

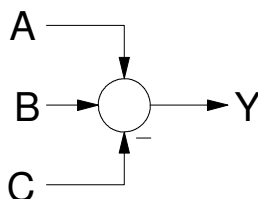
## Block Diagrams and Simulink / VisSim

### Block Diagrams

Block Diagrams are a graphical way to describe how dynamic systems are interconnected. They help explain how a control system will be built and how the signals flow through a system.

The symbols for a block diagram are as follows:

**Summing Junction:** A circle indicates a summing junction. A minus sign by an arrow signifies that the signal is subtracted.



Summing Junction:  $Y = A + B - C$

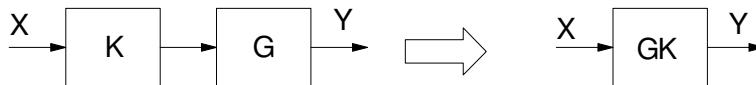
**Gain:** A rectangle indicates a gain.



Gain:  $Y = G X$

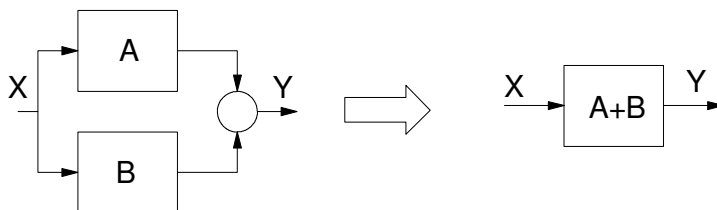
Part of the 'fun' of block diagrams is trying to simplify them to find the overall gain from the input to the output. Some rules are as follows:

**Cascade Blocks:** Cascaded blocks multiply.

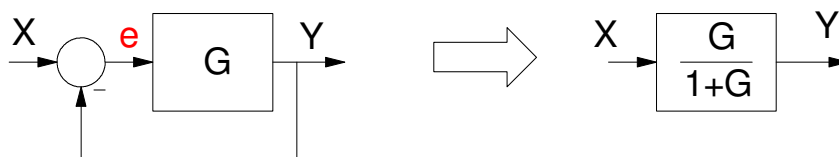


Cascade Blocks:  $Y = (GK) X$

Parallel Blocks: Blocks in parallel add:



Feedback: Blocks with unity feedback simplify as  $\left(\frac{G}{1+G}\right)$



To see this, add a dummy variable at the output of the summing junction (e). You have two unknowns (Y and e), so you need two equations to solve for two unknowns:

$$Y = G e$$

$$e = X - Y$$

Simplify and you get

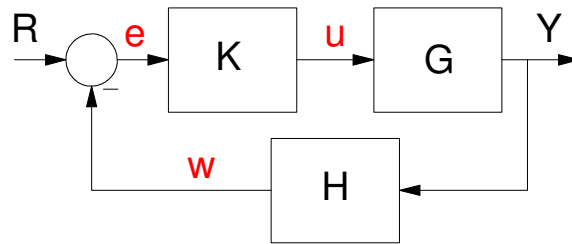
$$Y = \left(\frac{G}{1+G}\right) X$$

General Case: More complex block diagrams can be simplified two different ways:

- Assign dummy variables to each node. Write N equations and solve for N unknowns. (This can take a while but always works).
- Write the transfer function by inspection as:

$$\left( \frac{\text{Gain from input to output}}{1 + \sum \text{loop gains}} \right)$$

For example, a more general feedback system is as follows:



You have four unknowns ( $Y$ ,  $u$ ,  $e$ ,  $w$ ), so you need to write four equations for four unknowns:

$$Y = G u$$

$$u = K e$$

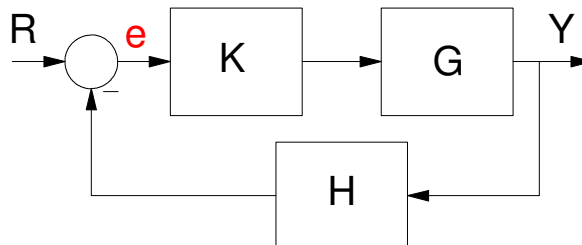
$$e = R - w$$

$$w = H Y$$

Solve and after about 20 minutes of algebra, you eventually get

$$Y = \left( \frac{GK}{1+GKH} \right) R$$

Note that you can use fewer equations if you use fewer unknowns. The approach I prefer is to only label the summing junction outputs:



Now you only have two unknowns, so you only need to write (and solve) two equations:

$$Y = G \cdot K \cdot e$$

$$e = R - H \cdot Y$$

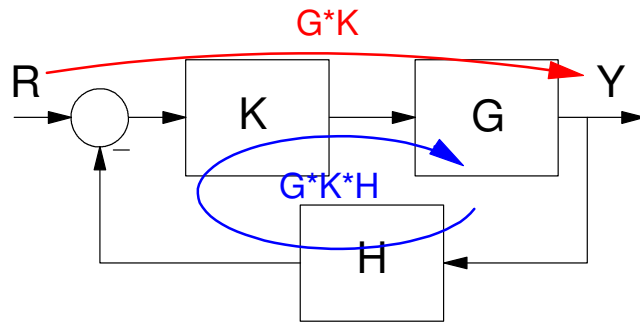
which again simplifies to

$$Y = \left( \frac{GK}{1+GKH} \right) R$$

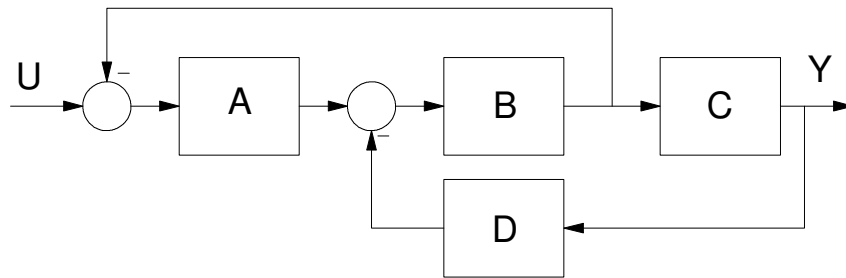
A simpler method is to note that the above transfer function is

$$\left( \frac{GK}{1+GKH} \right) = \left( \frac{\text{Gain from input to output}}{1 + \sum \text{loop gains}} \right)$$

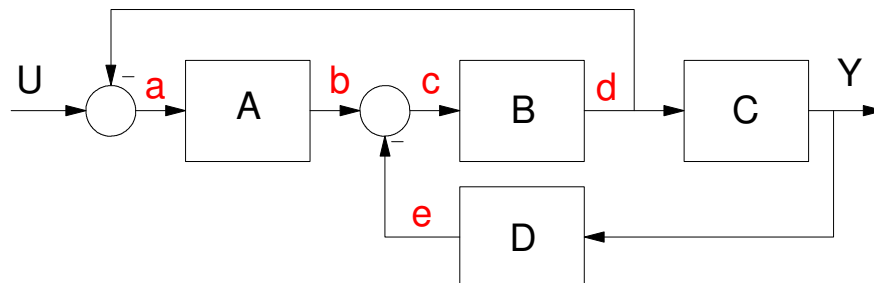
You can then write the transfer function by inspection:



As a second example, consider a more complex system: Find the transfer function from U to Y.



Method 1: Label everything. This gives six nodes, requiring six equations to solve for six unknowns



$$a = U - d$$

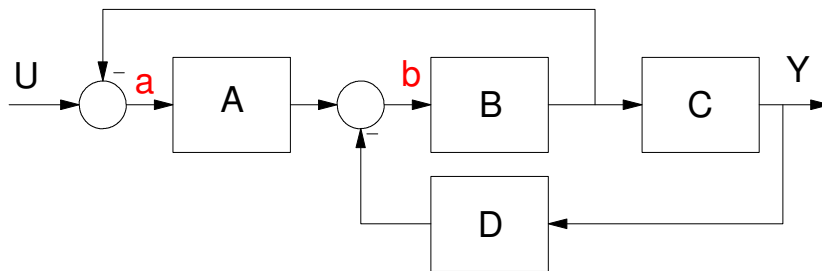
$$b = A a$$

$$\begin{aligned}c &= b - e \\d &= B c \\Y &= C d \\e &= D y\end{aligned}$$

Solve and in about 20 minutes you'll get the answer.

$$Y = \left( \frac{ABC}{1+AB+BCD} \right) U$$

Method 2: Just label the output of the summing junction. This gives three equations so solve for three unknowns:



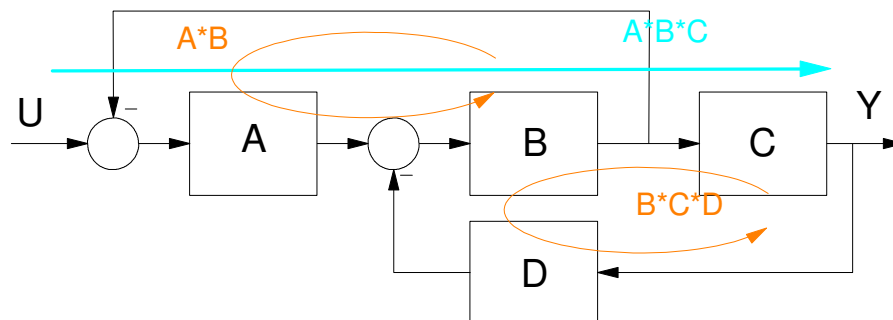
$$\begin{aligned}a &= U - Bb \\b &= Aa - DY \\Y &= CB b\end{aligned}$$

Solve using algebra and in about 5 minutes you'll get

$$Y = \left( \frac{ABC}{1+AB+BCD} \right) U$$

Method 3: Use the shortcut

$$G(s) = \left( \frac{\text{Gain from input to output}}{1 + \sum \text{loop gains}} \right)$$



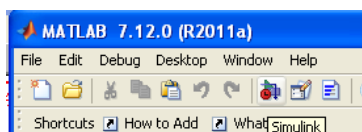
By inspection

$$Y = \left( \frac{ABC}{1+AB+BCD} \right) U$$

## VisSim / Simulink

VisSim and Simulink are graphical tools that allows you to draw block diagrams and see what the step response will be. They're good tools to use in this class to check your answer: if the resulting step response meets your design criteria, you designed your compensator correctly.

- Simulink is the graphical user interface from Mathworks. It should be available on any computer with Matlab on campus (NDSU has a site license for both Matlab and Simulink). The icon will vary depending upon which version of Matlab you're running



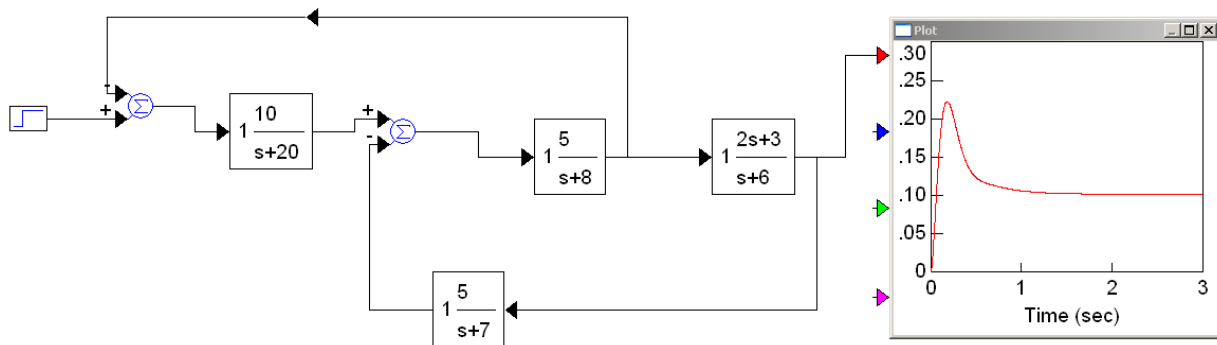
Icon for running Simulink in Matlab 7.12.0

- VisSim<sup>1</sup> is a similar program which I personally prefer and has been available since 1991. (search VisSim32.exe to find).

Both programs make testing your designs much easier than running Matlab scripts.

For example, suppose you want to see what the step response of the previous system is for a given transfer function for A, B, C, and D. You could solve by hand. You could also input the system in VisSim - which is a lot easier. The resulting picture would look like the following:

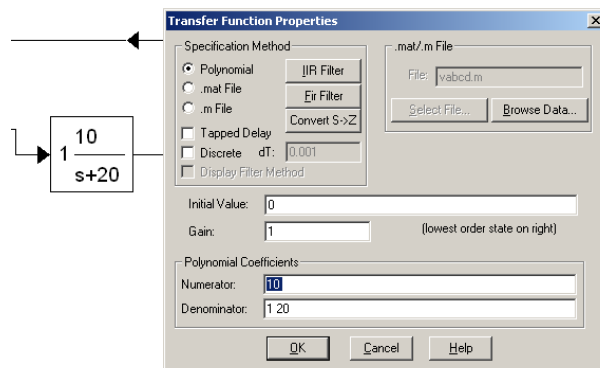
<sup>1</sup> <https://en.wikipedia.org/wiki/VisSim>



Each block comes from a pull down menu. If you scroll through them, you'll find what you need. For this diagram, the blocks are:

- Step Input: Block / Signal Producer / Step
- Summing Junction: Block / Arithmetic / Summing Junction  
note: Control / right click to change the sign on the +/- inputs
- Transfer Function: Block / Linear System / Transfer Function.

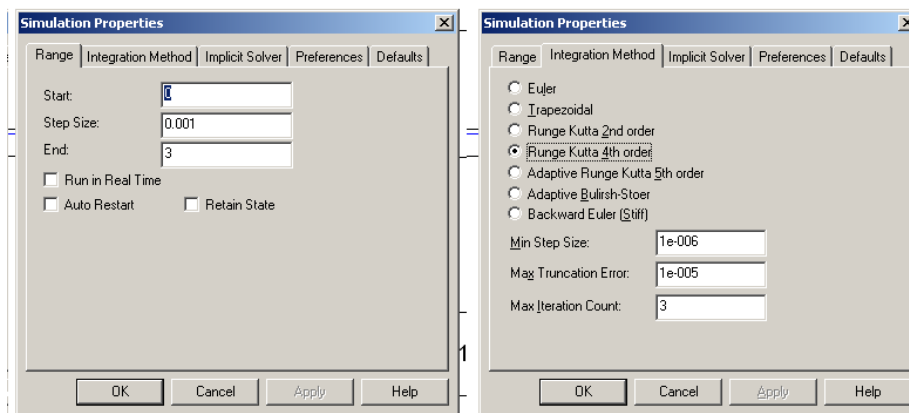
note: Double click on the transfer function block. The transfer function is input in decreasing powers of 's'. (s+20) is input as (1 20):



- Plot: Block / Signal Consumer / Plot
- Flipping a block: Select the block, go to Edit / Flip Horizontal

Once you have the blocks, drag and click to connect the outputs to the inputs.

To change the simulating time, click on Simulate / Simulation Properties



This lets you vary the integration step size and duration of the simulation. Integration method lets you vary what form of numerical integration you're using.

In addition, you can add

- Noise,
- Nonlinearities,
- Sampling effects, and
- Mixed (continuous and discrete) systems.

Each of these make the model more accurate as well as harder to analyze.

### Validating your Homework Solutions:

As a suggestion (or request), please use Simulating and/or VisSim to verify your design works. For example, if the homework assignment was to specify block A so that you had a 3 second settling time and you conclude that  $A = \left(\frac{10}{s+20}\right)$ , run a VisSim simulation as shown above to verify that the design is correct. This is doubly so when we get to discrete-time systems and you want to know how the mixed system

$$K(z)G(s) = \left(\frac{0.5(z-0.9)}{(z-1)(z-0.5)}\right) \left(\frac{20}{(s+1)(s+5)}\right)$$

behaves.

In this class, each problem has many solutions. The real test to see if your solution is 'correct' is if it meets the design specifications. Simulink or VisSim simulations are a good way to check this. (It also makes grading a lot easier.)