

## Step-1

Let following be the differential equation of matrices:

$$\frac{du}{dt} = Au$$

Here, matrix  $A$  is defined as follows:

$$A = \begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}$$

Initial condition:

$$u(0) = (3, 1)$$

Find the general and specific solution that matches the initial condition. Also, find the steady state when  $t \rightarrow \infty$ .

## Step-2

First step is to find the Eigen values and Eigen vectors of matrix  $A$ . To calculate the Eigen values do the following calculations;

$$A - \lambda I = \begin{bmatrix} -1-\lambda & 1 \\ 1 & -1-\lambda \end{bmatrix}$$

$$\det(A - \lambda I) = 0$$

$$(-1-\lambda)(-1-\lambda) - 1 = 0$$

$$\lambda^2 + 2\lambda = 0$$

After solving following values are obtained:

$$\lambda_1 = 0$$

$$\lambda_2 = -2$$

## Step-3

Therefore, Eigen values are  $0, -2$

## Step-4

To calculate Eigen vectors do the following calculations:

$$(A - \lambda I)x = 0$$

$$\begin{bmatrix} -1+2 & 1 \\ 1 & -1+2 \end{bmatrix} \begin{bmatrix} y \\ z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} y \\ z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

On solving, values of  $y$  and  $z$  corresponding to  $\lambda = -2$  are as follows:

$$x_1 = \begin{bmatrix} y \\ z \end{bmatrix}$$

$$= \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

## Step-5

Similarly, Eigen vectors corresponding to Eigen value  $\lambda = 0$  is as follows:

$$(A - \lambda I)x = 0$$

$$\begin{bmatrix} -1-0 & 1 \\ 1 & -1-0 \end{bmatrix} \begin{bmatrix} y \\ z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} y \\ z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

On solving values of  $y$  and  $z$  corresponding to  $\lambda = 0$  is as follows:

$$x_2 = \begin{bmatrix} y \\ z \end{bmatrix}$$

$$= \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

## Step-6

Therefore Eigen values are:

$$x_1 = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

$$x_2 = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

## Step-7

Recall that:  $e^{At} = Se^{At}S^{-1}$

Here, Eigen value matrix is given as follows:

$$\Lambda = \begin{bmatrix} -2 & 0 \\ 0 & 0 \end{bmatrix}$$

## Step-8

Therefore, the general solution of the differential equation is:

$$u(t) = c_1 e^{\lambda_1 t} x_1 + c_2 e^{\lambda_2 t} x_2$$

Or

$$u(t) = \begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} e^{-2t} & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \end{bmatrix}$$

Here,  $c_1$  and  $c_2$  are constants. Their values are determined by the following values:

$$c = S^{-1}u(0)$$

## Step-9

So, the solution for differential equation can be written as follows:

$$\begin{aligned} u(t) &= Se^{At}S^{-1}u(0) \\ &= \begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} e^{-2t} & 0 \\ 0 & e^{0t} \end{bmatrix} \begin{bmatrix} 1/2 & -1/2 \\ 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} 3 \\ 1 \end{bmatrix} \\ &= \frac{1}{2} \begin{bmatrix} e^{-2t} & 1 \\ -e^{-2t} & 1 \end{bmatrix} \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} 3 \\ 1 \end{bmatrix} \\ &= \frac{1}{2} \begin{bmatrix} e^{-2t} + 1 & -e^{-2t} + 1 \\ -e^{-2t} + 1 & e^{-2t} + 1 \end{bmatrix} \begin{bmatrix} 3 \\ 1 \end{bmatrix} \\ &= \frac{1}{2} \begin{bmatrix} 2e^{-2t} + 4 \\ -2e^{-2t} + 4 \end{bmatrix} \\ u(t) &= \begin{bmatrix} e^{-2t} + 2 \\ -e^{-2t} + 2 \end{bmatrix} \end{aligned}$$

## Step-10

Therefore, specific solution of the differential equation is:

$$u(t) = \begin{bmatrix} e^{-2t} + 2 \\ -e^{-2t} + 2 \end{bmatrix}$$

Steady state when  $t \rightarrow \infty$  will be:

$$u_{ss} = \begin{bmatrix} 2 \\ 2 \end{bmatrix}$$