Skeleton-search:
Category-specific object segmentation/recognition using a skeletal shape model

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Category-specific object recognition

• Q: Is there a giraffe in this image?
• A: Yes.
• Q: Really? Can you delineate it?
giraffe
Faces of Object Recognition

- **increasing difficulty**

- **giraffe**
  - Image classification
- **giraffe**
  - Object detection
- Segmentation + Part labeling

Skeleton Search:
Our goal
Top-down approach

1. How to represent shapes of an object category?
2. How to measure support for a shape in an image?
3. How to search for the best supported shapes?
Contributions

1. How to represent shapes of an object category?
   → Fragment-Based Generative Model for Shape

2. How to measure support for a shape in an image?
   → Improvement to Oriented Chamfer Matching

3. How to search for the best supported shapes?
   → Extension to the Viterbi algorithm to compute multiple solutions
1. How to represent shapes of an object category?
Giraffes in Images

Courtesy of Vittorio Ferrari
Giraffe Shapes
Giraffe Skeleton
Shared Skeletal Topology
Idea:
Represent a shape using its skeleton
Intrinsic Symmetry-based Shape Model (Trinh and Kimia (ICCV07))
Intrinsic Shape Model for Segmentation

• **Drawback:** global dependency of each fragment’s boundary on other fragments.

• **New model:** able to reconstruct each fragment **LOCALLY** from its adjacent nodes.
Fragment-Based Generative Model for Shape

Parameter Set $Z = \{z_0, z_1, \ldots, z_N\}$

Degree-2 node: 5 parameters

Degree-3 node: 6 parameters
• Interpolate $A \rightarrow B$ and $D \rightarrow C$ contours using smooth bi-arcs (Kimia et al., IJCV 2003).
Generative Model
2. How to measure support for a shape in an image?
Cost function

- Cost of a shape = sum of its fragments’ costs.

\[ f(Z) = \sum_{i=1}^{N} f_i(F_i) \]

\[ = \sum_{i=1}^{N} f_i(z_i, z_j) \]
Cost of a shape fragment

\[ f_i(F_i) = g_i(F_i) + d_i(F_i) \]

- **Shape prior**: uniform distribution on the fragment’s intrinsic parameters.
- **Image support**:
  - Region appearance
  - Edge support for pair of boundary contours

\[ f_i(F_i) = g_i(F_i) + d_i(F_i) \]
Oriented Chamfer Matching (OCM)
(Shotton et al, PAMI’08 and Jain et al, CVIU’07)
Oriented Chamfer Matching (OCM)  
(Shotton et al, PAMI’08 and Jain et al, CVIU’07)

• Match each contour point to its closest edge

• OCM cost:

\[
d_{OCM} = \frac{1}{N} \sum_{i=1}^{N} \left[ \lambda_1 \min \left( \frac{d_i}{\tau_1}, 1 \right) + \lambda_2 \min \left( \frac{\theta_i}{\tau_2}, 1 \right) \right]
\]

- normalized distance
- normalized orientation difference
Drawbacks of OCM

- Over-counting support when edges missing.
- Under-counting support when many spurious edges present.
- Awarding accidental alignment.
Improvement: Contour Chamfer Matching (CCM)

- Partition edges into thin stripes.
- Match contour points to image edges using OCM cost.
- Penalize orientation discrepancies between query contour and the contour connecting image edges.

\[
\begin{align*}
W_i & \quad 2\varepsilon \\
2\tau_0 & \\
\end{align*}
\]
How to search for the best supported shapes?
Single Global Solution

- Use Viterbi algorithm on a tree.

\[ f(Z) = \sum_{i=1}^{N} f_i(z_i, z_{\hat{i}}) \]

\[ Z^* = \arg\min_{Z} f(Z) \]
The need for multiple solutions
Single-Pass Multiple Solution Using DP

- **Candidate pool**: optimal solutions for each position of root node.
- **Differential Exclusion Principle**
- **Trimming**: discarding non-max solutions the candidate pool.
Experiments
Dataset: ETHZ Shape Classes

- 255 images
- 5 categories: giraffes, bottles, apple logos, swans, mugs.

Courtesy of Vittorio Ferrari
Detection / Segmentation - Giraffes
Detection/Segmentation - Bottles
Detection/Segmentation - Swans
Detection/Segmentation - Applelogos
Detection/Segmentation - Mugs
False Positives
Object Detection Evaluation

• PASCAL criterion:

\[
\frac{\text{area}(\text{det} \cap \text{gt})}{\text{area}(\text{det} \cap \text{gt})} \geq 0.5
\]
Object Detection Performance

- Zhu ECCV08 - Contour Selection
- Ferrari TR08 - using hand drawn model
- Ravishankar ECCV08
- Our method
Evaluation: Segmentation Performance

(Ferrari et al, INRIA Tech Report 2008)

- **Boundary Coverage**: proportion of the ground-truth that is close to the segmented shape.
- **Boundary Precision**: proportion of the segmented shape that is close to the ground-truth.
Performance – boundary coverage

- **Bounding box**
- **Ferrari TR 2008**
- **Our method**
Performance – Boundary Precision

- **Bounding box**
- **Ferrari TR08**
- **Our method**
Summary

• A skeleton-based generative model for shape where each fragment can be reconstructed locally.
• Improvement to Oriented Chamfer Matching cost.
• Extension to Viterbi algorithm to compute multiple solutions in a single pass.
Thank you

Questions?

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