Reconstructing Virtual Rooms from Panoramic Images

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Introduction

- Panoramic images are widely used to advertise hotel rooms or real-estate, or record group meetings.

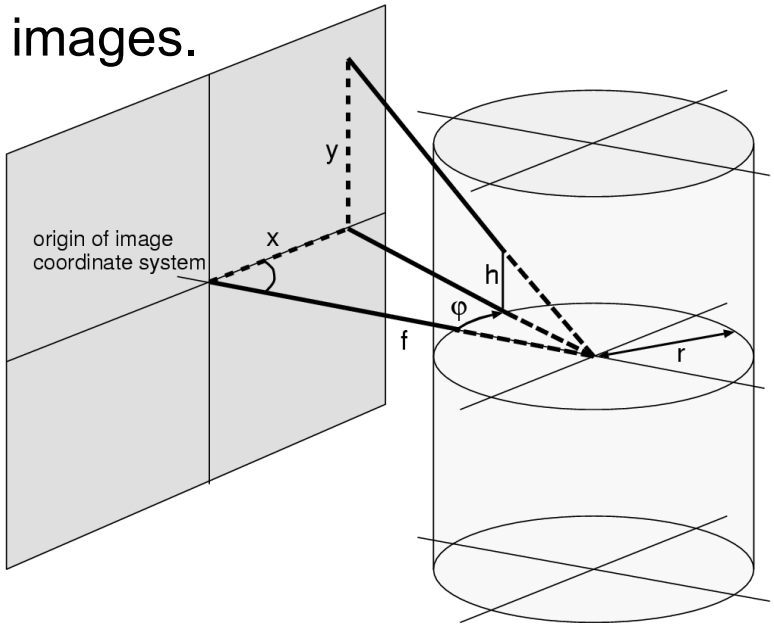
Portable meeting recorder [Ricoh]

- Panoramic images usually span full 360° horizontally.
  - Provides complete overview of a scene.
  - Many people have difficulties to understand panoramic images.
    - Human vision has a maximum of 200° horizontally, not 360°.
    - Panoramic image shows backward and forward view at the same time.

- We present a new visualization technique for panoramic images.
  - Room walls provide a main cue for orientation in the environment.
  - Reconstruct the layout of the walls from the image.
  - Here, we concentrate on special case of indoor recordings in rectangular rooms.

Cylindrical Panoramic Images

- Panoramic images (horizontal camera pan) are synthesized by
  - projecting all input frames onto a virtual cylinder,
  - computing the angular shift to align the images.



- Conversion to cylindrical coordinates:

$$\tan\phi = x/f \quad \text{and} \quad h = \frac{y}{\sqrt{f^2 + x^2}}$$

- f = focal length

Visualization 1: Unwrapped Cylinder

- Unwrap surface of the virtual cylinder around camera.

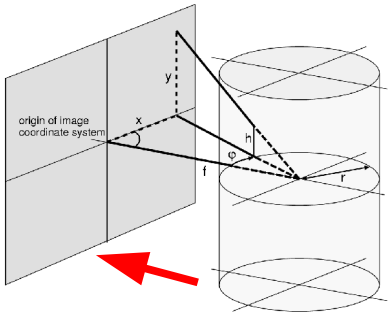
- Static display of 360° views.
- Unusual viewing experience since a 360° view is condensed into one image.
- Straight lines are not preserved.
  - Concepts like *parallel lines* and *vanishing points* cannot be applied easily.

Visualization 2: Panoramic Image Browser (1/2)

- Interactive browser without image rectification
  - easy implementation, fast
  - straight lines are not preserved
  - no real advantage to full 360° image

Visualization 2: Panoramic Image Browser (2/2)

- Interactive browser with image rectification
  - provides realistic views
  - straight lines are preserved
  - limited view, interactivity is required

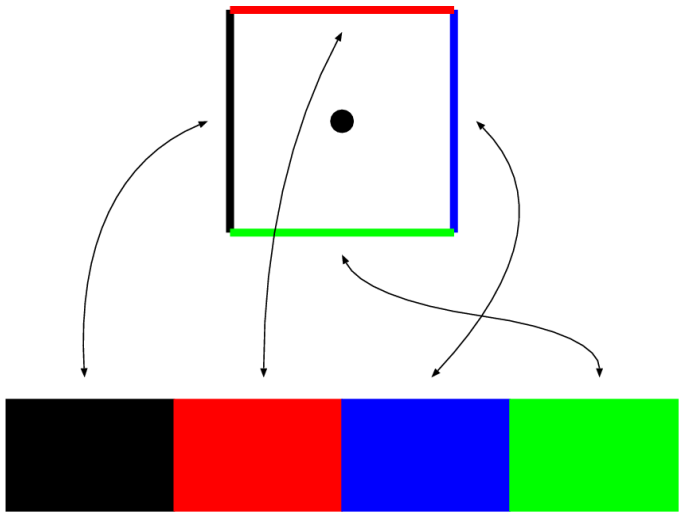


Visualization 3: 3-D Cylinder Projection

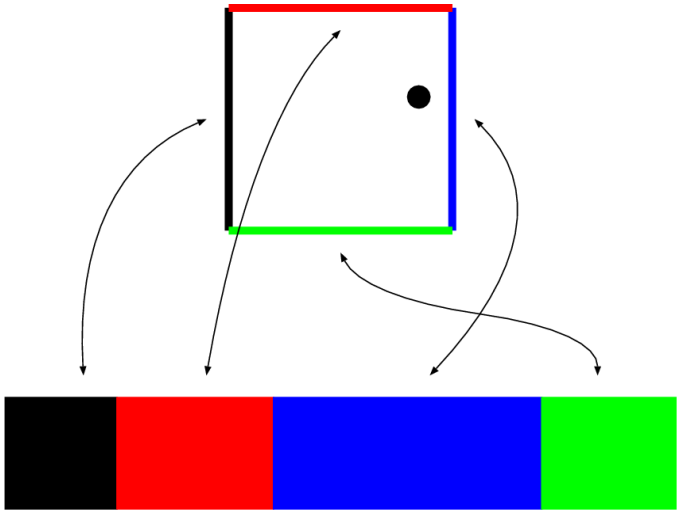
- Build 3-D model of a virtual cylinder with the panorama as texture.
- If virtual camera is placed in center of cylinder,
  - we see realistic, rectified views.
- Outside view gives scene overview, but
  - spatial relations can be misleading.

The Rectangular Room in the Panorama

- The sizes of the walls in the panoramic image depends on the camera position.
  - Walls of a square room not necessarily span 90° in the panorama.



Camera in room center, walls span 90°.



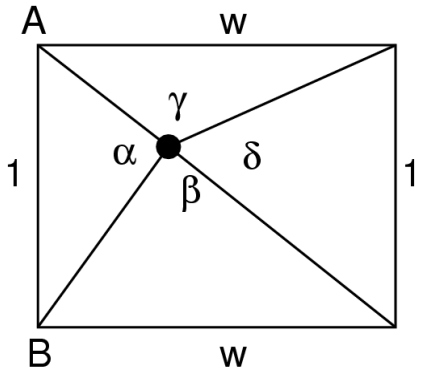
Camera somewhere else, walls span unequal angles.

Visualization 4: 3-D Room Projection

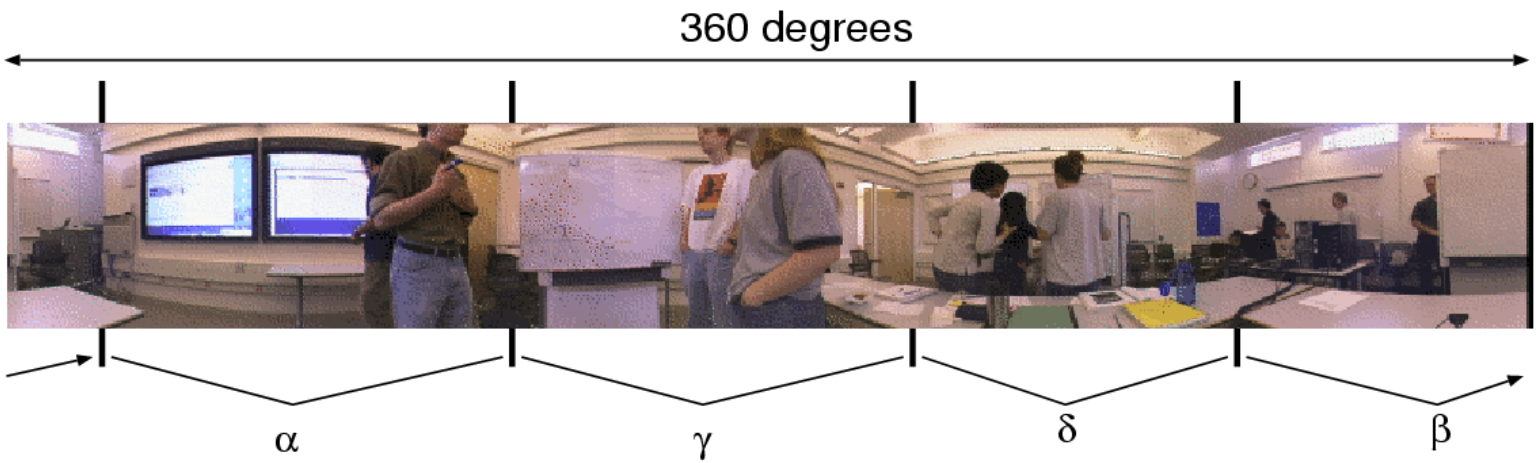
- Our new proposal:
  - Reconstruct 3-D model of room and project texture onto walls.

- Very flexible visualization:
  - virtual camera outside of the room: realistic scene overview,
  - virtual camera inside of the room: realistic inside view, equivalent to interactive panoramic image browser.

Room Reconstruction

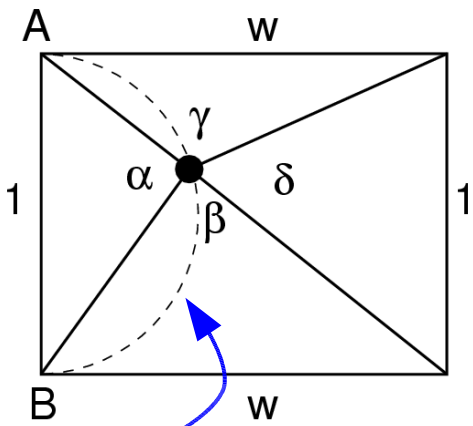


- Absolute room size is not important.
  - Normalize size of one dimension to unity.
- Unknown parameters:
  - room width (1), camera position (2)
- Reconstruction approach:
  - User marks the four corners in the panoramic image.
  - Distance between marks corresponds to camera angles.
  - Angles sum to 360°, so only three independent measurements.



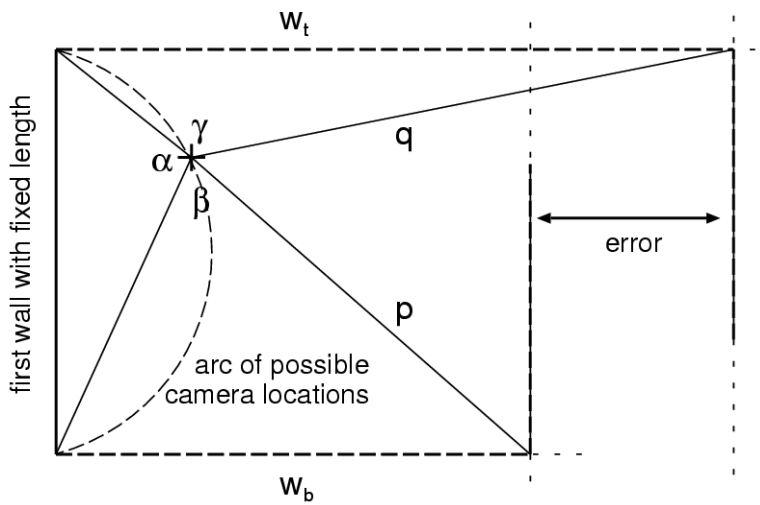
Room Reconstruction Algorithm

- Specialized algorithm for rectangular rooms.
- Normalize one wall size (AB) to unity.



- Consider angle α in which the camera sees AB.
- The angle α restricts the possible camera locations to a curve.

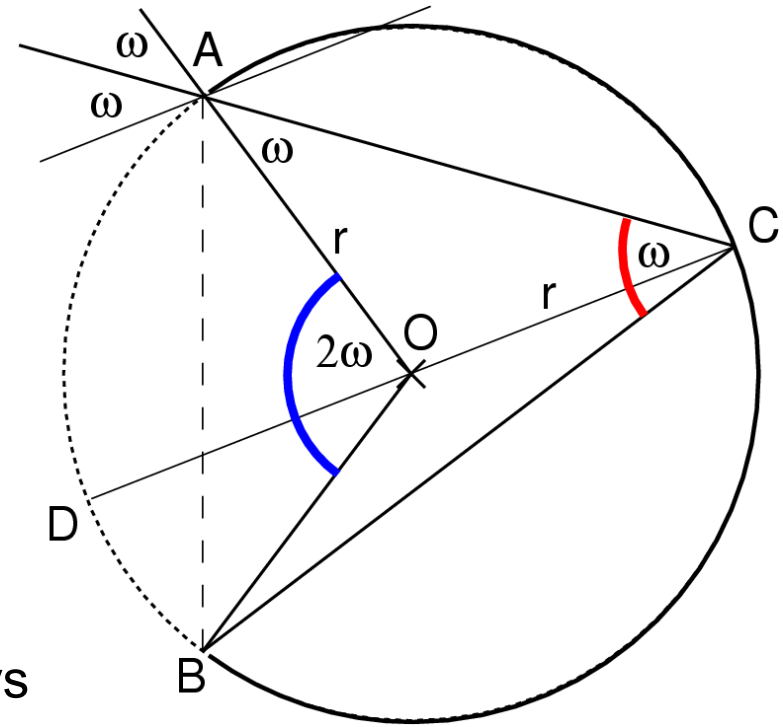
- For each candidate camera position, we can determine the size of the top and bottom walls.
- Top and bottom walls should have ***same*** size.
- Search for camera position to equalize the wall sizes.



Candidate Camera Positions

- Euclid's *Double Angle* theorem:
  Given a circle with center O and three points A,B,C on the circle.

The angle ∠AOB is two times the angle ∠ACB.

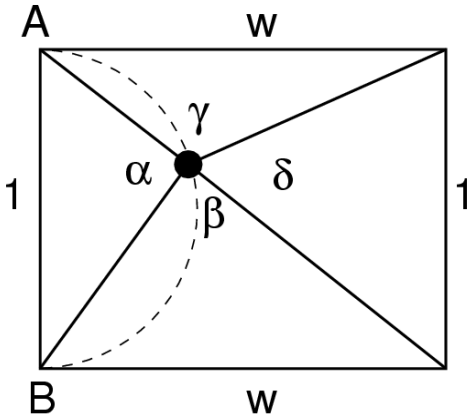


- Assume A,B is fixed.
- Moving C along the circular arc keeps the angle ∠ACB constant.
  - ∠AOB independent of C, and always
  - ∠ACB = ½ ∠AOB

- In our application: AB is a room wall which is observed with angle α.
- Then, camera position C must lie on a circular arc.

Determining the Circular Arc Location

- Size of wall AB is unity.
- Camera C observes this wall in an angle α.
- Determine center and radius of circular arc that includes A,B,C and for which $\angle ACB=\alpha$.



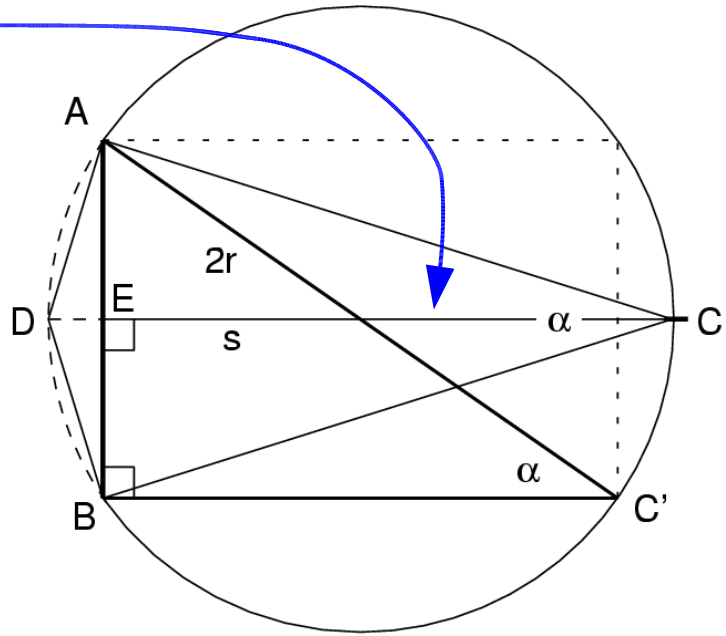
- Center of circular arc lies on orthogonal bisection of AB.
- From camera position C, we get

$$\tan \alpha/2 = \frac{1/2}{s}$$

- From camera position C', we get

$$\sin \alpha = \frac{1}{2r}$$

- Hence, we can compute radius *r* and camera distance from wall *d*=*s*-*r*.

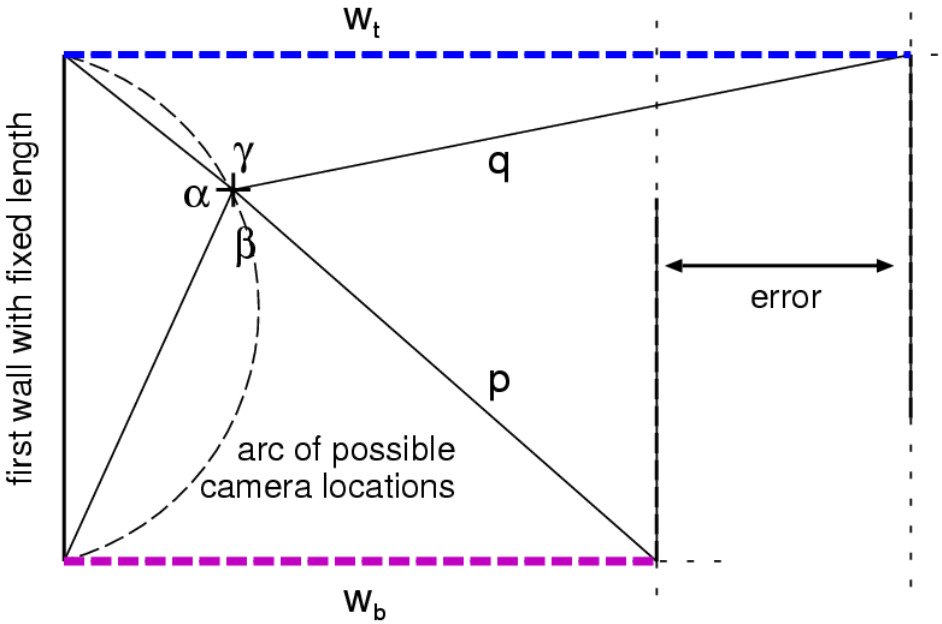


Determine Correct Camera Location on Arc (1/3)

- Assume an arbitrary camera position on the arc.
- Using angles γ and β, construct rays that intersect the top and bottom walls.
- Since the room should be rectangular,
  - **size of top wall w_t** should be equal to **size of bottom wall w_b**

- If $w_t > w_b$, camera is too low.
- If $w_t < w_b$, camera is too high.

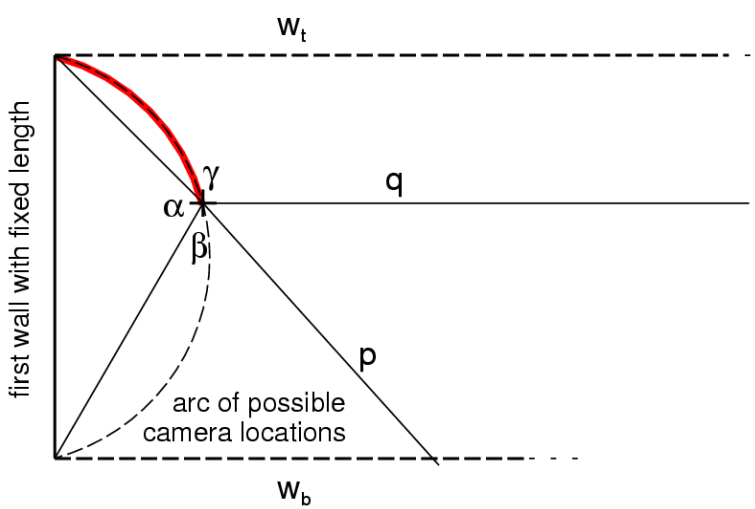
- Use binary search to find camera position.



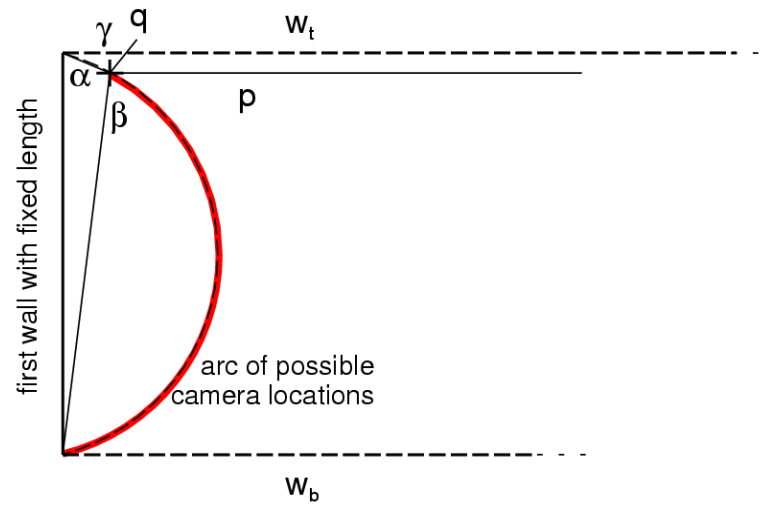
Determine Correct Camera Location on Arc (2/3)

- Determine initial range for binary search.

- At a certain position, projection rays **p** or **q** get horizontal.
  - No intersection with wall.
  - Use these extremal camera positions to define search range.



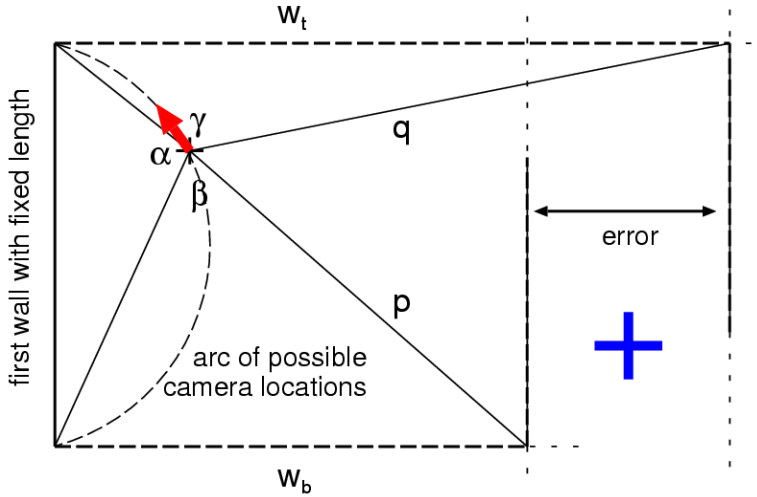
Camera can only be in indicated area. Cannot be lower.



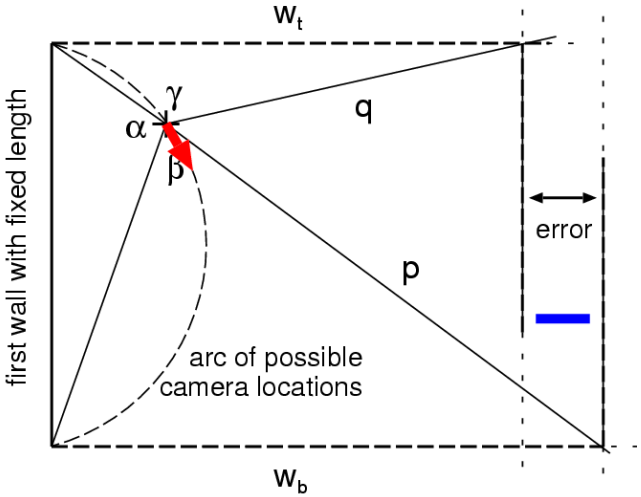
Camera can only be in indicated area. Cannot be higher.

Determine Correct Camera Location on Arc (3/3)

- Carry out a binary search on the circular arc to find camera position.
- Error $E = w_t - w_b$ should be zero.



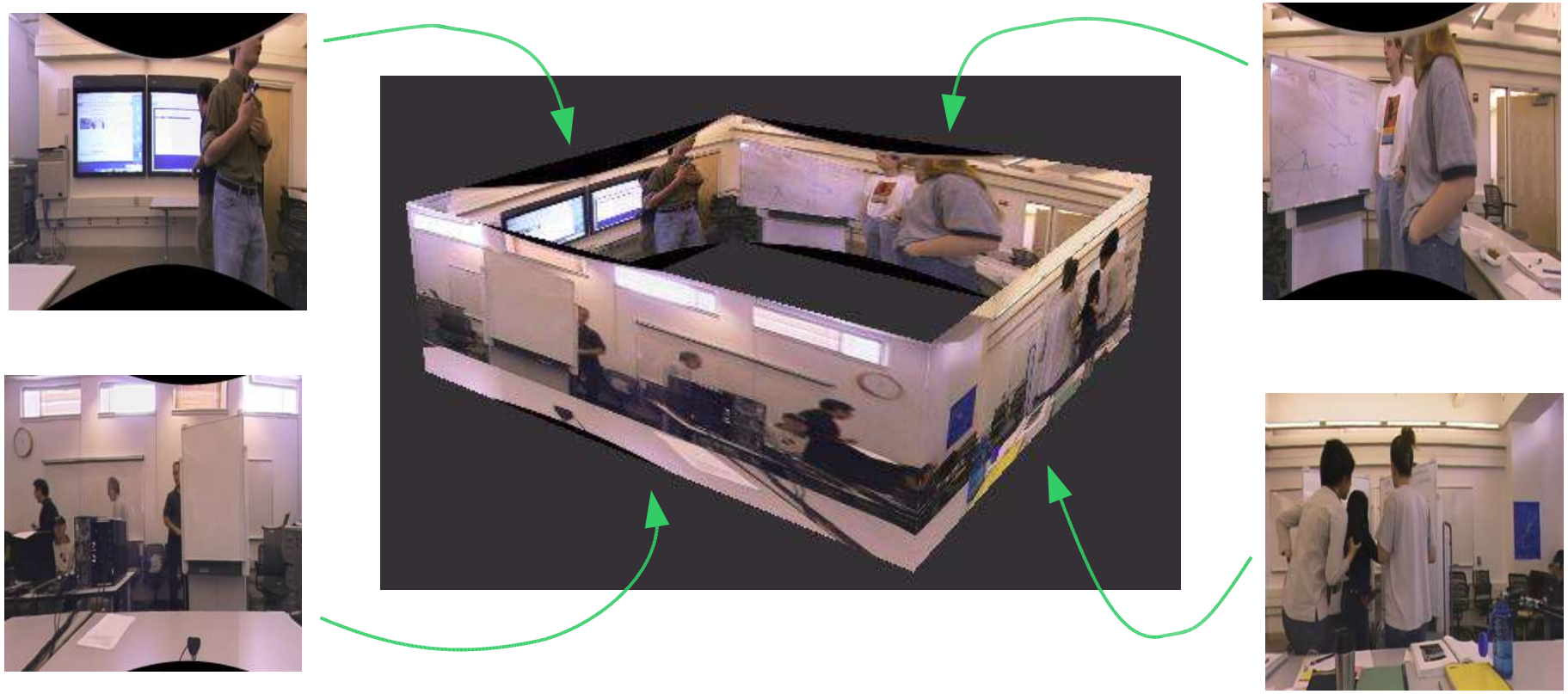
E>0. Camera should be higher.



E<0. Camera should be lower.

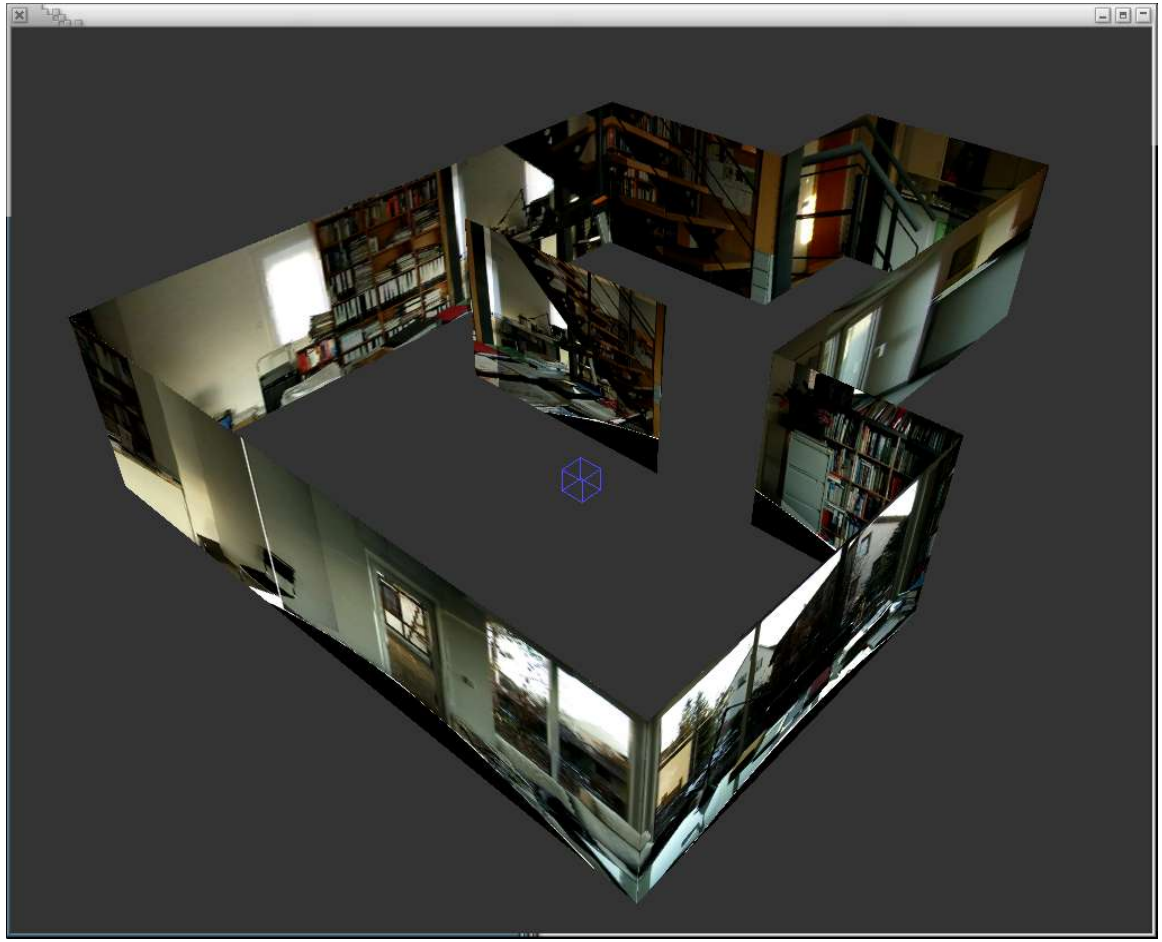
Generate Texture Maps

- Compute wall textures using the inverse of the cylindrical coordinate transform.



Look into the future...

- Currently working on reconstruction of arbitrary room shapes.



Conclusions

- Panoramic images are difficult to understand intuitively.
  - 360° views vs. human 180-200° field of view
  - scene layout difficult to see in the image
- We presented a new algorithm to reconstruct a 3-D model of the scene environment.
  - Simple user-interface (only mark four room corners).
  - Fast and easy reconstruction algorithm.
- 3-D model enables a flexible visualization
  - Virtual camera placed outside shows scene layout.
  - Virtual camera placed inside shows realistic views.