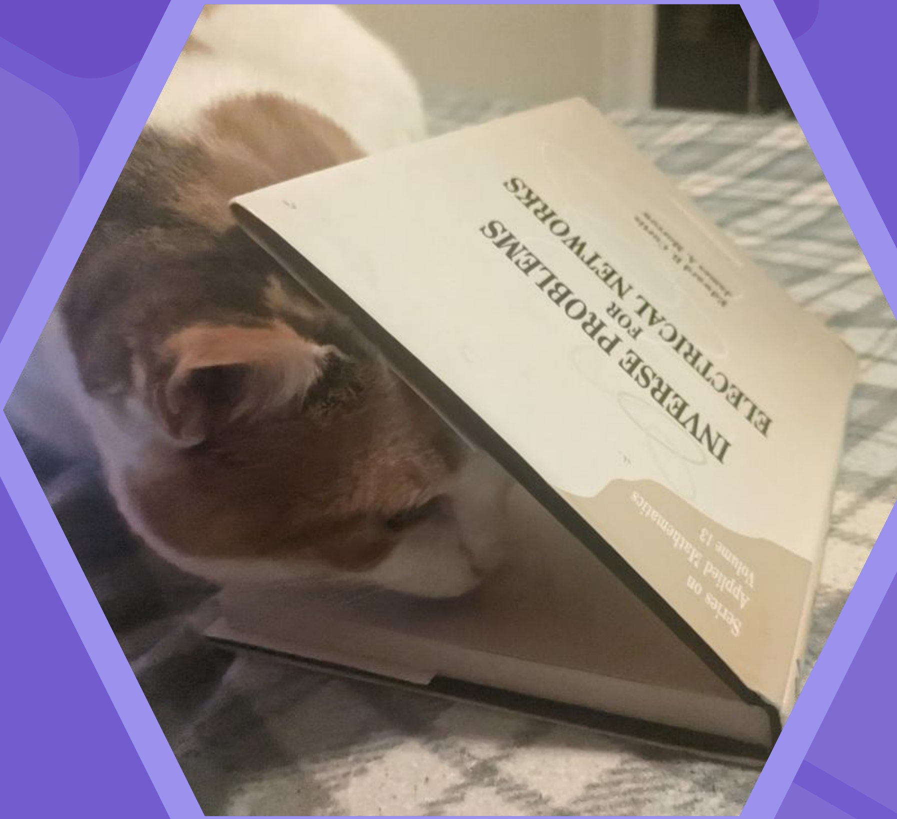
02: Introduction to Circuits

Reminders:

- Complete HW01 (short survey) by Monday
  (everyone should do this, not just people wanting to get on the waitlist)
- Complete Prelab 1 by Monday
  Bring kits to lab if you have them (we'll ask people who don't have kits to form groups with people who do)



Group project/Capstone

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

- Demo & project report, revisions after feedback

More details after shopping period

Capstone: additional functionality you add on to final project + demo to me

Review

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

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

In lab you will begin working with an MCU and embedded hardware

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

Hardware constrains what kind of software we write
Understanding what kind of computations are optimized for your hardware
Need to know the assumptions behind the input you are getting
Less constrained to what exists already
Limitations o

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

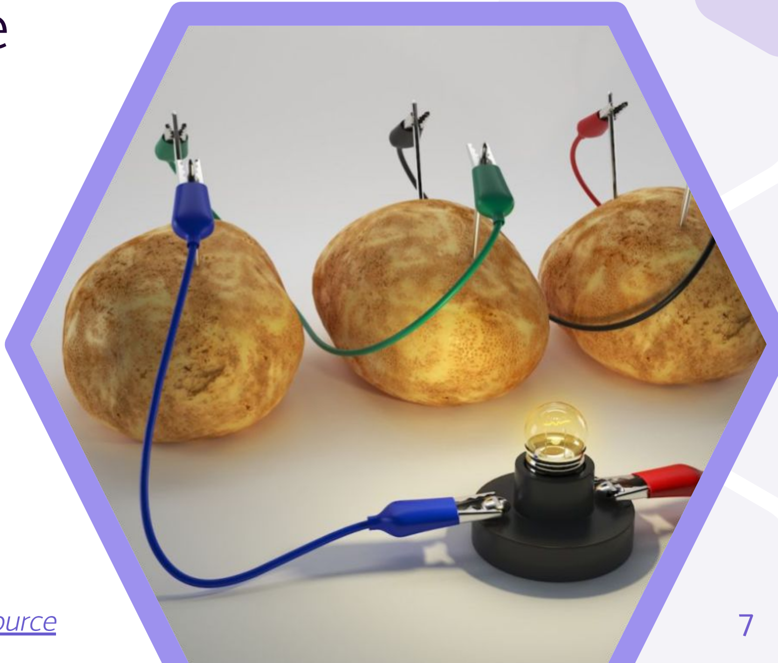
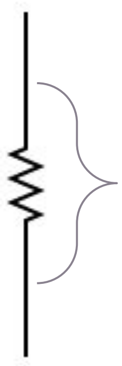


Image source

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

Ohm’s law & power law

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

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

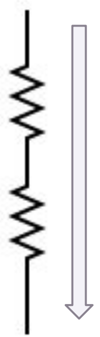
Useful for:

- 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

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)

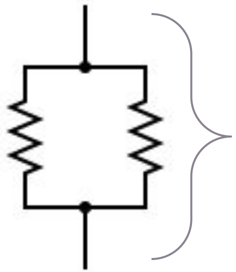
Parallel and series components

Series



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

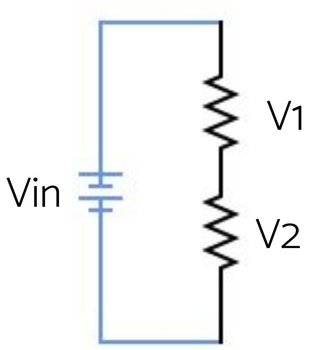
Parallel



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

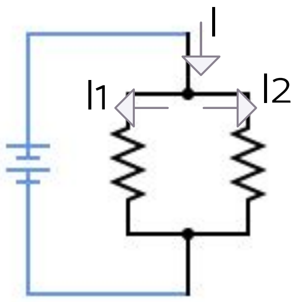
Kirchoff's laws

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



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

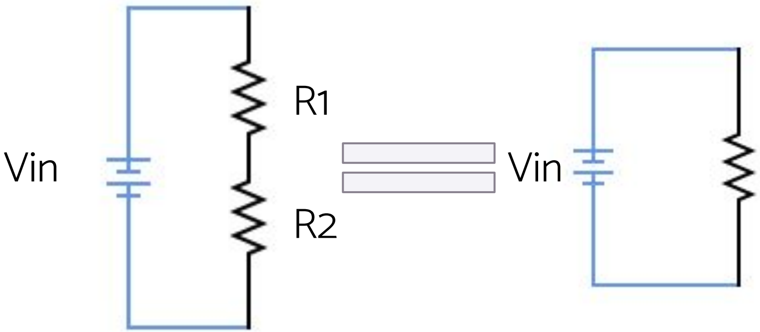
Sum of **currents** flowing *into* a node is the same as sum of currents flowing *out* of the node

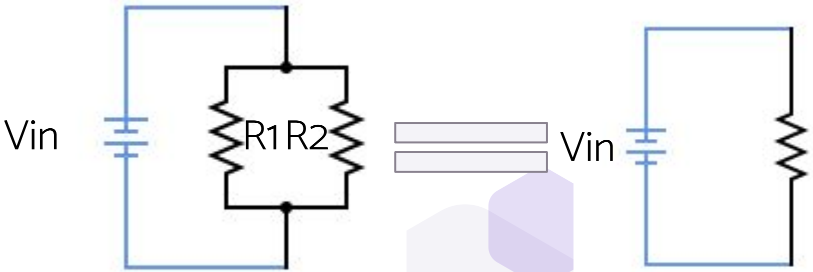


I = I1 + I2

Thevenin equivalent circuit

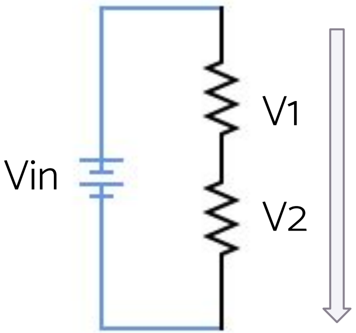
Any linear electrical network containing current sources, voltage sources, and resistors can be replaced by an equivalent circuit with one voltage source and one resistor





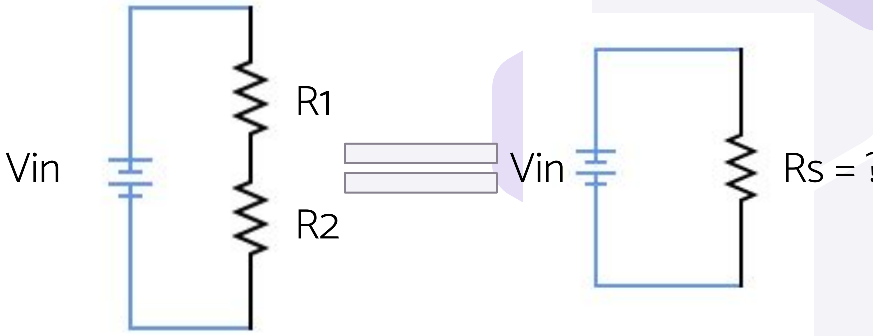
Thevenin for resistors in series

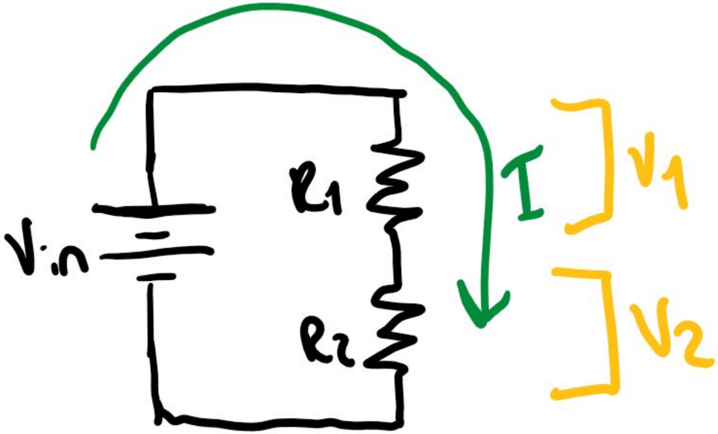
V = IR



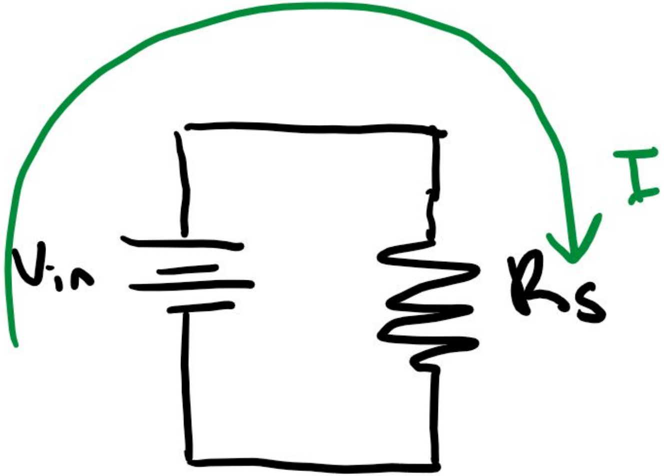
Vin = V1 + V2

Current **is the same through both components**





$$V_1 = R_1 \cdot I$$
$$V_2 = R_2 \cdot I$$



$$V_{in} = R_S \cdot I$$
$$(V_1 + V_2) = R_S \cdot I$$
$$(R_1 \cdot I + R_2 \cdot I) = R_S \cdot I$$
$$R_S = R_1 + R_2$$

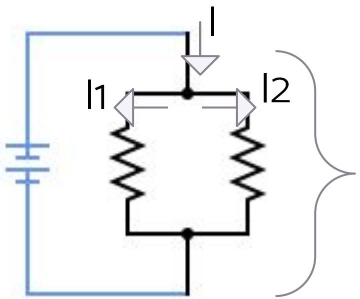
What’s the point?

Understanding that resistance in series is additive helps you reason about the limitations of how much you can attach in series to one pin

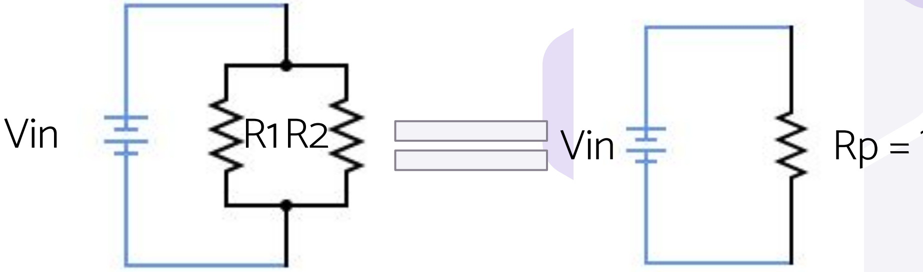
You have more flexibility in terms of the resistors you use

Thevenin for resistors in parallel

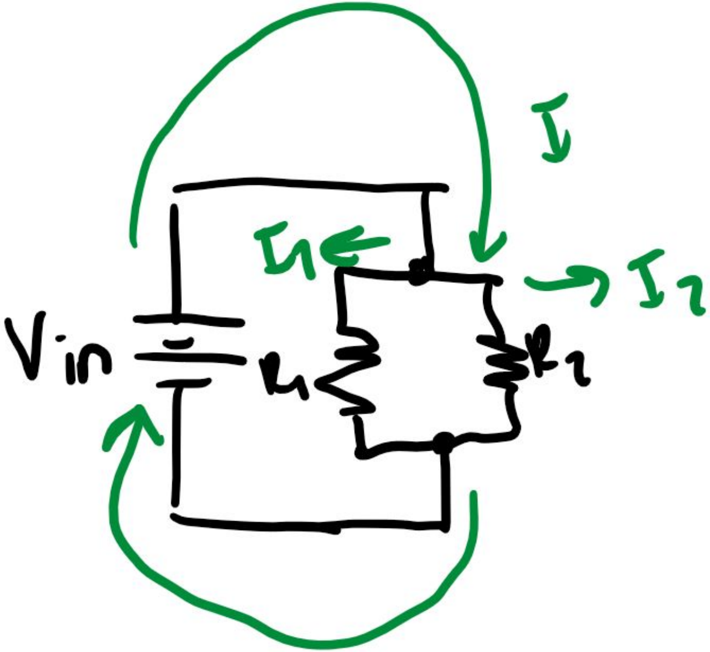
V = IR



Voltage **is the same across both components**

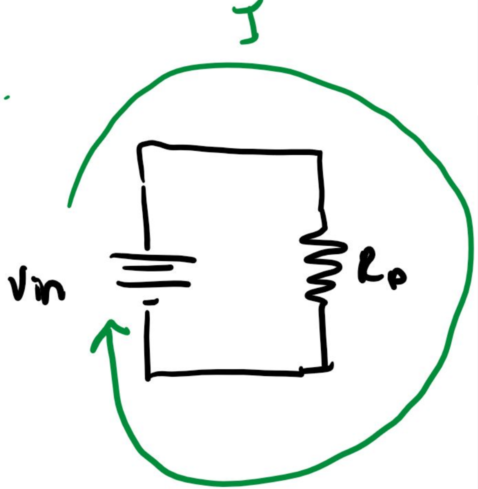


I = I1 + I2



$$I = I_1 + I_2$$

$$V_{in} = I_1 \cdot R_1$$



$$V_{in} = I \cdot R_p$$

$$V_{in} = (I_1 + I_2) R_p$$

$$V_{in} = \left(\frac{V_{in}}{R_1} + \frac{V_{in}}{R_2}\right) R_p$$

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

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

What’s the point?

Resistance of circuit connected in parallel will be smaller than resistance of each resistor

The smaller the resistance, the larger the current $\longrightarrow$ connecting too many components in parallel might draw too much current