

Lecture 16: Introduction to Object Recognition and the Nearest Neighbor Approach

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Stanford Vision Lab

What we will learn today?

- Introduction
- K-nearest neighbor algorithm
- A simple Object Recognition pipeline

What are the different visual recognition tasks?



Classification:

Does this image contain a building? [yes/no]



Classification:

Is this an beach?



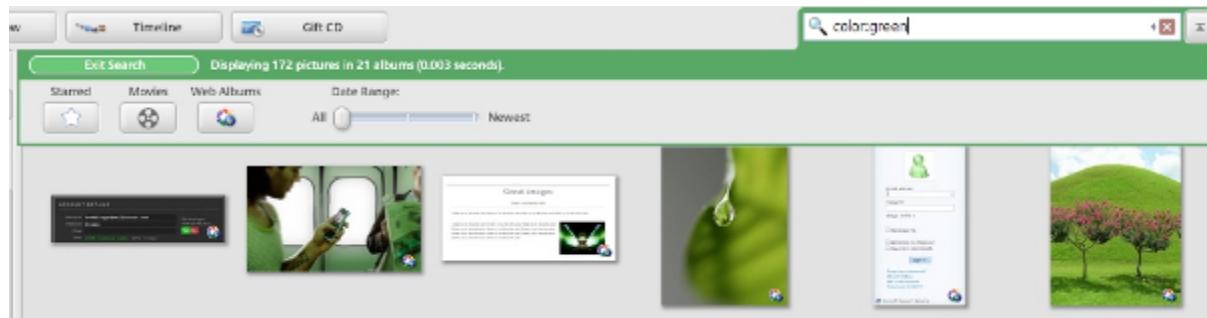
Image Search



A screenshot of a Google Images search results page. The search term 'street' is entered in the search bar. The results show six image thumbnails, each with its title, dimensions, and source URL. The titles include 'Street sweeper', 'Street Maintenance', 'Main Street Station', 'SHPO Wayne Donaldson at Main Street ...', 'Lombard Street, worlds crookedest See Street Bike (DS70 4A) Details', and 'Street Bike (DS70 4A) Details'. The images show various street scenes and vehicles.

Image Title	Dimensions	Source URL
Street sweeper	345 x 352 - 17k - jpg	www.town.teluno.co.us
Street Maintenance	407 x 402 - 18k - jpg	www.town.teluno.co.us
Main Street Station	360 x 392 - 30k - jpg	www.rmaonline.org
SHPO Wayne Donaldson at Main Street ...	410 x 314 - 41k - jpg	ohp.parks.ca.gov
Lombard Street, worlds crookedest See Street Bike (DS70 4A) Details	500 x 387 - 59k - jpg	www.inetours.com
Street Bike (DS70 4A) Details	380 x 360 - 38k - jpg	bashan.en.alibaba.com

Organizing photo collections



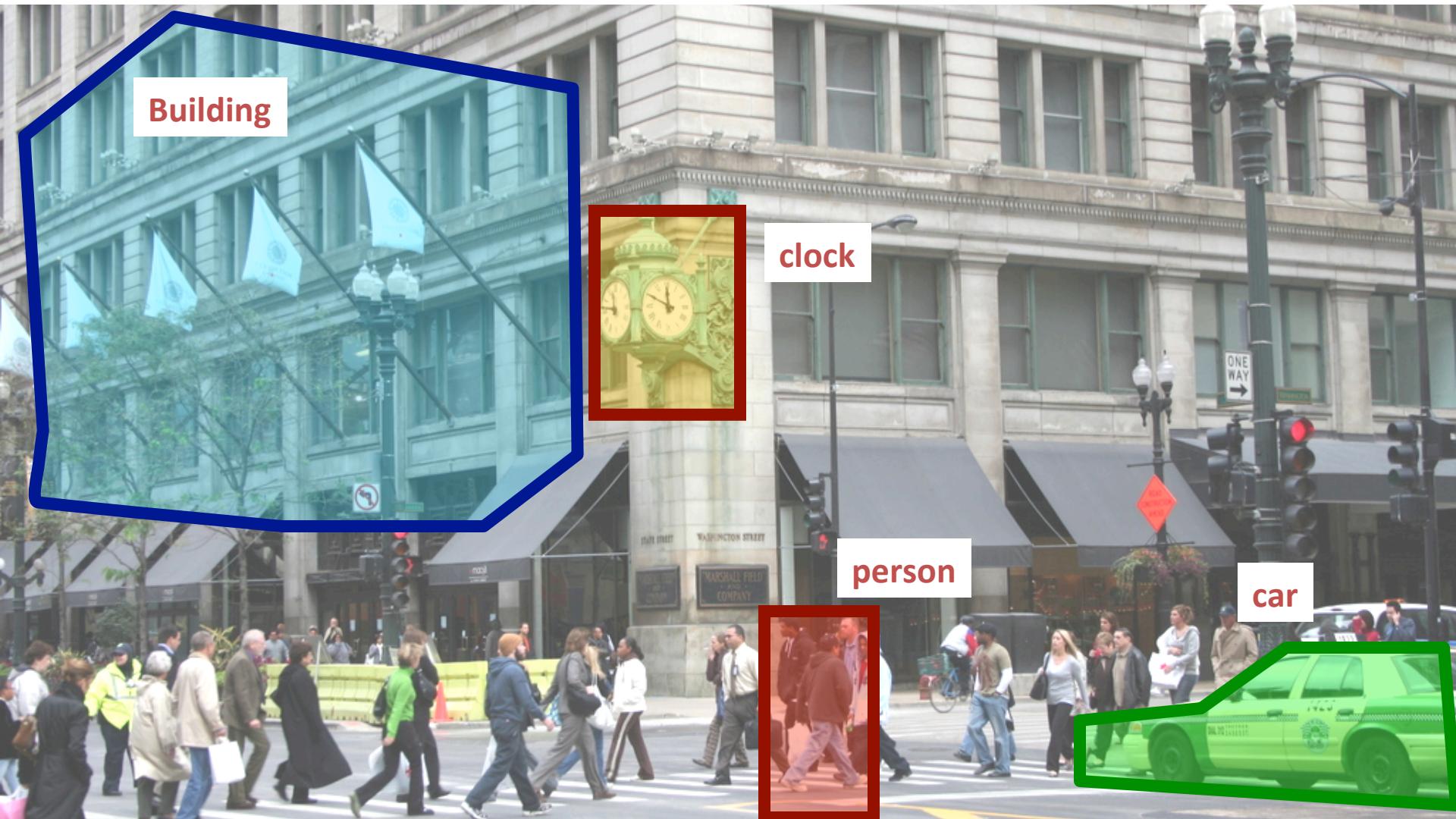
Detection:

Does this image contain a car? [where?]



Detection:

Which object does this image contain? [where?]

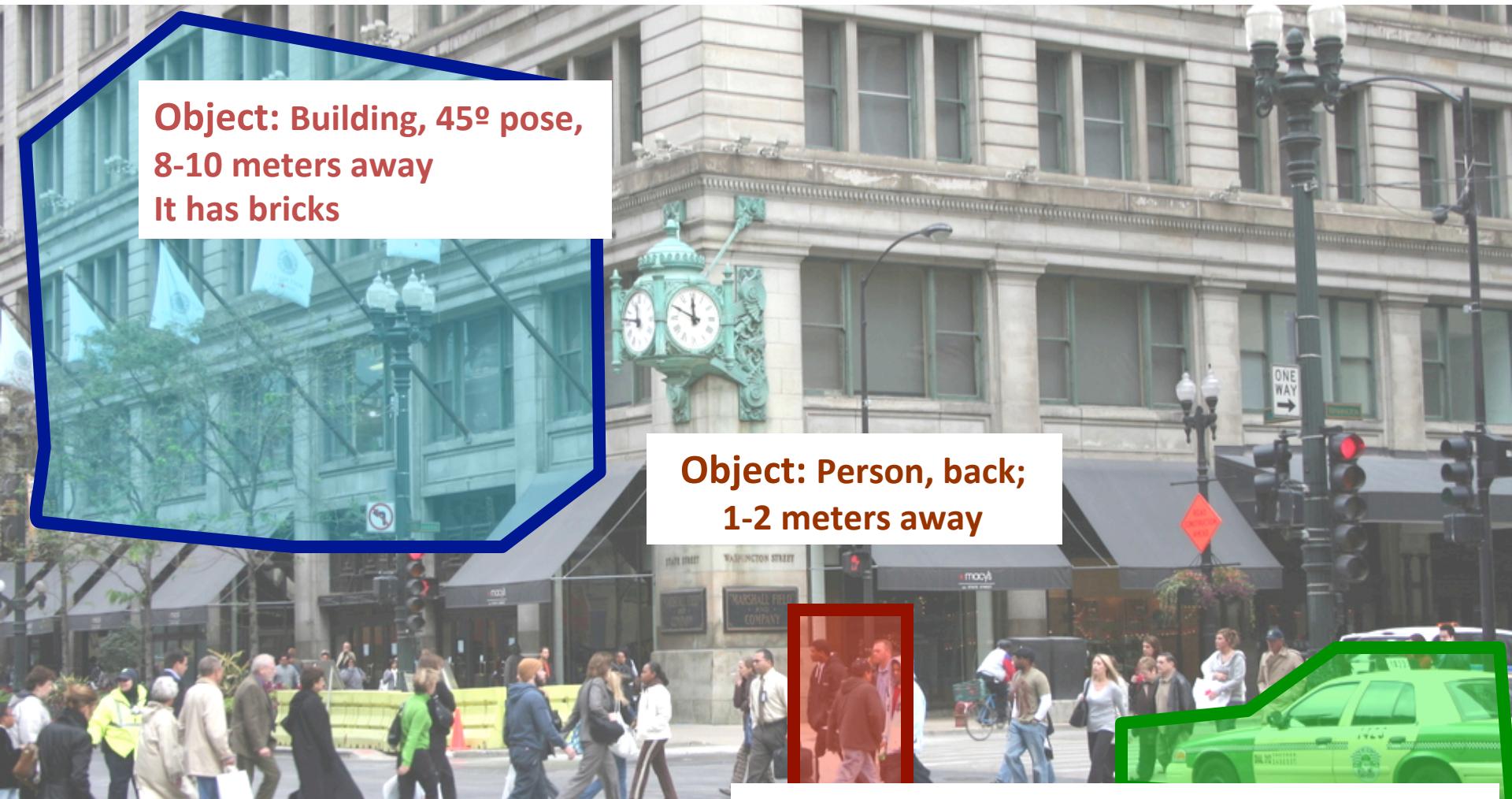


Detection:

Accurate localization (segmentation)



Detection: Estimating object semantic & geometric attributes



Applications of computer vision



Computational photography



Assistive technologies



Surveillance



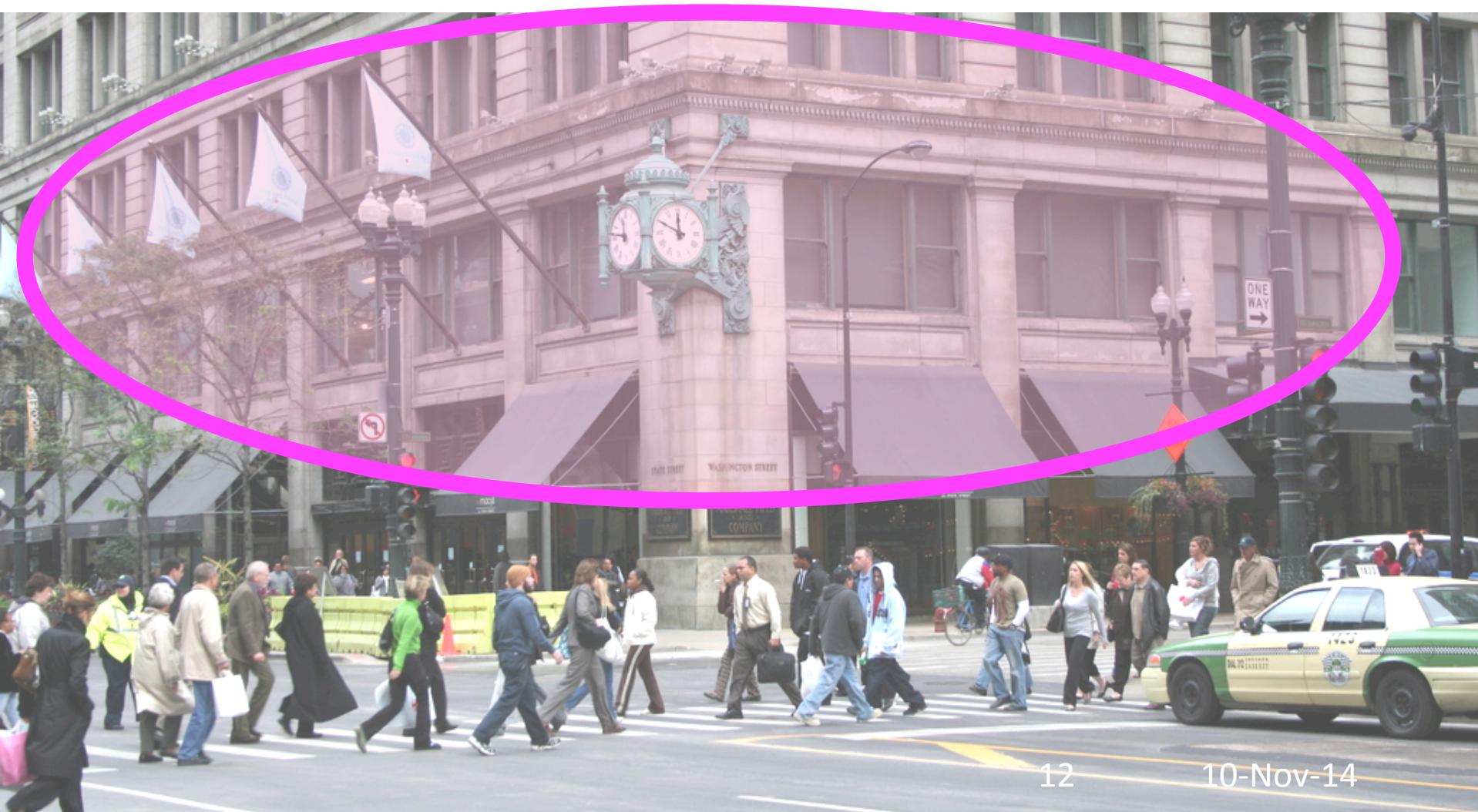
Security



Assistive driving

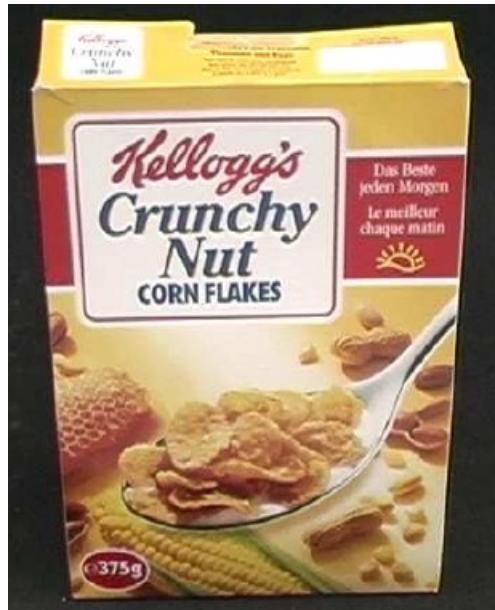
Categorization vs Single instance recognition

Does this image contain the Chicago Macy building's?

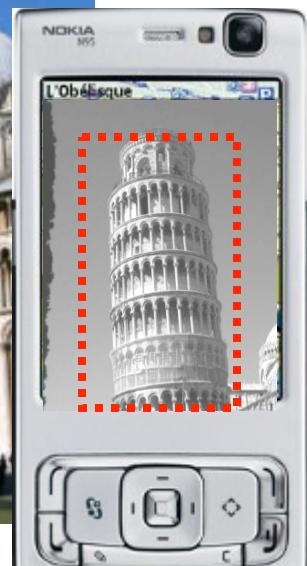


Categorization vs Single instance recognition

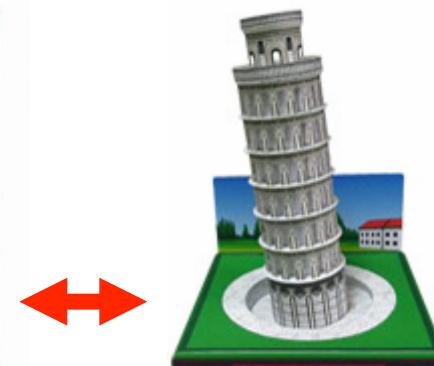
Where is the crunchy nut?



Applications of computer vision



- Recognizing landmarks in mobile platforms



+ GPS

Activity or Event recognition

What are these people doing?



Visual Recognition

- Design algorithms that are capable to
 - Classify images or videos
 - Detect and localize objects
 - Estimate semantic and geometrical attributes
 - Classify human activities and events

Why is this challenging?

How many object categories are there?

~10,000 to 30,000



Challenges: viewpoint variation



Michelangelo 1475-1564

Challenges: illumination

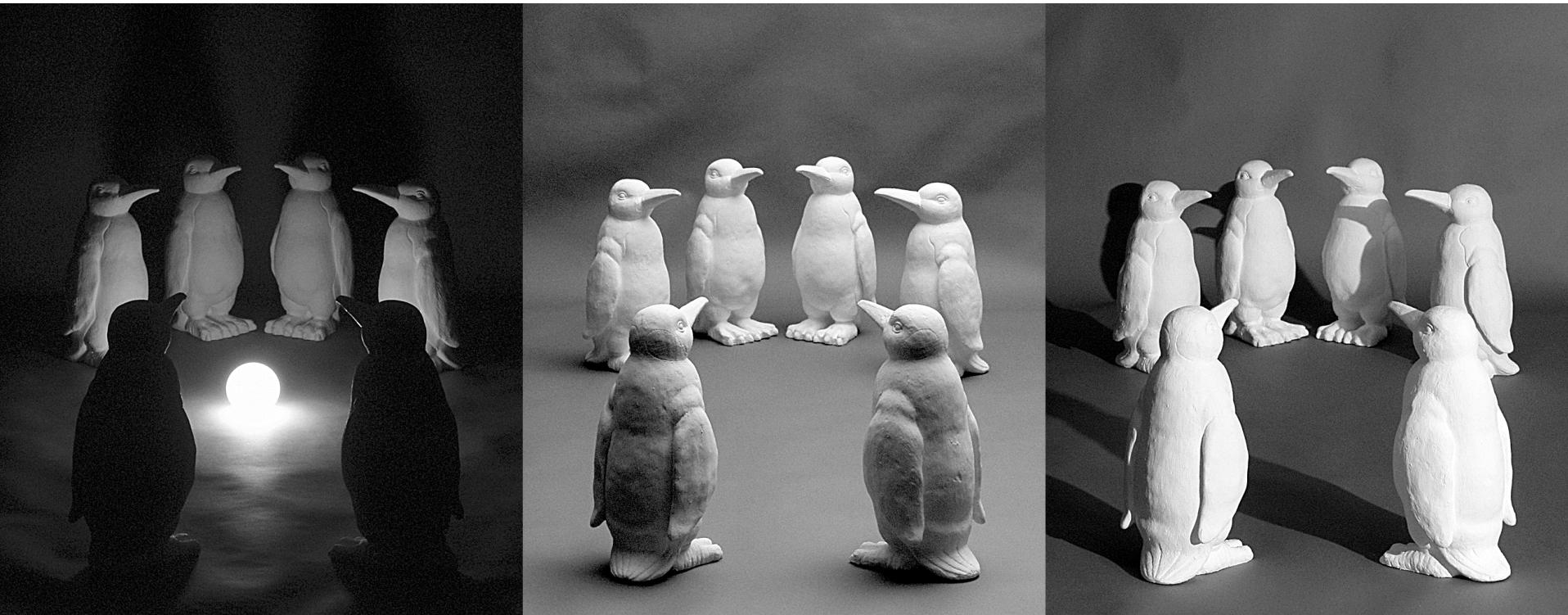


image credit: J. Koenderink

Challenges: scale



Challenges: deformation

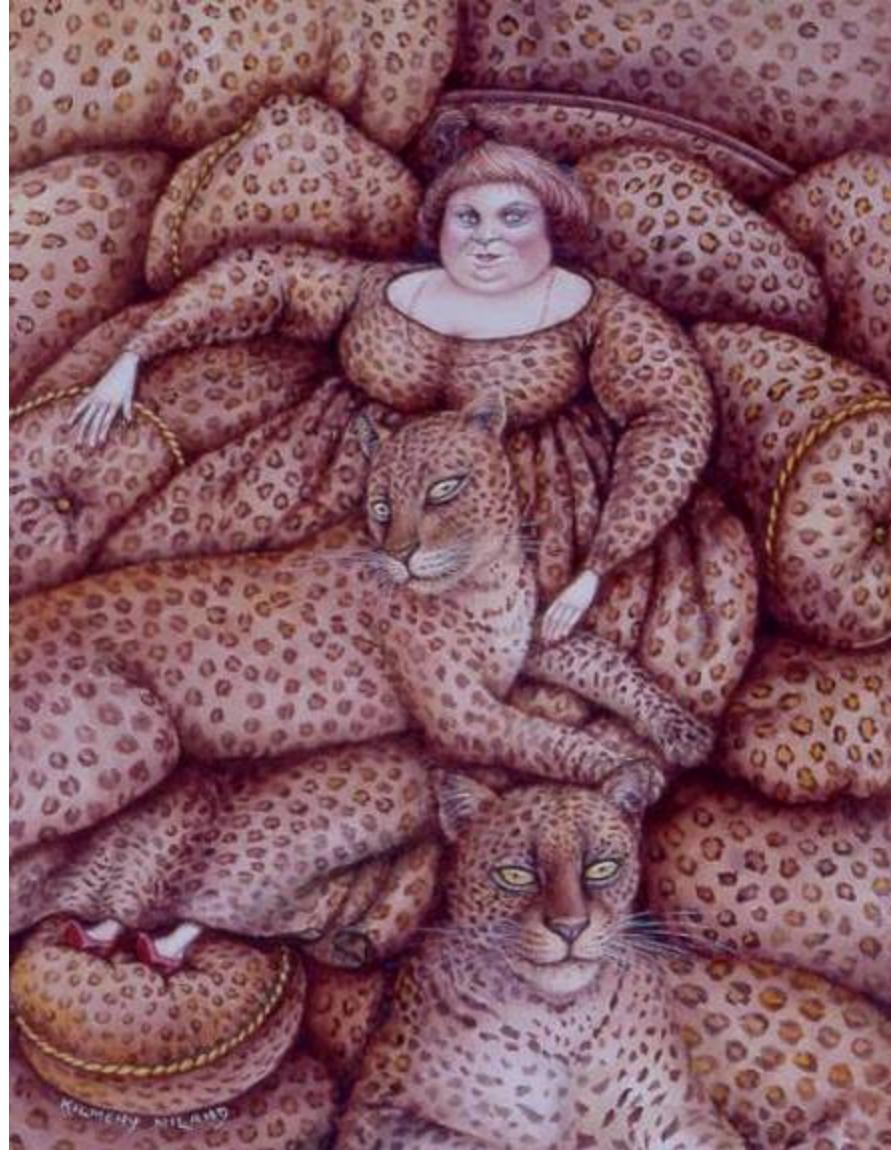


Challenges: occlusion

Magritte, 1957

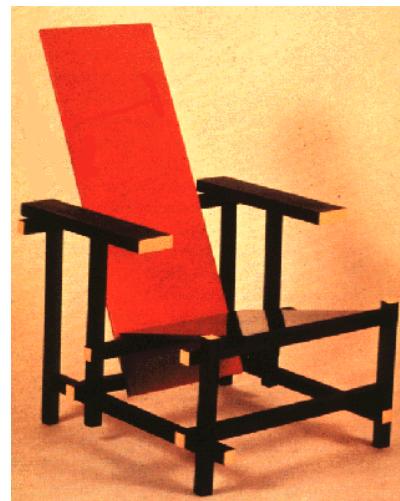


Challenges: background clutter



Kilmeny Niland. 1995

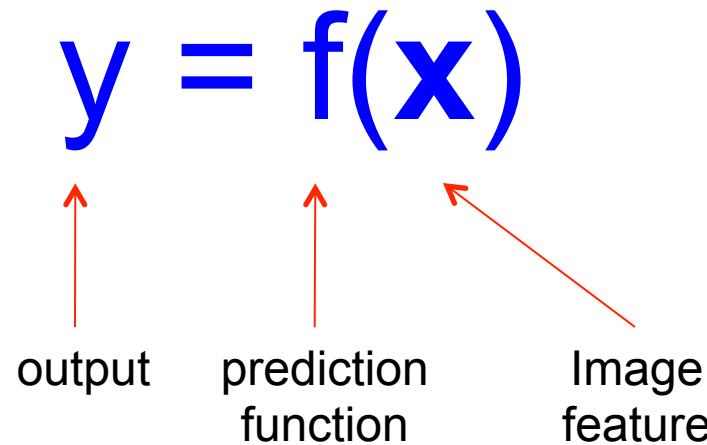
Challenges: intra-class variation



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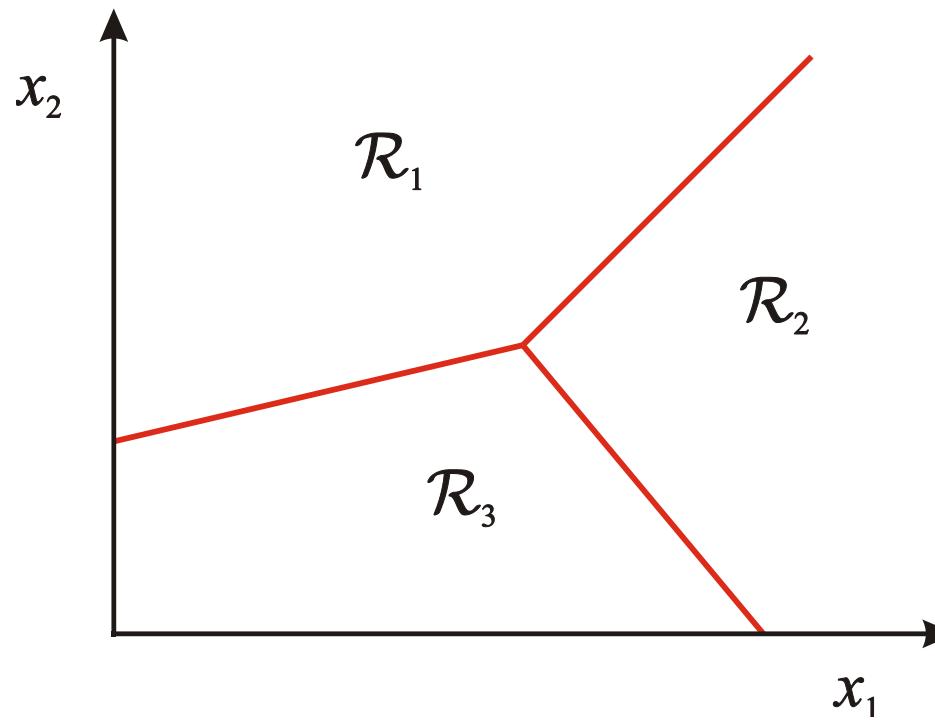
The machine learning framework



- **Training:** given a *training set* of labeled examples $\{(\mathbf{x}_1, y_1), \dots, (\mathbf{x}_N, y_N)\}$, estimate the prediction function f by minimizing the prediction error on the training set
- **Testing:** apply f to a never before seen *test example* \mathbf{x} and output the predicted value $y = f(\mathbf{x})$

Classification

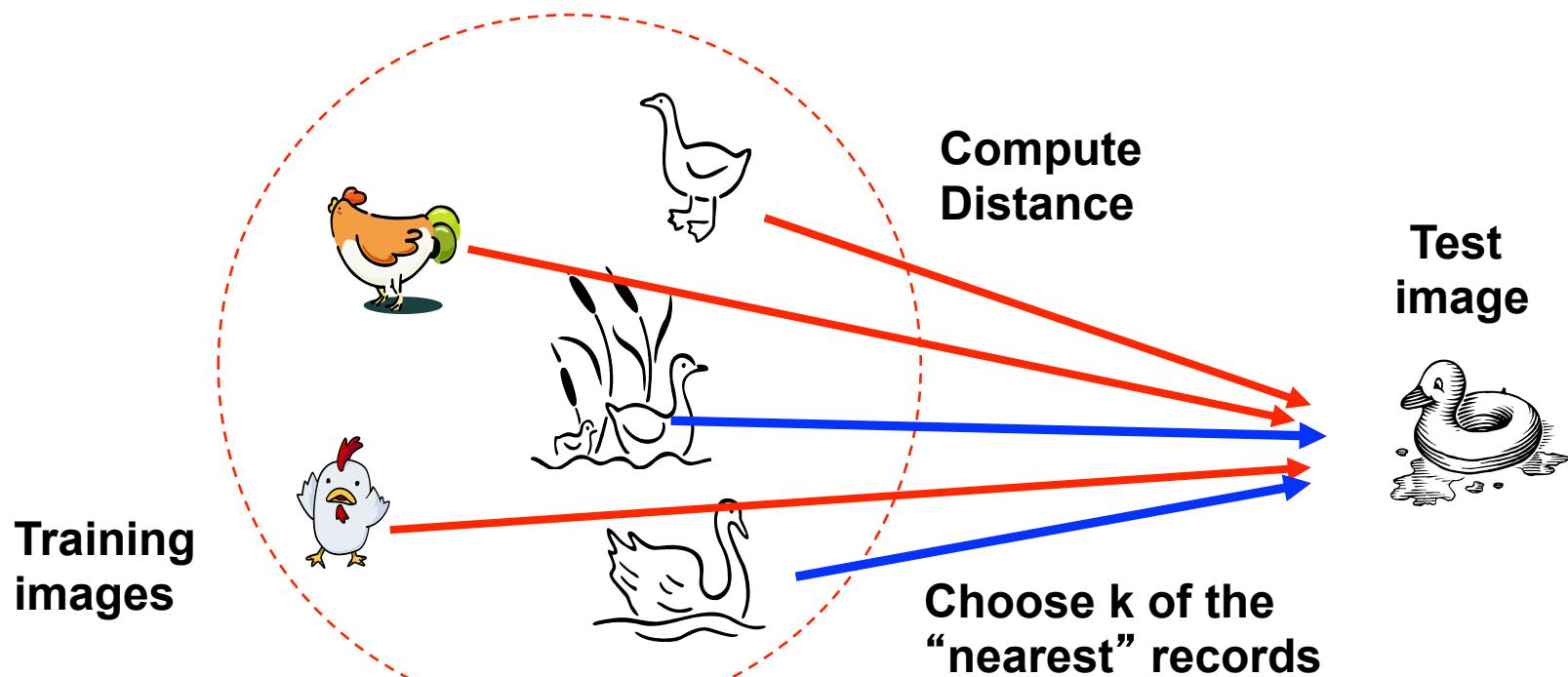
- Assign input vector to one of two or more classes
- Any decision rule divides input space into *decision regions* separated by *decision boundaries*



Slide credit: L. Lazebnik

Nearest Neighbor Classifier

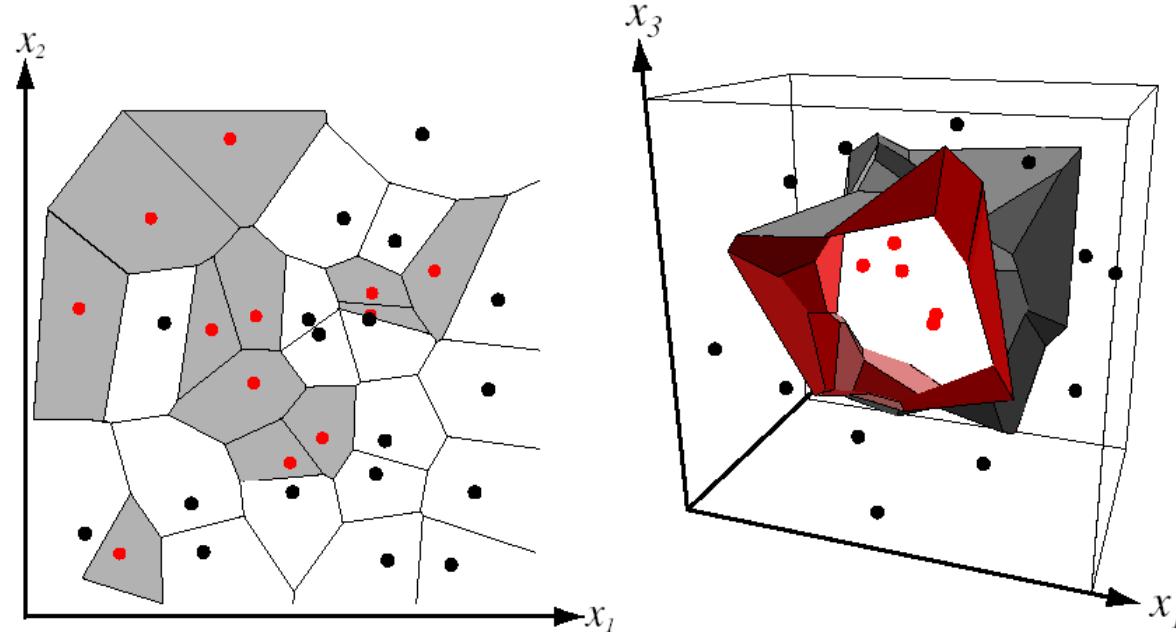
- Assign label of nearest training data point to each test data point



Source: N. Goyal

Nearest Neighbor Classifier

- Assign label of nearest training data point to each test data point



from Duda *et al.*

partitioning of feature space
for two-category 2D and 3D data

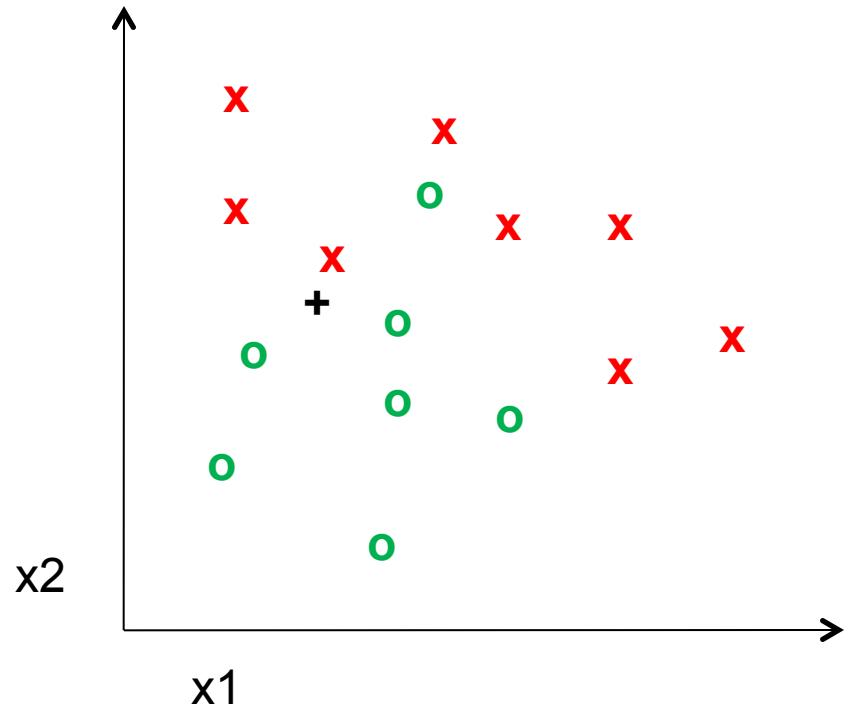
Source: D. Lowe

K-nearest neighbor

Distance measure - Euclidean

$$Dist(X^n, X^m) = \sqrt{\sum_{i=1}^D (X_i^n - X_i^m)^2}$$

Where X^n and X^m are the n-th and m-th data points

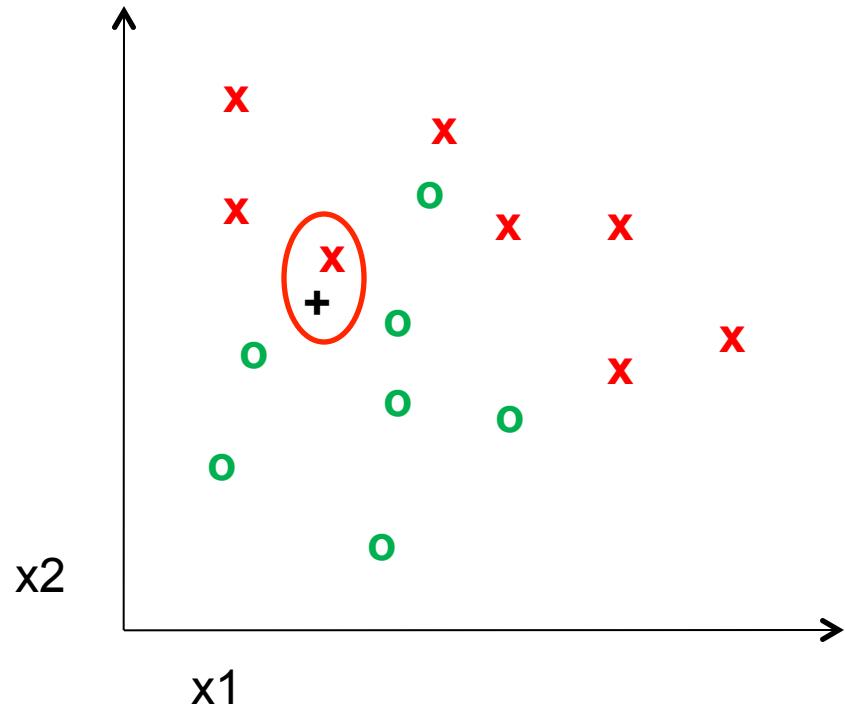


1-nearest neighbor

Distance measure - Euclidean

$$Dist(X^n, X^m) = \sqrt{\sum_{i=1}^D (X_i^n - X_i^m)^2}$$

Where X^n and X^m are the n-th and m-th data points

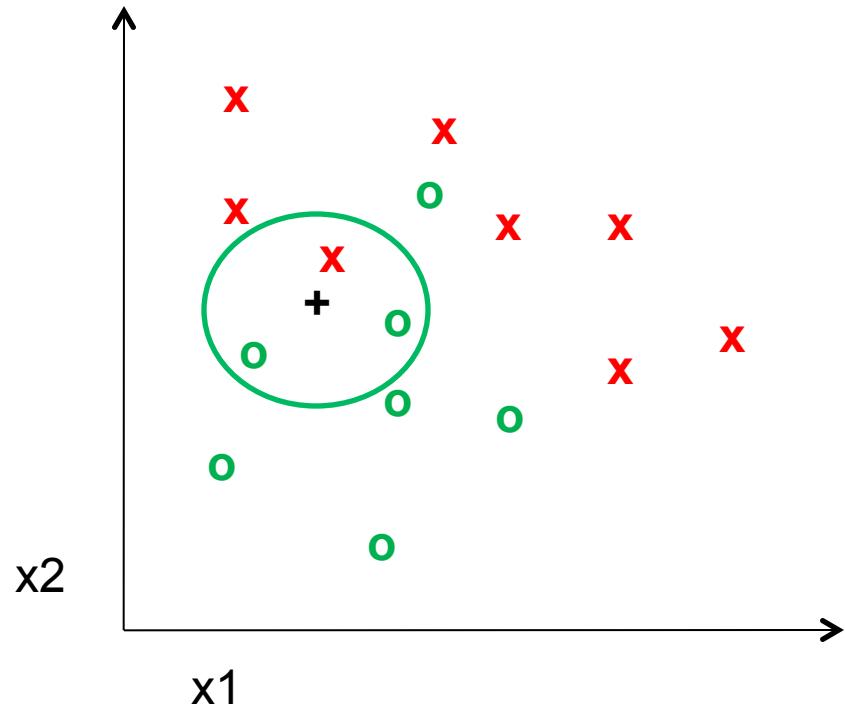


3-nearest neighbor

Distance measure - Euclidean

$$Dist(X^n, X^m) = \sqrt{\sum_{i=1}^D (X_i^n - X_i^m)^2}$$

Where X^n and X^m are the n-th and m-th data points

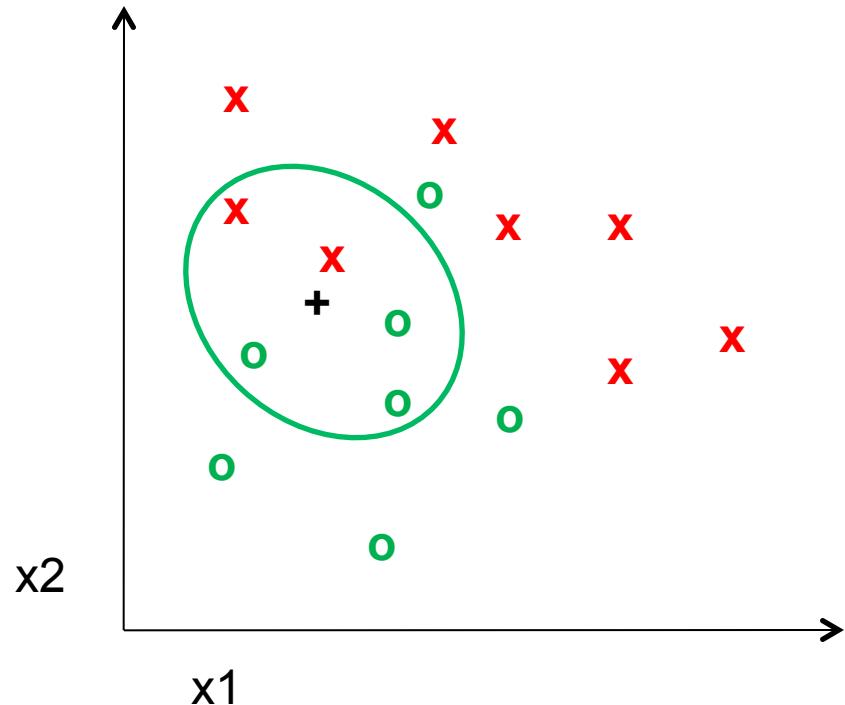


5-nearest neighbor

Distance measure - Euclidean

$$Dist(X^n, X^m) = \sqrt{\sum_{i=1}^D (X_i^n - X_i^m)^2}$$

Where X^n and X^m are the n-th and m-th data points

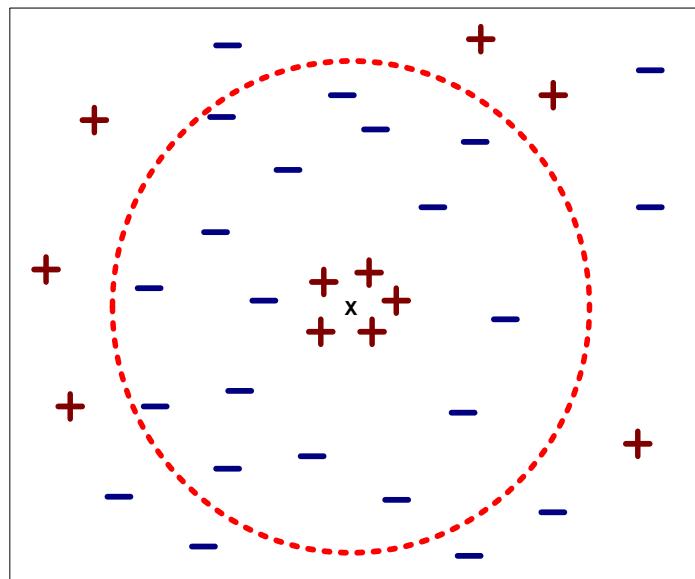


k -NN: a very useful algorithm

- Simple, a good one to try first
- Very flexible decision boundaries
- With infinite examples, 1-NN provably has error that is at most twice Bayes optimal error

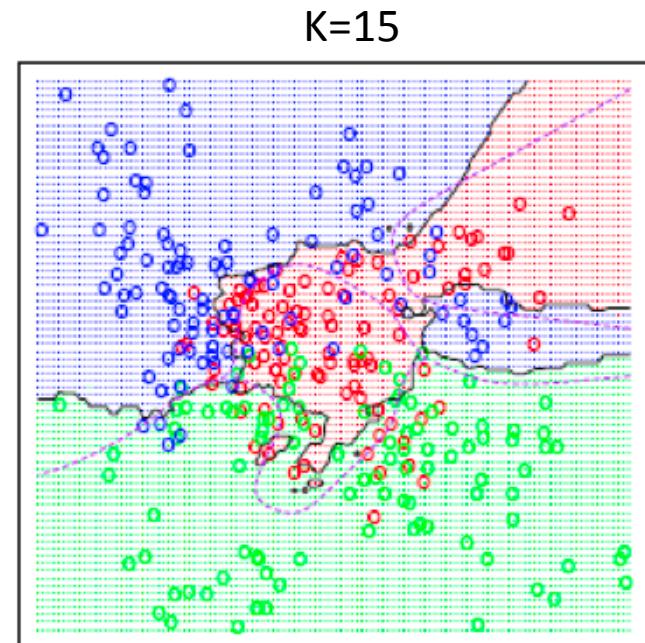
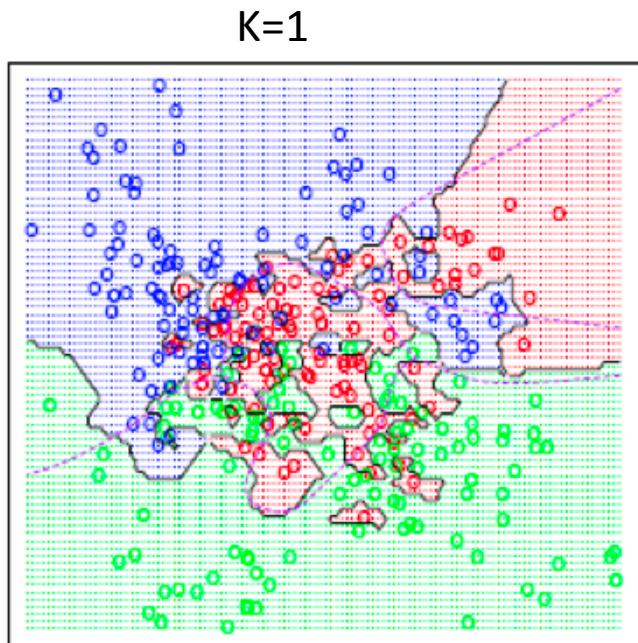
K-NN: issues to keep in mind

- Choosing the value of k:
 - If too small, sensitive to noise points
 - If too large, neighborhood may include points from other classes



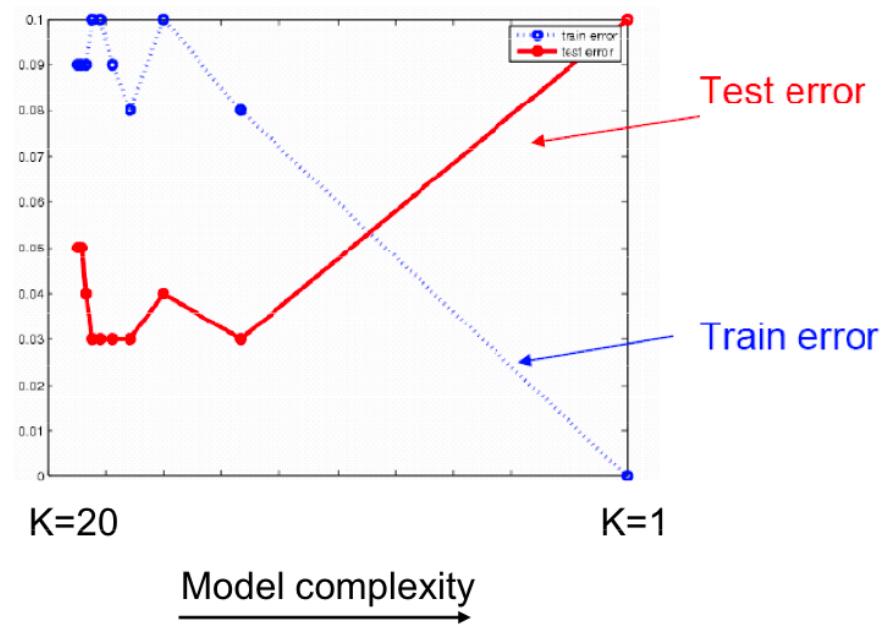
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K-NN: issues to keep in mind

- Choosing the value of k:
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 - Solution: cross validate!



K-NN: issues to keep in mind

- Choosing the value of k:
 - If too small, sensitive to noise points
 - If too large, neighborhood may include points from other classes
 - Solution: cross validate!
- Can produce counter-intuitive results (using Euclidean measure)

1 1 1 1 1 1 1 1 1 1 1 0

0 1 1 1 1 1 1 1 1 1 1 1

vs

1 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1

$d = 1.4142$

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K-NN: issues to keep in mind

- Choosing the value of k:
 - If too small, sensitive to noise points
 - If too large, neighborhood may include points from other classes
 - Solution: cross validate!
- Can produce counter-intuitive results (using Euclidean measure)
 - Solution: normalize the vectors to unit length

1 1 1 1 1 1 1 1 1 1 1 0

0 1 1 1 1 1 1 1 1 1 1 1

vs

1 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 1

$$d = 1.4142$$

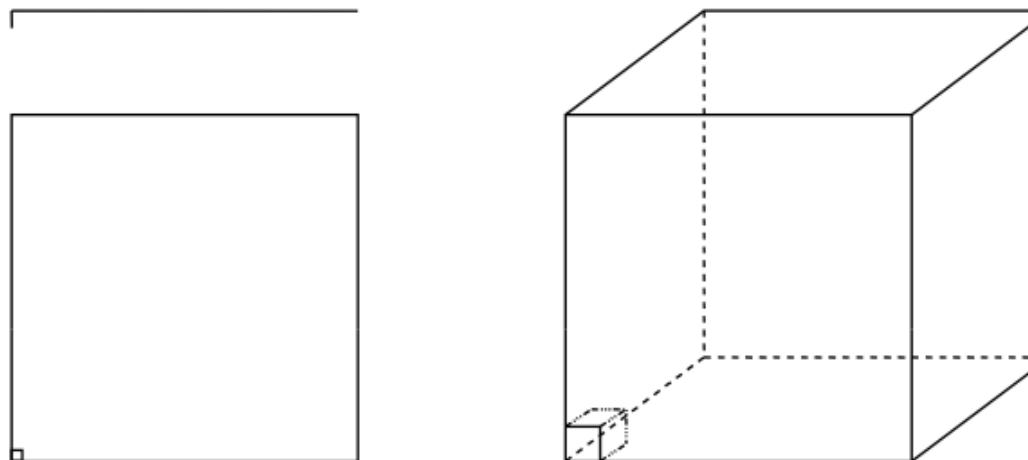
$$d = 1.4142$$

K-NN: issues to keep in mind

- Choosing the value of k:
 - If too small, sensitive to noise points
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 - Solution: cross validate!
- Can produce counter-intuitive results (using Euclidean measure)
 - Solution: normalize the vectors to unit length
- Curse of Dimensionality

Curse of dimensionality

- Assume 5000 points uniformly distributed in the unit hypercube and we want to apply 5-NN. Suppose our query point is at the origin.
 - In 1-dimension, we must go a distance of $5/5000=0.001$ on the average to capture 5 nearest neighbors.
 - In 2 dimensions, we must go $\sqrt{0.001}$ to get a square that contains 0.001 of the volume.
 - In d dimensions, we must go $(0.001)^{1/d}$



K-NN: issues to keep in mind

- Choosing the value of k:
 - If too small, sensitive to noise points
 - If too large, neighborhood may include points from other classes
 - Solution: cross validate!
- Can produce counter-intuitive results (using Euclidean measure)
 - Solution: normalize the vectors to unit length
- Curse of Dimensionality
 - Solution: no good one

Many classifiers to choose from

- **K-nearest neighbor** Which is the best one?
- SVM
- Neural networks
- Naïve Bayes
- Bayesian network
- Logistic regression
- Randomized Forests
- Boosted Decision Trees
- RBMs
- Etc.

Slide credit: D. Hoiem

Generalization



Training set (labels known)



Test set (labels unknown)

- How well does a learned model generalize from the data it was trained on to a new test set?

Slide credit: L. Lazebnik

Generalization

- Components of generalization error
 - **Bias:** how much the average model over all training sets differ from the true model?
 - Error due to inaccurate assumptions/simplifications made by the model
 - **Variance:** how much models estimated from different training sets differ from each other
- **Underfitting:** model is too “simple” to represent all the relevant class characteristics
 - High bias and low variance
 - High training error and high test error
- **Overfitting:** model is too “complex” and fits irrelevant characteristics (noise) in the data
 - Low bias and high variance
 - Low training error and high test error

No Free Lunch Theorem

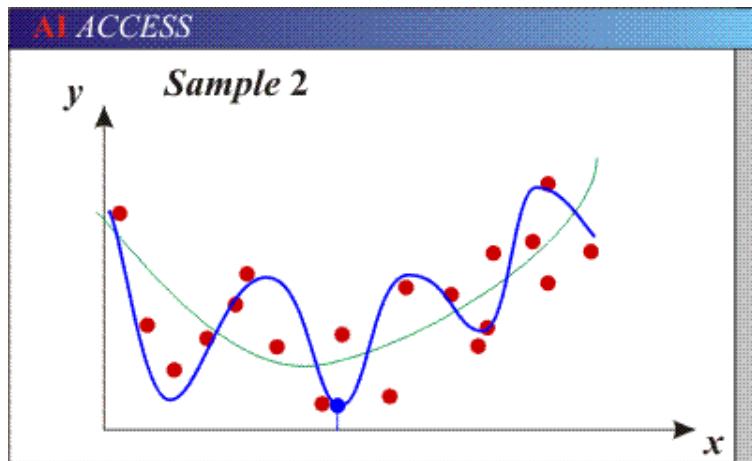
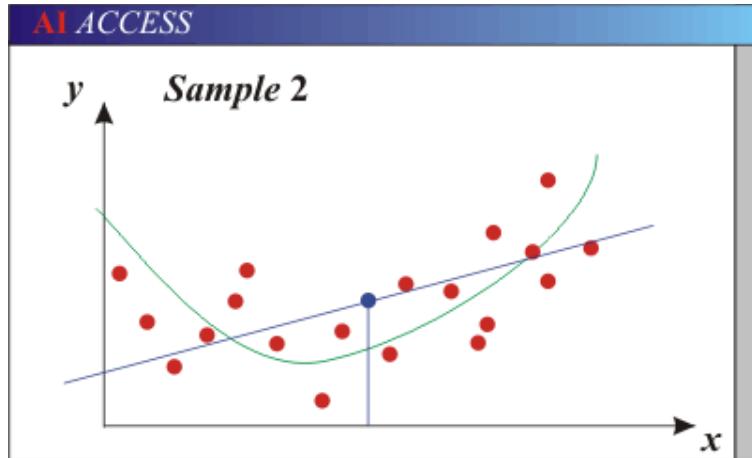
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Slide credit: D. Hoiem

Bias-Variance Trade-off



- Models with too few parameters are inaccurate because of a large bias (not enough flexibility).
- Models with too many parameters are inaccurate because of a large variance (too much sensitivity to the sample).

Remember...

- No classifier is inherently better than any other: you need to make assumptions to generalize
- Three kinds of error
 - Inherent: unavoidable
 - Bias: due to over-simplifications
 - Variance: due to inability to perfectly estimate parameters from limited data



How to reduce variance?

- Choose a simpler classifier
- Regularize the parameters
- Get more training data

Last remarks about applying machine learning methods to object recognition

- There are machine learning algorithms to choose from
- Know your data:
 - How much supervision do you have?
 - How many training examples can you afford?
 - How noisy?
- Know your goal (i.e. task):
 - Affects your choices of representation
 - Affects your choices of learning algorithms
 - Affects your choices of evaluation metrics
- Understand the math behind each machine learning algorithm under consideration!

What we will learn today?

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- K-nearest neighbor algorithm
- A simple Object Recognition pipeline

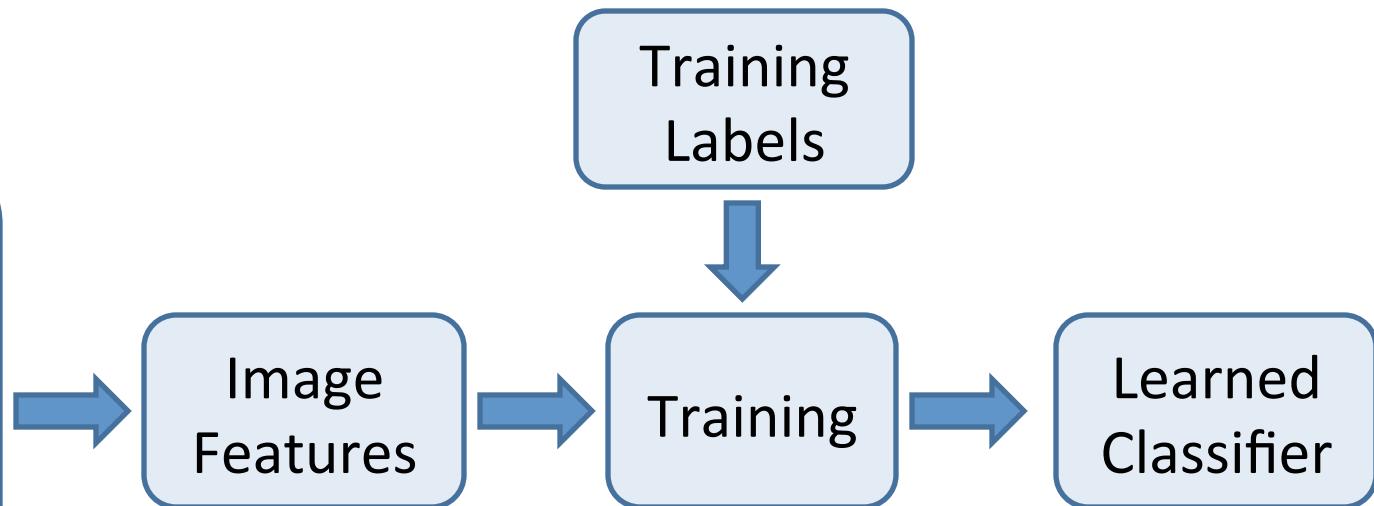
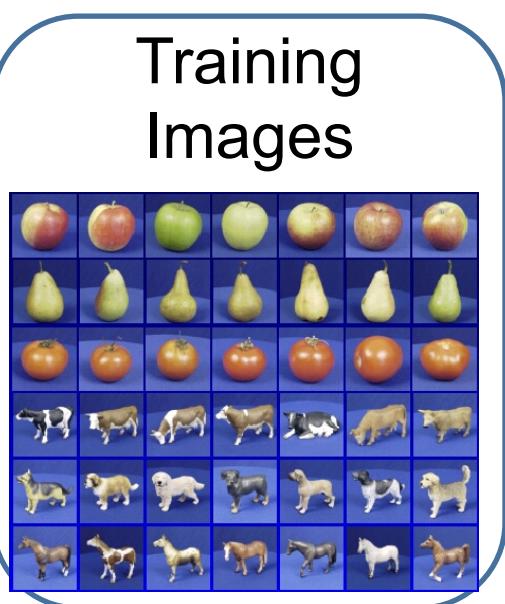
Object recognition: a classification framework

- Apply a prediction function to a feature representation of the image to get the desired output:

$$f(\text{apple}) = \text{"apple"}$$
$$f(\text{tomato}) = \text{"tomato"}$$
$$f(\text{cow}) = \text{"cow"}$$

A simple pipeline

Training



Testing

Test Image



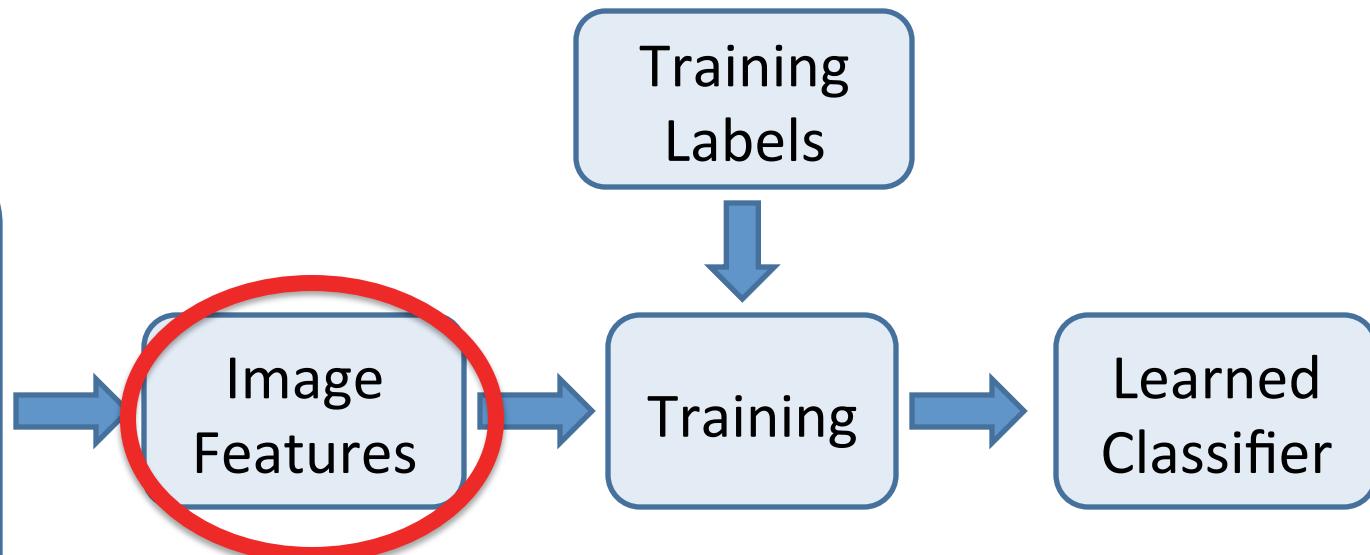
Dataset: ETH-80, by B. Leibe

Slide credit: D. Hoiem, L. Lazebnik

A simple pipeline

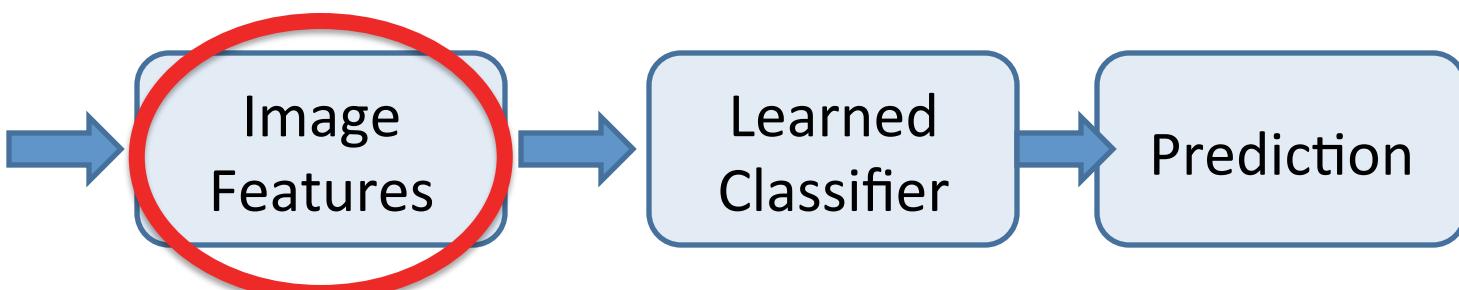
Training

Training Images



Testing

Test Image



Dataset: ETH-80, by B. Leibe

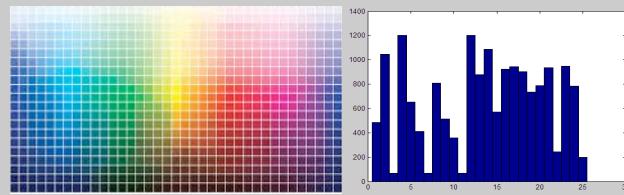
Slide credit: D. Hoiem, L. Lazebnik

Image features

Input image



Color: Quantize RGB values



Invariance?

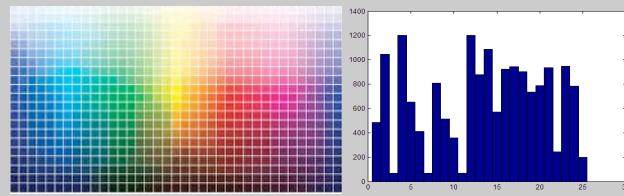
- ? Translation
- ? Scale
- ? Rotation
- ? Occlusion

Image features

Input image



Color: Quantize RGB values



Invariance?

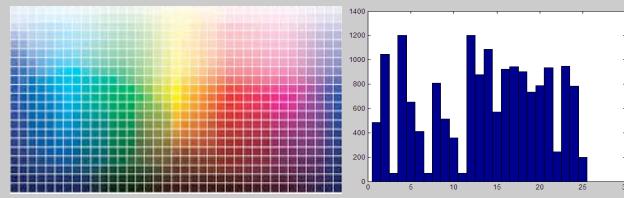
- 😊 Translation
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- 😢 Occlusion

Image features

Input image



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Invariance?

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Global shape: PCA space



Invariance?

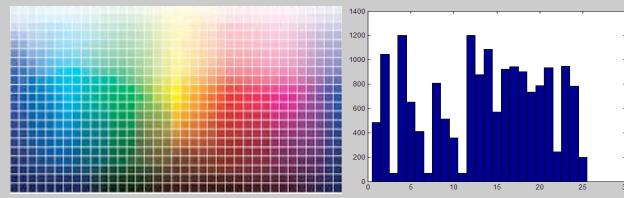
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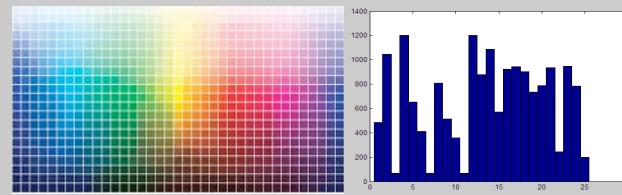
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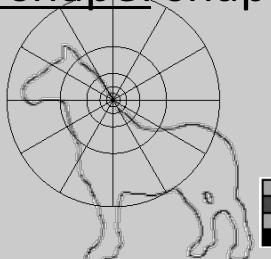
Global shape: PCA space



Invariance?

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Local shape: shape context



Invariance?

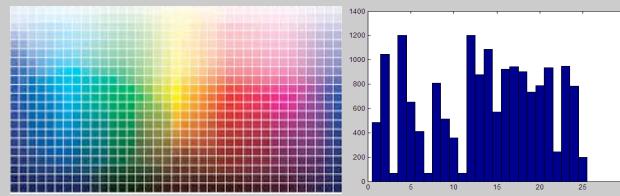
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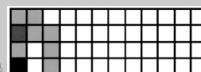
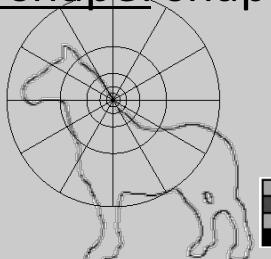
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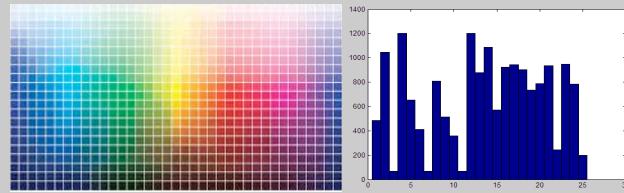
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Image features

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Color: Quantize RGB values



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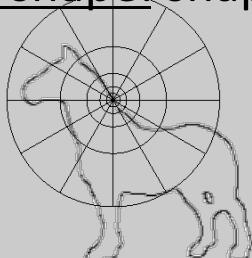
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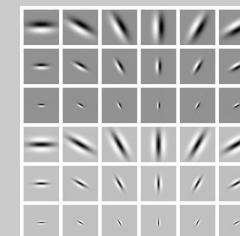
Local shape: shape context



Invariance?

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- 😊 Scale
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- 😢 Occlusion

Texture: Filter banks



Invariance?

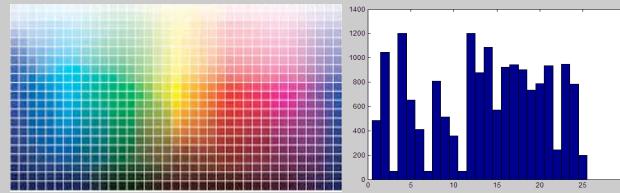
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Image features

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Color: Quantize RGB values



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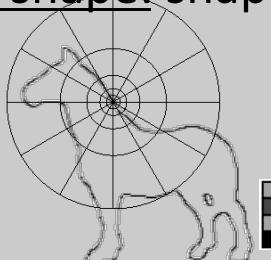
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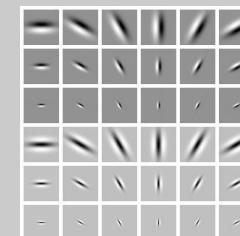
Local shape: shape context



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Texture: Filter banks

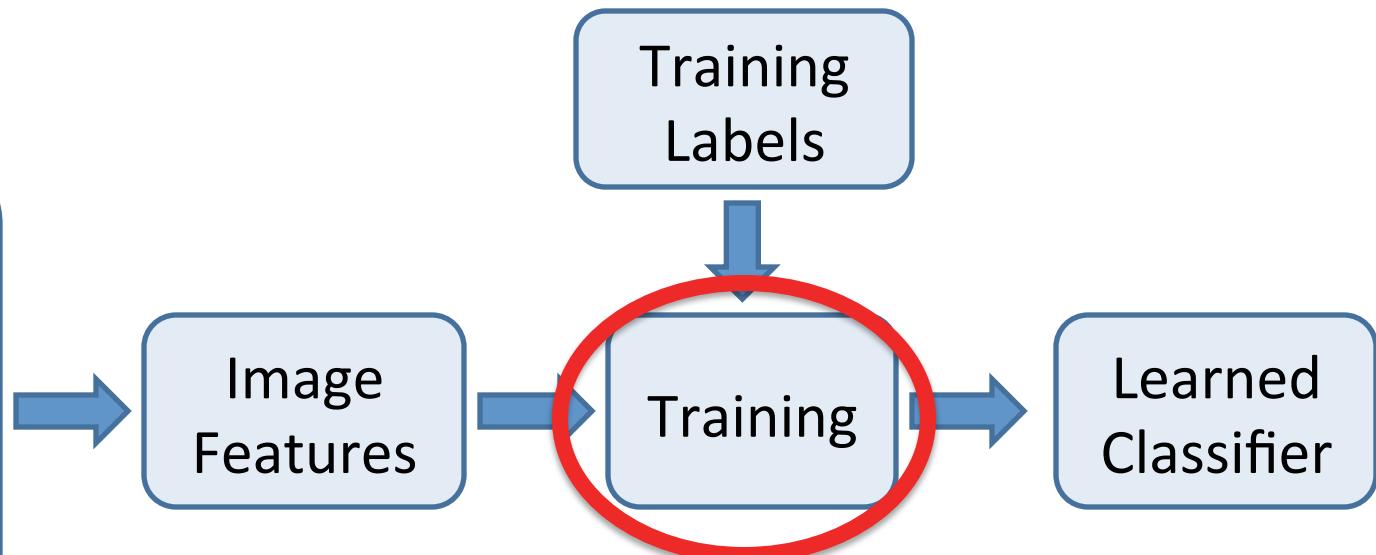
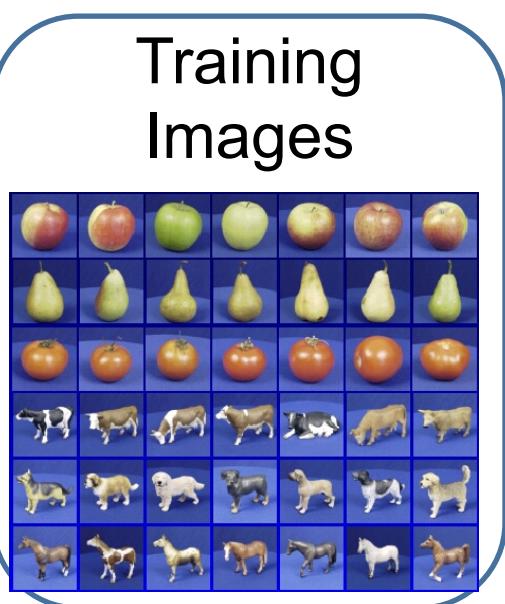


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A simple pipeline

Training



Testing

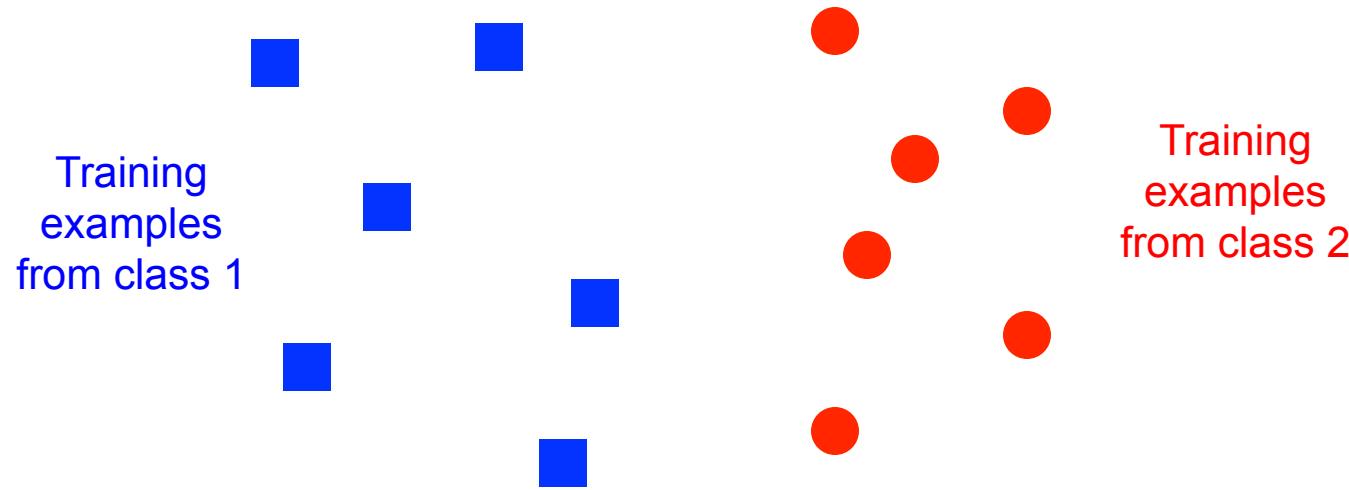
Test Image



Dataset: ETH-80, by B. Leibe

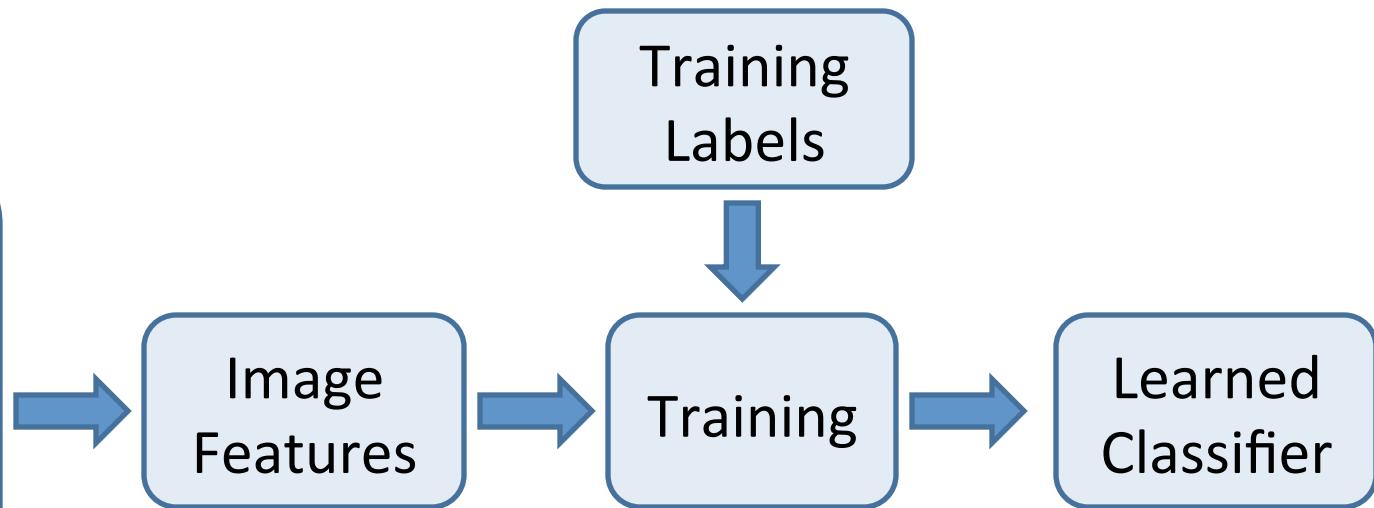
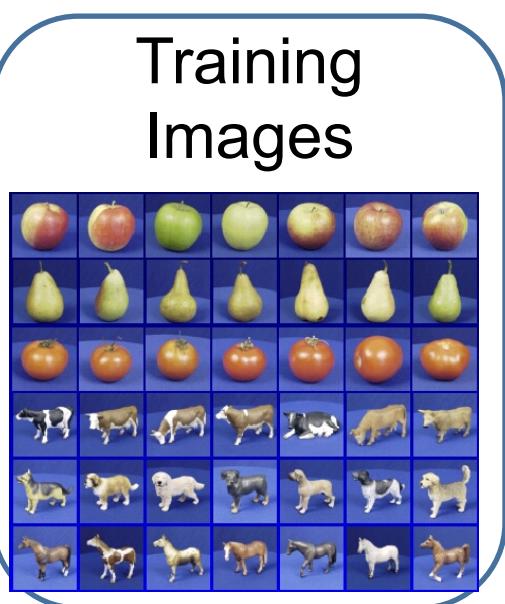
Slide credit: D. Hoiem, L. Lazebnik

Classifiers: Nearest neighbor



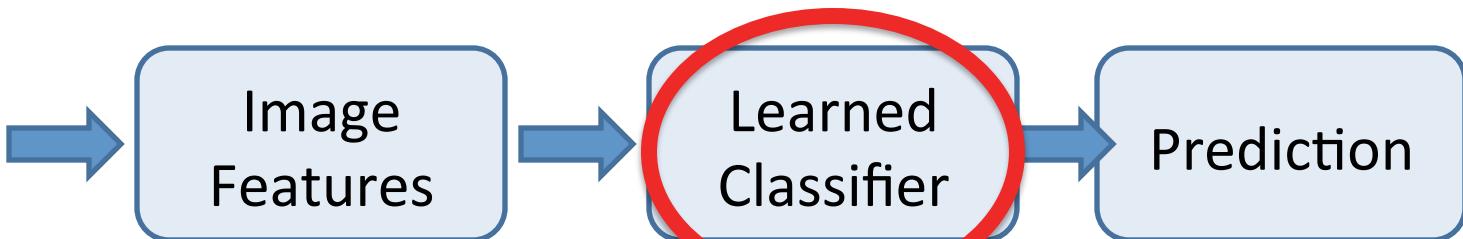
A simple pipeline

Training



Testing

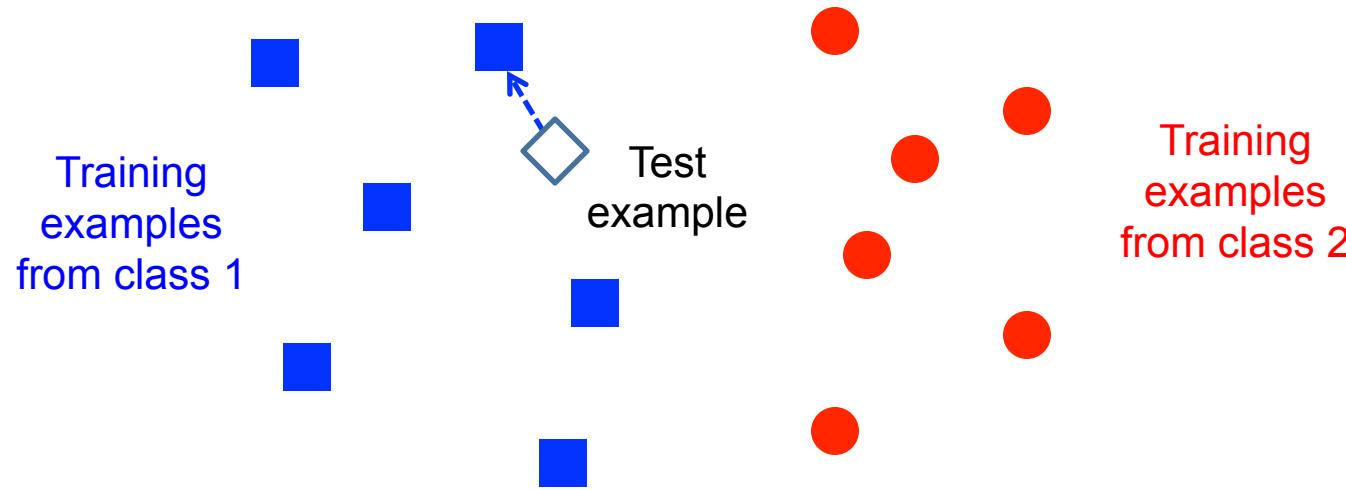
Test Image

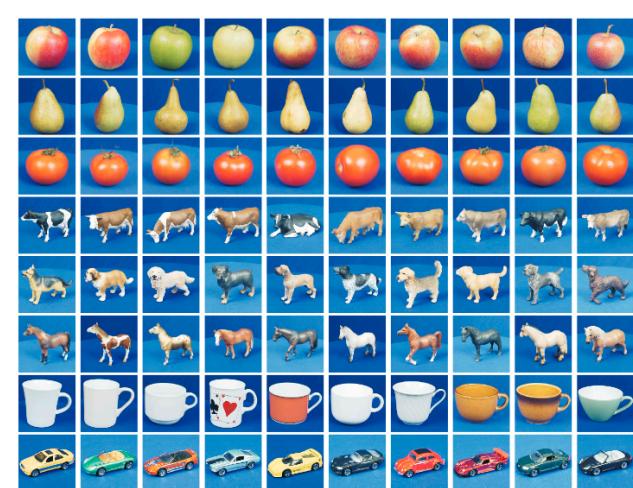


Dataset: ETH-80, by B. Leibe

Slide credit: D. Hoiem, L. Lazebnik

Classifiers: Nearest neighbor





Results

	Color	$D_x D_y$	Mag-Lap	PCA Masks	PCA Gray	Cont. Greedy	Cont. DynProg	Avg.
apple	57.56%	85.37%	80.24%	78.78%	88.29%	77.07%	76.34%	77.66%
pear	66.10%	90.00%	85.37%	99.51%	99.76%	90.73%	91.71%	89.03%
tomato	98.54%	94.63%	97.07%	67.80%	76.59%	70.73%	70.24%	82.23%
cow	86.59%	82.68%	94.39%	75.12%	62.44%	86.83%	86.34%	82.06%
dog	34.63%	62.44%	74.39%	72.20%	66.34%	81.95%	82.93%	67.84%
horse	32.68%	58.78%	70.98%	77.80%	77.32%	84.63%	84.63%	69.55%
cup	79.76%	66.10%	77.80%	96.10%	96.10%	99.76%	99.02%	87.81%
car	62.93%	98.29%	77.56%	100.0%	97.07%	99.51%	100.0%	90.77%
total	64.85%	79.79%	82.23%	83.41%	82.99%	86.40%	86.40%	80.87%

Dataset: ETH-80, by B. Leibe, 2003

Results



Category	Primary feature(s)	Secondary feature(s)
apple	PCA Gray	Texture $D_x D_y$
pear	PCA Gray / Masks	
tomato	Color	Texture Mag-Lap
cow	Texture Mag-Lap	Contour / Color
dog	Contour	
horse	Contour	
cup	Contour	PCA Gray / Masks
car	PCA Masks / Contour	Texture $D_x D_y$

Dataset: ETH-80, by B. Leibe, 2003

What we have learned today?

- Introduction
- K-nearest neighbor algorithm
- A simple Object Recognition pipeline