CE-352: Digital Signal Processing

Using DSP for Object Detection in Computer Vision

Techniques & Applications

Presented by Samiya & Javeria

Introduction to DSP in Computer Vision

Define DSP: Digital Signal Processing involves analyzing and manipulating signals, such as sound and images, using mathematical algorithms. In computer vision, DSP techniques are used to process and extract information from images and videos.

Relevance to Computer Vision? DSP plays a crucial role in applications like image enhancement, compression, feature extraction, and object detection.

Why Object Detection Matters?

Why Object Detection Matters?

Object detection plays a crucial role in various applications, enabling systems to identify and locate objects within images or videos.

Why Object Detection Matters?

Surveillance

Helps monitor and track people or vehicles.

Monitoring parameter security.

Facilitating facial recognition.

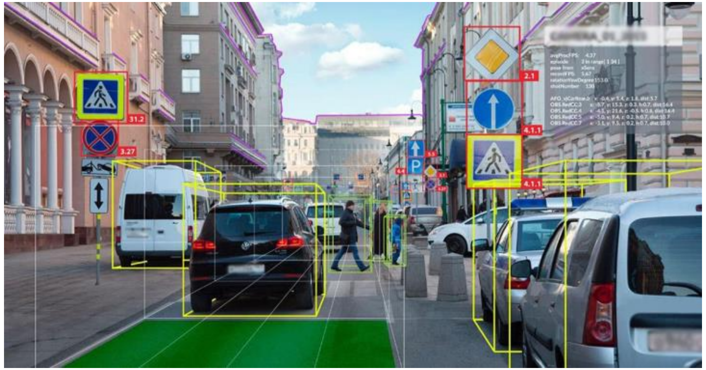
Why Object Detection Matters?

Self-Driving Cars

Detecting lane boundaries for safe navigation.

Identifying other vehicles.

Recognizing traffic signs and signals.



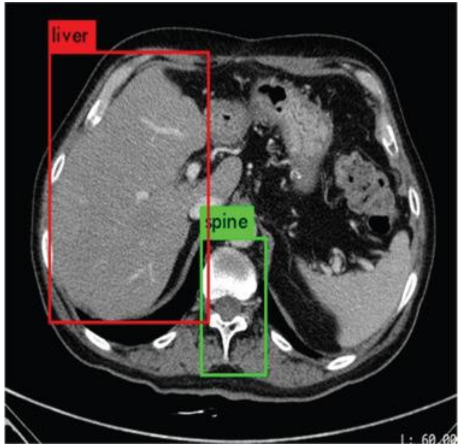
Why Object Detection Matters?

Medical Imaging

Detecting tumors or abnormalities in diagnostic scans.

Identifying key anatomical structures for surgical planning.

Locating foreign objects or irregularities.



Key DSP Techniques for Object Detection

Key DSP Techniques for Object Detection

Edge Detection

Finding boundaries in images based on changes in pixel intensity. Common Methods include Sobel, Canny, and Laplacian.

$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G}_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * \mathbf{A}$$

Canny Edge Detector

Sobel Edge Detector

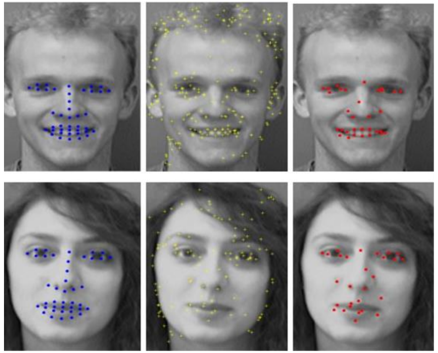
Key DSP Techniques for Object Detection

Feature Extraction

Extracting significant features from images to identify and classify objects. Scale-Invariant Feature Transform (SIFT) can be used for this.

SIFT identifies keypoints in an image by locating extrema in a Difference of Gaussian (DoG) scale space.

SIFT's keypoints and descriptors are robust to scaling, rotation, translation, and moderate changes in illumination, making them ideal for various computer vision applications.



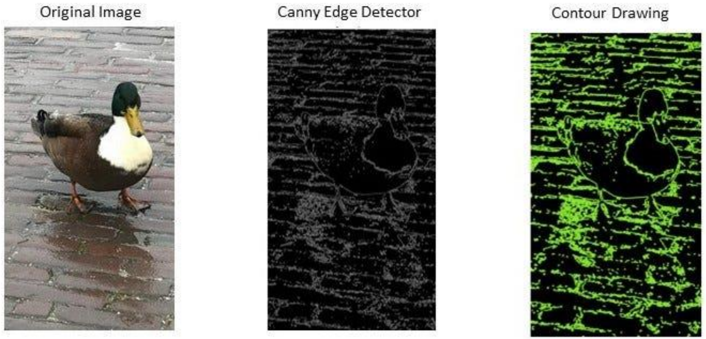
Key DSP Techniques for Object Detection

Contour Detection

Contour detection identifies continuous boundaries or outlines within an image, often representing the shapes of objects or regions.

Contour detection often begins with edge detection to locate significant intensity gradients in an image, providing initial boundary points for contour tracing.

Some contour detection methods rely on predefined shapes, like circles or rectangles, and use techniques such as the **Hough transform** to find them in images.



The Hough Transform

Hough Transform

It is used to detect specific shapes, like lines and circles, in images. It converts geometric shapes into parameterized representations.

Initially invented for machine analysis of bubble chamber photographs by Hough (1962).

The rho-theta parameterization universally used today was first described by Duda & Hart (1972).

It works by mapping points in an image space to curves in a parameter space, allowing detection of shapes through peaks or accumulations in the parameter space.

Line Detection

Hough Transform: Line Detection

Given: Edge points (x_i, y_i)

Task: Detect line $y = mx + c$

Consider the point (x_i, y_i)

Then, $\boldsymbol{y_i = mx_i + c \leftrightarrow c = -mx_i + y_i}$

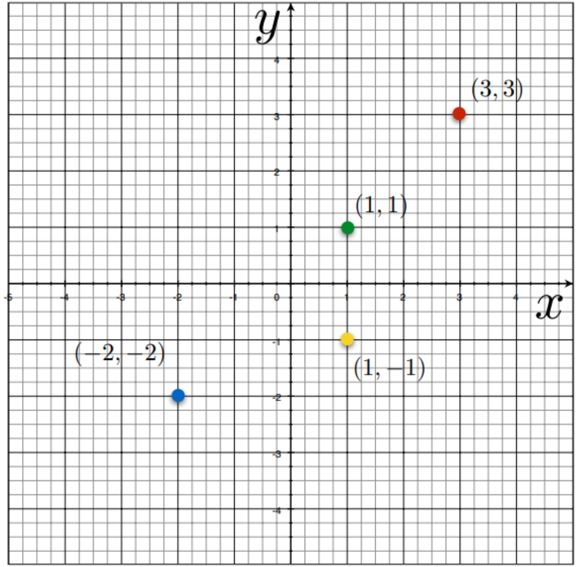


Image space

Hough Transform: Line Detection

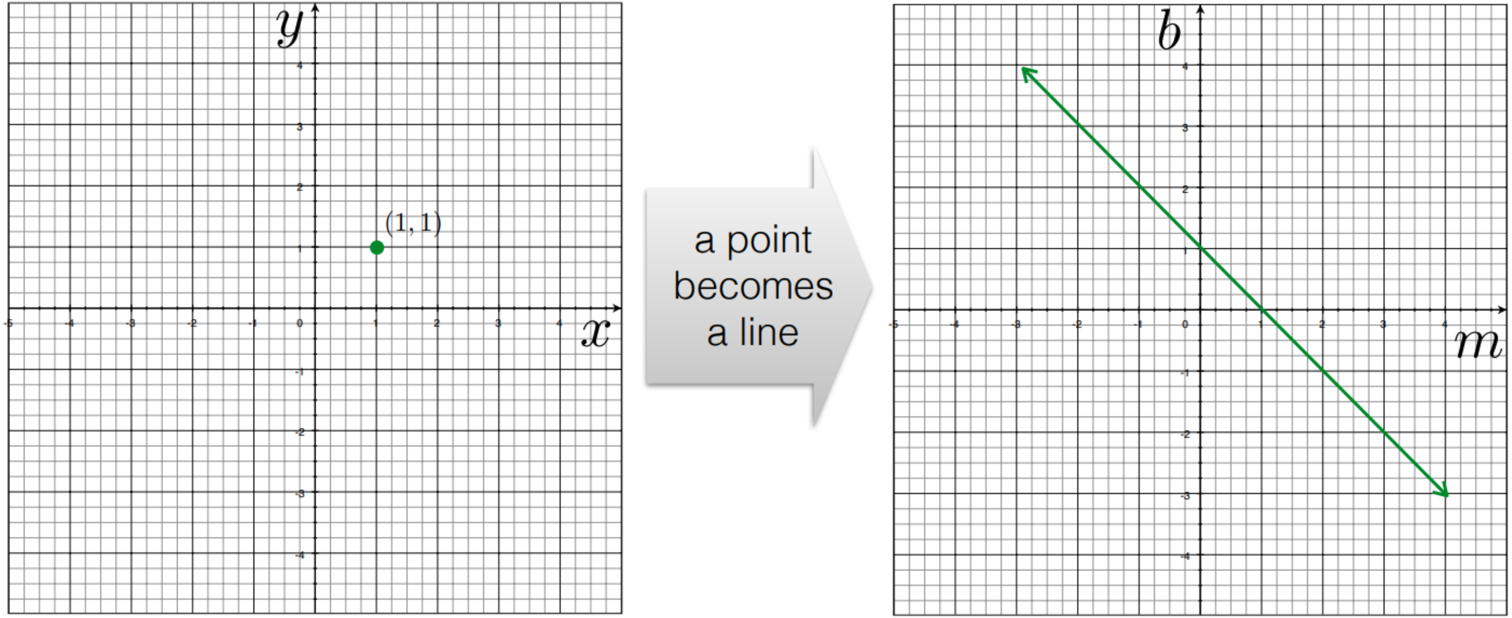


Image space

Parameter space

Hough Transform: Line Detection

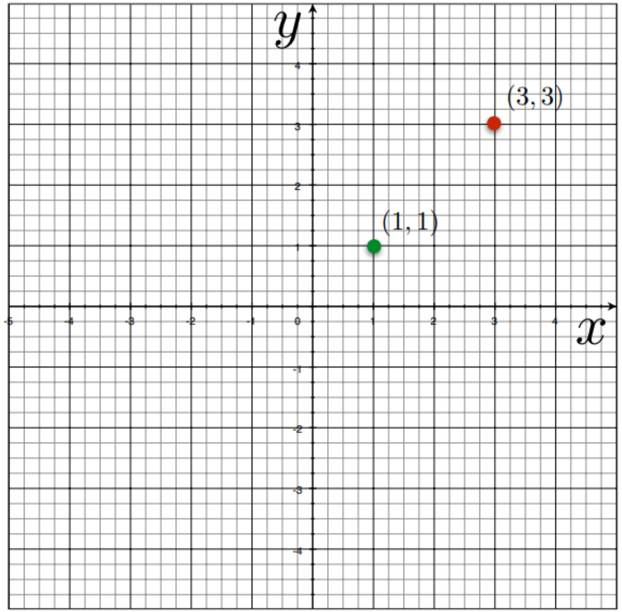
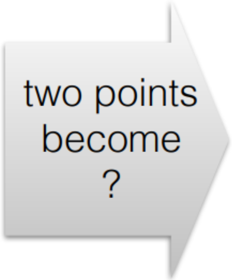
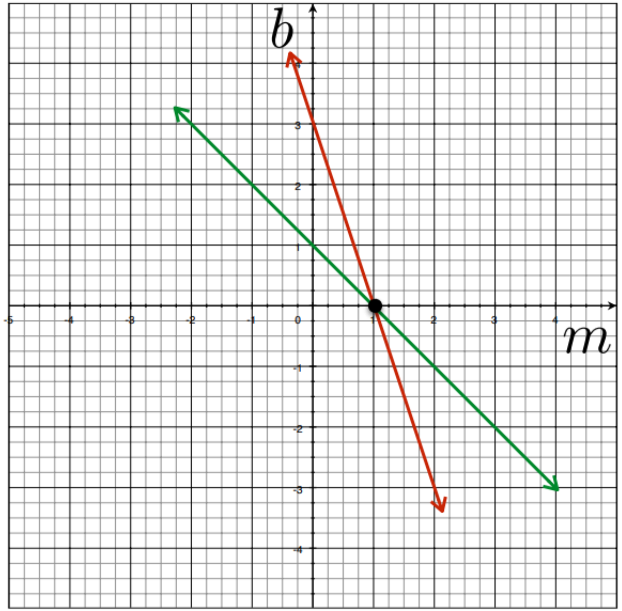


Image space





Parameter space

Hough Transform: Line Detection

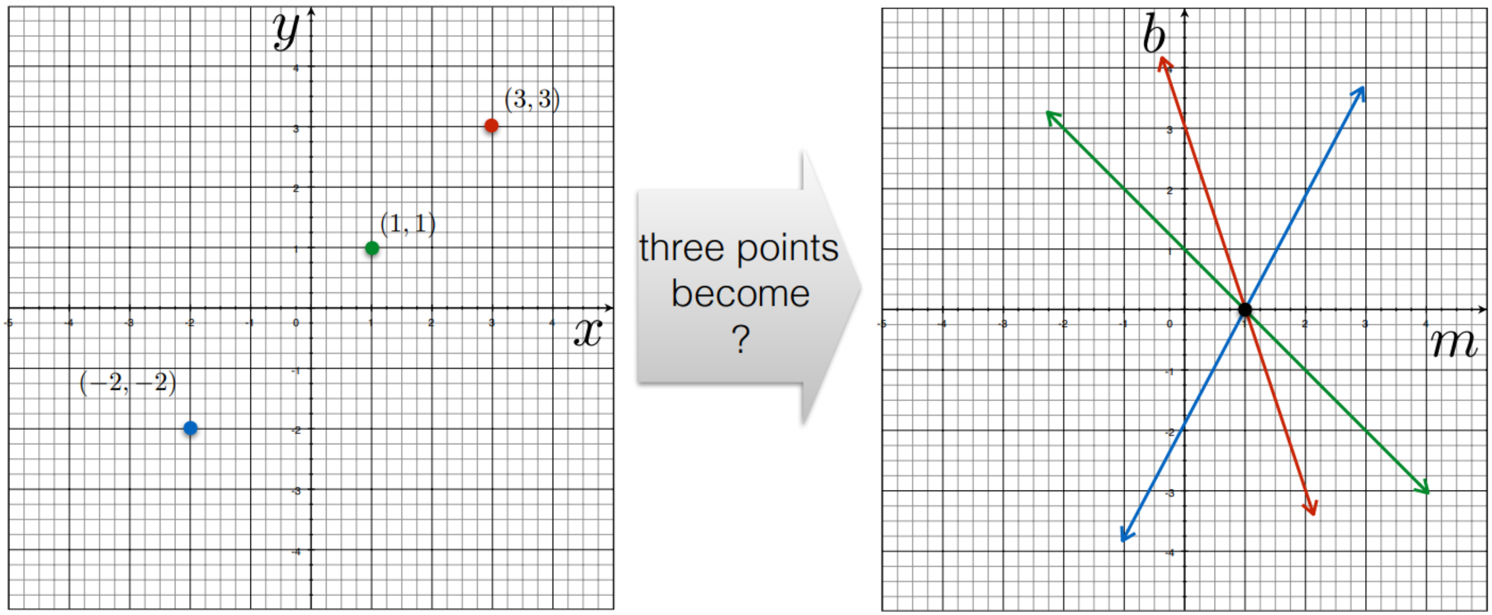


Image space

Parameter space

Hough Transform: Line Detection

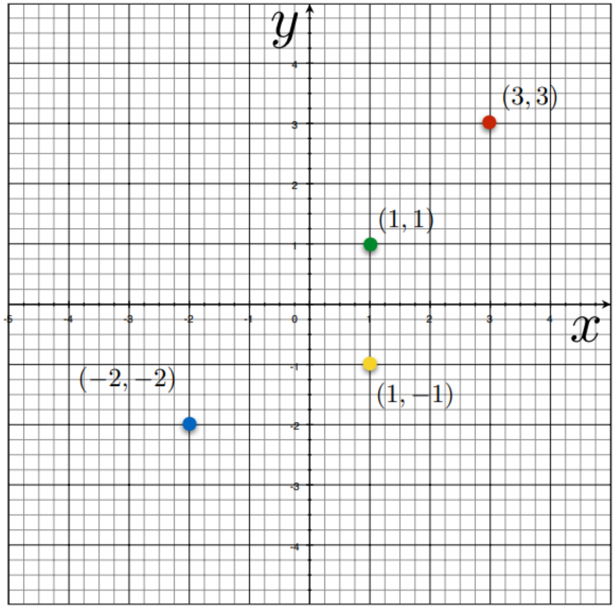
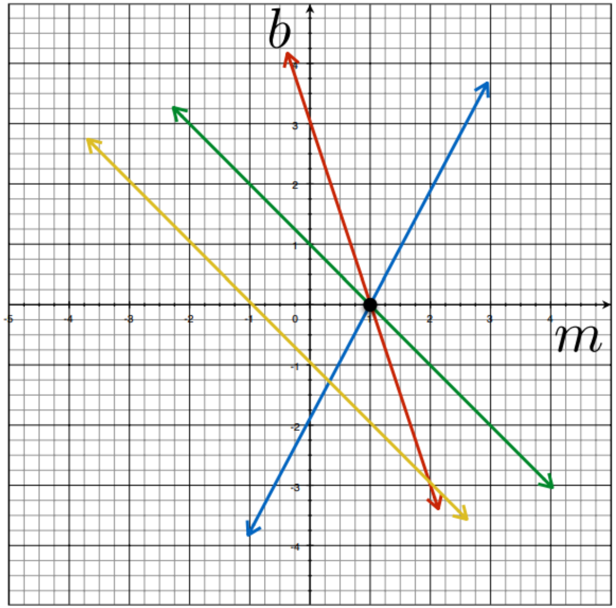


Image space

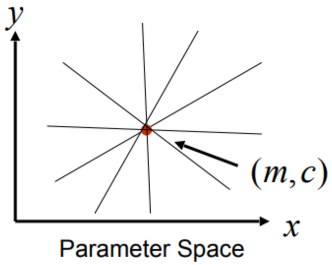
four points become ?



Parameter space

Hough Transform: Line Detection

Line Detection Algorithm

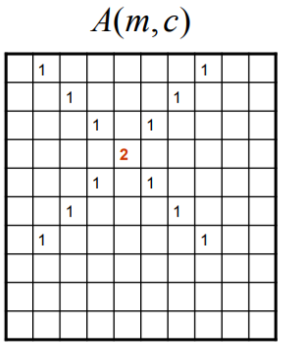


1. Quantize Parameter Space (m, c)
2. Create Accumulator Array $A(m, c)$
3. Set $A(m, c) = 0, \ \forall \mathrm{m}, \mathrm{c}$
4. For each image edge (x_i, y_i)

   For each element in $A(m, c)$

   If (m, c) lies on the line: $c = -x_i m + y_i$

   Increment $A(m, c) = A(m, c) + 1$
5. Find local maxima in $A(m, c)$



Hough Transform: Line Detection

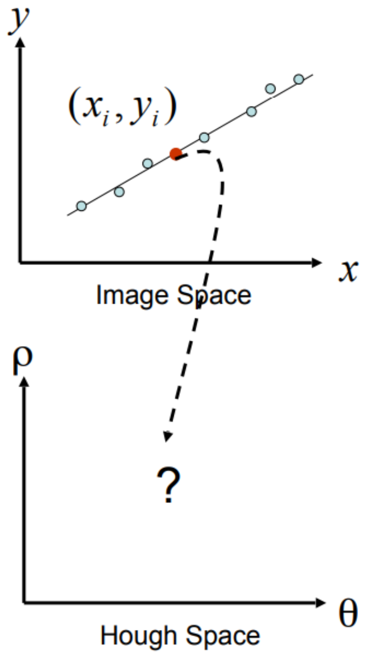
Better Parameterization

Issue: Slope of the line $-\infty \leq m \leq \infty$

- Large Accumulator
- More Memory and Computation

Solution: Use $x cos\theta + y sin\theta = \rho$

- Orientation θ is finite, $0 \leq \theta \leq 2\pi$
- Distance ρ is finite



Improved Line Detection

Hough Transform: Improved Line Detection

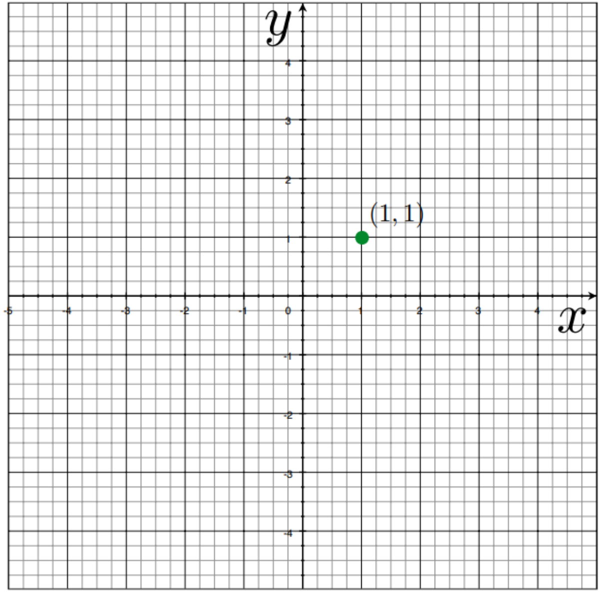
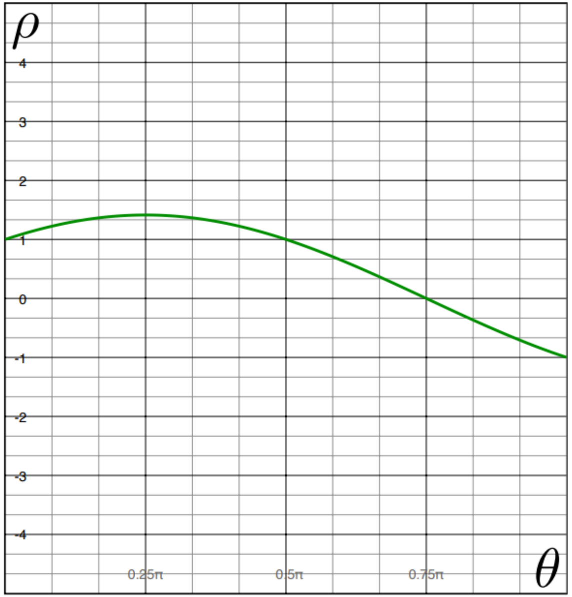


Image space

a point becomes a wave



Parameter space

Hough Transform: Improved Line Detection

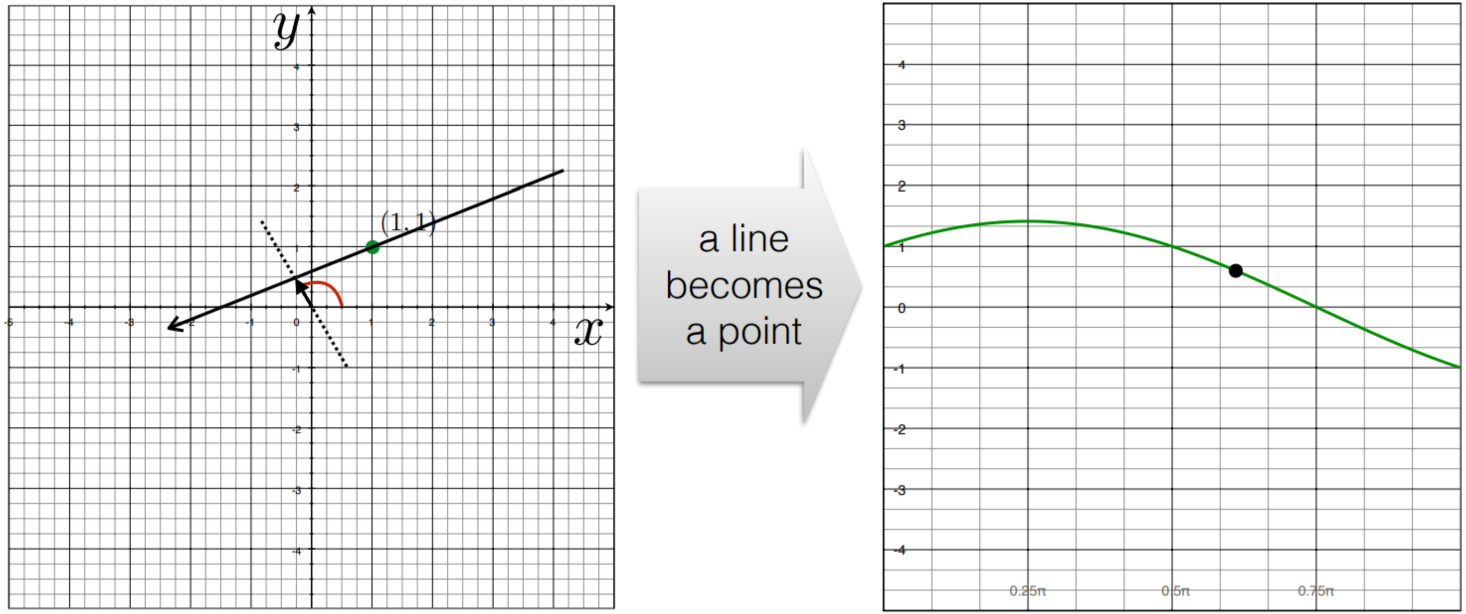
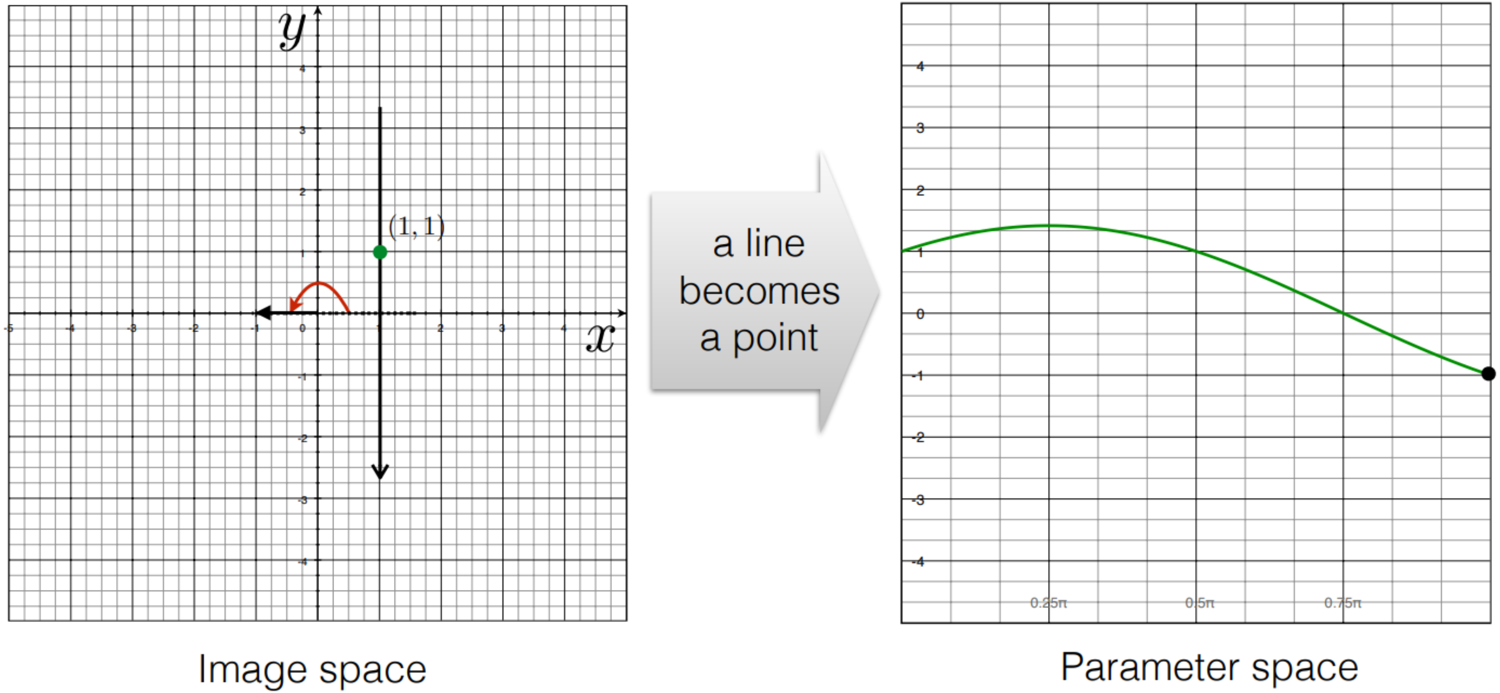


Image space

Parameter space

Hough Transform: Improved Line Detection



Hough Transform: Improved Line Detection

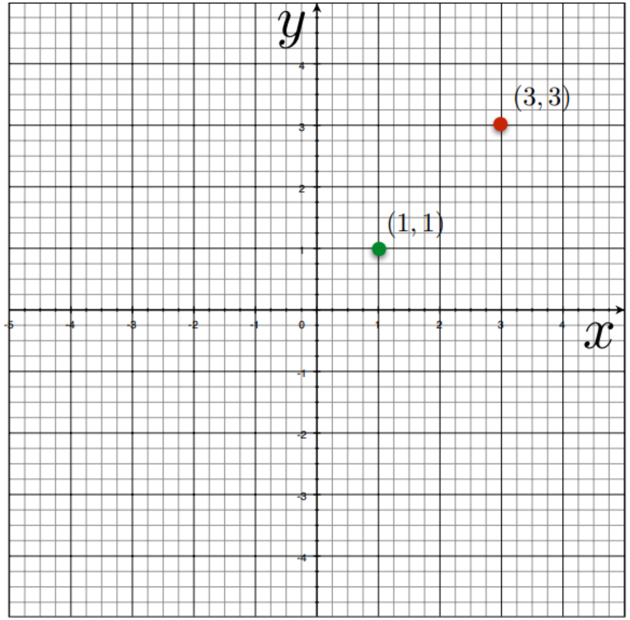
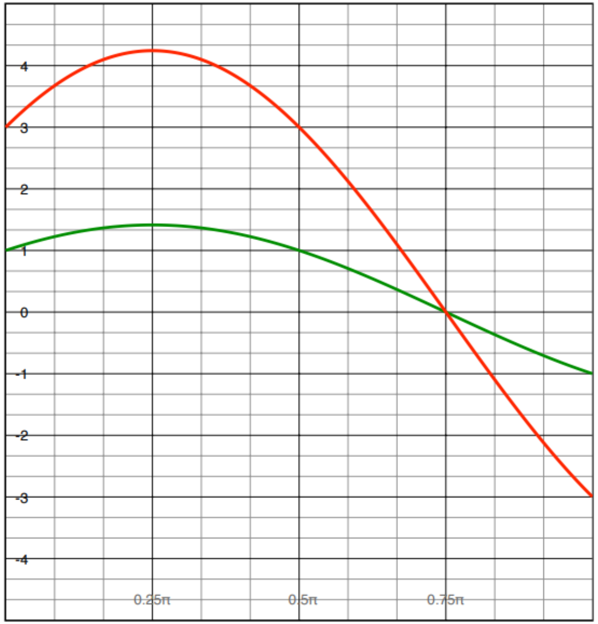


Image space

two points become ?



Parameter space

Hough Transform: Improved Line Detection

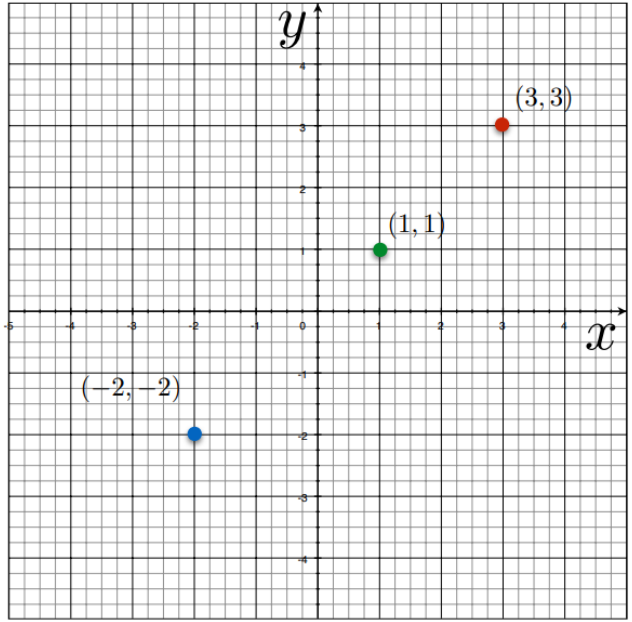
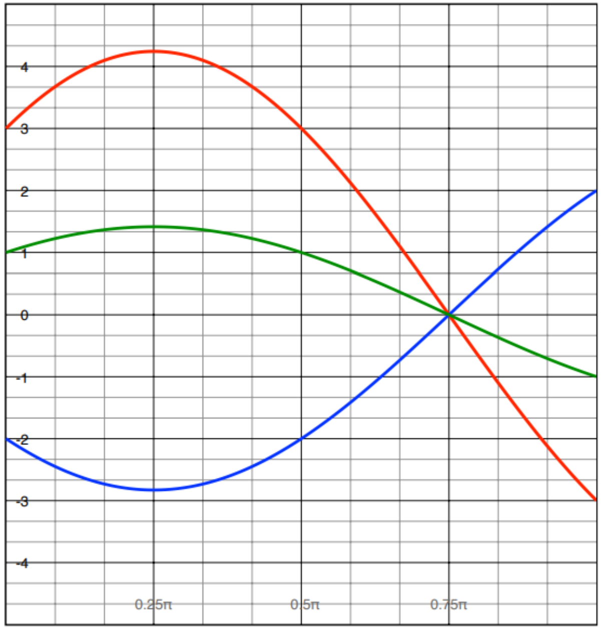


Image space

three points become ?



Parameter space

Hough Transform: Improved Line Detection

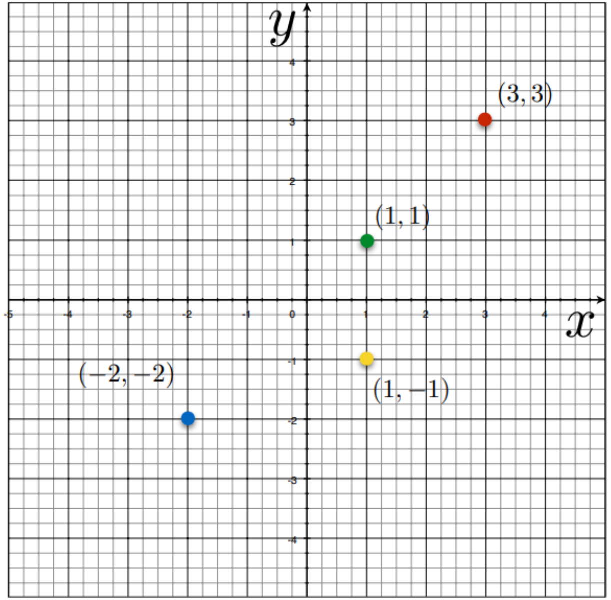
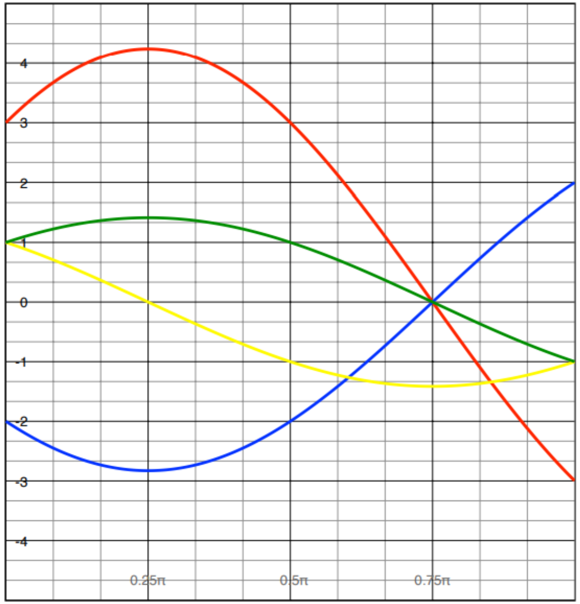


Image space

four points become ?



Parameter space

Hough Transform: Improved Line Detection

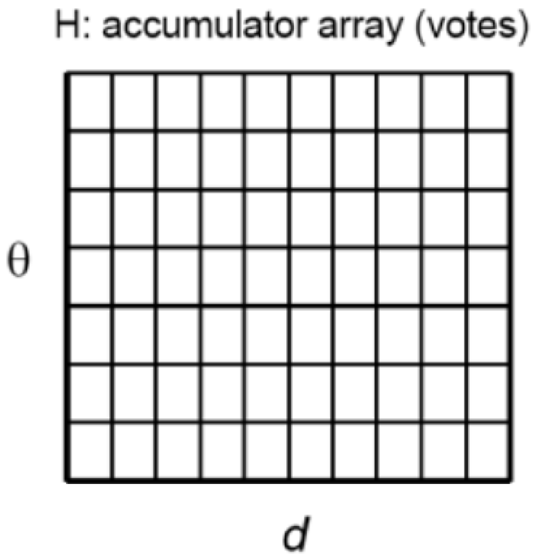
Improved Algorithm

1. Initialize accumulator H with all zeros
2. For each edge point (x, y) in the image

   for $\theta = 0\ to\ 180$

   $\rho = xcos\theta + ysin\theta$

   $H(\theta, \rho) = H(\theta, \rho) + 1$
3. Find the value(s) of (θ, ρ) where $H(\theta, \rho)$ is a local maximum
4. The detected line in the image is given by $\rho = xcos\theta + ysin\theta$



Advantages & Limitations of Classical DIP

Advantages and Limitations of DSP in Object Detection

Advantages

- **Efficiency**: DSP techniques are computationally efficient, making them suitable for real-time object detection applications where speed is crucial.
- **Robustness**: DSP methods excel at handling noise and disturbances in data, enabling reliable object detection even in challenging environments.
- **Versatility**: DSP techniques are applicable across various domains and tasks within object detection, offering flexibility and adaptability to different scenarios.

Limitations

- **Noise Sensitivity**: Some DSP techniques may be sensitive to noise in the data, necessitating preprocessing steps to enhance signal quality and improve detection accuracy.
- **Parameter Tuning**: DSP methods often require careful tuning of parameters to achieve optimal results, which can be time-consuming and may require domain expertise.
- **Complex Object Shapes**: Traditional DSP approaches may struggle with detecting objects with complex or irregular shapes, as they rely on predefined features and patterns.

Current Trends

Current Trends in DIP & Computer Vision

DSP techniques are increasingly integrated with machine learning and deep learning, enhancing object detection capabilities. This integration enables more complex tasks, such as object recognition and advanced segmentation.

Beyond traditional applications, DSP is being used in emerging fields like robotics and drones, where real-time object detection is critical.

Current research focuses on improving computational efficiency and reducing the resource requirements for DSP-based object detection, making it more accessible for a broader range of applications.

Resources

- Duda, R.O.; Hart, P. E. (January 1972). "Use of the Hough Transformation to Detect Lines and Curves in Pictures". Comm. ACM. 15: 11–15. doi:10.1145/361237.361242. S2CID 1105637.
- https://www.youtube.com/watch?v=XRBc_xkZREg&t=2s
- https://www.youtube.com/watch?v=t1GXMvK9m84
- https://www.cs.cmu.edu/~16385/s17/Slides/5.3_Hough_Transform.pdf

Thank you