Lecture 22: Image-based Rendering

Fall 2004

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Announcements

- In-class exam next week Nov 18th
  - Will post last year's exam on CMS
- HW 3
  - First, make it work
  - Then optimize
  - Use results reported as guide

Complexity

- Lighting: many lights, environment maps
  - Global illumination, shadows
- Materials: BRDFs, textures
- Geometry: Level-of-detail, point-based representations
- All: image-based rendering

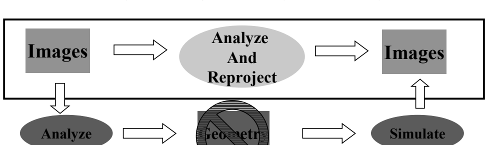
Idea

- **Can we use photographs?**

- **Photographs capture**
  - High geometric complexity
  - High lighting and material (BRDF) complexity
- **How do we use them?**

Image-based Approaches

- Combine vision and graphics
- Given images and *some* geometry
  - Render new images from existing images
  - New idea: Image is input *and* rendering primitive
  - No (or very little) geometry recovery

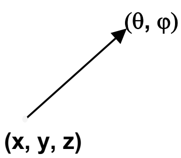


Pros

- Promising approach to handle complexity
- Benefits:
  - No labor-intensive modeling
  - Captures high geometric/material complexity
  - Rendering time constant: proportional to image size, independent of scene complexity

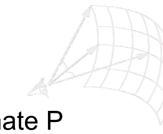
The Plenoptic Function

- $P(x, y, z, \theta, \varphi)$: radiance over all points in space and in all directions
  - 5D function: theoretical concept
- Why do we care? Rendering computes P



Images are subset of P

- Think of an image in a new way!!!
- Image = radiance for each ray in image
  = radiance through a collection of rays
  = subset of plenoptic function P



- 1 Input image = subset of P
- Several input images approximate P
- All possible images = P

IBR idea

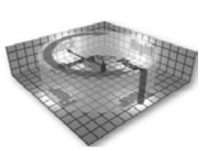
- Idea: Replace scene by images
- Output: new viewpoint
  - Look up plenoptic fn. → look up input images
- What are the assumptions?
  - Existing scene
  - Static scene
  - Fixed lighting

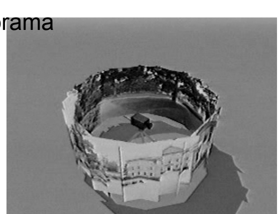
Approaches

- Systems that have no depth
  - Quicktime VR
  - Plenoptic Modeling
  - Lightfields/Lumigraphs
  - Image-based visual hulls
- Systems that have full geometry
  - Surface Lightfields
- Systems that have partial geometry: Image-Based Modeling
  - Façade
- Synthetic systems: impostors

QuickTime VR

- Fixed viewpoint + full range of viewing directions (360^0)
- Panoramic images:
  - Stitch image to form panorama
  - Can look around panorama





Quicktime VR

- Demo
- Pros
  - Simple, fast, effective
- Cons
  - Camera position is confined to predefined observer positions
  - Distortion when user deviates from position

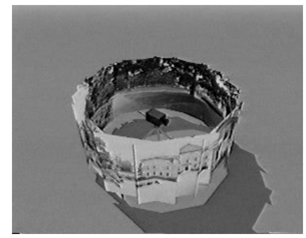
McMillan's IBR

- Input: set of images (panoramic)
- Output: images from new viewpoint
  - Removes constraint on new viewpoint position

- How?
  - Reconstruct the plenoptic function from the images
  - Assumes depth/disparity information

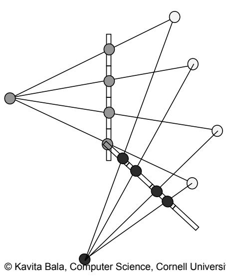
McMillan's IBR

- Construct panorama from one viewpoint
- Collect many such panoramas



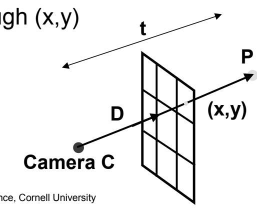
Pixel Reprojection

- Goal: Want image at new viewpoint
- Reproject points from input images



Pixel Reprojection

- Assume have depth/disparity per pixel
- If pixel (x,y) sees point P,
- $P = C + t D$
- C is camera position,
- D is direction from C through (x,y)
- t is distance along D

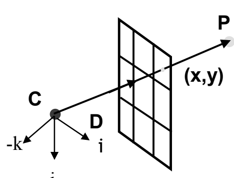


Pixel Reprojection

- Direction D

$D = C + x\,i + y\,j + d\,k$

(x, y) = pixel



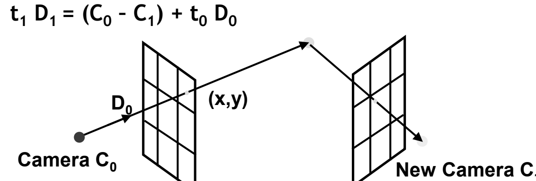
- C = camera center
- d = distance of image plane from C
- C, d are known

Reprojection

$P = C_0 + t_0 D_0(x,y)$

$C_0 + t_0 D_0 = C_1 + t_1 D_1$

$t_1 D_1 = (C_0 - C_1) + t_0 D_0$

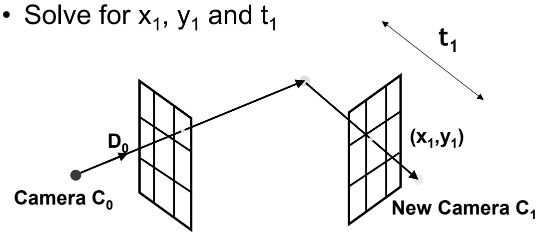


C_0, C_1, D_0, t_0 are known

$t_1 D_1$ defines the reprojected pixel

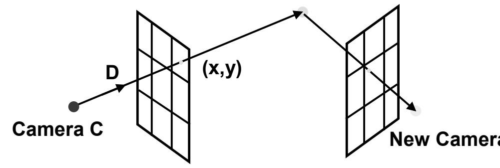
Pixel Reprojection

- $D_1 = C_1 + x_1\, i + y_1\, j + d_1\, k$
- Solve for x_1, y_1 and t_1



Pixel Reprojection

- Reproject points from input panoramas
  - Project points onto the new image plane
  - Color pixel upon intersection with new image plane



Reprojection Example

Problems with Reprojection

- Holes: Information in new view not in original (disocclusion)

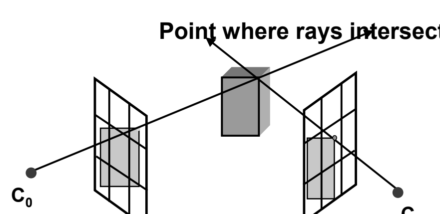
- Solutions:
  - Interpolation
  - Multiple images
  - Re-render missing pixels (only for synthetic scenes!)

Problems with Reprojection

- Aliasing: pixels do not project to pixel centers
  - Solution: Splatting
- Multiple pixels project to same pixel in new view
  - Solution: z-buffer

How to compute depth/disparity?

- Assumption: disparity is known
- Correspondences specified by user
- Recover point (depth/disparity)

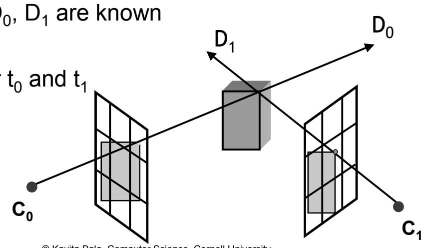


Computing depth/disparity

- $P = C_0 + t_0 D_0(x,y)$

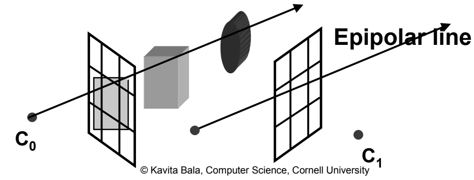
- $C_0 + t_0 D_0 = C_1 + t_1 D_1$
- C_0, C_1, D_0, D_1 are known

- Solve for t_0 and t_1



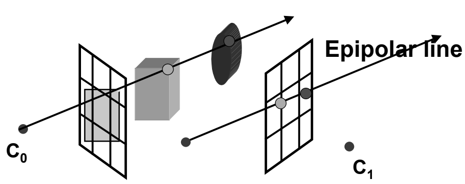
Epipolar geometry

- Specifying correspondence: tedious
- Disparity/depth recovery using epipolar geometry
- Ray corresponds to epipolar line in C_1's image plane



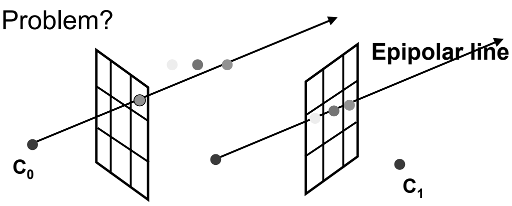
Epipolar geometry

- Different depths correspond to different points on epipolar line



Epipolar geometry

- We don't know depth, but we know the ray
- Given color at pixel (x,y) search along epipolar line for pixel of same color
- Find match, recover depth/disparity
- Problem?



Demo

- Cylindrical epipolar geometry

Plenoptic Issues

- Hard to get accurate depth/disparity
  - View-dependence

- From new viewpoints have holes to fill
  - Interpolation blurs

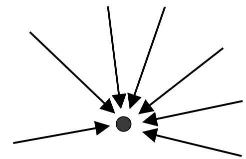
Lumigraph / Light field

- Idea: capture many photographs from different views

- No depth information
- Render image from new viewpoint using existing images
  - Have to lie outside object

What is an image?

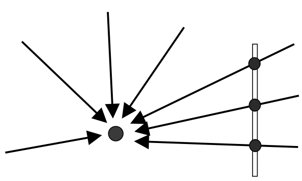
- Image = rays going through one point



- Usually restricted to viewing frustum, but can also be panoramic

What is an image?

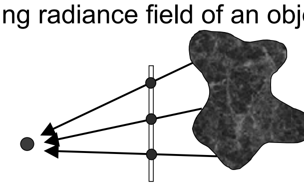
- Image = rays going through 1 point + image plane



- 2D function (position on image plane)

What is an object?

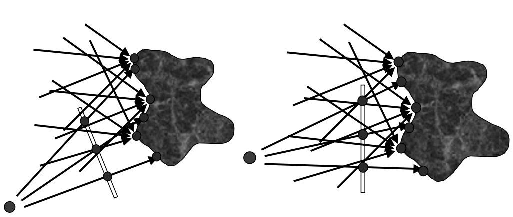
- Outgoing radiance field of an object



- Radiance varies at points on surface
  - 2D function (position on surface)
- Radiance varies in all directions
  - 2D function

What is an object?

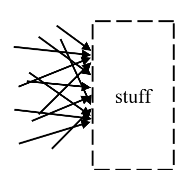
- All possible images of an object



- We don't really need the object

Replace object by images

- Object is only defined by its radiance field
- Images capture all information about object

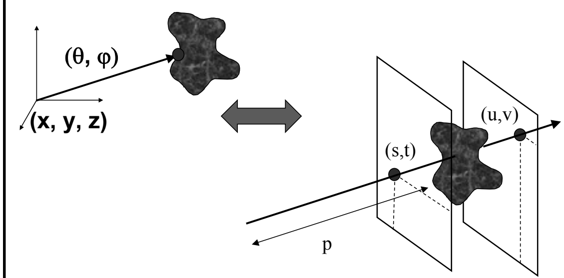


- New viewpoint: look up appropriate images

Questions

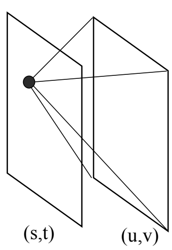
- How to capture the input images?
- How to store the images efficiently for retrieval?
- How to render new images?

Rays: 2 plane parameterization



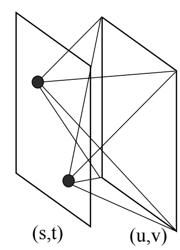
Lumigraph organization

- Hold (s,t) constant: an image



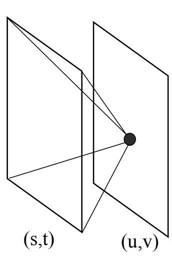
Lumigraph organization

- Hold (s,t) constant: an image



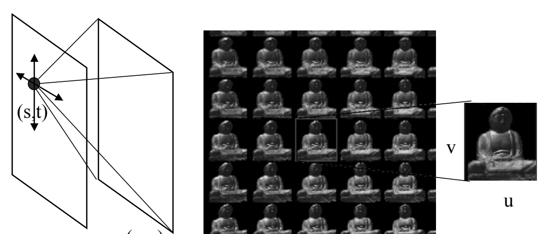
Lumigraph organization

- Is this an image?



LightField/Lumigraph Idea

- Move camera carefully in (s,t) plane
- Each image is a 2D slice of 4D function
- Hold (s,t) constant and get an image

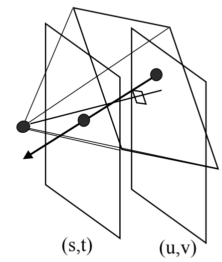


Fish LightField

- Images are a database of rays
  - store in 4D array
- Demo (1,2)

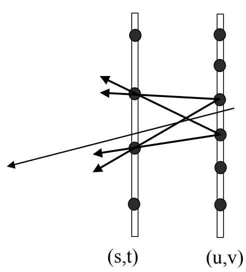
Lumigraph - rendering

- Look for closest (s,t,u,v) tuplet



Lumigraph - rendering

- Interpolation of 16 values

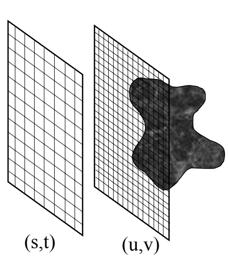


Lumigraph - rendering

- From the new viewpoint
  - Cast a ray for each pixel of image
  - Intersect it with the (s,t) and (u,v) plane
  - Find the closest (s,t) point as a reference image
  - Select closest (u,v) point (i.e., ray whose orientation is closest to desired orientation)
  - Do quadralinear interpolation
- Demo 1
- Demo 2

Lumigraph organization

- Higher resolution near object
  - captures texture
- Lower resolution far away
  - captures direction



LightField/Lumigraph Pros/Cons

- Pros
  - No depth information at all
  - Interactive performance
- Cons
  - Lots of images!!! (w/ compression 100s MB)
  - Specialized hardware to compute images
  - Constrained to lie outside the object
  - Works for small objects
  - Blurry results