The Prescient Engineer	The Flailing Engineer
get it right	get right to it
cheaper	not cheap
safe	not safe
for grown-ups	for children
complex, and/or expensive systems	simple, literally trivial systems

(wizzards)

Modeling is a critical step

Learning to model has served me well

An understanding of a model always enhances our ability to control the device.

A Simple Strategy for Finding Models

(1) Force, Charge, Current etc. Balance Relationships (Find 'Em) (This is why you didn't sell your physics book!)

Electrical

(1) Sum of voltages around a circuit loop (ends where it starts) must be zero. KVL

(2) Sum of currents entering (leaving) a circuit node must be zero. KCL

Mechanical

(1) Translational Systems

$F = ma$

force, mass, acceleration

(2) Rotational Systems

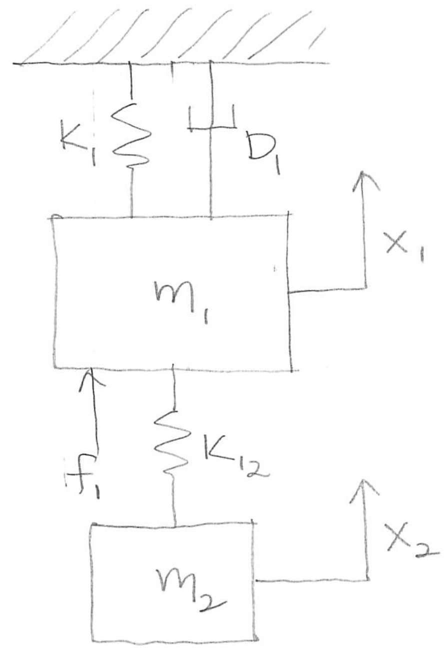
$T = J\ddot{\theta}$

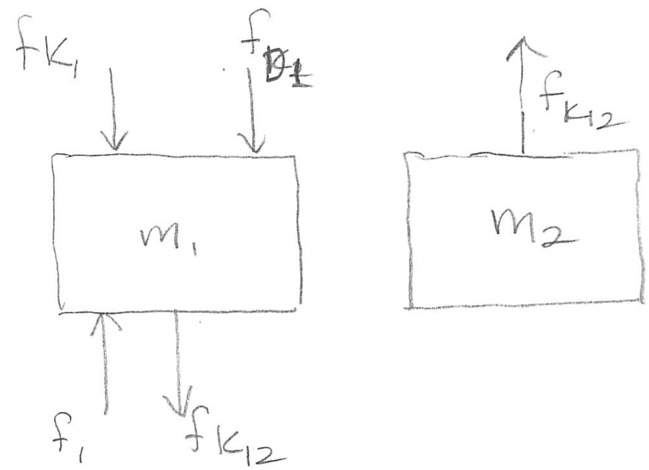
torque, moment of inertia, angular acceleration

(2) Write Down What You Know

(Put a placeholder for things you don't know)

Example 1





Free Body Diagram

Assume that the system is hanging at a gravitational equilibrium
($x_1 = x_2 = 0$)

m_1 Equation (F=ma)

$$m_1 a_1 = m_1 \ddot{x}_1 = f_1 - f_{K_1} - f_{D_1} - f_{K_{12}}$$ (why negatives?)

(3) Figure Out What You Don't Know

$$f_{K_1} = K_1 x_1$$

$$f_{D_1} = D_1 \dot{x}_1$$

$$f_{K_{12}} = K_{12}(x_1 - x_2)$$

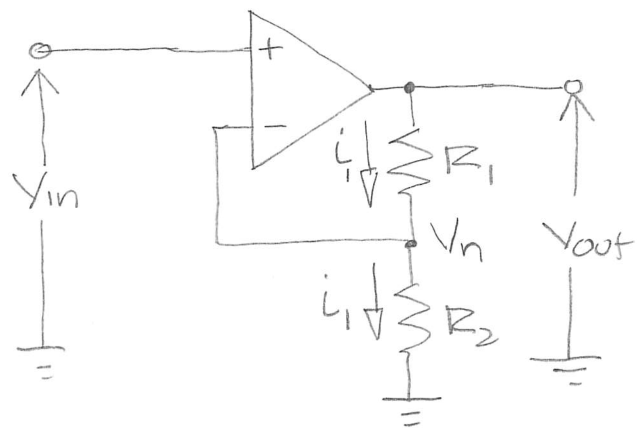
m_2 Equation

$$m_2 \ddot{x}_2 = 0 + f_{K_{\cancel{12}}}$$

$$f_{K_{21}} = K_{12}(x_2 - x_1)$$

Example 2

Find the ratio $\frac{V_{out}}{V_{in}}$



node voltage is V_n

$V_n = ?$ (V_{in} from (a))

$$i_1 = \frac{V_{OUT} - V_n}{R_1} = \frac{V_{OUT} - V_{in}}{R_1}$$

$$= \frac{V_{in}}{R_2}$$ can be manipulated into the form $\frac{V_{out}}{V_{in}} = 1 + \frac{R_1}{R_2}$

(1) Applicable balance law

KCL node currents
Ohm's Law

(2) What we 'know'

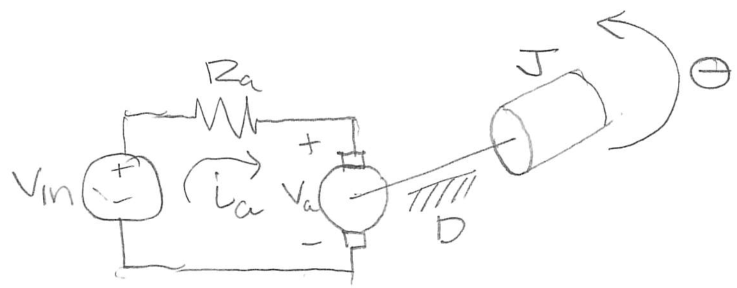
(a) an op-amp in a negative feedback arrangement will "do what it has to do" in order to keep the voltages at the + − terminals the same.

(b) no current flows into the + − terminals

Example 3

Permanent Magnet DC-Motor (Equal Opportunity)

Schematically the motor is represented as



Two systems in one a circuit and a mechanical rotational system

(i) What balance equations do we know? (ahhh....)

KVL voltages around a loop sum to zero

$J\ddot{\Theta} = T$

(2) writing what we know

KVL

$-V_{in} + i_a R_a + V_a = 0$ (whew!)

Rotational

$J\ddot{\theta} = T = T_a - D\dot{\theta}$

(3) What don't we know yet?

$V_a = ?$

$T_a = ?$

what has to happen here? (these terms hook the electrical and mechanical systems together)
(called coupling terms)

$V_a = f(\theta, \dot{\theta})$ $T_a = g(v, i)$

We are hoping the system is linear (hey, we're engineers after all)

If it were true, or nearly so, then

$V_a = K_0 \Theta$ or $K_0 \dot{\Theta}$

$T_a = K_1 V$ or $K_1 i$

both are related to kinetic rather than potential energy terms so...

potential kinetic

$V_a = K_0 \dot{\Theta}$ (called the back EMF (electro-motive force))

$T_a = K_1 i$ (motor torque)

Units

$[K_0 \dot{\Theta}] =$ volts $\dot{\Theta}$ has units of ? rad/sec

$[K_0] = \frac{\text{volt-sec}}{\text{rad}}$ or just a volt-second

$[K_1 i] =$ newton-m i has units of amps

flow of charge

amp = columb/sec

$[K_1] = \frac{\text{newton-m-sec}}{\text{coulomb}} =$ volt-second