

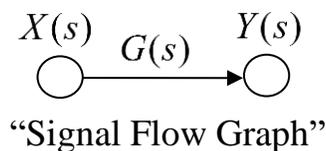
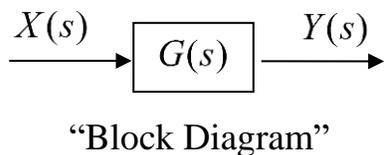
## ME 3600 Control Systems

### Block Diagrams and Transfer Functions

- The concepts of block diagrams and transfer functions can be used to develop **graphical representations** of how systems function. For example, suppose a system with transfer function  $G(s)$  has input  $X(s)$  and output  $Y(s)$ , then

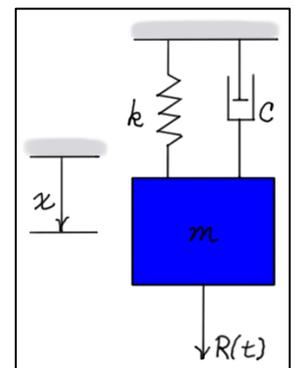
$$\boxed{\frac{Y(s)}{X(s)} = G(s)} \quad \text{or} \quad \boxed{Y(s) = G(s)X(s)}$$

- This algebraic equation may be **represented graphically** as either a block diagram or a signal flow graph. In a block diagram representation, the signals are represented as “arrows” (a line segment with direction of signal flow indicated) and the process (or system) is represented by a “box” showing the transfer function. In a signal flow graph representation, the signals are represented by “nodes” and the process is indicated by an “arrow” with the transfer function indicated.



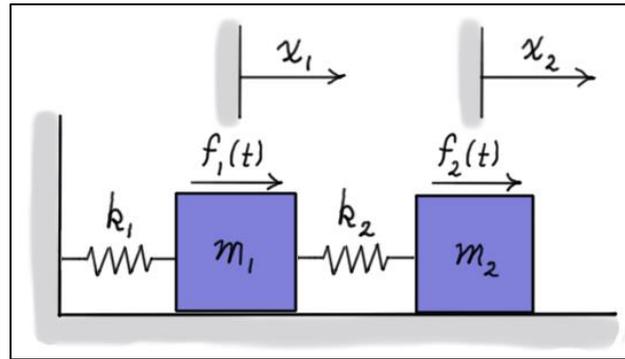
- Block diagrams and signal flow graphs can be used to represent much more complicated systems. The notes that follow focus on the use of block diagrams.
- Example: Mass-Spring-Damper

The differential equation of motion of the spring-mass-damper system has been found in previous notes to be  $m\ddot{x} + b\dot{x} + kx = f(t)$ . Applying Laplace transforms and solving for the ratio of output over input gives the transfer function  $G(s)$ . This, in turn, can be put into a simple block diagram as follows.

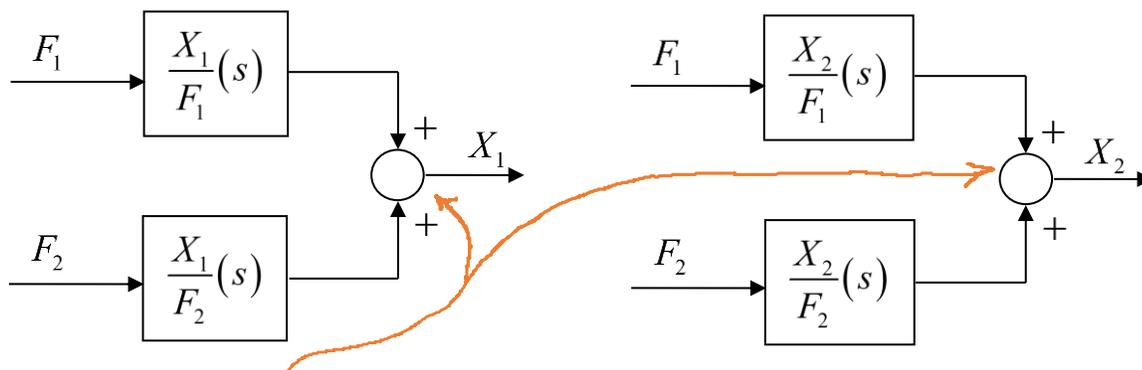


$$\frac{X(s)}{R(s)} = \frac{1}{ms^2 + cs + k} = G(s) \quad \rightarrow \quad \boxed{\frac{1}{ms^2 + cs + k}} \quad \rightarrow \quad X(s)$$

- More complex systems may have **multiple inputs and multiple outputs**. For example, consider the two degree-of-freedom, mass-spring-damper system shown below.



- This system has two **input forces**  $f_1(t)$  and  $f_2(t)$ , and it has two **output displacements**  $x_1(t)$  and  $x_2(t)$ . This system can be **represented graphically** as follows.



The **summation blocks** are used to **add** the **responses** of the masses to **each** of the forces. Recall that the transfer functions associated with force  $f_1(t)$  assume that  $f_2(t)$  is zero and the transfer functions associated with force  $f_2(t)$  assume that  $f_1(t)$  is zero. Hence, each of the four transfer functions provide only **part** of the total response. The total response is the **sum** of the **responses** due to each of the input forces.

- The block diagrams above represent the algebraic equations

$$\boxed{X_1(s) = \left(\frac{X_1}{F_1}\right) F_1 + \left(\frac{X_1}{F_2}\right) F_2} \quad \text{and} \quad \boxed{X_2(s) = \left(\frac{X_2}{F_1}\right) F_1 + \left(\frac{X_2}{F_2}\right) F_2}$$

- In general, the block diagram representation of a system will contain a number of simple blocks connected in a **network**. Complex networks can be reduced to simpler networks using **block diagram reduction transformations** discussed in the notes that follow.