Announcements

- Project 1 artifact voting (email announce later today)
- Project 2 out today (help session at end of class)
- **IMPORTANT**: choose Proj 2 partner and SIGNUP for panorama equip TODAY:
  - http://www.cs.washington.edu/htbin-post/admin/preserve.cgi/www/htdocs/education/courses/cse576/panorama

Mosaics

http://www.panoramas.dk/
http://www.vrseattle.com/html/vrview.php?cat_id=11&vrs_id=vrs380

Today's Readings

- R. Szeliski and H.-Y. Shum. Creating full view panoramic image mosaics and texture-mapped models, Computer Graphics (SIGGRAPH'97), pages 251-258, August 1997
- J. F. Blinn, Jim Blinn's Corner: Compositing, Part 1: Theory, IEEE Computer Graphics and Application, 14(5), Sept. 1994, pp 83-87

Image Mosaics

Goal

- Stitch together several images into a seamless composite

How to do it?

Basic Procedure

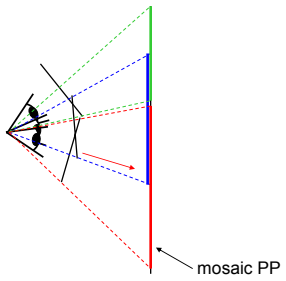
- Take a sequence of images from the same position
  - Rotate the camera about its optical center
- Compute transformation between second image and first
  - Lucas & Kanade registration
- Shift the second image to overlap with the first
- Blend the two together to create a mosaic
- If there are more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

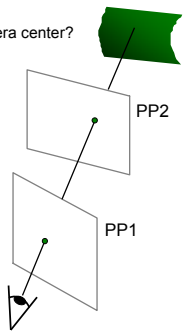
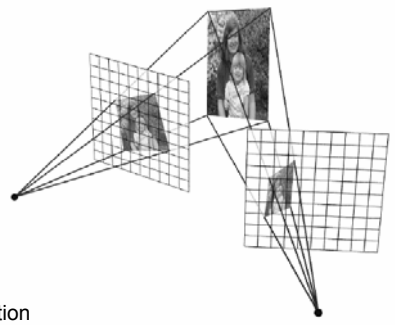


Image reprojection



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

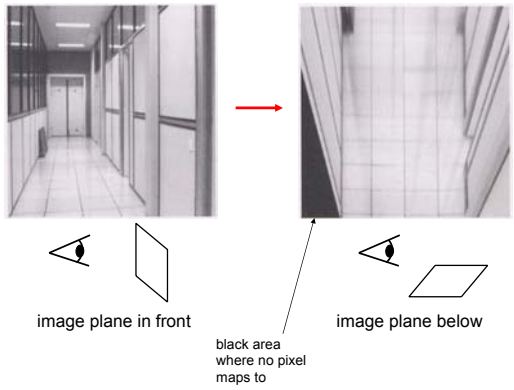
$$\begin{bmatrix} wx' \\ wy' \\ w \end{bmatrix} = \begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

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

To apply a homography **H**

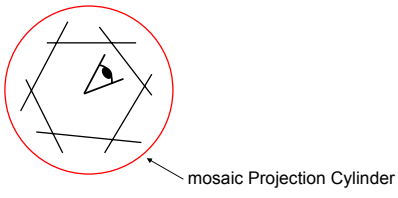
- Compute **p' = Hp** (regular matrix multiply)
- Convert **p'** from homogeneous to image coordinates
  - divide by w (third) coordinate

Image warping with homographies

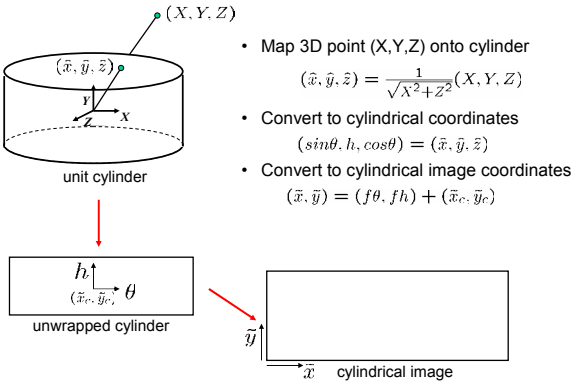


Panoramas

What if you want a 360° field of view?



Cylindrical projection



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

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

- Convert to cylindrical coordinates

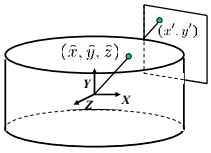
$$(sin\theta, h, cos\theta) = (\tilde{x}, \tilde{y}, \tilde{z})$$

- Convert to cylindrical image coordinates

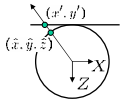
$$(\tilde{x}, \tilde{y}) = (f\theta, fh) + (\tilde{x}_c, \tilde{y}_c)$$

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)

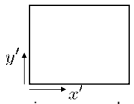


image coords

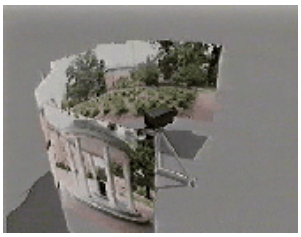
Cylindrical reprojection

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

Map image to cylindrical coordinates

- need to know the camera 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

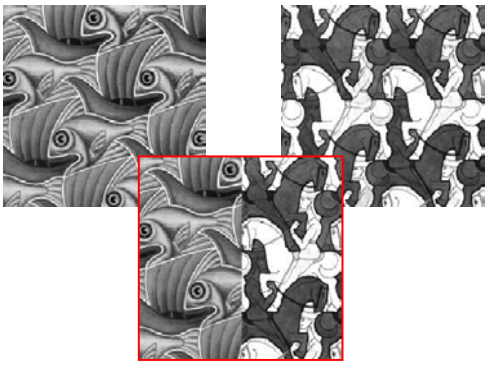
Different projections are possible

Szeliski-Shum, SIGGRAPH 97 video

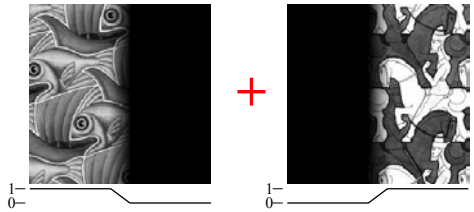
Project 2 (out today)

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



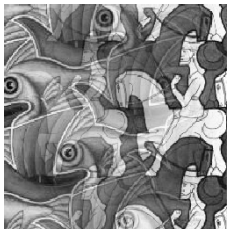
Encoding transparency

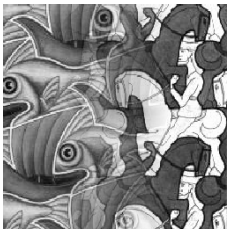
$I(x,y) = (\alpha R, \alpha G, \alpha B, \alpha)$

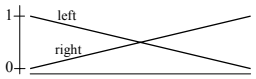
$I_{blend} = I_{left} + I_{right}$

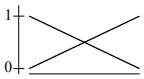
See Blinn reading (CGA, 1994) for details

Effect of window size

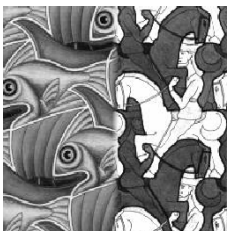


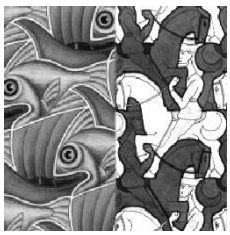




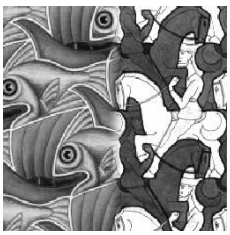


Effect of window size





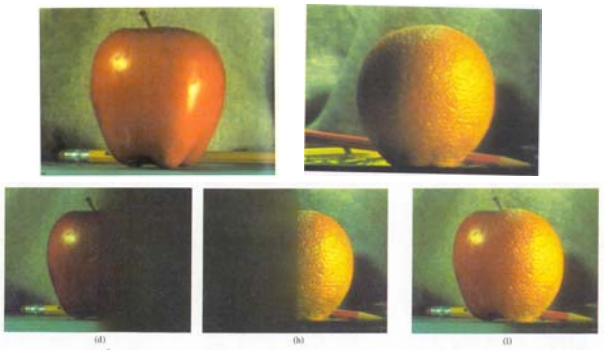
Good window size



"Optimal" window: smooth but not ghosted

- Doesn't always work...

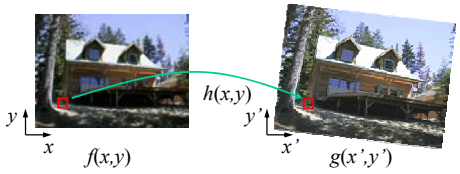
Pyramid blending



Create a Laplacian pyramid, blend each level

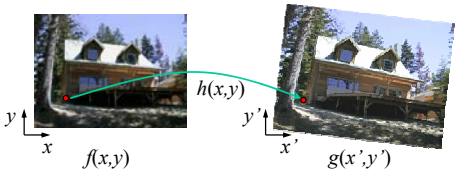
- Burt, P. J. and Adelson, E. H., A multiresolution spline with applications to image mosaics, ACM Transactions on Graphics, 42(4), October 1983, 217-236.

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*))?

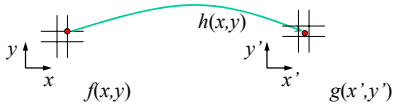
Forward warping



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



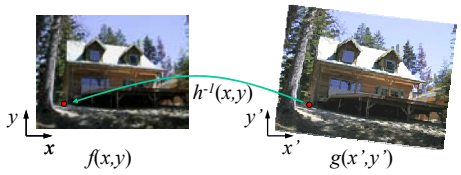
Send each pixel *f*(*x*,*y*) to its corresponding location
(*x',y'*) = *h*(*x*,*y*) in the second image

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

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

– Known as "splatting"

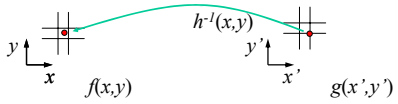
Inverse warping



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

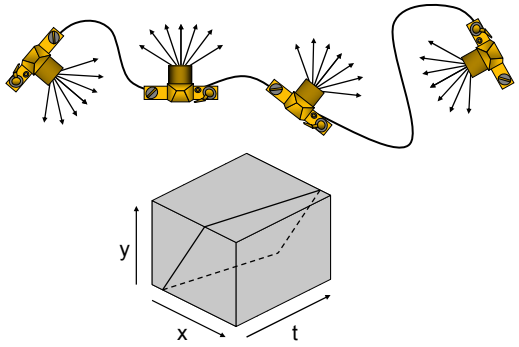
- however, it requires an invertible warp function—not always possible...

Other types of mosaics

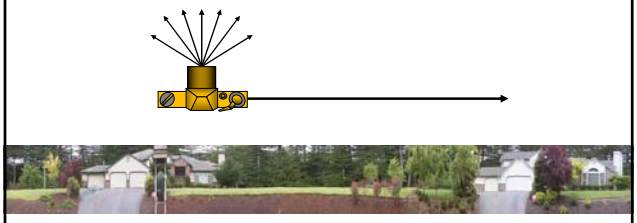
Can mosaic onto *any* surface if you know the geometry

- See NASA's Visible Earth project for some stunning earth mosaics
  - http://earthobservatory.nasa.gov/Newsroom/BlueMarble/

Path Images

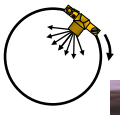


Pushbroom image



http://grail.cs.washington.edu/projects/stereo/

Cyclograph



http://grail.cs.washington.edu/projects/stereo/

Some path image references

Manifold mosaics:

- S. Peleg and J. Herman. Panoramic mosaics by manifold projection. In *IEEE Conf. on Computer Vision and Pattern Recognition (CVPR)*, 997, pp. 338-343,(extended version in PAMI 2000)
  - http://www.cs.huji.ac.il/labs/vision/papers/cvpr97-manifold.pdf

Stereo Panoramas

- S. Peleg, Y. Pritch, and M. Ben-Ezra, *Cameras for Stereo Panoramic Imaging*, CVPR'00, 2000, pp. 208-214.
  - http://www.cs.huji.ac.il/~peleg/papers/cvpr00-stereocamera.pdf
- S. M. Seitz and J. Kim, The Space of All Stereo Images, *Proc. Intl. Conf. on Computer Vision (ICCV)* , 2001, pp. 307-314.
  - http://grail.cs.washington.edu/projects/stereo/

Concentric Mosaics

- H.-Y. Shum and L.-W. He, Rendering with concentric mosaics, Proc. SIGGRAPH, 1999, pp. 299—306.
  - http://www.research.microsoft.com/users/lhe/papers/cm-siggraph99.pdf