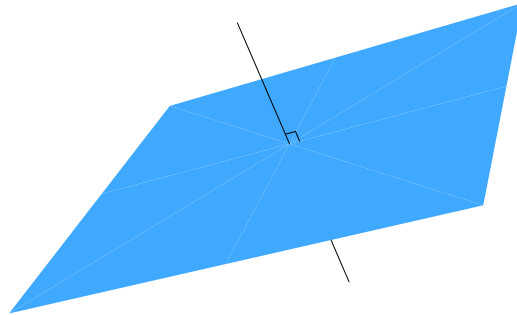


More on orthogonal complements

Definition. Given a subspace S of \mathbb{R}^n , its orthogonal complement S^\perp is the set

$$\{\mathbf{v} \mid \mathbf{v} \cdot \mathbf{w} = 0 \text{ for all } \mathbf{w} \in S\}.$$



Examples.

1. The orthogonal complement of a line through the origin in \mathbb{R}^3 is a plane through the origin.
2. The orthogonal complement of a plane through the origin in \mathbb{R}^3 is a line through the origin.
3. Consider an $m \times n$ matrix

$$\mathbf{A} = \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \vdots \\ \mathbf{r}_m \end{bmatrix}.$$

What can you say about a vector \mathbf{v} in \mathbb{R}^n that is orthogonal to all of the rows of \mathbf{A} ?

Theorem. Let S be a subspace of \mathbb{R}^n and let S^\perp be its orthogonal complement. Then

1. S^\perp is a subspace of \mathbb{R}^n ,
2. $\dim(S^\perp) = n - \dim(S)$,
3. $(S^\perp)^\perp = S$, and
4. every vector \mathbf{v} in \mathbb{R}^n can be written uniquely as $\mathbf{v} = \mathbf{v}_1 + \mathbf{v}_2$, where \mathbf{v}_1 is in S and \mathbf{v}_2 is in S^\perp .

It helps to have a little more theory before we can verify properties 2, 3, and 4, but we can verify property 1 directly from the definition.

Orthogonal sets

Definition. A set of vectors $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_k\}$ is an orthogonal set if $\mathbf{v}_i \cdot \mathbf{v}_j = 0$ for all $i \neq j$.

Example 1. Consider the vectors

$$\mathbf{v}_1 = \begin{bmatrix} 2 \\ -1 \\ 4 \\ 5 \end{bmatrix}, \quad \mathbf{v}_2 = \begin{bmatrix} 0 \\ -1 \\ 1 \\ -1 \end{bmatrix}, \quad \text{and} \quad \mathbf{v}_3 = \begin{bmatrix} 0 \\ 3 \\ 2 \\ -1 \end{bmatrix}.$$

Theorem. Suppose that $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_k\}$ is an orthogonal set of nonzero vectors.

1. If $\mathbf{u} = c_1\mathbf{v}_1 + c_2\mathbf{v}_2 + \dots + c_k\mathbf{v}_k$, then the weights c_i are given by $c_i = \frac{\mathbf{u} \cdot \mathbf{v}_i}{\mathbf{v}_i \cdot \mathbf{v}_i}$.
2. The set $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_k\}$ is linearly independent.

Example. Using the orthogonal set $\{\mathbf{v}_1, \mathbf{v}_2, \mathbf{v}_3\}$ in Example 1, apply this theorem to the vector

$$\mathbf{v} = \begin{bmatrix} -45 \\ -4 \\ 3 \\ 1 \end{bmatrix}.$$

Instant replay. Enlarge the orthogonal set in Example 1 by including the vector

$$\mathbf{v}_4 = \begin{bmatrix} -21 \\ -1 \\ 4 \\ 5 \end{bmatrix}.$$

Orthonormal sets

Definition. A set of vectors $\{\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_k\}$ is orthonormal if it is orthogonal and $\mathbf{v}_i \cdot \mathbf{v}_i = 1$ for all i .

Example. Consider the vectors

$$\mathbf{v}_1 = \begin{bmatrix} 2 \\ -1 \\ 2 \end{bmatrix}, \quad \mathbf{v}_2 = \begin{bmatrix} -1 \\ 2 \\ 2 \end{bmatrix}, \quad \text{and} \quad \mathbf{v}_3 = \begin{bmatrix} 2 \\ 2 \\ -1 \end{bmatrix}.$$