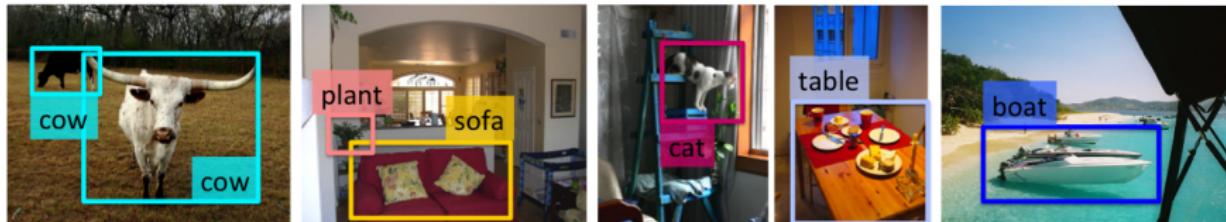


Object Detection

Object Detection

- The goal of object detection is to localize objects in an image and tell their class
- Localization: **place a tight bounding box around object**
- A few years ago, most approaches could find only objects of one or a few specific classes, e.g. car or cow but YOLO 9000 detects 9000 classes!!



Type of Approaches

Different approaches tackle detection differently. They can roughly be categorized into three main types:

- Find **interest points**, followed by Hough voting

Interest Point Based Approaches

- Compute interest points (e.g., Harris corner detector is a popular choice)
- Vote for where the object could be given the content around interest points



Interest points

Interest Point Based Approaches

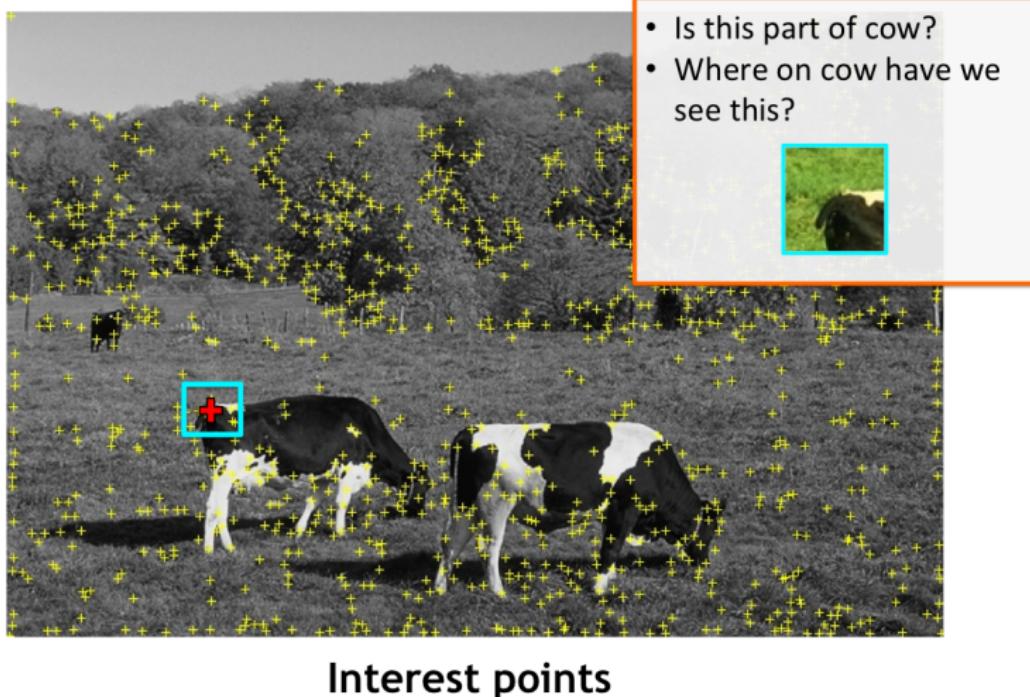
- Compute interest points (e.g., Harris corner detector is a popular choice)
- Vote for where the object could be given the content around interest points



Interest points

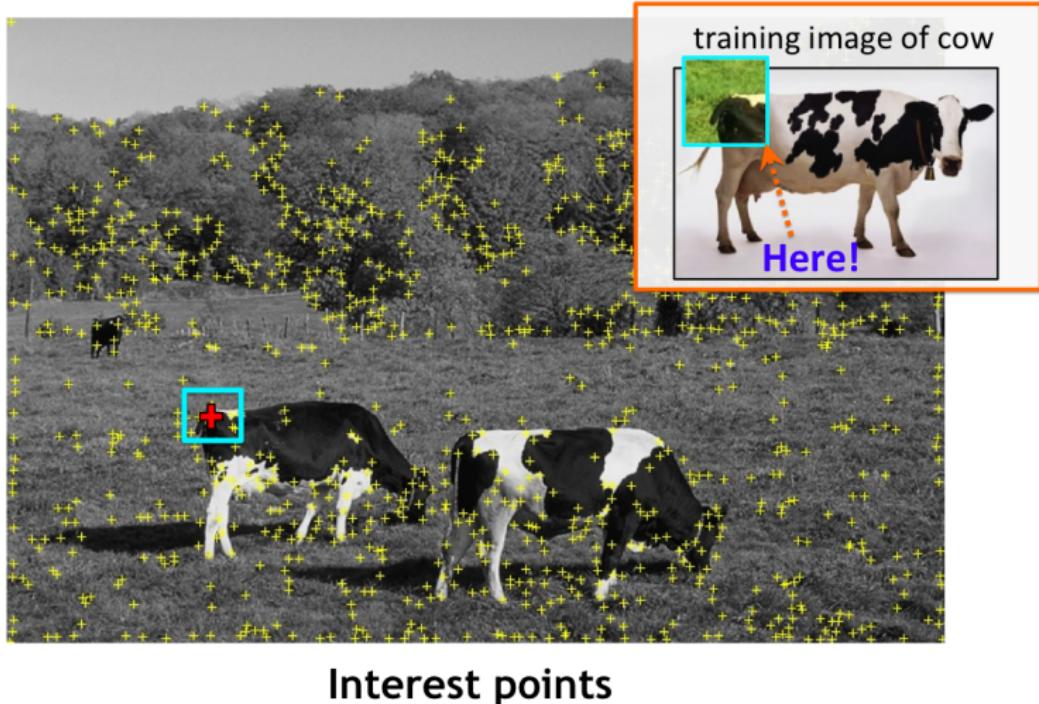
Interest Point Based Approaches

- Compute interest points (e.g., Harris corner detector is a popular choice)
- Vote for where the object could be given the content around interest points



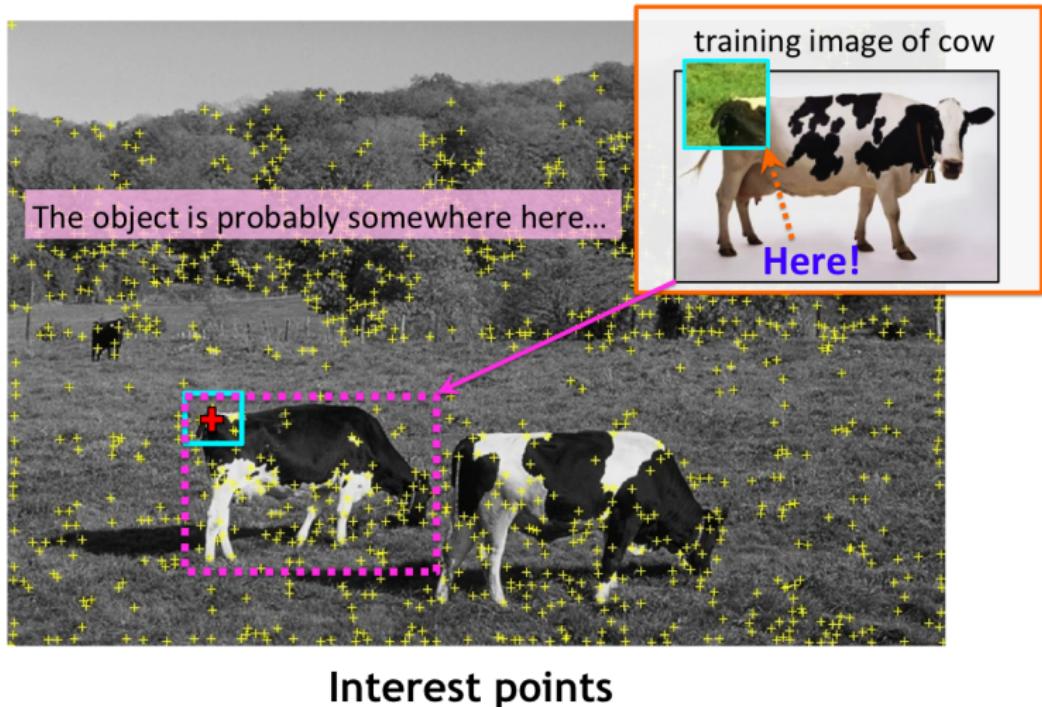
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Interest Point Based Approaches

- Compute interest points (e.g., Harris corner detector is a popular choice)
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Different approaches tackle detection differently. They can roughly be categorized into three main types:

- Find **interest points**, followed by Hough voting
- **Sliding windows**: “slide” a box around image and classify each image crop inside a box (contains object or not?)

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



0.1
confidence

[Slide: R. Urtasun]

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



[Slide: R. Urtasun]

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



-0.1

[Slide: R. Urtasun]

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



[Slide: R. Urtasun]

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



...
1.5
...

[Slide: R. Urtasun]

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



[Slide: R. Urtasun]

Sliding Window Approaches

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[Slide: R. Urtasun]

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[Slide: R. Urtasun]

Sliding Window Approaches

- Slide window and ask a classifier: “Is sheep in window or not?”



[Slide: R. Urtasun]

Type of Approaches

Different approaches tackle detection differently. They can roughly be categorized into three main types:

- Find **interest points**, followed by Hough voting
- **Sliding windows**: “slide” a box around image and classify each image crop inside a box (contains object or not?)
- Generate **region (object) proposals**, and classify each region

Region Proposal Based Approaches

- Group pixels into object-like regions



Region Proposal Based Approaches

- Group pixels into object-like regions



Region Proposal Based Approaches

- Group pixels into object-like regions



Region Proposal Based Approaches

- Generate **many** different regions



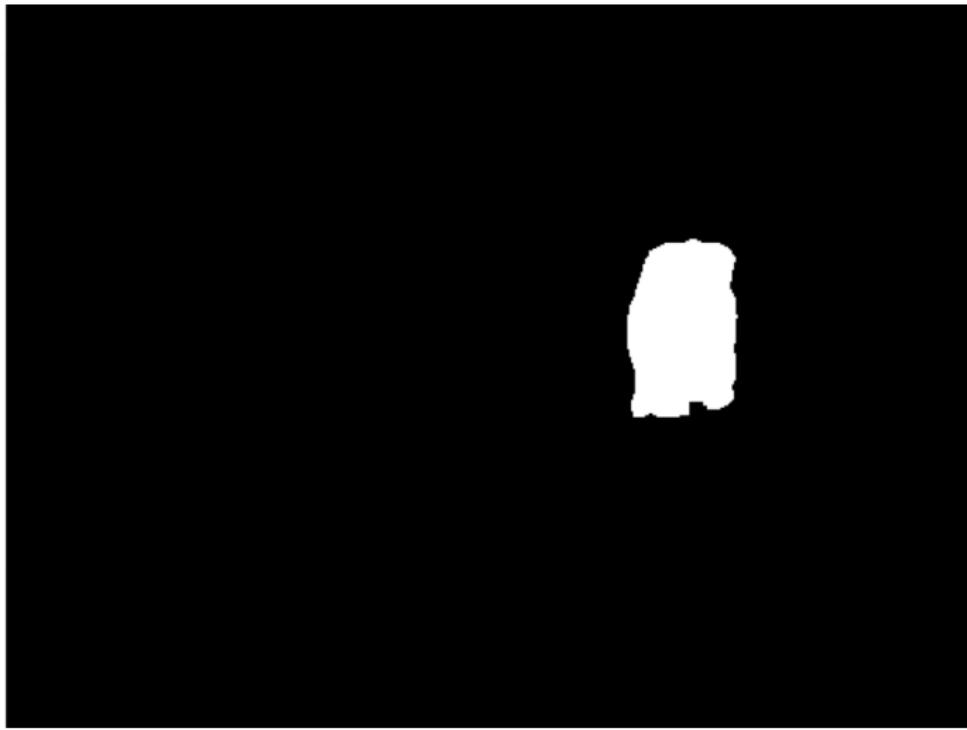
Region Proposal Based Approaches

- Generate **many** different regions



Region Proposal Based Approaches

- Generate **many** different regions



Region Proposal Based Approaches

- The hope is that at least a few will cover real objects



Region Proposal Based Approaches

- The hope is that at least a few will cover real objects



Region Proposal Based Approaches

- Select a region



Region Proposal Based Approaches

- Crop out an image patch around it, throw to classifier (e.g., Neural Net)



classifier
“dog” or not?

confidence: -2.5

Region Proposal Based Approaches

- Do this for every region



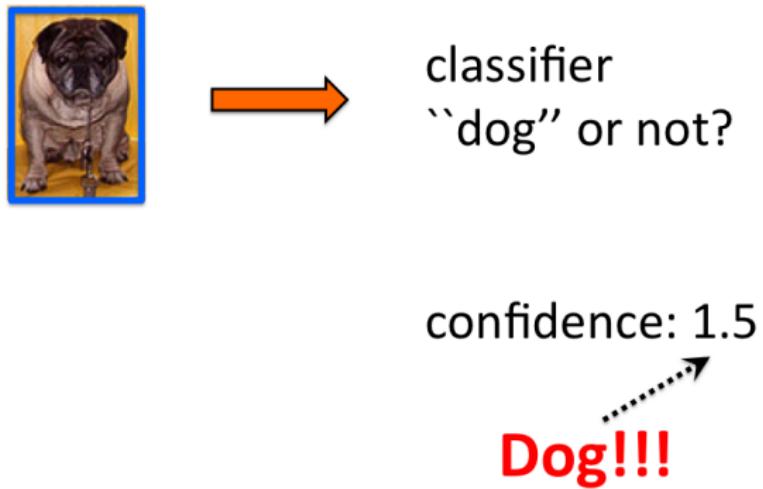
Region Proposal Based Approaches

- Do this for every region



Region Proposal Based Approaches

- Do this for every region



Type of Approaches

Different approaches tackle detection differently. They can roughly be categorized into three main types:

- Find **interest points**, followed by Hough voting ← **Let's first look at one example method for this**
- **Sliding windows**: “slide” a box around image and classify each image crop inside a box (contains object or not?)
- Generate **region (object) proposals**, and classify each region

Object Detection via Hough Voting: Implicit Shape Model

B. Leibe, A. Leonardis, B. Schiele

*Robust Object Detection with Interleaved Categorization and
Segmentation*

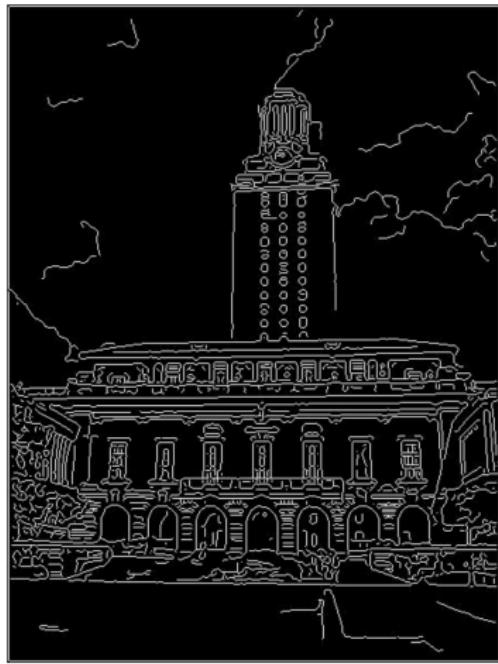
IJCV, 2008

Paper:

<http://www.vision.rwth-aachen.de/publications/pdf/leibe-interleaved-ijcv07final.pdf>

Start with Simple: Line Detection

- How can I find lines in this image?



[Source: K. Grauman]

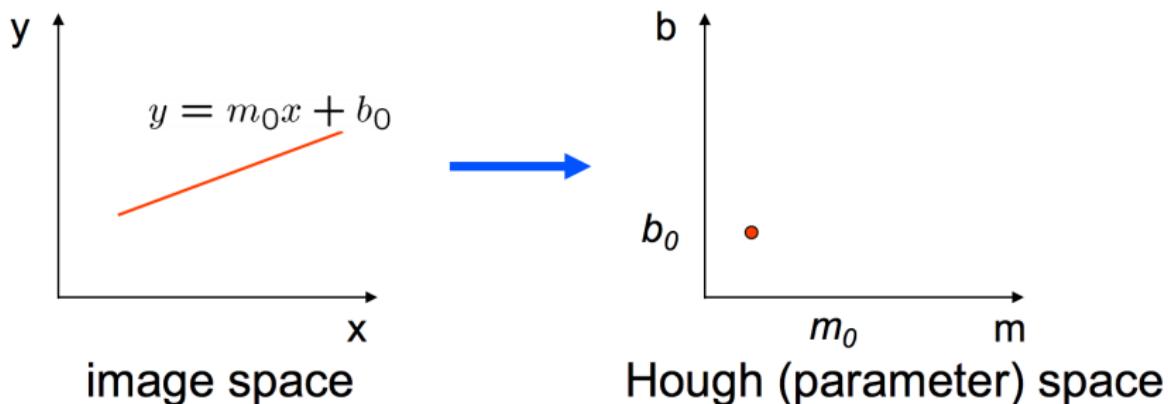
Hough Transform

- Idea: Voting (Hough Transform)
- Voting is a general technique where we let the features vote for all models that are compatible with it.
 - Cycle through features, cast votes for model parameters.
 - Look for model parameters that receive a lot of votes.

[Source: K. Grauman]

Hough Transform: Line Detection

- Hough space: parameter space

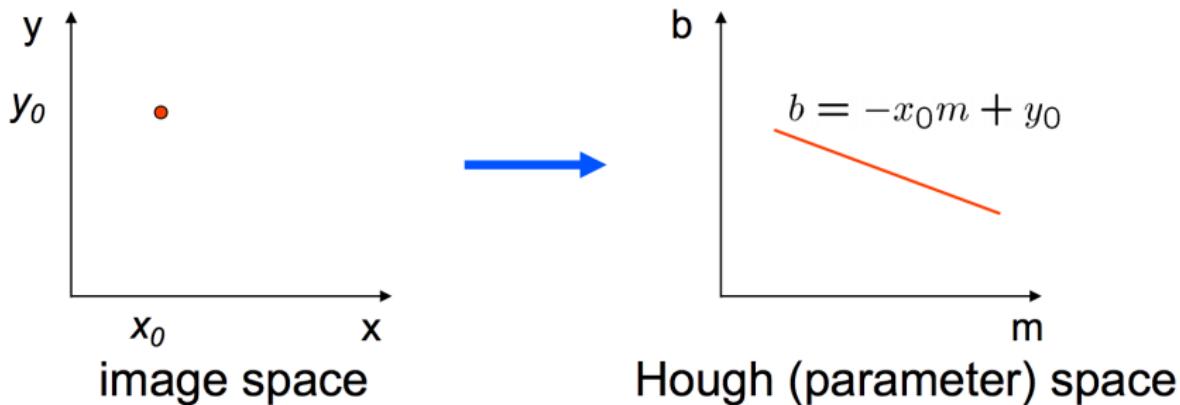


- Connection between image (x, y) and Hough (m, b) spaces
 - A line in the image corresponds to a point in Hough space
 - What does a point (x_0, y_0) in the image space map to in Hough space?

[Source: S. Seitz]

Hough Transform: Line Detection

- Hough space: parameter space

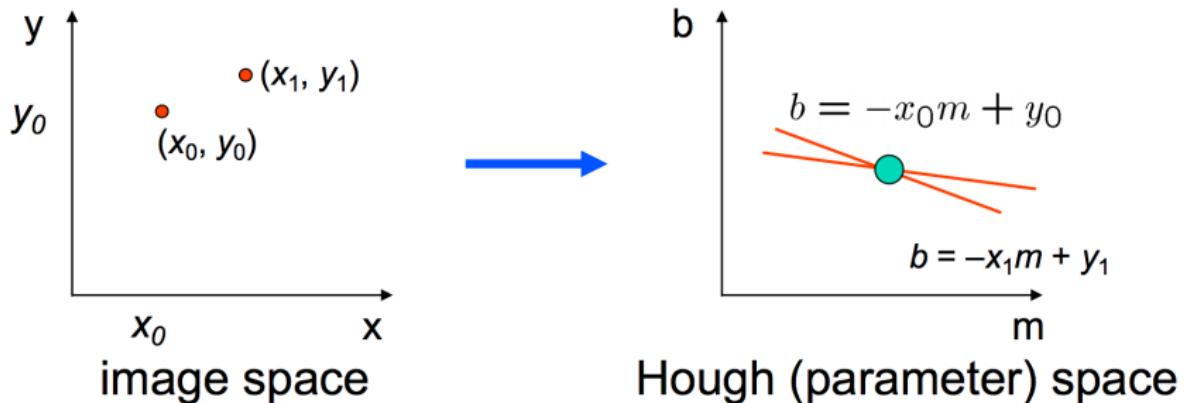


- Connection between image (x, y) and Hough (m, b) spaces
 - A line in the image corresponds to a point in Hough space
 - A point in image space votes for all the lines that go through this point. These votes are a line in the Hough space.

[Source: S. Seitz]

Hough Transform: Line Detection

- Hough space: parameter space

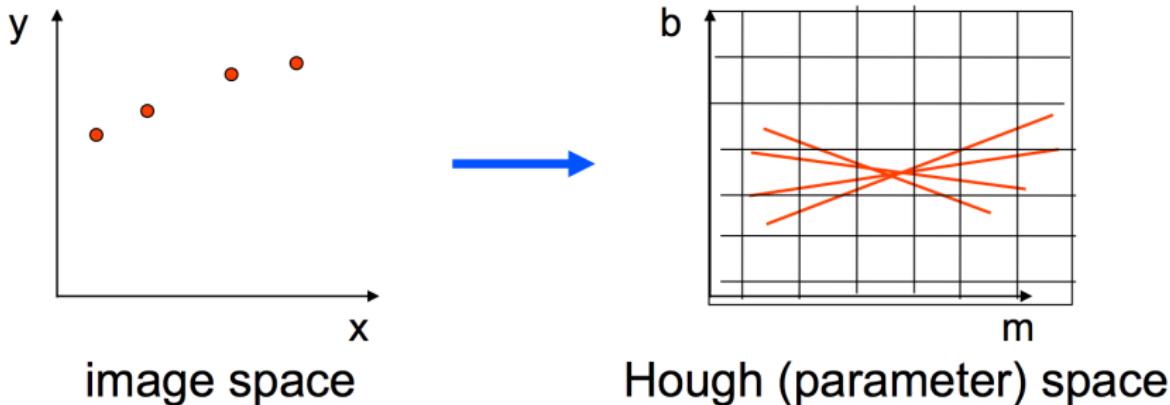


- Two points: Each point corresponds to a line in the Hough space
- A point where these two lines meet defines a line in the image!

[Source: S. Seitz]

Hough Transform: Line Detection

- Hough space: parameter space

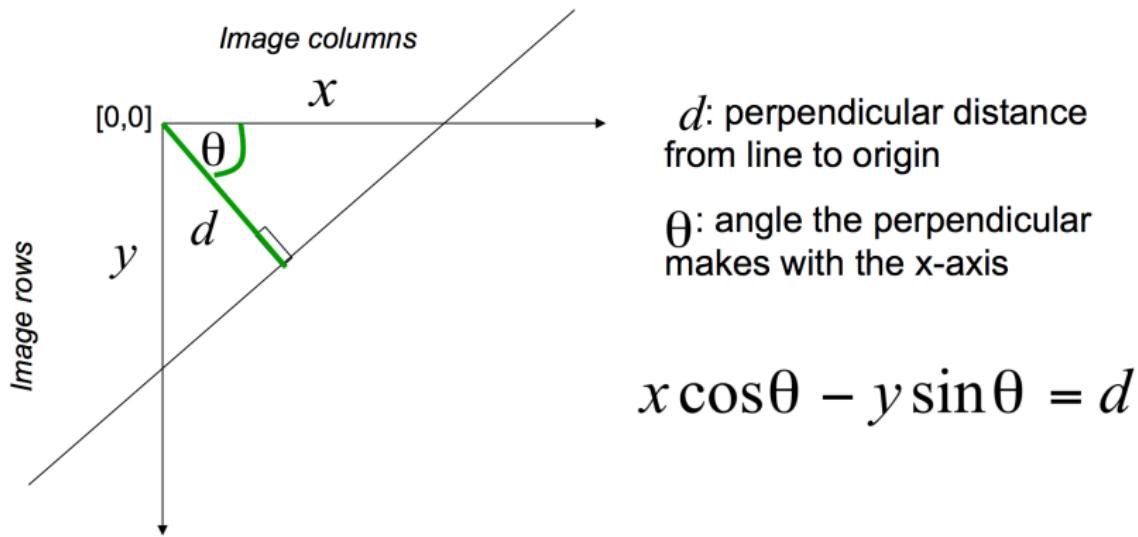


- Vote with each image point
- Find peaks in Hough space. Each peak is a line in the image.

[Source: S. Seitz]

Hough Transform: Line Detection

- Issues with usual (m, b) parameter space: undefined for vertical lines
- A better representation is a polar representation of lines



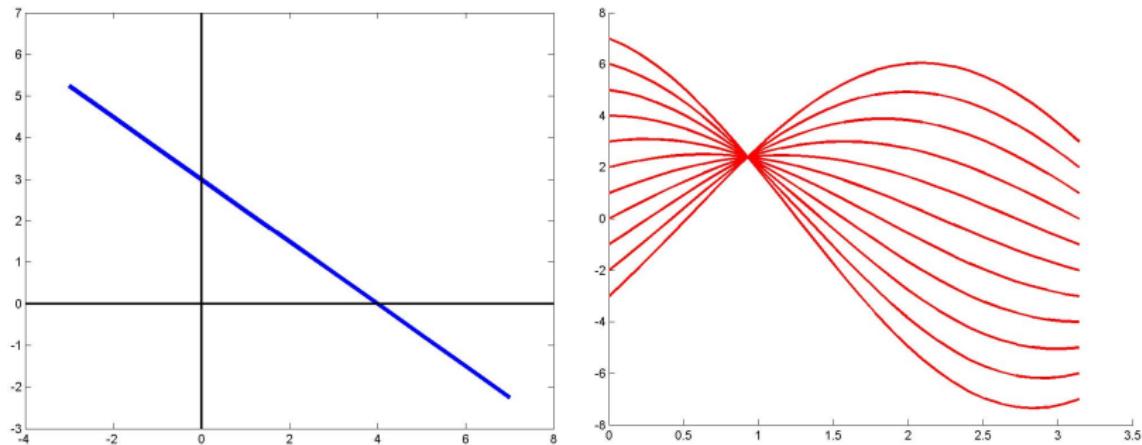
Point in image space \rightarrow sinusoid segment in Hough space

[Source: S. Seitz]

Example Hough Transform

With the parameterization $x \cos \theta + y \sin \theta = d$

- Points in picture represent sinusoids in parameter space
- Points in parameter space represent lines in picture
- Example $0.6x + 0.4y = 2.4$, Sinusoids intersect at $d = 2.4$, $\theta = 0.9273$



[Source: M. Kazhdan, slide credit: R. Urtasun]

Hough Transform: Line Detection

- **Hough Voting algorithm**

Using the polar parameterization:

$$x \cos\theta - y \sin\theta = d$$

Basic Hough transform algorithm

1. Initialize $H[d, \theta] = 0$

2. for each edge point $I[x, y]$ in the image

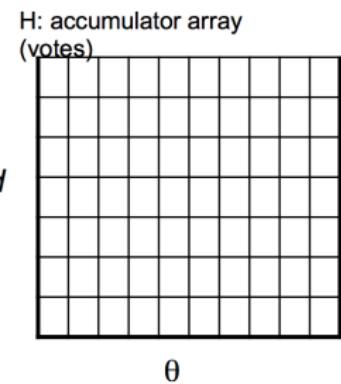
for $\theta = [\theta_{\min} \text{ to } \theta_{\max}]$ // some quantization

$$d = x \cos\theta - y \sin\theta$$

$$H[d, \theta] += 1$$

3. Find the value(s) of (d, θ) where $H[d, \theta]$ is maximum

4. The detected line in the image is given by



$$d = x \cos\theta - y \sin\theta$$

[Source: S. Seitz]

Hough Transform: Circle Detection

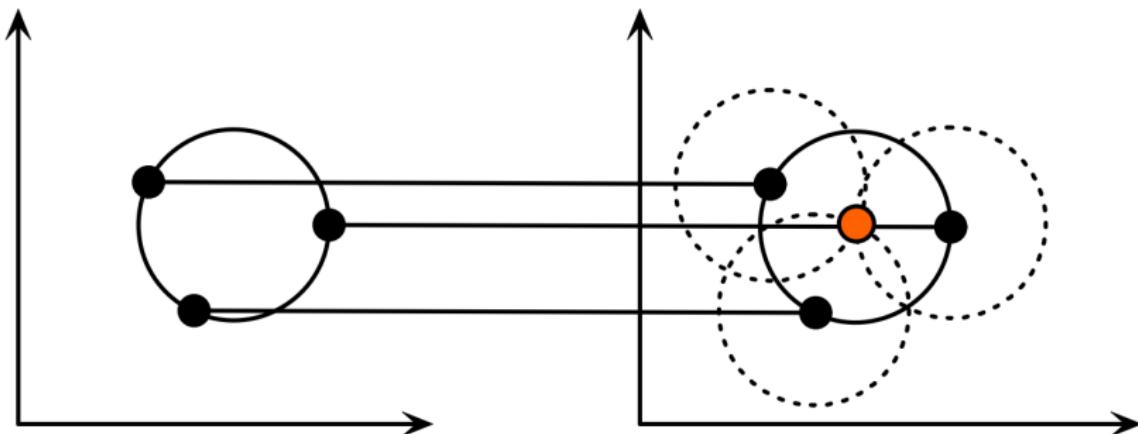
- What about circles? How can I fit circles around these coins?



Hough Transform: Circle Detection

Assume we are looking for a circle of known radius r

- Circle: $(x - a)^2 + (y - b)^2 = r^2$
- Hough space (a, b) : A point (x_0, y_0) maps to $(a - x_0)^2 + (b - y_0)^2 = r^2 \rightarrow$ a circle around (x_0, y_0) with radius r
- Each image point votes for a circle in Hough space



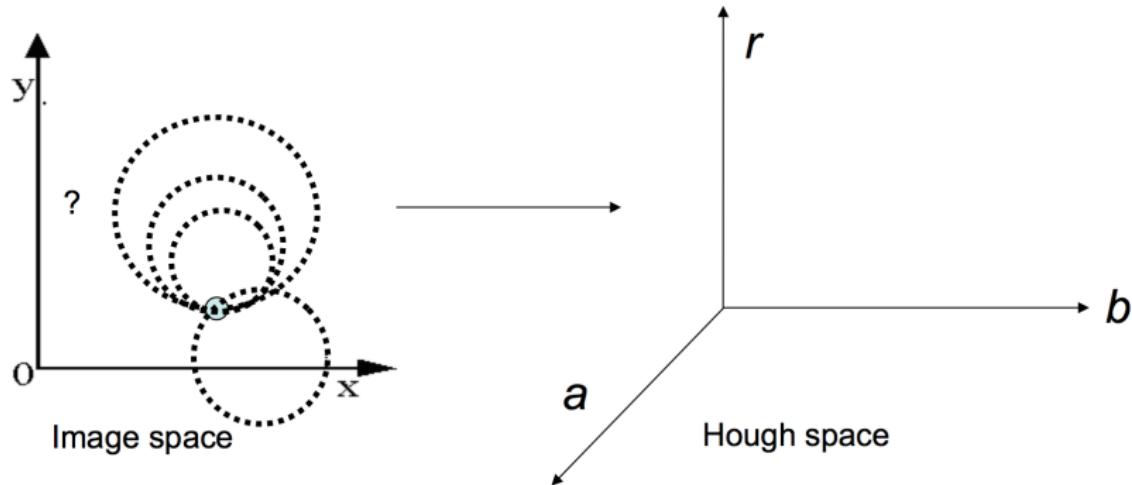
Each point in geometric space (left) generates a circle in parameter space (right). The circles in parameter space intersect at the (a, b) that is the center in geometric space.

[Source: H. Rhody]

Hough Transform: Circle Detection

What if we don't know r ?

- Hough space: ?

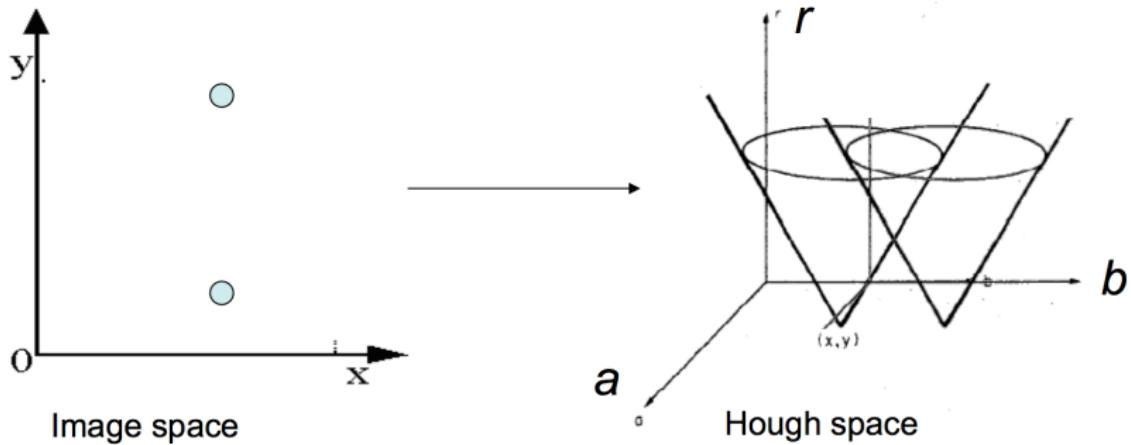


[Source: K. Grauman]

Hough Transform: Circle Detection

What if we don't know r ?

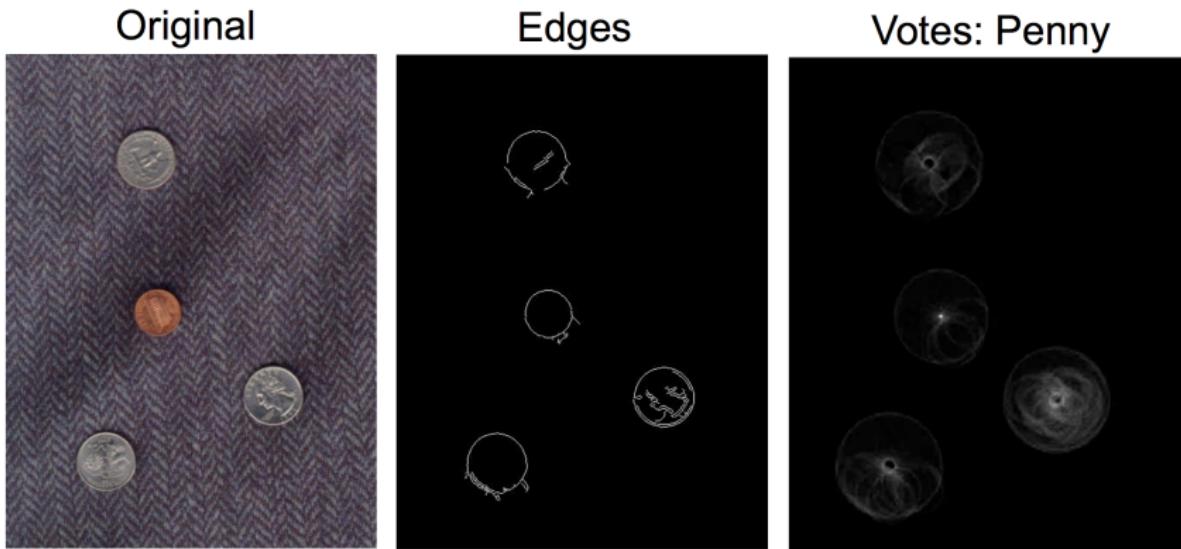
- Hough space: conics



[Source: K. Grauman]

Hough Transform: Circle Detection

- Find the coins



[Source: K. Grauman]

Hough Transform: Circle Detection

- Iris detection



Gradient+threshold

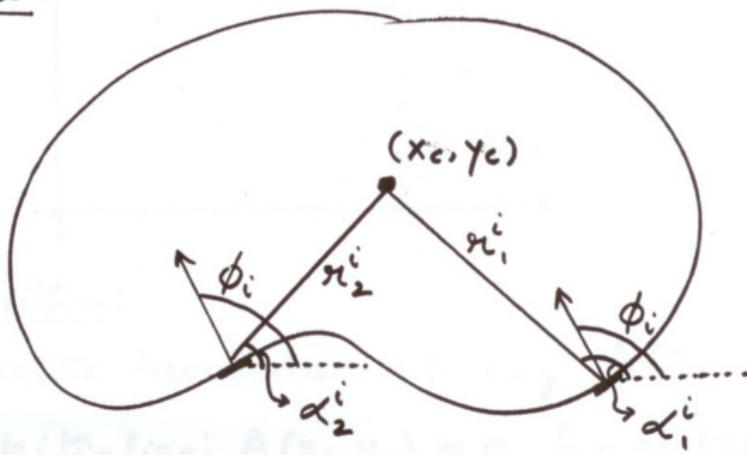
Hough space
(fixed radius)

Max detections

[Source: K. Grauman]

Generalized Hough Transform

Model :



[Source: Kris Kitani]

ϕ -Table

Edge Direction	$\bar{\pi} = (\pi, \alpha)$
ϕ_1	$\bar{\pi}_1^1, \bar{\pi}_2^1, \bar{\pi}_3^1$
ϕ_2	$\bar{\pi}_1^2, \bar{\pi}_2^2$
ϕ_i	$\bar{\pi}_1^i, \bar{\pi}_2^i$
ϕ_n	$\bar{\pi}_1^n, \bar{\pi}_2^n$

[Source: Kris Kitani]

Generalized Hough Transform

Find Object Center (x_c, y_c) given edges (x_i, y_i, ϕ_i)

Create Accumulator Array $A(x_c, y_c)$

Initialize: $A(x_c, y_c) = 0 \quad \forall (x_c, y_c)$

For each edge point (x_i, y_i, ϕ_i)

 For each entry \bar{r}_k^i in table, compute:

$$x_c = x_i + r_k^i \cos \alpha_k^i$$

$$y_c = y_i + r_k^i \sin \alpha_k^i$$

 Increment Accumulator: $A(x_c, y_c) = A(x_c, y_c) + 1$

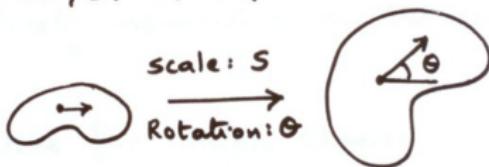
Find Local Maxima in $A(x_c, y_c)$

[Source: Kris Kitani]

Scale & Rotation:

Use Accumulator Array:

$$A[x_c, y_c, S, \theta]$$



Use:

$$x_c = x_i + r_k^i S \cos(\alpha_k^i + \theta)$$

$$y_c = y_i + r_k^i S \sin(\alpha_k^i + \theta)$$

$$A(x_c, y_c, S, \theta) = A(x_c, y_c, S, \theta) + 1.$$

[Source: Kris Kitani]

A. Train phase:

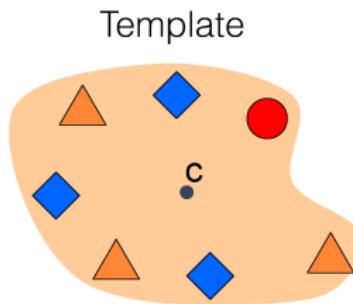
1. Get features

2. Store all displacements of feature from center

B. Test phase:

1. Get features & lookup displacements

2. Vote for center location



[Source: Kris Kitani]

A. Train phase:

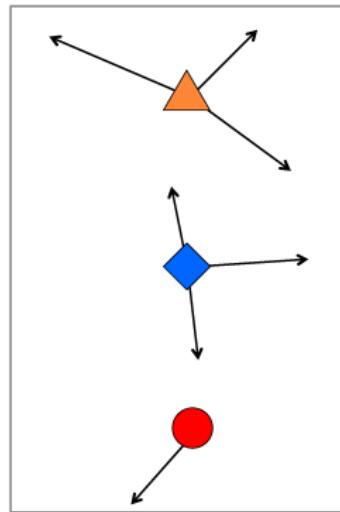
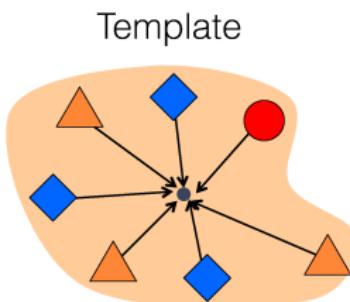
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[Source: Kris Kitani]

A. Train phase:

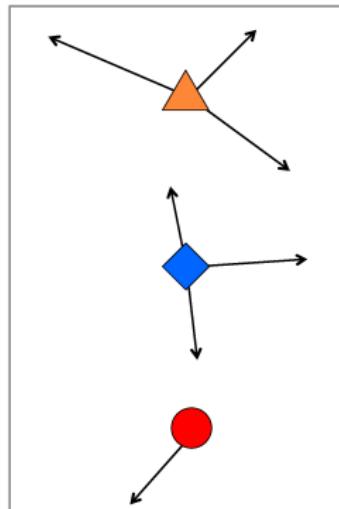
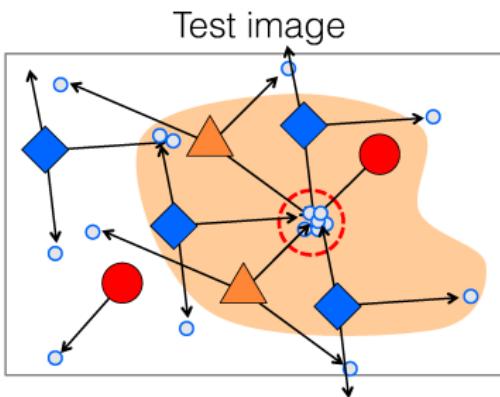
1. Get features

2. Store all displacements of feature from center

B. Test phase:

1. Get features & lookup displacements

2. Vote for center location



[Source: Kris Kitani]

Implicit Shape Model

- Implicit Shape Model adopts the idea of voting
- Basic idea:
 - Find interest points in an image
 - Match patch around each interest point to a training patch
 - Vote for object center given that training instance

Implicit Shape Model: Basic Idea

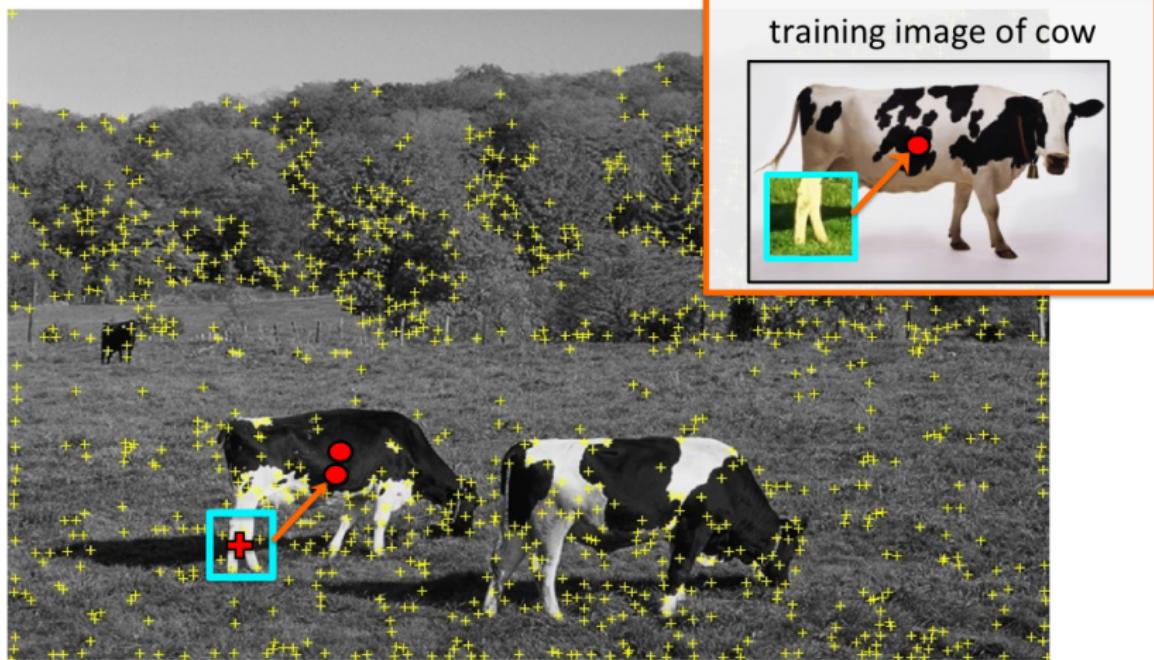
- Vote for object center



vote for center of object

Implicit Shape Model: Basic Idea

- Vote for object center



vote for center of object

Implicit Shape Model: Basic Idea

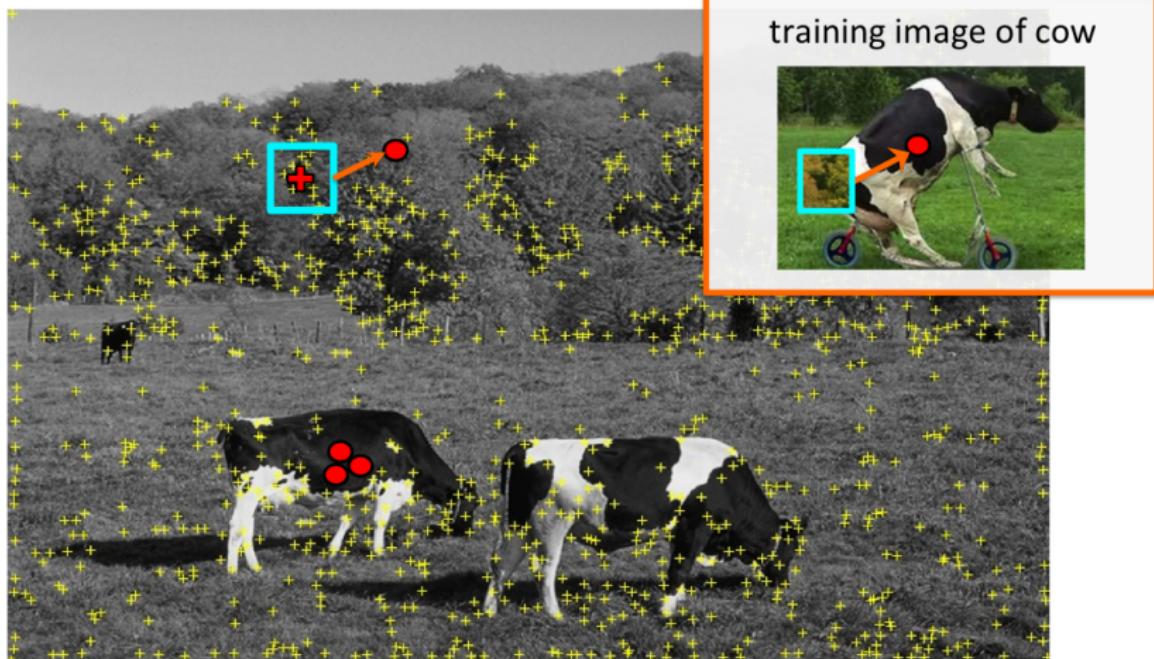
- Vote for object center



vote for center of object

Implicit Shape Model: Basic Idea

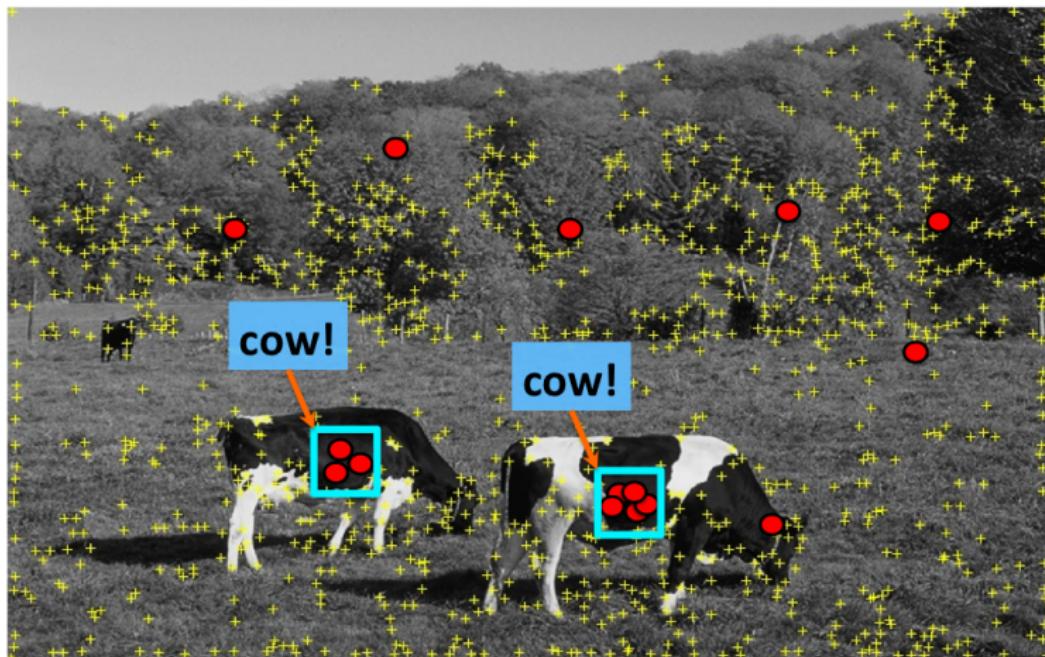
- Vote for object center



of course some wrong votes are bound to happen...

Implicit Shape Model: Basic Idea

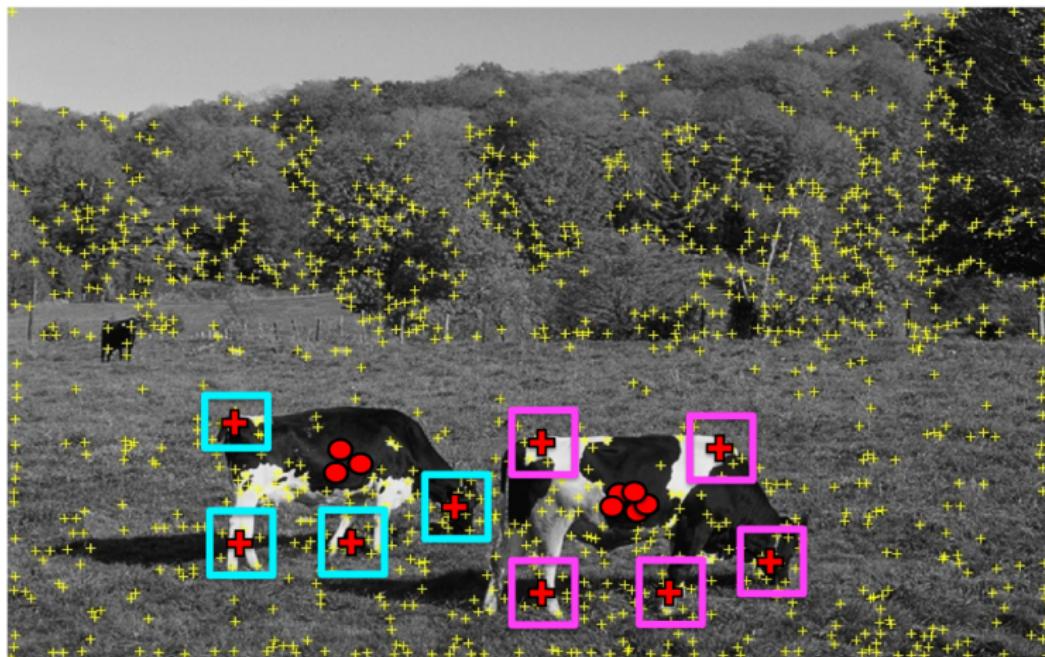
- Vote for object center



But that's ok. We want only **peaks** in voting space.

Implicit Shape Model: Basic Idea

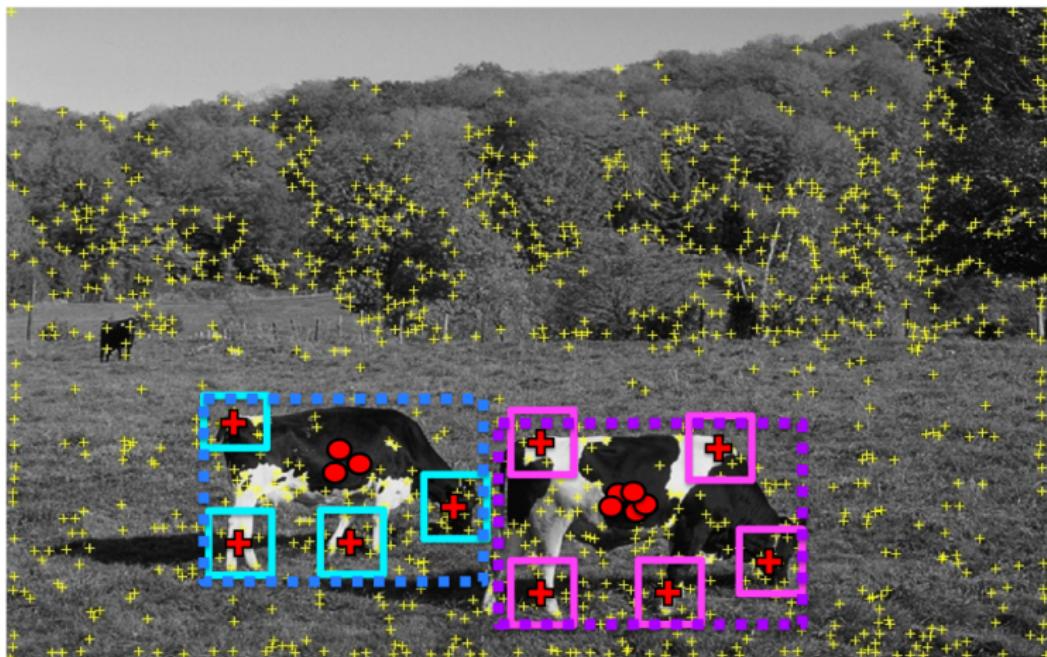
- Find the patches that produced the peak



Find patches that voted for the peaks (back-projection).

Implicit Shape Model: Basic Idea

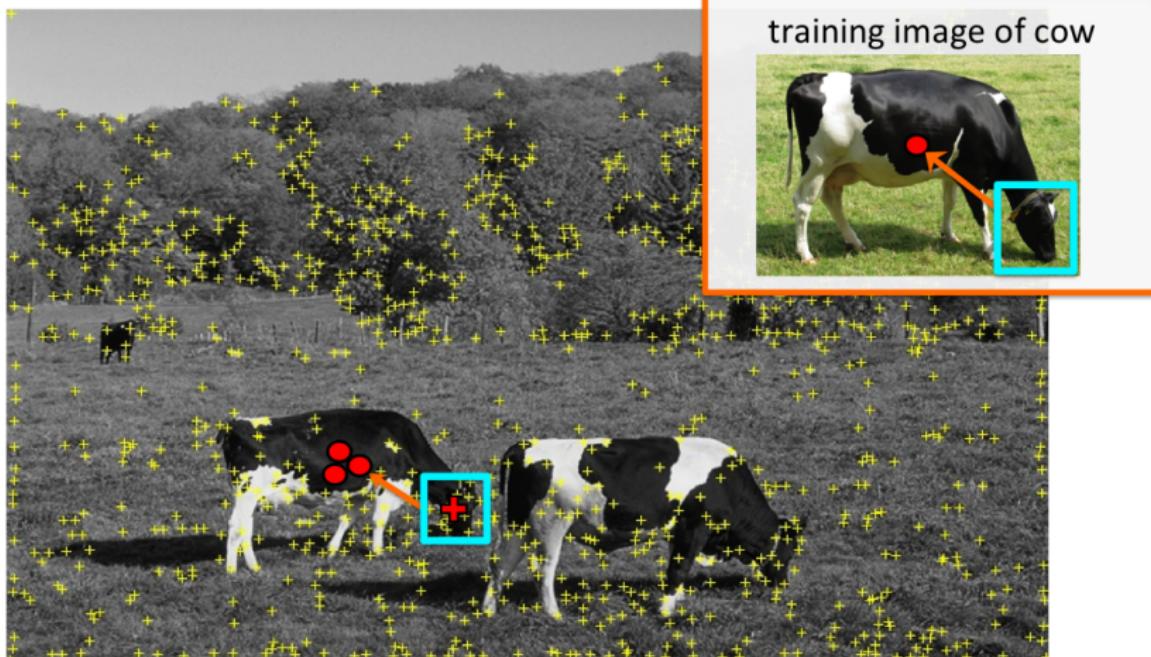
- Place a box around these patches → objects!



Find full objects based on the back-projected patches.

Implicit Shape Model: Basic Idea

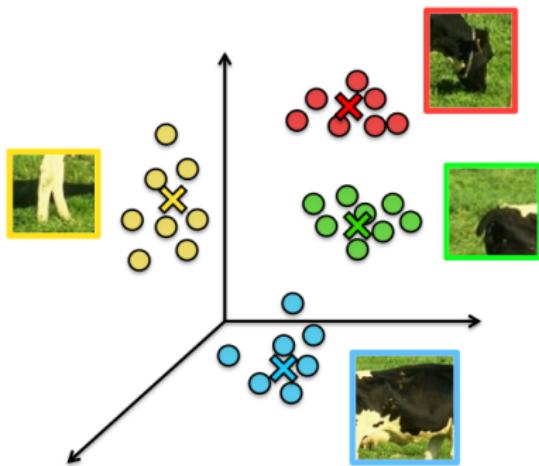
- Really easy. Only one problem... Would be slow... How do we make it fast?



we need to match a patch around each yellow + to all patches in all training images → **SLOW**

Implicit Shape Model: Basic Idea

- **Visual vocabulary** (we saw this for retrieval)
- Compare each patch to a small set of visual words (clusters)



Visual words (visual codebook)!

Implicit Shape Model: Basic Idea

- Training: Getting the vocabulary

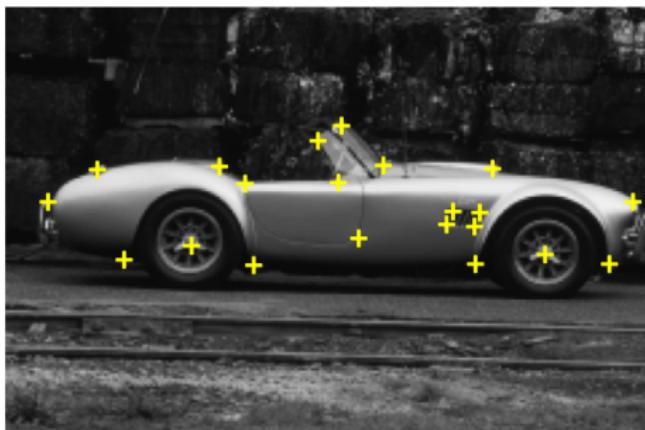
training image



Implicit Shape Model: Basic Idea

- Find interest points in each training image

training image

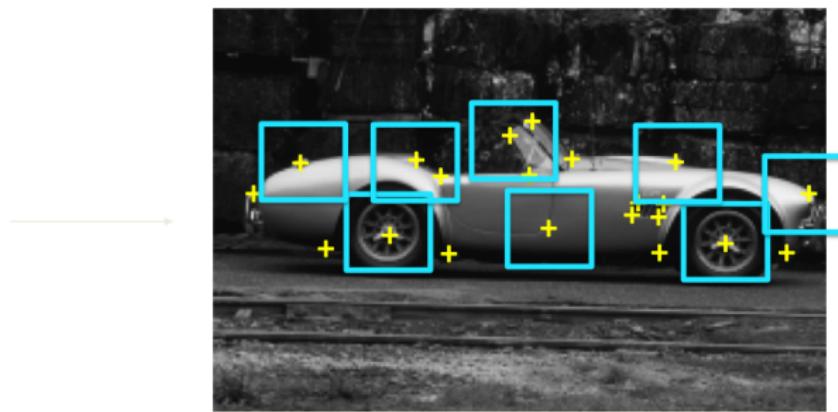


detect interest points (e.g. Harris)

Implicit Shape Model: Basic Idea

- Collect patches around each interest point

training image

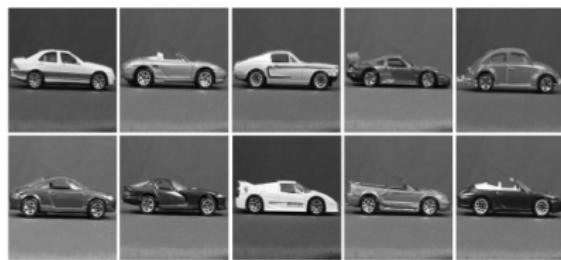


extract an image patch around each interest point

Implicit Shape Model: Basic Idea

- Collect patches across all training examples

training images



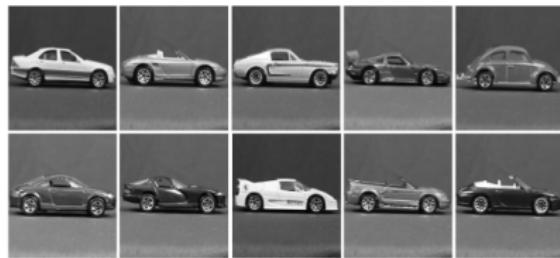
collect all patches



Implicit Shape Model: Basic Idea

- Cluster the patches to get a small set of “representative” patches

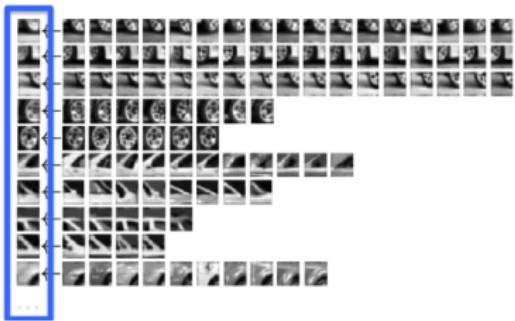
training images



collect all patches



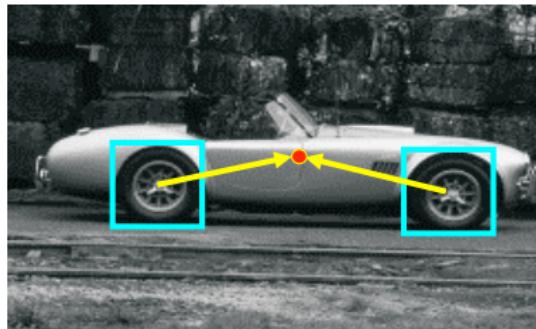
visual codebook



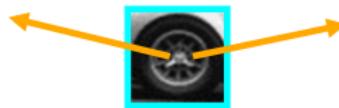
- cluster the patches to get a few “representative” patches
- each cluster represented as the average of all patches that belong to the cluster

Implicit Shape Model: Training

- Represent each training patch with the closest visual word.
- Record the displacement vectors for each word across all training examples.



Training image



Visual codeword with
displacement vectors

[Leibe et al. IJCV 2008]

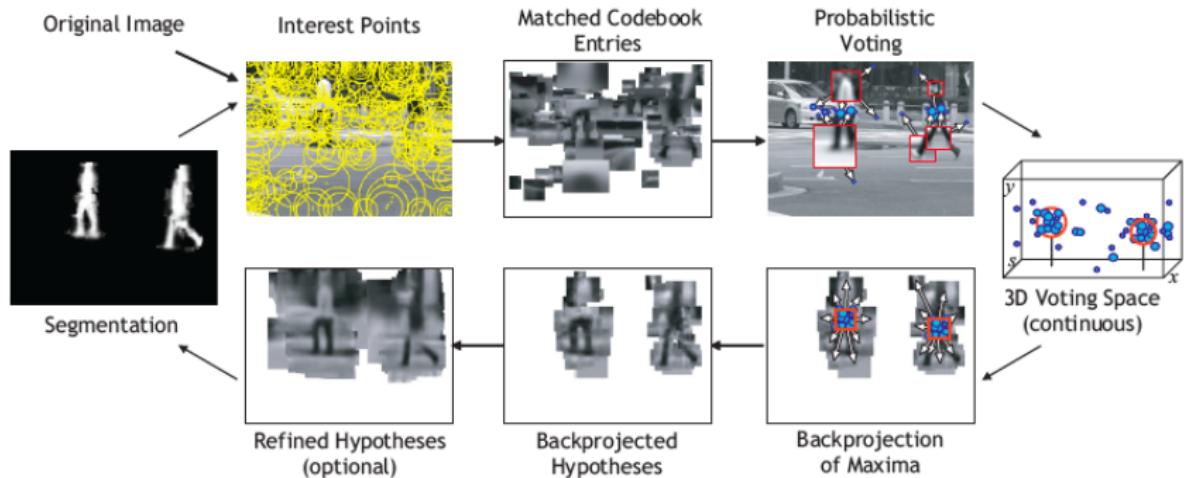
Implicit Shape Model: Test

- At test times detect interest points
- Assign each patch around interest point to closes visual word
- Vote with all displacement vectors for that word



[Source: B. Leibe]

Recognition Pipeline



[Source: B. Leibe]

Recognition Summary

- Apply interest points and extract features around selected locations.
- Match those to the codebook.
- Collect consistent configurations using Generalized Hough Transform.
- Each entry votes for a set of possible positions and scales in continuous space.
- Extract maxima in the continuous space using Mean Shift.
- Refinement can be done by sampling more local features.

[Source: R. Urtasun]

Example



Original image

[Source: B. Leibe, credit: R. Urtasun]

Example



Interest points

[Source: B. Leibe, credit: R. Urtasun]

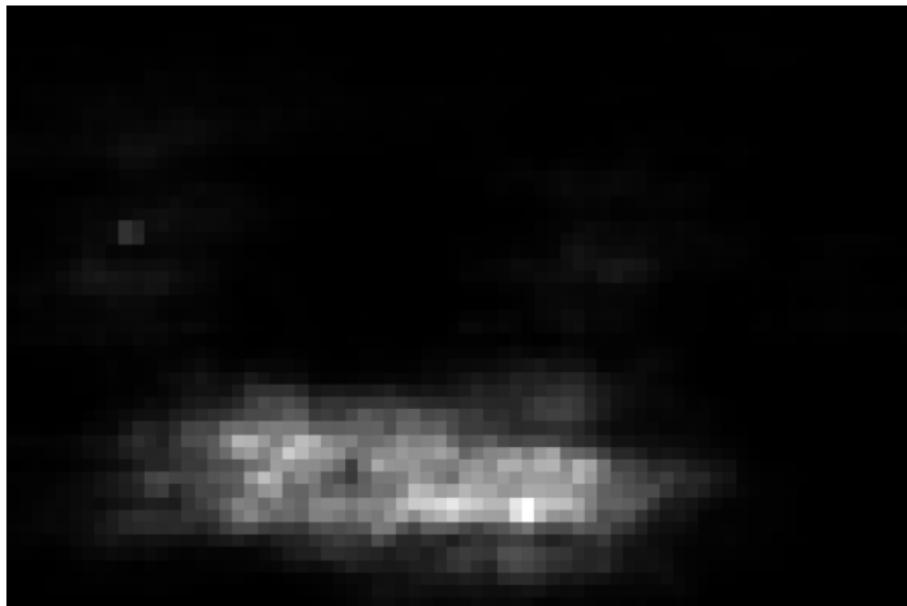
Example



Matched patches

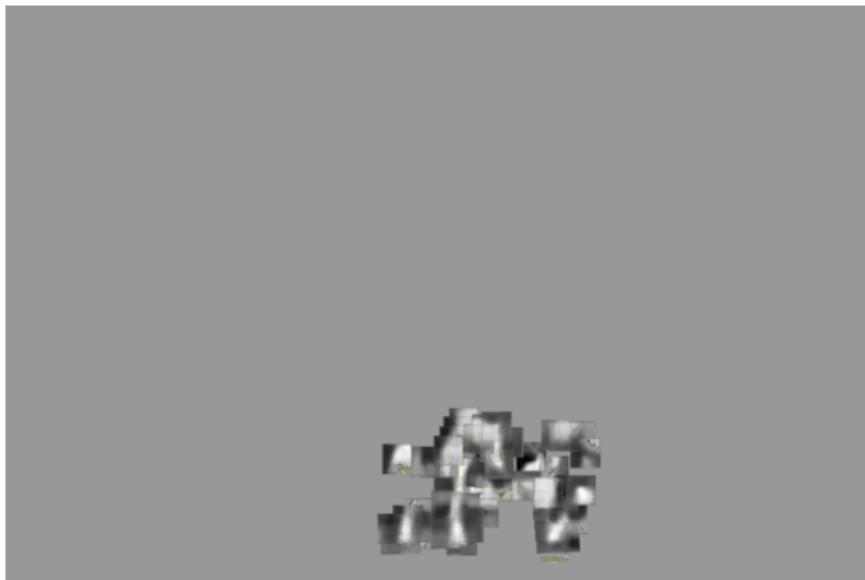
[Source: B. Leibe, credit: R. Urtasun]

Example



[Source: B. Leibe, credit: R. Urtasun]

Example



1st hypothesis

[Source: B. Leibe, credit: R. Urtasun]

Example



2nd hypothesis

[Source: B. Leibe, credit: R. Urtasun]

Example



3rd hypothesis

[Source: B. Leibe, credit: R. Urtasun]

Scale Invariant Voting

Scale-invariant feature selection

- Scale-invariant interest points
- Based on patches around interest points, at training time a codebook of visual words is created.
- Associated with each codebook entry, the displacements to object centre are stored along with the scale at which the interest point (mapped to the respective codebook entry) occurs... x_{occ} , y_{occ} , s_{occ} .

Scale Invariant Voting

Generate scale votes (Suppose an image feature was found at x_{img} , y_{img} , s_{img} , and gets mapped to a codebook entry that was observed while training at x_{occ} , y_{occ} , s_{occ} , then vote for the following location and scale:

- Scale as 3rd dimension in voting space

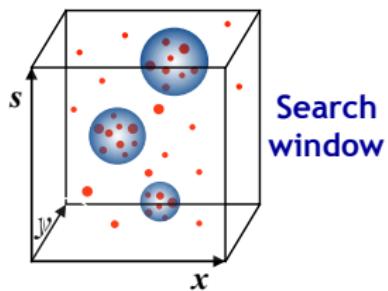
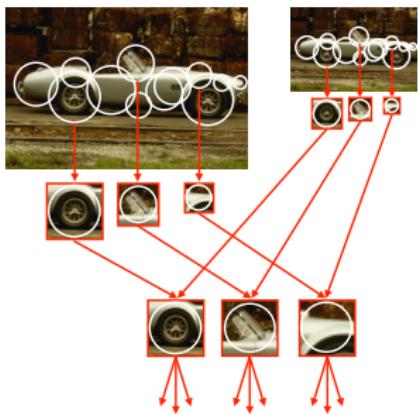
$$x_{vote} = x_{img} - x_{occ} \left(s_{img} / s_{occ} \right)$$

$$y_{vote} = y_{img} - y_{occ} \left(s_{img} / s_{occ} \right)$$

$$s_{vote} = s_{img} / s_{occ}$$

- Search for maxima in 3D voting space

Scale Invariant Voting

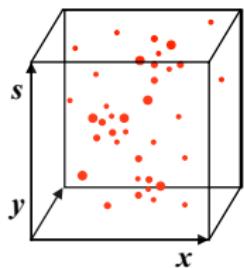


[Slide credit: R. Urtasun]

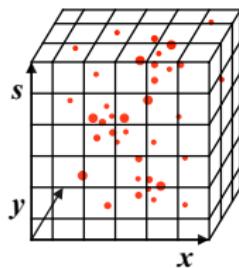
Scale Voting: Efficient Computation

Continuous Generalized Hough Transform

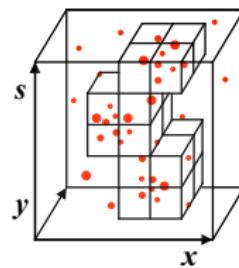
- Binned accumulator array similar to standard Gen. Hough Transf.
- Quickly identify candidate maxima locations
- Refine locations by Mean-Shift search only around those points
- Avoid quantization effects by keeping exact vote locations.



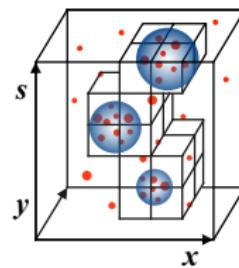
Scale votes



Binned
accum.
array



Candidate
maxima

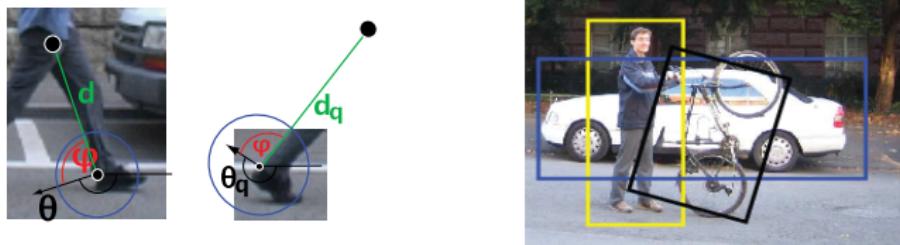


Refinement
(Mean-Shift)

[Source: B. Leibe, credit: R. Urtasun]

Extension: Rotation-Invariant Detection

- Polar instead of Cartesian voting scheme
- Recognize objects under image-plane rotations
- Possibility to share parts between articulations
- But also increases false positive detections



[Source: B. Leibe, credit: R. Urtasun]

Sometimes it's Necessary

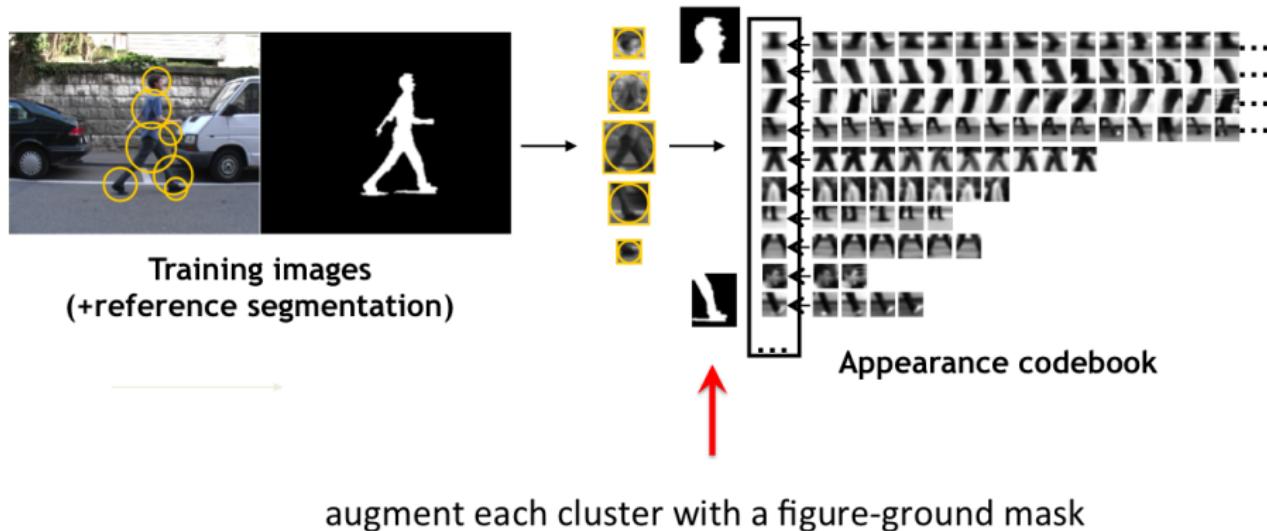


Figure from [Mikolajczyk et al., CVPR'06]

B. Leibe

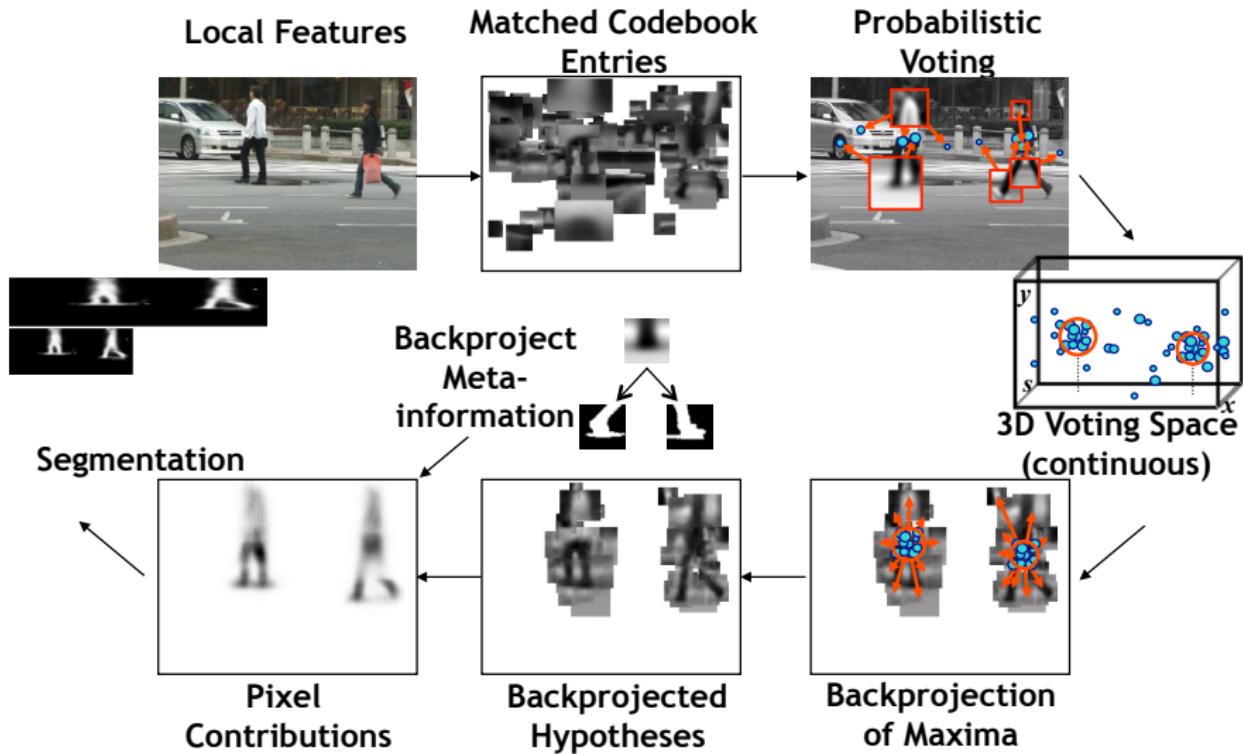
[Source: B. Leibe, credit: R. Urtasun]

Recognition and Segmentation

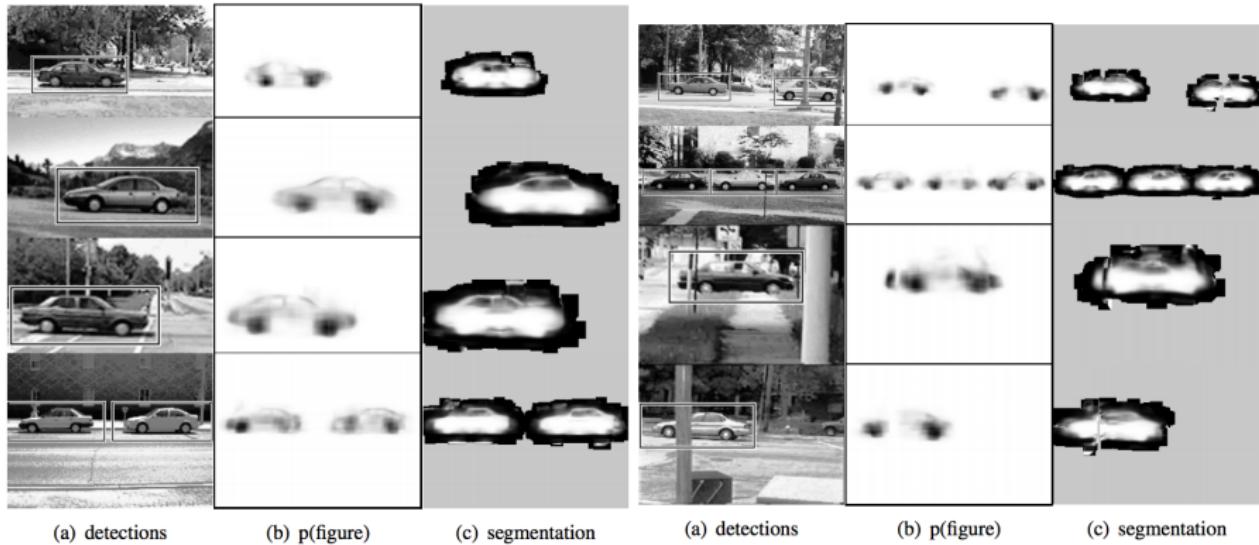


- Augment each visual word with meta-data: for example, segmentation mask

Recognition and Segmentation



Results



[Source: B. Leibe]

Results



[Source: B. Leibe]

Results



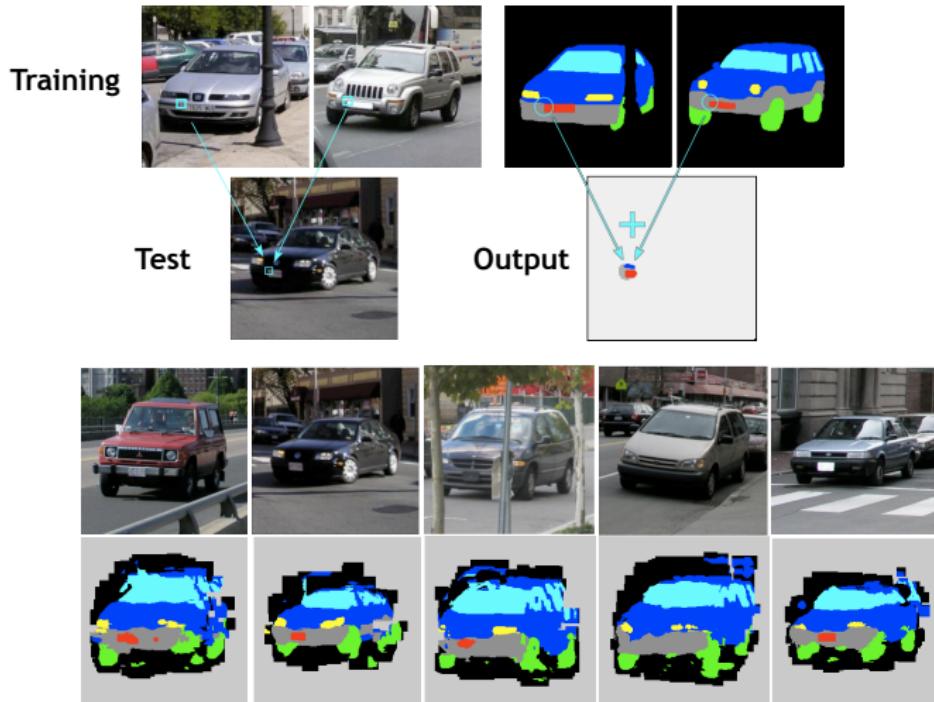
[Source: B. Leibe]

Results



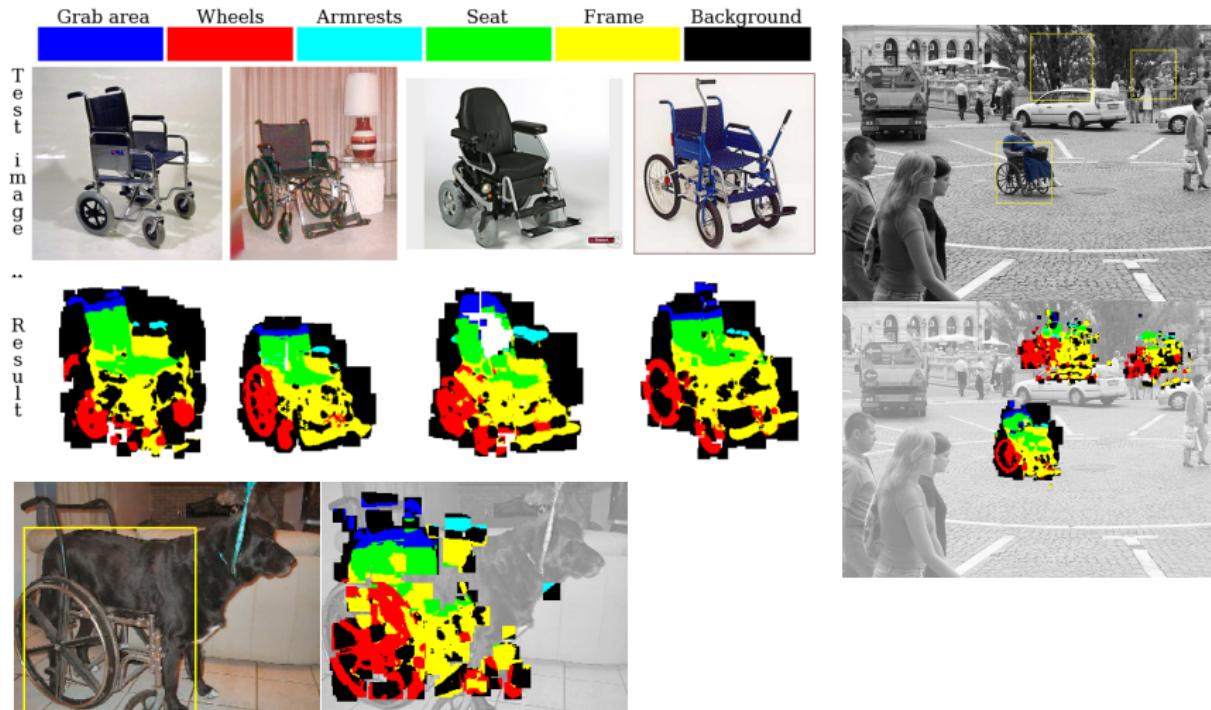
[Source: B. Leibe]

Inferring Other Information: Part Labels



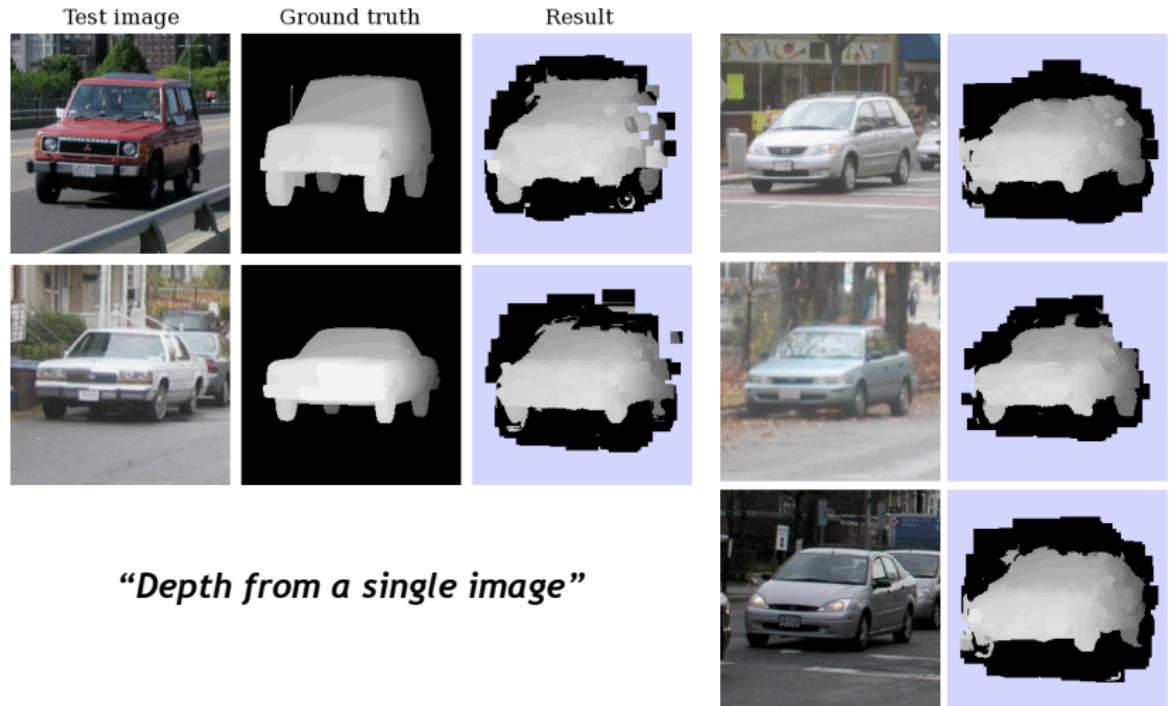
[Source: B. Leibe]

Inferring Other Information: Part Labels



[Source: B. Leibe]

Inferring Other Information: Depth



[Source: B. Leibe]

Conclusion

- Exploits a lot of parts (as many as interest points)
- Very simple Voting scheme: Generalized Hough Transform
- Works well, but not as well as Deformable Part-based Models with latent SVM training
- Extensions: train the weights discriminatively.
- Code, datasets & several pre-trained detectors available at
<http://www.vision.ee.ethz.ch/bleibe/code>

[Source: B. Leibe, credit: R. Urtasun]