Announcements

- Project 1 artifact voting
- Project 2 out today (help session at end of class)

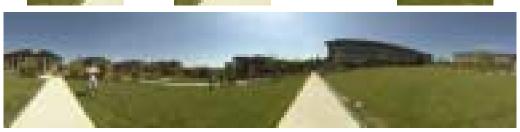
Mosaics

http://www.destination360.com/start1.htm
http://www.vrseattle.com/html/vrview.php?cat_id=11&vrs_id=vrs380

Today's Readings

- Szeliski and Shum paper (sections 1 and 2, skim the rest)
  - http://www.acm.org/pubs/citations/proceedings/graph/258734/p251-szeliski/

Image Mosaics



Goal

- Stitch together several images into a seamless composite

How to do it?

Basic Procedure

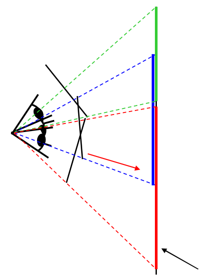
- Take a sequence of images from the same position
  - Rotate the camera about its optical center
- Compute transformation between second image and first
  - Lucas & Kanade registration
- Shift the second image to overlap with the first
- Blend the two together to create a mosaic
- If there are more images, repeat

Aligning images

How to account for warping?

- Translations are not enough to align the images
- Photoshop demo

Image reprojection



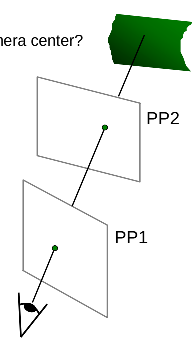
The mosaic has a natural interpretation in 3D

- The images are reprojected onto a common plane
- The mosaic is formed on this plane

Image reprojection

Basic question

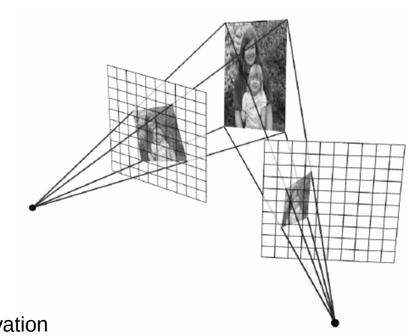
- How to relate two images from the same camera center?
  - how to map a pixel from PP1 to PP2



Answer

- Cast a ray through each pixel in PP1
- Draw the pixel where that ray intersects PP2

Image reprojection



Observation

- Rather than thinking of this as a 3D reprojection, think of it as a 2D image warp from one image to another

Homographies

Perspective projection of a plane

- Lots of names for this:
  - **homography**, texture-map, colineation, planar projective map
- Modeled as a 2D warp using homogeneous coordinates

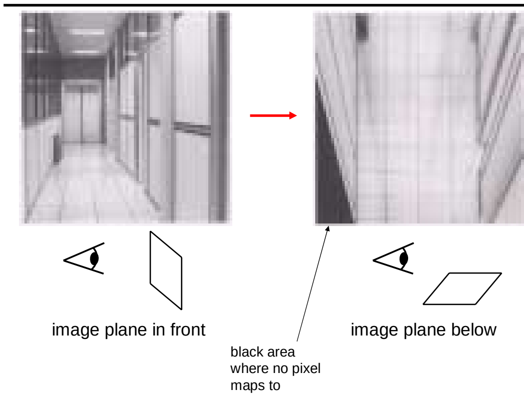
$$\begin{bmatrix} wx' \\ wy' \\ w \end{bmatrix} = \begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

p' **H** **p**

To apply a homography **H**

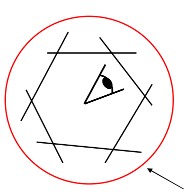
- Compute **p'** = **Hp** (regular matrix multiply)
- Convert **p'** from homogeneous to image coordinates
  - divide by w (third) coordinate

Image warping with homographies

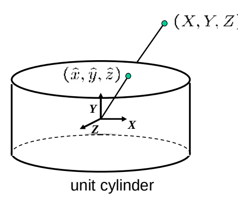


Panoramas

What if you want a 360° field of view?



Cylindrical projection



- Map 3D point (X,Y,Z) onto cylinder

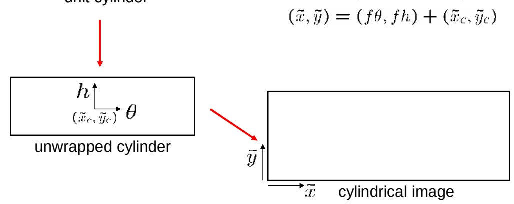
$$(\hat{x}, \hat{y}, \hat{z}) = \frac{1}{\sqrt{X^2+Z^2}}(X, Y, Z)$$

- Convert to cylindrical coordinates

$$(sin\theta, h, cos\theta) = (\hat{x}, \hat{y}, \hat{z})$$

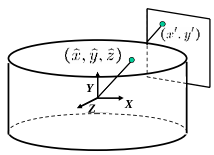
- Convert to cylindrical image coordinates

$$(\tilde{x}, \tilde{y}) = (f\theta, fh) + (\tilde{x}_c, \tilde{y}_c)$$

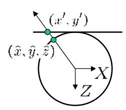


Cylindrical reprojection

How to map from a cylinder to a planar image?



side view



top-down view

- Apply camera projection matrix
  - for project 2, account for focal length and assume principle point is at center of image
    - » x'_c = ½ image width, y'_c = ½ image height

$$\begin{bmatrix} wx' \\ wy' \\ w \end{bmatrix} = \begin{bmatrix} -f & 0 & w/2 & 0 \\ 0 & -f & h/2 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \\ 1 \end{bmatrix}$$

- Convert to image coordinates
  - divide by third coordinate (w)

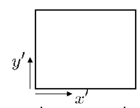


image coords

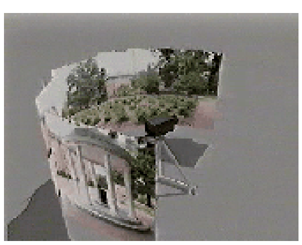
Cylindrical reprojection

Image 384x300 **f = 180 (pixels)** **f = 280** **f = 380**

Map image to cylindrical coordinates

- need to know the focal length

Cylindrical panoramas



Steps

- Reproject each image onto a cylinder
- Blend
- Output the resulting mosaic

Cylindrical image stitching

What if you don't know the camera rotation?

- Solve for the camera rotations
  - Note that a rotation of the camera is a **translation** of the cylinder!
  - Use Lukas-Kanade to solve for translations of cylindrically-warped images

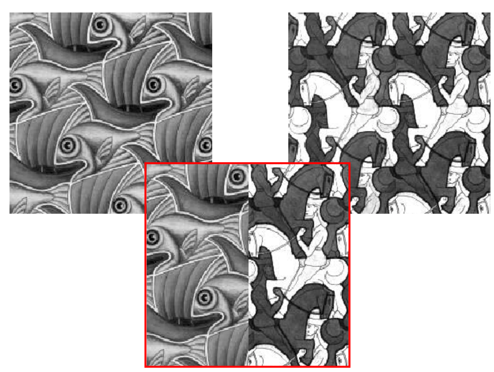
Full-view Panorama

Different projections are possible

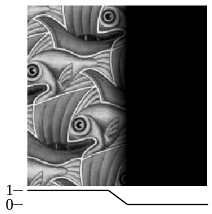
Project 2 (out today)

1. Take pictures on a tripod (or handheld)
2. Warp to cylindrical coordinates
3. Automatically compute pair-wise alignments
4. Correct for drift
5. Blend the images together
6. Crop the result and import into a viewer

Image Blending



Feathering



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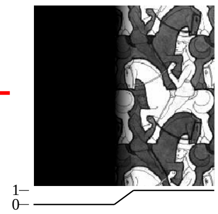

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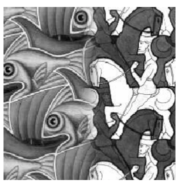


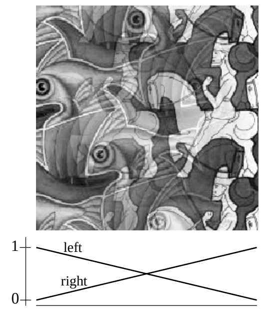
Encoding transparency

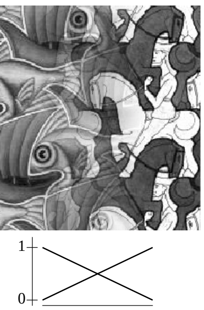
$I(x,y) = (\alpha R, \alpha G, \alpha B, \alpha)$

$I_{blend} = I_{left} + I_{right}$

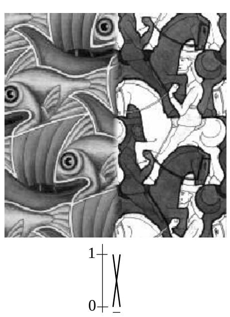
See Blinn reading (CGA, 1994) for details

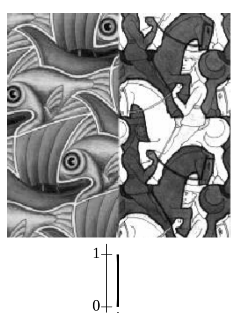
Effect of window size



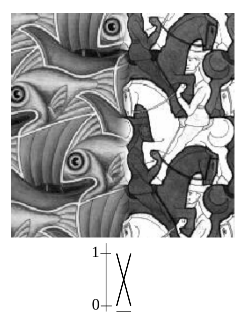


Effect of window size





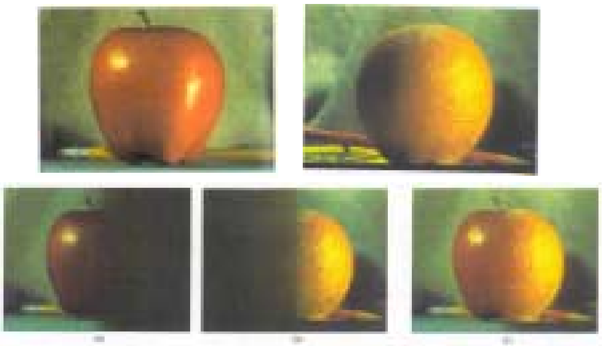
Good window size



"Optimal" window: smooth but not ghosted

- Doesn't always work...

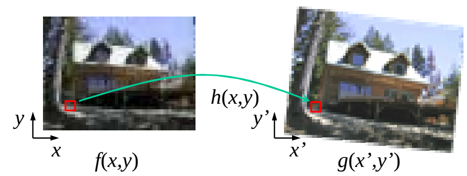
Pyramid blending



Create a Laplacian pyramid, blend each level

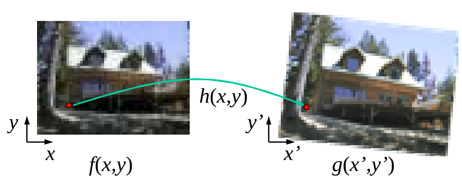
- Burt, P. J. and Adelson, E. H., A multiresolution spline with applications to image mosaics, ACM Transactions on Graphics, 42(4), October 1983, 217-236.

Image warping



Given a coordinate transform *(x',y')* = *h*(*x*,*y*) and a source image *f*(*x*,*y*), how do we compute a transformed image *g*(*x',y'*) = *f*(*h*(*x*,*y*))?

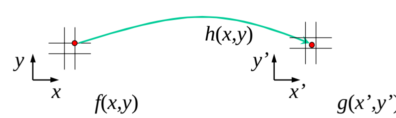
Forward warping



Send each pixel *f*(*x,y*) to its corresponding location (*x',y'*) = *h*(*x*,*y*) in the second image

Q: what if pixel lands "between" two pixels?

Forward warping



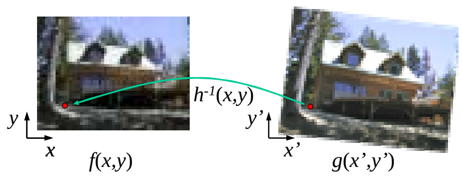
Send each pixel *f*(*x,y*) to its corresponding location (*x',y'*) = *h*(*x*,*y*) in the second image

Q: what if pixel lands "between" two pixels?

A: distribute color among neighboring pixels (x',y')

- Known as "splatting"

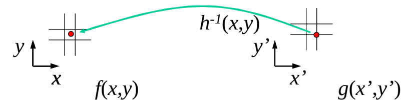
Inverse warping



Get each pixel $g(x',y')$ from its corresponding location
$(x,y) = h^{-1}(x',y')$ in the first image

Q: what if pixel comes from "between" two pixels?

Inverse warping



Get each pixel $g(x',y')$ from its corresponding location
$(x,y) = h^{-1}(x',y')$ in the first image

Q: what if pixel comes from "between" two pixels?

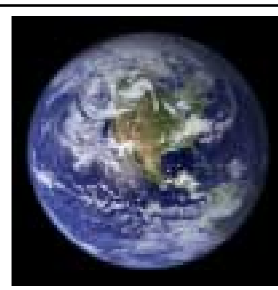
A: *resample* color value
- We discussed resampling techniques before
  - nearest neighbor, bilinear, Gaussian, bicubic

Forward vs. inverse warping

Q: which is better?

A: usually inverse—eliminates holes
- however, it requires an invertible warp function—not always possible...

Other types of mosaics



Can mosaic onto *any* surface if you know the geometry
- See NASA's [Visible Earth project](http://earthobservatory.nasa.gov/Newsroom/BlueMarble/) for some stunning earth mosaics
  - http://earthobservatory.nasa.gov/Newsroom/BlueMarble/

Summary

Things to take home from this lecture

- Image alignment
- Image reprojection
  - homographies
  - cylindrical projection
- Radial distortion
- Creating cylindrical panoramas
- Image blending
- Image warping
  - forward warping
  - inverse warping
  - bilinear interpolation