Image-Based Rendering
Using Image Warping

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Conventional 3-D Graphics

✔ Simulation

Geometry

Physics

Simulation

Computer

Display
Computer Vision

✔ Analysis

Images → Analysis → Geometry

Assumptions about Physics

The Image-Based Approach

✔ Transformation

Images → Analyze & Reproject → Images

Analyze

Geometry

Simulate
Images as a Collection of Rays

An image is a subset of the rays seen from a given point. This “space” of rays occupies two dimensions.

The Plenoptic Function

The set of rays seen from all points ...

\[ p = P(\theta, \phi, x, y, z, \lambda, t) \]
Image-based rendering is about

...reconstructing a plenoptic function from a set of samples taken from it.

✔ Ignoring time, and selecting a discrete set of wavelengths gives a 5-D plenoptic function

Where to Begin?

✔ Pinhole camera model

- Defines a mapping from image points to rays in space
Mapping from Rays to Points

Simple Derivation

\[ P = \begin{bmatrix} u_x & v_x & o_x \\ u_y & v_y & o_y \\ u_z & v_z & o_z \end{bmatrix} \]

\[ \hat{X} = \hat{C} + t \vec{P}_x \]

Correspondence

\[ \hat{C}_2 + t_2 P_2 \hat{x}_2 = \hat{C}_1 + t_1 P_1 \hat{x}_1 \]

\[ t_2 P_2 \hat{x}_2 = \hat{C}_1 - \hat{C}_2 + t_1 P_1 \hat{x}_1 \]

\[ t_2 \hat{x}_2 = P^{-1}_2 (\hat{C}_1 - \hat{C}_2) + t_1 P^{-1}_1 \hat{x}_1 \]

\[ \frac{\delta}{\delta t} \hat{x}_2 = \frac{1}{t_2} P^{-1}_2 (\hat{C}_1 - \hat{C}_2) + \frac{1}{t_1} P^{-1}_1 \hat{x}_1 \]

\[ \hat{x}_2 = \frac{1}{t_2} P^{-1}_2 (\hat{C}_1 - \hat{C}_2) + \frac{1}{t_1} P^{-1}_1 \hat{x}_1 \]
Planar Warping Equation

\[ \bar{x}_2 = \delta(\bar{x}_1)P_2^{-1}(\bar{C}_1 - \bar{C}_2) + P_2^{-1}P_1\bar{x}_1 \]

\[
\begin{align*}
\delta(\tau_i)(\bar{C}_i - \bar{C}_j) & \\
\delta(\tau_i)(\bar{C}_i - \bar{C}_j) & \\
\end{align*}
\]

Resulting Warping Function

✓ A perturbed planar warp ...

\[ \bar{x}_3 = \delta \bar{e}_3 + H_{31}\bar{x}_1 \]
Special Case

✔ A simple Planar warp

\[ x_2 = H_{21}x_1 \]

Warping in Action

✔ A 3D Warp
Visibility

- The warping equation determines where points go...

... but that is not sufficient

Partition Reference Image

- Project the *desired* center-of-projection onto the reference image
Enumeration

- Drawing toward the projected point guarantees an *occlusion compatible* ordering.
- Ordering is consistent with a painter's algorithm.
- Independent of the scene's contents.
- Easily generalized to other viewing surfaces.
- No auxiliary information required.

Reconstruction

- Typical images are discrete, not continuous.
- An image can be formed by different geometries.
Gaussian Cloud Model

- Represents samples as Gaussian cloud densities
- Excessive exposure errors

Bilinear Patch Model

- Fits a bilinear patch through grid points in reference image
- Excessive occlusion errors
Comparison of Models

- **Gaussian-Cloud Model**
  - Excessive exposure errors
  - Pinhole problems
  - Generally preferred

- **Bilinear-Patch Model**
  - Excessive occlusion errors
  - Rasterization H/W
  - Difficult to navigate

Problems with Planar Cameras

- Invisible occluder problem
- 5 intrinsic parameters
- Non-uniform sampling of solid angle
Panoramic Cameras

✔ Warping equation can be easily adapted
✔ Visibility algorithm works
✔ Nonlinear mapping functions

Examples

✔ Cylindrical camera
Constructing Panoramas

✔ Images are related by a projective transforms

\[ \tilde{x}_2 = H_{21} \tilde{x}_1 \]

✔ Optimization problem
  - maximize normalized correlation
  - minimize sum of squared error

Initial Guesses and Constraints

✔ Sum of angles is $2\pi$
  - constrains focal length

✔ Skew of camera is near 0

✔ Aspect ratio near 1
Finding Disparity

✔ How to get it
- 3-D laser scanners
- Depth-from-stereo
- Depth-from-motion
- Depth-from-focus
- Depth-from-light-fields
- Manual layer segmentation

✔ How accurate must it be?

Visual Hulls

✔ Depth-from-silhouettes
✔ Simple computer vision methods
  - blue screening
  - image differencing

✔ Can be computed in image space
Image-based Visual Hulls

✔ Volume-like
✔ Self-consistent
✔ Discrete-continuous

Depth from Redundant Structure

✔ Light fields for depth acquisition

• Depth-from
  - stereo
  - motion
  - focus
  - silhouettes
Comparing Rendering Approaches

✔ Geometry Based
  ● Forward Mapping (graphics pipeline)
  ● Inverse Mapping (ray tracing)

✔ Image based
  ● Greater spatial coherence
  ● Lower depth complexity

Image-Based Pipeline

Geometry-Based Rendering Pipeline

Image-Based Rendering Pipeline
Forward-warping

✔ Single depth value per pixel

Forward-Mapped Visual Hull

✔ Draws a line segment for each interval
Merging Forward Warps

✔ Draw textured line segments

Image-Based Ray Tracing

✔ Inverse warping

\[ x = a(1 - t) + b t \]

Linear Interpolation

\[ x = a\left(\frac{\vartheta}{1 - \vartheta}\right) + b\left(\frac{1}{1 - \vartheta}\right) \]

Harmonic Interpolation
Algorithm Properties

- ✔ Search is confined to a line
- ✔ First intersection is closest point
- ✔ Incremental line drawing
- ✔ Reconstruction in reference image
- ✔ Work is proportional to size of output image

Applications of IBR

- ✔ IBR combined with traditional methods
- ✔ Decouples rendering from interaction
- ✔ Latency compensation
Conclusions

✔ IBR provides
  • new representations for 3D graphics
    - easy to acquire
    - allows efficient rendering
  • scalable performance
    - depends on number of pixels rather than the number of geometric primitives
  • amenable to HW acceleration