Advanced Computer Vision

Supervised Learning
(A Review)

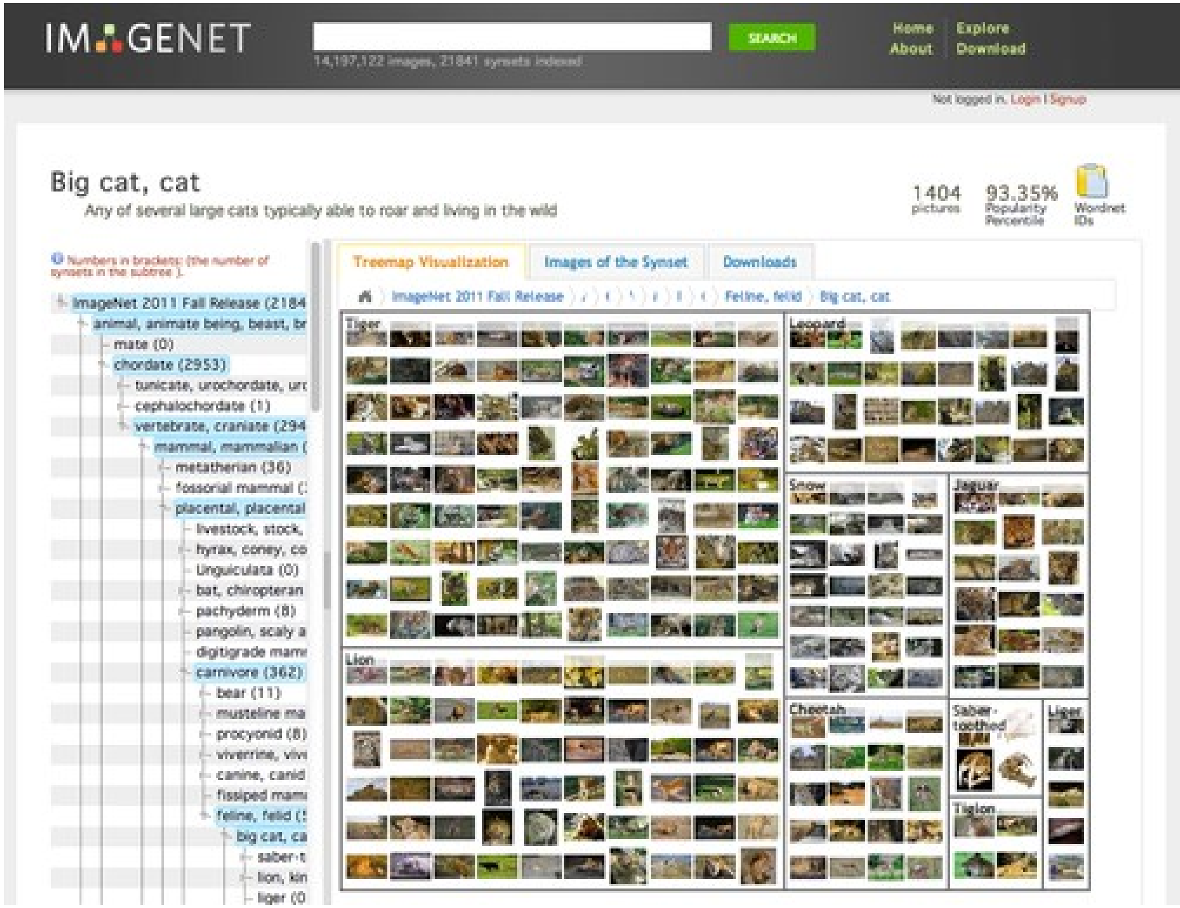
Machine Learning Problems

	Supervised Learning	Unsupervised Learning
Discrete	classification or categorization	clustering
Continuous	regression	dimensionality reduction

ImageNet

- Images for each category of WordNet
- 1000 classes
- 1.2mil images
- 100k test

- Top 5 error



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Dataset split

Training
Images

- Train classifier

Validation
Images

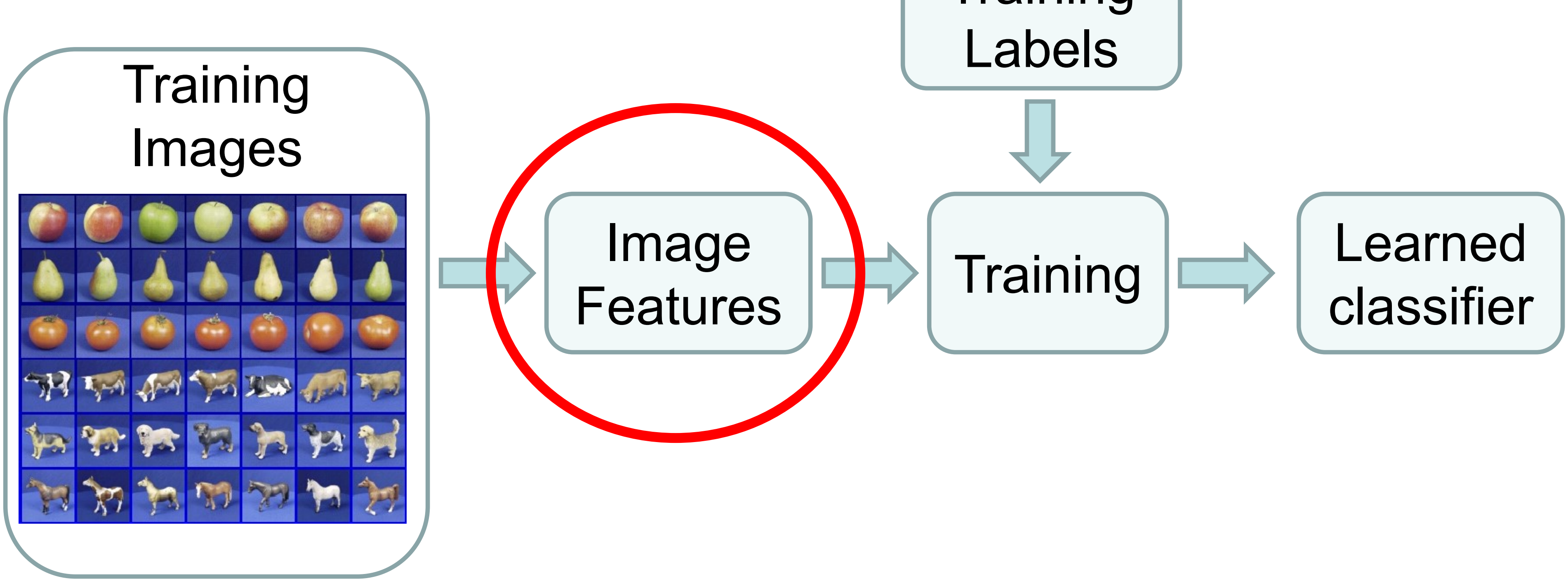
- Measure error
- Tune model hyperparameters

Testing
Images

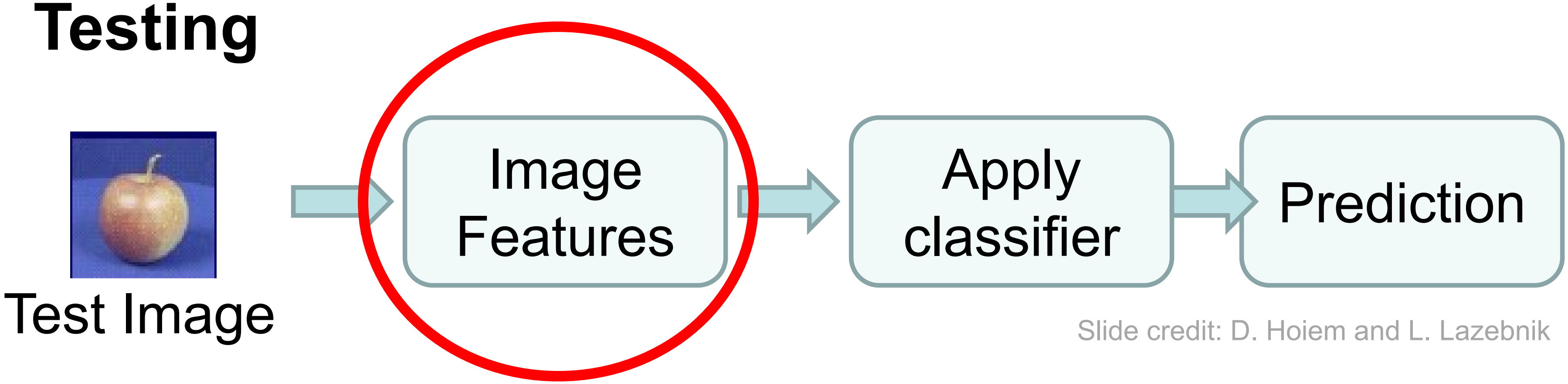
- Secret labels
- Measure error

Random train/validate splits = cross validation

Training



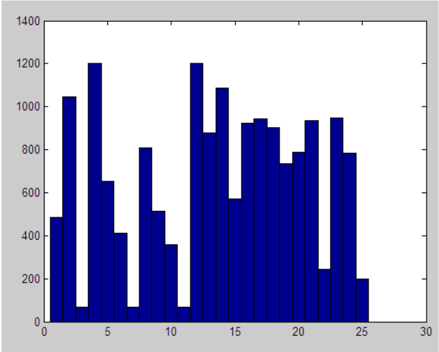
Testing

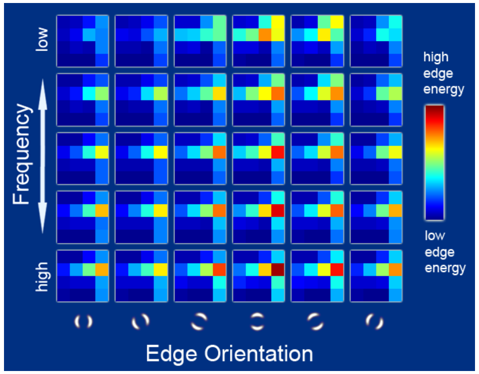


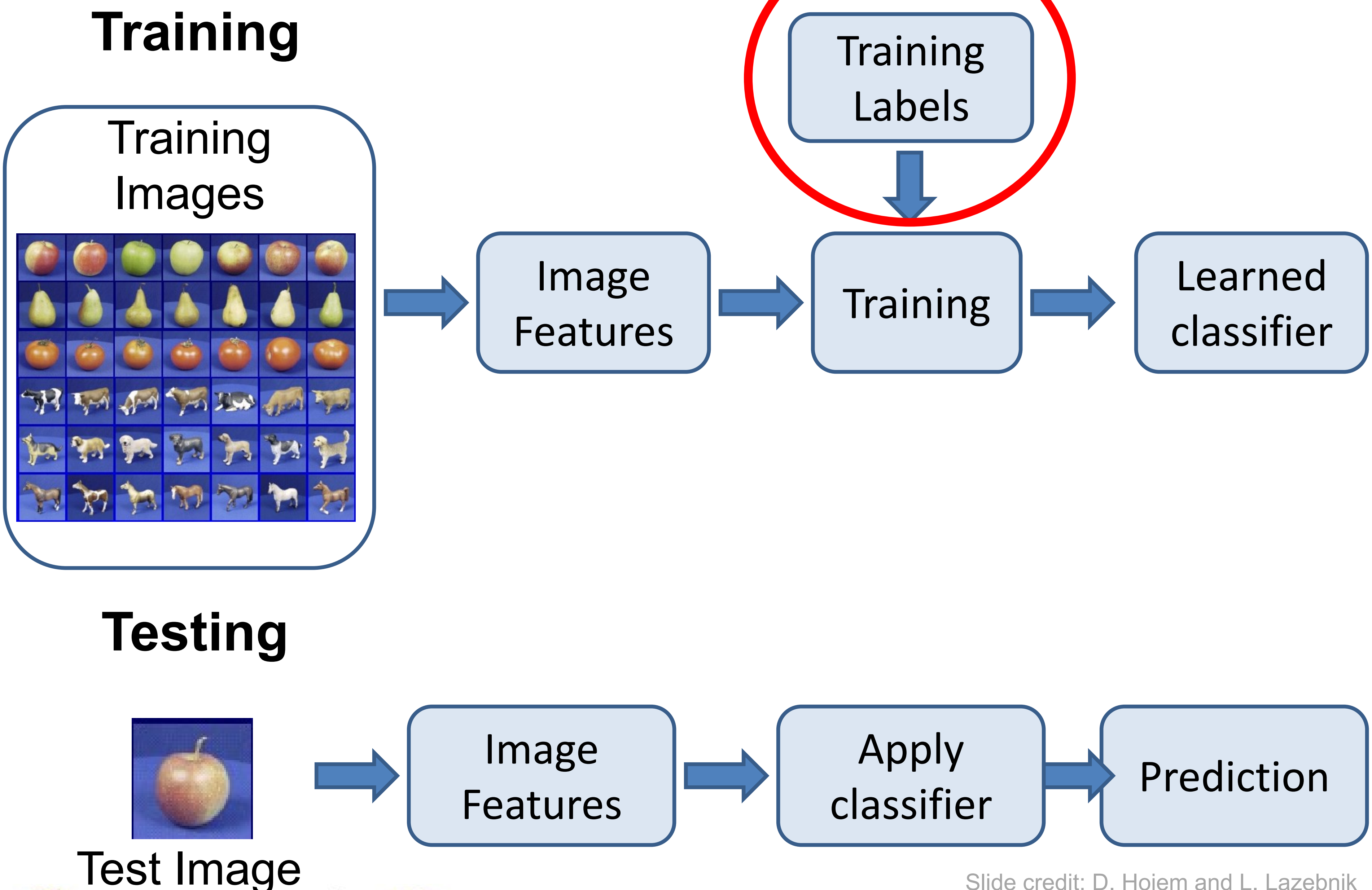
Slide credit: D. Hoiem and L. Lazebnik

Features

- Raw pixels
- Histograms
- Templates
- SIFT descriptors
  - GIST
  - ORB
  - HOG
  - CNN….





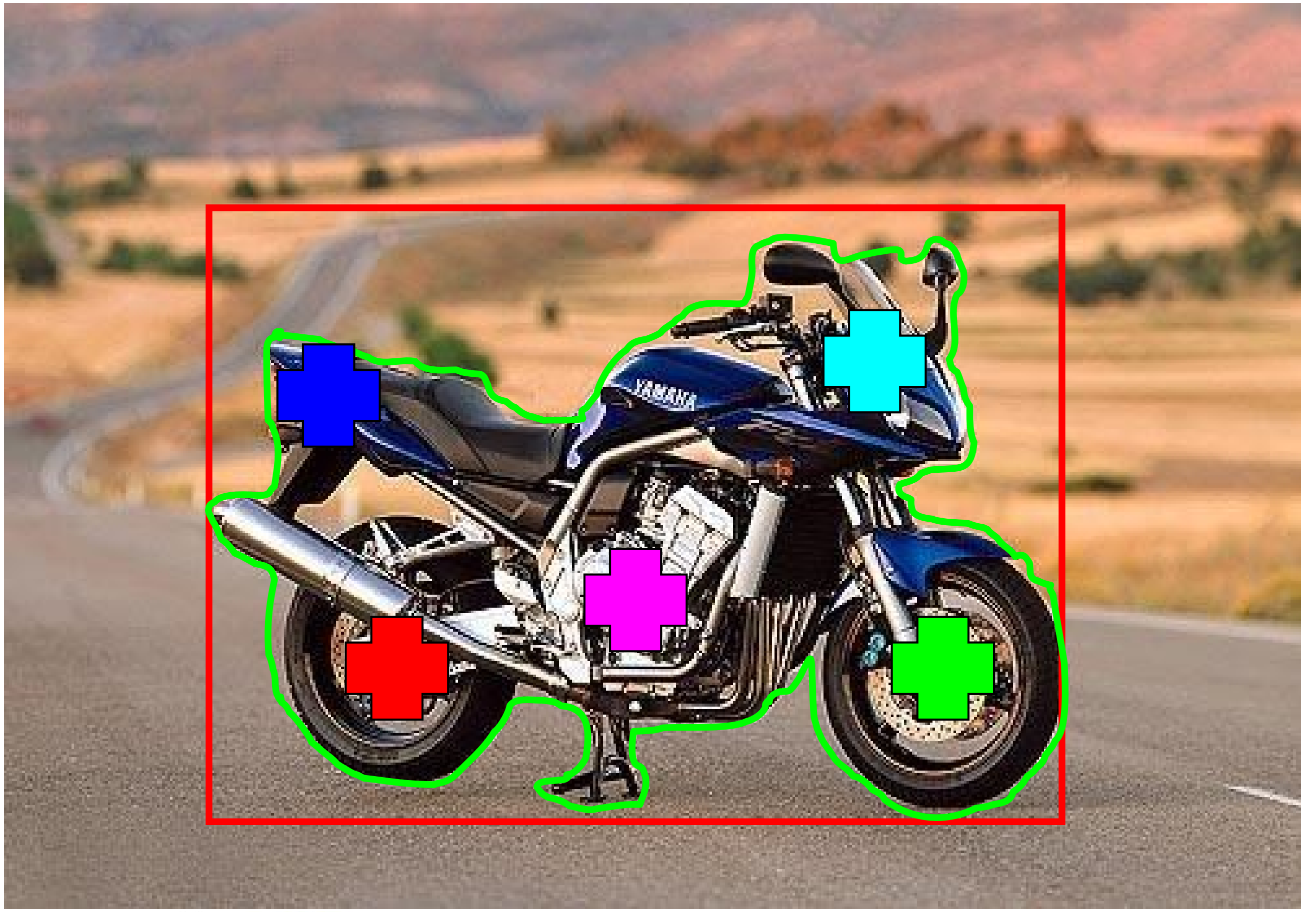


Slide credit: D. Hoiem and L. Lazebnik

Recognition task and supervision

- Images in the training set must be annotated with the "correct answer" that the model is expected to produce

Contains a motorbike



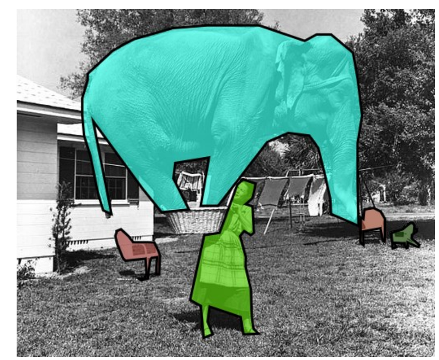
Spectrum of supervision

Less

More

E.G., ImageNet

E.G., MS Coco



Unsupervised

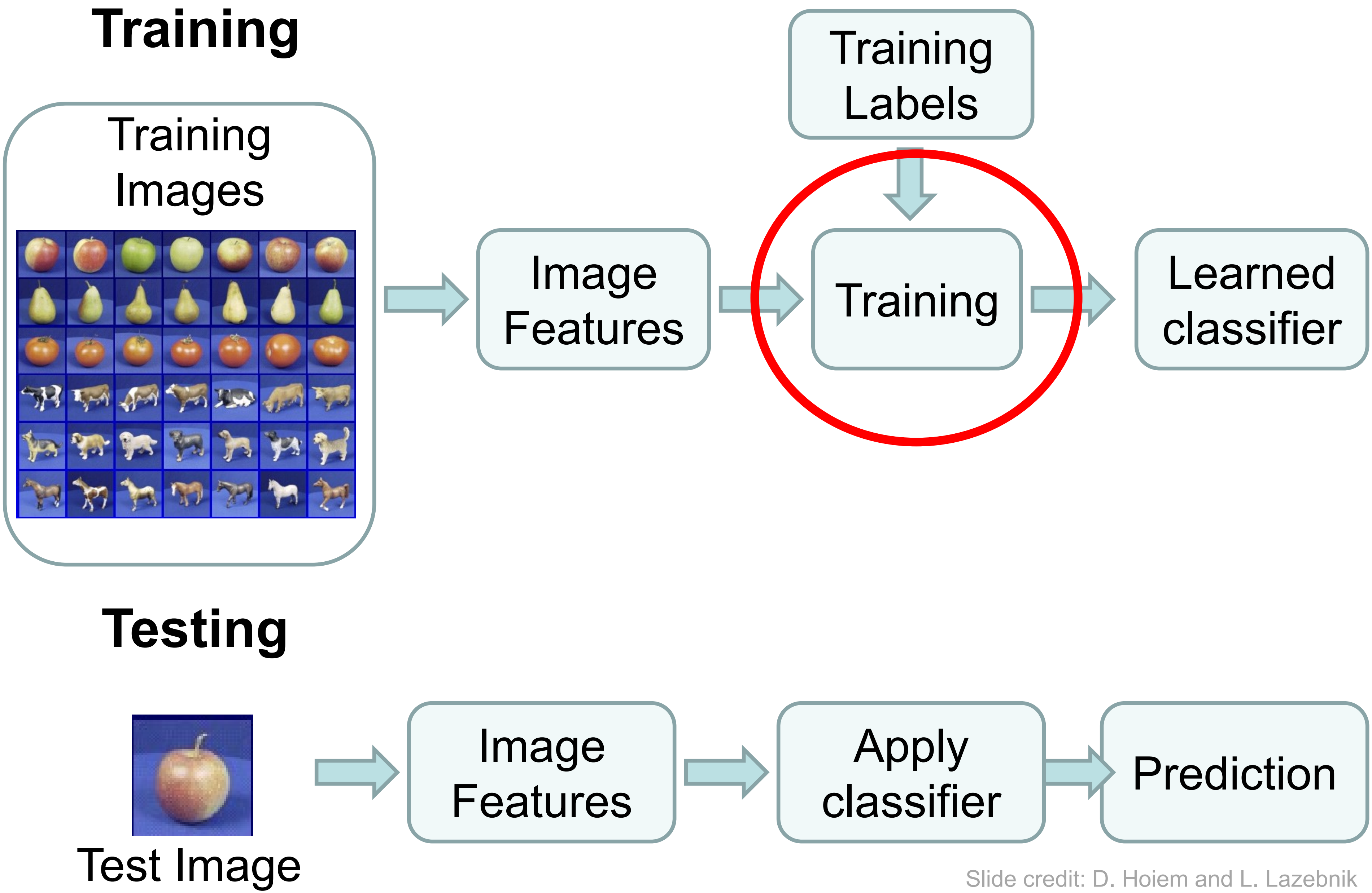
“Weakly” supervised

Fully supervised

Fuzzy; definition depends on task

‘Semi-supervised’: small partial labeling

Lazebnik



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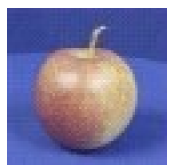
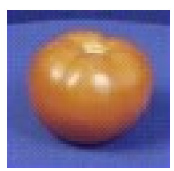
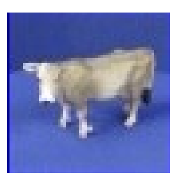
The machine learning framework

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

f() = "apple"

f() = "tomato"

f() = "cow"

Slide credit: L. Lazebnik

The machine learning framework

$$\mathbf{f(x) = y}$$

Prediction function or *classifier*

Image feature

Output (label)

Training: Given a *training set* of labeled examples:

$\{(\mathbf{x}_1,y_1), \ldots, (\mathbf{x}_N,y_N)\}$

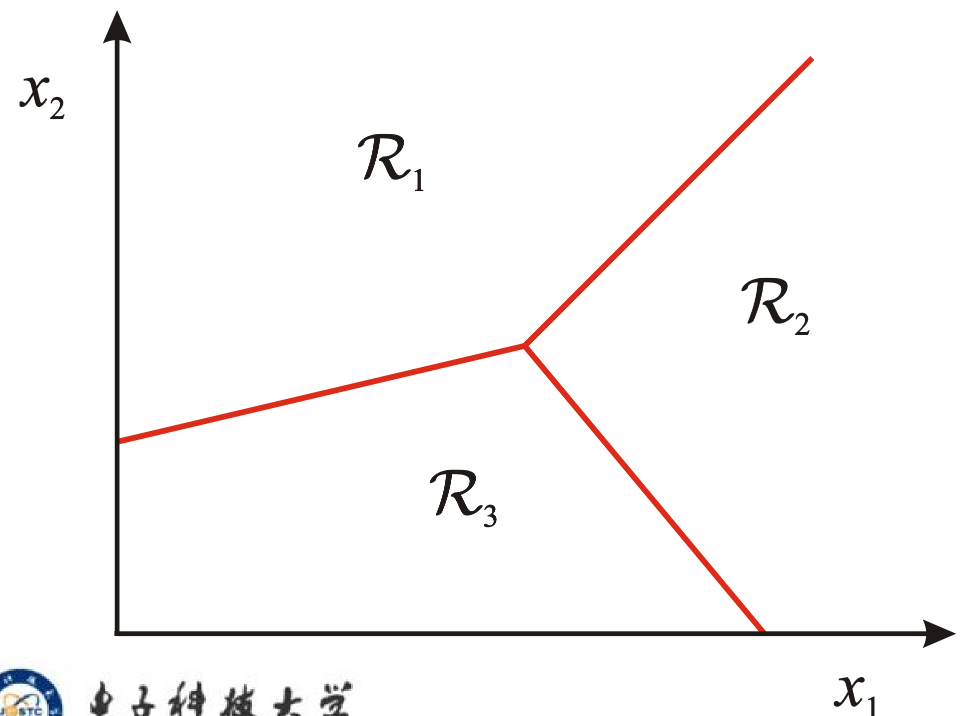
Estimate the prediction function f by minimizing the prediction error on the training set.

Testing: Apply f to a unseen *test example* $\mathbf{x}_u$ and output the predicted value $y_u = f(\mathbf{x}_u)$ to *classify* $\mathbf{x}_u$.

Classification

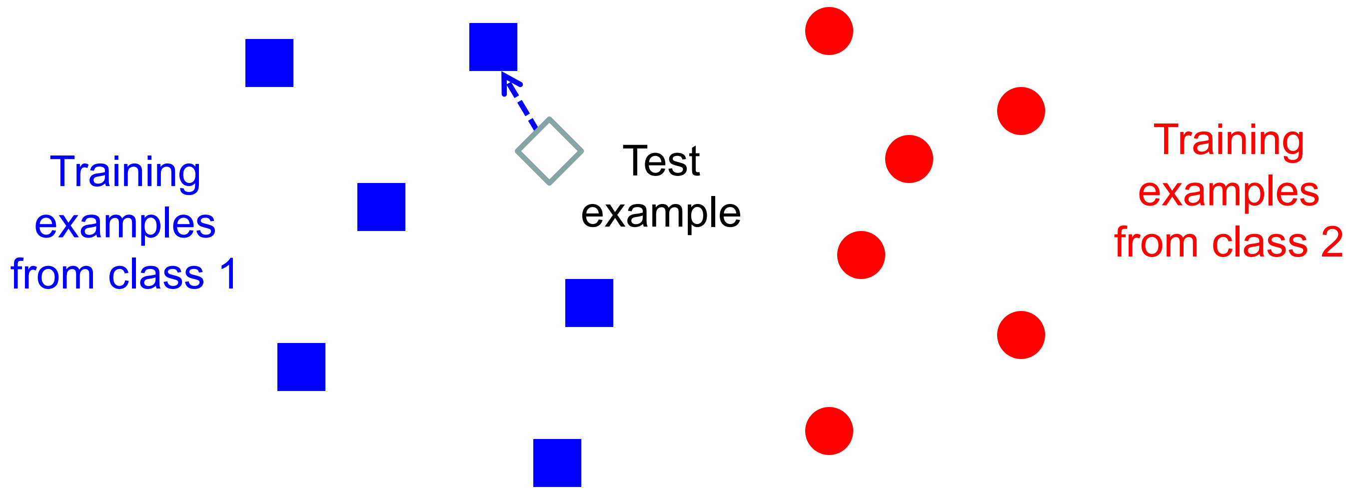
Assign **x** to one of two (or more) classes.

A decision rule divides input space into *decision regions* separated by *decision boundaries.*



L. Lazebnik

Classifiers: Nearest neighbor

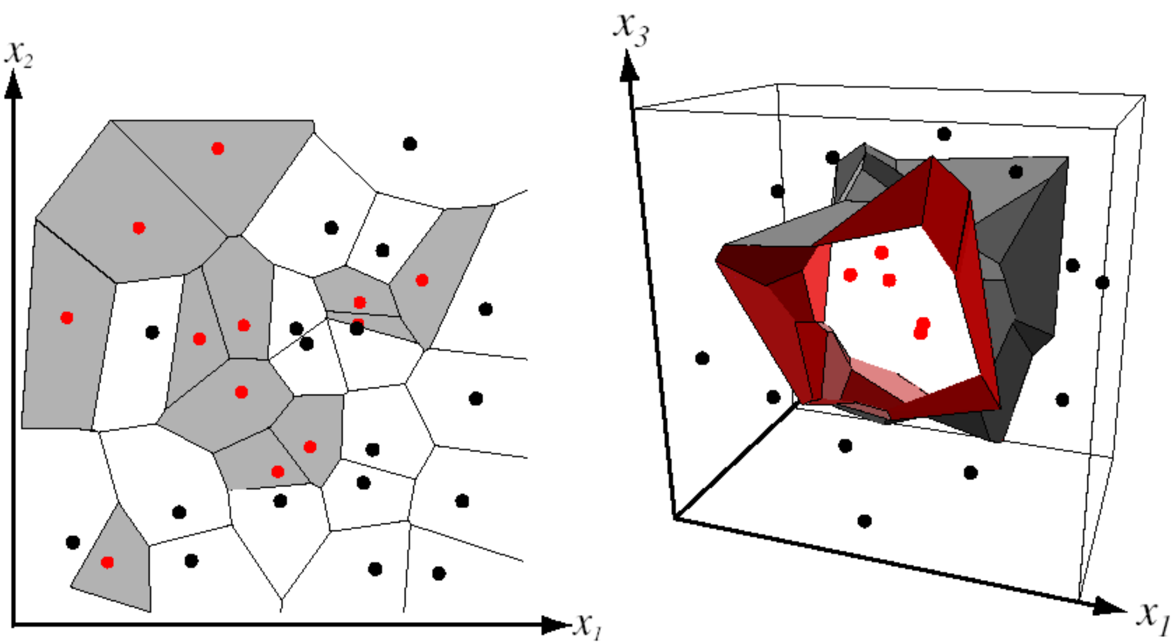


$f(\mathbf{x})$ = label of the training example nearest to $\mathbf{x}$

- All we need is a distance function for our inputs
- No training required!
- What does the decision boundary look like?

Decision boundary for Nearest Neighbor Classifier

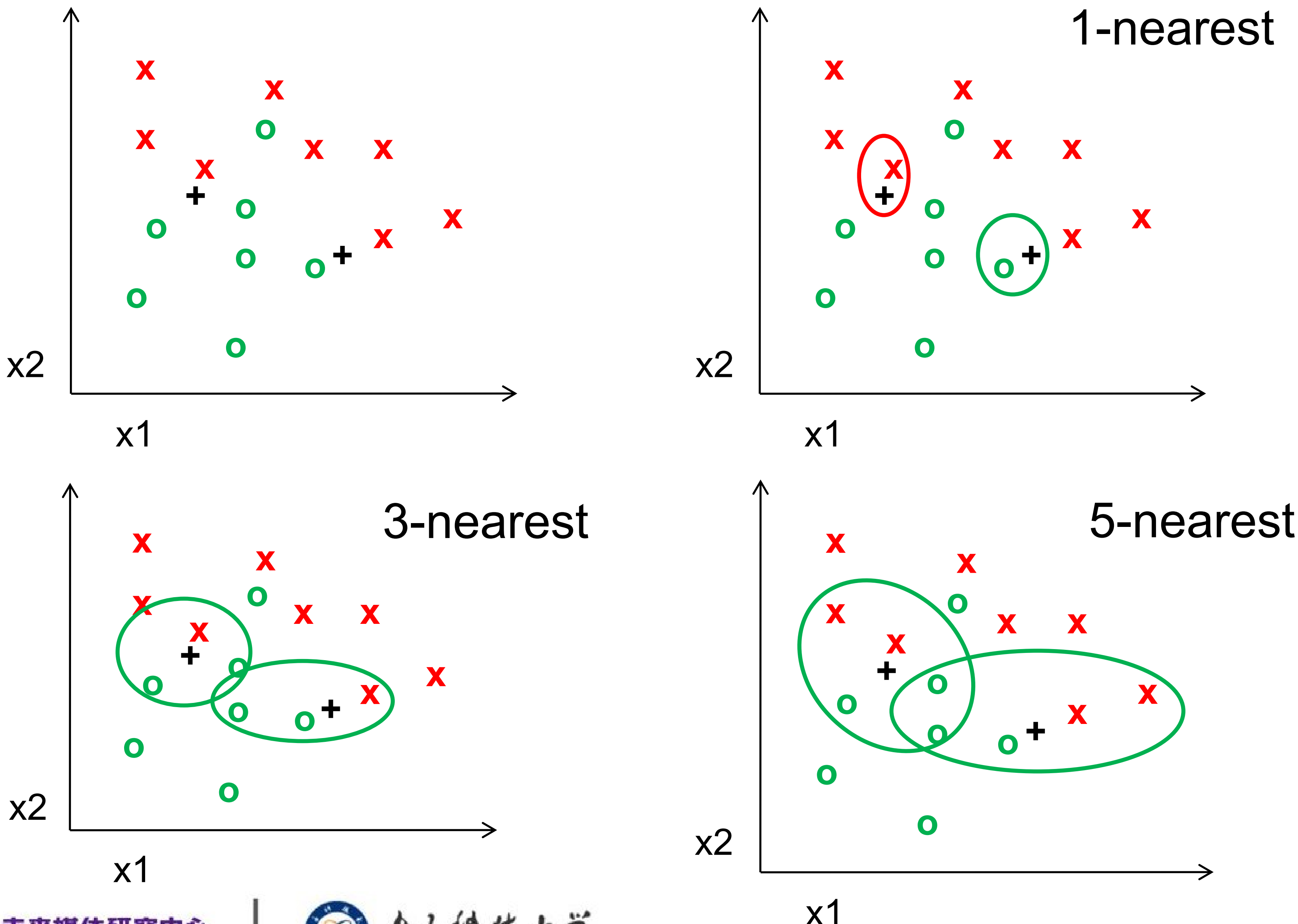
Divides input space into *decision regions* separated by *decision boundaries – Voronoi.*



from Duda *et al.*

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

k-nearest neighbor



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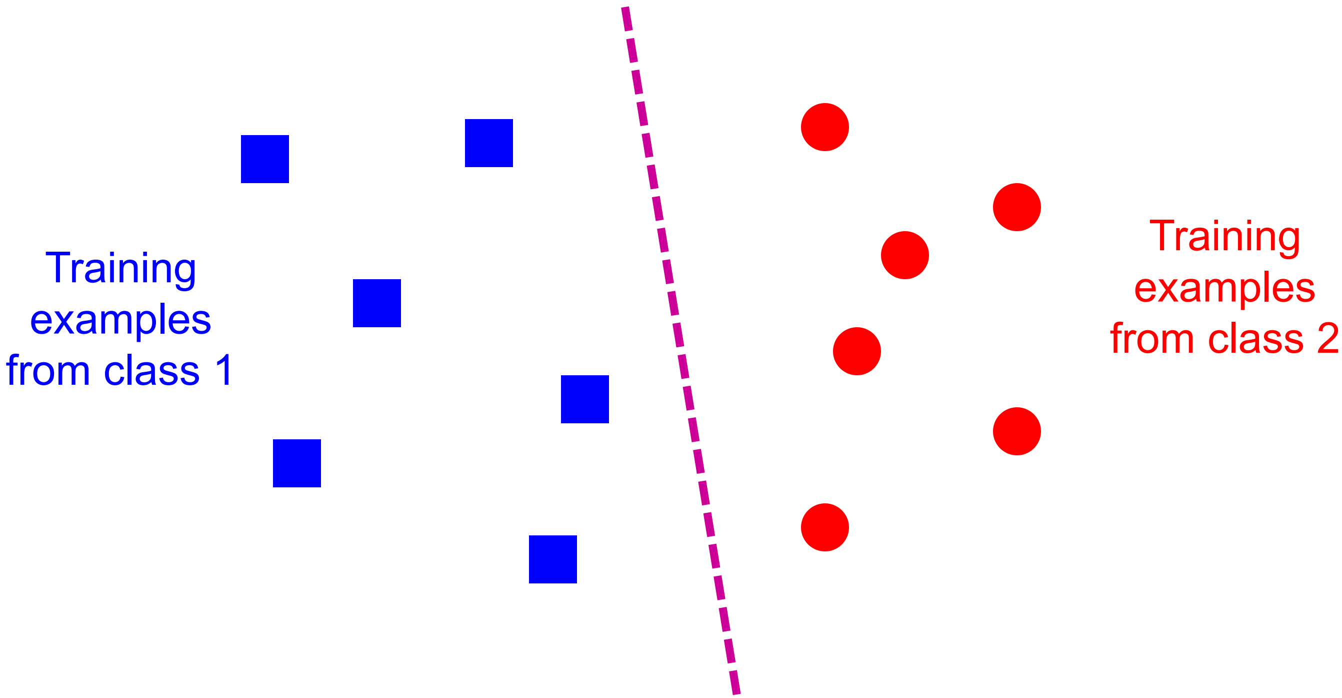
Classifiers: Linear

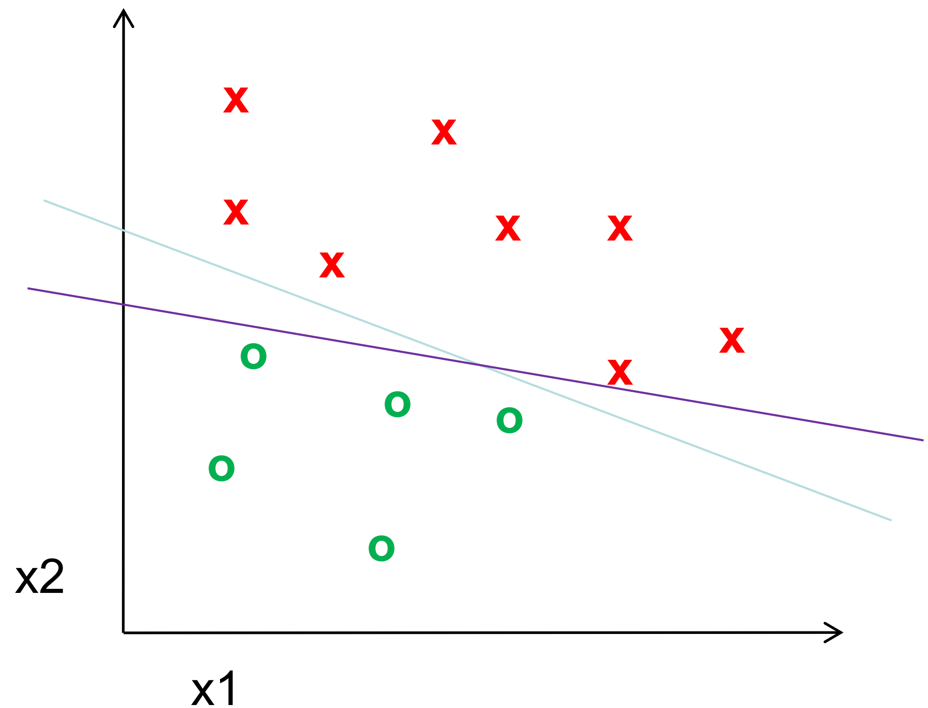


Find a *linear function* to separate the classes

Classifiers: Linear SVM

Find a *linear function* to separate the classes:

$f(\mathbf{x}) = \mathrm{sgn}(\mathbf{w} \cdot \mathbf{x} + b)$



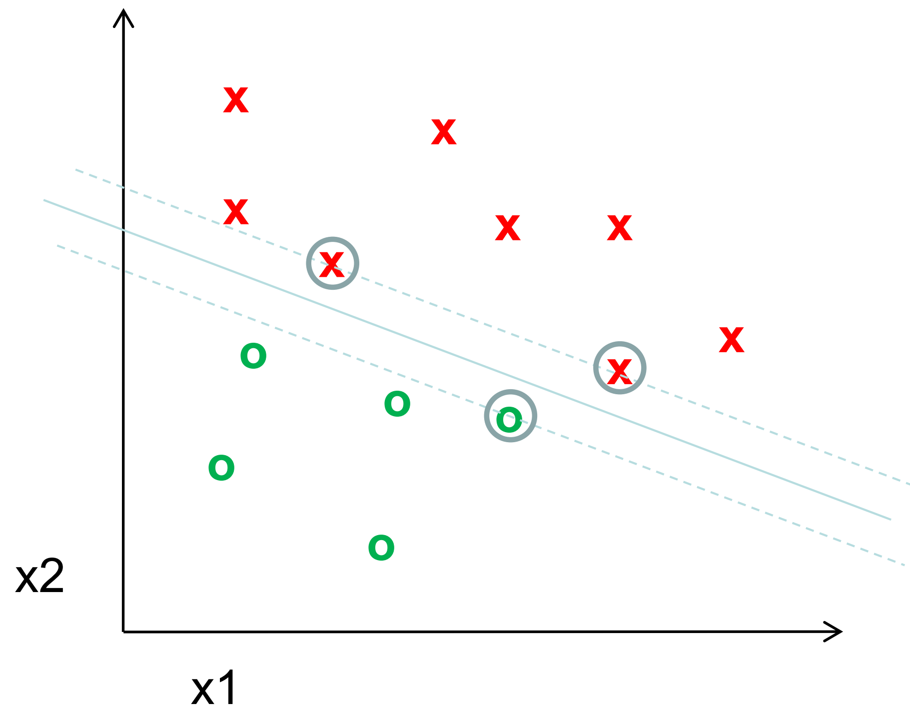
Classifiers: Linear SVM

Find a *linear function* to separate the classes:

$f(\mathbf{x}) = \text{sgn}(\mathbf{w} \cdot \mathbf{x} + b)$

How?

$\mathbf{X}$ = all data points



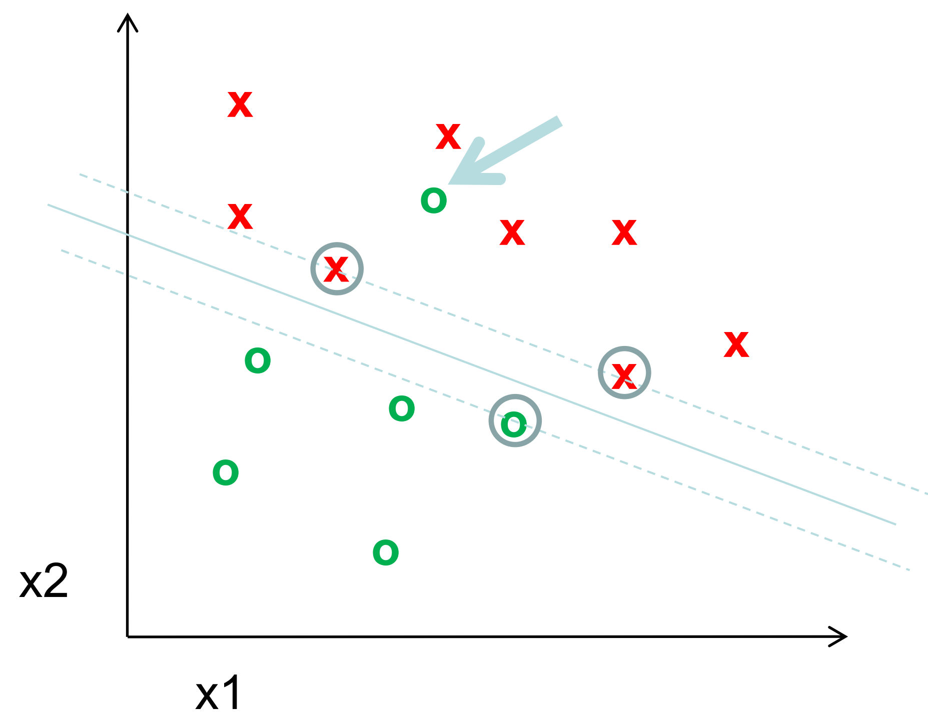
Define *hyperplane* **tX-b = 0**, where **t** is tangent to hyperplane.

Minimize $||\mathbf{t}||$ s.t. **tX-b** produces correct label for all **X**

Classifiers: Linear SVM

Find a *linear function* to separate the classes:

$f(\mathbf{x}) = \text{sgn}(\mathbf{w} \cdot \mathbf{x} + b)$

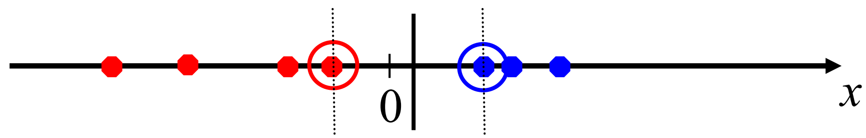


What if my data are not linearly separable?

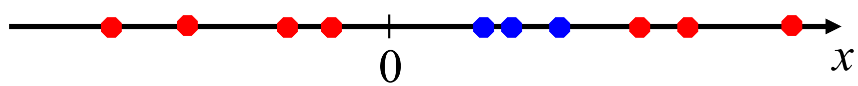
Introduce flexible 'hinge' loss (or 'soft-margin')

Nonlinear SVMs

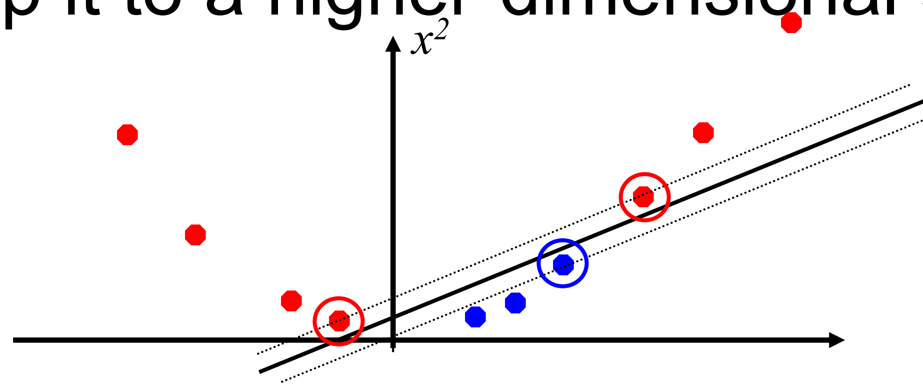
- Datasets that are linearly separable work out great:



- But what if the dataset is just too hard?

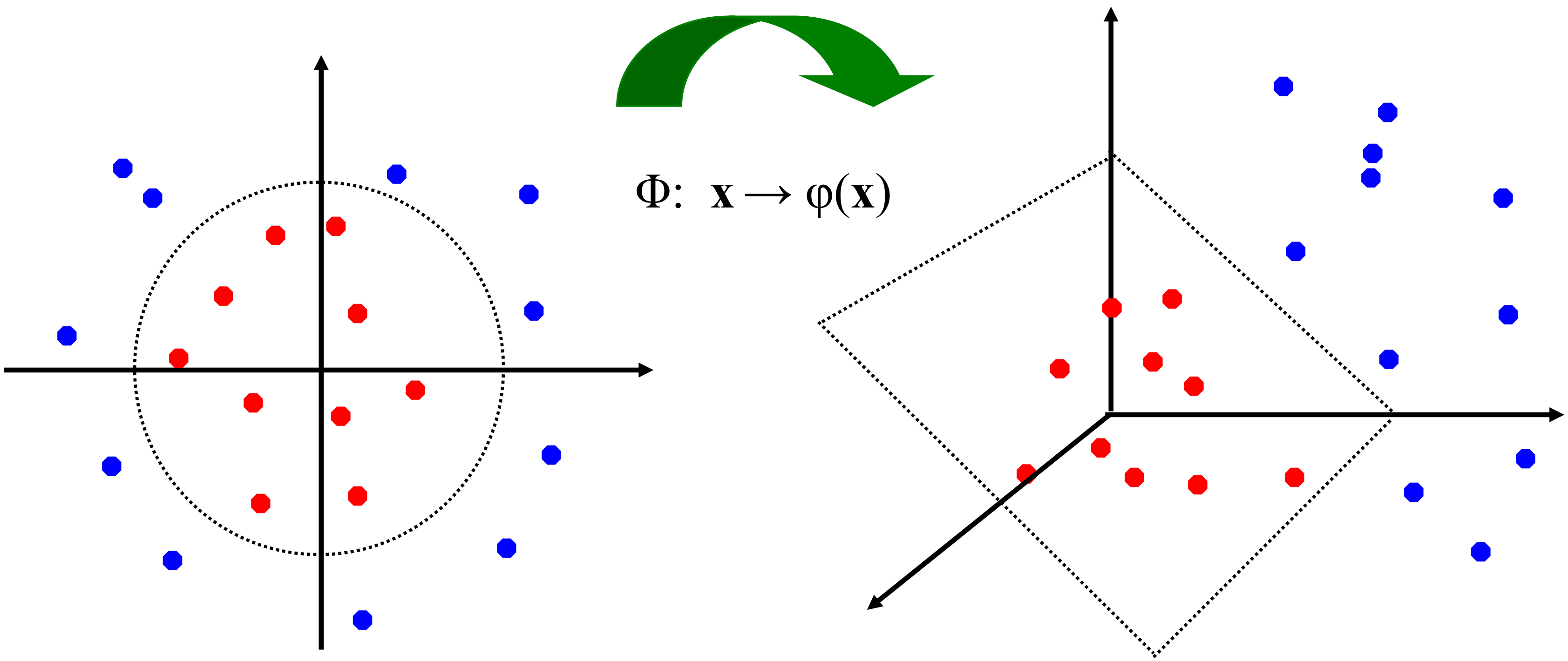


- We can map it to a higher-dimensional space:



Nonlinear SVMs

Map the original input space to some higher-dimensional feature space where the training set is separable:



Slide credit: Andrew Moore

What about multi-class SVMs?

- Unfortunately, there is no “definitive” multi-class SVM.
- In practice, we combine multiple two-class SVMs
- One vs. others
  - Training: learn an SVM for each class vs. the others
  - Testing: apply each SVM to test example and assign to it the class of the SVM that returns the highest decision value
- One vs. one
  - Training: learn an SVM for each pair of classes
  - Testing: each learned SVM “votes” for a class to assign to the test example

SVMs: Pros and cons

- Pros
  - Many publicly available SVM packages: http://www.kernel-machines.org/software
  - Kernel-based framework is very powerful, flexible
  - SVMs work very well in practice, even with very small training sample sizes

- Cons
  - No "direct" multi-class SVM, must combine two-class SVMs
  - Computation, memory
    - During training time, must compute matrix of kernel values for every pair of examples
    - Learning can take a very long time for large-scale problems

What to remember about classifiers

- No free lunch: machine learning algorithms are tools, not dogmas
- Try simple classifiers first
- Better to have smart features and simple classifiers than simple features and smart classifiers
- Use increasingly powerful classifiers with more training data (bias-variance tradeoff)

Slide credit: D. Hoiem

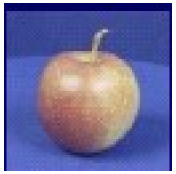
Training

Training Labels → Training

Training Images

→ Image Features → Training → Learned classifier

Testing



Test Image

→ Image Features → Apply classifier → Prediction

Slide credit: D. Hoiem and L. Lazebnik

Features and **distance measures**

define visual similarity.

Training labels

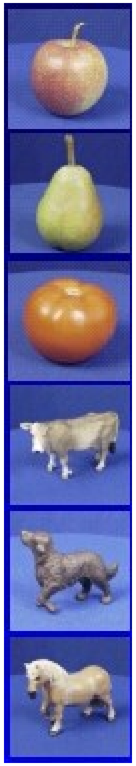
dictate that examples are the same or different.

Classifiers

learn weights (or parameters) of features and distance measures…
so that visual similarity predicts label similarity.

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 Error

Bias:

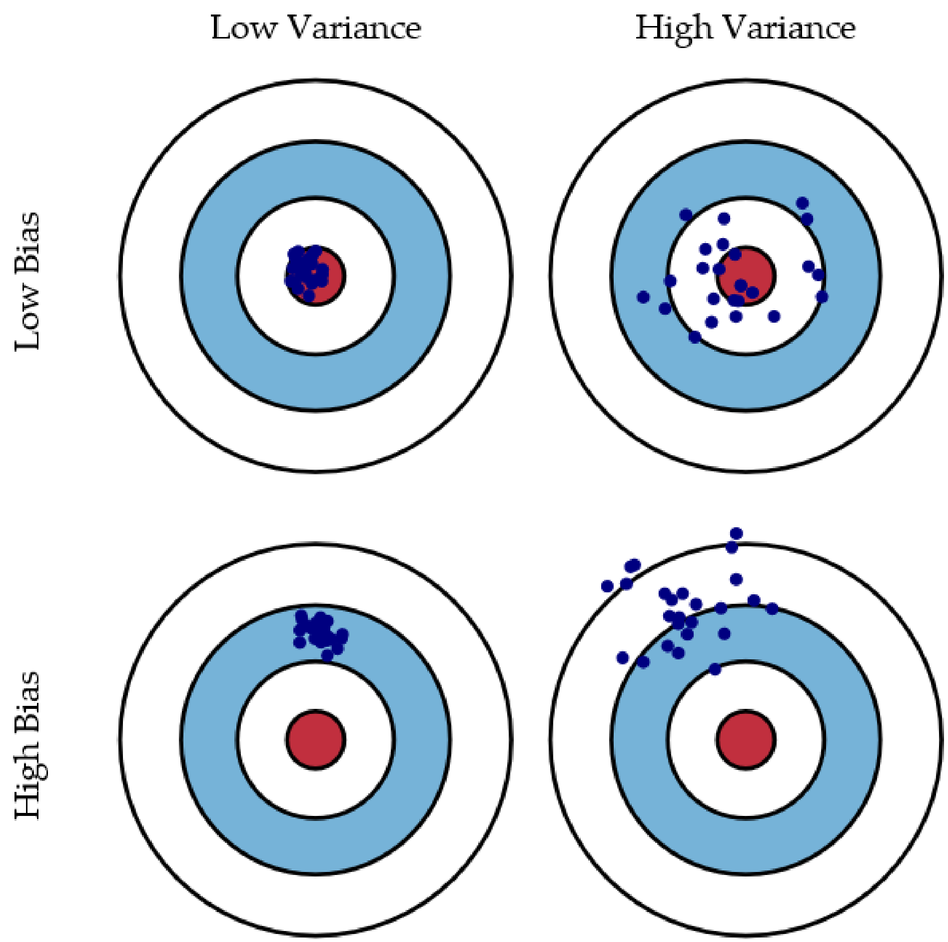
- Difference between the expected (or average) prediction of our model and the correct value.
- Error due to inaccurate assumptions/simplifications.

Variance:

- Amount that the estimate of the target function will change if different training data was used.

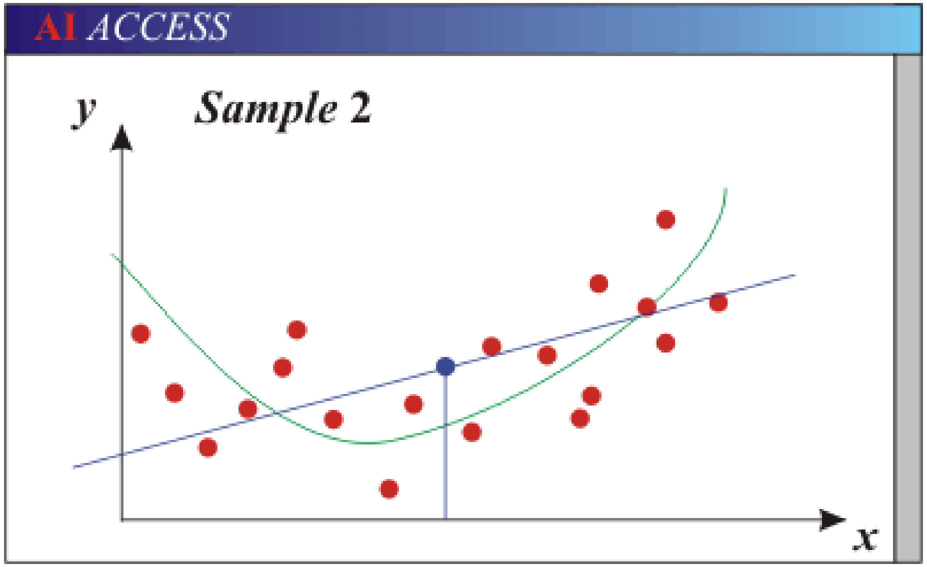
Slide credit: L. Lazebnik

Bias/variance trade-off



Generalization Error Effects

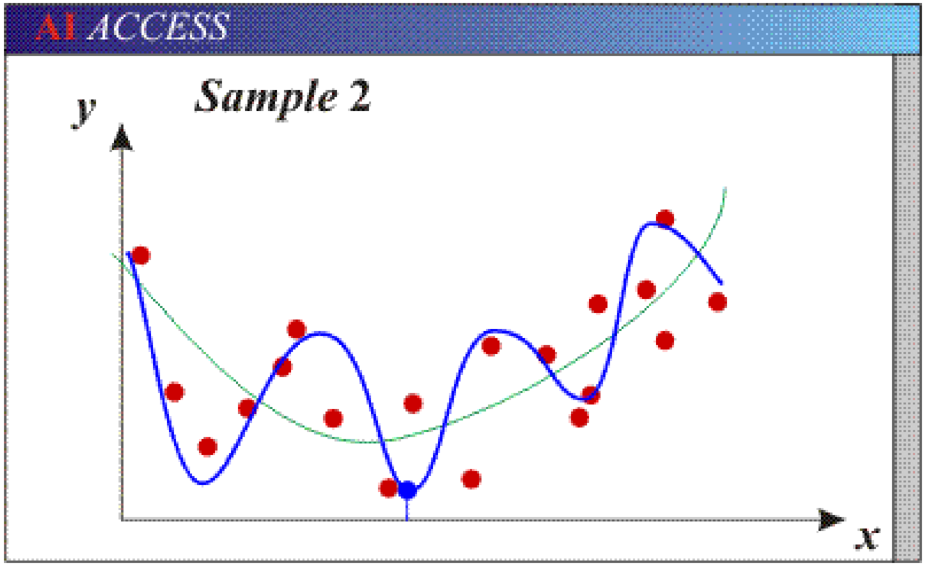
- **Underfitting:** model is too "simple" to represent all the relevant class characteristics
  - High bias (few degrees of freedom) and low variance
  - High training error and high test error



Slide credit: L. Lazebnik

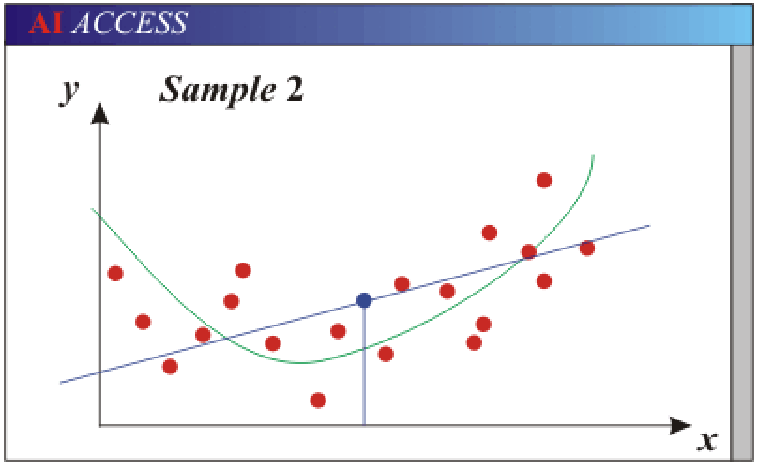
Generalization Error Effects

- **Overfitting:** model is too "complex" and fits irrelevant characteristics (noise) in the data
  - Low bias (many degrees of freedom) and high variance
  - Low training error and high test error



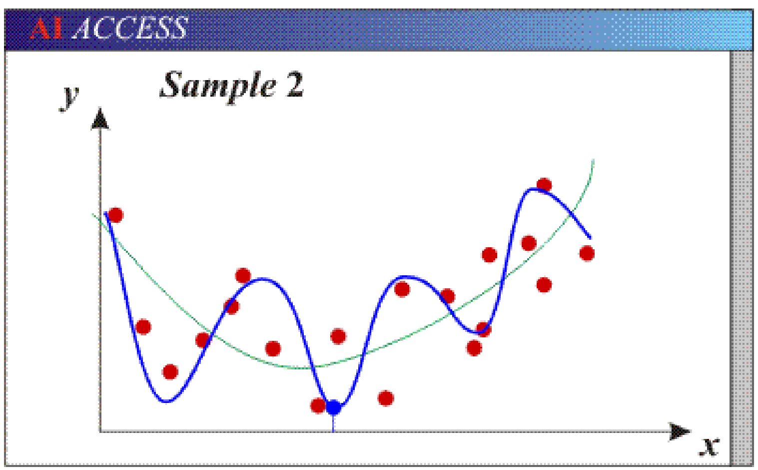
Slide credit: L. Lazebnik

Bias-Variance Trade-off



Models with too few parameters are inaccurate because of a large bias.

- Not enough flexibility!
- Too many assumptions



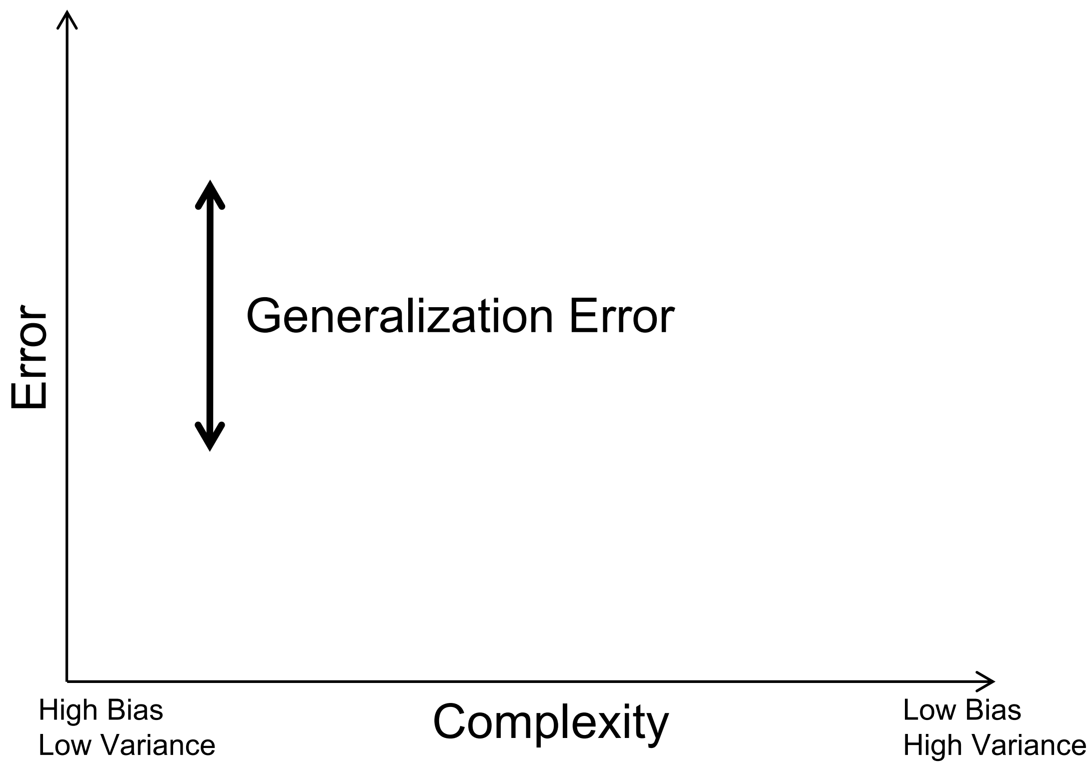
Models with too many parameters are inaccurate because of a large variance.

- Too much sensitivity to the sample.
- Slightly different data ->
  very different function.

Slide credit: D. Hoiem

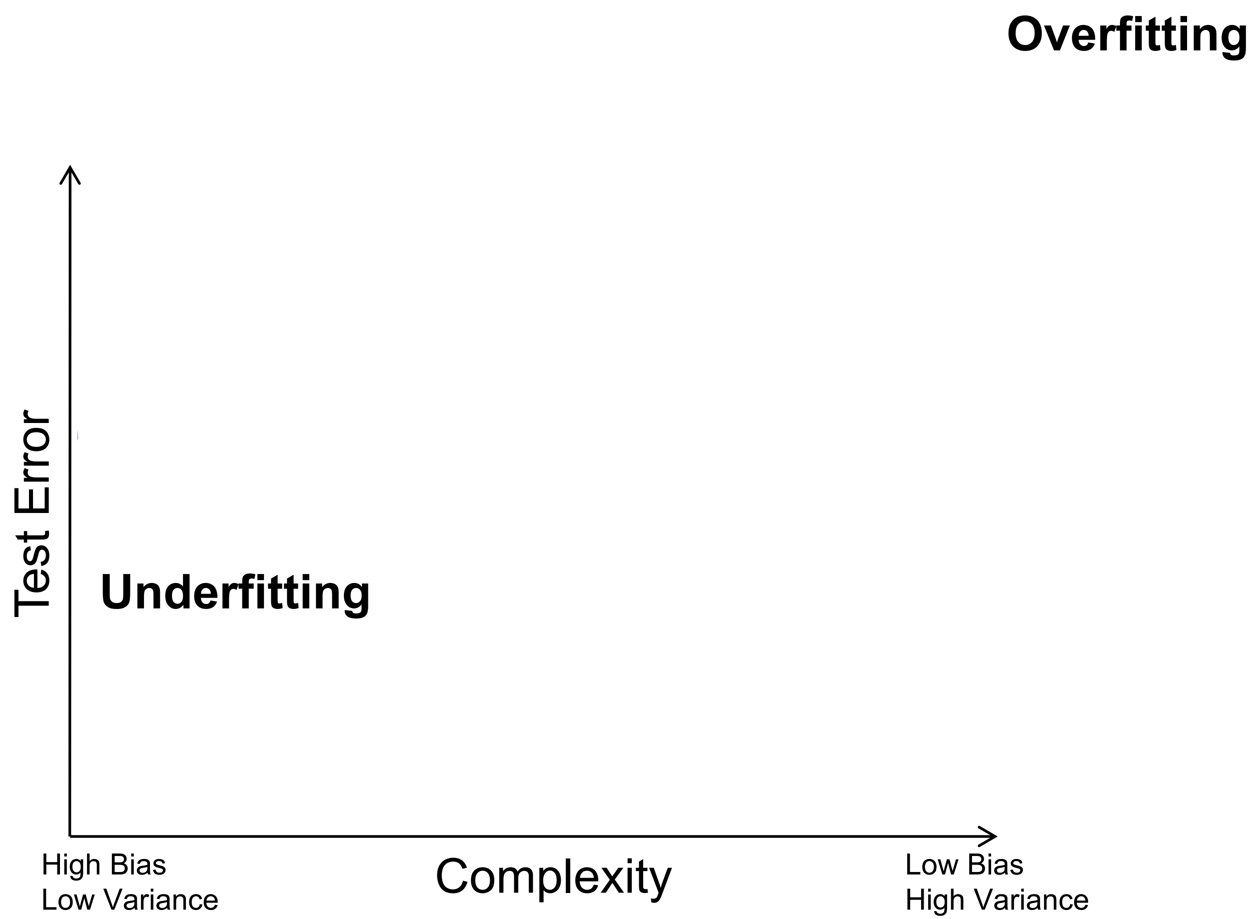
Bias-variance tradeoff

Underfitting **Overfitting**



Slide credit: D. Hoiem

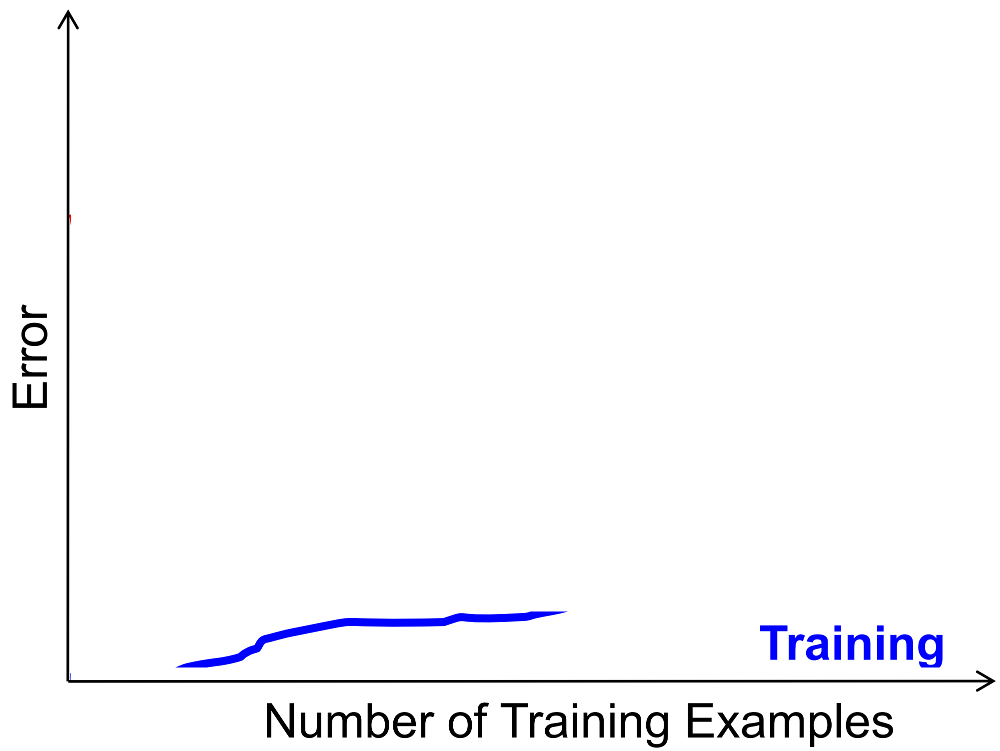
Bias-variance tradeoff

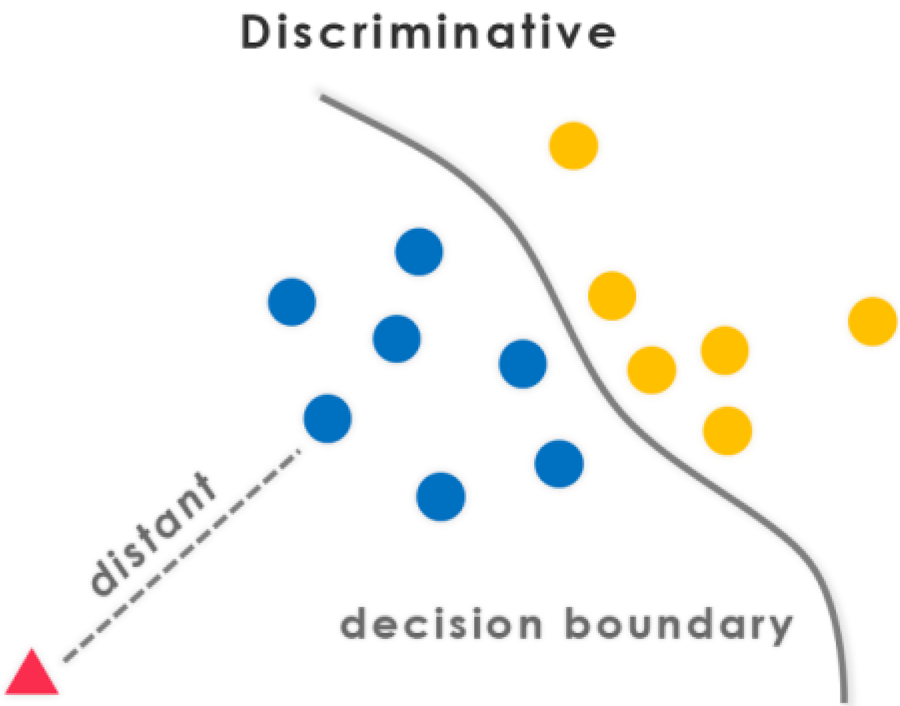


Slide credit: D. Hoiem

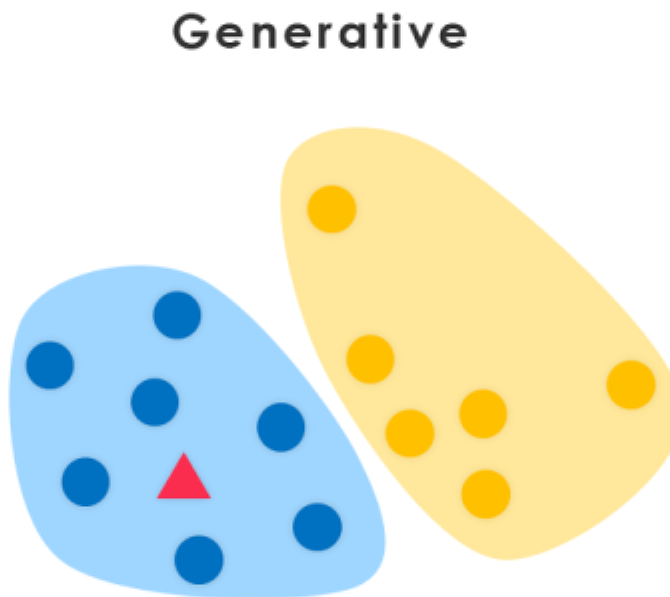
Effect of Training Size

Fixed prediction model





“Learn the data boundary”



“Represent the data + boundary”

Bayesian methods:
Condition model on
data probabilistically

Many classifiers to choose from…

- K-nearest neighbor
- SVM
- Naïve Bayes
- Bayesian network
- Logistic regression
- Randomized Forests
- Boosted Decision Trees
- Restricted Boltzmann Machines
- Neural networks
- Deep Convolutional Network
- …

Which is the best?

Claim:

It is more important to have more or better labeled data than to use a different supervised learning technique.

*Again, deep learning may be an exception here for the same reason, but deep learning _needs_ a lot of labeled data in the first place.

"The Unreasonable Effectiveness of Data" - Norvig