Segmentation Induced by Scale Invariance

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Task: Segment Images of Variety and Complexity

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Challenge: Illusory Contour and Texture Dilemma

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edges $\overset{?}{\Rightarrow}$ boundaries

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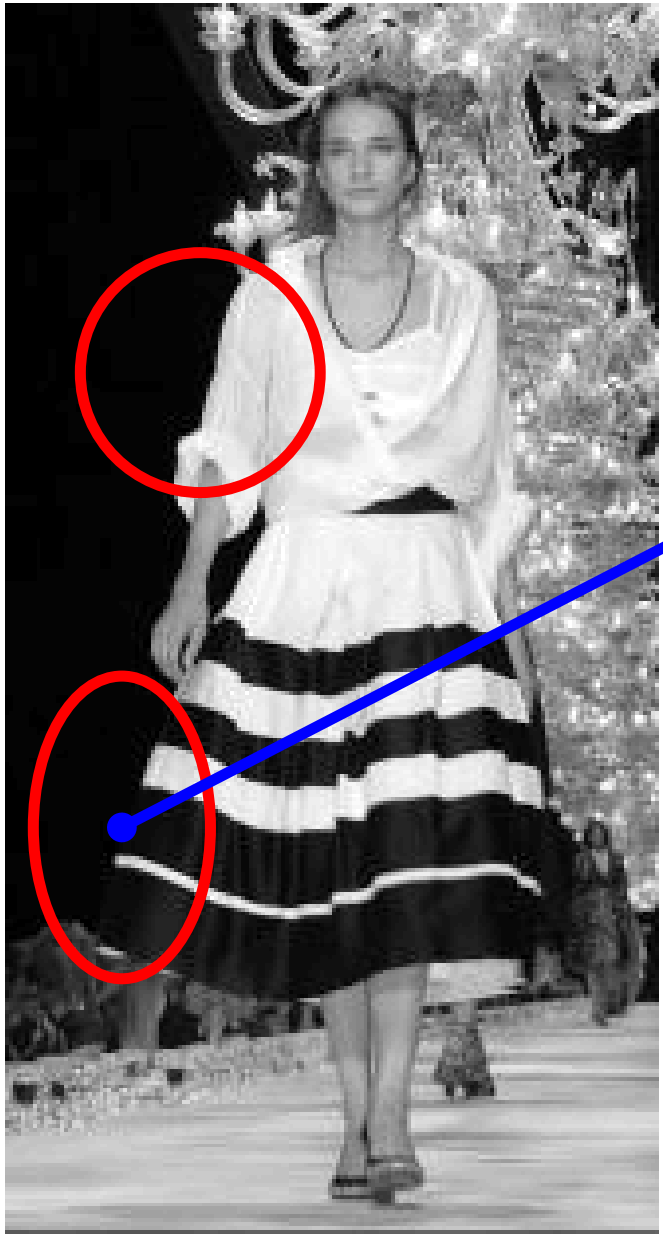
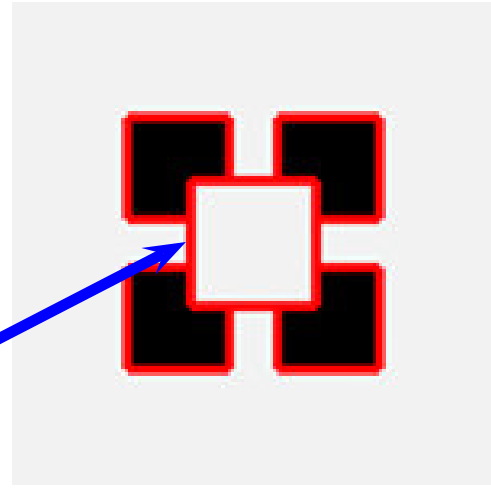


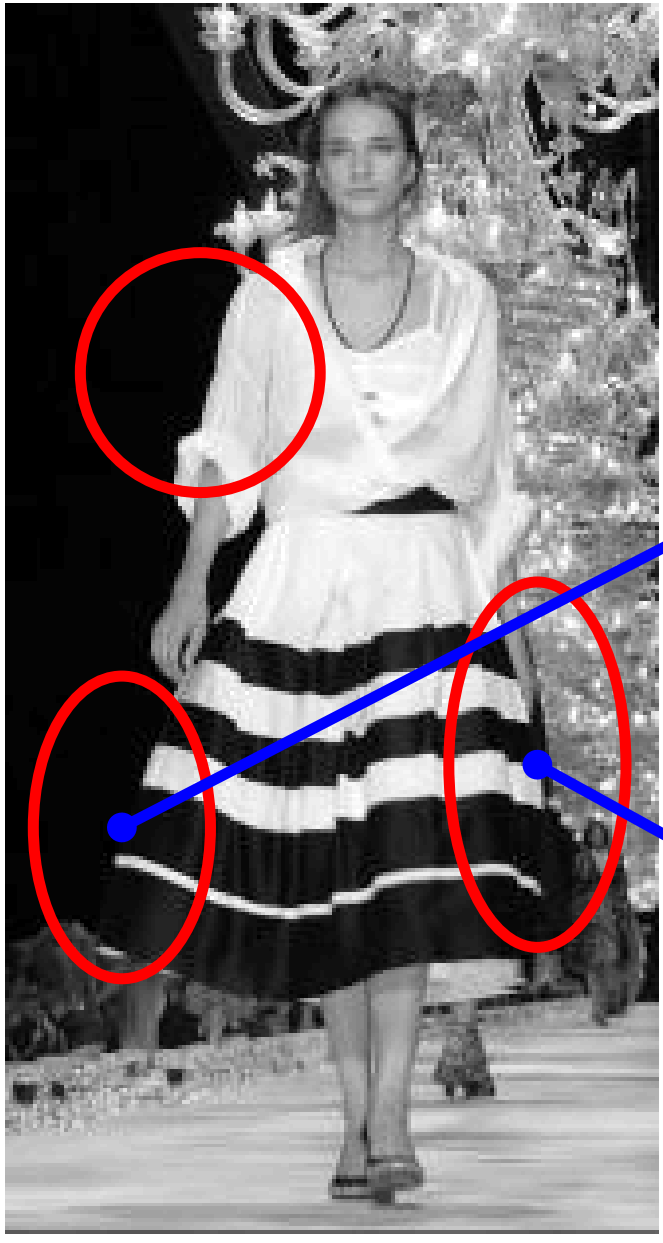


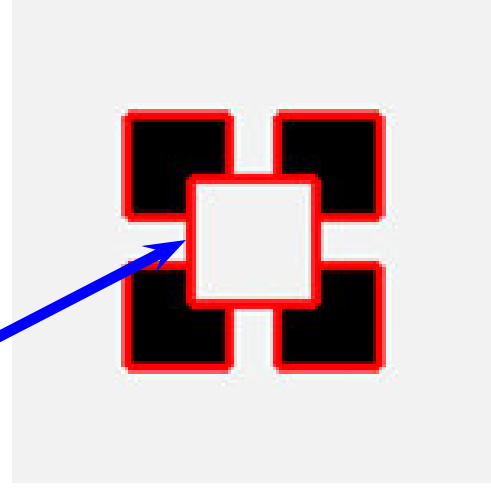
edges $\overset{?}{\Rightarrow}$ boundaries

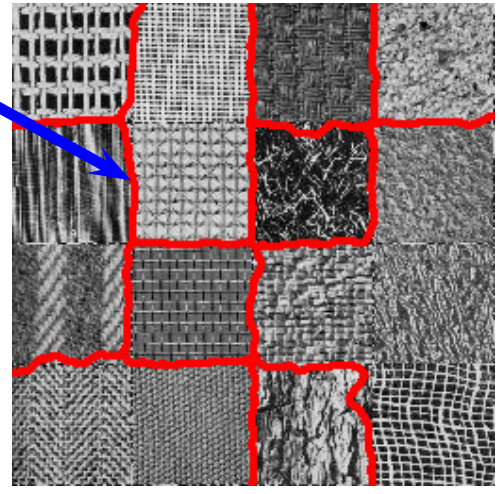
missing edges $\Rightarrow$ gaps

precise continuation

Challenge: Illusory Contour and Texture Dilemma







edges $\overset{?}{\Rightarrow}$ boundaries

missing edges $\Rightarrow$ gaps

precise continuation

massive edges $\Rightarrow$ noise

window discrimination

Overview: Specialized vs. General-Purpose

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1. Contour Completion — Williams & Jacobs

- Good at small gaps on smooth curves
- Poor at junctions/texture; local scale critical

2. Texture Segmentation — Hofmann et al

- Fine discrimination with specific training
- Oblivious to contrast; local scale critical

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3. Hybrid Approaches — Tu & Zhu, Malik et al

- Contours and texture explicitly monitored
- Cross interference among features or models

4. Integrated Approach — Yu

- **Single mechanism based entirely on edges**

Insight: Perception Is Scale-Invariant

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Insight: Perception Is Scale-Invariant

Insight: Seek Scale-Invariant Segmentation

Segmentation rated good
at all scales
is the desired one.

Model Outline: The One Good For All Scales

Q1: How to score a segmentation over edges at a single scale?

A1: Elongated Intervening Contours.

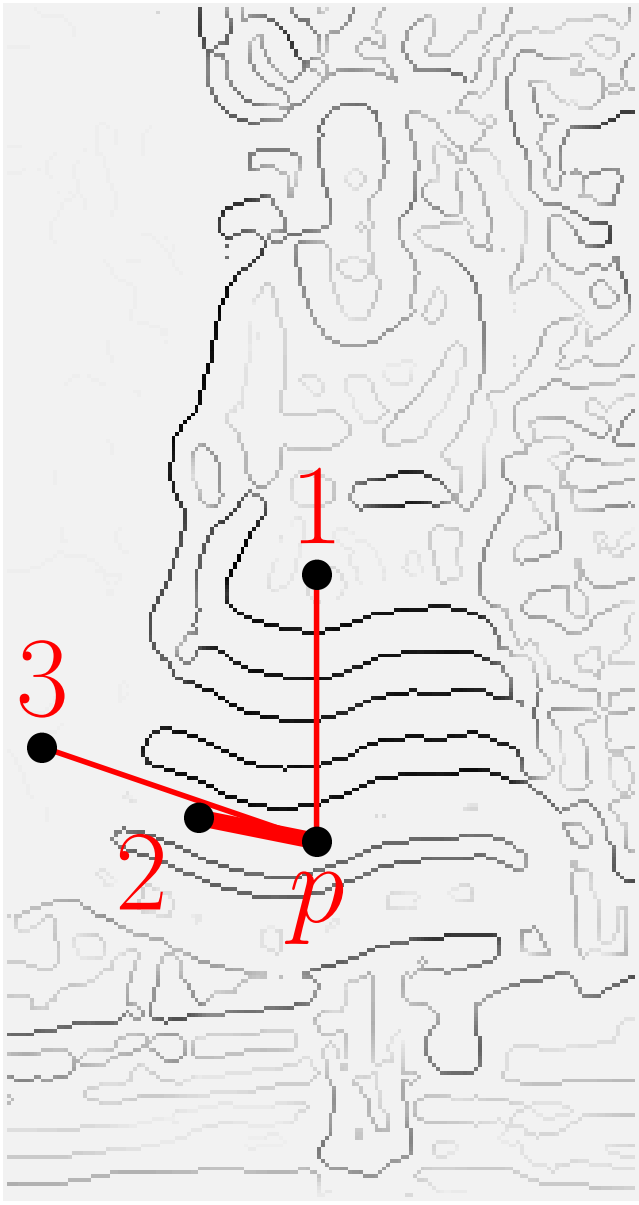
Q2: How to relate these scores across scales?

A2: Interior Pixels.

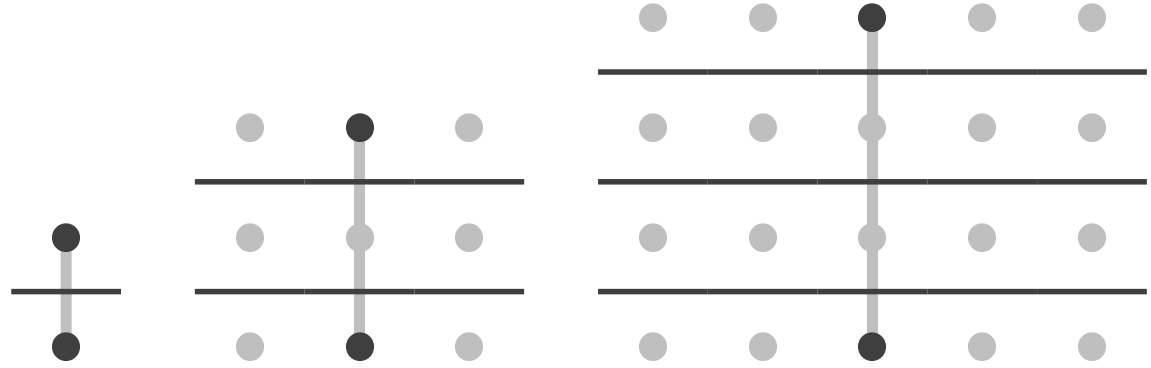
Q3: How to integrate these scores over space and scales?

A3: Spectral Graph Cuts.

Local Scores: Elongated Intervening Contours



Pixel Affinity $\propto$ (Inbetween Edges)$^{-1}$



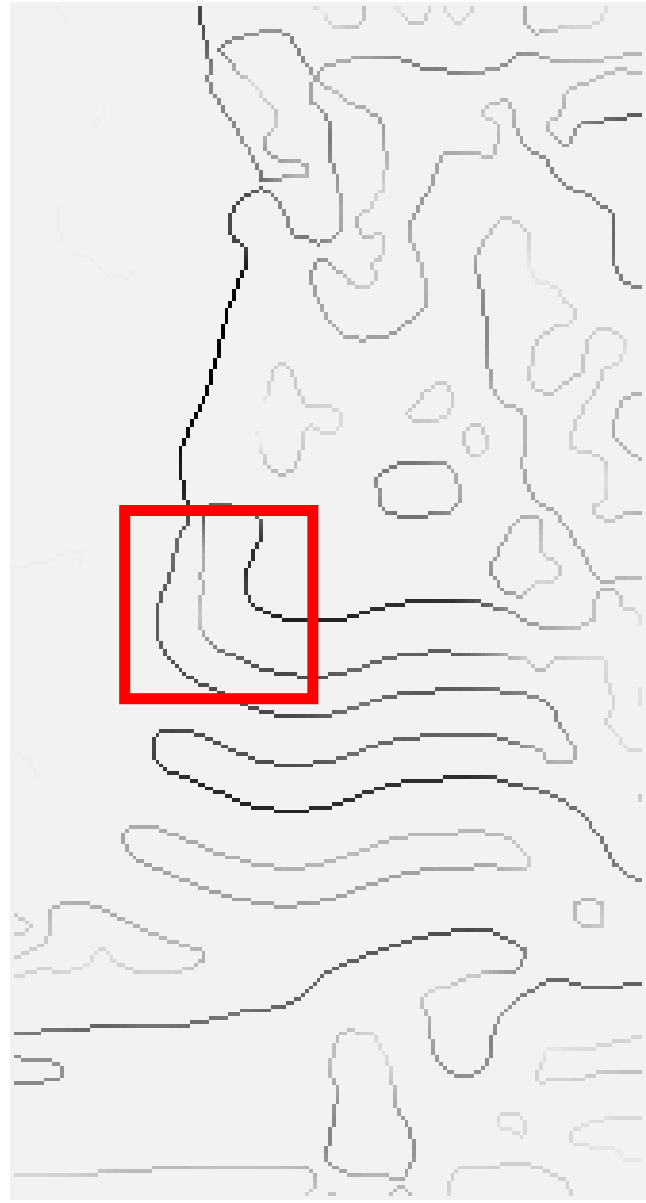
intensity similarity

closure

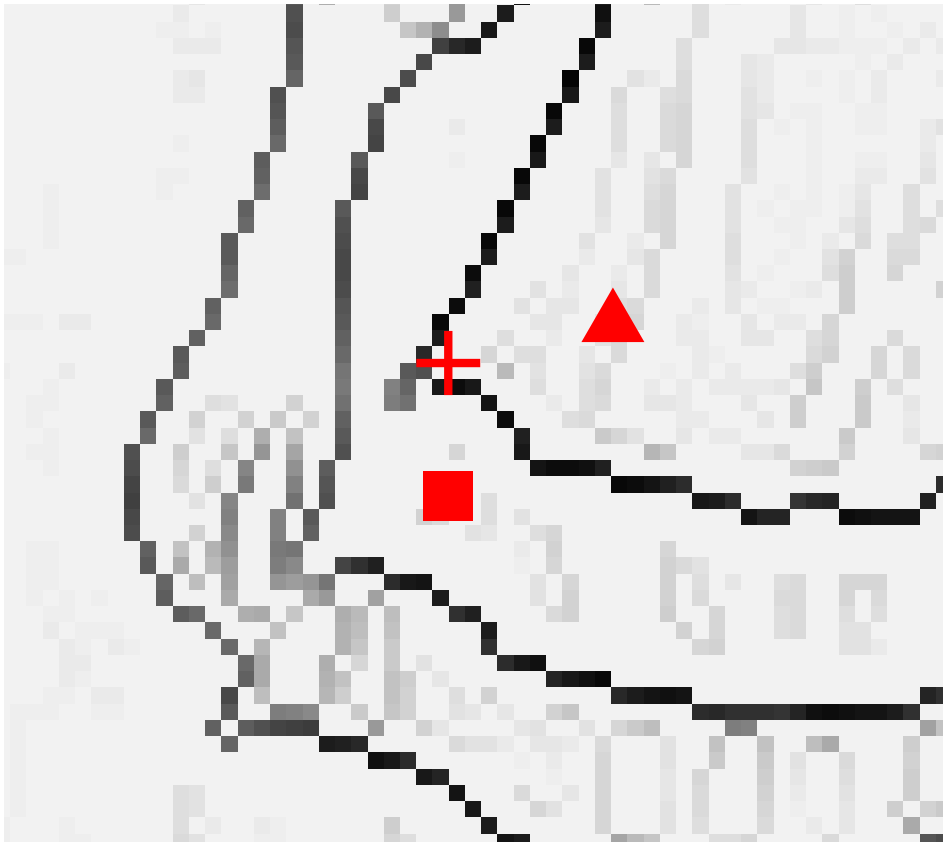
convexity

curvilinearity

Relate Scores: Edges At Different Scales



Relate Scores: Consistency Of Pixel Affinity



$(+, \blacktriangle) = 1$
$(+, \blacksquare) = 0$

No!

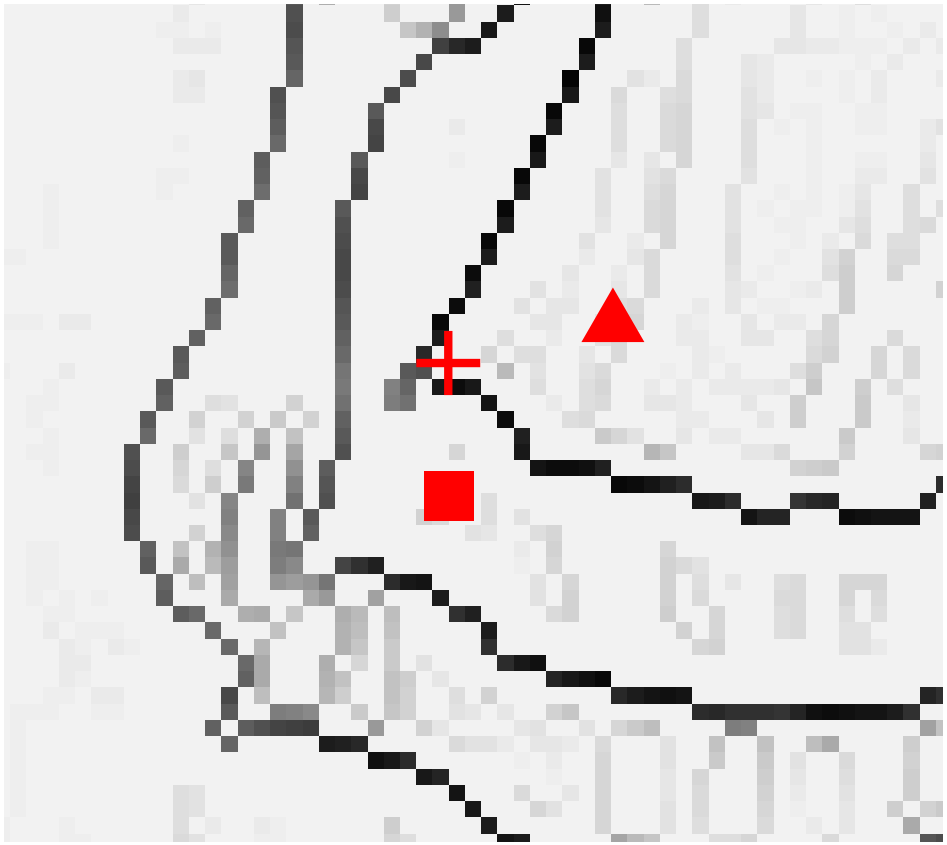
$(+, \blacktriangle) = 0$
$(+, \blacksquare) = 1$

$(\blacktriangle, \blacksquare) = 0$

Yes!

$(\blacktriangle, \blacksquare) = 0$

Relate Scores: Correspondence By Interior Pixels



$+ \Rightarrow \blacktriangle$

$\blacktriangle \Rightarrow \blacktriangle$

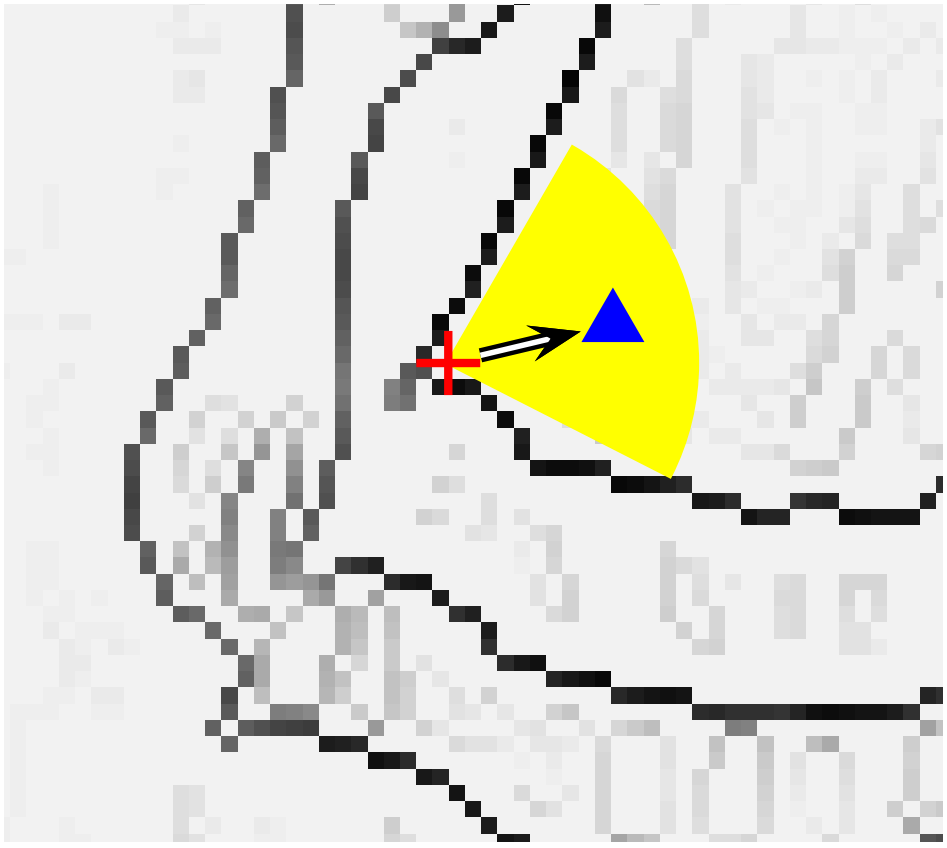
$\blacksquare \Rightarrow \blacksquare$

$(+, \blacktriangle) = (\blacktriangle, \blacktriangle) = 1$

$(+, \blacksquare) = (\blacktriangle, \blacksquare) = 0$

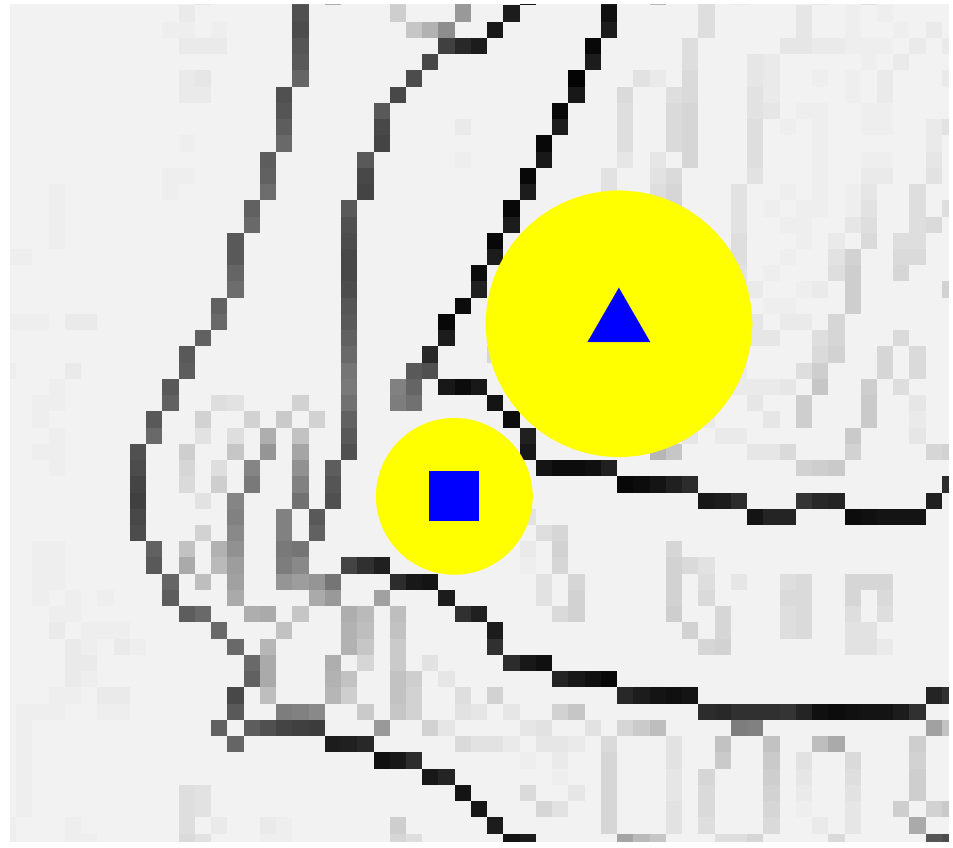
$(\blacktriangle, \blacksquare) = (\blacktriangle, \blacksquare) = 0$

Relate Scores: Interior Pixels By Affinity Centers



Affinity Center(+) = ▲

Shift inward for border pixels

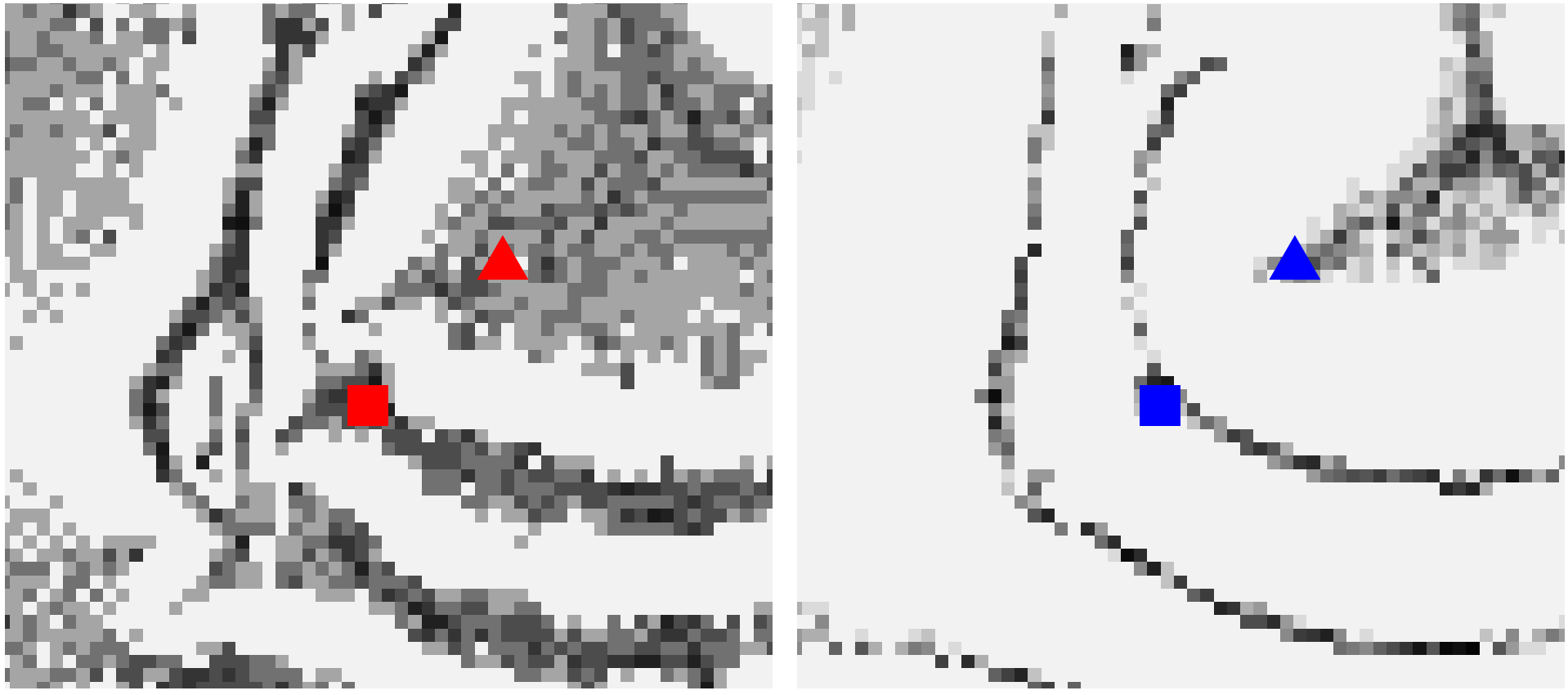


Affinity Center(▲) = ▲

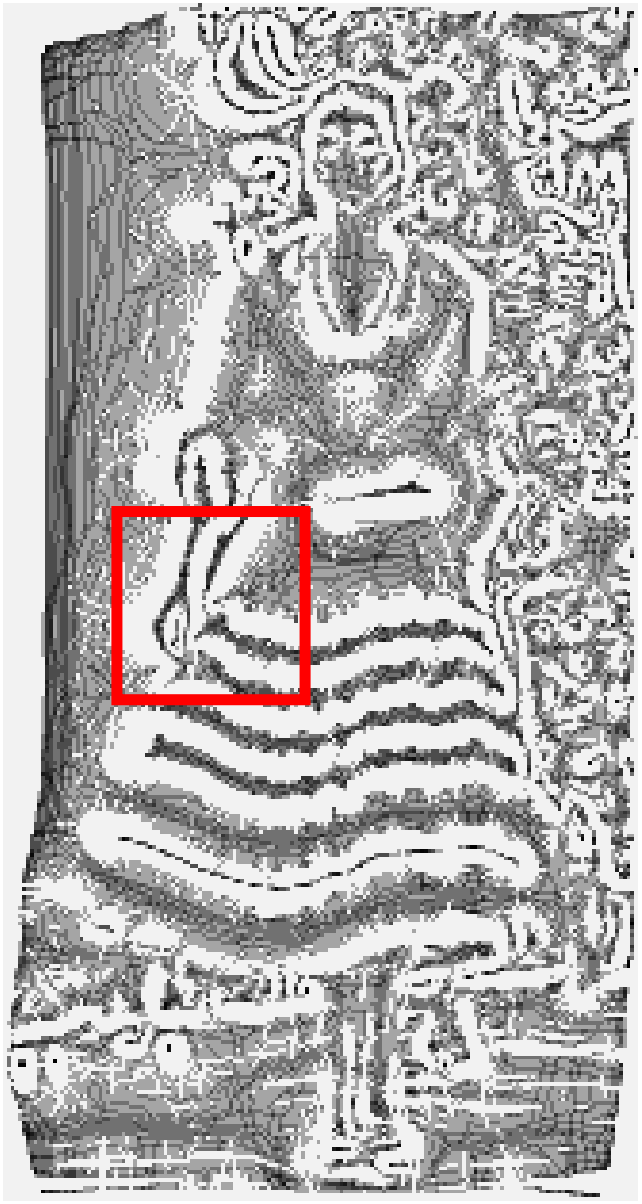
Affinity Center(■) = ■

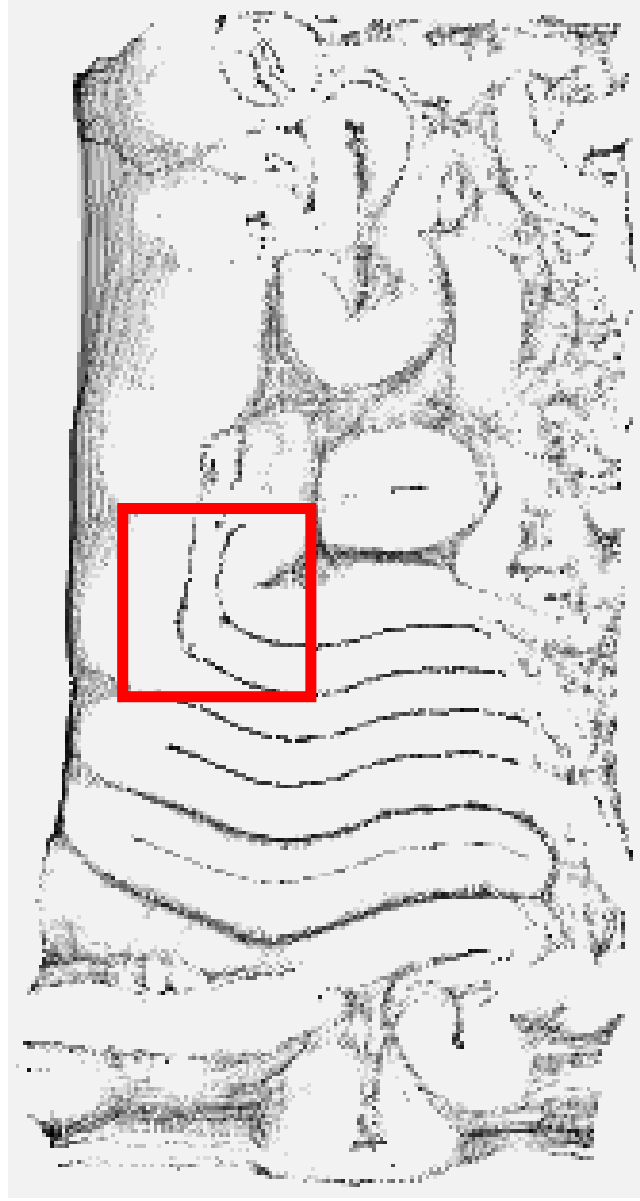
Stay for interior pixels

Relate Scores: Interior Pixels



Relate Scores: Interior Pixels





Integrate Scores: Spectral Graph Cuts

Criterion: Average Cuts of Normalized Affinity

$$\text{satisfaction}(p;s) = \sum_q \frac{A_s(p,q) : p,q \text{ in one group}}{\text{total affinity } p \text{ has}}$$

$$\text{score}(s) = \sum_k \frac{\sum_{p \in \text{group } k} \text{satisfaction}(p;s)}{\text{size of group } k}$$

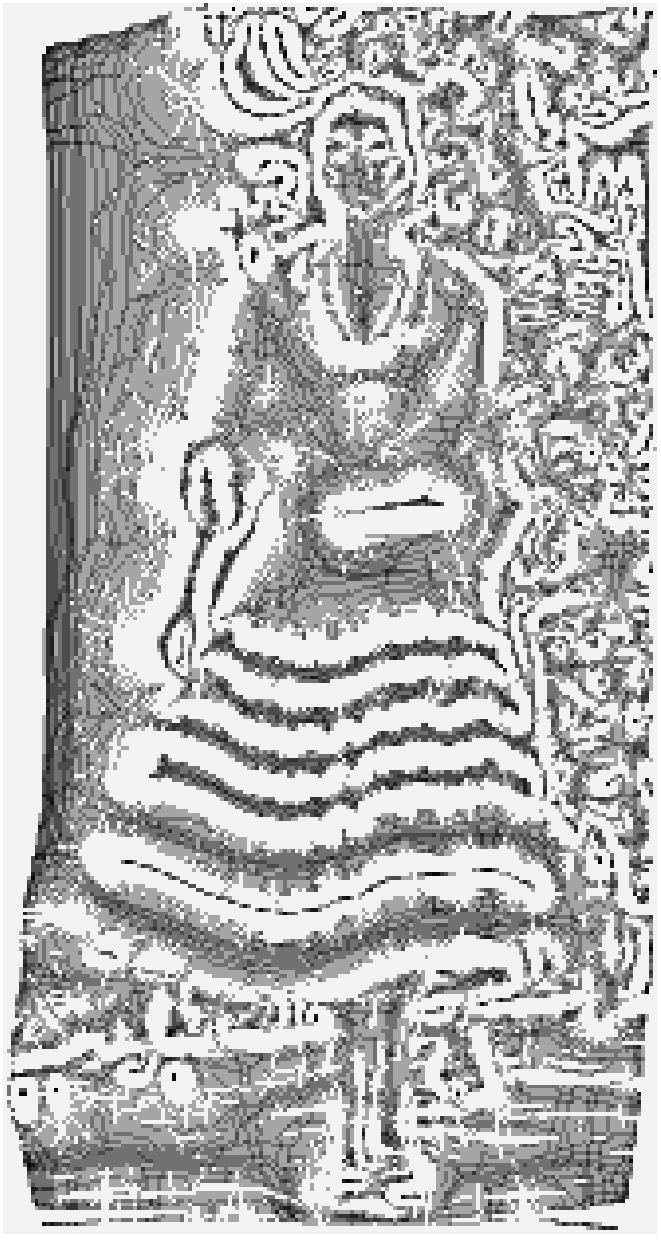
$$\text{total score} = \sum_s \text{score}(s)$$

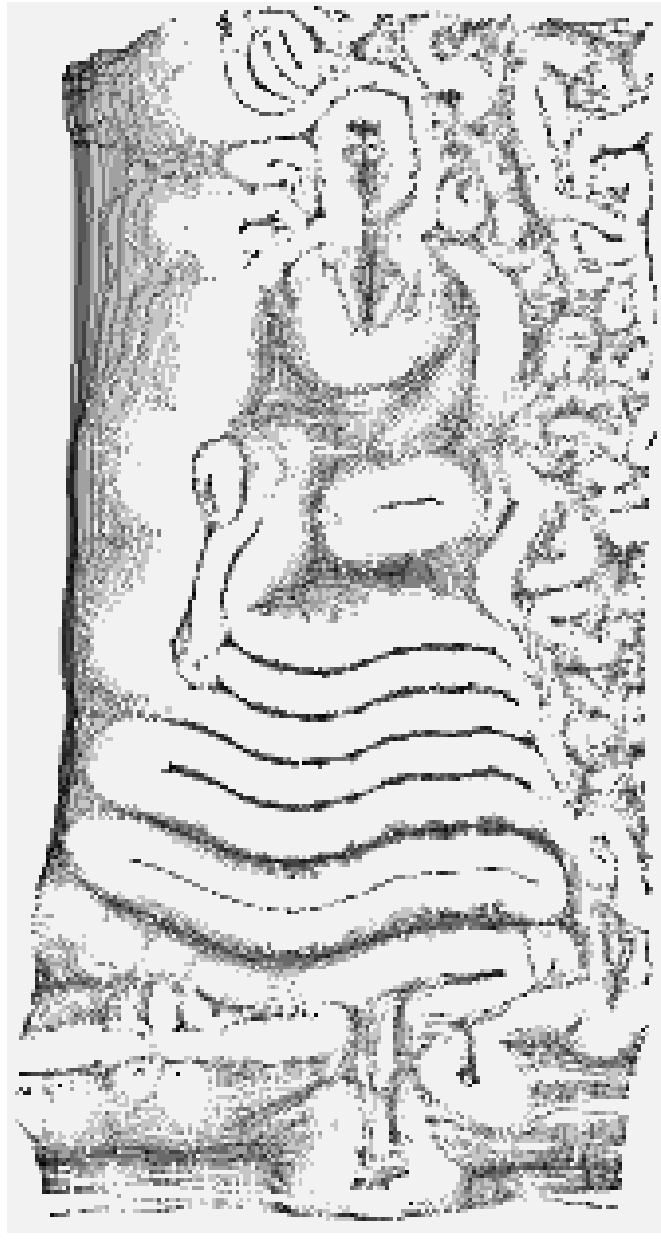
Solution: Near-global Optima by Eigendecomposition

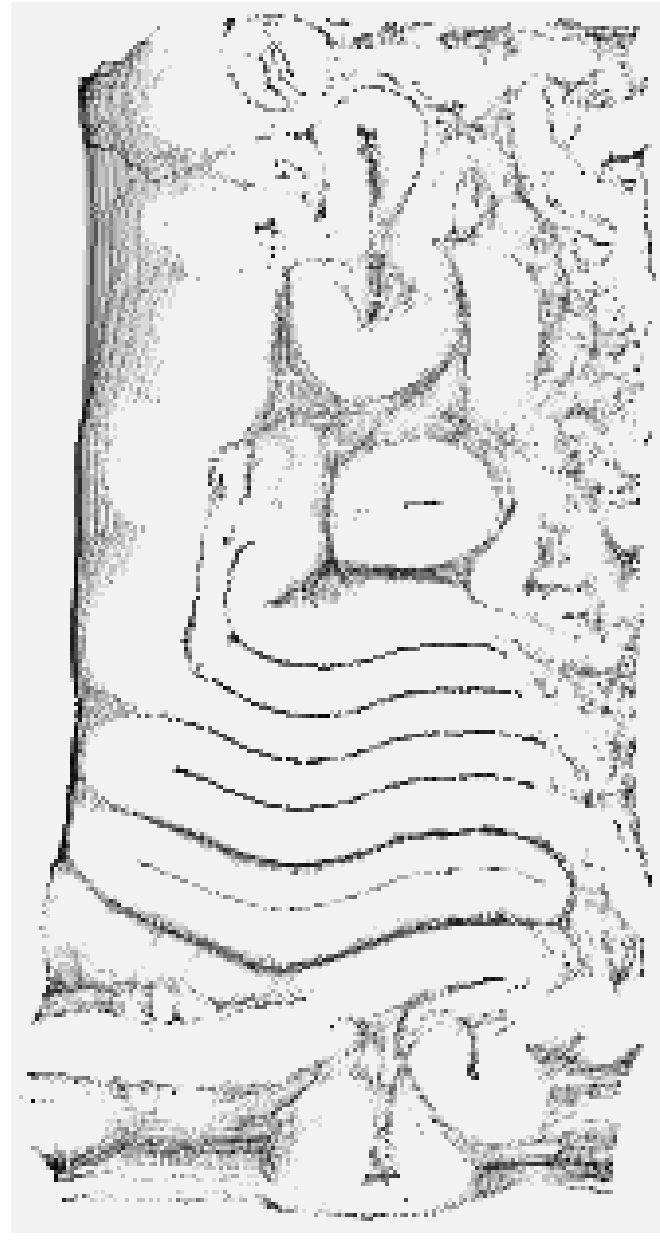
$$W = \sum_s A_s D_s^{-1} + D_s^{-1} A_s$$

Algorithm: 1. Edges $\Rightarrow$ Pixel Affinity

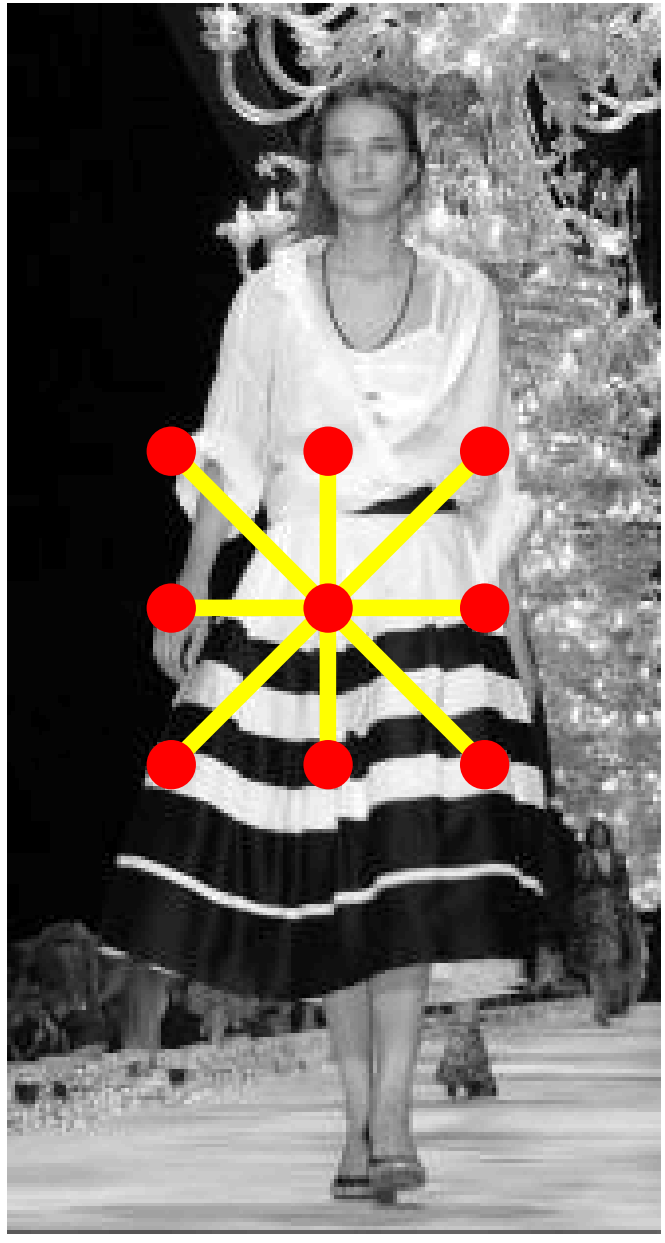
Algorithm: 2. Pixel Affinity $\Rightarrow$ Interior Pixels

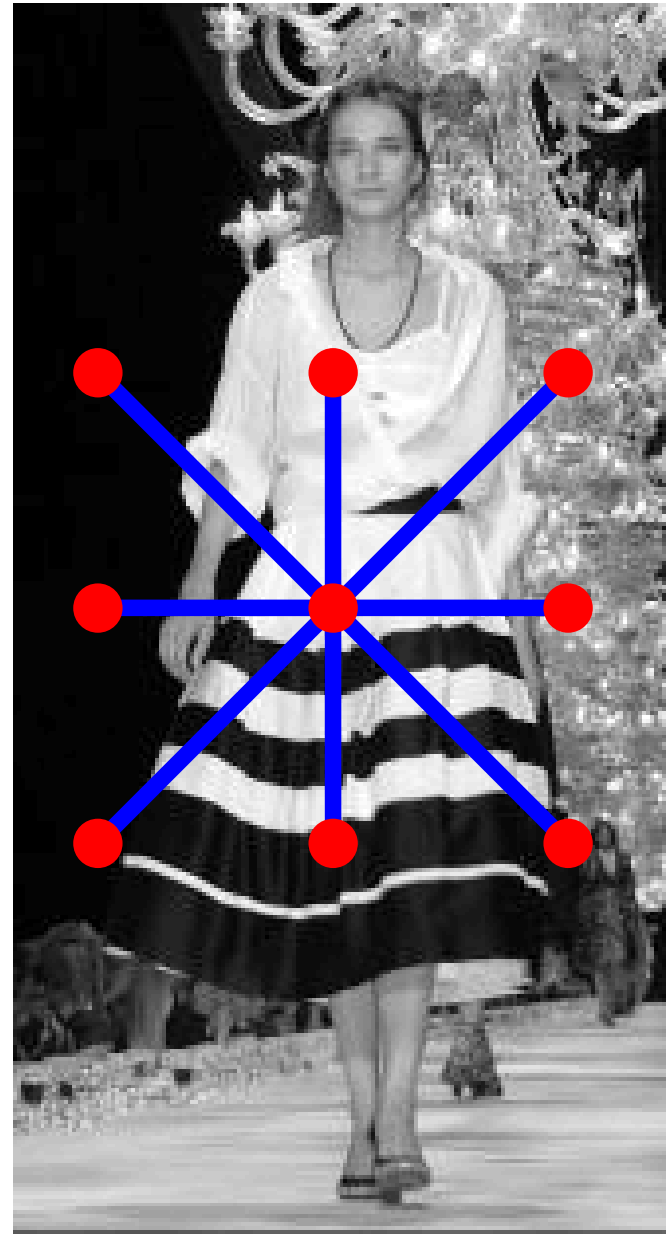






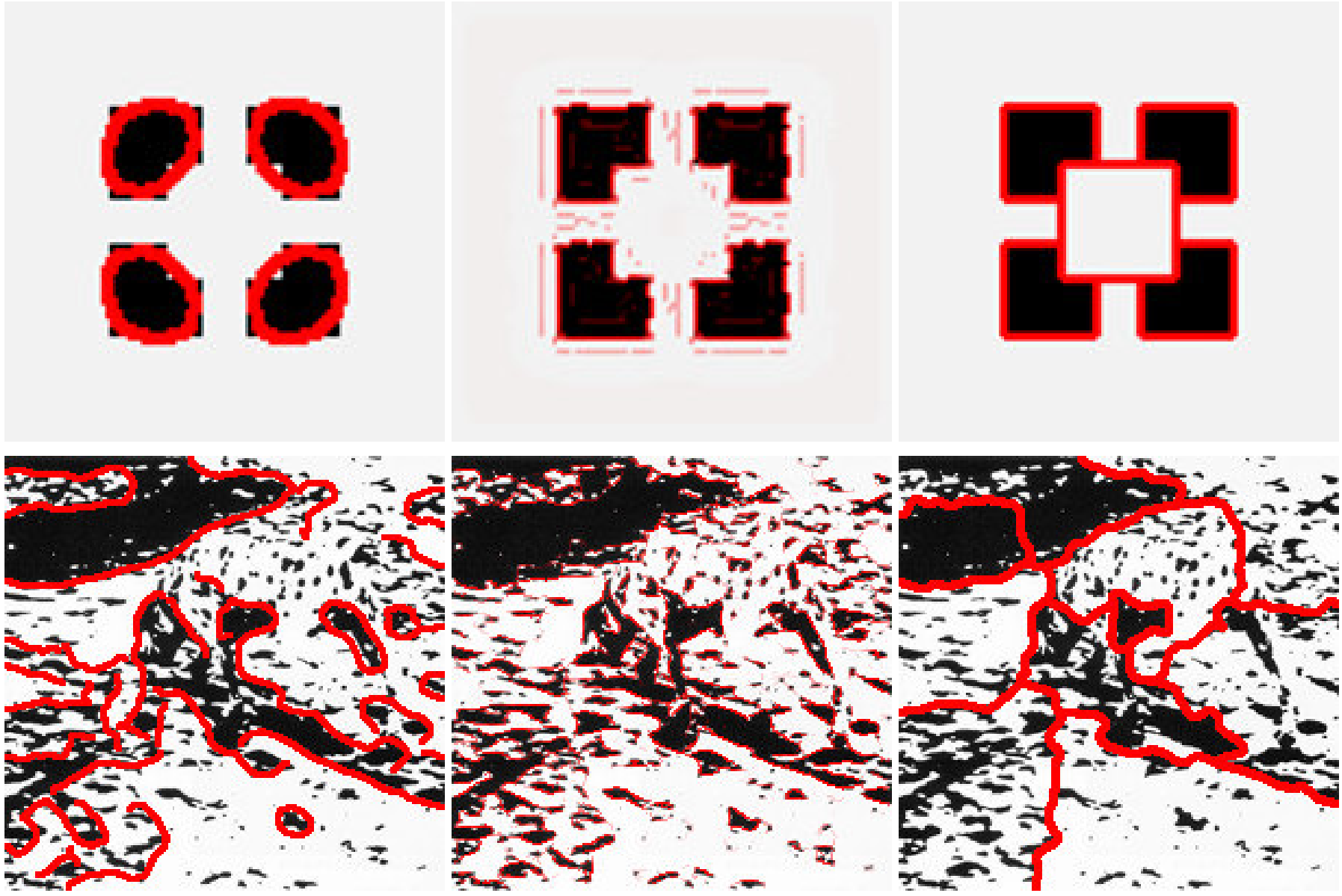
Algorithm: 3. Interior Pixels $\Rightarrow$ Rectified Affinity





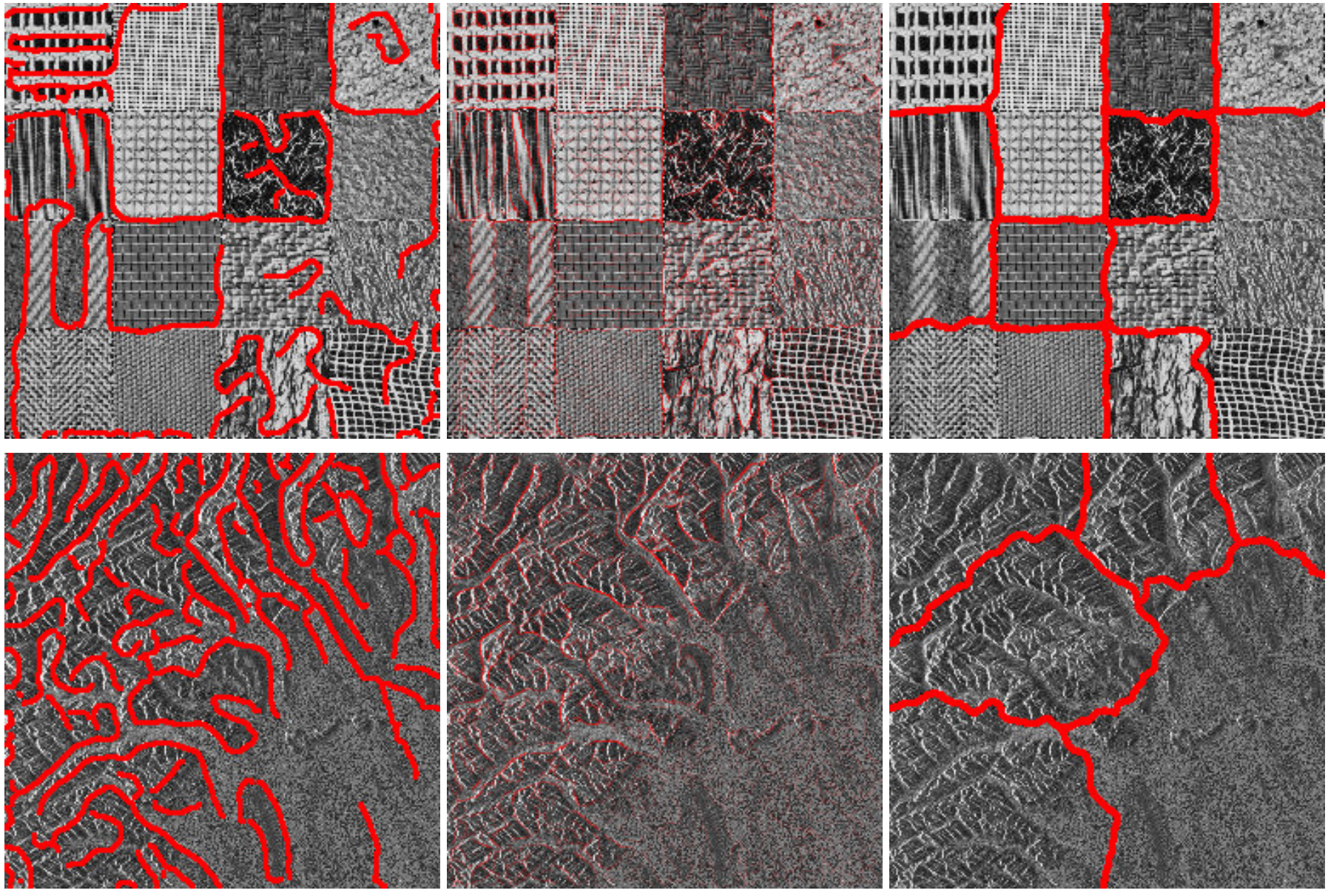
Algorithm: 4. Rectified Affinity $\Rightarrow$ Segmentations

Comparison: Special Contour Images



Canny Martin et al Yu

Comparison: Special Texture Images



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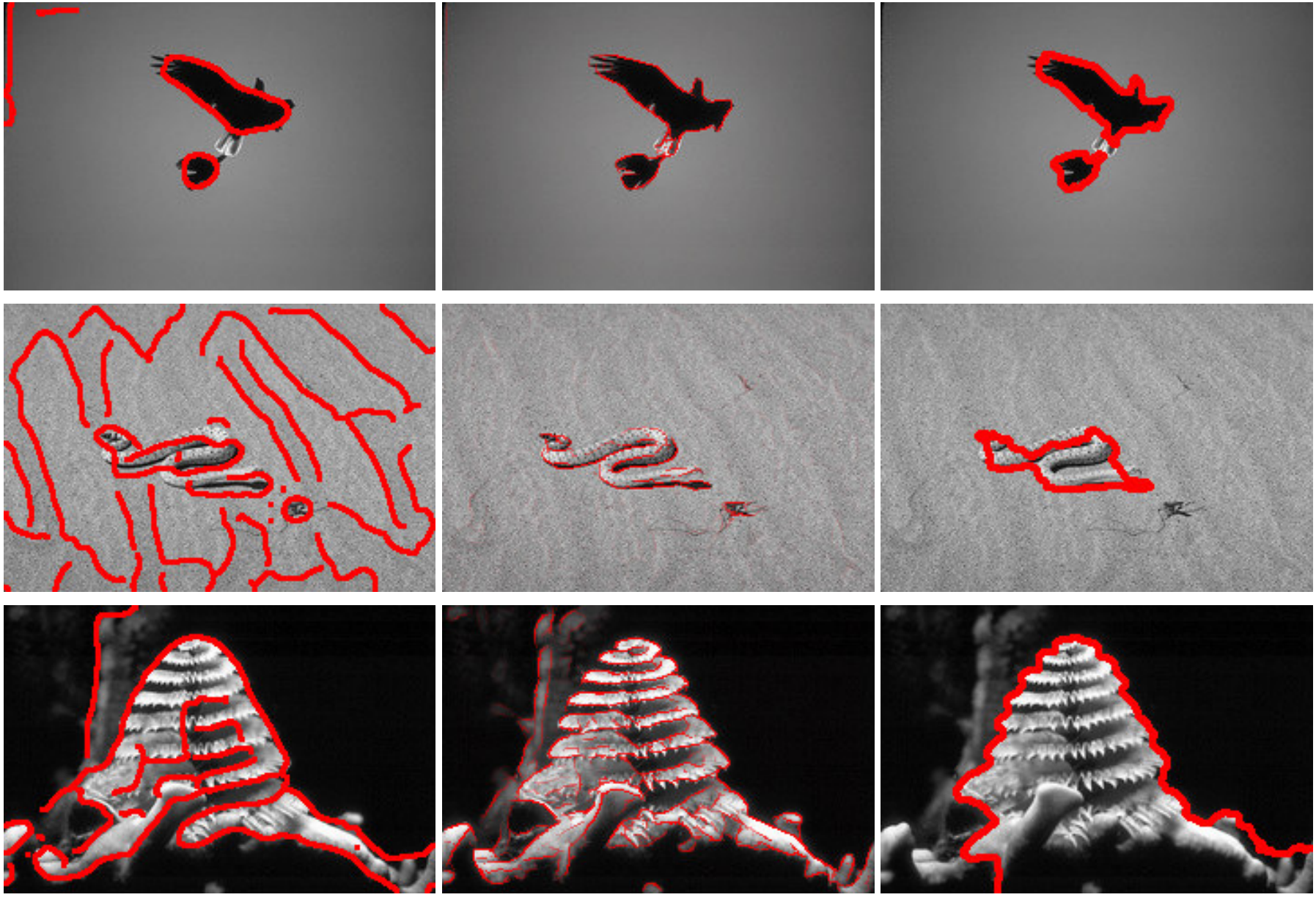
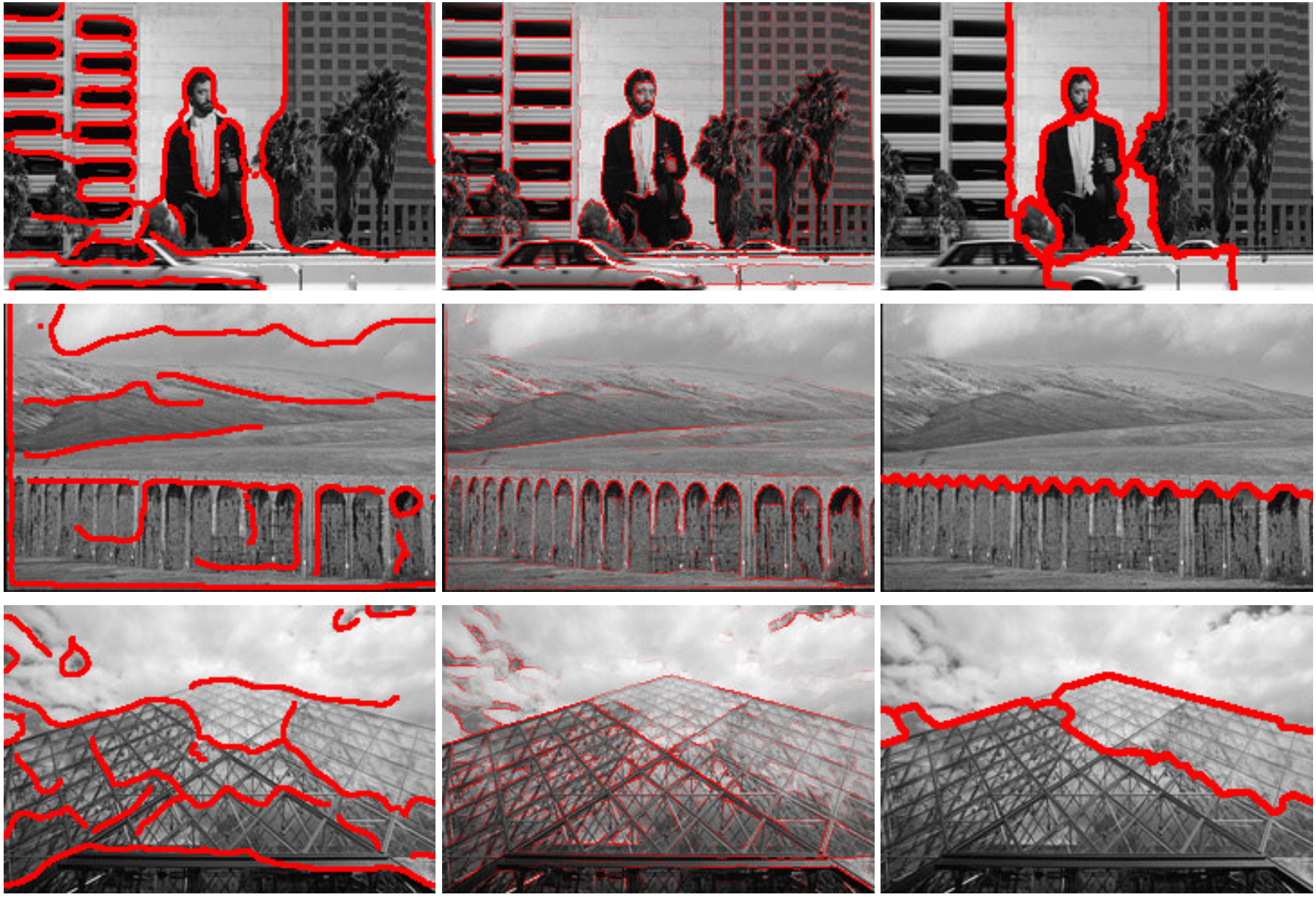
Comparison: Simple Images



Canny Martin et al Yu

Comparison: Contour Completion



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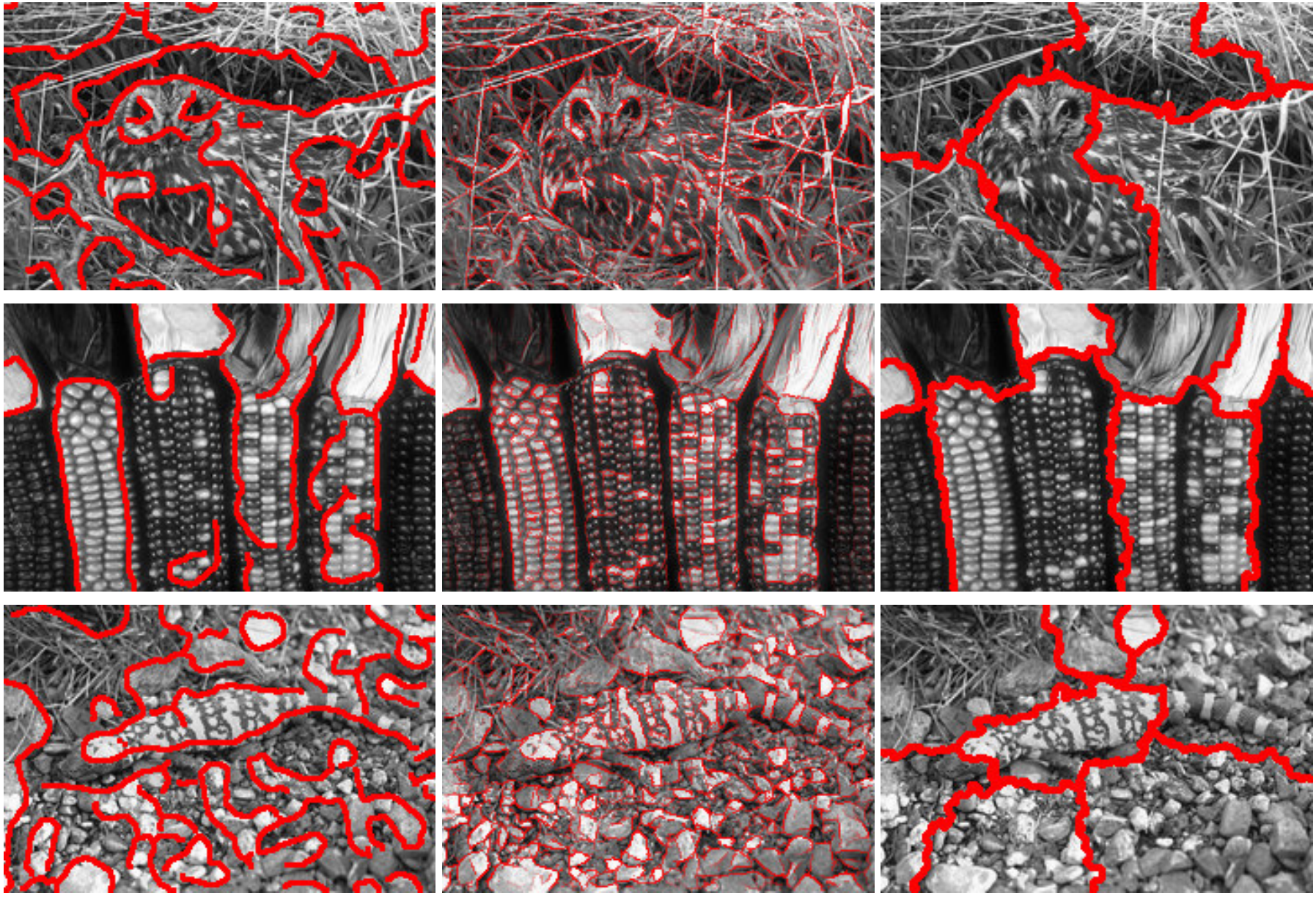
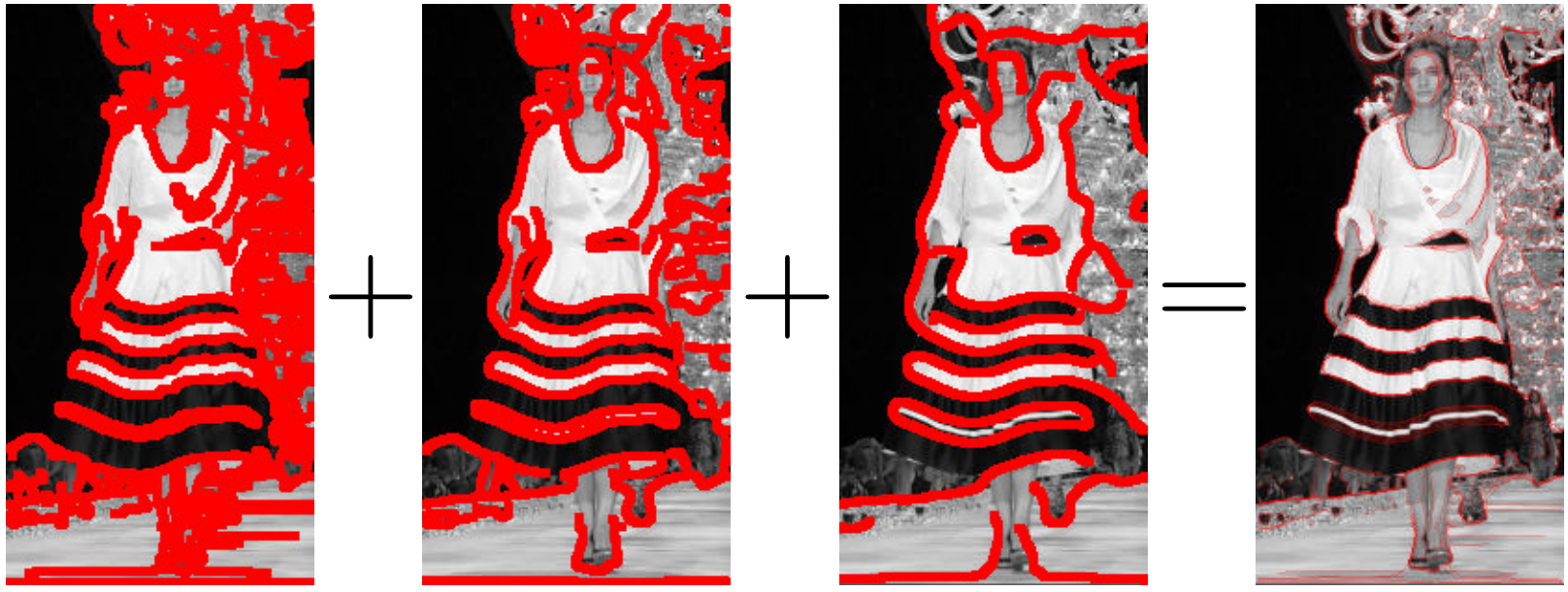
Comparison: Texture



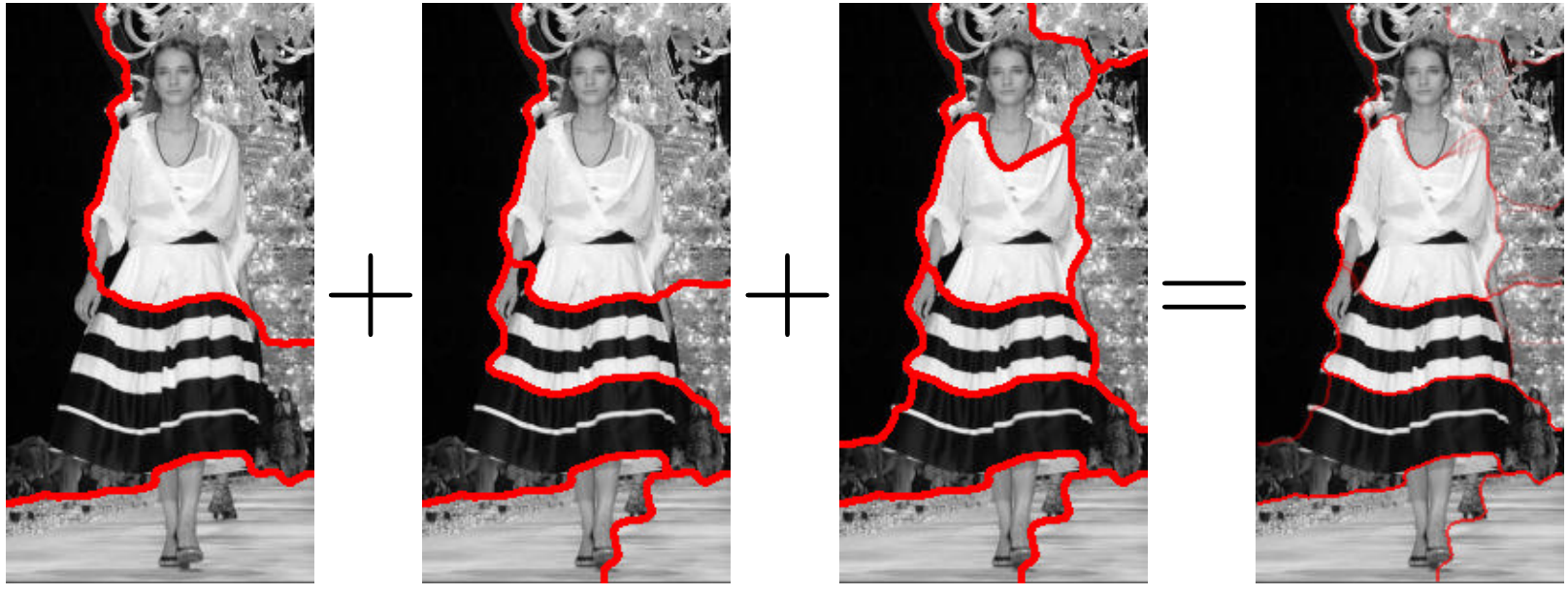
Canny Martin et al Yu

Benchmark: Lump Into Probability On Boundary

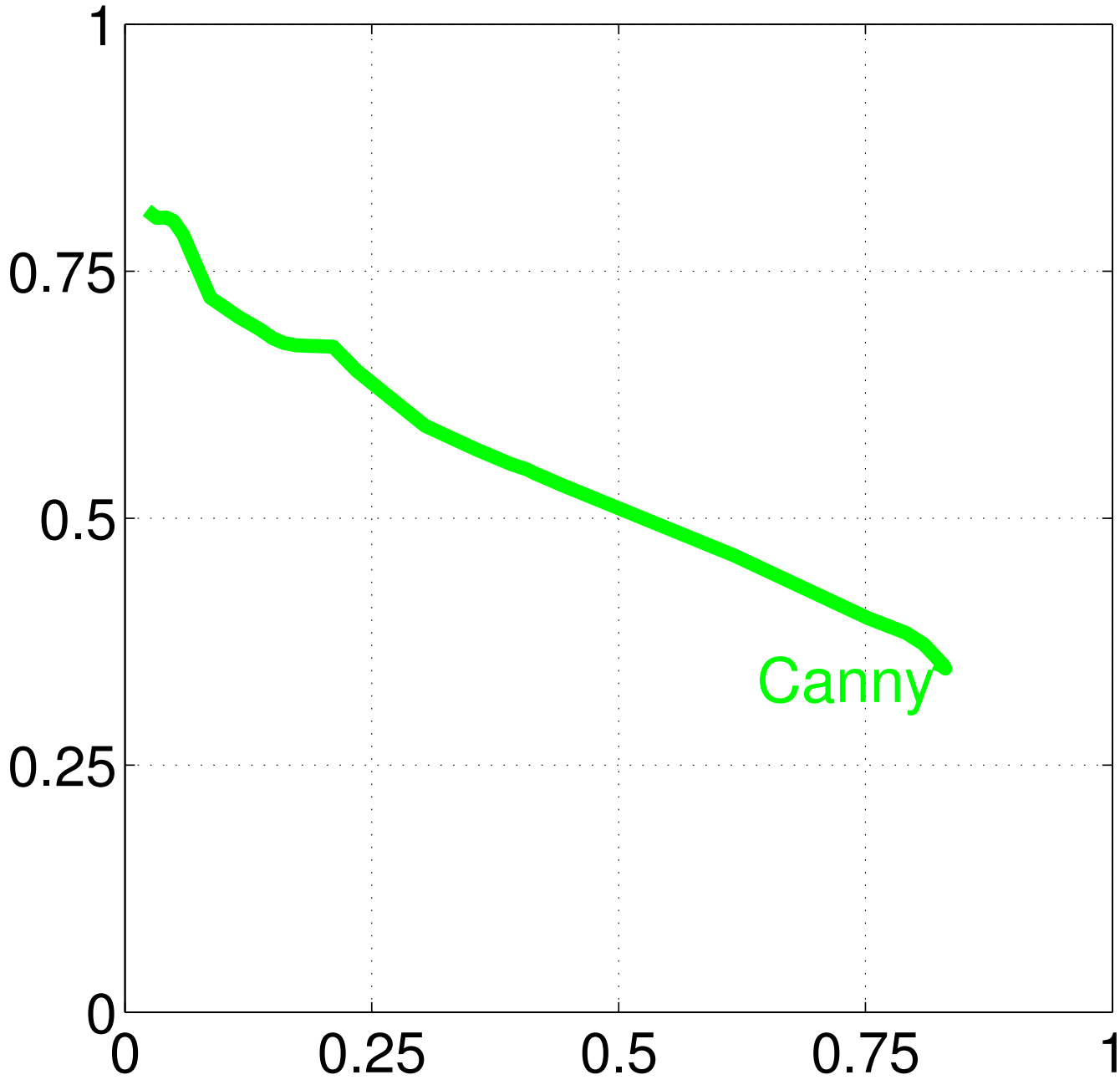
Canny



Yu



Benchmark: Precision vs. Recall



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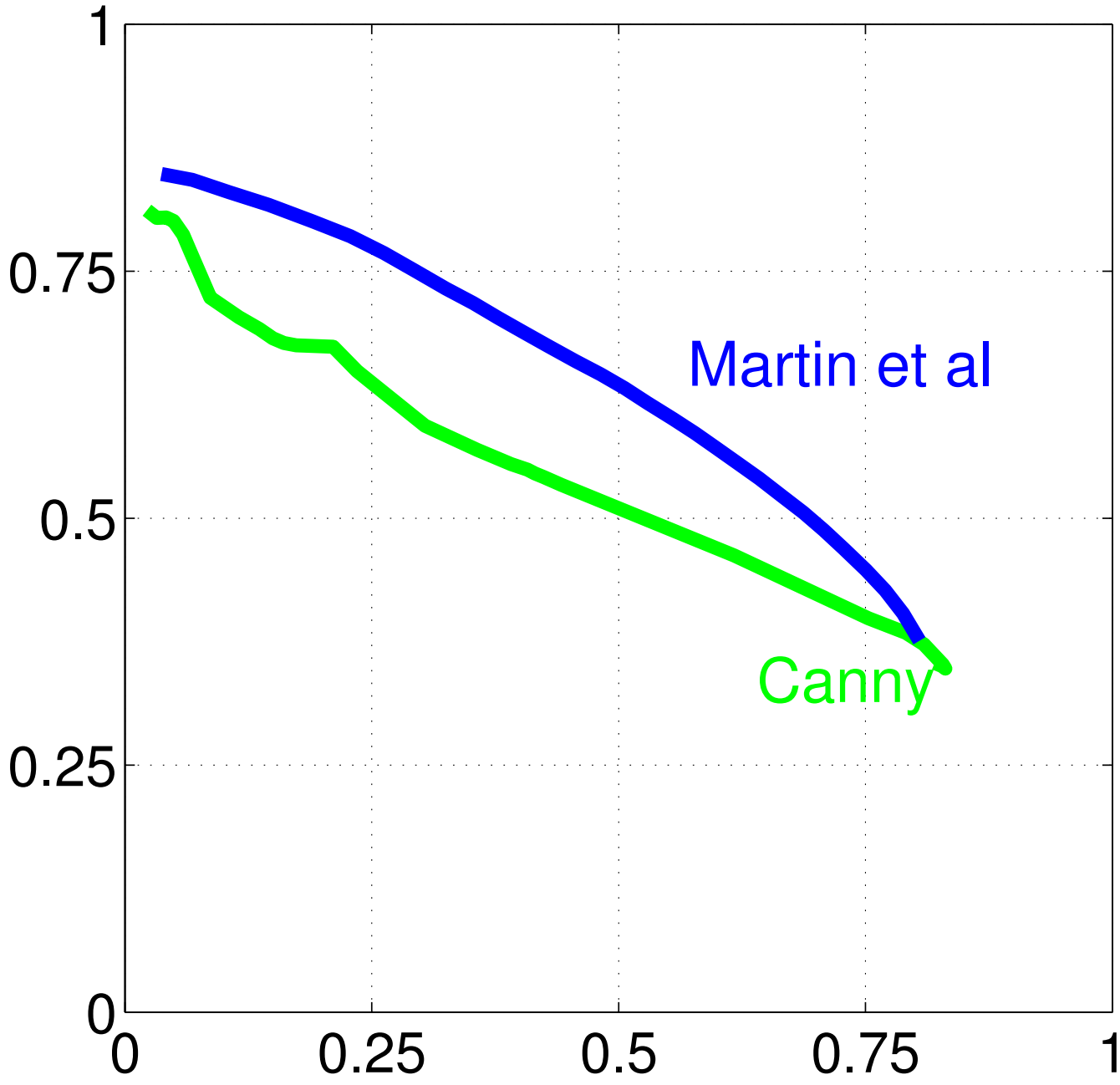

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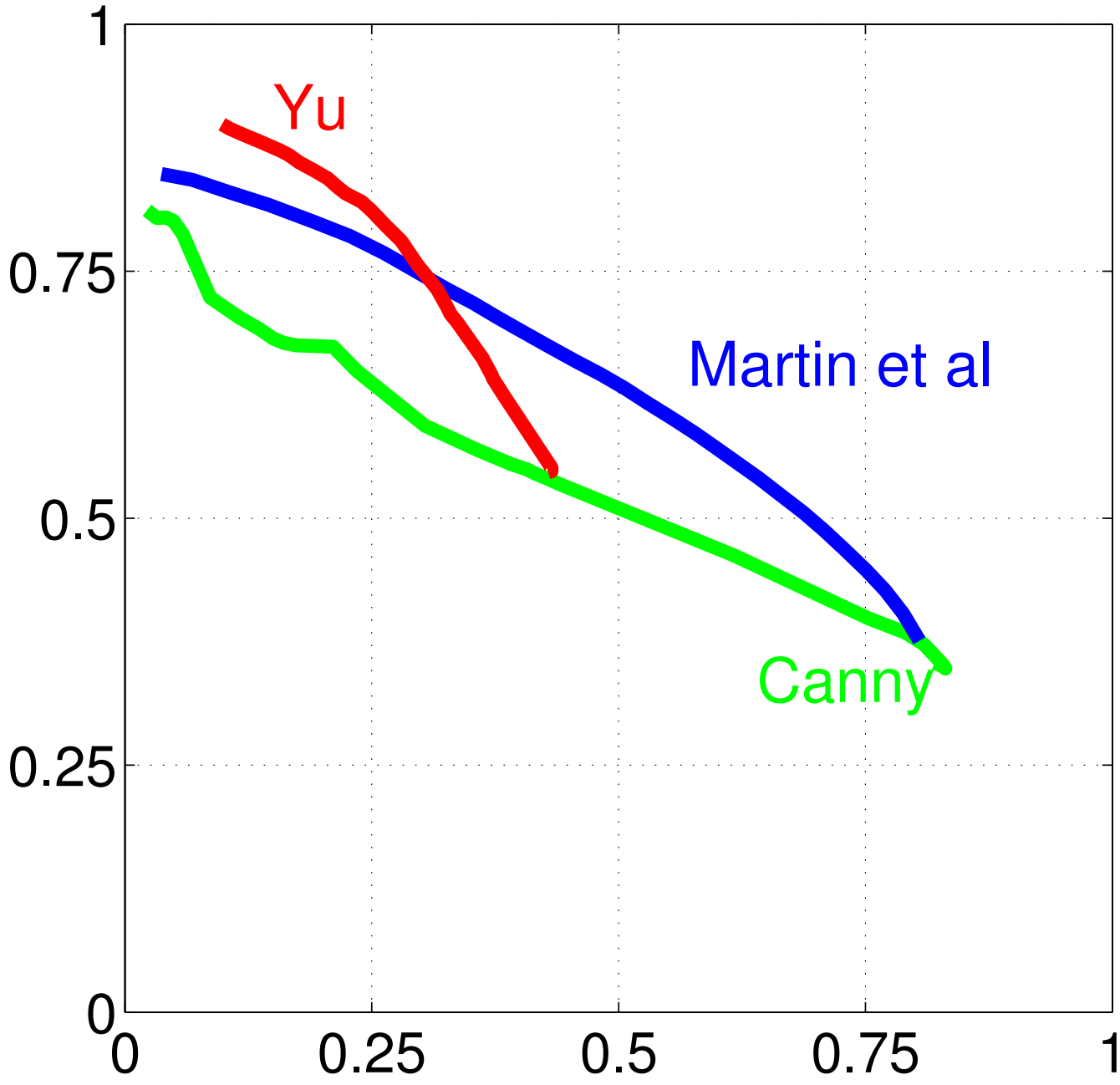
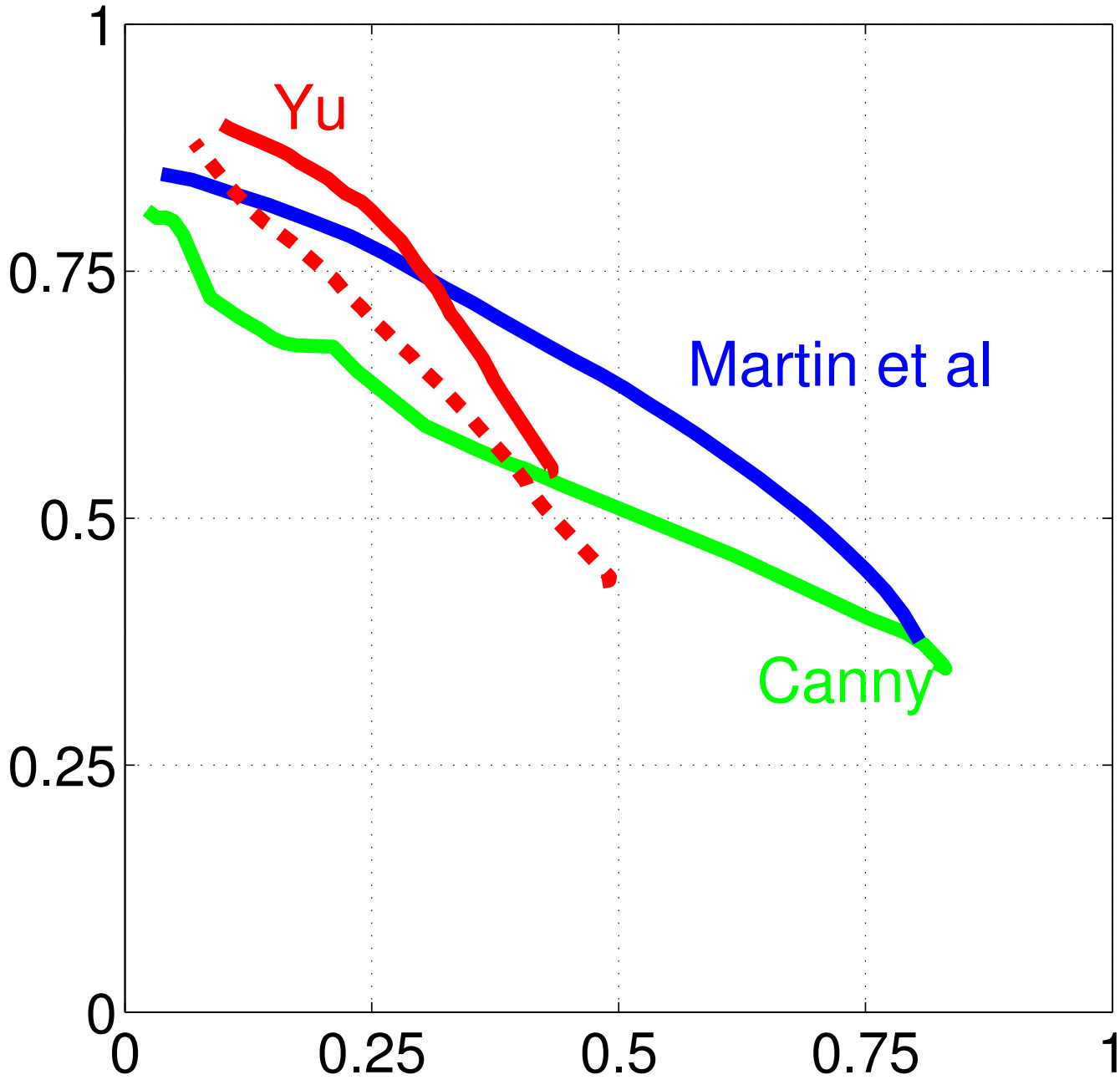
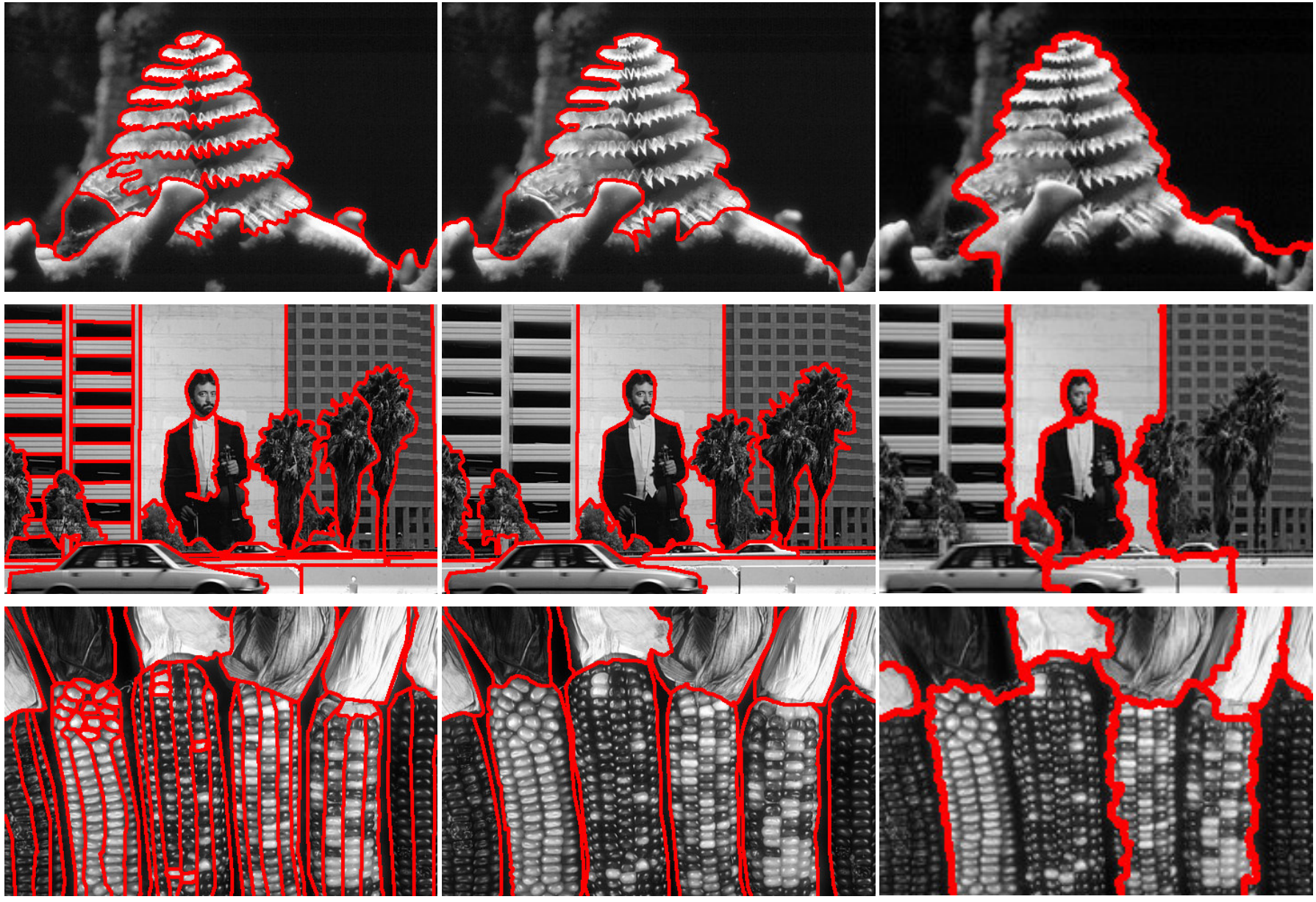


Benchmark: Precision vs. Recall



Benchmark: Higher Precision, Lower Recall



Elaborate Sketchy Yu

Summary: Questions

$$\text{Edges} \overset{?}{\Longrightarrow} \text{Boundaries}$$

Illusory Contour and Texture Dilemma ?

Summary: Answers

Consistent Multiscale Edges $\Rightarrow$ Boundaries

Summary: Answers

Consistent Multiscale Edges $\Rightarrow$ Boundaries

Treat Illusory Contour and Texture By Global Integration

One Feature:	Edges
One Grouping Cue:	Elongated Intervening Contours
One Criterion:	Scale Invariance

Multi-Scale At Different Levels

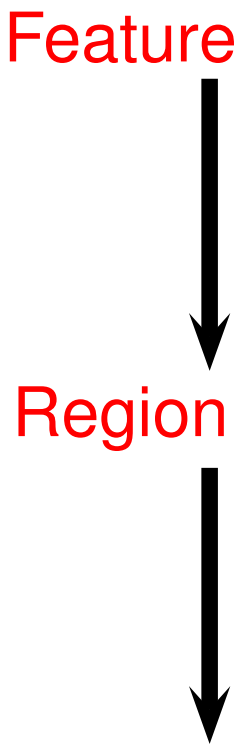
Modelling Level

Feature	edges, wavelets
Grouping cue	ranges, parts
Integration	hierarchical, flat

Computation Level

Swendsen-Wang	Barbu & Zhu
Coarse-to-fine BP	Felzenszwalb et al
Algebraic multigrid	Sharon et al
Multi-range graphs	Benezit et al

Scale Invariance At Different Levels



SIFT

Lowe

Segmentation

Yu

Recognition