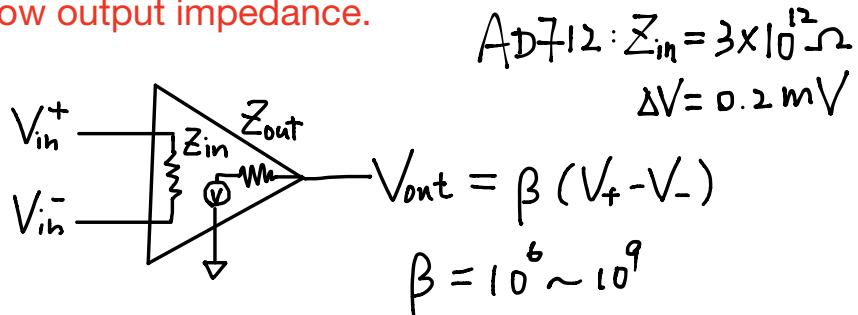


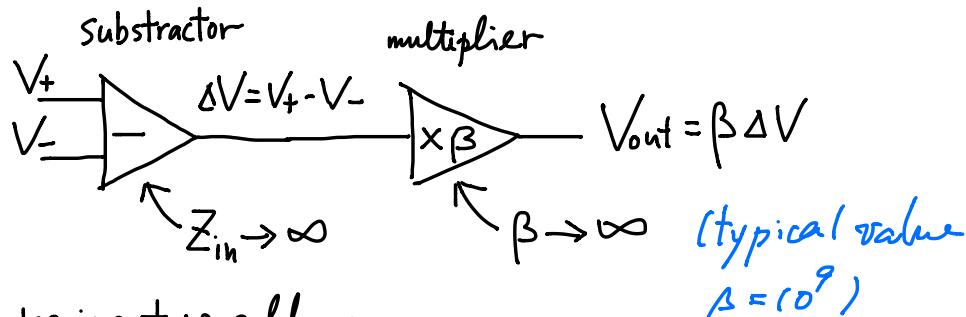
Golden rules are not really how operational amplifiers work!

Op-amp is fundamentally just a fast, high gain amplifier with high input impedance and low output impedance.



it's just a nice packaged transistor amplifier.

A better model for an ideal op-amp is



Golden rules is not so golden:

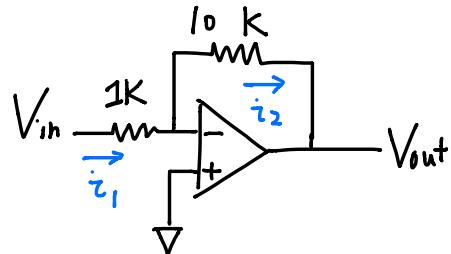
1. terminals V_+ & V_- still take a little bit current. $\mu\text{A} \sim \text{nA}$
called offset current

2. $V_+ \approx V_-$ is just the condition for op-amp to work properly

V_{out} reaches positive rail if $V_+ > V_-$ by more than few μV
reaches negative rail if $V_+ < V_-$ by \approx

3. $V_+ = V_-$ is only an approximation. Important.

Let us review inverted amplifier, shall me?



Golden rules

$$i_1 = \frac{V_{in}}{1k} = i_2 = -\frac{V_{out}}{10k}$$

$$\Rightarrow V_{out} = -\frac{10k}{1k} V_{in}$$

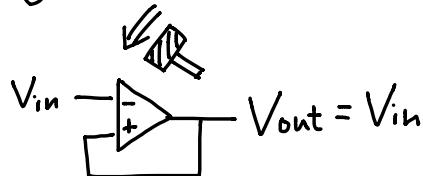
How it really works:

1. Assume $V_{in} = 1V$
2. When V_- connects to $V_- = 1V$, $i_1 = i_2 = 0$ @ this instance.
3. On its way to $-\infty$, V_{out} also pull down V_- by drawing current from V_- .
4. V_- is pulled down closer to $V_{in} - iR$, closer to zero
5. If $V_{in} - iR$ goes below zero V_{out} will start increasing to $+\infty$ and pull $V_{in} - iR$ up toward zero.
6. Eventually $V_{in} - iR$ stabilized to zero and thus V_{out} stabilized to $V_{out} = -iR = -\frac{V_{in}}{r}R$



Feedback stability analysis (basic level)

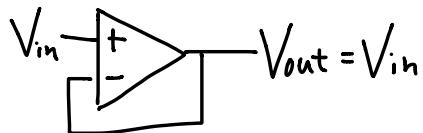
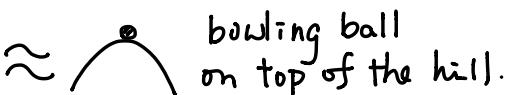
negative or positive feedback



This is called
Positive feedback

Assume a glitch of $\delta V_{out} = \epsilon > 0$
 $\Rightarrow \delta V_+ = \epsilon > 0, \delta V_{out} = \epsilon + \beta \epsilon + \dots$

It will spiral out of control : bad.



This is called
Negative feedback

Now if $\delta V_{out} = \epsilon \Rightarrow \delta V_- = \epsilon$
 $\delta V_{out} = \epsilon - \beta \epsilon \Rightarrow$ self-correcting

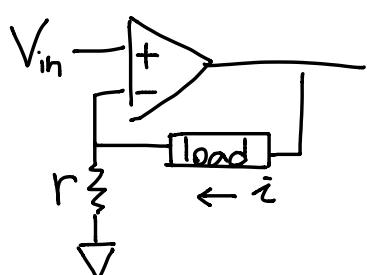
$$\delta V_{out} = \epsilon - \beta \epsilon + \beta(\beta-1)\epsilon - \dots$$



Note that this does not guarantee stability.

Exercise:

stable current source?



Golden rules :

$$V_{in} = V_+ = V_- = iR$$

$$\Rightarrow i = V_{in}/r$$

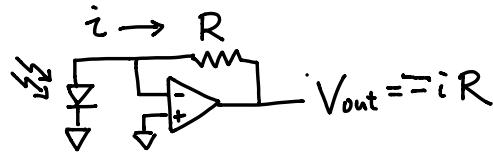
Stability analysis :

$$\text{if } \delta V_{out} = \epsilon > 0$$

$$\Rightarrow \delta V_{in} = \epsilon \frac{r}{r+load}$$

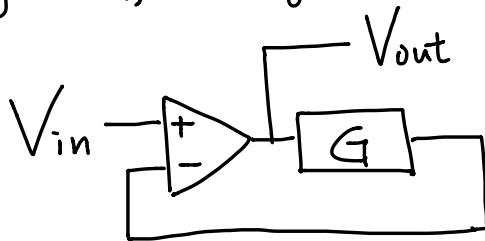
$$\Rightarrow \delta V_{out} = \epsilon - \beta \delta V_{in}$$

Current-voltage converter



$$\begin{aligned}\delta V_{out} &= \epsilon > 0 \\ \Rightarrow \delta V_- &= \epsilon \Rightarrow \text{Negative feedback.}\end{aligned}$$

Solving an differential eqn:



$$\text{Since } V_- = V_+ = \hat{G} V_{out} \Rightarrow$$

$$V_{out} = \hat{G}' V_{in}$$

$$V_{in} = G V_{out}$$

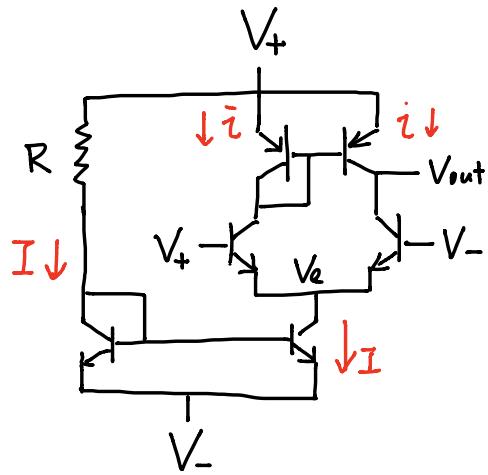
Say, if we insert the following \boxed{G}

A circuit diagram showing a differentiator circuit. A resistor R is connected between the non-inverting input and ground. A capacitor C is connected between the inverting input and ground. The output is taken from the inverting input. The transfer function G is given as $G = \frac{1}{r}[R + j\omega L] = \frac{R}{r} + \frac{L}{r} \frac{d}{dt}$. This results in the differential equation $\frac{L}{r} \frac{d}{dt} V_{out} + \frac{R}{r} V_{out} = V_{in}$, which is equivalent to $y'(t) + Ay(t) = X(t)$.

If you put in a delta function, you get

The Green's function as the output!!

How do you make an op-amp?



$$I = \frac{V_+ - V_- - 0.6}{R}$$

$$= 2\bar{i}$$

When $V_+ \uparrow \Rightarrow V_b \uparrow$
 $\Rightarrow V_{-b} \downarrow \Rightarrow V_{out} \rightarrow V_+ - 0.6$

When $V_- \uparrow \Rightarrow V_{-b} \uparrow$
 $\Rightarrow V_{out} \rightarrow V_- + 0.6$

$$\Rightarrow V_{out} = \beta(V_+ - V_-)$$

