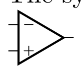
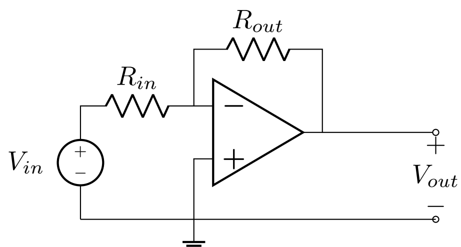
# Lecture 21, Mar 7, 2022

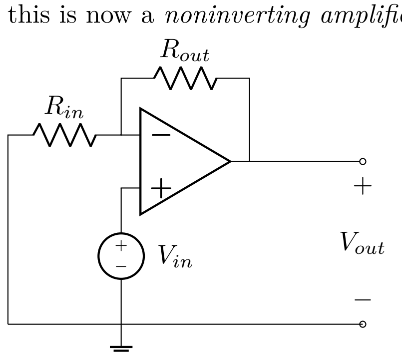
## Operational Amplifiers (Op-Amps)

- Op amps have 3 terminals that are relevant for this course: the positive (non-inverting) terminal, the negative (inverting) terminal, and then output terminal
  - Inverting input has voltage $v_1$ and current $i_2$, non-inverting input has voltage $v_2$ and current $i_2$; output has voltage $v_{out}$ and current $i_{out}$ (voltages measured wrt ground)
  - The symbol is

    
    
- If there is a path between the inverting input and output (either a short or any resistance), then the op amp as a *negative feedback connection*
  - Under a negative feedback connection, $v_1 = v_2$, i.e. it forces 2 voltages to be the same (under ideal conditions), and $i_1 = i_2 = 0$ (infinite input impedance)
- In this course we only discuss ideal op amps
- Example circuit:

  - The path from the output to the inverting input forces $v_2 = v_1$, therefore the current through $R_{in}$ is $\frac{V_{in}}{R_{in}}$
    * No current goes into the op amp so current through $R_f$ is also $I_{in}$
    * Since $v_2 = 0$ the current through $R_f$ is also $-\frac{V_{out}}{R_f}$
    * Equating these currents: $\frac{V_{in}}{R_{in}} = I_{in} = \frac{V_{out}}{R_f} \implies \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$
    * This circuit is called an *inverting amplifier* since it switches the polarity, and amplifies it by a gain of $-\frac{R_f}{R_{in}}$
- If the input voltage now goes into the noninverting input, the output voltage is no longer inverted, so this is now a *noninverting amplifier*:

- In general, to solve an op amp circuit when there is a connection from output to inverting input, first try to find either $v_1$ or $v_2$, and then use the relationship $v_1 = v_2$ to find the voltage at the other terminal, and then solve the rest of the circuit