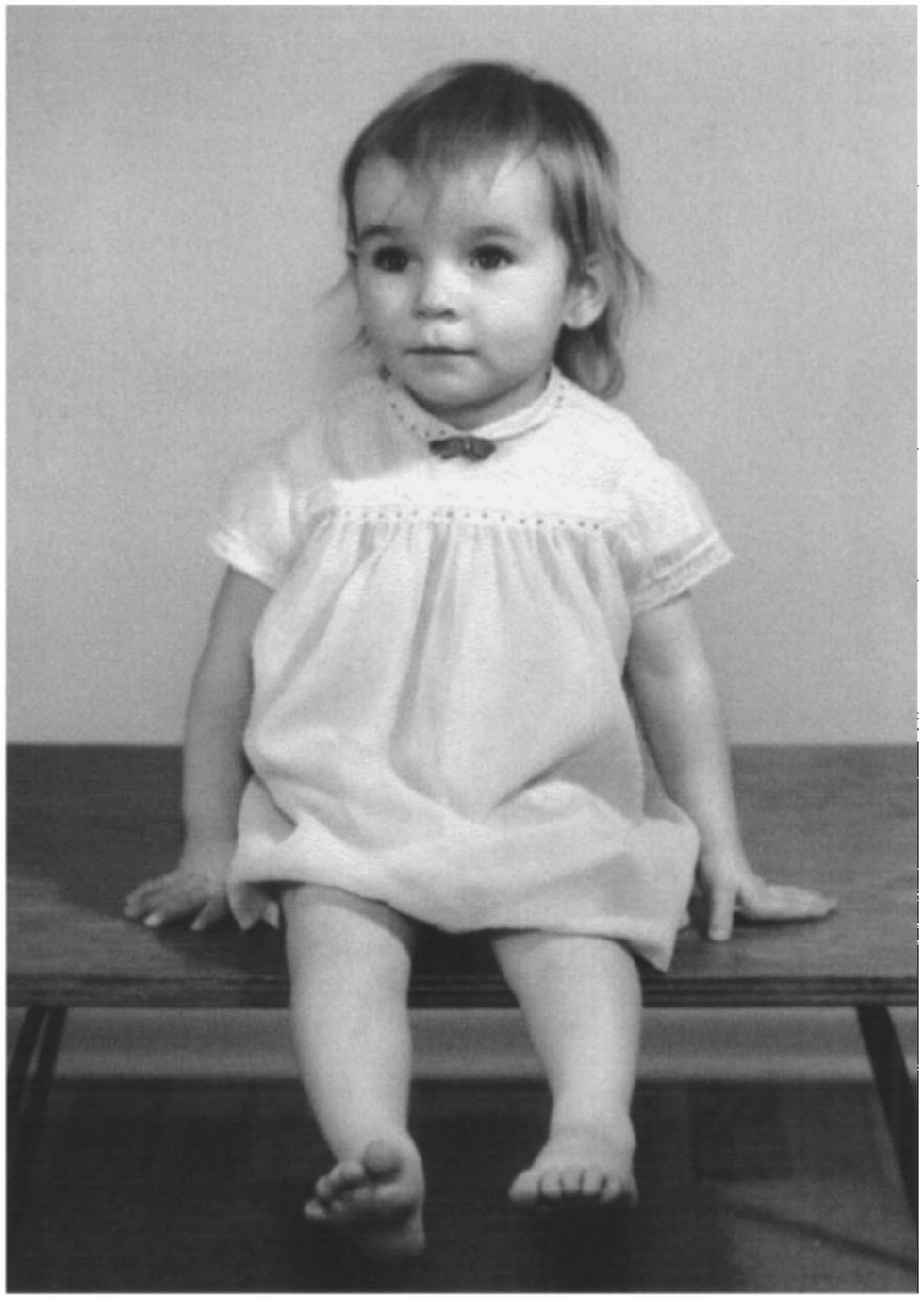
4.2 Edge Detection

Outline

- The Importance of Edges
- Local Filter Scale Control
- Local Filter Shape Control
- Image Reconstruction from Edges
- Application: Interactive Contour Editing
- Salient Edges

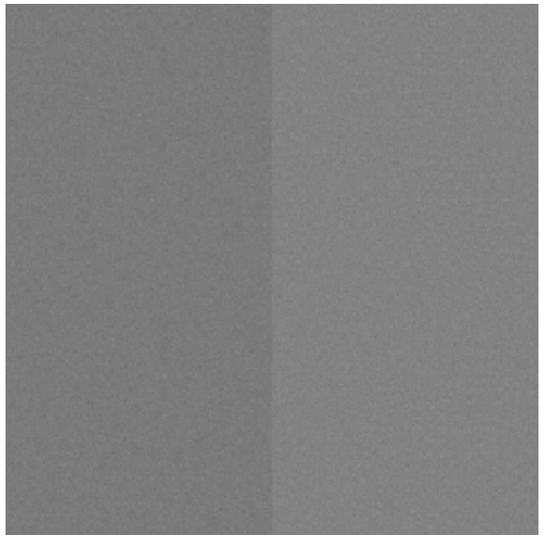
Edge Coding

- Edges carry a lot of information about the image

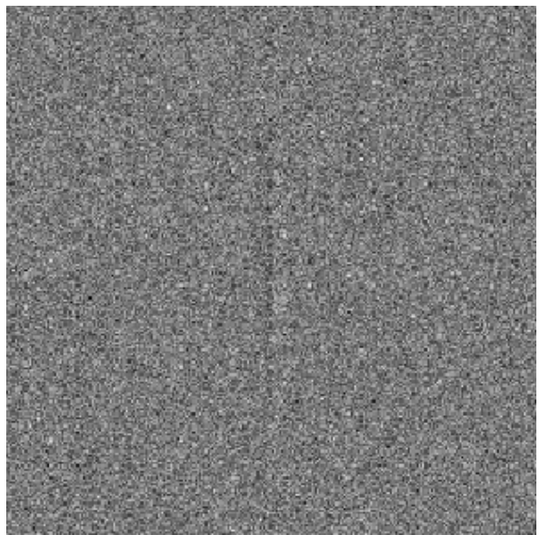


Edge Coding in the Human Brain

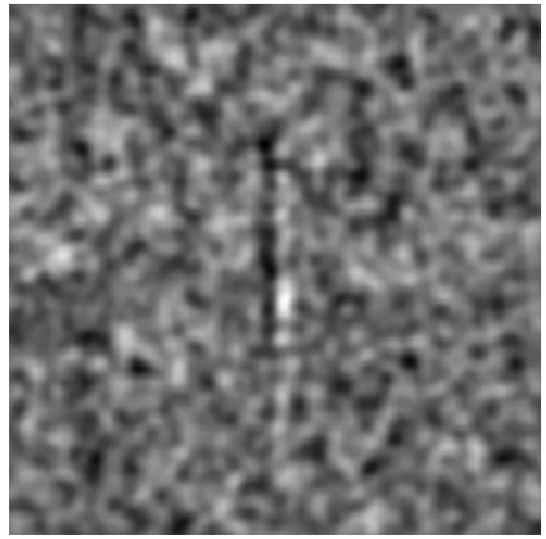
Noisy Stimulus



Estimated Filter

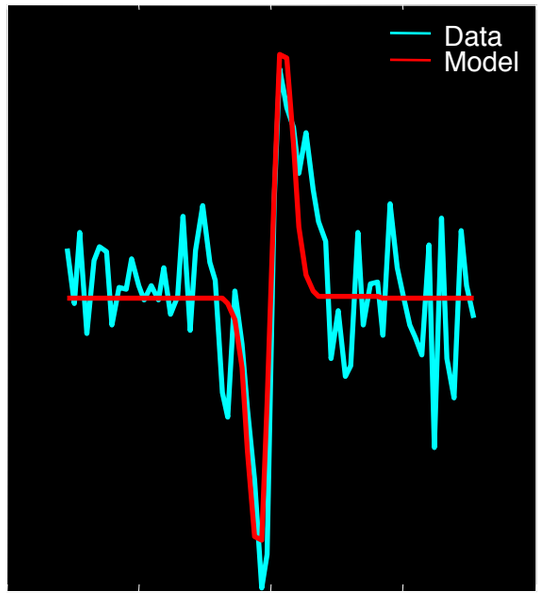


Estimated Filter (Smoothed)

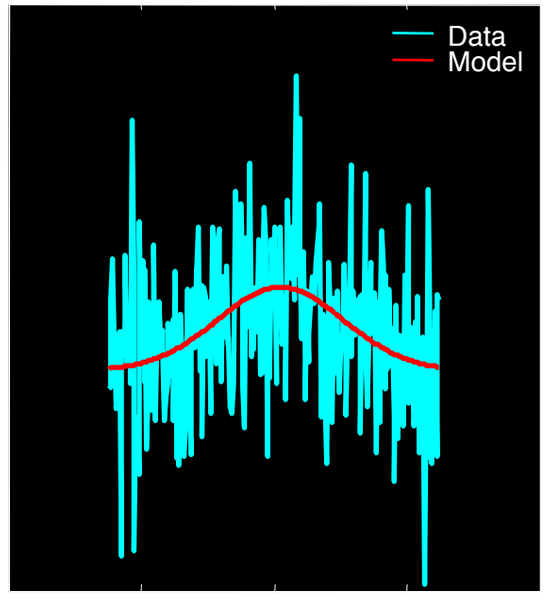


Estimated Filter (Modeled)

Horizontal Cross-Section

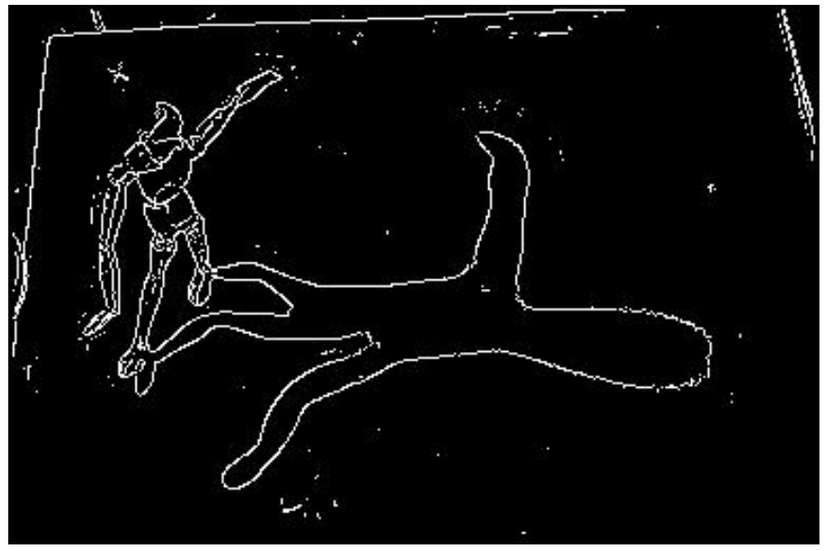


Vertical Cross-Section



How can we reliably detect edges?

?

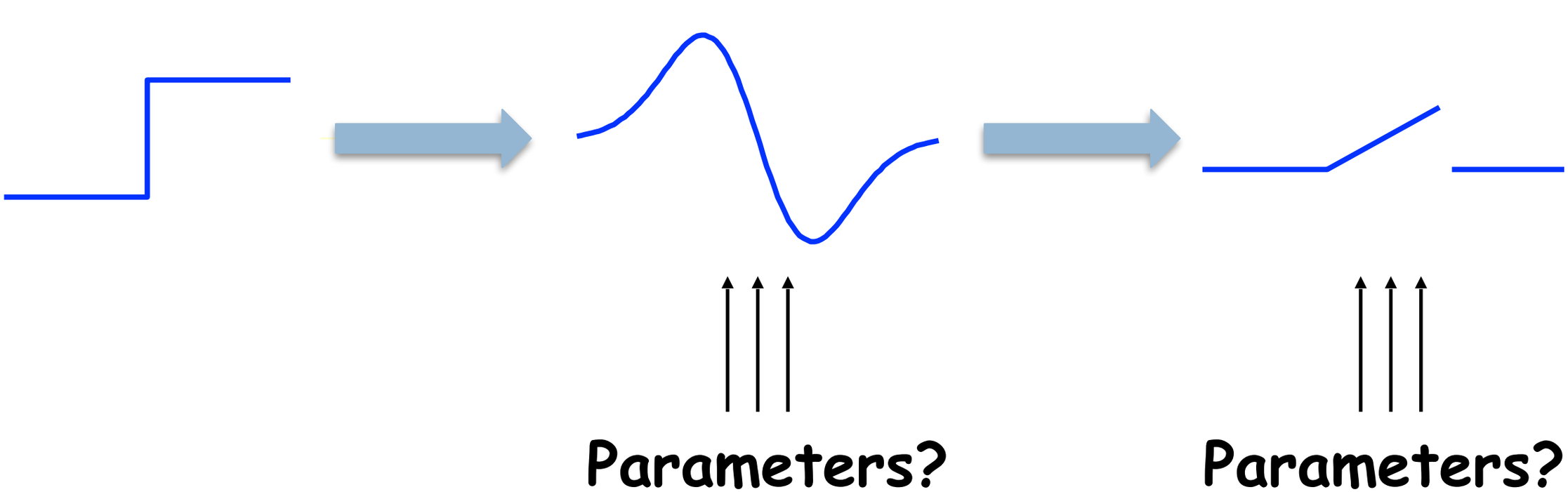


Standard Model for Edge Detection

Step Edge

Linear Filters

Decision



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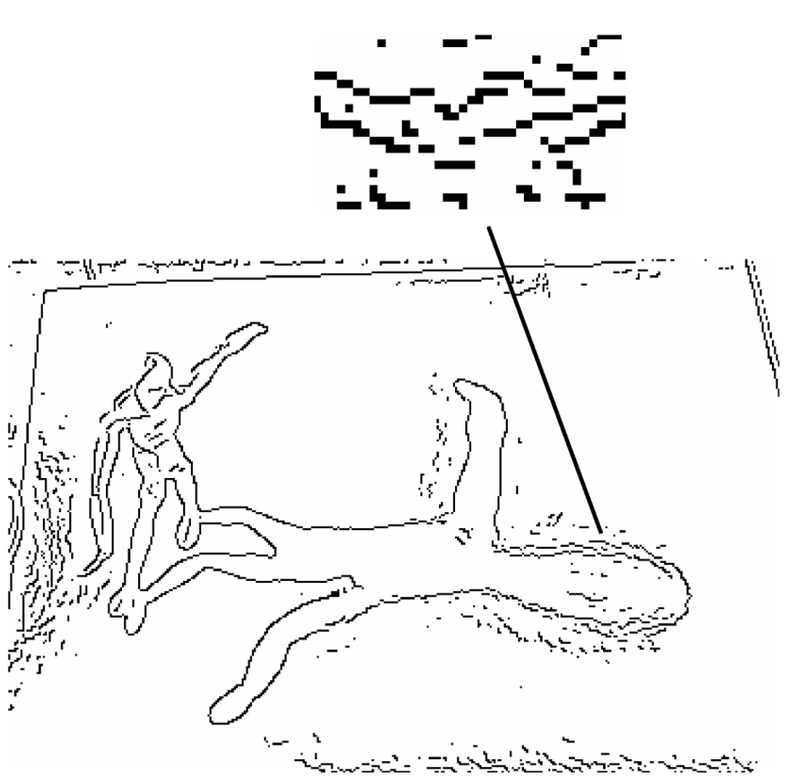
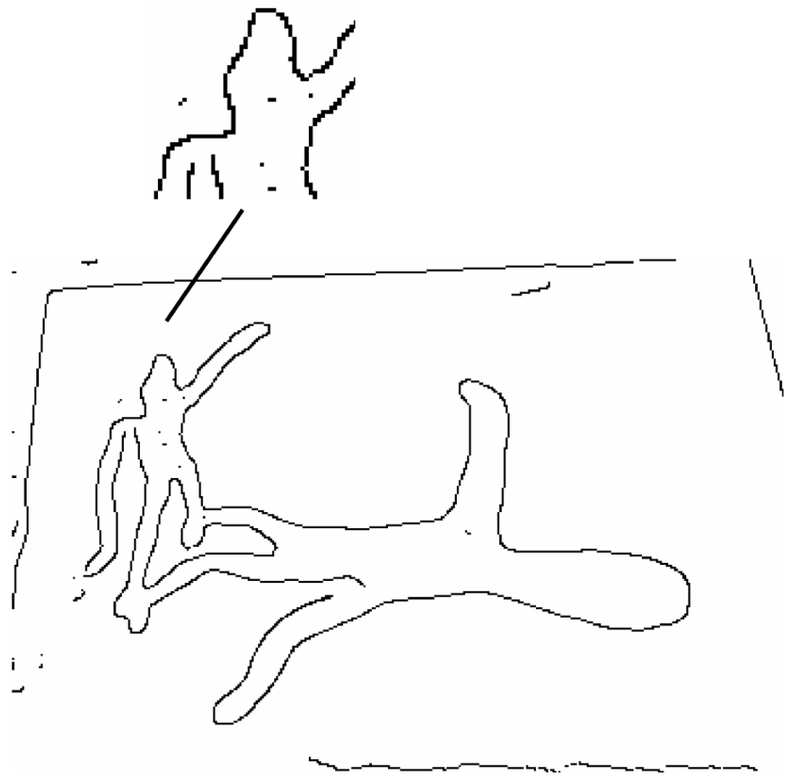
The Problem of Scale

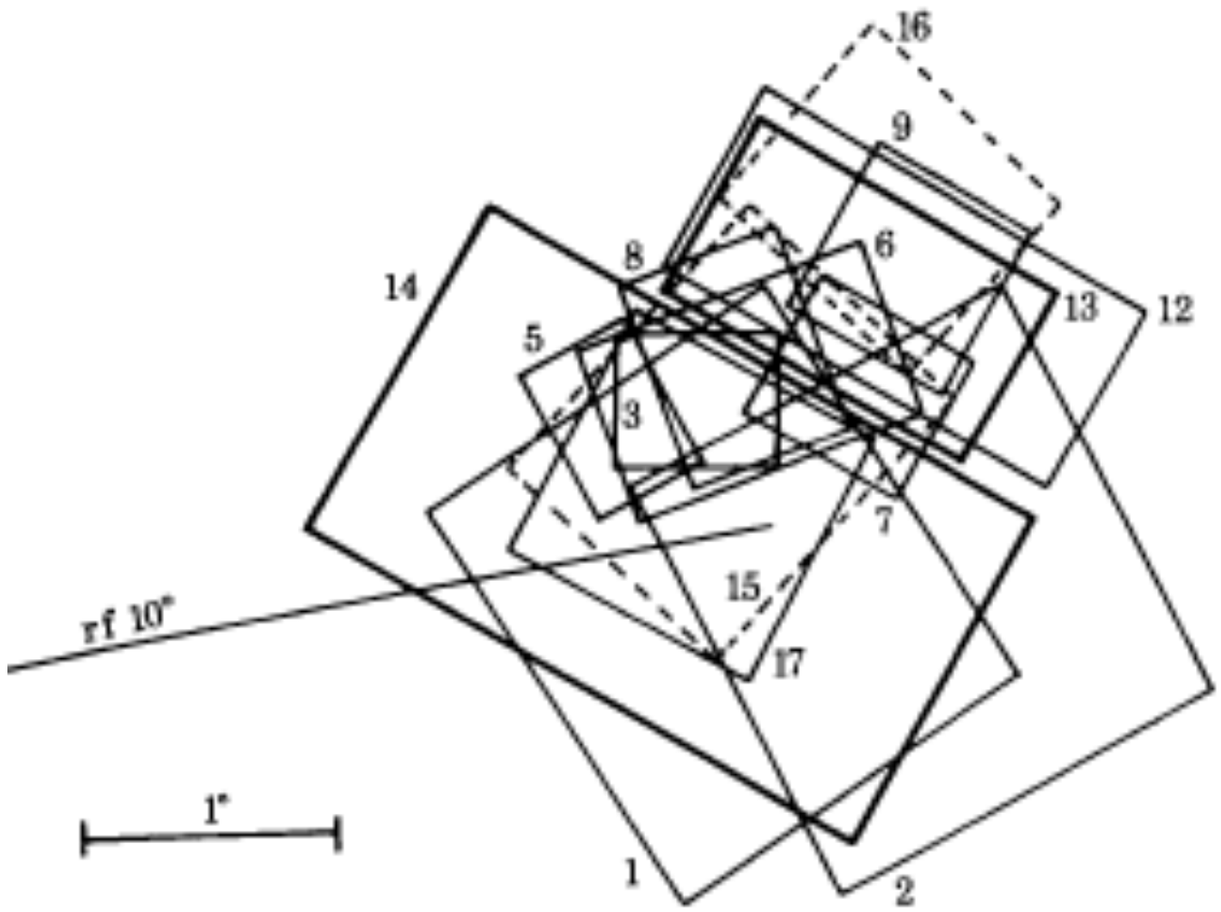


Small Scale



Large Scale

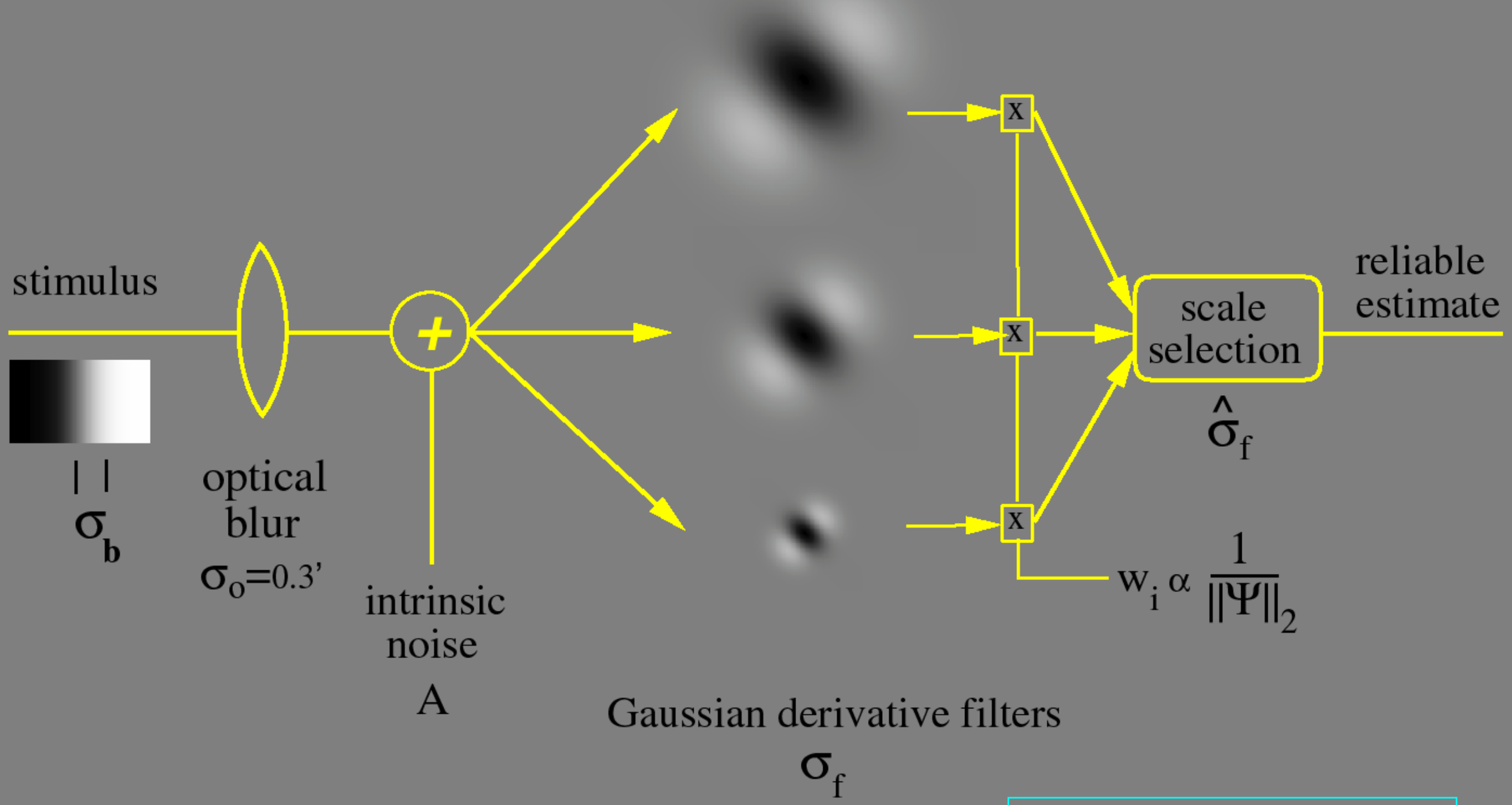
Multi-Scale Processing in Primary Visual Cortex



Sample of Receptive Field Extents in V1 of Monkey (Hubel & Wiesel 1968)

Scale Selection for Edge Detection

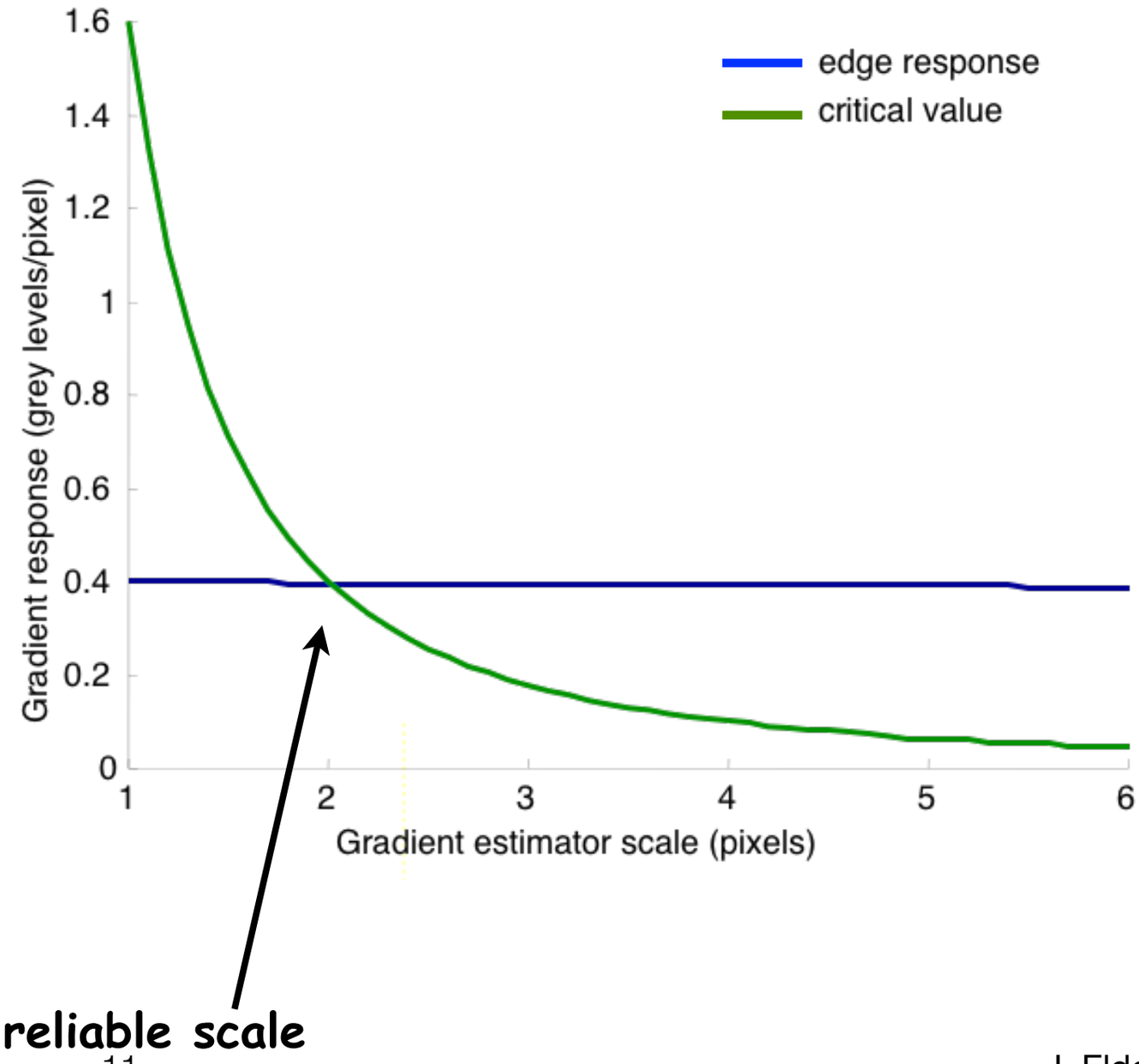
Local Scale Control



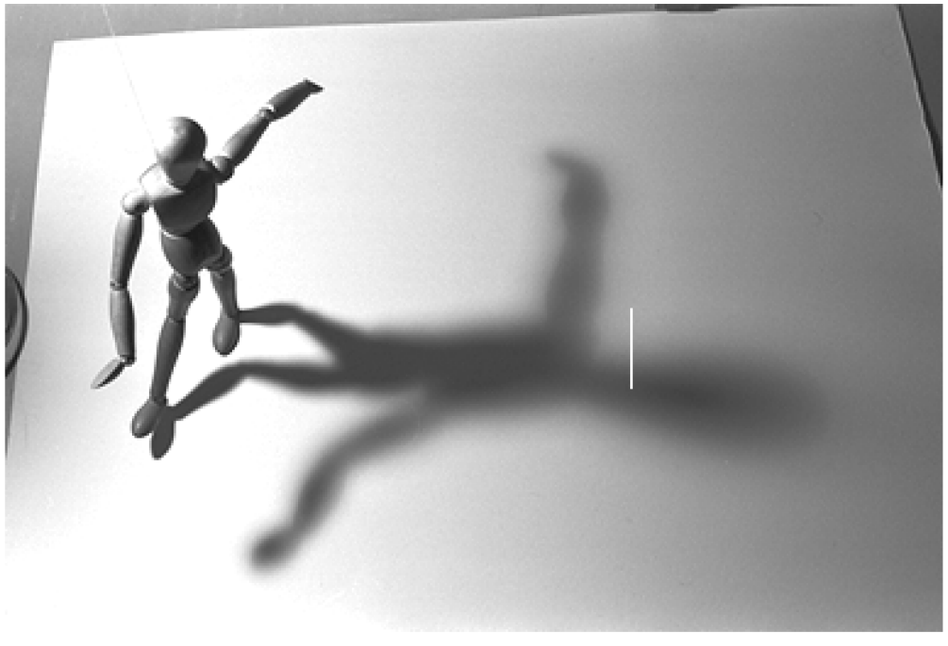
Elder & Zucker, PAMI 1998

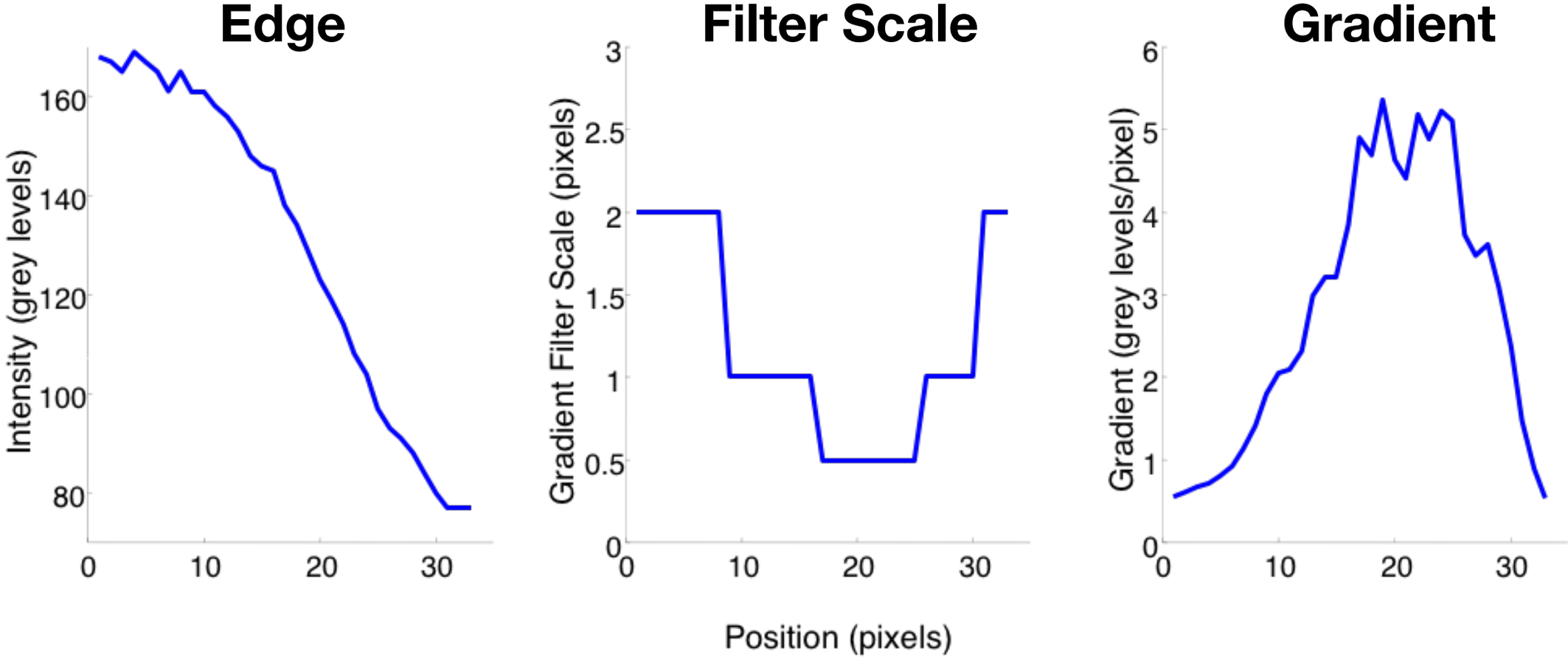
Critical Value Function s(σ)

- Lower bound on filter response for reliable inference,
- e.g. p(>0 errors over entire image) < 5%.
- Assumes known, stationary, additive sensor noise
- Prior computation based on:
  - 2nd moment of sensor noise σ_n
  - L_2 norm of operator
  - Required inference

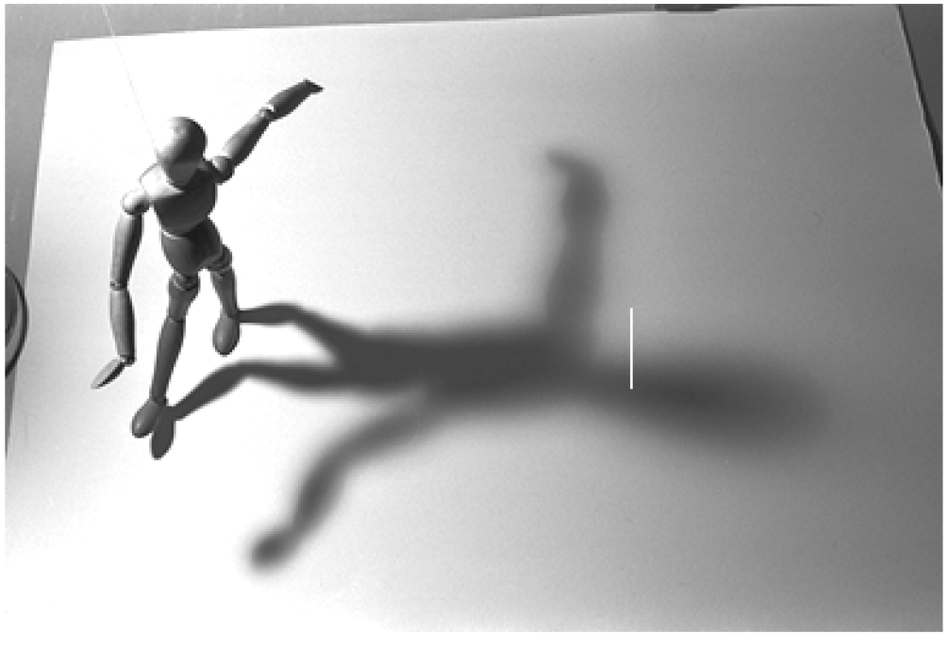


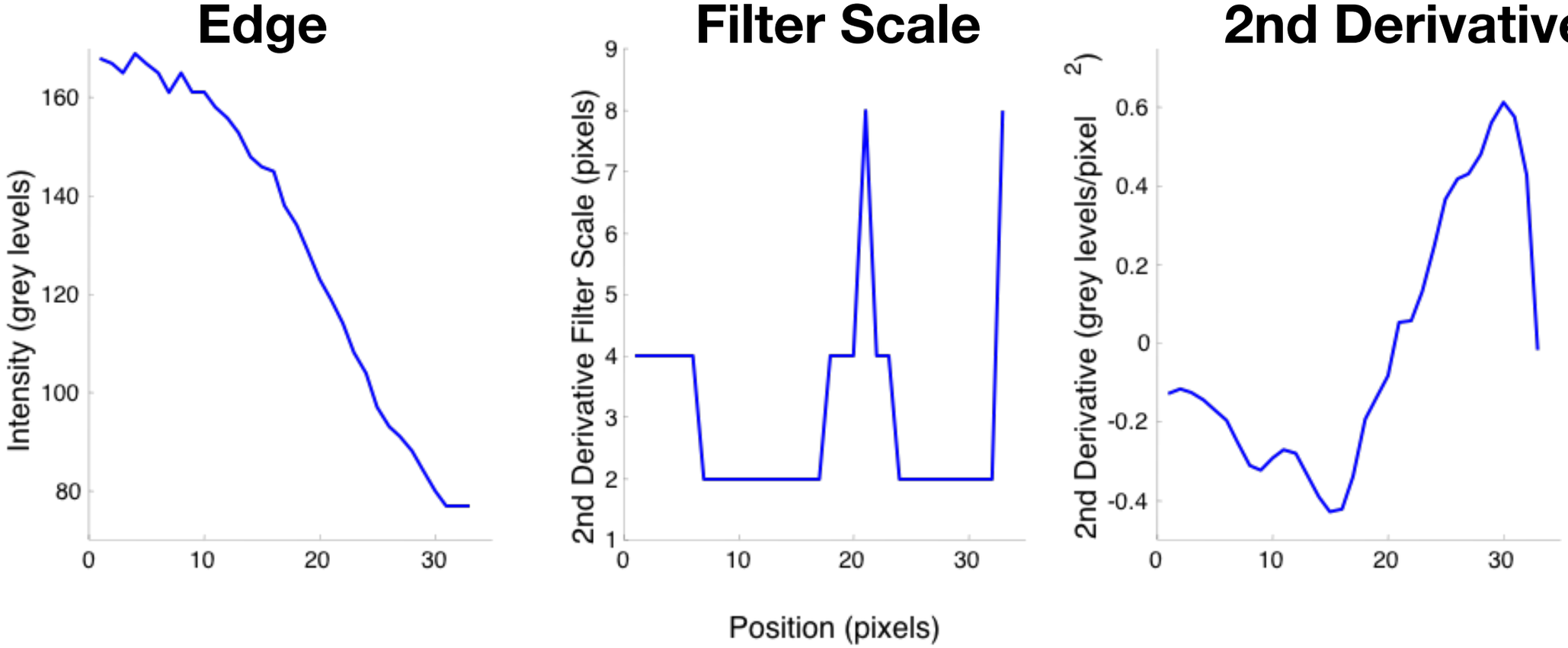
Gradient Estimation using Local Scale Control



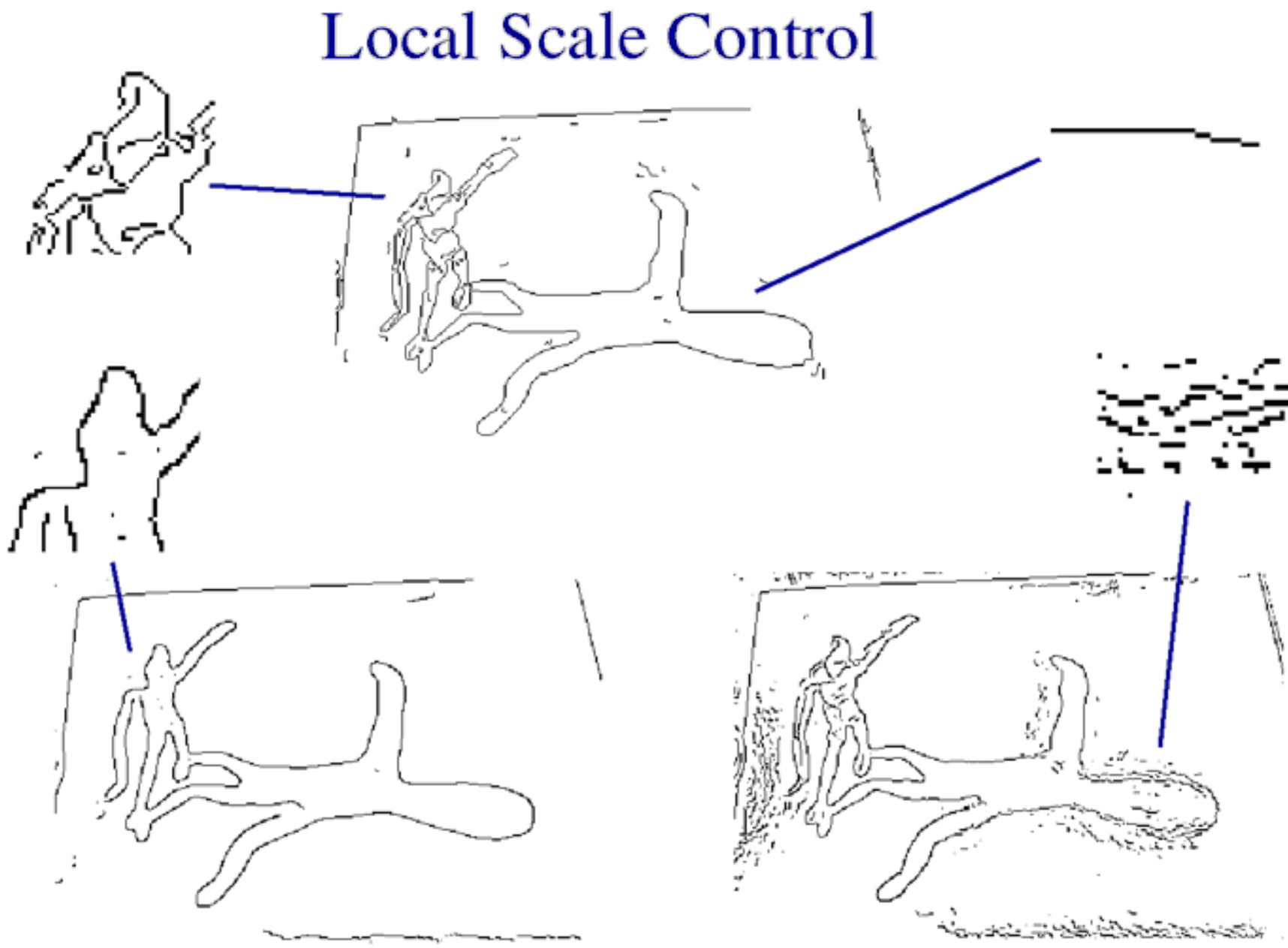


2nd Derivative Estimation Using Local Scale Control

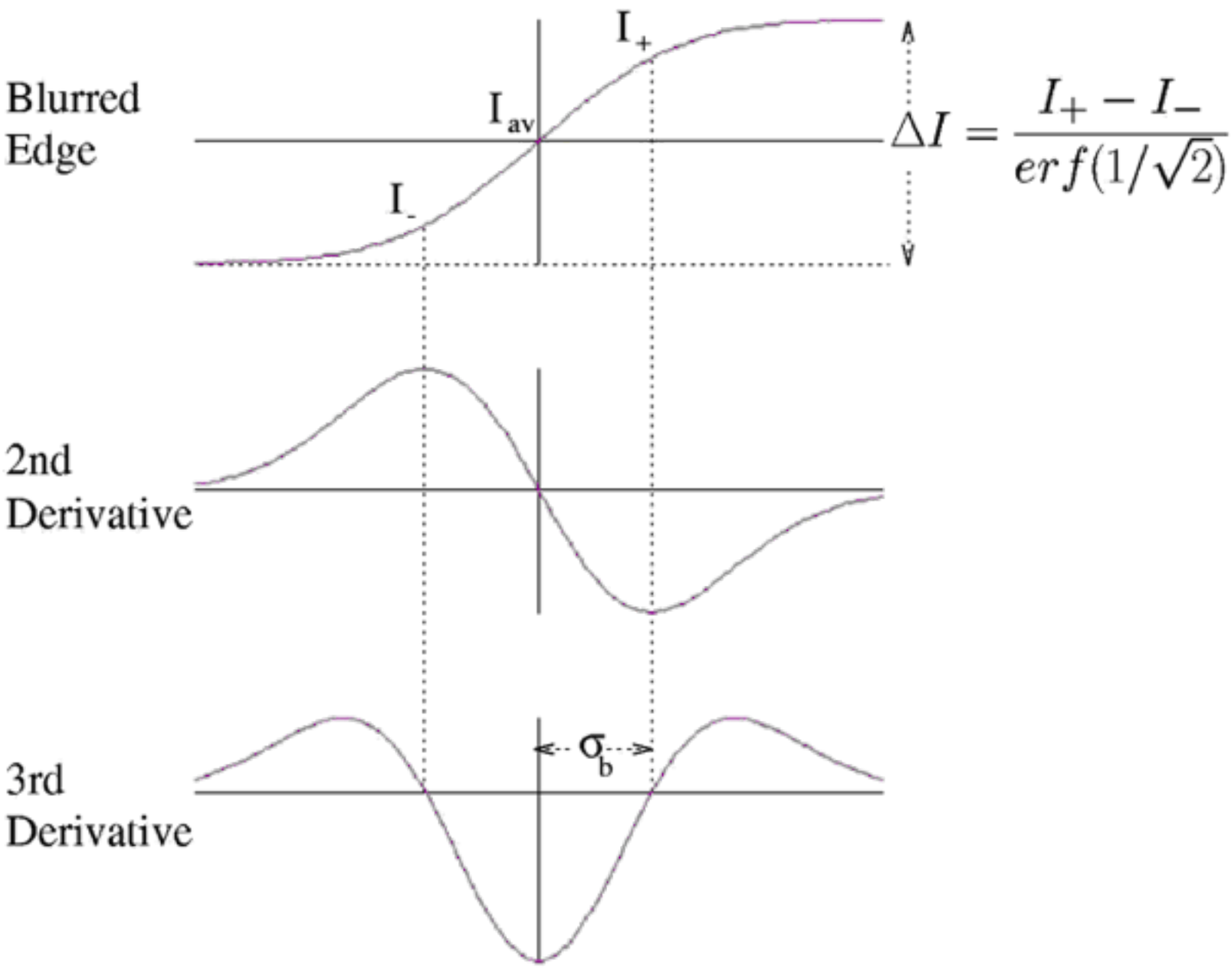




Results

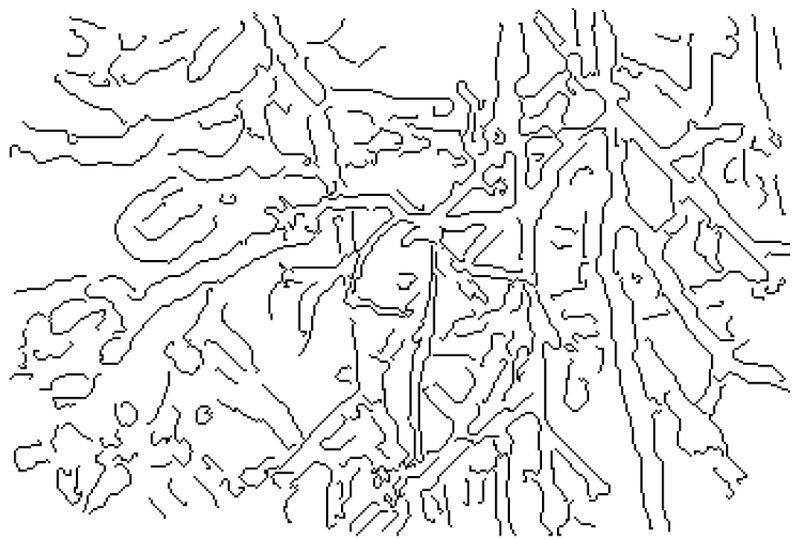


Estimating Photometric Parameters



Depth from Blur for Cluttered Scenes

(a)

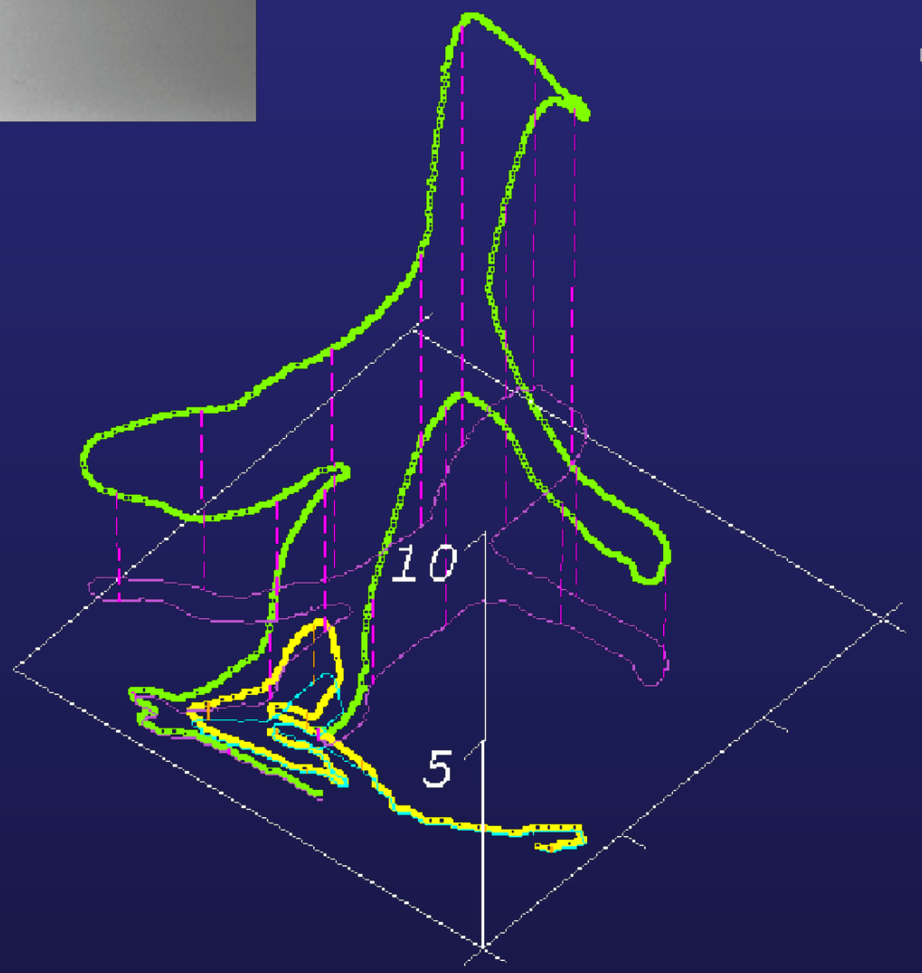


(b)

Foreground

Background

Depth from Shadows



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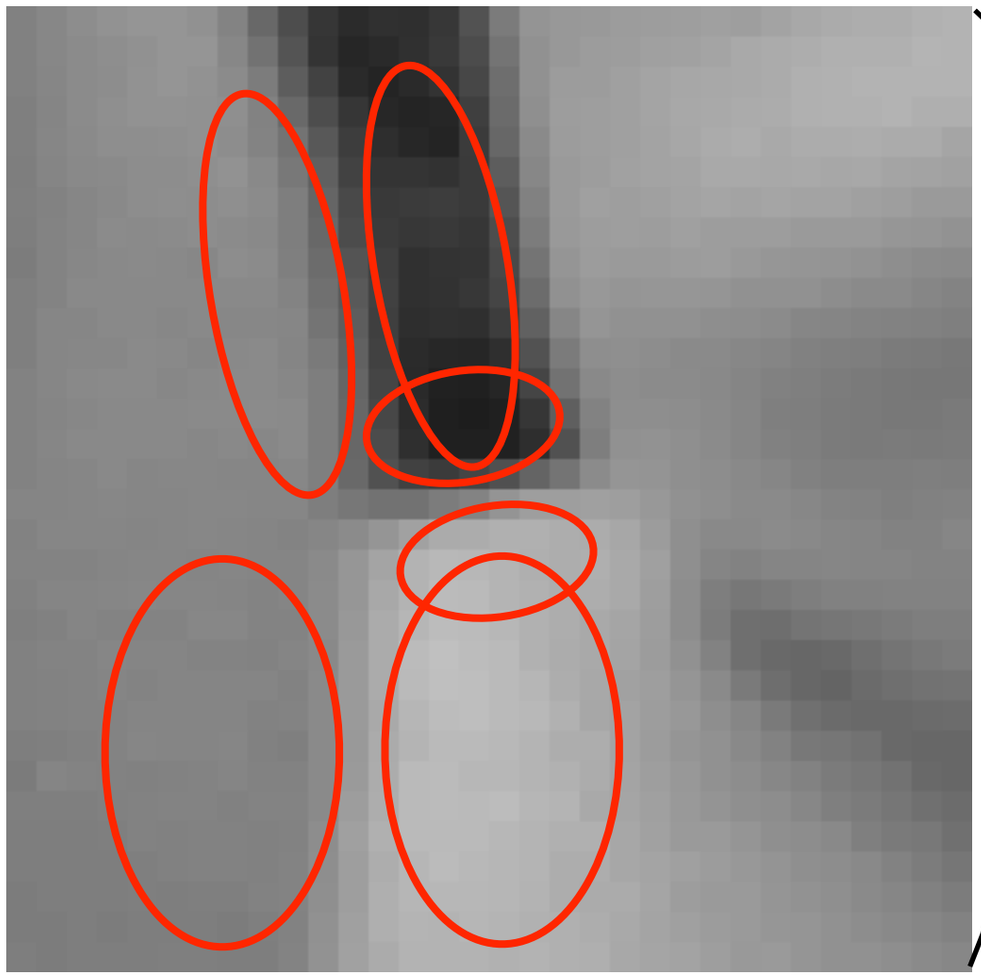
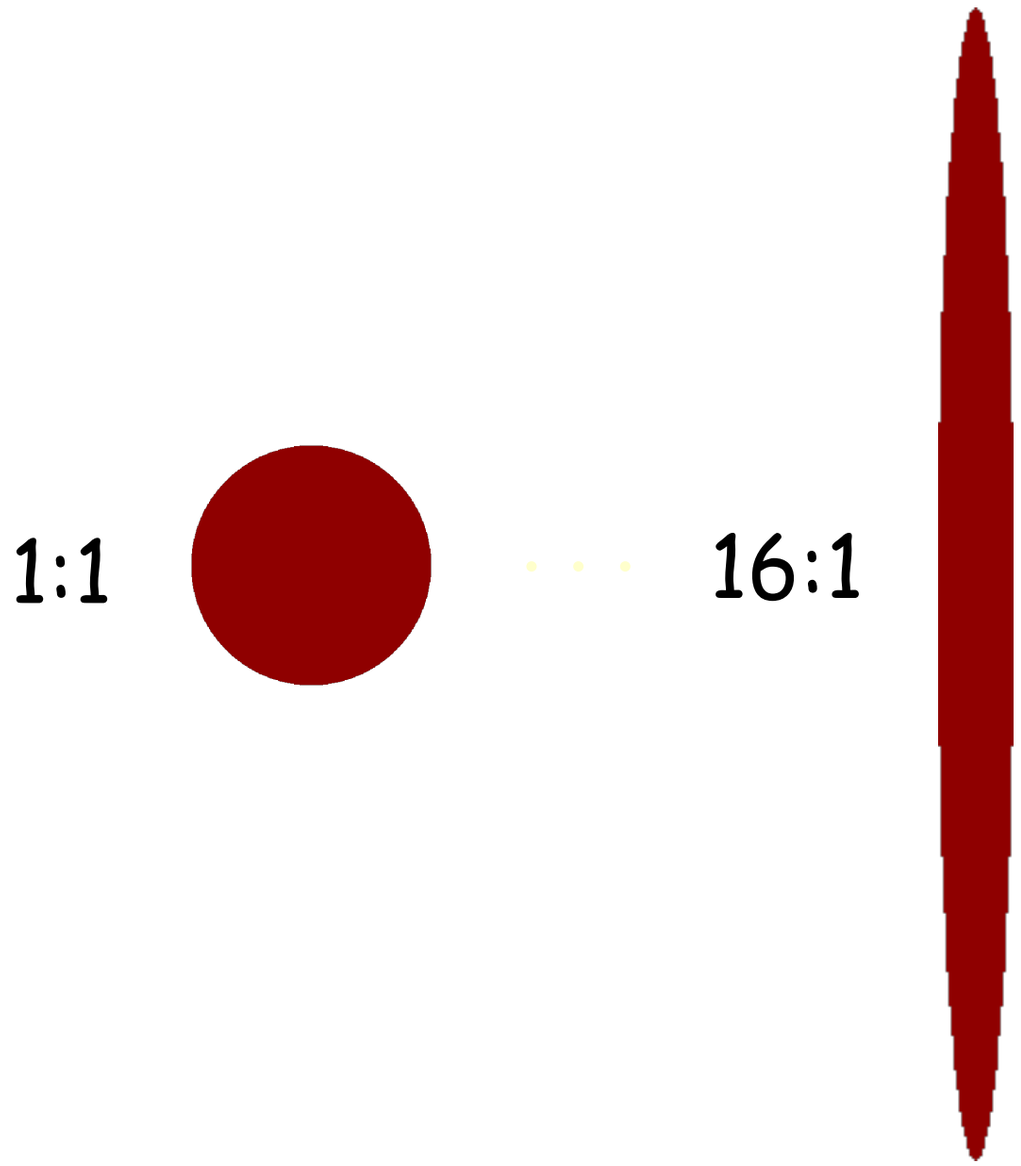
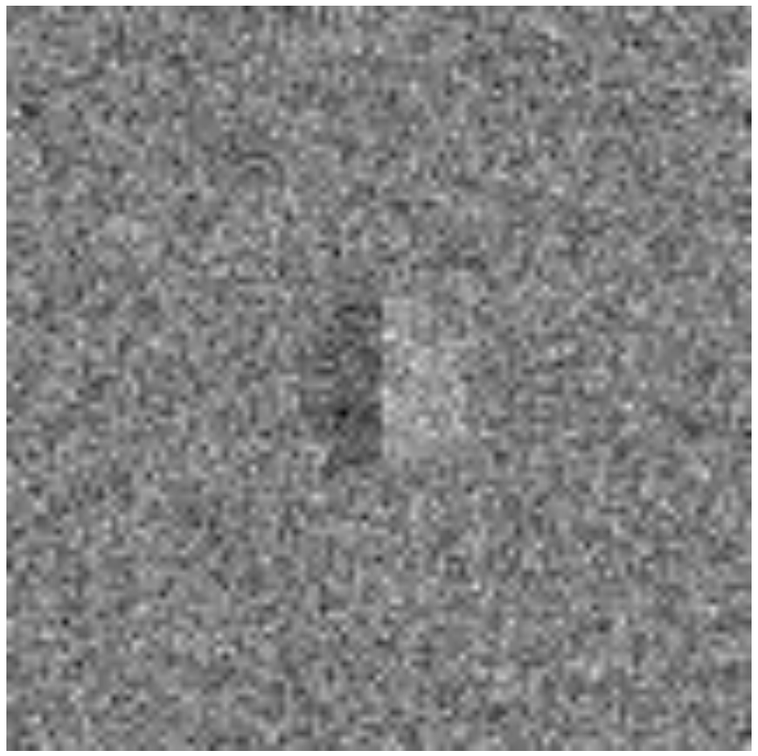
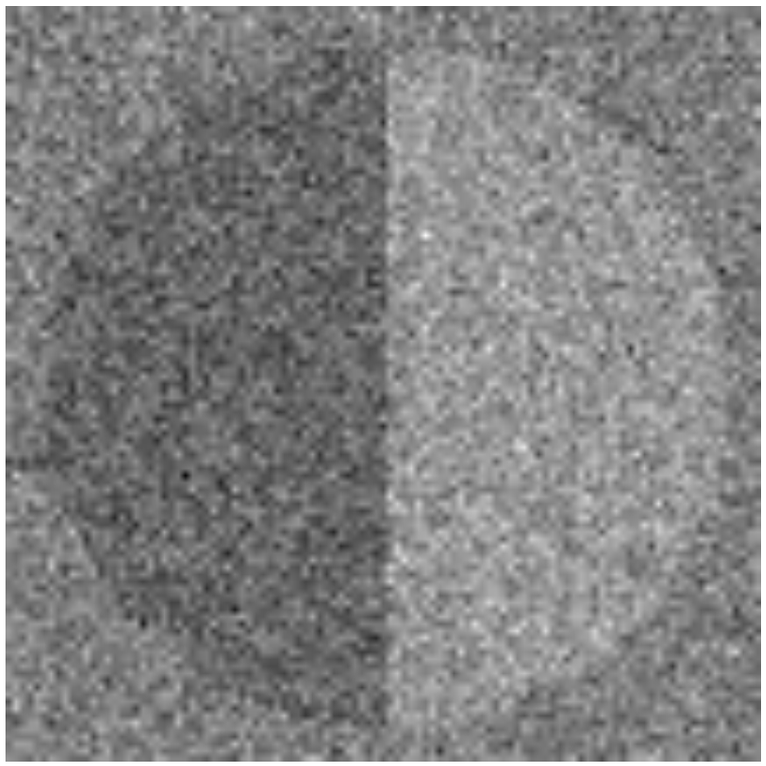
Edge detection in natural images: clutter and noise

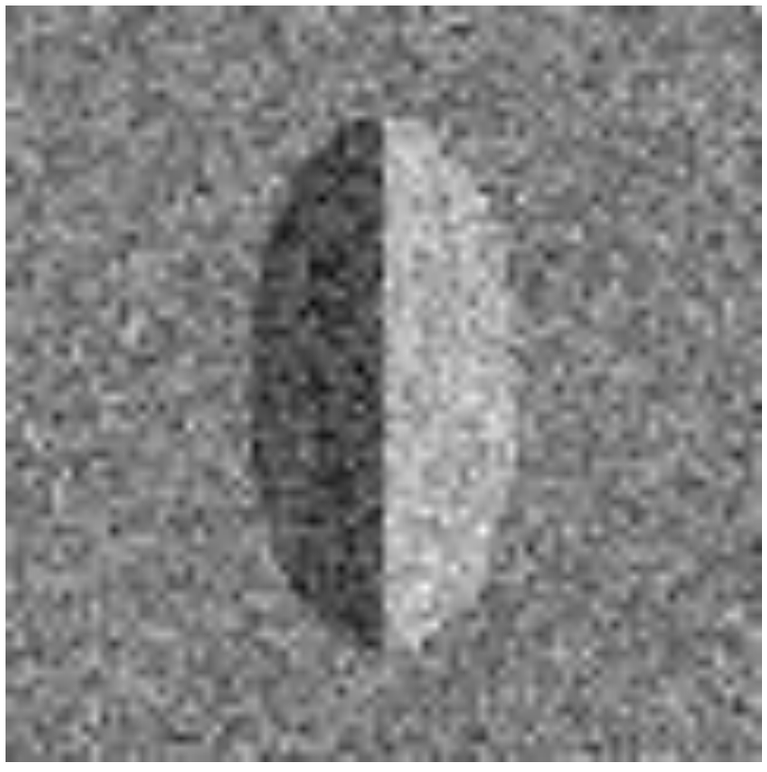


V1 Receptive Field Diversity in Shape



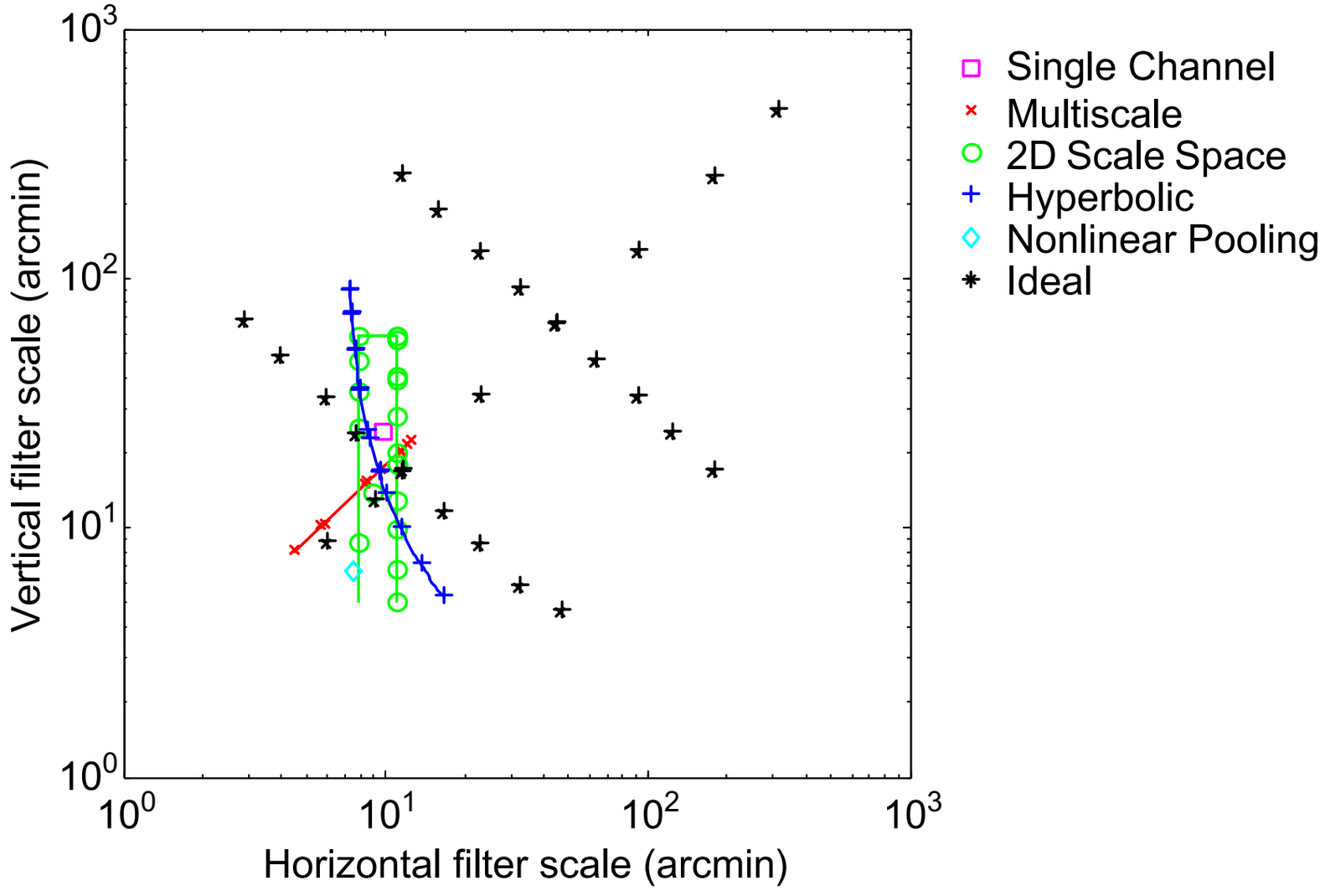
Example Psychophysical Stimuli

Edge Filter Shape Selection

- The human brain appears to select from a diversity of filter shapes for edge detection



Elder & Sachs, Vision Research 2004

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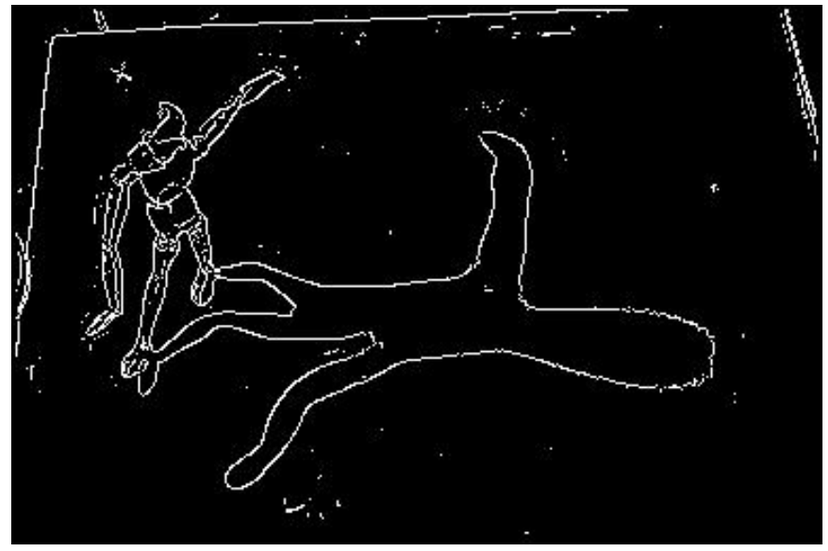
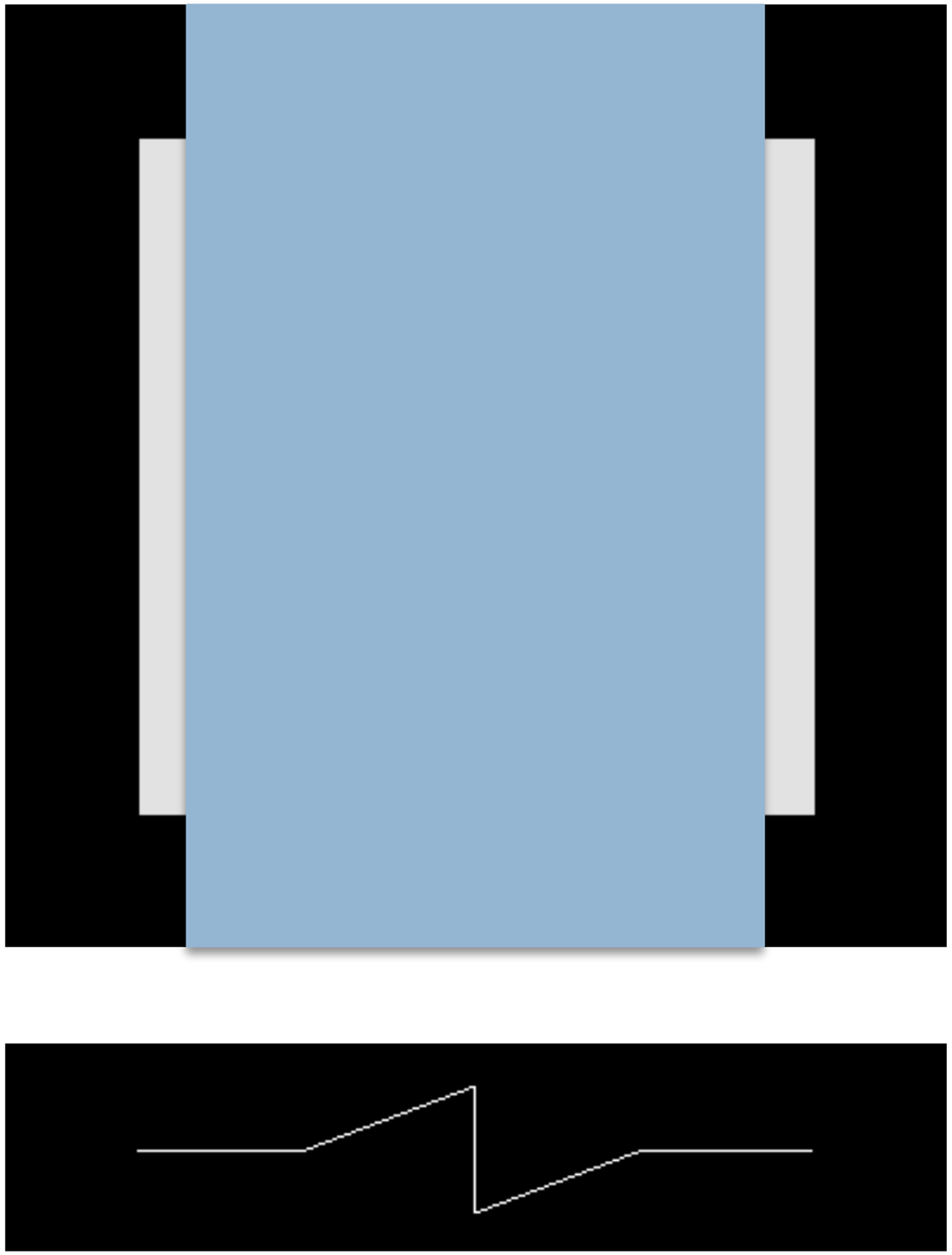
Information Loss?

- Does the brain discard the information not carried by edges?

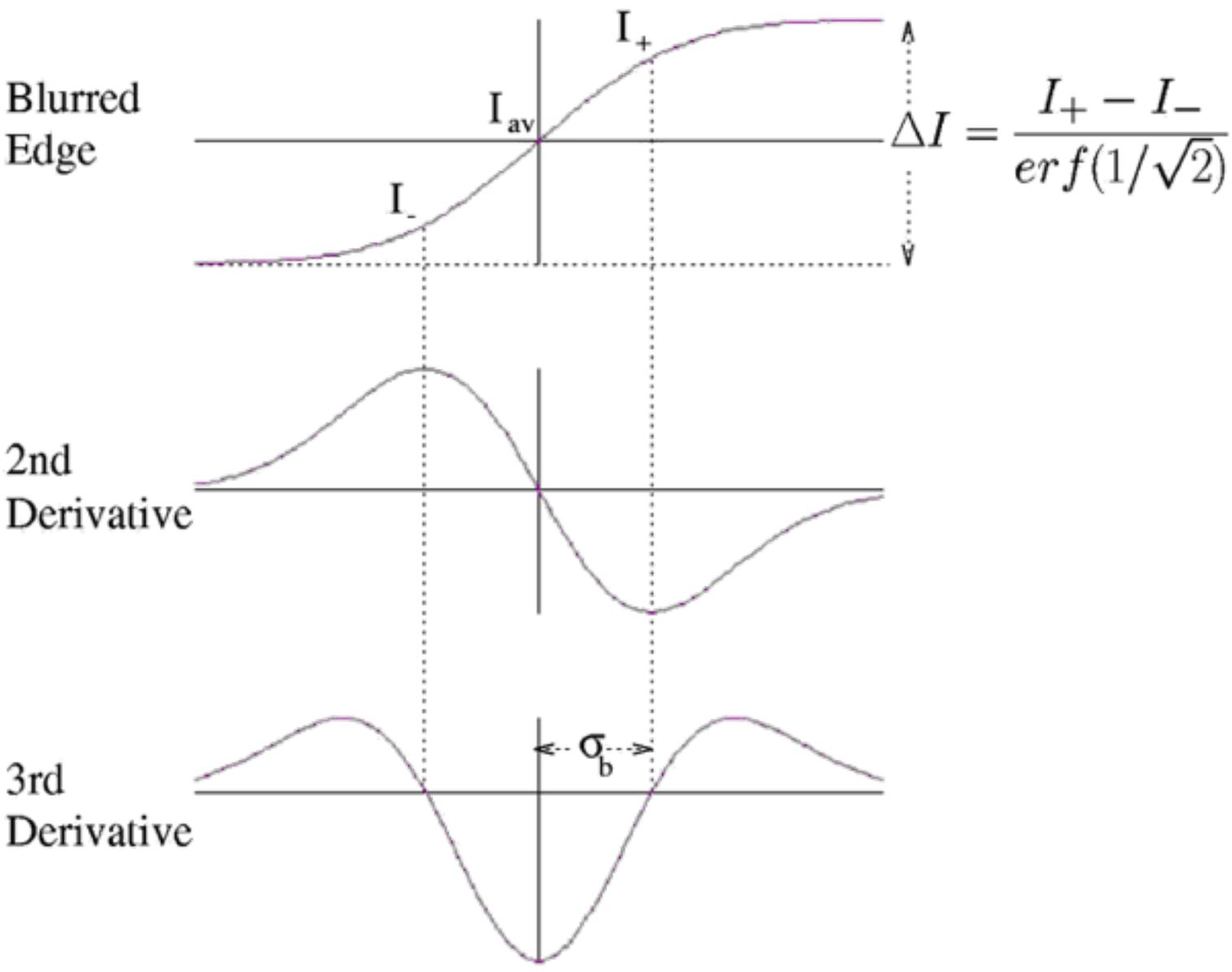


Brightness Filling-In



Cornsweet (1970)

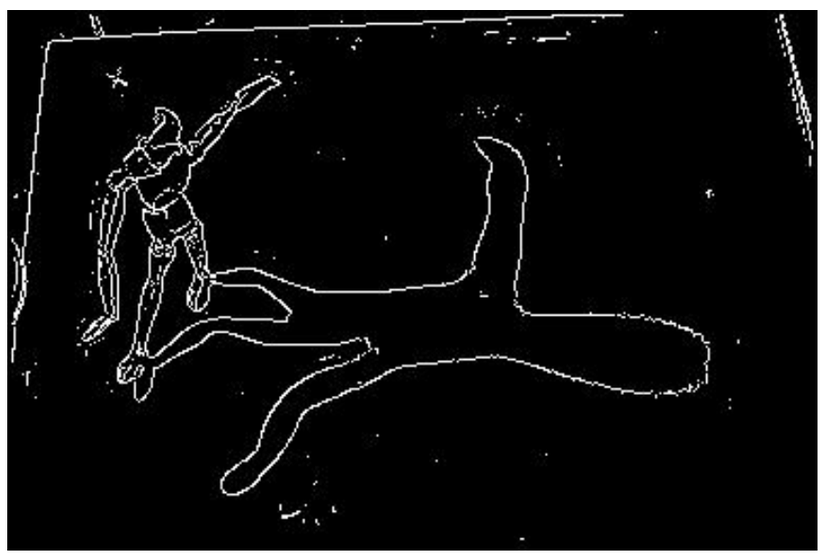
Estimating Photometric Parameters



Brightness Filling-In

Original

Edge Map



Intermediate

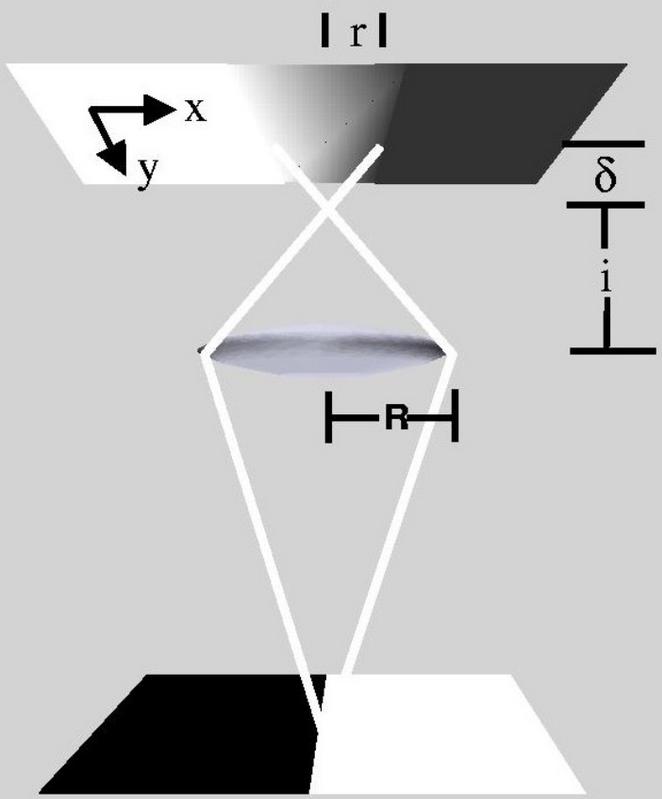
Reconstructed Intensities

Image Reconstruction from Contours

Elder, IJCV 1999

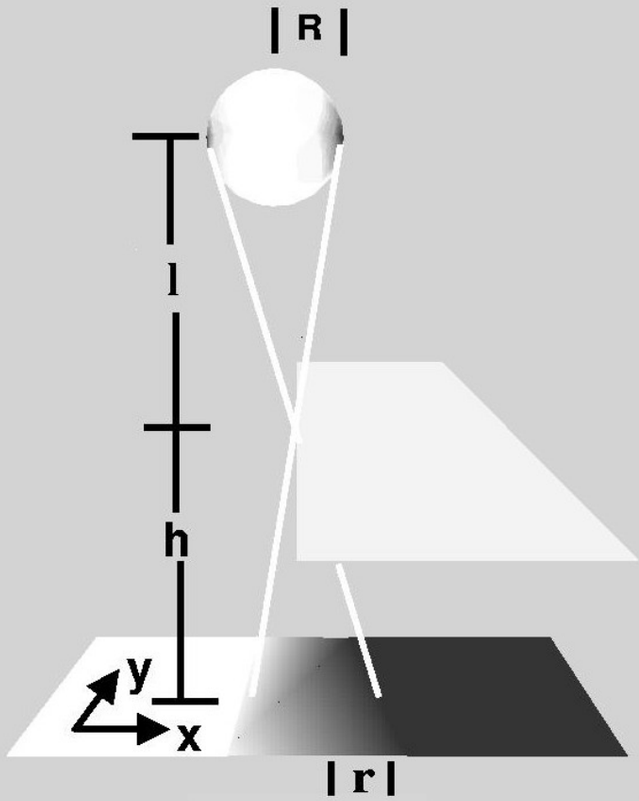
Origins of edge blur in natural scenes

Focal Blur



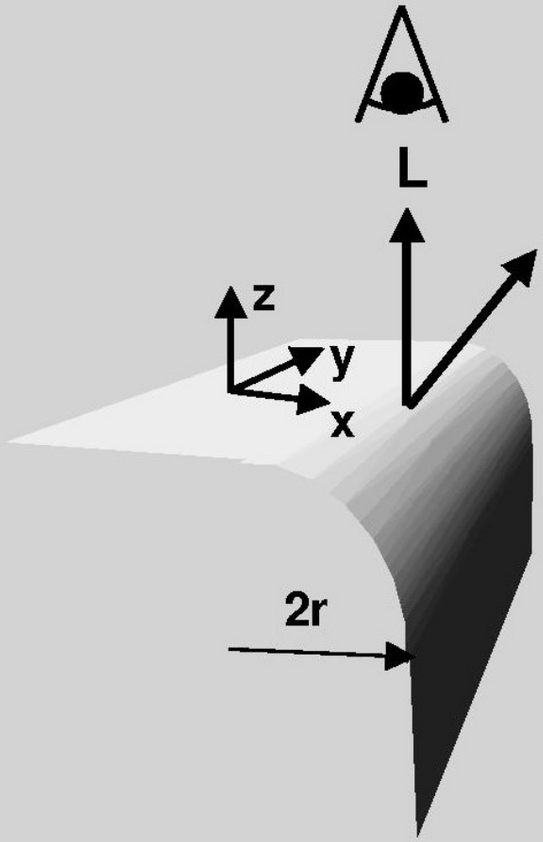
$$r = R\frac{\delta}{i}$$

Penumbral Blur



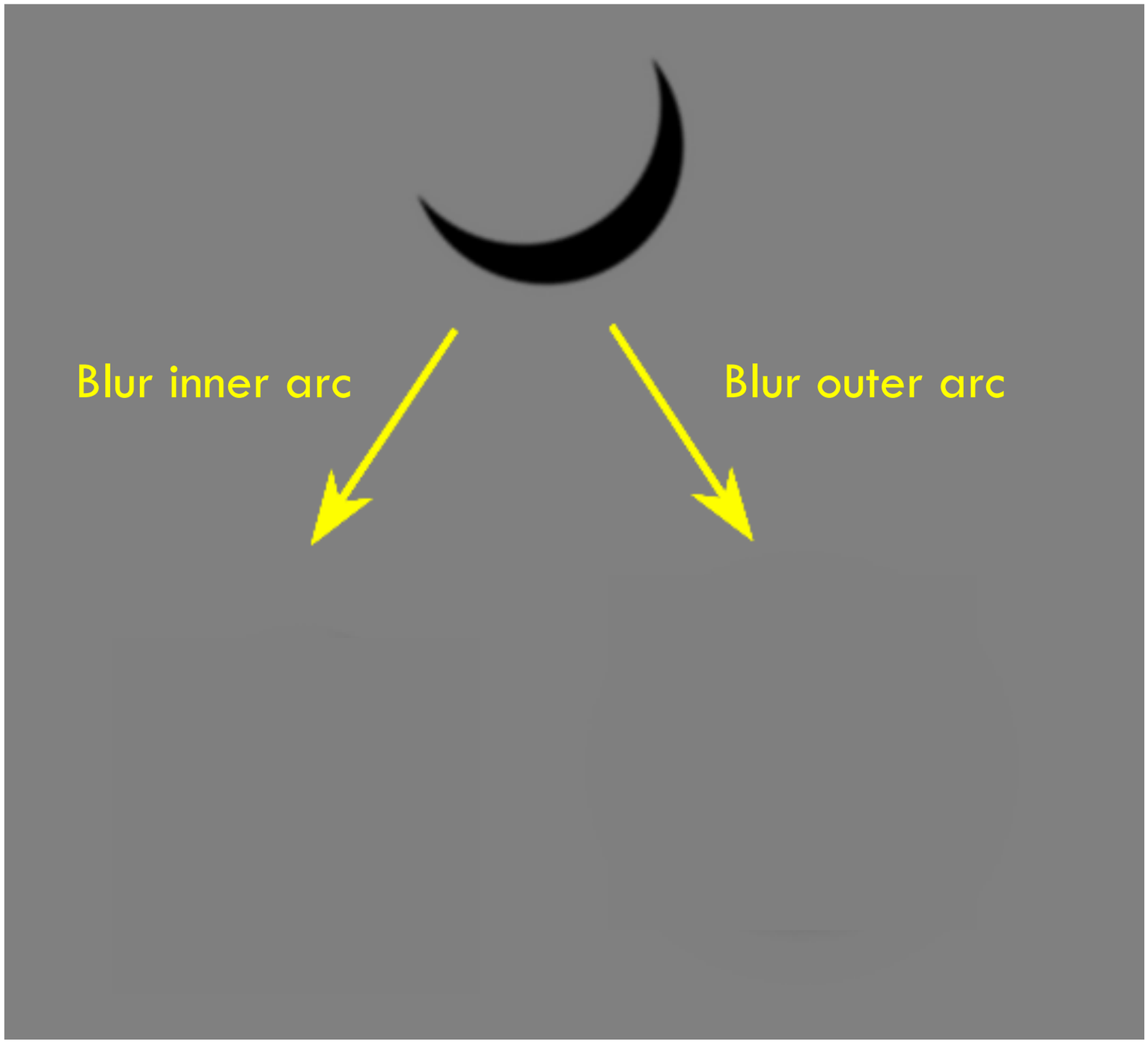
$$r = R\frac{h}{l}$$

Shading



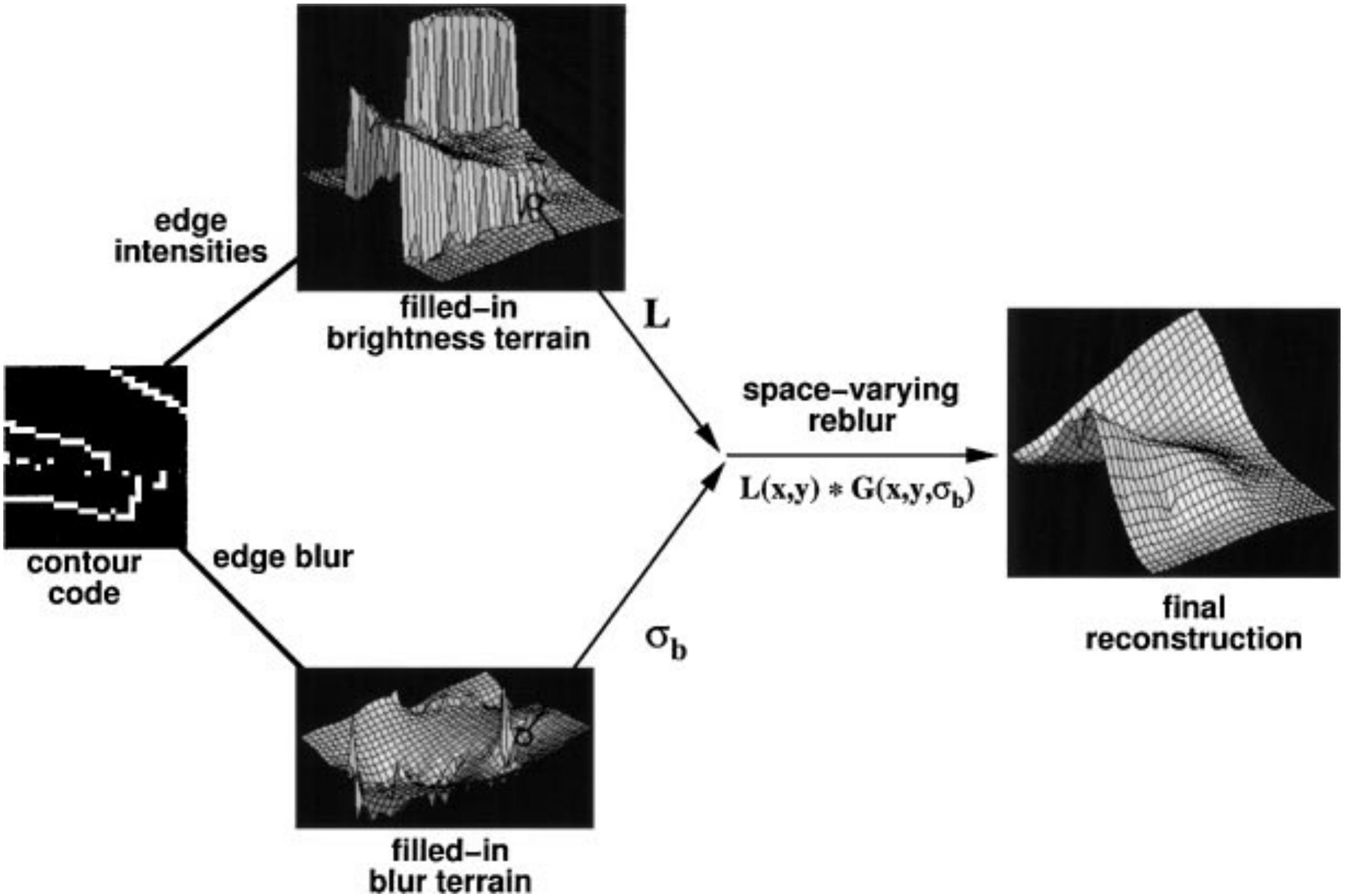
$$z(x) = -\int_0^x ([f(x/r)]^{-2} - 1)^{1/2} dx$$

Perception of shadow from edge



Elder et al., Perception 2004

Parallel Filling-In of Intensity and Blur



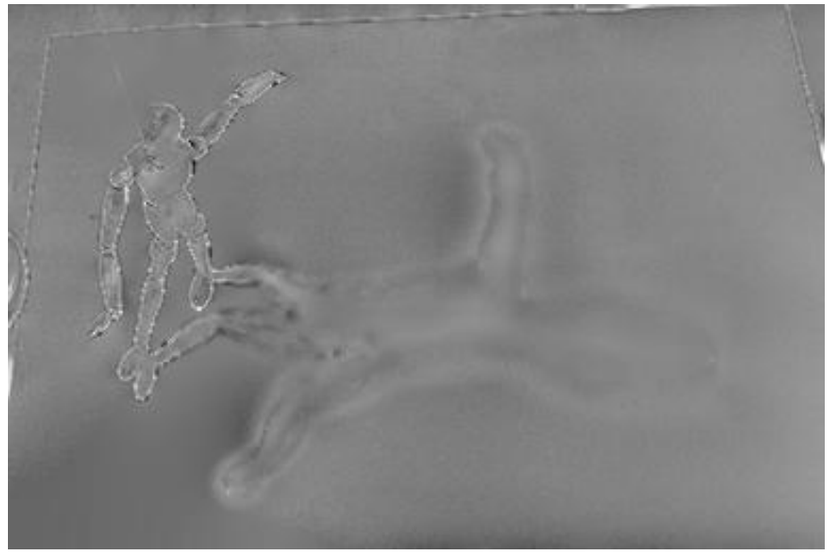
Restoring Blur

Original

Reconstructed Intensities

Reblurred Result

Error Map



Reconstruction Example

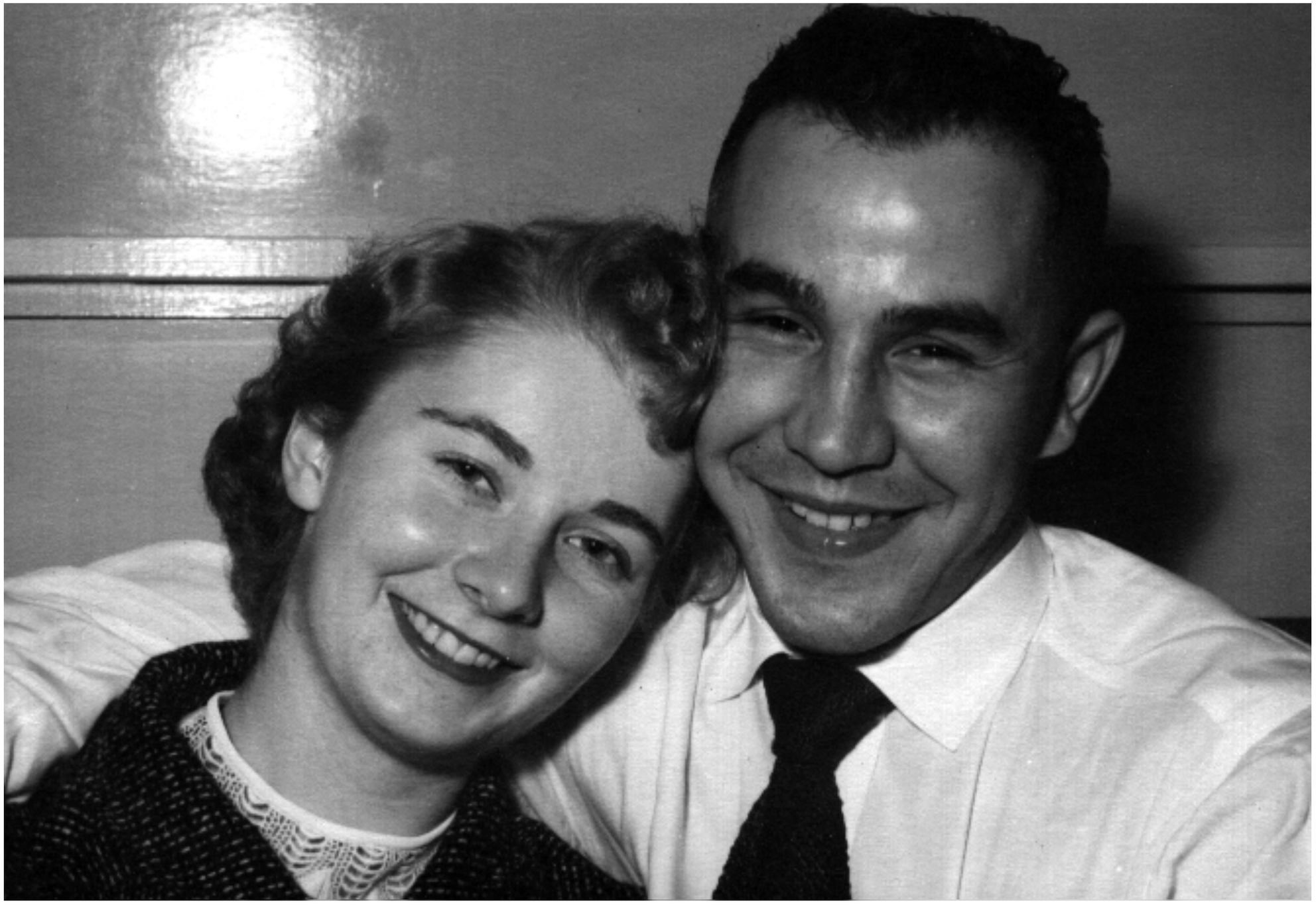
Original

Edge Map

Reconstructed Intensities

Reblurred Result

Reconstruction Example



Elder, IJCV 1999

Reconstruction Example

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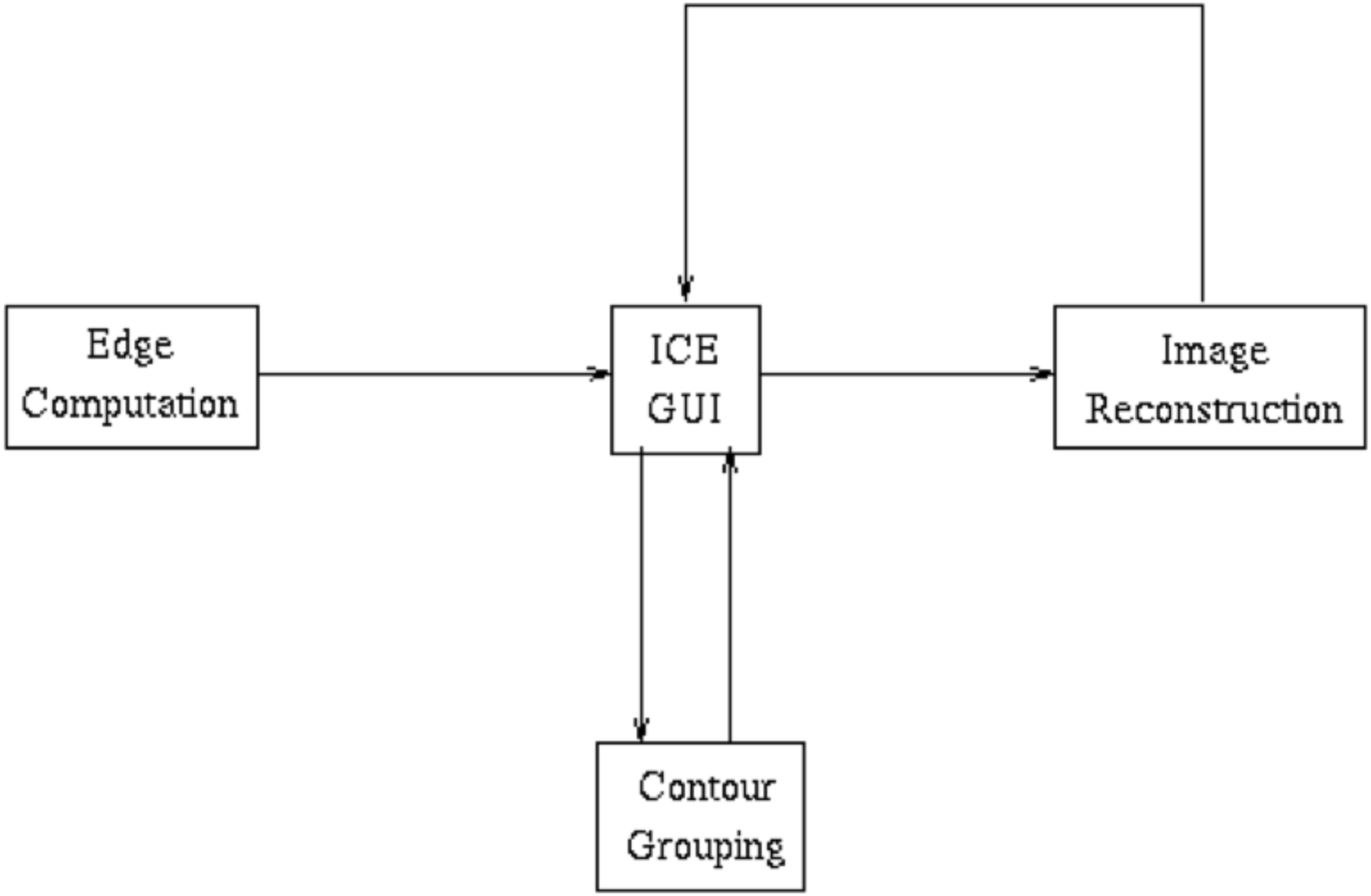
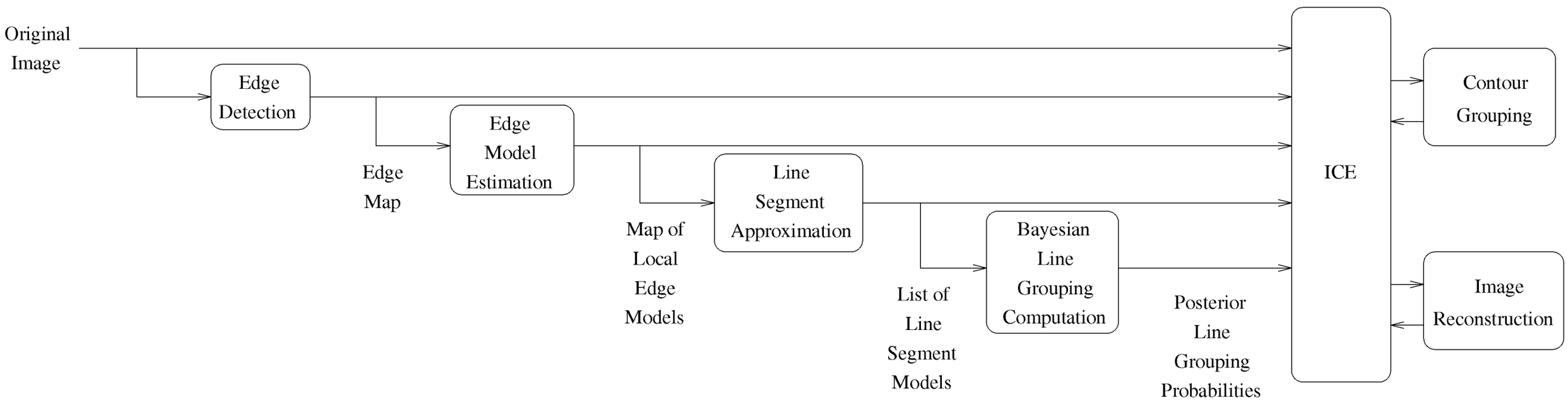
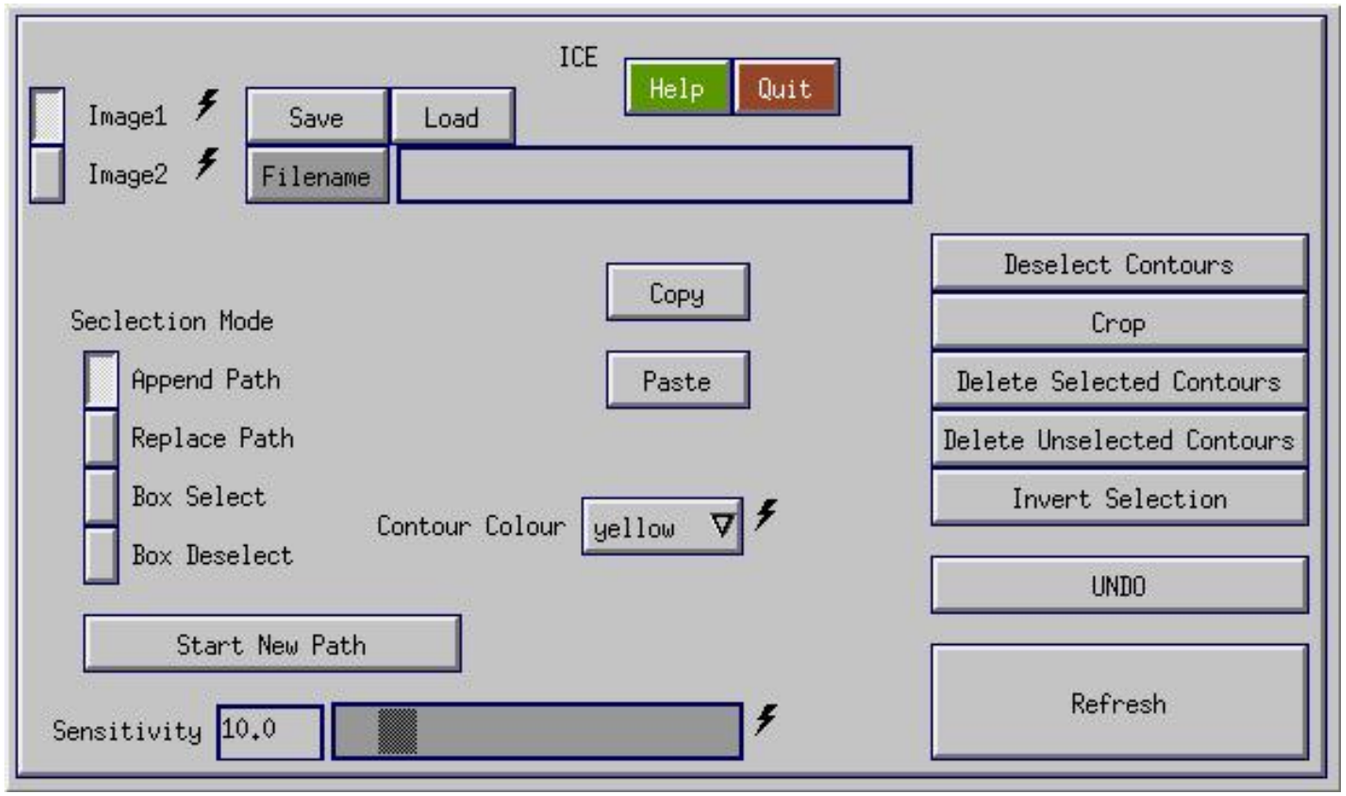


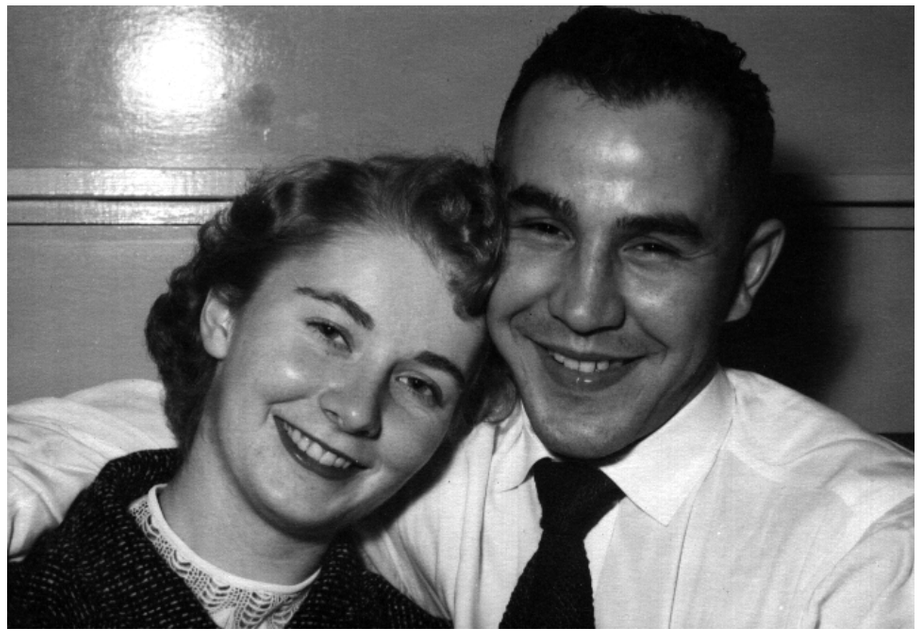
Elder, PAMI 2001

Input Representations

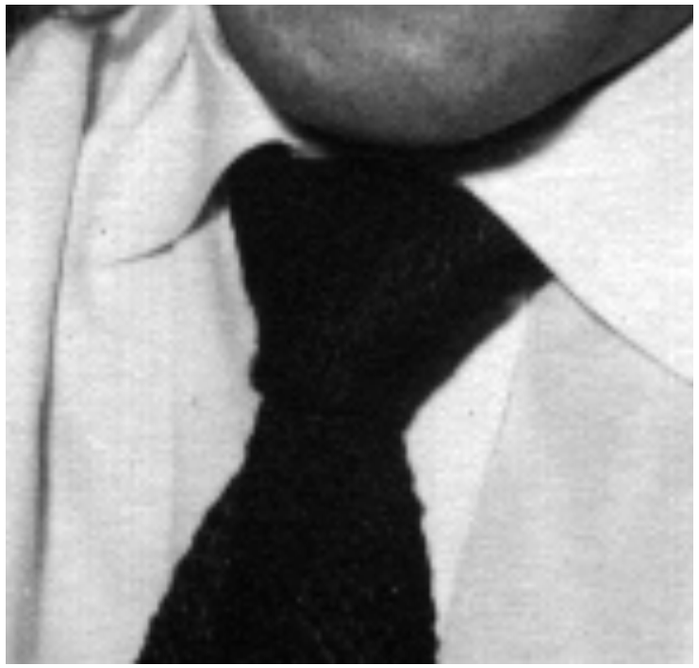


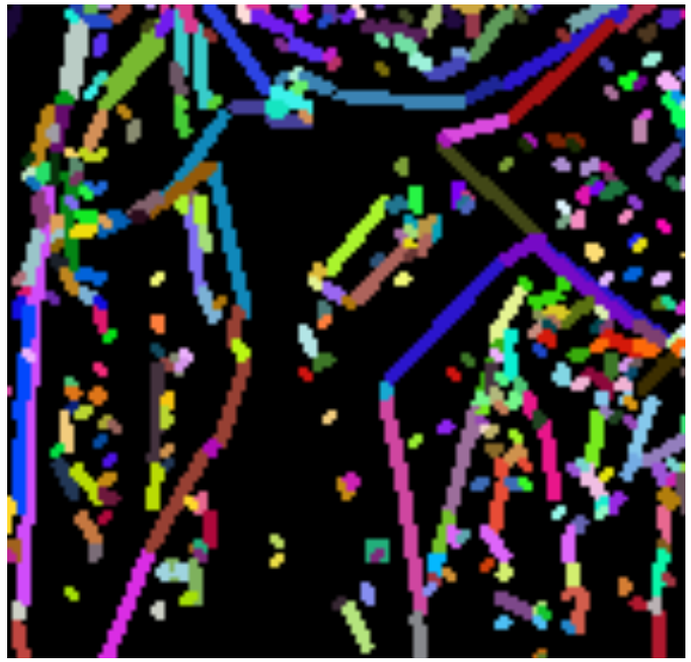
User Interface

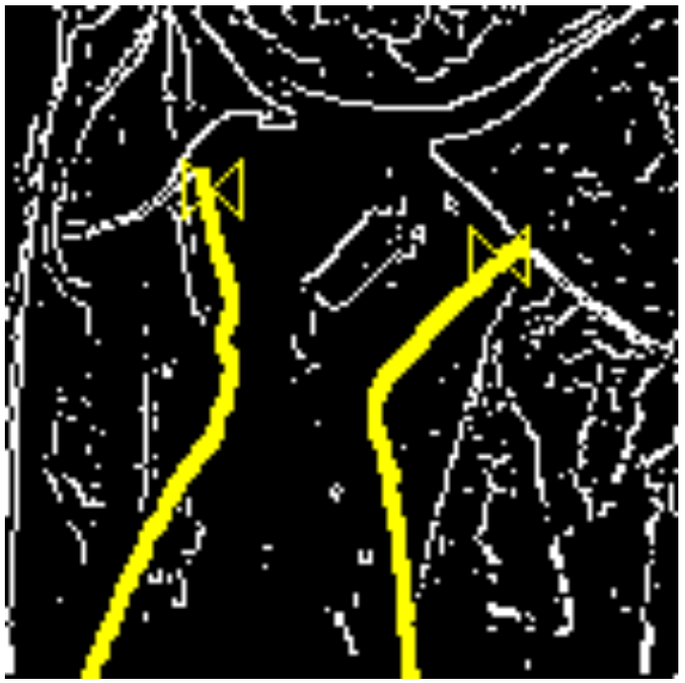




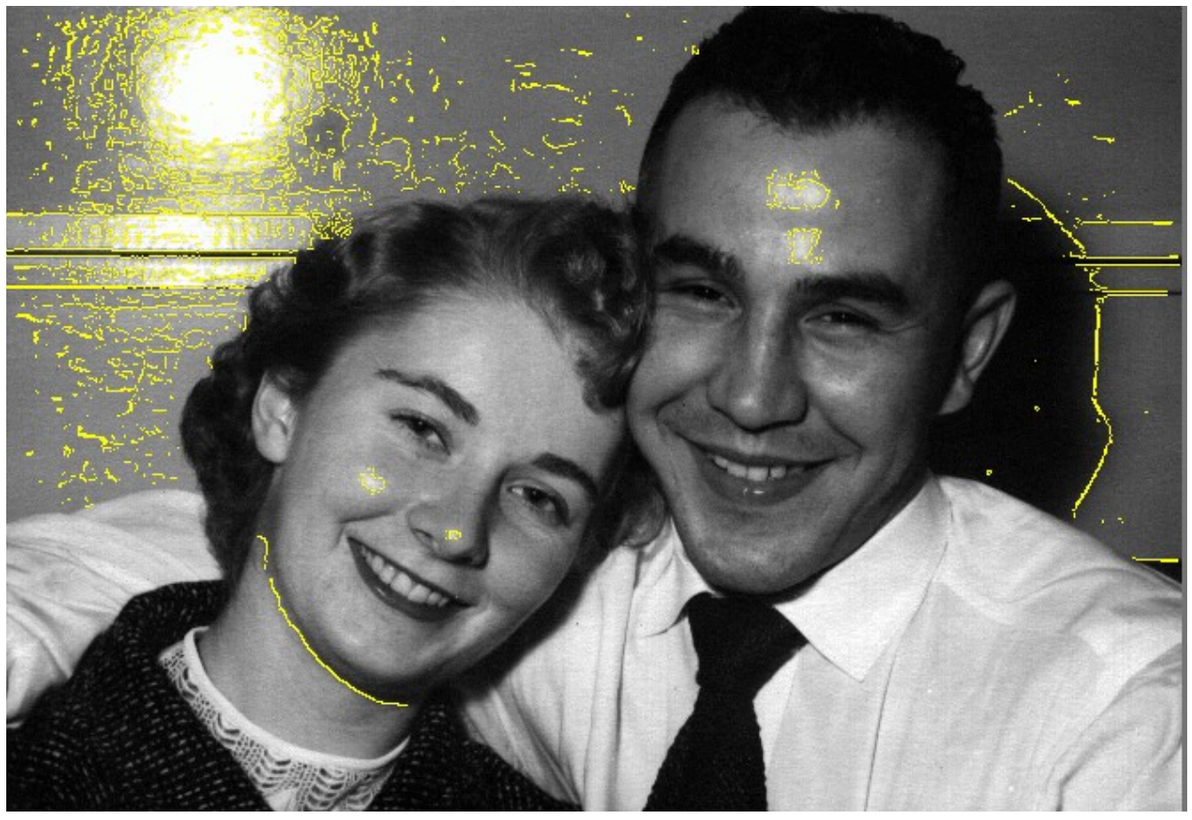
Rapid Interactive Contour Grouping with ICE





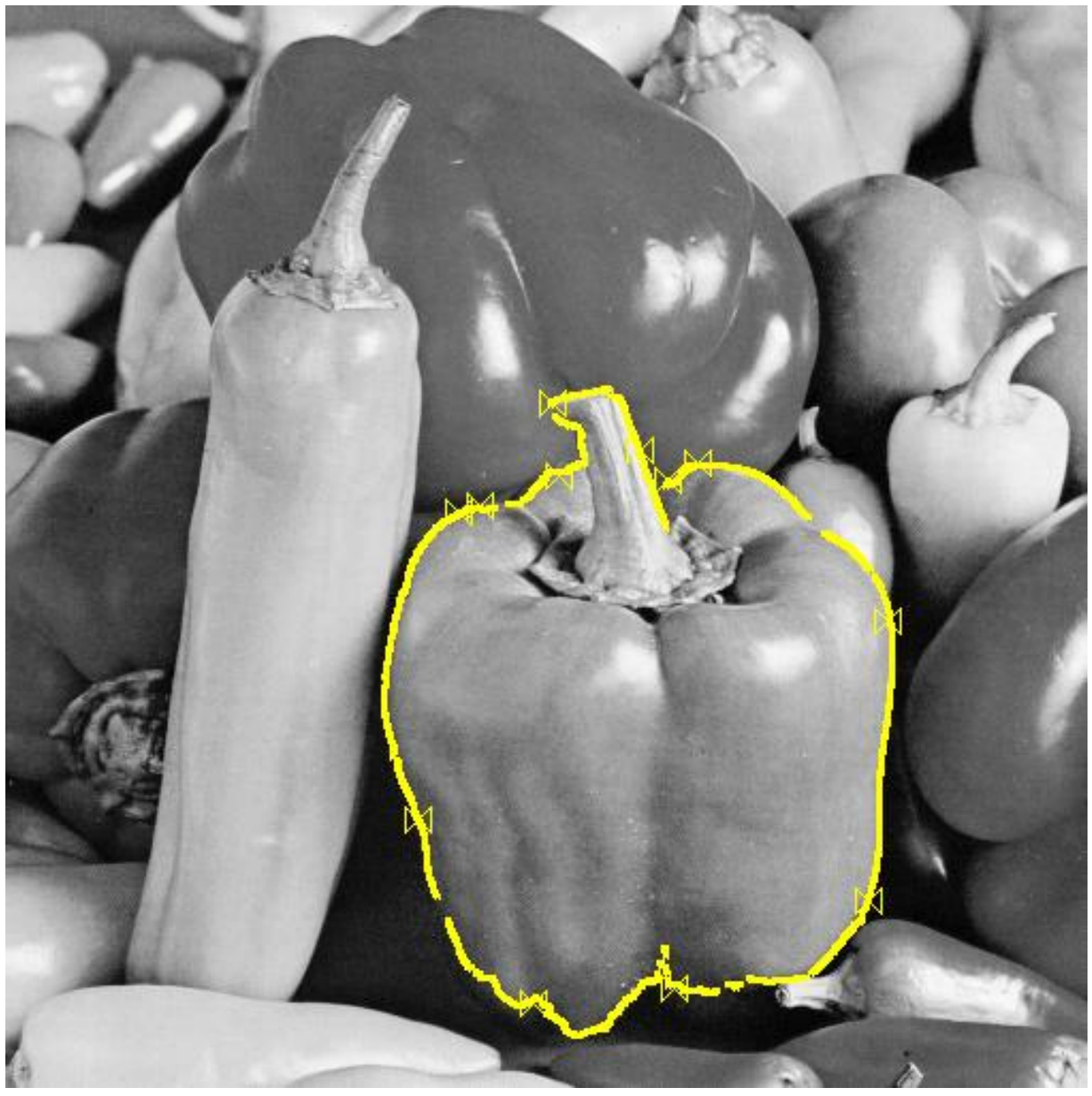


Examples

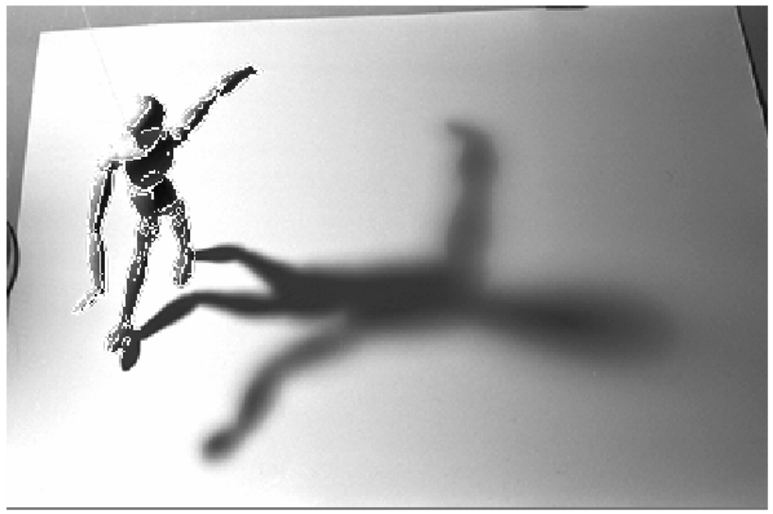


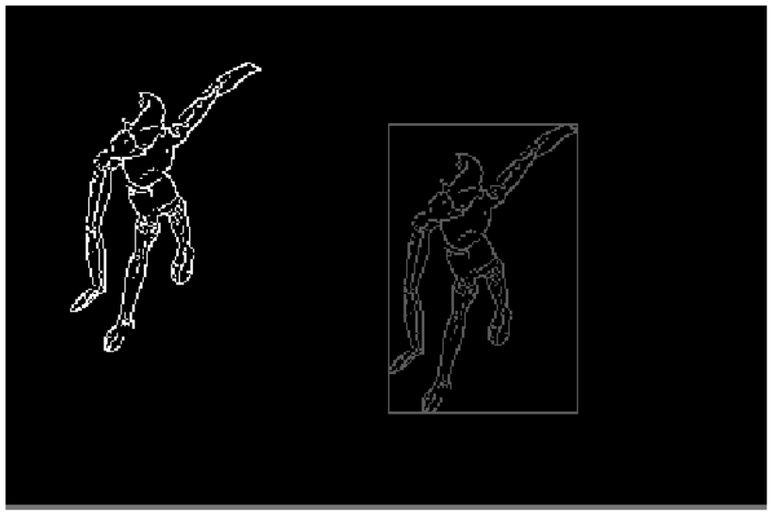
Examples

Examples



Examples





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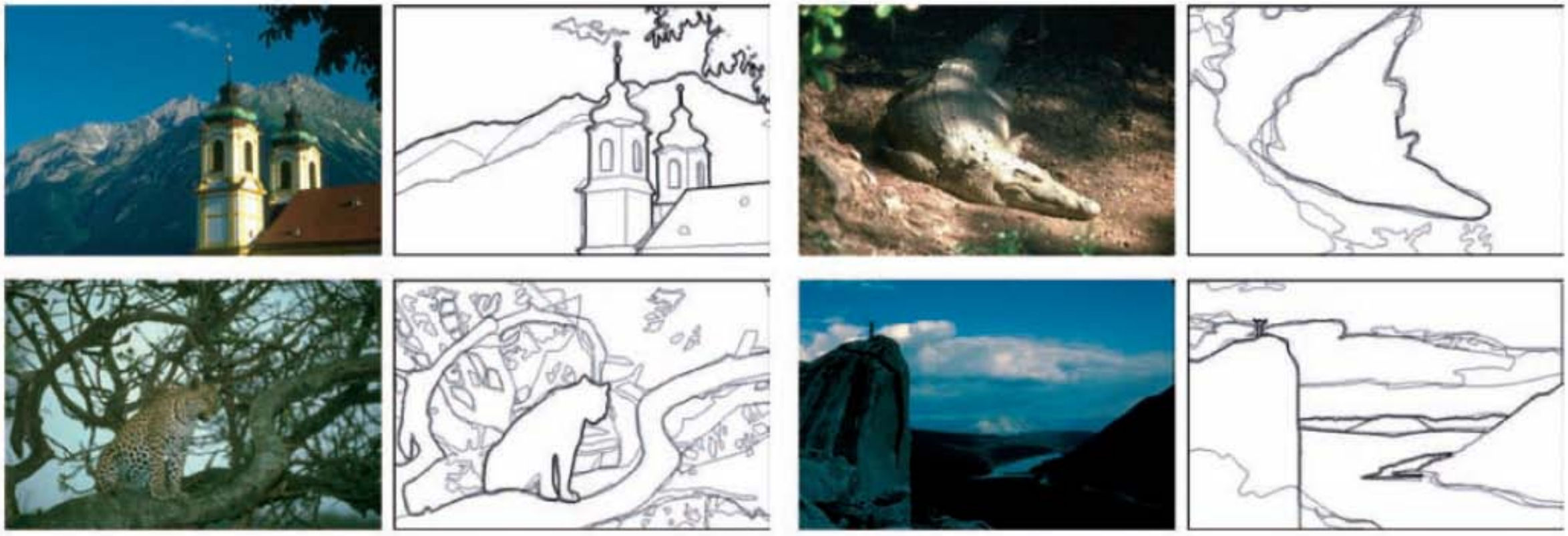
Salient Edges

- Luminance edges are generated by many causes
  - Object boundaries and creases
  - Reflectance changes
  - Shadows
- Not all of these may be important for the task at hand
- This motivates the problem of **salient** edge detection

Berkeley Segmentation Dataset

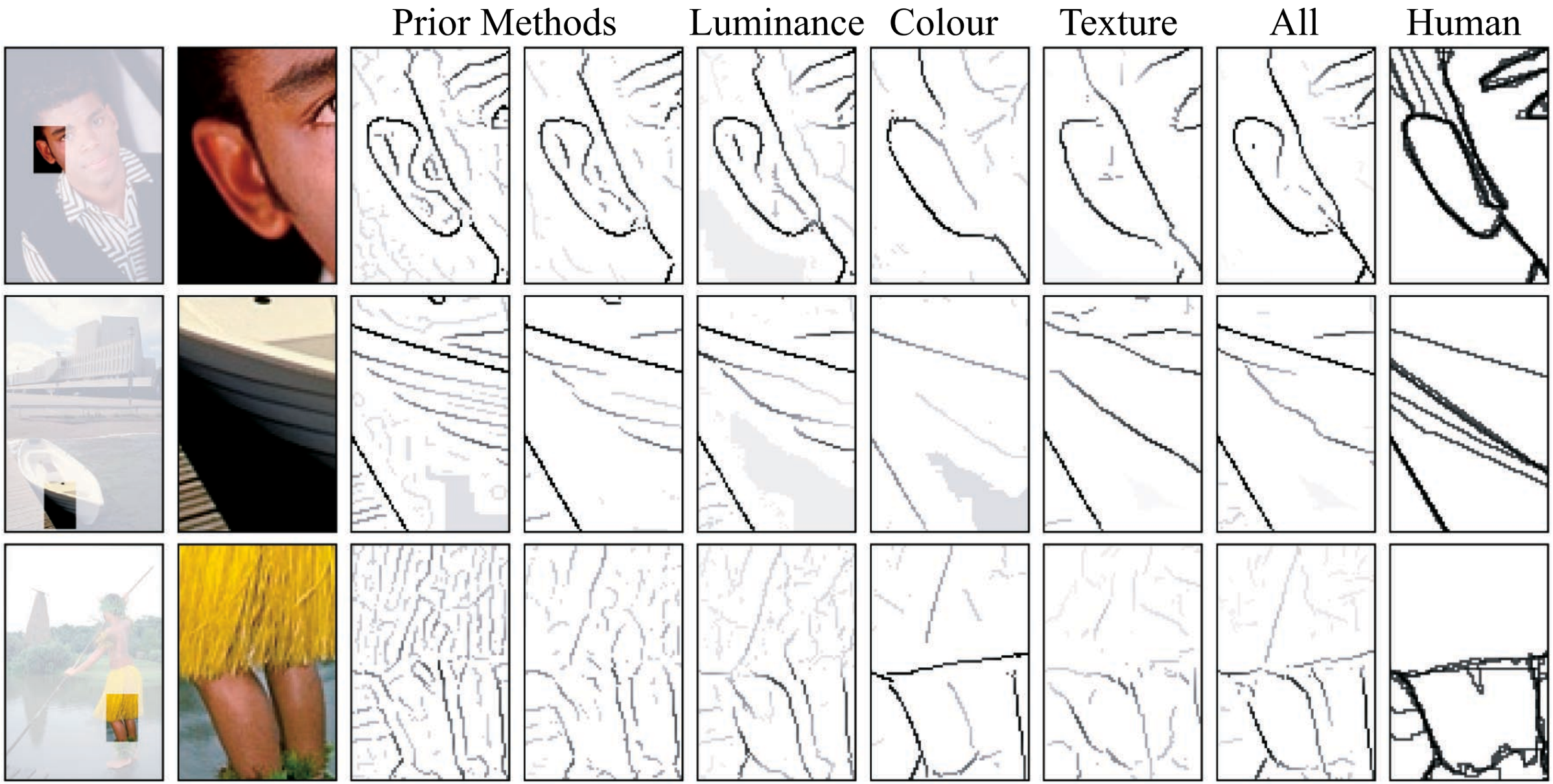
- Martin, Fowlkes & Malik (2004) defined salient edges based on human segmentation of images



Probability of Boundary (Pb) Detector

- Based on this dataset, Martin et al designed a probabilistic edge detector that fused multiple cues to distinguish salient edges, including:
  - Luminance (L*)
  - Colour (a*, b*)
  - Texture (Gabor filter responses)
- Cues were fused using logistic regression to generate a decision (edge, no-edge)

Performance



State of the Art

- Bertasius, G., Shi, J., and Torresani, L. (2015). Deepedge: A multi-scale bifurcated deep network for top-down contour detection. In 2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pages 4380–4389.

- Dollar, P. and Zitnick, C. L. (2015). Fast edge detection using structured forests. IEEE Transactions on Pattern Analysis and Machine Intelligence, 37(8):1558–157

- Holistically-nested edge detection. In 2015 IEEE International Conference on Computer Vision (ICCV), pages 1395–1403.

- Yang, J., Price, B., Cohen, S., Lee, H., and Yang, M. (2016). Object contour detection with a fully convolutional encoder-decoder network. In 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pages 193–202.

- Li, Y., Paluri, M., Rehg, J. M., and Doll´ar, P. (2016). Unsupervised learning of edges. In 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pages 1619–1627.

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Outline

- The Importance of Edges
- Local Filter Scale Control
- Local Filter Shape Control
- Image Reconstruction from Edges
- Application: Interactive Contour Editing
- Salient Edges