



# LINEAR ALGEBRA CHEAT SHEET

16

PAGES

## BONUS: LINEAR ALGEBRA THEOREMS

$A = C$

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### Linear Algebra

#### Vector Operations

- **Vector addition** is a component-wise operation. Two vectors  $\mathbf{v}$  and  $\mathbf{w}$  may be added together as long as they contain the same number  $n$  of components. Their sum is another vector, whose  $i$ th component is the sum of the  $i$ th components of  $\mathbf{v}$  and  $\mathbf{w}$ :

$$\begin{bmatrix} 1 \\ 2 \end{bmatrix} + \begin{bmatrix} 3 \\ 4 \end{bmatrix} = \begin{bmatrix} 1+3 \\ 2+4 \end{bmatrix}$$

- Vectors may be multiplied by a scalar. The product  $c\mathbf{v}$  is a vector, whose  $i$ th component is the product of  $c$  and the  $i$ th component of  $\mathbf{v}$ :

$$5 \begin{bmatrix} 1 \\ 2 \end{bmatrix} = \begin{bmatrix} 5(1) \\ 5(2) \end{bmatrix}$$

- A **linear combination** of vectors is a sum of scalar multiples of vectors (with the same number of components):

$$2 \begin{bmatrix} 1 \\ 2 \end{bmatrix} + 3 \begin{bmatrix} 3 \\ 4 \end{bmatrix} = 2 \begin{bmatrix} 1 \\ 2 \end{bmatrix} + 3 \begin{bmatrix} 3 \\ 4 \end{bmatrix}$$

- The **dot product** of two vectors is a scalar, and is only defined when the vectors have the same number of components. It is the sum of the products of the  $i$ th components of the vectors:

$$\begin{bmatrix} 1 \\ 2 \end{bmatrix} \cdot \begin{bmatrix} 3 \\ 4 \end{bmatrix} = (1)(3) + (2)(4)$$

- The **length** of a vector is a scalar. It is found by taking the square root of the sum of the squares of the vector's components:

$$\left\| \begin{bmatrix} 1 \\ 2 \end{bmatrix} \right\| = \sqrt{1^2 + 2^2 + 2^2}$$

- A **unit vector** is a vector of length one. For example,  $(1, 0, 0)$  and  $(1/\sqrt{2}, 1/\sqrt{2})$ .

- The **angle  $\theta$**  between two vectors  $\mathbf{v}$  and  $\mathbf{w}$  is related to their lengths and dot products by the formula:

$$\cos(\theta) = \frac{\mathbf{v} \cdot \mathbf{w}}{\|\mathbf{v}\| \|\mathbf{w}\|}$$

- Two vectors are **perpendicular** (also called **orthogonal**) if they have a dot product of 0.

### Linear Algebra Theorems

#### Theorem 1.1 Uniqueness of Reduced Echelon Form

Two matrices are row equivalent to one and only one reduced echelon matrix.

#### Theorem 1.2 Existence and Uniqueness Theorem

A linear system is consistent if and only if the rightmost column of the augmented matrix is not a pivot column - that is, and only if an echelon form of the augmented matrix has no row of the form

$$[0 \cdots 0 \mid b] \text{ with } b \neq 0.$$

If a linear system is consistent, then the solution set contains either (i) a unique solution, when there are no free variables or (ii) infinitely many solutions, when there is at least one free variable.

#### Theorem 1.3

If  $A$  is an  $m \times n$  matrix, with columns  $\mathbf{a}_1, \mathbf{a}_2, \dots, \mathbf{a}_n$ , and if  $\mathbf{b}$  is in  $\mathbb{R}^m$ , the matrix equation

$$A\mathbf{x} = \mathbf{b}$$

has the same solution set as the vector equation

$$x_1\mathbf{a}_1 + x_2\mathbf{a}_2 + \cdots + x_n\mathbf{a}_n = \mathbf{b}$$

which, in turn, has the same solution set as the system of linear equations whose augmented matrix is

$$[\mathbf{a}_1 \ \mathbf{a}_2 \ \cdots \ \mathbf{a}_n \ \mathbf{b}].$$

#### Theorem 1.4

Let  $A$  be an  $m \times n$  matrix. Then the following statements are logically equivalent. That is, for a particular  $A$ , either  $n$  are all true statements or they are all false.

- For each  $\mathbf{b}$  in  $\mathbb{R}^m$ , the equation  $A\mathbf{x} = \mathbf{b}$  has a solution.
- Each  $\mathbf{b}$  in  $\mathbb{R}^m$  is a linear combination of the columns of  $A$ .
- The columns of  $A$  span  $\mathbb{R}^m$ .
- $A$  has a pivot position in every row.

#### Theorem 1.5

If  $A$  is an  $m \times n$  matrix,  $\mathbf{u}$  and  $\mathbf{v}$  are vectors in  $\mathbb{R}_n$ , and  $c$  is a scalar, then:

- $A(\mathbf{u} + \mathbf{v}) = A\mathbf{u} + A\mathbf{v}$
- $A(c\mathbf{u}) = c(A\mathbf{u})$

#### Theorem 1.6

Suppose the equation  $A\mathbf{x} = \mathbf{b}$  is consistent for some given  $\mathbf{b}$ , and let  $\mathbf{p}$  be a solution. Then the solution set of  $A\mathbf{x} = \mathbf{b}$  is the set of all vectors of the form  $\mathbf{w} = \mathbf{p} + \mathbf{w}_h$ , where  $\mathbf{w}_h$  is any solution of the homogeneous equation  $A\mathbf{x} = \mathbf{0}$ .

#### Theorem 1.7

Let  $\mathcal{B} = \{\mathbf{v}_1, \dots, \mathbf{v}_k\}$  be a set of vectors in  $\mathbb{R}^n$ . The following statements are equivalent:

- $\mathcal{B}$  is a linearly independent set.
- The equation  $x_1\mathbf{v}_1 + \cdots + x_k\mathbf{v}_k = \mathbf{0}$  has only the trivial solution.
- The SLS  $\{\mathbf{v}_1, \dots, \mathbf{v}_k\} \mathbf{x} = \mathbf{0}$  has a unique solution.
- In the matrix  $[\mathbf{v}_1 \ \cdots \ \mathbf{v}_k]$ , every column is a pivot column.
- No vector in  $\mathcal{B}$  lies in the span of the remaining vectors.

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