

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

$$\mathbf{S}_x = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

$$\mathbf{S}_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

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

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

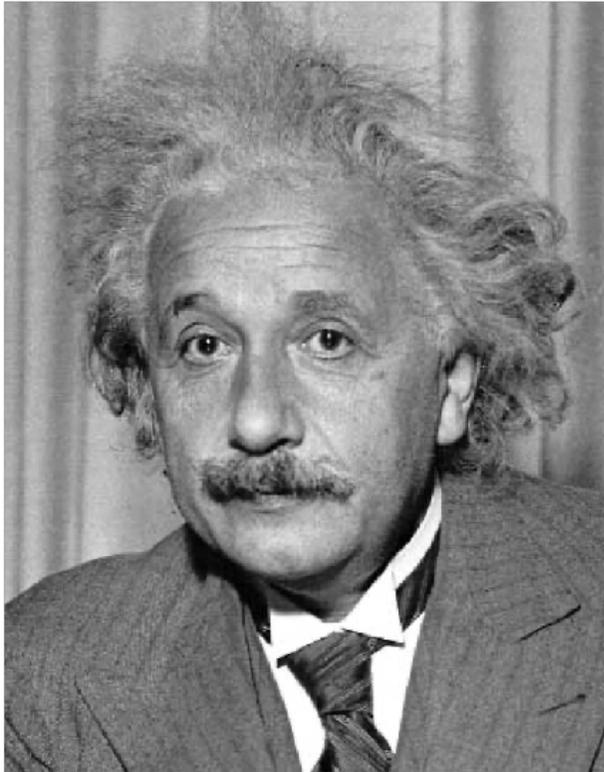
direction

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

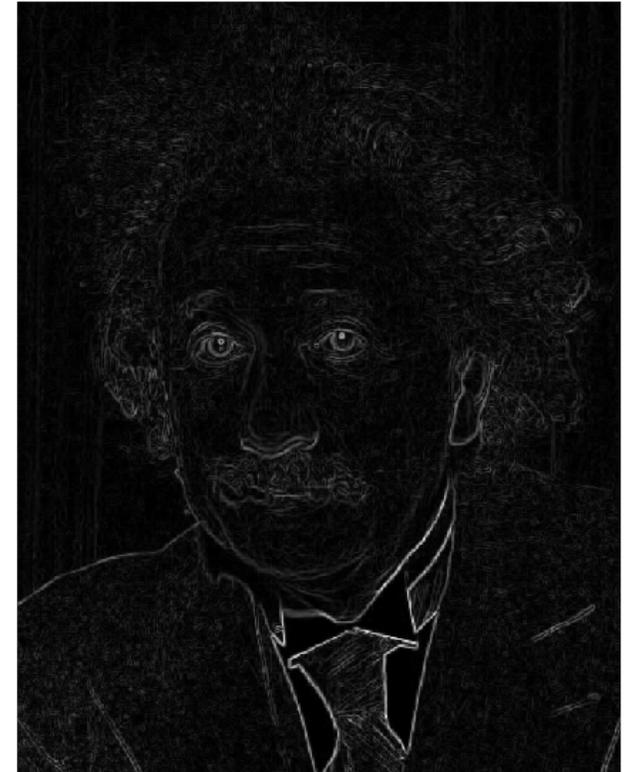
amplitude

Gradient-Based Filtering

originale



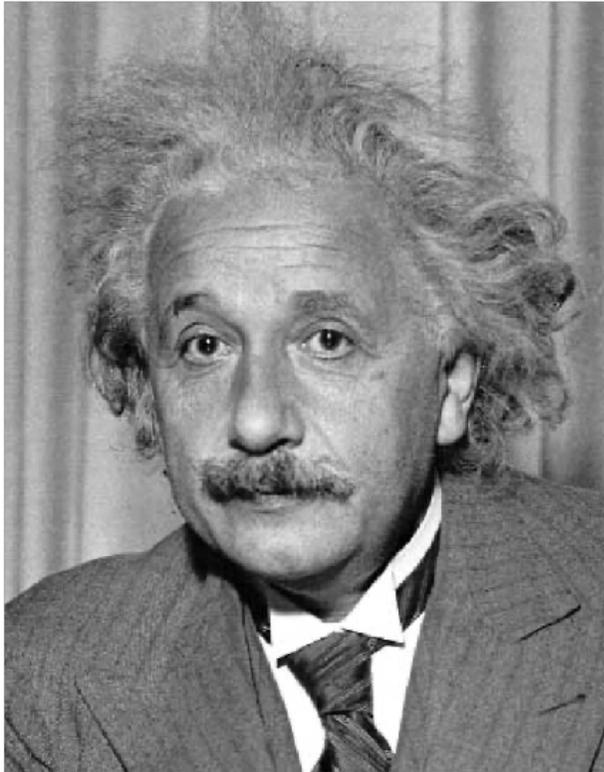
Ampiezza



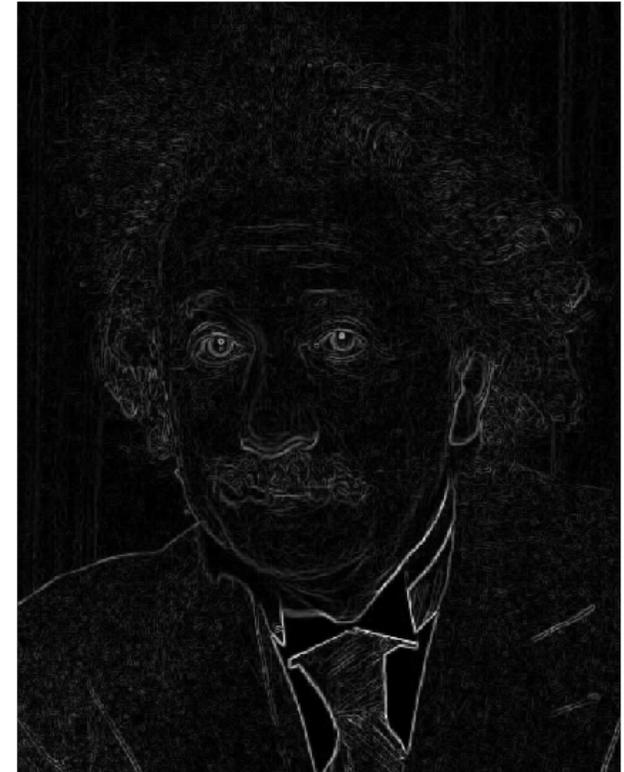
- Cosa c'è che non va?

Gradient-Based Filtering

originale



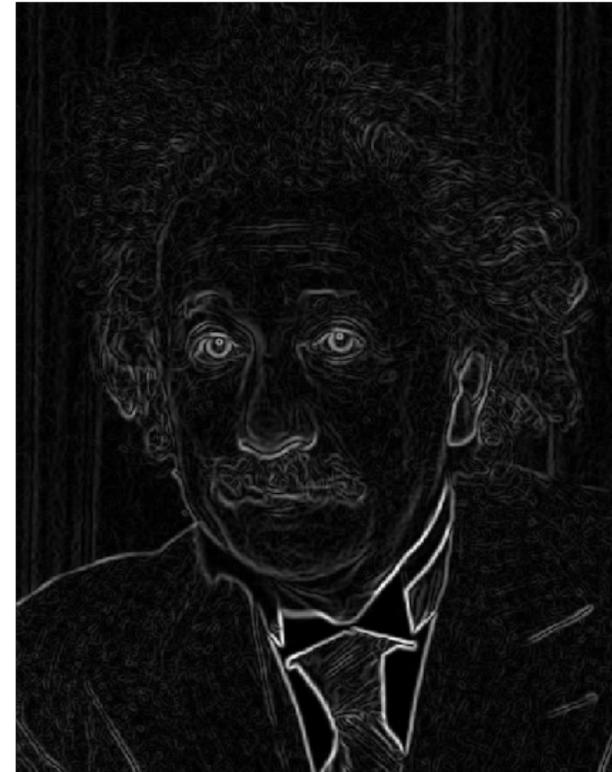
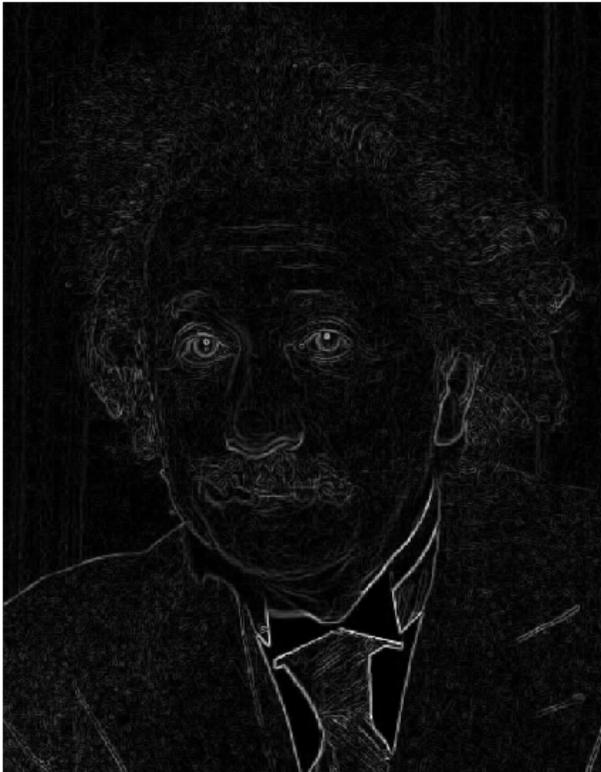
Ampiezza



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

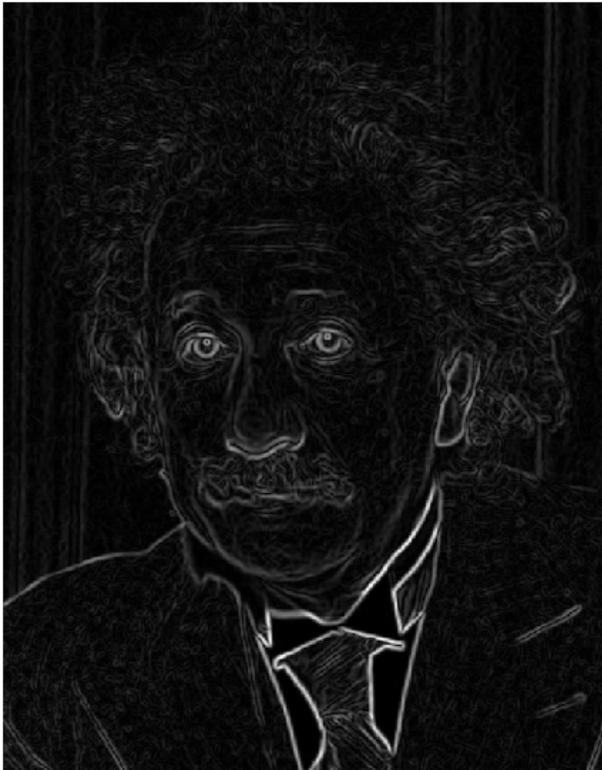
Gradient-Based Filtering

- Noise
 - Lo trattiamo con il filtro gaussiano



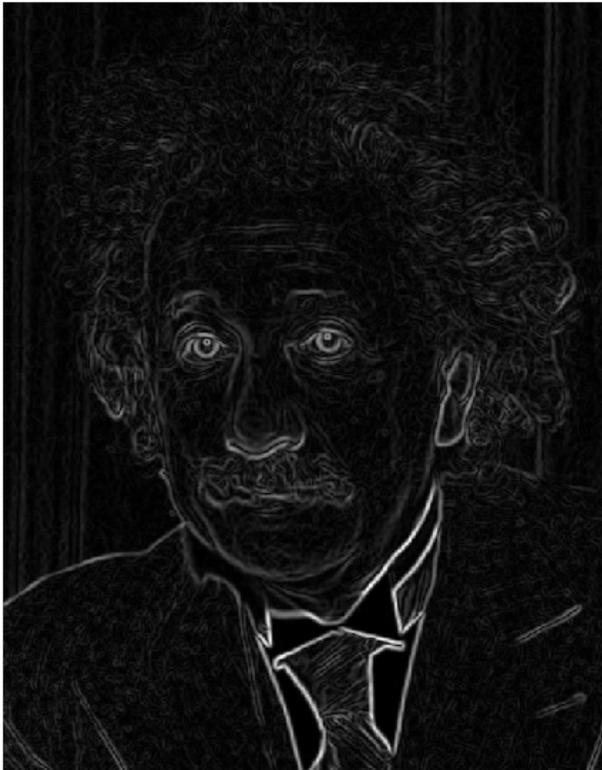
Gradient-Based Filtering

- Troppi toni di grigio
 - Thresholding



Gradient-Based Filtering

- Diversi spessori
 - ?

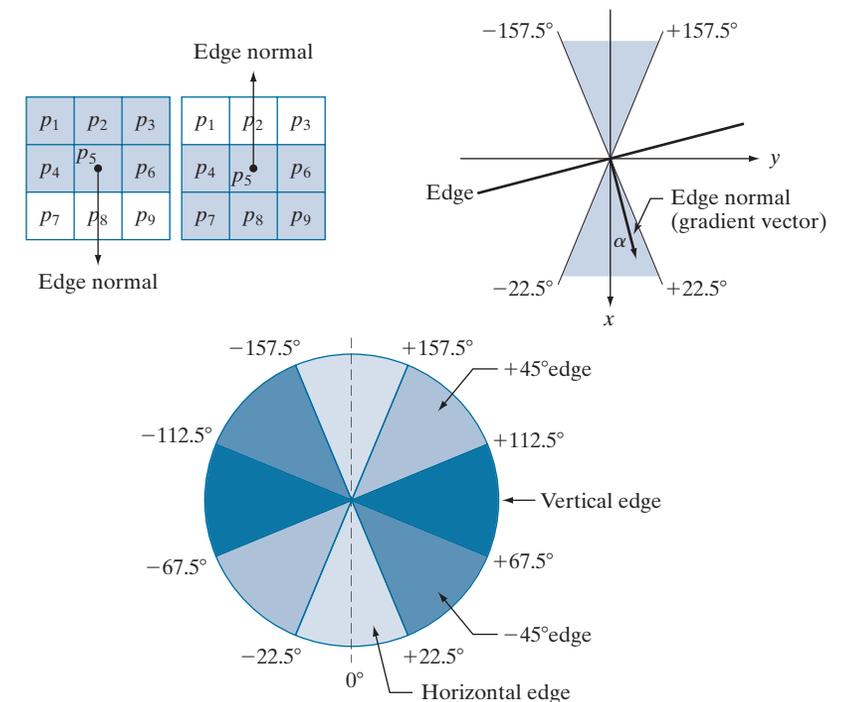
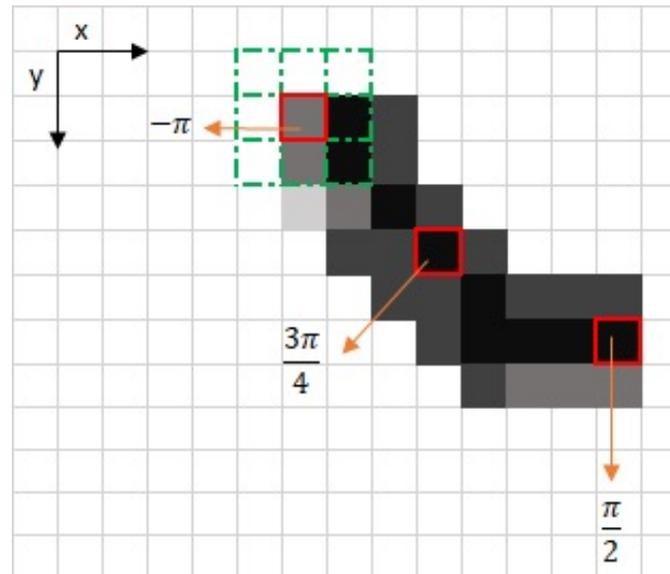


Canny Edge Detector

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

Non maximal suppression

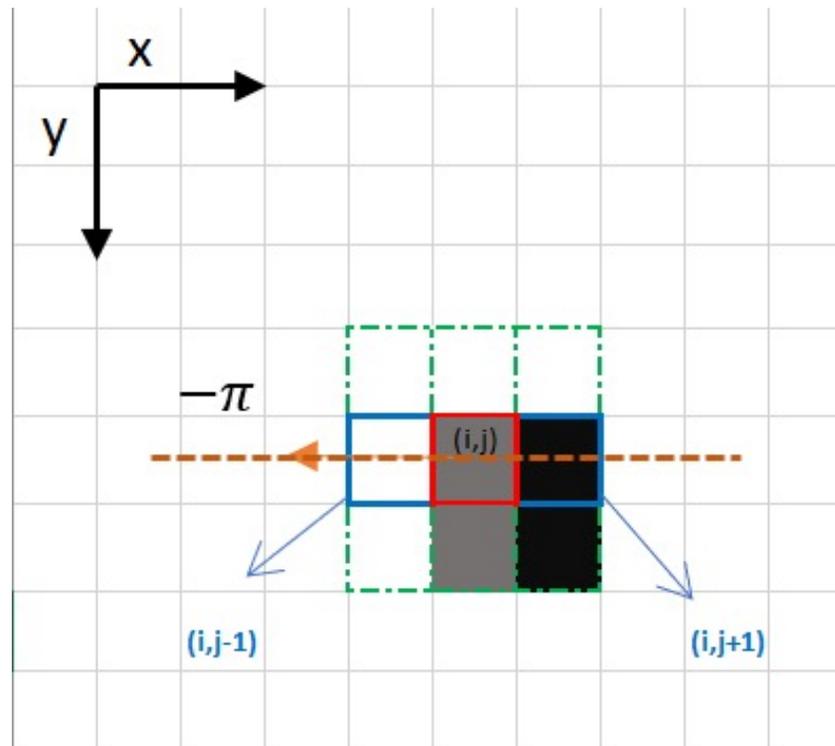
- Basata sulla direzione del gradiente $\theta = \tan^{-1} \left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x} \right)$



- Il gradiente punta a valori alti di intensità

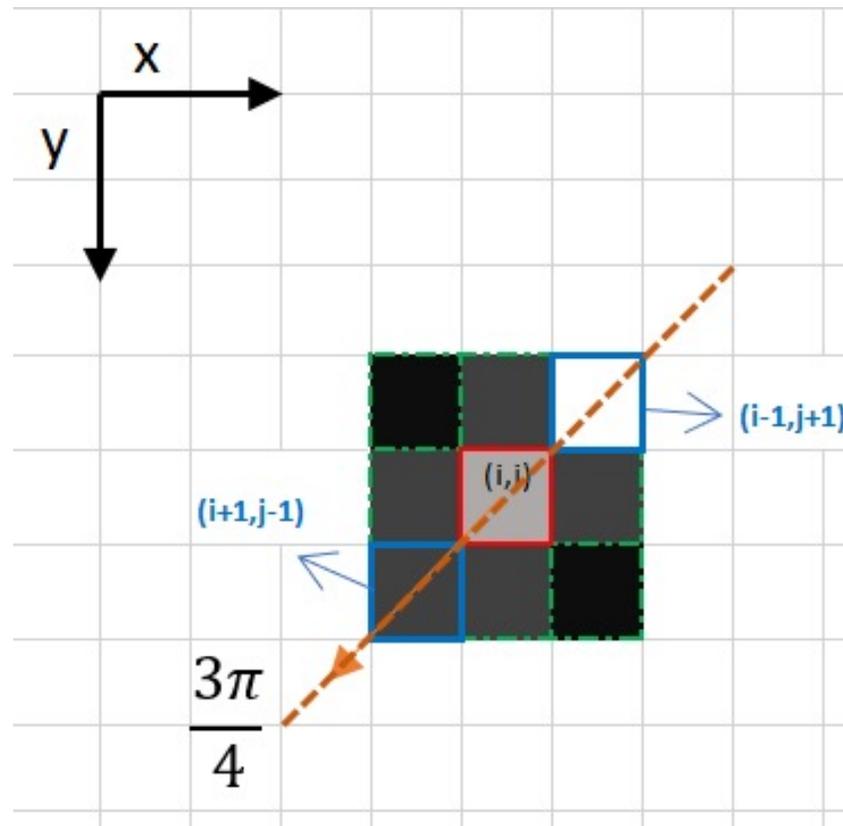
Non maximal suppression

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

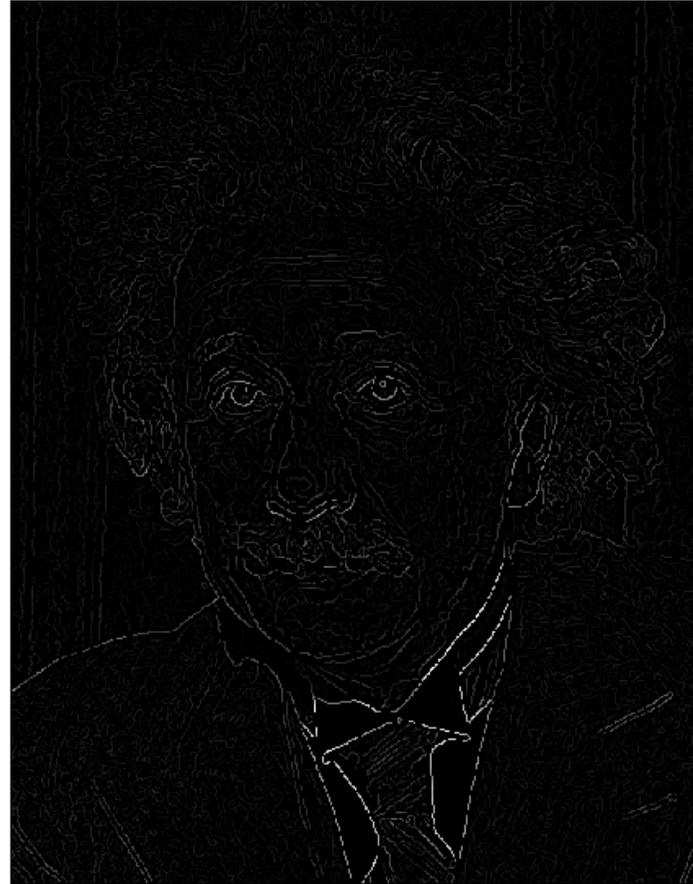
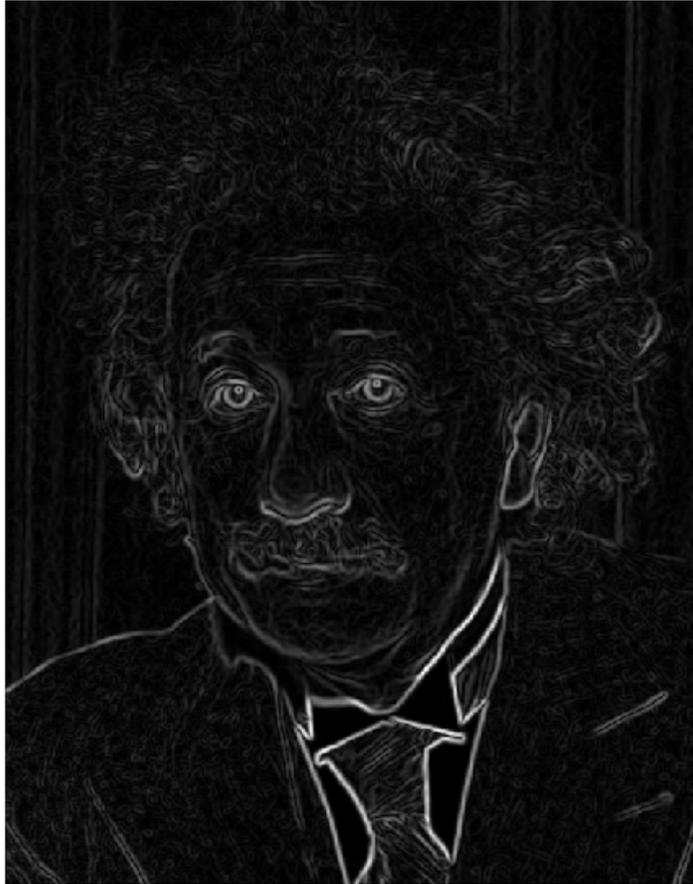


Non maximal suppression

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



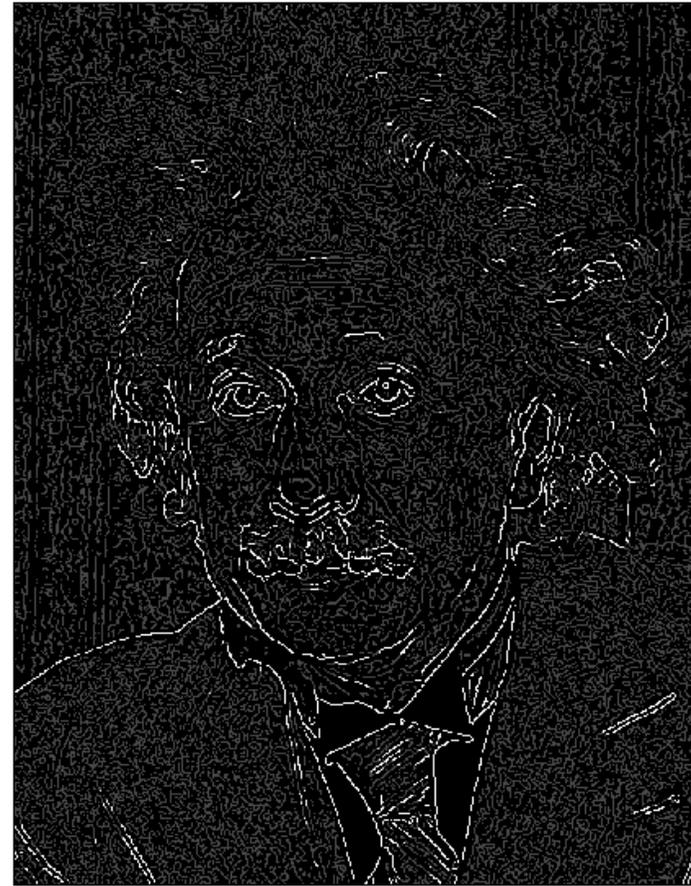
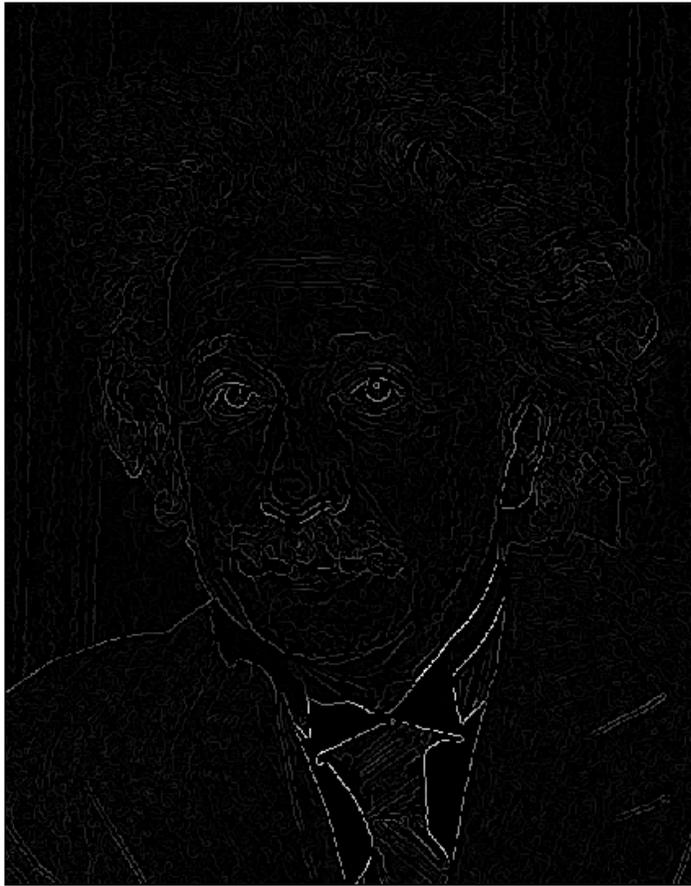
Non-Maximal Suppression



Level-wise thresholding, hysteresis

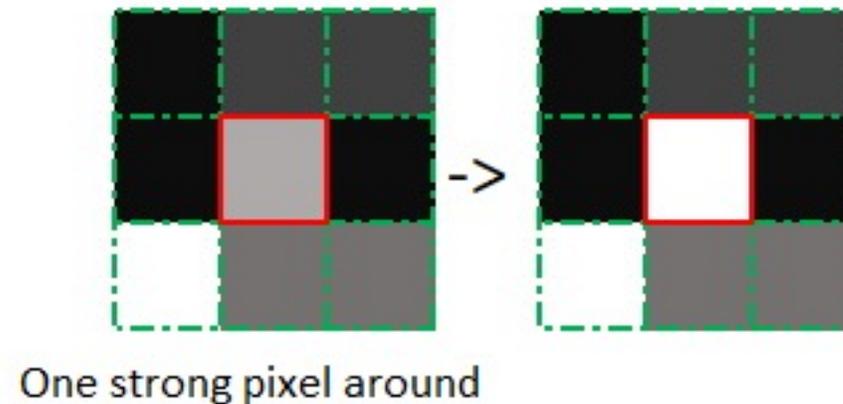
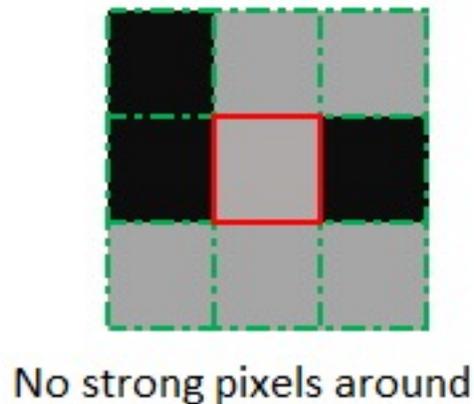
- Strong/Weak/irrelevant pixels
 - Strong pixels: intensità alta (contribuiscono sicuramente ai bordi)
 - Weak pixels: intensità non alta, ma neanche bassa
 - Li teniamo da parte
 - Irrelevant pixels: intensità bassa, da rimuovere
- Usiamo due soglie
 - High threshold per identificare strong pixels
 - 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

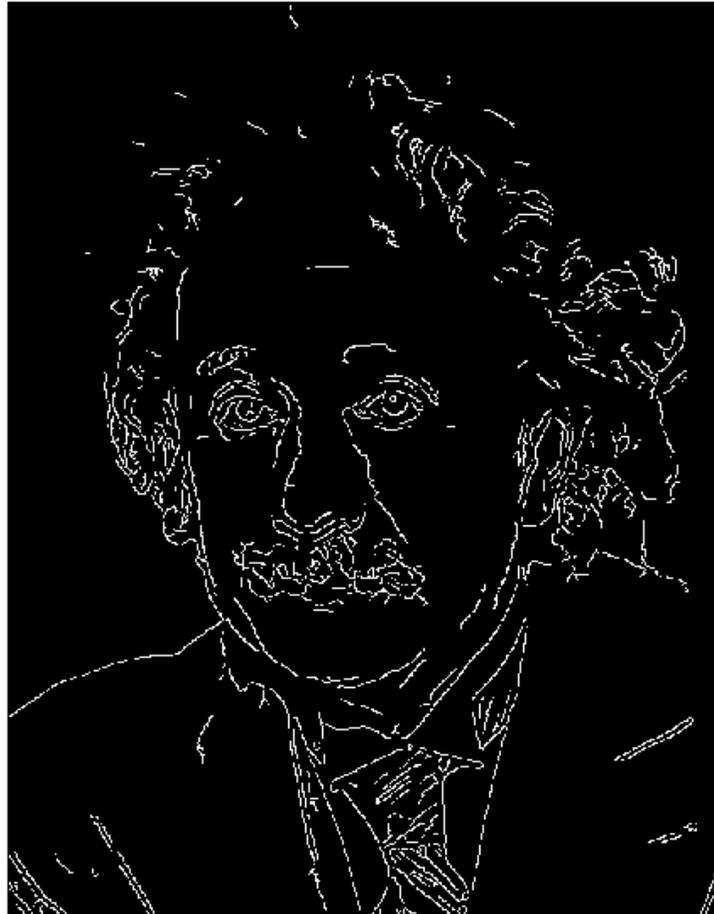


Hysteresis

- «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

$$y = mx + b$$

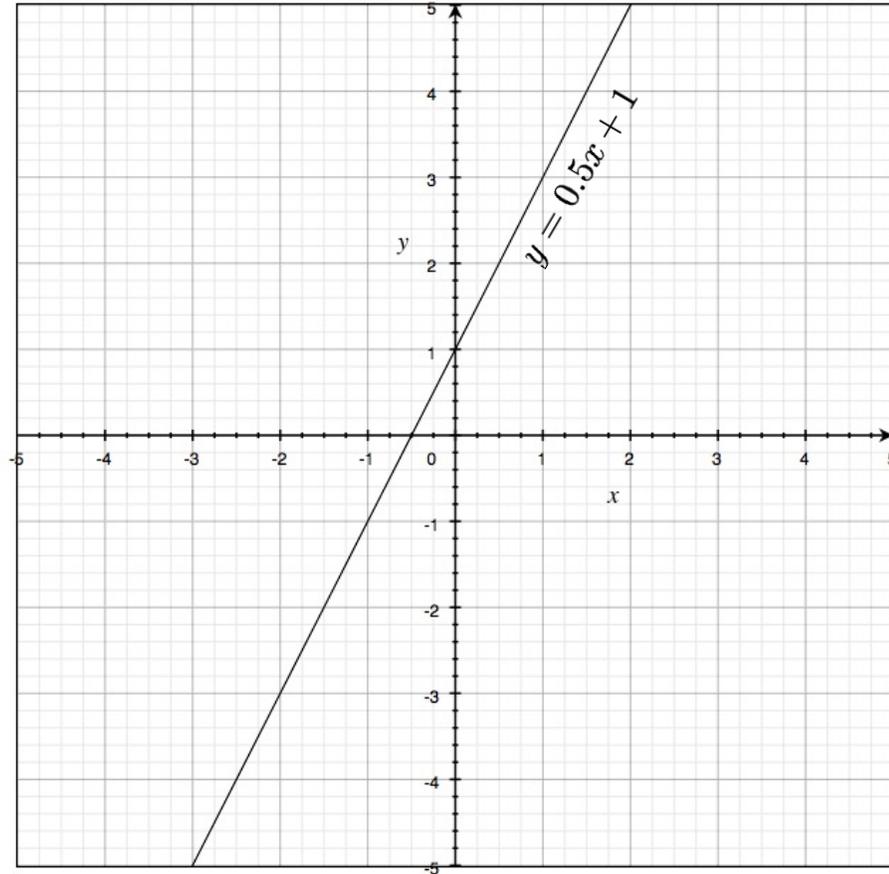
 
slope y-intercept

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

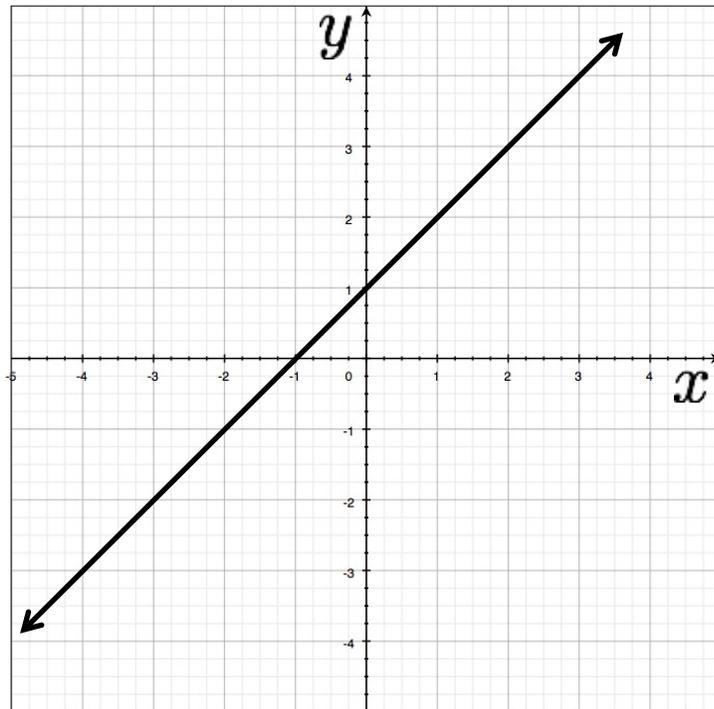
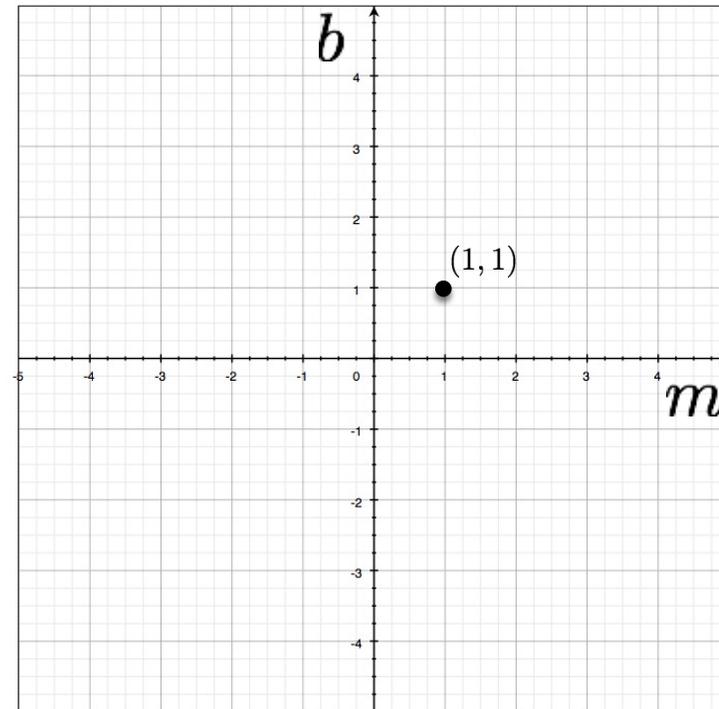


Image space

Una linea diventa un punto



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

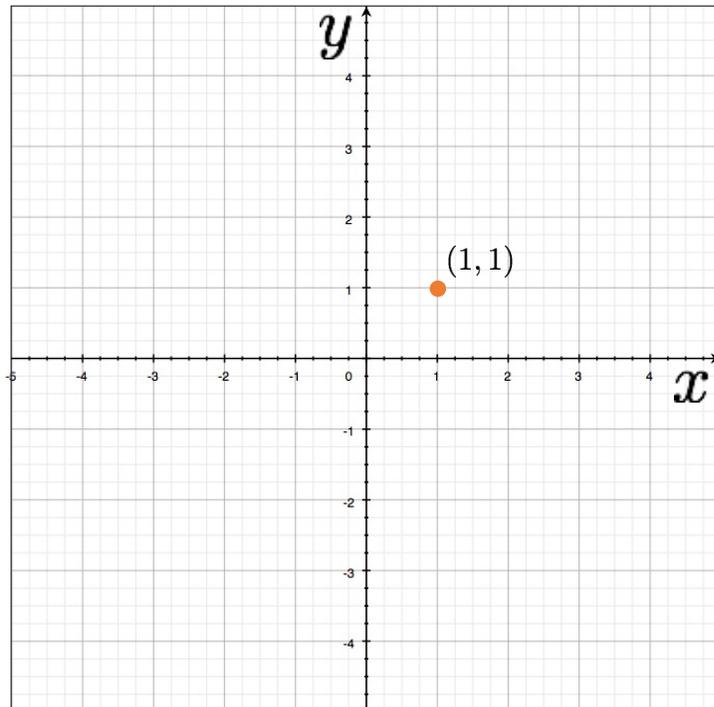
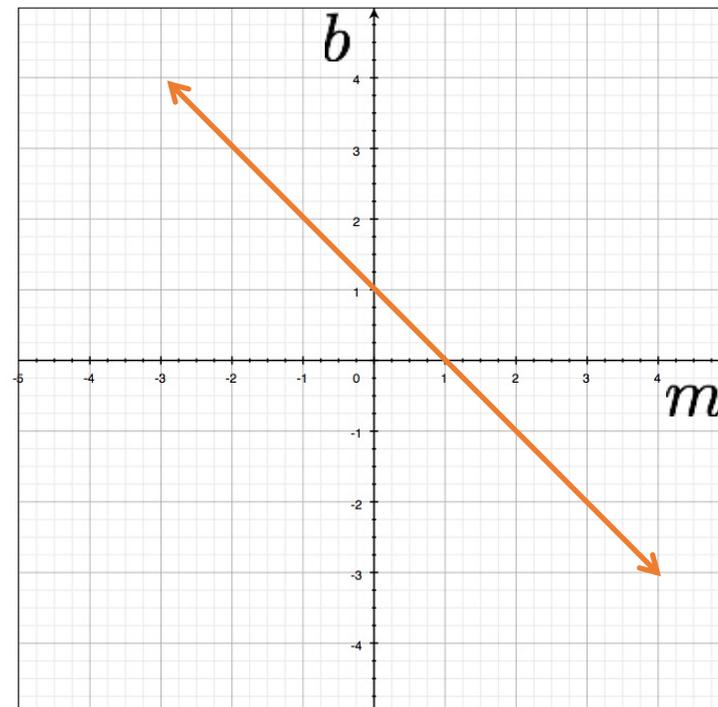


Image space

Un punto
diventa una
linea



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

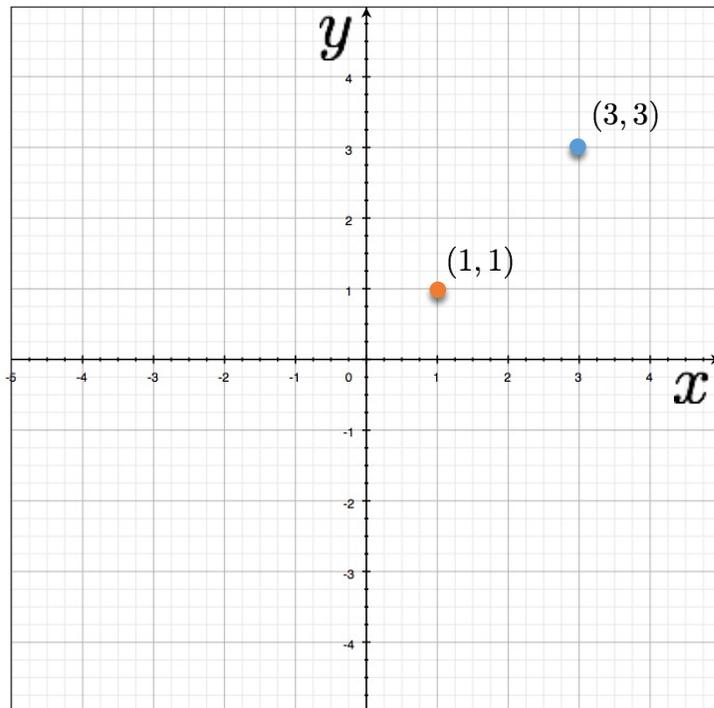
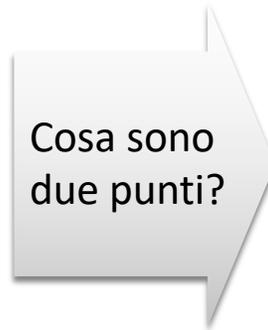
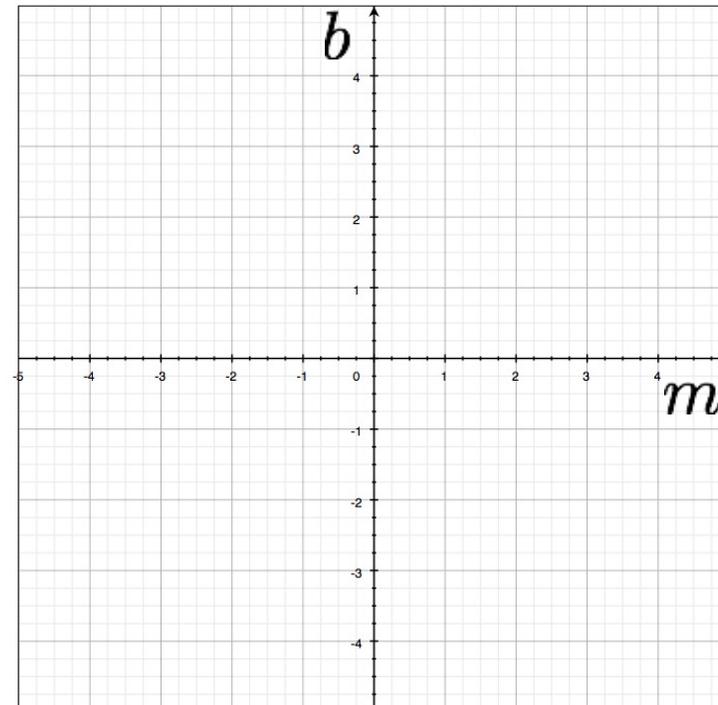


Image space



Cosa sono
due punti?



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

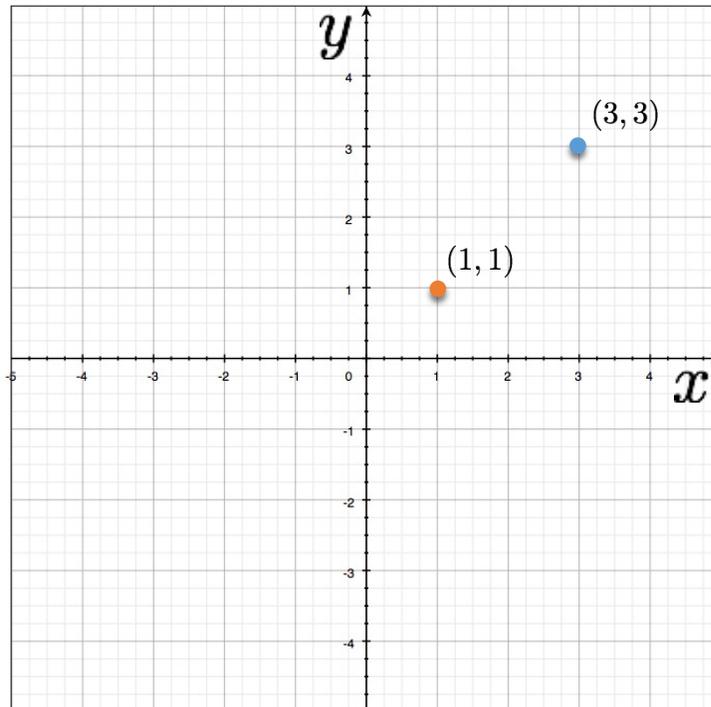
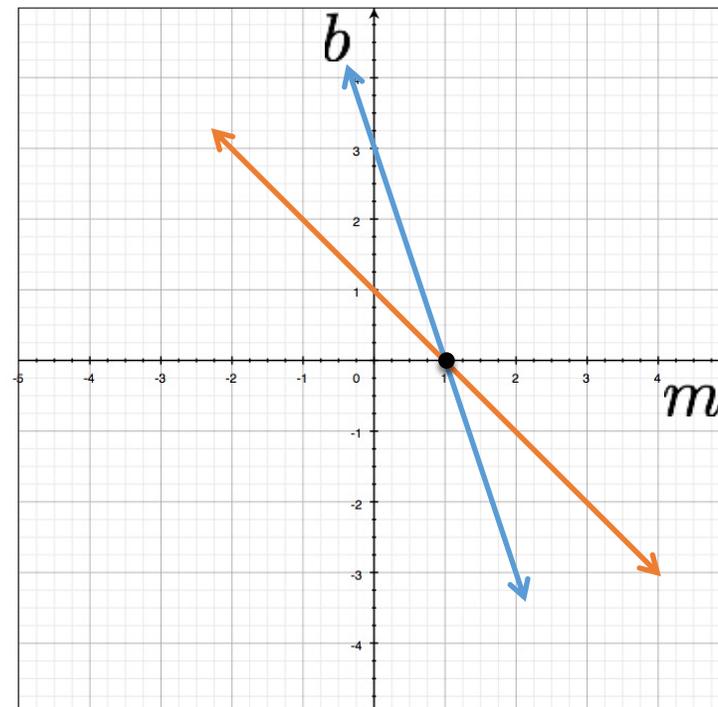
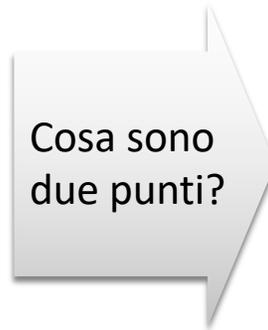


Image space



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

$$y - mx = b$$

variabili

parametri

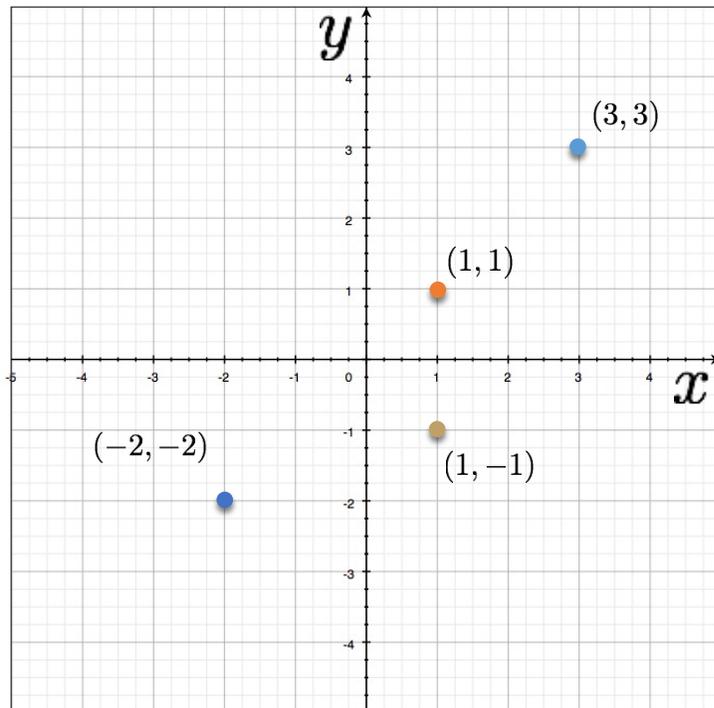
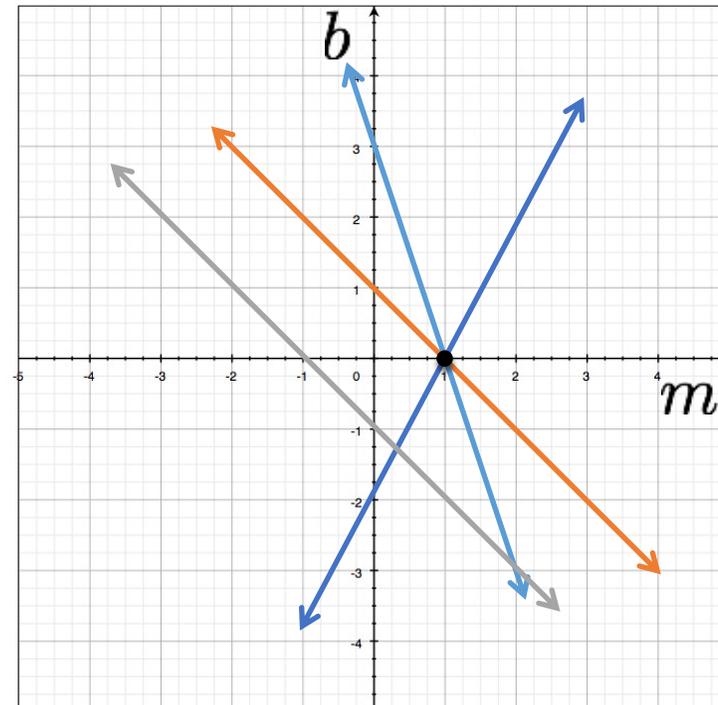


Image space

Cosa sono 4 punti?



Parameter space

Qual è la linea più compatibile con i dati?

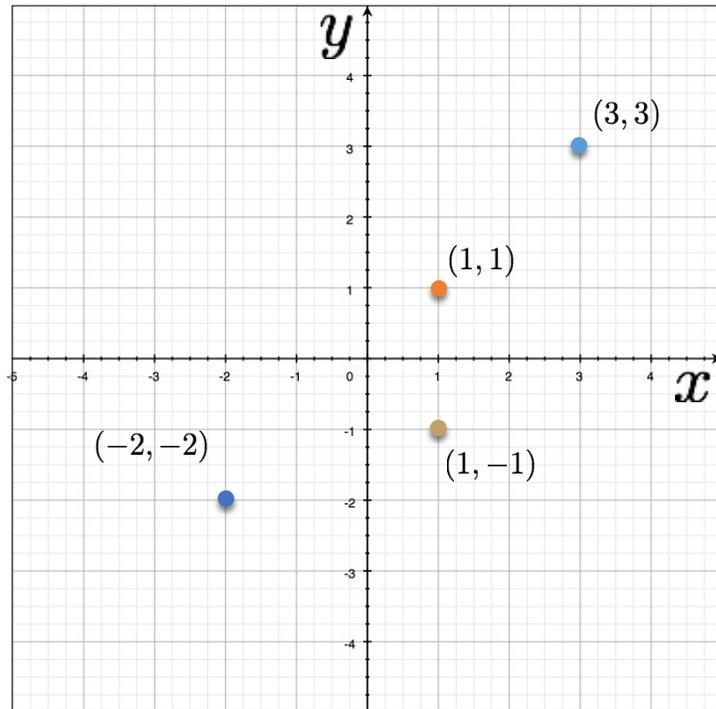
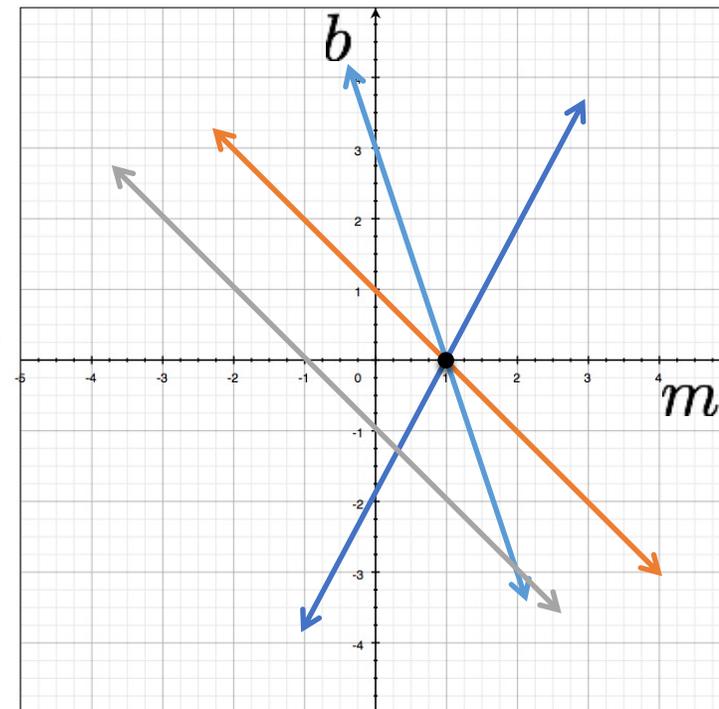


Image space



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?

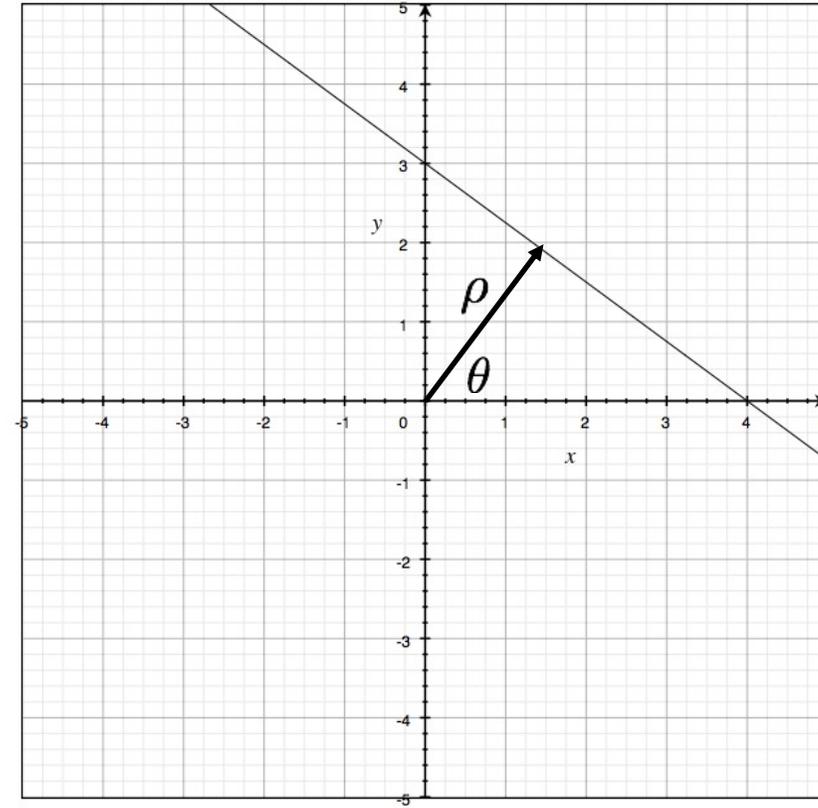
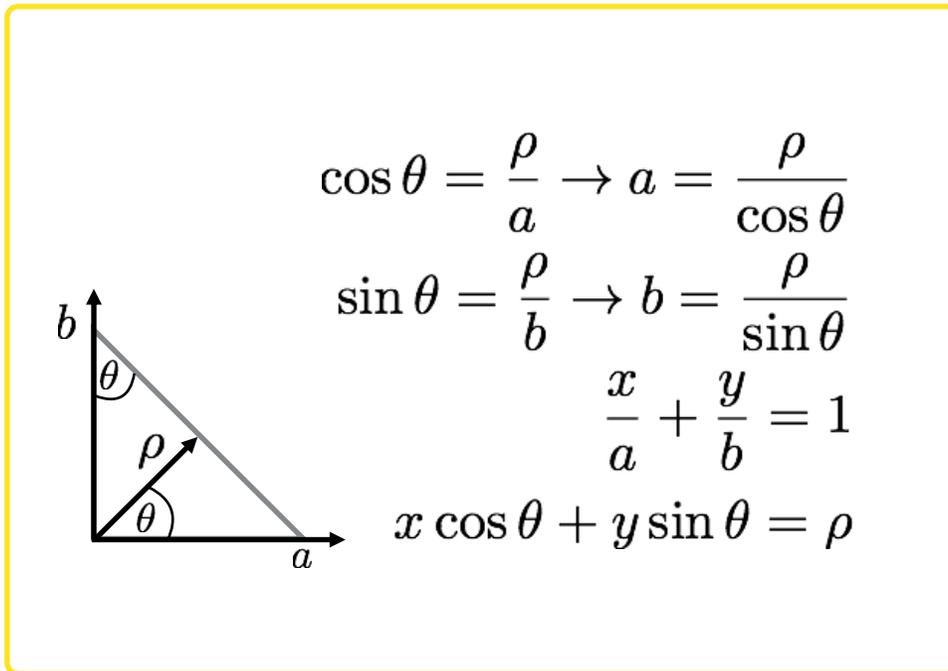
Coordinate polari

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

Cosa sono ρ e θ ?

Coordinate polari

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



Coordinate polari

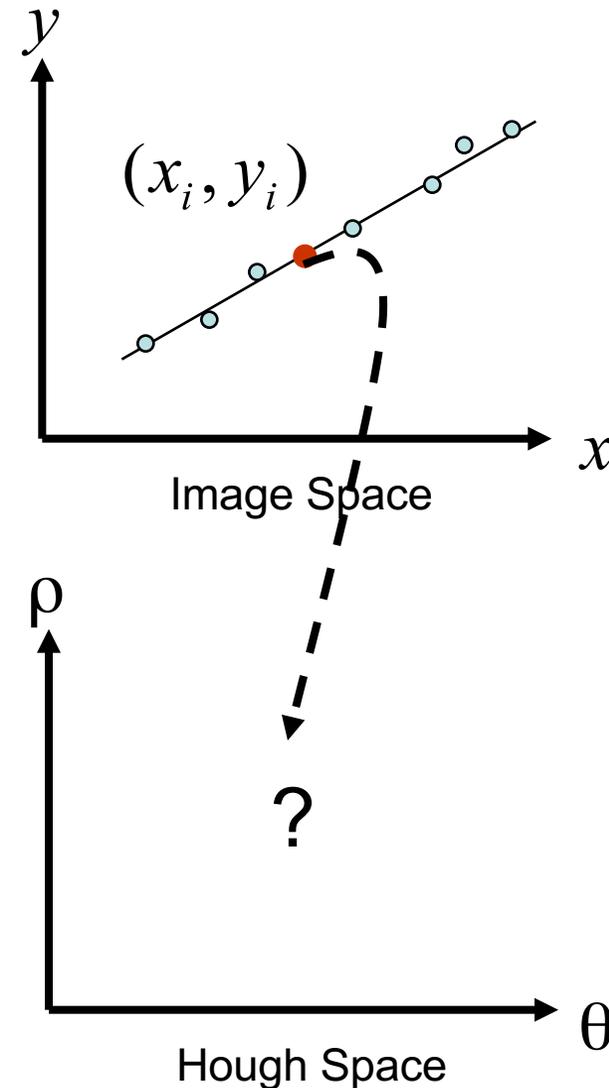
- Usiamo la forma normale

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

- 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

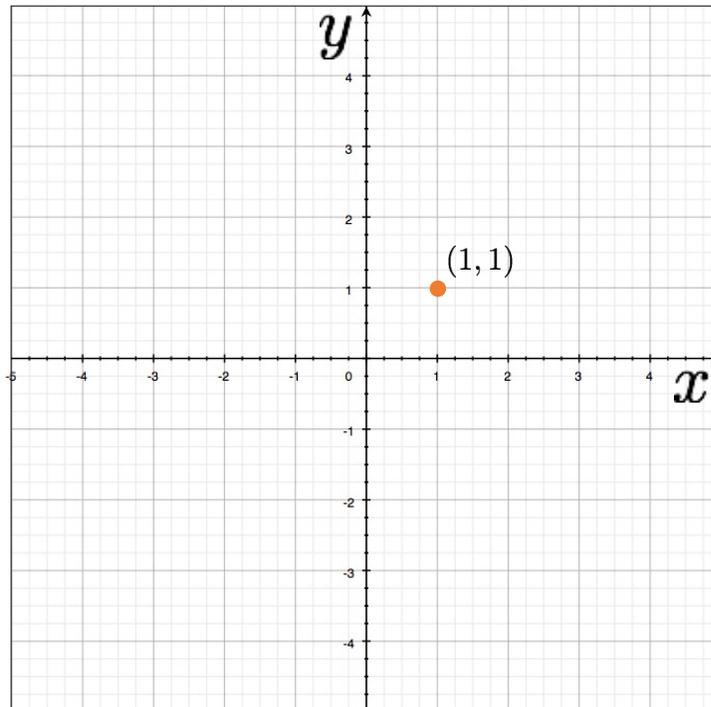
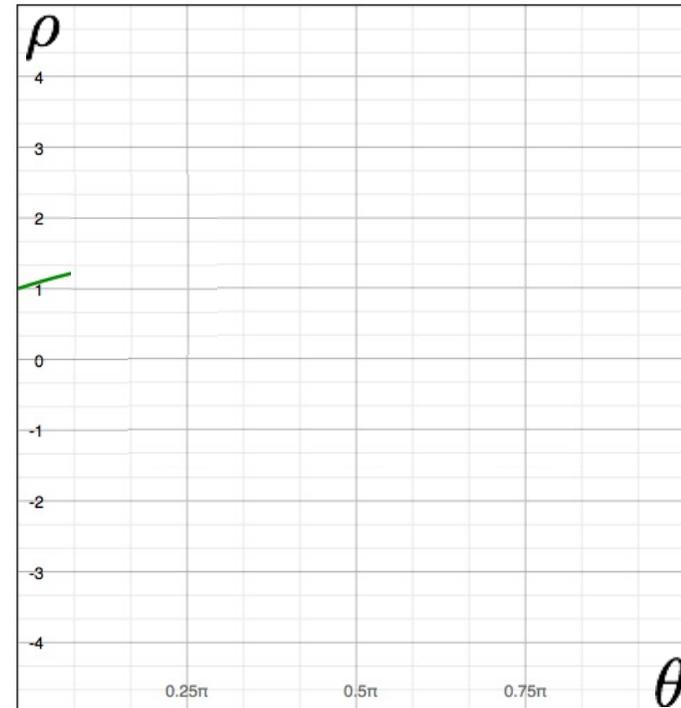


Image space



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

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

parametri

variabili

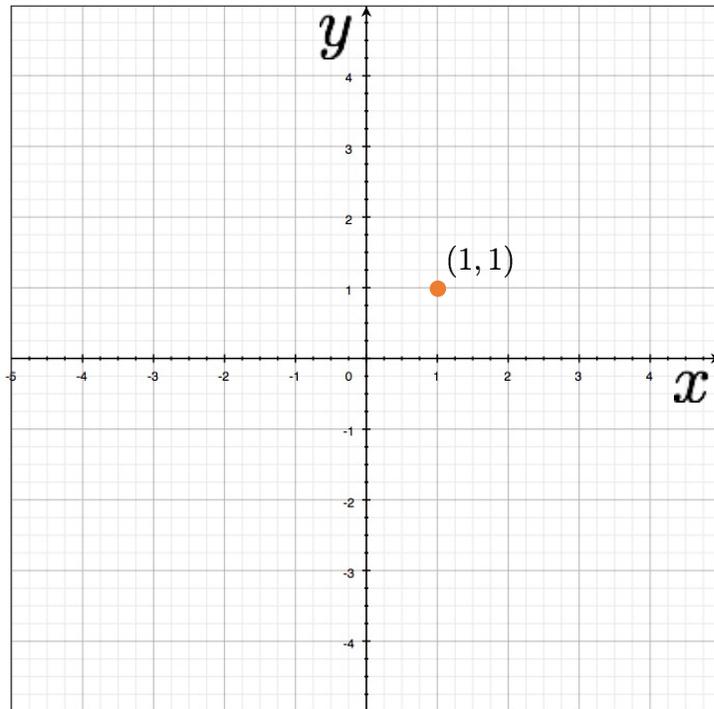
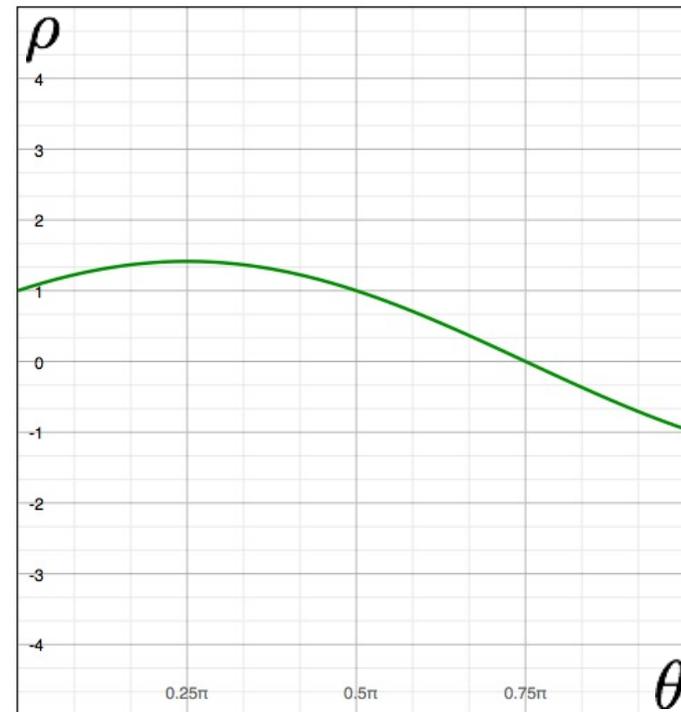


Image space



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

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

parametri

variabili

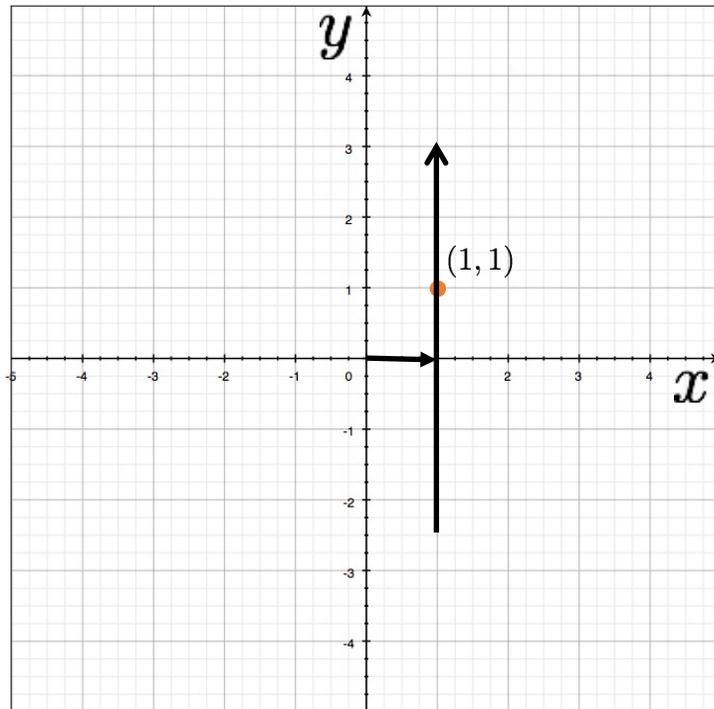
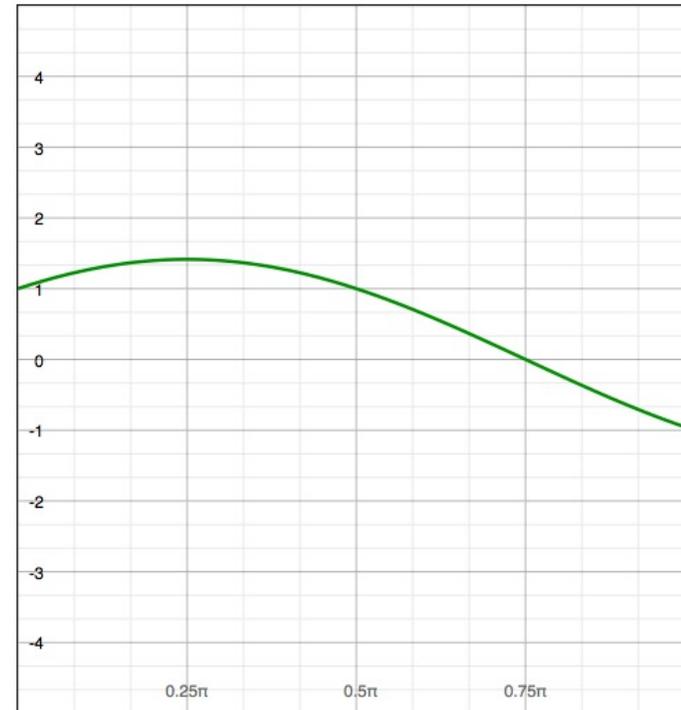


Image space

Cos'è una
linea?



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

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

parametri

variabili

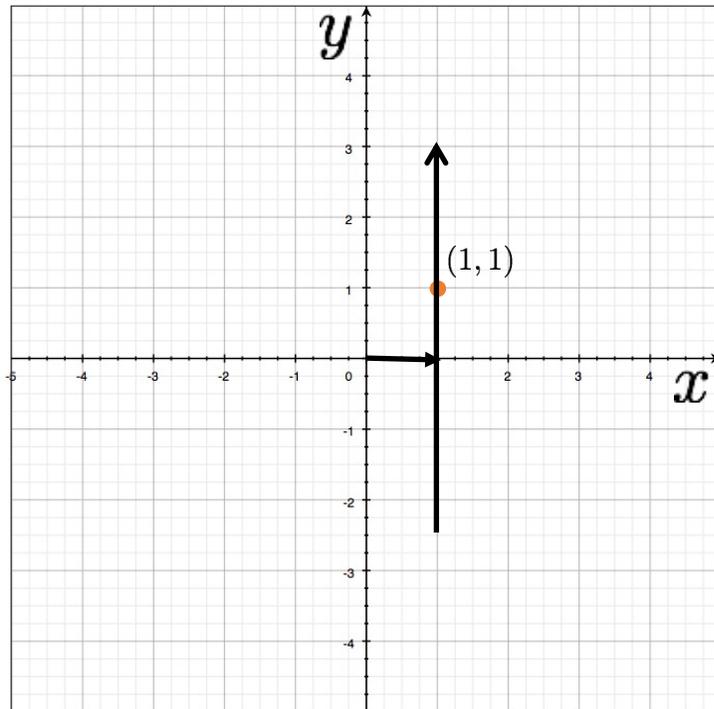
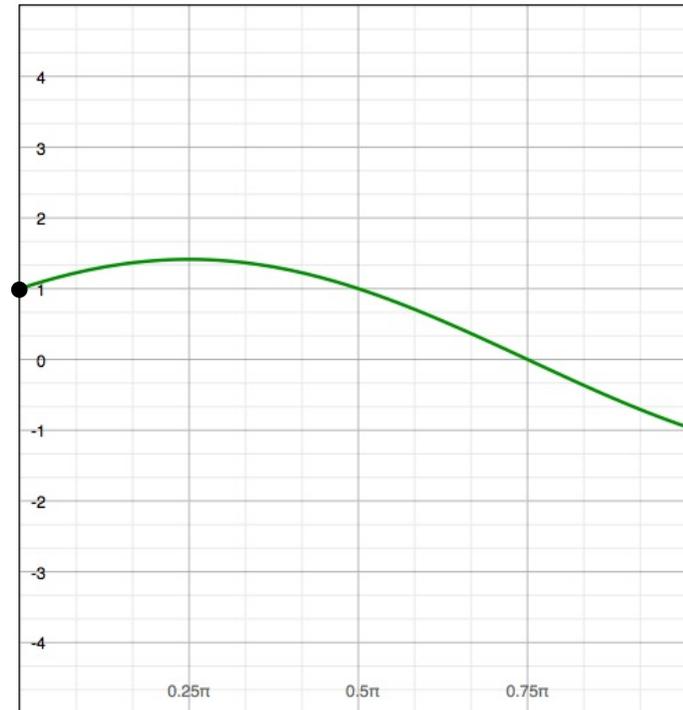


Image space

Una linea diventa un punto



Parameter space

Lo spazio dei parametri

variabili

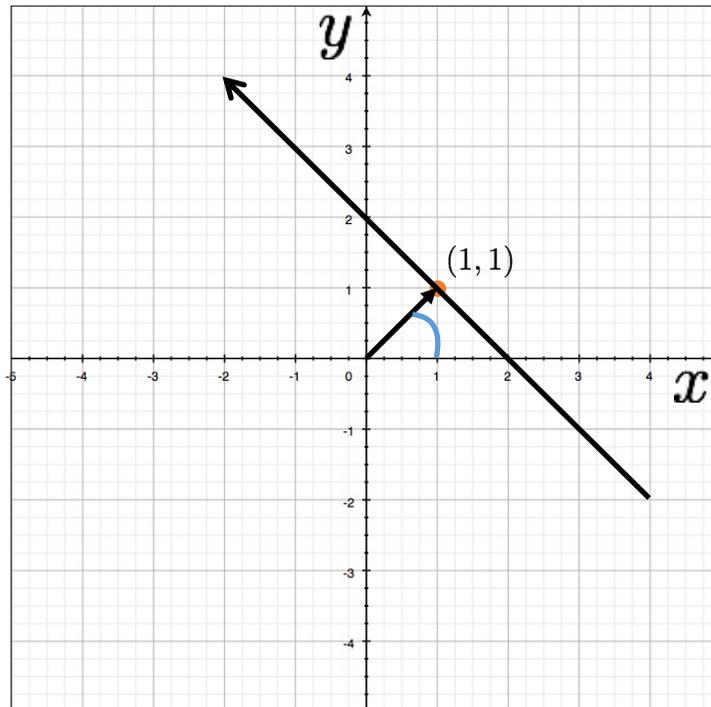
$$y = mx + b$$

parametri

parametri

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

variabili



Una linea diventa un punto

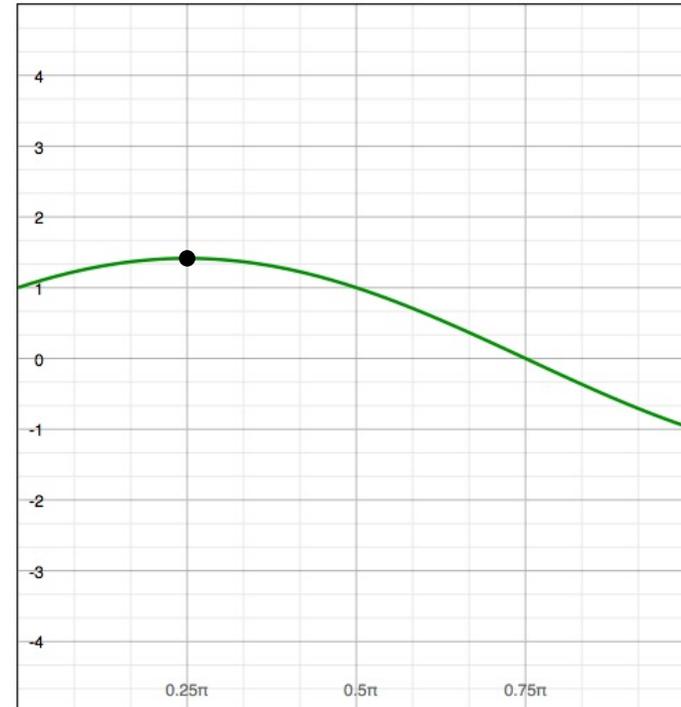


Image space

Parameter space

Lo spazio dei parametri

variabili

$$y = mx + b$$

parametri

parametri

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

variabili

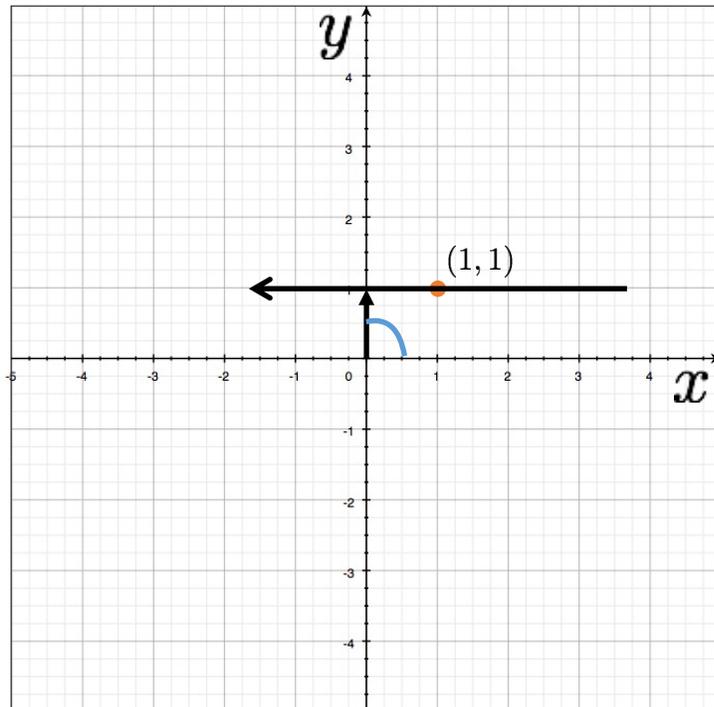
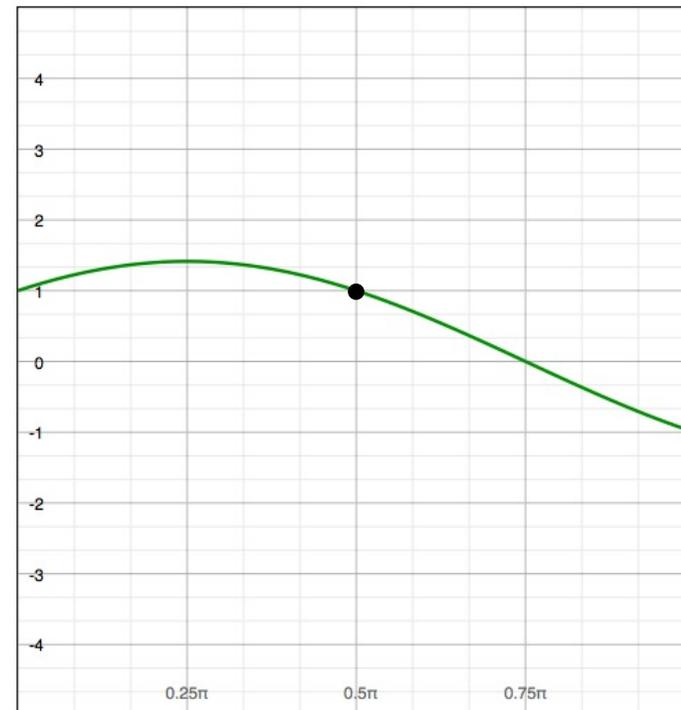


Image space

Una linea diventa un punto



Parameter space

Lo spazio dei parametri

$$y = mx + b$$

variabili

parametri

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

parametri

variabili

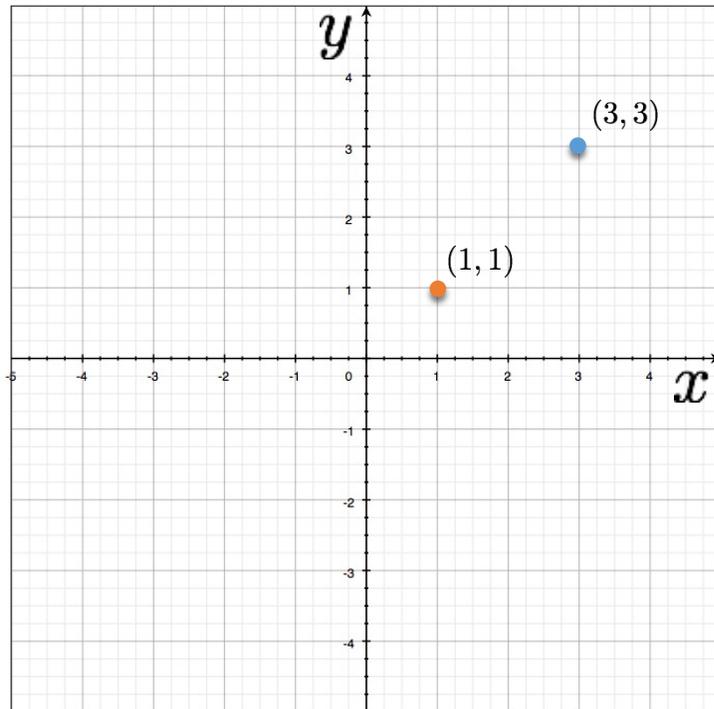
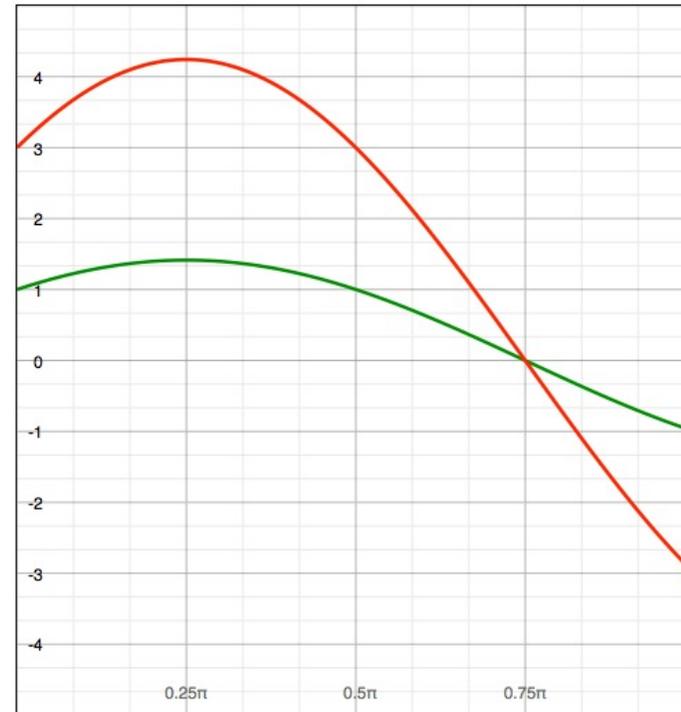


Image space



Due punti
diventano?



Parameter space

Lo spazio dei parametri

variabili

$$y = mx + b$$

parametri

parametri

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

variabili

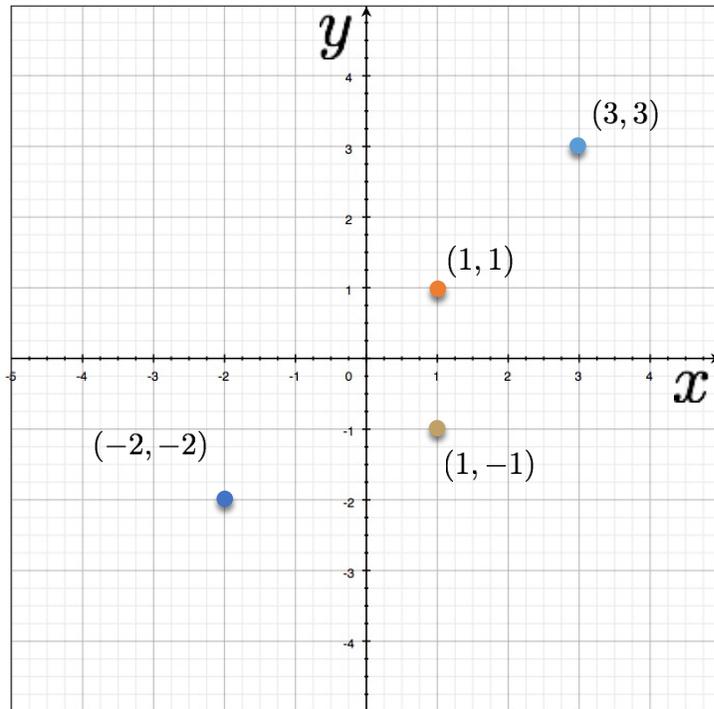
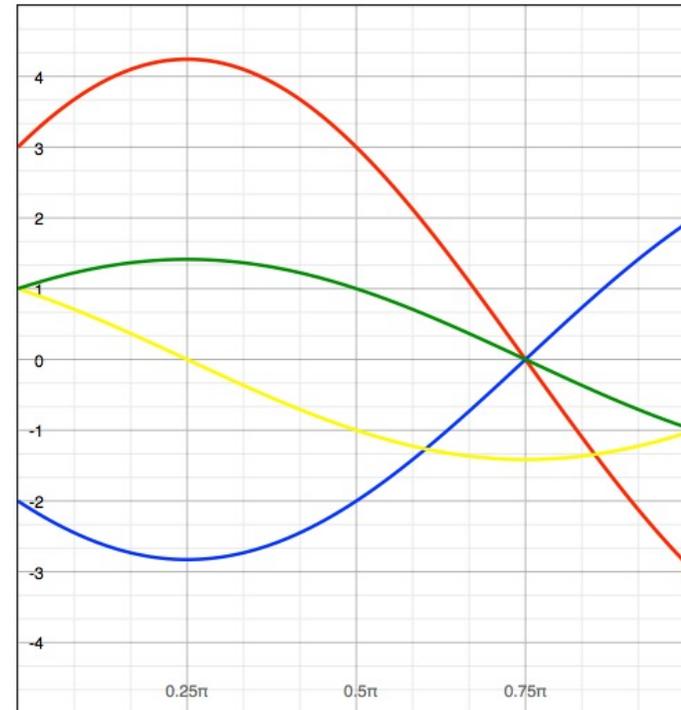
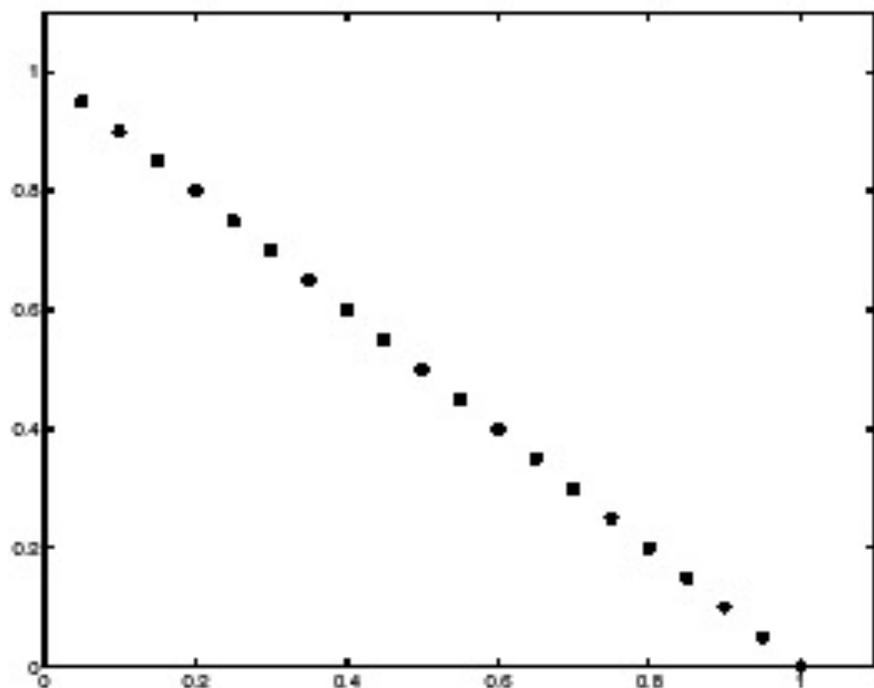


Image space

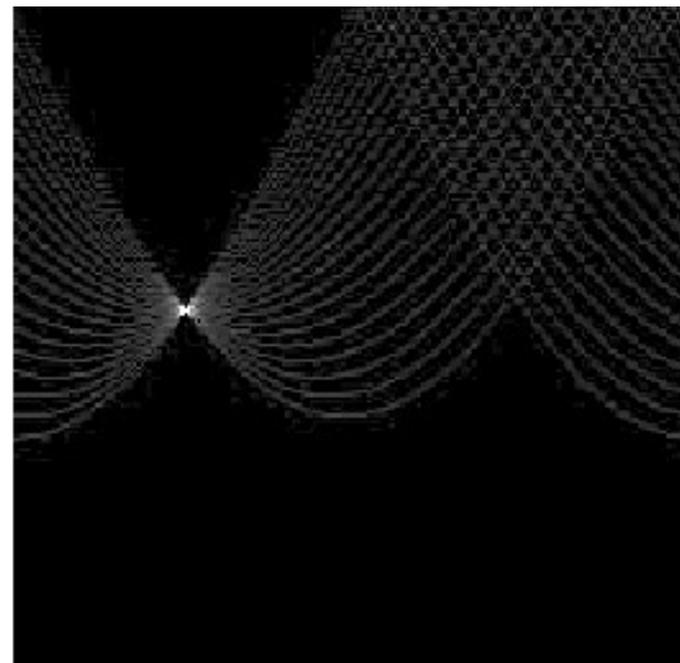
Quattro
punti
diventano?



Parameter space

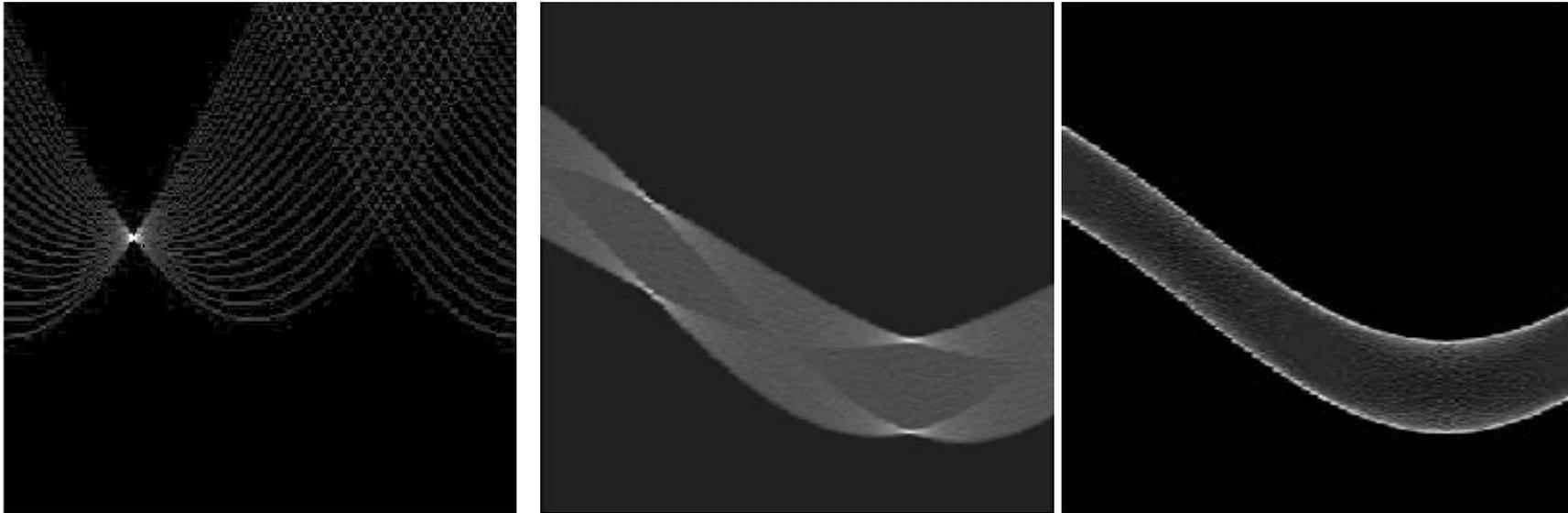


Immagine



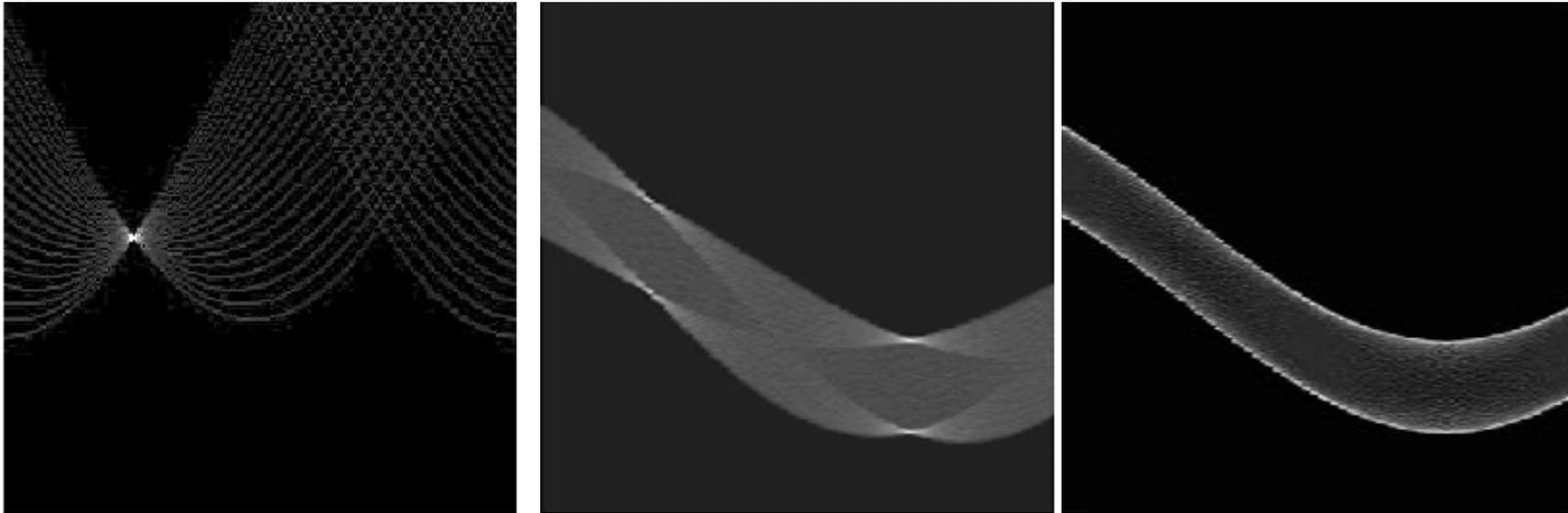
Voti

Lo spazio dei parametri



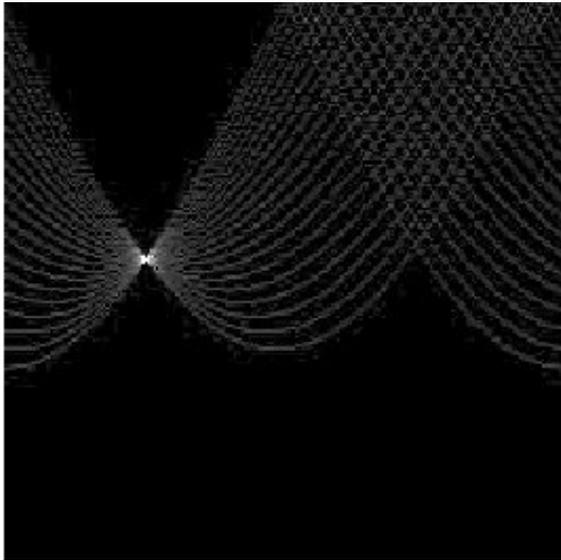
Qual è la forma?

Lo spazio dei parametri

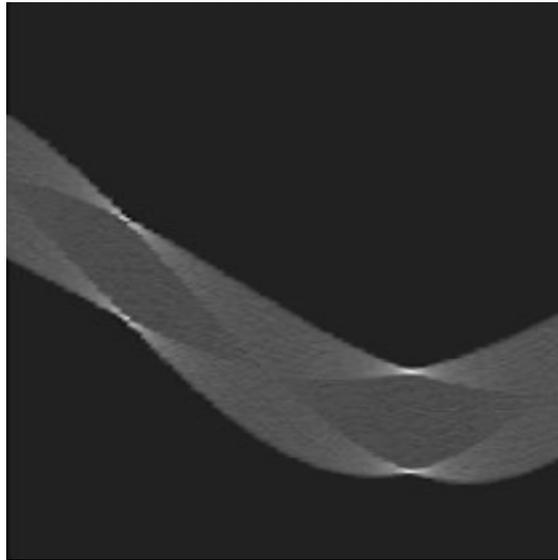


linea

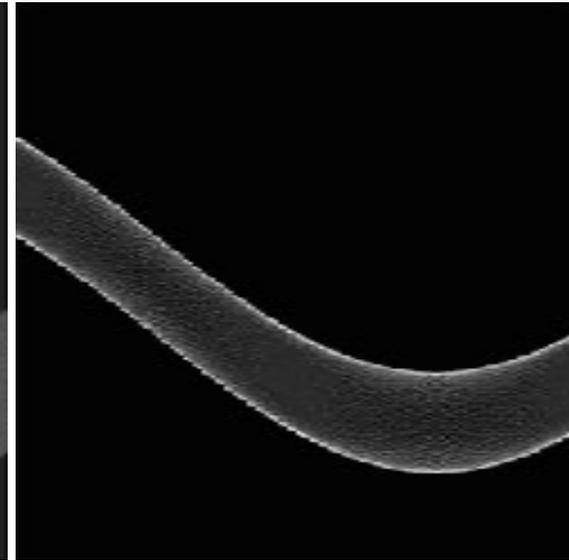
Lo spazio dei parametri



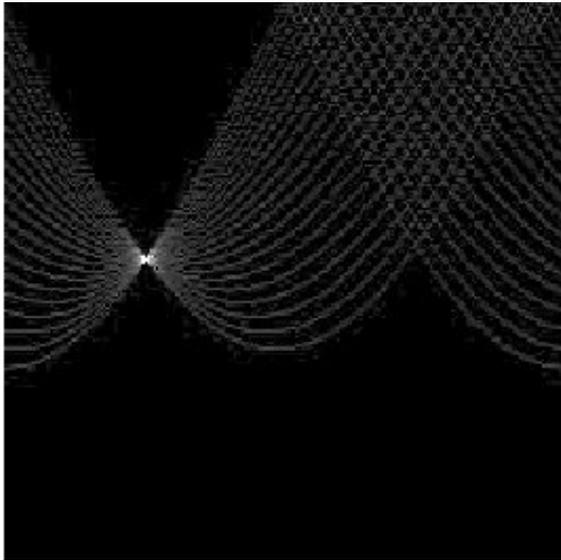
line



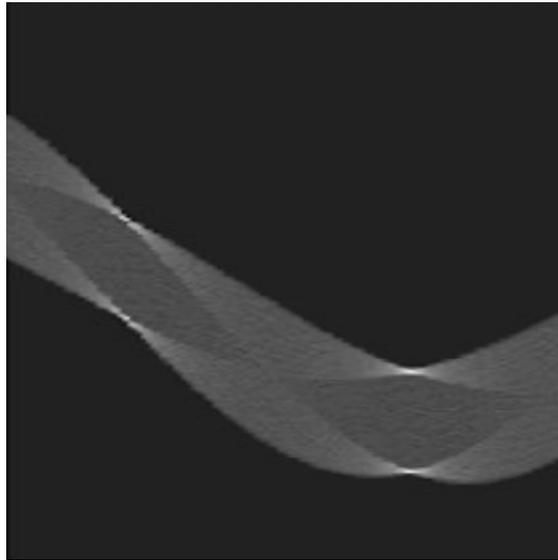
Rettangolo



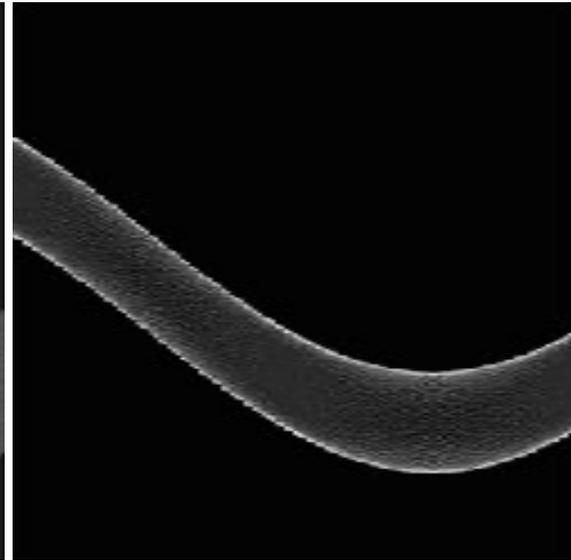
Lo spazio dei parametri



line



rectangle

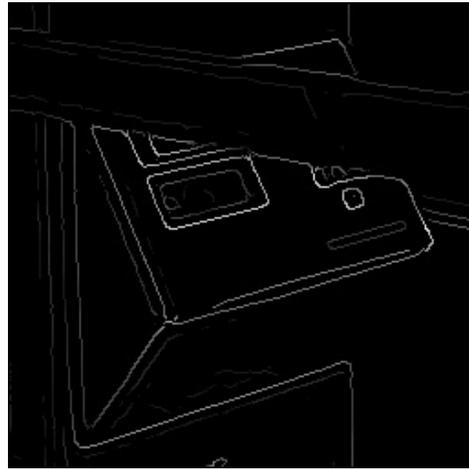


Cerchio

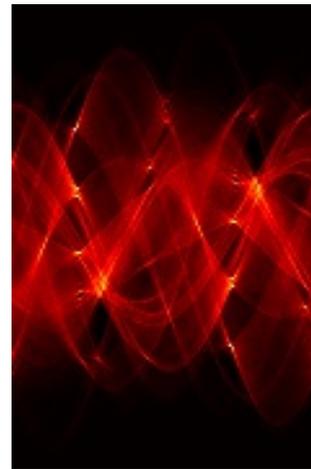
Esempio



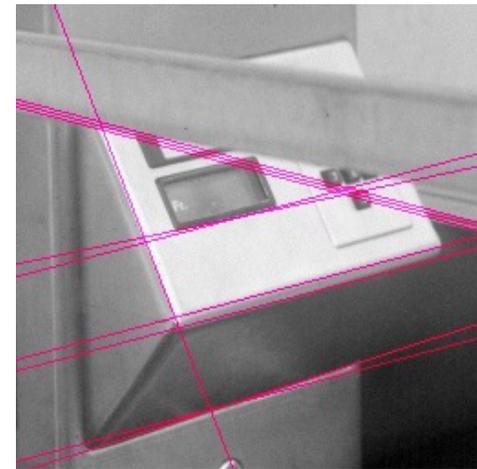
Original



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

parametri

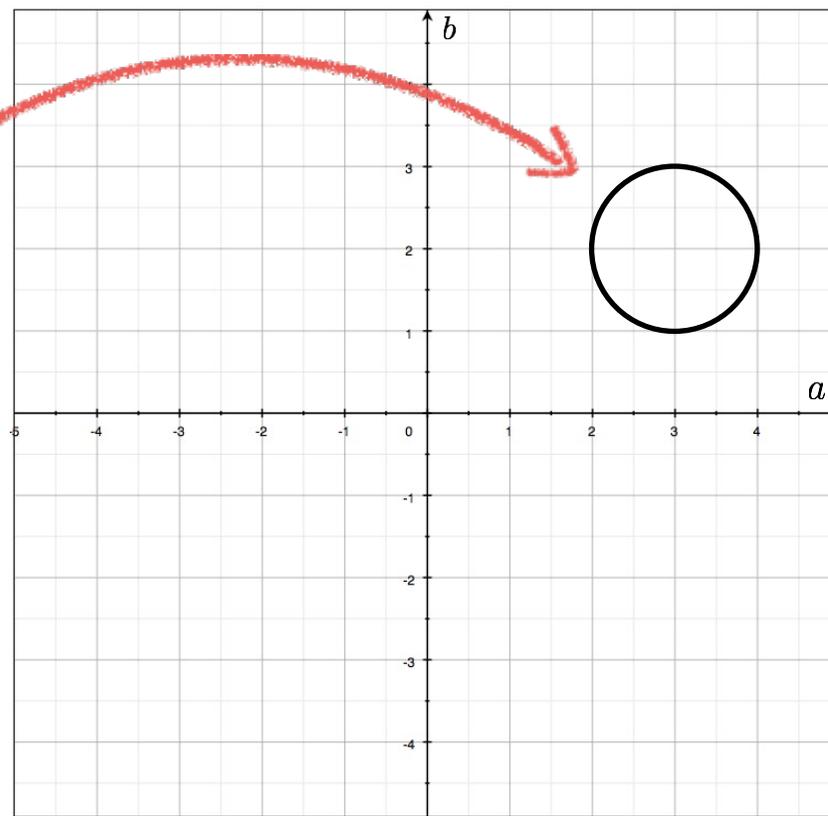
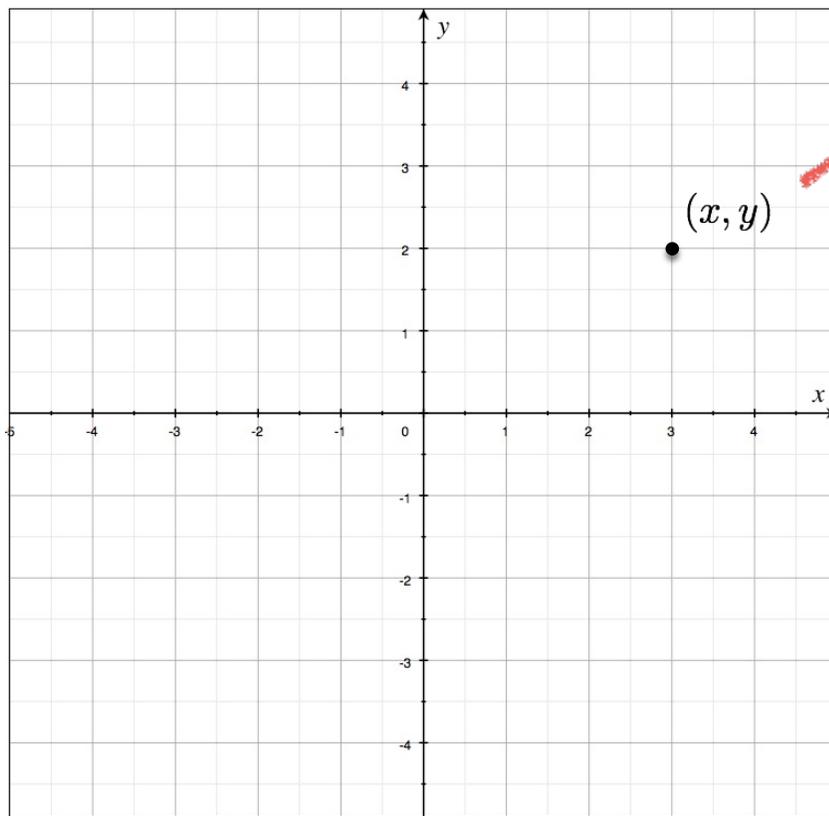
$$(x - a)^2 + (y - b)^2 = r^2$$

variabili

parametri

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

variabili



parametri

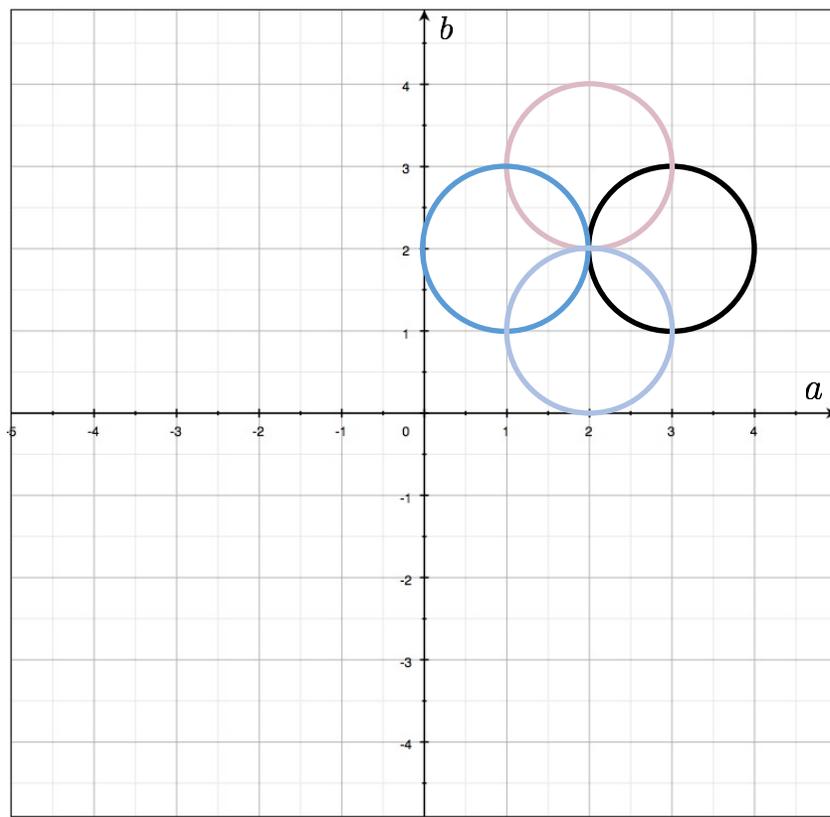
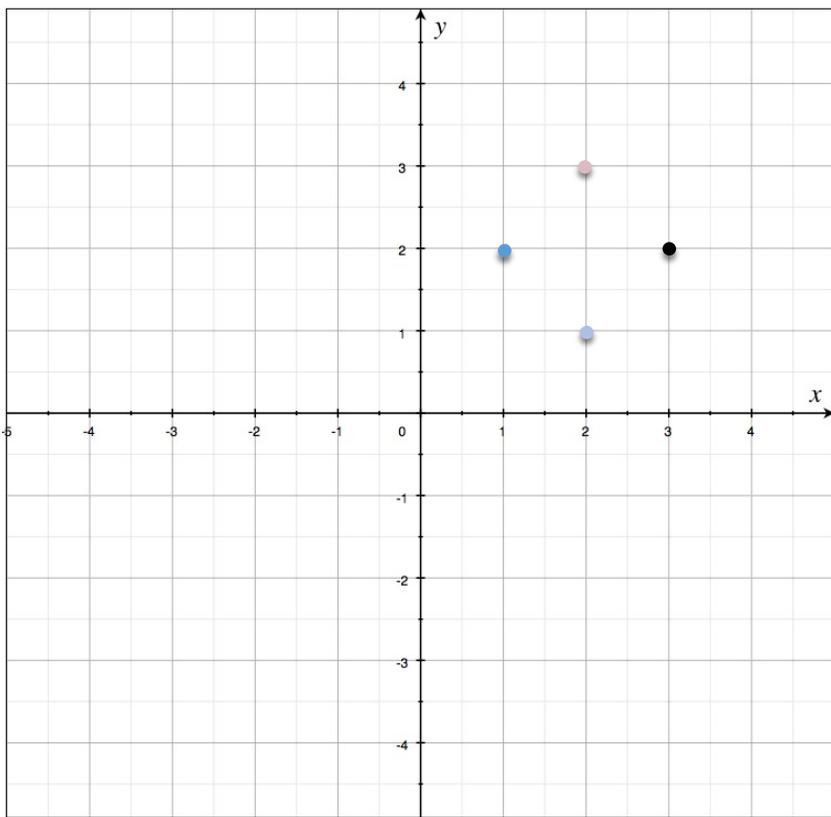
$$(x - a)^2 + (y - b)^2 = r^2$$

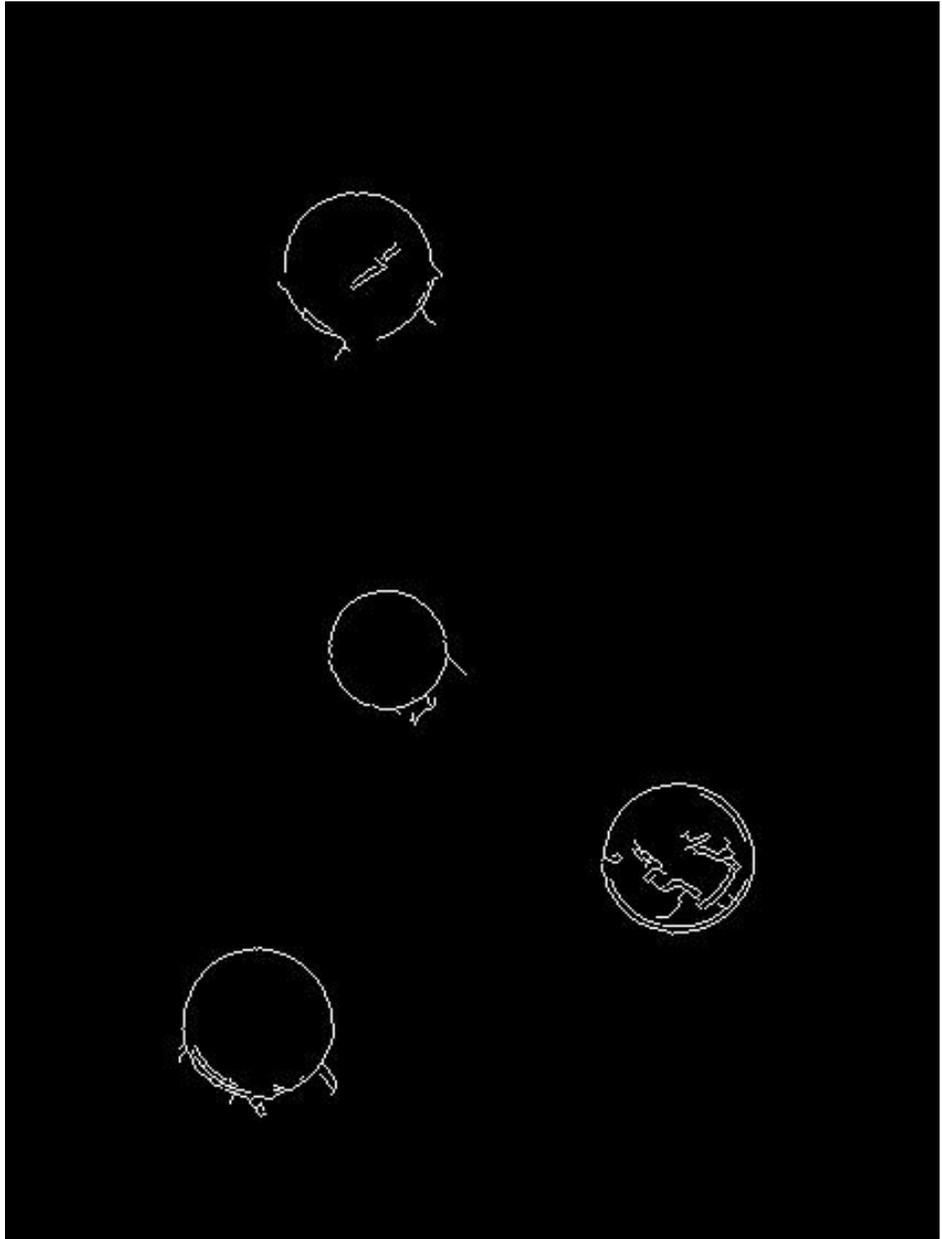
variabili

parametri

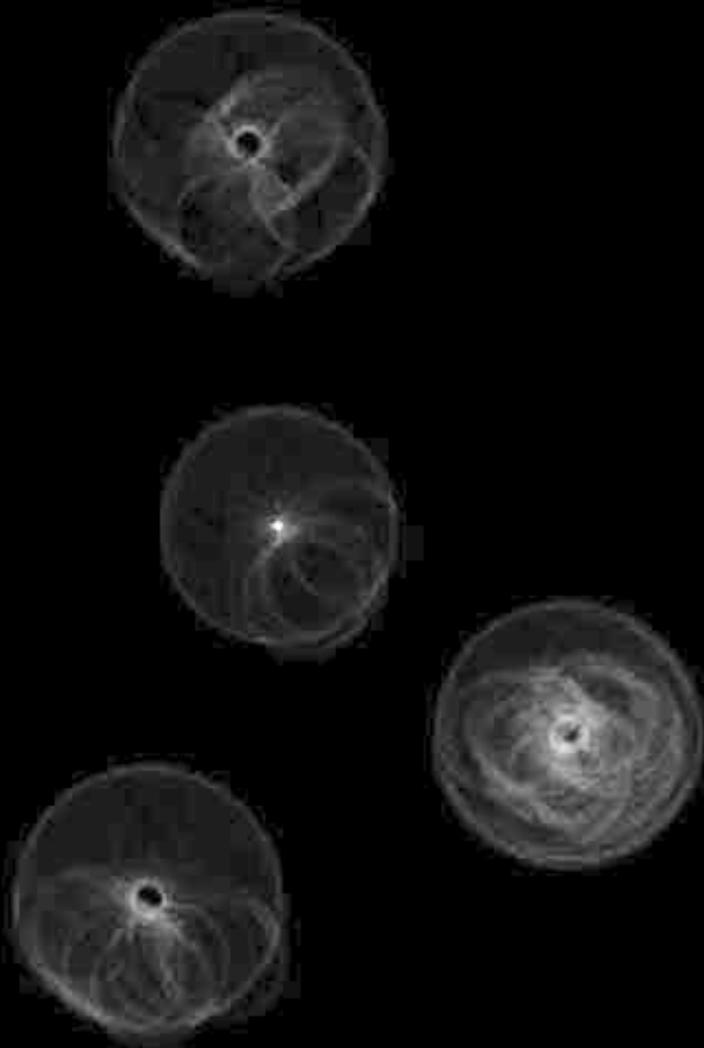
$$(x - a)^2 + (y - b)^2 = r^2$$

variabili





Raggio piccolo



Raggio grande

