Computer Vision Systems Programming VO

Specific Object Recognition

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Topics

Introduction to object recognition

Specific object recognition

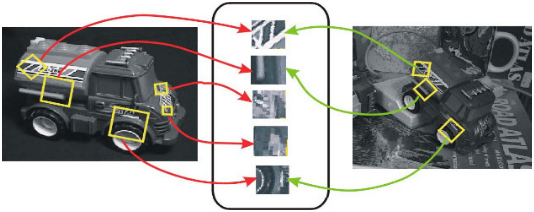


Image from Grauman and Leibe 2011

Object Recognition

Fundamental problem in Computer Vision

Many applications

- Panorama stitching, 3D reconstruction
- HCI and surveillance (face recognition)
- Image understanding (recall Fei-Fei Li's TED talk)

Instance recognition (specific object recognition)

- Recognize a specific, uniquely looking object
- Face of a certain person, the Eiffel tower

Object category recognition

- Recognize objects of a certain category
- Human faces, buildings

Object Recognition
Taxonomy – Instance vs. Category

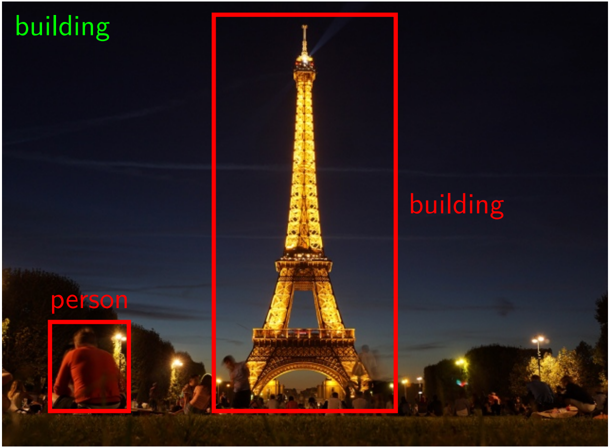
Object classification

- Recognize main object in image
- Location and other objects not relevant

Object detection

- Recognize multiple objects, possibly of different category

Object Recognition
Taxonomy – Classification vs. Detection



Object Recognition
Challenges

Instances of same category can look very differently

- Illumination, pose, viewpoint, occlusions, background

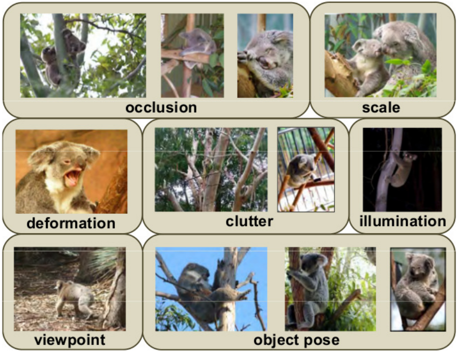


Image from Grauman and Leibe 2011

Planar Rigid Object Detection

We want to detect specific rigid planar objects

- Like markers, books
- Comparatively easy problem

Challenges

- Unknown object pose and scale
- Varying illumination
- Partial occlusions

Planar Rigid Object Detection

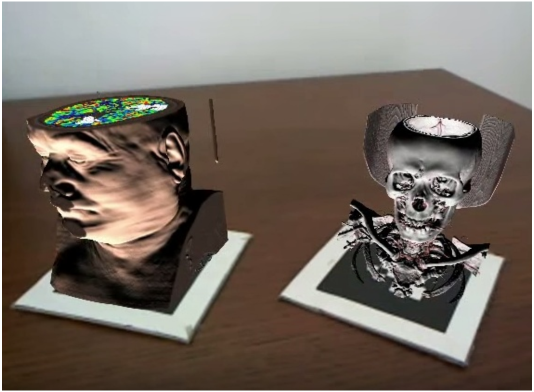


Image from youtube.com

Planar Rigid Object Detection

Selecting $\mathbf{x}$ and $\mathbf{w}$

Our problem formulation is

- Given a pixel location in a query image
- Predict location on object surface

So we know how to select $\mathbf{x}$ and $\mathbf{w}$

- $\mathbf{x} = (x, y)$: pixel location in query image
- $\mathbf{w} = (u, v)$: corresponding location on object surface

As $\mathbf{w} \in \mathbb{R}^2$ this is a regression problem

Planar Rigid Object Detection

Selecting $\mathbf{x}$ and $\mathbf{w}$

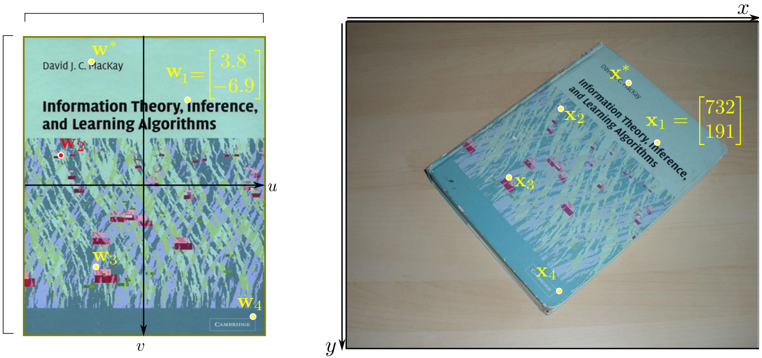


Image adapted from Prince 2012

Images of planar objects are always related by a homography $\mathbf{\Phi}$

- 3×3 matrix mapping between corresponding points

In homogeneous coordinates this means that

$$\lambda \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{\Phi} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

The model of choice is thus (disregarding noise)

$$\mathbf{w} = \Gamma(\mathbf{x}) = \begin{pmatrix} u \\ v \end{pmatrix} \quad , \quad \lambda \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \mathbf{\Phi} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

We again learn parameters $\boldsymbol{\theta}$ from samples $\{(\mathbf{x}_i, \mathbf{w}_i)\}_{i=1}^{n}$

- $\boldsymbol{\theta}$ contains 9 parameters comprising $\boldsymbol{\Phi}$

Usually no exact solution because of noisy $\mathbf{x}_i$

- Formulate as a least squares problem instead

$$\hat{\boldsymbol{\theta}} = \underset{\boldsymbol{\theta}}{\arg\min} \left[\sum_{i=1}^{n} (\mathbf{w}_i - \Gamma(\mathbf{x}_i))^\top (\mathbf{w}_i - \Gamma(\mathbf{x}_i)) \right]$$

This least squares approach is optimal

- If noise is distributed normally with spherical covariance

This is a nonlinear optimization problem

- Solvable using any general nonlinear least squares solver
- OpenCV has an own function `findHomography`

$\mathbf{\Phi}$ is a 2D transformation

We may want to know the position and orientation of the object

- This is called pose estimation
- Required e.g. for marker-based AR like above

This information can be extracted from $\mathbf{\Phi}$

- If we know the intrinsic camera parameters
- See Prince 2012 for details

How can we compute $\{(\mathbf{x}_i, \mathbf{w}_i)\}_{i=1}^{n}$ automatically?

- We first select $\mathbf{w}_i$, then search corresponding $\mathbf{x}_i$

$\mathbf{w}_i$ can be selected

- Manually (e.g. specific corners on markers)
- Automatically (e.g. SIFT)

We adopt the second approach and use SIFT (or similar)

- Features invariant to rotation, scale, illumination
- Robust to affine transformations

Approach

- Compute keypoints and descriptors in both images
- Match descriptors (e.g. nearest neighbor association)
- Use keypoint locations of matches as $\{(\mathbf{x}_i, \mathbf{w}_i)\}_{i=1}^{n}$

There will likely be incorrect matches

- Would greatly impact the least squares solution
- Hence we use a robust alternative like RANSAC

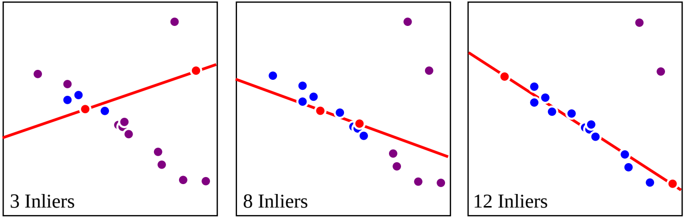


Image adapted from Prince 2012

Planar Rigid Object Detection
Obtaining Point Correspondences Using OpenCV

```
// read images (SIFT expects grayscale images)
cv::Mat object = cv::imread("object.jpg", cv::IMREAD_GRAYSCALE);
cv::Mat search = cv::imread("search.jpg", cv::IMREAD_GRAYSCALE);

cv::SIFT sift; // using default arguments here

// compute keypoints
std::vector<cv::KeyPoint> kobject, ksearch;
sift.detect(object, kobject); sift.detect(search, ksearch);

// compute descriptors
cv::Mat dobject, dsearch;
sift.compute(object, kobject, dobject); sift.compute(search, ksearch, dsearch);
```

Planar Rigid Object Detection

Obtaining Point Correspondences Using OpenCV

```
// find two nearest neighbors x,x' for each w
cv::FlannBasedMatcher matcher; // fast nearest neighbor search
std::vector<std::vector<cv::DMatch> > kMatches;
matcher.knnMatch(dobject, dsearch, kMatches, 2);

// keep match (x,w) if x is clearly more similar than x'
// this is a popular matching strategy
std::vector<cv::DMatch> matches;
for(const std::vector<cv::DMatch>& match : kMatches)
    if(match[0].distance < match[1].distance * 0.8) // x, x'
        matches.push_back(match[0]); // (x,w)
```

```cpp
// collect feature locations of correspondences from before
std::vector<cv::Point2f> pobject, psearch;
for(const cv::DMatch& match : matches) {
    pobject.push_back(kobject.at(match.queryIdx).pt);
    psearch.push_back(ksearch.at(match.trainIdx).pt);
}

// estimate homography using RANSAC for robustness
cv::Mat inliers; // contains indices of valid correspondences
cv::Mat homography = cv::findHomography(pobject, psearch, CV_RANSAC, 2, inliers);
```

Nonplanar Rigid Object Detection

What if sought objects are not planar?

Bibliography

Grauman, Kristen and Bastian Leibe (2011). *Visual object recognition*. Morgan & Claypool.

Prince, S.J.D. (2012). *Computer Vision: Models Learning and Inference*. Cambridge University Press.