

# Quadratic Functions

Linear Algebra  
MATH 2076



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The above objects are described via *quadratic equations*, which in turn use *quadratic functions*.

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It follows that the level set  $q(\vec{x}) = 1$  (i.e.,  $\vec{x}^T A \vec{x} = 1$ ) can be easily determined once we know the level set  $\vec{u}^T D \vec{u} = 1$ .

## A simple $2 \times 2$ Example

Consider  $A = \begin{bmatrix} 2 & 0 \\ 0 & 3 \end{bmatrix}$ , so  $q\left(\begin{bmatrix} x \\ y \end{bmatrix}\right) = \begin{bmatrix} x & y \end{bmatrix} A \begin{bmatrix} x \\ y \end{bmatrix} = 2x^2 + 3y^2$ .



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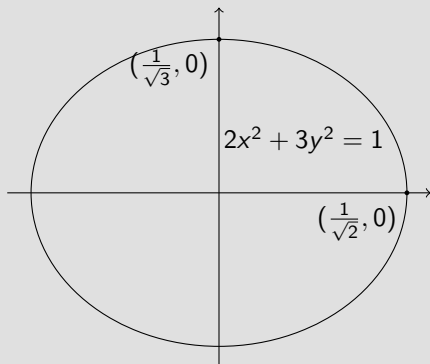
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For  $A = \frac{1}{5} \begin{bmatrix} 14 & -2 \\ -2 & 11 \end{bmatrix}$  we get  $q\left(\begin{bmatrix} x \\ y \end{bmatrix}\right) = \frac{1}{5}(14x^2 - 4xy + 11y^2)$ . What does  $q = 1$  level curve look like?

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Here  $Q$  is an *orthogonal* matrix (i.e.,  $Q^T Q = I$ ) and therefore  $Q^T = Q^{-1}$ .

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$$A = QDQ^T \quad \text{where} \quad Q = [\vec{q}_1 \ \vec{q}_2] = \frac{1}{\sqrt{5}} \begin{bmatrix} 1 & -2 \\ 2 & 1 \end{bmatrix} \quad \text{and} \quad D = \begin{bmatrix} 2 & 0 \\ 0 & 3 \end{bmatrix}.$$

Here  $Q$  is an *orthogonal* matrix (i.e.,  $Q^T Q = I$ ) and therefore  $Q^T = Q^{-1}$ .

The change of variable  $\vec{x} = Q\vec{u}$  helps us to see the picture for the level curve  $14x^2 - 4xy + 11y^2 = 5$ .

$$A = \frac{1}{5} \begin{bmatrix} 14 & -2 \\ -2 & 11 \end{bmatrix} = QDQ^T \text{ where } Q = \frac{1}{\sqrt{5}} \begin{bmatrix} 1 & -2 \\ 2 & 1 \end{bmatrix} \text{ and } D = \begin{bmatrix} 2 & 0 \\ 0 & 3 \end{bmatrix}$$

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The change of variables  $\vec{x} = Q\vec{u}$  then gives us

$$\vec{x}^T A \vec{x} =$$

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To “see”  $q(\vec{x}) = 1$  (i.e.,  $14x^2 - 4xy + 11y^2 = 5$ ),

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So, the level curve  $\vec{u}^T D \vec{u} = 1$  is given by  $2u^2 + 3v^2 = 1$ , which

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So, the level curve  $\vec{u}^T D \vec{u} = 1$  is given by  $2u^2 + 3v^2 = 1$ , which is the equation of an ellipse with vertices  $(\pm\frac{1}{\sqrt{2}}, 0)$ ,  $(0, \pm\frac{1}{\sqrt{3}})$  as pictured below.

$$A = \frac{1}{5} \begin{bmatrix} 14 & -2 \\ -2 & 11 \end{bmatrix} = QDQ^T \text{ where } Q = \frac{1}{\sqrt{5}} \begin{bmatrix} 1 & -2 \\ 2 & 1 \end{bmatrix} \text{ and } D = \begin{bmatrix} 2 & 0 \\ 0 & 3 \end{bmatrix}$$

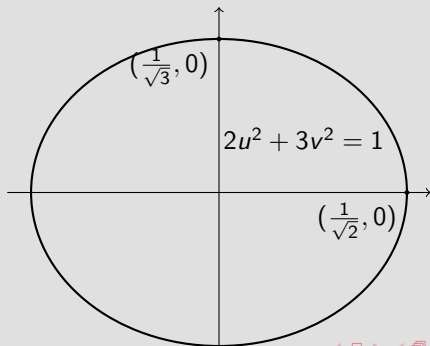
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We use `pix` for  $2u^2 + 3v^2 = 1$  to draw `pix` for  $14x^2 - 4xy + 11y^2 = 5$ .

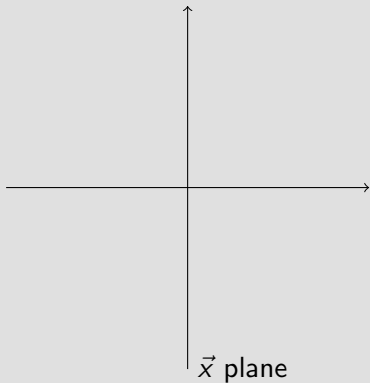
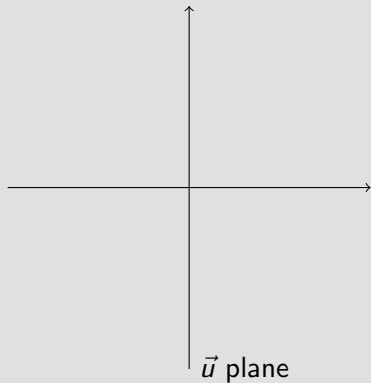
We use  $\text{pix}$  for  $2u^2 + 3v^2 = 1$  to draw  $\text{pix}$  for  $14x^2 - 4xy + 11y^2 = 5$ .

We have  $\begin{bmatrix} x \\ y \end{bmatrix} = \vec{x} = Q\vec{u} = \begin{bmatrix} u \\ v \end{bmatrix}$  so need both  $\vec{u}$ -plane and  $\vec{x}$ -plane.



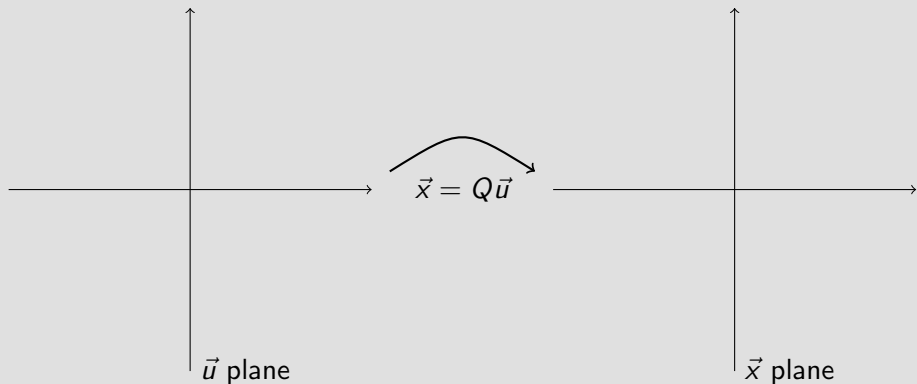
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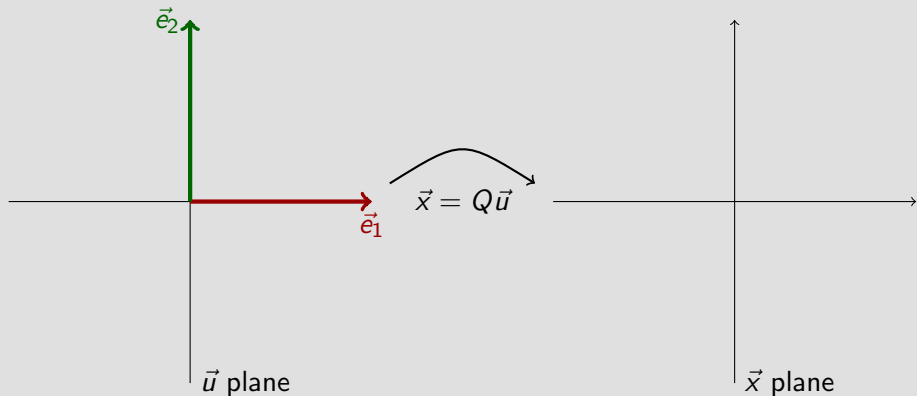
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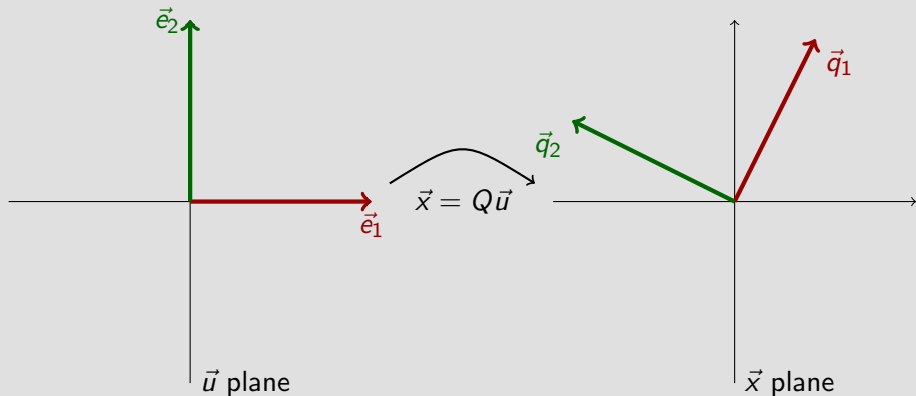
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The standard basis vectors  $\vec{e}_1, \vec{e}_2$  are mapped to  $\vec{q}_1, \vec{q}_2$ .

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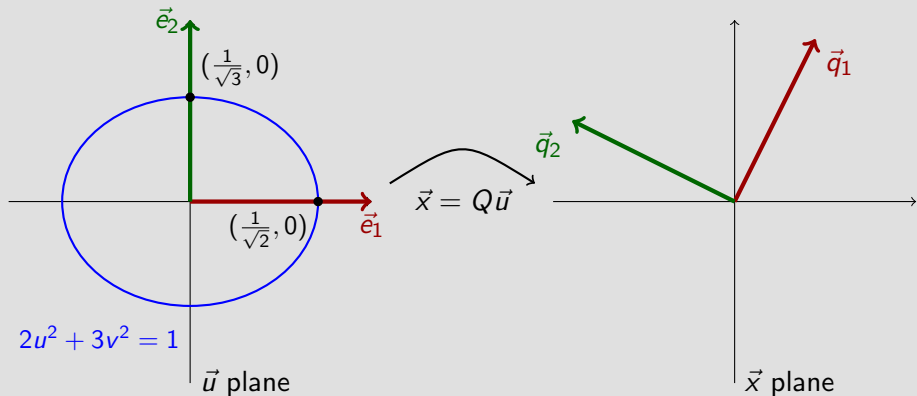
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The standard basis vectors  $\vec{e}_1, \vec{e}_2$  are mapped to  $\vec{q}_1, \vec{q}_2$ . So we see that  $\vec{x} = Q\vec{u}$  is a rotation of  $\mathbb{R}^2$  by the angle  $\theta$  where  $\tan \theta = 2$ .

We use pix for  $2u^2 + 3v^2 = 1$  to draw pix for  $14x^2 - 4xy + 11y^2 = 5$ .

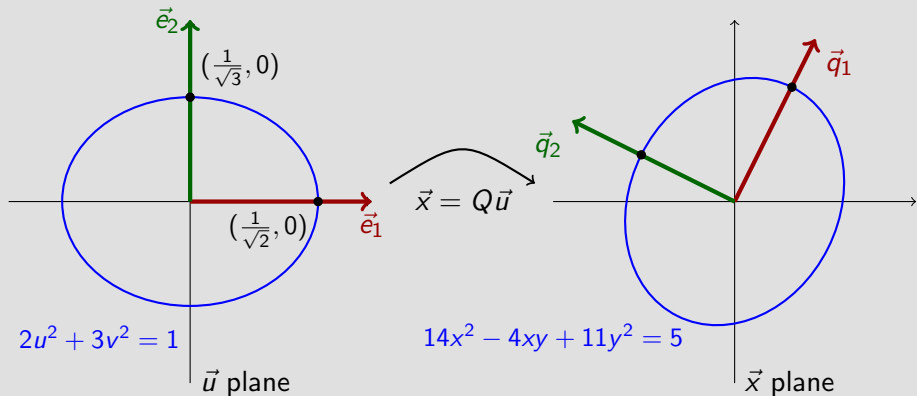
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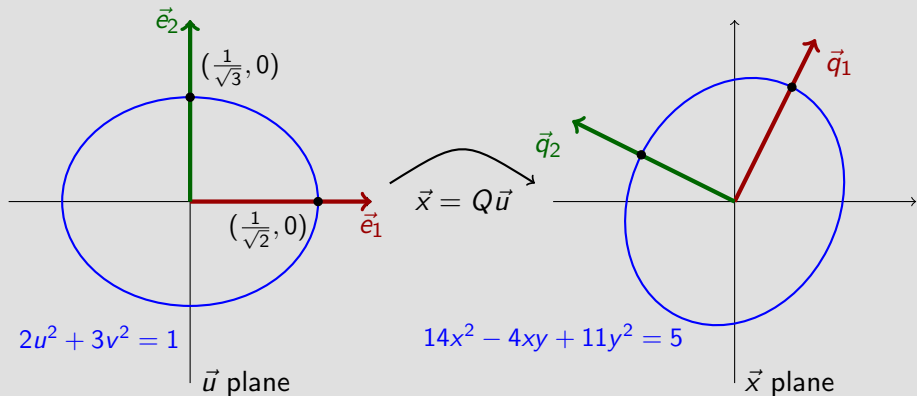
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