02: Introduction to Circuits

Group project

No exams for this class → convince me you **met the learning goals** via the project

- Demo & project report, revisions after feedback

Open-ended (with suggestions)

Must include concepts from class

More details after shopping period

Capstone

- Built on to final project
  - Some sort of related, additional functionality that you can do on your own
- After your group writes the project proposal:
  - You write up your proposal
  - We meet to chat about it
  - You do the work and write it up

Review

Embedded systems are everywhere, have specific purposes, and unique challenges

Microcontrollers (MCUs) have CPU, I/O, memory on one chip

In lab you began working with an MCU and embedded hardware

Why would we as software engineers care about circuits, analog components, how I/O works, etc?

Ideas

On a computer, OS abstracts hardware, but on embedded devices, we don't get that luxury

- protocols
- latency
- debouncing

Helps to know what's happening when debugging

Design circuits with regards to power, current, etc. limits

This is the extent of circuit math we will use in the course!

Prelabs and labs will always guide you through what you need to know

Electrical circuit

- Loop through which electricity flows
- Consists of at least a power source and conductors
- Some quantities that are useful to measure:
  - Voltage
  - Current
  - Power

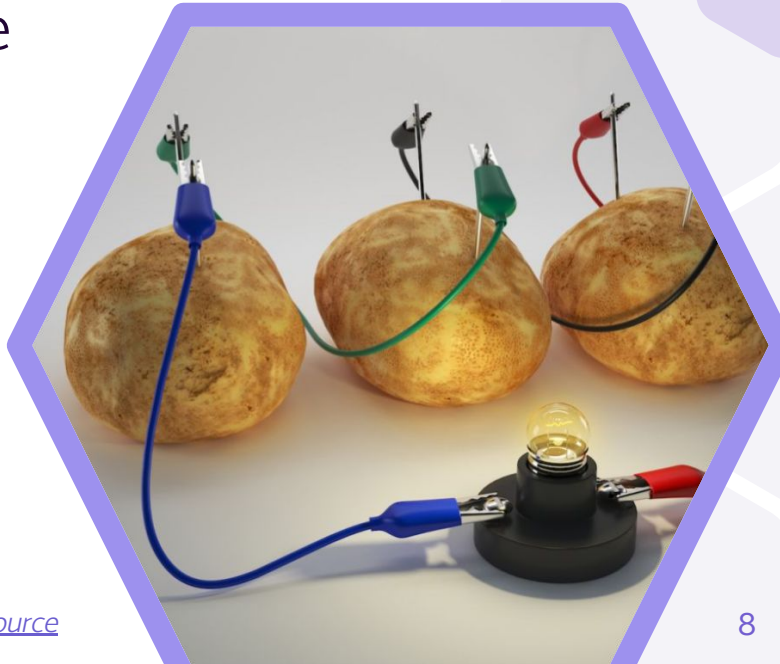
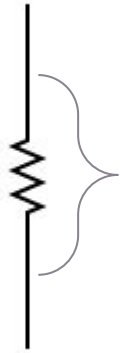


Image source

Voltage

Difference in electric potential

- Measured between two points (or one point and implicit ground)
- We say we measure voltage **across** a component



Voltage across resistor

Current

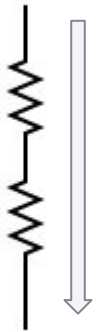
Rate of flow of charged particles through a circuit

- Convention in circuits: imagine particles flowing from positive to negative terminal (or from a power source to ground)
- We say we measure current **through** a component

Current through resistor

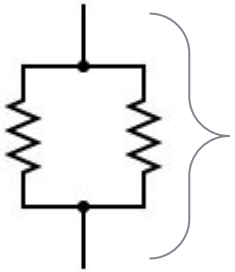
Parallel and series components

Series



Current **is the same through both components**
Voltage: ???

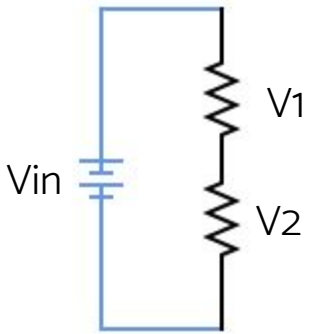
Parallel



Voltage **is the same across both components**
Current: ???

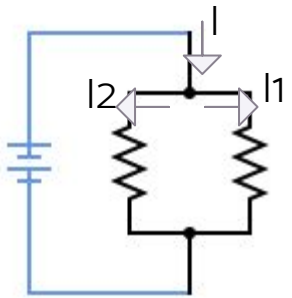
Kirchoff's laws

Sum of **voltages** around a closed loop is zero



-Vin + V1 + V2 = 0
Vin = V1 + V2

Sum of **currents** flowing *into* a node is the same as sum of currents flowing *out* of the node



I = I1 + I2

Ohm's law & power law

Ohm's law: **V = IR** (SI units: volts, amperes, ohms)

Power law: **P = IV** (SI units: watts, amperes, volts)

Useful for:

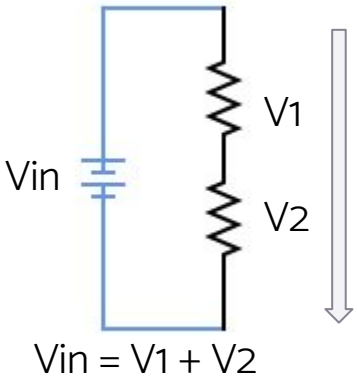
- Computing values needed to build circuit
- Figuring out the limits of what you can attach to your microcontroller
- Writing down accurate math for modeling your system

Thevenin equivalent circuit

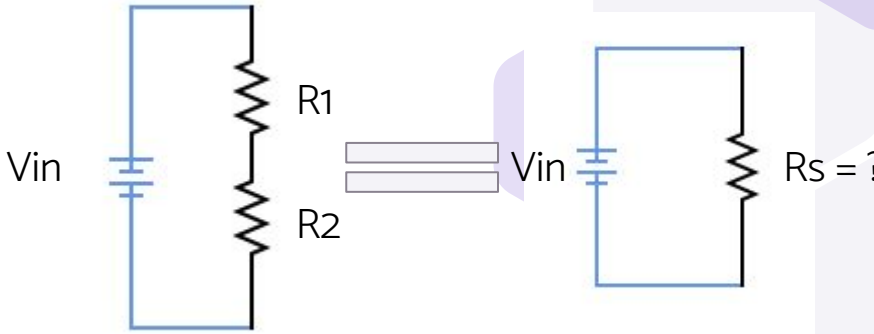
Any linear electrical network containing current sources, voltage sources, and resistors can be replaced by an equivalent circuit with one voltage source and one resistor

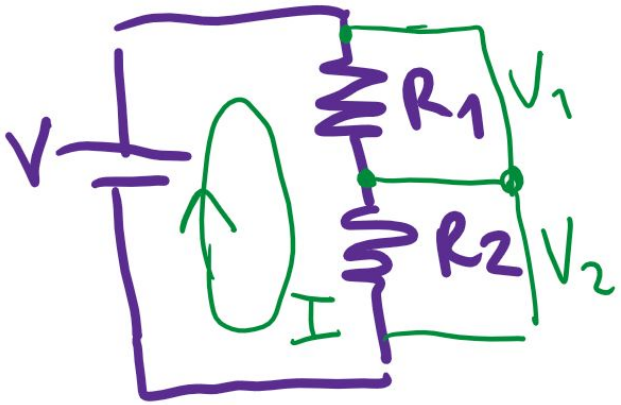
Thevenin for resistors in series

$V = IR$



***Current* is the same through both components**



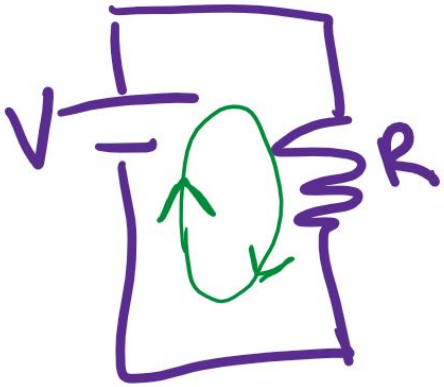


$V = V_1 + V_2$

$V = (I \cdot R_1) + (I \cdot R_2)$

$V = I(R_1 + R_2)$

$\Rightarrow I = \frac{V}{R_1 + R_2}$



$V = IR$

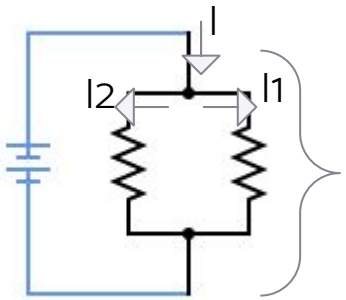
$\Rightarrow R = \frac{V}{I}$

$= \frac{V}{\frac{V}{R_1 + R_2}}$

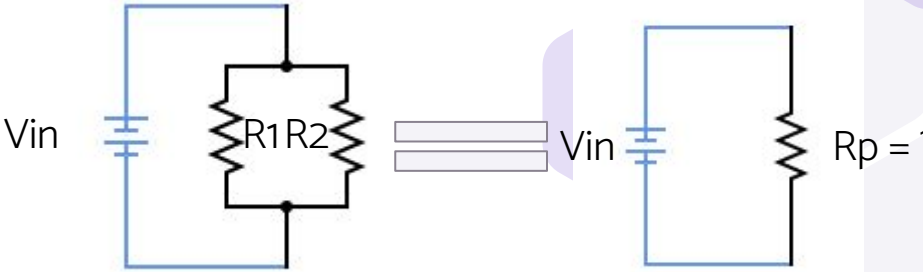
$= R_1 + R_2$

Thevenin for resistors in parallel

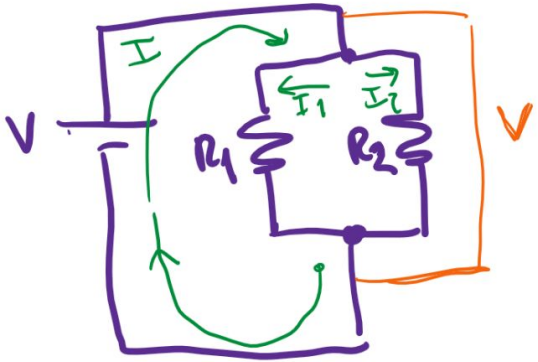
$V = IR$



***Voltage* is the same across both components**



$I = I1 + I2$

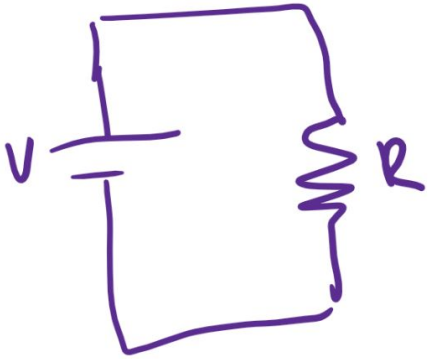


$$I = I_1 + I_2$$

$$V = I_1 \cdot R_1 = I_2 \cdot R_2$$

$$\Rightarrow I_1 = \frac{V}{R_1}$$

$$I_2 = \frac{V}{R_2}$$



$$V = I R$$

$$R = \frac{V}{I}$$

$$= \frac{V}{(I_1 + I_2)}$$

$$= \frac{V}{\left(\frac{V}{R_1} + \frac{V}{R_2}\right)} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

Given Ohm's law (V = IR) and the Power law (P = IV), what is the maximum power output of your Arduino pin (rated at 3.3 V, 7 mA)