

CS6670: Computer Vision

Noah Snavely

Lecture 24: Segmentation



From [Sandlot Science](#)

Announcements

- Final project presentations
 - Wednesday, December 16th, 2-4:45pm, Upson 315
 - Volunteers to present on Tuesday the 15th?
- Final quiz this Thursday

Deblurring Application: Hubble Space Telescope

- Launched with flawed mirror
- Initially used deconvolution to correct images before corrective optics installed

Image of star



Fast Separation of Direct and Global Images Using High Frequency Illumination

Shree K. Nayar

Gurunandan G. Krishnan

Columbia University

Michael D. Grossberg

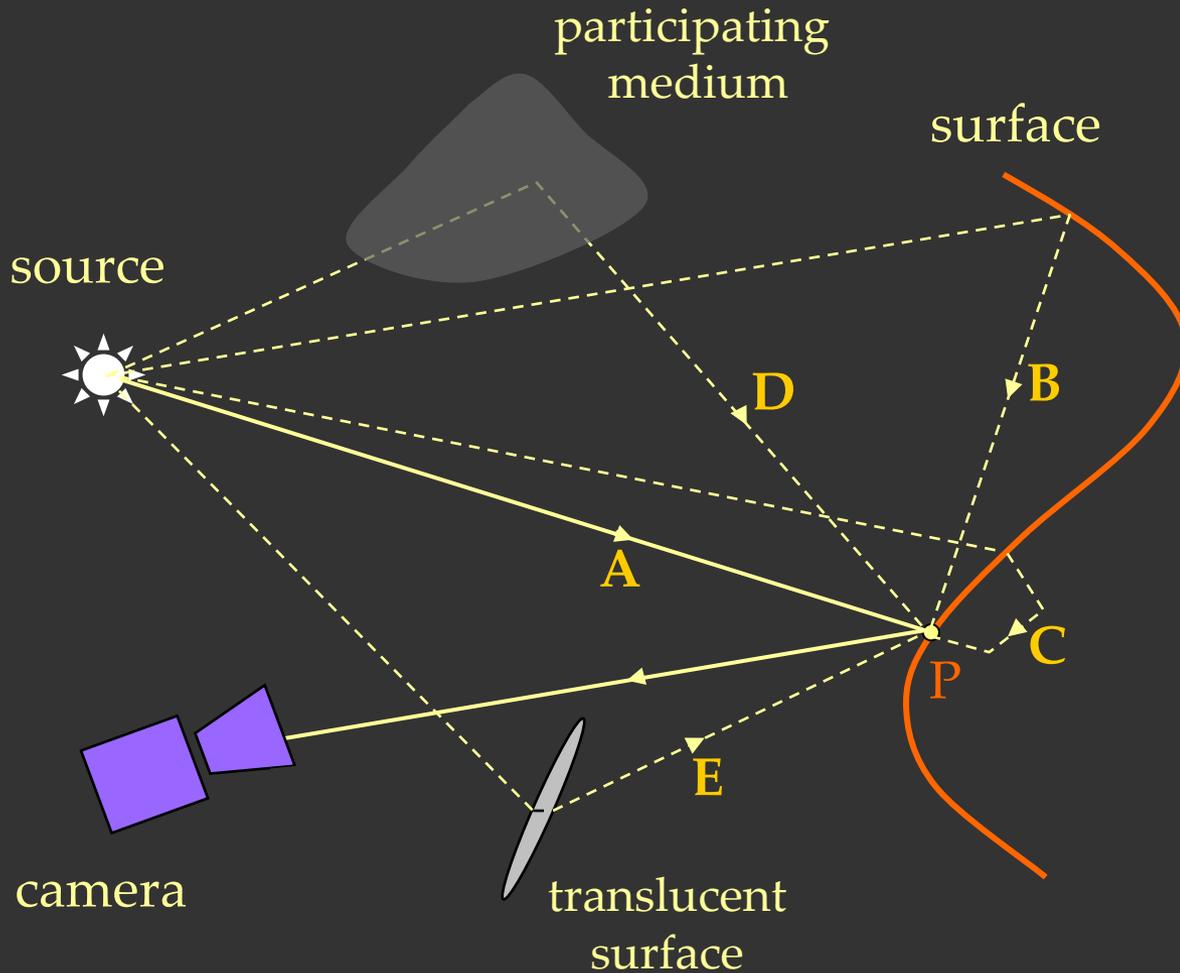
City College of New York

Ramesh Raskar

MERL

SIGGRAPH 2006

Direct and Global Illumination



A : Direct

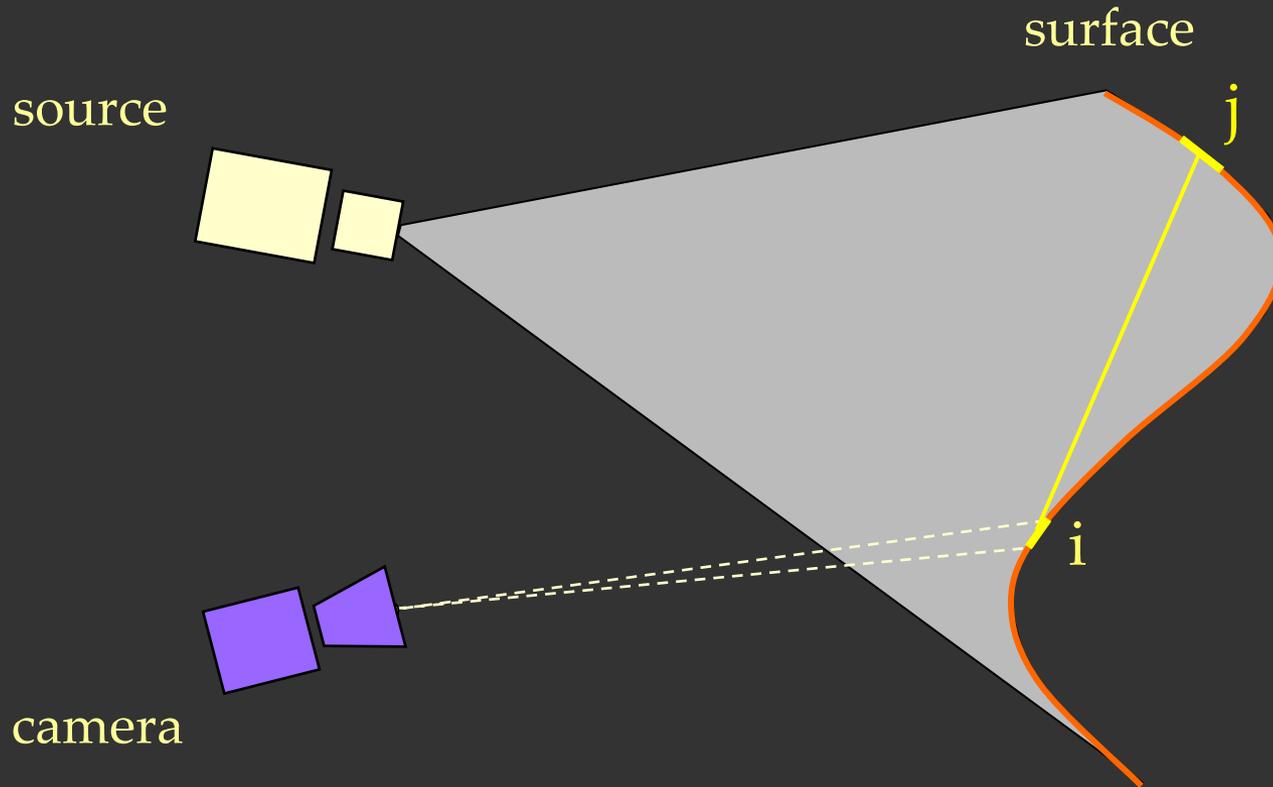
B : Interreflection

C : Subsurface

D : Volumetric

E : Diffusion

Direct and Global Components: Interreflections



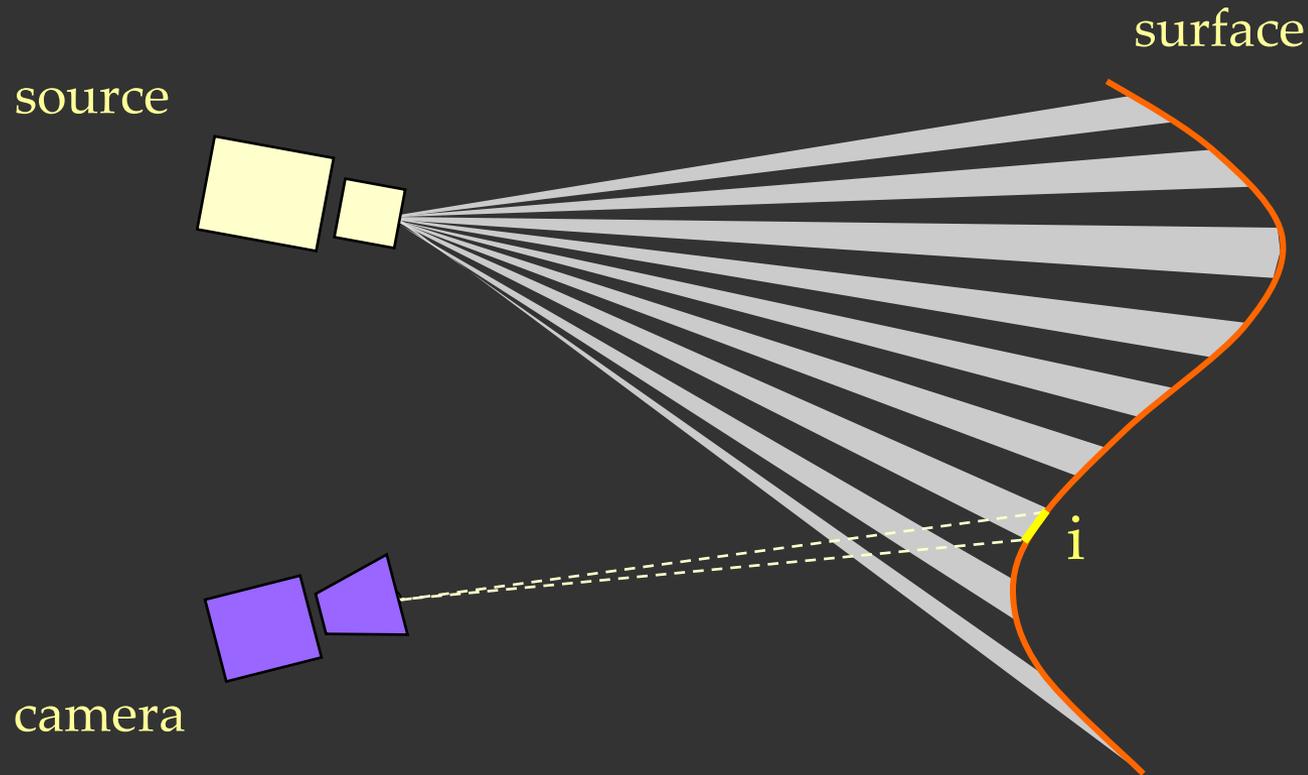
$$L[c, i] = L_d[c, i] + L_g[c, i]$$

radiance direct global

$$L_g[c, i] = \sum_P A[i, j] L[i, j]$$

BRDF and geometry

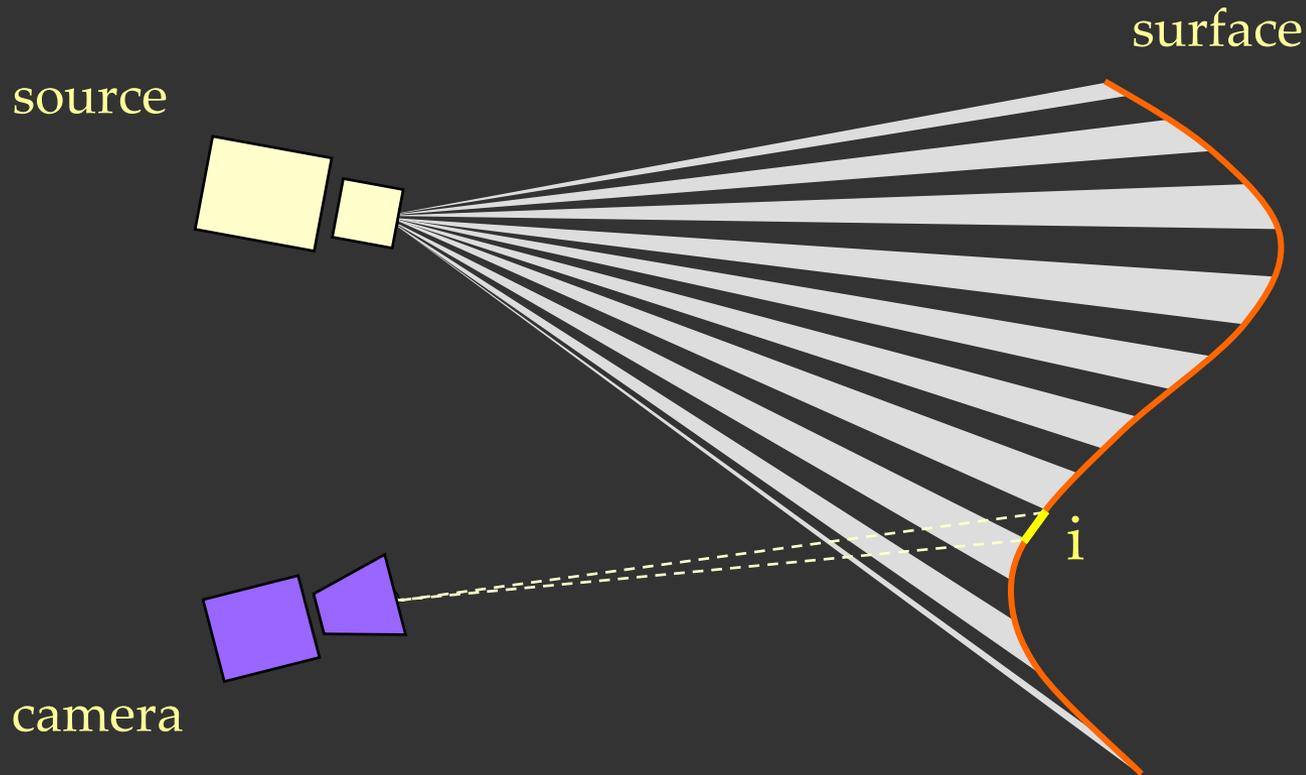
High Frequency Illumination Pattern



$$L^+[c, i] = L_d[c, i] + \alpha L_g[c, i]$$

fraction of activated source elements

High Frequency Illumination Pattern



$$L^+[c, i] = L_d[c, i] + \alpha L_g[c, i]$$

$$L^-[c, i] = (1 - \alpha) L_g[c, i]$$

fraction of activated source elements

Separation from Two Images

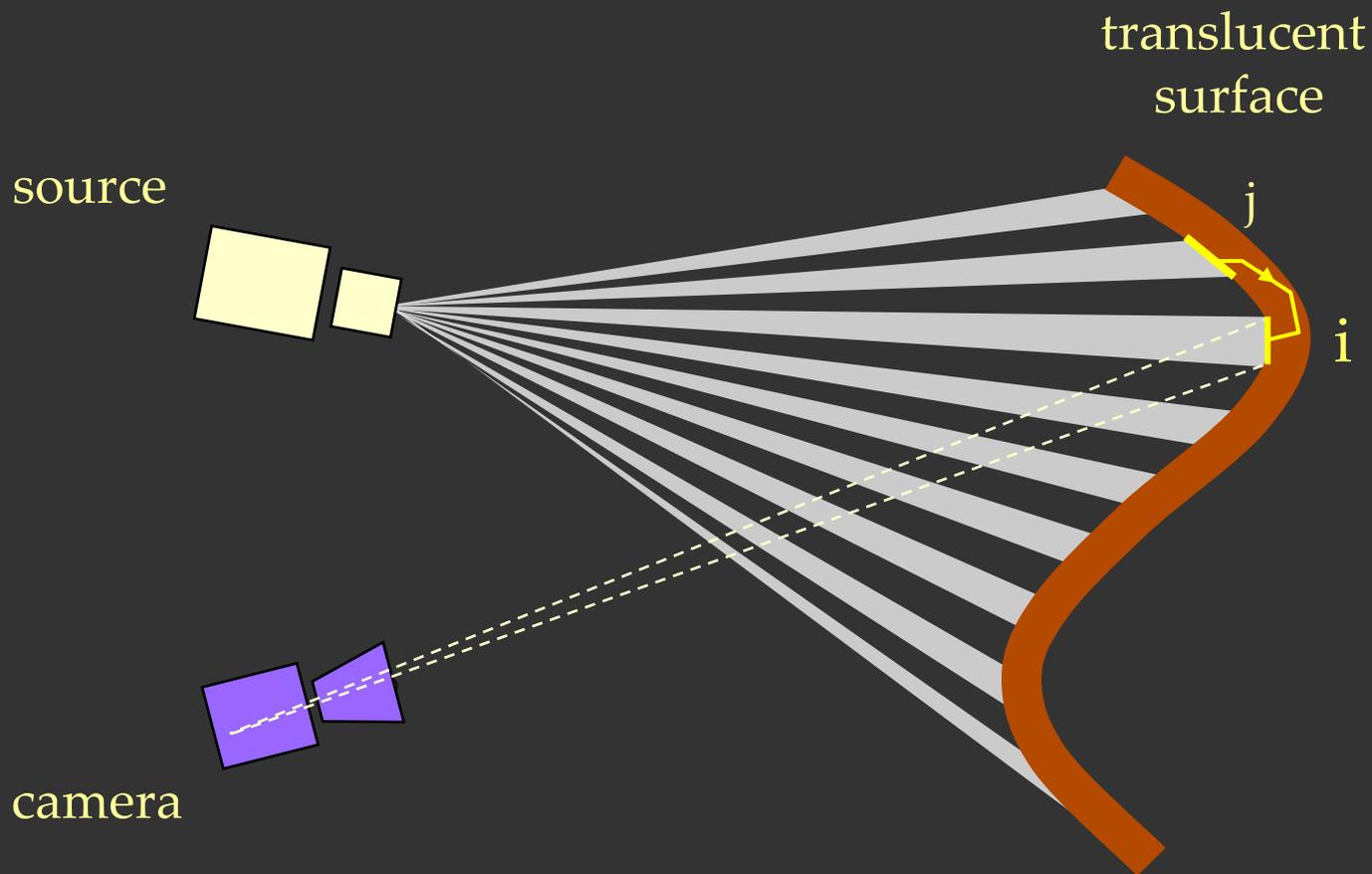
$$\alpha = \frac{1}{2}:$$

$$L_d = L_{\max} - L_{\min}, \quad L_g = 2L_{\min}$$

direct

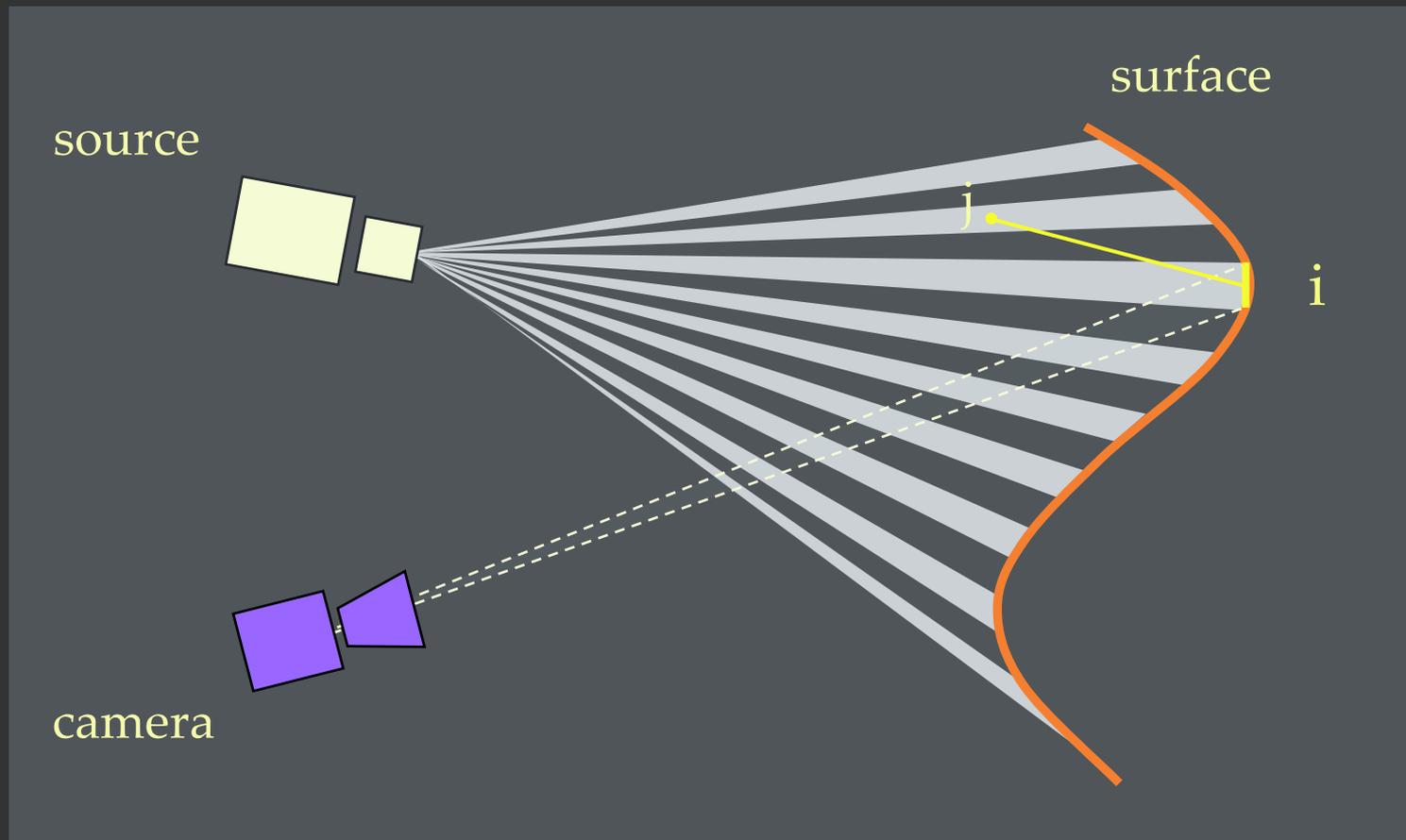
global

Other Global Effects: Subsurface Scattering



Other Global Effects: Volumetric Scattering

participating medium



Diffuse
Interreflections

Specular
Interreflections

Diffusion

Volumetric
Scattering

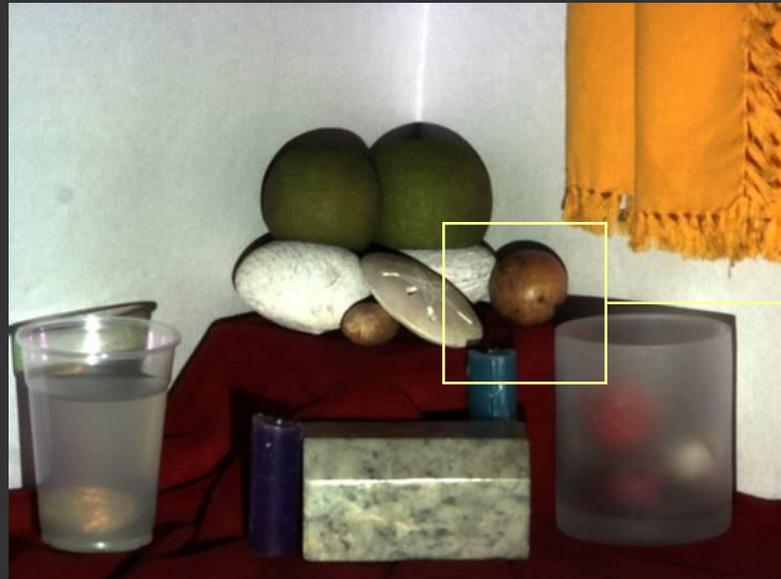
Subsurface
Scattering



Scene



Scene



Direct



Global

Real World Examples:

Eggs: Diffuse Interreflections

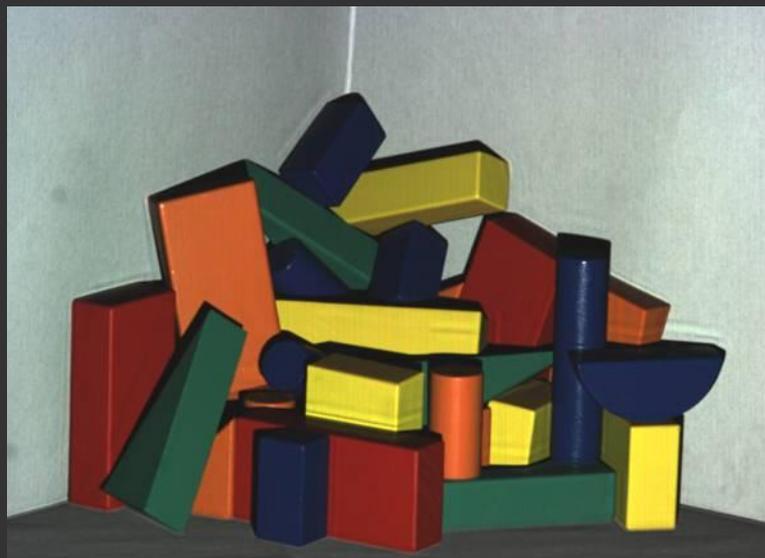
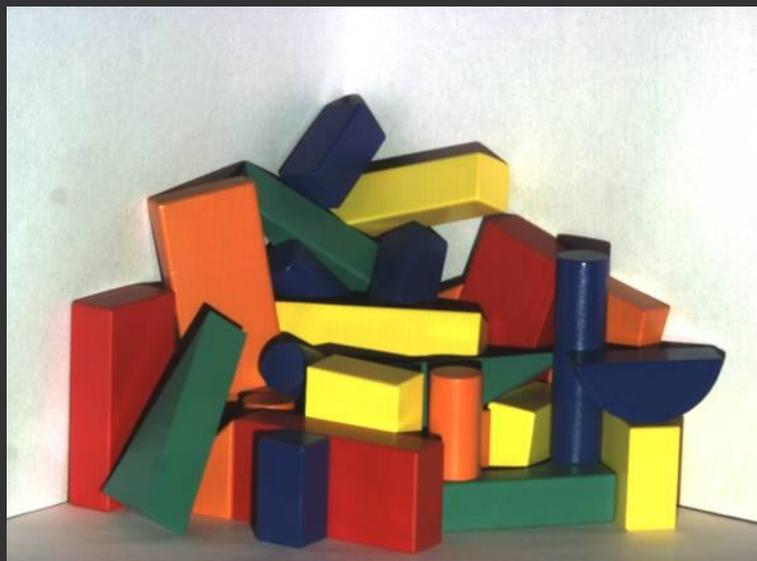


Direct



Global

Wooden Blocks: Specular Interreflections



Direct



Global

Kitchen Sink: Volumetric Scattering



Volumetric Scattering:
Chandrasekar 50, Ishimaru 78



Direct



Global

Peppers: Subsurface Scattering



Direct

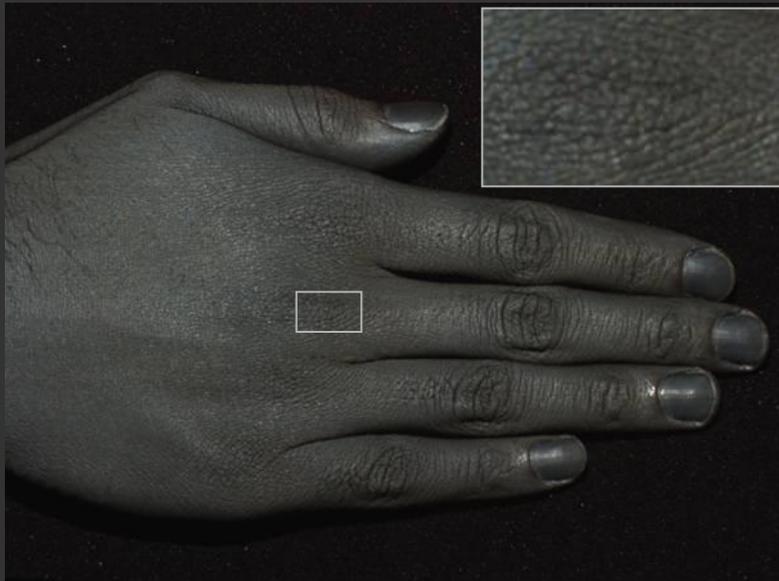


Global

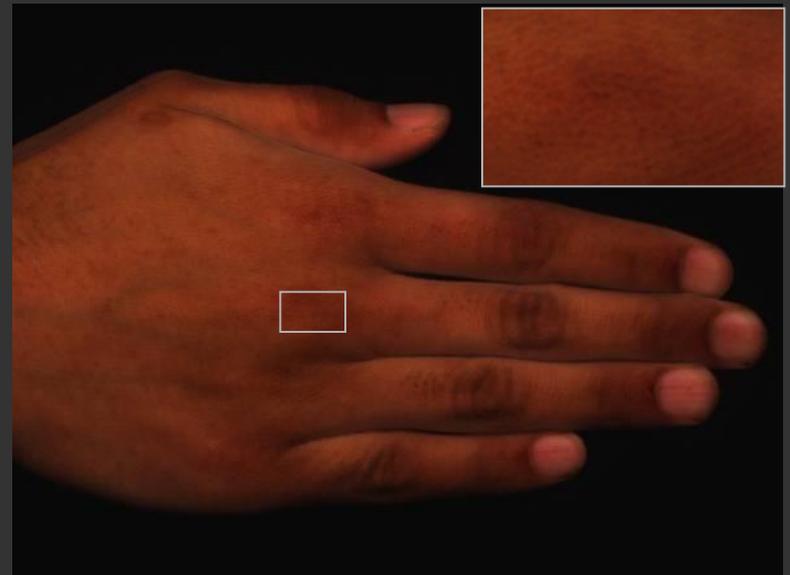
Hand



Skin: Hanrahan and Krueger 93,
Uchida 96, Haro 01, Jensen et al. 01,
Cula and Dana 02, Igarashi et al.
05, Weyrich et al. 05



Direct



Global

Face: Without and With Makeup

Without Makeup



Direct



Global



With Makeup



Direct



Global



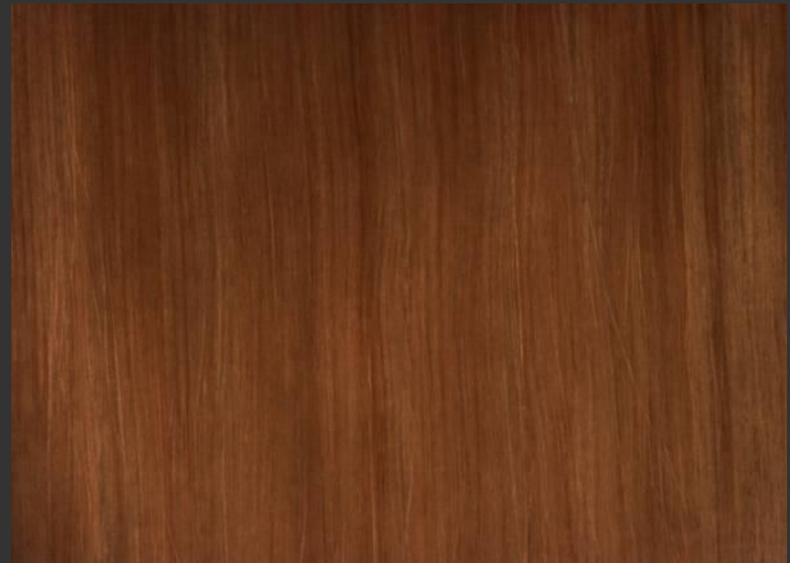
Blonde Hair



Hair Scattering: Stamm et al. 77,
Bustard and Smith 91, Lu et al. 00
Marschner et al. 03



Direct



Global

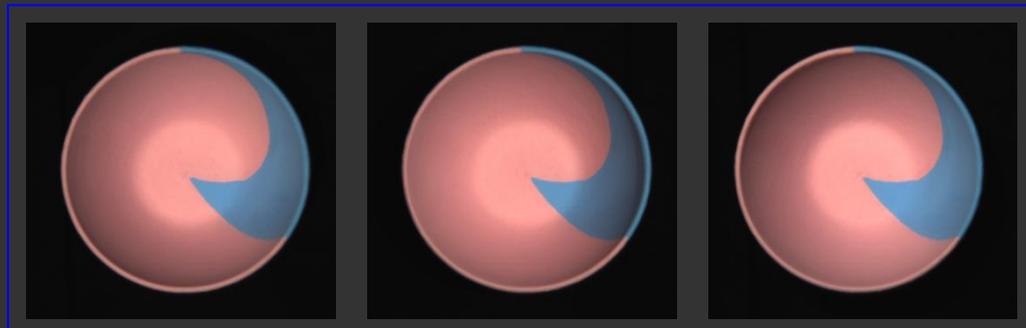
Photometric Stereo using Direct Images

Source 1

Source 2

Source 3

Bowl



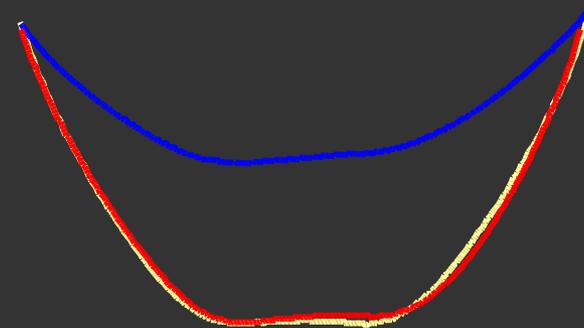
Global

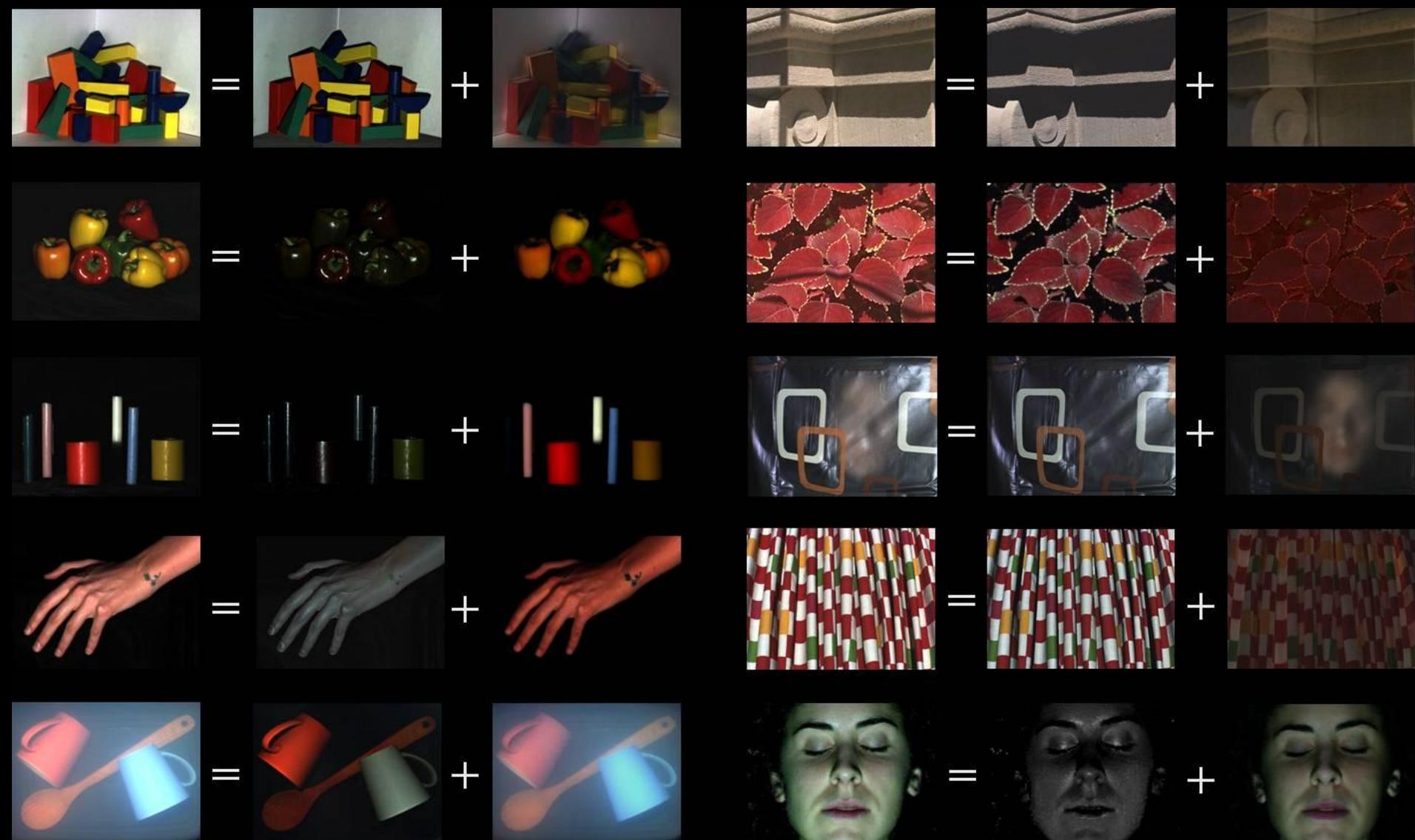


Direct



Shape

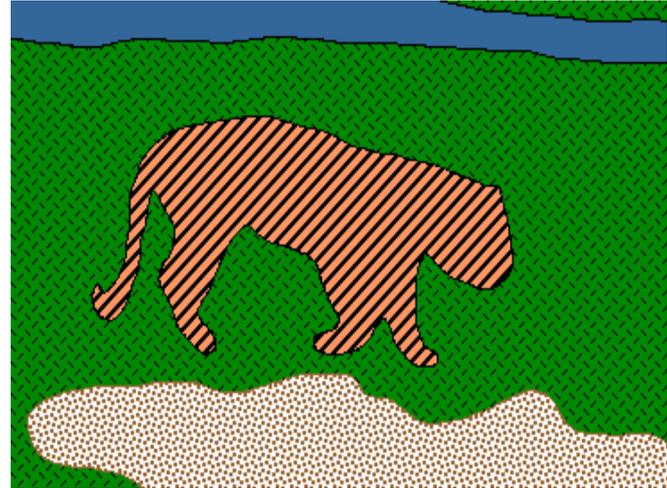




www.cs.columbia.edu/CAVE

Questions?

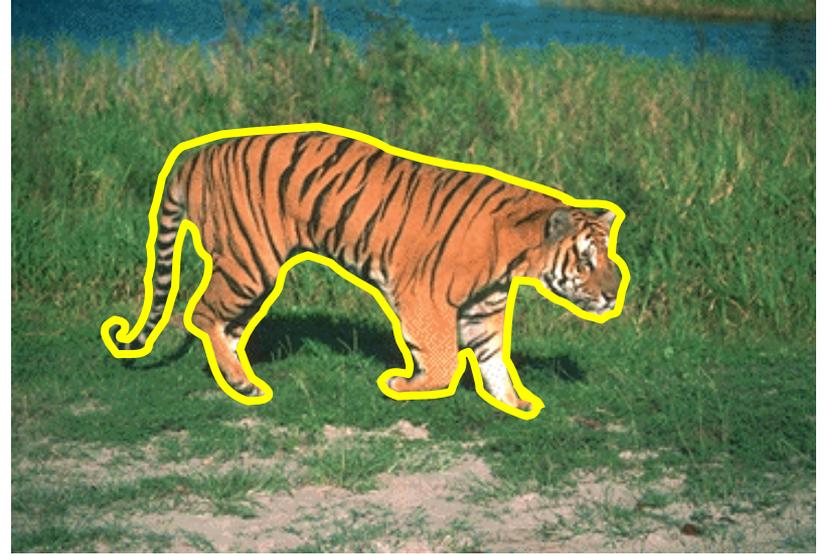
From images to objects



What defines an object?

- Subjective problem, but has been well-studied
- Gestalt Laws seek to formalize this
 - proximity, similarity, continuation, closure, common fate
 - see [notes](#) by Steve Joordens, U. Toronto

Extracting objects

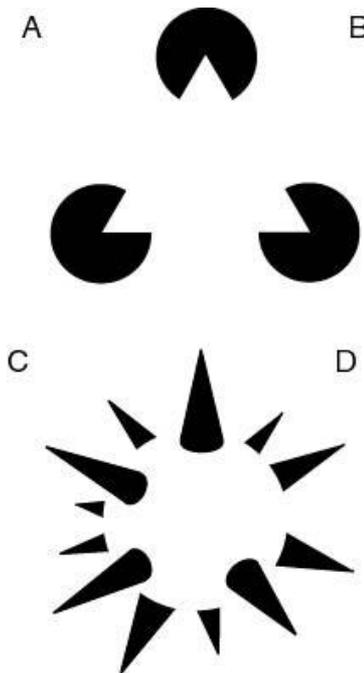


How could we do this automatically (or at least semi-automatically)?

The Gestalt school

- Grouping is key to visual perception
- Elements in a collection can have properties that result from relationships
 - “The whole is greater than the sum of its parts”

subjective contours



occlusion

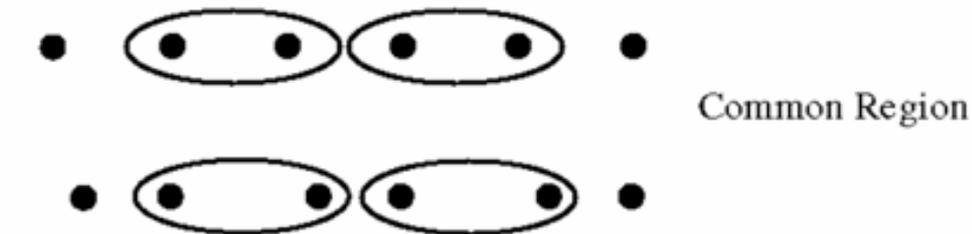


familiar configuration

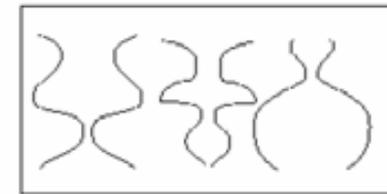
The ultimate Gestalt?



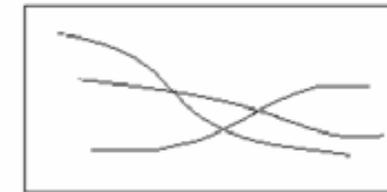
Gestalt factors



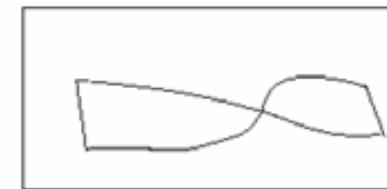
Parallelism



Symmetry



Continuity



Closure

- These factors make intuitive sense, but are very difficult to translate into algorithms

Semi-automatic binary segmentation



Intelligent Scissors (demo)

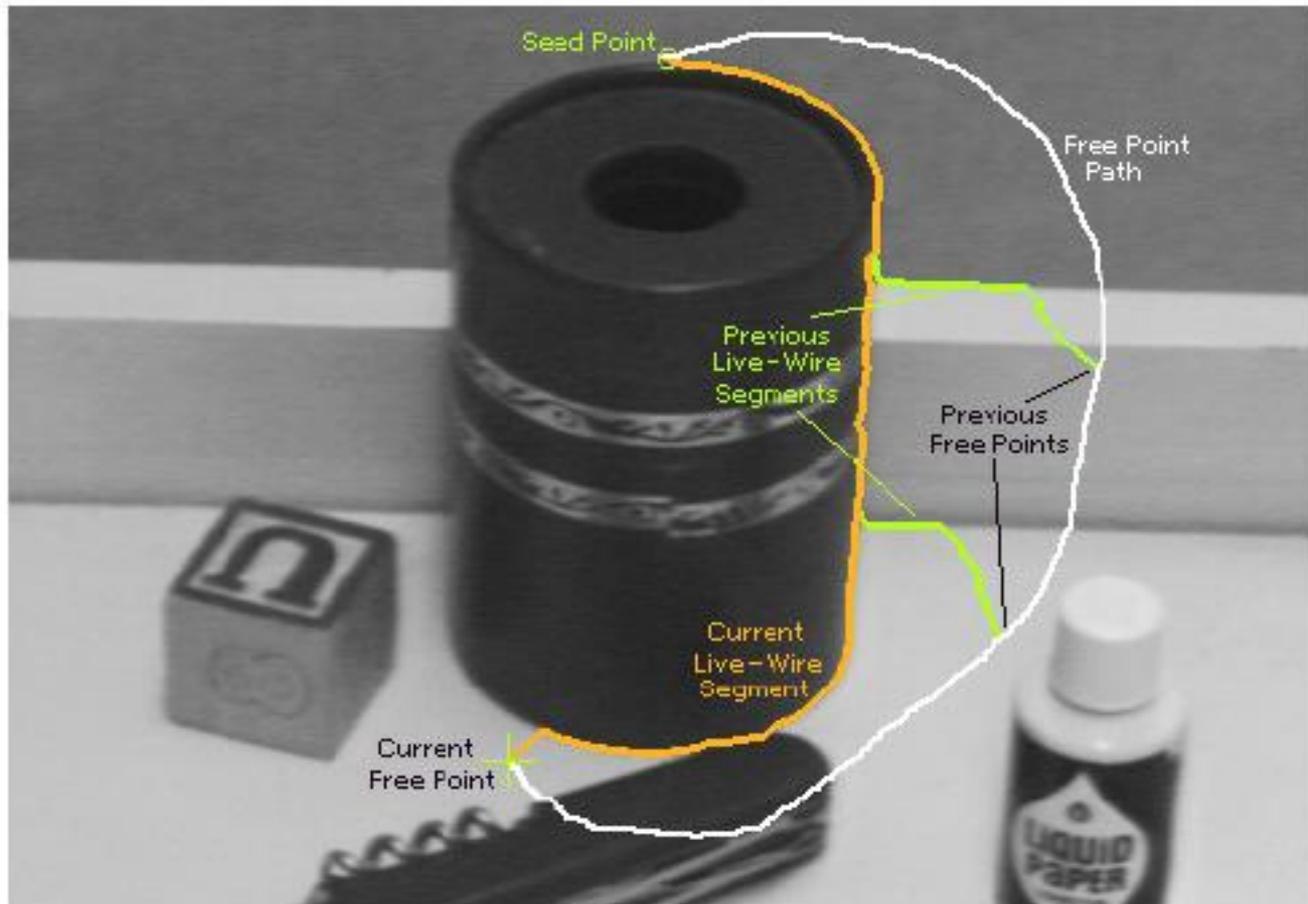


Figure 2: Image demonstrating how the live-wire segment adapts and snaps to an object boundary as the free point moves (via cursor movement). The path of the free point is shown in white. Live-wire segments from previous free point positions (t_0 , t_1 , and t_2) are shown in green.

Intelligent Scissors [Mortensen 95]

- Approach answers a basic question
 - Q: how to find a path from seed to mouse that follows object boundary as closely as possible?

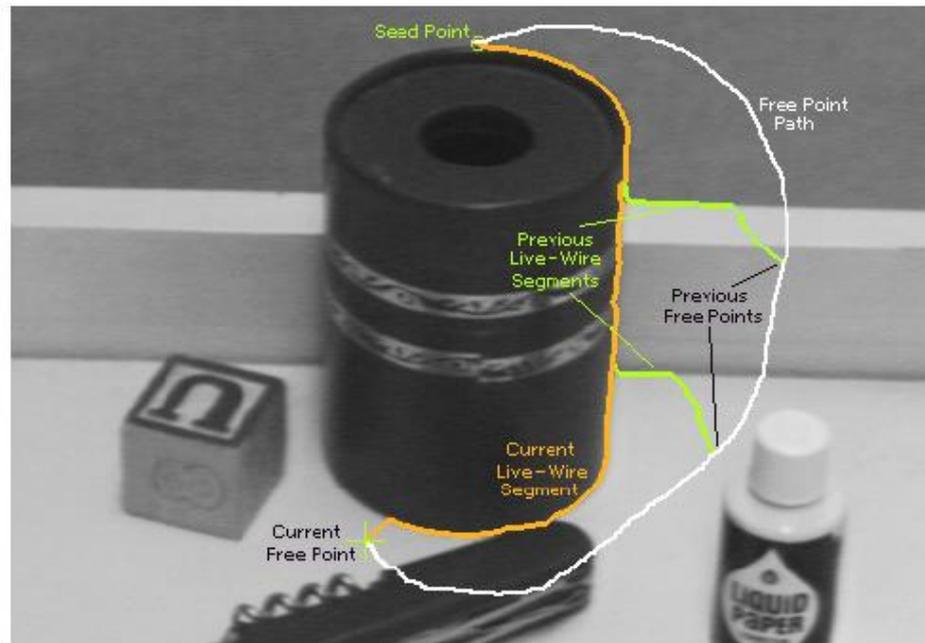


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GrabCut

Grabcut [[Rother et al., SIGGRAPH 2004](#)]



Is user-input required?

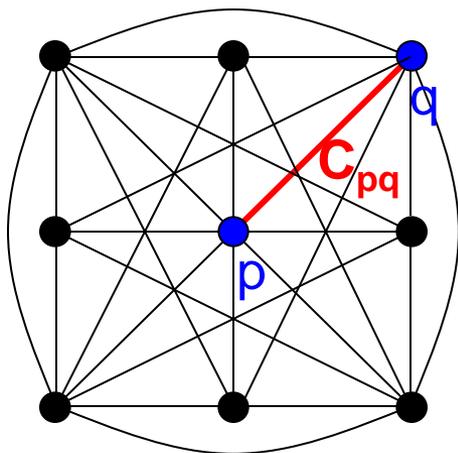
Our visual system is proof that automatic methods are possible

- classical image segmentation methods are automatic

Argument for user-directed methods?

- only user knows desired scale/object of interest

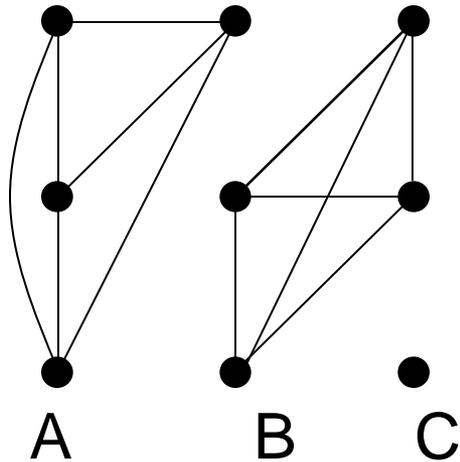
Automatic graph cut [Shi & Malik]



Fully-connected graph

- node for every pixel
- link between every pair of pixels, p, q
- cost C_{pq} for each link
 - C_{pq} measures *similarity*
 - » similarity is *inversely proportional* to difference in color and position

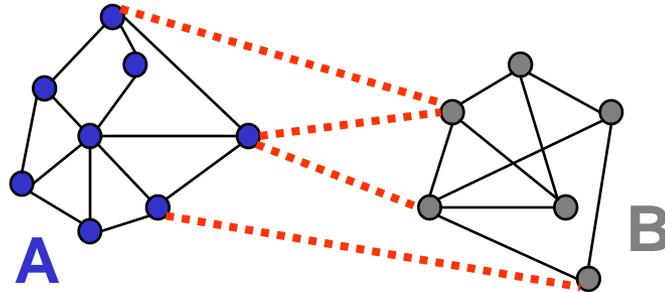
Segmentation by Graph Cuts



Break Graph into Segments

- Delete links that cross between segments
- Easiest to break links that have low cost (similarity)
 - similar pixels should be in the same segments
 - dissimilar pixels should be in different segments

Cuts in a graph



Link Cut

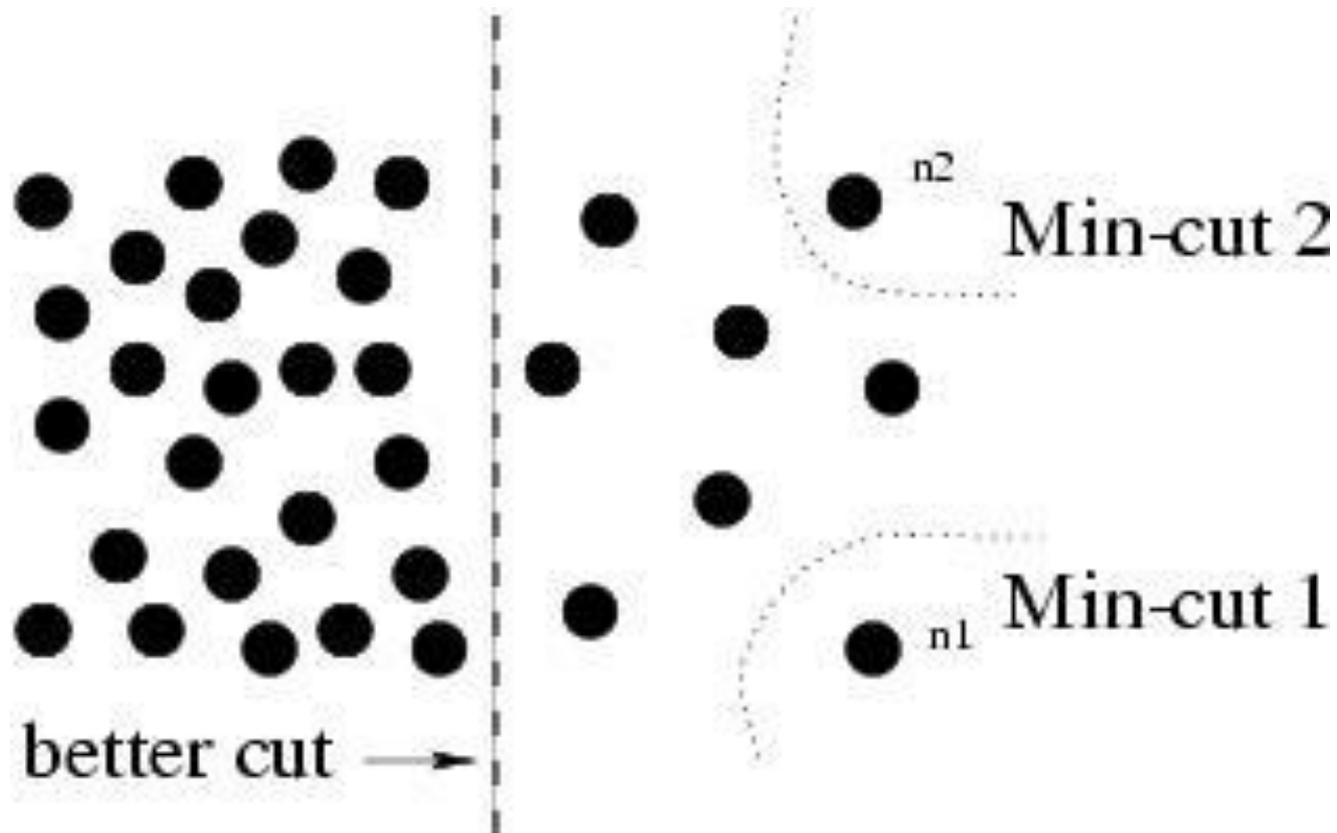
- set of links whose removal makes a graph disconnected
- cost of a cut:

$$cut(A, B) = \sum_{p \in A, q \in B} c_{p,q}$$

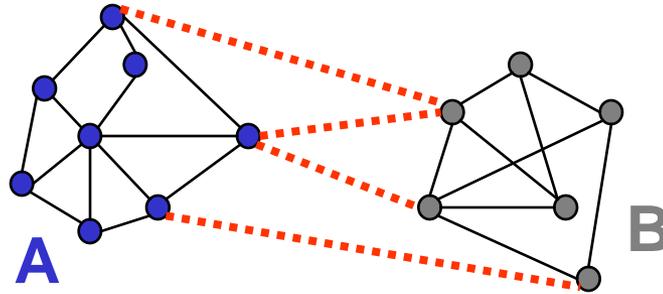
Find minimum cut

- gives you a segmentation

But min cut is not always the best cut...



Cuts in a graph



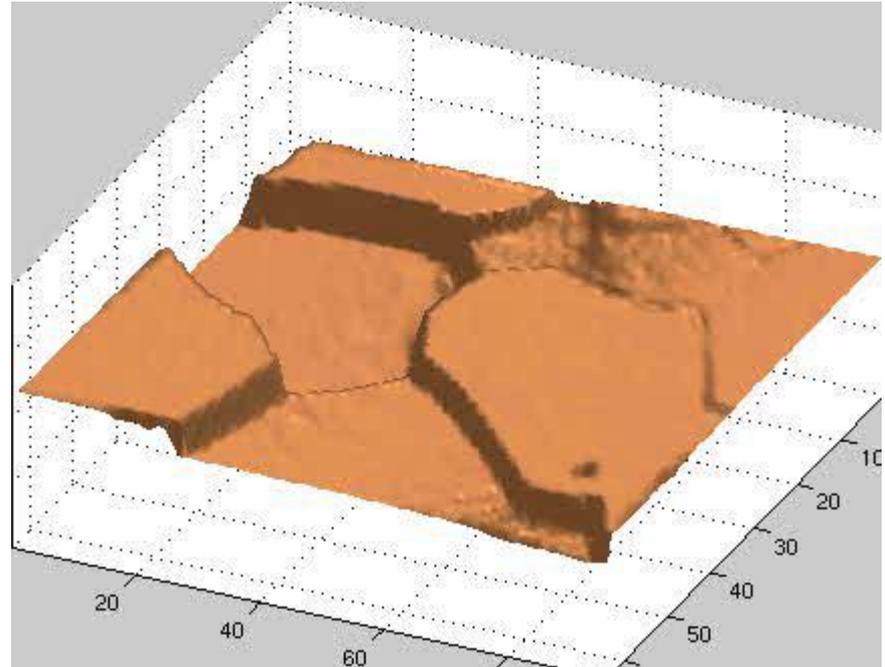
Normalized Cut

- a cut penalizes large segments
- fix by normalizing for size of segments

$$Ncut(A, B) = \frac{cut(A, B)}{volume(A)} + \frac{cut(A, B)}{volume(B)}$$

- $volume(A)$ = sum of costs of all edges that touch A

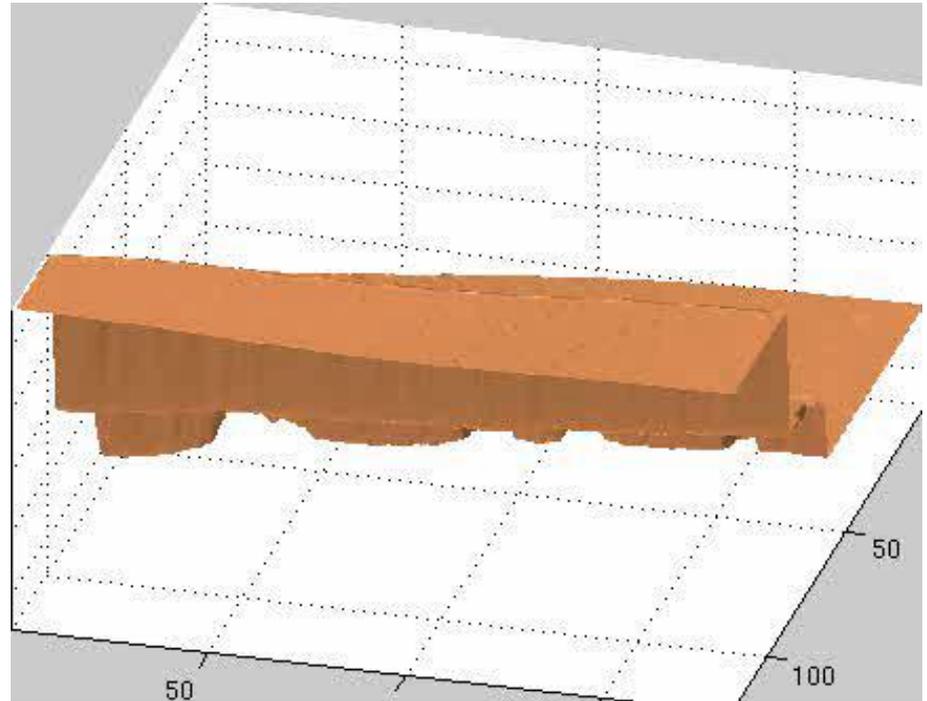
Interpretation as a Dynamical System



Treat the links as springs and shake the system

- elasticity proportional to cost
- vibration “modes” correspond to segments
 - can compute these by solving an eigenvector problem
 - http://www.cis.upenn.edu/~jshi/papers/pami_ncut.pdf

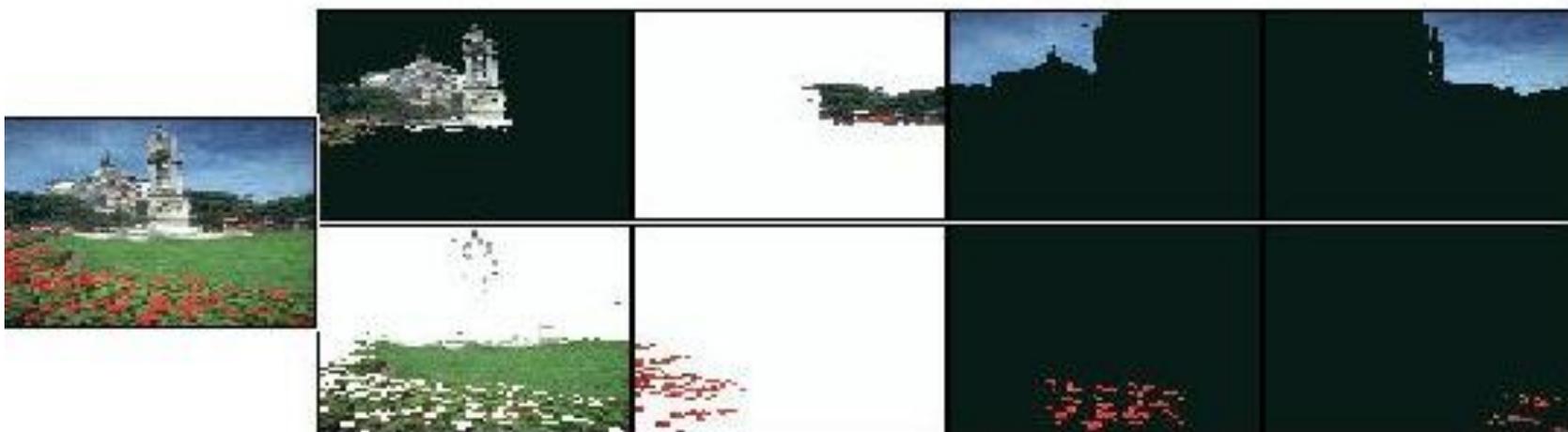
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Color Image Segmentation



Extension to Soft Segmentation

- Each pixel is convex combination of segments.
[Levin et al. 2006](#)
 - compute mattes by solving eigenvector problem

