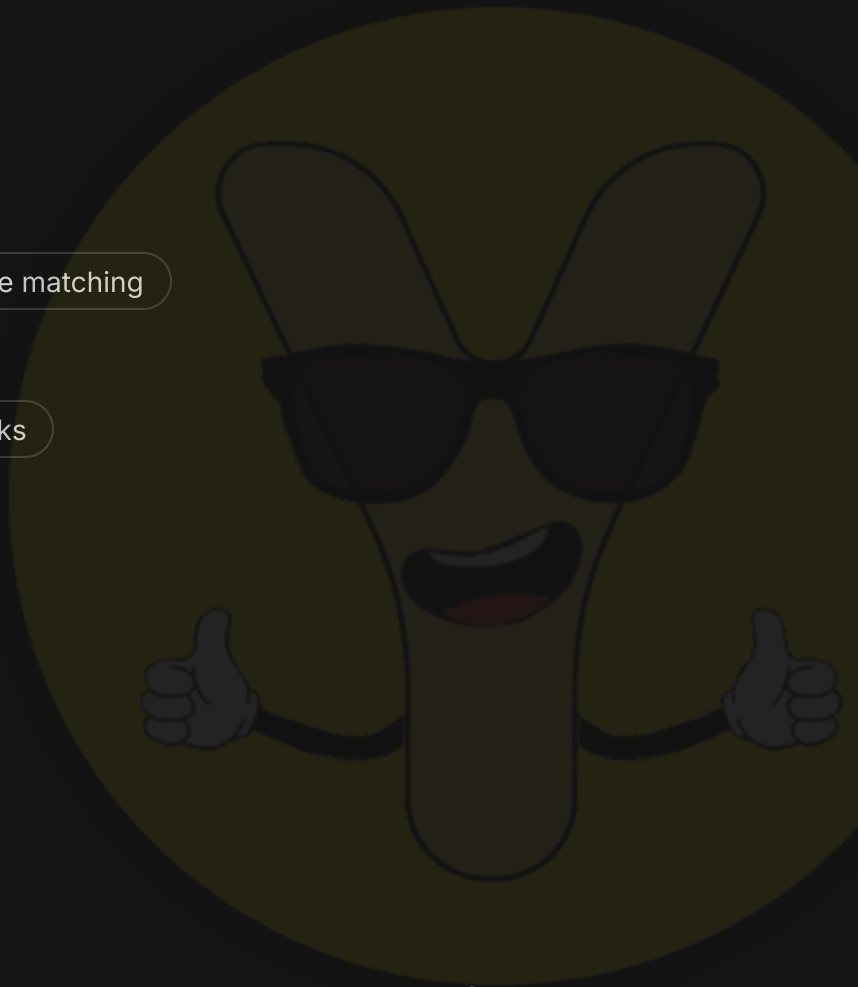
AKTU · 3RD YEAR · SEMESTER 6 · BCDS061

Image Analytics

Unit 5 — Image Pattern Classification

- Background (Image Pattern Classification)
- Patterns and Pattern Classes
- Pattern Classification by Prototype Matching: Minimum-Distance Classifier
- Using Correlation for 2-D prototype matching
- Matching SIFT Features
- Matching Structural Prototypes
- Optimum (Bayes) Statistical Classifiers
- Neural Networks and Deep Learning: Background
- The Perceptron
- Multilayer Feedforward Neural Networks



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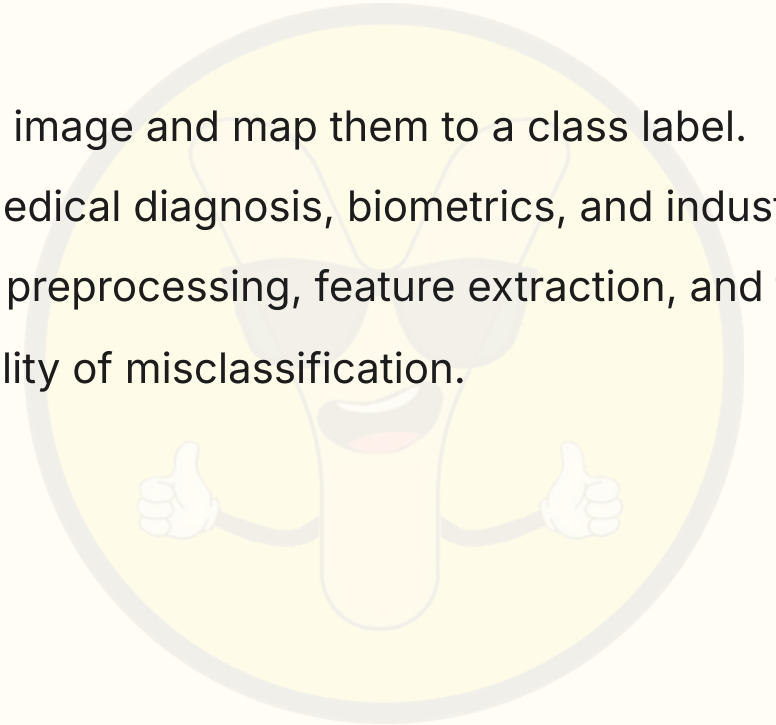
Chirag Jain

Founder, Ycotes · Gold Medalist in Artificial Intelligence, IIT Madras · taught 10,000+ students

Image Pattern Classification: Background

Pattern classification is the process of assigning an input image or feature vector to one of several predefined categories.

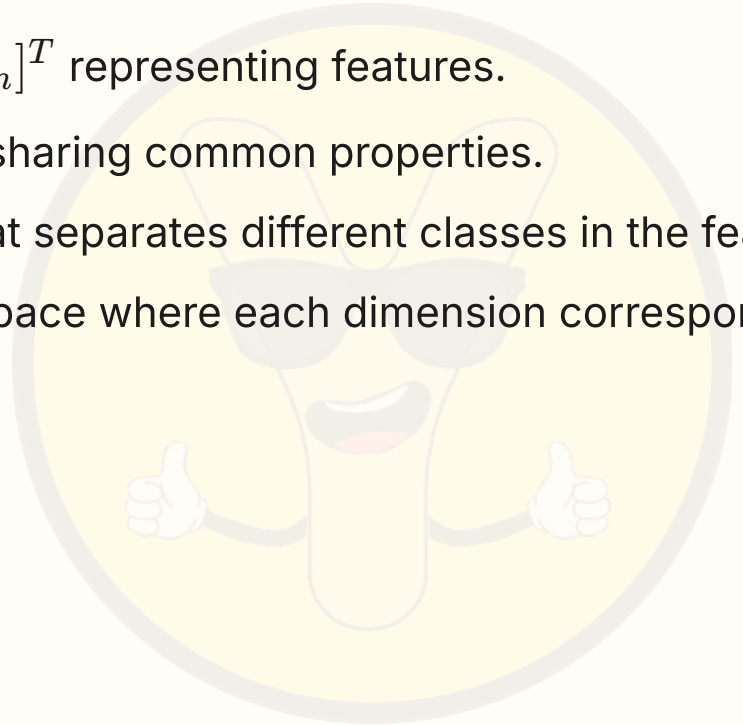
- Core task: Extract features from an image and map them to a class label.
- Applications: Object recognition, medical diagnosis, biometrics, and industrial inspection.
- Key components: Data acquisition, preprocessing, feature extraction, and the classifier.
- The goal is to minimize the probability of misclassification.



Patterns and Pattern Classes

A pattern is a quantitative or structural description of an object.

- Pattern: A vector $x = [x_1, x_2, ..., x_n]^T$ representing features.
- Pattern Class: A family of patterns sharing common properties.
- Decision Boundary: The surface that separates different classes in the feature space.
- Feature Space: An n-dimensional space where each dimension corresponds to a feature.



Minimum-Distance Classifier

A simple classifier that assigns an unknown pattern to the class whose prototype (mean) is closest.

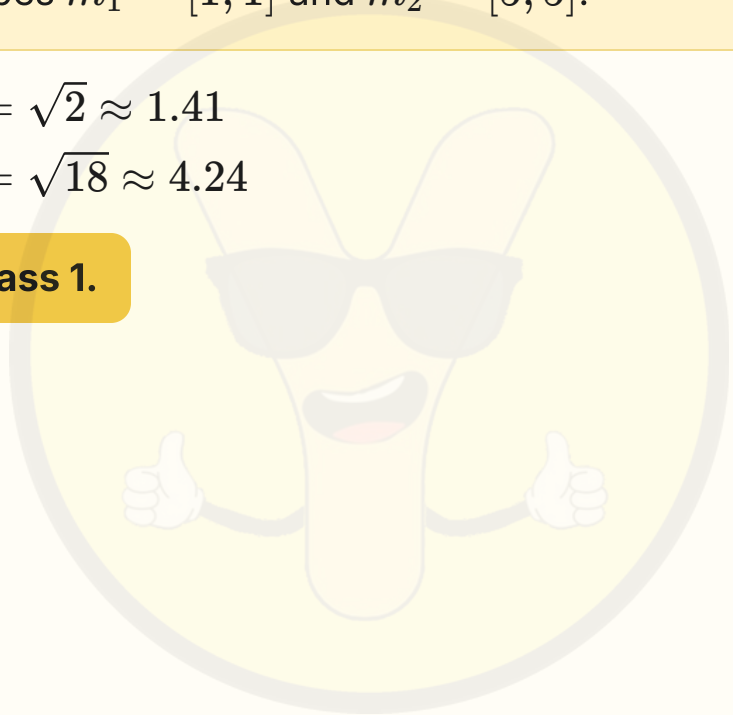
- Algorithm: Calculate distance between input x and class prototypes m_j.
- Decision Rule: Assign x to class j if $d_j(x) = ||x - m_j||$ is minimum.
- Euclidean distance is commonly used for calculation.
- Advantage: Computationally simple and easy to implement.
- Disadvantage: Fails when classes have high variance or non-spherical distributions.

Minimum-Distance Calculation

Classify a point $x = [2, 2]$ given prototypes $m_1 = [1, 1]$ and $m_2 = [5, 5]$.

1. Calculate $d_1 = \sqrt{(2-1)^2 + (2-1)^2} = \sqrt{2} \approx 1.41$
2. Calculate $d_2 = \sqrt{(2-5)^2 + (2-5)^2} = \sqrt{18} \approx 4.24$

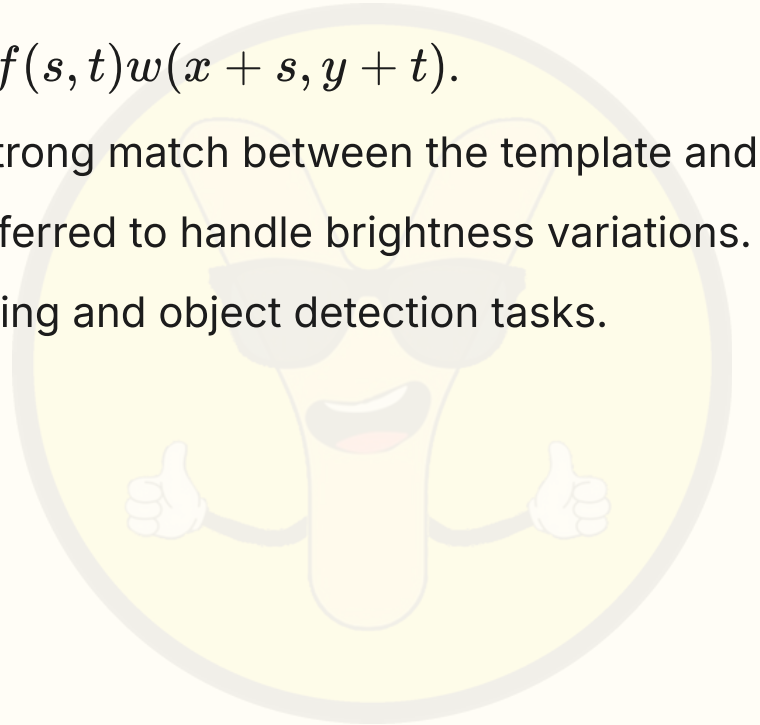
Since $d_1 < d_2$, the point x belongs to Class 1.



Correlation for 2-D Prototype Matching

Correlation measures the similarity between an image template and a sub-region of an image.

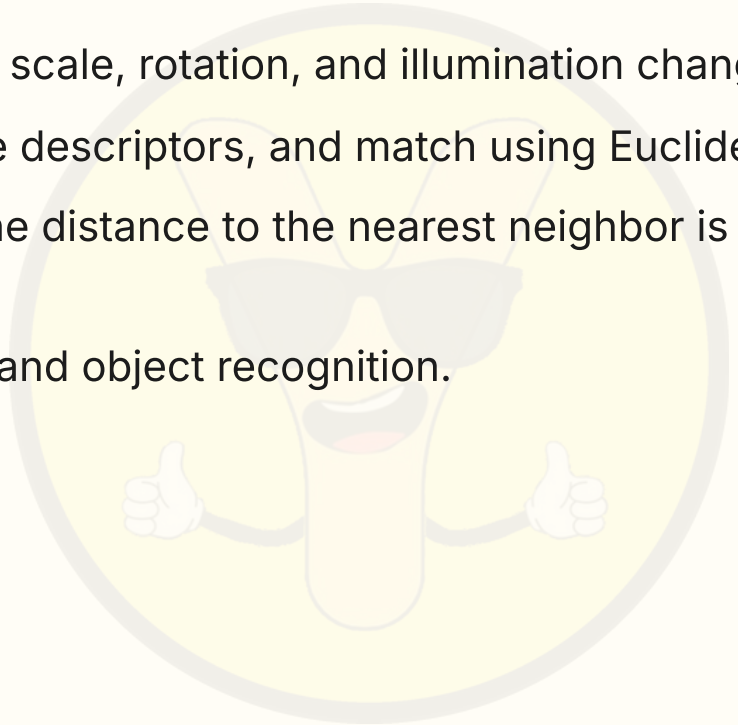
- Cross-correlation: $c(x, y) = \sum\sum f(s, t)w(x + s, y + t)$.
- High correlation value indicates a strong match between the template and the image region.
- Normalized cross-correlation is preferred to handle brightness variations.
- Used extensively in template matching and object detection tasks.



Matching SIFT Features

Scale-Invariant Feature Transform (SIFT) provides robust descriptors for matching.

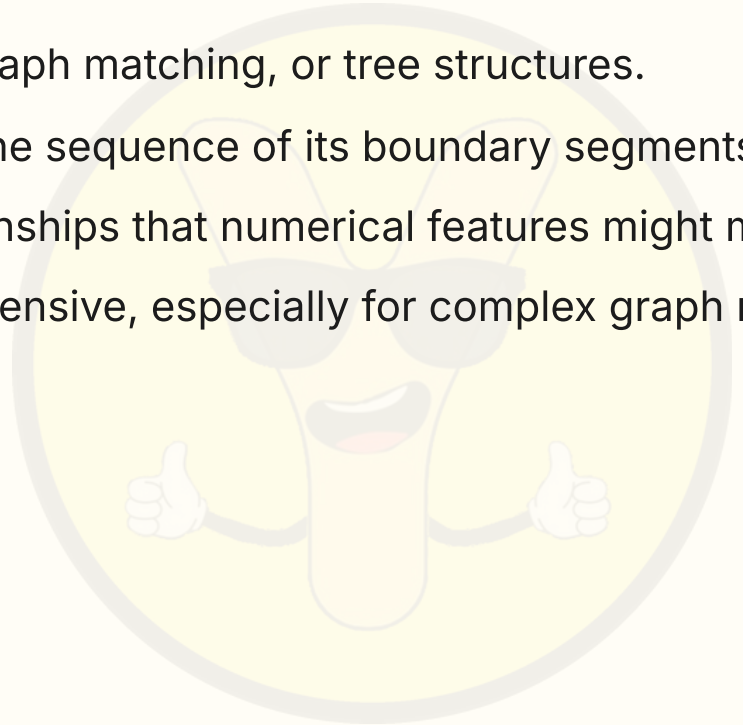
- SIFT features are invariant to image scale, rotation, and illumination changes.
- Process: Detect keypoints, compute descriptors, and match using Euclidean distance.
- Ratio Test: A match is accepted if the distance to the nearest neighbor is significantly smaller than the distance to the second-nearest.
- Highly effective for image stitching and object recognition.



Matching Structural Prototypes

Structural methods describe patterns using relationships between parts rather than numerical features.

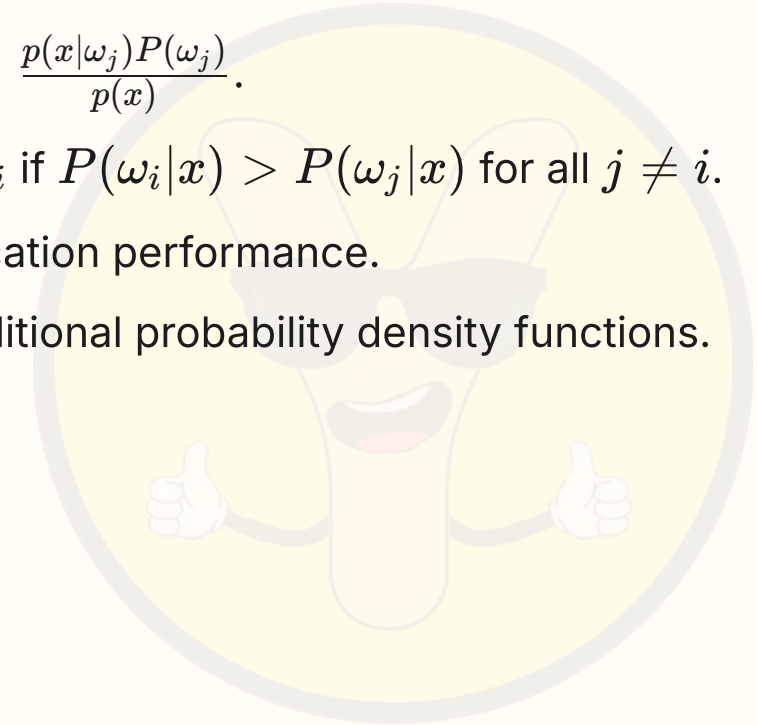
- Representation: String matching, graph matching, or tree structures.
- Example: Describing an object by the sequence of its boundary segments.
- Advantage: Captures spatial relationships that numerical features might miss.
- Disadvantage: Computationally expensive, especially for complex graph matching.



Optimum (Bayes) Statistical Classifier

A classifier that minimizes the probability of error based on probability theory.

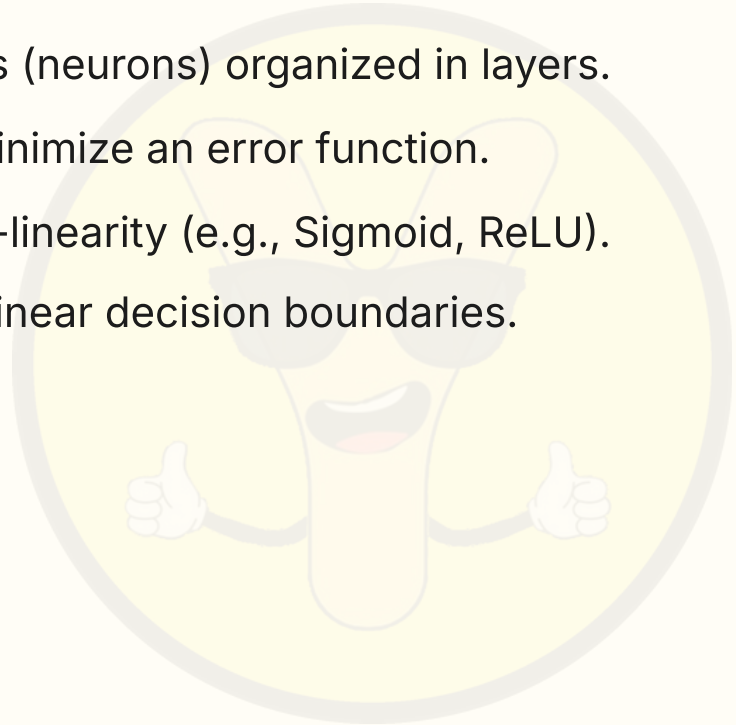
- Uses Bayes' Theorem: $P(\omega_j|x) = \frac{p(x|\omega_j)P(\omega_j)}{p(x)}$.
- Decision Rule: Assign x to class ω_i if $P(\omega_i|x) > P(\omega_j|x)$ for all $j \neq i$.
- It is the theoretical limit of classification performance.
- Requires knowledge of class-conditional probability density functions.



Neural Networks: Background

Neural networks are computational models inspired by the biological structure of the human brain.

- Composed of interconnected nodes (neurons) organized in layers.
- Learning: Adjusting weights w to minimize an error function.
- Activation functions: Introduce non-linearity (e.g., Sigmoid, ReLU).
- Capable of learning complex, non-linear decision boundaries.



The Perceptron Architecture

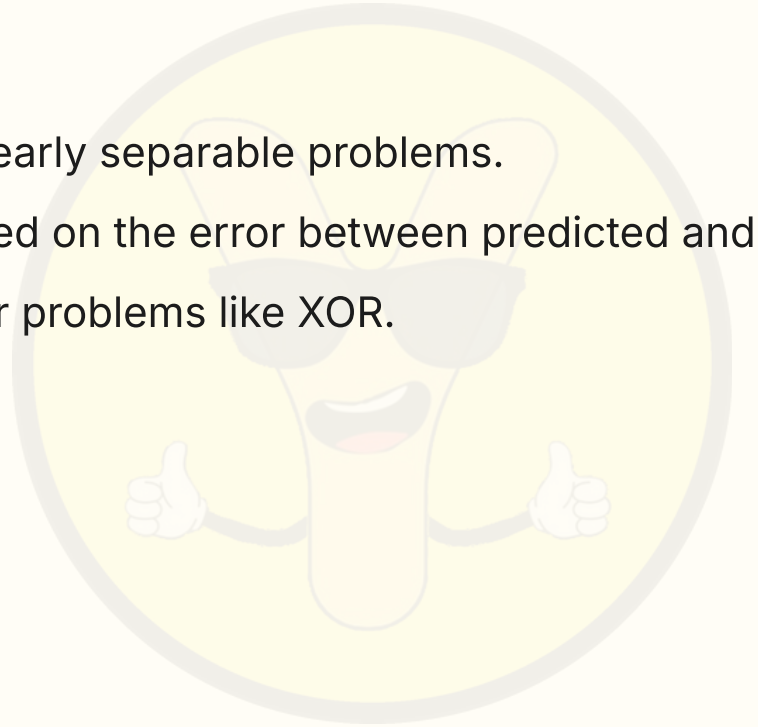


A single-layer perceptron model.

The Perceptron

The simplest form of a neural network used for binary classification.

- Formula: $y = f(\sum w_i x_i + b)$.
- Linear Classifier: Can only solve linearly separable problems.
- Learning Rule: Adjusts weights based on the error between predicted and actual output.
- Limitations: Cannot solve non-linear problems like XOR.

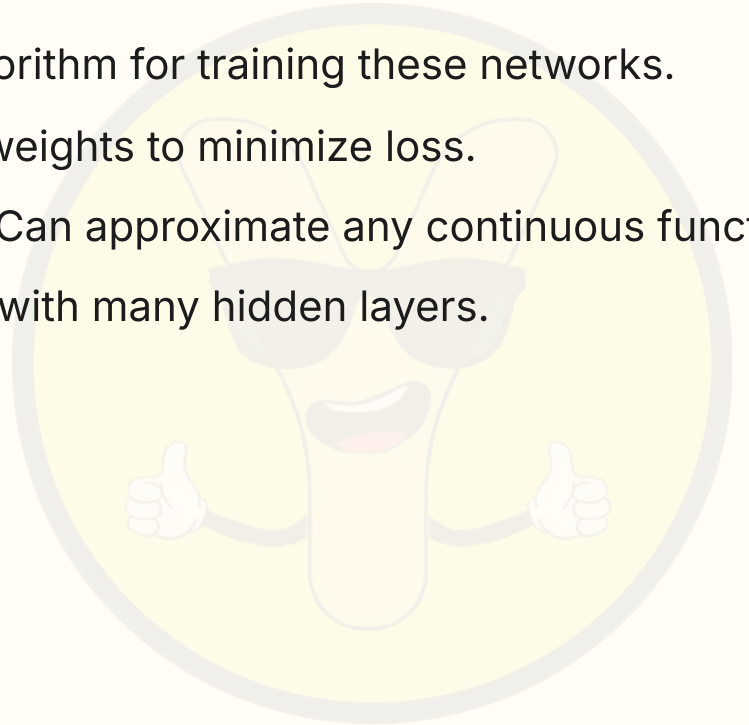


Multilayer Feedforward Neural Networks

Multilayer Feedforward Networks

Networks with one or more hidden layers to handle non-linear mapping.

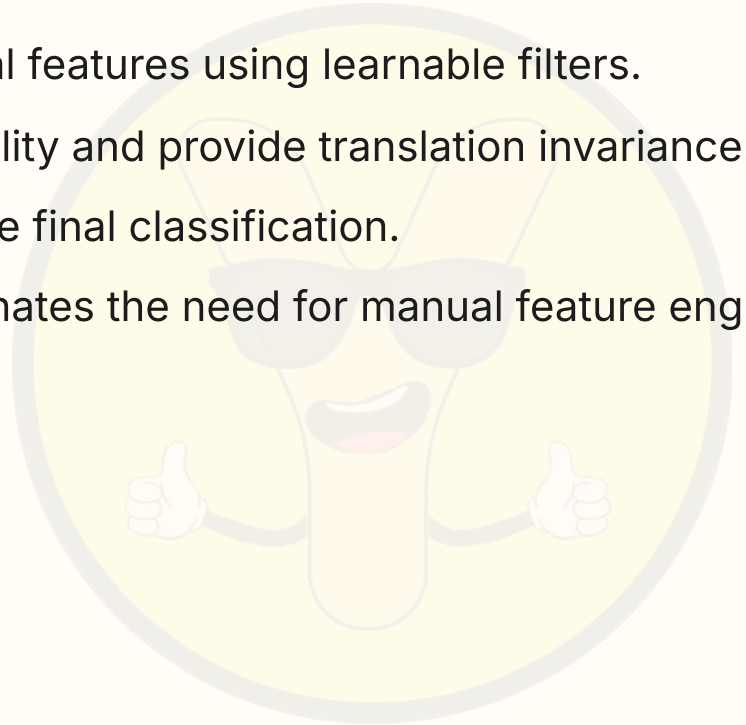
- Backpropagation: The standard algorithm for training these networks.
- Gradient Descent: Used to update weights to minimize loss.
- Universal Approximation Theorem: Can approximate any continuous function given enough neurons.
- Deep Learning: Refers to networks with many hidden layers.



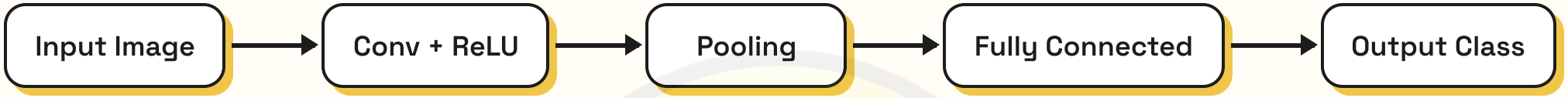
Deep Convolutional Neural Networks (DCNN)

DCNNs are specialized neural networks for processing grid-like data such as images.

- Convolutional Layers: Extract spatial features using learnable filters.
- Pooling Layers: Reduce dimensionality and provide translation invariance.
- Fully Connected Layers: Perform the final classification.
- Automatic Feature Extraction: Eliminates the need for manual feature engineering.



DCNN Architecture Flow



Standard pipeline of a Deep Convolutional Neural Network.

Exam corner

- **Q1** Explain the Minimum-Distance classifier with its mathematical formulation.
- **Q2** How does the Bayes classifier achieve optimal performance? Derive the decision rule.
- **Q3** Compare and contrast structural vs. statistical pattern recognition.
- **Q4** Explain the working of a Perceptron. Why can it not solve the XOR problem?
- **Q5** Describe the role of Convolution and Pooling layers in a DCNN.
- **Q6** What is the significance of the 'Ratio Test' in SIFT feature matching?
- **Q7** Explain the backpropagation algorithm in the context of multilayer neural networks.

Unit 5 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 1 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

