Eigenvalues and Eigenvectors

Linear Algebra

Instructor: Ben Huang

The Hierarchy of Matrices

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The second to the best - diagonal matrix:

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix}$$

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$$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix}^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1/2 & 0 \\ 0 & 0 & 1/3 \end{bmatrix}$$

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More generally,

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 3 \end{bmatrix}^{k} = \begin{bmatrix} 1^k & 0 & 0 \\ 0 & 2^k & 0 \\ 0 & 0 & 3^k \end{bmatrix}$$

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Consequently,

$$e^D = \sum_{k=0}^{\infty} \frac{1}{k!} D^k = \begin{bmatrix} e^1 & 0 & 0 \\ 0 & e^2 & 0 \\ 0 & 0 & e^3 \end{bmatrix}$$

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The almost as good - diagonalizable matrix:

$$A = \begin{bmatrix} 6 & -1 \\ 2 & 3 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} 5 & 0 \\ 0 & 4 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}^{-1}$$

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$$e^A = \sum_{k=0}^{\infty} \frac{1}{k!} A^k = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} e^5 & 0 \\ 0 & e^4 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}^{-1}$$

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A stronger version - orthogonally diagonalizable:

$$S = \begin{bmatrix} 1 & -2 \\ -2 & 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} 3 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}^T$$

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Applications:

(a) Classify quadric curves and surfaces

(b) Simplify the inertia tensor of a rigid body (classical mechanics)

(c) Principal Component Analysis

The Hierarchy of Matrices

Advanced decompositions:

- Singular Value decomposition

$$\begin{bmatrix} 3 & 2 & 2 \\ 2 & 3 & -2 \end{bmatrix} = \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} \end{bmatrix} \begin{bmatrix} 5 & 0 & 0 \\ 0 & 3 & 0 \end{bmatrix} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{18} & 2/3 \\ 1/\sqrt{2} & -1/\sqrt{18} & -2/3 \\ 0 & 4/\sqrt{18} & -1/3 \end{bmatrix}^T$$

- Jordan canonical form

$$\begin{bmatrix} -2 & 2 & 1 \\ -7 & 4 & 2 \\ 5 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 1 \\ -1 & -1 & 2 \\ 2 & 5 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & 1 & 1 \\ -1 & -1 & 2 \\ 2 & 5 & 0 \end{bmatrix}^{-1}$$

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Suppose $A = P \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} P^{-1}$, where $P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} = \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix}$.

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Definition: Let A be a square matrix. λ is called an **eigenvalue** of A if there is a non-zero column vector $\mathbf{v}$ such that

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Exercises on WeBWork

A 3-D Example on GeoGebra

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B.H.

Hierarchy

Eigenvalues

Diagonalization

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Definition: The polynomial $p(\lambda) = \det(\lambda I - A)$ is called the **characteristic polynomial** of A. Note that the roots of $p(\lambda)$ are precisely the eigenvalues of A.

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$\lambda_1 = 0$, $\lambda_2 = 7$.

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$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}t \\ t \end{bmatrix} = t \begin{bmatrix} \frac{1}{2} \\ 1 \end{bmatrix}, \text{ thus } \mathscr{B}_1 = \left\{ \begin{bmatrix} \frac{1}{2} \\ 1 \end{bmatrix} \right\}.$$

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$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} -3t \\ t \end{bmatrix} = t \begin{bmatrix} -3 \\ 1 \end{bmatrix}, \text{ thus } \mathscr{B}_2 = \left\{ \begin{bmatrix} -3 \\ 1 \end{bmatrix} \right\}.$$

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Step 4: Since the number of basis vectors is the same as the dimension of the ambient space (R^2), A is diagonalizable, and

$$D = P^{-1}AP,$$

where $D = \begin{bmatrix} 0 & 0 \\ 0 & 7 \end{bmatrix}$, $P = \begin{bmatrix} \frac{1}{2} & -3 \\ 1 & 1 \end{bmatrix}$.