MATLAB AND ITS CONTROL TOOLBOX

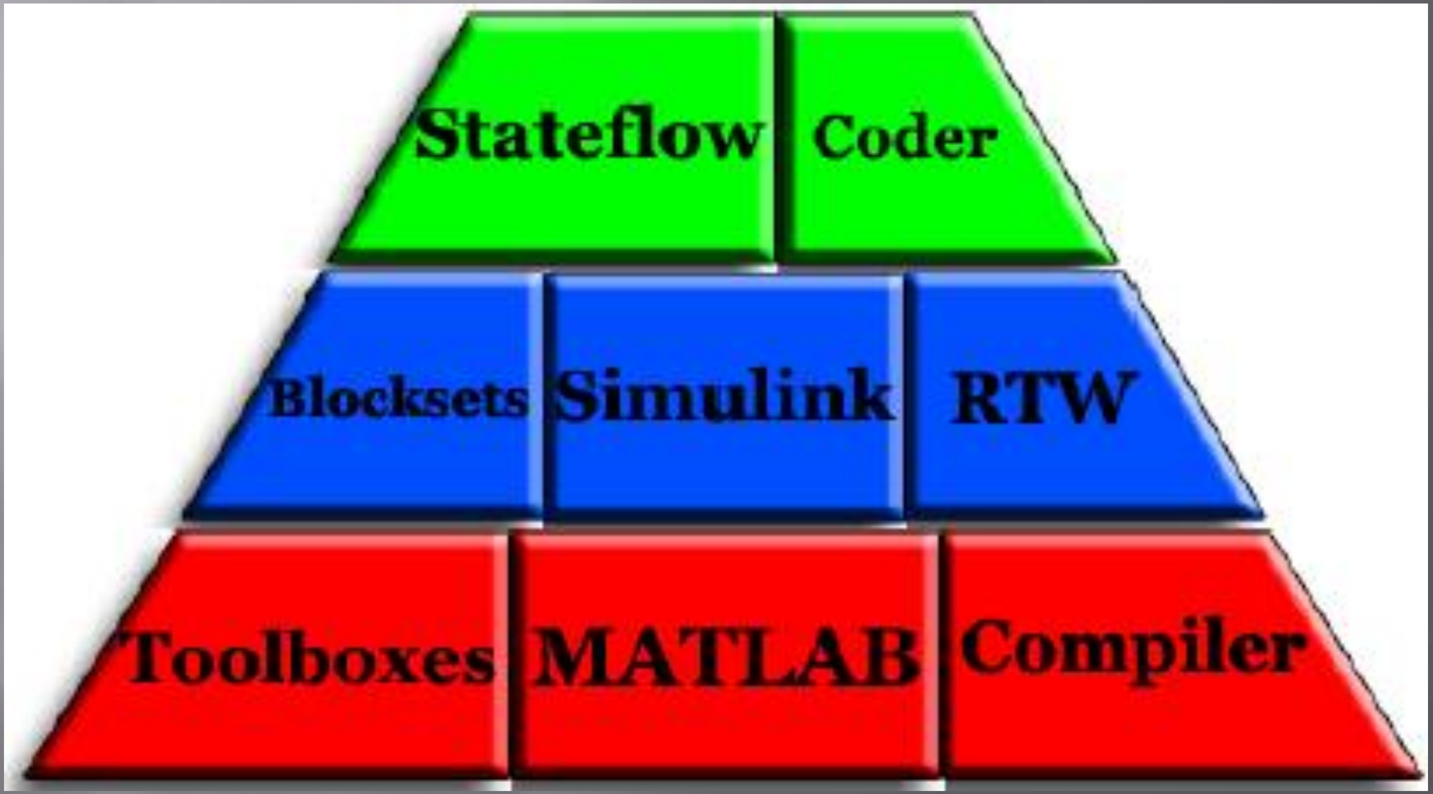
Outline

- MATLAB
- MATLAB and Toolboxes
- MATLAB and Control
- Control System Toolbox
- Simulink

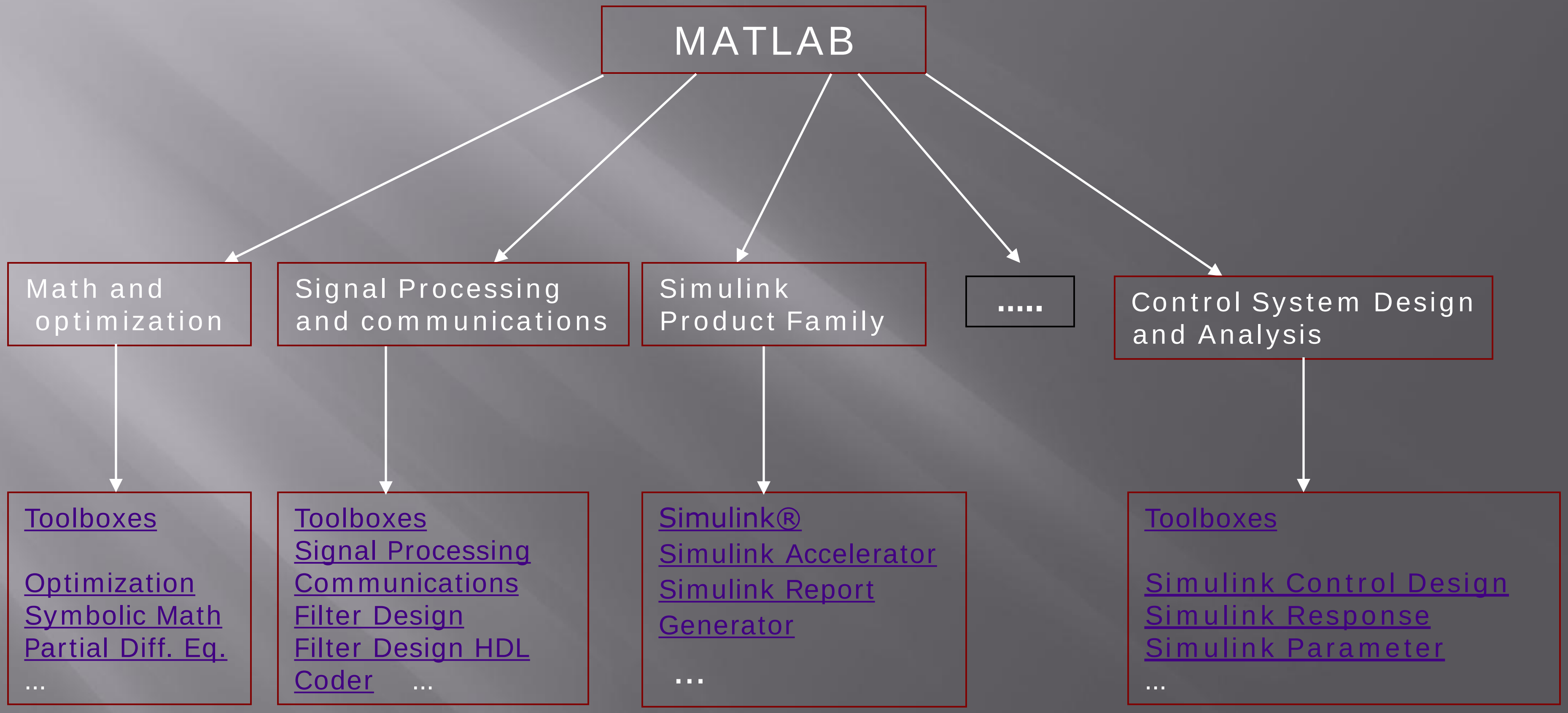
MATLAB

- Aerospace and Defense
- Automotive
- Biotech, Medical, and Pharmaceutical
- Chemical and Petroleum
- Communications
- Computers and Office Equipment
- Education
- Electronics and Semiconductor
- Financial Services
- Industrial Equipment and Machinery
- Instrumentation
- Utilities and Energy

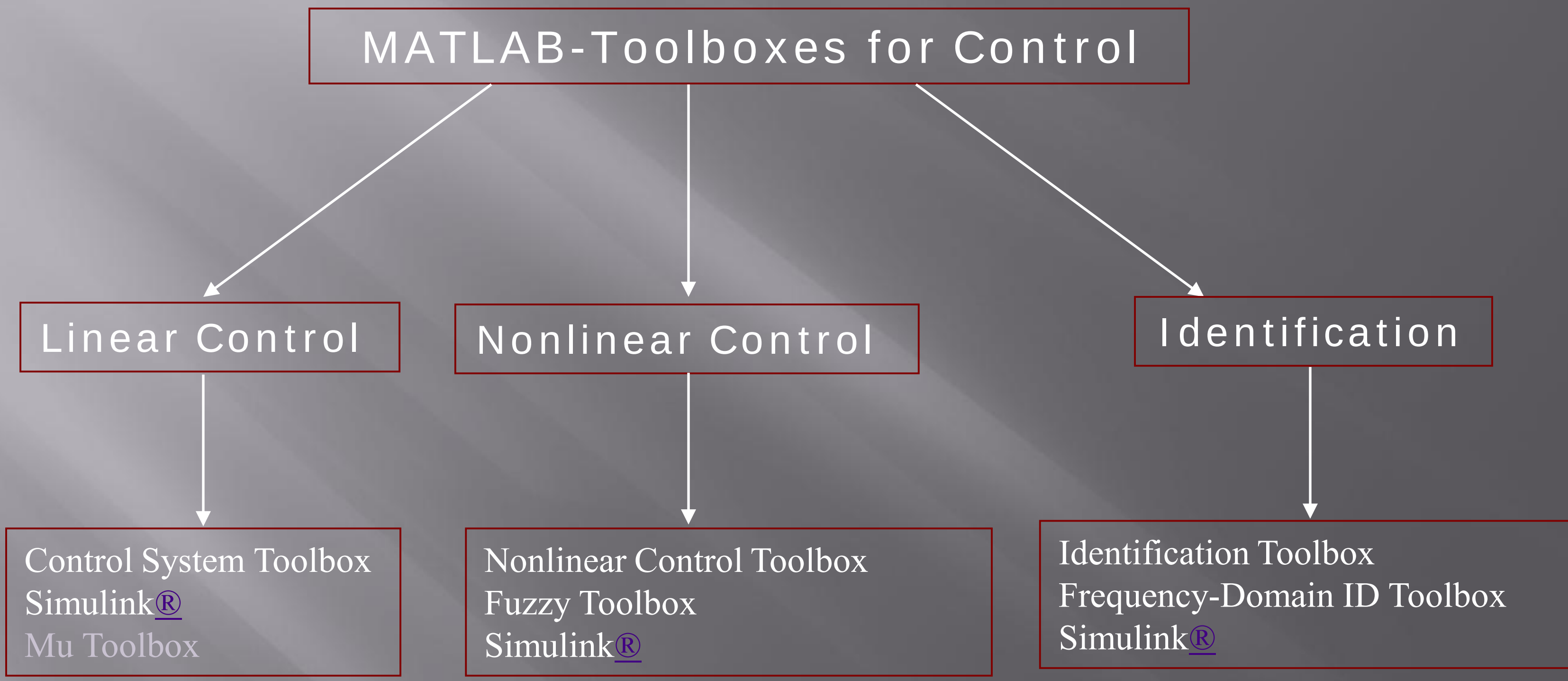
The MathWorks Product Family



MATLAB Toolboxes

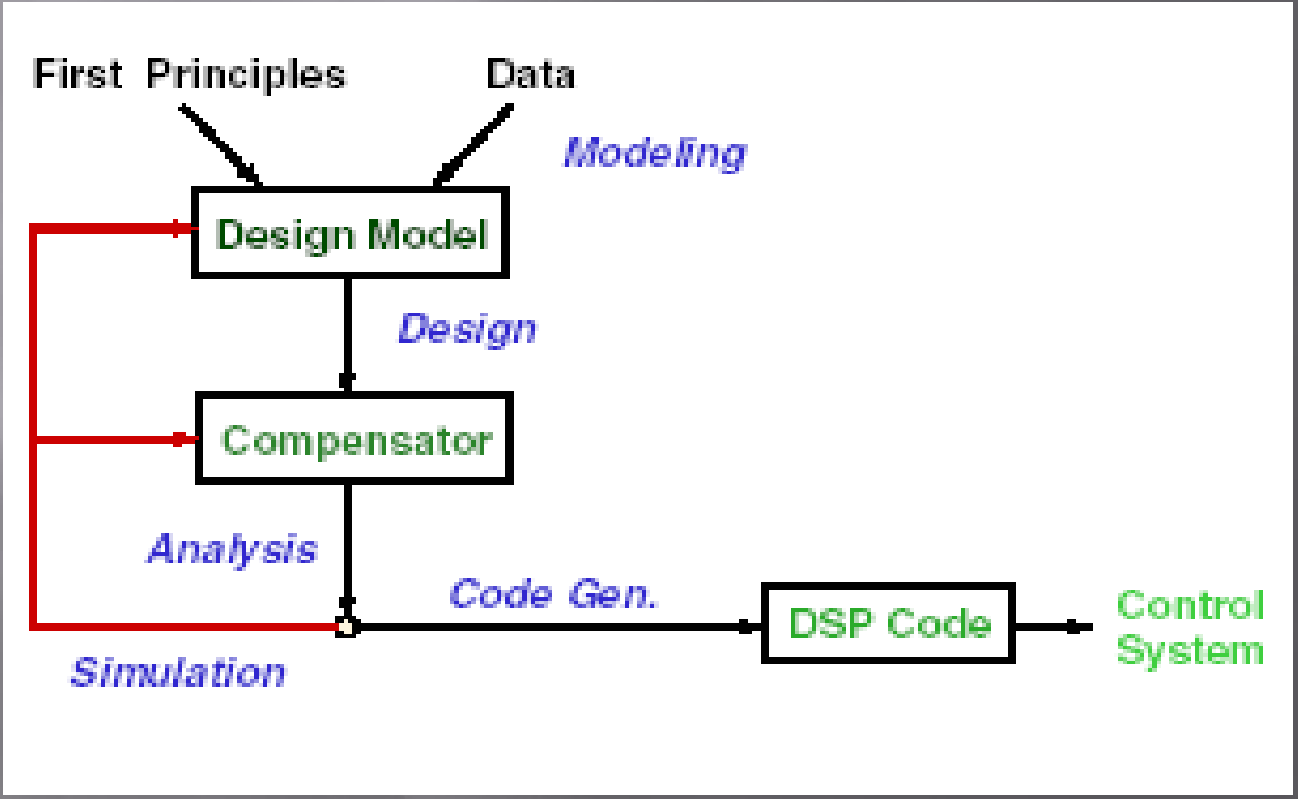


MATLAB and Control



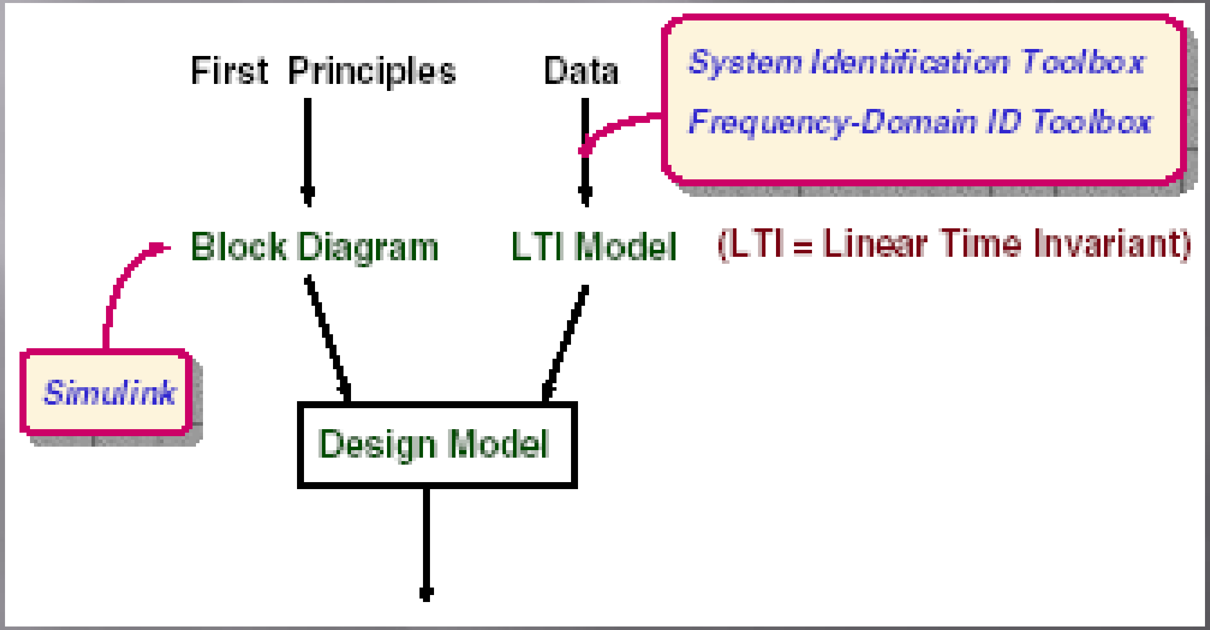
MATLAB and Control

- Control Design Process



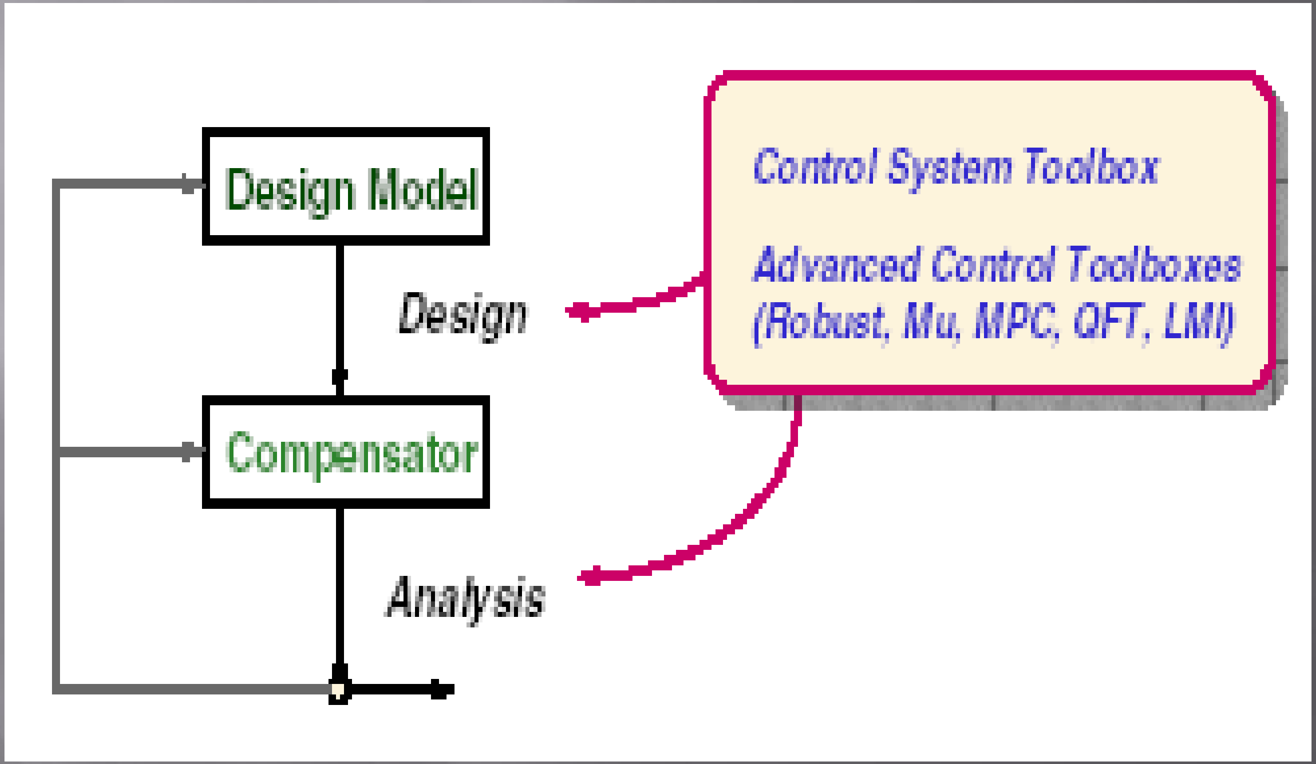
MATLAB and Control

- Modeling Tools



MATLAB and Control

- Design and Analysis



Control System Toolbox

Core Features

- **Tools to manipulate LTI models**

- **Classical analysis and design**
  - *Bode, Nyquist, Nichols diagrams*
  - *Step and impulse response*
  - *Gain/phase margins*
  - *Root locus design*

- **Modern state-space techniques**
  - *Pole placement*
  - *LQG regulation*

Control System Toolbox

LTI Objects (Linear Time Invariant)

- 4 basic types of LTI models
  - Transfer Function (TF)
  - Zero-pole-gain model (ZPK)
  - State-Space models (SS)
  - Frequency response data model (FRD)
- Conversion between models
- Model properties (dynamics)

Control System Toolbox

Transfer Function

$$H(s) = \frac{p_1 s^n + p_2 s^{n-1} + \ldots + p_{n+1}}{q_1 s^m + q_1 s^{m-1} + \ldots + q_{m+1}}$$

where

$p_1, p_2 \ldots p_{n+1}$ numerator coefficients

$q_1, q_1 \ldots q_{m+1}$ denominator coefficients

Control System Toolbox

Transfer Function

- Consider a linear time invariant (LTI) single-input/single-output system

$$y'' + 6y' + 5y = 4u' + 3u$$

- Applying Laplace Transform to both sides with zero initial conditions

$$G(s) = \frac{Y(s)}{U(s)} = \frac{4s+3}{s^2+6s+5}$$

Control System Toolbox

Transfer Function

```
>> num = [4 3];
>> den = [1 6 5];
>> sys = tf(num,den)
   Transfer function:
      4 s + 3
   -----------------
   s^2 + 6 s + 5
```

⟺

```
>> [num,den] =
      tfdata(sys,'v')
num =
     0   4   3
den =
     1   6   5
```

Control System Toolbox

Zero-pole-gain model (ZPK)

$$H(s) = K\,\frac{(s-p_1)(s-p_2)+\ldots+(s-p_n)}{(s-q_1)(s-q_2)+\ldots+(s-q_m)}$$

where

$p_1, p_2 \ldots p_{n+1}$ the zeros of H(s)

$q_1, q_1 \ldots q_{m+1}$ the poles of H(s)

Control System Toolbox

Zero-pole-gain model (ZPK)

- Consider a Linear time invariant (LTI) single-input/single-output system

$$y'' + 6y' + 5y = 4u' + 3u$$

- Applying Laplace Transform to both sides with zero initial conditions

$$G(s) = \frac{Y(s)}{U(s)} = \frac{4s+3}{s^2+6s+5} = \frac{4(s+0.75)}{(s+1)(s+5)}$$

Control System Toolbox

Zero-pole-gain model (ZPK)

```
>> sys1 =
 zpk(-0.75,[-1 -5],4)

Zero/pole/gain:
4 (s+0.75)
-----------
(s+1) (s+5)
```

```
>> [ze,po,k] = zpkdata(sys1,'v')
ze =
   -0.7500
po =
    -1
    -5
k =
     4
```

Control System Toolbox

State-Space Model (SS)

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

where

x	state vector
u *and* y	input and output vectors
A, B, C *and* D	state-space matrices

Control System Toolbox

State-Space Models

- Consider a Linear time invariant (LTI) single-input/single-output system

$$y'' + 6y' + 5y = 4u'' + 3u$$

- State-space model for this system is

$$\begin{bmatrix} x_1' \\ x_2' \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -5 & -6 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u \qquad \begin{bmatrix} x_1(0) \\ x_2(0) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$y = \begin{bmatrix} 3 & 4 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Control System Toolbox

State-Space Models

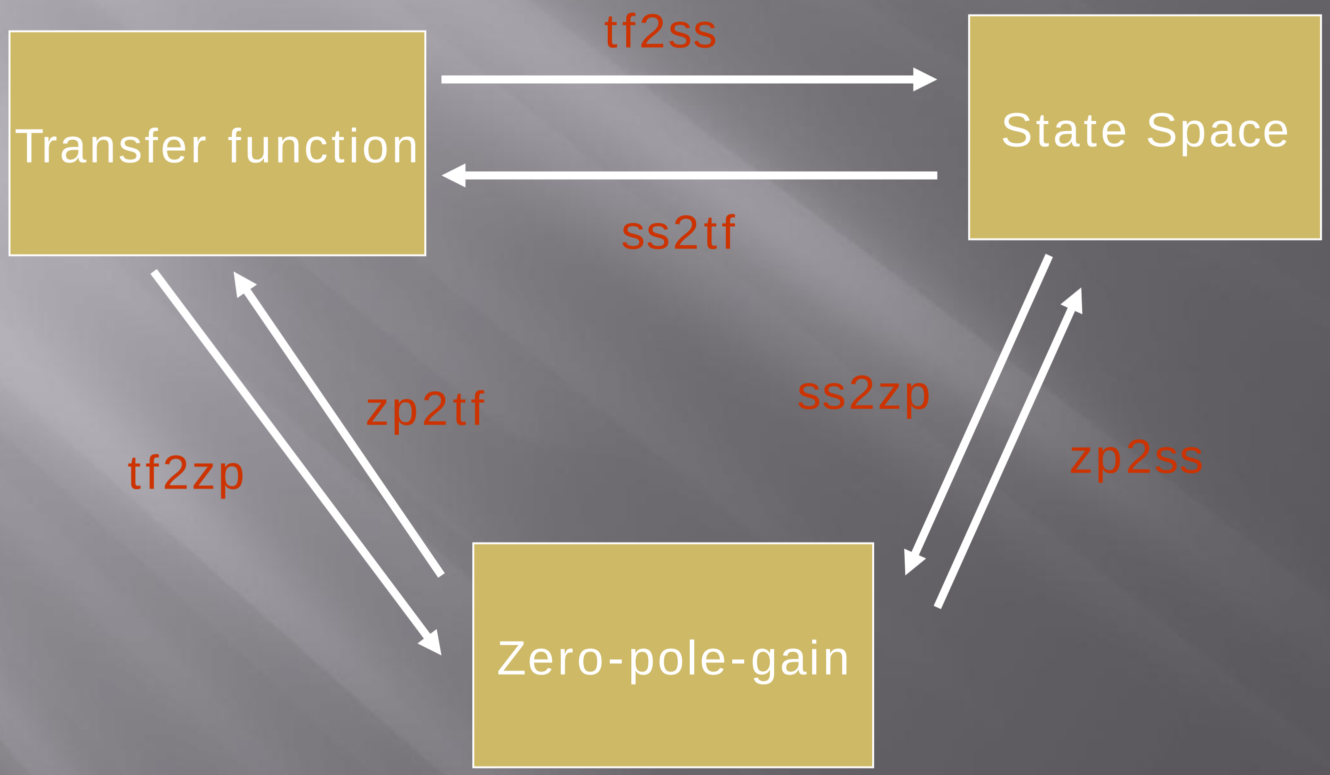
```
>> sys = ss([0 1; -5 -6],[0;1],[3,4],0)
 a =
       x1  x2
   x1   0   1
   x2  -5  -6

 b =
       u1
   x1   0
   x2   1

 c =
       x1  x2
   y1   3   4

 d =
       u1
   y1   0
```

Control System Toolbox

State Space Models

- **rss, drss** - Random stable state-space models.
- **ss2ss** - State coordinate transformation.
- **canon** - State-space canonical forms.
- **ctrb** - Controllability matrix.
- **obsv** - Observability matrix.
- **gram** - Controllability and observability gramians.
- **ssbal** - Diagonal balancing of state-space realizations.
- **balreal** - Gramian-based input/output balancing.
- **modred** - Model state reduction.
- **minreal** - Minimal realization and pole/zero cancellation.
- **sminreal** - Structurally minimal realization.

Conversion between different models



Model Dynamics

- pzmap: Pole-zero map of LTI models.
- pole, eig - System poles
- zero - System (transmission) zeros.
- dcgain: DC gain of LTI models.
- bandwidth - System bandwidth.
- iopzmap - Input/Output Pole-zero map.
- damp - Natural frequency and damping of system
- esort - Sort continuous poles by real part.
- dsort - Sort discrete poles by magnitude.
- covar - Covariance of response to white noise.

Control System Toolbox

Time Response of Systems

- Impulse Response (*impulse*)
- Step Response (*step*)
- General Time Response (*lsim*)
- Polynomial multiplication (*conv*)
- Polynomial division (*deconv*)
- Partial Fraction Expansion (*residue*)
- gensig - Generate input signal for lsim.

Control System Toolbox

Time Response of Systems

- The impulse *response* of a system is its output when the *input is a unit impulse*.
- The step *response* of a system is its output when the *input is a unit step*.
- The general *response* of a system to *any input* can be computed using the lsim command.

Control System Toolbox
Time Response of Systems

Problem Given the LTI system

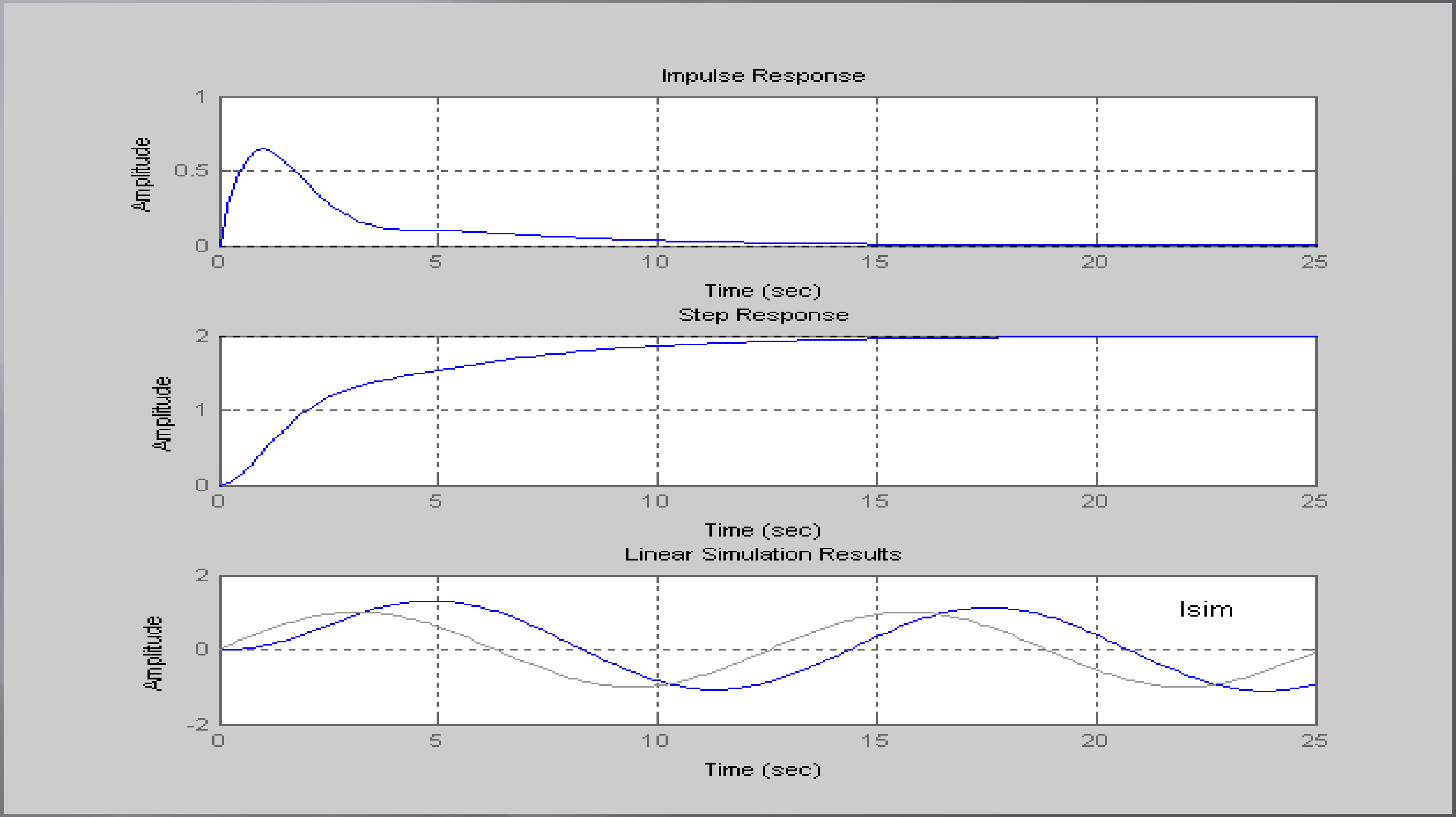
$$G(s) = \frac{3s+2}{2s^3+4s^2+5s+1}$$

Plot the following responses for:

- The impulse response using the `impulse` command.
- The step response using the `step` command.
- The response to the input $u(t) = sin(0.5t)$ calculated using both the `lsim` commands

Control System Toolbox

Time Response of Systems



Frequency Domain Analysis and Design

- Root locus analysis
- Frequency response plots
  - Bode
    - Phase Margin
    - Gain Margin
  - Nyquist

Frequency Domain Analysis and Design

Root Locus

- The root locus is a plot in the s-plane of all possible locations of the poles of a closed-loop system, as one parameter, usually the gain, is varied from 0 to ∞.

- By examining that plot, the designer can make choices of values of the controller's parameters, and can infer the performance of the controlled closed-loop system.

Frequency Domain Analysis and Design

Root Locus

- Plot the root locus of the following system

$$G(s) = \frac{K(s+8)}{s(s+2)(s^2+8s+32)}$$