Photographing Long Scenes with Multi-Viewpoint Panoramas

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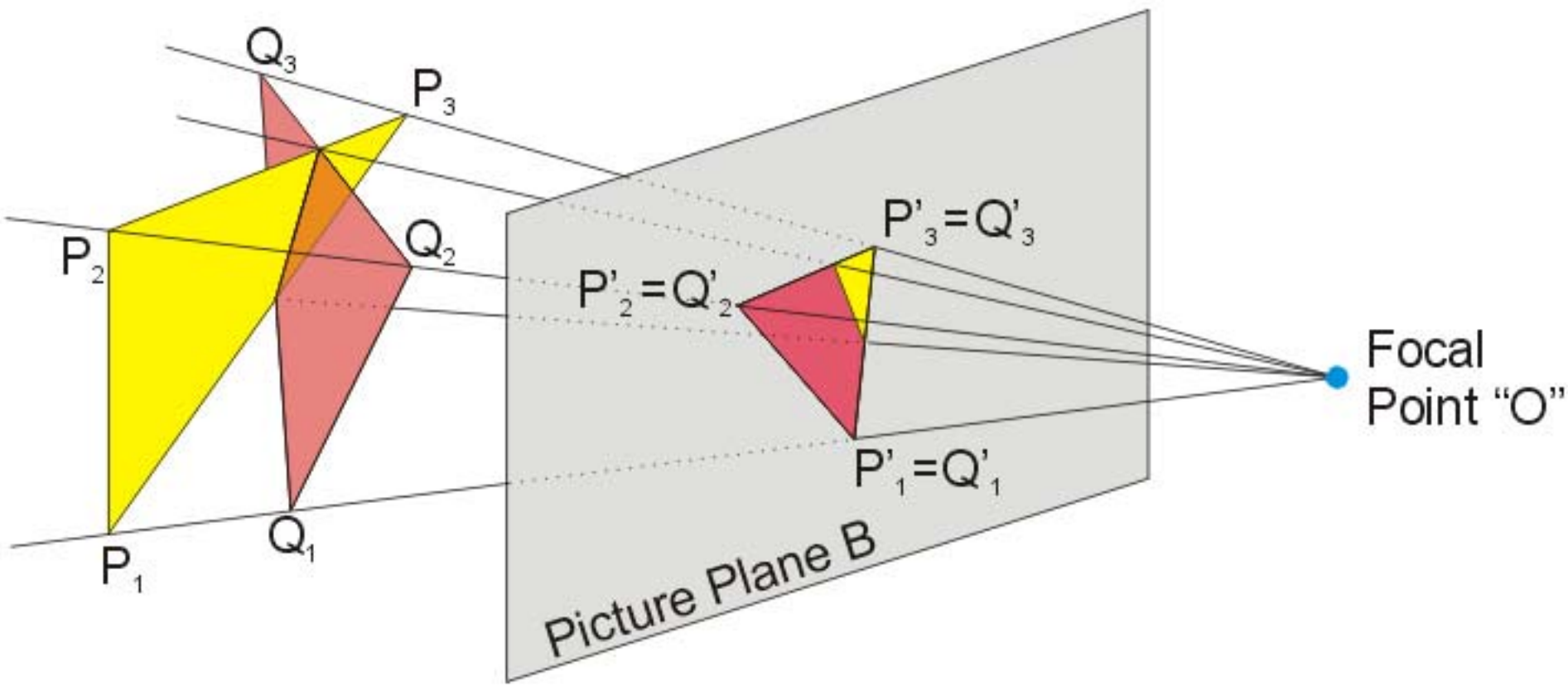
Keywords in the Title

- Multi-Viewpoint

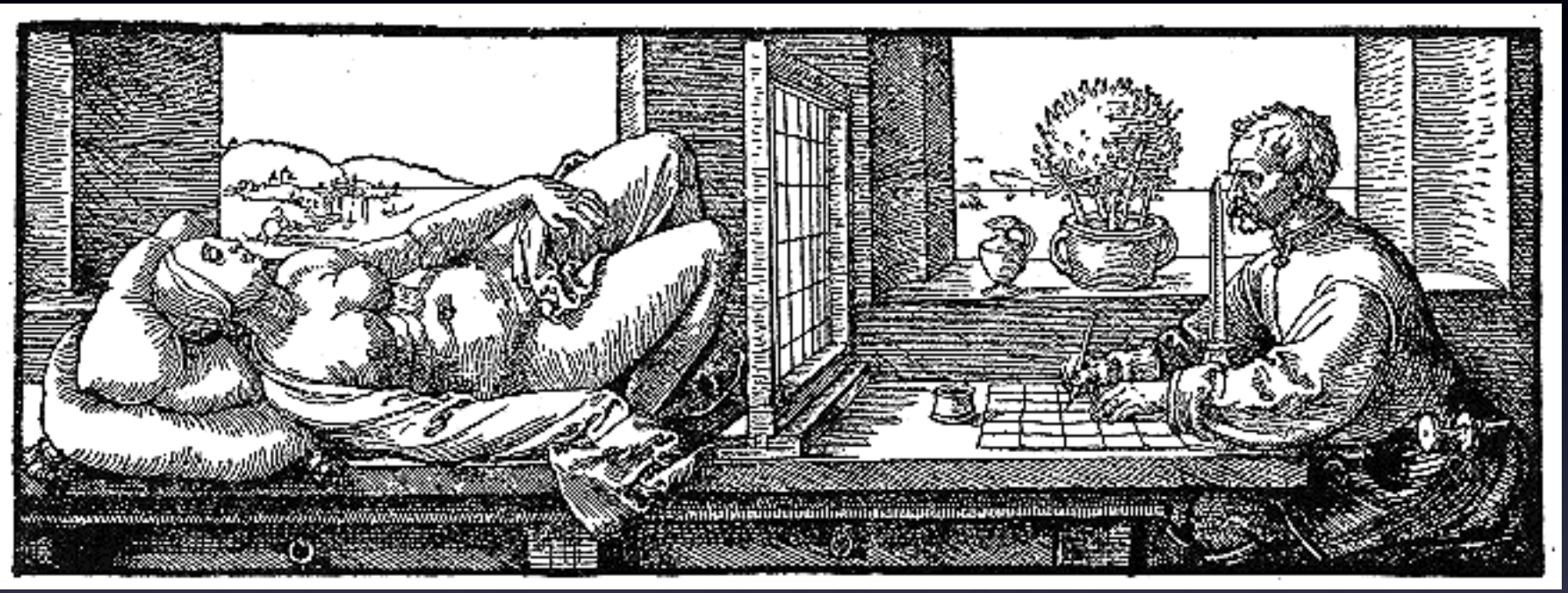
  Single-Viewpoint
- Panoramas
- Long Scenes

Single-Viewpoint

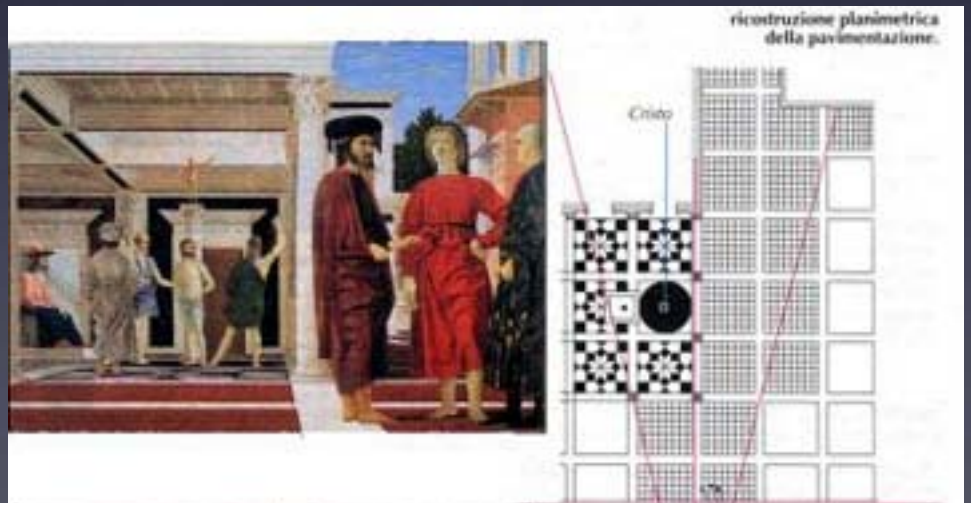


One "camera", one shot;
Unique perspective rule on one picture.

Single-Viewpoint



Ancient artists knew this.



Multi-Viewpoint

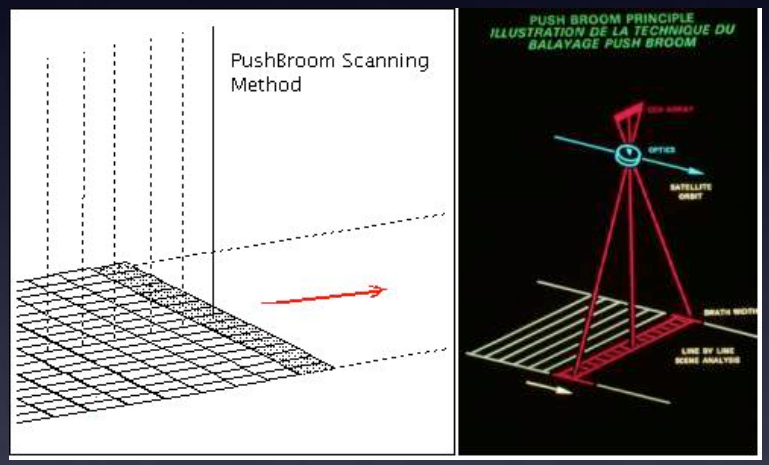
- Just many Single Viewpoint ...
- Inside one picture, different portion has different perspective rules.
- In this paper, many single-viewpoint photos rendered in one picture naturally.

Panoramas

- Strip Panoramas
- Single-Viewpoint Panoramas
- Multi-Viewpoint Panoramas

Panoramas

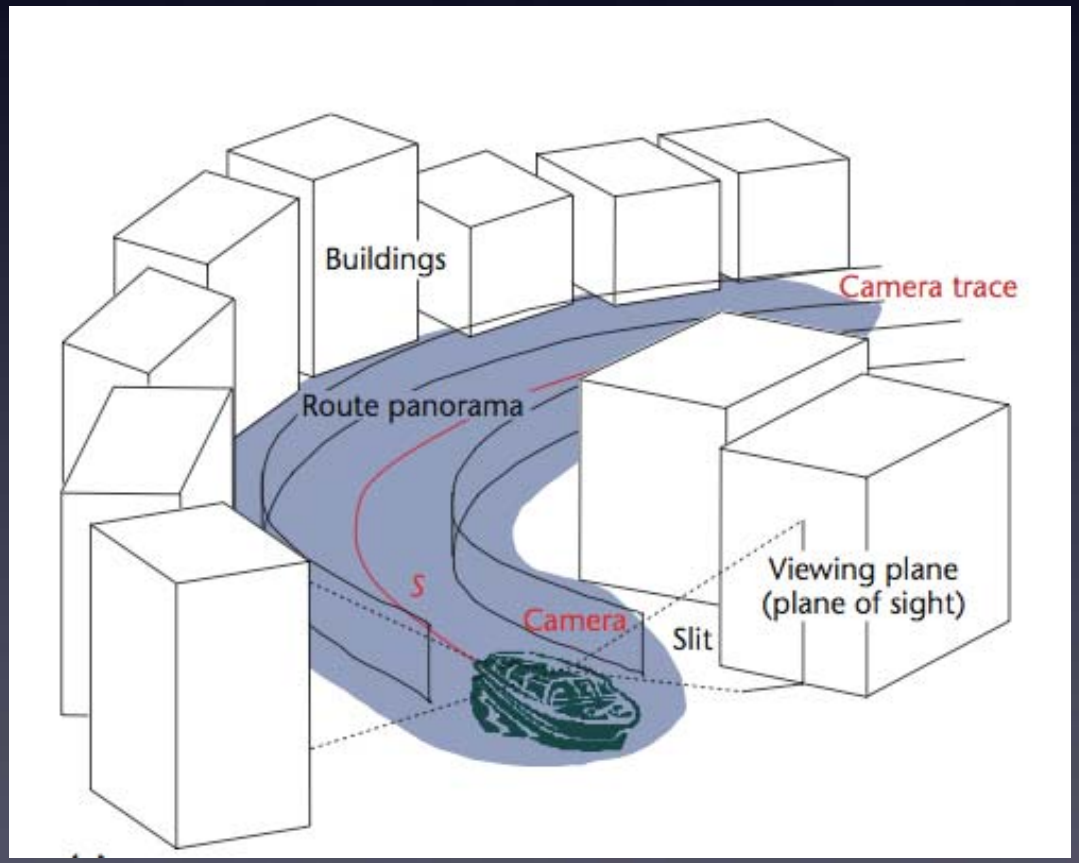
- Strip Panoramas
  - also known as “Slit Scan”.
  - pushbroom cameras/ 1D camera
  - satellite images.

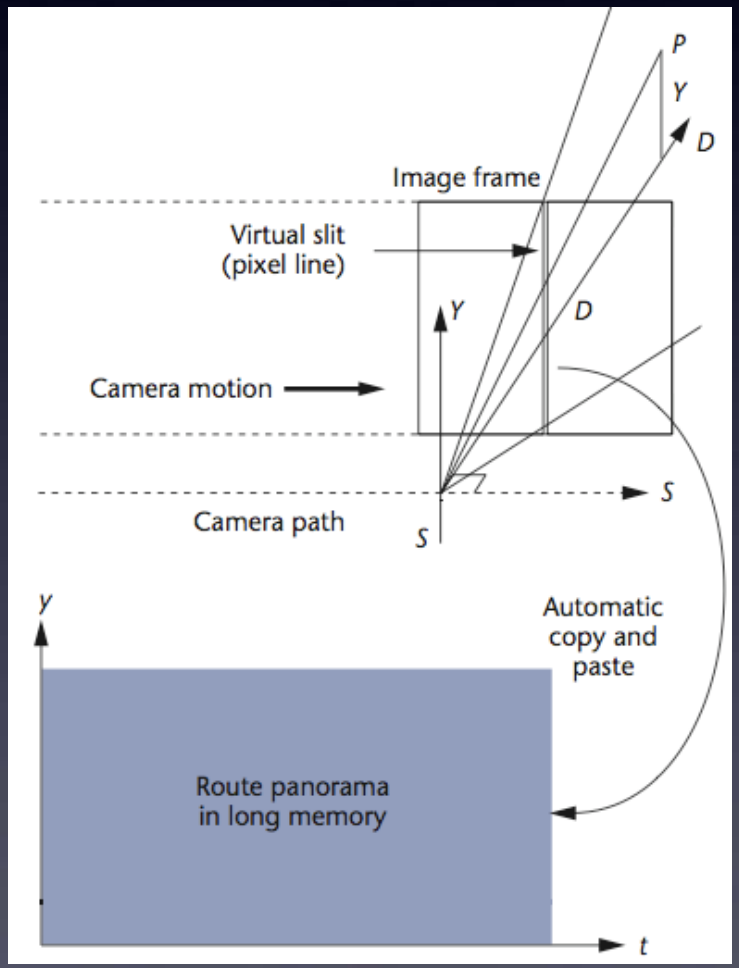


- also can obtained by sampling normal 2D image sequences [Zheng2003, Levin2005]. Vertical pixel strips from each image in the sequence.

Panoramas

- Strip Panoramas by sampling image sequences [Zheng 2003]





Panoramas

- Strip Panoramas by sampling image sequences

Orthographic projection along horizontal axis;
Perspective projection along vertical axis.

Main Problem
Different aspect ratio at different depth
->closer squashed; further stretched.

Panoramas

- Strip Panoramas by sampling image sequences

  Main Problem

  Different aspect ratio at different depth ->closer squashed; further stretched.

  many adaptive or interactive method to choose different width for pixel strip for objects at different depth. however, still open problem.

Panoramas

- Strip Panoramas by sampling image sequences

Main Problem

Different aspect ratio at different depth

->closer squashed; further stretched.

Panoramas

- Strip Panoramas by sampling image sequences

by different slit method [Roman 04, thesis 06]

Panoramas

- Strip Panoramas by sampling image sequences
  Other problems
  - Lose local perspective effects horizontally.
  - video cameras on cars: in general, lower resolution; shake, blurring; motion restricted as camera moving on a flat plane (ground).

Panoramas

- Single-Viewpoint Panoramas
  - most normal panoramas: wide angle cameras.
  - using images from pure rotating cameras [Szeliski 97]
  - using approximate rotating cameras [Lowe's autostitch]

Hard for long scene ...

Panoramas

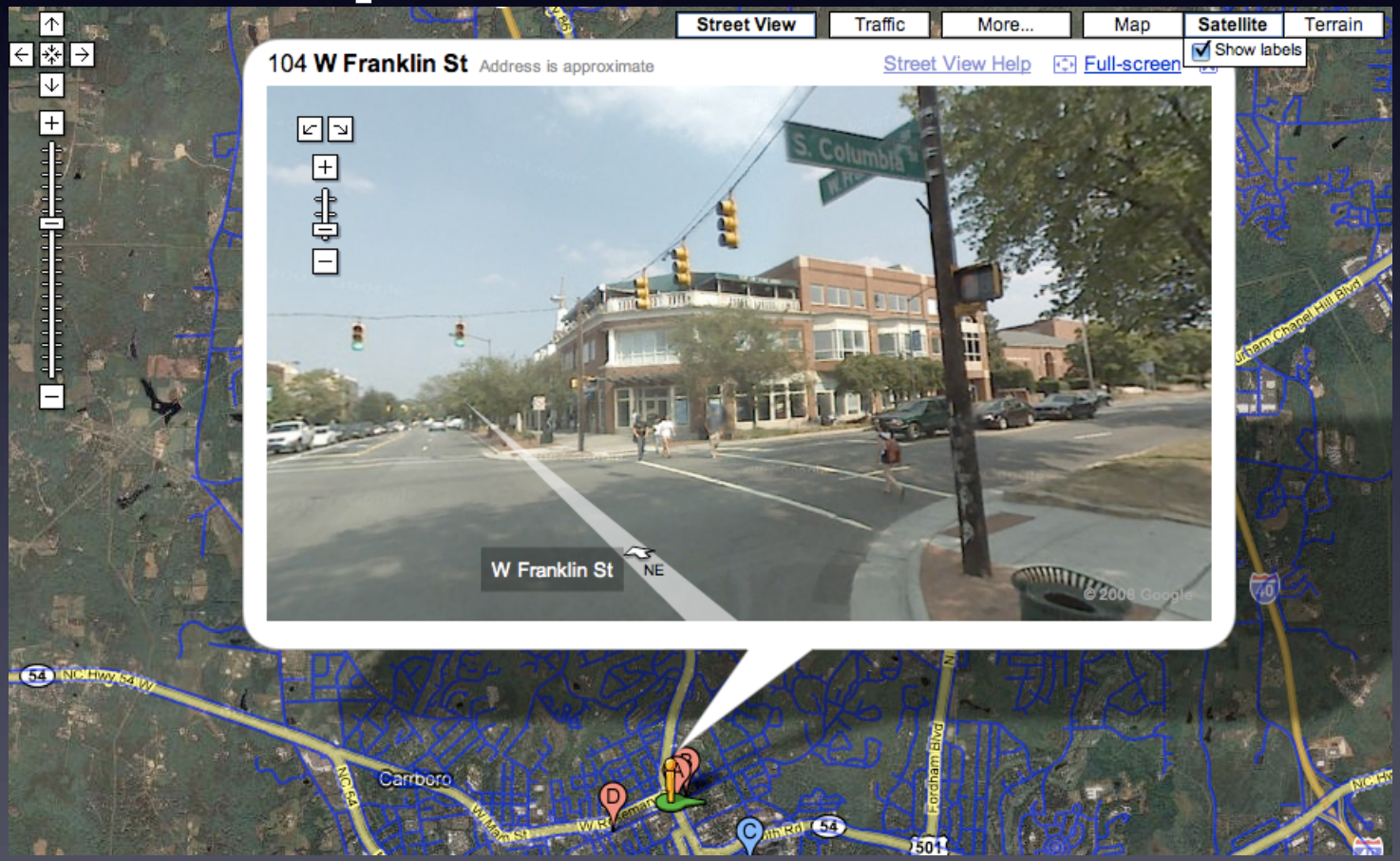
- Multi-Viewpoint Panoramas
  - by using multiple images
    - single cross-slits
    - multiple cross-slits
- This paper, totally different scheme.

Panoramas

- Multi-Viewpoint Panoramas
  Why?
  - A photograph with a wider field of view would cause distortion towards the edges of the image.
  - Far enough away from the scene we will lose the depth cues of the scene.
  - Such panoramas can be used to visually convey directions through a city,
  - or to visualize how proposed architecture would appear within the context of an existing street.

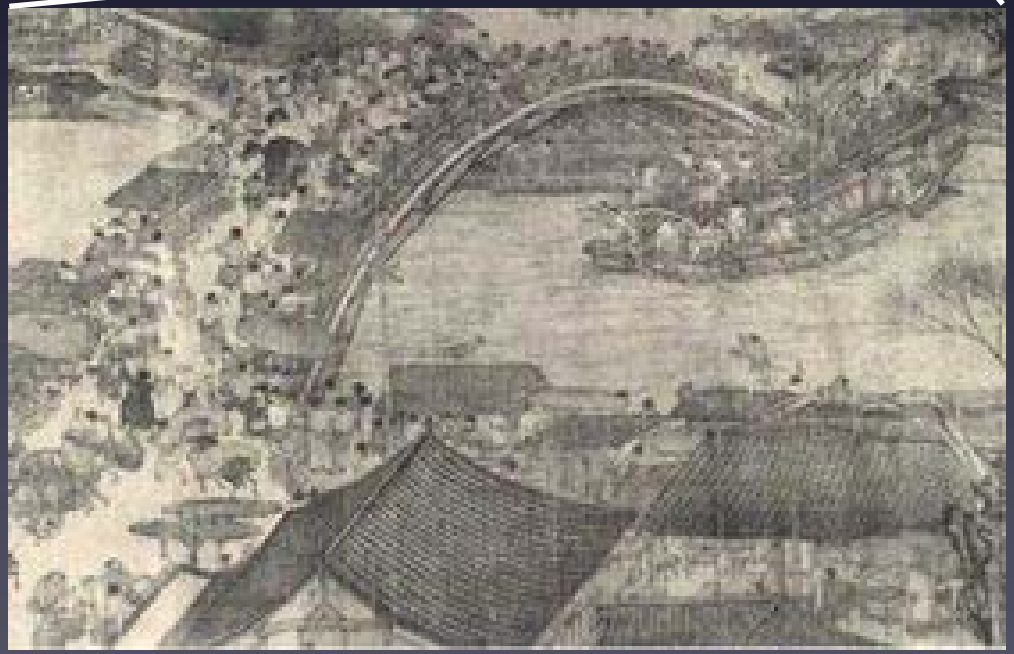
Long Scene Panorama Applications

- Street View - really long [Roman 04, thesis 06]...



Long Scene Panorama Applications

- Ancient Street View by royal artist Zhang Zeduan 800-900 years ago



Long Scene Panorama Applications

- Virtual Earth/Google Earth
  - really long in 2 directions

This work

- Multi-viewpoint panorama long roughly planar scenes (facades of the buildings along a city street).
- Significantly different from previous strip panoramas.
- After a small user interaction, the system will automatically compute a panorama with a MRF optimization.
- Users may exert additional control over the appearance of the result.

Quick Example

Quick Example

Quick Example

Quick Example

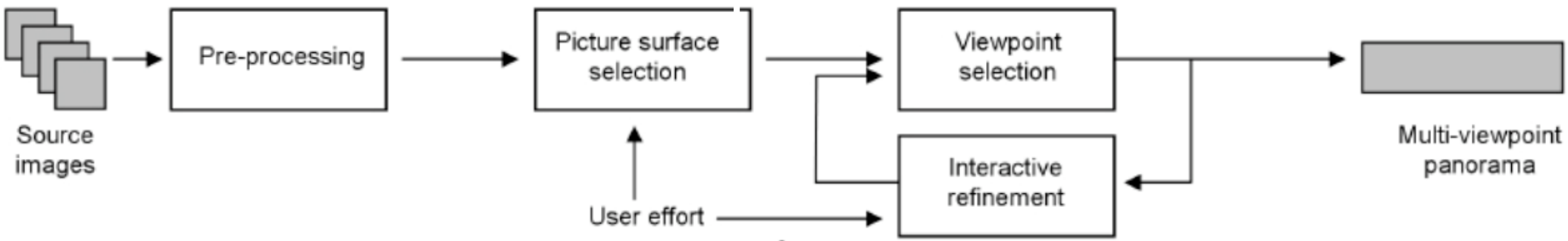
Previous Strip Panoramas

- Assumptions
  - Orthographic projection along the horizontal axis
  - Perspective projection along the vertical axis
- Shortcomings
  - Only objects at a certain depth from the camera plane can be shown with a correct aspect ratio.
  - Further objects appear horizontally stretched.
  - Closer objects appear squashed.

What is a Good Multi-Viewpoint Panorama

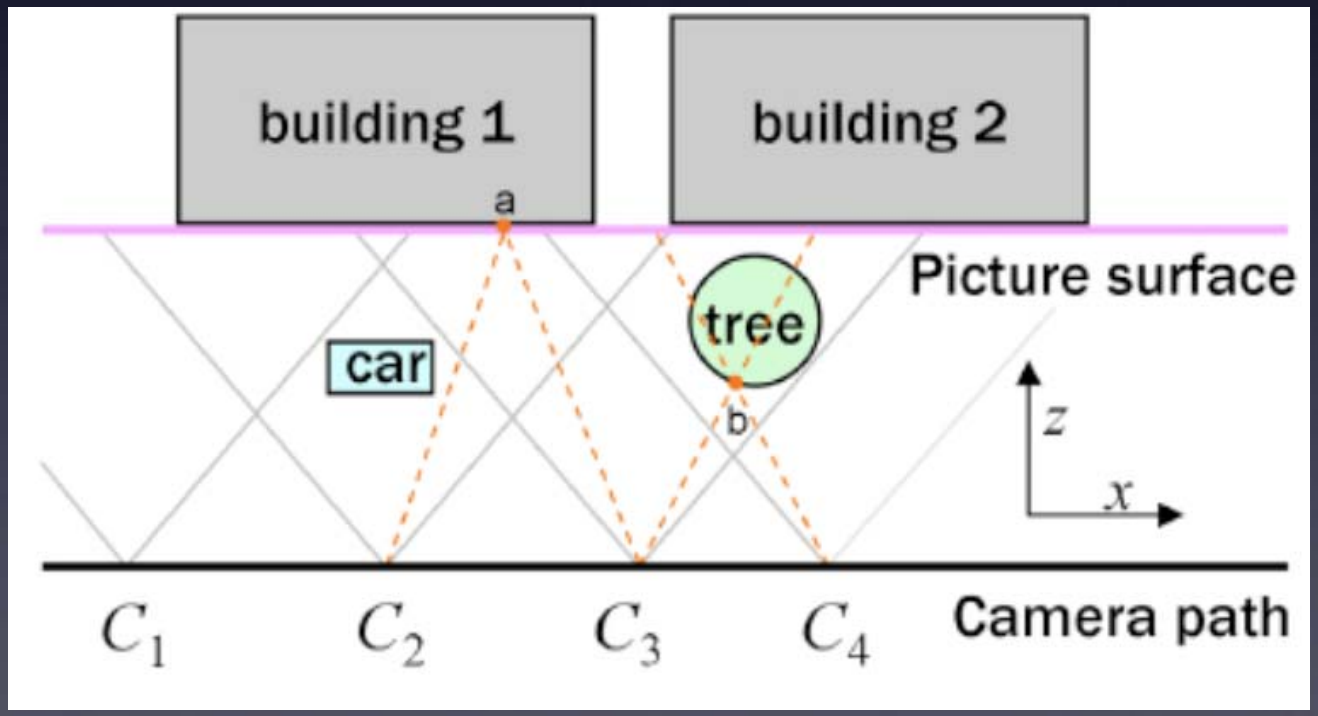
- Each object in the scene is rendered from a viewpoint roughly in front of it.
- The panoramas are composed of large regions of linear perspective.
- Local perspective effects are evident.
- The seams between these perspective regions do not draw attention.

System Overview



A Key Observation

- Images projected onto the picture surface from their original 3D viewpoints will agree in areas depicting scene geometry lying on the dominant plane.



Data Capture

- Handheld camera
  - walk along street and take picture every meter.
  - manually control exposure.
- Fisheye lens for some scenes.
  - Cover more scene content in one picture to avoid frequent “viewpoint transition”.

Preprocessing

- Image Correction
  - For photos from fisheye lens, use PtLens to remove the radial distortion. Then treat them as normal images.

Preprocessing

- Recovering of the projection matrices of each camera using the structure-from-motion system
  - The one in *Photo Tourism*, which is now open source.
  - Pair-wise matching on SIFT features enforces strong constraints for optimization.

Camera 3D position

$$C_i = -R_i^T t_i$$

Preprocessing

- SfM result
  - Each image's projection matrix and 3D point cloud for the scene strucure.

Picture not from
this project!!

Preprocessing

- Compensation of exposure variation
  - Brightness scale factor k_i for each image I_i
  - For pixels that depict the same geometry, asserting that
    $k_i * I_i = k_j * I_j$ for I_i , I_j
  - Each SIFT point match gives us three linear constraints of these form.

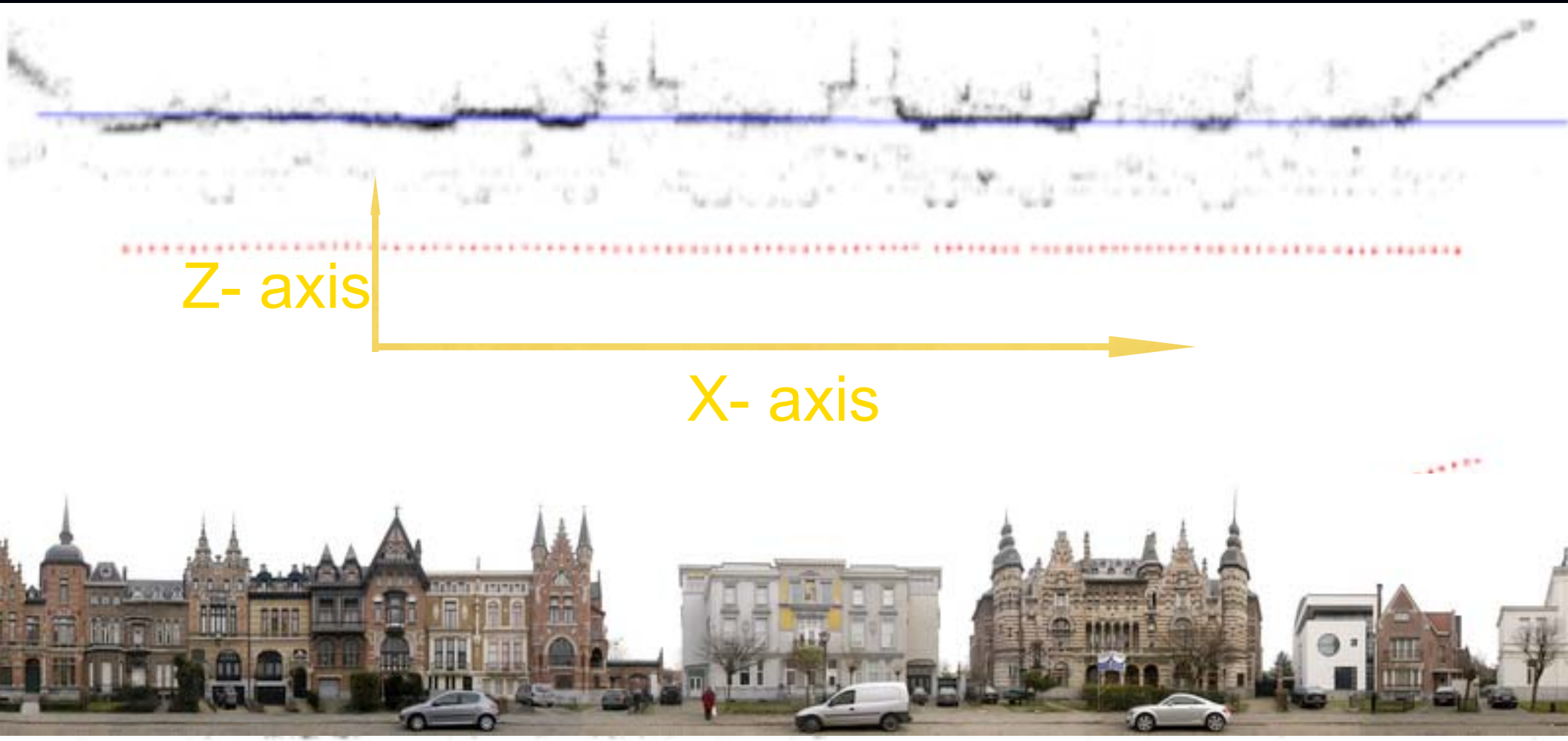
Picture Surface Selection

- Picture surface?
  A virtual 3D surface upon which the panorama will be formed.
  - It should be roughly aligned to the dominant plane of the scene.

  why? Good property 1.

Picture Surface Selection

Blue curves



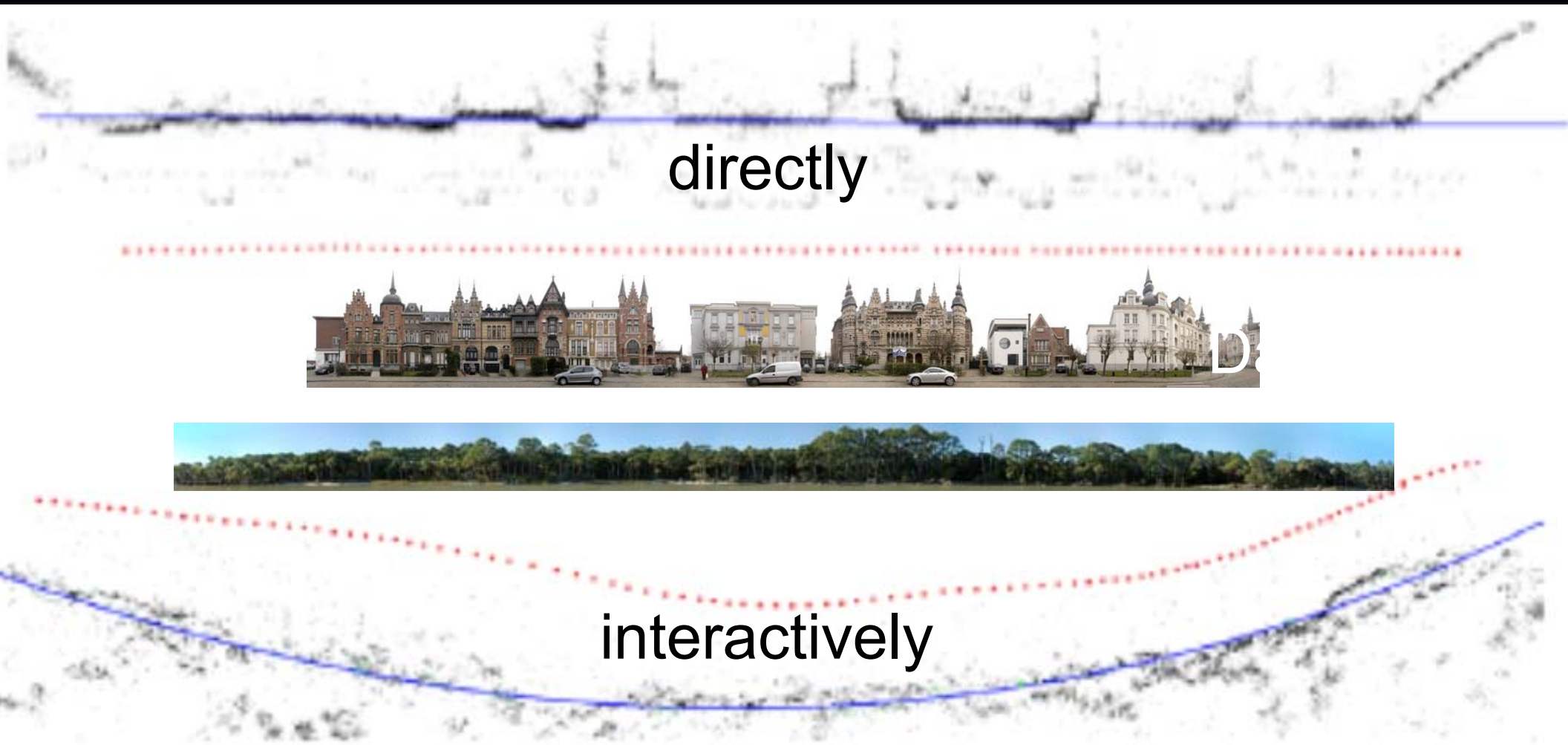
Picture Surface Selection

- Two steps: 1 Find world coordinate.
  2 Draw curve in xz plane.
- The system offers an automatic and an interactive approaches for choosing the coordinate system:
  - automatic approach -- PCA; largest variation is x-axis, least is y-axis. Because it's facade scene.
  - interactive approach -- The cross product from **two selected vectors** along the y and x-axis forms the z-axis; the cross product of z and y forms the new x-axis.

Picture Surface Selection

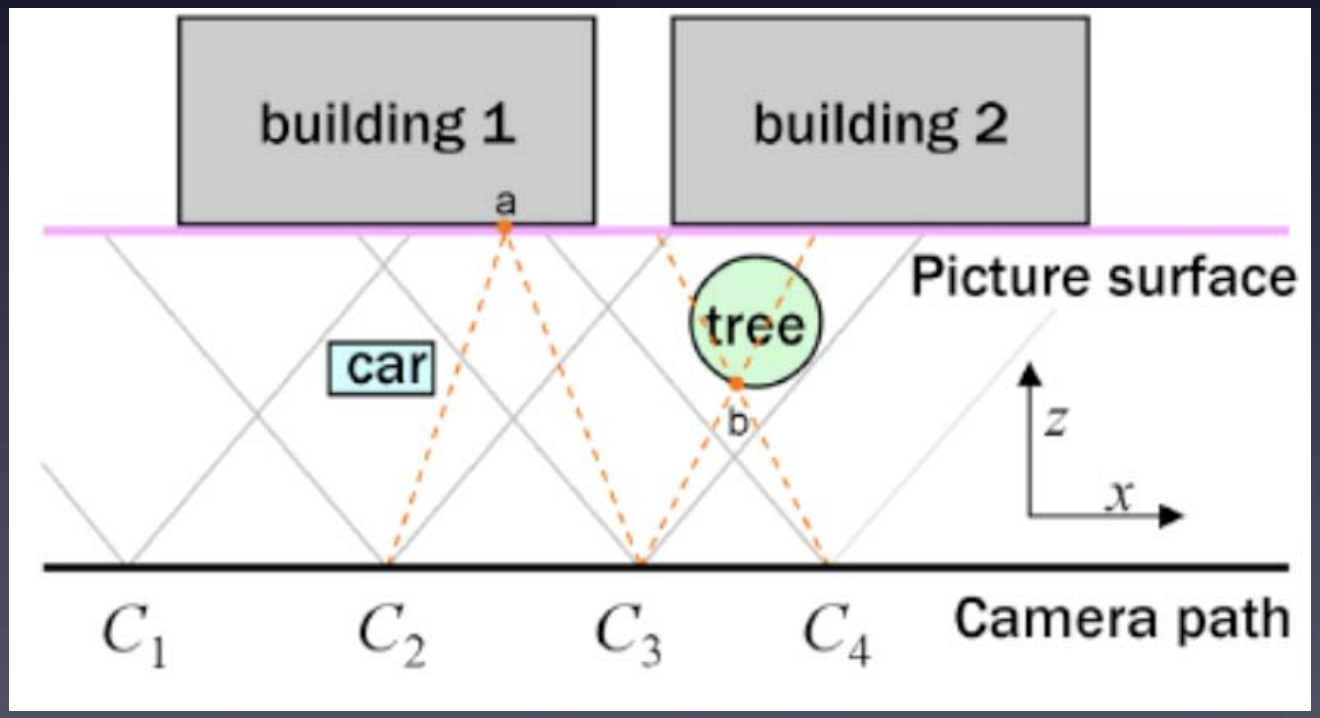
- The user is asked to draw a polyline into the plan view (xz slice).
- The system sweeps the polyline up and down the y−axis.
  - Directly draw manually
  - Interactively draw -- select clusters of scene points; remove outliers; fit a third-degree polynomial z (x) as a function of their x−coordinates; swept up this surface and down the y-axis.

Red: recovered camera trajectory.
Blue: user drawn polyline



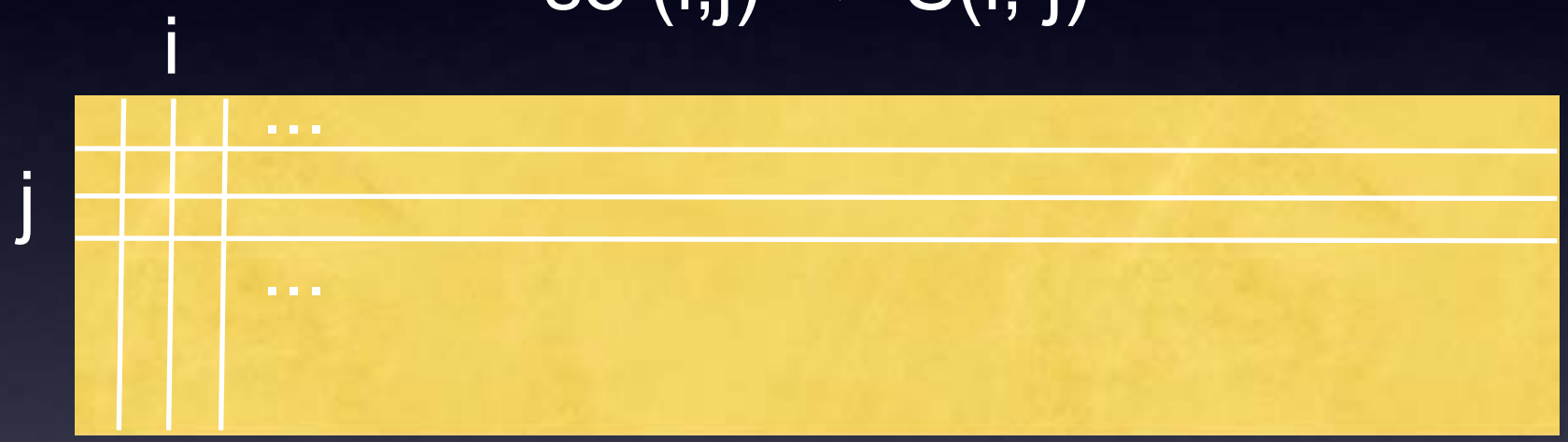
Sampling the Picture Surface

- The system samples the picture surface to form a regular 2D grid. This 2D grid will map to make the final panorama image space.
- S (i , j) refers the 3D location of the (i,j) sample.



Sampling the Picture Surface

it's a 3D surface.
so (i,j) --> S(i, j)



This surface will form the final panorama after projected to 2D

Sampling the Picture Surface

- Project all S(i, j) with each image's projection matrix.
- Each sample S (i , j) forms one pixel, if its projection is located inside that image.
  - so there will be black holes and edges highly distorted. (white board)

Sampling the Picture Surface

One Source Image

Its Sampled Image
(after a circular crop)

Sampling the Picture Surface

- They also call this process as projecting source images onto picture surface.

Average Image

- Project all source images to picture surface by “sampling picture surface”.
- Produce an average image with all these projected images.

...

average

Average Image

- After all source images get projected to 3D surface and sampled.

Street not straight, due to Sfm drifting

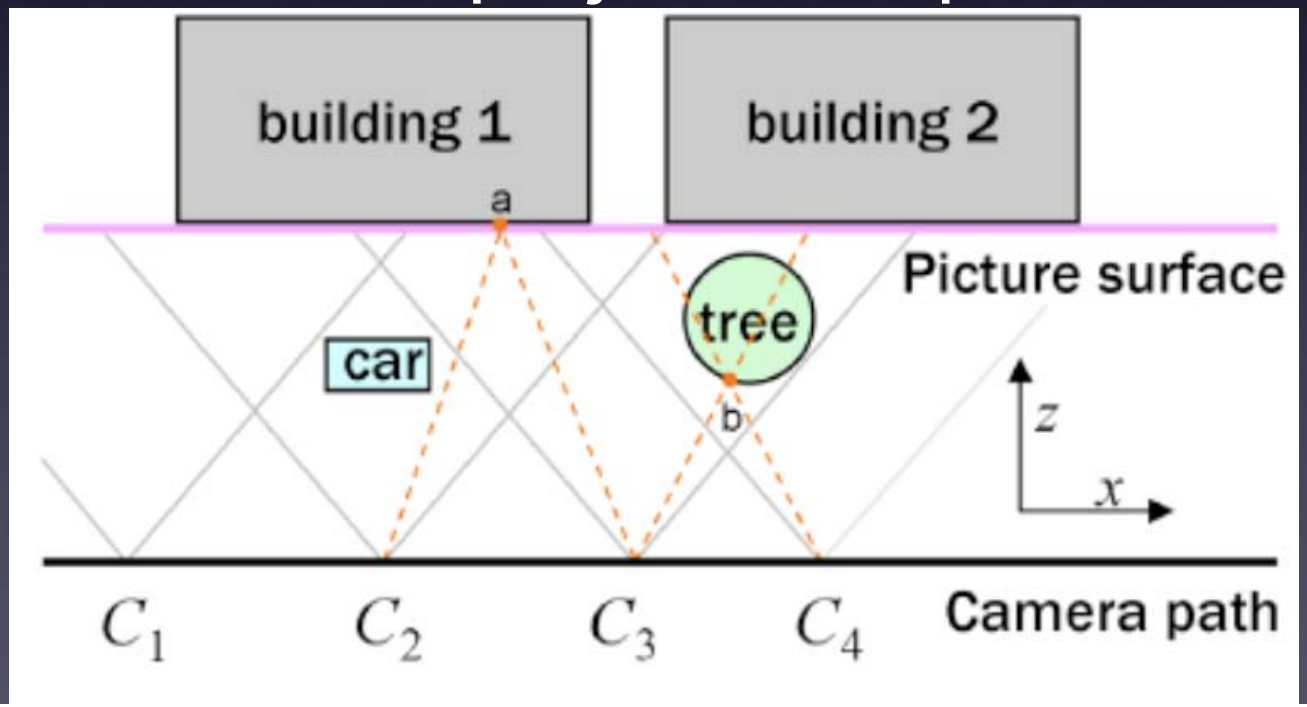
Average

Average with un-warping and cropping

Corrected by un-warping

Average Image

Recall: image areas on dominant plane will be consistent after reprojected to picture surface.



Viewpoint Selection

- We have now a series of n images I*i* of equivalent dimension.
- Image I*i* represents the *i*'th viewpoint.
- It's necessary to choose one source image I*i* for each pixel p = (px , py)

Again,
pixel labelling problem

Objective Function

- The MRF optimization computes a labeling L(p), where L(p) = i if pixel p of the panorama is assigned color I*i* (p).
- The objective function for choosing the viewpoint has three terms.

First Term

- The first term reflects the property that an object in the scene should be imaged from a viewpoint roughly in front of it.
- Assuming the cameras have roughly the same distance from the picture surface.
- It's possible to find pixel pi whose corresponding 3D Sample S (pi) is closest to camera position Ci .
- So, if pixel p chooses its color from Ii, formulate this heuristic as:

$$D(p, L(p)) = |p - p_{L(p)}|$$

Second Term

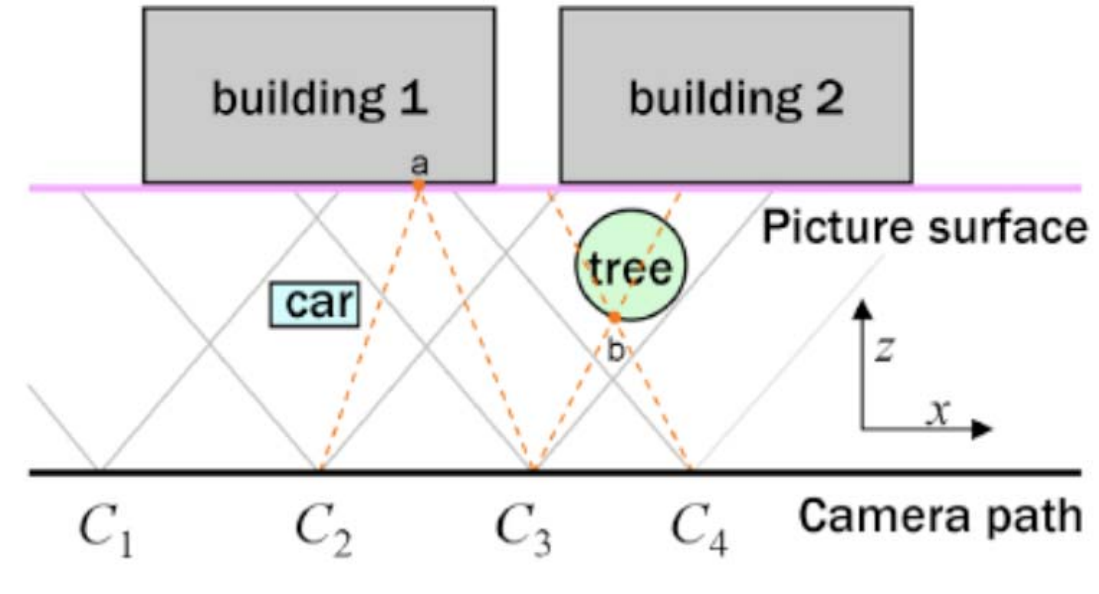
- The second term encourages transitions between different regions of linear perspective to be natural and seamless.

$$V(p, L(p), q, L(q)) = |I_{L(p)}(p) - I_{L(q)}(p)|^2 + |I_{L(p)}(q) - I_{L(q)}(q)|^2$$

For all neighboring pixels.

Third Term

- The third term encourages the panorama to resemble the average image in areas where the scene geometry intersects the picture surface.
  - Recall: the key observation



Also, it's used for many other variance, like motion blur, occlusion

Third Term

- A vector median filter is used to compute across the three color channels for a robust mean value.
- The median absolute deviation (MAD) is calculated as median L2 distance from the median color.

Third Term

- Assuming that image color channels vary from 0 to 255, it's possible to define the cost function:

$$H(p, L(p)) = \begin{cases} |M(p) - I_{L(p)}(p)| & \text{if } \sigma(p) < 10 \\ 0 & \text{otherwise} \end{cases}$$

Complete Cost Function

- Pixels in image i to which the ith camera does not project are set as null --> the black holes.
- L(p) = i is not possible if I_i (p) = null.

$$\sum_p(\alpha D(p, L(p)) + \beta H(p, L(p))) + \sum_{p,q} V(p, L(p), q, L(q))$$

- Higher values for α encourage pixels from more straight-on views at the expense of more noticeable seams.
- Lower values of both α and β are more likely to remove objects off of the dominant plane.

Solve it as a MRF Optimization

- The panorama is computed at a lower resolution so that the MRF optimization can be computed in reasonable time.
- Using the hierarchical approach a higher-resolution is recreated.
- The final panorama is composited in the gradient domain to smooth the seams.

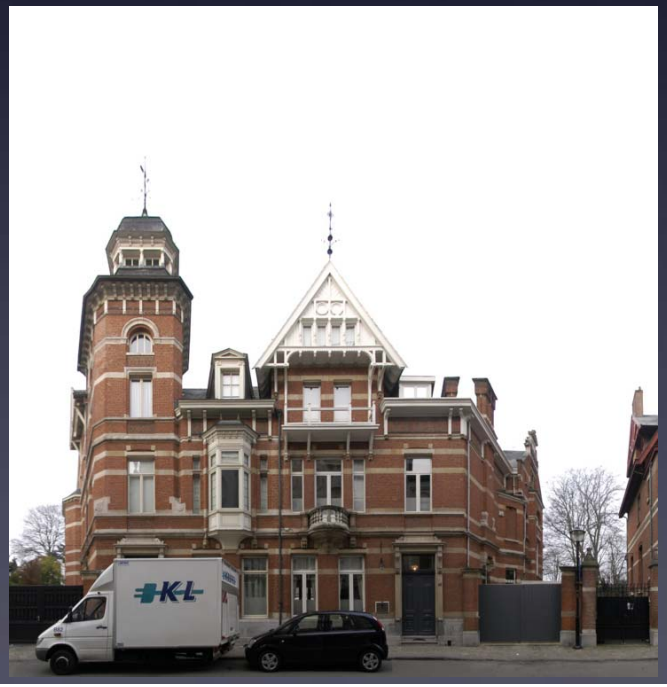
Interactive Refinement

- View selection
  - A certain viewpoint should be used for a certain region of the composite.
- Seam suppression
  - The user can indicate objects in a scene across which seams should never placed.
- Inpainting (Similar to image completion)
  The user can draw strokes to indicate areas that should be filled with zero gradients during gradient-domain composition (to remove for example power lines)

Seam Suppression

- The MRF Optimization try to route seams around objects that lie off the dominant plane.
- However, such objects don’t always exist.

Shortened car in the automatic panorama



User strokes in one source image

Seam Suppression

- Propagate the stroked pixels
  - assume the strokes are drawn on 3D planes.
  - transfer the pixels to other source images by a homography (2D/2D relationship)

Seam Suppression

- Constraints on these stroked pixels (on all images):
  for each pixel q adjacent to p that
  L(p) = i, if and only if L(q) = i.

  --> keep that whole region as much as possible.

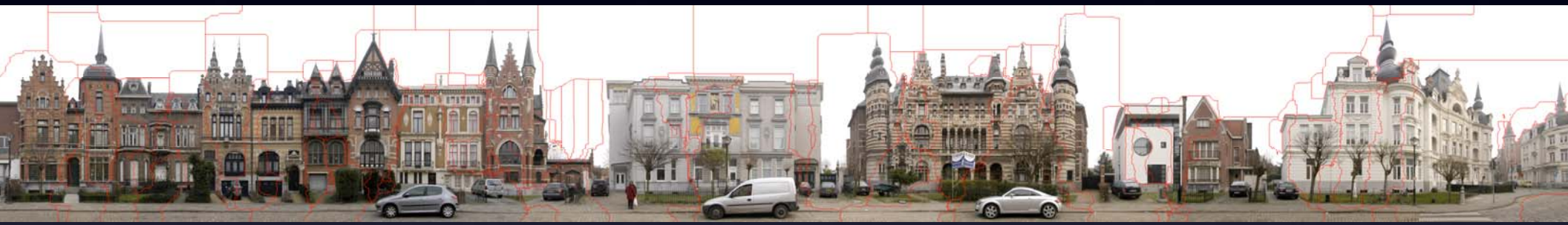
Full Example 1

Data

Projected Source

Average Image

Seams Found



Red lines are where the labeling changes-->Seams

Result

Automatically computed

Full Example 2

Data

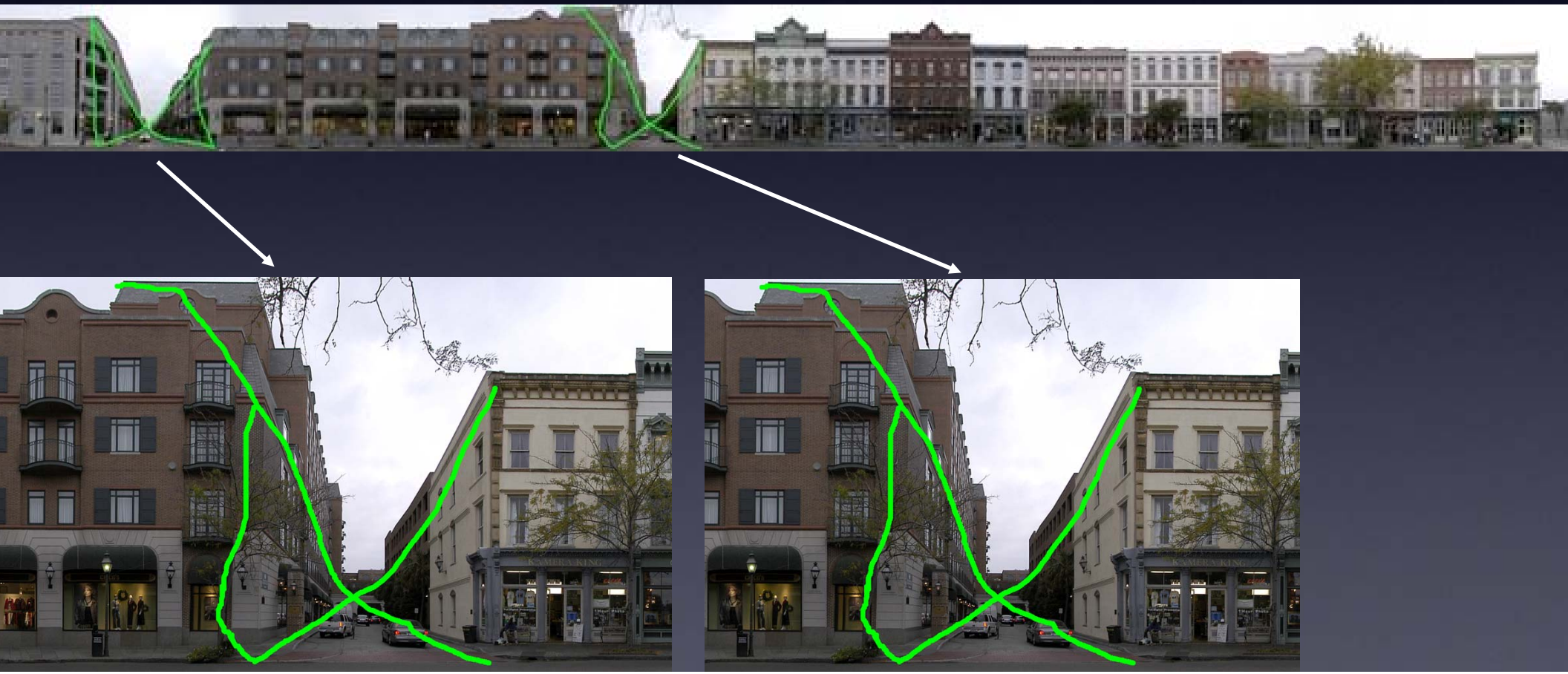
Projected Source

Initial Result

Automatically computed

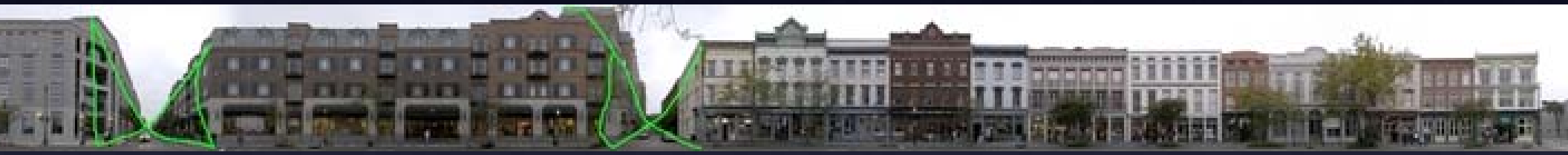
User Strokes

User wants to maintain perspective in these areas.



Seams

No seams pass the area covered by strokes.



Final Result

Before

After