



UNIVERSITY OF LEEDS

Class: Machine Learning

Preliminaries

Instructor: Matteo Leonetti

What is the derivative of

$$f(x) = 2x$$

$$f(x) = 2x + x^2$$

What is the derivative of

$$f(x) = 2x$$

$$f'(x) = 2$$

$$f(x) = 2x + x^2$$

$$f'(x) = 2 + 2x$$

Partial Derivatives



UNIVERSITY OF LEEDS

With functions of more than one variable, we can compute the derivative with respect to each variable, treating the others as constants:

$$f(x, y) = 2x + 3y \quad \frac{\partial f(x, y)}{\partial x} = 2 \quad \frac{\partial f(x, y)}{\partial y} = 3$$

What are the partial derivatives of:

$$f(x, y, z) = 2x^2 + xy + yz^2$$

Partial Derivatives

With functions of more than one variable, we can compute the derivative with respect of each variable, treating the others as constants:

$$f(x, y) = 2x + 3y \quad \frac{\partial f(x, y)}{\partial x} = 2 \quad \frac{\partial f(x, y)}{\partial y} = 3$$

What are the partial derivatives of:

$$f(x, y, z) = 2x^2 + xy + yz^2$$

$$\frac{\partial f(x, y, z)}{\partial x} = 4x + y \quad \frac{\partial f(x, y, z)}{\partial y} = x + z^2 \quad \frac{\partial f(x, y, z)}{\partial z} = 2yz$$

Partial Derivatives

The vector of partial derivatives is called the **gradient**:

$$f(x, y, z) = 2x^2 + xy + yz^2$$

$$\nabla f(x, y, z) = \begin{bmatrix} \frac{\partial f(x, y, z)}{\partial x} \\ \frac{\partial f(x, y, z)}{\partial y} \\ \frac{\partial f(x, y, z)}{\partial z} \end{bmatrix} = \begin{bmatrix} 4x + y \\ x + z^2 \\ 2yz \end{bmatrix}$$

More on calculus

Watch this video series!

<https://www.youtube.com/playlist?list=PLZHQObOWTQDMsr9K-rj53DwVRMYO3t5Yr>

On Partial derivatives:

<https://youtu.be/AXqhWeUEtQU>

Gradient:

<https://youtu.be/tlpKfDc295M>

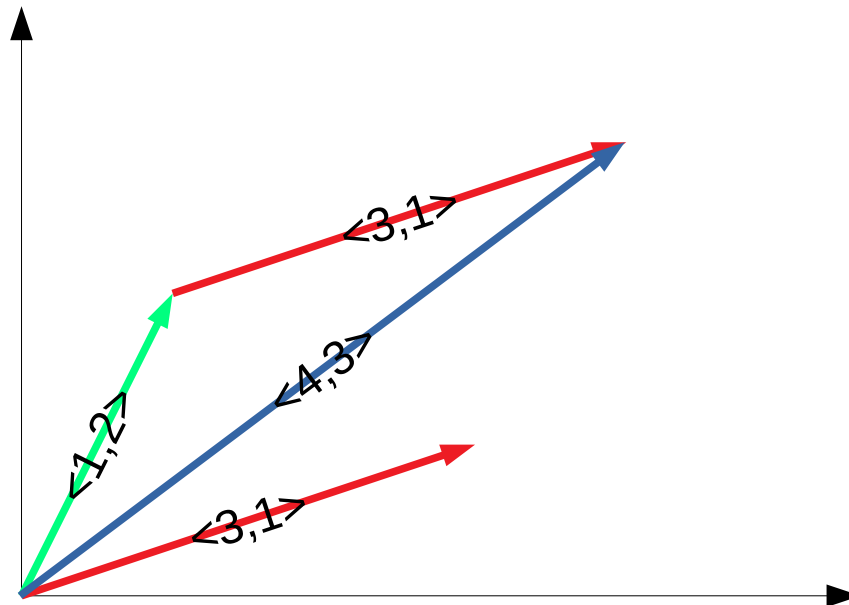
Vectors



UNIVERSITY OF LEEDS

Sum of two vectors: $\langle u_1, u_2, \dots, u_n \rangle + \langle v_1, v_2, \dots, v_n \rangle = \langle u_1 + v_1, u_2 + v_2, \dots, u_n + v_n \rangle$

Example: $\langle 1, 2 \rangle + \langle 3, 1 \rangle = \langle 4, 3 \rangle$



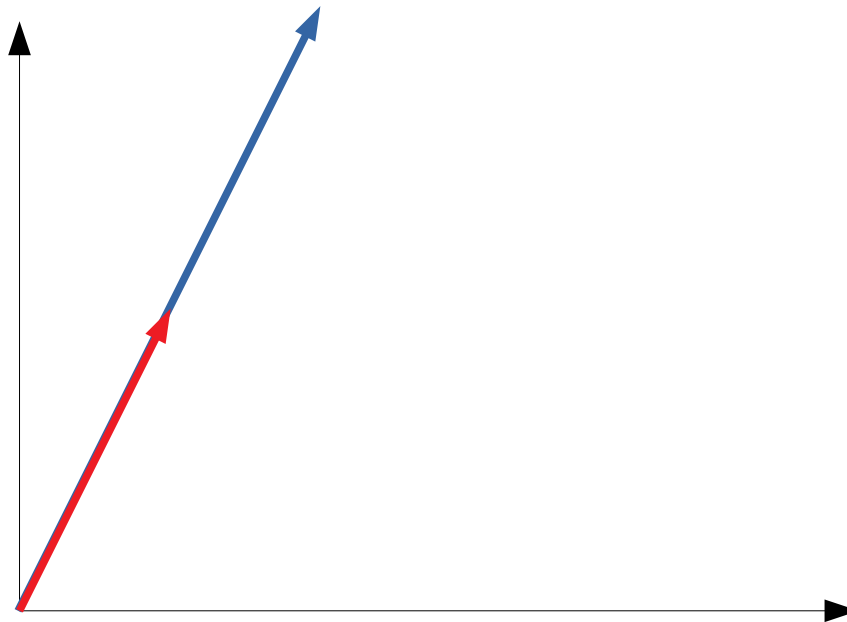
Vectors



UNIVERSITY OF LEEDS

Multiplication of vector by a constant: $c \cdot \langle v_1, v_2, \dots, v_n \rangle = \langle cv_1, cv_2, \dots, cv_n \rangle$

Example: $2 \cdot \langle 1, 2 \rangle = \langle 2, 4 \rangle$

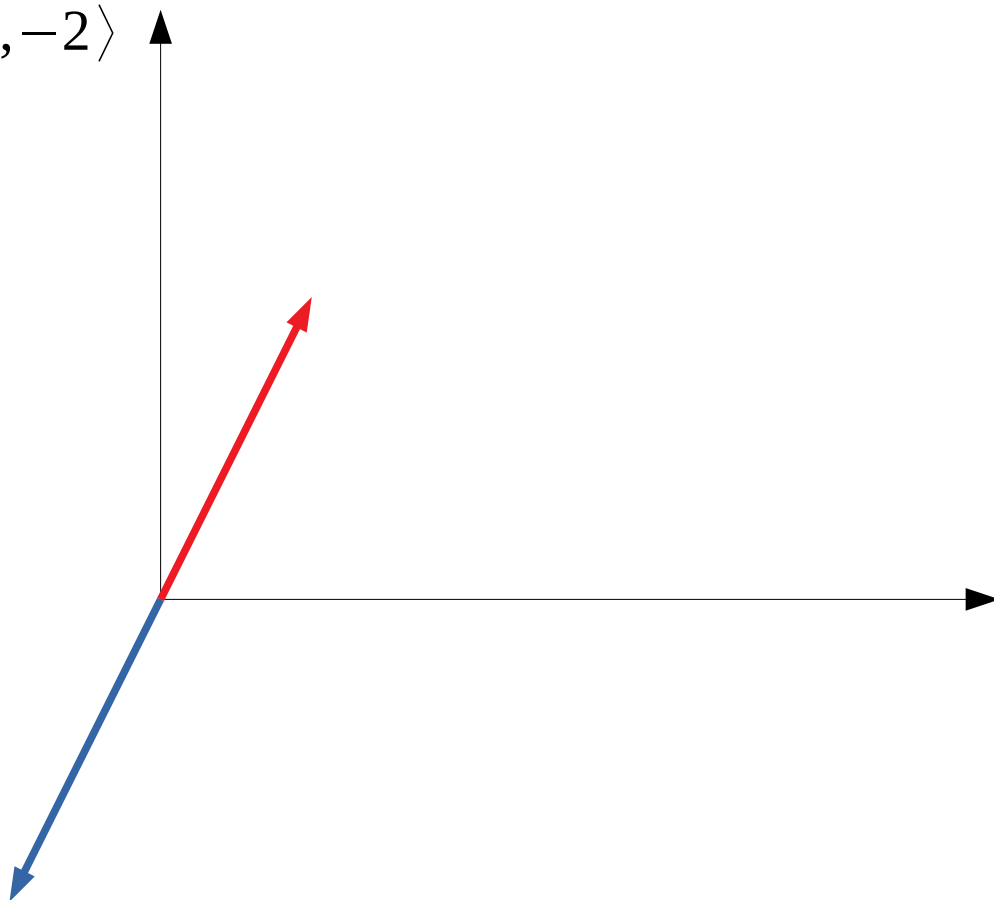


If the constant is different from 1, the length of the vector changes!

Vectors

If the constant is negative, the direction changes:

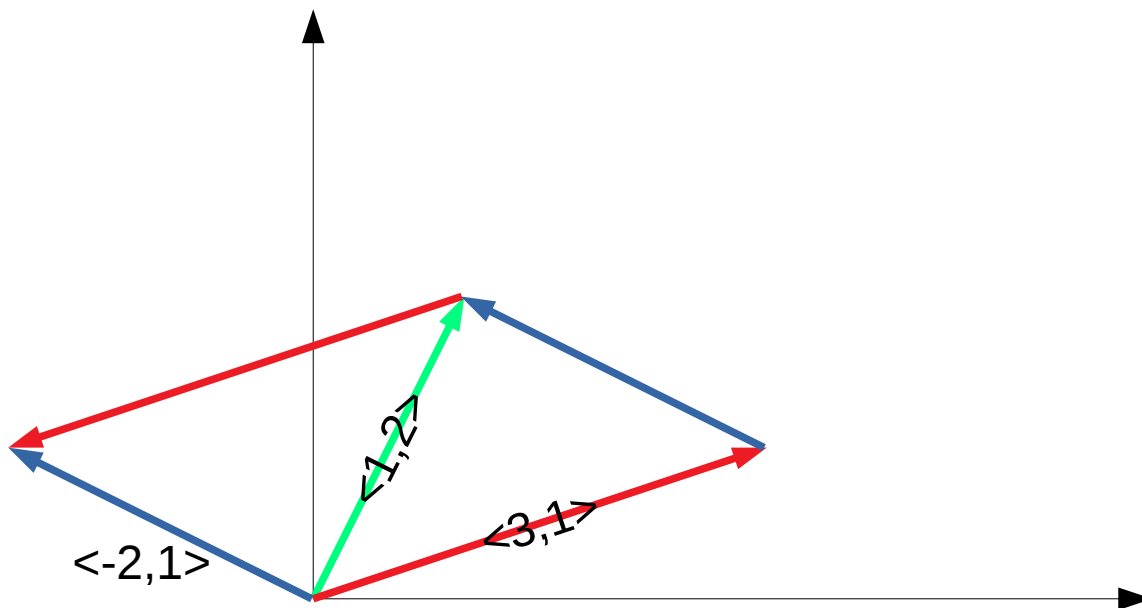
Example: $-1 \cdot \langle 1, 2 \rangle = \langle -1, -2 \rangle$



Vectors

With sum and multiplication by a constant we can subtract two vectors:

Example: $\langle 1, 2 \rangle + -1 \cdot \langle 3, 1 \rangle = \langle -2, 1 \rangle$



Dot product



UNIVERSITY OF LEEDS

The dot product of two vectors is:

$$\langle u_1, u_2, \dots, u_n \rangle \cdot \langle v_1, v_2, \dots, v_n \rangle = u_1 \cdot v_1 + u_2 \cdot v_2 + \dots + u_n \cdot v_n = \sum_{i=1}^n u_i \cdot v_i$$

Example:

$$\langle 1, 2 \rangle \cdot \langle -1, 3 \rangle = -1 + 6 = 5$$

Norm



UNIVERSITY OF LEEDS

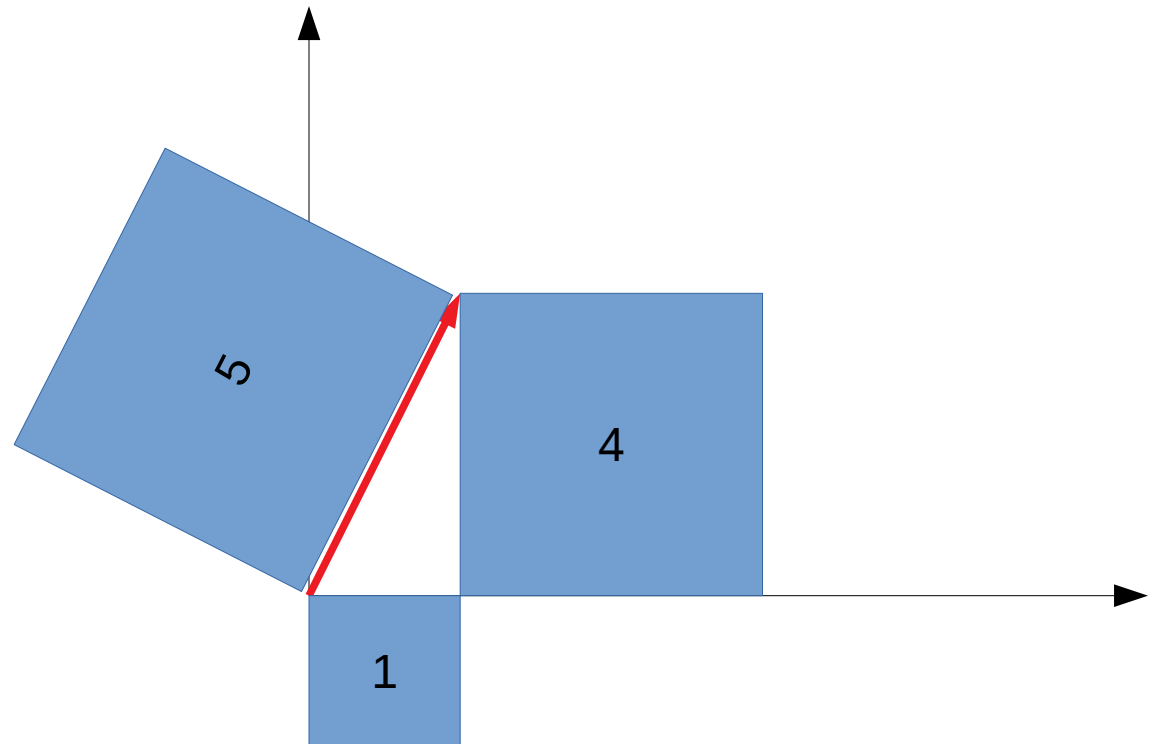
The **norm** of a vector is the square root of the dot product of the vector with itself:

$$\|\mathbf{v}\| = \sqrt{\mathbf{v} \cdot \mathbf{v}} = \sqrt{\langle v_1, v_2, \dots, v_n \rangle \cdot \langle v_1, v_2, \dots, v_n \rangle} = \sqrt{v_1^2 + v_2^2 + \dots + v_n^2} = \sqrt{\sum_{i=1}^n v_i^2}$$

Example:

$$\|\langle 1, 2 \rangle\| = \sqrt{1+4} = \sqrt{5}$$

But wait, this is the
Pythagorean theorem!



The norm of a vector is the
“length” of the vector.

Unit-length vector



UNIVERSITY OF LEEDS

If we divide a vector by its norm, we obtain a vector of the same direction, but length 1:

$$\|\mathbf{v}\| = \|\langle 2, 2 \rangle\| = \sqrt{8}$$

$$\mathbf{v}_u = \langle 2, 2 \rangle \cdot \frac{1}{\sqrt{8}} = \left\langle \frac{2}{\sqrt{8}}, \frac{2}{\sqrt{8}} \right\rangle$$

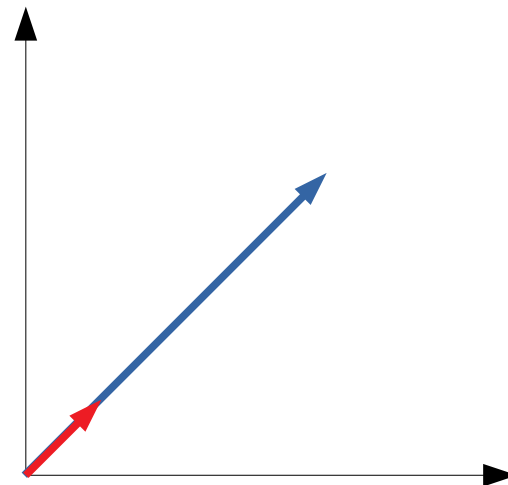
This new vector has norm 1:

$$\left\| \left\langle \frac{2}{\sqrt{8}}, \frac{2}{\sqrt{8}} \right\rangle \right\| = \frac{4}{8} + \frac{4}{8} = 1$$

Any vector \mathbf{u} parallel to \mathbf{v} can be written as:

$$\mathbf{u} = d \mathbf{v}_u$$

Where d is the length of \mathbf{u}



$$\text{For instance: } \langle 5, 5 \rangle = \frac{5\sqrt{8}}{2} \left\langle \frac{2}{\sqrt{8}}, \frac{2}{\sqrt{8}} \right\rangle$$

What is the norm of $\langle 5, 5 \rangle$?

Orthogonal vectors

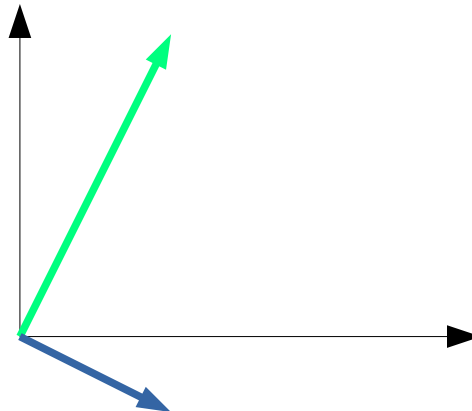
The dot product of two vectors has the following property:

$$\mathbf{u} \cdot \mathbf{v} = \|\mathbf{u}\| \cdot \|\mathbf{v}\| \cdot \cos \theta$$

Where θ is the angle between the vectors

It follows that the dot product between two non-null vectors is 0 if and only if the vectors are **orthogonal**

$$\langle 1, 2 \rangle \cdot \langle 1, -\frac{1}{2} \rangle = 0$$



More on vectors

Watch these videos!

Vectors: https://youtu.be/fNk_zzaMoSs

Dot product: <https://youtu.be/LyGKycYT2v0>

Surfaces



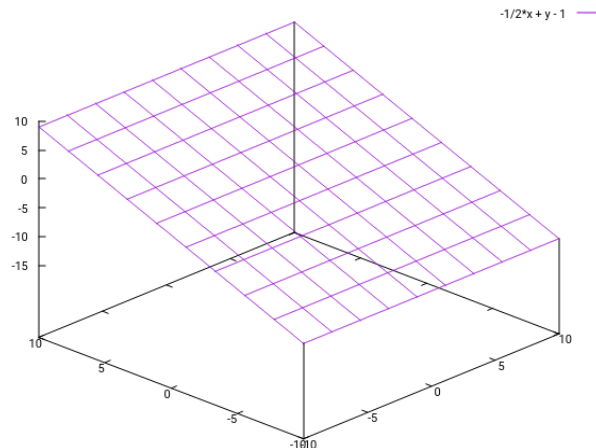
UNIVERSITY OF LEEDS

If $f(x_1, x_2, \dots, x_n)$ is a function of n variables.

The points satisfying the equation: $f(x_1, x_2, \dots, x_n) = 0$ lie on a surface in a space of n dimensions.

For example, consider the function: $f(x, y, z) = \frac{1}{2}x - y + z + 1$

The points satisfying the equation $\frac{1}{2}x - y + z + 1 = 0$ lie on a plane:



Surfaces



UNIVERSITY OF LEEDS

The points satisfying the inequality $f(x_1, x_2, \dots, x_n) \geq 0$ lie on one side of the surface

Which side? Let's see on hyperplanes, and in particular in this 2D example, on a straight line:

$$f(x, y) = \frac{1}{2}x - y + 1 \geq 0$$

Let's evaluate the function on some points:

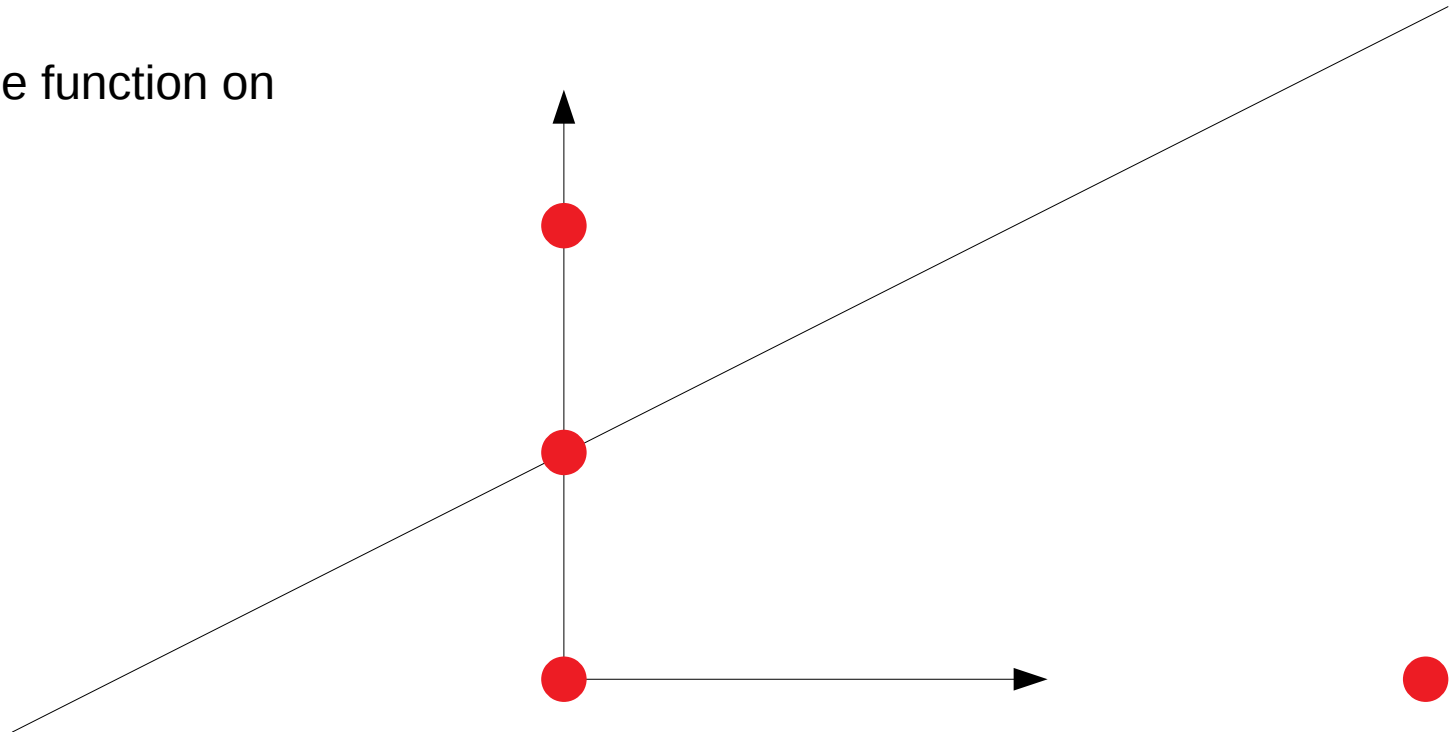
$$f(0, 0) = 1$$

$$f(0, 1) = 0$$

$$f(0, 2) = -1$$

$$f(4, 0) = 3$$

$$f(4, 4) = -1$$



Surfaces



UNIVERSITY OF LEEDS

$$f(x, y) = \frac{1}{2}x - y + 1 \geq 0$$

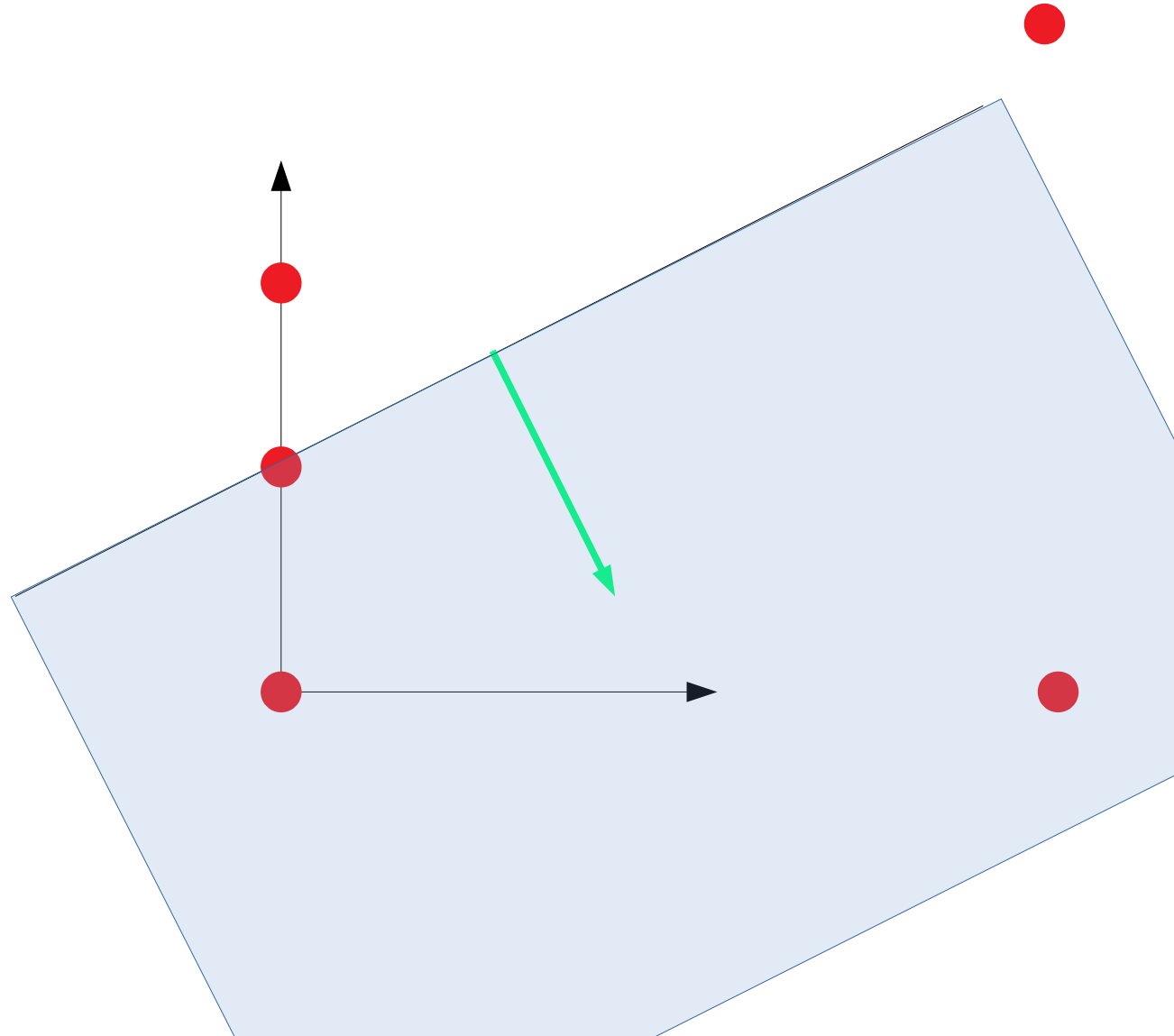
$$f(0, 0) = 1 \quad f(4, 0) = 3$$

$$f(0, 1) = 0$$

$$f(4, 4) = -1$$

$$f(0, 2) = -2$$

The solution of the inequality is a half-plane, which contains all the points on the same side, with respect to the line, as the vector of parameters multiplied by the variables of the line. The same is true in more dimensions.



Question



UNIVERSITY OF LEEDS

Is the inequality $\frac{1}{2}x - y + z + 1 \geq 0$ satisfied by the points above or below the corresponding plane?

