## Image Mosaic

## Why Mosaic?

- Are you getting the whole picture?
  - Compact Camera FOV = 50 x 35°

Slide from Brown & Lowe

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  - Human FOV = 200 x 135°

Slide from Brown & Lowe

## Why Mosaic?

- Are you getting the whole picture?
  - Compact Camera FOV = 50 x 35°
  - Human FOV = 200 x 135°
  - Panoramic Mosaic = 360 x 180°

Slide from Brown & Lowe

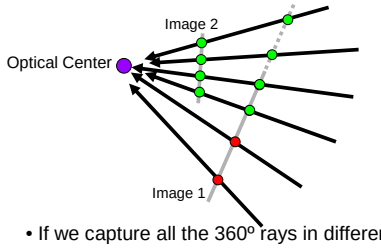
## Mosaics: stitching images together

Creating virtual wide-angle camera

## How to do it?

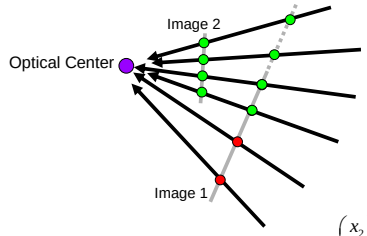
- Basic Procedure
  - Take a sequence of images from the same position
    - Rotate the camera about its optical center
  - Compute transformation between second image and first
  - Transform the second image to overlap with the first
  - Blend the two together to create a mosaic
  - If there are more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

## Geometric Interpretation of Mosaics




- If we capture all the 360º rays in different images, we can assemble them into a panorama.
- The basic operation is projecting an image from one plane to another
- The projective transformation is scene-INDEPENDENT

## What is the transformation?




$$\begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix} \sim \mathbf{K}_1 \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

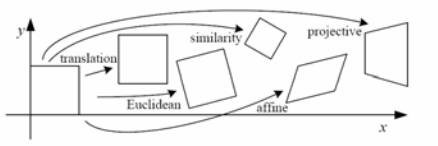
$$\begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix} \sim \mathbf{K}_2\mathbf{R} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \sim \begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & 0 & x_0 \\ 0 & f & y_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$\begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix} \sim \mathbf{K}_2\mathbf{R}\mathbf{K}_1^{-1} \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix}$$

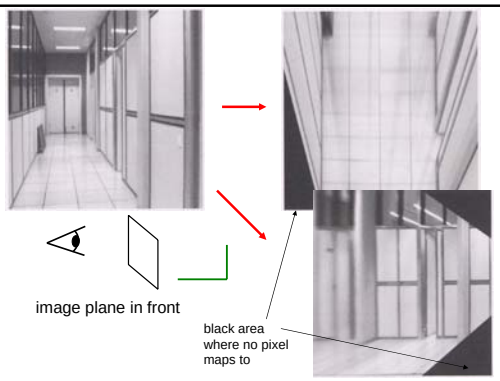
3x3 matrix
also called Homography

## Recall in the Image Warping Lecture:

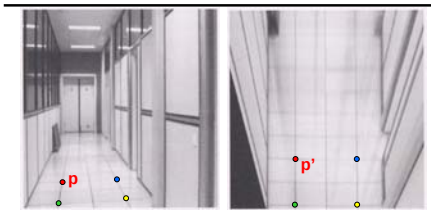



| Name | Matrix | # D.O.F. | Preserves: | Icon |
|---|---|---|---|---|
| translation | $\begin{bmatrix} \boldsymbol{I} \mid \boldsymbol{t} \end{bmatrix}_{2\times3}$ | 2 | orientation + ··· | |
| rigid (Euclidean) | $\begin{bmatrix} \boldsymbol{R} \mid \boldsymbol{t} \end{bmatrix}_{2\times3}$ | 3 | lengths + ··· | |
| similarity | $\begin{bmatrix} s\boldsymbol{R} \mid \boldsymbol{t} \end{bmatrix}_{2\times3}$ | 4 | angles + ··· | |
| affine | $\begin{bmatrix} \boldsymbol{A} \end{bmatrix}_{2\times3}$ | 6 | parallelism + ··· | |
| projective | $\begin{bmatrix} \tilde{\boldsymbol{H}} \end{bmatrix}_{3\times3}$ | 8 | straight lines | |

## Image warping with homographies




## Image rectification

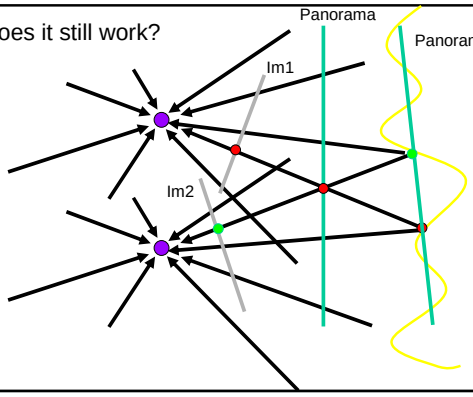



To unwarp (rectify) an image

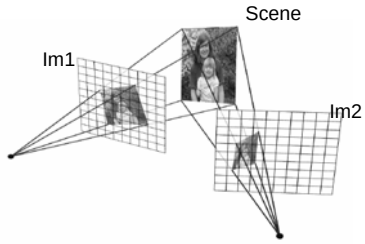
- Find the homography **H** given a set of **p** and **p'** pairs
- How many correspondences are needed?

## changing camera center

- Does it still work?



## Planar scene (or far away)



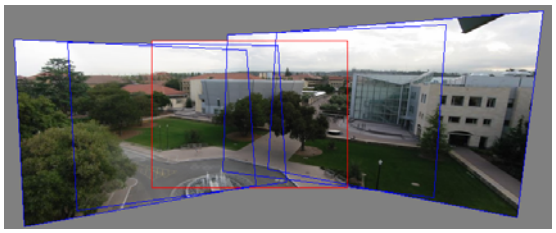

- If scene is planar, we are OK!
- This is how big aerial photographs are made

## Planar mosaic Examples

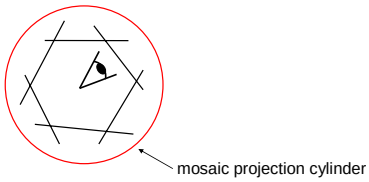
## Recap:

- With enough images from the same optical center, we can create panorama.
- If the camera moves, we can't in general
- If the scene is planar or faraway, we are OK.

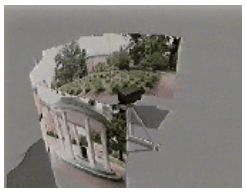
## Can we use homography to create a 360 panorama?



## Should use Cylindrical Projection




## Cylindrical panoramas



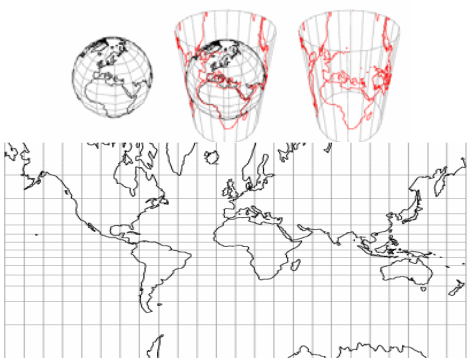
- Steps
  - Reproject each image onto a cylinder
  - Align and Blend
  - Output the resulting mosaic

## Taking pictures

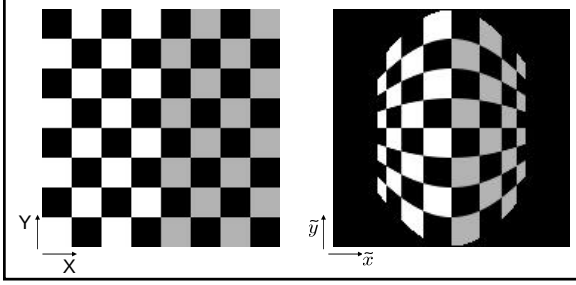
Kaidan panoramic tripod head

## Warped Images

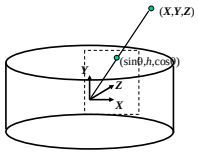
## Cylindrical projection (An Example)



## Cylindrical Projection

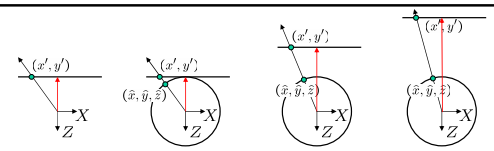



## Inverse Cylindrical projection




$$
\begin{aligned}
\theta &= (x_{cyl} - x_c)/f \\
h &= (y_{cyl} - y_c)/f \\
\hat{x} &= \sin\theta \\
\hat{y} &= h \\
\hat{z} &= \cos\theta \\
x &= f\hat{x}/\hat{z} + x_c \\
y &= f\hat{y}/\hat{z} + y_c
\end{aligned}
$$

## Need to know the focal length

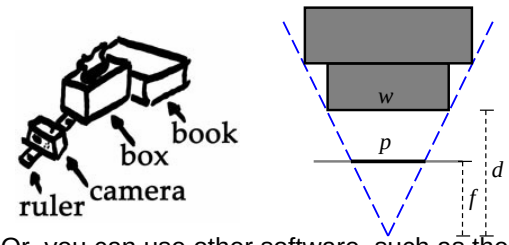



top-down view

Focal length – the dirty secret…

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

## A simple method for estimating f

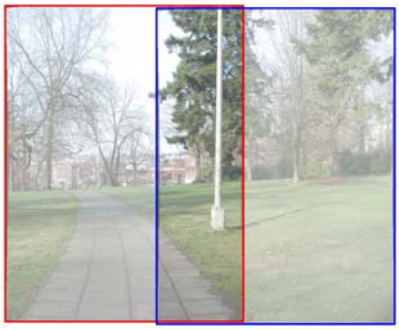




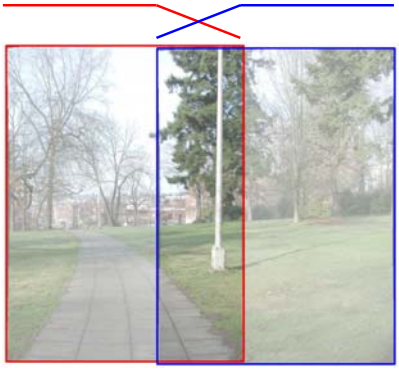


Or, you can use other software, such as the Caltech Camera Calibration Toolkit, to help.

## Blending

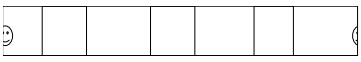


## Blending



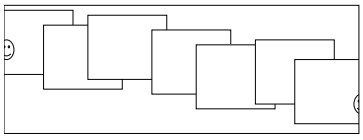
## Blending

## Assembling the panorama



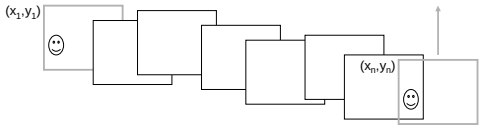
- Stitch pairs together, blend, then crop

## Problem: Drift



- Error accumulation
  - small errors accumulate over time

## Problem: Drift



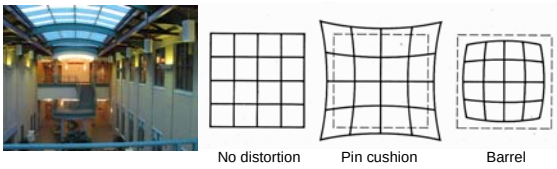

- Solution
  - add another copy of first image at the end
  - there are a bunch of ways to solve this problem
    - add displacement of $(y_1 - y_n)/(n-1)$ to each image after the first
    - compute a global warp: $y' = y + ax$
    - run a big optimization problem, incorporating this constraint
      - best solution, but more complicated
      - known as "bundle adjustment"
- copy of first image

## End-to-end alignment and crop

## Cylindrical panorama

1. Take pictures on a tripod (or handheld)
2. Warp to cylindrical coordinate
3. Compute pairwise alignments
4. Fix up the end-to-end alignment
5. Blending
6. Crop the result and import into a viewer

## Distortion




- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens

## Some panorama examples

Microsoft Lobby: http://www.acm.org/pubs/citations/proceedings/graph/258734/p251-szeliski

## Some panorama examples

Before Siggraph Deadline:
http://www.cs.washington.edu/education/courses/cse590ss/01wi/projects/project1/students/dougz/siggraph-hires.html

## Some panorama examples

What's inside your refrig?
http://www.cs.washington.edu/education/courses/cse590ss/01wi/

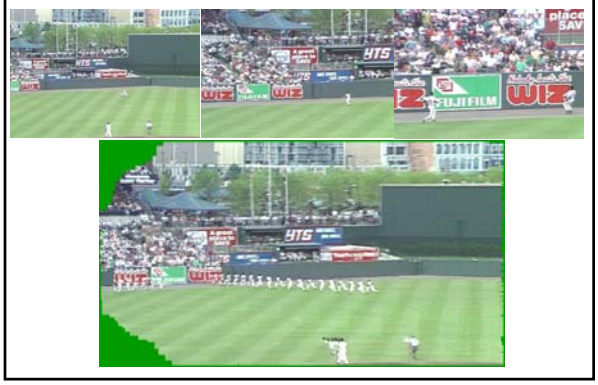
## Some panorama examples

Mars: http://www.panoramas.dk/fullscreen3/f2_mars97.html

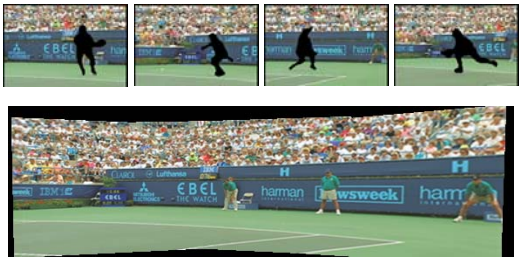
2003 New Years Eve: http://www.panoramas.dk/fullscreen3/f1.html

Video Summarization: http://www.vision.huji.ac.il/video-synopsis/

## Video Summarization



## Video compression



## Magic: ghost removal

**M. Uyttendaele, A. Eden, and R. Szeliski.**
***Eliminating ghosting and exposure artifacts in image mosaics.***
**In Proceedings of the Interational Conference on Computer Vision and Pattern Recognition, volume 2, pages 509--516, Kauai, Hawaii, December 2001.**

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## For dynamic Scenes

Point Grey Ladybug2

http://www.ptgrey.com/products/ladybug2/samples.asp

## For dynamic scenes

http://www1.cs.columbia.edu/CAVE/projects/cat_cam_360/cat_cam_360.php