note: black & white
Recap – Image Classification with Bags of Local Features

• Bag of Feature models were the state of the art for image classification for a decade
• BoF may still be the state of the art for instance retrieval
• We saw numerous strategies to fight back against lost spatial information (spatial pyramid) and lost feature detail due to quantization.
• Food for thought, doesn’t the spatial pyramid seem kind of recursive / hierarchical? Like a SIFT feature on top of SIFT features?
SIFT vector formation

- 4x4 array of gradient orientation histogram weighted by magnitude
- 8 orientations x 4x4 array = 128 dimensions
- Motivation: some sensitivity to spatial layout, but not too much.

Showing only 2x2 here but is 4x4
Spatial pyramid representation

- Extension of a bag of features
- Locally orderless representation at several levels of resolution

Lazebnik, Schmid & Ponce (CVPR 2006)
Recap – Image Classification with Bags of Local Features

• Food for thought, doesn’t the spatial pyramid seem kind of recursive / hierarchical? Like a SIFT feature on top of SIFT features?

• Seems like there is a tendency for features to involve convolution, spatial pooling, and non-linearities.
Object Detection

• Overview
• Viola-Jones
• Dalal-Triggs

• Later classes:
  – Deformable models
  – Deep learning
Person detection with HoG’s & linear SVM’s

• Histograms of Oriented Gradients for Human Detection, Navneet Dalal, Bill Triggs, International Conference on Computer Vision & Pattern Recognition - June 2005
• http://lear.inrialpes.fr/pubs/2005/DT05/
Object detection vs Scene Recognition

• What’s the difference?
• Objects (even if deformable and articulated) probably have more consistent shapes than scenes.
• Scenes can be defined by distribution of “stuff” – materials and surfaces with arbitrary shape.
• Objects are “things” that own their boundaries
• Bag of words models are less popular for object detection because they throw away shape info.
Object Category Detection

- Focus on object search: “Where is it?”
- Build templates that quickly differentiate object patch from background patch
Challenges in modeling the object class

Illumination  Object pose  Clutter

Occlusions  Intra-class appearance  Viewpoint

Slide from K. Grauman, B. Leibe
Challenges in modeling the non-object class

- True Detections
- Confused with Similar Object
- Confused with Dissimilar Objects
- Bad Localization
- Misc. Background

True Detections

Confused with Similar Object

Confused with Dissimilar Objects

Bad Localization

Misc. Background
General Process of Object Recognition

1. Specify Object Model
2. Generate Hypotheses
3. Score Hypotheses
4. Resolve Detections

What are the object parameters?
Specifying an object model

1. Statistical Template in Bounding Box
   - Object is some \((x,y,w,h)\) in image
   - Features defined wrt bounding box coordinates

Images from Felzenszwalb
Specifying an object model

2. Articulated parts model
   - Object is configuration of parts
   - Each part is detectable

Images from Felzenszwalb
Specify an object model

3. Hybrid template/parts model

Detections

Template Visualization

root filters
coarse resolution

part filters
finer resolution

deformation models

Felzenszwalb et al. 2008
Specifying an object model

4. 3D-ish model

- Object is collection of 3D planar patches under affine transformation
General Process of Object Recognition

1. Specify Object Model
2. Generate Hypotheses
   - Propose an alignment of the model to the image
3. Score Hypotheses
4. Resolve Detections
Generating hypotheses

1. Sliding window
   - Test patch at each location and scale
Generating hypotheses

1. Sliding window
   - Test patch at each location and scale

Note – Template did not change size
Each window is separately classified
Generating hypotheses

2. Voting from patches/keypoints

ISM model by Leibe et al.
Generating hypotheses

3. Region-based proposal
General Process of Object Recognition

1. Specify Object Model
2. Generate Hypotheses
3. Score Hypotheses
4. Resolve Detections

Mainly-gradient based features, usually based on summary representation, many classifiers.
General Process of Object Recognition

1. Specify Object Model
2. Generate Hypotheses
3. Score Hypotheses
4. Resolve Detections

Rescore each proposed object based on whole set
Resolving detection scores

1. Non-max suppression

Score = 0.8
Score = 0.1
Score = 0.8
Resolving detection scores

1. Non-max suppression

```
Score = 0.8
Score = 0.1
```

```
Score = 0.8
Score = 0.1
```

“Overlap” score is below some threshold
Resolving detection scores

2. Context/reasoning

(g) Car Detections: Local  (h) Ped Detections: Local

Hoiem et al. 2006
Influential Works in Detection

  – Basic idea of statistical template detection, bootstrapping to get “face-like” negative examples, multiple whole-face prototypes (in 1994)

  – “Parts” at fixed position, non-maxima suppression, simple cascade, rotation, pretty good accuracy, fast

  – Careful feature engineering, excellent results, cascade

• Viola-Jones (2001, 2004) : ~13,000
  – Haar-like features, Adaboost as feature selection, hyper-cascade, very fast

• Dalal-Triggs (2005) : ~16,000 citations
  – Careful feature engineering, excellent results, HOG feature, online code

• Felzenszwalb-McAllester-Ramanan (2008): ~4,600 citations
  – Template/parts-based blend

• Girshick et al. (2013): ~2000 citations
  – R-CNN / Fast R-CNN / Faster R-CNN. Deep learned models on object proposals.
Sliding Window Face Detection with Viola-Jones
Face detection and recognition
Consumer application: Apple iPhoto

http://www.apple.com/ilife/iphoto/
Consumer application: Apple iPhoto
Can be trained to recognize pets!

Consumer application: Apple iPhoto

Things iPhoto thinks are faces
Funny Nikon ads

"The Nikon S60 detects up to 12 faces."
Funny Nikon ads

"The Nikon S60 detects up to 12 faces."
Challenges of face detection

• Sliding window detector must evaluate tens of thousands of location/scale combinations

• Faces are rare: 0–10 per image
  • For computational efficiency, we should try to spend as little time as possible on the non-face windows
  • A megapixel image has \(~10^6\) pixels and a comparable number of candidate face locations
  • To avoid having a false positive in every image image, our false positive rate has to be less than \(10^{-6}\)
The Viola/Jones Face Detector

- A seminal approach to real-time object detection
- Training is slow, but detection is very fast
- Key ideas
  - *Integral images* for fast feature evaluation
  - *Boosting* for feature selection
  - *Attentional cascade* for fast rejection of non-face windows


Image Features

“Rectangle filters”

\[
\text{Value} = \sum \text{(pixels in white area)} - \sum \text{(pixels in black area)}
\]
Example

Source

Result
Fast computation with integral images

• The *integral image* computes a value at each pixel \((x,y)\) that is the sum of the pixel values above and to the left of \((x,y)\), inclusive

• This can quickly be computed in one pass through the image
Computing the integral image
Computing the integral image

Cumulative row sum: \( s(x, y) = s(x-1, y) + i(x, y) \)

Integral image: \( ii(x, y) = ii(x, y-1) + s(x, y) \)

MATLAB: \( ii = \text{cumsum(cumsum(double(i)), 2)}; \)
Computing sum within a rectangle

- Let $A, B, C, D$ be the values of the integral image at the corners of a rectangle
- Then the sum of original image values within the rectangle can be computed as:
  $$\text{sum} = A - B - C + D$$
- Only 3 additions are required for any size of rectangle!
Computing a rectangle feature

Integral Image

-1  +1
+2  -2
-1  +1
Feature selection

- For a 24x24 detection region, the number of possible rectangle features is \(~160,000\)!
Feature selection

• For a 24x24 detection region, the number of possible rectangle features is ~160,000!
• At test time, it is impractical to evaluate the entire feature set
• Can we create a good classifier using just a small subset of all possible features?
• How to select such a subset?
Boosting

- *Boosting* is a learning scheme that combines *weak learners* into a more accurate *ensemble classifier*.

- Weak learners based on rectangle filters:

\[
 h_t(x) = \begin{cases} 
 1 & \text{if } p_t f_t(x) > p_t \theta_t \\
 0 & \text{otherwise}
\end{cases}
\]

- Ensemble classification function:

\[
 C(x) = \begin{cases} 
 1 & \text{if } \sum_{t=1}^{T} \alpha_t h_t(x) > \frac{1}{2} \sum_{t=1}^{T} \alpha_t \\
 0 & \text{otherwise}
\end{cases}
\]
Training procedure

• Initially, weight each training example equally
• In each boosting round:
  • Find the weak learner that achieves the lowest weighted training error
  • Raise the weights of training examples misclassified by current weak learner
• Compute final classifier as linear combination of all weak learners (weight of each learner is directly proportional to its accuracy)
  • Exact formulas for re-weighting and combining weak learners depend on the particular boosting scheme (e.g., AdaBoost)

Boosting intuition

Slide credit: Paul Viola
Boosting illustration

Weights Increased
Boosting illustration

Weak Classifier 2
Boosting illustration

Weights
Increased
Boosting illustration

Weak Classifier 3
Boosting illustration

Final classifier is a combination of weak classifiers
Boosting for face detection

- First two features selected by boosting:

This feature combination can yield 100% recall and 50% false positive rate
Boosting for face detection

A 200-feature classifier can yield 95% detection rate and a false positive rate of 1 in 14084

Not good enough!

Receiver operating characteristic (ROC) curve
Attentional cascade

- We start with simple classifiers which reject many of the negative sub-windows while detecting almost all positive sub-windows.
- Positive response from the first classifier triggers the evaluation of a second (more complex) classifier, and so on.
- A negative outcome at any point leads to the immediate rejection of the sub-window.
Attentional cascade

- Chain classifiers that are progressively more complex and have lower false positive rates:

![Diagram of an attentional cascade with three classifiers: Classifier 1, Classifier 2, and Classifier 3, each with a decision to be a face (T) or non-face (F). The cascade moves from IMAGE SUB-WINDOW to Classifier 1, then to Classifier 2, and finally to Classifier 3, with decisions being made at each step. The receiver operating characteristic (ROC) curve is shown on the right, indicating the trade-off between the true positive rate and the false positive rate.]
Attentional cascade

• The detection rate and the false positive rate of the cascade are found by multiplying the respective rates of the individual stages.

• A detection rate of 0.9 and a false positive rate on the order of $10^{-6}$ can be achieved by a 10-stage cascade if each stage has a detection rate of 0.99 ($0.99^{10} \approx 0.9$) and a false positive rate of about 0.30 ($0.3^{10} \approx 6 \times 10^{-6}$).
Training the cascade

• Set target detection and false positive rates for each stage
• Keep adding features to the current stage until its target rates have been met
  • Need to lower AdaBoost threshold to maximize detection (as opposed to minimizing total classification error)
  • Test on a validation set
• If the overall false positive rate is not low enough, then add another stage
• Use false positives from current stage as the negative training examples for the next stage
The implemented system

• Training Data
  • 5000 faces
    – All frontal, rescaled to 24x24 pixels
  • 300 million non-faces
    – 9500 non-face images
  • Faces are normalized
    – Scale, translation

• Many variations
  • Across individuals
  • Illumination
  • Pose
System performance

- Training time: “weeks” on 466 MHz Sun workstation
- 38 layers, total of 6061 features
- Average of 10 features evaluated per window on test set
- “On a 700 Mhz Pentium III processor, the face detector can process a 384 by 288 pixel image in about .067 seconds”
  - 15 Hz
  - 15 times faster than previous detector of comparable accuracy (Rowley et al., 1998)
Output of Face Detector on Test Images
Other detection tasks

Facial Feature Localization

Profile Detection

Male vs. female
Profile Detection
Profile Features
Summary: Viola/Jones detector

- Rectangle features
- Integral images for fast computation
- Boosting for feature selection
- Attentional cascade for fast rejection of negative windows