

# UNIT 2 – ORTHOGONAL TRANSFORMATION OF A REAL SYMMETRIC MATRIX

## Diagonalization of a real symmetric matrix

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Method to diagonalise the symmetric matrix by orthogonal transformation

STEP 1: Find characteristic equation, Eigen values, eigen vectors of the given matrix A.

STEP 2: Eigen vector should be pair wise orthogonal

$$X_1^T X_2 = 0 \quad ; \quad X_2^T X_3 = 0 \quad ; \quad X_3^T X_1 = 0$$

STEP 3: Normalize each Eigen vector, if  $X = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}$  the normalized vector =  $\begin{pmatrix} x_1/l(x_1) \\ x_2/l(x_2) \\ x_3/l(x_3) \end{pmatrix}$  where

$$l(x) = \sqrt{x_1^2 + x_2^2 + x_3^2}$$

STEP 4: Form the normalized modal matrix N, using normalized Eigen vectors

STEP 5: The normalized modal matrix N should be orthogonal matrix

$$NN^T = N^T N = I$$

STEP 6: Find the  $N^T A N = D$ , Where D is diagonal matrix.

### Problem

1. Reduce the matrix to diagonalise  $A = \begin{bmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{bmatrix}$

$$\text{Let } A = \begin{bmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{bmatrix}$$

To find characteristic equation

$D_1 =$  Sum of leading diagonal elements

$$= 8 + 7 + 3 = 18$$

$D_2 =$  Sum of minors of leading diagonal elements

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$$=45$$

$$D_3=|A|$$

$$= \begin{vmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{vmatrix}$$

$$= 0$$

The characteristic equation is

$$\lambda^3 - 18\lambda^2 + 45\lambda = 0$$

The eigen values are 0,3,15

The eigen vectors are  $(A - \lambda I)X=0$

$$\left[ \begin{pmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{pmatrix} - \lambda \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \right] \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = 0$$

$$\begin{pmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = 0$$

$$\begin{pmatrix} 8-\lambda & -6 & 2 \\ -6 & 7-\lambda & -4 \\ 2 & -4 & 3-\lambda \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = 0$$

#### **CASE (i)**

When  $\lambda = 0$

$$\begin{pmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = 0$$

The cofactor of first row elements are  $\begin{pmatrix} 5 \\ 10 \\ 10 \end{pmatrix}$  ie  $\begin{pmatrix} 1 \\ 2 \\ 2 \end{pmatrix}$

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The Eigen vector when  $\lambda = 0$  is  $\begin{pmatrix} 1 \\ 2 \\ 2 \end{pmatrix}$

#### **CASE (ii)**

When  $\lambda = 3$

$$\begin{pmatrix} 5 & -6 & 2 \\ -6 & 4 & -4 \\ 2 & -4 & 0 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = 0$$

The cofactor of first row elements are  $\begin{pmatrix} -16 \\ -8 \\ 16 \end{pmatrix}$  ie  $\begin{pmatrix} 2 \\ 1 \\ -2 \end{pmatrix}$

The Eigen vector when  $\lambda = 3$  is  $\begin{pmatrix} 2 \\ 1 \\ -2 \end{pmatrix}$

#### **CASE (iii)**

When  $\lambda = 15$

$$\begin{pmatrix} -7 & -6 & 2 \\ -6 & -8 & -4 \\ 2 & -4 & -12 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = 0$$

The cofactor of first row elements are  $\begin{pmatrix} 80 \\ -80 \\ 40 \end{pmatrix}$  ie  $\begin{pmatrix} 2 \\ -2 \\ 1 \end{pmatrix}$

The Eigen vector when  $\lambda = 15$  is  $\begin{pmatrix} 2 \\ -2 \\ 1 \end{pmatrix}$

#### **STEP 2:**

To check pair wise orthogonality

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$$X_1^T X_2 = (1 \quad 2 \quad 2) \begin{pmatrix} 2 \\ 1 \\ -2 \end{pmatrix} = 0$$

$$X_2^T X_3 = (2 \quad 1 \quad -2) \begin{pmatrix} 2 \\ -2 \\ 1 \end{pmatrix} = 0$$

$$X_3^T X_1 = (2 \quad -2 \quad 1) \begin{pmatrix} 1 \\ 2 \\ 2 \end{pmatrix} = 0$$

### **STEP 3:**

To find normalized vector

Eigen vector	$l(x) = \sqrt{x_1^2 + x_2^2 + x_3^2}$	Normalized vector $= \begin{pmatrix} x_1/l(x_1) \\ x_2/l(x_2) \\ x_3/l(x_3) \end{pmatrix}$
$\begin{pmatrix} 1 \\ 2 \\ 2 \end{pmatrix}$	$\sqrt{1 + 4 + 4} = 3$	$\begin{pmatrix} 1/3 \\ 2/3 \\ 2/3 \end{pmatrix}$
$\begin{pmatrix} 2 \\ 1 \\ -2 \end{pmatrix}$	$\sqrt{1 + 4 + 4} = 3$	$\begin{pmatrix} 2/3 \\ 1/3 \\ -2/3 \end{pmatrix}$
$\begin{pmatrix} 2 \\ -2 \\ 1 \end{pmatrix}$	$\sqrt{1 + 4 + 4} = 3$	$\begin{pmatrix} 2/3 \\ -2/3 \\ 1/3 \end{pmatrix}$

### **STEP 4:**

Normalized modal matrix

$$N = \begin{bmatrix} 1/3 & 2/3 & 2/3 \\ 2/3 & 1/3 & -2/3 \\ 2/3 & -2/3 & 1/3 \end{bmatrix}$$

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$$N^T = \begin{bmatrix} 1/3 & 2/3 & 2/3 \\ 2/3 & 1/3 & -2/3 \\ 2/3 & -2/3 & 1/3 \end{bmatrix}$$

#### **STEP 5:**

$$NN^T = N^T N = I$$

$$\begin{aligned} N^T N &= \begin{pmatrix} 1/3 & 2/3 & 2/3 \\ 2/3 & 1/3 & -2/3 \\ 2/3 & -2/3 & 1/3 \end{pmatrix} \begin{pmatrix} 1/3 & 2/3 & 2/3 \\ 2/3 & 1/3 & -2/3 \\ 2/3 & -2/3 & 1/3 \end{pmatrix} \\ &= \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \\ &= I \end{aligned}$$

#### **STEP 6:**

To find diagonalize matrix

$$N^T A N = D$$

$$N^T A = \frac{1}{3} \begin{pmatrix} 1 & 2 & 2 \\ 2 & 1 & -2 \\ 2 & -2 & 1 \end{pmatrix} \begin{pmatrix} 8 & -6 & 2 \\ -6 & 7 & -4 \\ 2 & -4 & 3 \end{pmatrix}$$

$$= \frac{1}{3} \begin{pmatrix} 0 & 0 & 0 \\ 6 & 3 & -6 \\ 30 & 30 & 15 \end{pmatrix}$$

$$N^T A N = \frac{1}{9} \begin{pmatrix} 0 & 0 & 0 \\ 6 & 3 & -6 \\ 30 & 30 & 15 \end{pmatrix} \begin{pmatrix} 1 & 2 & 2 \\ 2 & 1 & -2 \\ 2 & -2 & 1 \end{pmatrix}$$

$$= \frac{1}{9} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 27 & 0 \\ 0 & 0 & 15 \end{pmatrix}$$

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$$= \begin{pmatrix} 0 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & 15 \end{pmatrix}$$

$$= D$$