05/03/2011

Computer Vision: Summary and Discussion

Computer Vision

CS 543 / ECE 549

University of Illinois

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Announcements

- Today is last day of regular class ☺
- Poster session next Tuesday
  - Reports due by Wed at noon
- Derek and Ian out of town Wed afternoon through Friday
  - I plan to be in office and available after class today (3:30-4:30) and Wed (10am-11am, 2pm-3pm)

Today's class

- Review of important concepts
- Some important open problems
- Feedback and course evaluation

Fundamentals of Computer Vision

- Geometry
  - How to relate world coordinates and image coordinates
- Matching
  - How to measure the similarity of two regions
- Alignment
  - How to align points/patches
  - How to recover transformation parameters based on matched points
- Grouping
  - What points/regions/lines belong together?
- Categorization
  - What similarities are important?

Geometry

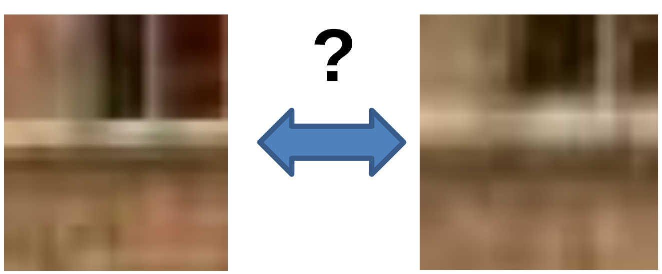
- $\mathbf{x} = \mathbf{K}\,[\mathbf{R}\ \mathbf{t}]\,\mathbf{X}$
  - Maps 3d point $\mathbf{X}$ to 2d point $\mathbf{x}$
  - Rotation $\mathbf{R}$ and translation $\mathbf{t}$ map into 3D camera coordinates
  - Intrinsic matrix $\mathbf{K}$ projects from 3D to 2D

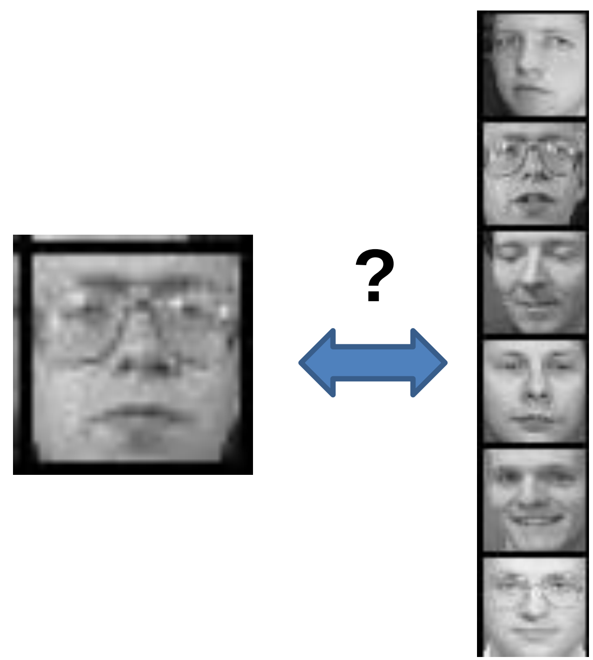
- Parallel lines in 3D converge at the **vanishing point** in the image
  - A 3D plane has a vanishing line in the image

- $\mathbf{x}'^{T}\,\mathbf{F}\,\mathbf{x} = 0$
  - Points in two views that correspond to the same 3D point are related by the fundamental matrix $\mathbf{F}$

Matching

- Does this patch match that patch?
  - In two simultaneous views? (stereo)
  - In two successive frames? (tracking, flow, SFM)
  - In two pictures of the same object? (recognition)





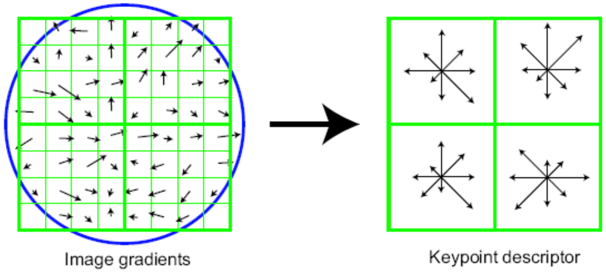
Matching

Representation: be invariant/robust to expected deformations but nothing else

- Often assume that shape is constant
  - Key cue: local differences in shading (e.g., gradients)
- Change in viewpoint
  - Rotation invariance: rotate and/or affine warp patch according to dominant orientations
- Change in lighting or camera gain
  - Average intensity invariance: oriented gradient-based matching
  - Contrast invariance: normalize gradients by magnitude
- Small translations
  - Translation robustness: histograms over small regions

But can one representation do all of this?

- SIFT: local normalized histograms of oriented gradients provides robustness to in-plane orientation, lighting, contrast, translation
- HOG: like SIFT but does not rotate to dominant orientation



Alignment of points

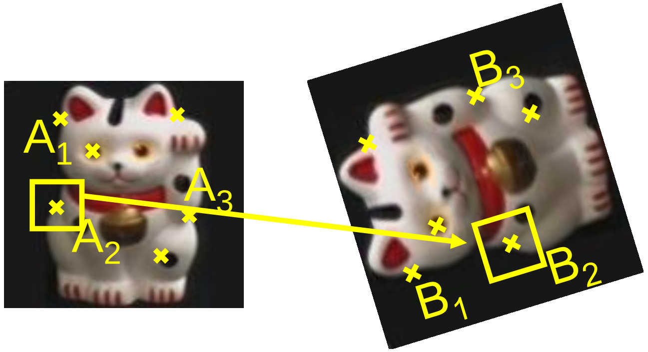
Search: efficiently align matching patches

- Interest points: find repeatable, distinctive points
  - Long-range matching: e.g., wide baseline stereo, panoramas, object instance recognition
  - Harris: points with strong gradients in orthogonal directions (e.g., corners) are precisely repeatable in x-y
  - Difference of Gaussian: points with peak response in Laplacian image pyramid are somewhat repeatable in x-y-scale
- Local search
  - Short range matching: e.g., tracking, optical flow
  - Gradient descent on patch SSD, often with image pyramid
- Windowed search
  - Long-range matching: e.g., recognition, stereo w/ scanline

Alignment of sets

Find transformation to align matching sets of points

- Geometric transformation (e.g., affine)
  - Least squares fit (SVD), if all matches can be trusted
  - Hough transform: each potential match votes for a range of parameters
    - Works well if there are very few parameters (3-4)
  - RANSAC: repeatedly sample potential matches, compute parameters, and check for inliers
    - Works well if fraction of inliers is high and few parameters (4-8)
- Other cases
  - Thin plate spline for more general distortions
  - One-to-one correspondence (Hungarian algorithm)



Grouping

- Clustering: group items (patches, pixels, lines, etc.) that have similar appearance
  - Discretize continuous values; typically, represent points within cluster by center
  - Improve efficiency: e.g., cluster interest points before recognition
  - Summarize data

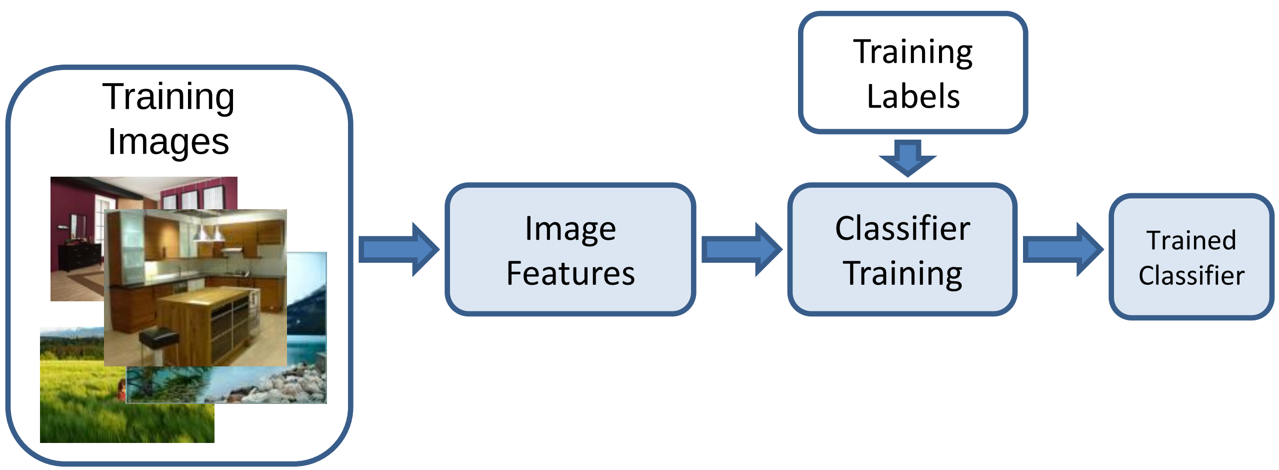
- Segmentation: group pixels into regions of coherent color, texture, motion, and/or label
  - Mean-shift clustering
  - Watershed
  - Graph-based segmentation: e.g., MRF and graph cuts

- EM, mixture models: probabilistically group items that are likely to be drawn from the same distribution, while estimating the distributions' parameters

Categorization

Match objects, parts, or scenes that may vary in appearance

- Categories are typically defined by human and may be related by function, cost, or other non-visual attributes
- Key problem: what are important similarities?
  - Can be learned from training examples



Categorization

Representation: ideally should be compact, comprehensive, direct

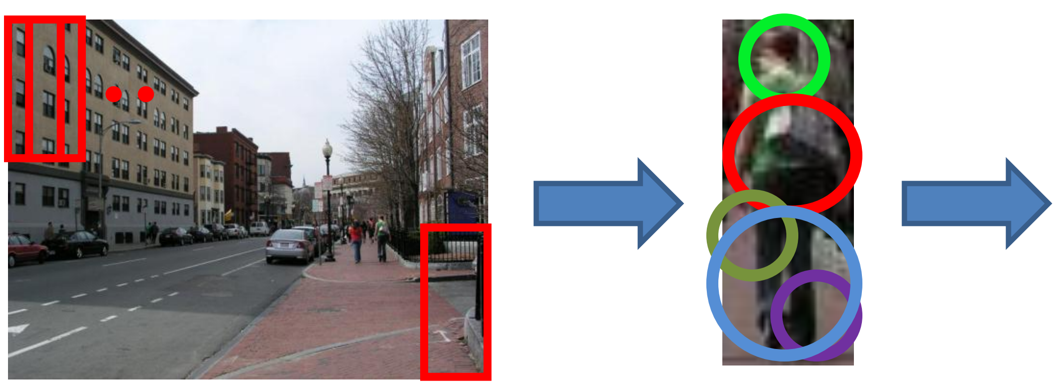
- Histograms of quantized interest points (SIFT, HOG), color, texture
  - Typical for image or region categorization
  - Degree of spatial encoding is controllable by using spatial pyramids
- HOG features at specified position
  - Often used for finding parts or objects

Object Categorization

Search by Sliding Window Detector

- May work well for rigid objects

- Key idea: simple alignment for simple deformations



Object or Background?

Object Categorization

Search by Parts-based model

- Key idea: more flexible alignment for articulated objects
- Defined by models of **part appearance**, **geometry** or spatial layout, and **search** algorithm

Vision as part of an intelligent system

3D Scene

Feature Extraction	Texture · Color · Optical Flow · Stereo Disparity
Grouping	Surfaces · Bits of objects · Sense of depth · Motion patterns
Interpretation	Objects · Agents and goals · Shapes and properties · Open paths · Words
Action	Walk, touch, contemplate, smile, evade, read on, pick up, …

Important open problems

Computer vision is potentially worth major $$$, but there are major challenges to overcome first.

- Driver assistance
  - MobileEye received >$100M in funding from Goldman Sachs
- Entertainment (Kinect, movies, etc.)
  - Intel is spending $100M for visual computing over next five years
- Security
  - Potential for billions of deployed cameras
- Robot workers
- Many more

Important open problems

Object category recognition: where is the cat?

Important open problems

Object category recognition: where is the cat?

Important questions:

- How can we better align two object instances?
- How do we identify the important similarities of objects within a category?
- How do we tell if two patches depict similar shapes?

Important open problems

Object representation: what is it?

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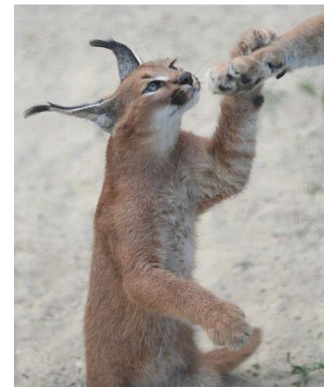
Important open problems

Object representation: what is it?



Important questions:

- How can we pose recognition so that it lets us deal with new objects?
- What do we want to predict or infer, and to what extent does that rely on categorization?
- How do we transfer knowledge of one type of object to another?

Important open problems

- Spatial understanding: what is it doing? Or how do I do it?

Important open problems

- Spatial understanding: what is it doing? Or how do I do it?

Important questions:

- What are good representations of space for navigation and interaction? What kind of details are important?
- How can we combine single-image cues with multi-view cues?

Important open problems

- Algorithms: works pretty well → perfect
  - E.g., stereo: top of wish list from Pixar guy Micheal Kass

Good directions:

- Incorporate higher level knowledge

Important open problems

- How should we adjust vision systems to solve particular tasks?

Important open problems

- Can we build a “core” vision system that can easily be extended to perform new tasks or even learn on its own?
  - What kind of representations might allow this?
  - What should be built in and what should be learned?

If you want to learn more…

- Read lots of papers: IJCV, PAMI, CVPR, ICCV, ECCV, NIPS

- Helpful topics for classes
  - David Forsyth’s optimization
  - Classes in machine learning or pattern recognition
  - Statistics, graphical models
  - Seminar-style paper-reading classes

- Just implement stuff, try demos, see what works

Feedback: very important

- My custom form

- ICES forms

See you next week!

- Project posters on Tuesday
  - Pizza provided
  - Posters: 24” wide x 32” tall