Tut 5

SC1004 Mar 2022 Tutorial 5

Mar 2021

Q1) Lay 6.1/pg 336/Q1

Compute the quantities in Exercises 1–8 using the vectors

$$\mathbf{u} = \begin{bmatrix} -1 \\ 2 \end{bmatrix}, \quad \mathbf{v} = \begin{bmatrix} 4 \\ 6 \end{bmatrix}, \quad \mathbf{w} = \begin{bmatrix} 3 \\ -1 \\ -5 \end{bmatrix}, \quad \mathbf{x} = \begin{bmatrix} 6 \\ -2 \\ 3 \end{bmatrix}$$

1. $\mathbf{u}\cdot\mathbf{u}$, $\mathbf{v}\cdot\mathbf{u}$, and $\dfrac{\mathbf{v}\cdot\mathbf{u}}{\mathbf{u}\cdot\mathbf{u}}$

2. $\mathbf{w}\cdot\mathbf{w}$, $\mathbf{x}\cdot\mathbf{w}$, and $\dfrac{\mathbf{x}\cdot\mathbf{w}}{\mathbf{w}\cdot\mathbf{w}}$

3. $\dfrac{1}{\mathbf{w}\cdot\mathbf{w}}\mathbf{w}$

4. $\dfrac{1}{\mathbf{u}\cdot\mathbf{u}}\mathbf{u}$

5. $\left(\dfrac{\mathbf{u}\cdot\mathbf{v}}{\mathbf{v}\cdot\mathbf{v}}\right)\mathbf{v}$

6. $\left(\dfrac{\mathbf{x}\cdot\mathbf{w}}{\mathbf{x}\cdot\mathbf{x}}\right)\mathbf{x}$

7. $\|\mathbf{w}\|$

8. $\|\mathbf{x}\|$

Q2) Lay/ 6.1/ pg 337/ Q19

In Exercises 19 and 20, all vectors are in $\mathbb{R}^n$. Mark each statement True or False. Justify each answer.

19. a. $\mathbf{v}\cdot\mathbf{v} = \|\mathbf{v}\|^2$.

b. For any scalar c, $\mathbf{u}\cdot(c\mathbf{v}) = c(\mathbf{u}\cdot\mathbf{v})$.

c. If the distance from $\mathbf{u}$ to $\mathbf{v}$ equals the distance from $\mathbf{u}$ to $-\mathbf{v}$, then $\mathbf{u}$ and $\mathbf{v}$ are orthogonal.

d. For a square matrix A, vectors in Col A are orthogonal to vectors in Nul A.

e. If vectors $\mathbf{v}_1, \ldots, \mathbf{v}_p$ span a subspace W and if $\mathbf{x}$ is orthogonal to each $\mathbf{v}_j$ for $j = 1, \ldots, p$, then $\mathbf{x}$ is in $W^\perp$.

Ans: T,T,T,F,T

Q3) Lay /6.1/ pg 337/Q30)

30. Let W be a subspace of $\mathbb{R}^n$, and let $W^\perp$ be the set of all vectors orthogonal to W. Show that $W^\perp$ is a subspace of $\mathbb{R}^n$ using the following steps.

a. Take $\mathbf{z}$ in $W^\perp$, and let $\mathbf{u}$ represent any element of W. Then $\mathbf{z}\cdot\mathbf{u} = 0$. Take any scalar c and show that $c\mathbf{z}$ is orthogonal to $\mathbf{u}$. (Since $\mathbf{u}$ was an arbitrary element of W, this will show that $c\mathbf{z}$ is in $W^\perp$.)

b. Take $\mathbf{z}_1$ and $\mathbf{z}_2$ in $W^\perp$, and let $\mathbf{u}$ be any element of W. Show that $\mathbf{z}_1 + \mathbf{z}_2$ is orthogonal to $\mathbf{u}$. What can you conclude about $\mathbf{z}_1 + \mathbf{z}_2$? Why?

c. Finish the proof that $W^\perp$ is a subspace of $\mathbb{R}^n$.

Q4) Lay Example 3, pg 340, Maths/LA/Tut6.2/Orthogonal Sets

EXAMPLE 3 Let $\mathbf{y} = \begin{bmatrix} 7 \\ 6 \end{bmatrix}$ and $\mathbf{u} = \begin{bmatrix} 4 \\ 2 \end{bmatrix}$. Find the orthogonal projection of $\mathbf{y}$ onto $\mathbf{u}$. Then write $\mathbf{y}$ as the sum of two orthogonal vectors, one in Span $\{\mathbf{u}\}$ and one orthogonal to $\mathbf{u}$.

Compute the quantities in Exercises 1–8 using the vectors

$$\mathbf{u} = \begin{bmatrix} -1 \\ 2 \end{bmatrix}, \quad \mathbf{v} = \begin{bmatrix} 4 \\ 6 \end{bmatrix}, \quad \mathbf{w} = \begin{bmatrix} 3 \\ -1 \\ -5 \end{bmatrix}, \quad \mathbf{x} = \begin{bmatrix} 6 \\ -2 \\ 3 \end{bmatrix}$$

1. $\mathbf{u}\cdot\mathbf{u}$, $\mathbf{v}\cdot\mathbf{u}$, and $\dfrac{\mathbf{v}\cdot\mathbf{u}}{\mathbf{u}\cdot\mathbf{u}}$

2. $\mathbf{w}\cdot\mathbf{w}$, $\mathbf{x}\cdot\mathbf{w}$, and $\dfrac{\mathbf{x}\cdot\mathbf{w}}{\mathbf{w}\cdot\mathbf{w}}$

3. $\dfrac{1}{\mathbf{w}\cdot\mathbf{w}}\mathbf{w}$

4. $\dfrac{1}{\mathbf{u}\cdot\mathbf{u}}\mathbf{u}$

5. $\left(\dfrac{\mathbf{u}\cdot\mathbf{v}}{\mathbf{v}\cdot\mathbf{v}}\right)\mathbf{v}$

6. $\left(\dfrac{\mathbf{x}\cdot\mathbf{w}}{\mathbf{x}\cdot\mathbf{x}}\right)\mathbf{x}$

7. $\|\mathbf{w}\|$

8. $\|\mathbf{x}\|$

1) $U\cdot U = 5$
$V\cdot U = 8$
$\dfrac{V\cdot U}{U\cdot U} = \dfrac{8}{5}$

2) $w\cdot w = 35$
$x\cdot w = 5$
$\dfrac{x\, w}{w\cdot w} = \dfrac{5}{35} = \dfrac{1}{7}$

3) $\dfrac{w}{w\cdot w} = \begin{bmatrix} 3/35 \\ -1/35 \\ -1/7 \end{bmatrix}$

4) $\dfrac{U}{U\cdot U} = \begin{bmatrix} -1/5 \\ 2/5 \end{bmatrix}$

5) $V\cdot V = 52$
$\left(\dfrac{U\cdot V}{V\cdot V}\right)V = \dfrac{8}{52}V = \dfrac{2}{13}V$
$= \begin{bmatrix} 8/13 \\ 12/13 \end{bmatrix}$

6) $x\cdot x = 49$
$\left(\dfrac{x\cdot w}{x\cdot x}\right)x = \dfrac{5}{49}x$
$= \begin{bmatrix} 30/49 \\ -10/49 \\ 15/49 \end{bmatrix}$

7) $\|w\| = \sqrt{w\cdot w}$
$= \sqrt{35}$

8) $\|x\| = \sqrt{x\cdot x}$
$= 7$

In Exercises 19 and 20, all vectors are in $\mathbb{R}^n$. Mark each statement True or False. Justify each answer.

19. a. $\mathbf{v}\cdot\mathbf{v} = \|\mathbf{v}\|^2$.
b. For any scalar c, $\mathbf{u}\cdot(c\mathbf{v}) = c(\mathbf{u}\cdot\mathbf{v})$.
c. If the distance from $\mathbf{u}$ to $\mathbf{v}$ equals the distance from $\mathbf{u}$ to $-\mathbf{v}$, then $\mathbf{u}$ and $\mathbf{v}$ are orthogonal.
d. For a square matrix A, vectors in Col A are orthogonal to vectors in Nul A.
e. If vectors $\mathbf{v}_1, \ldots, \mathbf{v}_p$ span a subspace W and if $\mathbf{x}$ is orthogonal to each $\mathbf{v}_j$ for $j = 1, \ldots, p$, then $\mathbf{x}$ is in $W^\perp$.

a	b	c	d	e
T	T	T	F	T

a. $V\cdot V = \|V\|\,\|V\|\cos(0)$

b. $U\cdot(cV) = \|U\|\,|c|\,\|V\|\cos(\theta)$
$= c\,\|U\|\,\|V\|\cos(\theta) = |c|\,(U\cdot V)$

c. distance of $U(-V) = \|U-(-V)\|$
$d^2 = \|U+V\|^2$
$= (U+V)\cdot(U+V)$
$= U\cdot(U+V) + V\cdot(U+V)$
$= \|U\|^2 + \|V\|^2 + 2U\cdot V$

distance of $U(V) = \|U\|^2 + \|-V\|^2 + 2U\cdot(-V)$
$= \|U\|^2 + \|V\|^2 - 2U\cdot V$

distances are equal when
$2U\cdot V = -2U\cdot V$
$U\cdot V = 0$

d. d) $\mathrm{Col}(A) \perp \mathrm{Null}(A)$?
let $A = \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix}$
$\mathrm{Col}(A) = \mathrm{span}\left\{\begin{pmatrix} 1 \\ 0 \end{pmatrix}\right\}$
$\mathrm{Null}(A) = \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$ $\quad \mathrm{Null}(A) = \mathrm{span}\left\{\begin{pmatrix} -1 \\ 1 \end{pmatrix}\right\}$
$\begin{pmatrix} 1 \\ 0 \end{pmatrix}\cdot\begin{pmatrix} -1 \\ 1 \end{pmatrix} = -1 \neq 0$

e) Every x is $\perp$ to every vector in W

e) $\mathrm{span}\{V_1, \ldots V_p\} = W$ subsp
$x \in W^\perp = \{v \in V : v\cdot w = 0$ for all $w \in W\}$
Show $x\cdot w = 0$ for all $w \in W$
$x\cdot w = x\cdot(\alpha_1 V_1 + \ldots \alpha_p V_p) = x\cdot\alpha_1 V_1 + \ldots + x\cdot\alpha_p V_p$
$= \alpha_1(x\cdot V_1) + \ldots + \alpha_p(x\cdot V_p)$
$= \alpha_1(0) + \ldots + \alpha_p(0) = 0$

$\boxed{\begin{array}{l} x\cdot V_1 = 0 \\ x\cdot V_2 = 0 \\ \vdots \\ x\cdot V_p = 0 \end{array}}$

30. Let W be a subspace of $\mathbb{R}^n$, and let $W^\perp$ be the set of all vectors orthogonal to W. Show that $W^\perp$ is a subspace of $\mathbb{R}^n$ using the following steps.

a. Take $\mathbf{z}$ in $W^\perp$, and let $\mathbf{u}$ represent any element of W. Then $\mathbf{z}\cdot\mathbf{u} = 0$. Take any scalar c and show that $c\mathbf{z}$ is orthogonal to $\mathbf{u}$. (Since $\mathbf{u}$ was an arbitrary element of W, this will show that $c\mathbf{z}$ is in $W^\perp$.)

b. Take $\mathbf{z}_1$ and $\mathbf{z}_2$ in $W^\perp$, and let $\mathbf{u}$ be any element of W. Show that $\mathbf{z}_1 + \mathbf{z}_2$ is orthogonal to $\mathbf{u}$. What can you conclude about $\mathbf{z}_1 + \mathbf{z}_2$? Why?

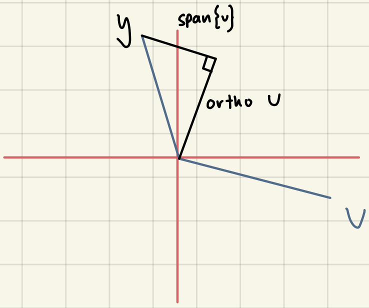
c. Finish the proof that $W^\perp$ is a subspace of $\mathbb{R}^n$.

Basically, 3 steps to prove subspace

1) Null vector included
2) Closed under addition
3) Closed under scalar multiplication

EXAMPLE 3 Let $\mathbf{y} = \begin{bmatrix} 7 \\ 6 \end{bmatrix}$ and $\mathbf{u} = \begin{bmatrix} 4 \\ 2 \end{bmatrix}$. Find the orthogonal projection of $\mathbf{y}$ onto $\mathbf{u}$. Then write $\mathbf{y}$ as the sum of two orthogonal vectors, one in Span $\{\mathbf{u}\}$ and one orthogonal to $\mathbf{u}$.

$v = \begin{bmatrix} 4 \\ 2 \end{bmatrix}$



Let ortho(v) = w

$y = w - k\begin{bmatrix} 4 \\ 2 \end{bmatrix}$, k is some constant

$w \cdot \begin{bmatrix} 4k \\ 2k \end{bmatrix} = 0$

$\therefore w = \begin{bmatrix} -1a \\ 2a \end{bmatrix}$, a is some constant

$k\begin{bmatrix} 4 \\ 2 \end{bmatrix} + a\begin{bmatrix} -1 \\ 2 \end{bmatrix} = \begin{bmatrix} 7 \\ 6 \end{bmatrix}$

$\begin{bmatrix} 4 & -1 \\ 2 & 2 \end{bmatrix}\begin{bmatrix} k \\ a \end{bmatrix} = \begin{bmatrix} 7 \\ 6 \end{bmatrix}$

$\left[\begin{array}{cc|c} 4 & -1 & 7 \\ 2 & 2 & 6 \end{array}\right] = \left[\begin{array}{cc|c} 1 & 0 & 2 \\ 0 & 1 & 1 \end{array}\right]$

$\therefore$ Span $\{v\} = \begin{bmatrix} 8 \\ 4 \end{bmatrix}$

$w = \begin{bmatrix} -1 \\ 2 \end{bmatrix}$

Q5) Lay/6.2/pg 345/Q17

In Exercises 17–22, determine which sets of vectors are orthonormal. If a set is only orthogonal, normalize the vectors to produce an orthonormal set.

17. $\begin{bmatrix} 1/3 \\ 1/3 \\ 1/3 \end{bmatrix}, \begin{bmatrix} -1/2 \\ 0 \\ 1/2 \end{bmatrix}$ **18.** $\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix}$

Q6) Lay/6.2/pg 345/Q23+24

In Exercises 23 and 24, all vectors are in $\mathbb{R}^n$. Mark each statement True or False. Justify each answer.

23. a. Not every linearly independent set in $\mathbb{R}^n$ is an orthogonal set.

b. If $\mathbf{y}$ is a linear combination of nonzero vectors from an orthogonal set, then the weights in the linear combination can be computed without row operations on a matrix.

c. If the vectors in an orthogonal set of nonzero vectors are normalized, then some of the new vectors may not be orthogonal.

d. A matrix with orthonormal columns is an orthogonal matrix.

e. If L is a line through $\mathbf{0}$ and if $\hat{\mathbf{y}}$ is the orthogonal projection of $\mathbf{y}$ onto L, then $\|\hat{\mathbf{y}}\|$ gives the distance from $\mathbf{y}$ to L.

24. a. Not every orthogonal set in $\mathbb{R}^n$ is linearly independent.

b. If a set $S = \{\mathbf{u}_1, \dots, \mathbf{u}_p\}$ has the property that $\mathbf{u}_i \cdot \mathbf{u}_j = 0$ whenever $i \neq j$, then S is an orthonormal set.

c. If the columns of an $m \times n$ matrix A are orthonormal, then the linear mapping $\mathbf{x} \mapsto A\mathbf{x}$ preserves lengths.

d. The orthogonal projection of $\mathbf{y}$ onto $\mathbf{v}$ is the same as the orthogonal projection of $\mathbf{y}$ onto $c\mathbf{v}$ whenever $c \neq 0$.

e. An orthogonal matrix is invertible.

Q7) Lay/6.2/pg 345/Q31

31. Show that the orthogonal projection of a vector $\mathbf{y}$ onto a line L through the origin in $\mathbb{R}^2$ does not depend on the choice of the nonzero $\mathbf{u}$ in L used in the formula for $\hat{\mathbf{y}}$. To do this, suppose $\mathbf{y}$ and $\mathbf{u}$ are given and $\hat{\mathbf{y}}$ has been computed by formula (2) in this section. Replace $\mathbf{u}$ in that formula by $c\mathbf{u}$, where c is an unspecified nonzero scalar. Show that the new formula gives the same $\hat{\mathbf{y}}$.

Q8) Lay/6.2/pg351/Example4

EXAMPLE 4 The distance from a point $\mathbf{y}$ in $\mathbb{R}^n$ to a subspace W is defined as the distance from $\mathbf{y}$ to the nearest point in W. Find the distance from $\mathbf{y}$ to $W = \text{Span}\,\{\mathbf{u}_1, \mathbf{u}_2\}$, where

$$\mathbf{y} = \begin{bmatrix} -1 \\ -5 \\ 10 \end{bmatrix}, \quad \mathbf{u}_1 = \begin{bmatrix} 5 \\ -2 \\ 1 \end{bmatrix}, \quad \mathbf{u}_2 = \begin{bmatrix} 1 \\ 2 \\ -1 \end{bmatrix}$$

Q9) Lay/pg353/Q21

In Exercises 17–22, determine which sets of vectors are orthonormal. If a set is only orthogonal, normalize the vectors to produce an orthonormal set.

17. $\begin{bmatrix} 1/3 \\ 1/3 \\ 1/3 \end{bmatrix}, \begin{bmatrix} -1/2 \\ 0 \\ 1/2 \end{bmatrix}$ **18.** $\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix}$

17. $\begin{bmatrix} 1/3 \\ 1/3 \\ 1/3 \end{bmatrix} \cdot \begin{bmatrix} -1/2 \\ 0 \\ 1/2 \end{bmatrix} = 0$ 18. $\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} = -1$

However, $\|U\|^2 = U \cdot U = 1/3$

$\|V\|^2 = V \cdot V = 1/2$

$\therefore$ not othonormal set

$\therefore$ normalize

$\begin{bmatrix} 1/3 \\ 1/3 \\ 1/3 \end{bmatrix} \div \sqrt{\tfrac{1}{3}} = \begin{bmatrix} \sqrt{3}/3 \\ \sqrt{3}/3 \\ \sqrt{3}/3 \end{bmatrix}$

$\begin{bmatrix} -1/2 \\ 0 \\ 1/2 \end{bmatrix} \div \sqrt{\tfrac{1}{2}} = \begin{bmatrix} -\sqrt{2}/2 \\ 0 \\ \sqrt{2}/2 \end{bmatrix}$ ← Othornomal sets are Splendid

In Exercises 23 and 24, all vectors are in $\mathbb{R}^n$. Mark each statement True or False. Justify each answer.

23. a. Not every linearly independent set in $\mathbb{R}^n$ is an orthogonal set.

b. If $\mathbf{y}$ is a linear combination of nonzero vectors from an orthogonal set, then the weights in the linear combination can be computed without row operations on a matrix.

c. If the vectors in an orthogonal set of nonzero vectors are normalized, then some of the new vectors may not be orthogonal.

d. A matrix with orthonormal columns is an orthogonal matrix.

e. If L is a line through $\mathbf{0}$ and if $\hat{\mathbf{y}}$ is the orthogonal projection of $\mathbf{y}$ onto L, then $\|\hat{\mathbf{y}}\|$ gives the distance from $\mathbf{y}$ to L.

24. a. Not every orthogonal set in $\mathbb{R}^n$ is linearly independent.

b. If a set $S = \{\mathbf{u}_1, \dots, \mathbf{u}_p\}$ has the property that $\mathbf{u}_i \cdot \mathbf{u}_j = 0$ whenever $i \neq j$, then S is an orthonormal set.

c. If the columns of an $m \times n$ matrix A are orthonormal, then the linear mapping $\mathbf{x} \mapsto A\mathbf{x}$ preserves lengths.

d. The orthogonal projection of $\mathbf{y}$ onto $\mathbf{v}$ is the same as the orthogonal projection of $\mathbf{y}$ onto $c\mathbf{v}$ whenever $c \neq 0$.

e. An orthogonal matrix is invertible.

a) linearly independent = Only solution for $Ax=0$ is 0

T ?

b) T

c) Normalizing vectors merely scales them.

Ortho set is subset of $\mathbb{R}^n$, $\therefore$ can be scaled

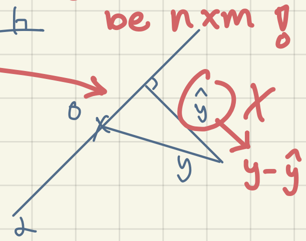
F

d) Matrix w. ortho columns is linearly independent

T ☆ False! Ortho matrix is square. Ortho colums can be $n \times m$!

e) Ortho is the shortest distance as $\perp$

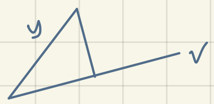
T ☆ False! $\|\hat{y}\|$



a) ? T! → L.I.

b) This means all vectors $\perp$, linearly independent

T ☆ F → It's othorgonal, not ortonomal set!



c) ? Yes, as othornomal modify direction as $\|A\| =$

↳ $\|Ax\|^2 = \|x\|^2$

24c. $A\mathbf{u} \cdot A\mathbf{v} = (A\mathbf{u})^T A\mathbf{v} = (\mathbf{u}^T A^T)A\mathbf{v} = \mathbf{u}^T(A^T A)\mathbf{v} = \mathbf{u}^T\mathbf{v} = \mathbf{u} \cdot \mathbf{v}$.

Replace v by u, we get $\|A\mathbf{u}\| = \|\mathbf{u}\|$

d) $\hat{y} = \dfrac{y \cdot u}{u \cdot u} u \; \dots > \; \dfrac{y \cdot (cu)}{(cu)\cdot(cu)}(cu) = \dfrac{c(y \cdot u)}{c^2(u \cdot u)}(c(u)) = \dfrac{y \cdot u}{u \cdot u} u = \hat{y}$

T

e) linear independent is invertible $QQ^T = I \; \dots \therefore Q^{-1} = Q^T$

T

In Exercises 21 and 22, all vectors and subspaces are in $\mathbb{R}^n$. Mark each statement True or False. Justify each answer.

21. a. If $\mathbf{z}$ is orthogonal to $\mathbf{u}_1$ and to $\mathbf{u}_2$ and if $W = \text{Span}\{\mathbf{u}_1, \mathbf{u}_2\}$, then $\mathbf{z}$ must be in $W^{\perp}$.

T, of course

b. For each $\mathbf{y}$ and each subspace W, the vector $\mathbf{y} - \text{proj}_W\,\mathbf{y}$ is orthogonal to W.

T, apply dot product

c. The orthogonal projection $\hat{\mathbf{y}}$ of $\mathbf{y}$ onto a subspace W can sometimes depend on the orthogonal basis for W used to compute $\hat{\mathbf{y}}$.

F,

d. If $\mathbf{y}$ is in a subspace W, then the orthogonal projection of $\mathbf{y}$ onto W is $\mathbf{y}$ itself.

e. If the columns of an $n \times p$ matrix U are orthonormal, then $UU^T\mathbf{y}$ is the orthogonal projection of $\mathbf{y}$ onto the column space of U.

Q10) Lay/pg 359/Q19+20

19. Suppose $A = QR$, where Q is $m \times n$ and R is $n \times n$. Show that if the columns of A are linearly independent, then R must be invertible. [*Hint:* Study the equation $R\mathbf{x} = \mathbf{0}$ and use the fact that $A = QR$.]

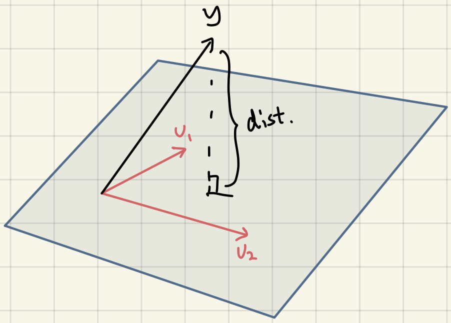
20. Suppose $A = QR$, where R is an invertible matrix. Show that A and Q have the same column space. [*Hint:* Given $\mathbf{y}$ in Col A, show that $\mathbf{y} = Q\mathbf{x}$ for some $\mathbf{x}$. Also, given $\mathbf{y}$ in Col Q, show that $\mathbf{y} = A\mathbf{x}$ for some $\mathbf{x}$.]

19. Suppose that $\mathbf{x}$ satisfies $R\mathbf{x} = 0$; then $QR\mathbf{x} = Q0 = 0$, and $A\mathbf{x} = \mathbf{0}$. Since the columns of A are linearly independent, $\mathbf{x}$ must be $\mathbf{0}$. This fact, in turn, shows that the columns of R are linearly indepedent. Since R is square, it is invertible by the Invertible Matrix Theorem.

20. If $\mathbf{y}$ is in Col$A$, then $\mathbf{y} = A\mathbf{x}$ for some $\mathbf{x}$. Then $\mathbf{y} = QR\mathbf{x} = Q(R\mathbf{x})$, which shows that $\mathbf{y}$ is a linear combination of the columns of Q using the entries in $R\mathbf{x}$ as weights. Conversly, suppose that $\mathbf{y} = Q\mathbf{x}$ for some $\mathbf{x}$. Since R is invertible, the equation $A = QR$ implies that $Q = AR^{-1}$. So $\mathbf{y} = AR^{-1}\mathbf{x} = A(R^{-1}\mathbf{x})$, which shows that $\mathbf{y}$ is in Col A.

Q7)

Show that the orthogonal projection of a vector $\mathbf{y}$ onto a line L through the origin in $\mathbb{R}^2$ does not depend on the choice of the nonzero $\mathbf{u}$ in L used in the formula for $\hat{\mathbf{y}}$. To do this, suppose $\mathbf{y}$ and $\mathbf{u}$ are given and $\hat{\mathbf{y}}$ has been computed by formula (2) in this section. Replace $\mathbf{u}$ in that formula by $c\mathbf{u}$, where c is an unspecified nonzero scalar. Show that the new formula gives the same $\hat{\mathbf{y}}$.



EXAMPLE 4 The distance from a point $\mathbf{y}$ in $\mathbb{R}^n$ to a subspace W is defined as the distance from $\mathbf{y}$ to the nearest point in W. Find the distance from $\mathbf{y}$ to $W = \text{Span}\{\mathbf{u}_1, \mathbf{u}_2\}$, where

$$\mathbf{y} = \begin{bmatrix} -1 \\ -5 \\ 10 \end{bmatrix}, \quad \mathbf{u}_1 = \begin{bmatrix} 5 \\ -2 \\ 1 \end{bmatrix}, \quad \mathbf{u}_2 = \begin{bmatrix} 1 \\ 2 \\ -1 \end{bmatrix}$$

$\hat{y} =$

Do this

EXAMPLE 3 If $\mathbf{u}_1 = \begin{bmatrix} 2 \\ 5 \\ -1 \end{bmatrix}$, $\mathbf{u}_2 = \begin{bmatrix} -2 \\ 1 \\ 1 \end{bmatrix}$, $\mathbf{y} = \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$, and $W = \text{Span}\{\mathbf{u}_1, \mathbf{u}_2\}$ as in Example 2, then the closest point in W to $\mathbf{y}$ is

$$\hat{y} = \frac{y \cdot u_1}{u_1 \cdot u_1} u_1 + \frac{y \cdot u_2}{u_2 \cdot u_2} u_2 = \begin{bmatrix} -2/5 \\ 2 \\ 1/5 \end{bmatrix}$$

Tut 6

2021/2022 SC1004 Tutorial 6

Q1: Find Orthogonal basis of A from the 3 vectors below in ex2.

EXAMPLE 2 Let $\mathbf{x}_1 = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$, $\mathbf{x}_2 = \begin{bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{bmatrix}$, and $\mathbf{x}_3 = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \end{bmatrix}$. Then $\{\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3\}$ is clearly linearly independent and thus is a basis for a subspace W of $\mathbb{R}^4$. Construct an orthogonal basis for W.

Q2: Form matrix A with the 3 column vectors x1,x2, x3 in Q1. Find its QR factorization.

Q3: Lay/Ch6.5/pg364/Ex4

EXAMPLE 4 Find a least-squares solution of $A\mathbf{x} = \mathbf{b}$ for

$$A = \begin{bmatrix} 1 & -6 \\ 1 & -2 \\ 1 & 1 \\ 1 & 7 \end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix} -1 \\ 2 \\ 1 \\ 6 \end{bmatrix}$$

Q4) Lay/ch6.5/pg 366/Q14/

14. Let $A = \begin{bmatrix} 2 & 1 \\ -3 & -4 \\ 3 & 2 \end{bmatrix}$, $\mathbf{b} = \begin{bmatrix} 5 \\ 4 \\ 4 \end{bmatrix}$, $\mathbf{u} = \begin{bmatrix} 4 \\ -5 \end{bmatrix}$, and $\mathbf{v} = \begin{bmatrix} 6 \\ -5 \end{bmatrix}$. Compute $A\mathbf{u}$ and $A\mathbf{v}$, and compare them with $\mathbf{b}$. Is it possible that at least one of $\mathbf{u}$ or $\mathbf{v}$ could be a least-squares solution of $A\mathbf{x} = \mathbf{b}$? (Answer this without computing a least-squares solution.)

Q5: Lay/ch6.5/pg366/Q17+18

In Exercises 17 and 18, A is an $m \times n$ matrix and $\mathbf{b}$ is in $\mathbb{R}^m$. Mark each statement True or False. Justify each answer.

17. a. The general least-squares problem is to find an $\mathbf{x}$ that makes $A\mathbf{x}$ as close as possible to $\mathbf{b}$.

Q1: Find Orthogonal basis of A from the 3 vectors below in ex2.

EXAMPLE 2 Let $\mathbf{x}_1 = \begin{bmatrix}1\\1\\1\\1\end{bmatrix}$, $\mathbf{x}_2 = \begin{bmatrix}0\\1\\1\\1\end{bmatrix}$, and $\mathbf{x}_3 = \begin{bmatrix}0\\0\\1\\1\end{bmatrix}$. Then $\{\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3\}$ is clearly linearly independent and thus is a basis for a subspace W of $\mathbb{R}^4$. Construct an orthogonal basis for W.

Orthogonal basis $V_1 = \begin{bmatrix}1\\1\\1\\1\end{bmatrix}$

$$V_2 = \begin{bmatrix}0\\1\\1\\1\end{bmatrix} - \frac{3}{4}\begin{bmatrix}1\\1\\1\\1\end{bmatrix} = \begin{bmatrix}-3/4\\1/4\\1/4\\1/4\end{bmatrix} \rightarrow \begin{bmatrix}-3\\1\\1\\1\end{bmatrix}$$

$$V_3 = \begin{bmatrix}0\\0\\1\\1\end{bmatrix} - \frac{2}{4}\begin{bmatrix}1\\1\\1\\1\end{bmatrix} - \frac{2}{12}\begin{bmatrix}-3\\1\\1\\1\end{bmatrix}$$

$$= \begin{bmatrix}0\\0\\1\\1\end{bmatrix} - \begin{bmatrix}1/2\\1/2\\1/2\\1/2\end{bmatrix} - \begin{bmatrix}-1/2\\1/6\\1/6\\1/6\end{bmatrix} = \begin{bmatrix}0\\-2/3\\1/3\\1/3\end{bmatrix}$$

$$\text{Ortho} = \begin{bmatrix}1\\1\\1\\1\end{bmatrix}, \begin{bmatrix}-3\\1\\1\\1\end{bmatrix}, \begin{bmatrix}0\\-2\\1\\1\end{bmatrix}$$

Q2: Form matrix A with the 3 column vectors x1,x2, x3 in Q1. Find its QR factorization.

$$Q = \begin{bmatrix}1 & -3 & 0\\1 & 1 & -2\\1 & 1 & 1\\1 & 1 & 1\end{bmatrix} \Rightarrow \text{must be othornomal}$$

$$= \begin{bmatrix}1 & -3/\sqrt{12} & 0\\1 & 1/\sqrt{12} & -2/\sqrt{6}\\1 & 1/\sqrt{12} & 1/\sqrt{6}\\1 & 1/\sqrt{12} & 1/\sqrt{6}\end{bmatrix}$$

$$Q^T = \begin{bmatrix}1 & 1 & 1 & 1\\-3/\sqrt{12} & 1/\sqrt{12} & 1/\sqrt{12} & 1/\sqrt{12}\\0 & -2/\sqrt{6} & 1/\sqrt{6} & 1/\sqrt{6}\end{bmatrix}\begin{bmatrix}1 & 0 & 0\\1 & 1 & 0\\1 & 1 & 1\\1 & 1 & 1\end{bmatrix}$$

$$= \begin{bmatrix}2 & 3/2 & 1\\0 & 3/\sqrt{12} & 2/\sqrt{12}\\0 & 0 & 2/\sqrt{6}\end{bmatrix}$$

$A = QR$

$Q^TA = Q^TQR$

$Q^TA = IR$

EXAMPLE 4 Find a least-squares solution of $A\mathbf{x} = \mathbf{b}$ for

$$A = \begin{bmatrix}1 & -6\\1 & -2\\1 & 1\\1 & 7\end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix}-1\\2\\1\\6\end{bmatrix}$$

The 3 important conditin

1) $A\hat{x} = \hat{b}$ has unique $\hat{b}$ sol
2) Col vect of A is LI
3) A^TA is invertible

Check: a_1 & a_2 are orthogonal

$$\hat{b} = \frac{b\cdot a_1}{a_1\cdot a_1}a_1 + \frac{b\cdot a_2}{a_2\cdot a_2}$$

$$= \frac{8}{4}a_1 + \frac{45}{90}a_2$$

$\therefore \; A\hat{x} = \hat{b}$

$$\hat{x} = \begin{bmatrix}8/4\\45/90\end{bmatrix} = \begin{bmatrix}2\\1/2\end{bmatrix}$$

b. A least-squares solution of $A\mathbf{x} = \mathbf{b}$ is a vector $\hat{\mathbf{x}}$ that satisfies $A\hat{\mathbf{x}} = \hat{\mathbf{b}}$, where $\hat{\mathbf{b}}$ is the orthogonal projection of $\mathbf{b}$ onto Col A.

c. A least-squares solution of $A\mathbf{x} = \mathbf{b}$ is a vector $\hat{\mathbf{x}}$ such that $\|\mathbf{b} - A\mathbf{x}\| \leq \|\mathbf{b} - A\hat{\mathbf{x}}\|$ for all $\mathbf{x}$ in $\mathbb{R}^n$.

d. Any solution of $A^TA\mathbf{x} = A^T\mathbf{b}$ is a least-squares solution of $A\mathbf{x} = \mathbf{b}$.

e. If the columns of A are linearly independent, then the equation $A\mathbf{x} = \mathbf{b}$ has exactly one least-squares solution.

Q6:

19. Let A be an $m \times n$ matrix. Use the steps below to show that a vector $\mathbf{x}$ in $\mathbb{R}^n$ satisfies $A\mathbf{x} = \mathbf{0}$ if and only if $A^TA\mathbf{x} = \mathbf{0}$. This will show that Nul A = Nul A^TA.

a. Show that if $A\mathbf{x} = \mathbf{0}$, then $A^TA\mathbf{x} = \mathbf{0}$.

b. Suppose $A^TA\mathbf{x} = \mathbf{0}$. Explain why $\mathbf{x}^TA^TA\mathbf{x} = \mathbf{0}$, and use this to show that $A\mathbf{x} = \mathbf{0}$.

20. Let A be an $m \times n$ matrix such that A^TA is invertible. Show that the columns of A are linearly independent. [*Careful:* You may not assume that A is invertible; it may not even be square.]

21. Let A be an $m \times n$ matrix whose columns are linearly independent. [*Careful:* A need not be square.]

a. Use Exercise 19 to show that A^TA is an invertible matrix.

b. Explain why A must have at least as many rows as columns.

c. Determine the rank of A.

Q7: Least-Squared Lines –best fit

In Exercises 1–4, find the equation $y = \beta_0 + \beta_1 x$ of the least-squares line that best fits the given data points.

1. $(0, 1), (1, 1), (2, 2), (3, 2)$

2. $(1, 0), (2, 1), (4, 2), (5, 3)$

14. Let $A = \begin{bmatrix} 2 & 1 \\ -3 & -4 \\ 3 & 2 \end{bmatrix}$, $\mathbf{b} = \begin{bmatrix} 5 \\ 4 \\ 4 \end{bmatrix}$, $\mathbf{u} = \begin{bmatrix} 4 \\ -5 \end{bmatrix}$, and $\mathbf{v} = \begin{bmatrix} 6 \\ -5 \end{bmatrix}$. Compute $A\mathbf{u}$ and $A\mathbf{v}$, and compare them with $\mathbf{b}$. Is it possible that at least one of $\mathbf{u}$ or $\mathbf{v}$ could be a least-squares solution of $A\mathbf{x} = \mathbf{b}$? (Answer this without computing a least-squares solution.)

Projection vector is unique

$$A u = \begin{bmatrix} 2 & 1 \\ -3 & -4 \\ 3 & 2 \end{bmatrix}\begin{bmatrix} 4 \\ -5 \end{bmatrix} = \begin{bmatrix} 3 \\ 8 \\ 2 \end{bmatrix}, \quad b - Au = \begin{bmatrix} 2 \\ -4 \\ 2 \end{bmatrix}, \quad \|b - Au\| = \sqrt{24}$$

$$A v = \begin{bmatrix} 2 & 1 \\ -3 & -4 \\ 3 & 2 \end{bmatrix}\begin{bmatrix} 6 \\ -5 \end{bmatrix} = \begin{bmatrix} -2 \\ 2 \\ -4 \end{bmatrix} \quad b - Av = \begin{bmatrix} -2 \\ 2 \\ -4 \end{bmatrix}, \quad \|b - Av\| = \sqrt{24}$$

In Exercises 17 and 18, A is an $m \times n$ matrix and $\mathbf{b}$ is in $\mathbb{R}^m$. Mark each statement True or False. Justify each answer.

17. a. The general least-squares problem is to find an $\mathbf{x}$ that makes $A\mathbf{x}$ as close as possible to $\mathbf{b}$. → T, find ortho

b. A least-squares solution of $A\mathbf{x} = \mathbf{b}$ is a vector $\hat{\mathbf{x}}$ that satisfies $A\hat{\mathbf{x}} = \hat{\mathbf{b}}$, where $\hat{\mathbf{b}}$ is the orthogonal projection of $\mathbf{b}$ onto Col A. → T

c. A least-squares solution of $A\mathbf{x} = \mathbf{b}$ is a vector $\hat{\mathbf{x}}$ such that $\|\mathbf{b} - A\mathbf{x}\| \le \|\mathbf{b} - A\hat{\mathbf{x}}\|$ for all $\mathbf{x}$ in $\mathbb{R}^n$. → F, this is biggest error

d. Any solution of $A^TA\mathbf{x} = A^T\mathbf{b}$ is a least-squares solution of $A\mathbf{x} = \mathbf{b}$. → T, normal Eq^n

e. If the columns of A are linearly independent, then the equation $A\mathbf{x} = \mathbf{b}$ has exactly one least-squares solution. → T !

19. Let A be an $m \times n$ matrix. Use the steps below to show that a vector $\mathbf{x}$ in $\mathbb{R}^n$ satisfies $A\mathbf{x} = \mathbf{0}$ if and only if $A^TA\mathbf{x} = \mathbf{0}$. This will show that Nul A = Nul A^TA. ✱ Study this

a. Show that if $A\mathbf{x} = \mathbf{0}$, then $A^TA\mathbf{x} = \mathbf{0}$.

b. Suppose $A^TA\mathbf{x} = \mathbf{0}$. Explain why $\mathbf{x}^TA^TA\mathbf{x} = \mathbf{0}$, and use this to show that $A\mathbf{x} = \mathbf{0}$.

a) $Ax = 0$
$A^TAx = A^T0$
$A^TAx = 0$

b) Prove, if $A^TAx = 0$, why $Ax = 0$

$A^TAx = 0$
$x^T(A^TAx) = x^T0$
$x^TA^TAx = 0$
$(Ax)^TAx = 0$
$Ax \cdot Ax = 0$
$\|Ax\|^2 = 0 \quad \therefore Ax = 0$

$U^TU = U \cdot U = \|U\|^2$

20. Let A be an $m \times n$ matrix such that A^TA is invertible. Show that the columns of A are linearly independent. [*Careful:* You may not assume that A is invertible; it may not even be square.]

The only way to compute is to find the rank
If $Ax = 0$, then $A^TAx = A^T0 = 0$, Since A^TA is invertible, $x = 0$,
$\therefore$ LI

If $Ax = 0$, $x = 0$ for linear independent
for $A_{m \times n}$, Null(A) = {0} ⇒ Null(A) = 0
Rank theorem: # of collum = Col Rank(A) + dimention of Null(A)
= n + 0

Col ⇒ n, ∴ LI

21. Let A be an $m \times n$ matrix whose columns are linearly independent. [*Careful:* A need not be square.]

a. Use Exercise 19 to show that $A^T A$ is an invertible matrix.

b. Explain why A must have at least as many rows as columns.

c. Determine the rank of A.

a) If A has linearly independent

b) A has full rank, as they are linearly independent

If A is LI, when sent to R^m, $\rightarrow$ Col(A)

Q7: Least-Squared Lines –best fit

In Exercises 1–4, find the equation $y = \beta_0 + \beta_1 x$ of the least-squares line that best fits the given data points.

1. (0, 1), (1, 1), (2, 2), (3, 2)
2. (1, 0), (2, 1), (4, 2), (5, 3)

Matrix :

$$x = \begin{bmatrix} 1 & 1 \\ 1 & 2 \\ 1 & 4 \\ 1 & 5 \end{bmatrix}$$

☆ invertible matrix theorem

☆ linear independence

$\sqrt{2}$ problem, identity which universe

① discrete

↓

② ∞

↓

Find out the steps.

① universe, exist exact & unique V^2 solution

just use $\hat{x} = (A^T A)^{-1} (A^T(b))$

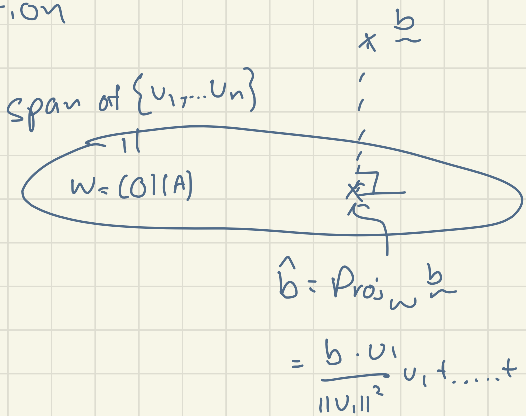
compute $\hat{x}$

② universe, no exact V^2 solution

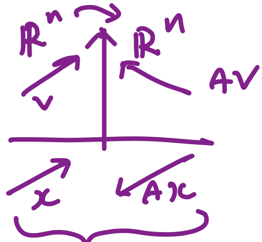
$Ax = b$

① Col (A) is LD

② $A^T A$ not invertible



also, if non-ortho, just use grand-smith nxn Square matrix



if $Ax \parallel x$,
Ax is eigenvect.

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Q1 Lay/Ch5.1/pg271/Ex6+7

6. Is $\begin{bmatrix} 1 \\ -2 \\ 1 \end{bmatrix}$ an eigenvector of $\begin{bmatrix} 3 & 6 & 7 \\ 3 & 3 & 7 \\ 5 & 6 & 5 \end{bmatrix}$? If so, find the eigenvalue.

7. Is $\lambda = 4$ an eigenvalue of $\begin{bmatrix} 3 & 0 & -1 \\ 2 & 3 & 1 \\ -3 & 4 & 5 \end{bmatrix}$? If so, find one corresponding eigenvector.

Some no eigen
↳ Rotation

Q2: Find the eigenvalues & eigenvectors of

$$A = \begin{pmatrix} 0 & -1 & -1 \\ 1 & 2 & 1 \\ 1 & 1 & 2 \end{pmatrix}$$ compute

Q3) Lay/Ch5/pg272/

Find an eigen -basis of the -2 eigenspace of A.

14. $A = \begin{bmatrix} 1 & 0 & -1 \\ 1 & -3 & 0 \\ 4 & -13 & 1 \end{bmatrix}, \lambda = -2$

Q4: If {u,v} are linearly independent eigenvectors, then they must correspond to distinct eigenvalues.

Q5) Lay/ch5.1/pg 274/Q5

25. Let λ be an eigenvalue of an invertible matrix A. Show that λ^{-1} is an eigenvalue of A^{-1}. [*Hint:* Suppose a nonzero $\mathbf{x}$ satisfies $A\mathbf{x} = \lambda\mathbf{x}$.]

Q6) Lay/Ch5.3/pg288

In Exercises 5 and 6, the matrix A is factored in the form PDP^{-1}. Use the Diagonalization Theorem to find the eigenvalues of A and a basis for each eigenspace.

5. $\begin{bmatrix} 2 & 2 & 1 \\ 1 & 3 & 1 \\ 1 & 2 & 2 \end{bmatrix} =$

$$\begin{bmatrix} 1 & 1 & 2 \\ 1 & 0 & -1 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} 5 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1/4 & 1/2 & 1/4 \\ 1/4 & 1/2 & -3/4 \\ 1/4 & -1/2 & 1/4 \end{bmatrix}$$

Q7) Lay/Ch5.3/pg 289/Q21+23

In Exercises 21 and 22, A, B, P, and D are $n \times n$ matrices. Mark each statement True or False. Justify each answer. (Study Theorems 5 and 6 and the examples in this section carefully before you try these exercises.)

21. a. A is diagonalizable if $A = PDP^{-1}$ for some matrix D and some invertible matrix P.

b. If $\mathbb{R}^n$ has a basis of eigenvectors of A, then A is diagonalizable.

c. A is diagonalizable if and only if A has n eigenvalues, counting multiplicities.

d. If A is diagonalizable, then A is invertible.

22. a. A is diagonalizable if A has n eigenvectors.

b. If A is diagonalizable, then A has n distinct eigenvalues.

c. If $AP = PD$, with D diagonal, then the nonzero columns of P must be eigenvectors of A.

d. If A is invertible, then A is diagonalizable.

Q8) Lay./Ch5.3/pg289/Q31+32

31. Construct a nonzero 2×2 matrix that is invertible but not diagonalizable.

32. Construct a nondiagonal 2×2 matrix that is diagonalizable but not invertible.

Q9) Lay/ch5.6/pg 311/Practise

PRACTICE PROBLEMS

1. The matrix A below has eigenvalues 1, $\frac{2}{3}$, and $\frac{1}{3}$, with corresponding eigenvectors $\mathbf{v}_1$, $\mathbf{v}_2$, and $\mathbf{v}_3$:

$$A = \frac{1}{9}\begin{bmatrix} 7 & -2 & 0 \\ -2 & 6 & 2 \\ 0 & 2 & 5 \end{bmatrix}, \quad \mathbf{v}_1 = \begin{bmatrix} -2 \\ 2 \\ 1 \end{bmatrix}, \quad \mathbf{v}_2 = \begin{bmatrix} 2 \\ 1 \\ 2 \end{bmatrix}, \quad \mathbf{v}_3 = \begin{bmatrix} 1 \\ 2 \\ -2 \end{bmatrix}$$

Find the general solution of the equation $\mathbf{x}_{k+1} = A\mathbf{x}_k$ if $\mathbf{x}_0 = \begin{bmatrix} 1 \\ 11 \\ -2 \end{bmatrix}$.

2. What happens to the sequence $\{\mathbf{x}_k\}$ in Practice Problem 1 as $k \to \infty$?

Q10:

Compute A^8, where $A = \begin{bmatrix} 4 & -3 \\ 2 & -1 \end{bmatrix}$.