

Source: [KBe2020math530refExr0nRetIndex](#)

## 1 | Prompt

Which of the following systems have a unique solution? You do NOT have to solve the 3 variable system by hand; you can graph it or use other resources. What does this have to do with linearly dependent/independent vectors??

## 2 | Ideas

I first focused on the systems of 2 var 2 equs. I thought of the first set

$$\begin{aligned} 2x - 3y &= 1 \\ x + 3y &= 3 \end{aligned}$$

as asking

$$(1, 3) \stackrel{?}{\in} \text{span}((2, 1), (-, 31))$$

but that didn't really get me anywhere.

Then, I tried writing it as a matrix equation:

$$\begin{bmatrix} 2 & -3 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 3 \end{bmatrix}$$

I figured that because we wanted to know whether the system is linearly independent or not, which is a boolean value, I had to compress the matrix down to some number that can then be compared. The only way I know how to do that is by taking the determinant, so I tried to find some connection between the determinant of a 2x2 matrix and whether it's component rows interpreted as vectors of  $\mathbb{F}^2$  are linearly dependant.

## 3 | Lemma

A pair of vectors  $u, v$  in a vector space  $V$  over  $\mathbb{F}^2$  are linearly dependent iff  $\begin{vmatrix} u_1 & u_2 \\ v_1 & v_2 \end{vmatrix} = 0$ .

## 4 | Proof

### In the forwards direction

Showing that if  $u, v$  are linearly dependent, then

$$\begin{vmatrix} u_1 & u_2 \\ v_1 & v_2 \end{vmatrix} = 0$$

Suppose  $u, v$  are linearly dependent. Then, we can write  $v$  as  $au : a \in \mathbb{F}$ . Then the target determinant can be written as

$$\begin{vmatrix} u_1 & u_2 \\ au_1 & au_2 \end{vmatrix} = u_1 au_2 + -u_2 au_1$$

Because  $u_1 au_2 = -u_2 au_1$ , their sum is clearly 0.

**In the reverse direction**

Showing that if  $\begin{vmatrix} a & b \\ c & d \end{vmatrix} = 0$ , then the vectors  $(a, b), (c, d)$  are linearly dependent.

Two vectors  $u, v \in \mathbb{F}^2 : u = (a, b), v = (c, d)$  and  $a, b, c, d \in \mathbb{F}$  are linearly dependent if one is a linear combination of the other, or  $(a, b) = u = kv = (kc, kd)$  wlog.

$$\begin{aligned} \begin{vmatrix} a & b \\ c & d \end{vmatrix} &= ad - bc = 0 \\ \Rightarrow ad &= bc \\ \Rightarrow \frac{a}{c} &= \frac{b}{d} \end{aligned}$$

If we define

$$k = \frac{a}{c} = \frac{b}{d}$$

then it is clear that

$$\begin{aligned} a &= kc \\ b &= kd \\ \Rightarrow (a, b) &= (kc, kd) \end{aligned}$$

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