

## Module 3 - Eigenvalues and Eigenvectors

ME3001 - Mechanical Engineering Analysis

Mechanical Engineering

Tennessee Technological University

### Topic 1 - What is an Eigenvalue and Eigenvector?

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- Mathematical Definition of Eigenvalue and Eigenvector
- Standard form Eigenvalue Problem
- The Geometrical Explanation
- A Simple Example by Hand

# Mathematical Definition of Eigenvalue and Eigenvector

## Did you study this in calculus? Differential Equations?

In linear algebra, an eigenvector or characteristic vector of a linear transformation is a non-zero vector whose direction does not change when that linear transformation is applied to it. More formally, if  $T$  is a linear transformation from a vector space  $V$  over a field  $F$  into itself and  $\mathbf{v}$  is a vector in  $V$  that is not the zero vector, then  $\mathbf{v}$  is an eigenvector of  $T$  if  $T(\mathbf{v})$  is a scalar multiple of  $\mathbf{v}$ . This condition can be written as the equation

$$T(\mathbf{v}) = \lambda \mathbf{v}$$

# Mathematical Definition of Eigenvalue and Eigenvector

where  $\lambda$  is a scalar in the field  $F$ , known as the eigenvalue, characteristic value, or characteristic root associated with the eigenvector  $v$ .

If the vector space  $V$  is finite-dimensional, then the linear transformation  $T$  can be represented as a square matrix  $A$ , and the vector  $v$  by a column vector, rendering the above mapping as a matrix multiplication on the left hand side and a scaling of the column vector on the right hand side in the equation.

$$[A]\mathbf{v} = \lambda\mathbf{v}$$

## Standard form Eigenvalue Problem

$$\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ & \cdot & & \\ & \cdot & & \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \times \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_n \end{bmatrix} = \lambda \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_n \end{bmatrix}$$

$$\left( \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ & \cdot & & \\ & \cdot & & \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} - \lambda \begin{bmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ 0 & 0 & 1 & 0 \\ & \cdot & & \\ 0 & 0 & \dots & 1 \end{bmatrix} \right) \times \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{bmatrix}$$

# Standard form Eigenvalue Problem

The Equations

$$(a_{11} - \lambda)x_1 + a_{12}x_2 + \dots + a_{1n}x_n = 0 \quad a_{21}x_1 + (a_{22} - \lambda)x_2 + \dots + a_{2n}x_n = 0$$

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$$a_{n1}x_1 + a_{n2}x_2 + \dots + (a_{nn} - \lambda)x_n = 0$$

The Matrix Form

$$\begin{pmatrix} (a_{11} - \lambda) & a_{12} & \dots & a_{1n} \\ a_{21} & (a_{22} - \lambda) & \dots & a_{2n} \\ & \cdot & & \\ & \cdot & & \\ a_{n1} & a_{n2} & \dots & (a_{nn} - \lambda) \end{pmatrix} \times \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{bmatrix}$$

## The Geometrical Explanation

**Let us look at the second matrix form more closely**

$$([A] - \lambda[I])\{x\} = \{0\}$$

First we need to realize that this matrix system is *Homogeneous*. This follows a different rule regarding the existence of a solution.

A *Homogeneous* system has a non-trivial solution if and only if the determinant of the coefficient matrix is zero.

$$|[A]| = 0$$

Therefore

$$|[A] - \lambda[I]| = 0$$

This leads to a long  $n^{th}$  order polynomial in terms of  $\lambda$ . This will have  $n$  roots which may be real or complex.

# The Geometrical Explanation

3x3 example

$$\begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a \begin{vmatrix} e & f \\ h & i \end{vmatrix} - b \begin{vmatrix} d & f \\ g & i \end{vmatrix} + c \begin{vmatrix} d & e \\ g & h \end{vmatrix}$$
$$= a(ei - fh) - b(di - fg) + c(dh - eg)$$
$$= aei + bfg + cdh - ceg - bdi - afh.$$



# A Simple Example by Hand

Example with 2D Vectors

# The Geometrical Explanation

Example with 2D Vectors

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Example with 2D Vectors