

Image Stitching and Panoramas



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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: $50^{\circ} \times 35^{\circ}$

[Brown 2003]



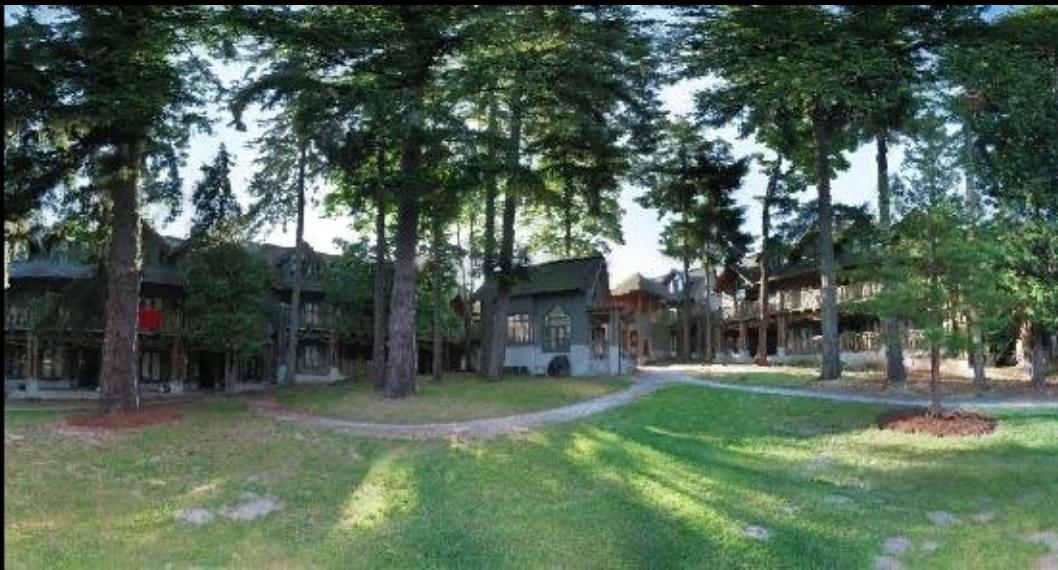
Why Panoramas ?

- Getting the whole picture

- Consumer camera: $50^{\circ} \times 35^{\circ}$

[Brown 2003]

- Human Vision: $176^{\circ} \times 135^{\circ}$



Why Panoramas ?

- Getting the whole picture

- Consumer camera: $50^{\circ} \times 35^{\circ}$

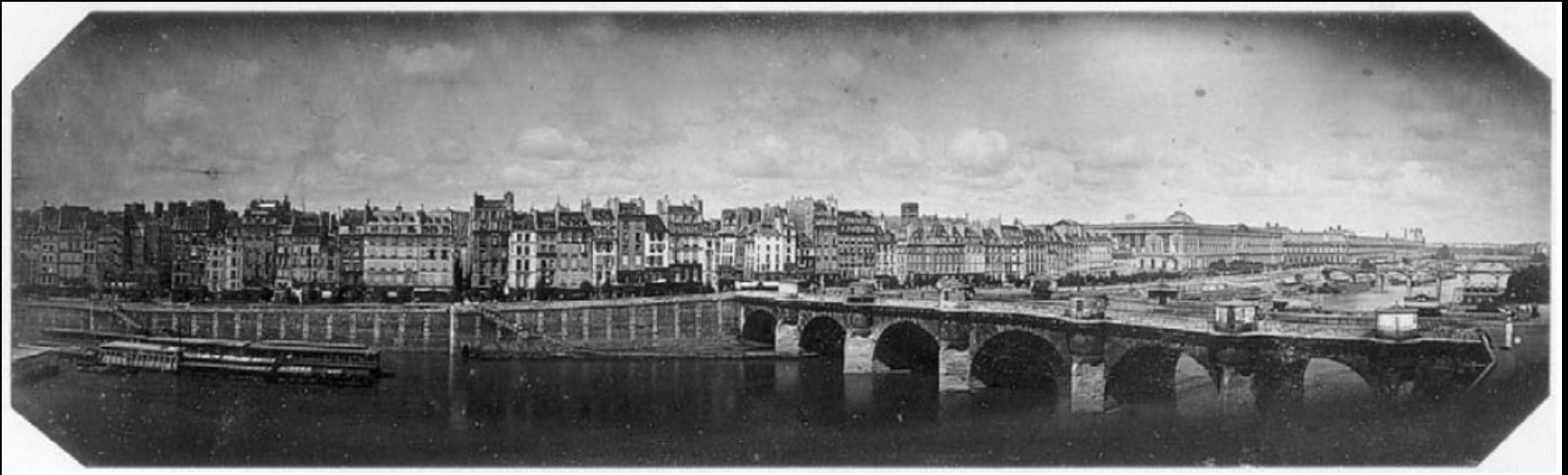
[Brown 2003]

- Human Vision: $176^{\circ} \times 135^{\circ}$

- Panoramic mosaics: up to $360^{\circ} \times 180^{\circ}$



The First Panoramas ...



Paris, c. 1845-50, photographer unknown



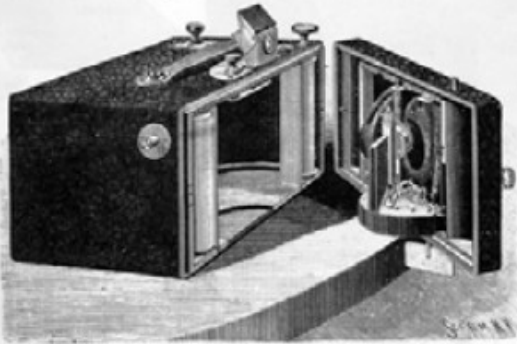
San Francisco from Rincon Hill, 1851, by Martin Behrmanx

... and Panoramic Cameras

FIVE Cameras in ONE for the Price of ONE.

The "AL-VISTA" Panoramic Camera

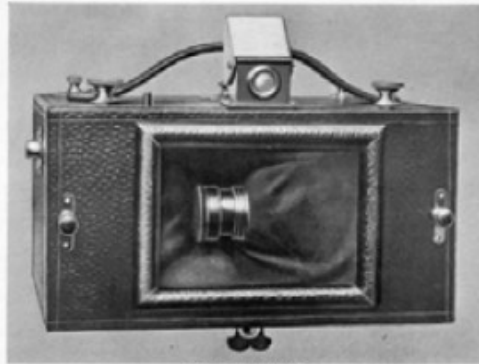
has accomplished the feat of covering, in a single exposure, a sweep of about 180 degrees. When you consider that this is one-half of the horizon exposed from any given location, the surprising nature of the accomplishment is realized. Two streets running



A ROLA HOLDER FILM PANORAMIC CAMERA.

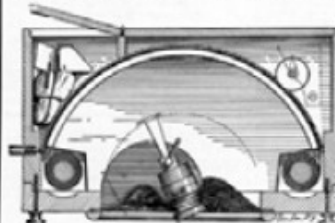
at right angles can now be photographed successfully at one exposure, and other equally difficult feats are possible. For photographing Broad Landscapes, Mountain Ranges, Marine Views, Yacht Races, Field Sports of all kinds—in fact, any view spreading over a large area—the "AL-VISTA" does what no other Camera ever did or can do.

THE AL-VISTA



8 3/4" x 10" AND SMALLER.

Sweeps the Field. Takes everything in sight, rotating in such a way as to take a series of separate views, covering an area of one hundred and eighty degrees. The most wonderful of all modern cameras. If you are looking for holiday presents, ask the nearest dealer to show you an AL-VISTA. It will satisfy all demands for an acceptable gift.



This diagram shows the wonderful field covered by the AL-VISTA. It is eminently fitted for broad landscapes, marine views, mountain ranges, yacht races and field sports. Uses regular stock film and is light and compact.

A large catalogue containing reproductions of marvellous pictures taken with the AL-VISTA and an insight of how made.

THE MULTISCOPE AND FILM COMPANY - - BURLINGTON, WIS.

PLEASE DESIGN CAMERA CRAFT

"THE TRAVELLING LENS DOES IT."

You touch the button, and in an instant it records everything within its sweep. IT CAN BE LOADED AND UNLOADED in broad daylight.

Uses the regular stock sizes of Film, which are procurable from any dealer in supplies.

Pictures of varying lengths can be made with one Camera and on the same roll of Film—something accomplished by no other Camera.

THE "AL-VISTA" PANORAMIC CAMERA



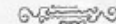
THIS ILLUSTRATION IS FROM A PICTURE TAKEN WITH A 4x12 "AL-VISTA" NO. 4 CAMERA AND IS 1/4" SIZE OF ORIGINAL. READ OF NO. 4 CAMERA FULL ON. TRANSPARENT IS 2 1/2 x 7 1/2 IN TOTAL. YET THE SPOT RECORDS 18 DEGREES.

The 4 B makes pictures 4x4, 4x6, 4x8, 4x10, or 4x12.

The 5 B makes pictures 5x4, 5x6, 5x8, 5x10, or 5x12.

The "AL-VISTA" PANORAMIC CAMERAS are all made for time and snapshot exposures.

Our large Catalogue shows reproduction of surprising results obtained with the "AL-VISTA" PANORAMIC CAMERA, mailed free on request.



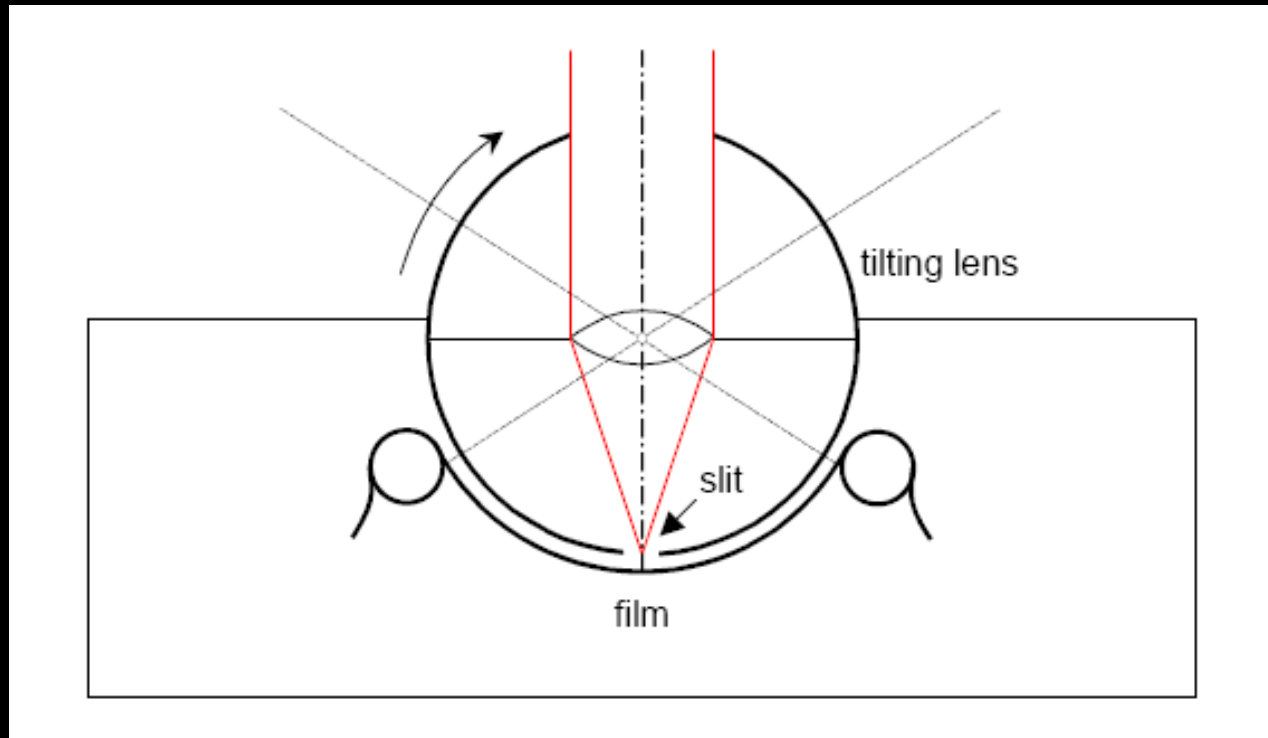
MULTISCOPE & FILM CO.

BURLINGTON, WIS., U.S.A.

23 JEFFERSON STREET.

Al-Vista, 1899 (\$20)

How they work



Swing lens (1843 – 1980s)

How they work (using Computer Vision)

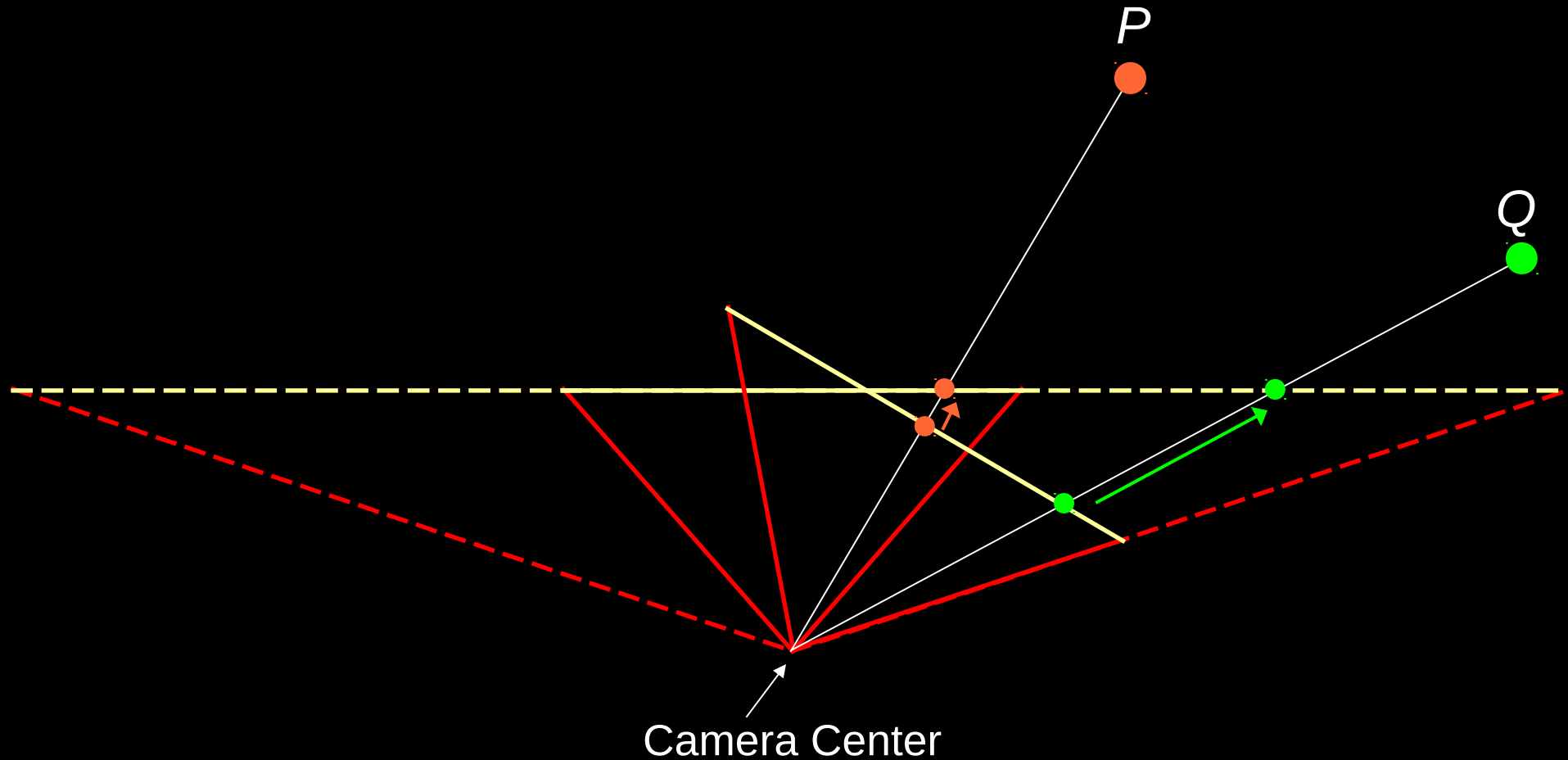


Goal: Combine pixels from multiple images to compute a bigger image.

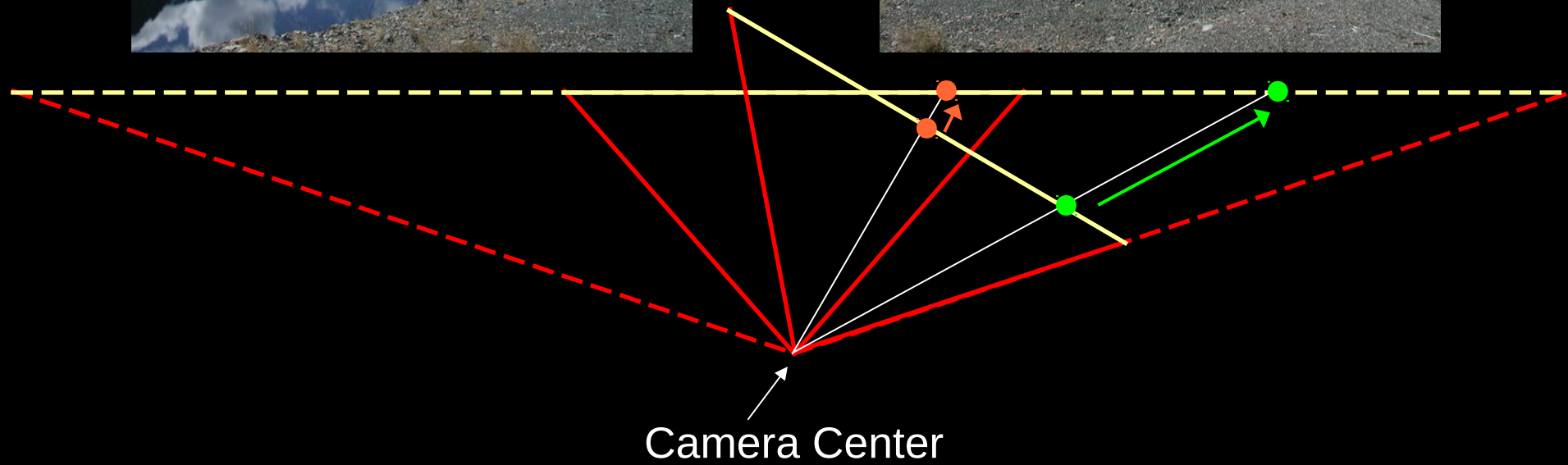
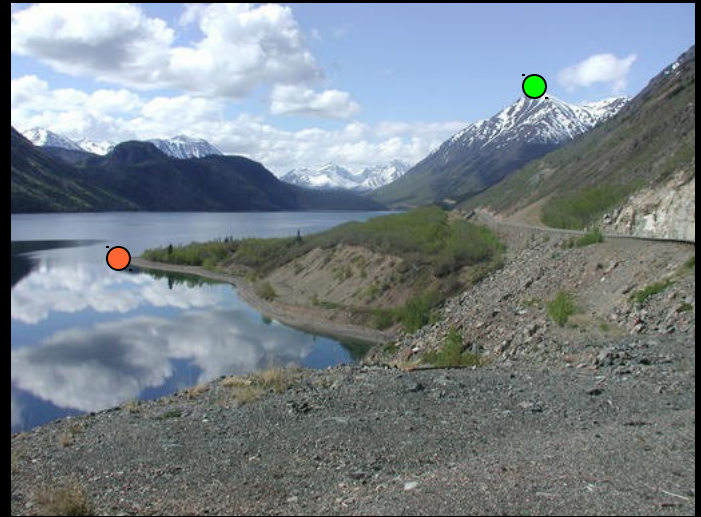
Today's Agenda

- 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



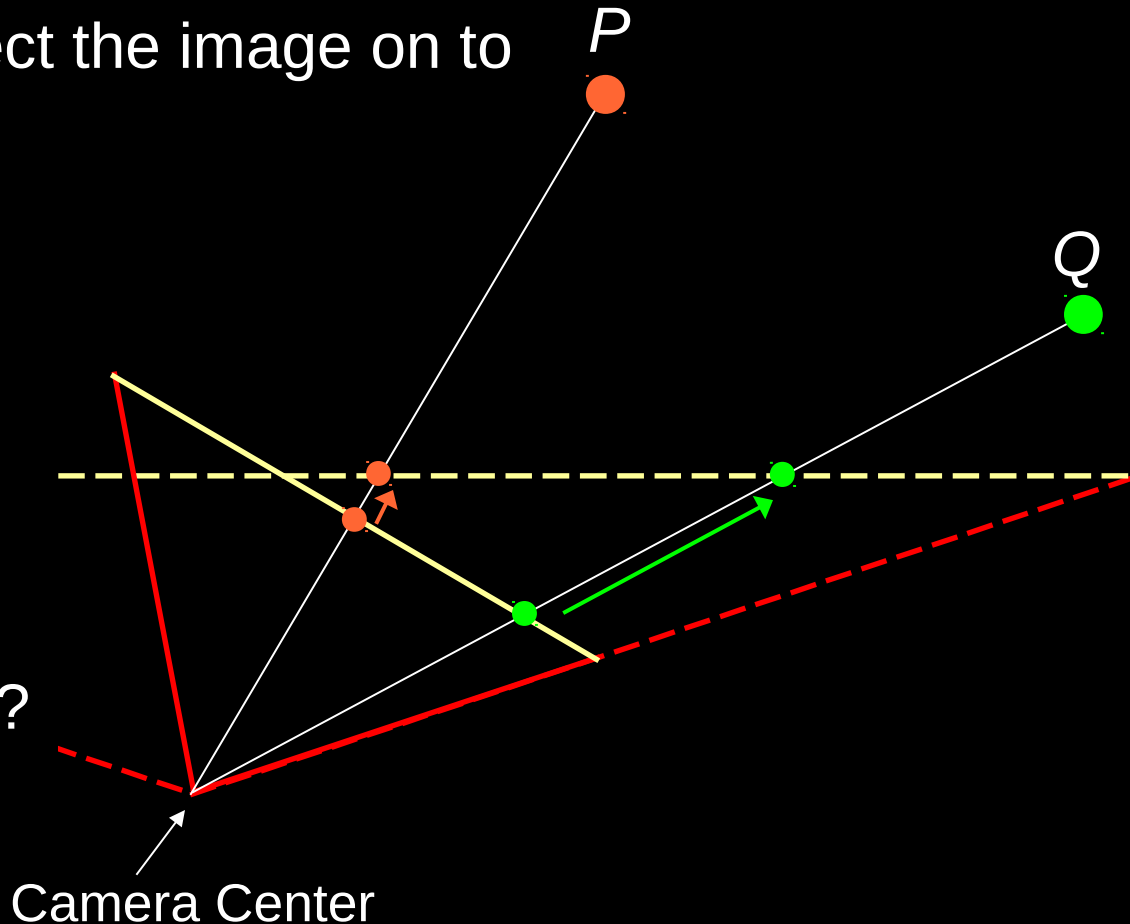
Example



Projection on to Common Image Plane

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

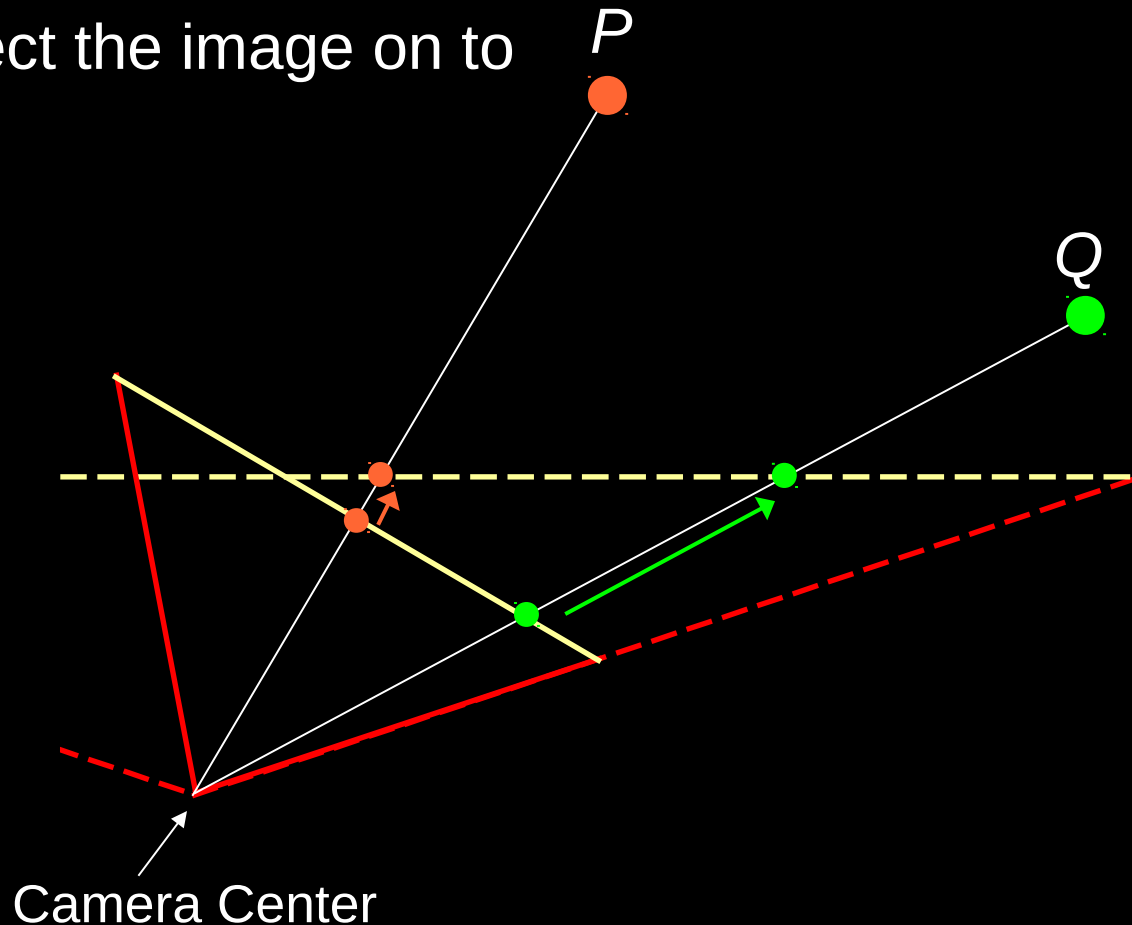
- Scaling ?
- Translation ?
- Rotation ?
- Affine transform ?
- Perspective projection ?



Projection on to Common Image Plane

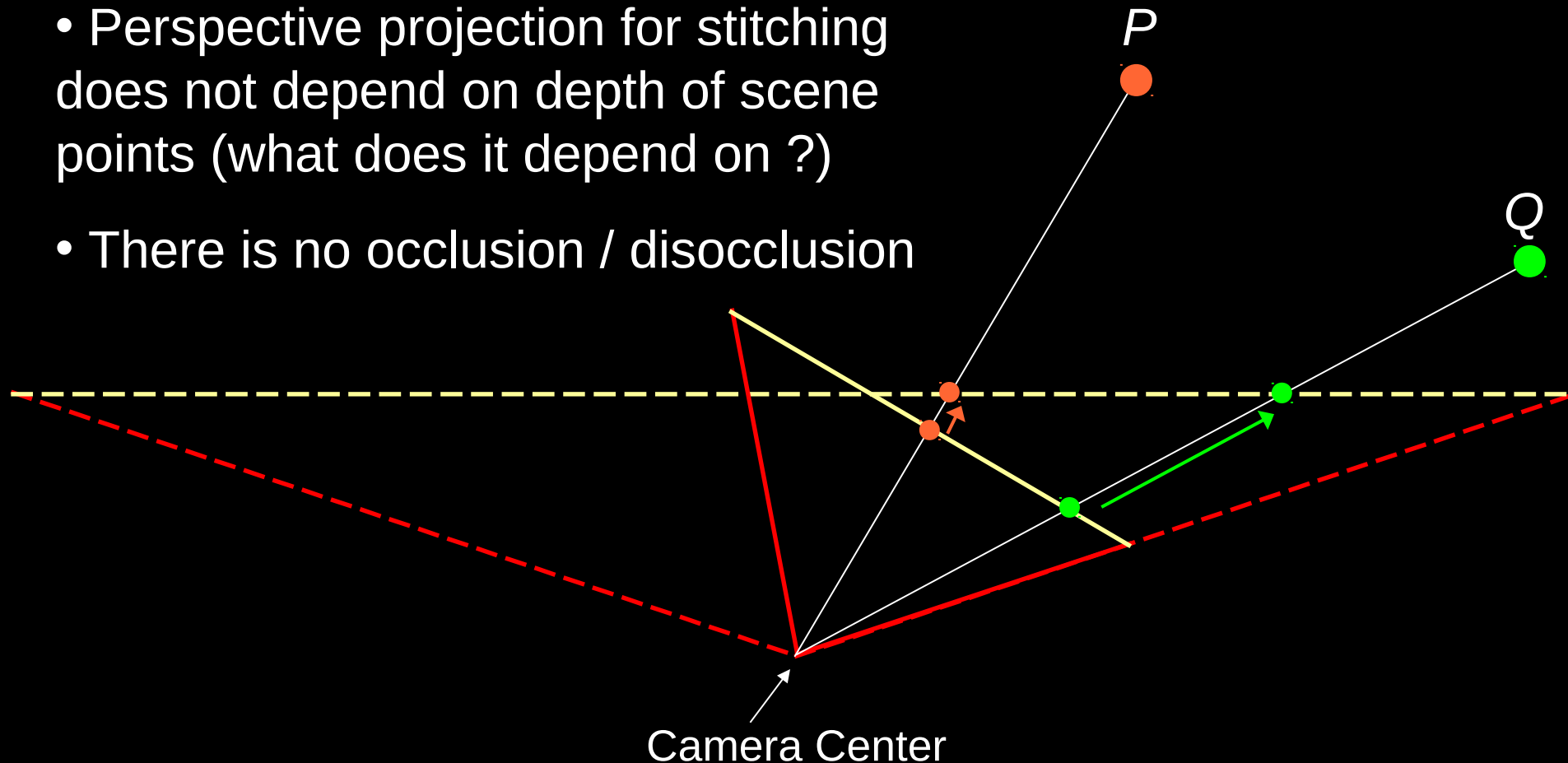
What is required to project the image on to the desired plane ?

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



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?

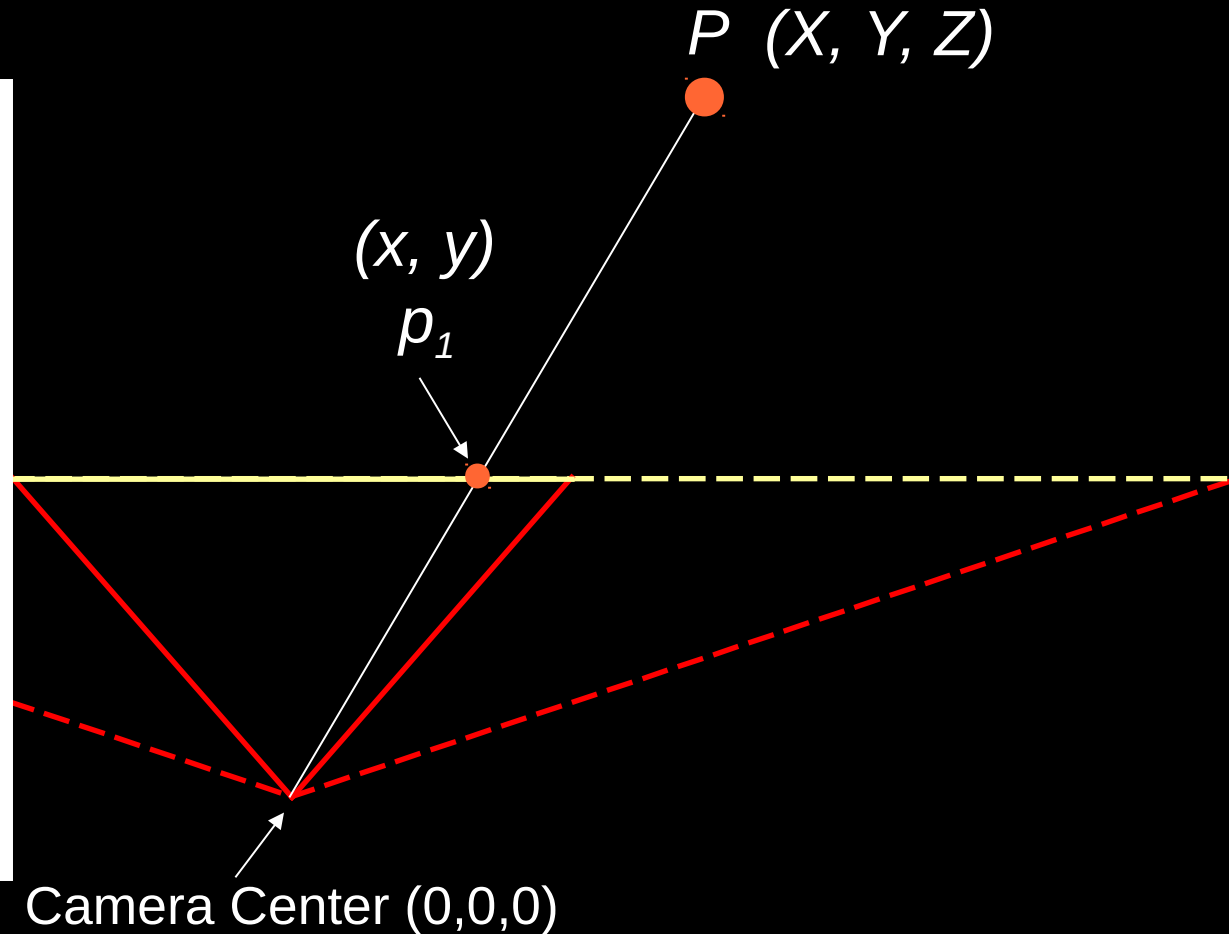
Perspective warps (Homographies)

$$p_1 \approx K P$$

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

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

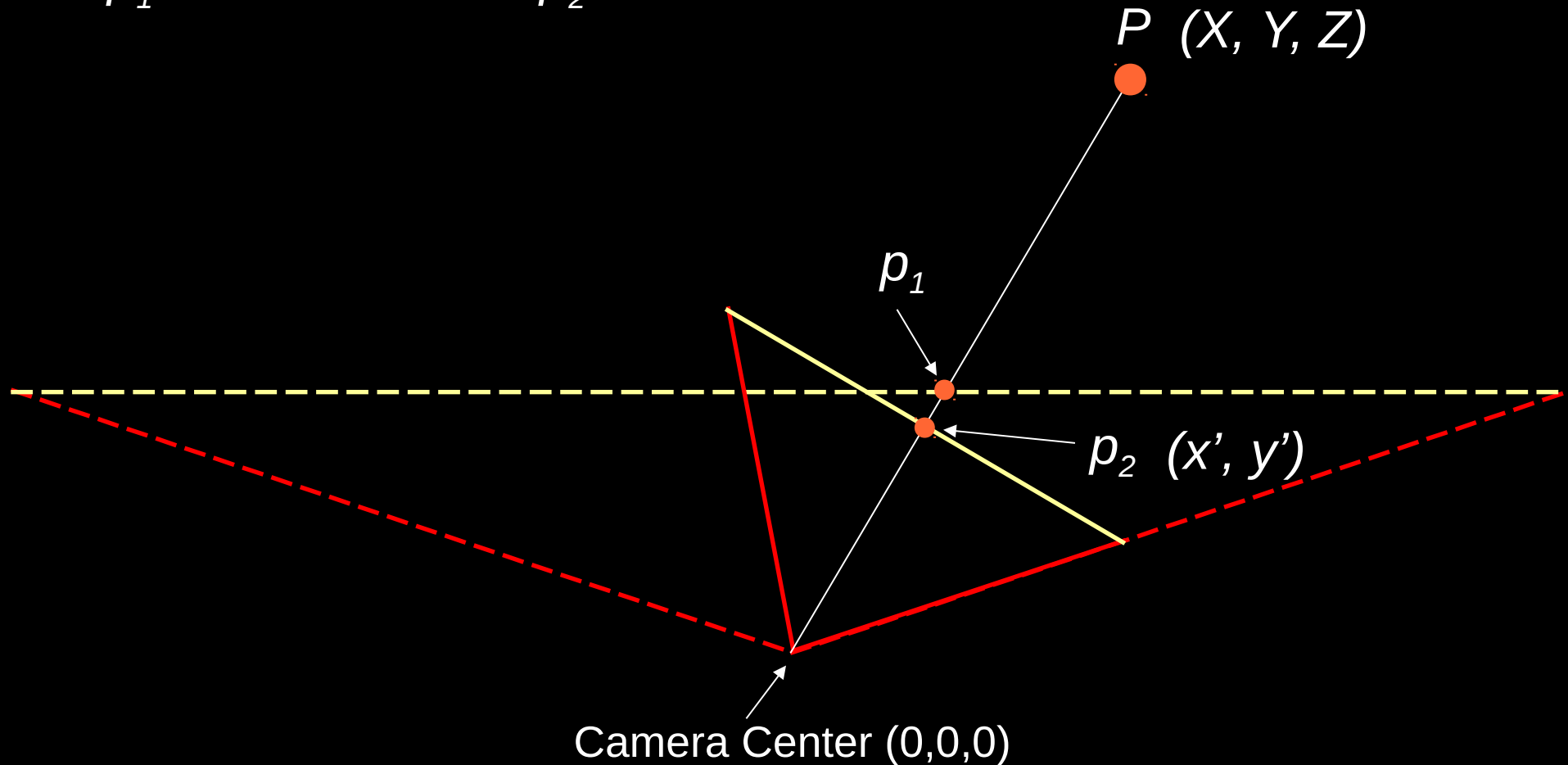
$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \approx \begin{bmatrix} f & 0 & o_x \\ 0 & f & o_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



Perspective warps (Homographies)

$$p_1 \approx K P$$

$$p_2 \approx K R P$$



Perspective warps (Homographies)

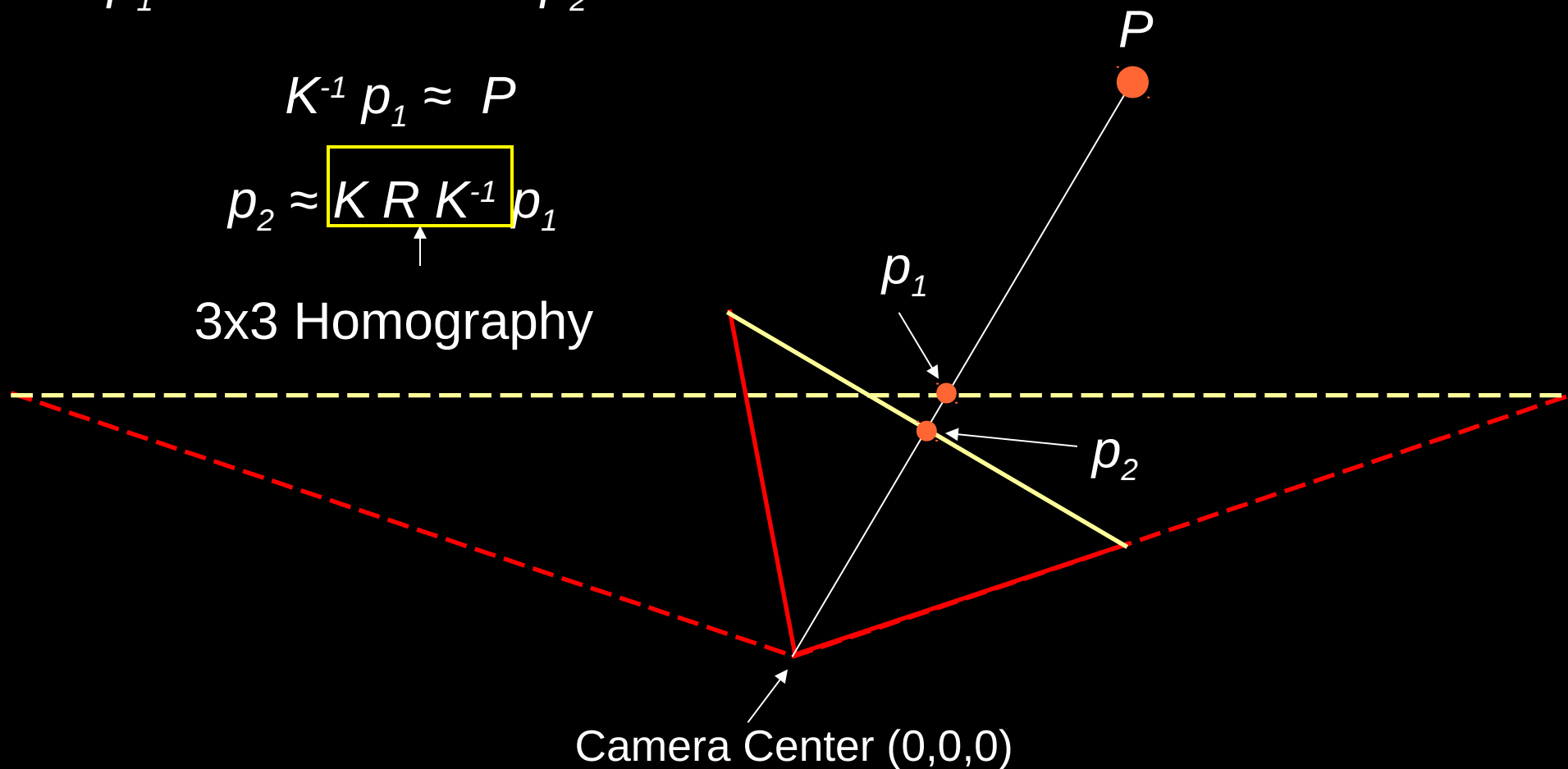
$$p_1 \approx K P$$

$$p_2 \approx K R P$$

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

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

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 ?

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

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!

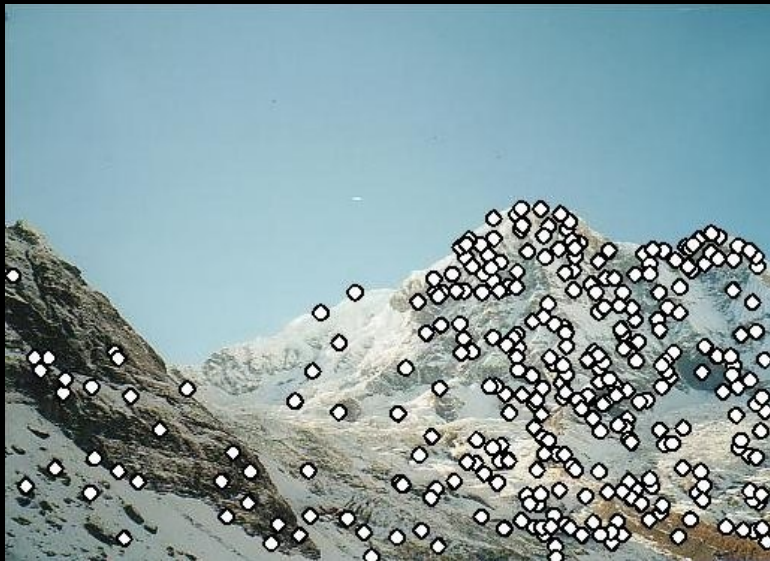
Sebastian's Counting Game

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

0	1	2	3	4	5	6	7	8	n
			✓	✓					

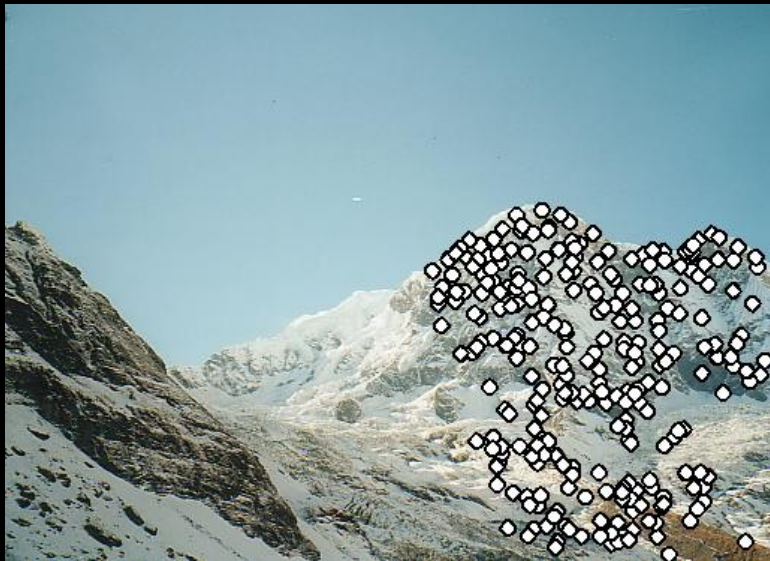
- Fixed intrinsics (square pixels): 3
- Varying intrinsics (eg. autofocus): 4

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 = $O(N * \text{RANSAC cost})$

Do we have to project on to a plane ?

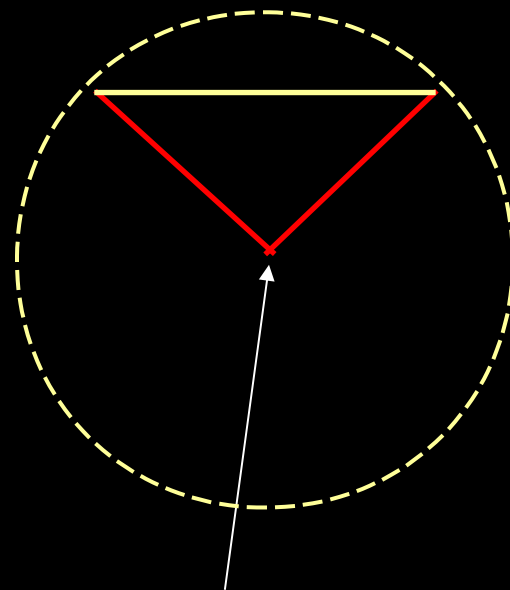


Camera Center

Cylindrical Projection



360° Panorama
[Szeliski & Shum 97]

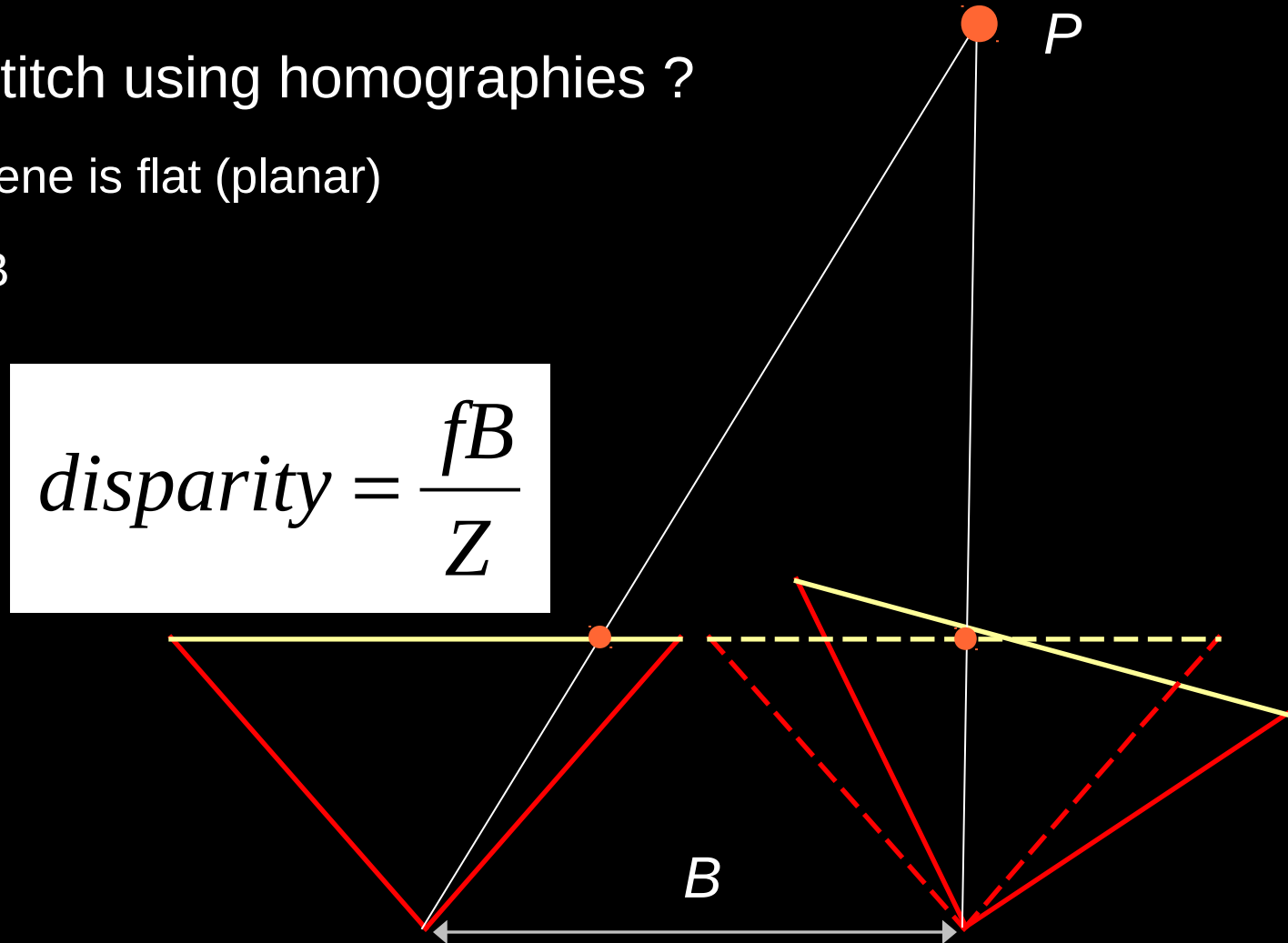


Camera Center

General Camera Motion

Can we still stitch using homographies ?

- When the scene is flat (planar)
- When $Z \gg B$



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- Single perspective panoramas
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- **Stitching software**
- Current research: computing photographs

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]

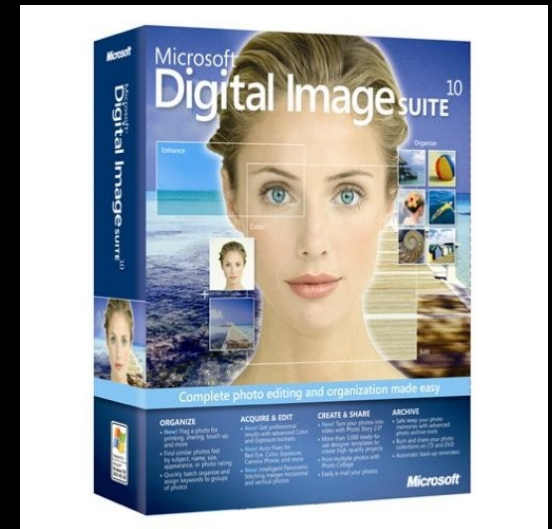
Autostitch

- 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

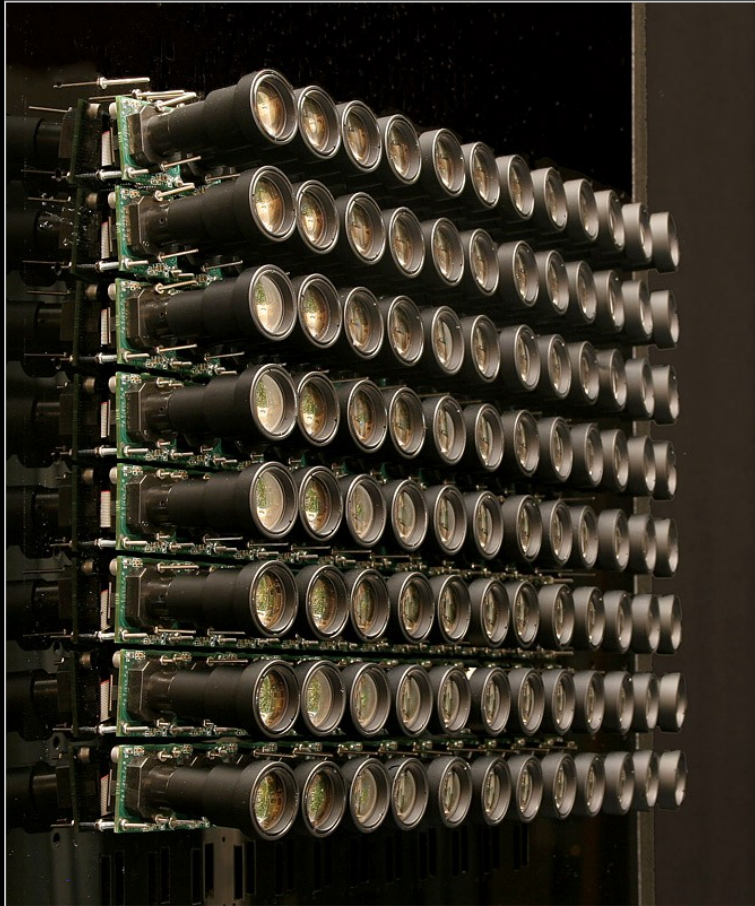
- Lens distortion and vignetting
- Off-centered camera motion
- Moving objects
- Single perspective may not be enough!

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

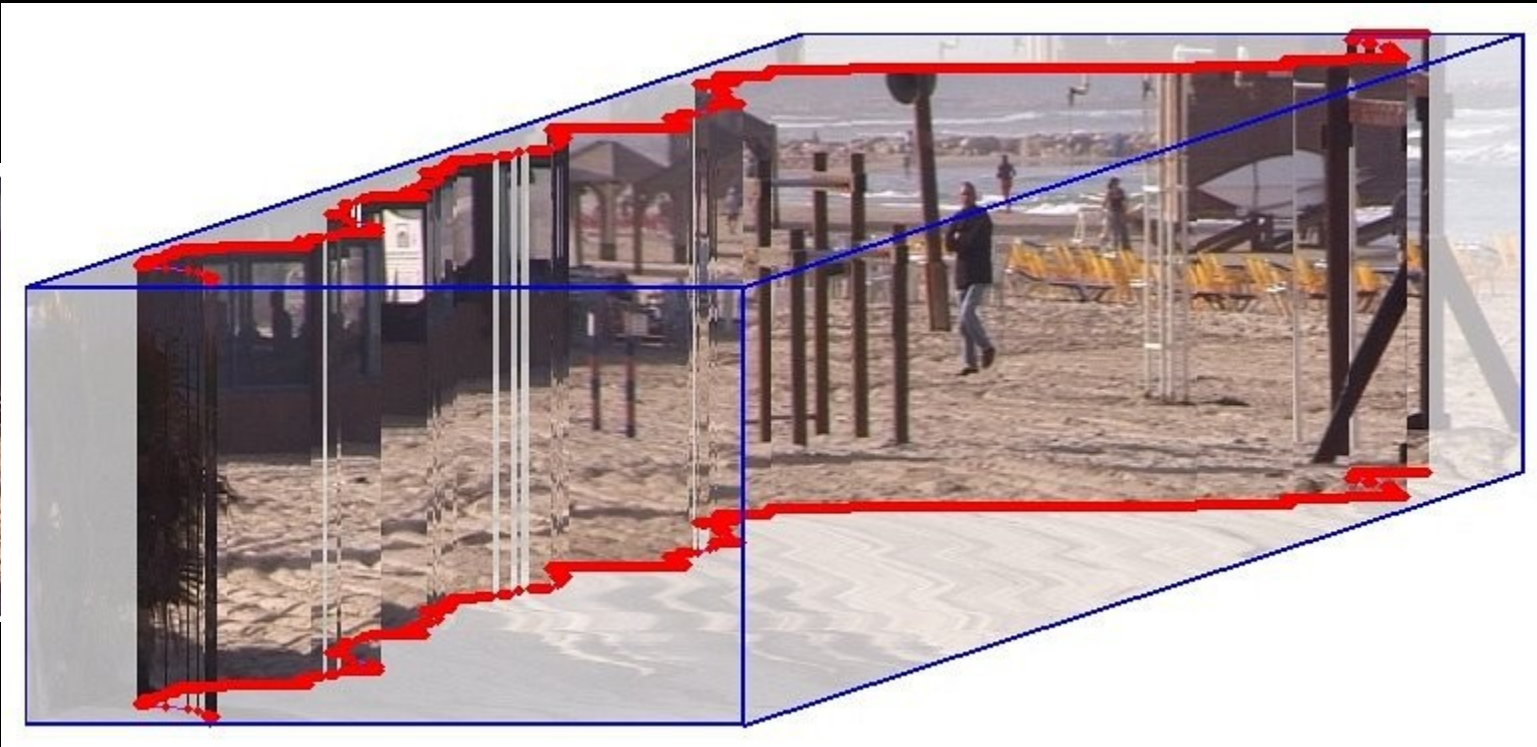


Input Video

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

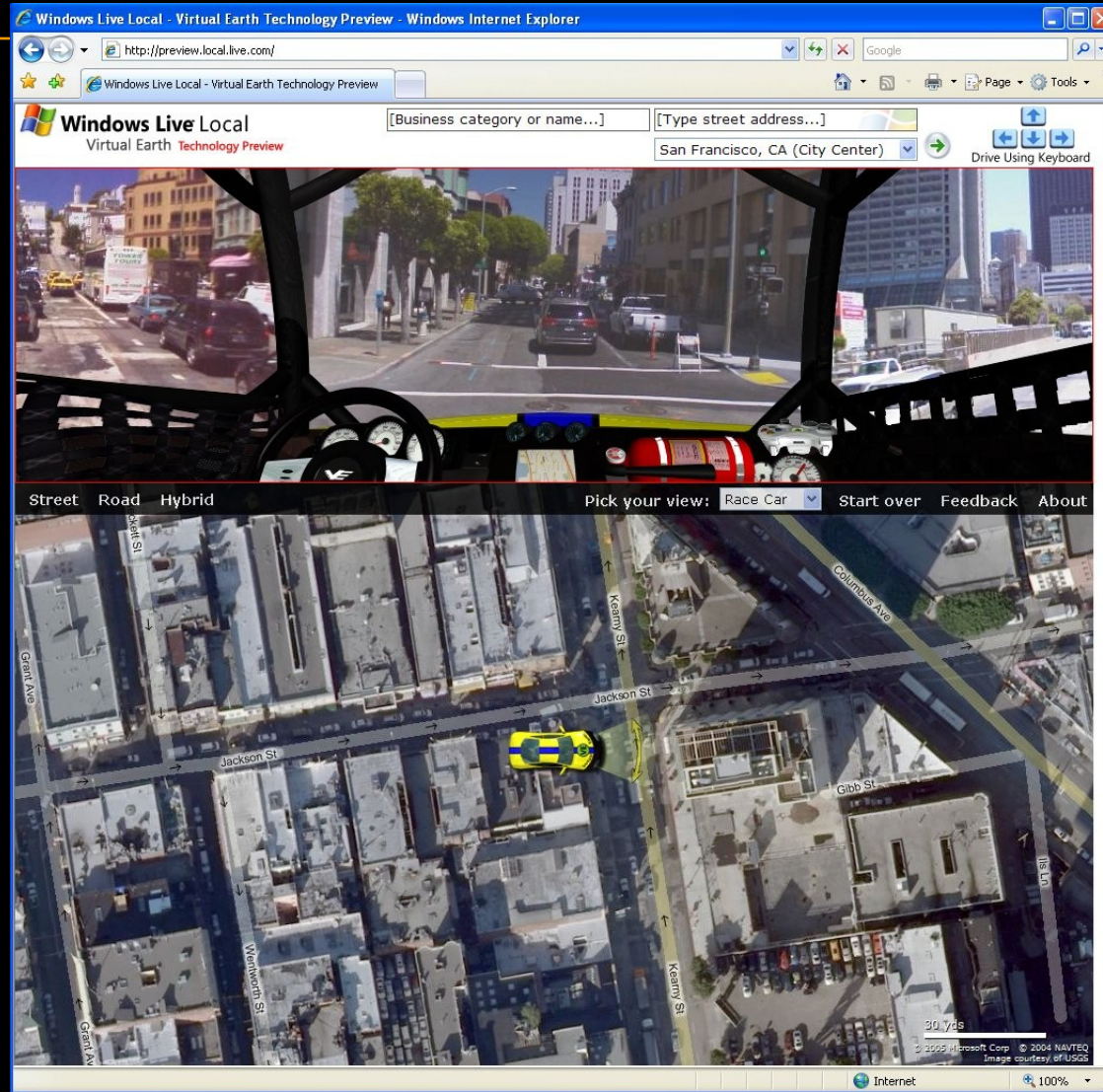
Multi-perspective Panoramas



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]