Topics:

1) Op Amps as Amplifiers
   - Example
   - “Golden Rules” of their Use
   - Analyze example
   - More Examples

2) Op Amp as a Comparator

Op Amps:

- Op amps are semiconductor devices.
- Op amps are mostly optimized to have high-speed or low-noise features.
- Even though they are remarkably sophisticated circuits, they are really easy to work with.
- If you connect the power supply incorrectly, the op amp might blow up.

Comparator:

- Remarkably useful: Feed two voltages, and comparator compares them.
- The comparator is heart of digital electronics because of its ability to decide whether a voltage is higher or lower than a threshold value.
Question 1: What is the output going to be?

\[ \Delta V = IR = 1mA \times 10k\Omega = 10V \]
\[ \Rightarrow V_{OUT} = -10V \]

Question 2: If instead of 1V, the input is half a volt.
- You would get half the output.

Question 3: What about double?
- Tricky! The op amp saturates at -15V, so output cannot go beyond -15V.

Op amps are usually run off bipolar supplies (+/-15V).

Op Amps:
- 2 Inputs: \((V_+, V_-)\)
- Non-inverting Input
- Inverting Input
- 1 Output: \((-V < V_{OUT} < +V)\)
- 2 Voltage Supplies: \((+V, -V)\)

Golden Rules:
1) The Op-Amp Inputs draw no current.
2) With Negative Feedback, the inputs are at the same voltage (i.e., \(V_+ = V_-\))
Now, one can generalize the first circuit:

\[ I_{IN} = \frac{V_{IN} - V_-}{R_l} \]

Golden Rule #2 tells us Golden Rule #1 requires

\[ V_- = 0 \]
\[ \Rightarrow I_{IN} = \frac{V_{IN}}{R_l} \]
\[ I_F = I_{IN} \]
\[ \Rightarrow \left( V_{IN} - V_{OUT} \right) = I_F R_F \]
\[ \Rightarrow -V_{OUT} = \frac{V_{IN}}{R_l} R_F \]
\[ \Rightarrow V_{OUT} = -\frac{R_F}{R_l} V_{IN} \]

"Negative Feedback" means there is a current path from \( V_{OUT} \) to the "-" input.

More examples: \( V_{OUT} = f(V_{IN}) \)
\[
V_- = V_+ = V_{IN} \left( \frac{R_2}{R_1 + R_2} \right)
\]

\[
\frac{V_{OUT} - V_-}{R_4} = \frac{V_-}{R_3}
\]

\[
\frac{R_3}{R_4} V_{OUT} = V_- \left( 1 + \frac{R_3}{R_4} \right)
\]

\[
\frac{R_3}{R_4} V_{OUT} = V_{IN} \left( \frac{R_2}{R_1 + R_2} \right) \left( \frac{R_4 + R_3}{R_4} \right)
\]

\[
V_{OUT} = \frac{R_2}{R_3} \left( \frac{R_3 + R_4}{R_1 + R_2} \right) V_{IN}
\]
Assignment:
- Work out the following circuits before next Lab.
- For the following circuits, $V_{OUT} = f(V_A, V_B)$
- Find $V_{OUT}$.

Circuit A

Circuit B