EECS 16A Designing Information Devices and Systems I
Fall 2018 Discussion 5A

Consider a vector in the standard basis,

$$\vec{x} = a\vec{e}_1 + b\vec{e}_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \mathbf{I}\vec{x} \tag{1}$$

where, a, b are $\vec{x}$'s coordinates in the standard basis.

Given a new set of basis vectors, $\mathscr{V} = \{\vec{v}_1, \vec{v}_2\}$, if $\vec{x} \in span\{\mathscr{V}\}$, then we can find new coordinates in terms of this new basis. The new coordinates are called a_v, b_v and are described,

$$\vec{x} = a_v\vec{v}_1 + b_v\vec{v}_2 = \begin{bmatrix} | & | \\ \vec{v}_1 & \vec{v}_2 \\ | & | \end{bmatrix} \begin{bmatrix} a_v \\ b_v \end{bmatrix} = \mathbf{V}\vec{x}_v \tag{2}$$

Now consider another set of basis vectors, $\mathscr{U} = \{\vec{u}_1, \vec{u}_2\}$, if $\vec{x} \in span\{\mathscr{U}\}$, then we can find the coordinates in terms of this basis. These coordinates are called a_u, b_u and are described,

$$\vec{x} = a_v\vec{u}_1 + b_v\vec{u}_2 = \begin{bmatrix} | & | \\ \vec{u}_1 & \vec{u}_2 \\ | & | \end{bmatrix} \begin{bmatrix} a_u \\ b_u \end{bmatrix} = \mathbf{U}\vec{x}_u \tag{3}$$

All of these bases are equivalent representations of any vector $\vec{x} \in \mathbb{R}^2$; each with their own set of coordinates.

$$\vec{x} = \begin{bmatrix} | & | \\ \vec{e}_1 & \vec{e}_2 \\ | & | \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} | & | \\ \vec{u}_1 & \vec{u}_2 \\ | & | \end{bmatrix} \begin{bmatrix} a_u \\ b_u \end{bmatrix} = \begin{bmatrix} | & | \\ \vec{v}_1 & \vec{v}_2 \\ | & | \end{bmatrix} \begin{bmatrix} a_v \\ b_v \end{bmatrix} \tag{4}$$

$$\vec{x} = I\vec{x} = \mathbf{V}\vec{x}_v = \mathbf{U}\vec{x}_u \tag{5}$$

1. Coordinate Change Examples

(a) **Transformation From Standard Basis To Another Basis in $\mathbb{R}^3$**

Calculate the coordinate transformation between the following bases

$$\mathbf{U} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \qquad \mathbf{V} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix},$$

i.e. find a matrix $\mathbf{T}$, such that $\vec{x}_v = \mathbf{T}\vec{x}_u$ where $\vec{x}_u$ contains the coordinates of a vector in a basis of the columns of $\mathbf{U}$ and $\vec{x}_v$ is the coordinates of the same vector in the basis of the columns of $\mathbf{V}$.

Let $\vec{x}_u = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$ and compute $\vec{x}_v$. Repeat this for $\vec{x}_u = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$. Now let $\vec{x}_u = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$. What is $\vec{x}_v$?

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(b) **Transformation Between Two Bases in $\mathbb{R}^3$**

Calculate the coordinate transformation between the following bases

$$\mathbf{U} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}, \qquad \mathbf{V} = \begin{bmatrix} 0 & 0 & 1 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix},$$

i.e. find a matrix $\mathbf{T}$, such that $\vec{x}_v = \mathbf{T}\vec{x}_u$. Let $\vec{x}_u = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$ and compute $\vec{x}_v$. Repeat this for $\vec{x}_u = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$.

Now let $\vec{x}_u = \begin{bmatrix} \frac{1}{\sqrt{2}} \\ 1 \\ \frac{1}{\sqrt{2}} \end{bmatrix}$. What is $\vec{x}_v$?

(c) What is the coordinate transformation from $\vec{x}_v$ to $\vec{x}_u$, i.e. find $\mathbf{W}$ such $\vec{x}_u = \mathbf{W}\vec{x}_v$?

(d) **Transformation Between General Bases in $\mathbb{R}^2$**

Calculate the coordinate transformation between the following bases

$$\mathbf{U} = \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}, \qquad \mathbf{V} = \begin{bmatrix} 1 & -1 \\ 0 & 1 \end{bmatrix},$$

i.e. find a matrix $\mathbf{T}$, such that $\vec{x}_v = \mathbf{T}\vec{x}_u$. Let $\vec{x}_u = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ and compute $\vec{x}_v$. Repeat this for $\vec{x}_u = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$.

Now let $\vec{x}_u = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$. What is $\vec{x}_v$?

2. Proofs

(a) Let $\mathbf{A}$ be an invertible matrix. Show that if λ is an eigenvalue of $\mathbf{A}$, then $\frac{1}{\lambda}$ is an eigenvalue of $\mathbf{A}^{-1}$.

3. Steady and Unsteady States

(a) You're given the matrix $\mathbf{M}$ (below) which describes some physical system (could describe either people or water):

$$\mathbf{M} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & -\frac{1}{2} \\ 0 & 1 & -2 \\ 0 & 0 & 2 \end{bmatrix}$$

Find the eigenspaces associated with the following eigenvalues:

i. span($\vec{v}_1$), associated with $\lambda_1 = 1$

ii. span($\vec{v}_2$), associated with $\lambda_2 = 2$

iii. span($\vec{v}_3$), associated with $\lambda_3 = \frac{1}{2}$

(b) Define $\vec{x} = \alpha\vec{v}_1 + \beta\vec{v}_2 + \gamma\vec{v}_3$. The values $\alpha, \beta,$ and γ are the coordinates for the basis $\{\vec{v}_1, \vec{v}_2, \vec{v}_3\}$. For each of the cases in the table, determine if

$$\lim_{n\to\infty} \mathbf{M}^n\vec{x}$$

converges. If it does, what does it converge to?

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α	β	γ	Converges?	$\lim_{n\to\infty} \mathbf{M}^n \vec{x}$
0	0	$\neq 0$		
0	$\neq 0$	0		
0	$\neq 0$	$\neq 0$		
$\neq 0$	0	0		
$\neq 0$	0	$\neq 0$		
$\neq 0$	$\neq 0$	0		
$\neq 0$	$\neq 0$	$\neq 0$		

4. More Practice with Column Spaces and Null Spaces

- The **column space** is the possible outputs of a transformation/function/linear operation. It is also the **span** of the column vectors of the matrix.
- The **null space** is the set of input vectors that output the zero vector.

For the following matrices, answer the following questions:

i. What is the column space of $\mathbf{A}$? What is its dimension?
ii. What is the null space of $\mathbf{A}$? What is its dimension?
iii. Are the column spaces of the row reduced matrix $\mathbf{A}$ and the original matrix $\mathbf{A}$ the same?
iv. Do the columns of $\mathbf{A}$ form a basis for $\mathbb{R}^2$ (or $\mathbb{R}^3$ for part (b))? Why or why not?

(a) $\begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix}$

(b) $\begin{bmatrix} 1 & 2 \\ -1 & 1 \end{bmatrix}$

(c) $\begin{bmatrix} -2 & 4 \\ 3 & -6 \end{bmatrix}$

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