Image compositing
Course announcements

• If you haven’t started Homework 2 yet, you should do that ASAP.

• Today we will post more details about the final project.

• Guest lecture on Monday: Ravi Teja Mullapudi, “High-performance image processing.”

• RI Seminar on Friday: Anat Levin, “Light-sensitive displays.”
Overview of today’s lecture

• Leftover from color lecture.

• Some motivational examples.

• Cut-and-paste.

• Alpha (linear) blending.

• Multi-band blending.

• Seam stitching.
Most of these slides were adapted from:

- Kris Kitani (15-463, Fall 2016).

Some slides were inspired or taken from:

- Fredo Durand (MIT).
- James Hays (Georgia Tech).
Some motivational examples
Gangster, Frankie Yale, killed by a drive-by in Brooklyn in 1928.
A tragic photo from 1959 after three-year-old Martha Cartagena was killed while riding her tricycle in Brooklyn.
In 1958 there was a fatal fire at the Elkins Paper & Twine Co. on Wooster Street in SoHo. The building burned to the ground.
Berlin, 1945/2010, Mehringdamm
Forrest Gump (1994)
Techniques for compositing

- Cut-and-paste.
- Alpha (linear) blending.
- Multi-band blending.
- Poisson blending.
- Seam stitching.
Cut-and-paste
Cut and paste procedure

1. Extract Sprites (e.g., using *Intelligent Scissors* in Photoshop)

2. Blend them into the composite (in the right order)

You may have also heard it as collaging
Cut and paste

Sometimes it produces visually compelling results.
Cut and paste

Other times, not so much.

What is wrong with this composite?
Alpha (linear) blending
Output = foreground * mask + background * (1 - mask)

Alpha blending
a.k.a. alpha matte or alpha composite
Binary alpha mask

Does this look unnatural?
Does this look unnatural?
How can we fix it?
Non-binary alpha mask

binary alpha mask
feathering (smoothed alpha)

How would you implement feathering?
Setting the alpha mask: center seam

How would you create a binary alpha mask for these two images?
Setting the alpha mask: center seam

Step 1: Compute their distance transform ($\texttt{bwdist}$)
Setting the alpha mask: center seam

\[
alpha = \text{logical}(\text{dtrans1} > \text{dtrans2})
\]
Setting the alpha mask: center seam

Anything wrong with this alpha matte?
Setting the alpha mask: center seam

alpha = blur(alpha)

Step 3: blur the mask
Setting the alpha mask: center seam

Still doesn’t look terribly good
Setting the alpha mask: center seam

Step 4: go beyond blurring for non-binary

alpha = 0.5 in overlap region
Setting the alpha mask: center seam

Still not OK
Setting the alpha mask: center seam

alpha = dtrans1 / (dtrans1+dtrans2)

Step 5: more elaborate non-binary
Setting the alpha mask: center seam

Looks better but some dangers remain.
Another blending example

Let’s blend these two images...

left side

right side

What kind of mask would you use?
Another blending example

How would you select this window?
Effects of different windows

Bad window: non-smooth seam.

Bad windows: ghosting.

Good window: smooth but no ghosting.

Bad window: non-smooth seam.
What is a good window size?

To avoid discontinuities:
window = size of largest prominent feature

To avoid ghosting:
window <= 2*size of smallest prominent feature
What is a good window size?

Fourier domain interpretation:

To avoid discontinuities:
window = size of largest prominent feature

linear blending should work when:
image frequency content occupies roughly one “octave” (power of two)

To avoid ghosting:
window <= 2*size of smallest prominent feature

linear blending should work when:
largest frequency <= 2*size of smallest frequency

What if the frequency spread is too wide?
What is a good window size?

**Fourier domain interpretation:**

To avoid discontinuities:
window = size of largest prominent feature

linear blending should work when:
image frequency content occupies roughly one “octave” (power of two)

To avoid ghosting:
window <= 2*size of smallest prominent feature

linear blending should work when:
largest frequency <= 2*size of smallest frequency

Most natural images have a very wide frequency spread. What do we do then?
Multi-band blending
Time to use pyramids again

At low frequencies, blend slowly to avoid seams
At high frequencies, blend quickly to avoid ghosts

Which mask goes where?
Time to use pyramids again

At low frequencies, blend slowly to avoid seams
At high frequencies, blend quickly to avoid ghosts
Remember our two types of pyramids

Gaussian pyramid

Laplacian pyramid
Remember our two types of pyramids

1. Build Laplacian pyramids for each image

2. Blend each level of pyramid using region mask

\[ L_{12}^i = L_1^i \cdot R_i + L_2^i \cdot (1 - R_i) \]

image 1 at level i, image 2 at level i, region mask at level i

3. Collapse the pyramid to get the final blended image

How large should the blending region be at each level?
1. Build Laplacian pyramids for each image

2. Blend each level of pyramid using region mask

\[ L_{12}^i = L_1^i \cdot R^i + L_2^i \cdot (1 - R^i) \]

image 1 at level i  image 2 at level i  region mask at level i

How large should the blending region be at each level?

About the size of that level’s blur

3. Collapse the pyramid to get the final blended image
Multi-band blending using the Laplacian pyramid

Laplacian level 4

Laplacian level 2

Laplacian level 0

left pyramid  right pyramid  blended pyramid
A famous result (for its time)
A famous result (for its time)
A creepier result

Can we get the same result with less computation?
Two-band blending

Only use two bands: high frequency and low frequency

• Blend low frequency with smooth alpha
• Blend high frequency with binary alpha
Example: blending panoramas

original collage

blended collage
Example: blending panoramas

low frequency blend

high frequency blend
Linear blending
Two-band blending
One more comparison

copy-paste

linear

two-band
Why do these images look weirdly cropped?

They were warped using homographies before being aligned.

Homework 6: autostitching
Seam stitching
Cut and paste procedure

1. Extract Sprites

Two different ways to think about the same thing:

- Finding seams (i.e., finding the pixels where to cut an image)
- Segmentation (i.e., splitting the image into “foreground” and “background”)

I will be using the two terms interchangeable.
Question about blending

When blending multiple images of the same scene, moving objects become ghosts!

What can we do instead of blending?
Question about blending

When blending multiple images of the same scene, moving objects become ghosts!

Instead of blending the images, cut them and stitch them together!
Image as a graph
Fundamental theme of today’s lecture

Images can be viewed as graphs

Nodes: pixels

Edges: Constraints between neighboring pixels
Graph-view of segmentation problem

Segmentation is node-labeling

Nodes: pixels

Edges: Constraints between neighboring pixels

Given pixel values and neighborhoods, decide:
- which nodes to label as foreground/background
- which nodes to label as seams using graph algorithms
### Graph-view of segmentation problem

Today we will cover:

<table>
<thead>
<tr>
<th>Method</th>
<th>Labeling problem</th>
<th>Algorithm</th>
<th>Intuition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intelligent scissors</strong></td>
<td>label pixels as seams</td>
<td>Dijkstra’s shortest path (dynamic programming)</td>
<td>short path is a good <strong>boundary</strong></td>
</tr>
<tr>
<td><strong>GrabCut</strong></td>
<td>label pixels as foreground/background</td>
<td>max-flow/min-cut (graph cutting)</td>
<td>good <strong>region</strong> has low cutting cost</td>
</tr>
</tbody>
</table>
Shortest graph paths and intelligent scissors
Intelligent scissors

Problem statement:
Given two seed points, find a good boundary connecting them

Challenges:
• Make this real-time for interaction
• Define what makes a good boundary

Mortenson and Barrett (SIGGRAPH 1995)
(you can tell it’s old from the paper’s low quality teaser figure)
Graph-view of this problem

Images can be viewed as graphs

Nodes: pixels

Edges: Constraints between neighboring pixels
Graph-view of this problem

Graph-view of intelligent scissors:

1. Assign weights (costs) to edges
Graph-view of this problem

Graph-view of intelligent scissors:

1. Assign weights (costs) to edges
2. Select the seed nodes
Graph-view of this problem

Graph-view of intelligent scissors:

1. Assign weights (costs) to edges
2. Select the seed nodes
3. Find shortest path between them
Graph-view of this problem

Graph-view of intelligent scissors:

Start

1. Assign weights (costs) to edges

2. Select the seed nodes

3. Find shortest path between them

What algorithm can we use to find the shortest path?
Graph-view of this problem

Graph-view of intelligent scissors:

1. Assign weights (costs) to edges
2. Select the seed nodes
3. Find shortest path between them

What algorithm can we use to find the shortest path?
• Dijkstra’s algorithm (dynamic programming)
Dijkstra’s shortest path algorithm

Initialize, given seed $s$ (pixel ID):
- $\text{cost}(s) = 0$ % total cost from seed to this point
- $\text{cost}(\neg s) = \text{big}$
- $\mathbf{A} = \{\text{all pixels}\}$ % set to be expanded
- $\text{prev}(s) = \text{undefined}$ % pointer to pixel that leads to $q=s$

Precompute $\text{cost}_2(q, r)$ % cost between $q$ to neighboring pixel $r$

Loop while $\mathbf{A}$ is not empty

1. $q = \text{pixel in } \mathbf{A} \text{ with lowest cost}$
2. Remove $q$ from $\mathbf{A}$
3. For each pixel $r$ in neighborhood of $q$ that is in $\mathbf{A}$
   a) $\text{cost}_{\text{tmp}} = \text{cost}(q) + \text{cost}_2(q, r)$ %this updates the costs
   b) if ($\text{cost}_{\text{tmp}} < \text{cost}(r)$)
      i. $\text{cost}(r) = \text{cost}_{\text{tmp}}$
      ii. $\text{prev}(r) = q$
1. Assign weights (costs) to edges
2. Select the seed nodes
3. Find shortest path between them

What algorithm can we use to find the shortest path?
• Dijkstra’s algorithm (dynamic programming)

How should we select the edge weights to get good boundaries?
Selecting edge weights

Define boundary cost between neighboring pixels:

1. Lower if an image edge is present (e.g., as found by Sobel filtering).
2. Lower if the gradient magnitude at that point is strong.
3. Lower if gradient is similar in boundary direction.
Selecting edge weights

Gradient magnitude

Edge image

Pixel-wise cost
Making it more interactive

1. Use cursor as the “end” seed, and always connect start seed to that

2. Every time the user clicks, use that point as a new starting seed and repeat
Examples
Seam collaging

Another use for image seam selection

Kwatra et al., Graphcut Textures: Image and Video Synthesis using Graph Cuts, SIGGRAPH 2003
1. Assign weights (costs) to edges
2. Select the seed nodes
3. Find shortest path between them

What edge weights would you use for collaging?
Selecting edge weights for seam collaging

Good places to cut:
- similar color in both images
- high gradient in both images
Seam carving

Another use for image seam selection

Avidan and Shamir, Seam Carving for Content-Aware Image Resizing, SIGGRAPH 2007
Seam stitching

Another use for image seam selection:
• instead of blending the images, cut them and stitch them together
Seam stitching

alpha blending

AutoStitch
Examples

Where will intelligent scissors work well, or have problems?
Some notes about cutting-and-pasting
Real or composite, and why?
Real: Lahaina noon (or noon at subsolar point)
Real or composite, and why?
Composite: Inconsistent shadows
Composite: Inconsistent shadows

Fig. 1. Our algorithm finds that the shadows in this 1969 moon landing photo are physically consistent with a single light source. The solid lines correspond to constraints from cast shadows and dashed lines correspond to constraints from attached shadows. The region outlined in black, which extends beyond the figure boundary, contains the projected light locations that satisfy all of these constraints.
Photorealistic compositing

Karsch et al., “Rendering Synthetic Objects into Legacy Photographs,” SIGGRAPH Asia 2011
Photorealistic compositing

Karsch et al., “Rendering Synthetic Objects into Legacy Photographs,” SIGGRAPH Asia 2011
Photorealistic compositing

Karsch et al., “Rendering Synthetic Objects into Legacy Photographs,” SIGGRAPH Asia 2011
Photorealistic compositing

Karsch et al., “Rendering Synthetic Objects into Legacy Photographs,” SIGGRAPH Asia 2011
Photorealistic compositing

Karsch et al., “Rendering Synthetic Objects into Legacy Photographs,” SIGGRAPH Asia 2011
Photorealistic compositing

Karsch et al., “Rendering Synthetic Objects into Legacy Photographs,” SIGGRAPH Asia 2011
Photorealistic compositing

How would you do this?
References

Basic reading:
• Szeliski textbook, Sections 3.13, 3.5.5, 9.3.4, 10.4.3.

Additional reading:
  the original Poisson blending paper.
  a paper from Adobe describing the version of Poisson blending implemented in Photoshop’s “healing brush”.
  the above references provide an overview of gradient-domain processing as a general image processing paradigm, which can be used for a broad set of applications beyond blending, including tone-mapping, colorization, converting to grayscale, edge enhancement, image abstraction and non-photorealistic rendering.
References

Basic reading:
• Szeliski textbook, Sections 3.13, 3.5.5, 5.1.3, 5.3.1, 9.3.2, 9.3.3, 9.3.4, 10.4.3.

Additional reading:
• Felzenszwalb and Zabih, “Dynamic Programming and Graph Algorithms in Computer Vision,” PAMI 2010. A great review of graph-based techniques, including shortest path and graph-cut, in computer vision.
• Kee et al., “Exposing photo manipulation with inconsistent shadows,” ToG 2013. The paper demonstrating how image forgeries can be detecting by reasoning about the physical accuracy of shadows in an image.
• Karsch et al., “Rendering synthetic objects into legacy photographs”, SIGGRAPH 2011. The paper where the photorealistic compositing examples came from.