Image Stitching and Panoramas

Vaibhav Vaish

Stanford CS223B Computer Vision, Winter 2007

Professors Sebastian Thrun and Jana Kosecka


Map
Satellite
Hybrid
200 ft
100 m
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Why Panoramas ?

- Virtual reality: a sense of being there

Demo: Quicktime VR [Chen & Williams 95]

Why Panoramas ?

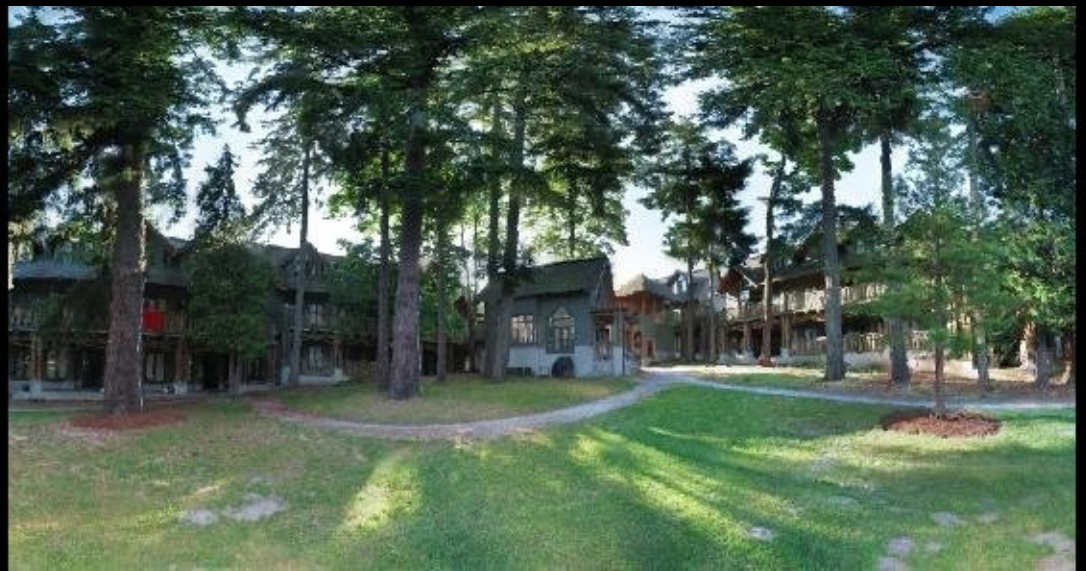
- Getting the whole picture
  - Consumer camera: 50˚ x 35˚

[Brown 2003]

Why Panoramas ?

- Getting the whole picture
  - Consumer camera: 50˚ x 35˚
  - Human Vision: 176˚ x 135˚

[Brown 2003]



Why Panoramas ?

- Getting the whole picture
  - Consumer camera: 50˚ x 35˚
  - Human Vision: 176˚ x 135˚
  - Panoramic mosaics: up to 360˚ x 180˚

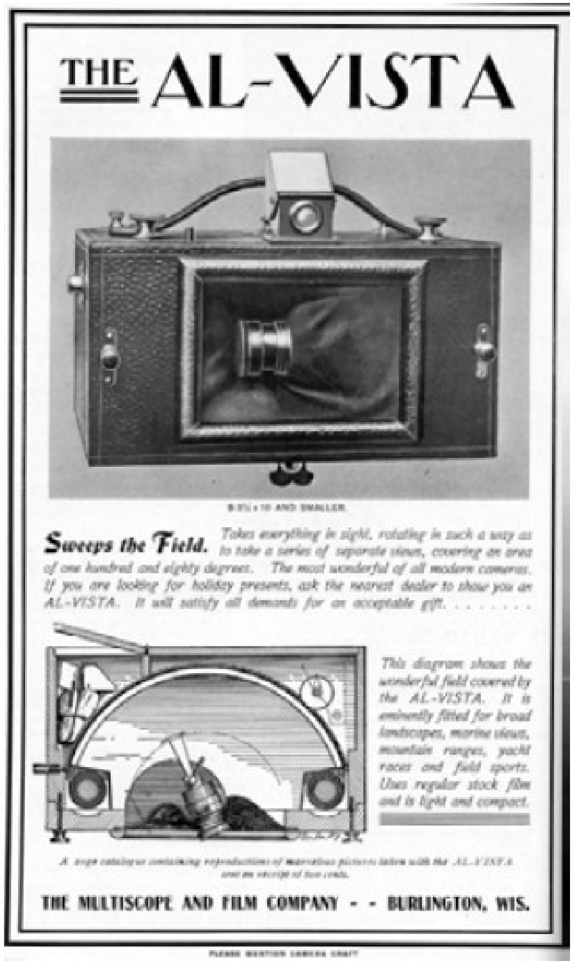
[Brown 2003]

The First Panoramas …

Paris, c. 1845-50, photographer unknown

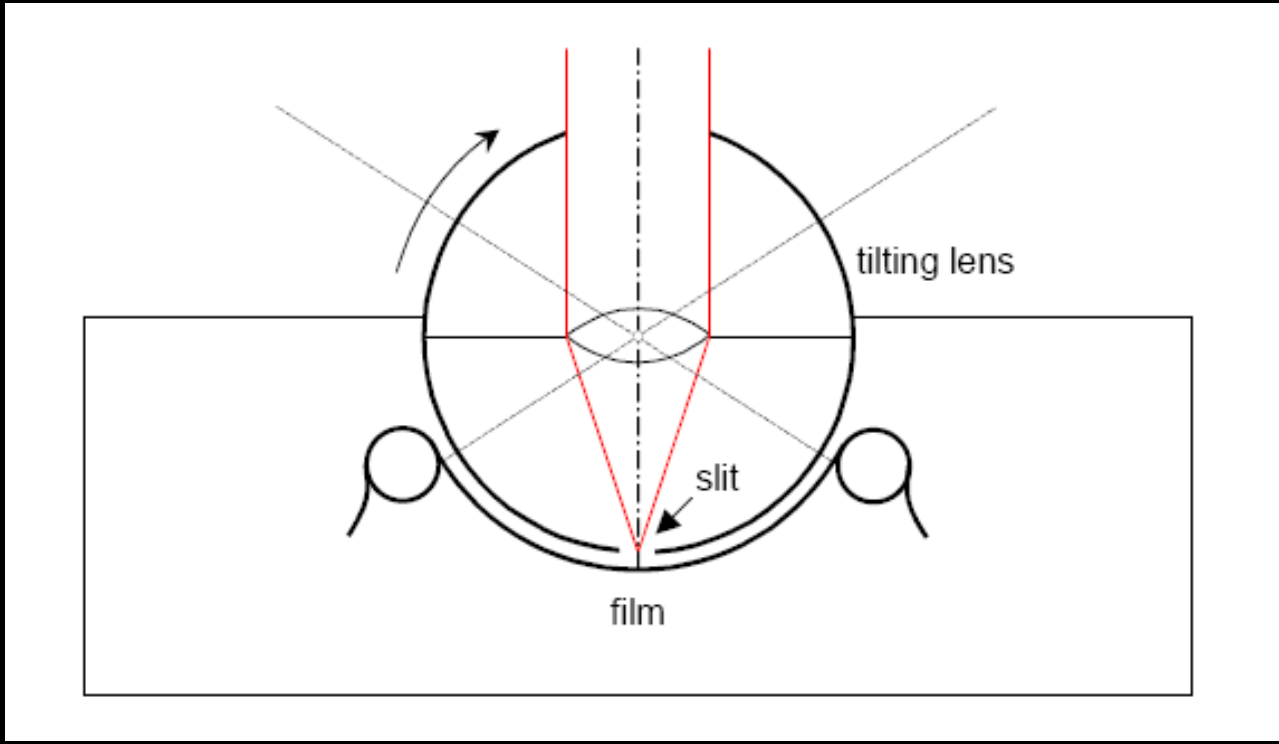
San Francisco from Rincon Hill, 1851, by Martin Behrmanx

… and Panoramic Cameras



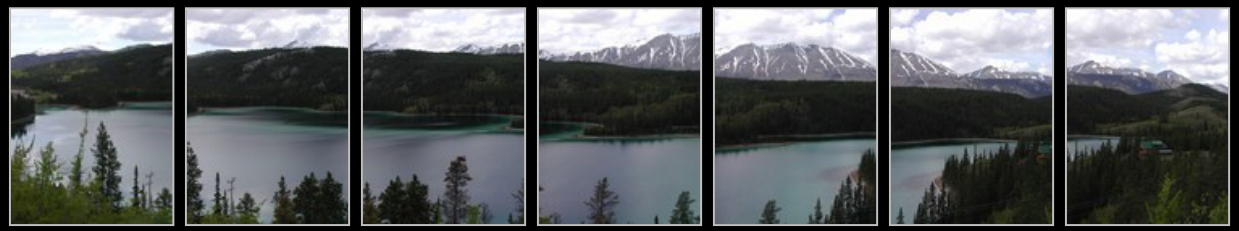
Al-Vista, 1899 ($20)

How they work



Swing lens (1843 – 1980s)

How they work (using Computer Vision)

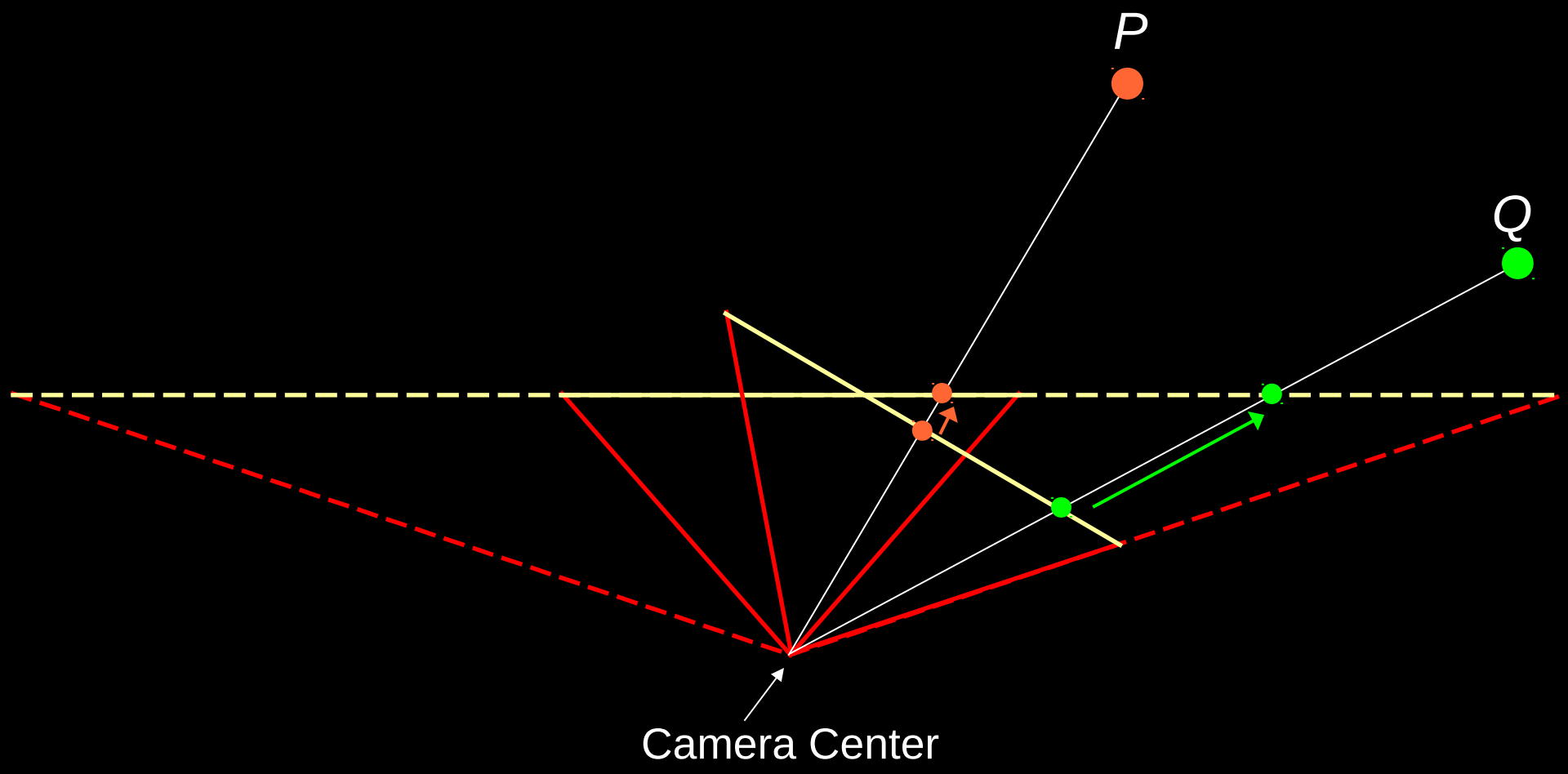


Goal: *Combine pixels from multiple images to compute a bigger image.*

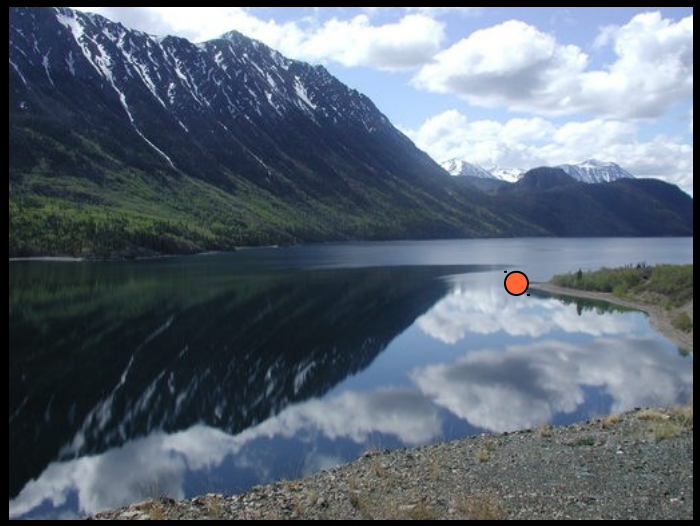
Today's Agenda

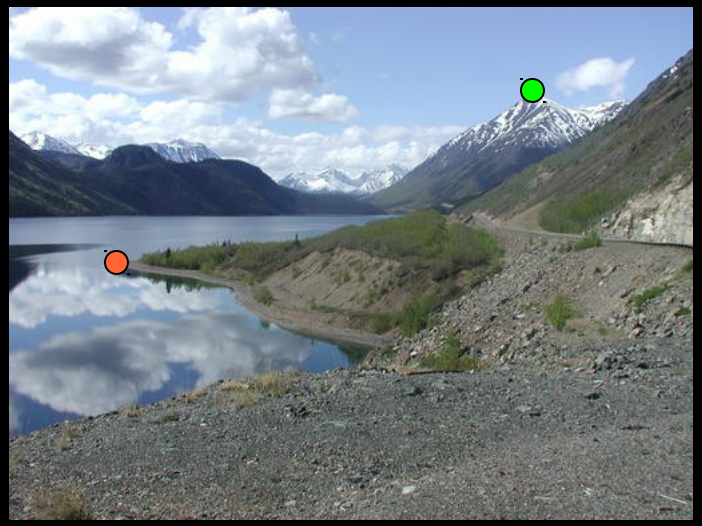
- Single perspective panoramas
  - Acquiring the images
  - Perspective warps (homographies)
  - Stitching images
  - Multi-band blending
- Stitching software
- Current research: computing photographs

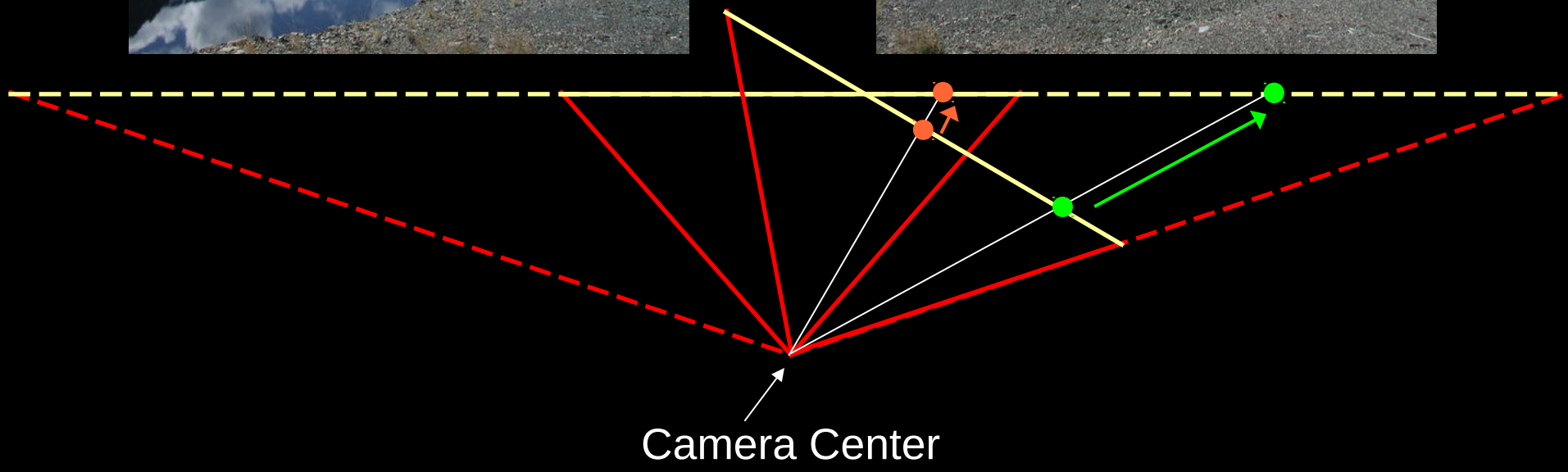
Increasing the Field of View



Example



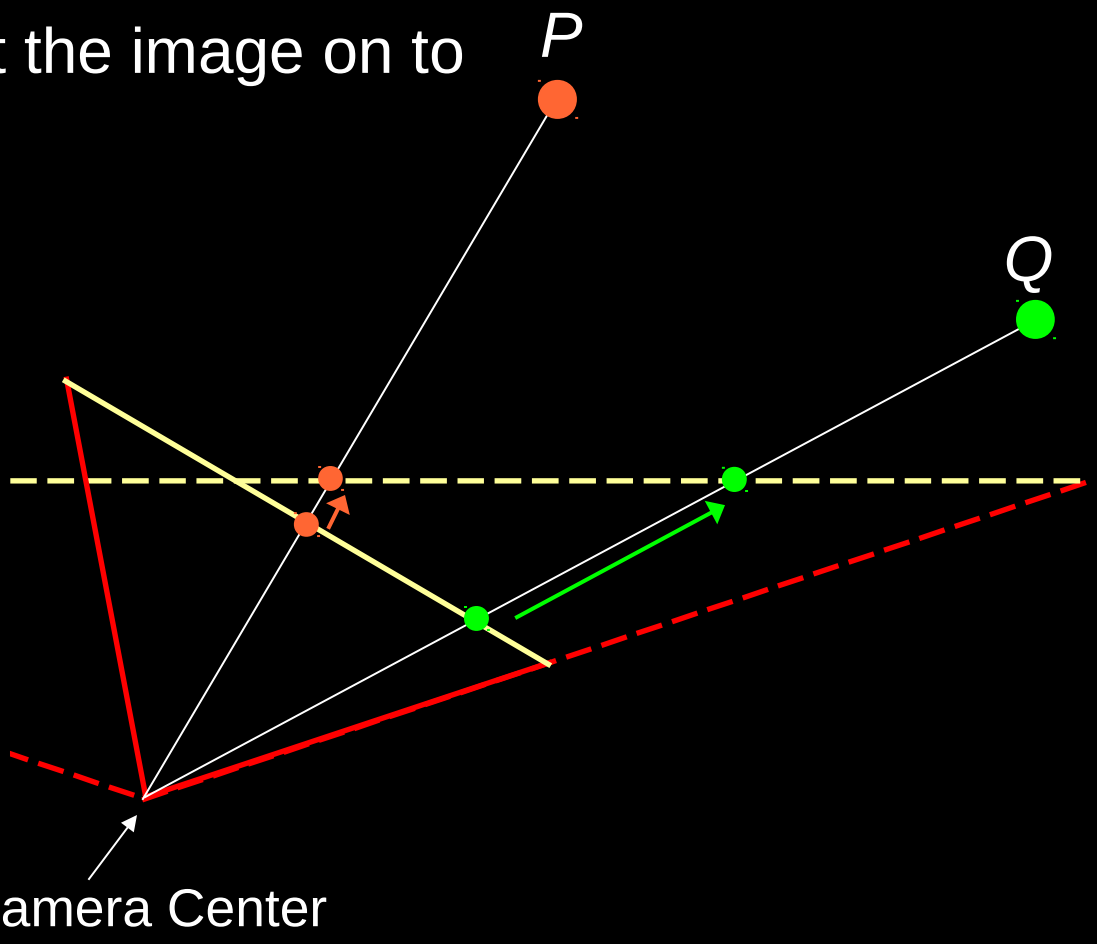




Projection on to Common Image Plane

What is required to project the image on to the desired plane ?

- Scaling ?
- Translation ?
- Rotation ?
- Affine transform ?
- Perspective projection ?



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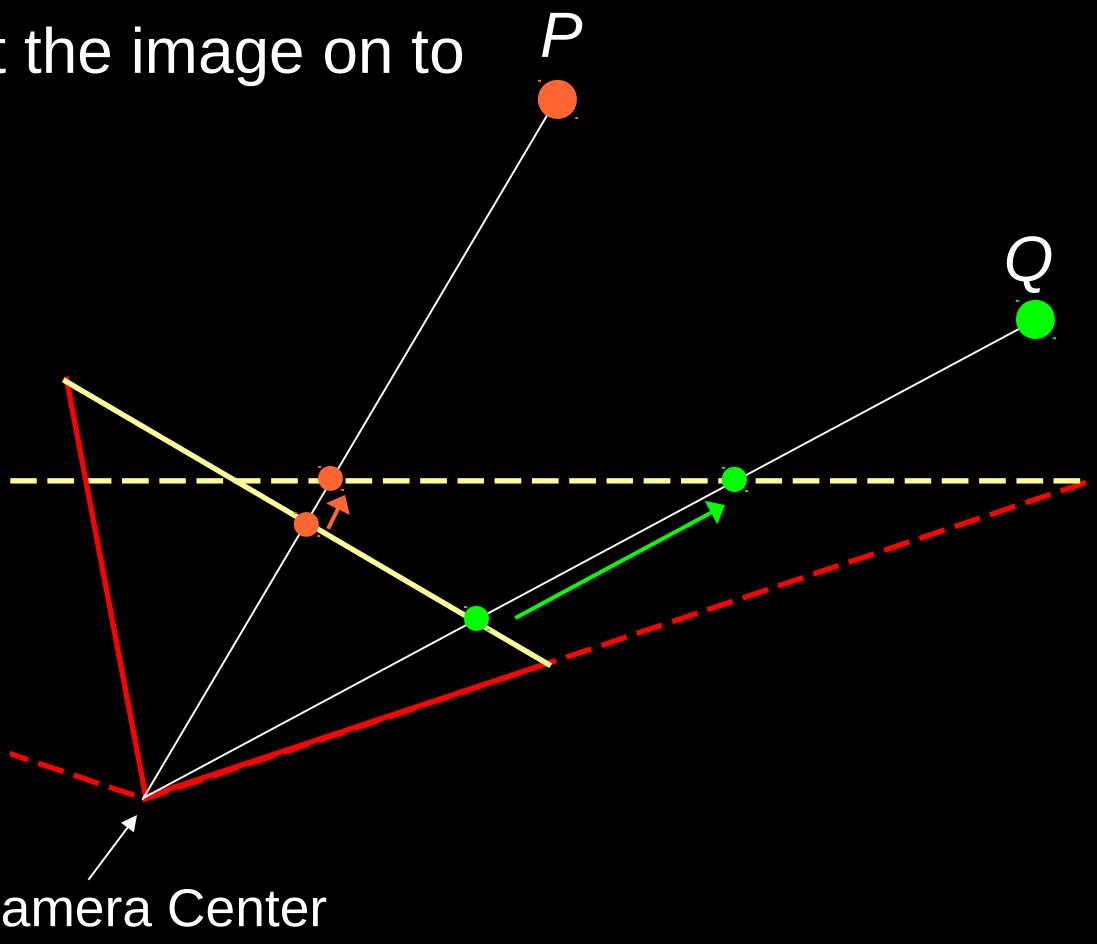
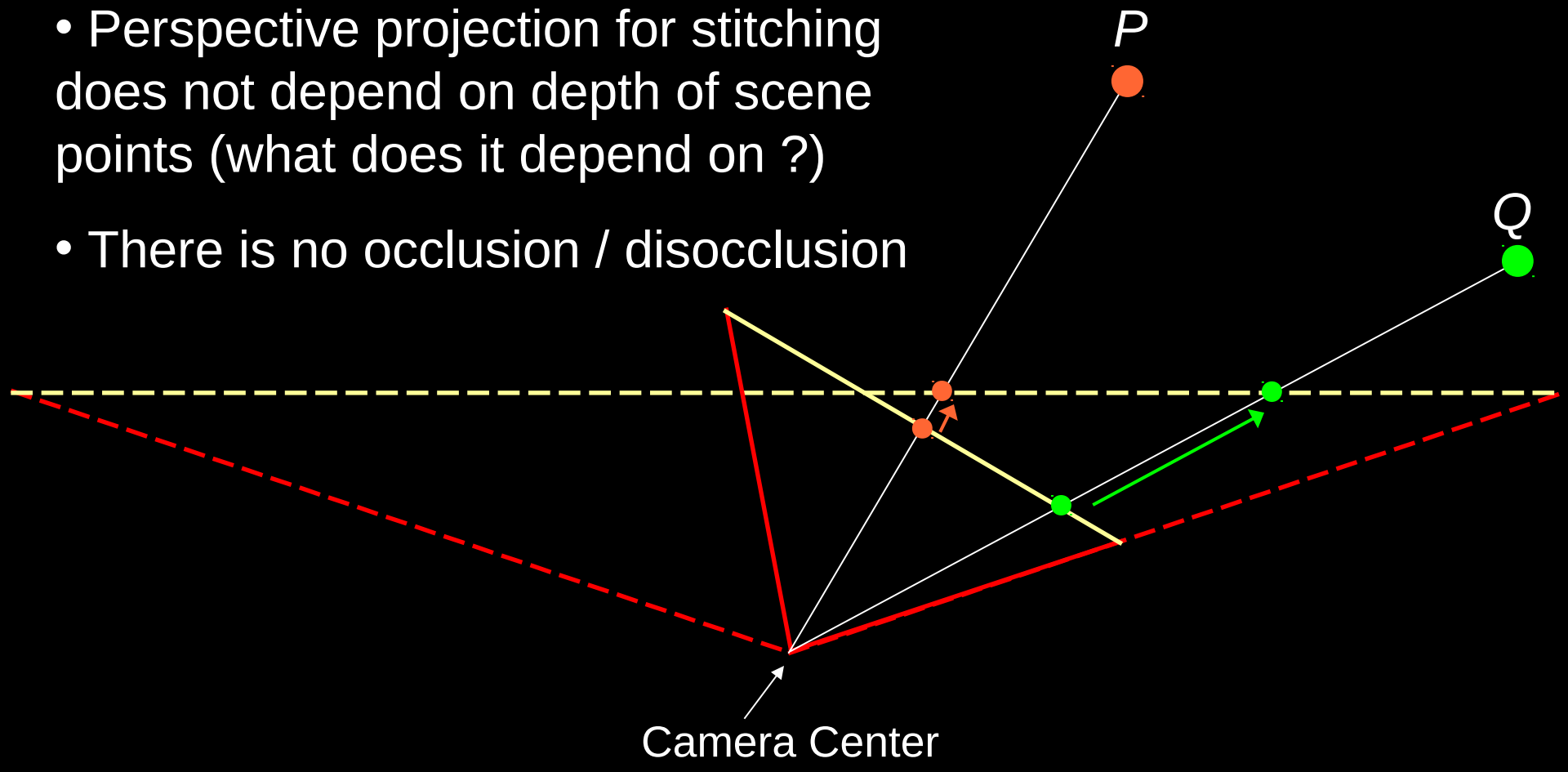
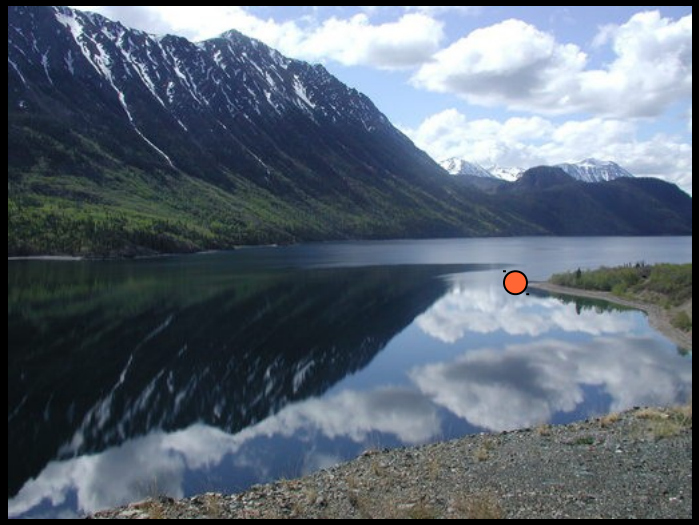


Why Rotation about Camera Center ?

- Perspective projection for stitching does not depend on depth of scene points (what does it depend on ?)
- There is no occlusion / disocclusion



Aligning Images



What's the relation between corresponding points?

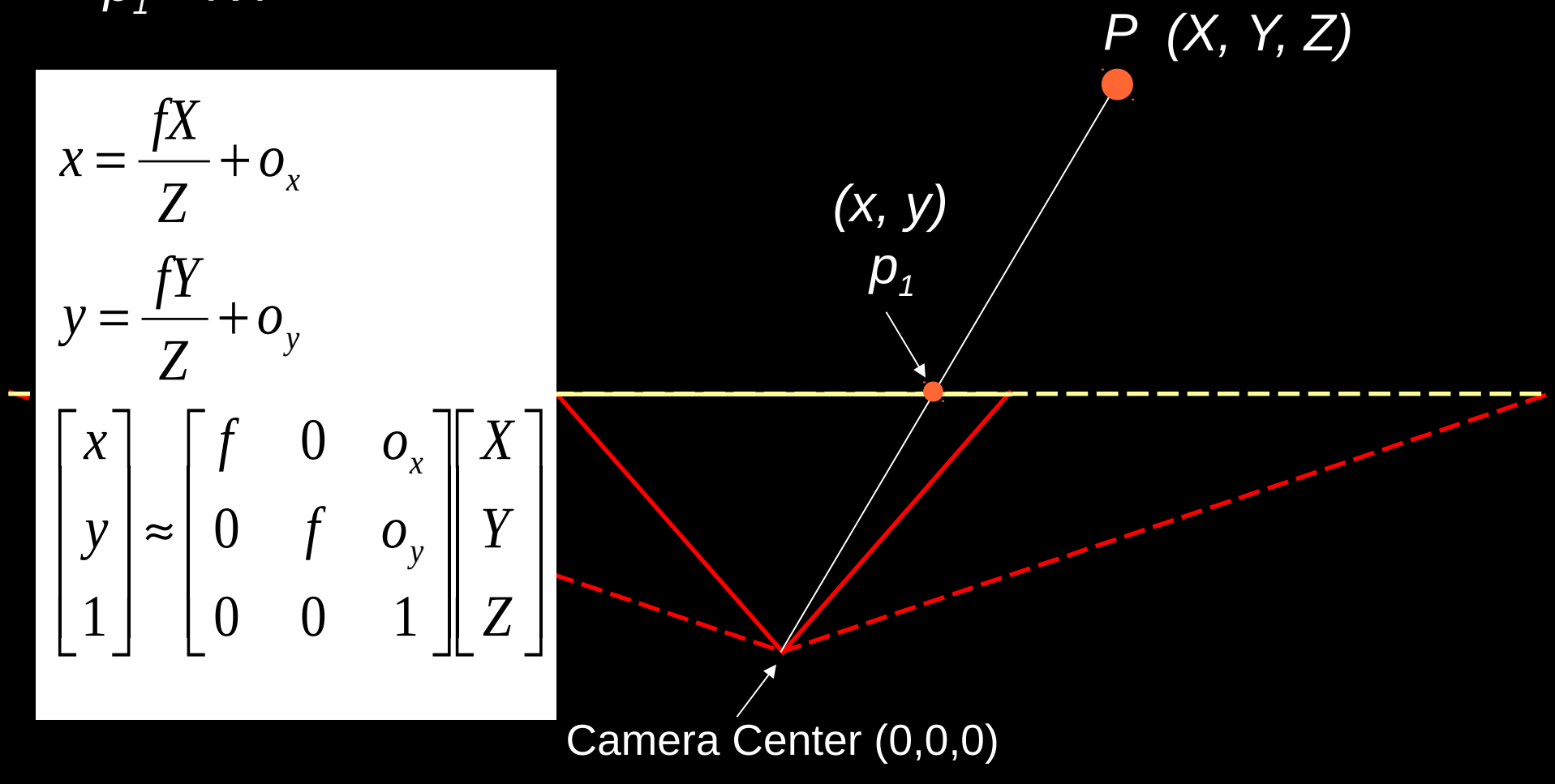
Perspective warps (Homographies)

$p_1 \approx K\,P$

$$x = \frac{fX}{Z} + o_x$$

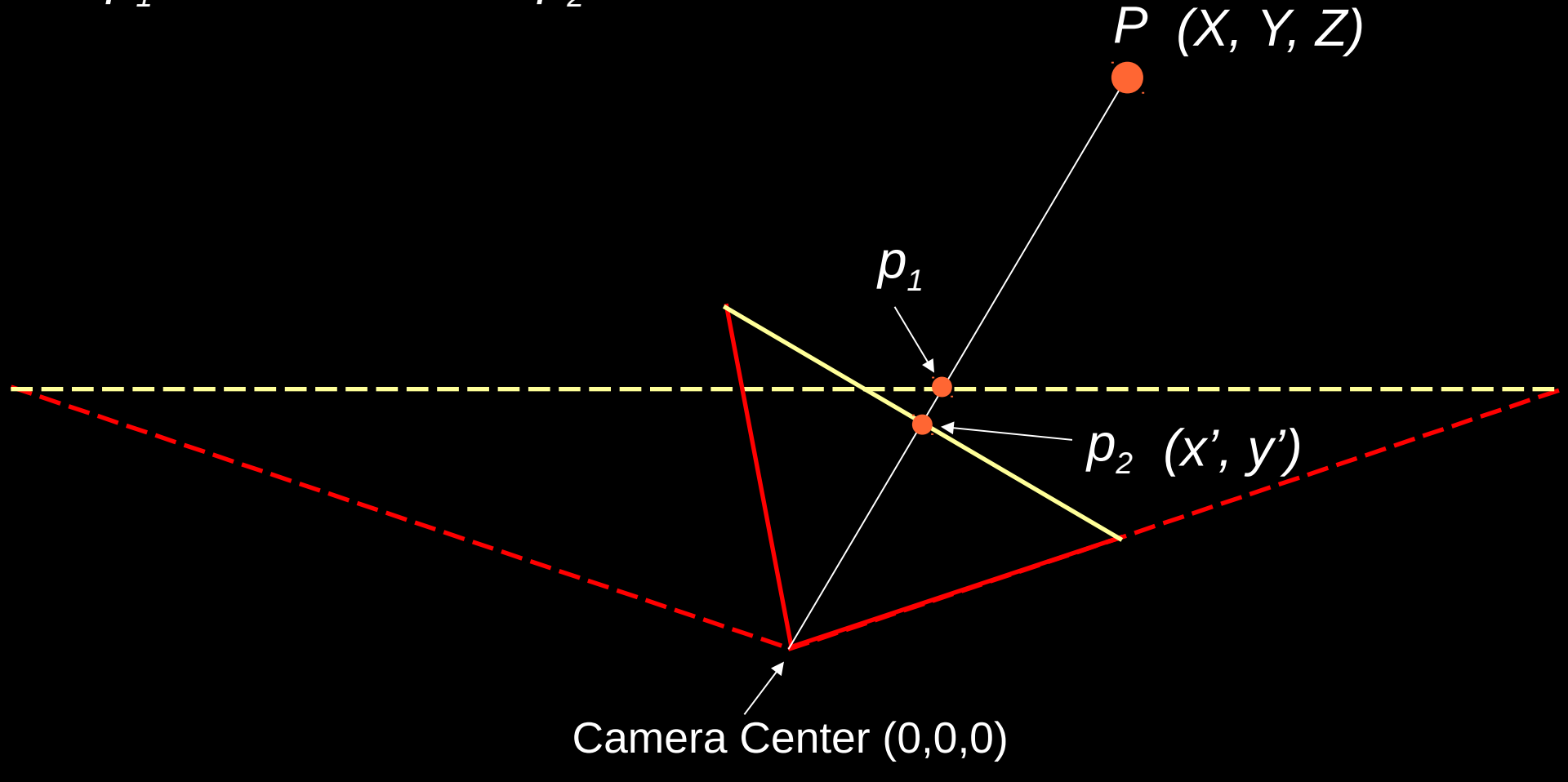
$$y = \frac{fY}{Z} + o_y$$

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \approx \begin{bmatrix} f & 0 & o_x \\ 0 & f & o_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



Perspective warps (Homographies)

$p_1 \approx K\,P$ $p_2 \approx K\,R\,P$



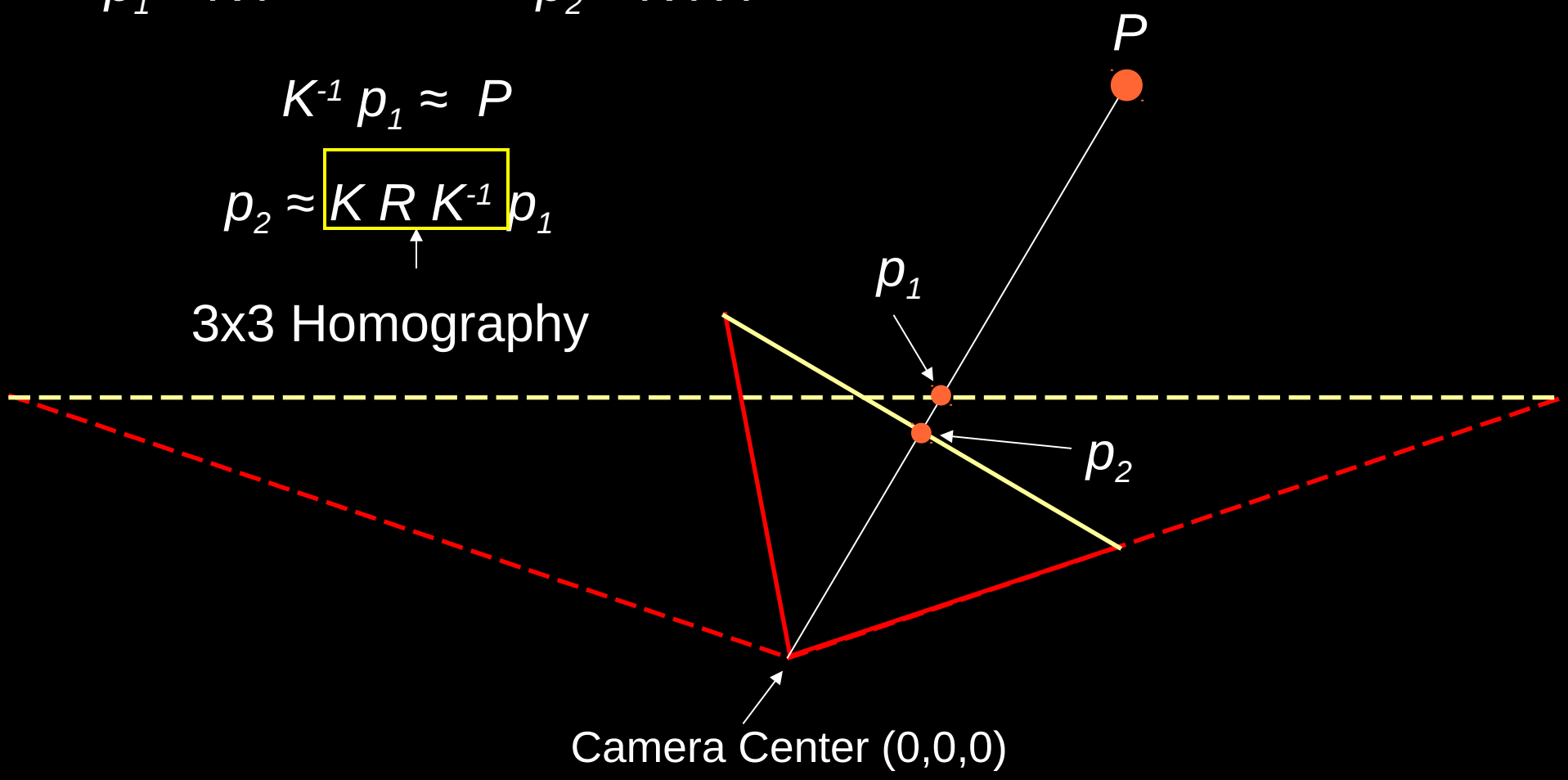
Perspective warps (Homographies)

$p_1 \approx K\,P$ $\qquad$ $p_2 \approx K\,R\,P$

$K^{-1}\,p_1 \approx P$

$p_2 \approx \boxed{K\,R\,K^{-1}}\,p_1$

3x3 Homography



Sebastian’s Counting Game

How many unknowns are there in the perspective warp (homography matrix) ?

0	1	2	3	4	5	6	7	8	9

Place Your Bet!

Sebastian’s Counting Game

How many unknowns are there in the perspective warp (homography matrix) ?

0	1	2	3	4	5	6	7	8	9
									

- Fixed intrinsics (square pixels): 6
- Varying intrinsics (eg. autofocus): 8

Finding the homographies

How can we find the homographies required for stitching ?

- From calibration parameters
  - Works, but these aren’t always known
- By matching features across images

Finding the homographies

- By matching features across images
  - What features should we match ?
  - How many ?

Finding the homographies

What features do we match across images ?

- Pixel values ?
- Canny edges ?
- Harris Corners ?
- cvGoodFeaturesToTrack() ?
- SIFT features ?
- Hough lines ?

Finding the homographies

What features do we match across images ?

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Homographies by Feature Matching

$$p_2 \approx K\, R\, K^{-1}\, p_1$$

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} \approx \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Homographies by Feature Matching

$$p_2 \approx K\, R\, K^{-1}\, p_1$$

$$x' = \frac{a_1 x + a_2 y + a_3}{c_1 x + c_2 y + c_3}$$

$$y' = \frac{b_1 x + b_2 y + b_3}{c_1 x + c_2 y + c_3}$$

Two linear equations per matching feature

Sebastian’s Counting Game

How many corresponding features do we need to compute the homography ?

0	1	2	3	4	5	6	7	8	n

Place Your Bet!

Sebastian's Counting Game

How many corresponding features do we need to compute the homography ?

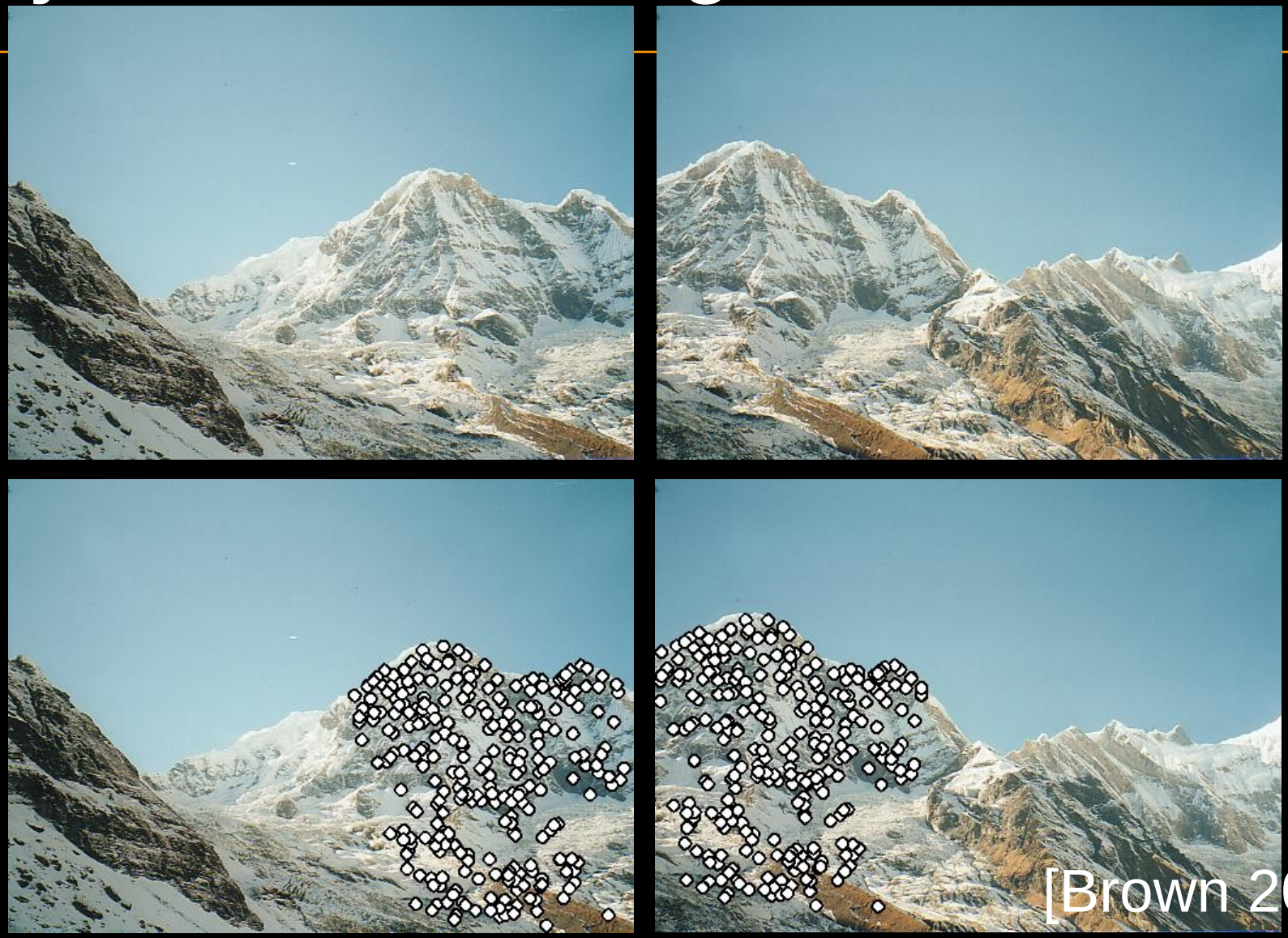
0	1	2	3	4	5	6	7	8	n
			✓	✓					

- Fixed intrinsics (square pixels): 3
- Varying intrinsics (eg. autofocus): 4

Matching SIFT Features

[Brown 2003]

Reject Outliers using RANSAC



[Brown 2003]

Stitching Images via Homographies

[Brown 2003]

Why do we get seams ?

- Differences in exposure
- Vignetting
- Small misalignments

[Brown 2003]

Multi-band Blending

- [Burt and Adelson 1983]
- Multi-resolution technique using image pyramid
- Hides seams but preserves sharp detail

[Brown 2003]

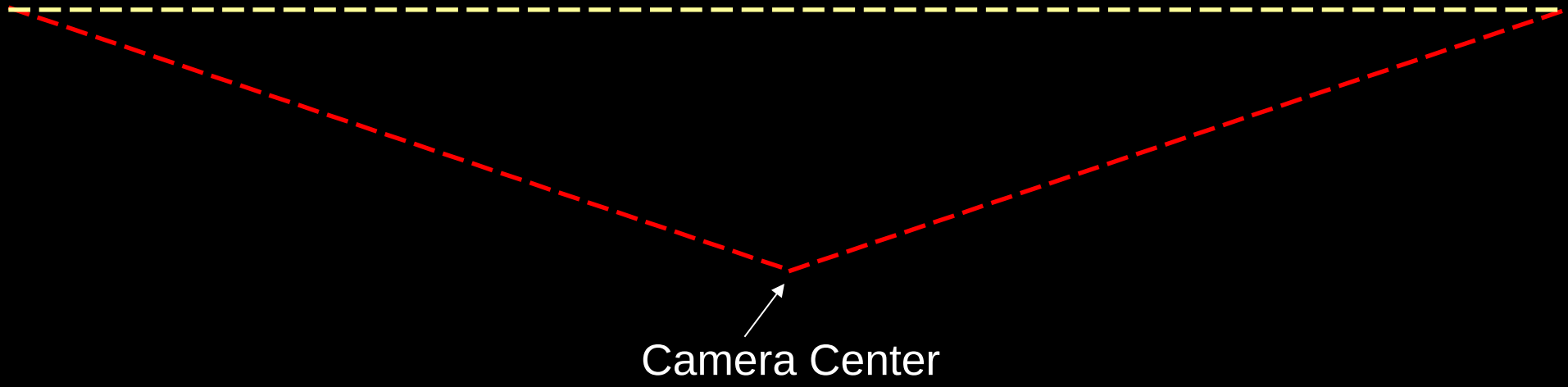
Panoramic Stitching Algorithm

Input: *N* images from camera rotating about center

1. Find SIFT features in all images
2. For adjacent images:
    1. Match features to get correspondences
    2. Eliminate outliers using RANSAC
    3. Solve for homography
3. Project images on common “image plane”
4. Blend overlapping images to obtain panorama

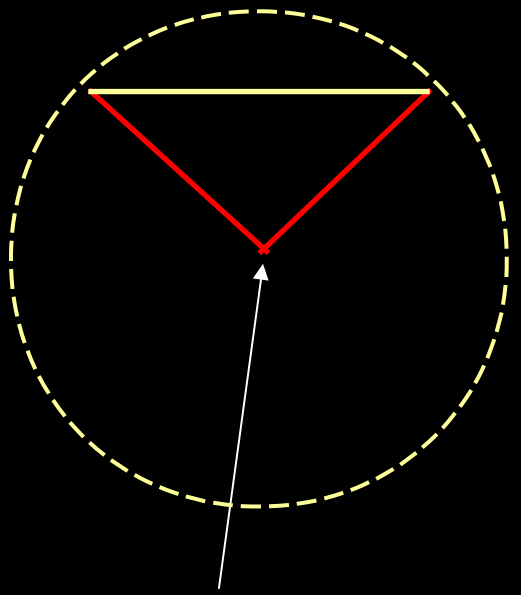
Time complexity = O(*N* * RANSAC cost)

Do we have to project on to a plane ?



Cylindrical Projection

360˚ Panorama
[Szeliski & Shum 97]

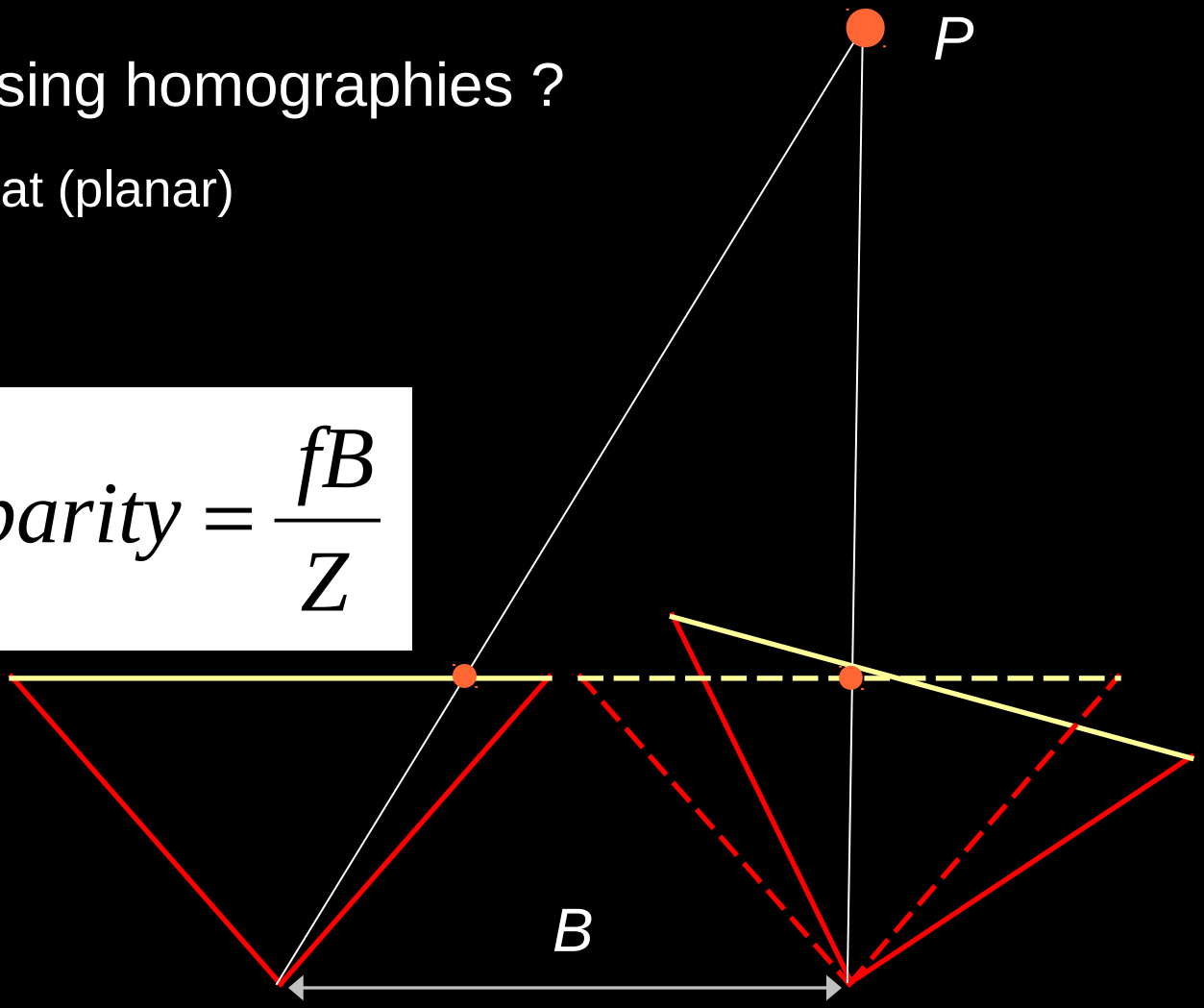


General Camera Motion

Can we still stitch using homographies ?

- When the scene is flat (planar)
- When *Z* >> B

$$disparity = \frac{fB}{Z}$$



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Autostitch

Recognizing Panoramas.

M. Brown, D. Lowe, in ICCV 2003.

- Searches collection of photos for sets which can be stitched together

Autostitch: Example

Input:

Output:

[Brown 2003]

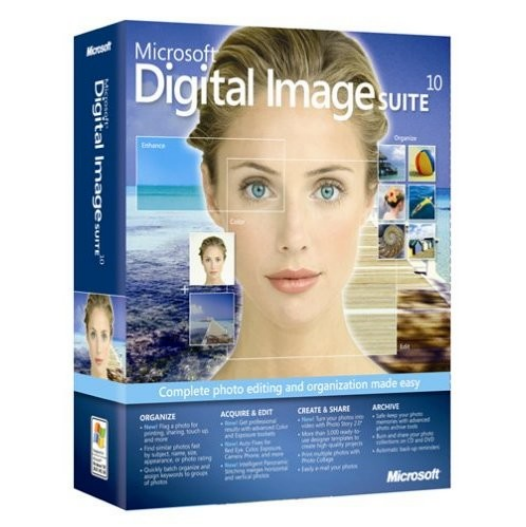
Autostitch

- Huge number of SIFT features to match
  - Uses efficient approx. nearest-neighbour search
  - O(n log n) where n = number of features
  - Uses priors to accelerate RANSAC
- Handle full space of rotations
- Estimate camera intrinsics for each photo
  - Bundle adjustment

http://www.cs.ubc.ca/~mbrown/autostitch/autostitch.html

More Software

- Microsoft Digital Image Suite
  - Co-developed by Matt Brown



- autopano-sift
  - http://user.cs.tu-berlin.de/~nowozin/autopano-sift/
  - C# source for Linux and windows

Summary

- Rotate camera about center of projection
- Align images using homographies
  - Determined by feature correspondence
- Stitch images and blend
- Project on to desired surface (cylinder, sphere, cube)

Limitations

- Lens distortion and vignetting
- Off-centered camera motion
- Moving objects
- Single perspective may not be enough!

Let's see how some of these could be tackled …

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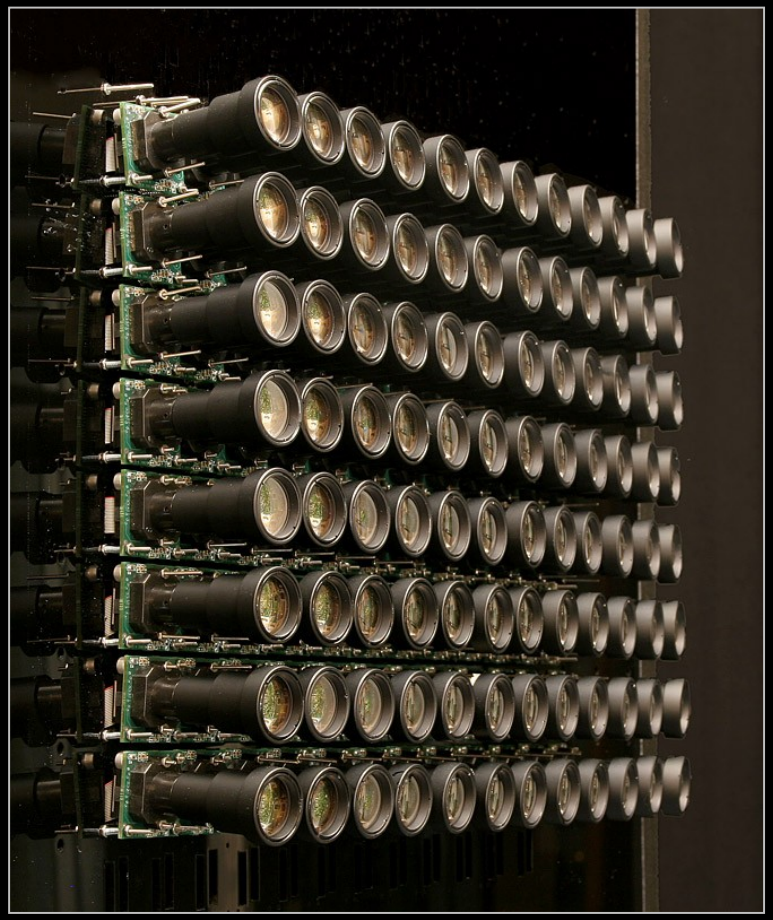
Video Panoramas



- 12 × 8 array of VGA cameras
- total field of view = 29° wide
- seamless stitching
- cameras individually metered

[Wilburn 2005]

Video Panorama: 7 Megapixels

Panoramic Video Textures

Input Video:

[Agarwala et al, 2005]

Panoramic Video Textures

Output Video

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

[Agarwala et al, 2005]

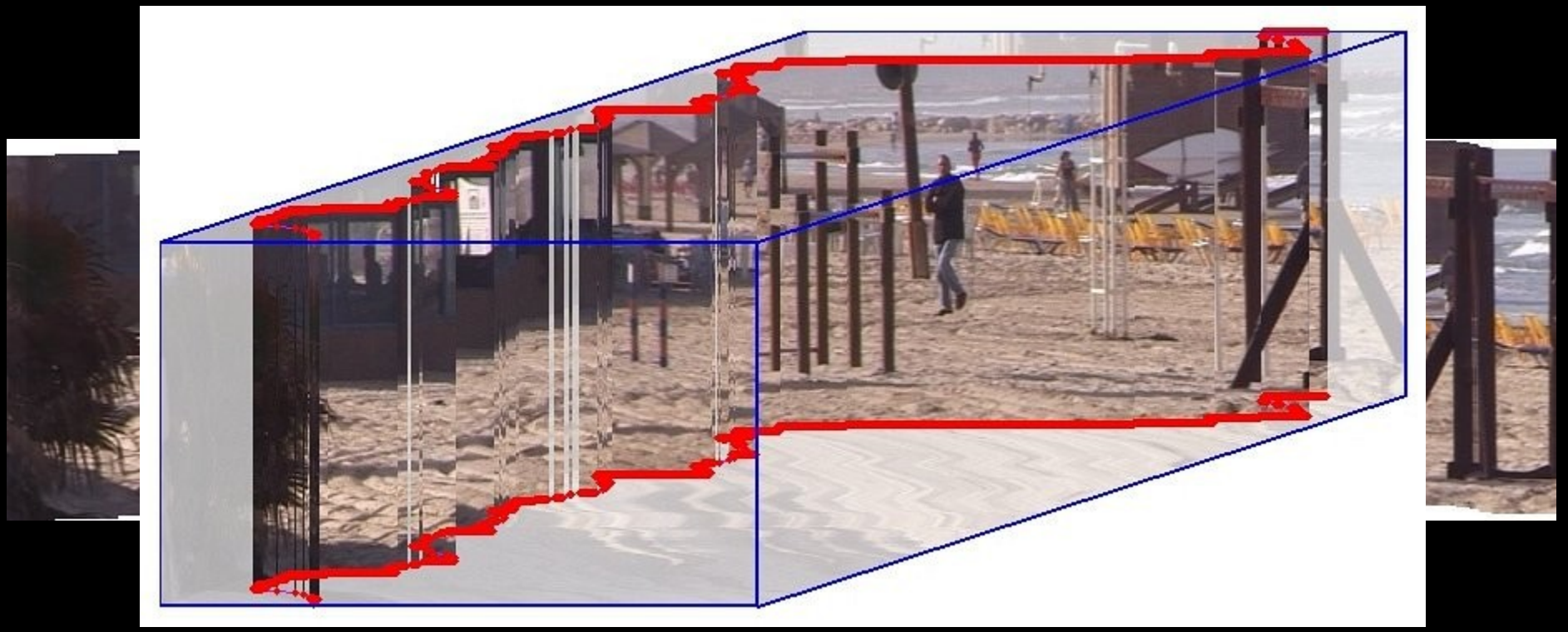
Multi-perspective Panoramas

Input Video

Space-time Scene Manifolds. Y. Wexler, D. Simakov

In ICCV 2005

Multi-perspective Panoramas



Space-time Scene Manifolds. Y. Wexler, D. Simakov

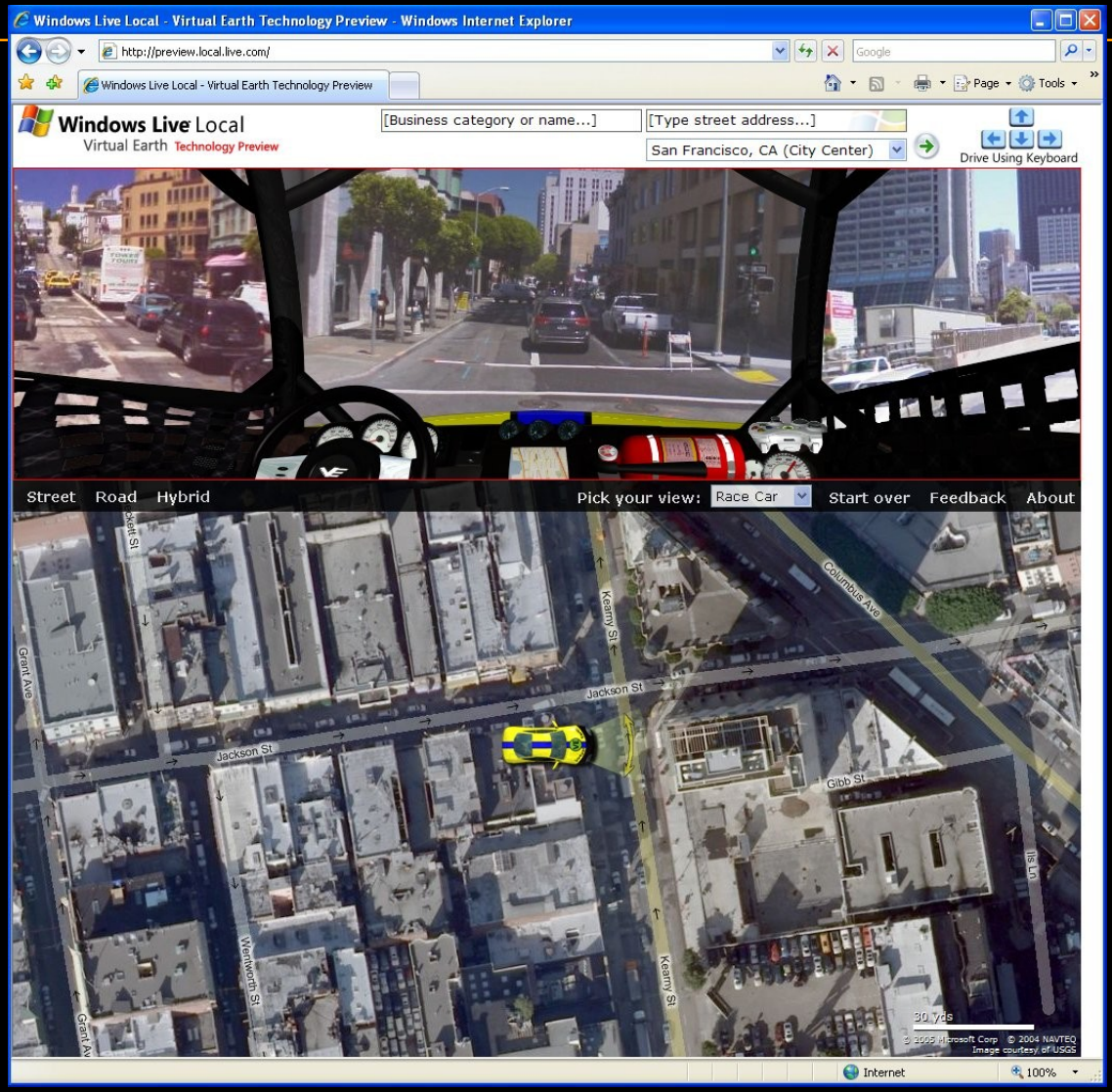
In ICCV 2005

Multi-perspective Panoramas

Input Video

[Roman 2006]

Driving directions of the future ?



Loftier Goal: computing photographs

Combine pixels from multiple images to compute a ~~bigger~~ image.

Combine pixels from multiple images to compute a better image.

- Multiple viewpoints
- Multiple exposures
- …

Multi-perspective Panoramas

Input Video

[Roman 2006]