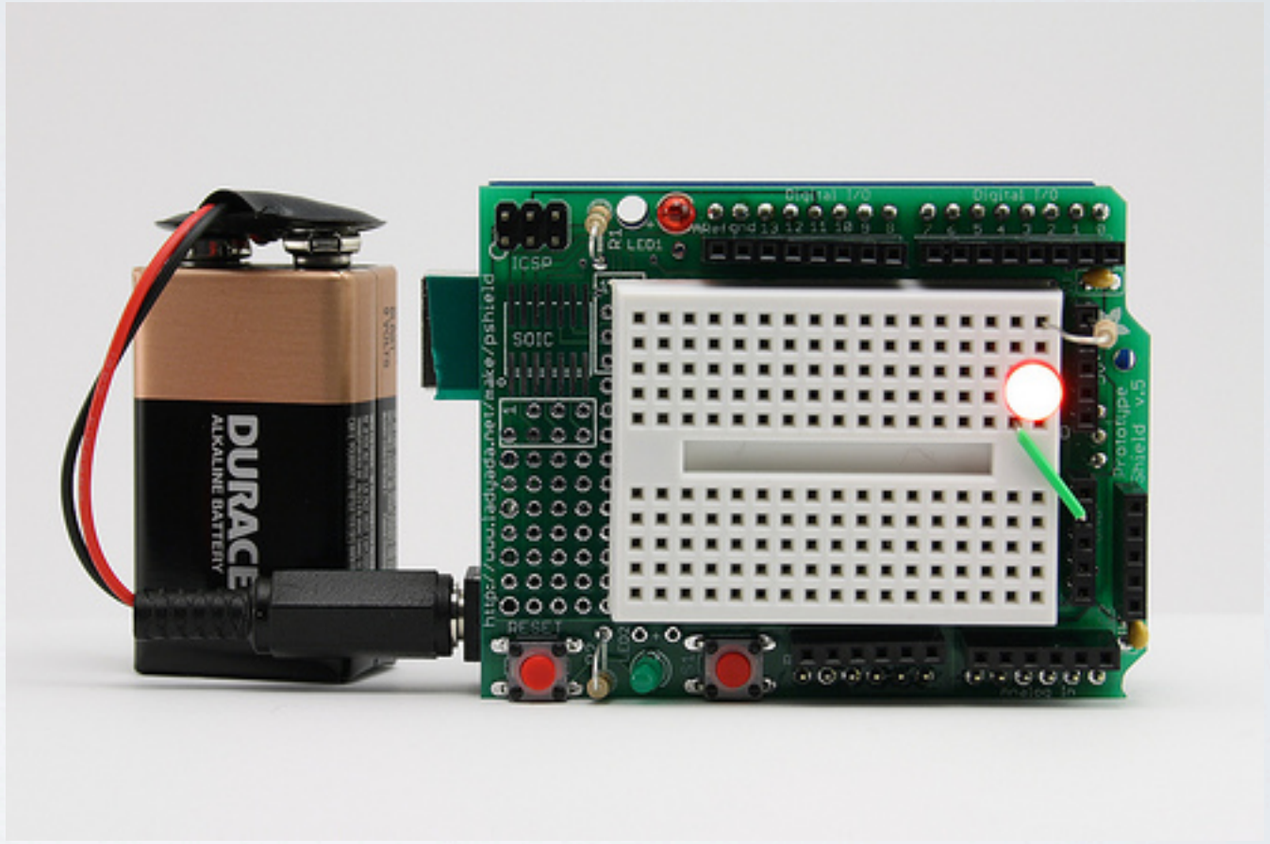

RGB LED
r1
1 (R)
r2
3 (G)
2
GND
r3
4 (B)
1 2 3 4
r1 (180 ohm)
r2 (100 ohm)
r3 (100 ohm)

DIGITAL INPUT & OUTPUT

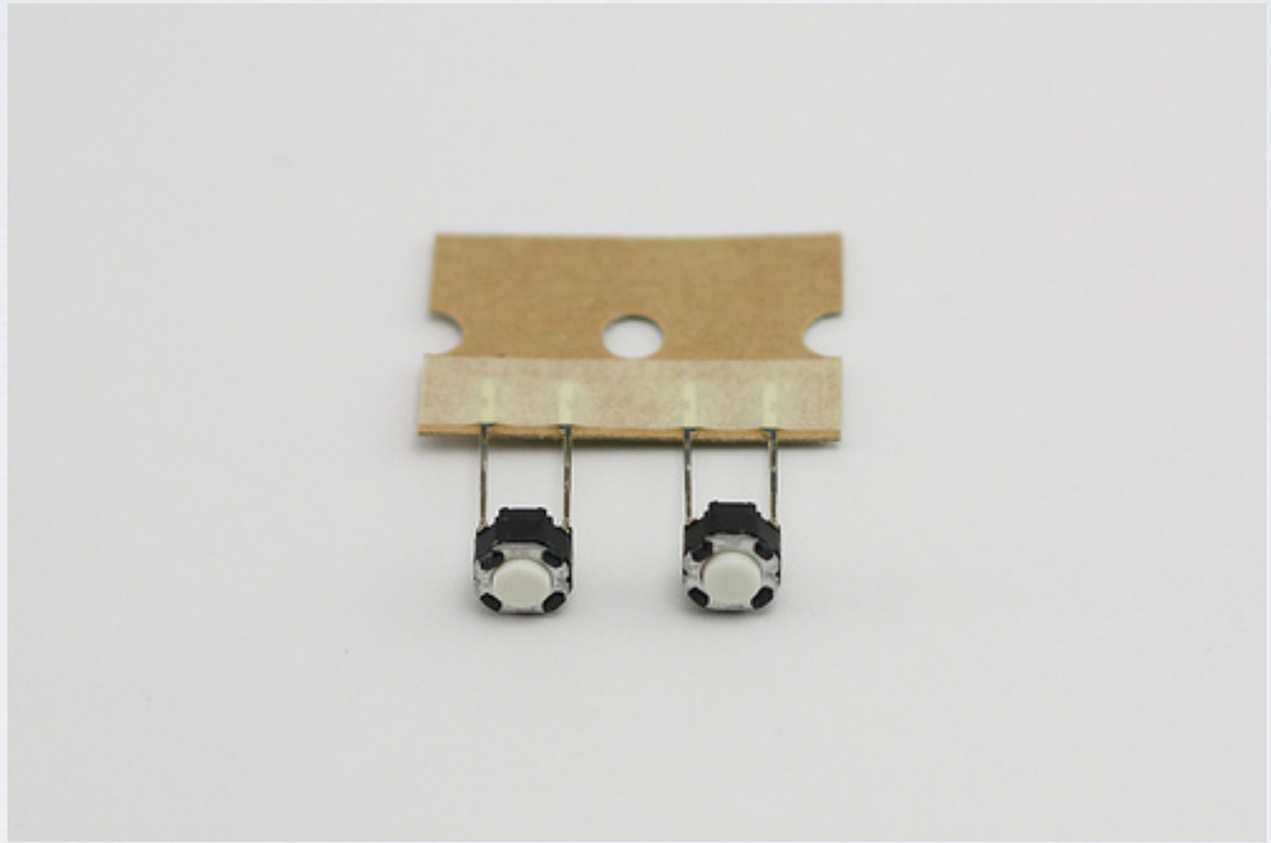
Switches and LEDs

MY FIRST CIRCUIT



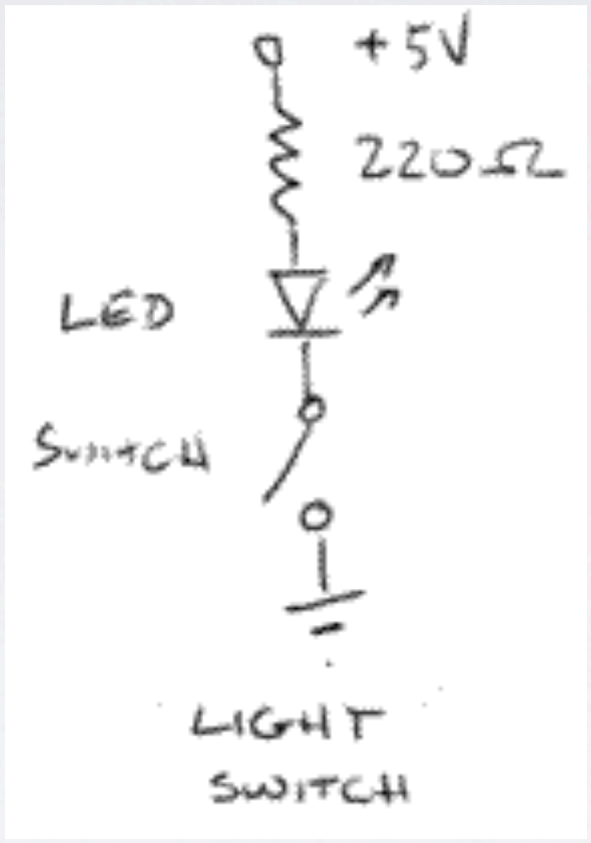


BUTTONS AND SWITCHES

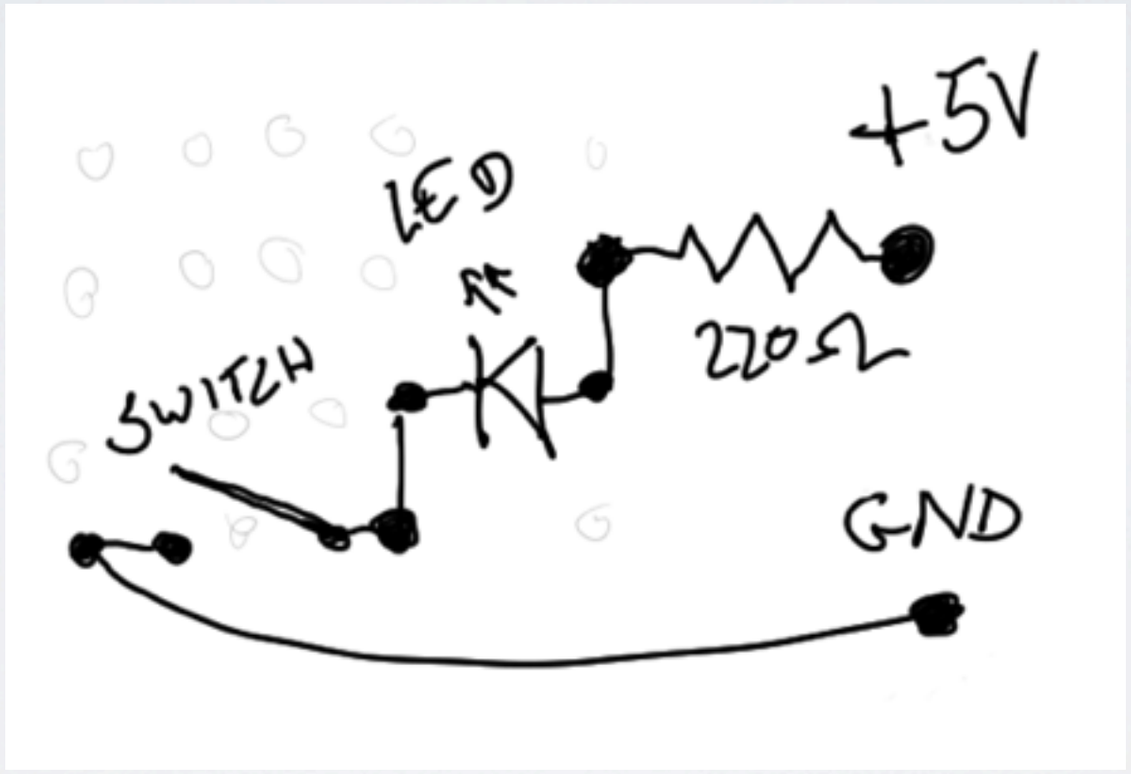


ROCKER SWITCH

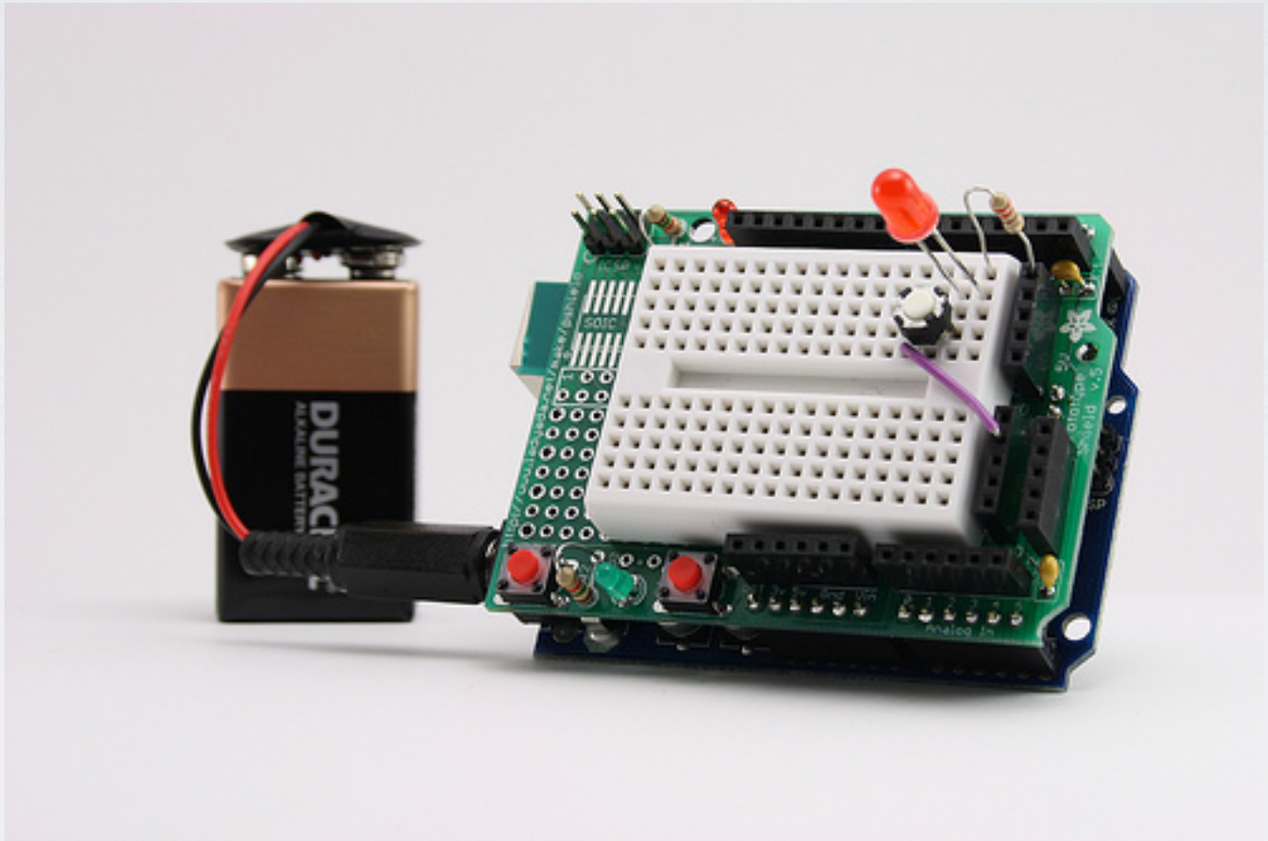
LIGHT SWITCH



LIGHT SWITCH HINT



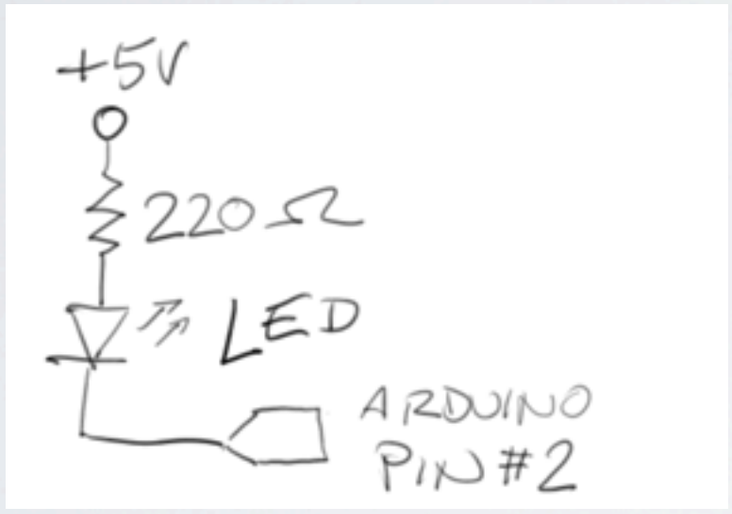
LIGHT SWITCH SOLUTION



MAKE A LIGHT SWITCH PROGRAMMATICALLY

- Step 1: Programmatically turn on LED
- Step 2: Programmatically sense button press
- Step 3: Programmatically link button to turn on LED

STEP 1: LED



sketch_jul02a | Arduino 0022

sketch_jul02a §

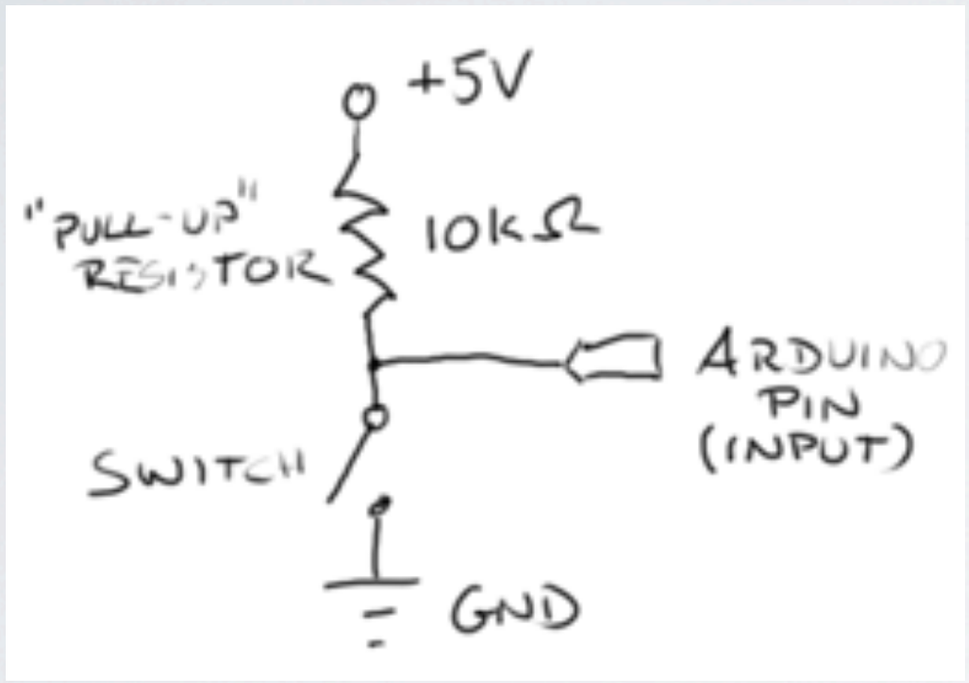
```
int ledPin = 2;
void setup() {
  pinMode(ledPin, OUTPUT);
}

void loop() {
  digitalWrite(ledPin, HIGH);   // set the LED on
  delay(1000);                  // wait for a second
  digitalWrite(ledPin, LOW);    // set the LED off
  delay(1000);                  // wait for a second
}
```

Done uploading.

```
Binary sketch size: 1026 bytes (of a 14336 byte maximum)
```

9

STEP 2: BUTTON



Button_Step2 | Arduino 0022

Button_Step2

```
const int buttonPin = 7;     // the number of the pushbutton pin

// variables will change
int buttonState = 0;

void setup() {
  //Create Serial Object
  Serial.begin(9600);
  pinMode(buttonPin, INPUT);
}

void loop(){

   // read the state of the pushbutton value:
  buttonState = digitalRead(buttonPin);

  // check if the pushbutton is pressed.
  // if it is, the buttonState is LOW:
  if (buttonState == LOW) {
    Serial.println("button pressed");
  }
}
```

Done Saving.

Binary sketch size: 2456 bytes (of a 14336 byte maximum)

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STEP 3: MAPPING I/O

ARDUINO + GUI

PROCESSING

- Download from: http://processing.org

- Processing is an open source programming language and environment for people who want to create images, animations, and interactions

- developed to serve as a software sketchbook and to teach fundamentals of computer programming within a visual context

PROCESSING EXAMPLE

ARDUINO & PROCESSING

- Communication over serial port
- Step 1: Arduino to Processing
- Step 2: Processing to Arduino

ARDUINO TO PROCESSING

Processing_button | Arduino 0022

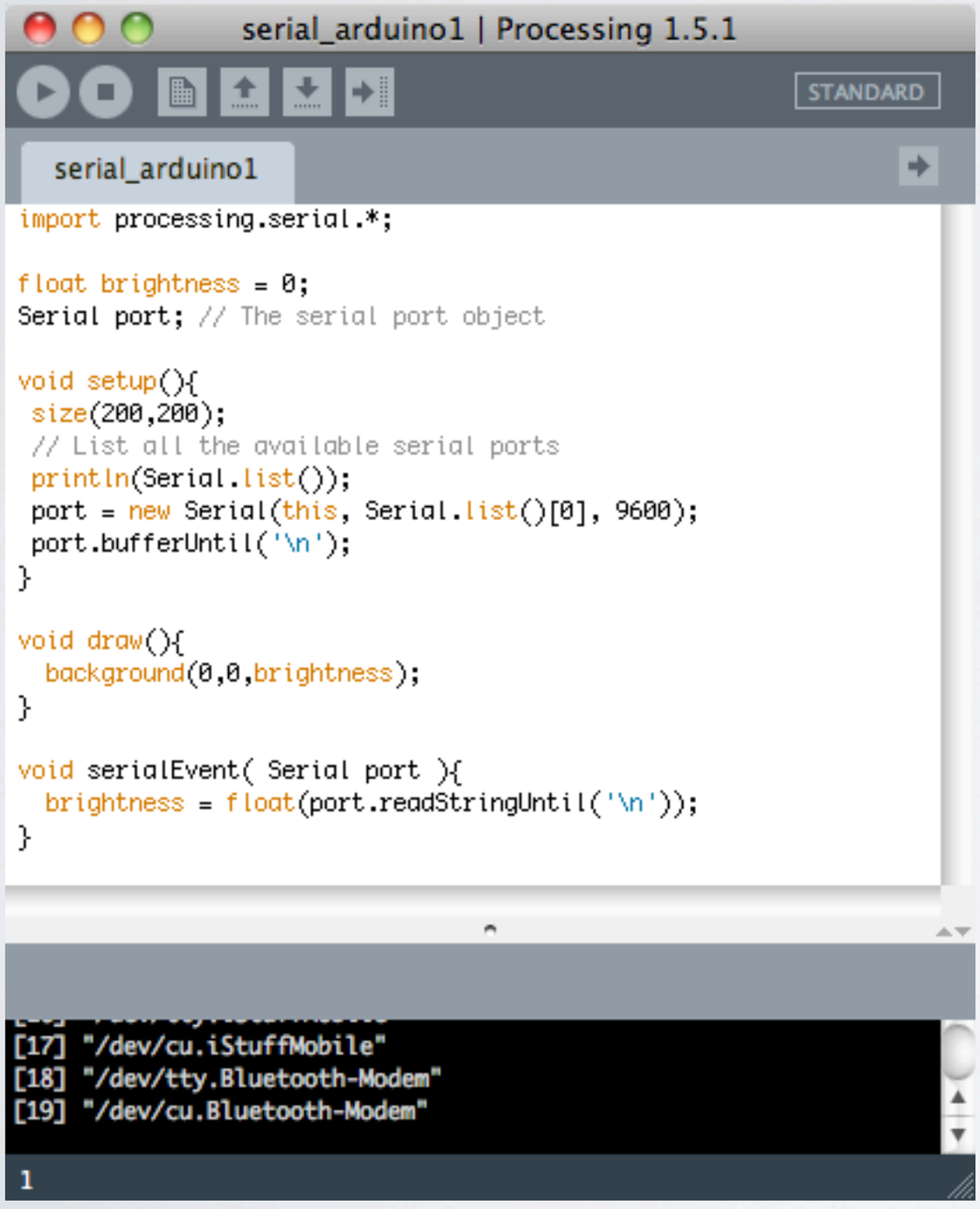
Processing_button

```
const int buttonPin = 7;     // the number of the pushbutton pin

// variables will change
int buttonState = 0;
int lastButtonState = 0;

void setup() {
  //Create Serial Object
  Serial.begin(9600);
  pinMode(buttonPin, INPUT);
}

void loop(){

   // read the state of the pushbutton value:
  buttonState = digitalRead(buttonPin);

  if(buttonState != lastButtonState){
    // check if the pushbutton is pressed.
    // if it is, the buttonState is LOW:
    if (buttonState == LOW) {
      Serial.println(255);
    }else{
      Serial.println(0);
    }
  }
  lastButtonState = buttonState;
}
```

Done Saving.

Arduino

ARDUINO TO PROCESSING



Processing

PROCESSING TO ARDUINO

Processing_button_led | Arduino 0022

Processing_button_led §

```
const int ledPin = 2;
const int buttonPin = 7;     // the number of the pushbutton pin

// variables will change
int buttonState = 0;
int lastButtonState = 0;

void setup() {
  //Create Serial Object
  Serial.begin(9600);
  pinMode(buttonPin, INPUT);
  pinMode(ledPin, OUTPUT);

}

void loop(){
   // read the state of the pushbutton value:
  buttonState = digitalRead(buttonPin);

  if(Serial.available() != 0){
    int val = Serial.read();
    if(val == 0){
        digitalWrite(ledPin, LOW);
    } else if (val == 1){
        digitalWrite(ledPin, HIGH);
    }
  }

  // check if the pushbutton has changed
  if(lastButtonState != buttonState){
    // if it is, the buttonState is LOW:
    if (buttonState == LOW) {
      Serial.println(255);
    }else{
      Serial.println(0);
    }
  }
  lastButtonState = buttonState;
}
```

Arduino

PROCESSING TO ARDUINO

serial_arduino2 | Processing 1.5.1

STANDARD

serial_arduino2

```
import processing.serial.*;

float brightness = 0;
Serial port; // The serial port object
boolean lastMousePressed = false;

void setup(){
 size(200,200);
 // List all the available serial ports
 println(Serial.list());
 port = new Serial(this, Serial.list()[0], 9600);
 port.bufferUntil('\n');
}

void draw(){
  background(0,0,brightness);
  if(lastMousePressed != mousePressed){
    if(mousePressed == true){
      port.write(0);
    }else{
      port.write(1);
    }
  }
  lastMousePressed = mousePressed;
}

void serialEvent( Serial port ){
  brightness = float(port.readStringUntil('\n'));
}
```

[19] "/dev/cu.Bluetooth-Modem"

Processing

PROCESSING SUPPORT FOR ARDUINO

- http://www.arduino.cc/playground/Interfacing/Processing
- Don't forget to restart processing after installing the libraries

FIRMATA

- Generic protocol for communicating with microcontrollers from software on a host computer.

- It is intended to work with any host computer software package.

- Works with a number of languages.

- The aim is to allow people to completely control the Arduino from software on the host computer.

LOAD FIRMATA FIRMWARE

- Arduino: File > Examples > Firmata > StandardFirmata

FIRST FIRMATA PROGRAM

sketch_jul03b | Processing 1.5.1

STANDARD

sketch_jul03b §

```
import processing.serial.*;
import cc.arduino.*;

Arduino arduino;
int ledPin=2;

void setup()
{
  size(256, 256);
  arduino = new Arduino(this, Arduino.list()[1], 57600);
  arduino.pinMode(ledPin, Arduino.OUTPUT);
  background(0);
}

void draw()
{
  if(mousePressed == true){
      arduino.digitalWrite(ledPin, Arduino.LOW);
  } else {
      arduino.digitalWrite(ledPin, Arduino.HIGH);
  }
}
```

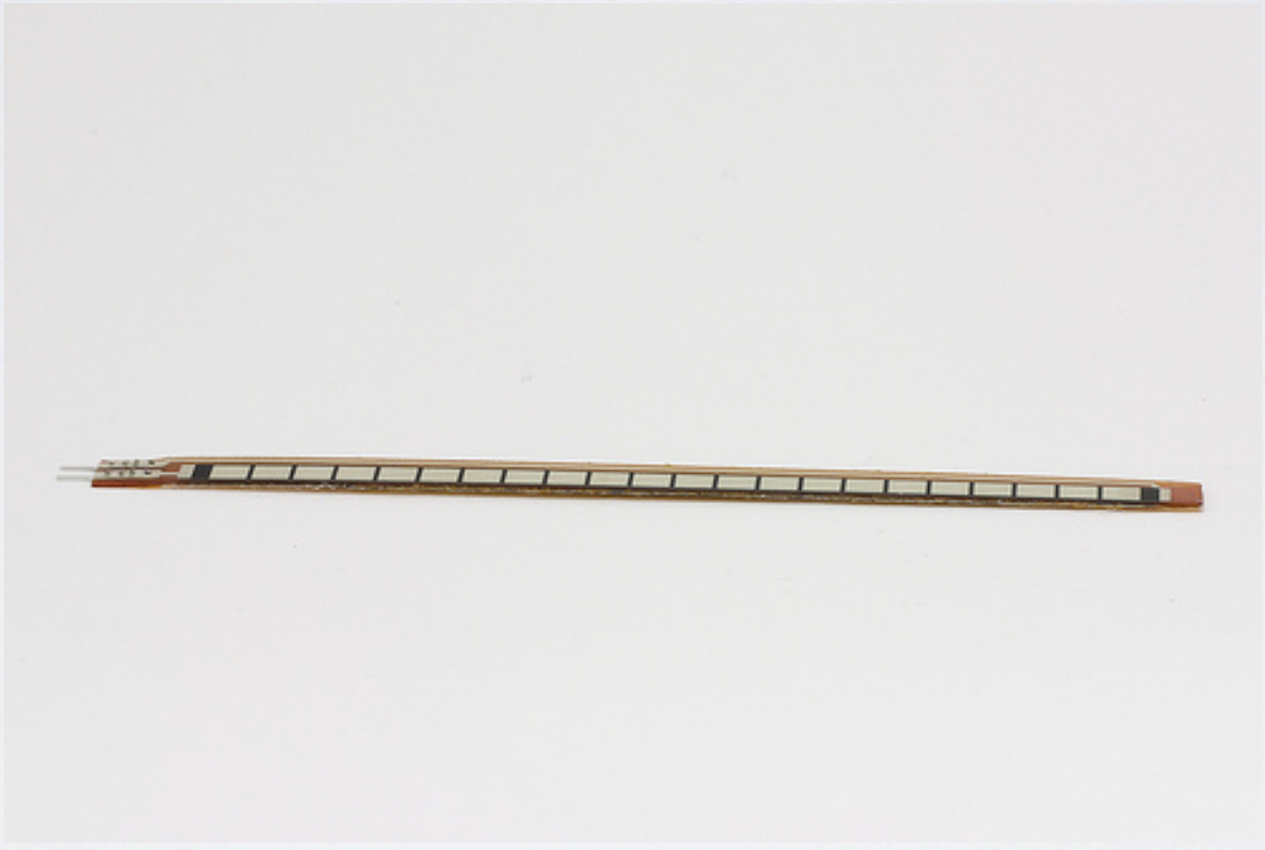
```
native lib Version = RXTX-2.2pre2
Invalid memory access of location 0xb17b9be0 eip=0x24bc690c
```

5

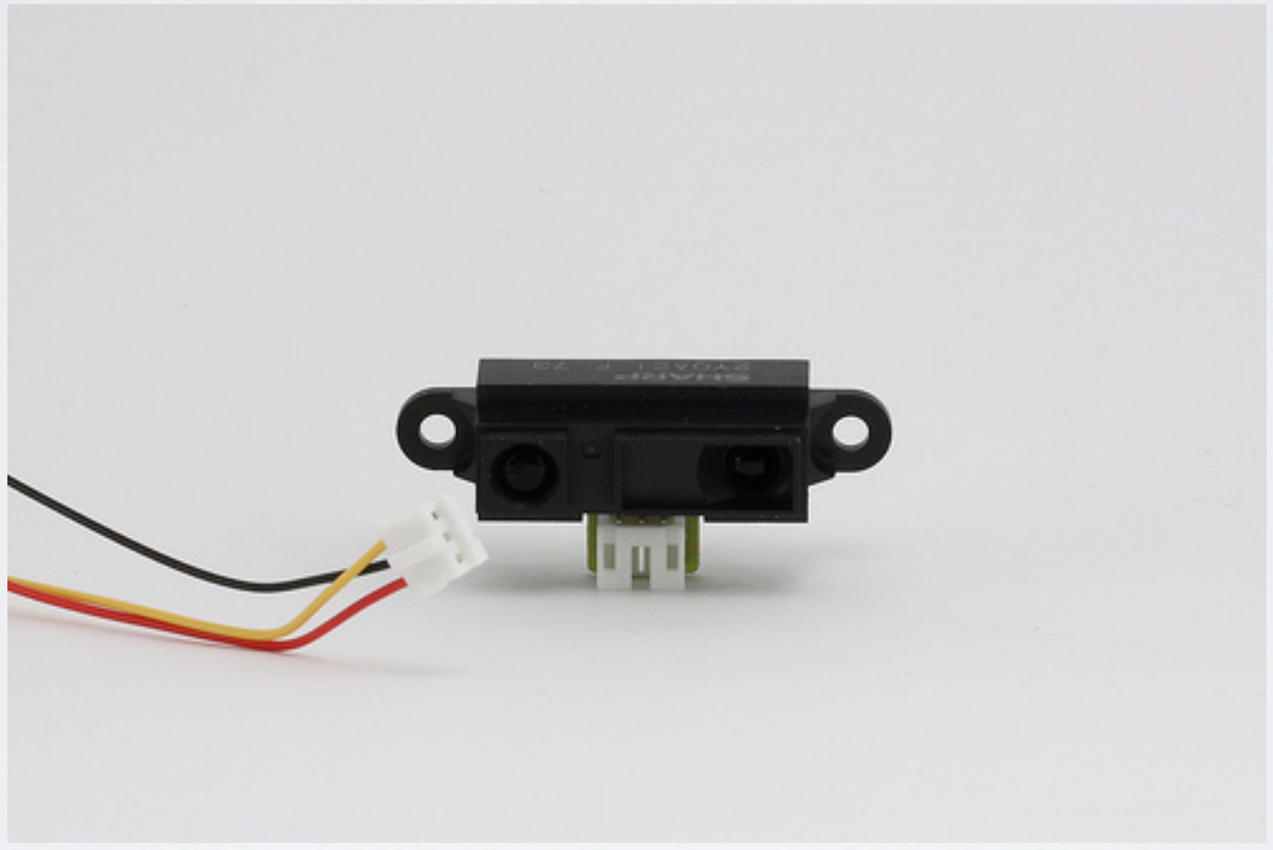
ANALOG SENSORS

POTENTIOMETERS

BEND SENSOR



INFRARED DISTANCE RANGER

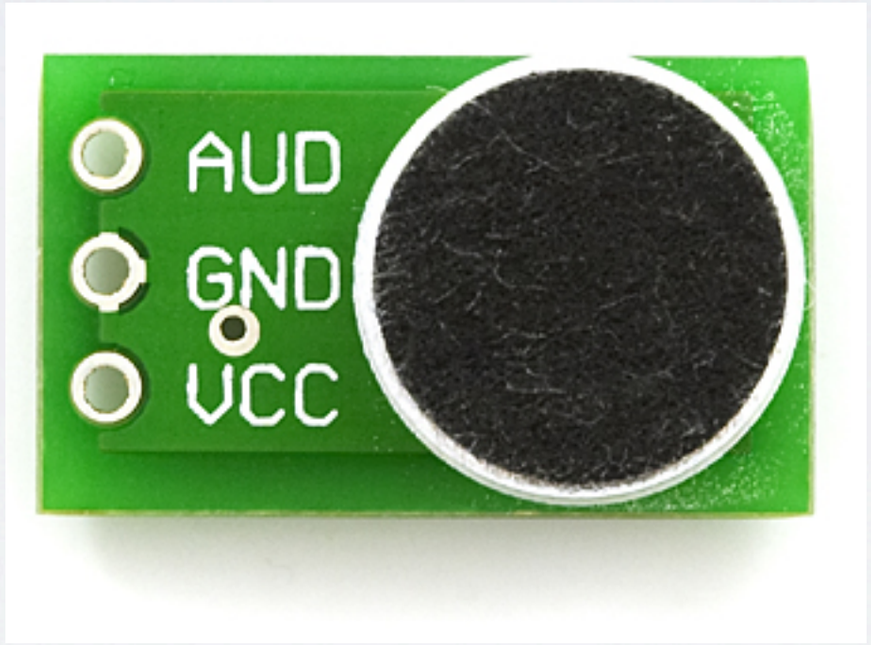


2-AXIS ACCELEROMETER

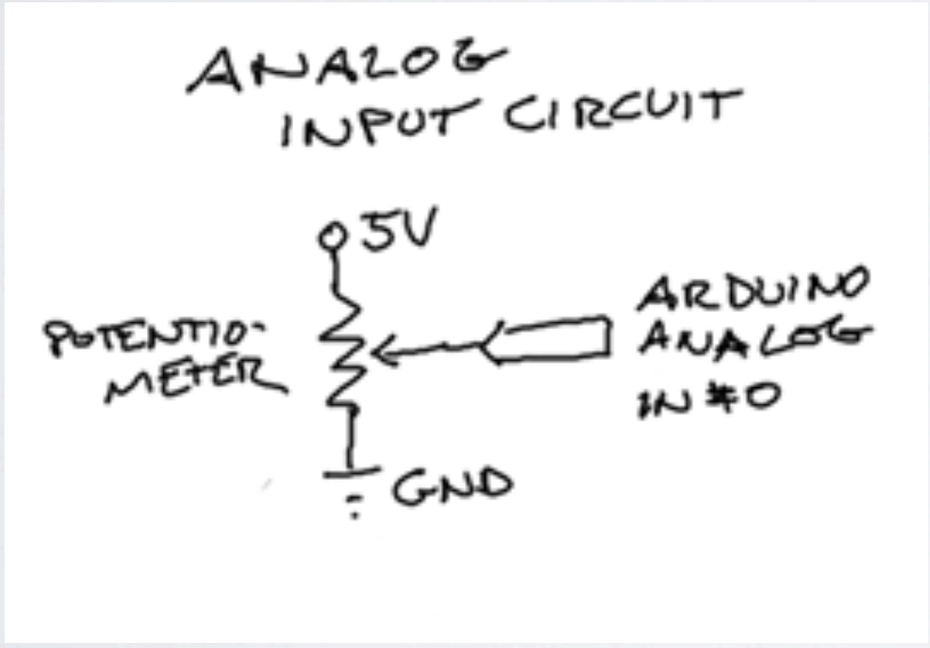
FORCE SENSITIVE RESISTORS

THUMB JOYSTICK

MICROPHONE



PRINCIPLES OF ANALOG INPUT



- 10 bit Analog to Digital Converter
- 2^10 = 1024
- Sampling rate up to ~10 kHz
- V = 5 * s / 1024

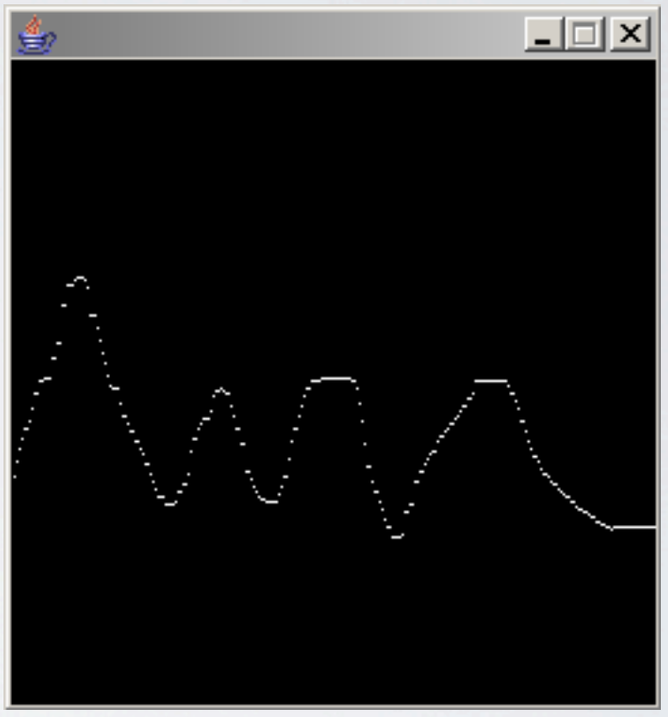
VISUALIZING ANALOG INPUT

analogInput | Processing 1.5.1

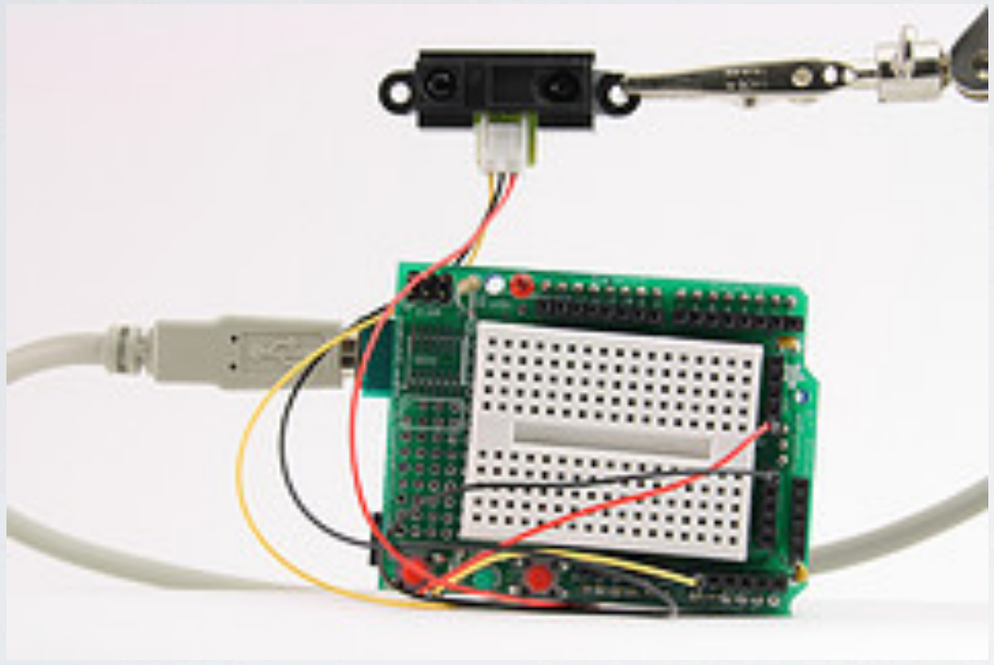
STANDARD

analogInput

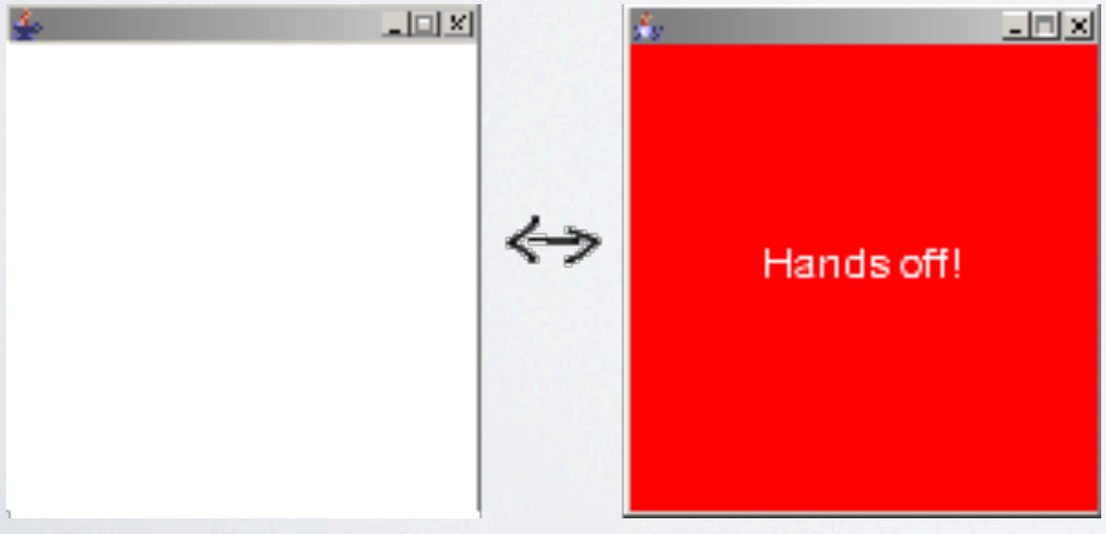
```
/**
* Graph sensor values
*/
import processing.serial.*;
import cc.arduino.*;

int[] xvals;
int arrayindex = 0;
Arduino arduino;
int ledPin=9;
int potPin=0;
void setup()
{
  size(256, 256);
  xvals = new int[width];
  arduino = new Arduino(this, Arduino.list()[1], 57600);
}

void draw()
{
  background(0);
  //shift array left by one
  for(int i=1; i<width; i++) {
    xvals[i-1] = xvals[i];
  }
  // Add the new values to the end of the array
  // read potentiometer (0..1024), divide by four (0..255)
  // to stay within canvas drawing limits
  xvals[width-1] = arduino.analogRead(potPin)/4;
  for(int i=1; i<width; i++) {
    stroke(255);
    point(i, 255-xvals[i]);
  }
}
```



THRESHOLDING



- process of turning continuous data into discrete yes / no decision

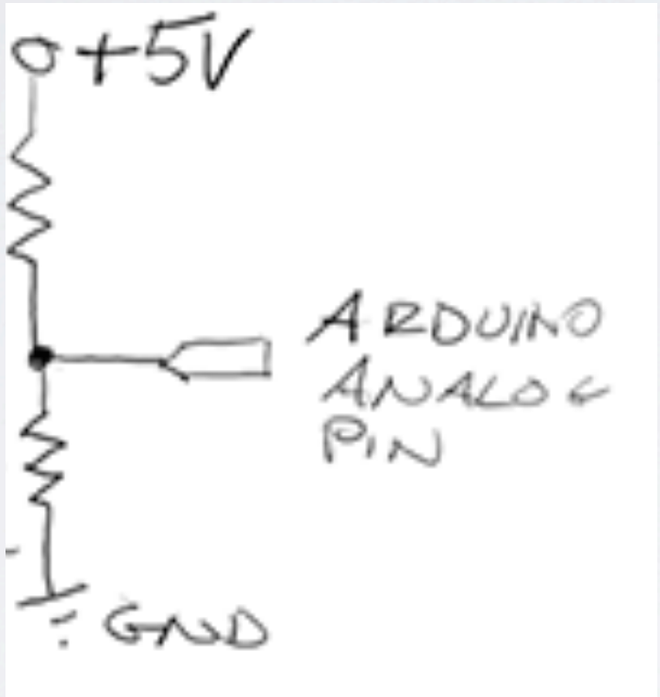


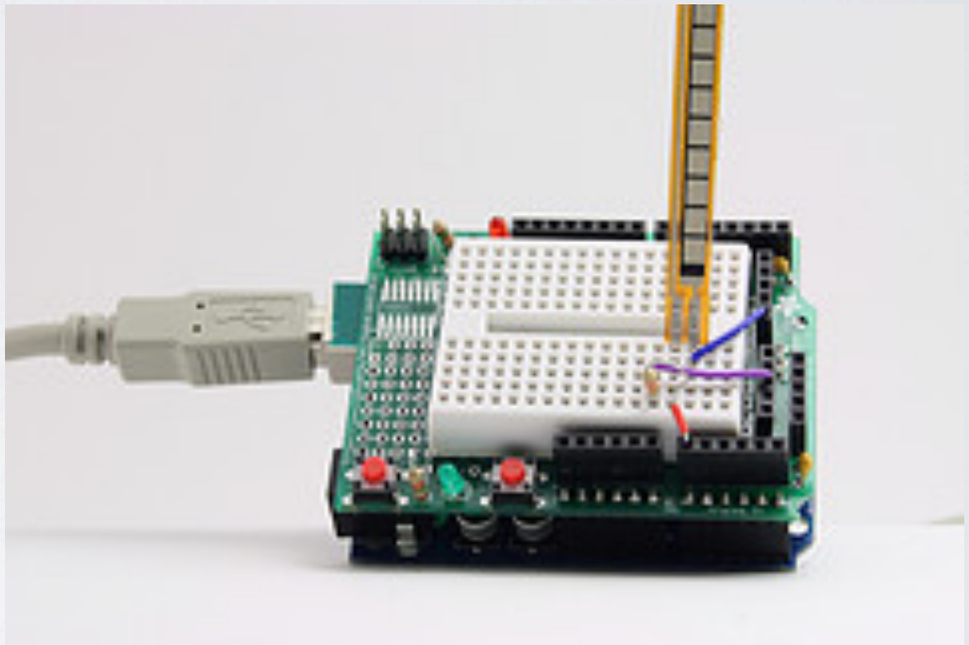
BEND SENSOR

Bend Sensor

10k - 40k

??





CALCULATIONS

$$V_{OUT} = \frac{R_2}{R_1 + R_2} \cdot V_{IN}$$

$V_{in} = 5V$

$R_2 = 22k\Omega$

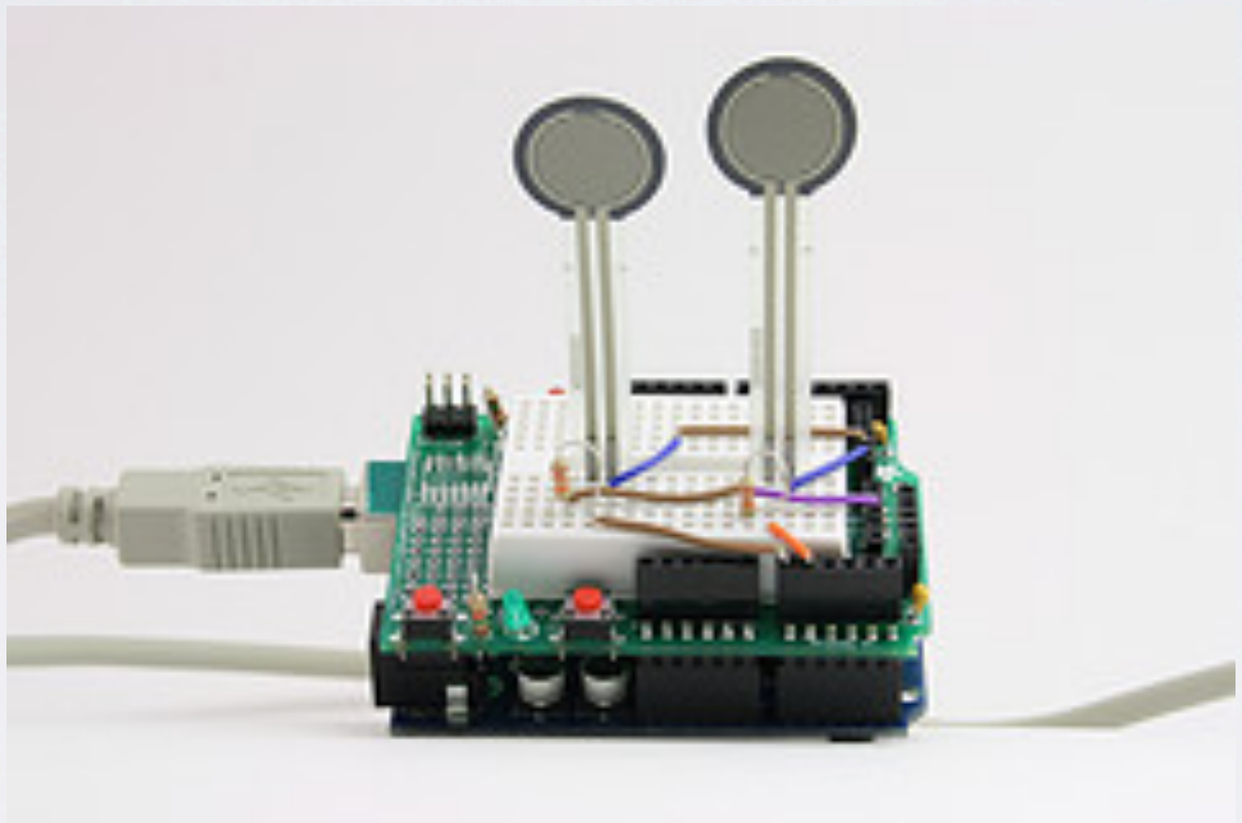
R_1: $10k - 40k\Omega$

WE EXPECT:

$$V_{STRAIGHT} = \frac{22k\Omega}{(10+22)k\Omega} \cdot 5V = 3.44V$$

$$V_{BENT} = \frac{22k\Omega}{40+22k\Omega} \cdot 5V = 1.77V$$

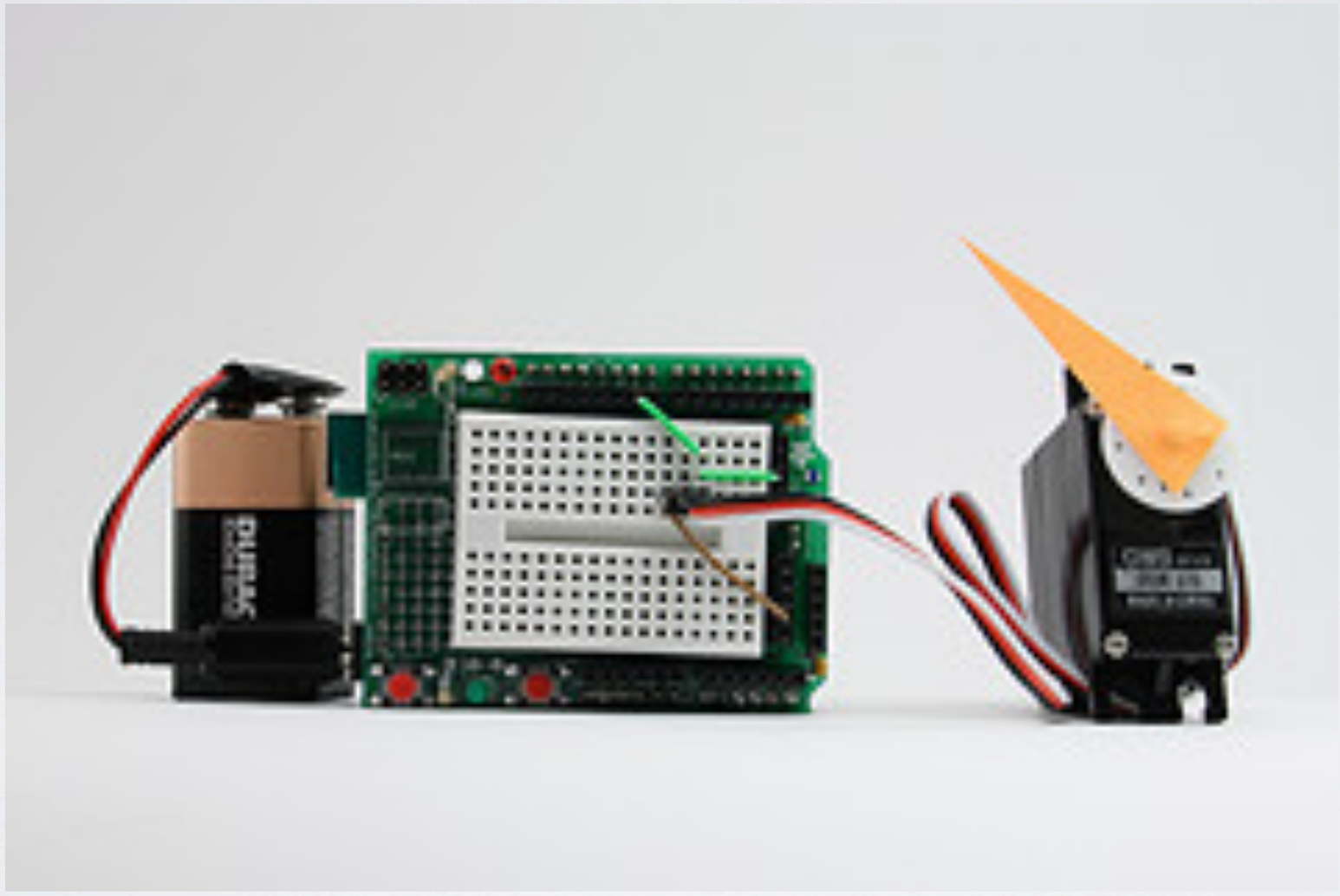
EXAMPLE: FSR THUMB WRESTLING



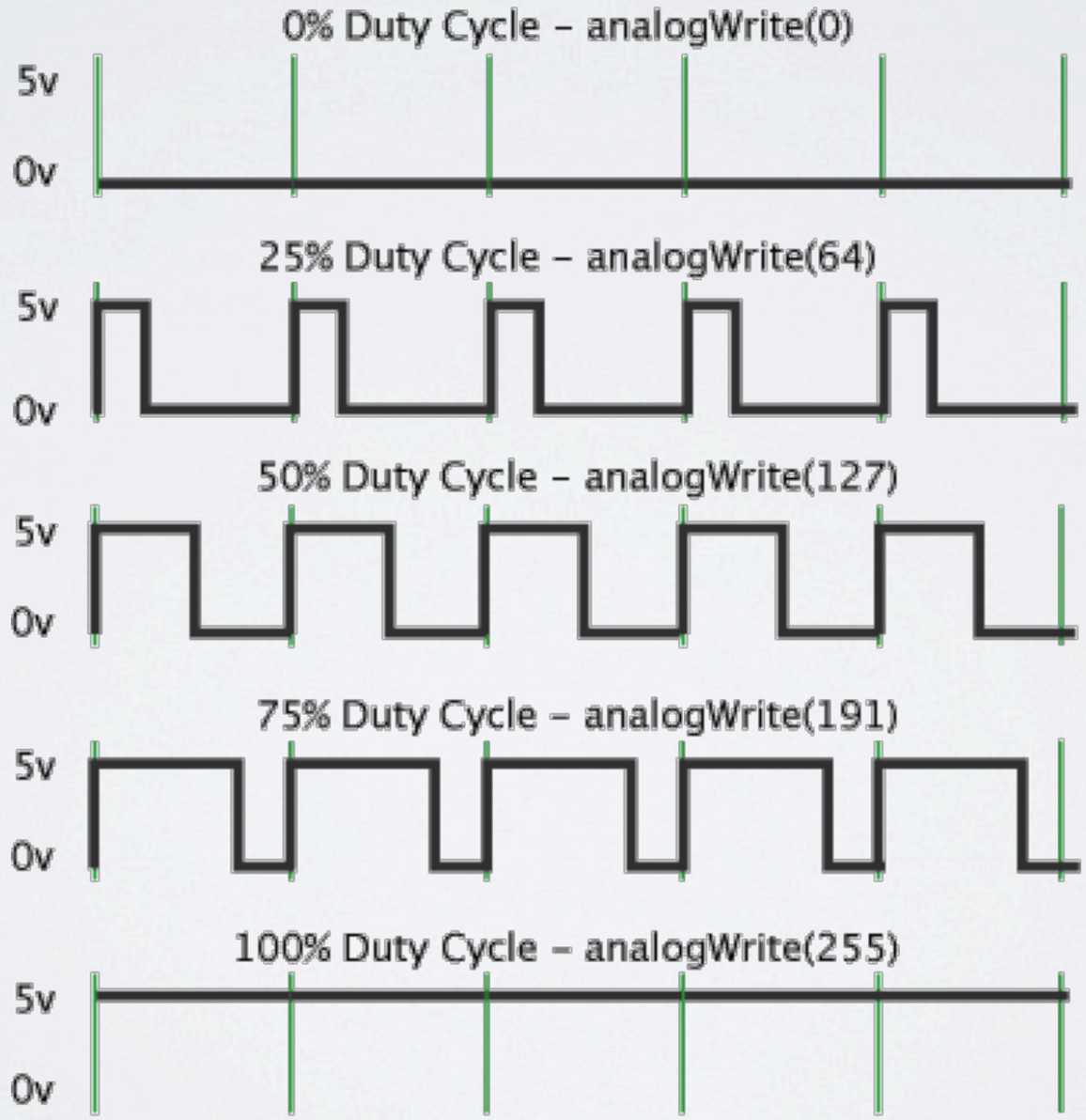
ACTUATORS

Making things move

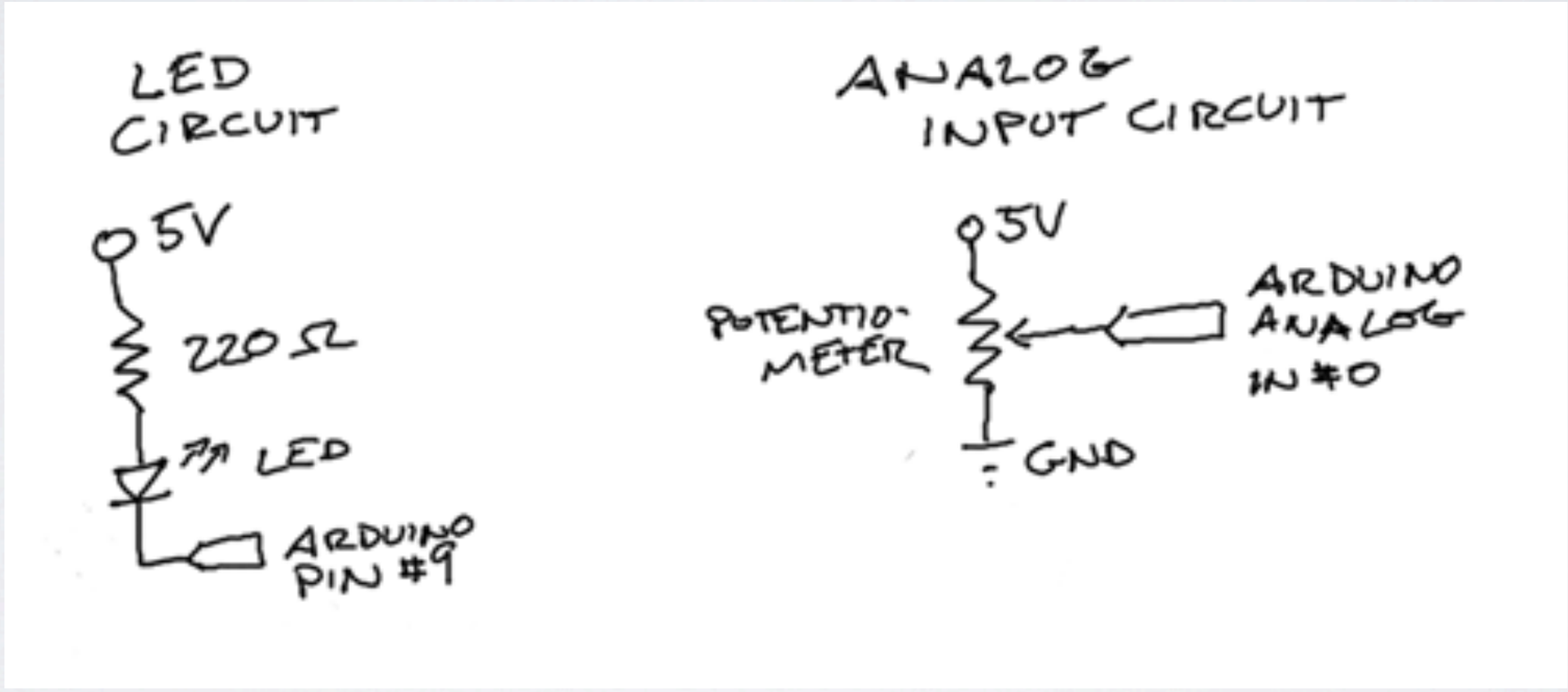
SERVO MOTORS



PULSE WIDTH MODULATION



EXAMPLE: DIMMER



SERVO EXAMPLE

servo | Processing 1.5.1

STANDARD

servo §

```
import processing.serial.*;
import cc.arduino.*;

Arduino arduino;
int pos=0; //servo position in degrees (0..180)
int servoPin=9;

void setup() {
  size(360, 200);

  arduino = new Arduino(this, Arduino.list()[1], 57600); //your

  arduino.pinMode(servoPin, Arduino.OUTPUT);

}

void draw() {
  // read mouseX coordinate
  int newPos = constrain(mouseX/2,0,180);

  // update bg & servo position if mouseX changed
  if(newPos != pos) {
    background(newPos);
    arduino.analogWrite(servoPin,newPos);
    pos=newPos; //update servo position storage variable
  }
}
```

DESIGN EXERCISE

RESEARCH IN PHYSICAL PROTOTYPING

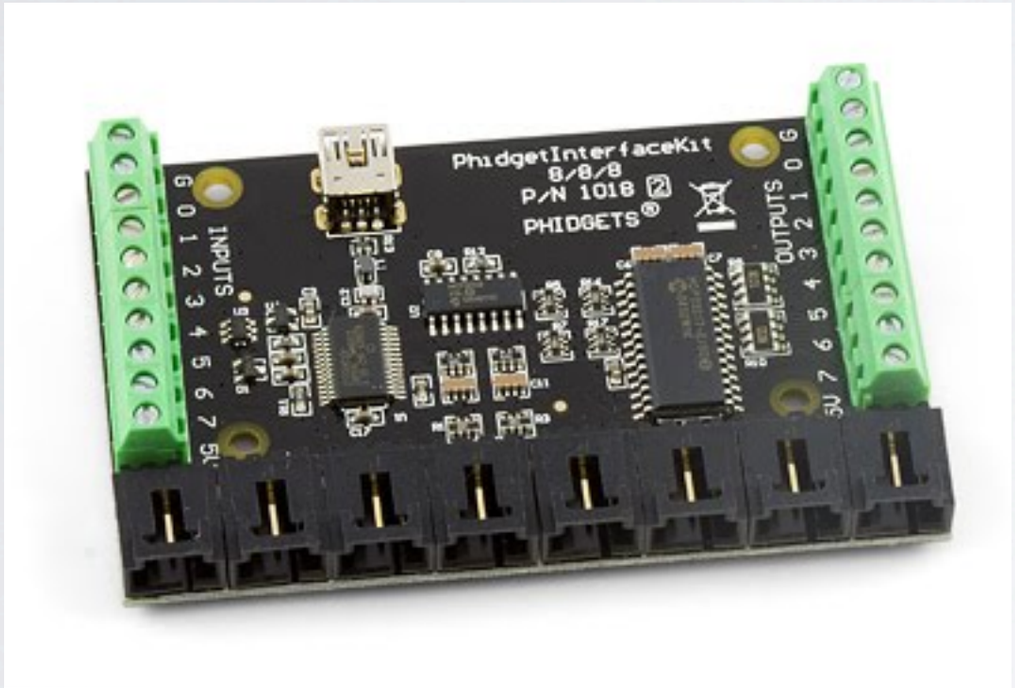
KEY RESEARCH GOAL

- Low Threshold
- High Ceiling

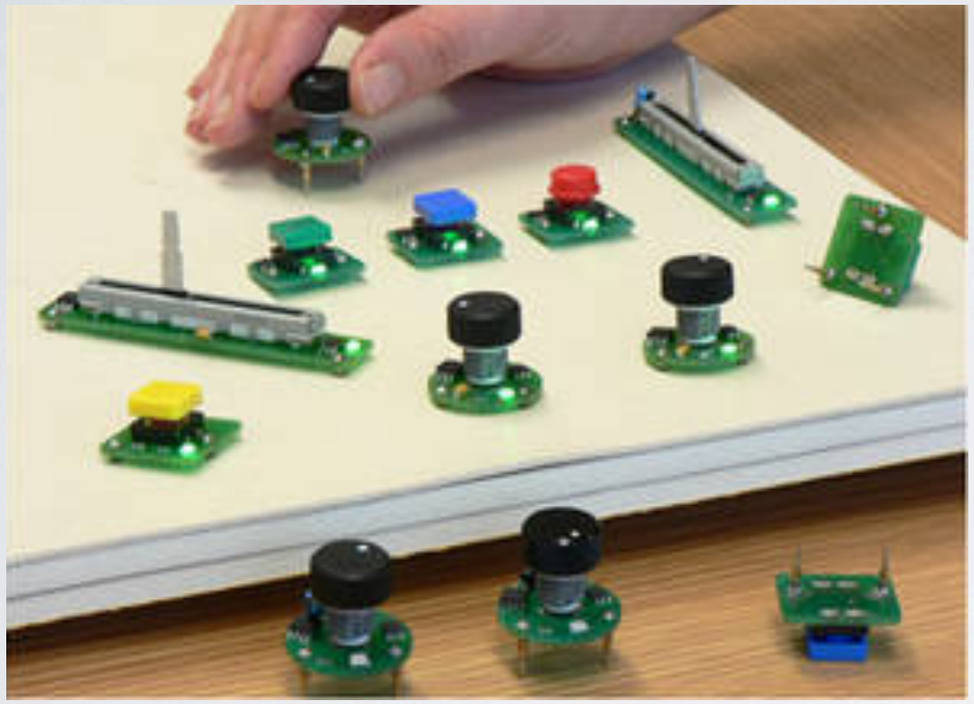
[Greenberg, UIST 2001]

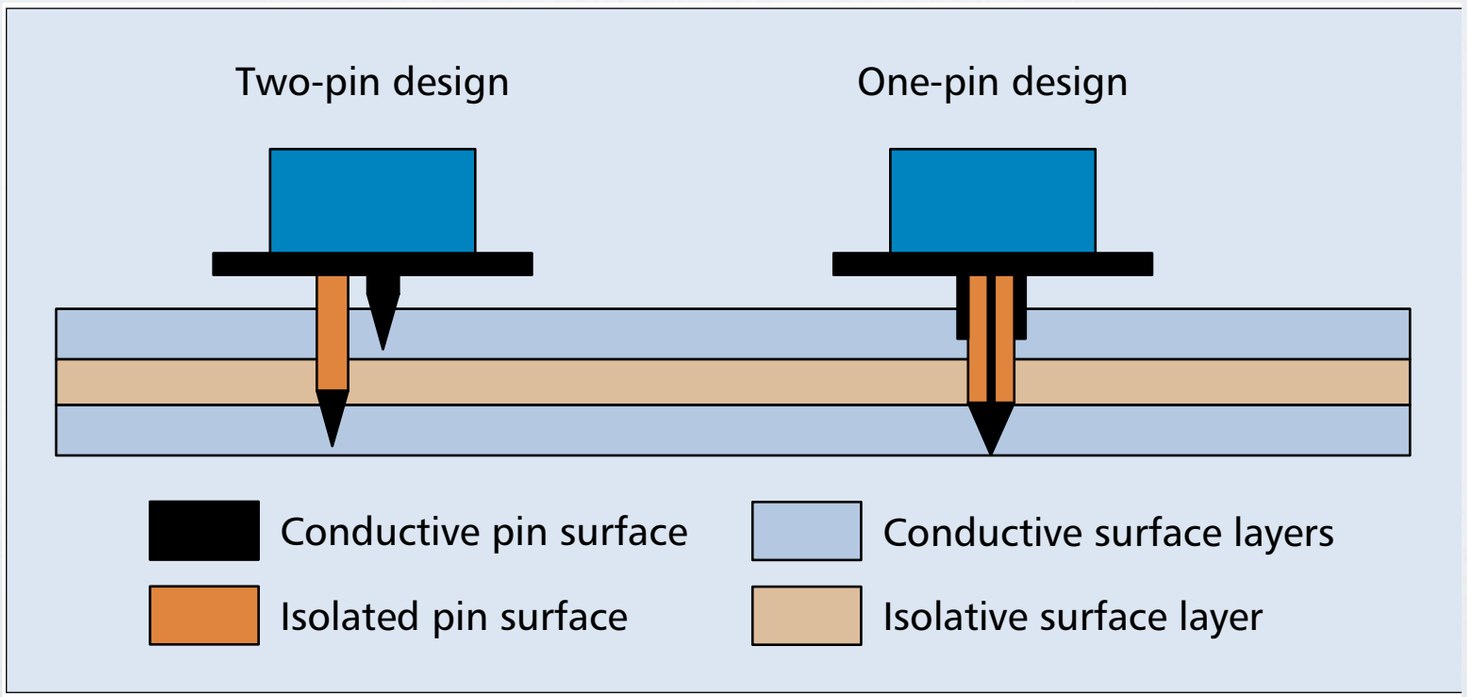
PHIDGETS

www.phidgets.com



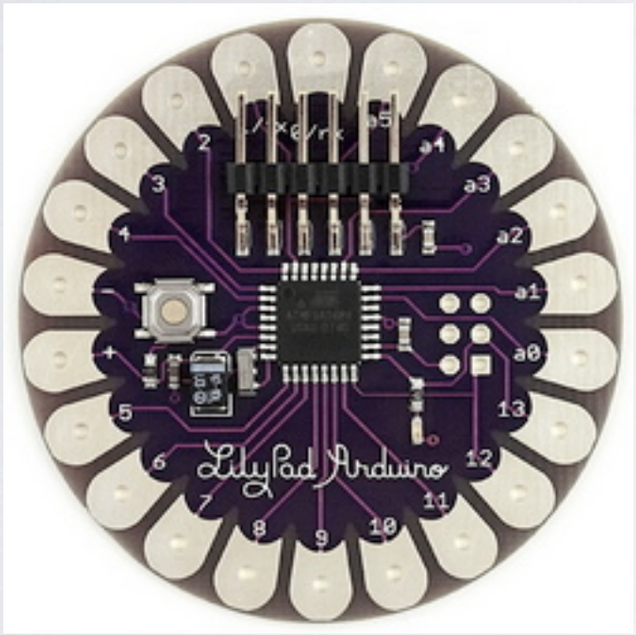
VOODOO I/O

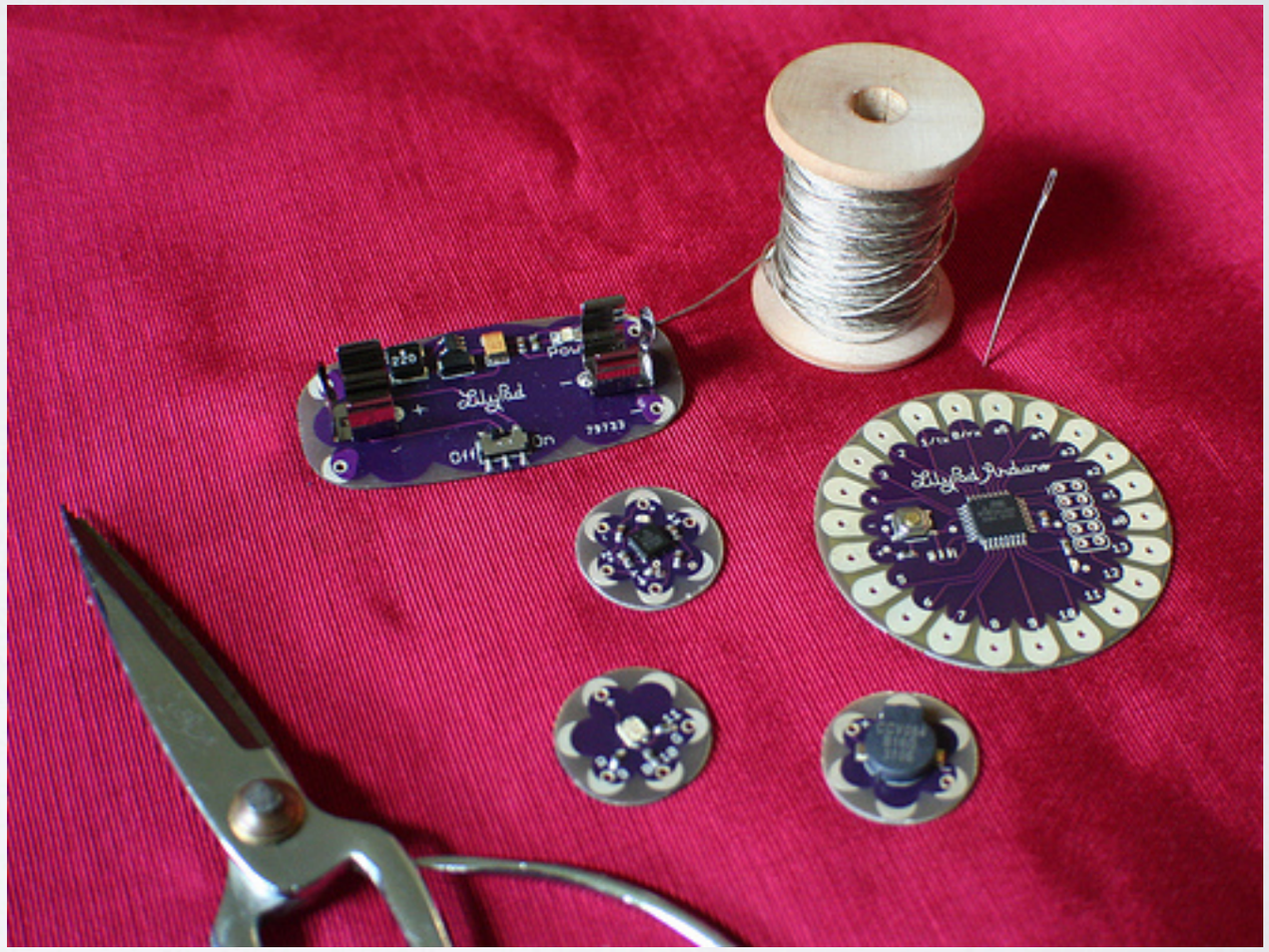



Two-pin design
One-pin design
Conductive pin surface
Isolated pin surface
Conductive surface layers
Isolative surface layer

[Buechley, CHI '08]

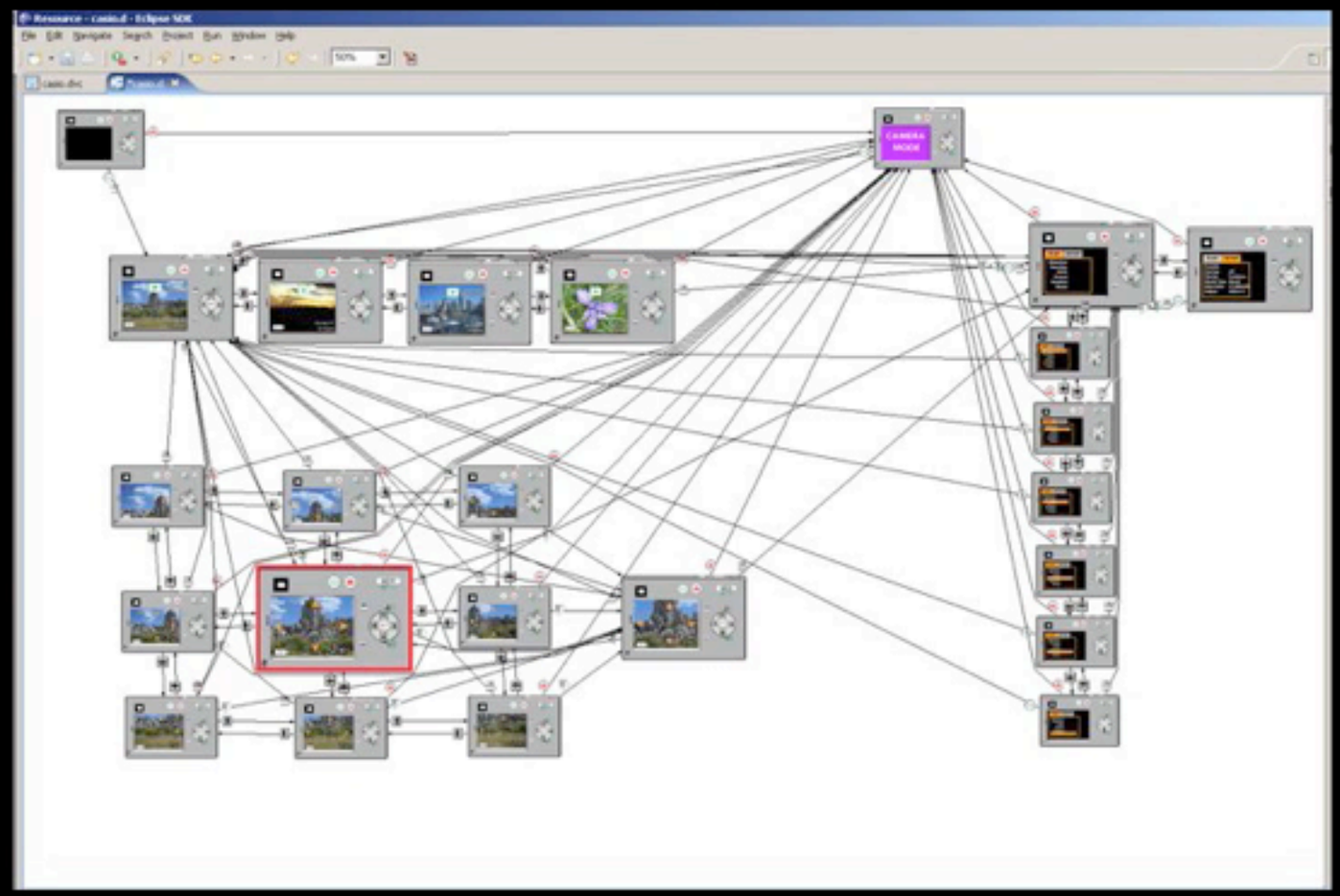
LILYPAD ARDUINO





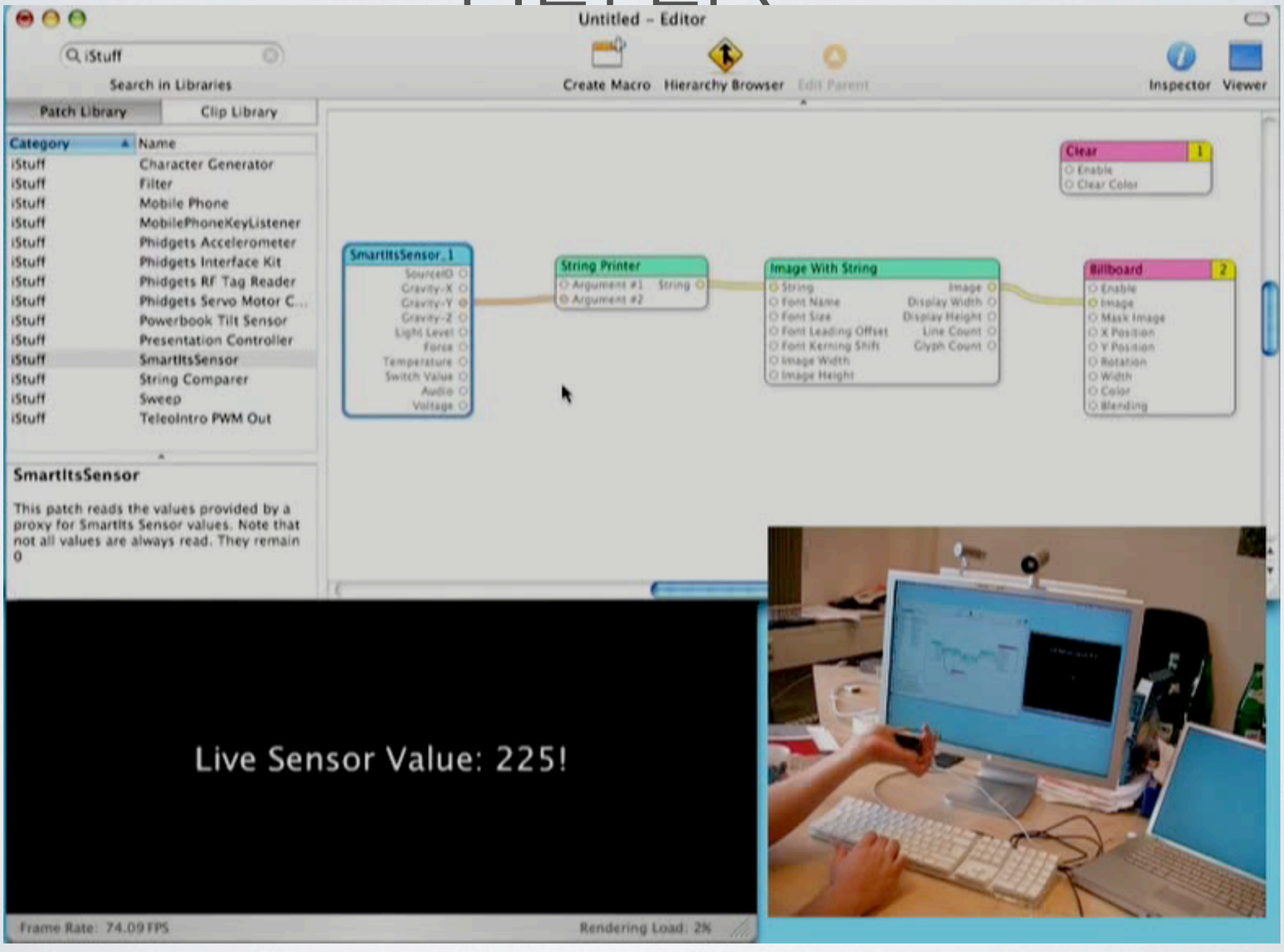
[Hartmann, UIST 2006]

D.TOOLS: STATE CHART EDITING

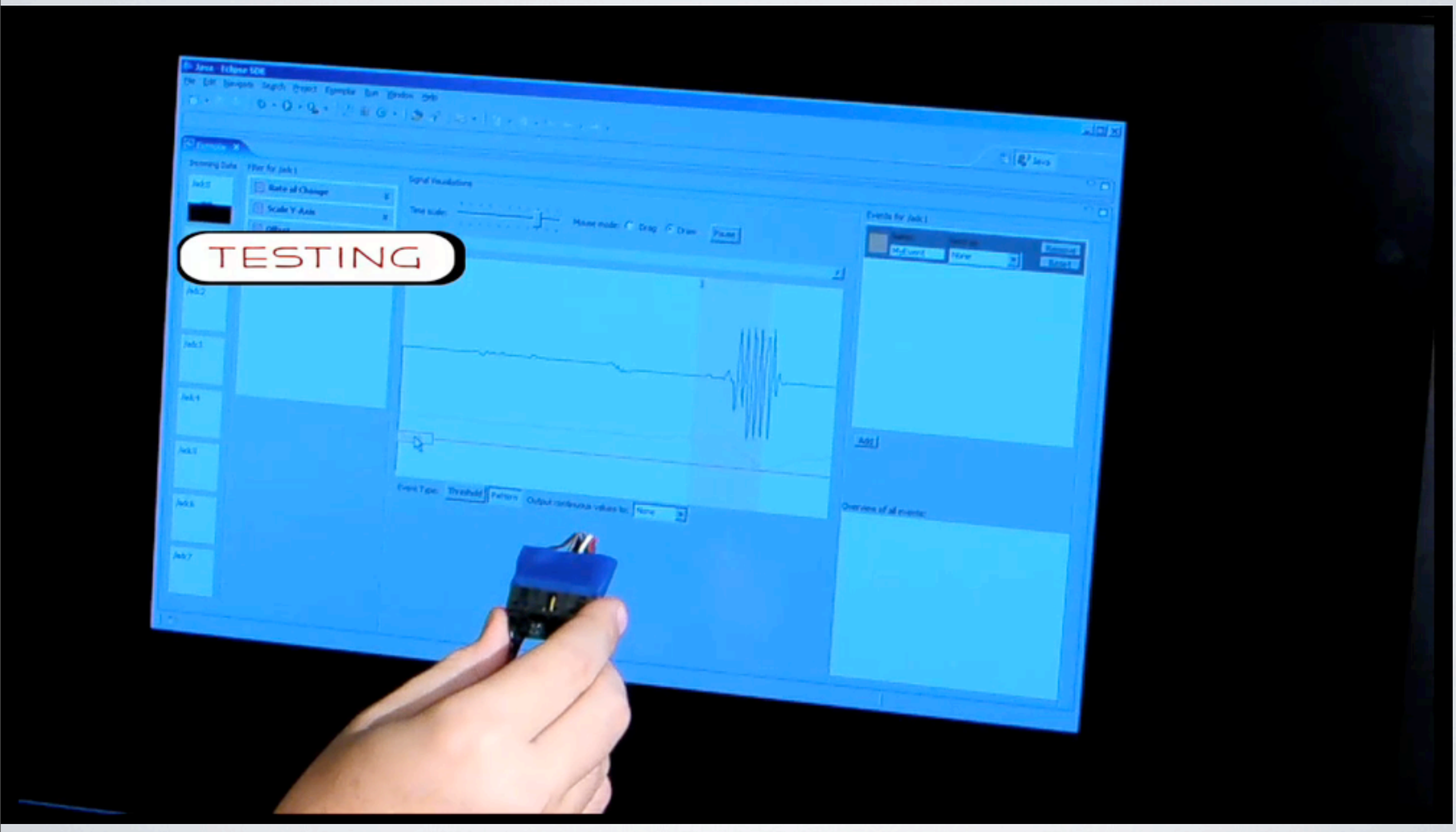


[Ballagas, CHI 2007]

iSTUFF MOBILE: PIPE & FILTER

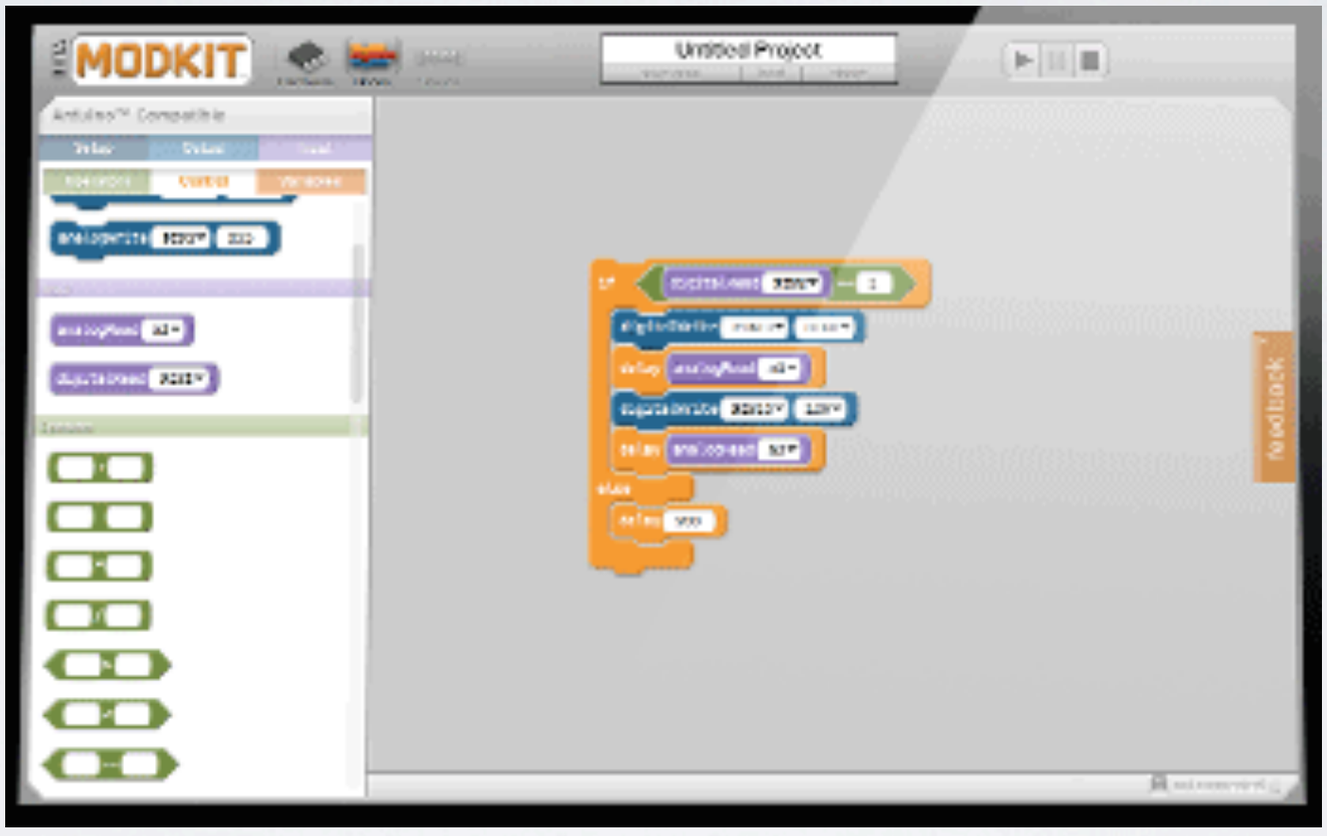


EXEMPLAR: PROG. BY DEMONSTRATION

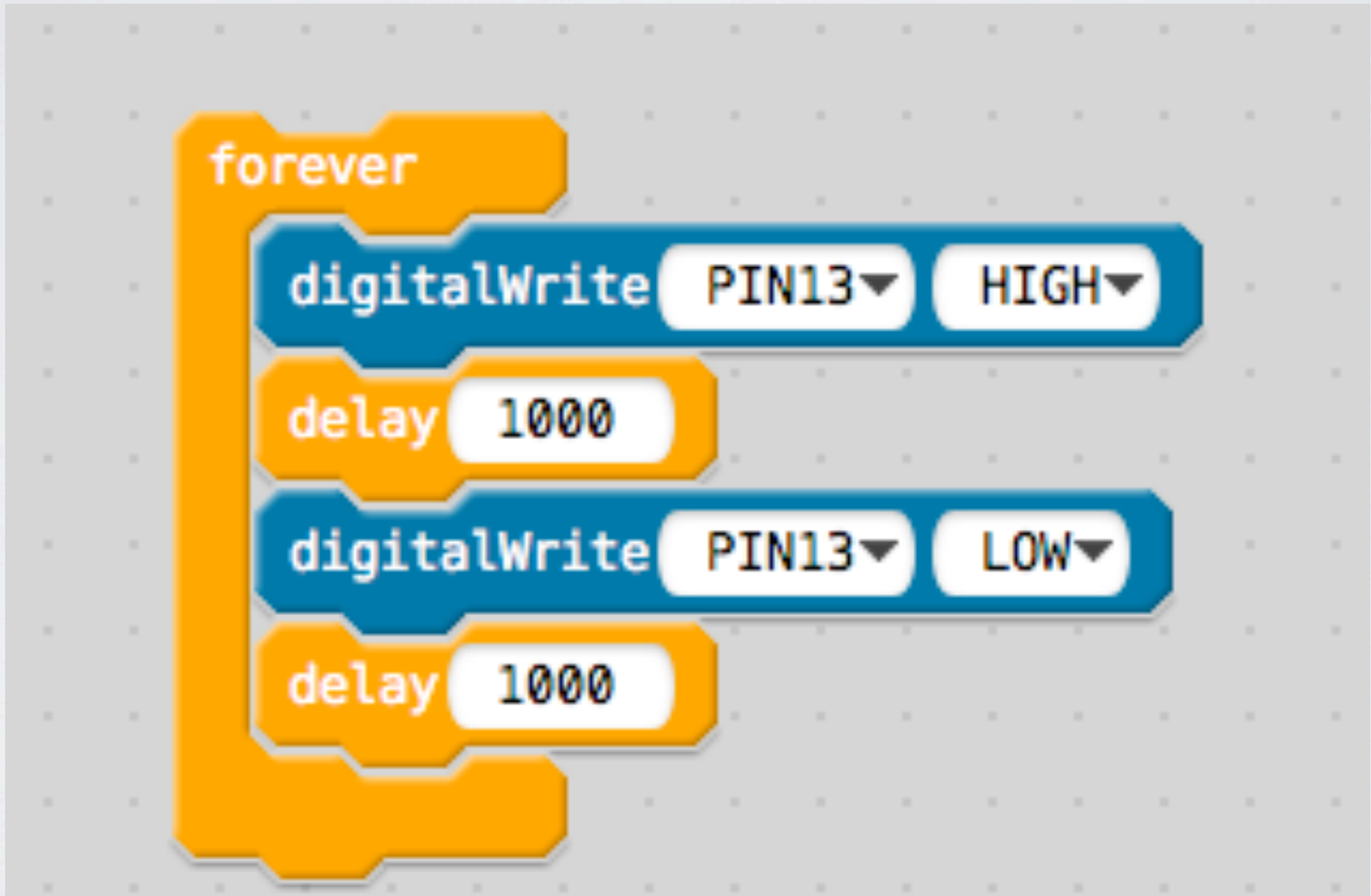


MODKIT

- Scratch Meets Arduino

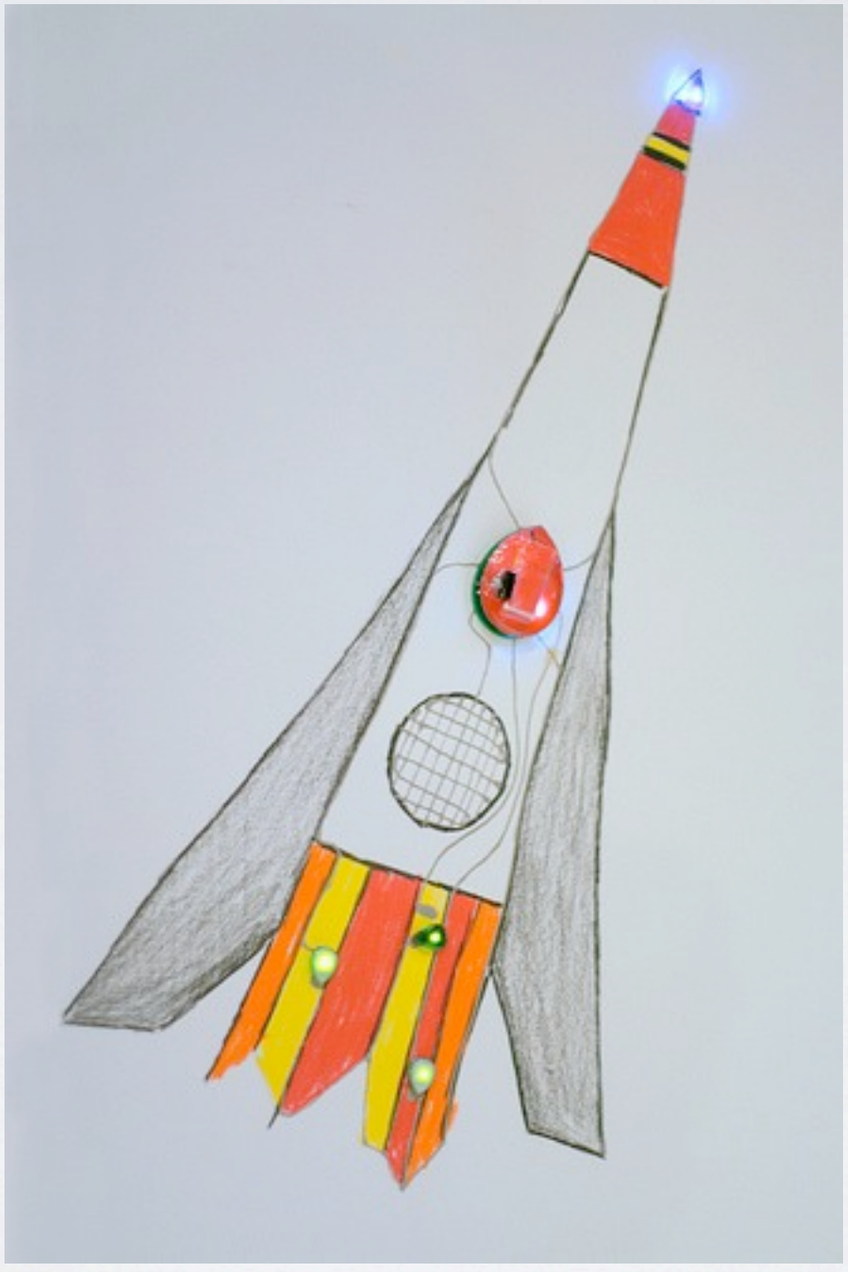


MODKIT EXAMPLE



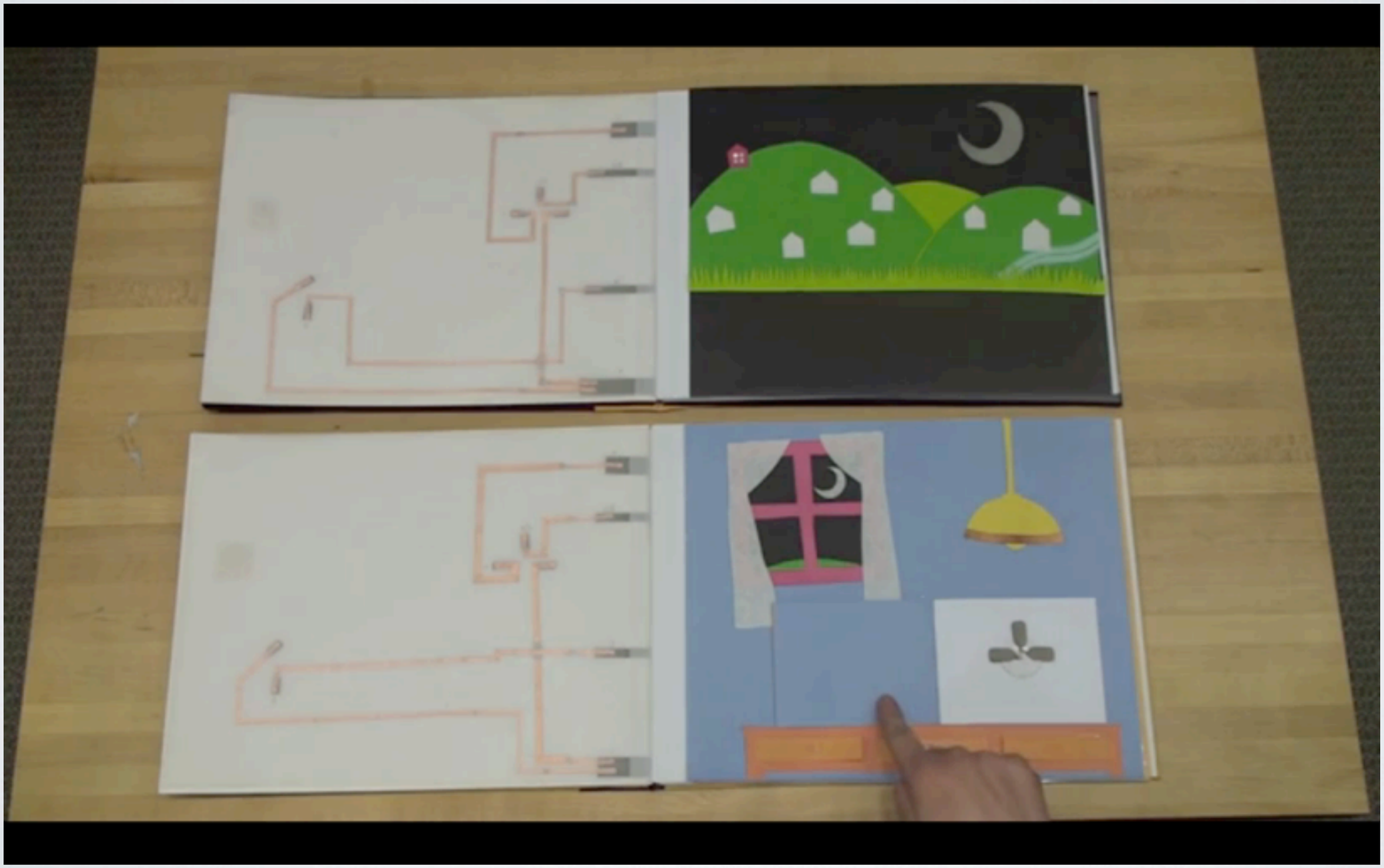
[Buechley, TEI '09]

TEAR DROP



[Freed, IDC '11]

TELESCRAPBOOKS



TAKEAWAYS

- Build lots of prototypes, both parallel and iterative.
- Key is to *fail early and often*
- Good prototyping tools provide a low threshold and a high ceiling.