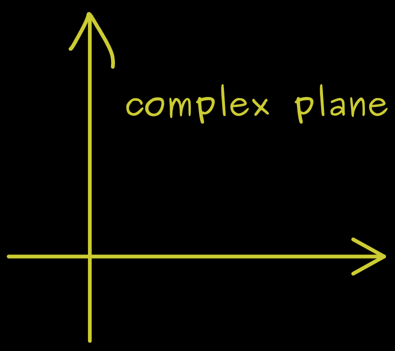
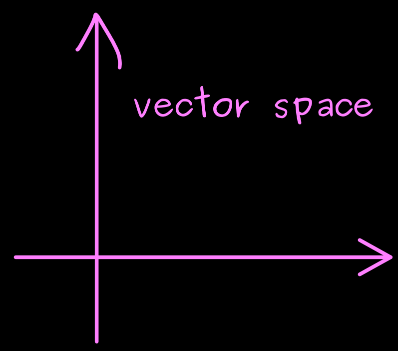
# Complex Analysis – Part 5

$\mathbb{C}$ :




$\mathbb{R}^2$ :

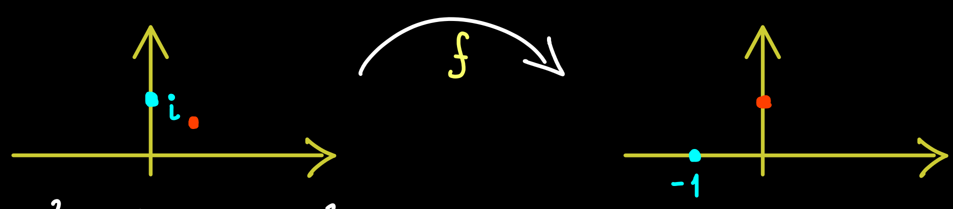



$\mathbb{C}$ is $\mathbb{R}^2$ with a multiplication

**Remember:** Each map $f : \mathbb{C} \longrightarrow \mathbb{C}$ induces a map $f_\mathbb{R} : \mathbb{R}^2 \longrightarrow \mathbb{R}^2$ (and vice versa)

**Example:**

$$f : \mathbb{C} \longrightarrow \mathbb{C}$$
$$z \longmapsto z^2$$
$$x + iy \longmapsto (x+iy)^2 = x^2 + 2ixy - y^2$$




$$f_\mathbb{R} : \mathbb{R}^2 \longrightarrow \mathbb{R}^2$$
$$\begin{pmatrix} x \\ y \end{pmatrix} \longmapsto \begin{pmatrix} x^2 - y^2 \\ 2xy \end{pmatrix}$$

$$f_\mathbb{R}\left(\begin{pmatrix} 0 \\ 1 \end{pmatrix}\right) = \begin{pmatrix} -1 \\ 0 \end{pmatrix}$$

**Definition:** A map $f_\mathbb{R} : \mathbb{R}^2 \longrightarrow \mathbb{R}^2$ is called <u>(totally) differentiable</u> at $\begin{pmatrix} x_0 \\ y_0 \end{pmatrix} \in \mathbb{R}^2$ if there is a matrix $J \in \mathbb{R}^{2\times 2}$ and a map $\phi : \mathbb{R}^2 \longrightarrow \mathbb{R}^2$ with:

$$f_\mathbb{R}\left(\begin{pmatrix} x \\ y \end{pmatrix}\right) = \underbrace{f_\mathbb{R}\left(\begin{pmatrix} x_0 \\ y_0 \end{pmatrix}\right) + J\left(\begin{pmatrix} x \\ y \end{pmatrix} - \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}\right)}_{\text{linear approximation}} + \phi\left(\begin{pmatrix} x \\ y \end{pmatrix}\right)$$

where $$\frac{\phi\left(\begin{pmatrix} x \\ y \end{pmatrix}\right)}{\left\| \begin{pmatrix} x \\ y \end{pmatrix} - \begin{pmatrix} x_0 \\ y_0 \end{pmatrix} \right\|} \xrightarrow{\begin{pmatrix} x \\ y \end{pmatrix} \to \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}} 0$$

$\sqrt{(x-x_0)^2 + (y-y_0)^2}$ = (Euclidean) norm

$J$ is called the Jacobian matrix of $f_R$ at $\begin{pmatrix} x_0 \\ y_0 \end{pmatrix} \in \mathbb{R}^2$.

$$J = \begin{pmatrix} | & | \\ \frac{\partial f_R}{\partial x} & \frac{\partial f_R}{\partial y} \\ | & | \end{pmatrix} \quad \text{(evaluate at } \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}\text{)}$$

Example:

$$f_R : \mathbb{R}^2 \longrightarrow \mathbb{R}^2$$
$$\begin{pmatrix} x \\ y \end{pmatrix} \longmapsto \begin{pmatrix} x^2 - y^2 \\ 2xy \end{pmatrix}$$

$$J = \begin{pmatrix} 2 \cdot x & -2 \cdot y \\ 2 \cdot y & 2 \cdot x \end{pmatrix}$$