Module 04
Block Diagrams and Graphical Representations of Intertwined Dynamic Systems

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EE 3413: Analysis and Desgin of Control Systems

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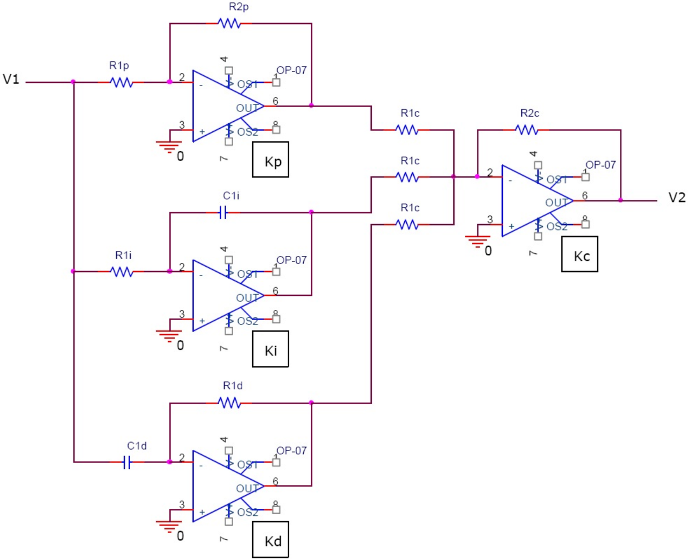
Module 4 Outline

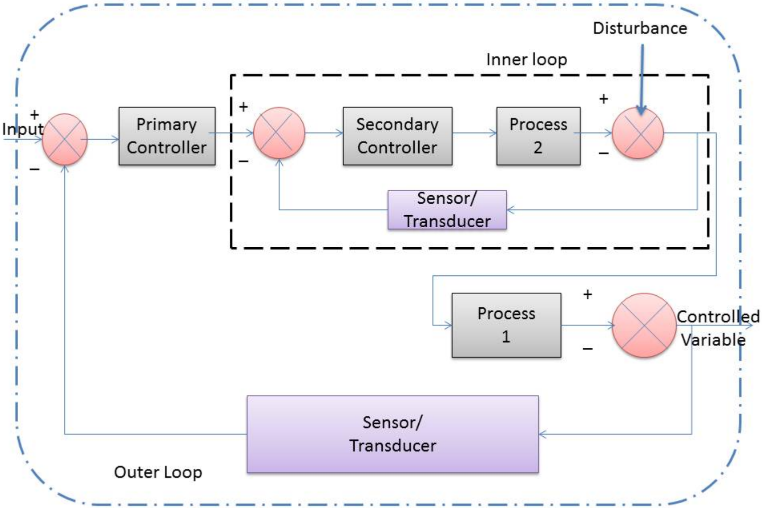
1. Introduction to block diagrams
2. Physical meaning and importance
3. Block diagram reduction
4. Examples

– Reading material: Dorf & Bishop, Section 2.6

Examples of Block Diagrams — Op Amps (Eww)



Examples of Block Diagrams — Temperature Control



Importance of Block Diagrams

- Graphical representation of interconnected systems are important
- A system may consist of multiple subsystems: the output of one may be the input to another, and so on
- Each subsystem is represented by a functional block, labeled with the corresponding transfer function
- Blocks are connected by arrows to indicate signal flow directions
- **Advantages:**

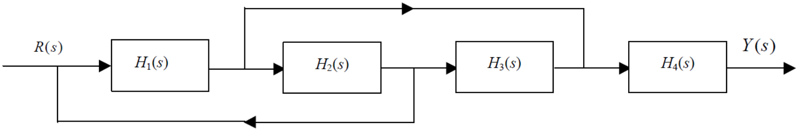
– Easy for visualization purpose

– Can represent a class of similar systems

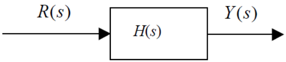
– Most importantly: **can infer overall relationship between inputs and outputs**, and hence analyze the system stability and performance

Objective of Block Diagram Representation

- **Main objective: reduce intertwined blocks of subsystems into one unified block or 1 TF**
- **Implications:** given an overall TF for a system of subsystems, we can compactly analyze the dynamics of the system via one equation that depicts the dynamics.
- Example:

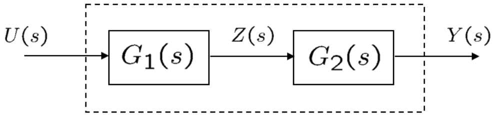


into

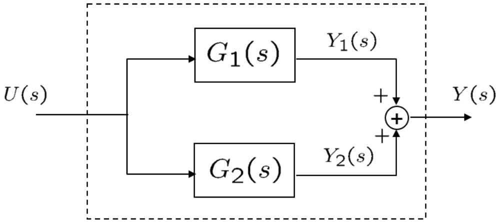


Cascaded/Parallel Connected Systems

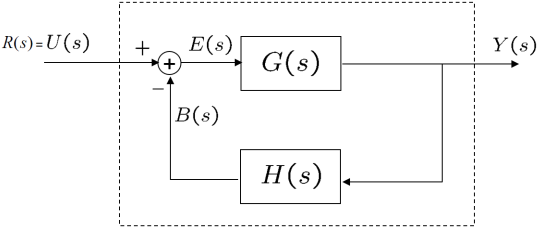
Cascaded systems:



Parallel connected systems:



Important Definitions — 1



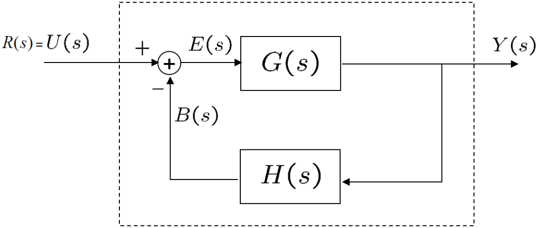
- In this class, we will be studying how to design the above system
- The above block representation is so common for so many systems
- **Control (reference) input**: $U(s)$ ($R(s)$); **Output**: $Y(s)$
- **Plant dynamics:** $G(s)$—this is often given, defines physical systems
- **Control objective**: design $H(s)$ (gain) so that the system is stable
- $H(s)$, $G(s)$ are all internal transfer functions, mapping their inputs to defined outputs

(Negative) Feedback System[1] — 1

- Negative feedback occurs when some function of the output is fed back to reduce the output fluctuations
- Fluctuations often caused by changes in the input or disturbances
- *Well, why not +ve feedback? Who likes −ve feedback anyway?*
- Hmm, in control systems the theme is different
- If someone's applying -ve feedback, then they're most likely helping you
- +ve feedback tends to lead to instability via exponential growth
- −ve feedback promotes stability and error minimization
- −ve feedback applications: electrical & mechanical systems, economics, nature, chemistry

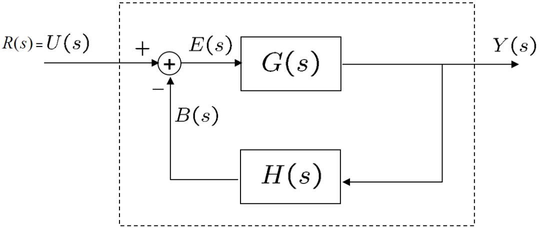
[1] From Wikipedia...Oh and don't ever let anyone lecture you when you get your *very basic* research from Wikipedia.

(Negative) Feedback System — 2



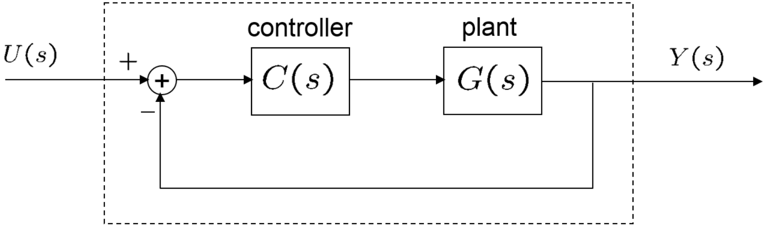
- **Tracking error:** $\boxed{E(s) = R(s) - B(s)}$
- **Feedforward transfer function (FTF)**: $\boxed{\dfrac{Y(s)}{E(s)} = G(s)}$
- **Open-loop transfer function (OLTF)**: $\boxed{\dfrac{B(s)}{E(s)} = G(s)H(s)}$
- **Closed-loop transfer function (CLTF)**: $\boxed{\dfrac{Y(s)}{R(s)} = ??}$

Examples



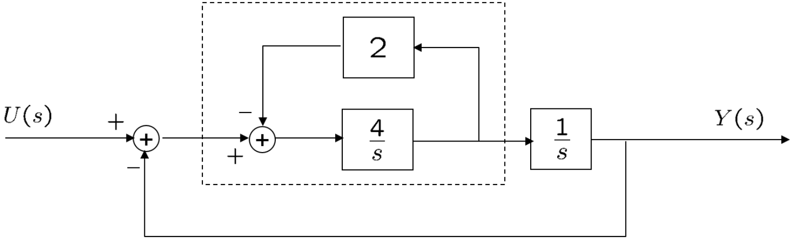
- Example 1: *What if we have positive feedback?*
- **Solution:**
- Example 2: *What if* $H(s) = 1$? Unity feedback?
- **Solution:**

Feedback Control Systems



- Example 3: *What is the CLTF for the above system?*
- By adjusting the controller $C(s)$, one can change the CLTF to achieve desired properties
- This control architecture is different than the one previously discussed
- However, both can provide desired system performance

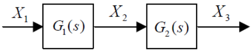
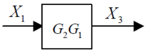
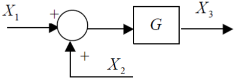
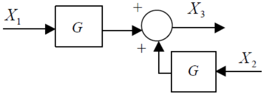
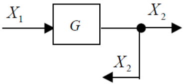
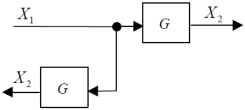
Block Diagram Simplifcation — Example



- **Objective:** find the CLTF, $\dfrac{Y(s)}{U(s)}$
- **Solution:**
- The above example is simple, but sometimes things can be messy
- Hence, we need block diagram transformations

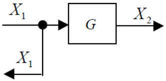
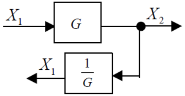
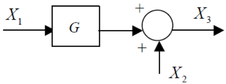
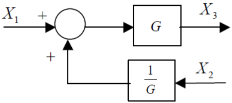
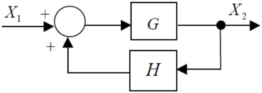
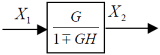
Important Block Diagram Transformations — 1

Block Diagram Transformations [Taken from Dorf & Bishop Textbook]

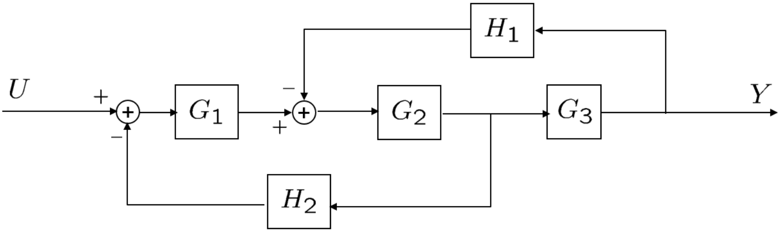
Transformation	Original Diagram	Equivalent Diagram
1. Combining blocks in cascade		 or 
2. Moving a summing point behind a block		
3. Moving a pickoff point ahead of a block		

Important Block Diagram Transformations — 2

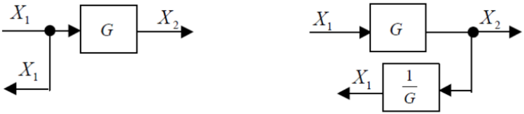
Block Diagram Transformations [Taken from Dorf & Bishop Textbook]

Transformation	Original Diagram	Equivalent Diagram
4. Moving a pickoff point behind a block		
5. Moving a summing point ahead of a block		
6. Eliminating a feedback loop		

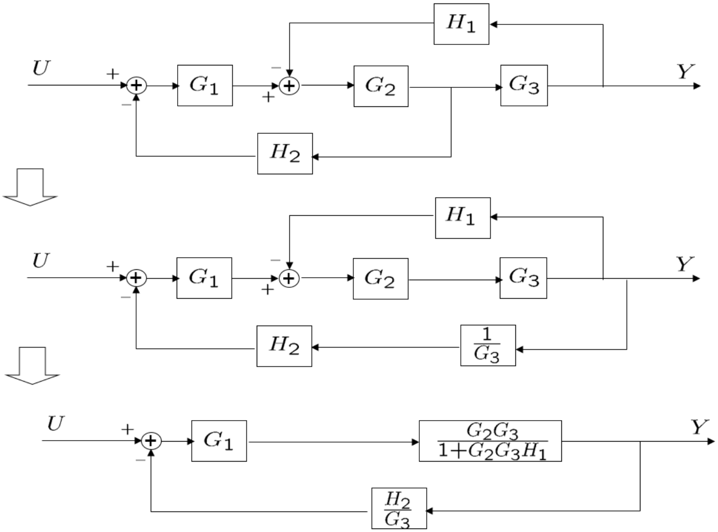
Block Diagram Simplification



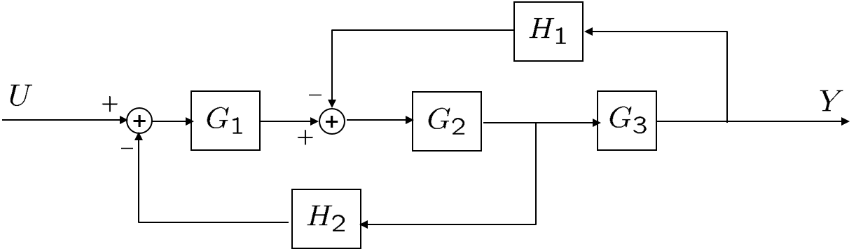
- Find the CLTF utilizing the previous transformations
- Hint: use property 4 (see previous slide)
- Property 4: sliding a branch point past a function block



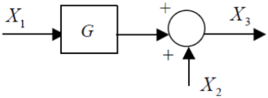
Solution to the Previous Example

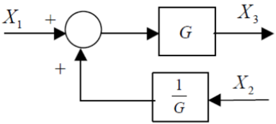


Another Approach

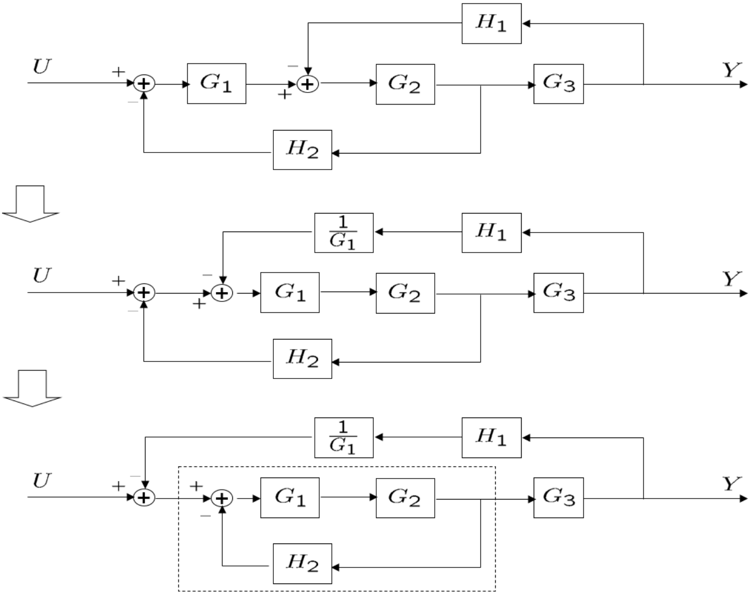


- Can we use another property?
- Yes, we can use Property 5 (moving a summing point ahead of a block)

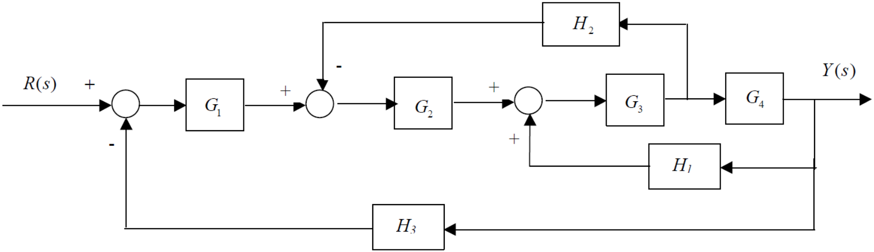




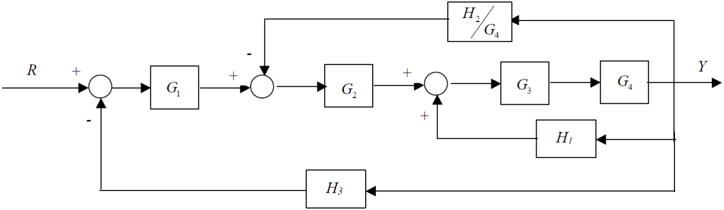
Solution via Property 5



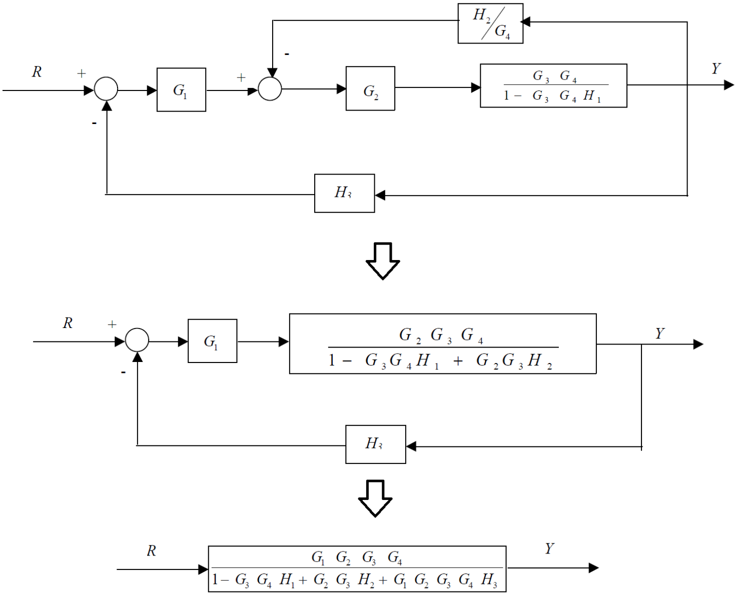
Another Example



- **Solution:** First, let's move H_2 behind block G_4 so that we can isolate the $G_3 - G_4 - H_1$ feedback loop
- Again, we use Property 4 to get:



Solution to the Previous Example



Mason's Formula

- The previous approach can be a bit tricky in some scenarios
- It's a great approach if you can see things easily
- If you can't or don't want to, there's a more algorithmic approach
- Mason's Formula:
  - A systematic way to compute TFs from any input to any output
  - Based on an algorithmic method and signal flow graphs
  - Not discussed in class, but you can read more about (Mason's Gain Rule handout on Blackboard)

Roadmap Revisited

Modeling (5-6 Weeks)	*Analysis* (7-8 Weeks)	*Design* (5-6 Weeks)

Modeling (5-6 Weeks)

- ~~**Laplace Transforms**~~
- ~~**Transfer Functions**~~
- ~~**Solution of ODEs**~~
- ~~**Modeling of Systems**~~
- ~~**Block Diagrams**~~
- ~~**Linearization**~~

Analysis (7-8 Weeks)

- 1st & 2nd Order Systems
  - Time Response
  - Transient & Steady State
- Frequency Response
- Bode Plots
- RH Criterion
- Stability Analysis

Design (5-6 Weeks)

- Root-Locus
- Modern Control
- State-Space
- MIMO System Properties

Questions And Suggestions?

Thank You!

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IFF you want to know more ☺