Simultaneous Segmentation and Figure/Ground Organization using Angular Embedding

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Abstract

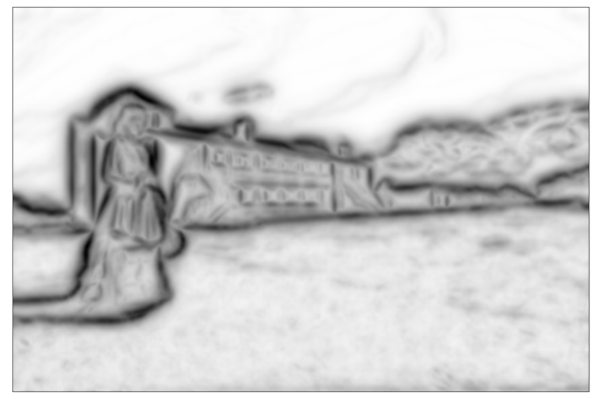
Image segmentation and figure/ground organization are fundamental steps in visual perception. We introduce an algorithm that couples these tasks together in a single grouping framework driven by low-level image cues. By encoding both affinity and ordering preferences in a common representation and solving an Angular Embedding problem, we allow segmentation cues to influence figure/ground assignment and figure/ground cues to influence segmentation. Results are comparable to state-of-the-art automatic image segmentation systems, while additionally providing a global figure/ground ordering on regions.

Segmentation and Figure/Ground

Image

→

Local Contours (mPb)



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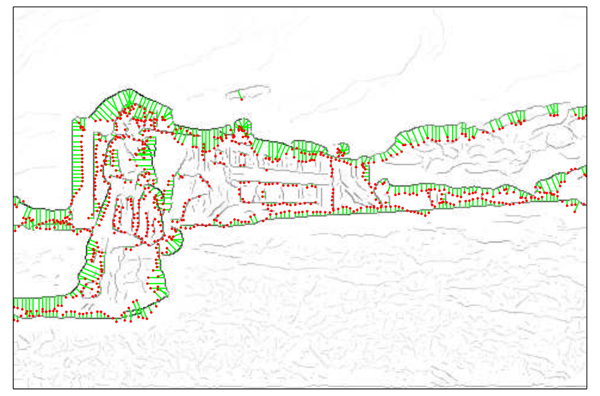
Local Figure/Ground

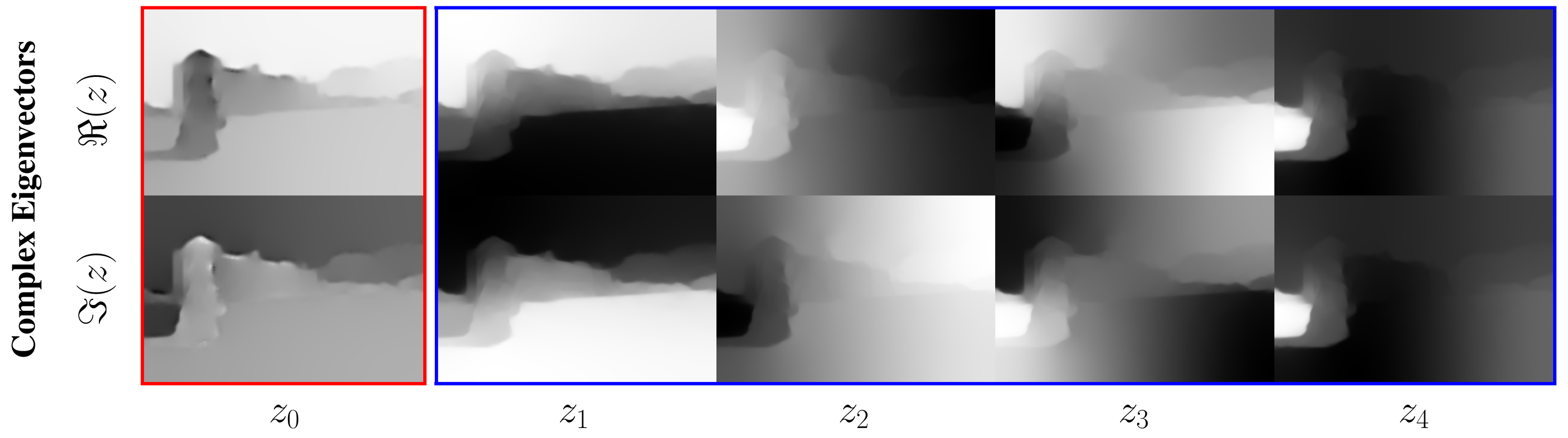


Pairwise Affinity
C_{pb}

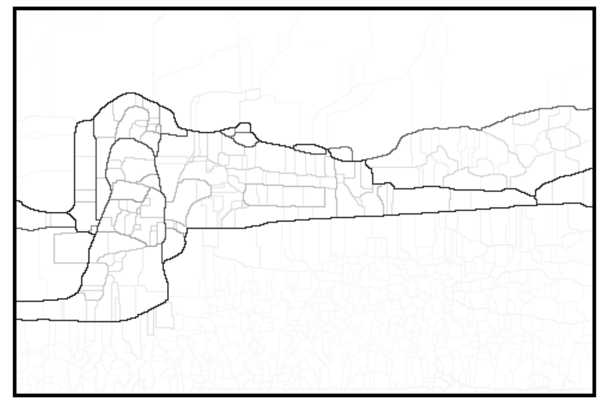
Pairwise Ordering
(C_{fg}, Θ_{fg})

$$\hookrightarrow \quad M = C_{pb} + \alpha C_{fg} \bullet e^{i\Theta_{fg}} \quad \hookleftarrow$$

Angular Embedding



$\sum_{k=1}^{n} \nabla z_k$ $\angle z_0$



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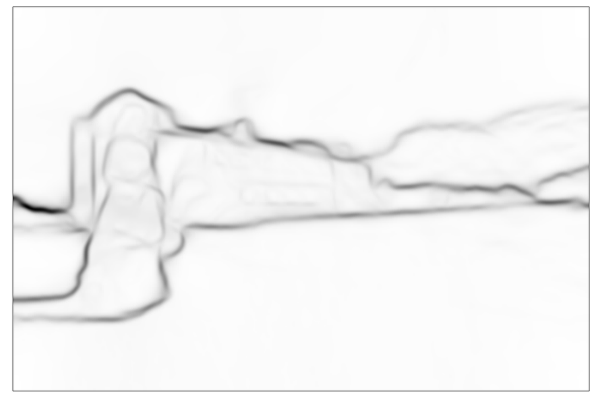
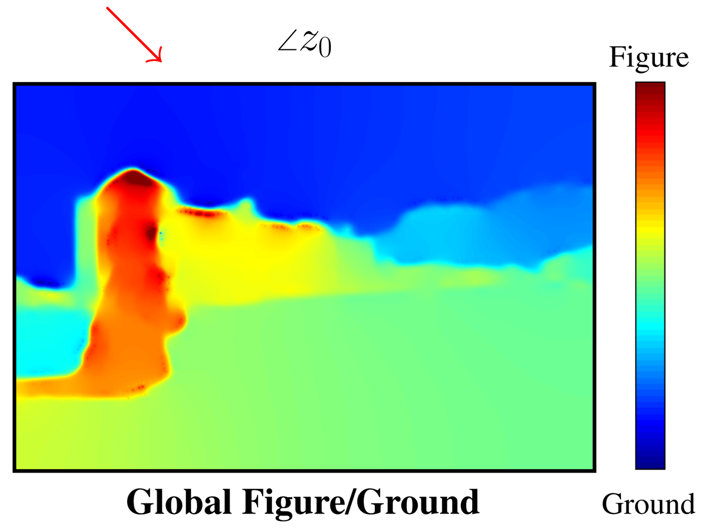
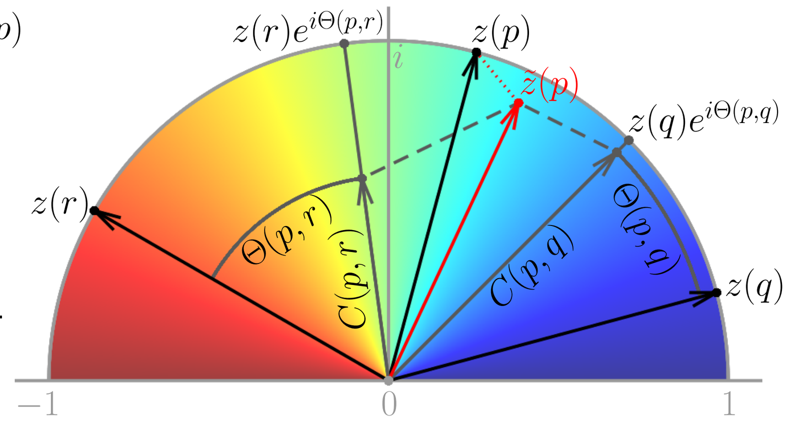




Hierarchical Segmentation (UCM) [1] **Global Contours** **Global Figure/Ground**

Angular Embedding [2]

- Recover global ordering $\theta(p)$ by embedding into the unit circle: $p \rightarrow z(p) = e^{i\theta(p)}$
- Relative angular displacement respects local ordering constraints
- Minimize disagreement between $z(p)$ and the neighborhood expectation $\tilde{z}(p)$



A pair of real-valued matrices (C, Θ) defines the problem. Θ is a skew-symmetric matrix specifying the local *ordering* constraints. C is a symmetric *confidence* matrix defining the relative importance of each constraint. We minimize error:

$$\varepsilon = \sum_p D(p) \cdot |z(p) - \tilde{z}(p)|^2$$

where D is a diagonal degree matrix, $\tilde{z}(p)$ is the estimated position of $z(p)$:

$$D(p) = \frac{\sum_q C(p,q)}{\sum_{p,q} C(p,q)} \qquad \tilde{z}(p) = \sum_q \tilde{C}(p,q) \cdot z(q) \cdot e^{i\Theta(p,q)}$$

and $\tilde{C}(p,q) = \frac{C(p,q)}{\sum_q C(p,q)}$ is the normalized confidence. Relaxing the unit circle requirement to $z^* D z = 1$ yields the generalized eigenproblem (W, D) where:

$$W = (I - M)^* D (I - M) \qquad M = Diag(C1)^{-1} C \bullet e^{i\Theta}$$

Pairwise Cues

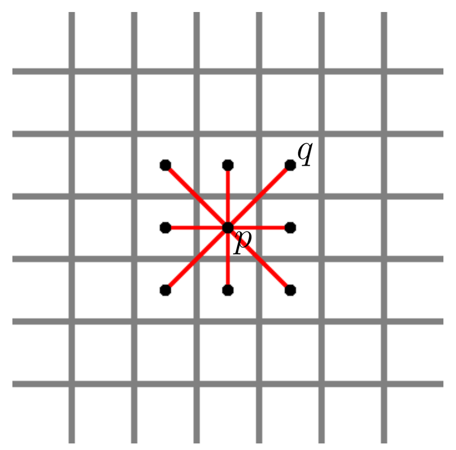
We design C and Θ so that the leading eigenvector of (W, D) encodes figural ordering and the other eigenvectors encode region membership.

Intervening Contour

We connect pixel p to each of its neighbors q with confidence:

$$C_{pb}(p,q) = \exp\left(-\max_{(x,y)\in\overline{pq}} \{mPb(x,y)\}/\rho\right)$$

and ordering $\Theta_{pb}(p,q) = 0$ where ρ is a constant.



Local Figure/Ground Classifier

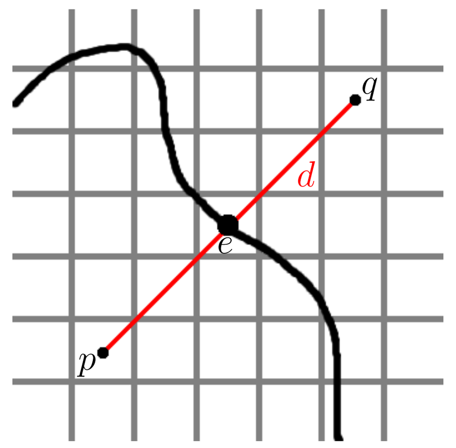
Let $f(e) \rightarrow [-1, 1]$ be a classifier predicting the figural side of edge pixel e. Define p and q to be distance d from e on opposite sides of the edge. We connect pixels p and q with confidence:

$$C_{fg}(p,q) = C_{fg}(q,p) = |f(e)| \cdot mPb(e)$$

and ordering:

$$\Theta_{fg}(p,q) = -\Theta_{fg}(q,p) = sign(f(e)) \cdot \phi$$

where ϕ is a constant.



Figure/Ground Globalization

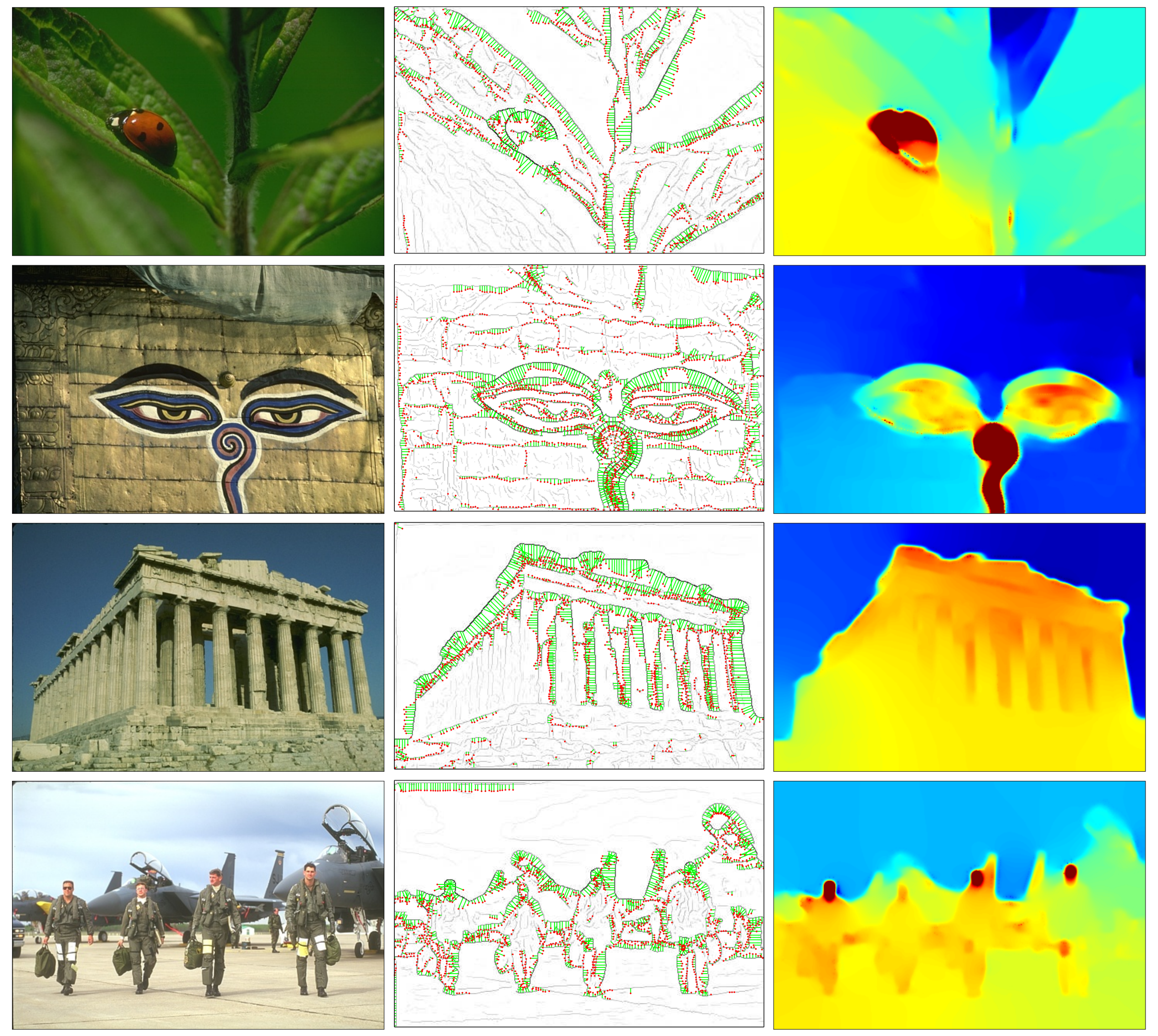
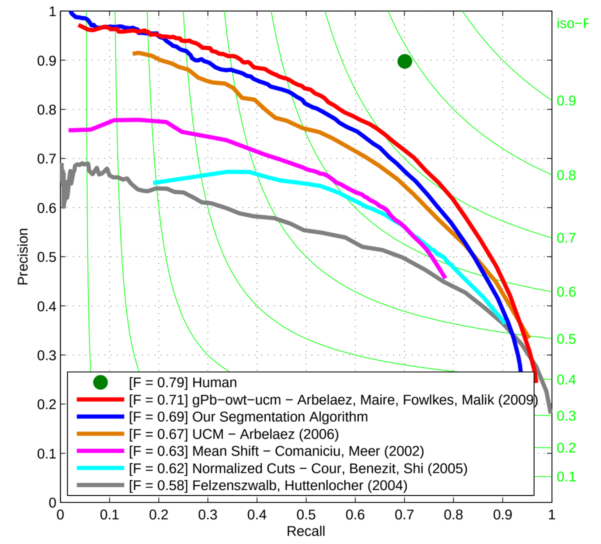
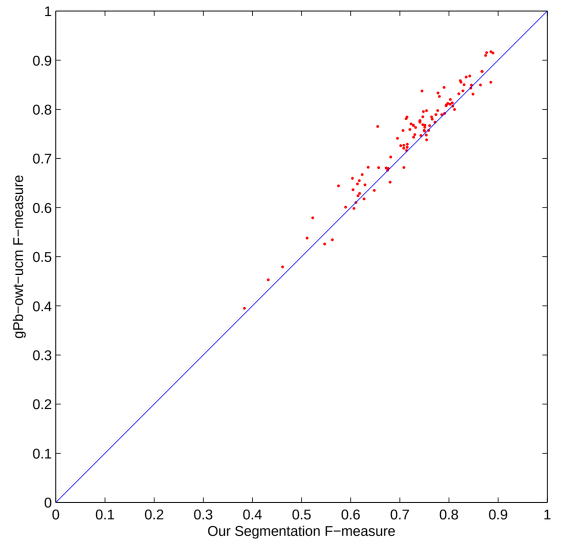


Image **Local F/G** **Global F/G**

Our local figure/ground classifier makes predictions using features computed on the nonmax-suppressed local contours. Above, vectors drawn from edge points indicate the predicted figural side by their red tip.

Benchmarks





Evaluation on the Berkeley Segmentation Dataset:

- Our algorithm can be seen as a generalization of gPb-owt-ucm [1] and achieves similar segmentation quality.
- We outperform all segmentation algorithms other than [1].
- Our system is the only one that also solves for figure/ground.

Results

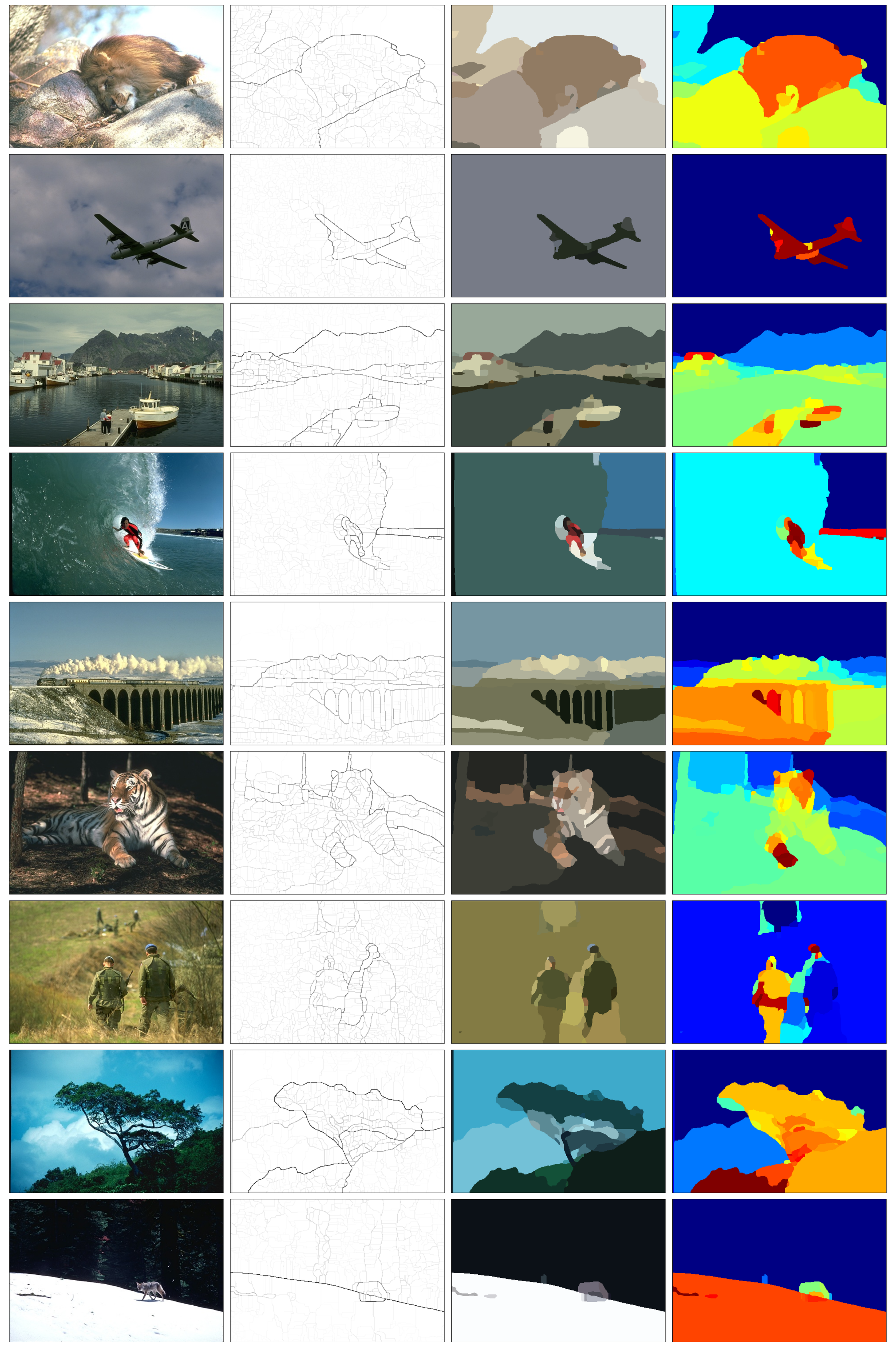


Image **UCM** **Segmentation** **Global F/G**

References

[1] Arbeláez, P., Maire, M., Fowlkes, C., Malik, J.: From Contours to Regions: An Empirical Evaluation. CVPR (2009)

[2] Yu, S.X.: Angular Embedding: From Jarring Intensity Differences to Perceived Luminance. CVPR (2009)