Image-based modeling

Digital Visual Effects, Spring 2008

Yung-Yu Chuang

2008/5/6

with slides by Richard Szeliski, Steve Seitz and Alexei Efros

Announcements

- Project #3 is extend to 5/16
- Project #2 artifact voting results

Honorable mention (7): 張子捷 游知澔

Honorable mention (9): 胡傳牲 高紹航

Third place (10): 吳懿倫 張哲瀚

Second place (13):賴韻芊 黃柏瑜

First place (24): 游名揚 曾照涵

Outline

- Models from multiple (sparse) images
  - Structure from motion
  - Facade
- Models from single images
  - Tour into pictures
  - Single view metrology
  - Other approaches

Models from multiple images (Façade, Debevec *et. al.* 1996)

Facade

DigiVFX

- Use a sparse set of images
- Calibrated camera (intrinsic only)
- Designed specifically for modeling architecture
- Use a set of blocks to approximate architecture
- Three components:
  - geometry reconstruction
  - texture mapping
  - model refinement

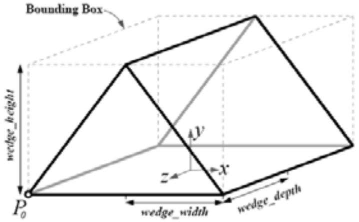
Idea

DigiVFX

Idea

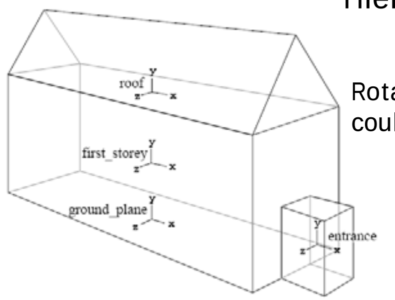
DigiVFX

Geometric modeling

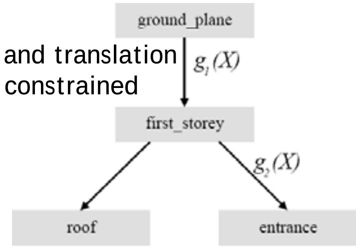


A block is a geometric primitive with a **small** set of parameters

Hierarchical modeling for a scene



Rotation and translation could be constrained



Reasons for block modeling

- Architectural scenes are well modeled by geometric primitives.
- Blocks provide a high level abstraction, easier to manage and add constraints.
- No need to infer surfaces from discrete features; blocks essentially provide prior models for architectures.
- Hierarchical block modeling effectively reduces the number of parameters for robustness and efficiency.

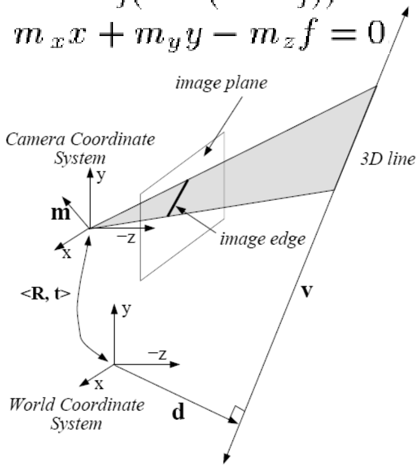
Reconstruction

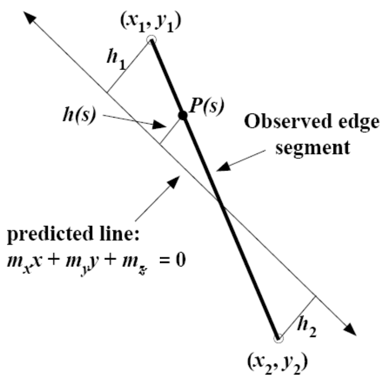
minimize $\mathcal{O} = \sum Err_i$

$$\mathbf{m} = R_j(\mathbf{v} \times (\mathbf{d} - t_j))$$

$$m_x x + m_y y - m_z f = 0$$

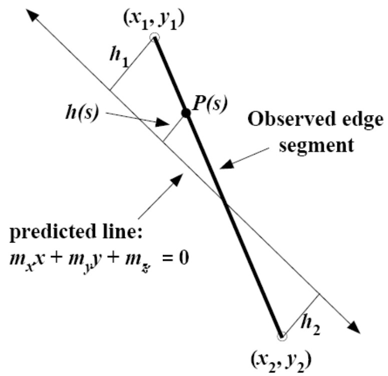
$$Err_i = \int_0^l h^2(s)ds$$





Reconstruction

$$Err_i = \int_0^l h^2(s)ds$$



$$h_1 = \frac{m_x x_1 + m_y y_1 + m_z}{\sqrt{m_x^2 + m_y^2}}$$

$$h_2 = \frac{m_x x_2 + m_y y_2 + m_z}{\sqrt{m_x^2 + m_y^2}}$$

$$h(s) = h_1 + s\frac{h_2 - h_1}{l}$$

$$Err_i = \int_0^l h^2(s)ds$$

$$= \frac{l}{3}(h_1^2 + h_1 h_2 + h_2^2)$$

Reconstruction

$$Err_i = \int_0^l h^2(s)ds = \frac{l}{3}(h_1^2+h_1h_2+h_2^2) = \mathbf{m}^T(A^TBA)\mathbf{m}$$

$$\mathbf{m} = (m_x, m_y, m_z)^T \qquad \mathbf{m} = R_j(\mathbf{v} \times (\mathbf{d} - t_j))$$

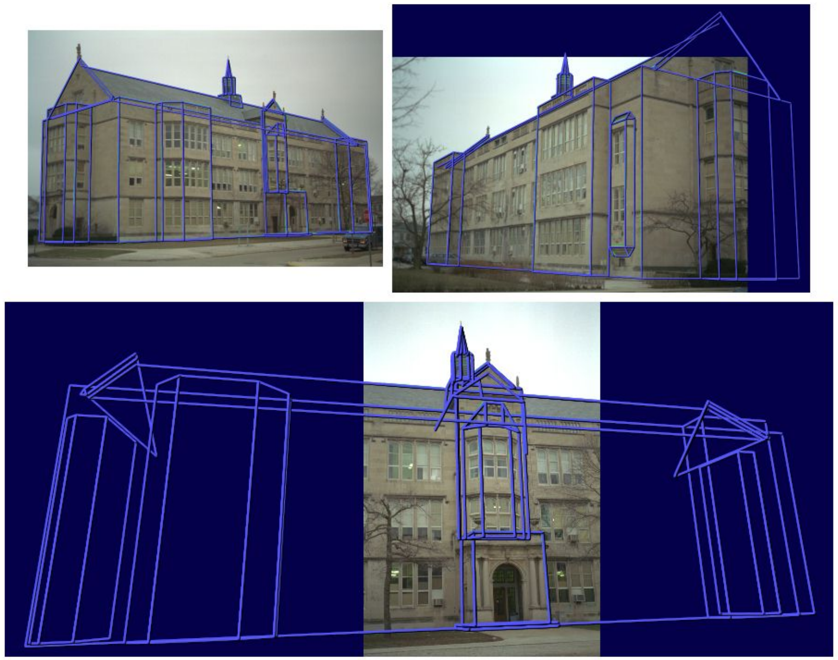
$$A = \begin{pmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \end{pmatrix}$$

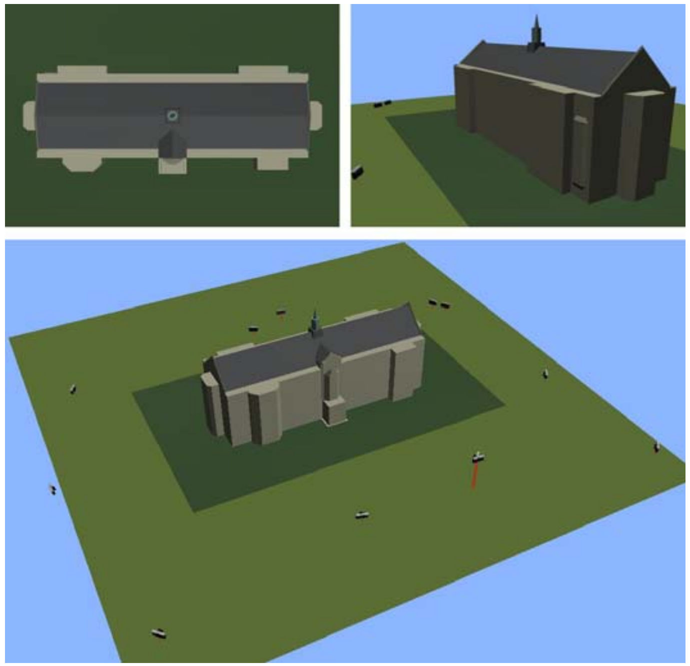
$$B = \frac{l}{3(m_x^2 + m_y^2)} \begin{pmatrix} 1 & 0.5 \\ 0.5 & 1 \end{pmatrix}$$

nonlinear w.r.t. camera and model

Results

3 of 12 photographs



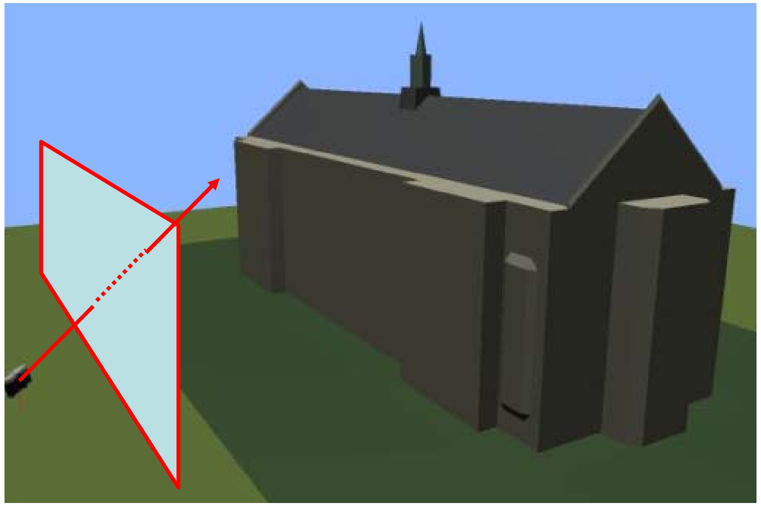


Texture mapping

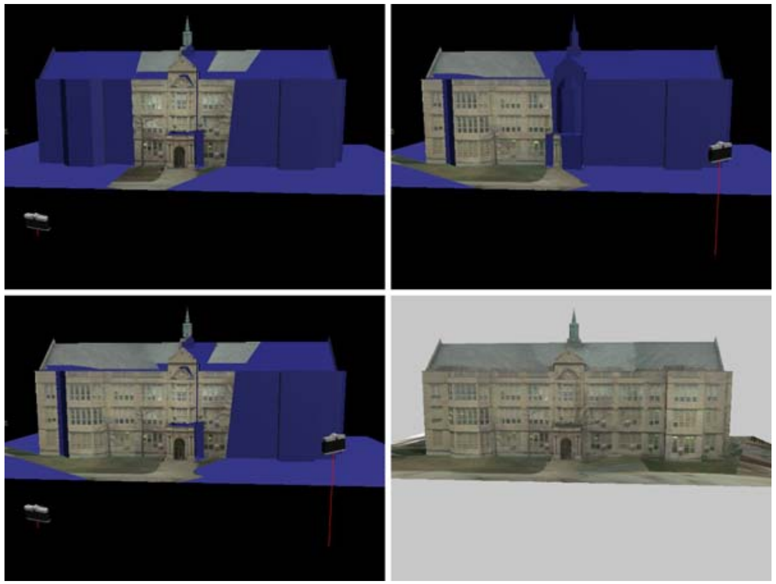
Texture mapping in real world

Demo movie
Michael Naimark,
San Francisco Museum of Modern Art, 1984

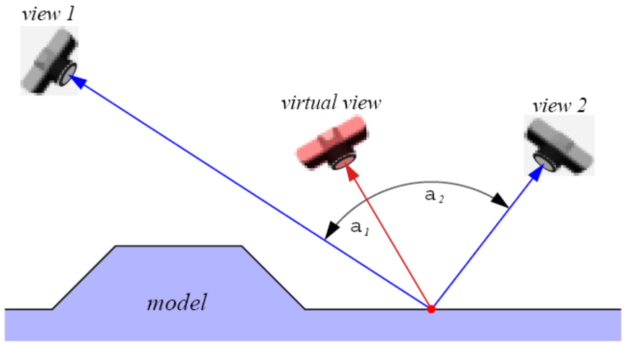
Texture mapping



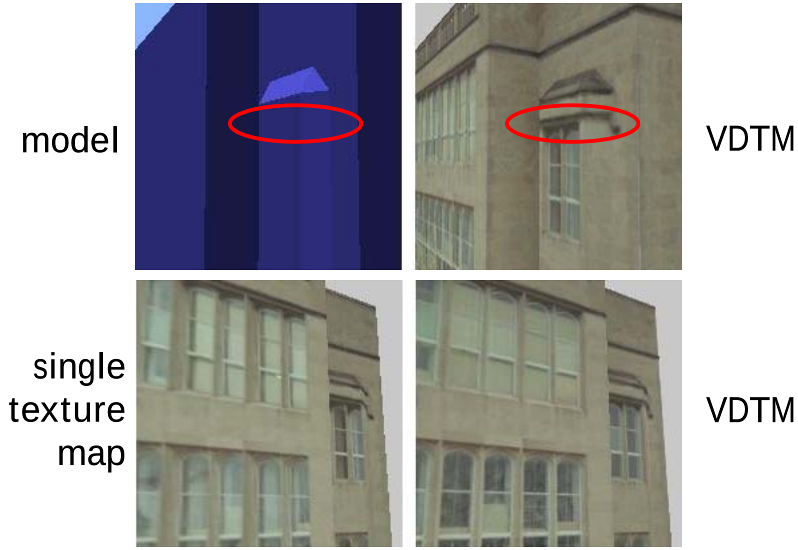
Texture mapping



View-dependent texture mapping



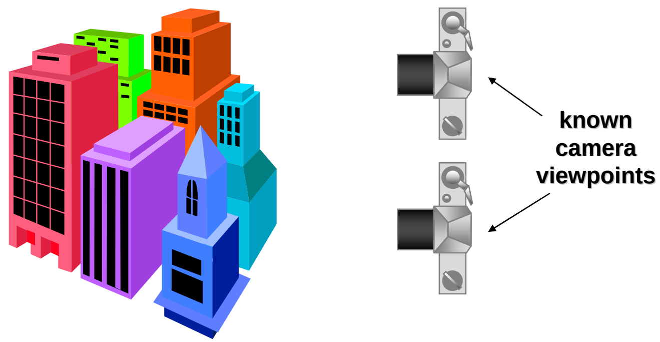
View-dependent texture mapping



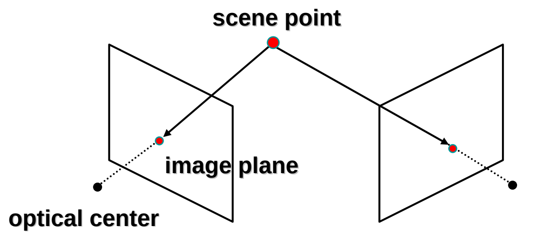
View-dependent texture mapping

Model-based stereo

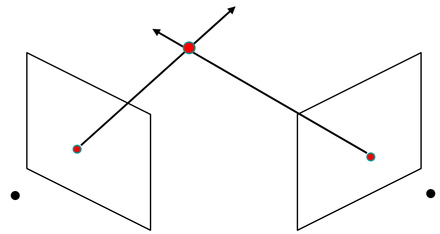
- Use stereo to refine the geometry



Stereo



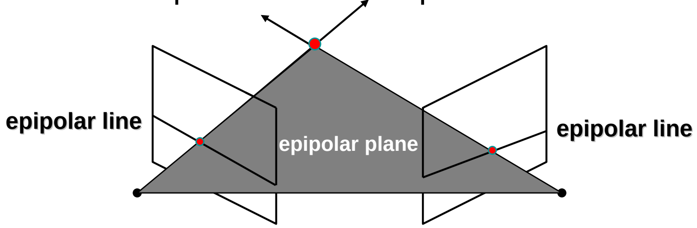
Stereo



- Basic Principle: Triangulation
  - Gives reconstruction as intersection of two rays
  - Requires
    - calibration
    - *point correspondence*

Stereo correspondence

- Determine Pixel Correspondence
  - Pairs of points that correspond to same scene point



- Epipolar Constraint
  - Reduces correspondence problem to 1D search along *conjugate epipolar lines*

Finding correspondences

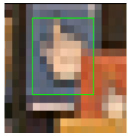
- apply feature matching criterion (e.g., correlation or Lucas-Kanade) at *all* pixels simultaneously
- search only over epipolar lines (much fewer candidate positions)

Image registration (revisited)

- How do we determine correspondences?
  - *block matching* or *SSD* (sum squared differences)

$$E(x,y;d) = \sum_{(x',y') \in N(x,y)} [I_L(x'+d,y') - I_R(x',y')]^2$$

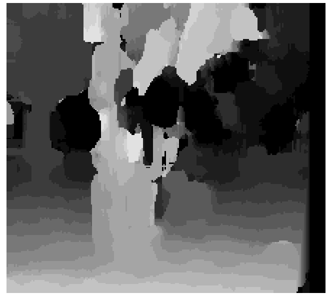
d is the *disparity* (horizontal motion)




- How big should the neighborhood be?

Neighborhood size

- Smaller neighborhood: more details
- Larger neighborhood: fewer isolated mistakes

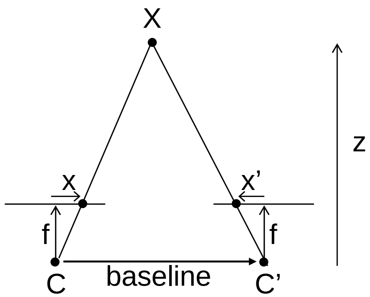



Depth from disparity


input image (1 of 2)


depth map [Szeliski & Kang '95]


3D rendering



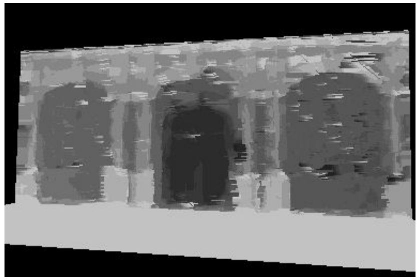
$$disparity = x - x' = \frac{baseline * f}{z}$$

Stereo reconstruction pipeline

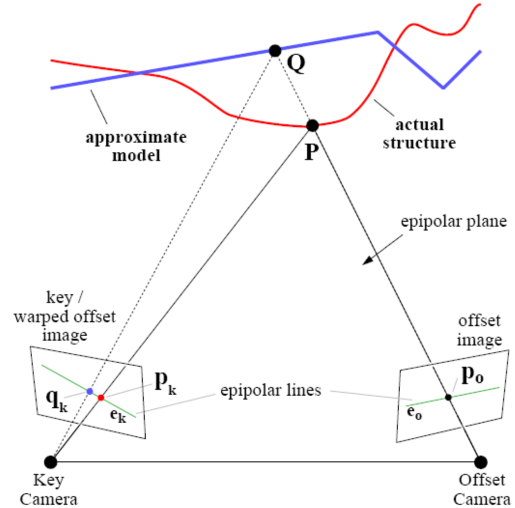
- Steps
  - Calibrate cameras
  - Rectify images
  - Compute disparity
  - Estimate depth

- What will cause errors?
  - Camera calibration errors
  - Poor image resolution
  - Occlusions
  - Violations of brightness constancy (specular reflections)
  - Large motions
  - Low-contrast image regions

Model-based stereo



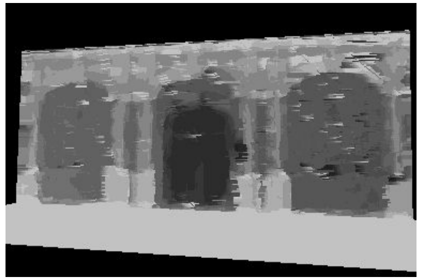
Epipolar geometry



Results

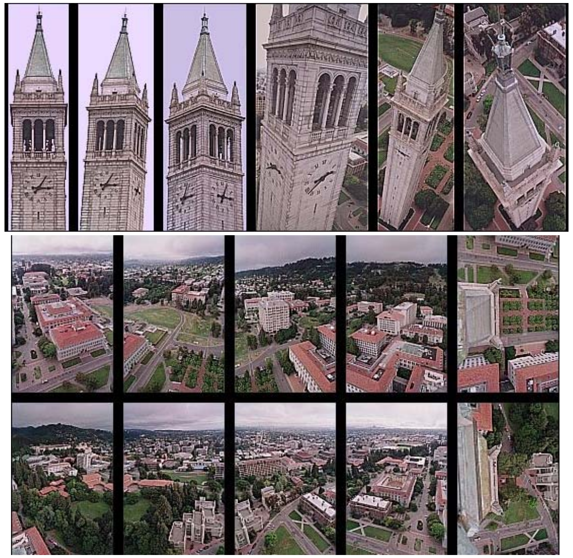
Comparisons

VDTM, model-based stereo



Final results

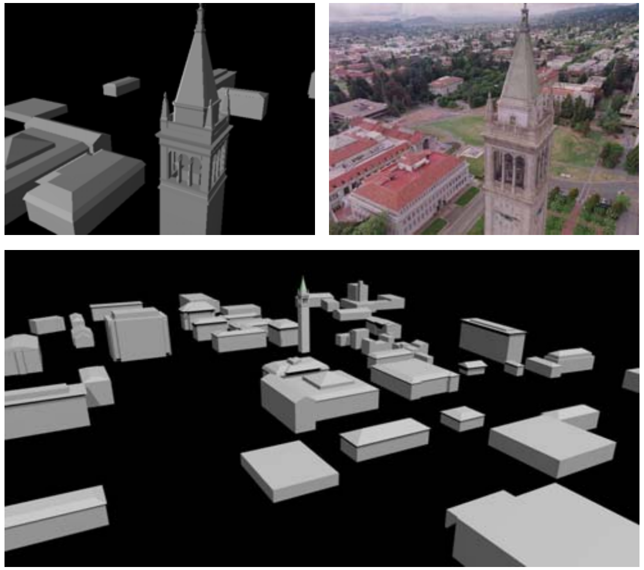
DigiVFX

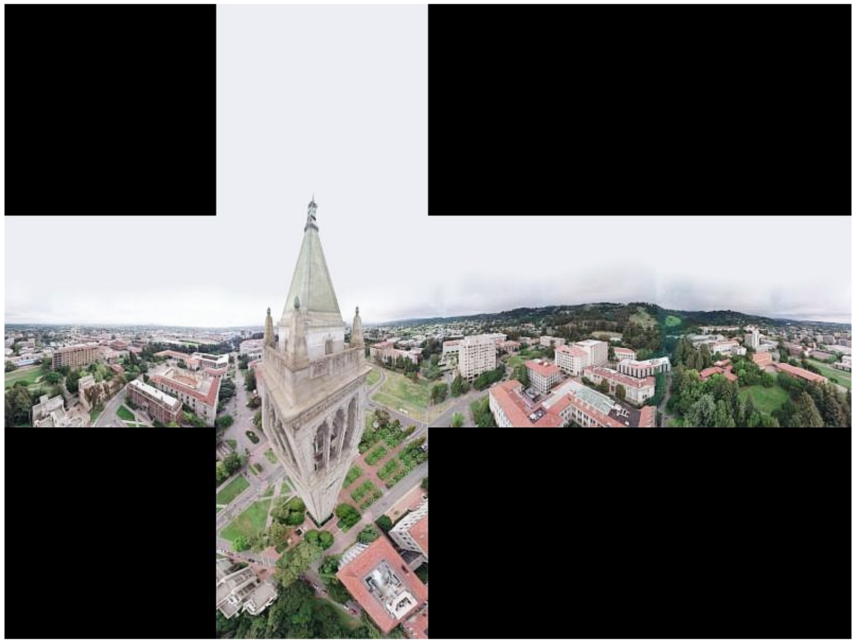


Kite photography

Final results

DigiVFX





Results

DigiVFX

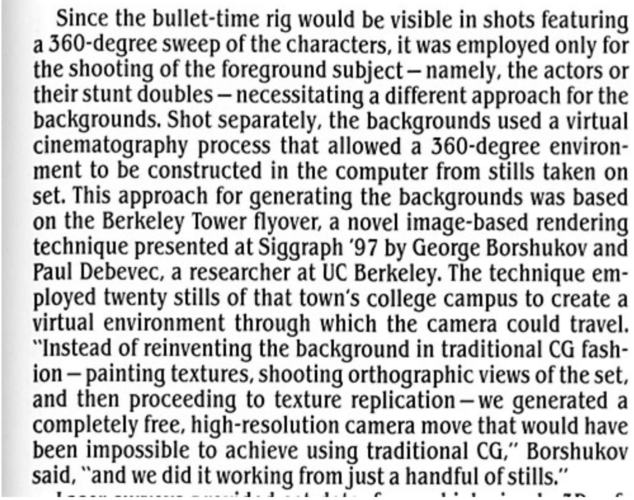
Results

Commercial packages

- REALVIZ ImageModeler

The Matrix

Cinefex #79, October 1999.



Since the bullet-time rig would be visible in shots featuring a 360-degree sweep of the characters, it was employed only for the shooting of the foreground subject – namely, the actors or their stunt doubles – necessitating a different approach for the backgrounds. Shot separately, the backgrounds used a virtual cinematography process that allowed a 360-degree environment to be constructed in the computer from stills taken on set. This approach for generating the backgrounds was based on the Berkeley Tower flyover, a novel image-based rendering technique presented at Siggraph '97 by George Borshukov and Paul Debevec, a researcher at UC Berkeley. The technique employed twenty stills of that town's college campus to create a virtual environment through which the camera could travel. "Instead of reinventing the background in traditional CG fashion – painting textures, shooting orthographic views of the set, and then proceeding to texture replication – we generated a completely free, high-resolution camera move that would have been impossible to achieve using traditional CG," Borshukov said, "and we did it working from just a handful of stills."

The Matrix

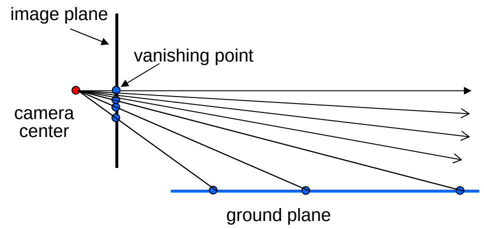
- *Academy Awards for Scientific and Technical achievement for 2000*

  To George Borshukov, Kim Libreri and Dan Piponi for the development of a system for image-based rendering allowing choreographed camera movements through computer graphic reconstructed sets.

This was used in The Matrix and Mission Impossible II; See The Matrix Disc #2 for more details

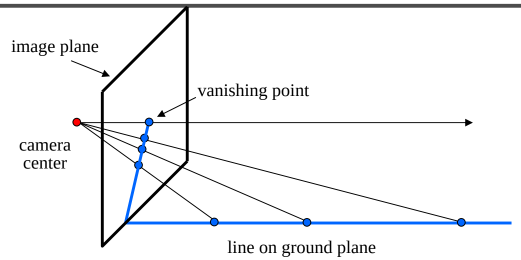
Models from single images

Vanishing points

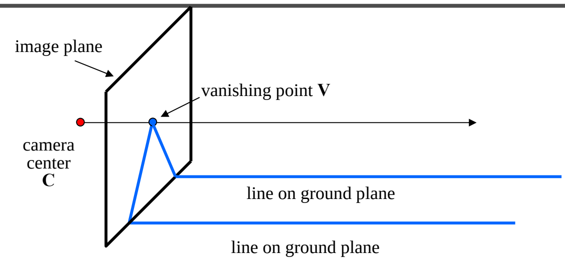


- Vanishing point
  - projection of a point at infinity

Vanishing points (2D)

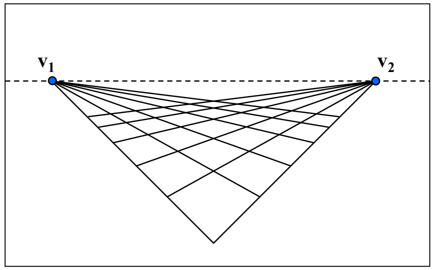


Vanishing points



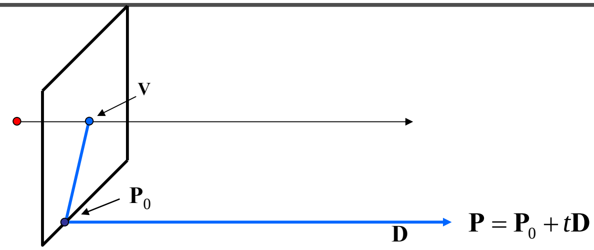
- Properties
  - Any two parallel lines have the same vanishing point **v**
  - The ray from **C** through **v** is parallel to the lines
  - An image may have more than one vanishing point

Vanishing lines



- Multiple Vanishing Points
  - Any set of parallel lines on the plane define a vanishing point
  - The union of all of these vanishing points is the *horizon line*
    - also called *vanishing line*
  - Note that different planes define different vanishing lines

Computing vanishing points



$$\mathbf{P}_t = \begin{bmatrix} P_X + tD_X \\ P_Y + tD_Y \\ P_Z + tD_Z \\ 1 \end{bmatrix} \cong \begin{bmatrix} P_X / t + D_X \\ P_Y / t + D_Y \\ P_Z / t + D_Z \\ 1/t \end{bmatrix} \qquad t \to \infty \qquad \mathbf{P}_\infty \cong \begin{bmatrix} D_X \\ D_Y \\ D_Z \\ 0 \end{bmatrix}$$

- Properties $\mathbf{v} = \mathbf{\Pi} \mathbf{P}_\infty$
  - $\mathbf{P}_\infty$ is a point at *infinity*, **v** is its projection
  - They depend only on line *direction*
  - Parallel lines $\mathbf{P}_0$ + t**D**, $\mathbf{P}_1$ + t**D** intersect at $\mathbf{P}_\infty$

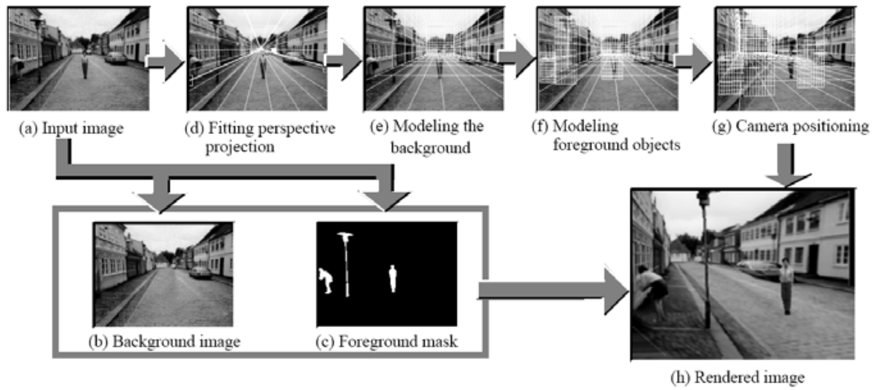
Tour into pictures

- Create a 3D "theatre stage" of five billboards

- Specify foreground objects through bounding polygons

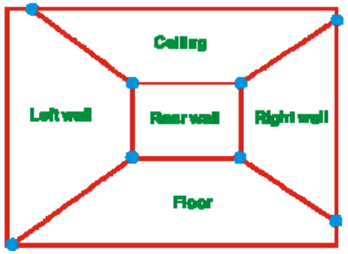
- Use camera transformations to navigate through the scene

Tour into pictures

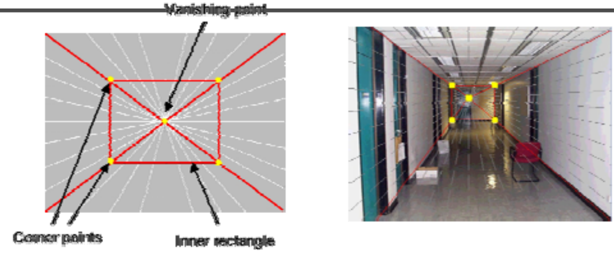


The idea

- Many scenes (especially paintings), can be represented as an axis-aligned box volume (i.e. a stage)
- Key assumptions:
  - All walls of volume are orthogonal
  - Camera view plane is parallel to back of volume
  - Camera up is normal to volume bottom
  - Volume bottom is y=0
- Can use the vanishing point to fit the box to the particular Scene!



Fitting the box volume

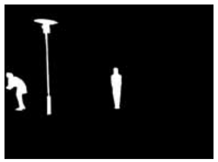


- User controls the inner box and the vanishing point placement (6 DOF)

Foreground Objects

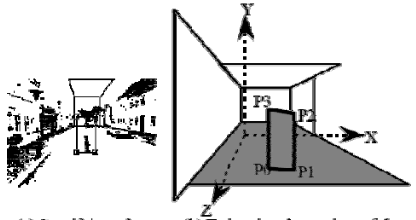
- Use separate billboard for each

- For this to work, three separate images used:
  - Original image.
  - Mask to isolate desired foreground images.
  - Background with objects removed



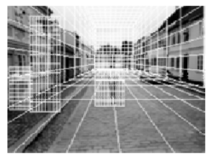
Foreground Objects

- Add vertical rectangles for each foreground object
- Can compute 3D coordinates P0, P1 since they are on known plane.
- P2, P3 can be computed as before (similar triangles)



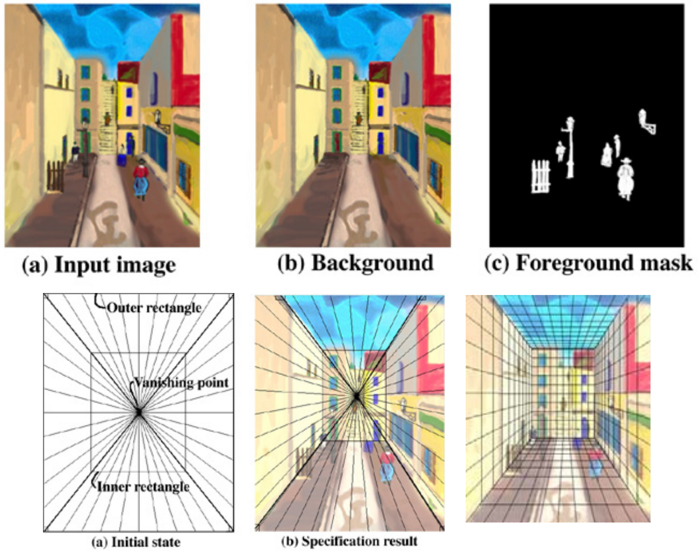
(a) Specifying of a foreground object

(b) Estimating the vertices of the foreground object model

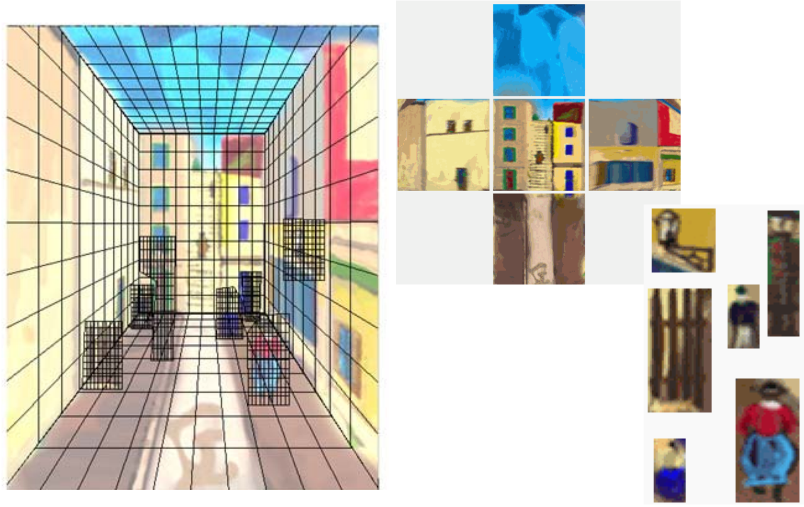


(c) Three foreground object models

Example



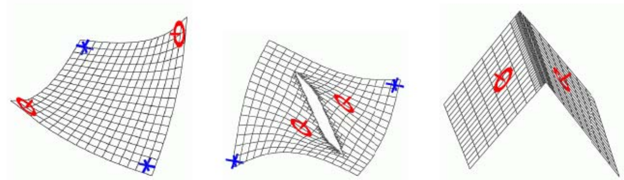
Example

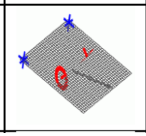
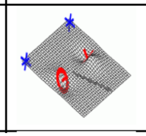
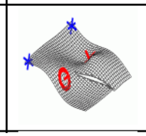
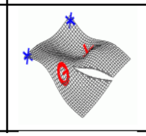
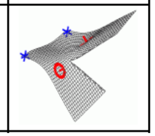


glTip

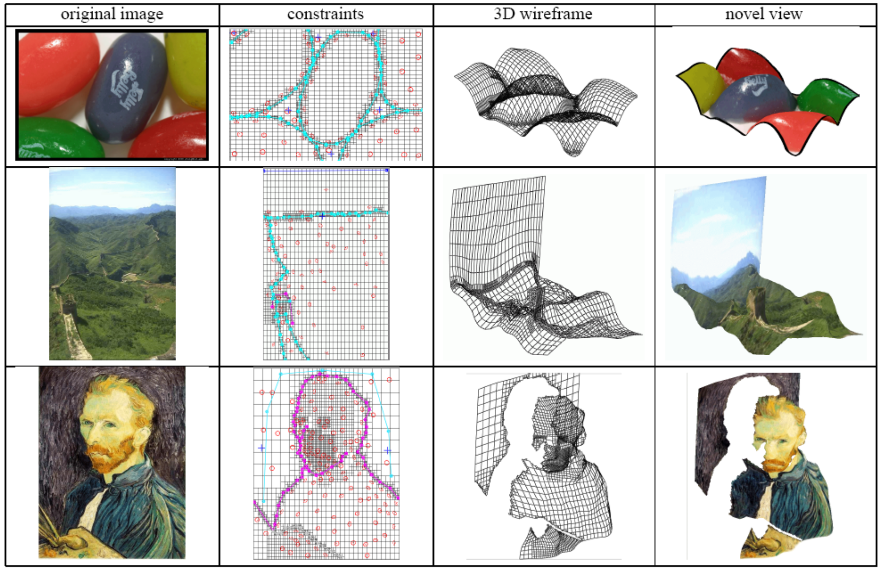
- http://www.cs.ust.hk/~cpegnel/glTIP/


Zhang *et. al.* CVPR 2001

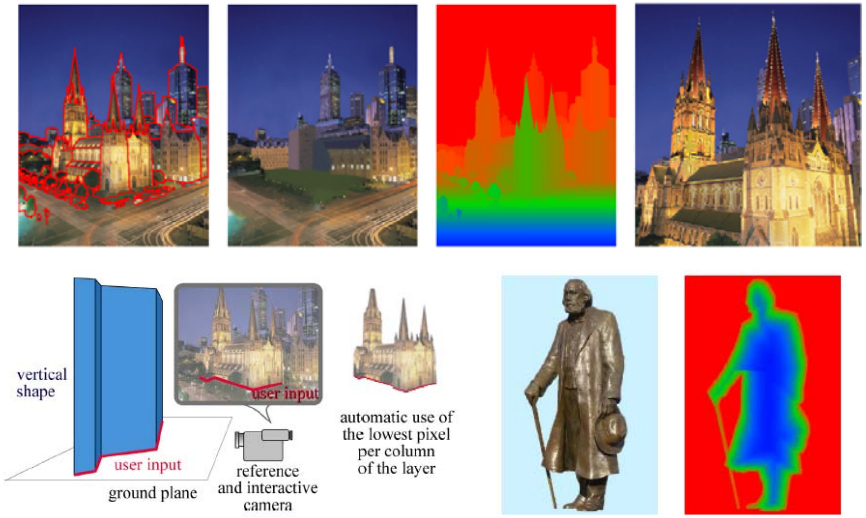


Methods	Iteration 0	Iteration 200	Iteration 1200	Iteration 2500	Iteration 9500
No hierarchical transformation					

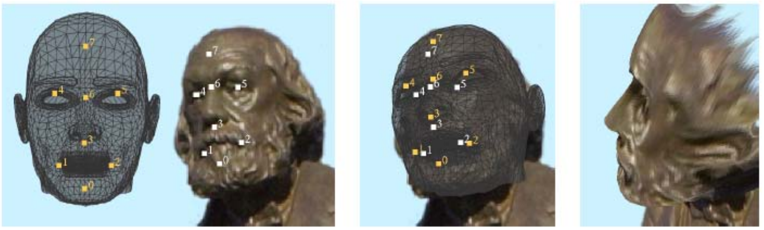
Zhang *et. al.* CVPR 2001

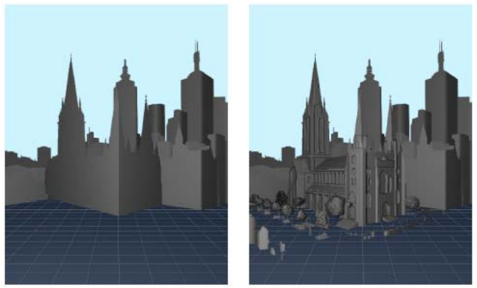


Oh *et. al.* SIGGRAPH 2001



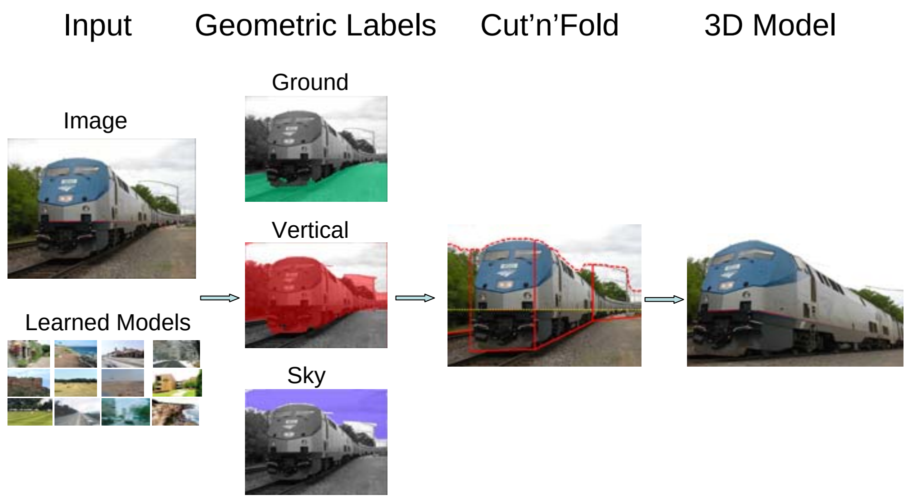
Oh *et. al.* SIGGRAPH 2001



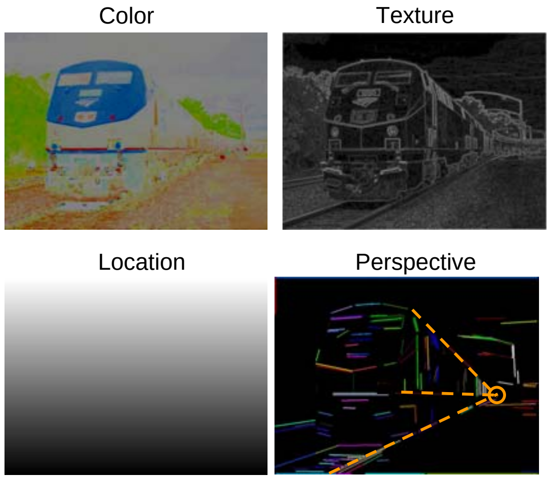


video

Automatic popup



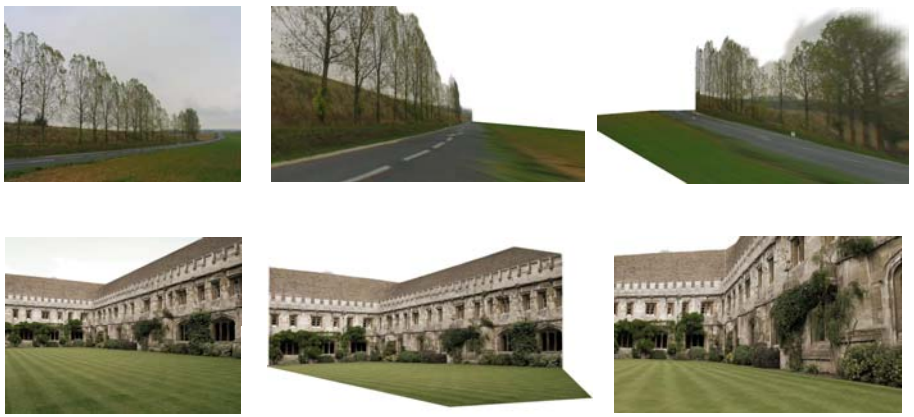
Geometric cues



Automatic popup

Feature Descriptions	Num	Used
Color	**15**	**15**
C1. RGB values: mean	3	3
C2. HSV values: conversion from mean RGB values	3	3
C3. Hue: histogram (5 bins) and entropy	6	6
C4. Saturation: histogram (3 bins) and entropy	3	3
Texture	**29**	**13**
T1. DOOG Filters: mean abs response	12	3
T2. DOOG Filters: mean of variables in T1	1	0
T3. DOOG Filters: id of max of variables in T1	1	1
T4. DOOG Filters: (max - median) of variables in T1	1	1
T5. Textons: mean abs response	12	7
T6. Textons: max of variables in T5	1	0
T7. Textons: (max - median) of variables in T5	1	1
Location and Shape	**12**	**10**
L1. Location: normalized x and y, mean	2	2
L2. Location: norm. x and y, 10^{th} and 90^{th} percentile	4	4
L3. Location: norm. y wrt horizon, 10^{th} and 90^{th} pctl	2	2
L4. Shape: number of superpixels in constellation	1	1
L5. Shape: number of sides of convex hull	1	0
L6. Shape: *num pixels/area(convex hull)*	1	1
L7. Shape: whether the constellation region is contiguous	1	0
3D Geometry	**35**	**28**
G1. Long Lines: total number in constellation region	1	1
G2. Long Lines: % of nearly parallel pairs of lines	1	1
G3. Line Intersection: hist. over 12 orientations, entropy	13	11
G4. Line Intersection: % right of center	1	1
G5. Line Intersection: % above center	1	1
G6. Line Intersection: % far from center at 8 orientations	8	4
G7. Line Intersection: % very far from center at 8 orientations	8	5
G8. Texture gradient: x and y "edginess" (T2) center	2	2

Results



Input Images

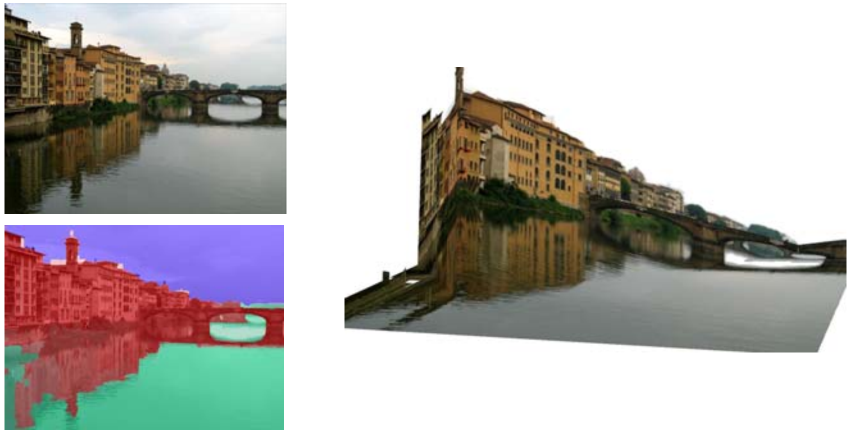
Automatic Photo Pop-up

Results

This approach works roughly for 35% of images.

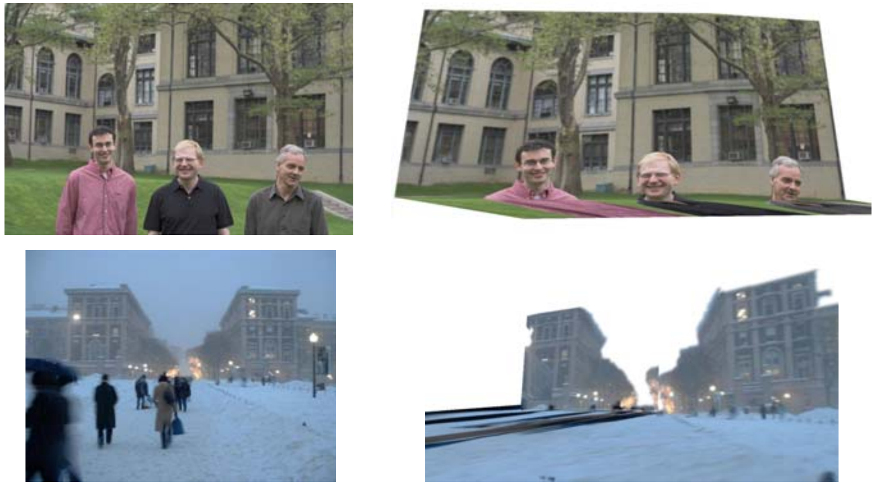
Failures

Labeling Errors



Failures

Foreground Objects



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