Evaluating Segmentation

David Martin
dmartin@cs.bc.edu
Computer Science Department
Boston College
How do you know when a segmentation algorithm is good?
How do you know when a segmentation algorithm is good?

(1) The results look good on these two images.*

* Not acceptable!
How do you know when a segmentation algorithm is good?

(2) Higher performance on the standard vision application test suite as a result of using the improved segmentation sub-system.*

How do you know when a segmentation algorithm is good?

(3) It performed well on a standard segmentation benchmark.*

* Let’s talk!
Benchmarks are Good

Requirements:
• A clear problem specification.
• A representative dataset.
• An evaluation methodology.

Successes:
• Handwritten digit recognition (MNIST)
• Face recognition (FERET, CMU PIE)
• Object recognition (COIL, Trademarks, Web Images)
Layered Benchmarks: A Necessary Result of Complexity

High-level end-to-end application-level benchmarks
• Systems: Database TPS on TPC workload
• Vision: DARPA-sponsored robot race across So. Cal. desert

Mid-level sub-system benchmarks
• Systems: Lock manager, block cache, TCP stack, query planner
• Vision: Tracking, segmentation, pose estimation

Low-level micro-benchmarks
• Systems: CPU functional units/cache, disc seeks
• Vision: Edge detection, optical flow
Layered Benchmarks: Where are the challenges?

*High-level end-to-end application-level benchmarks*
- **Hard**: Specification, Dataset
- **Easy**: Measurement

*Mid-level sub-system benchmarks*
- **Hard**: Specification, Dataset, Measurement
- **Easy**: None

*Low-level micro-benchmarks*
- **Hard**: Measurement
- **Easy**: Dataset, Specification
Def: Segmentation

(1) A division of the pixels of an image into disjoint groups (where the groups correspond to objects or parts of objects).
Def: Segmentation

(1) A division of the pixels of an image into disjoint groups.

(2) The partition given by a binary pixel affinity function $s$, where $s(i,j)=1$ when pixels $i$ and $j$ belong together, and $s(i,j)=0$ otherwise.
Step #1: Define Segmentation

(1) A division of the pixels of an image into disjoint groups.

(2) The partition given by a binary pixel affinity function $s(i,j)$.

(3) The set of edge elements (edgels) denoting segment boundaries. An edgel has a location and orientation.
Step #2: Representative Dataset
Step #2.5: Groundtruthing

You will be presented a photographic image. Divide the image into some number of segments, where the segments represent “things” or “parts of things” in the scene. The number of segments is up to you, as it depends on the image. Something between 2 and 30 is likely to be appropriate. It is important that all of the segments have approximately equal importance.

- Custom segmentation tool
- Subjects obtained from work-study program (UC Berkeley undergraduates)
Dataset Summary

• 30 subjects, age 19-23
  – 17 men, 13 women
  – 9 with artistic training
• 8 months
• 1,458 person hours
• 1,020 Corel images
• 11,595 Segmentations
  – 5,555 color, 5,554 gray, 486 inverted/negated
What is your $s(i,j)$?

Do you even have one?
Step #3: Measuring Error

Approach: Region overlap
\[ E(S_1, S_2, p_i) = \frac{|R(S_1, p_i) \setminus R(S_2, p_i)|}{|R(S_1, p_i)|} \]
\[ E(S_1, S_2, p_i) = \frac{|R(S_1, p_i) \backslash R(S_2, p_i)|}{|R(S_1, p_i)|} \]
Local Refinement Error

\[ E(S_1, S_2, p_i) \]

\[ E(S_2, S_1, p_i) \]
Min \( E(S_1, S_2) \)

Min \( E(S_2, S_1) \)

LCE
LCE Between Pairs of Human Segmentations
$S_1$  \[ E(S_1, S_2) \]  \[ \text{Max} \]  \[ \text{BCE} \]

$S_2$  \[ E(S_2, S_1) \]  \[ \text{Min} \]  \[ \text{LCE} \]

CVPR 2004 Graph-Based Image Segmentation Tutorial
Step #3 (again): Measuring Error

Approach: Edgel matching
How do we correspond boundary elements?
Simply overlaying does not work...
Compute correspondence via min-cost assignment on bipartite graph.
Groundtruth + Signal
Groundtruth + Signal
### ROC vs. Precision/Recall

<table>
<thead>
<tr>
<th>Truth</th>
<th>P</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>P</td>
<td>TP</td>
</tr>
<tr>
<td>N</td>
<td>FN</td>
<td>TN</td>
</tr>
</tbody>
</table>

**Hit Rate** = \( \frac{TP}{TP+FN} \)

**False Alarm Rate** = \( \frac{FP}{FP+TN} \)

**ROC Curve**

**PR Curve**

Precision = \( \frac{TP}{TP+FP} \)

Recall = \( \frac{TP}{TP+FN} \)

**F Measure** = \( \frac{2PR}{P+R} \)

\[
F = \frac{2}{\left(R^{-1}+P^{-1}\right)} = \frac{2PR}{(P+R)}
\]
PR Curve

Goal
(P=R=F=1)

Fewer False Positives

Fewer Misses
But how do we compute hits, misses, and false positives?
Fast min-cost assignment for sparse graphs?

- Andrew Goldberg’s CSA package for max-flow / min-cut graph problems
- Sparse graphs
- Linear time (!)
- C code, but I have C++ / MATLAB wrappers
Advantages of edgel matching over region overlap

- Far more discriminative
  - More sensitive to boundary complexity
  - Does not match offset interiors
- Intuitive measures and units
  - Detection-oriented framework
- Both a low-level and mid-level benchmark
  - Sensible for evaluating both edges and regions
  - Leverage data collection / groundtruthing cost
  - We can quantify improvement between levels
One last error measure…

A micro-benchmark for $W(i,j)$, the internal representation used in spectral clustering algorithms.
Image $\rightarrow$ EigenBoundaries $\rightarrow$ P(boundary) $\rightarrow$ Segments $\rightarrow$ Groundtruth

$W(i,j)$
Task: Evaluate $W(i,j)$ given $S(i,j)$

$W(i,j)$ is real-valued, $S(i,j)$ is binary-valued

1. Compute mutual information between $W$ and $S$
Task: Evaluate $W(i,j)$ given $S(i,j)$

$W(i,j)$ is real-valued, $S(i,j)$ is binary-valued

1. Compute mutual information between $W$ and $S$
2. Treat $W$ as a detector for $S$, and compute PR curves as before.
Task: Evaluate $W(i,j)$ given $S(i,j)$

$W(i,j)$ is real-valued, $S(i,j)$ is binary-valued

- Compute mutual information between $W$ and $S$
- Treat $W$ as a detector for $S$, and compute PR curves as before

- Equally discriminative
- Equally arbitrary
- PR curve more informative
Summary

- Benchmarks are worth the effort
  - Borrow techniques from other areas
- Leverage dataset/groundtruth effort by formulating benchmarks at many levels
  - Application-level / Mid-Level / Micro
- Edgel matching is our measure of choice
  - Intuitive, flexible, useful
- Code & Data:
  - http://www.cs.berkeley.edu/projects/vision/grouping