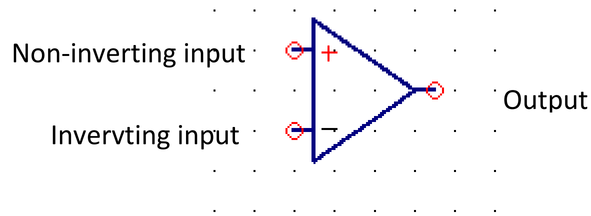
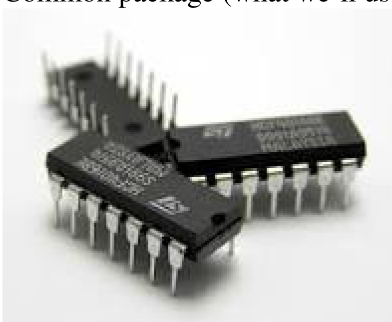
Op(erational) Amplifiers

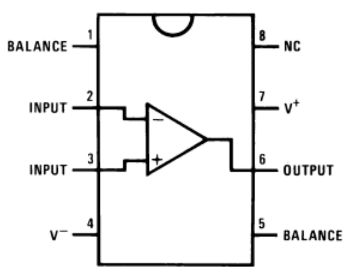
- Really high voltage gain
- High input impedance
- Use with feedback

General symbol (Fig at right):
Power connections not usually shown to reduce clutter.



Common package (what we'll use): DIP (Dual Inline Package)


(from Wikipedia).



Pin out: **Figure 3. PDIP – Top View** (from Texas Instruments data sheet for LF411 OpAmp.)
See also: http://www.ti.com/product/lf411

We will not work out how the guts of this work, but rather the handy rules for making good use of them. Part of the point of these is to make them close enough to an ideal that they can be considered a fundamental building block for many purposes.

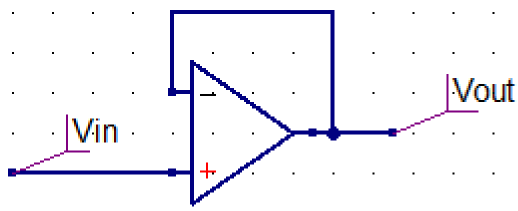
Basic behavior:
$V_{out} = A\ (v_+ - v_-)$
"A" is called the "open loop gain"

All voltages are w.r.t. ground, as usual.

If A is big, say ~ 10^4 - 10^5 , interesting things happen. Direct use is insane ($A = 10^5 \rightarrow 1$ m V input $\rightarrow$ 100V output! Not what we usually want. Also, we don't usually deal with 100V DC supplies. So why have A so big?

Feed back!
Feedback means we take some of the output signal (V_{out}) and feed it back to the input to achieve particular behavior.

Consider this example:



Looks stupid, but turns out to be remarkably clever.
How to analyze?
$V_{out}=A(v_+-v_-)$
Here this means:
$V_{out}=A(v_{in}-v_-)$
But… we made it so that v_- is the same as V_{out}! This gives us:
$V_{out}=A(v_{in}-V_{out})$
solve for V_{out} to get
$V_{out} = \frac{A}{A+1} v_{in}$

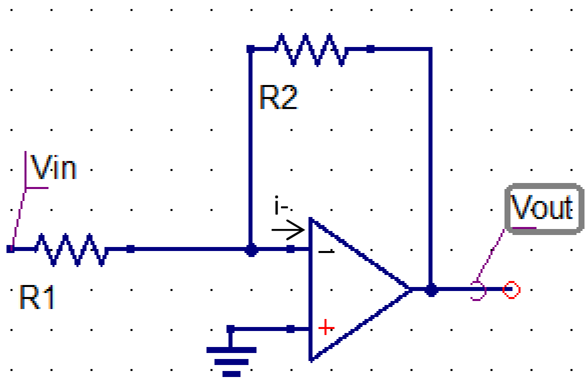
And if A is really large compared to one, the A/(A+1) term goes to 1. So $V_{out}= v_{in}$, which is a follower!

Another thing to note is that the gain of the circuit is independent of the open-loop gain of the device (A), as long as A is large compared to one. This is much like what we took advantage of with transistors: we generally wanted circuit behavior that only required β to be large, not that it had a particular value. Same thing with op-amps and A.

Note also that for the circuit above, one result is that the circuit ends up making $v_-=v_+$.

This was an example using negative feedback (part of output signal fed back to *inverting* input). Generally, negative feedback improves stability (at the expense of gain: note here the voltage gain of the closed-loop circuit we've built is 1—much less than the open loop gain of 10000 or more). There are positive feedback circuits as well, but these lead to oscillations, not stability. We may get to oscillators, but for now, we'll be dealing with negative feedback.

Here's another circuit:



If $i_- << i_1$, then $i_1=i_2\equiv i$.
Then
$V_{in}-v_-=iR_1$
and also $v_--V_{out}= iR_2$. (1)
Which gives $i = (v_- - V_{out})/R_2$ (2)

Since $V_{out}=A(v_+-v_-)$ and v_+ is ground, $V_{out}= -v_-$ or $v_-=-V_{out}/A$ (3)
Use (2) in (1) to get
$V_{in}-v_- = (v_- - V_{out})*(R_1/R_2)$

And now use the last result of (3) to replace v- in this:
$V_{in}-(-V_{out}/A) = (-V_{out}/A – V_{out})R_1/R_2$
Multiply out and then let $A >> R_1/R_2$

And we are left with $V_{out}/V_{in}= -R_2/R_1$
An inverting amplifier with a voltage gain of $–R_2/R_1$! Independent of A!

You can analyze every op-amp circuit this way (keep all the terms and let A→ infinity at the end), but there are some simple equivalent rules for op-amp usage:

"Golden Rules" for op-amps:

Treat op-amp as ideal which means

- A=infinity
- Z_{in}=infinity
- $Z_{out}=0$
- And when used with negative feedback, the ideal op-amp does "whatever it can do" to make $v_-=v_+$!

Revisiting the inverting amp this way, $i_- = 0$ (because Z_{in}=infinity). And $i_1=i_2 = i$. If op-amp keeps $v_-=v_+$, then v_- is ground (since it is at ground due to op-amp action, we call this "virtual ground") . Then $V_{in}=iR_1$ and $V_{out}=-iR_2$ (signs matter: if $v_- = 0V$, then if i_1 is to right, so must i_2 which means V_{out} must be below 0V).
Then $V_{out}/V_{in}=-R_2/R_1$ as arrived at above, but with much less algebra.