

# Analisi di Immagini e Video (Computer Vision)

Giuseppe Manco

# Outline

- Image Processing avanzato
  - Canny Edge Detector
  - Hough Transform

# Crediti

- Slides adattate da vari corsi
  - Analisi di Immagini (F. Angiulli) – Unical
  - Intro to Computer Vision (J. Tompkin) – CS Brown Edu
  - Computer Vision (I. Gkioulekas), CS CMU Edu

# Recap: Gradient-based filtering

1. Scegli la derivata

$$\mathbf{S}_x = \begin{array}{|c|c|c|} \hline 1 & 0 & -1 \\ \hline 2 & 0 & -2 \\ \hline 1 & 0 & -1 \\ \hline \end{array}$$

$$\mathbf{S}_y = \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 0 & 0 & 0 \\ \hline -1 & -2 & -1 \\ \hline \end{array}$$

2. Convolvi con l'immagine

$$\frac{\partial f}{\partial x} = \mathbf{S}_x * f$$

$$\frac{\partial f}{\partial y} = \mathbf{S}_y * f$$

3. Calcola direzione e ampiezza del gradiente.

$$\nabla f = \left[ \frac{\partial f}{\partial x}, \frac{\partial f}{\partial y} \right]$$

gradient

$$\theta = \tan^{-1} \left( \frac{\partial f}{\partial y} / \frac{\partial f}{\partial x} \right)$$

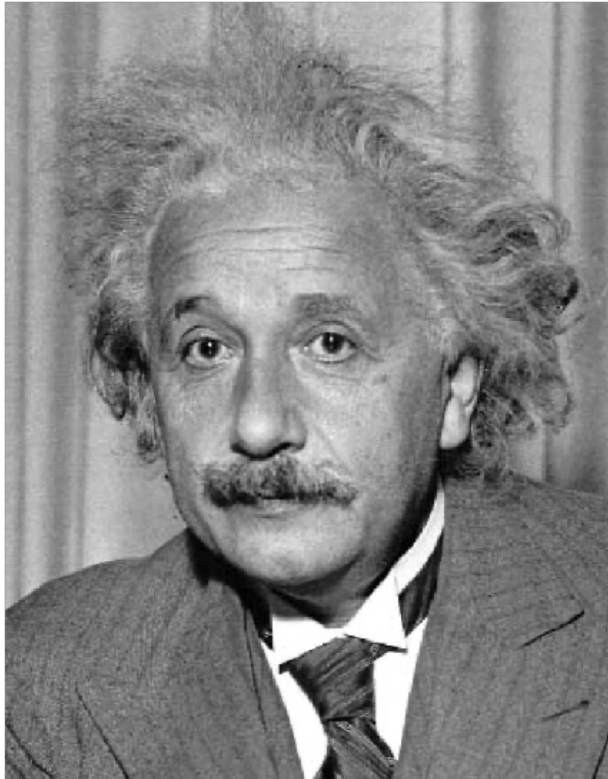
direction

$$\|\nabla f\| = \sqrt{\left( \frac{\partial f}{\partial x} \right)^2 + \left( \frac{\partial f}{\partial y} \right)^2}$$

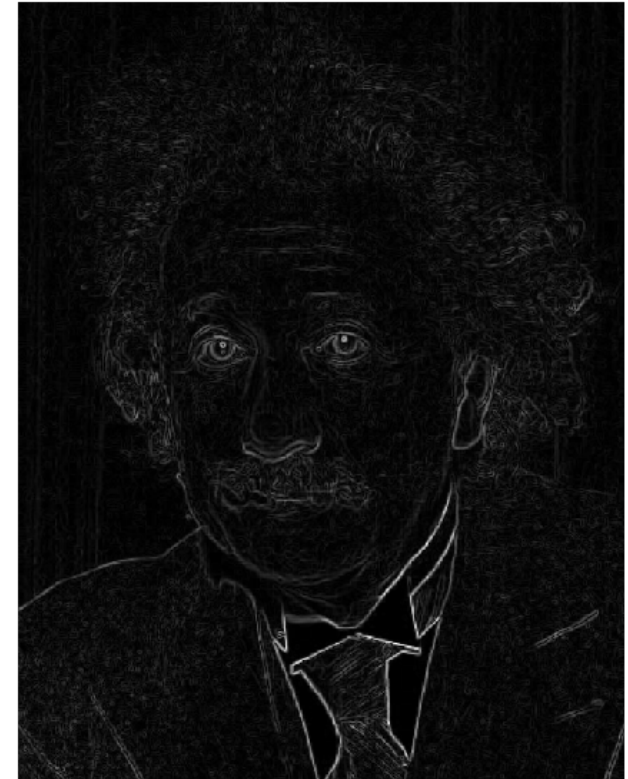
amplitude

# Gradient-Based Filtering

originale



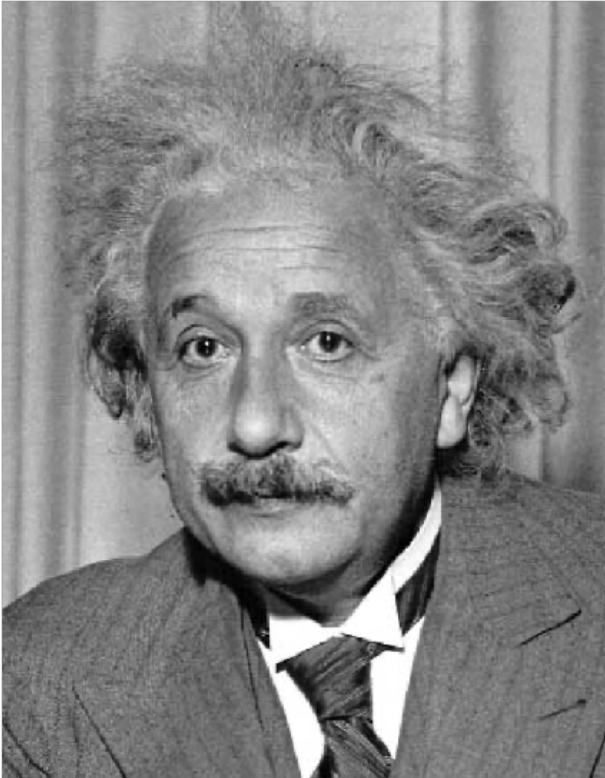
Ampiezza



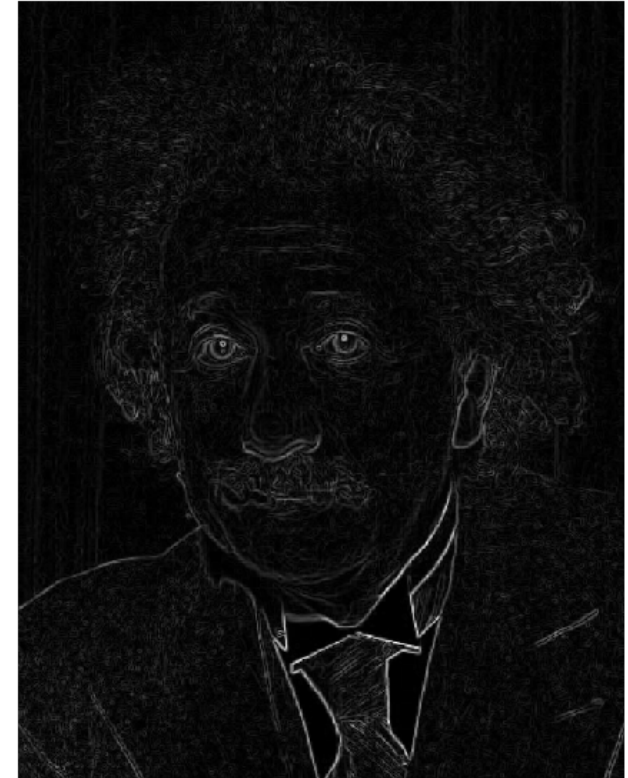
- Cosa c'è che non va?

# Gradient-Based Filtering

originale



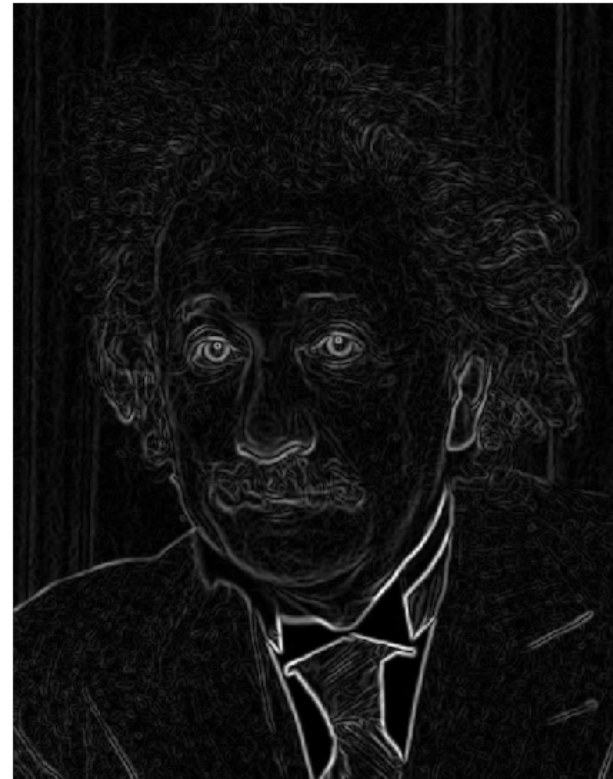
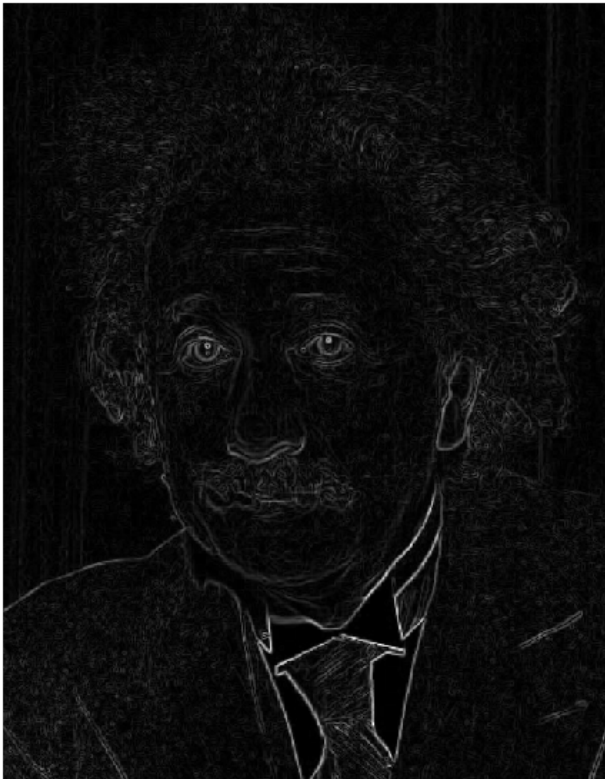
Ampiezza



- Cosa c'è che non va?
  - Troppi artefatti

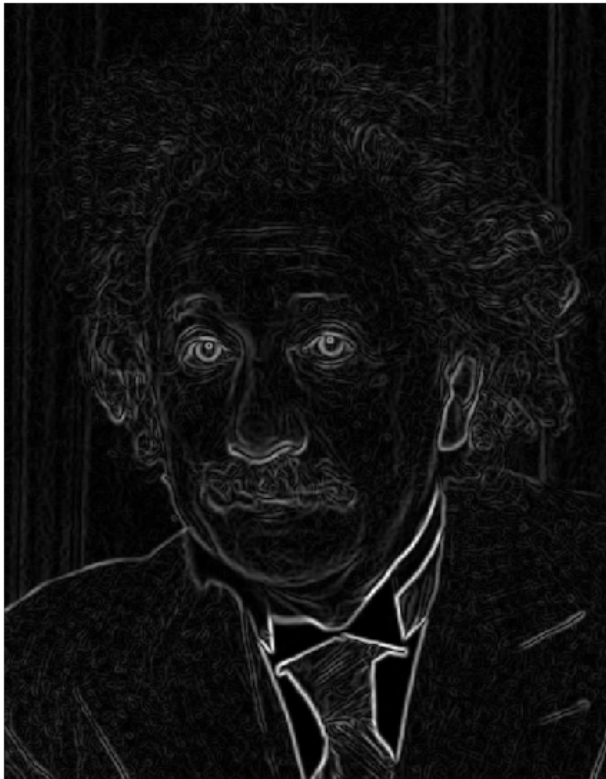
# Gradient-Based Filtering

- Noise
  - Lo trattiamo con il filtro gaussiano



# Gradient-Based Filtering

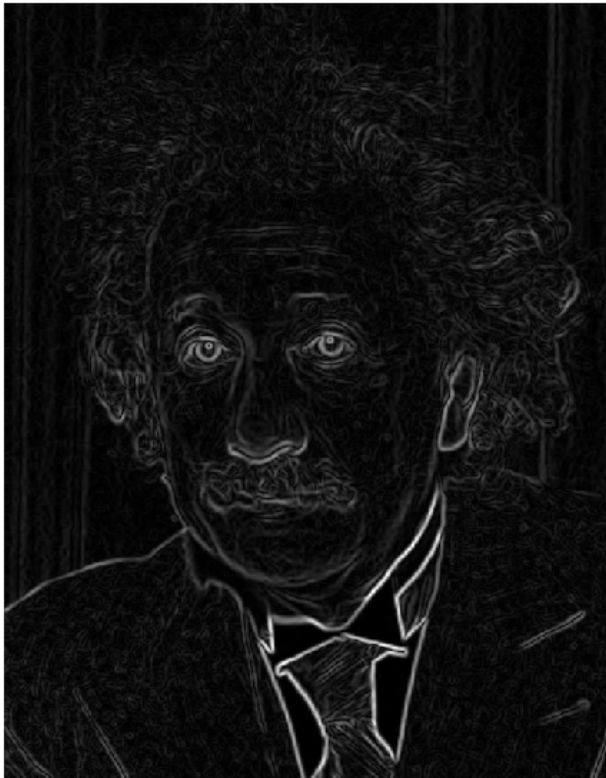
- Troppi toni di grigio
  - Thresholding





# Gradient-Based Filtering

- Diversi spessori
  - ?

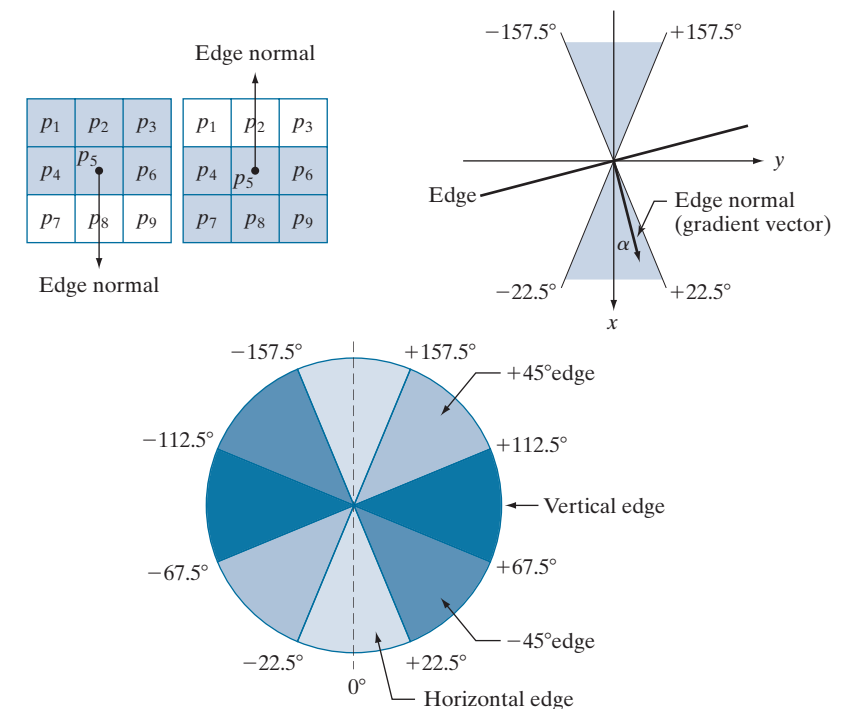
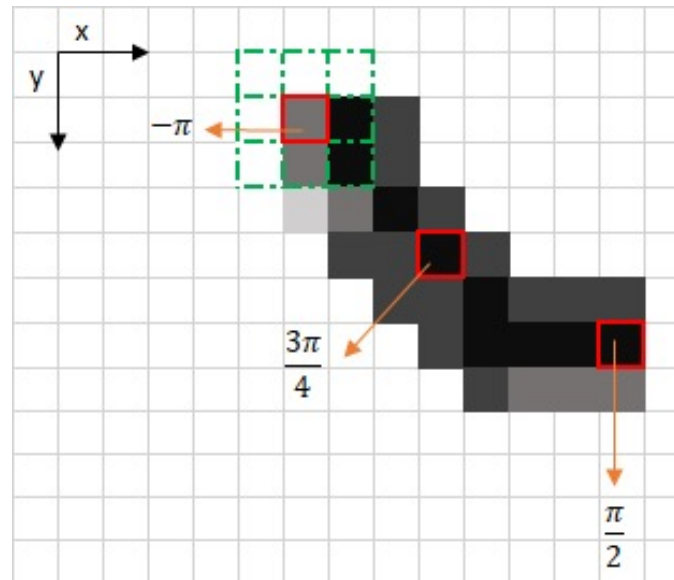


# Canny Edge Detector

- Algoritmo semplice
  - Estensione del gradient-based filtering
  - Spessori uniformi
    - Non-maximal suppression
  - Rimozione di artefatti
    - Double thresholding, hysteresis

# Non maximal suppression

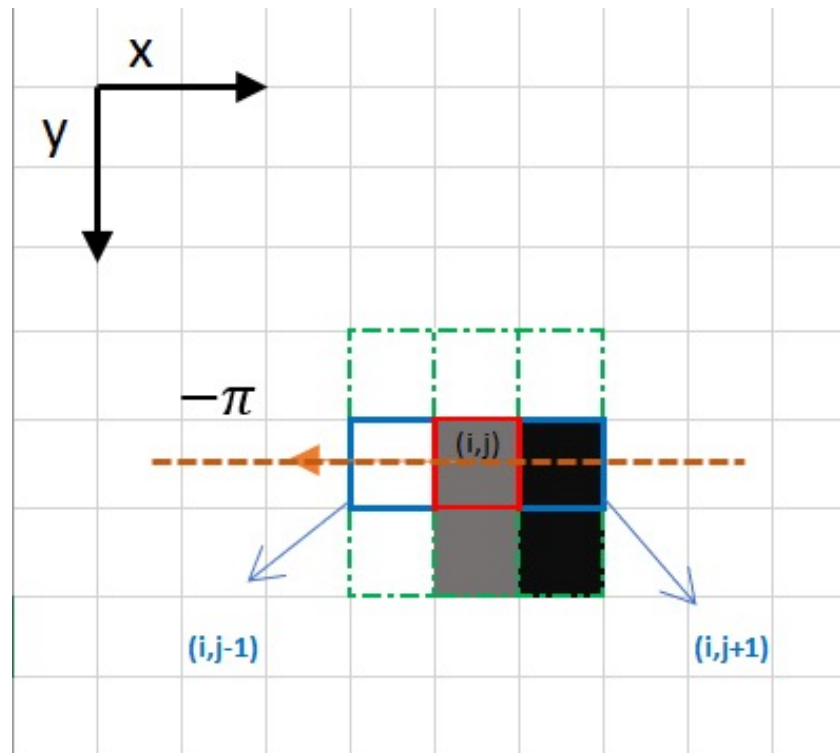
- Basata sulla direzione del gradiente  $\theta = \tan^{-1} \left( \frac{\partial f}{\partial y} / \frac{\partial f}{\partial x} \right)$



- Il gradiente punta a valori alti di intensità

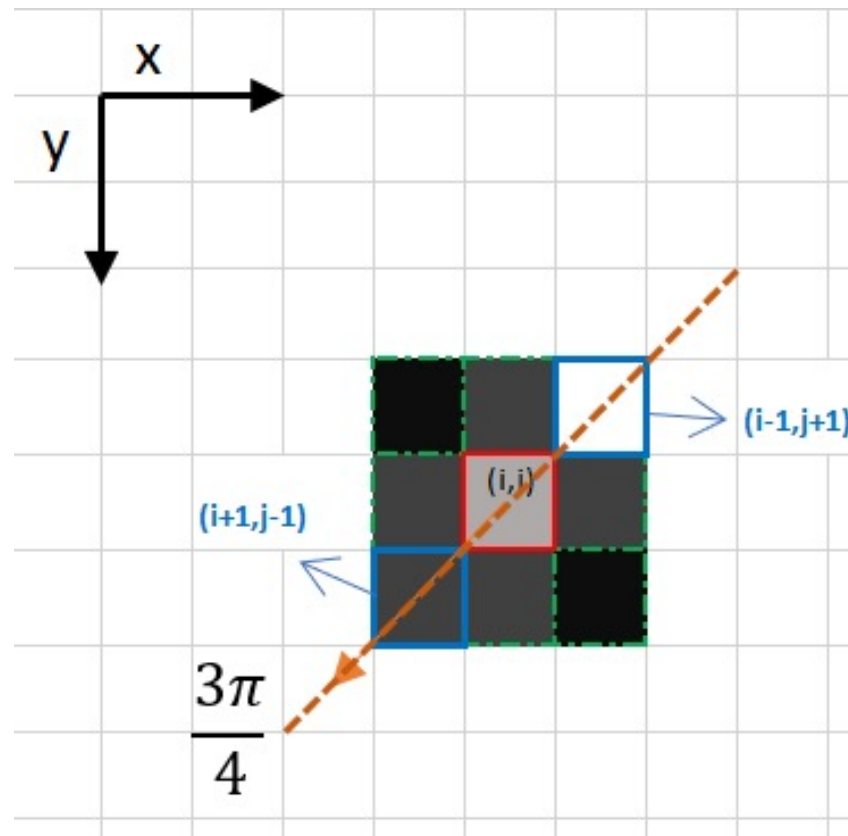
# Non maximal suppression

- Sopprimiamo il pixel se lungo la direzione del gradiente i pixel adiacenti hanno un valore più alto

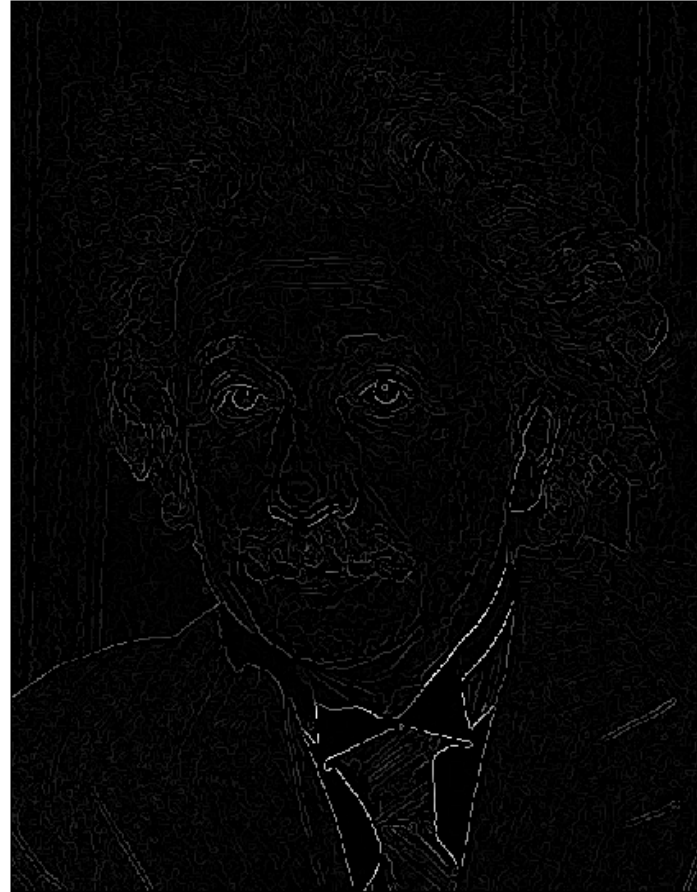
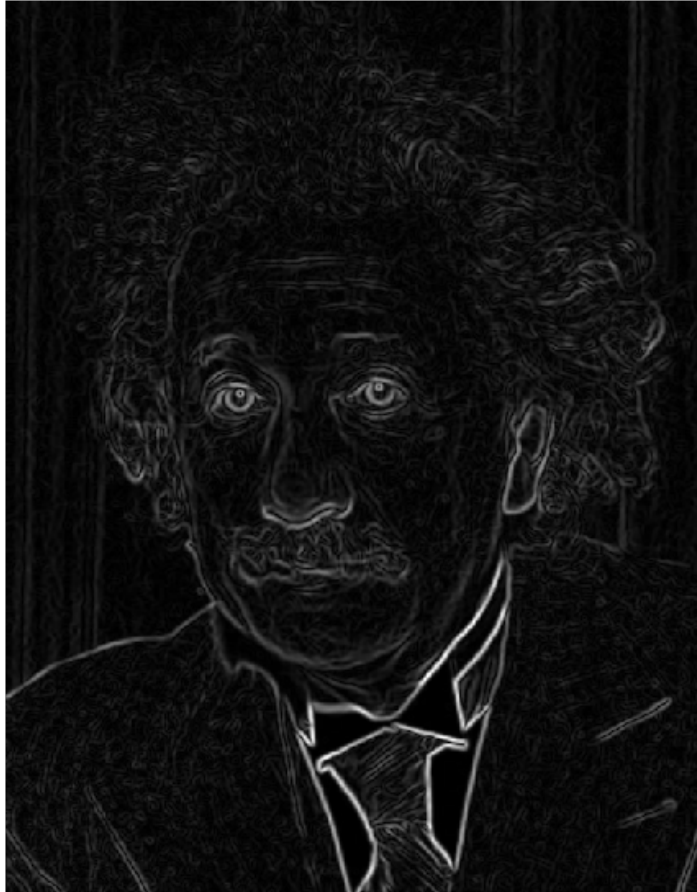


# Non maximal suppression

- Sopprimiamo il pixel se lungo la direzione del gradiente i pixel adiacenti hanno un valore più alto



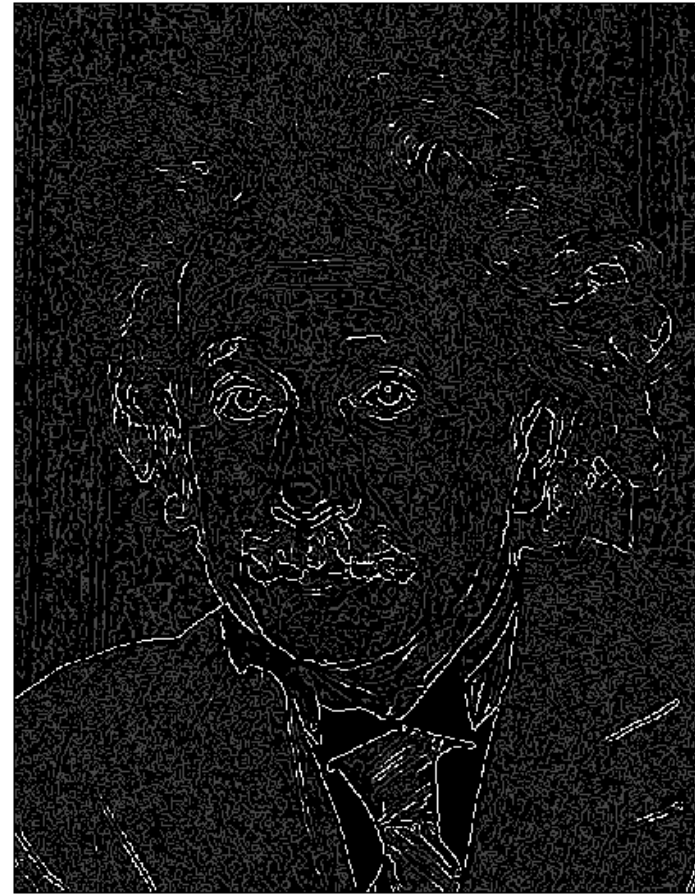
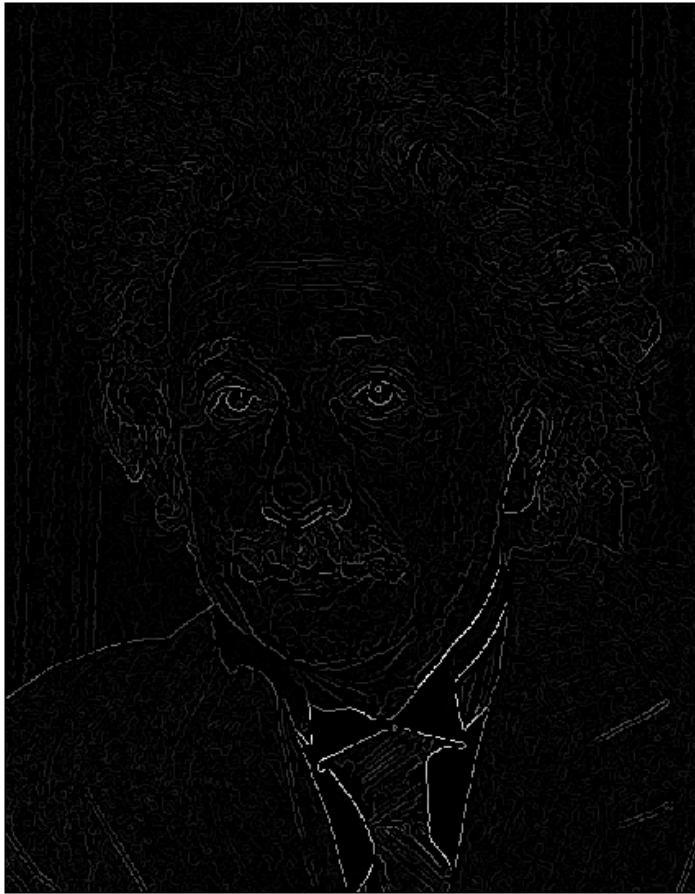
# Non-Maximal Suppression



# Level-wise thresholding, hysteresis

- Strong/Weak/irrelevant pixels
  - Strong pixels: intensità alta (contribuiscono sicuramente ai bordi)
  - Weak pixels: intensità non alta, ma neanche bassa
    - Li teniamo da parte
  - Irrelevant pixels: intensità bassa, da rimuovere
- Usiamo due soglie
  - High threshold per identificare strong pixels
  - Low threshold per identificare irrelevant pixels
- Tutti i pixel nel mezzo delle due soglie sono weak e verranno gestiti dal meccanismo dell'isteresi

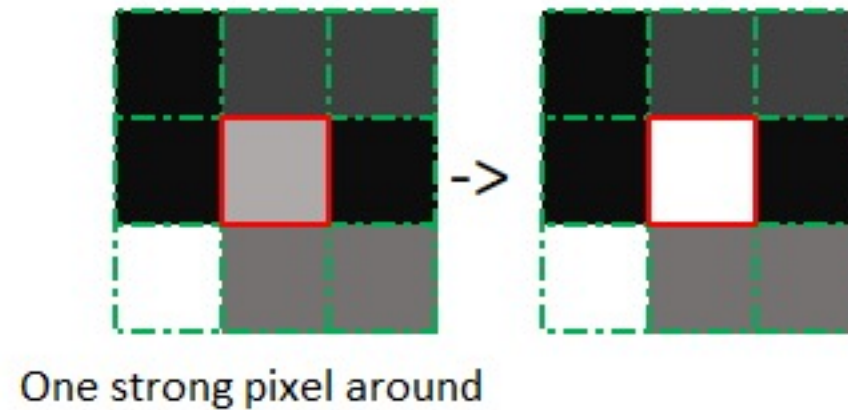
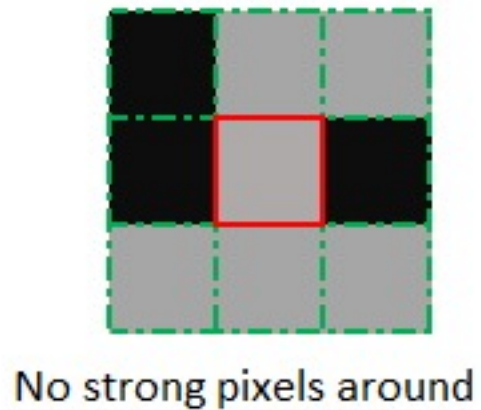
# Level-wise thresholding



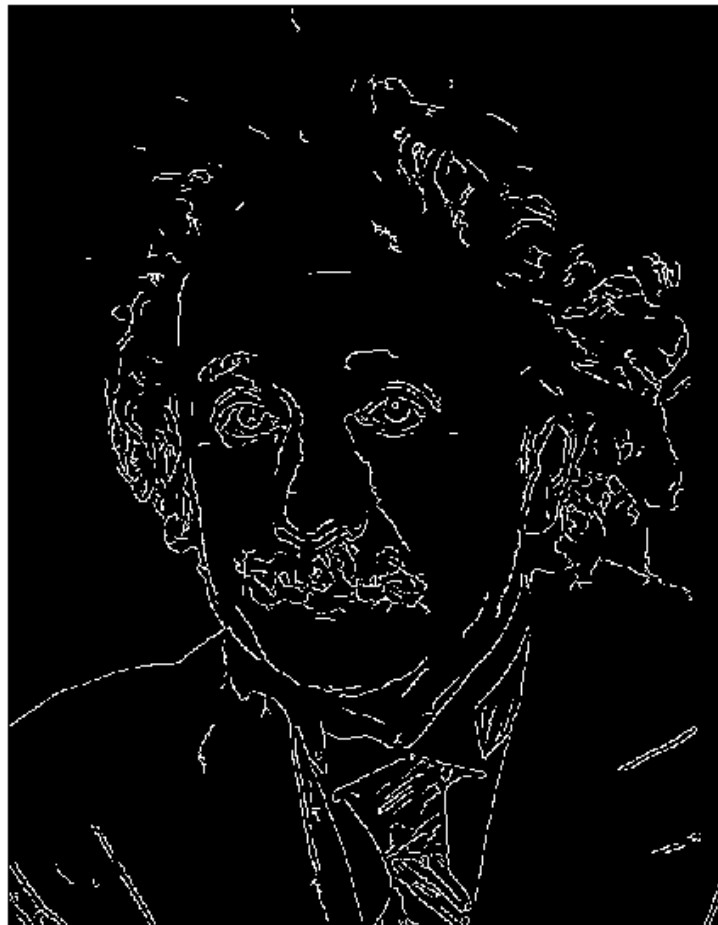


# Hysteresis

- «Attrazione gravitazionale»
  - Se un weak Pixel ha uno strong pixel nel vicinato, diventa anch'esso uno strong pixel, altrimenti diventa irrelevant e viene soppresso



# Hysteresis



Shift to Computer Vision

# Image Processing, Image Understanding

- Image Processing:  $I[x, y] \mapsto I'[x, y]$
- Image Analysis, Computer vision:  $I[x, y] \mapsto$  Features, elements

# Esempio

- Cosa caratterizza questa immagine?



# Esempio

- Cosa caratterizza questa immagine?
  - Linee
  - Cerchi, curve
  - Forme



# Esempio

- Cosa caratterizza questa immagine?
  - Linee
  - Cerchi, curve
  - Forme
- In diverse situazioni gli edge points determinati dalla tecnica di edge detection sono sparsi piuttosto che essere raggruppati in linee o curve





Line parameterizations



# Forma classica

$$y = mx + b$$

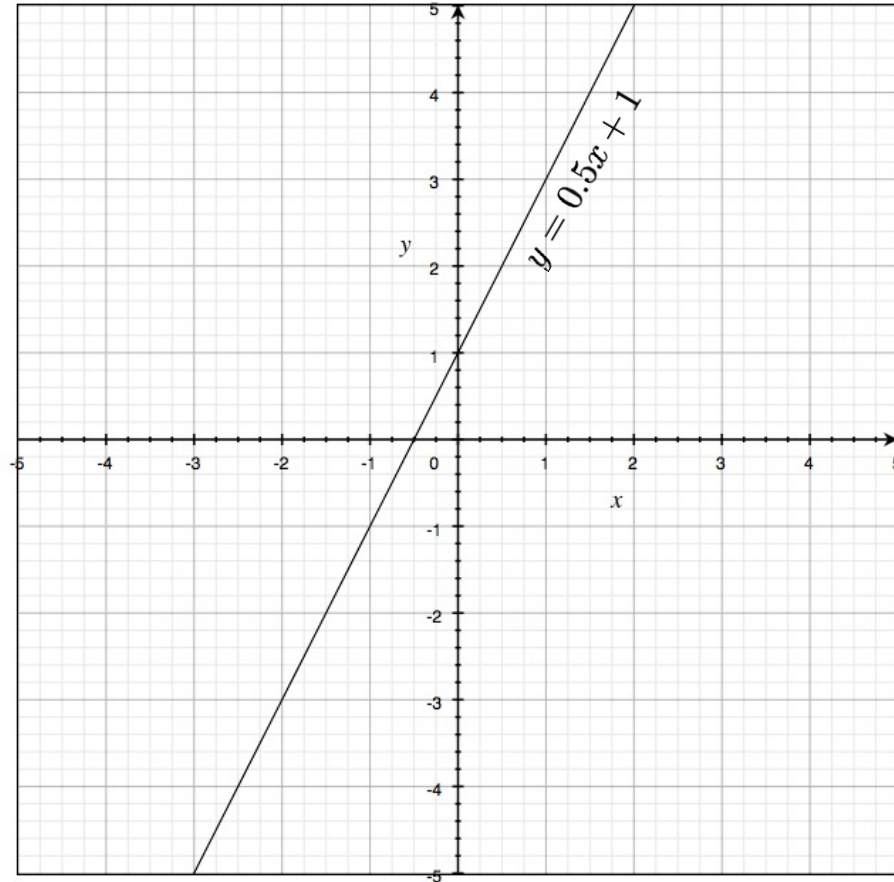
   
slope      y-intercept

*Cosa sono m e b?*

# Forma Classica



$$y = mx + b$$

↑                      ↑  
slope                  y-intercept



# Forma equivalente

$$\frac{x}{a} + \frac{y}{b} = 1$$

x-intercept  y-intercept 

*Cosa sono x e y?*

# Hough transform

- Framework generico per determinare i parametri di un modello
- I bordi non sono necessariamente connessi
- Le linee possono essere occluse
- **Votazione**

# Lo spazio dei parametri

variabili

$$y = mx + b$$

parametri

variabili

$$y - mx = b$$

parametri

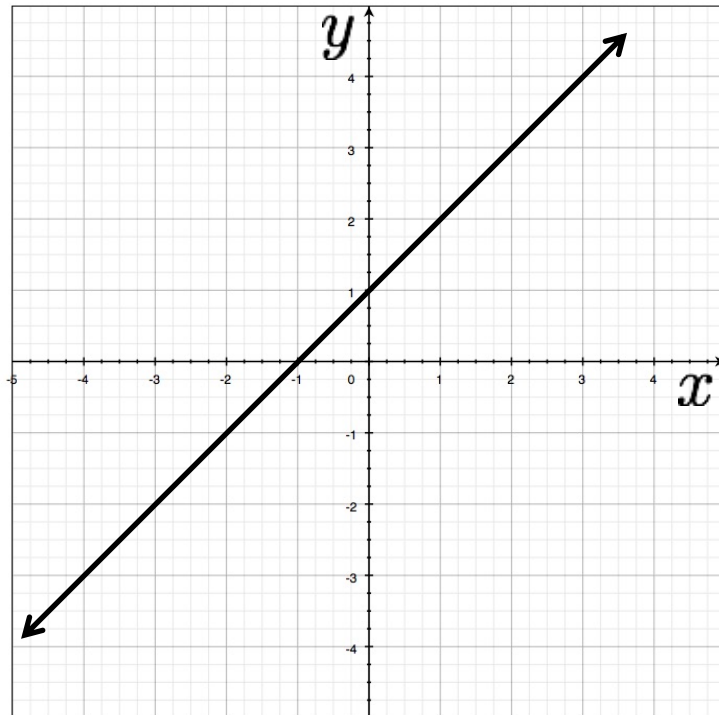
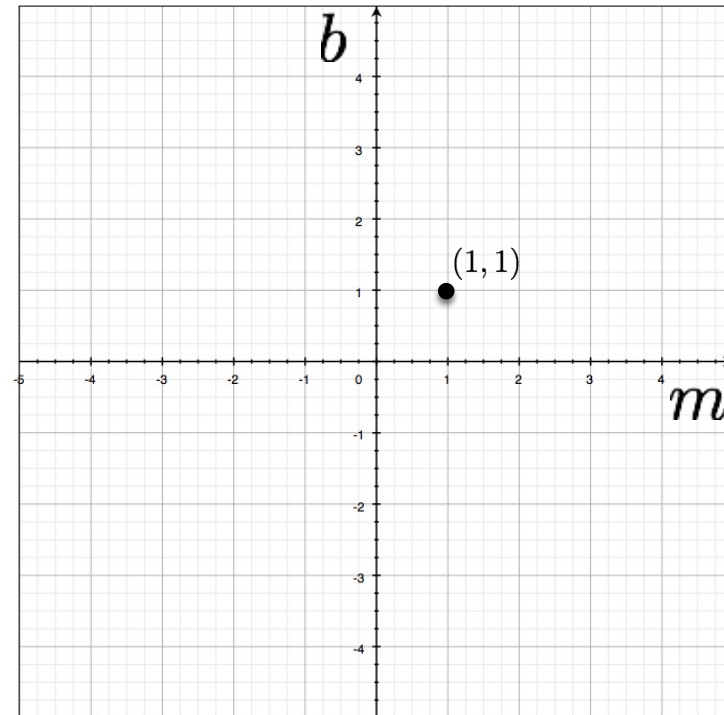


Image space

Una linea diventa un punto



Parameter space

# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

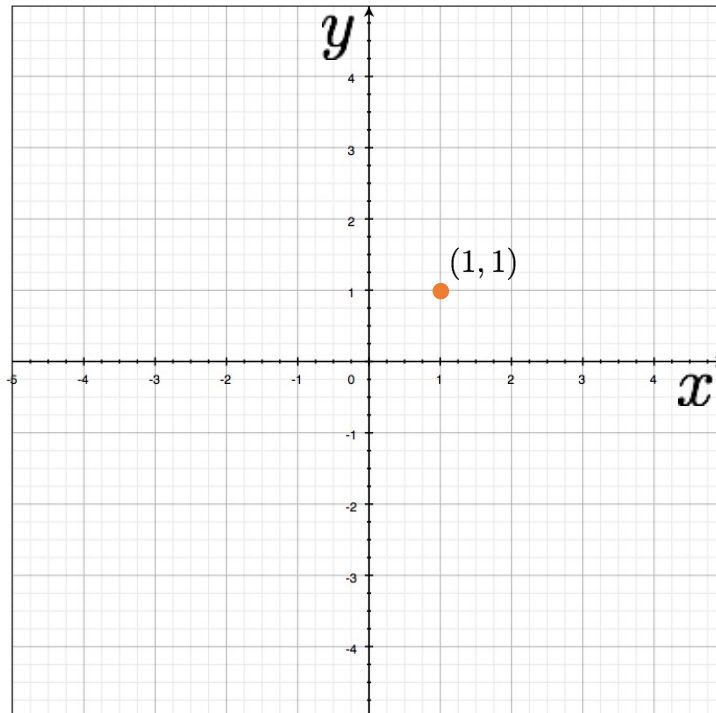
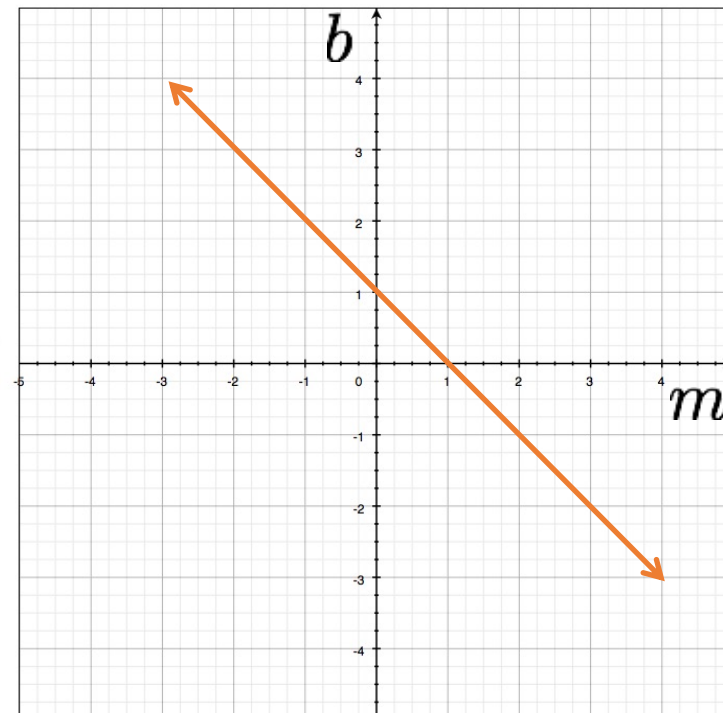


Image space

Un punto  
diventa una  
linea



Parameter space

# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

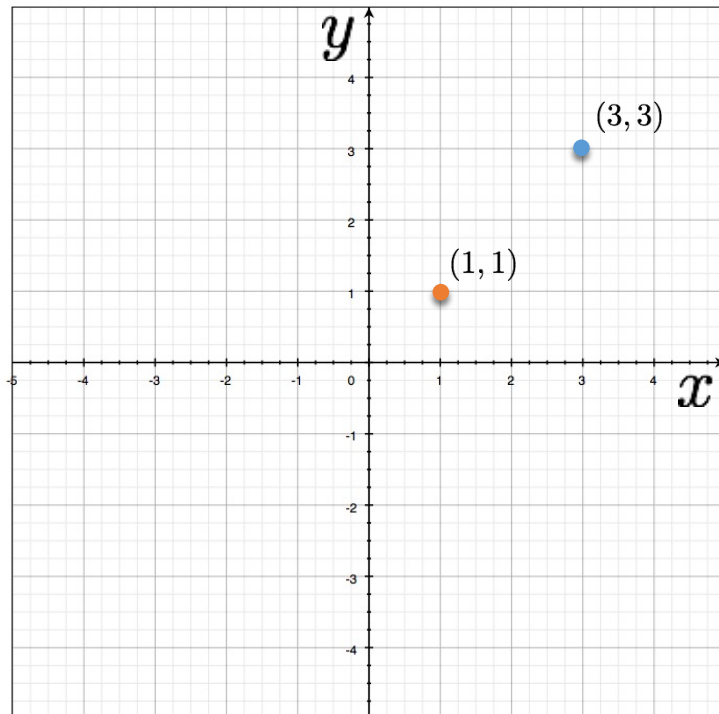
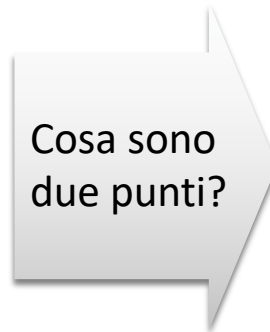
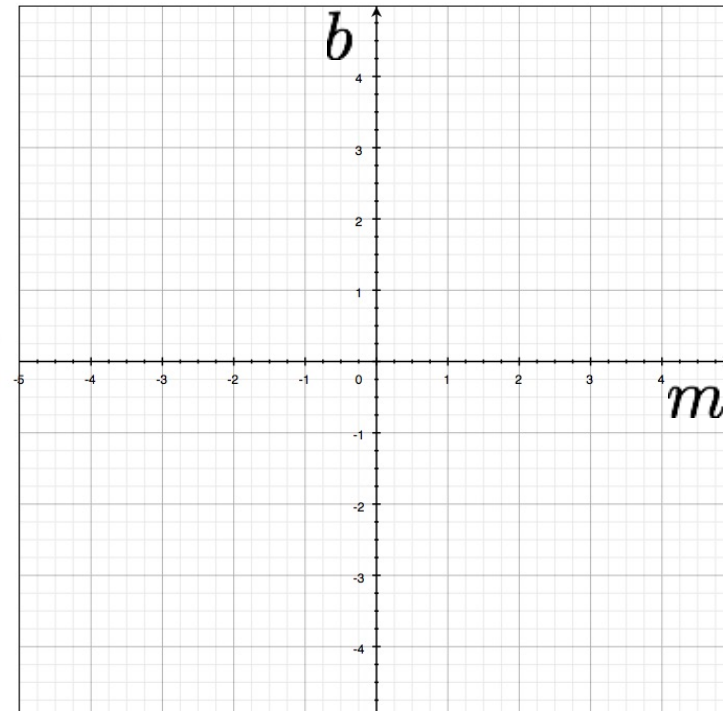


Image space



Cosa sono  
due punti?



Parameter space

# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

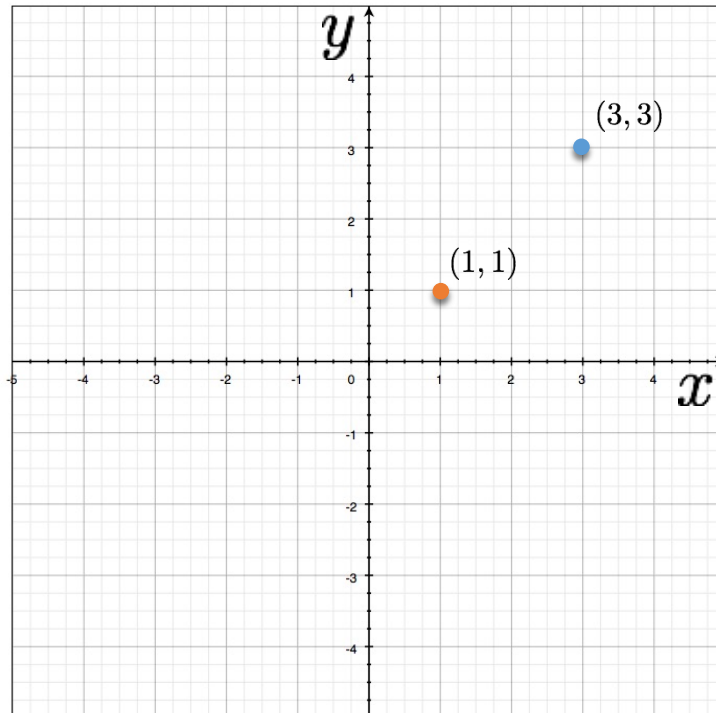
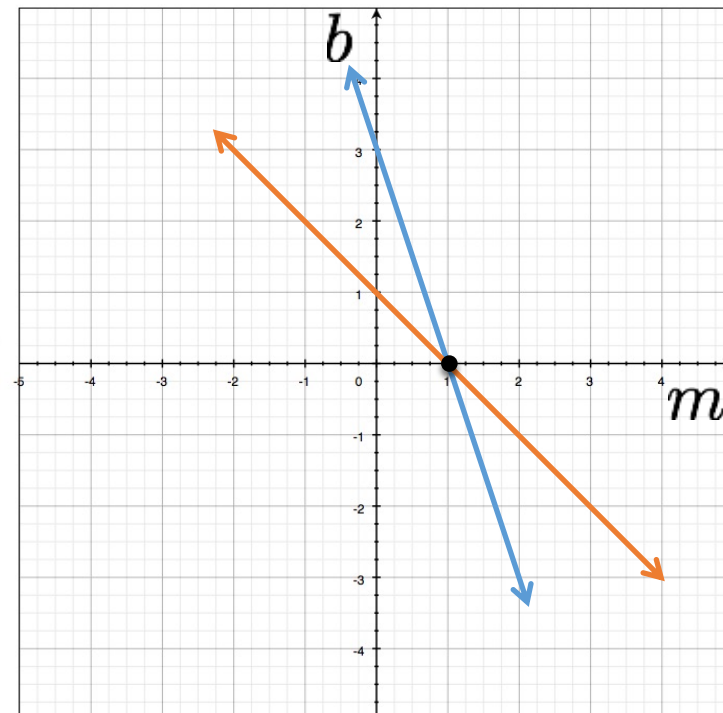
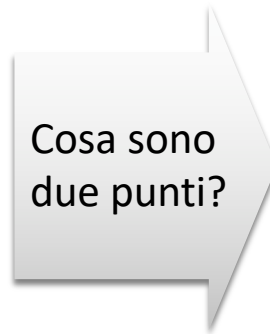


Image space



Parameter space



# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

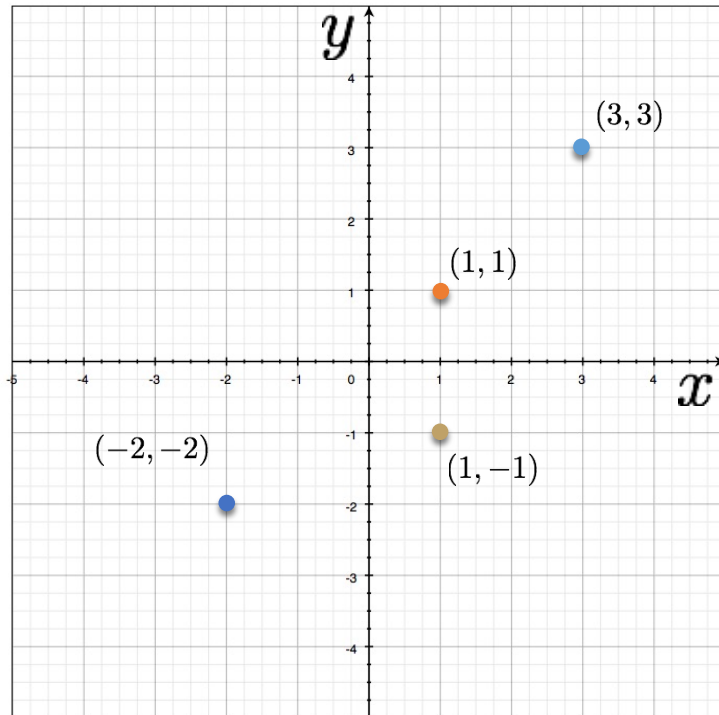
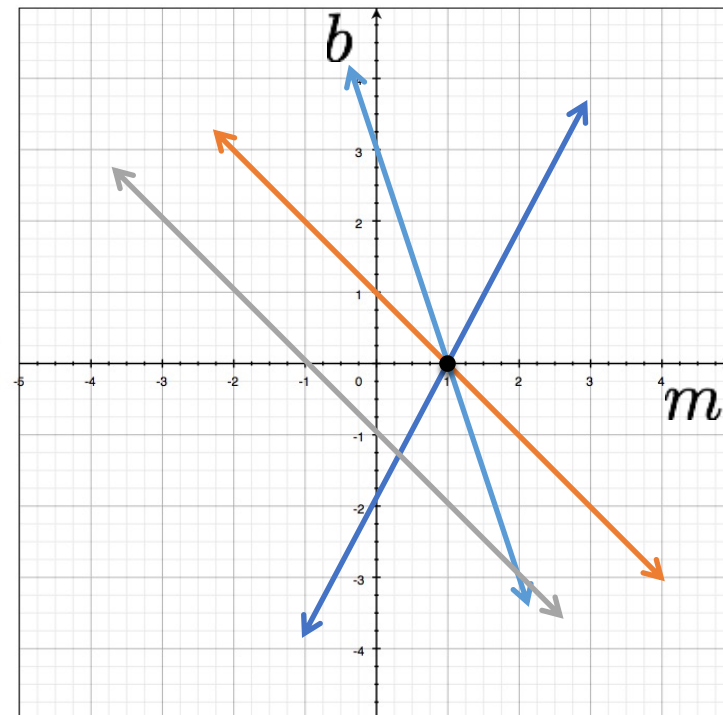


Image space

Cosa sono 4 punti?



Parameter space

# Qual è la linea più compatibile con i dati?

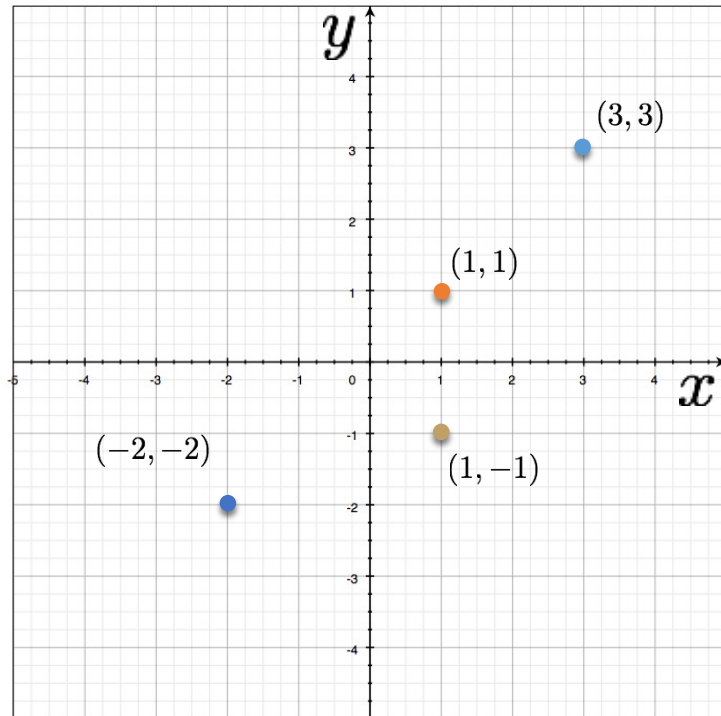
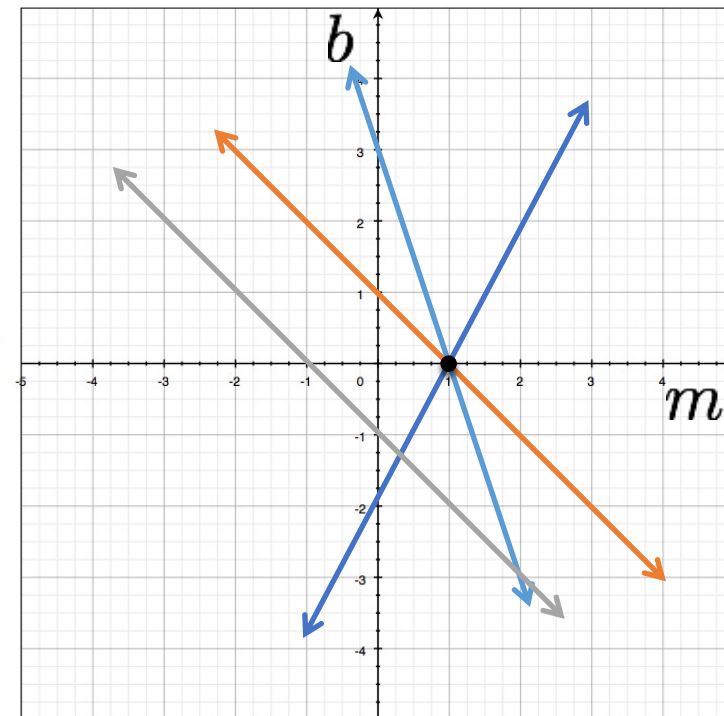


Image space



Parameter space

*Tollerante al rumore?*

# Perché non va bene

- I parametri  $m$  e  $b$  hanno un range potenzialmente infinito
- Se dovessimo accumulare le incidenze, quanti accumulatori ci servirebbero?

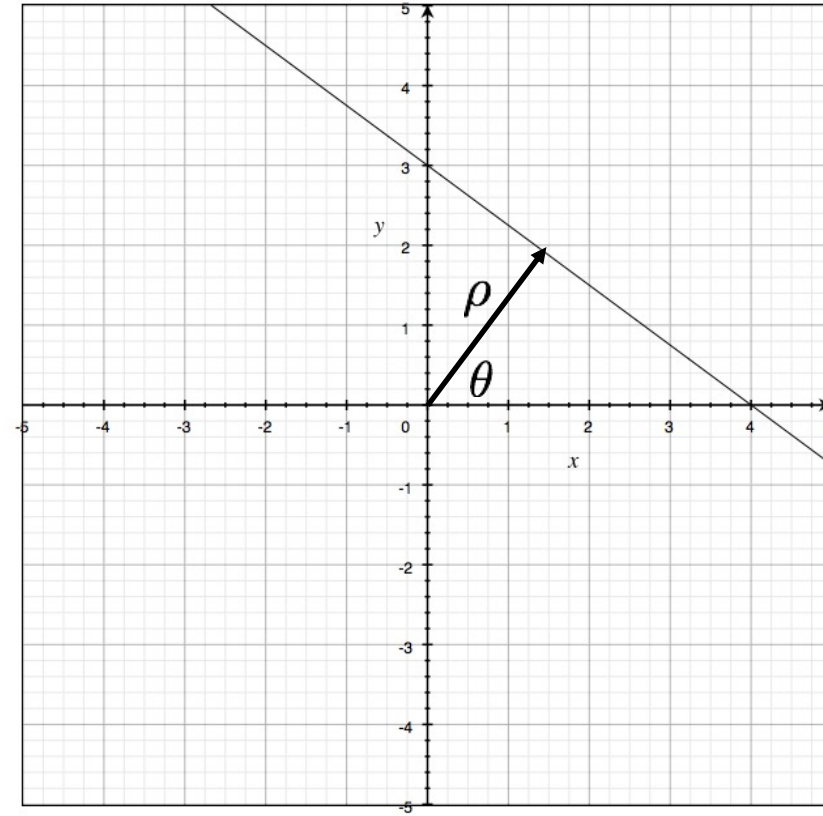
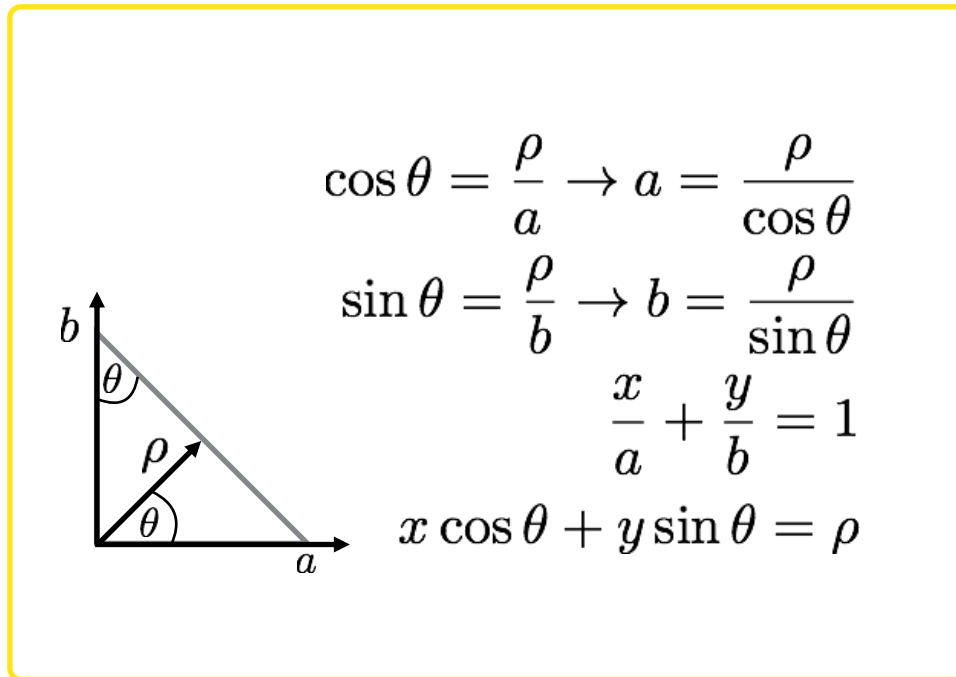
# Coordinate polari

$$x \cos \theta + y \sin \theta = \rho$$

*Cosa sono  $\rho$  e  $\theta$ ?*

# Coordinate polari

$$x \cos \theta + y \sin \theta = \rho$$



# Coordinate polari

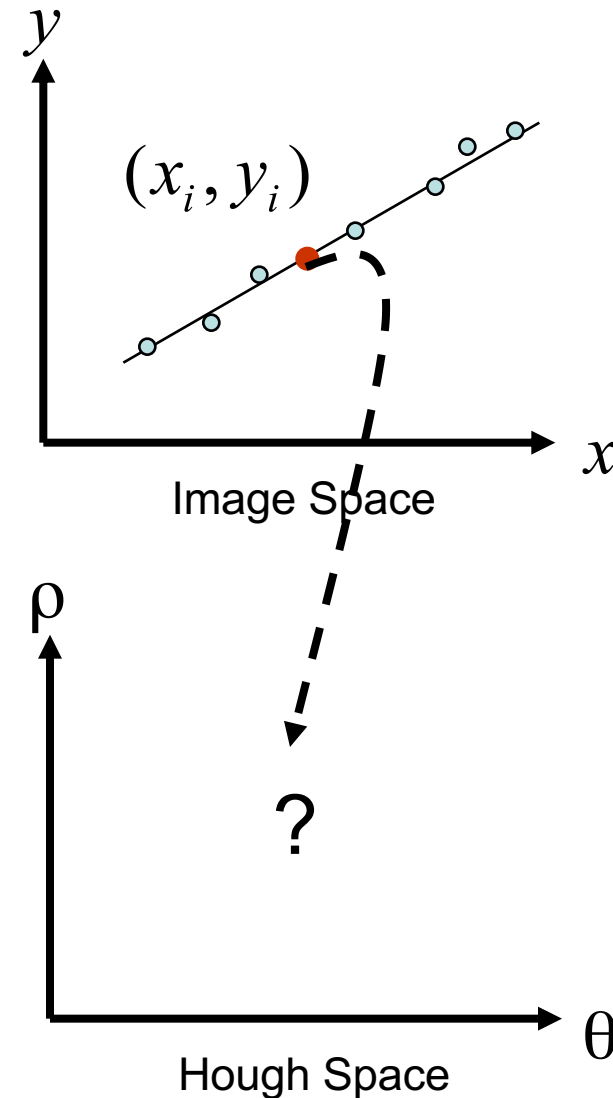
- Usiamo la forma normale

$$x \cos \theta + y \sin \theta = \rho$$

- Parametri con range controllabile

$$0 \leq \theta \leq 2\pi$$

$$0 \leq \rho \leq \rho_{\max}$$



# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$x \cos \theta + y \sin \theta = \rho$$

parametri

variabili

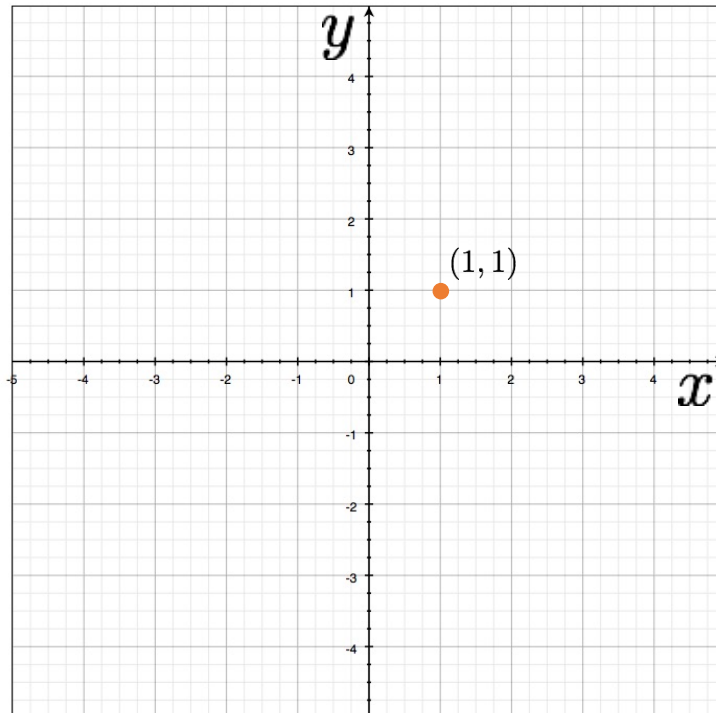
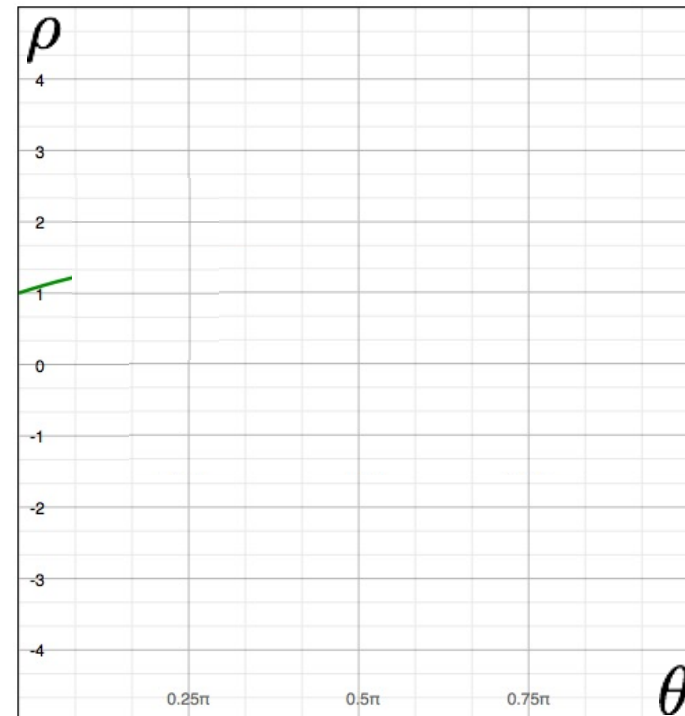
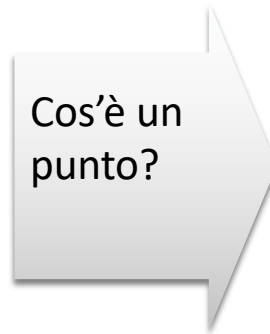


Image space



Parameter space

# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$x \cos \theta + y \sin \theta = \rho$$

parametri

variabili

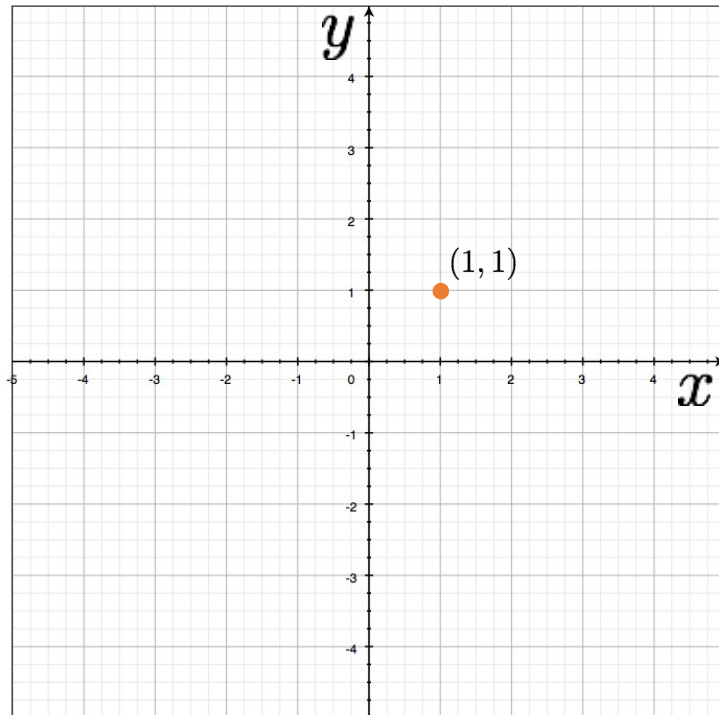
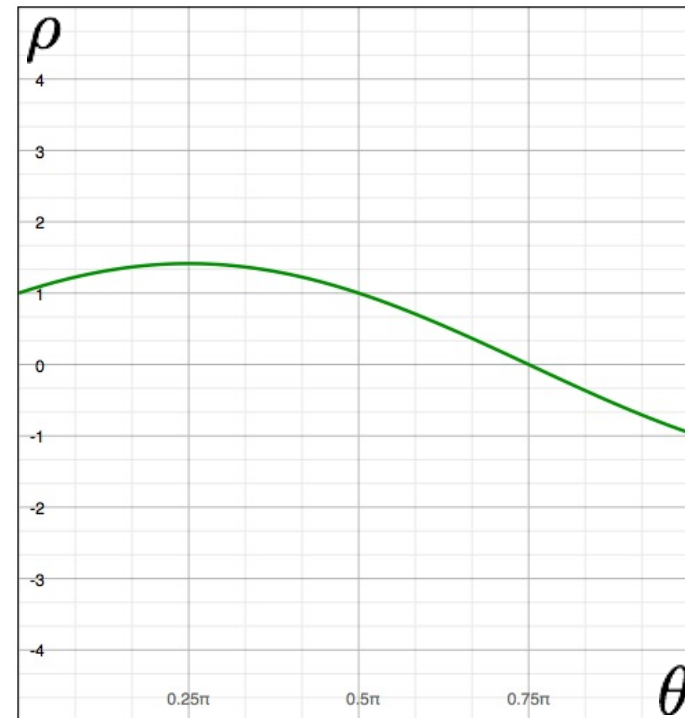


Image space



Parameter space



# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$x \cos \theta + y \sin \theta = \rho$$

parametri

variabili

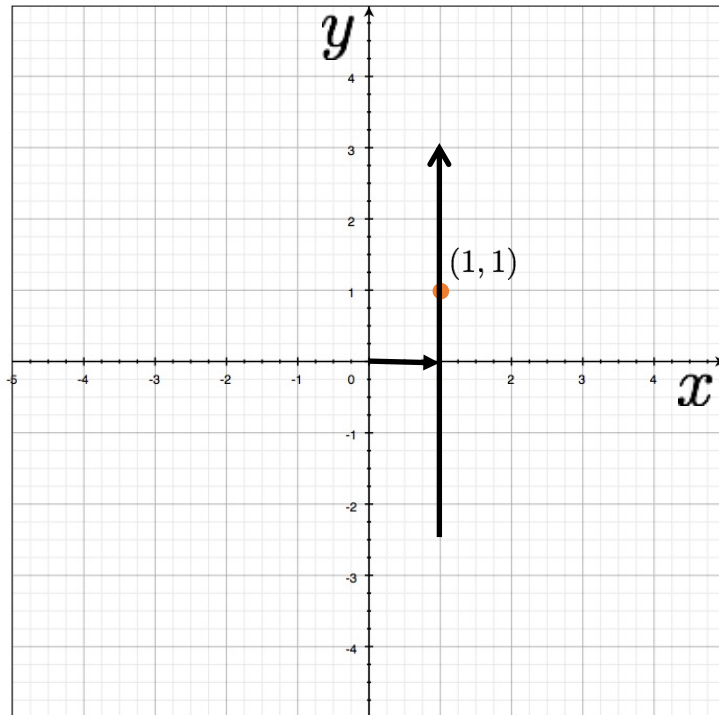
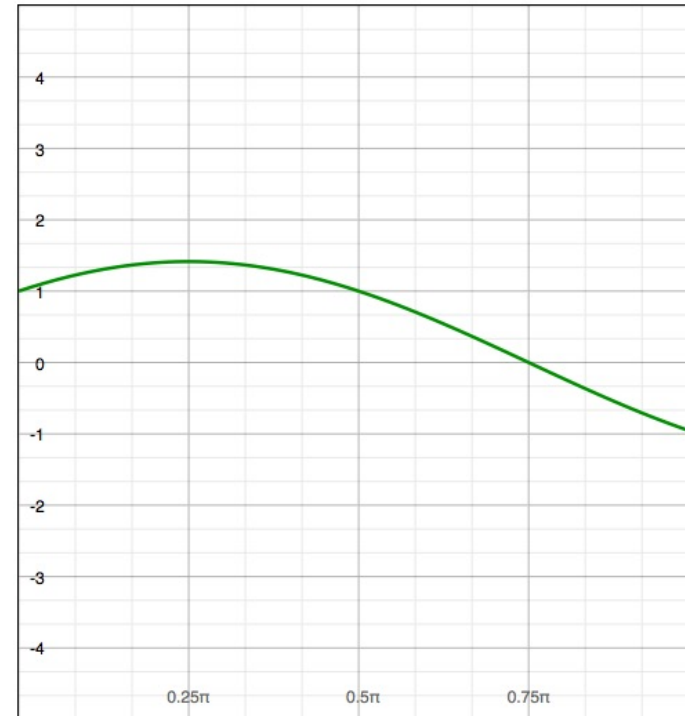


Image space

Cos'è una  
linea?



Parameter space

# Lo spazio dei parametri

variabili

$$y = mx + b$$

parametri

parametri

$$x \cos \theta + y \sin \theta = \rho$$

variabili

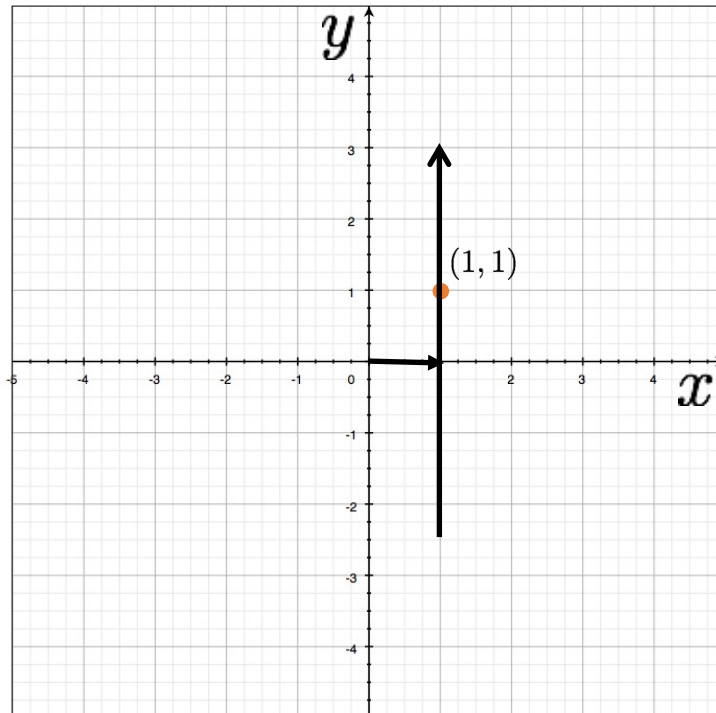
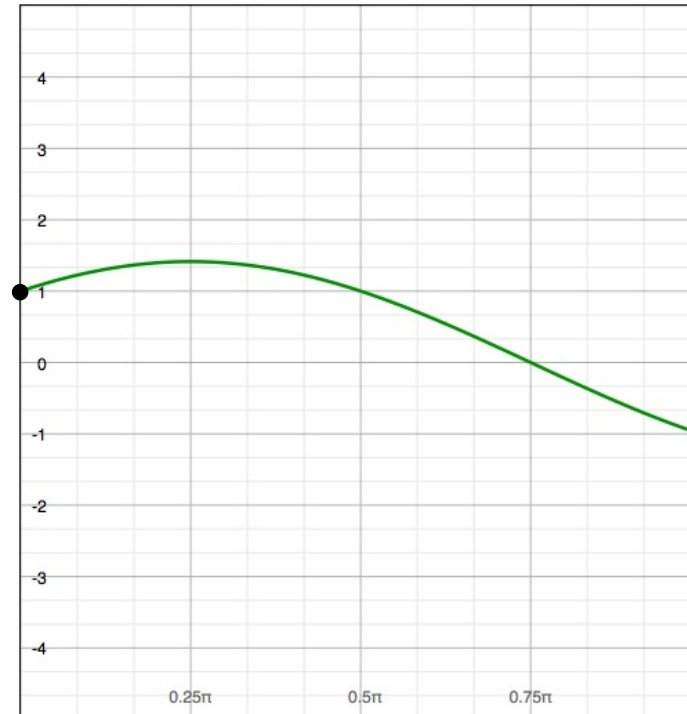


Image space

Una linea diventa un punto



Parameter space

# Lo spazio dei parametri

variabili

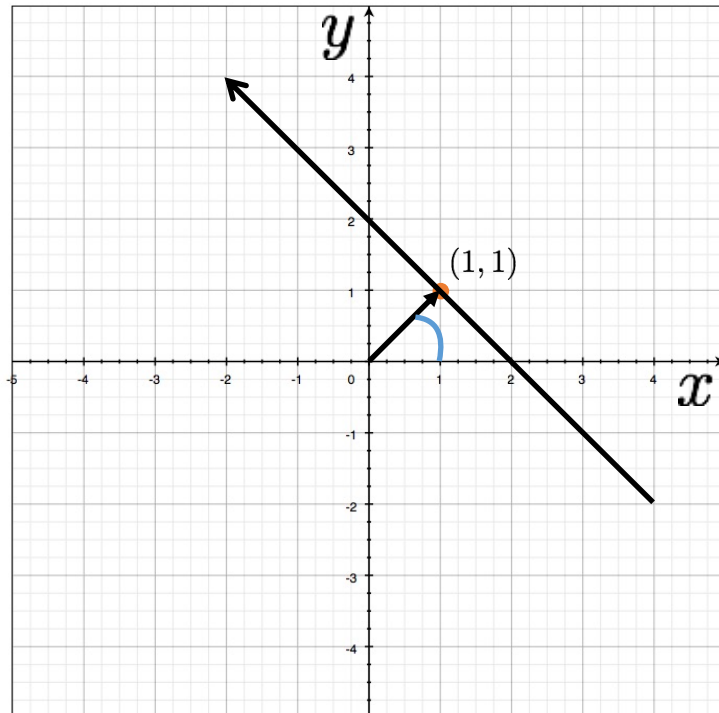
$$y = mx + b$$

parametri

parametri

$$x \cos \theta + y \sin \theta = \rho$$

variabili



Una linea diventa un punto

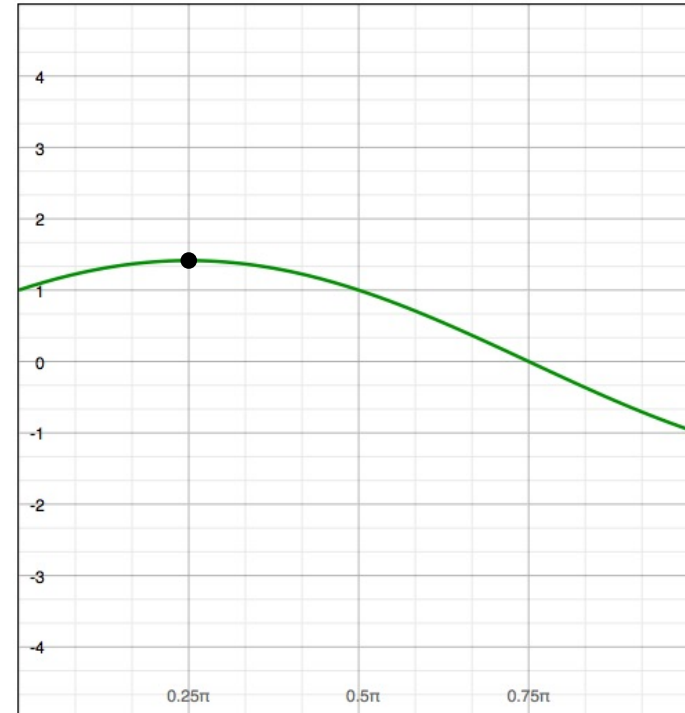


Image space

Parameter space

# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$x \cos \theta + y \sin \theta = \rho$$

parametri

variabili

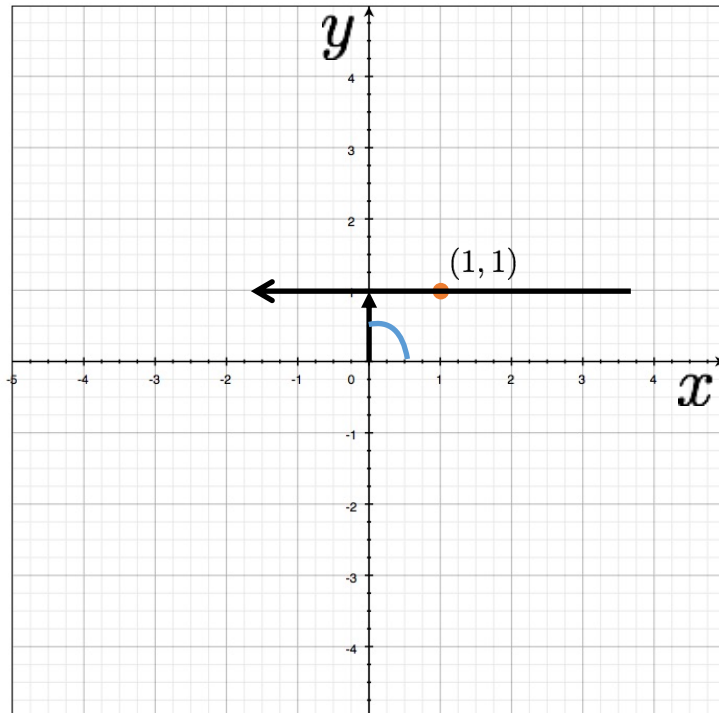
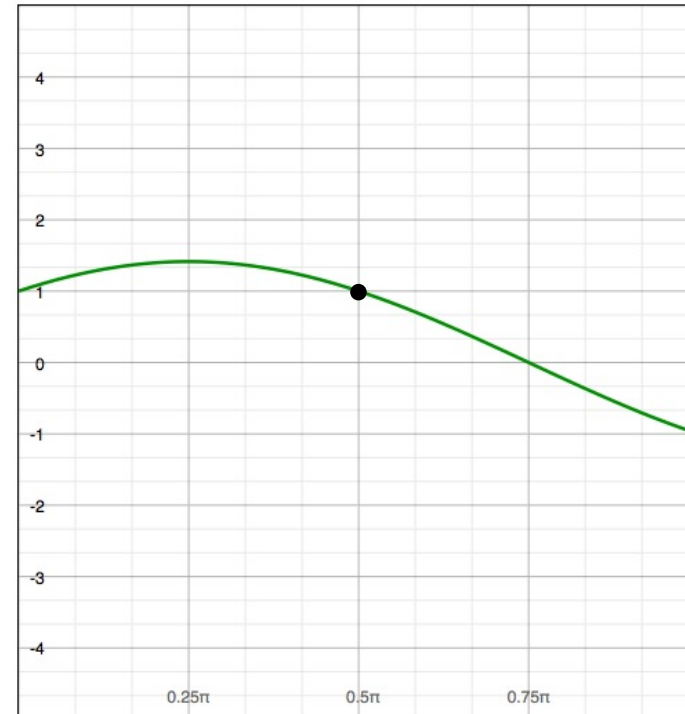


Image space

Una linea diventa un punto



Parameter space

# Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$x \cos \theta + y \sin \theta = \rho$$

parametri

variabili

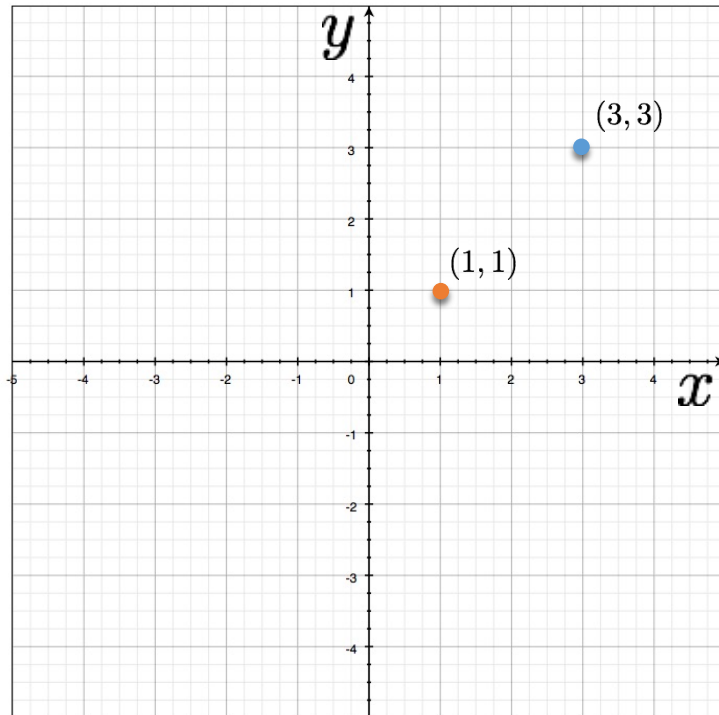
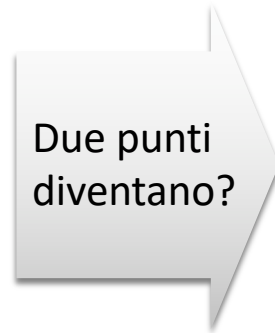
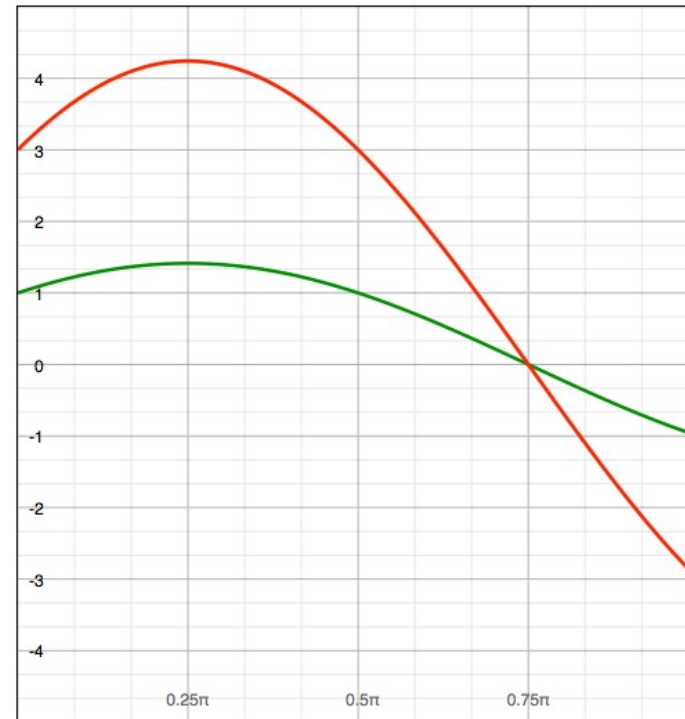


Image space



Due punti  
diventano?



Parameter space

# Lo spazio dei parametri

variabili

$$y = mx + b$$

parametri

parametri

$$x \cos \theta + y \sin \theta = \rho$$

variabili

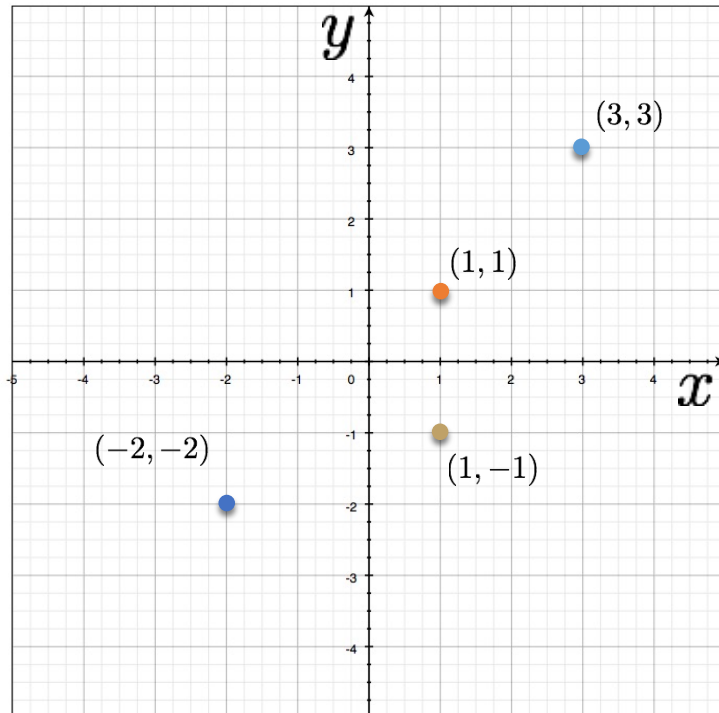
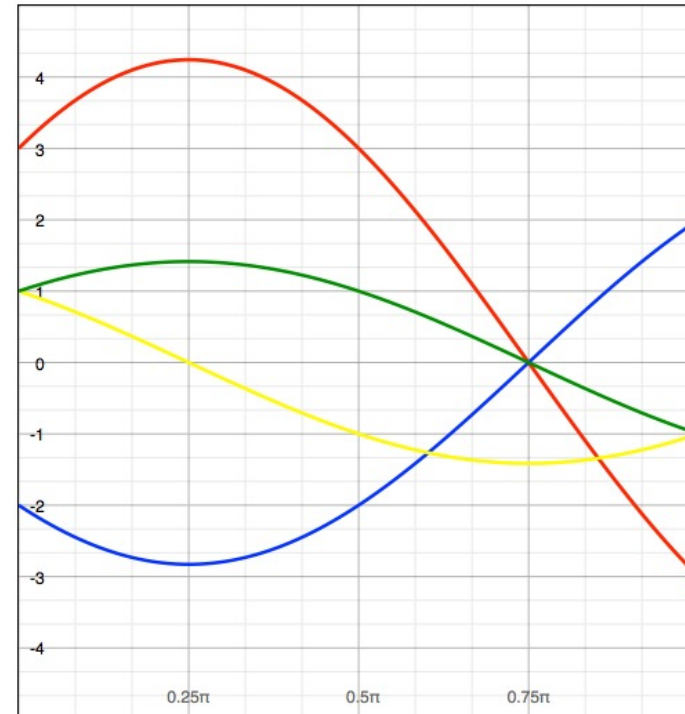
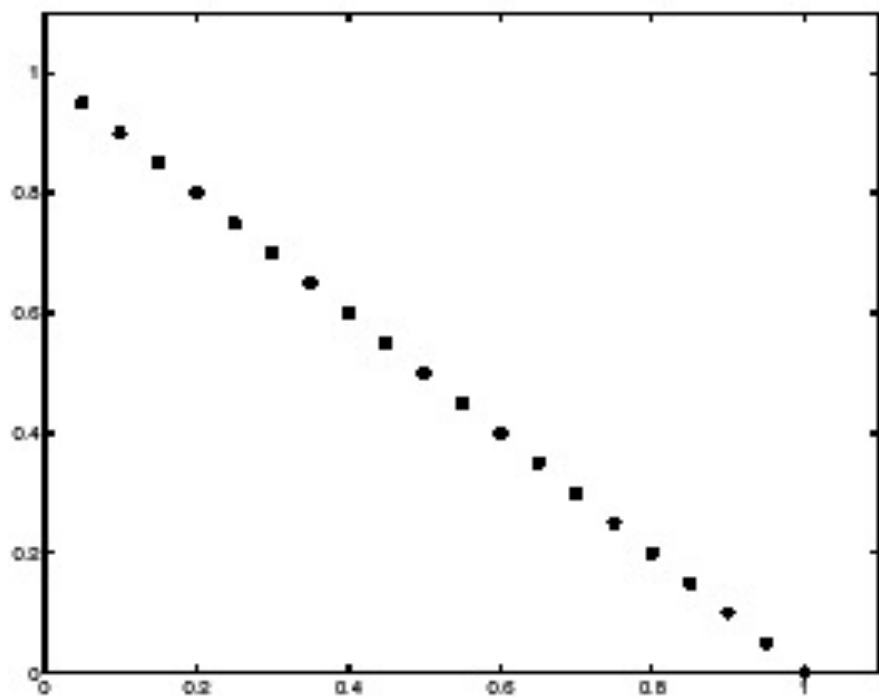


Image space

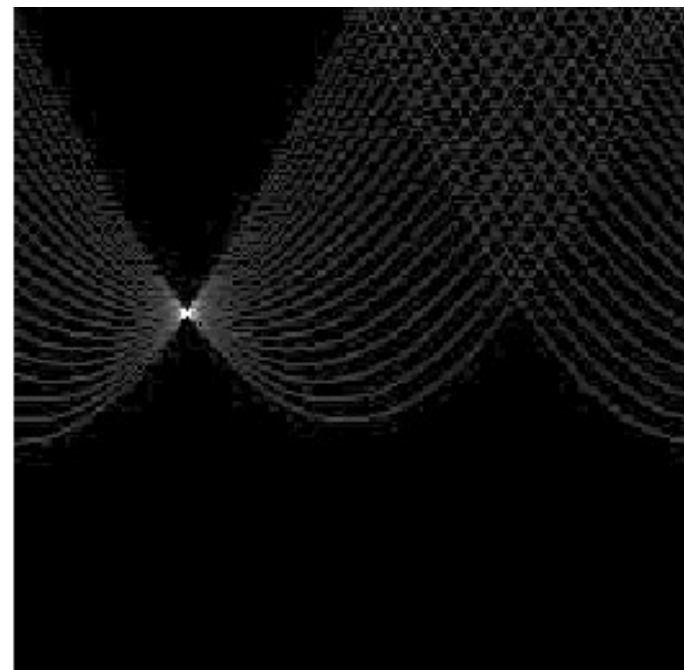
Quattro  
punti  
diventano?



Parameter space

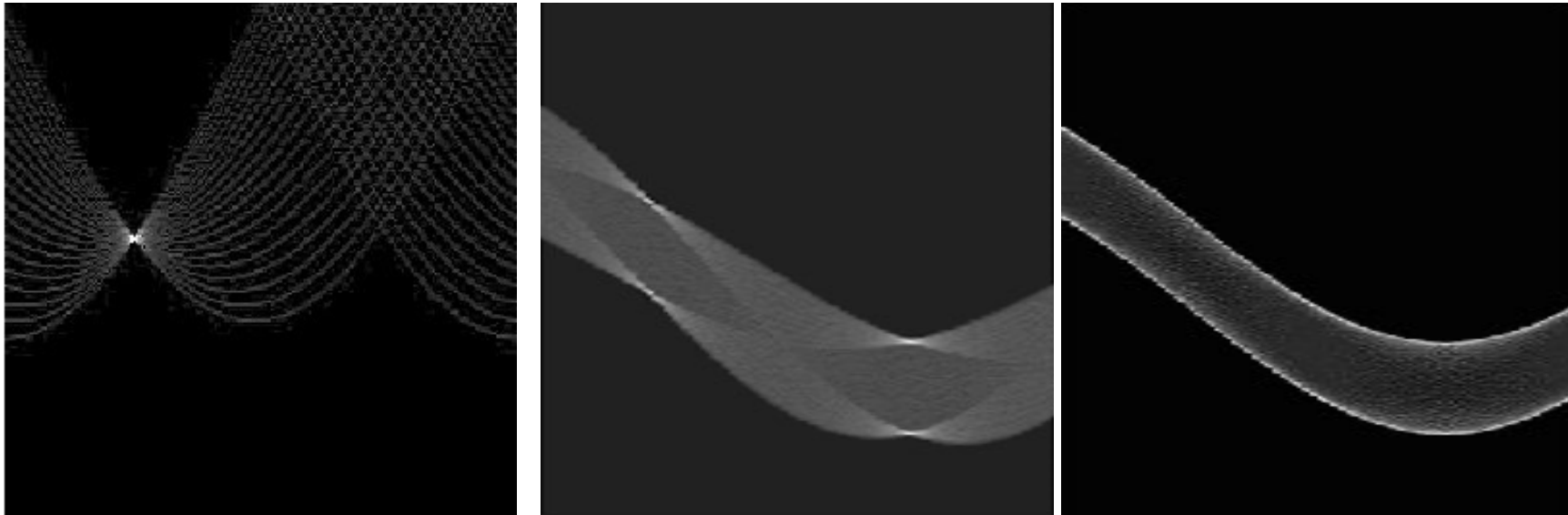


Immagine



Voti

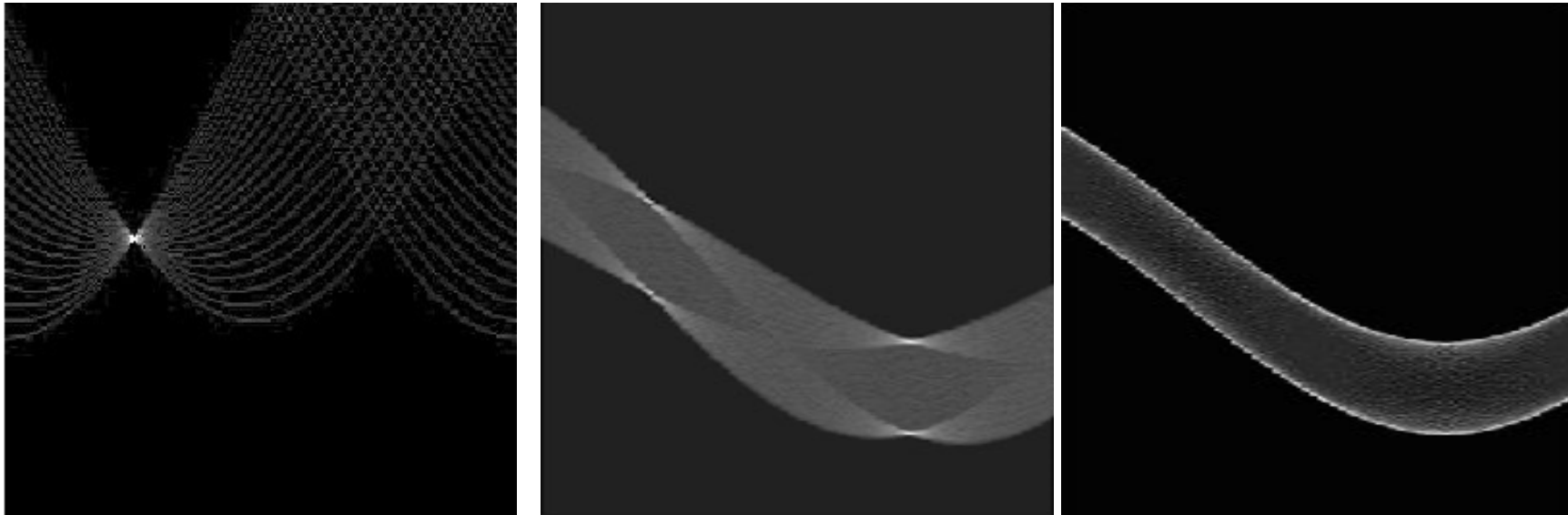
# Lo spazio dei parametri



*Qual è la forma?*

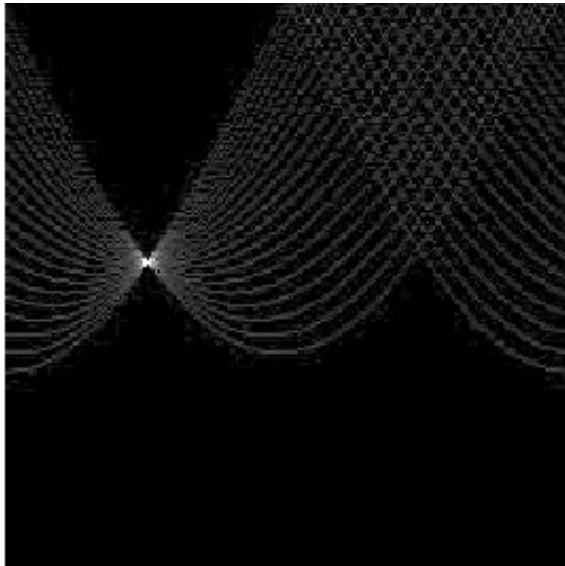


# Lo spazio dei parametri

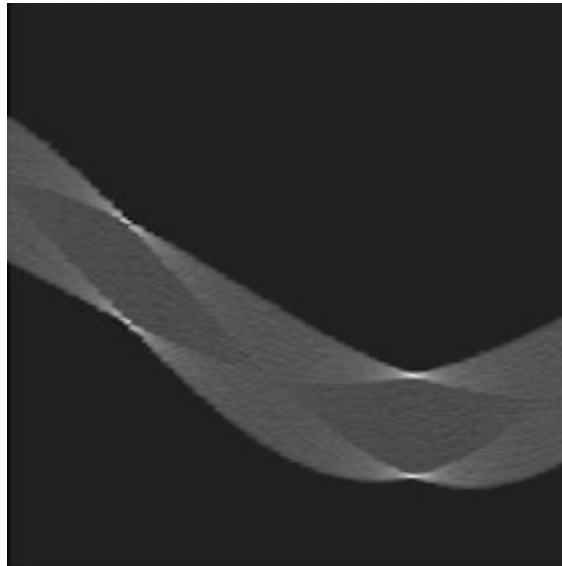


linea

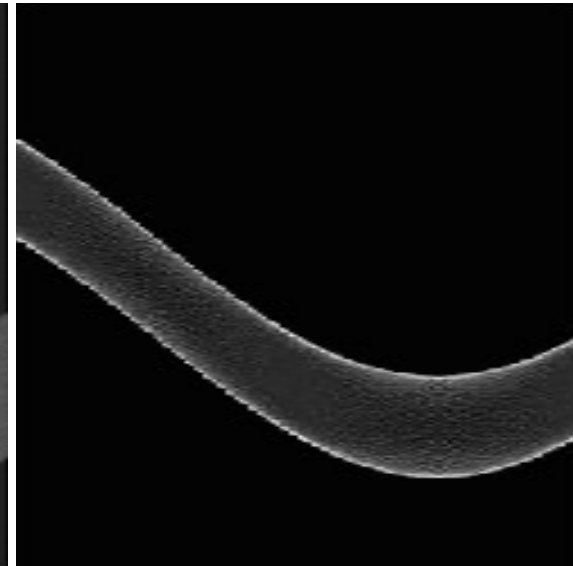
# Lo spazio dei parametri



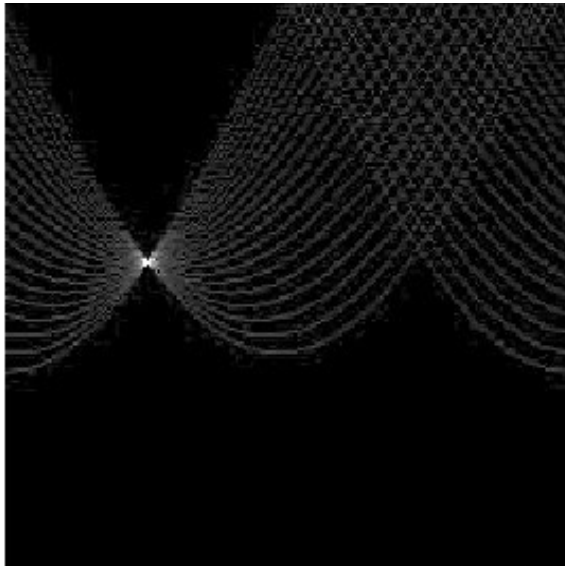
line



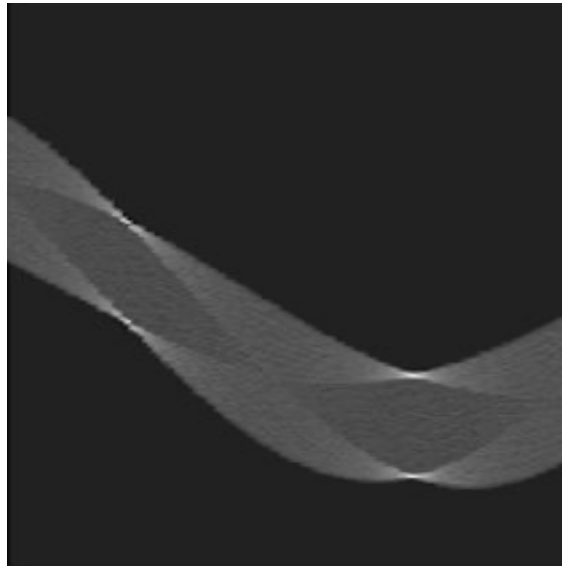
Rettangolo



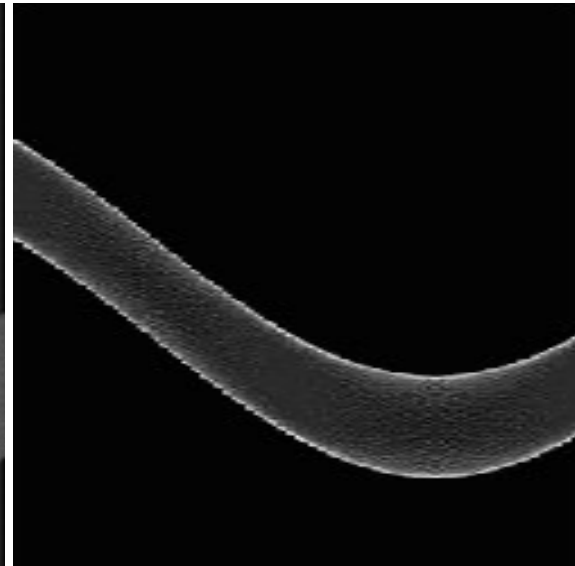
# Lo spazio dei parametri



line



rectangle

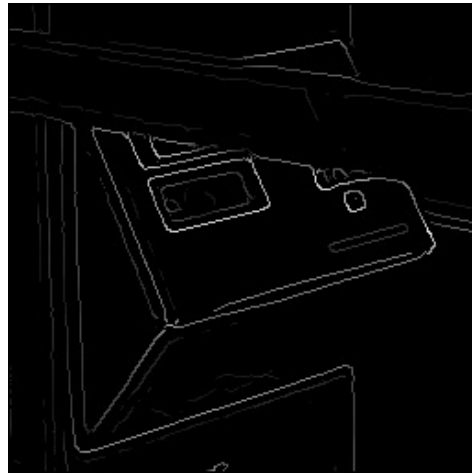


Cerchio

# Esempio



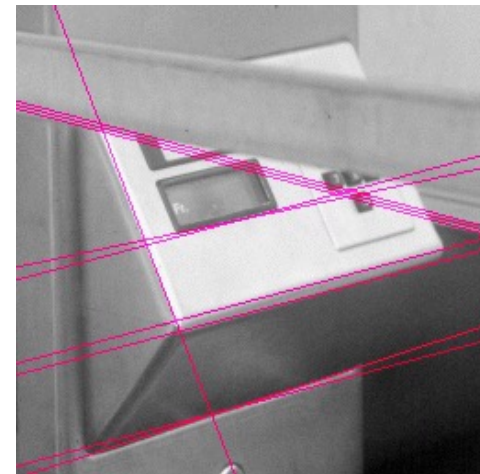
Original



Edges



parameter space



Hough Lines

# Possiamo individuare cerchi direttamente?

- L'equazione del cerchio

$$(x - a)^2 + (y - b)^2 = r^2$$

parametri

variabili

$$(x - a)^2 + (y - b)^2 = r^2$$

parametri

variabili

$$(x - a)^2 + (y - b)^2 = r^2$$

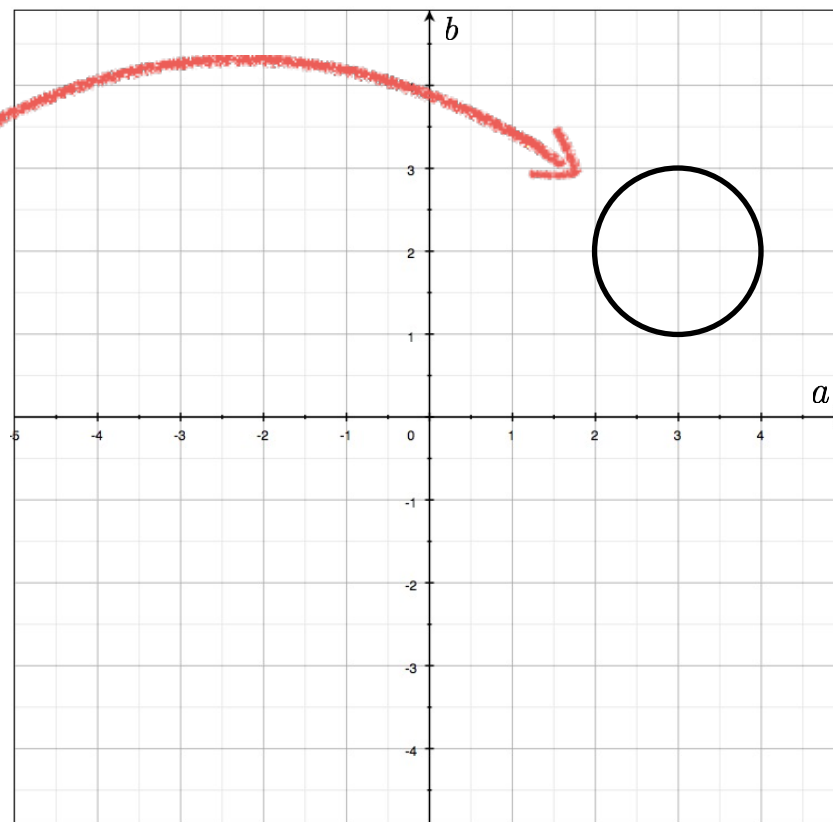
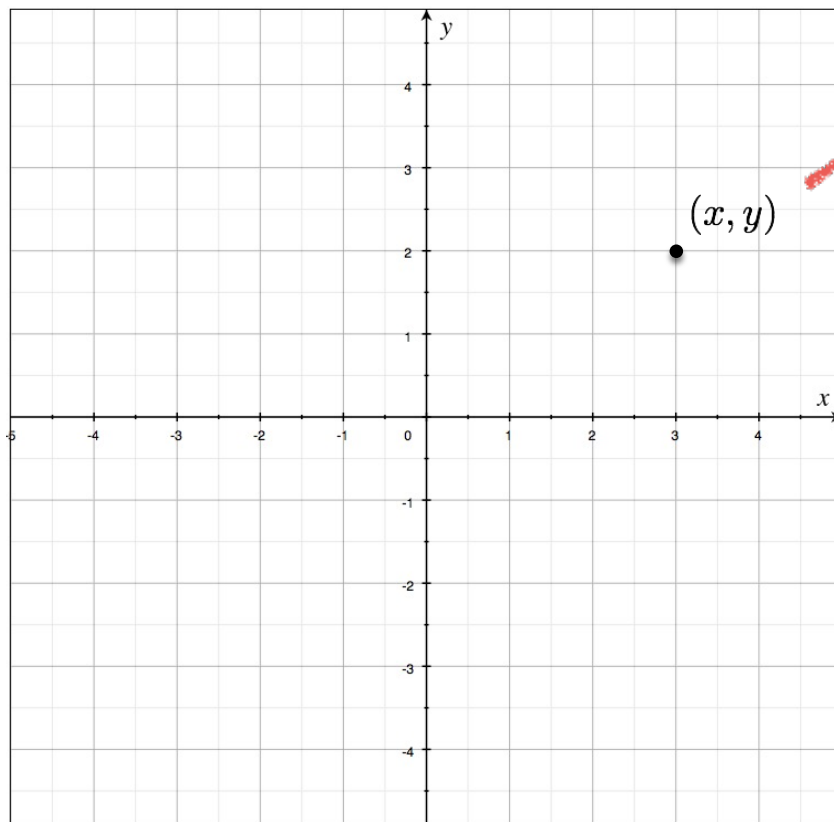
parametri

variabili

$$(x - a)^2 + (y - b)^2 = r^2$$

parametri

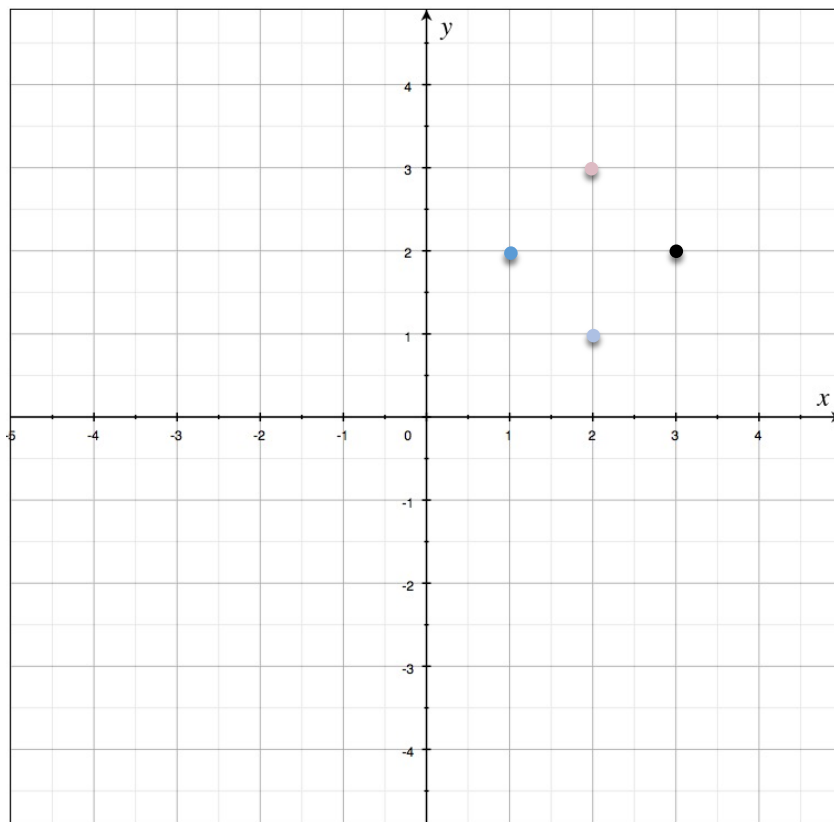
variabili



parametri

$$(x - a)^2 + (y - b)^2 = r^2$$

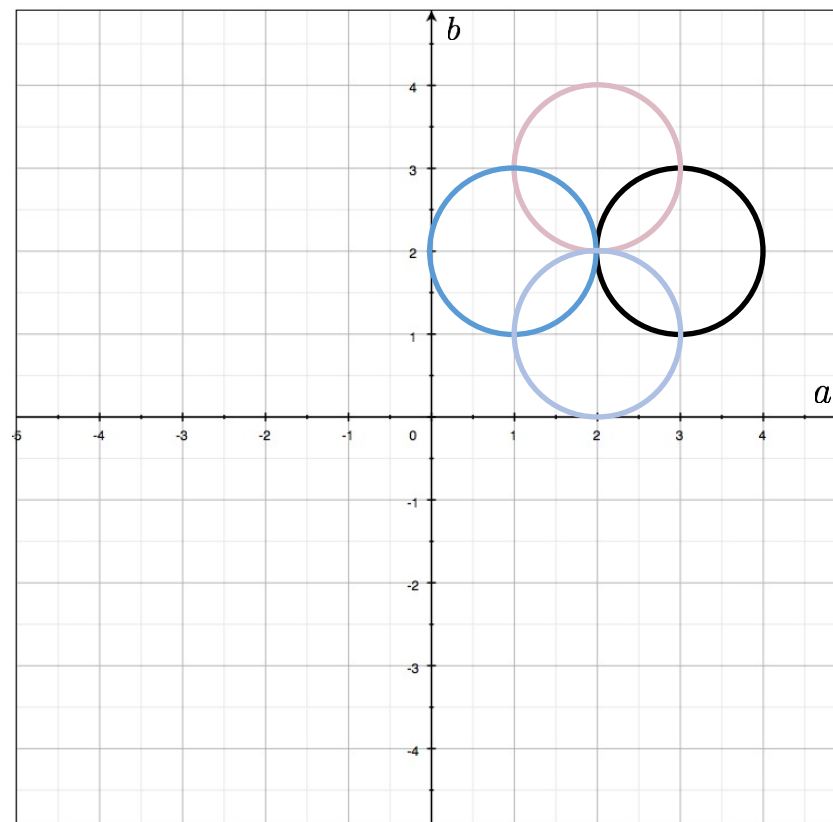
variabili

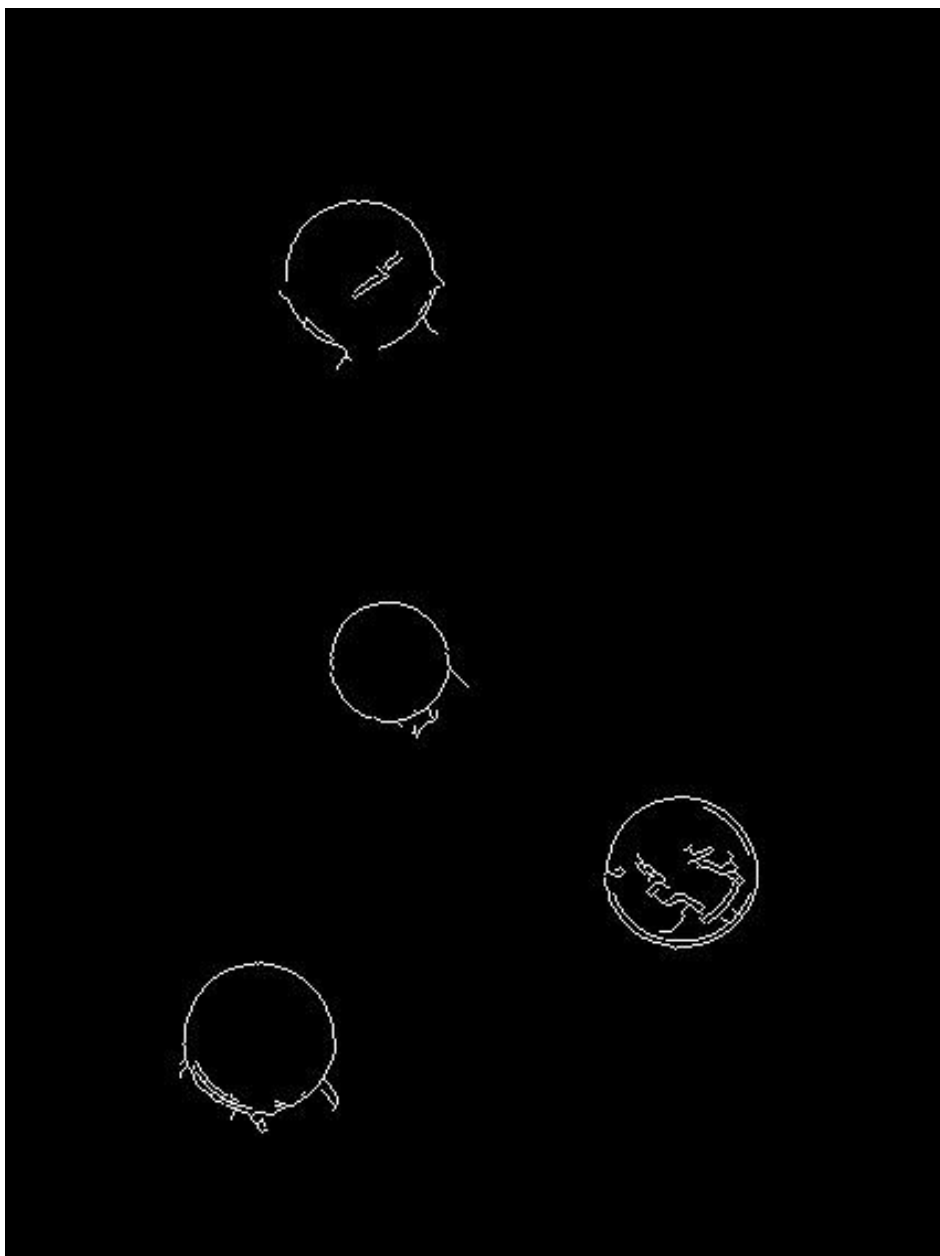
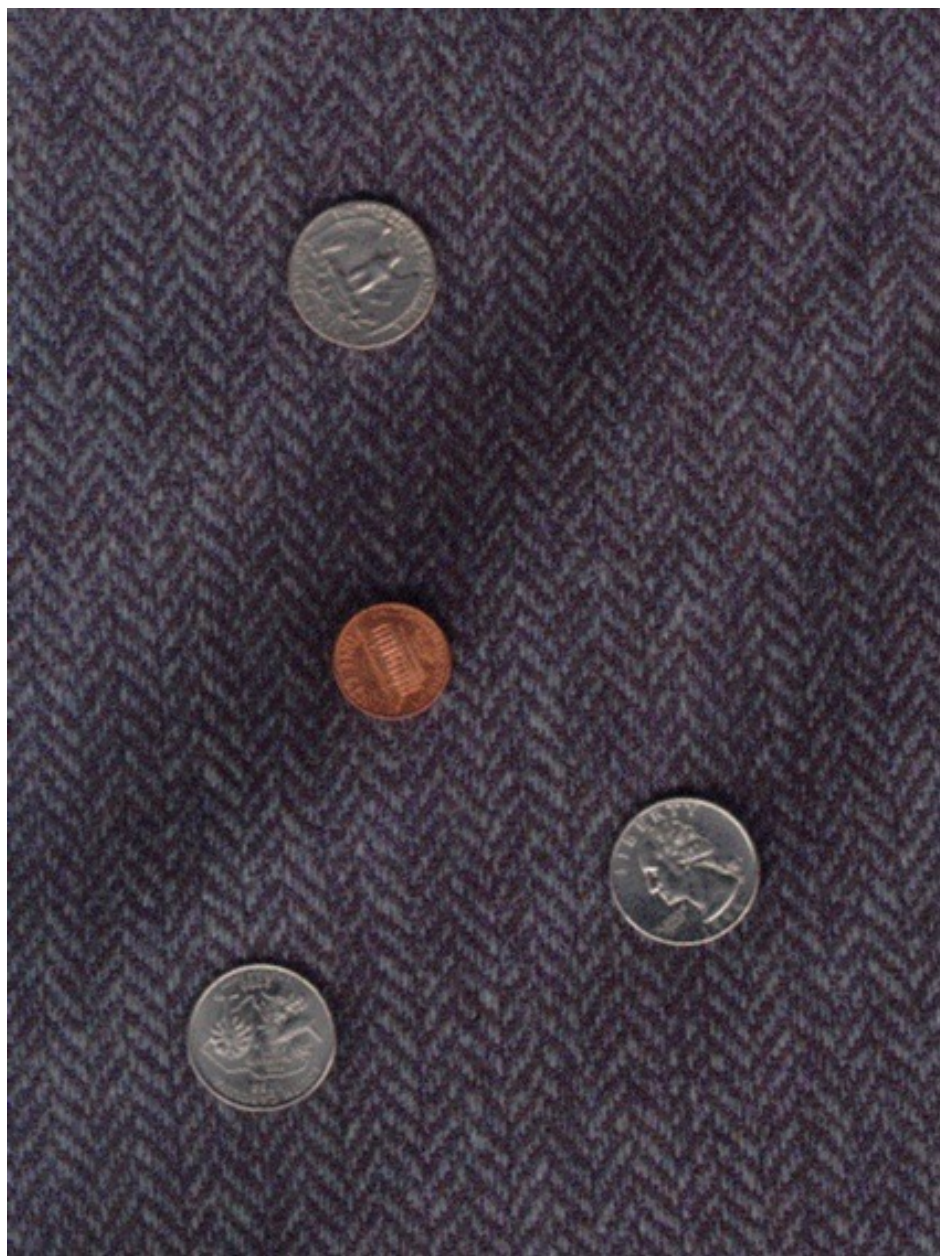


parametri

$$(x - a)^2 + (y - b)^2 = r^2$$

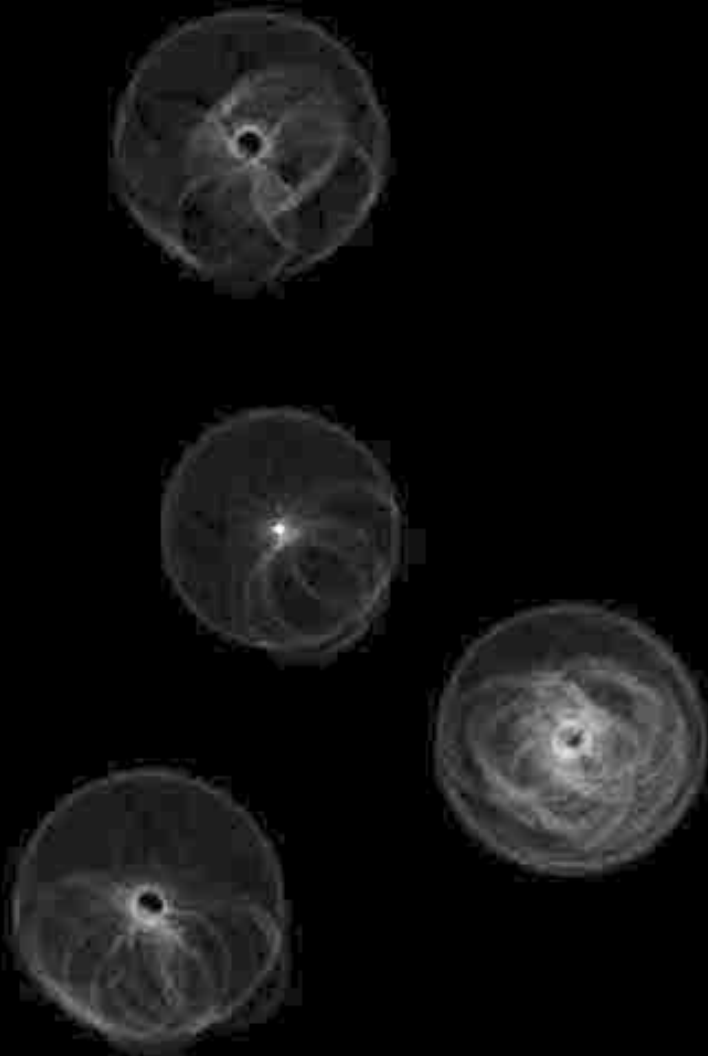
variabili







Raggio piccolo



Raggio grande

