Image-Based Rendering to Accelerate Interactive Walkthroughs

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Bell Labs Innovations

3D Models
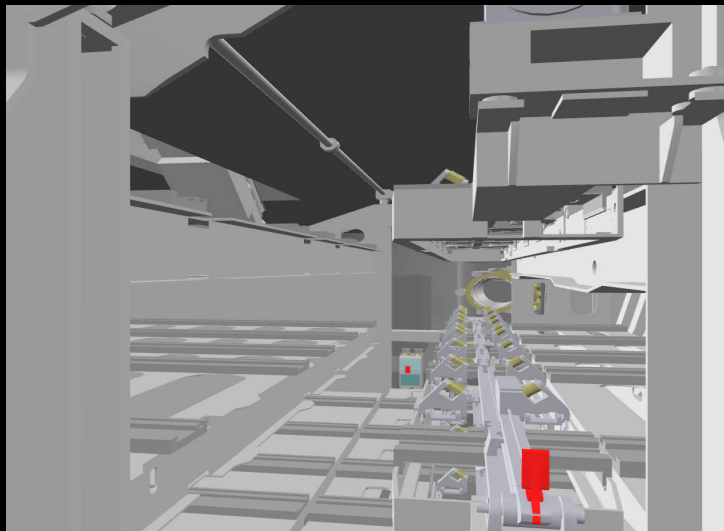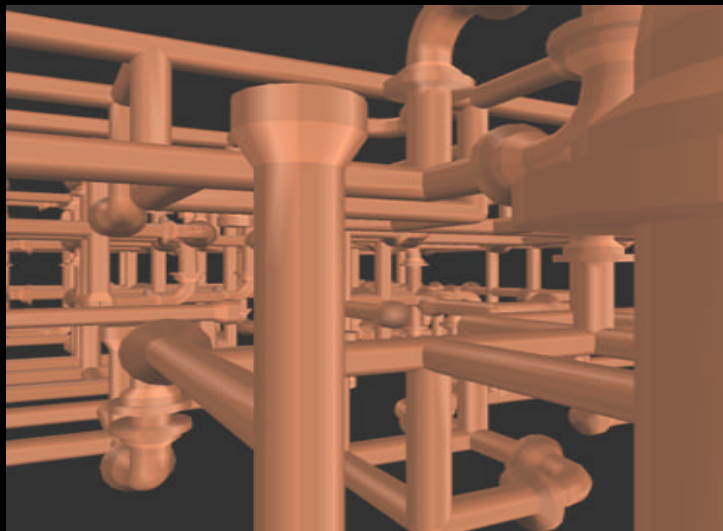

1.7M primitives

2.0M primitives
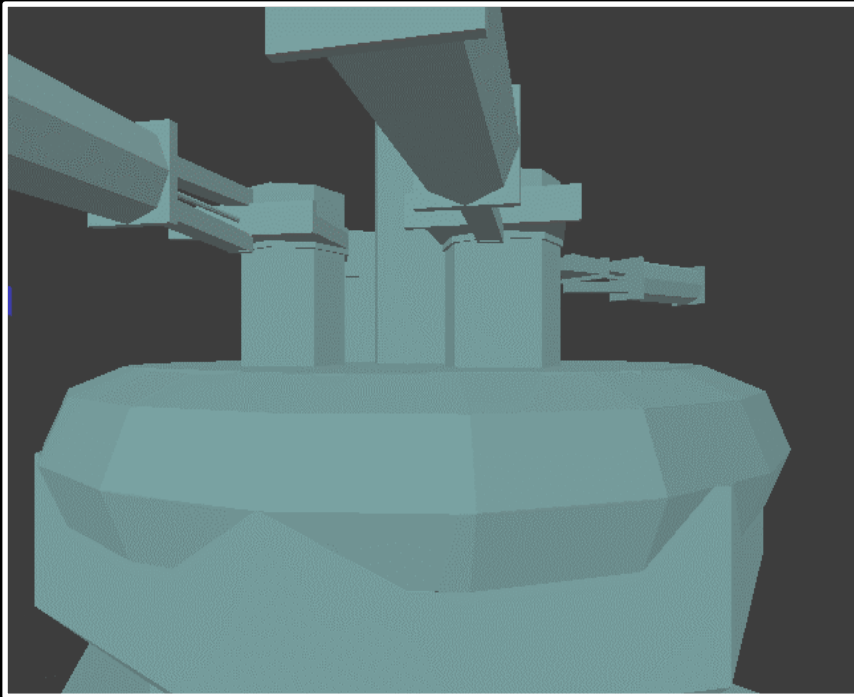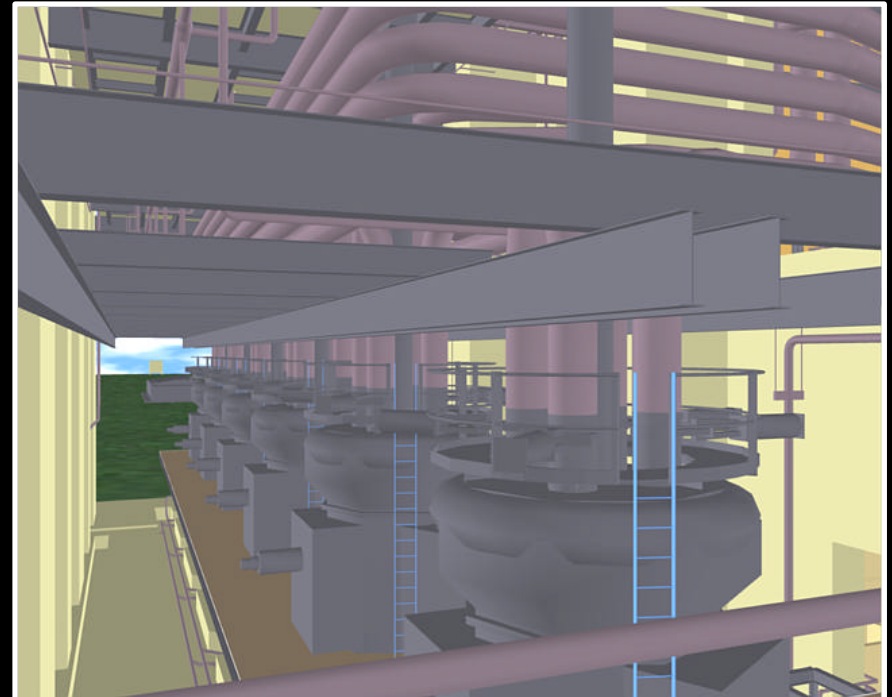
0.9M primitives

1.0M primitives

Why Use Images?

- Independent of scene complexity

640x480 pixels

640x480 pixels

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Flight Simulators

- Mid-1980's
  - E&S CT-6 one of first to use real-time photo textures
- Hand-selected objects:
  - Terrain, trees, airplanes, buildings, etc.
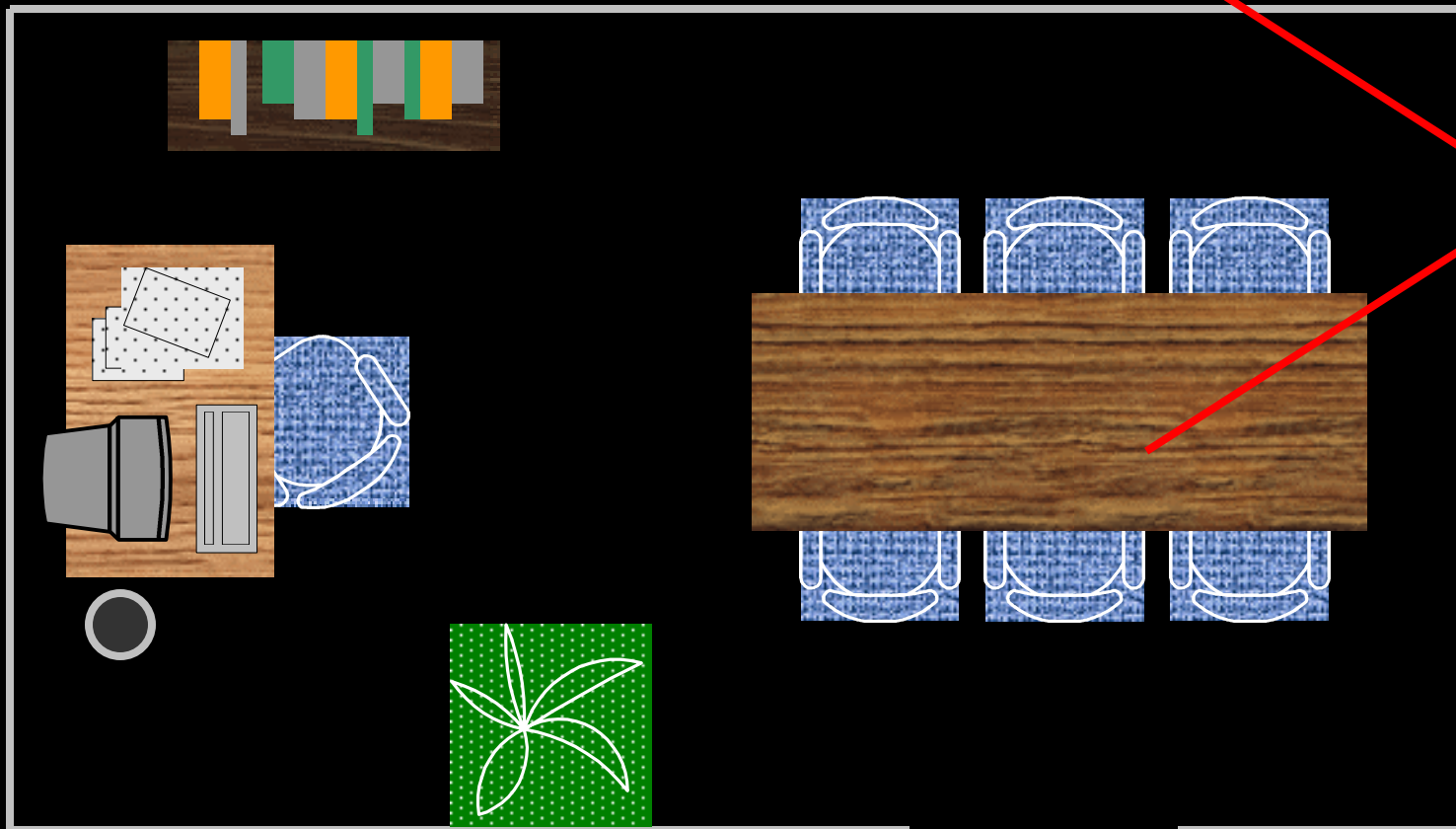- 30-60 Hz
  - High visual fidelity

Outline

- **Replacing Geometry with Images**
- Displaying Images
  - Texture-mapping and error metrics
  - Geometry and image warping
  - Meshes, Lightfield/Lumigraph
- Image Placement
  - Automatically Bounding Model Complexity
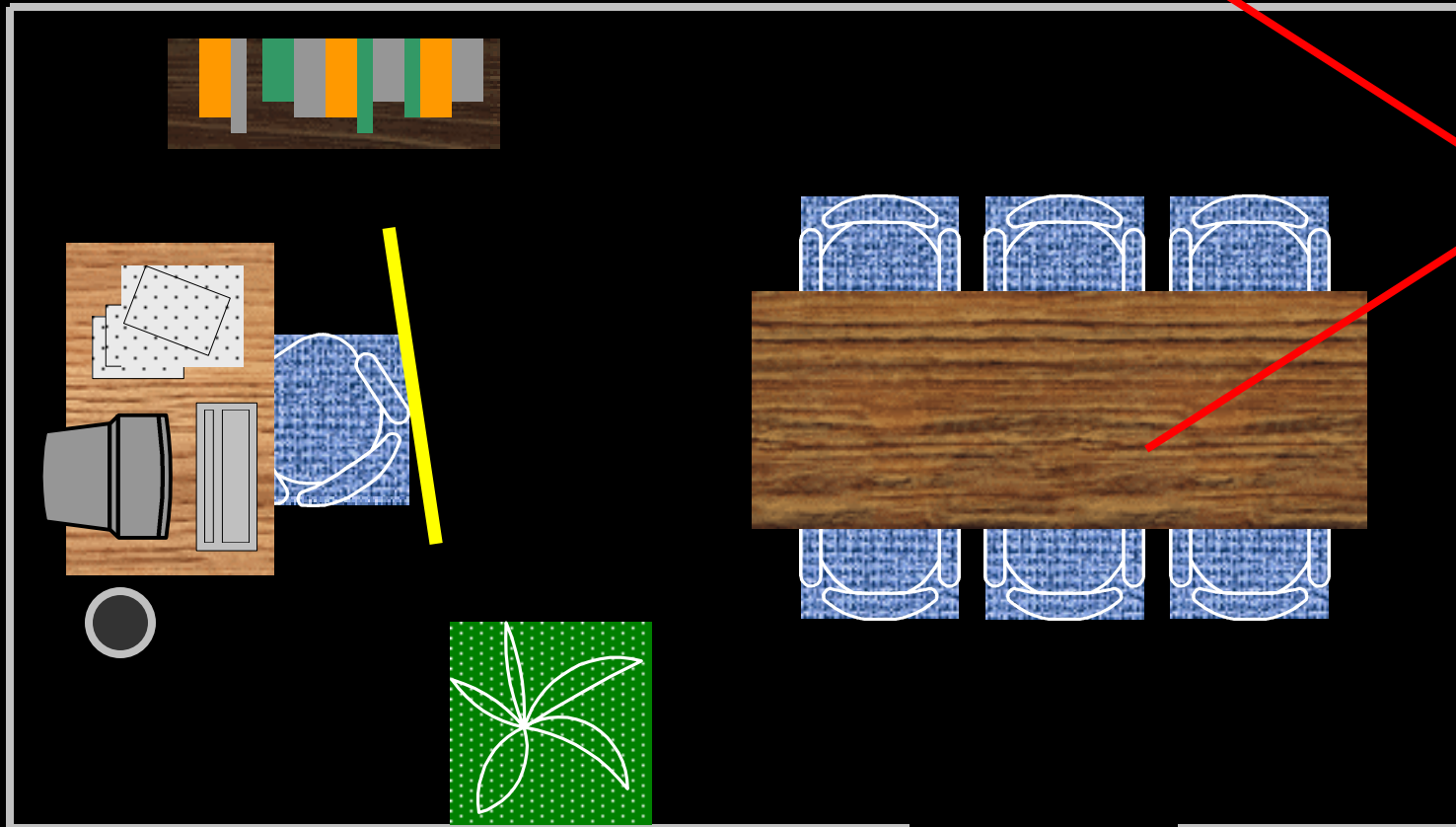 - Cells and Portals
- Conclusions

Replacing Geometry with Images

- Algorithm
  - Select subset of model
  - Create image of the subset
  - Cull subset and replace with image
- Why?
  - Image displayed in (approx.) constant time
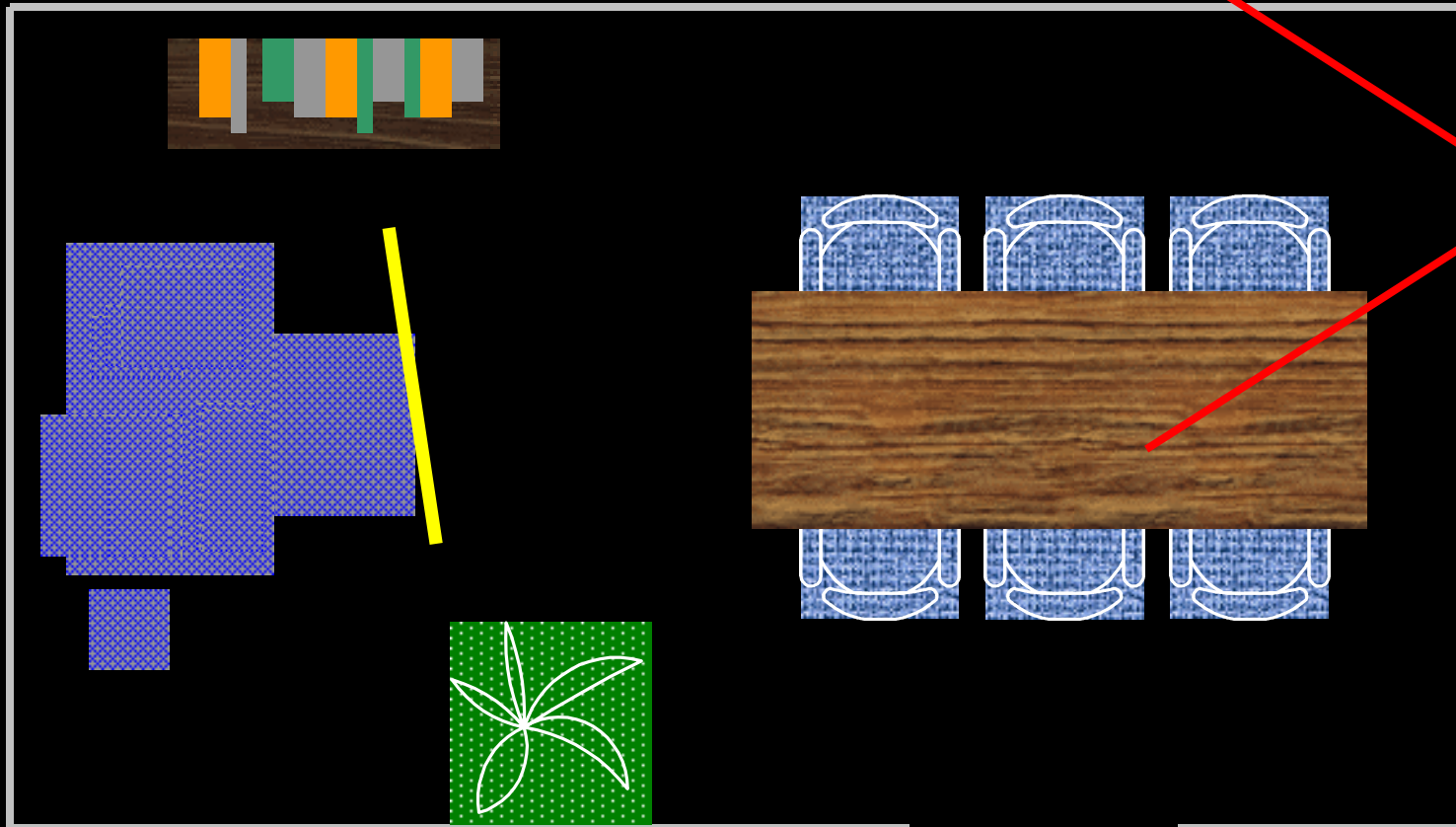 - Image reused for several frames
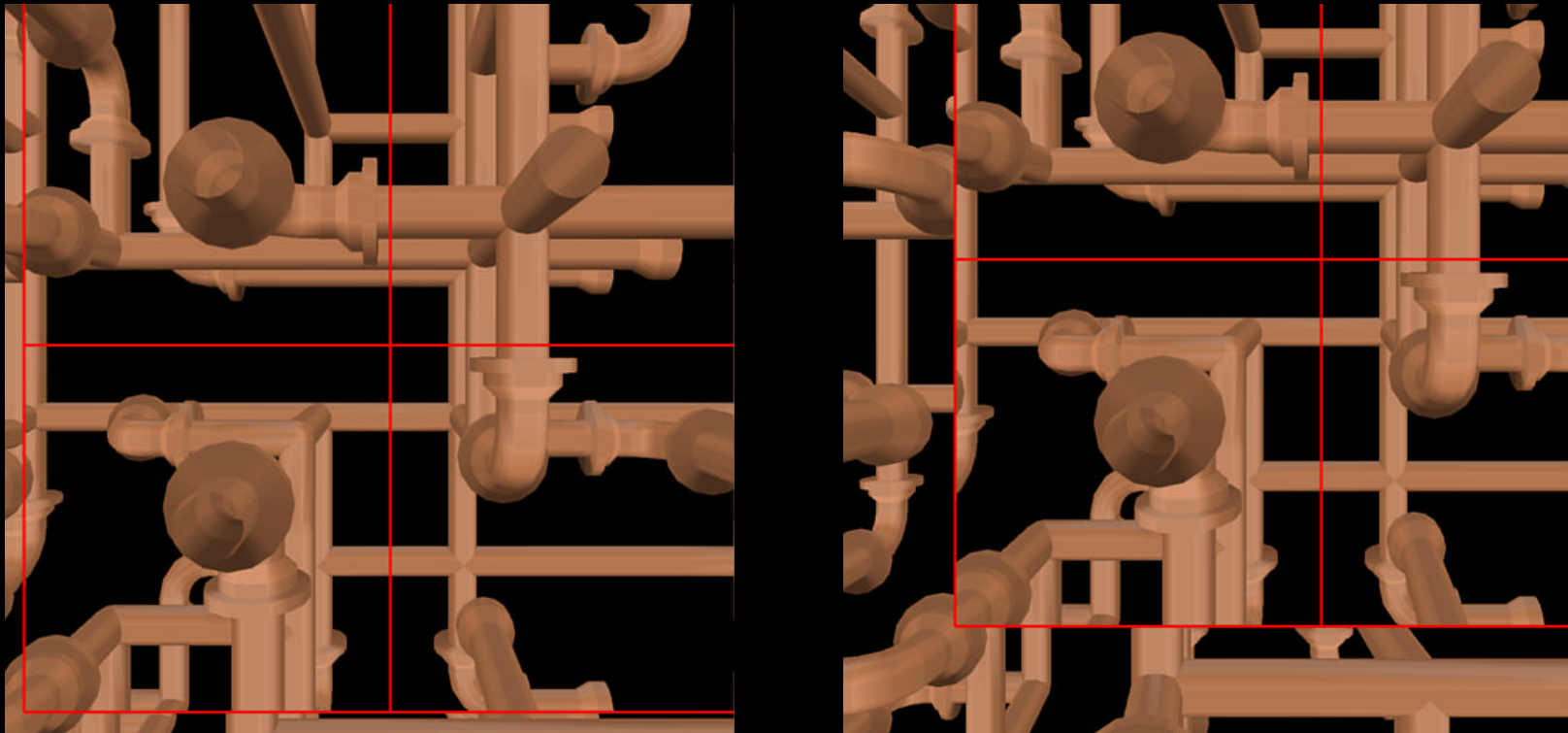
Simple Example

Simple Example

Simple Example

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Geometric Discontinuity

- If we move from the center-of-projection, discontinuities appear at the border
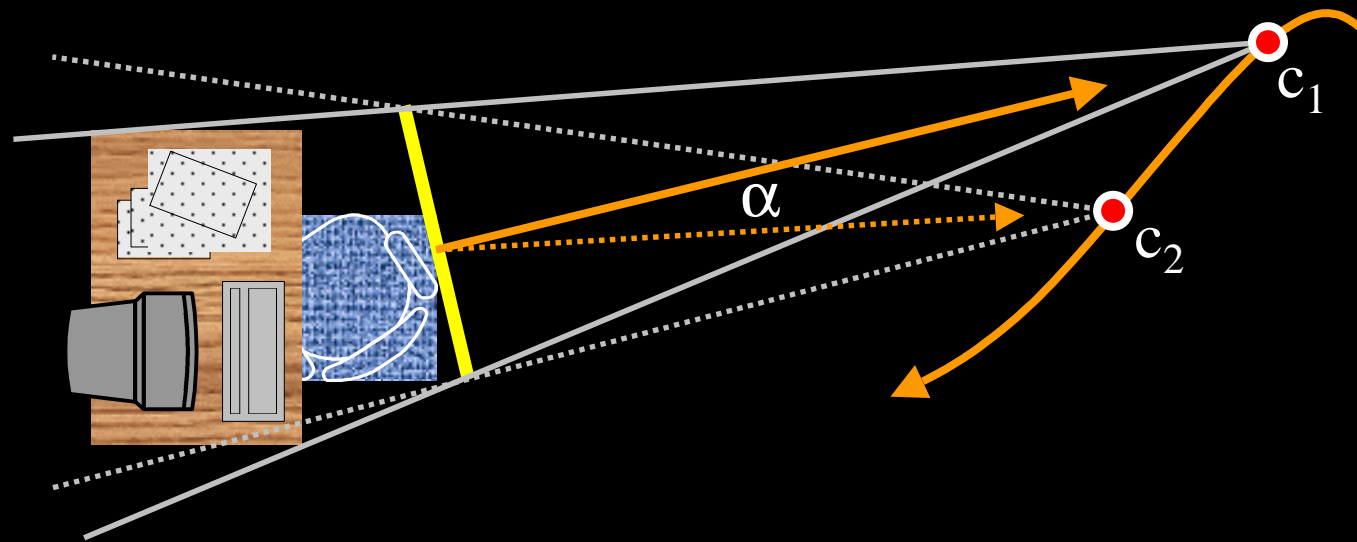
Temporal Discontinuity
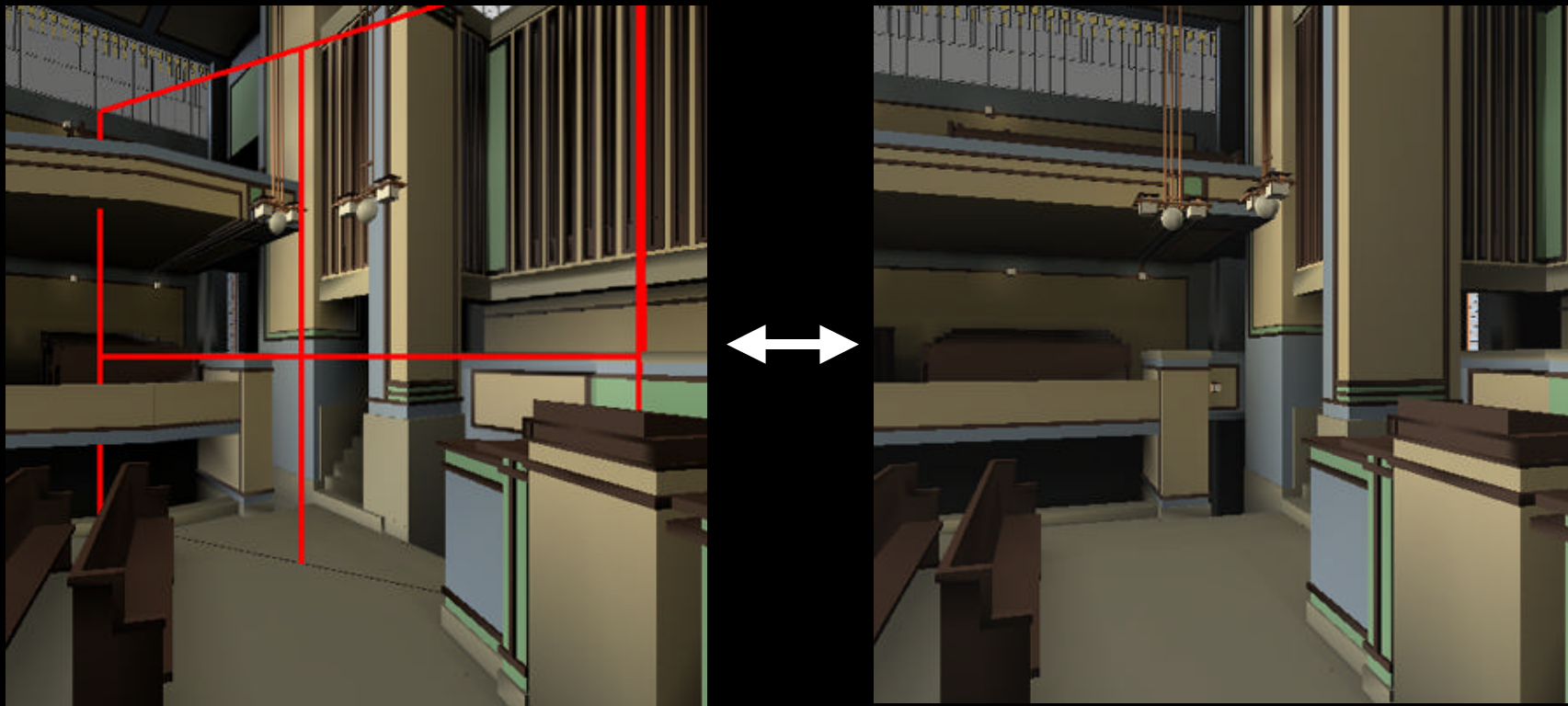
- While moving, if we switch between geometry and image, a sudden *pop* occurs

Approaches

- Geometric and Temporal Continuity
  - Error metrics
  - Geometry warping
  - Image warping
  - Lightfield/Lumigraph

Error Metrics

- Use an *error metric* to control amount of discontinuity

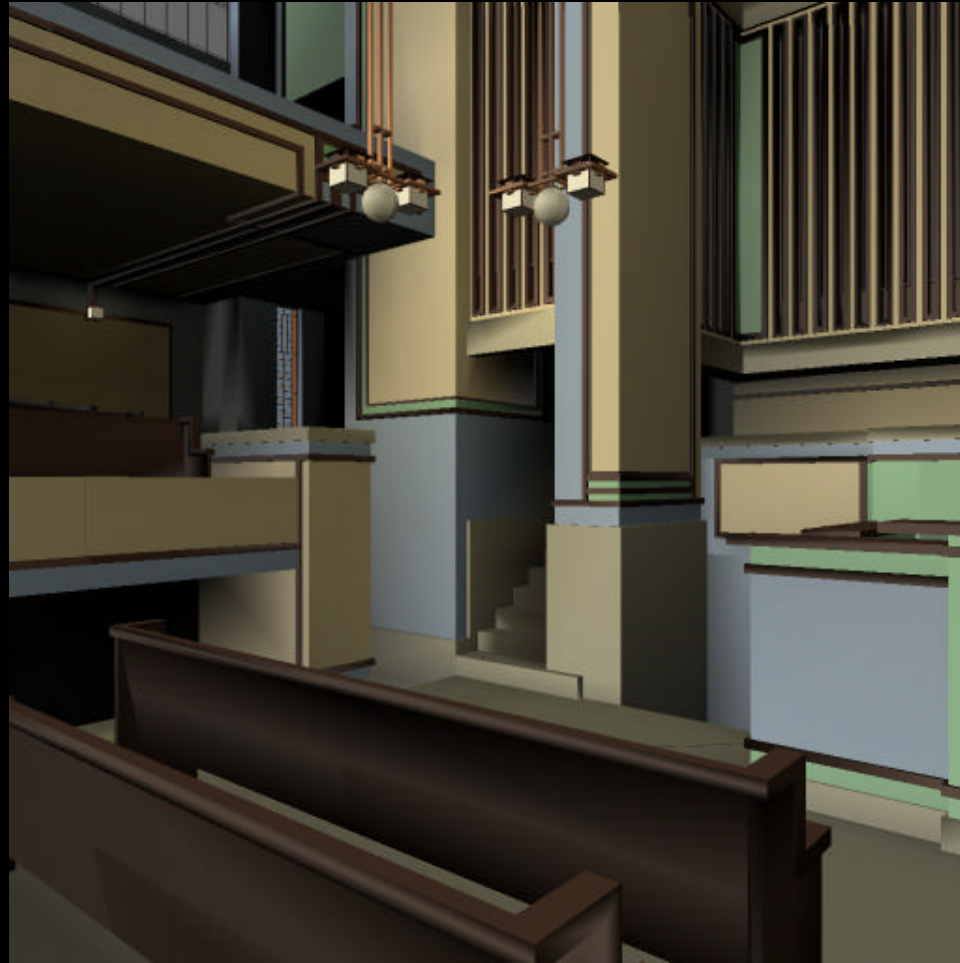[Maciel95][Shade96][Schaufler96]

Error Metric

- Relies on "angular-deviation" measuring the visual quality of using the (same) image

Video Segment I

- Pre-rendered Impostors
  - Maciel95
- Dynamic Image-Caching
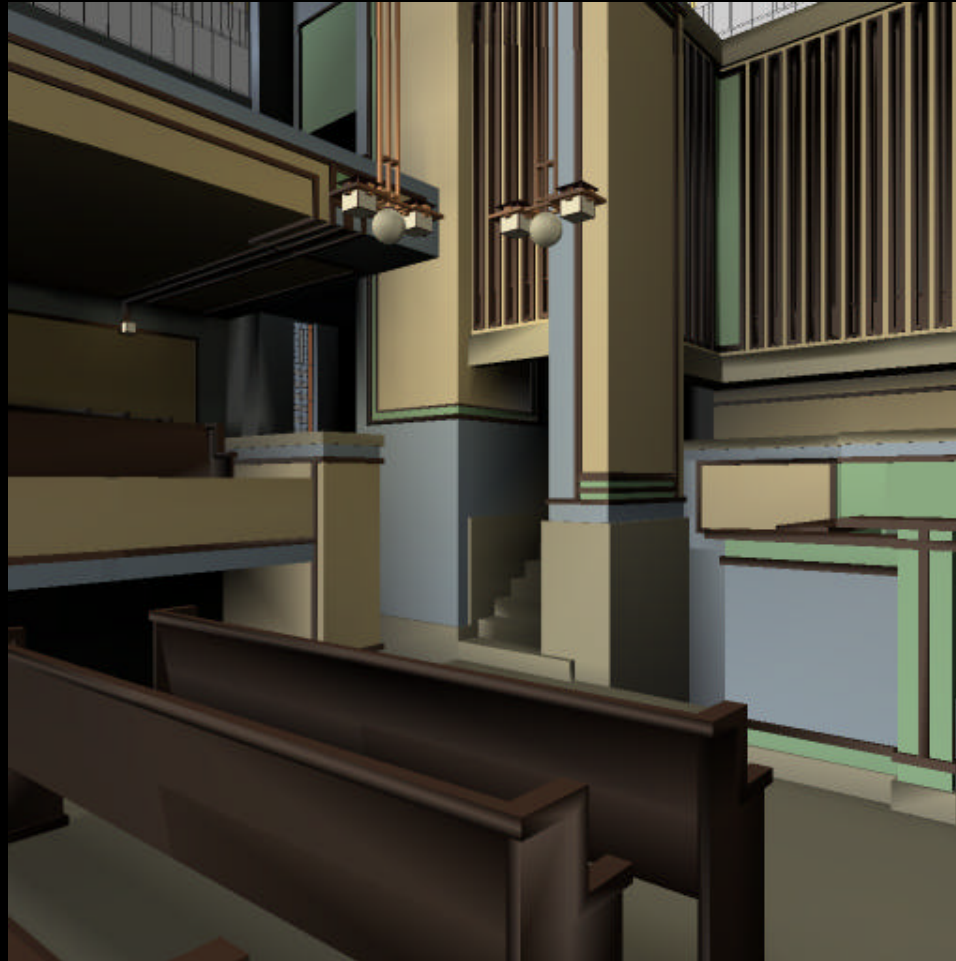 - Shade96, Schaufler96
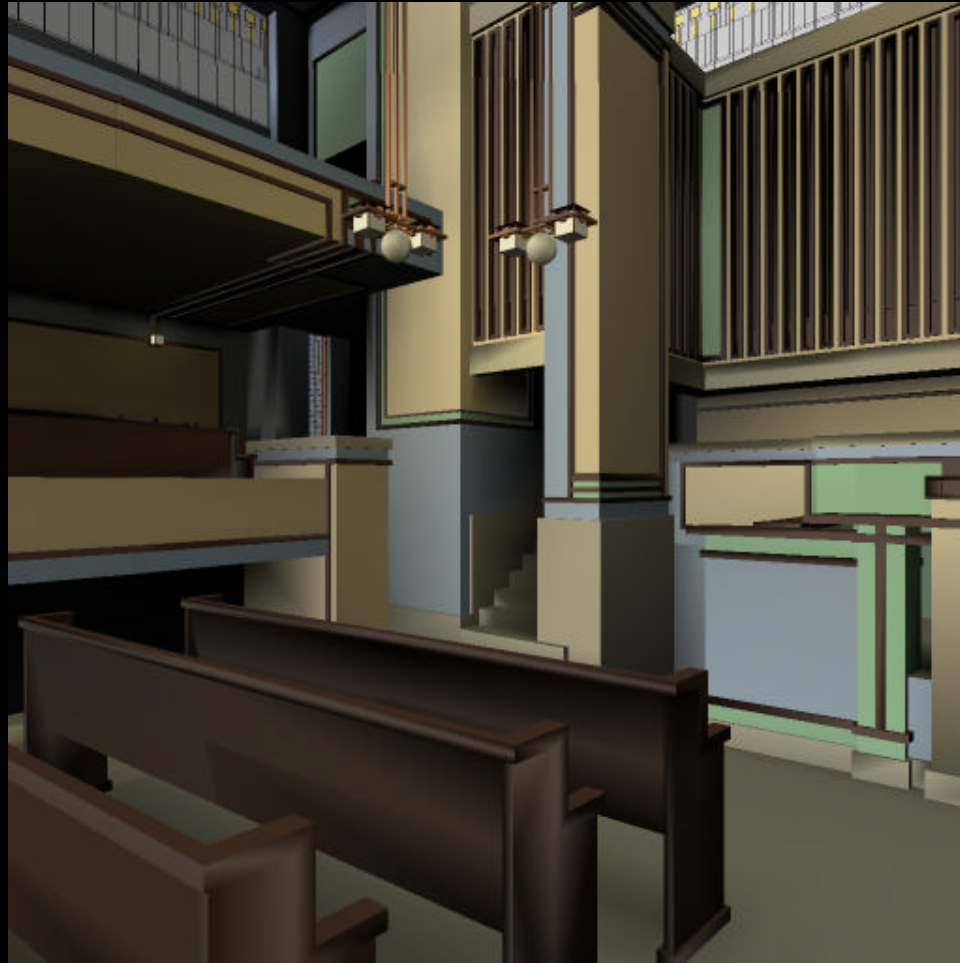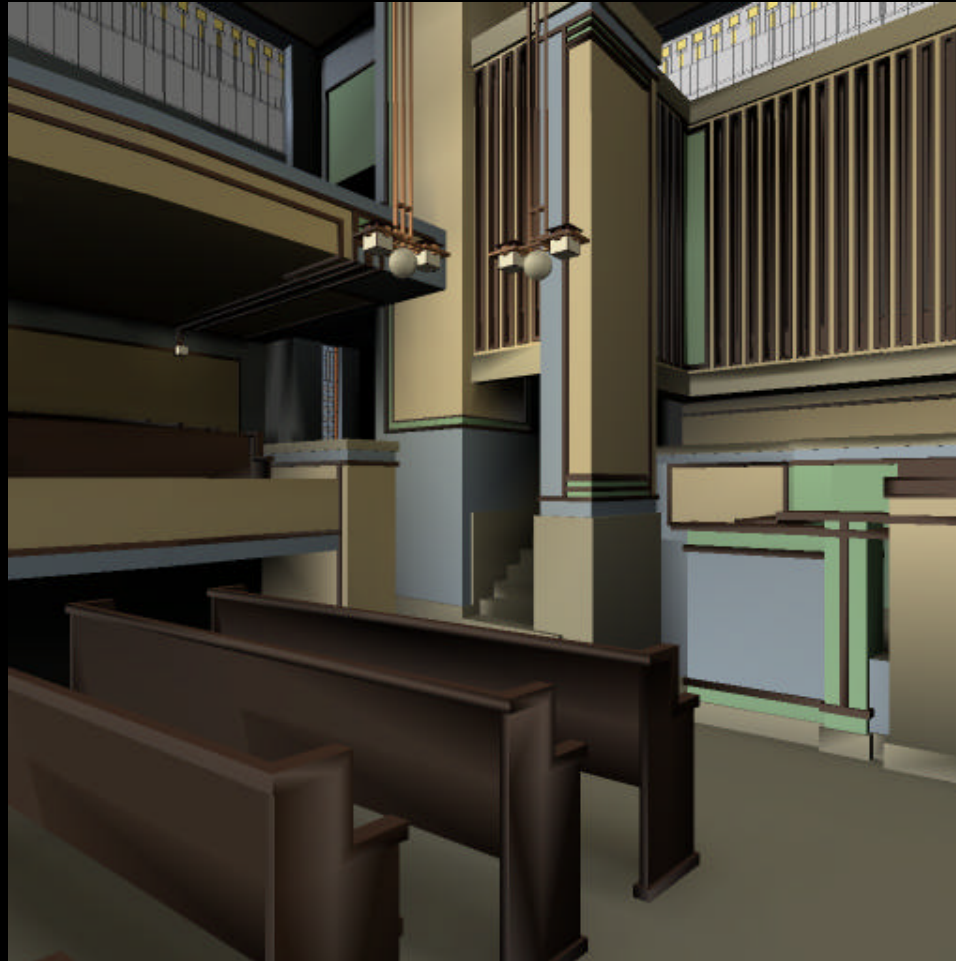
Geometry Warping

[Aliaga96]

Geometry Warping
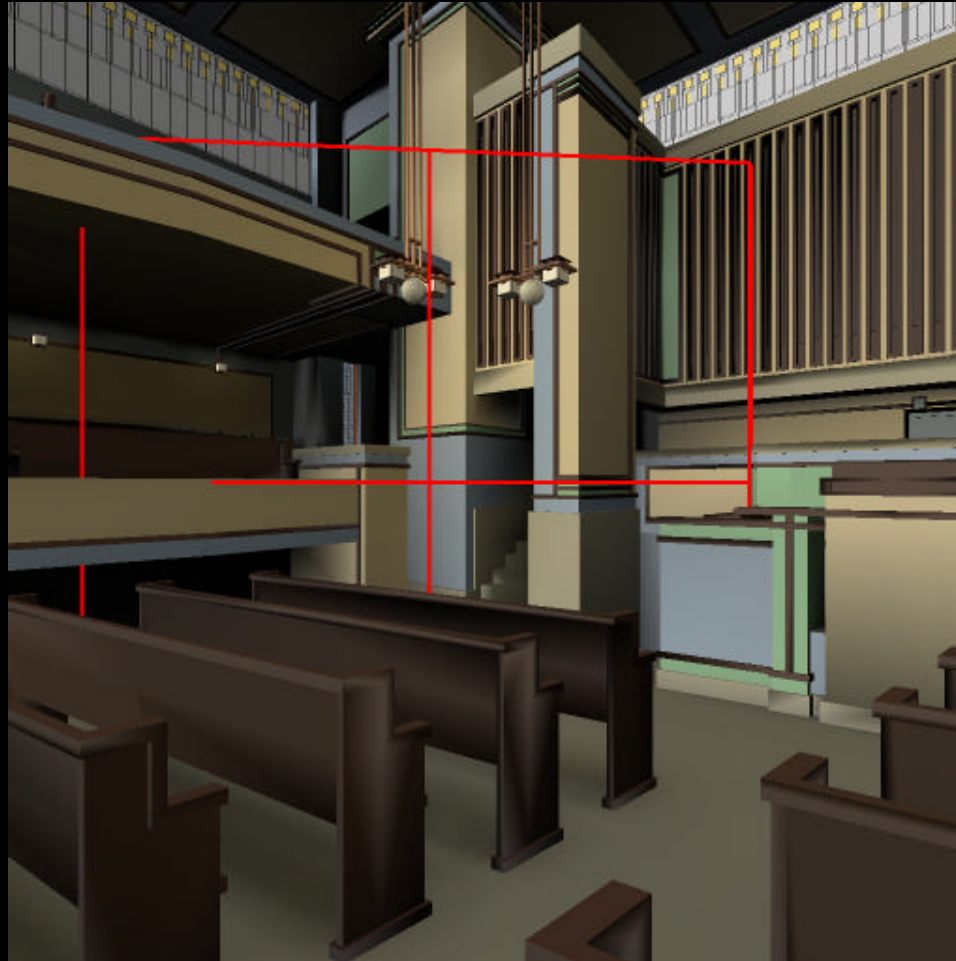
Geometry Warping

Geometry Warping
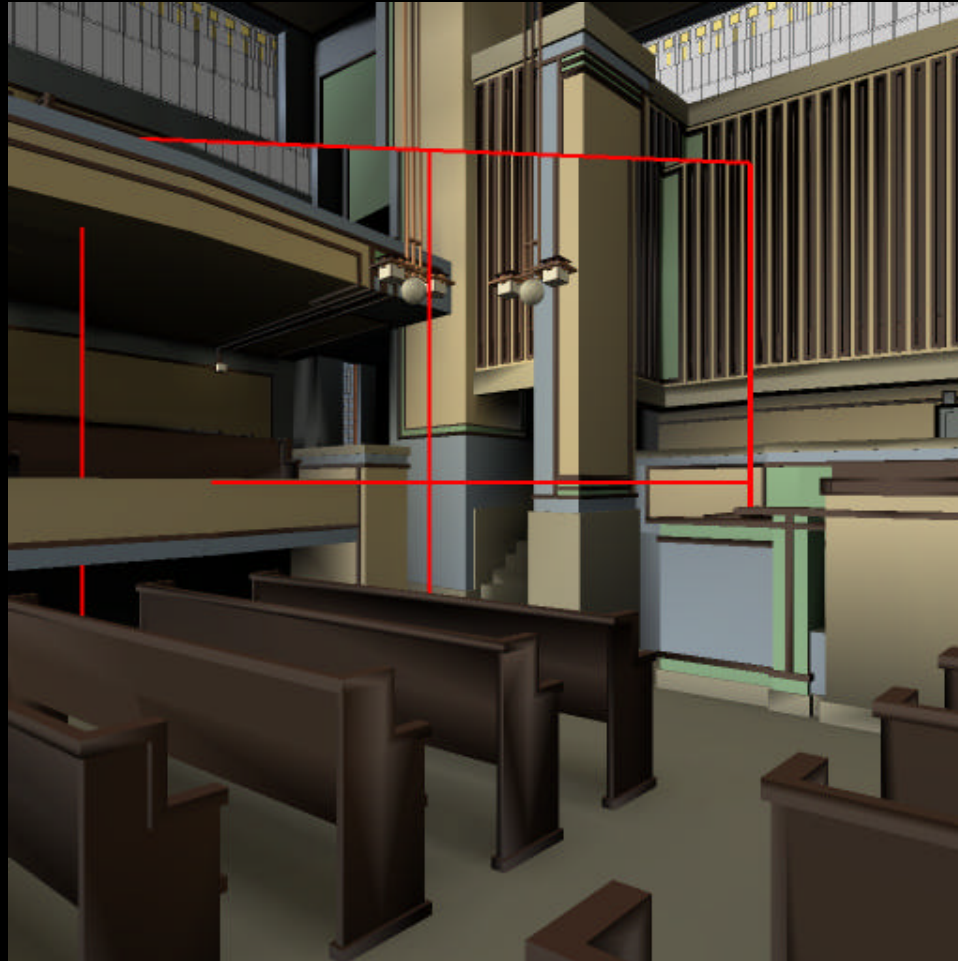
Geometry Warping

Geometry Warping

Geometry Warping

Geometry Warping
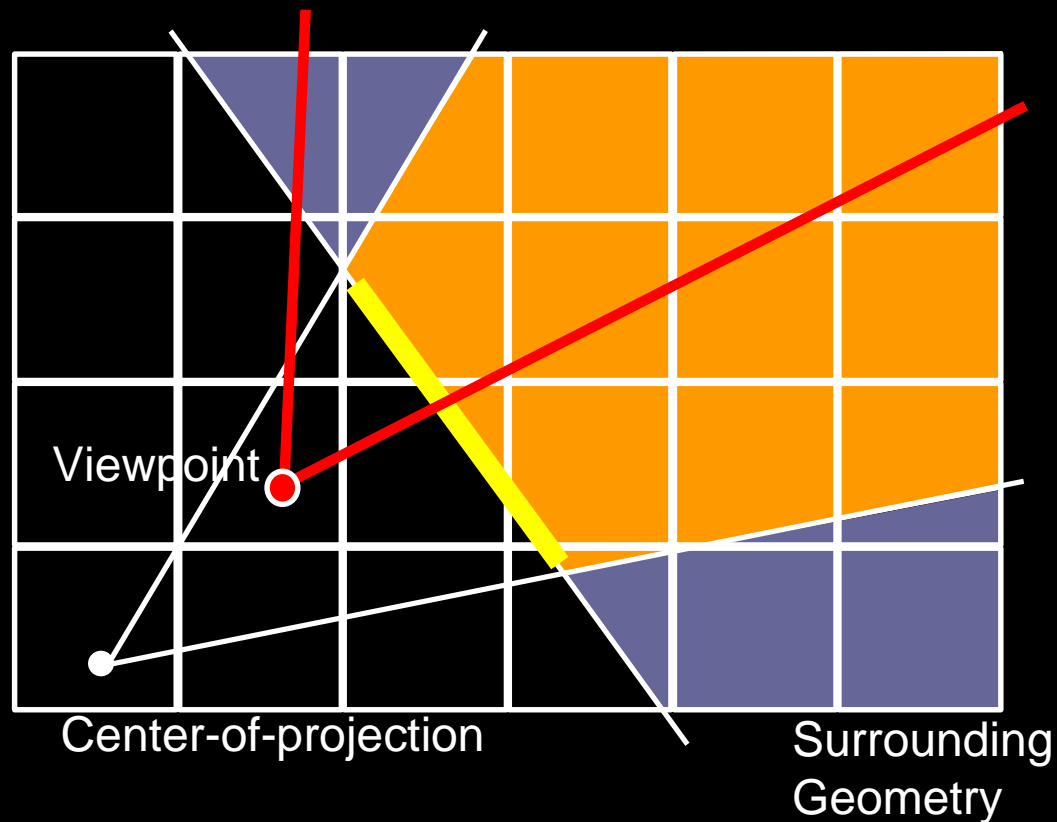
Geometry Warping

Surrounding geometry warped
(incorrect perspective)

Correct perspective

Geometry Warping

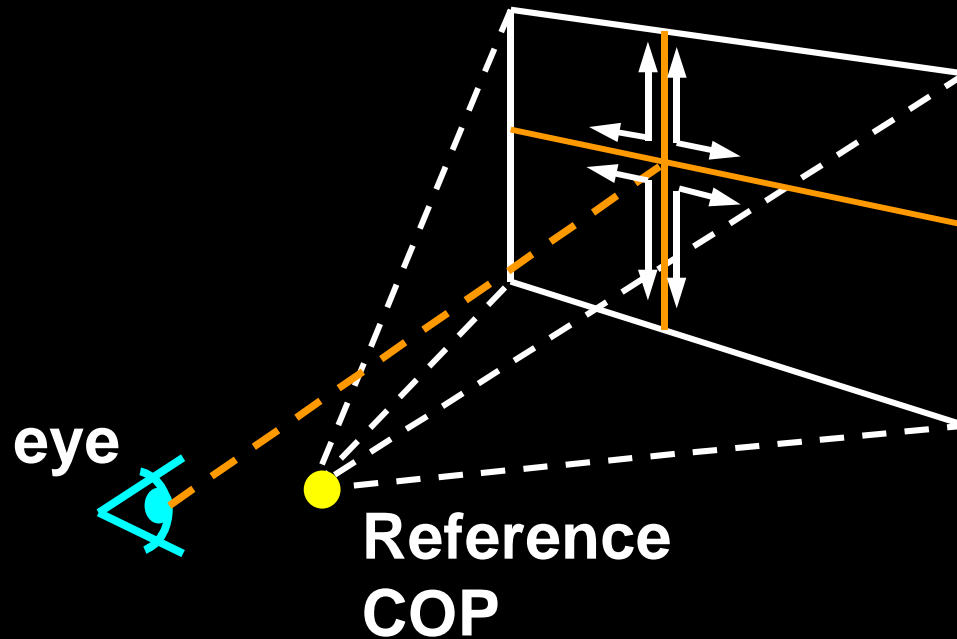- Surrounding geometry warped to match image

Video Segment II

- Geometry Warping
  - Aliaga96

Image Warping

- Change the image itself
  - Re-project the image to the current viewpoint
    - [Chen93][McMillan95][Max95][Shade98]
  - Display image as a (simplified, textured) mesh
    - [Darsa97][Sillion97]

Image Warping

- A raster scan of each sheet produces a back-to-front ordering of warped pixels
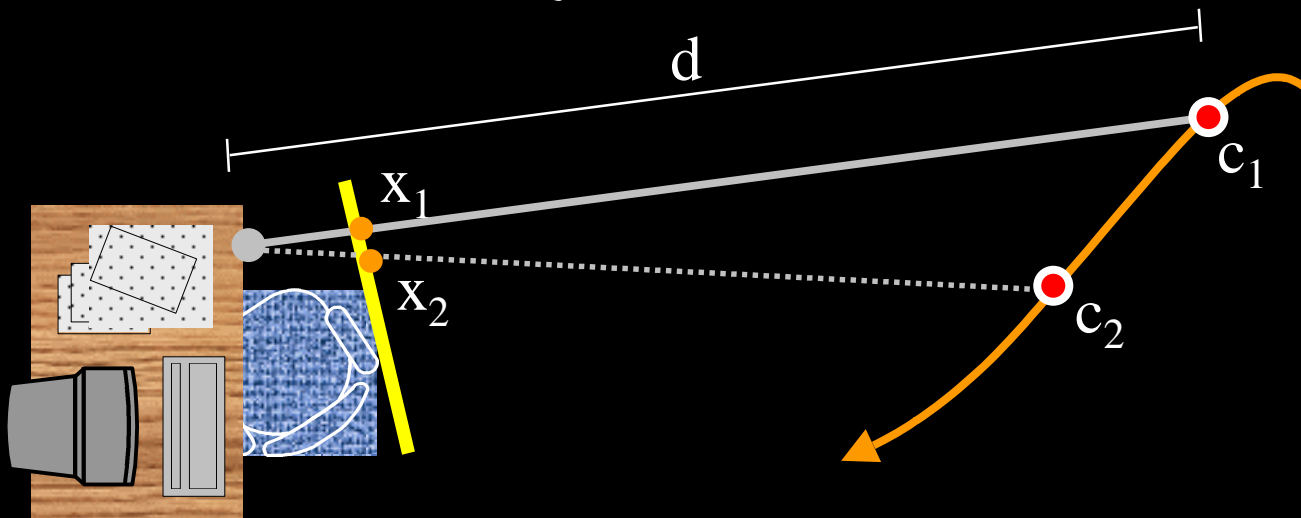
Image Warping

- McMillan and Bishop's Warping Equation

$$x_2 = \delta(x_1) \, P_2^{-1} \, (c_1 - c_2) + P_2^{-1} P_1 \, x_1$$

Move pixels based on distance to eye   ***~Texture mapping***
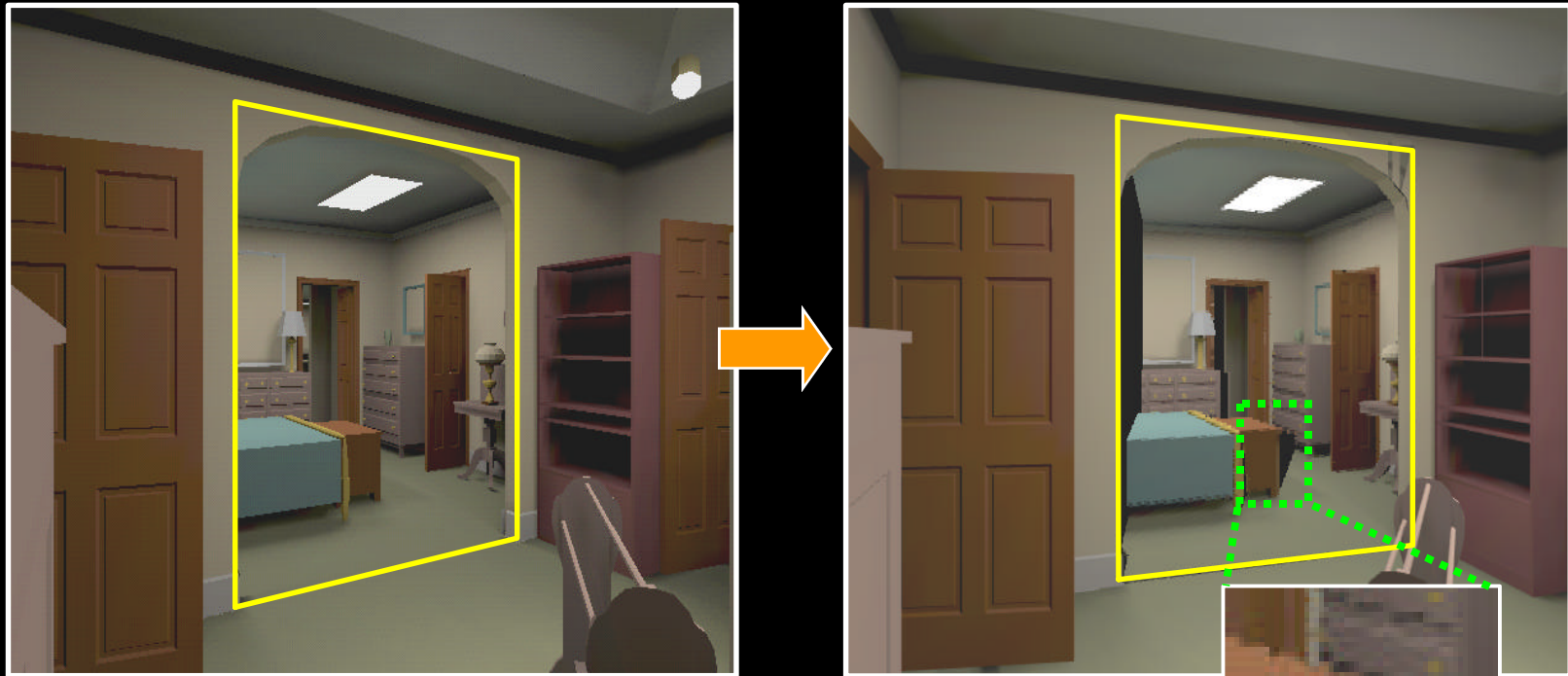
Example...

- Image outlined in yellow
- Viewed from image's center-of-projection

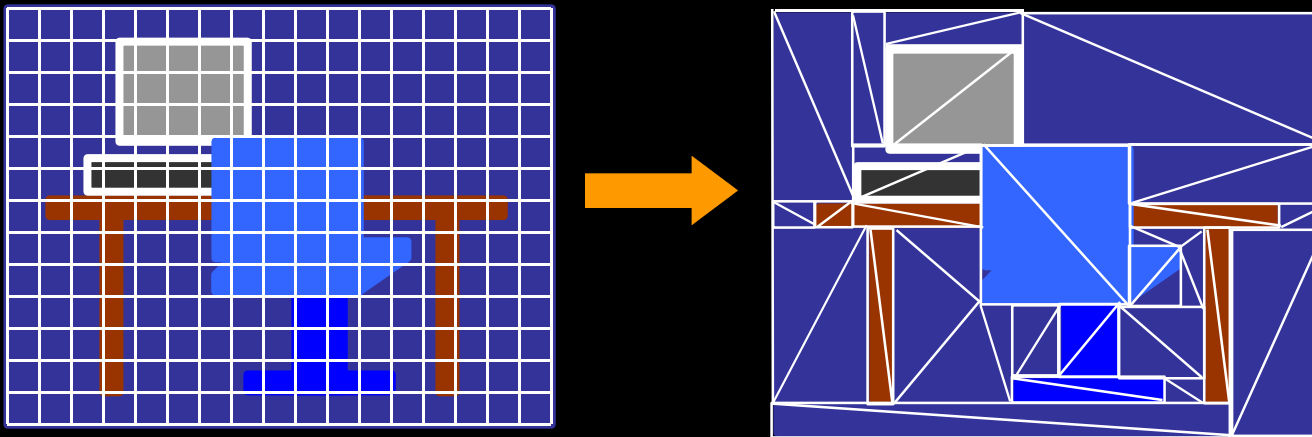# 3D Image Warp

- Single sample per pixel

Layered Depth Image Warp

- Multiple samples per pixel
  - Previous occlusions are filled-in   [Popescu98]

Meshes

- (Simplified) Textured Depth Mesh
  - Per-pixel depth creates mesh that approximates 3D parallax effects
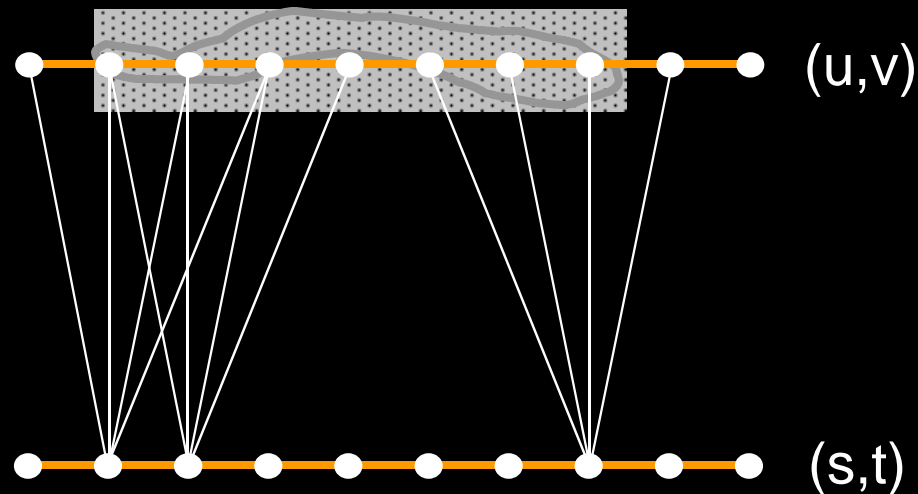 - Image is texture-mapped onto mesh

Video Segment III

- 3D Image Warping
  - McMillan95
- Textured Meshes
  - Darsa97, Sillion97

Lightfield/Lumigraph

- Flow of light at all positions and directions
  - [Levoy96][Gortler96]
- Large number of images are used as 2D slices of a 4D light function

(u,v)

(s,t)

Video Segment IV

- Light field
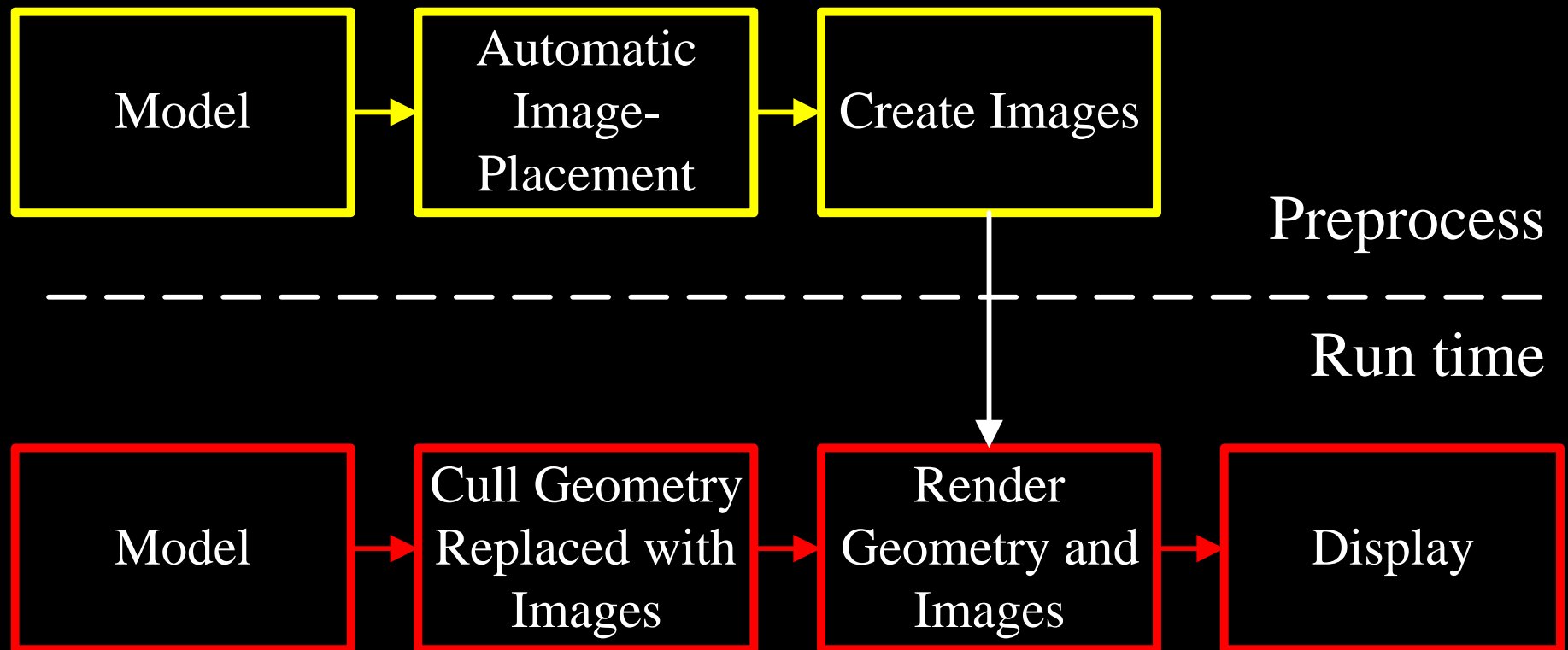 - Levoy96

- Lumigraph
  - Gortler96

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Automatic Image-Placement

- As a preprocess
  - Select geometry to replace with an image in order to limit the number of primitives to render for any frame

- At run time
  - Display selected geometry as a (depth) image
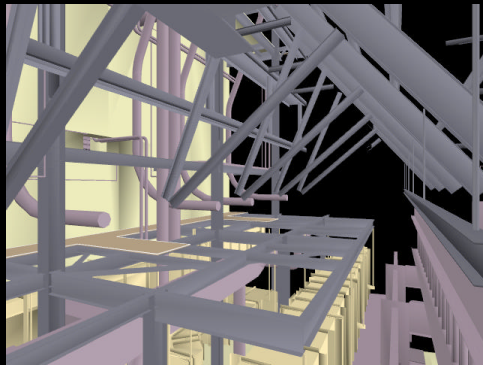 - Render remaining geometry normally
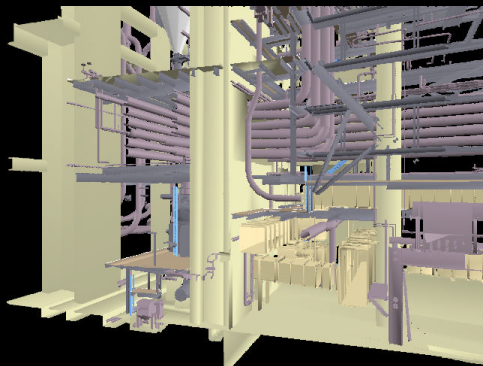
Automatic Image-Placement

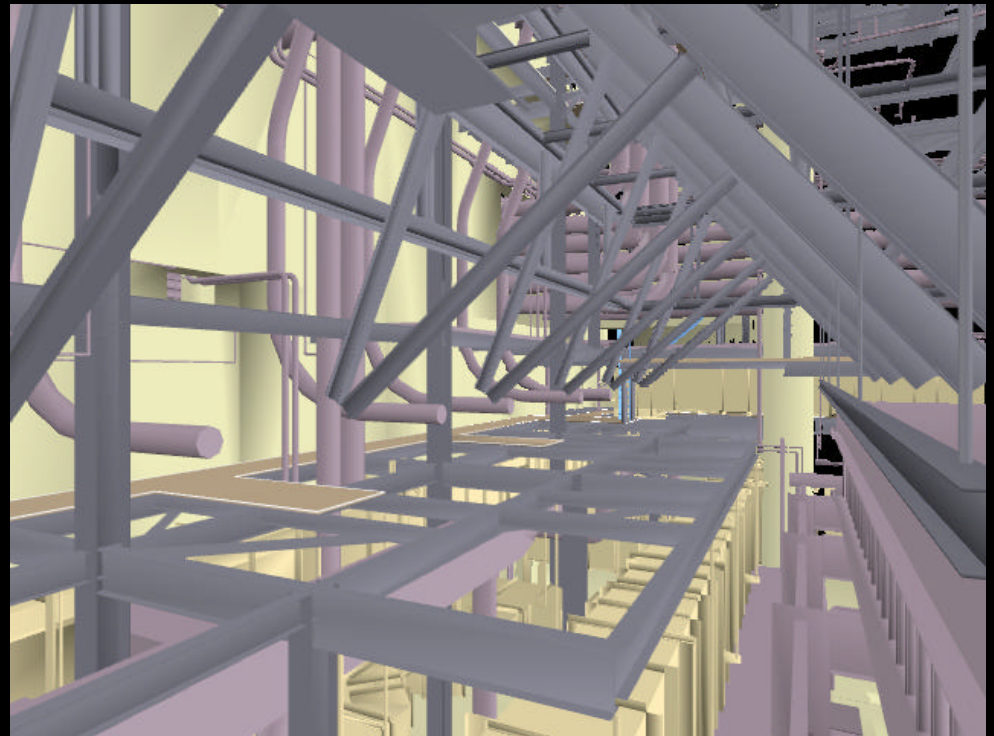Model → Automatic Image-Placement → Create Images

Preprocess

- -

Run time

Model → Cull Geometry Replaced with Images → Render Geometry and Images → Display
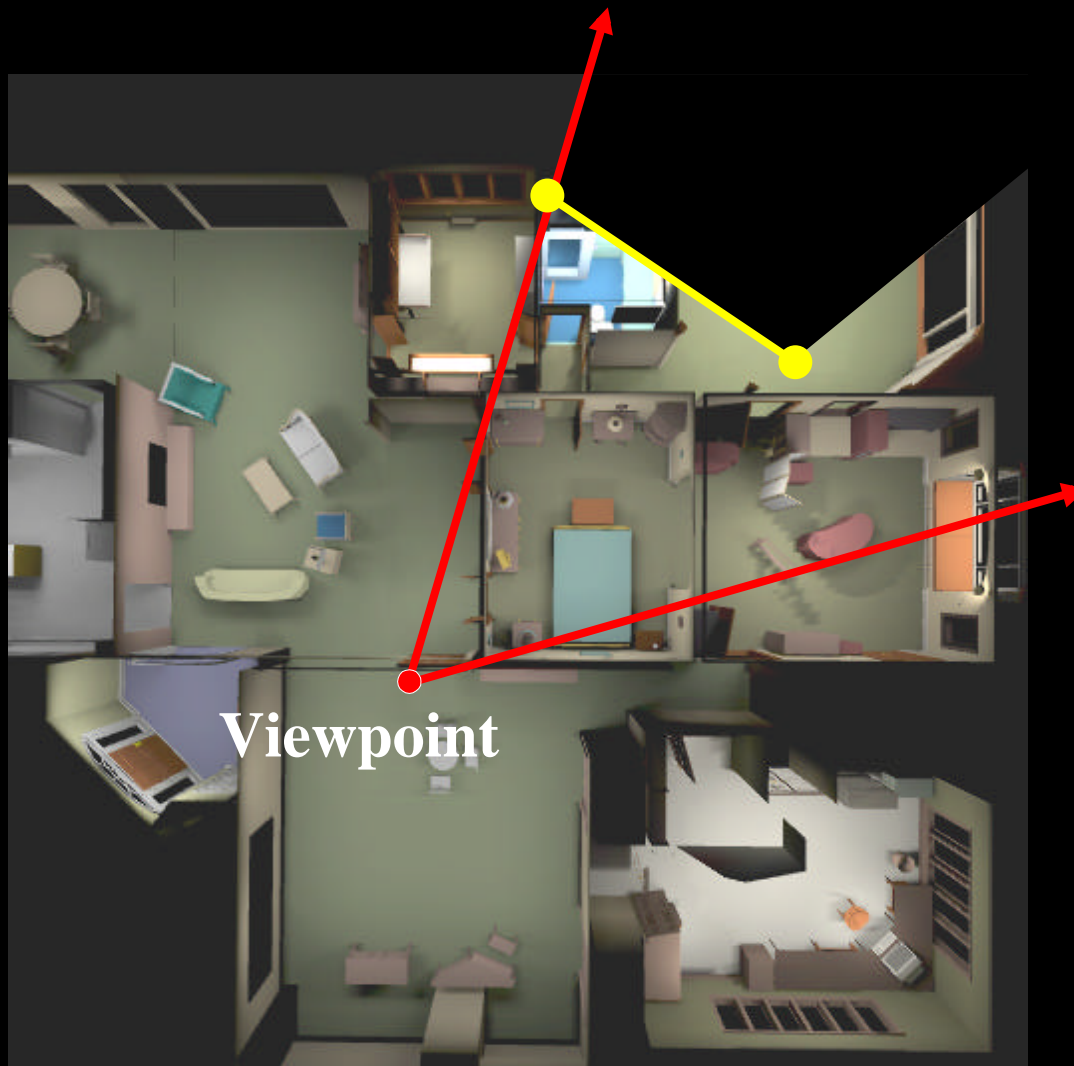
40

Example Rendering

Geometry

+

=

Image

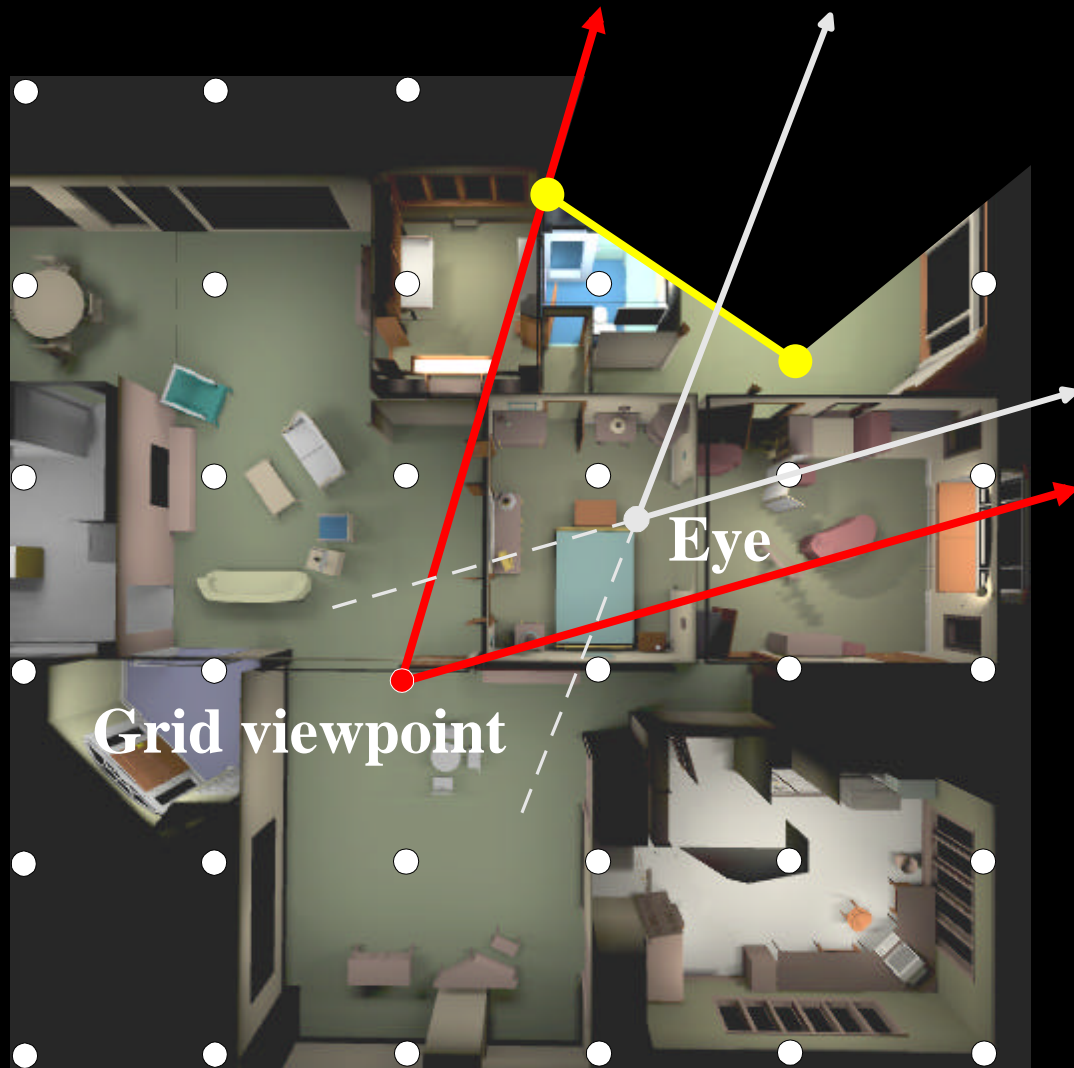Final Scene

Key Observation
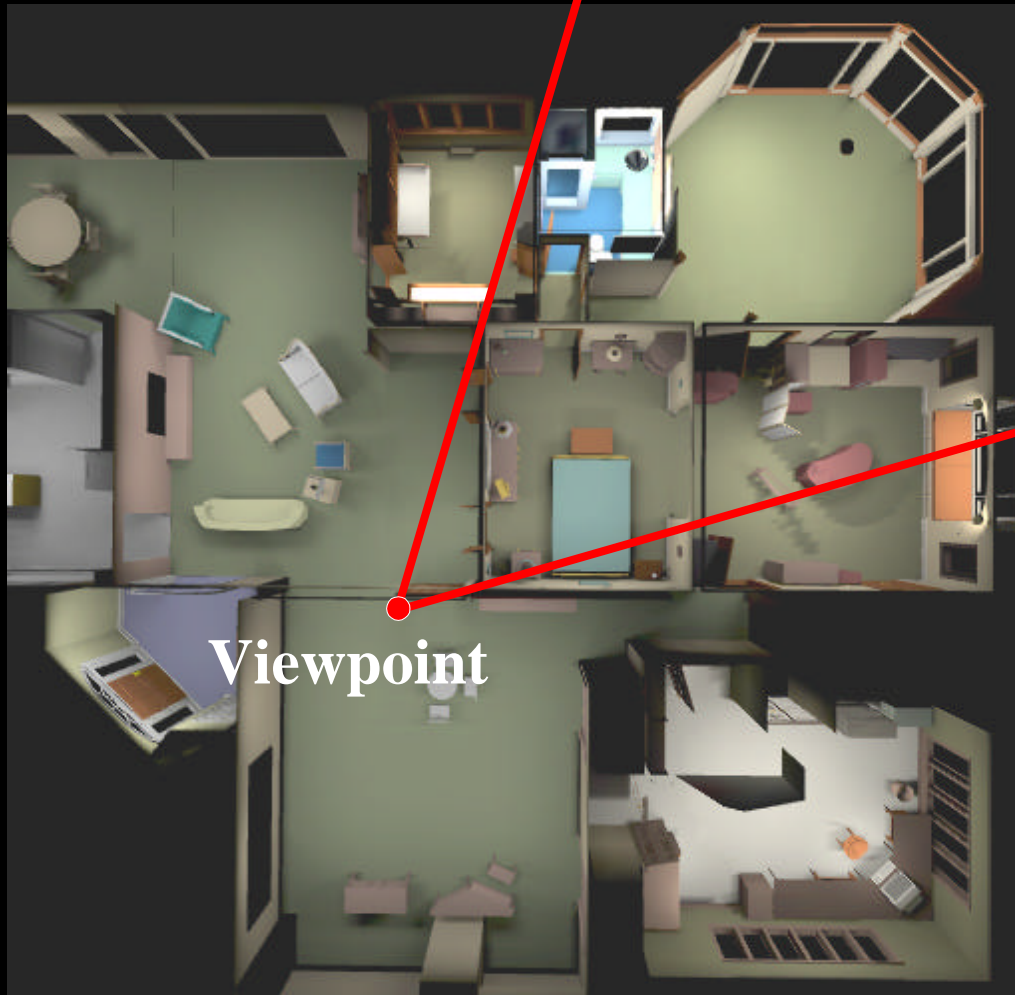
Viewpoint

- Example model
- Too much geometry in view frustum
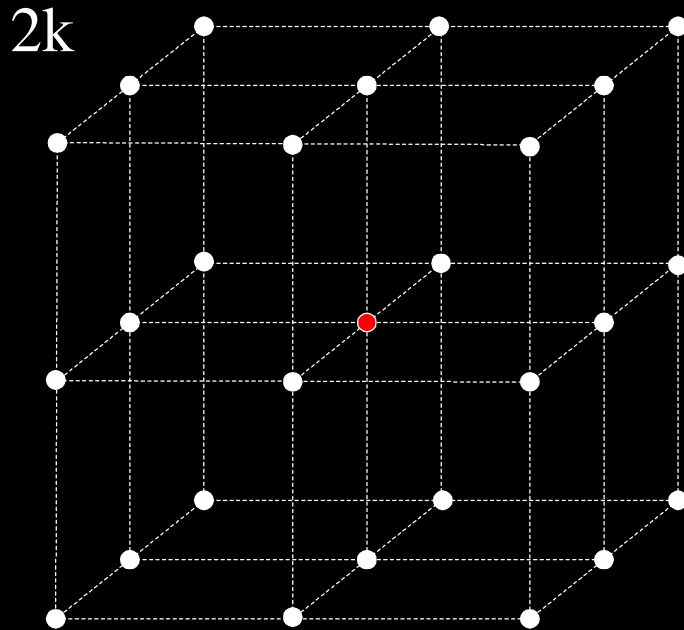
42

Key Observation

Viewpoint

- Geometry is replaced by image to limit the number of primitives to render
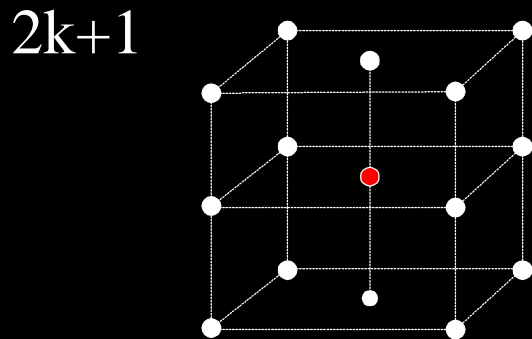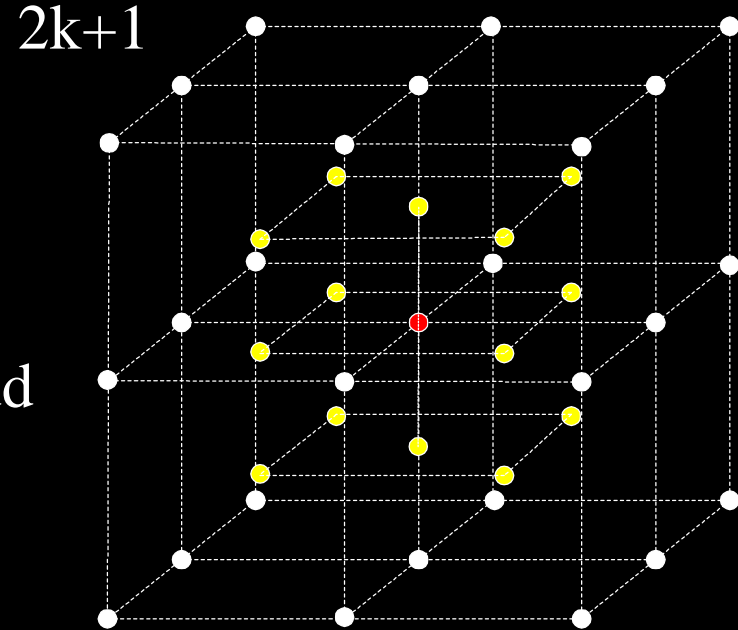
43

Key Observation

- Less geometry is in the view frustum from the eye than the one from the grid viewpoint
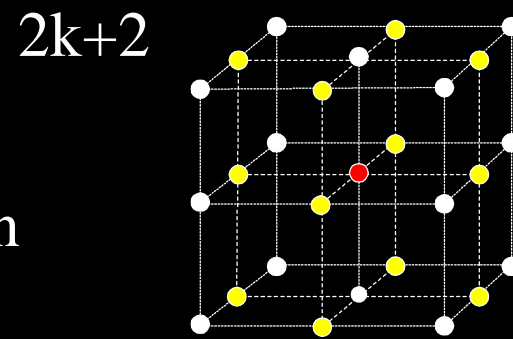
44

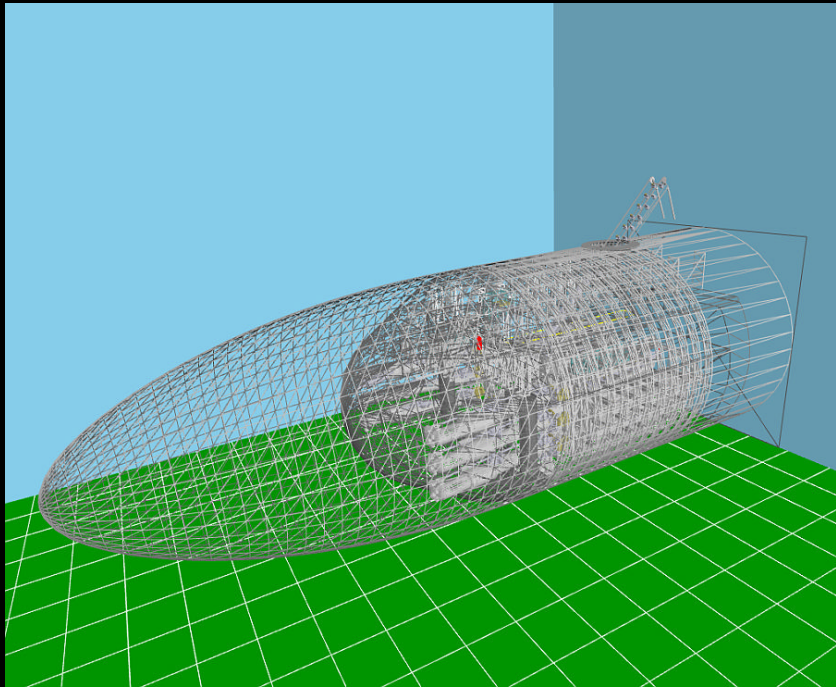# Recursive Subdivision Algorithm

2k

2k+1

Even to odd
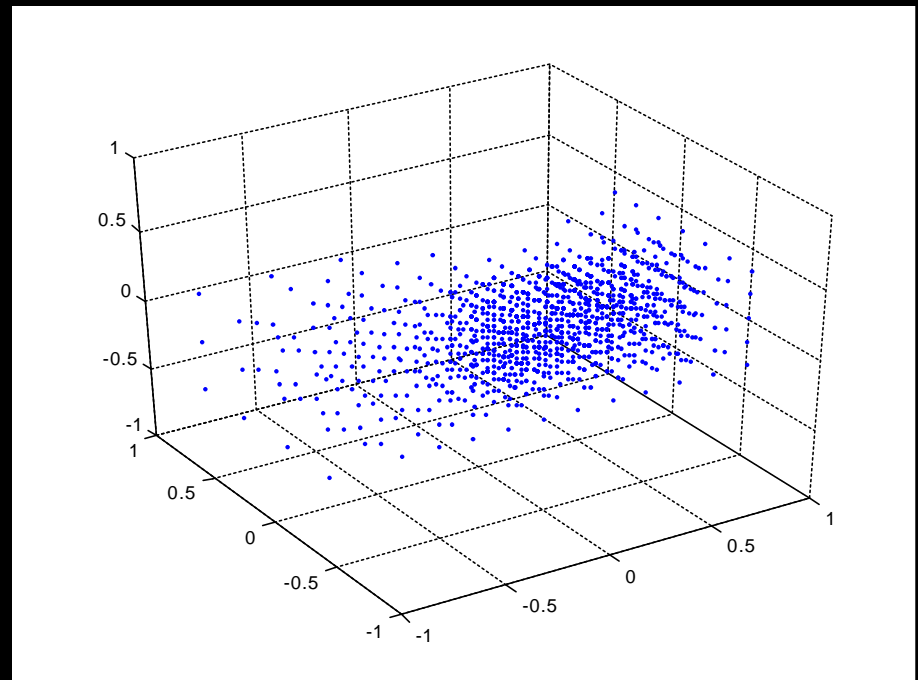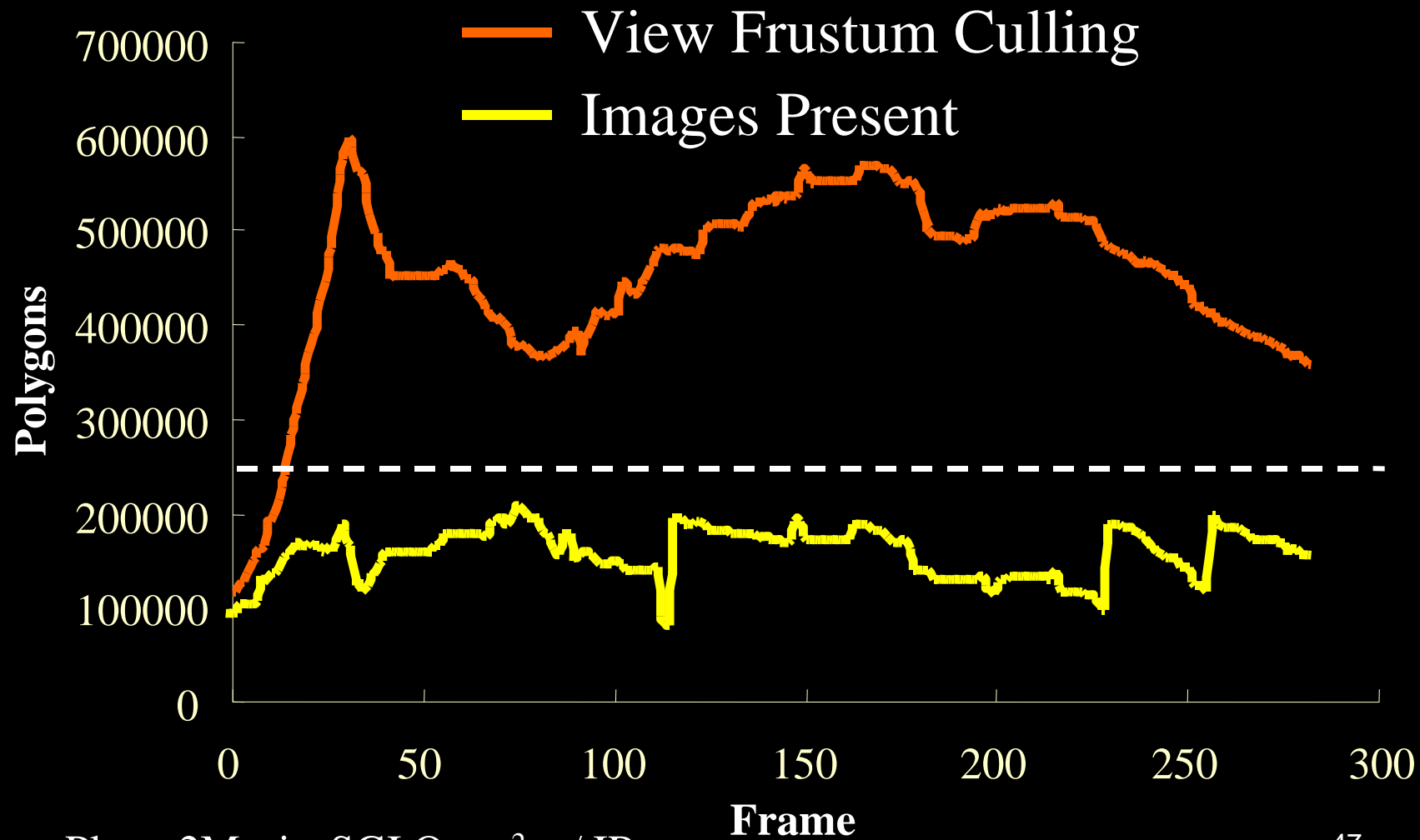
2k+1

2k+2

Odd to even

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Example Grid

Wireframe rendering

3D grid of 1557 viewpoints

Sample Path

Power Plant, 2M tris, SGI Onyx^2 w/ IR

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Images Per Triangle

Legend:
- Power Plant
- Torpedo Room
- Brooks House
- Pipes
- Best Case
- Worst Case

Y-axis: **Images Per Model Triangle**

X-axis: **Maximum Rendered Triangles (% of Model)**
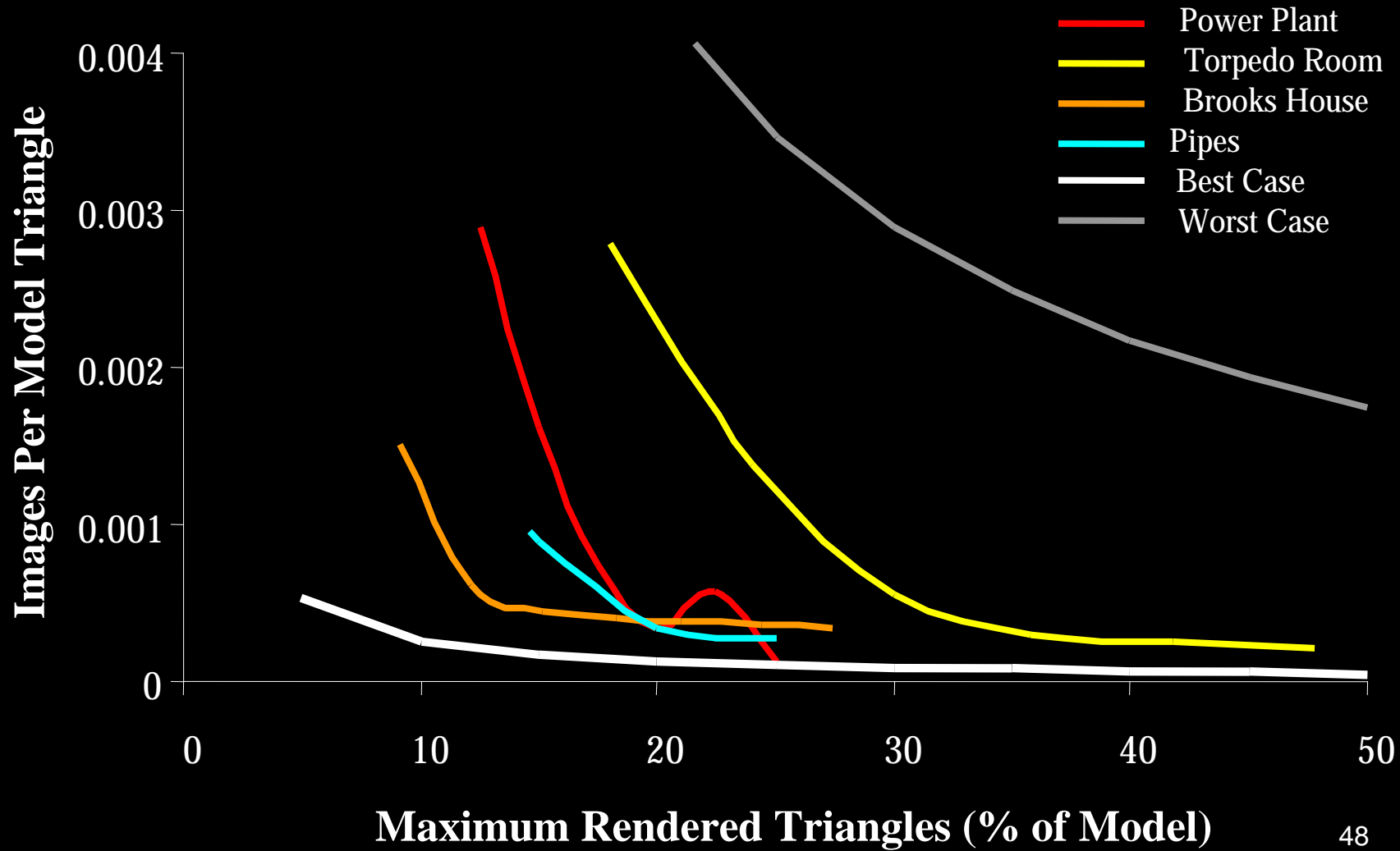
Preprocessing Summary

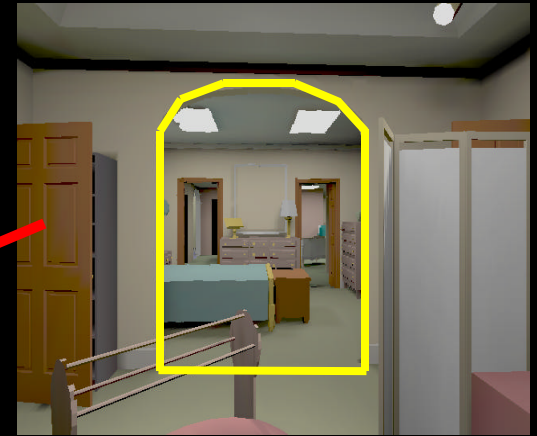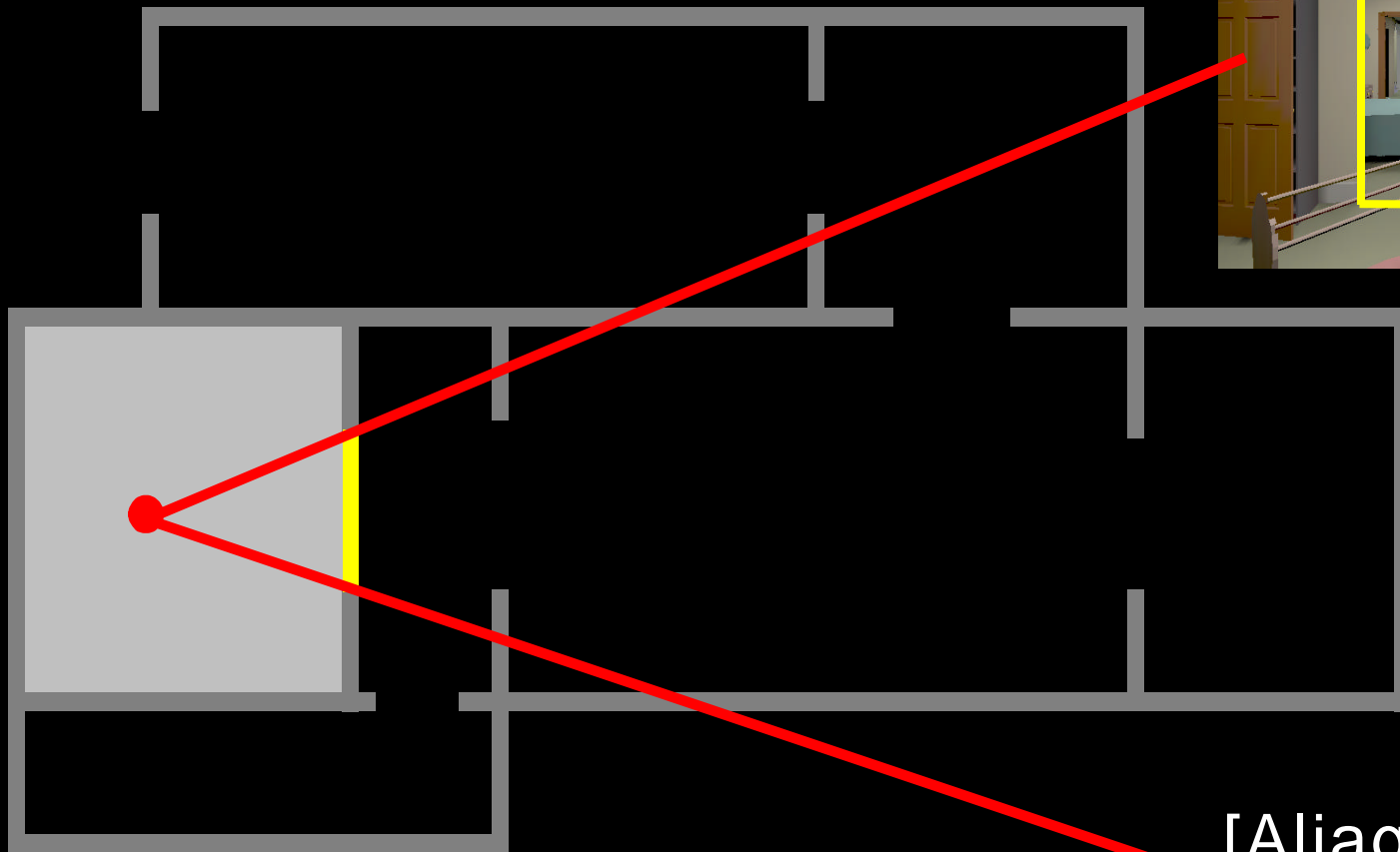| Model	No. of Images	Prep. Time (hours)	Estimated Space (MB)
Power Plant (2M)	239-5815	1.2-21.7	156-3802
Torpedo Room (850k)	181-2333	1.1-11.8	72- 933
Brooks House (1.7M)	561-2492	11.4-28.4	388-1725
Pipes (1M)	282- 893	2.4- 4.6	175- 554

Video Segment V

- Automatically Bounding Geometric Complexity by Using Images
  - Aliaga99

Cells and Portals
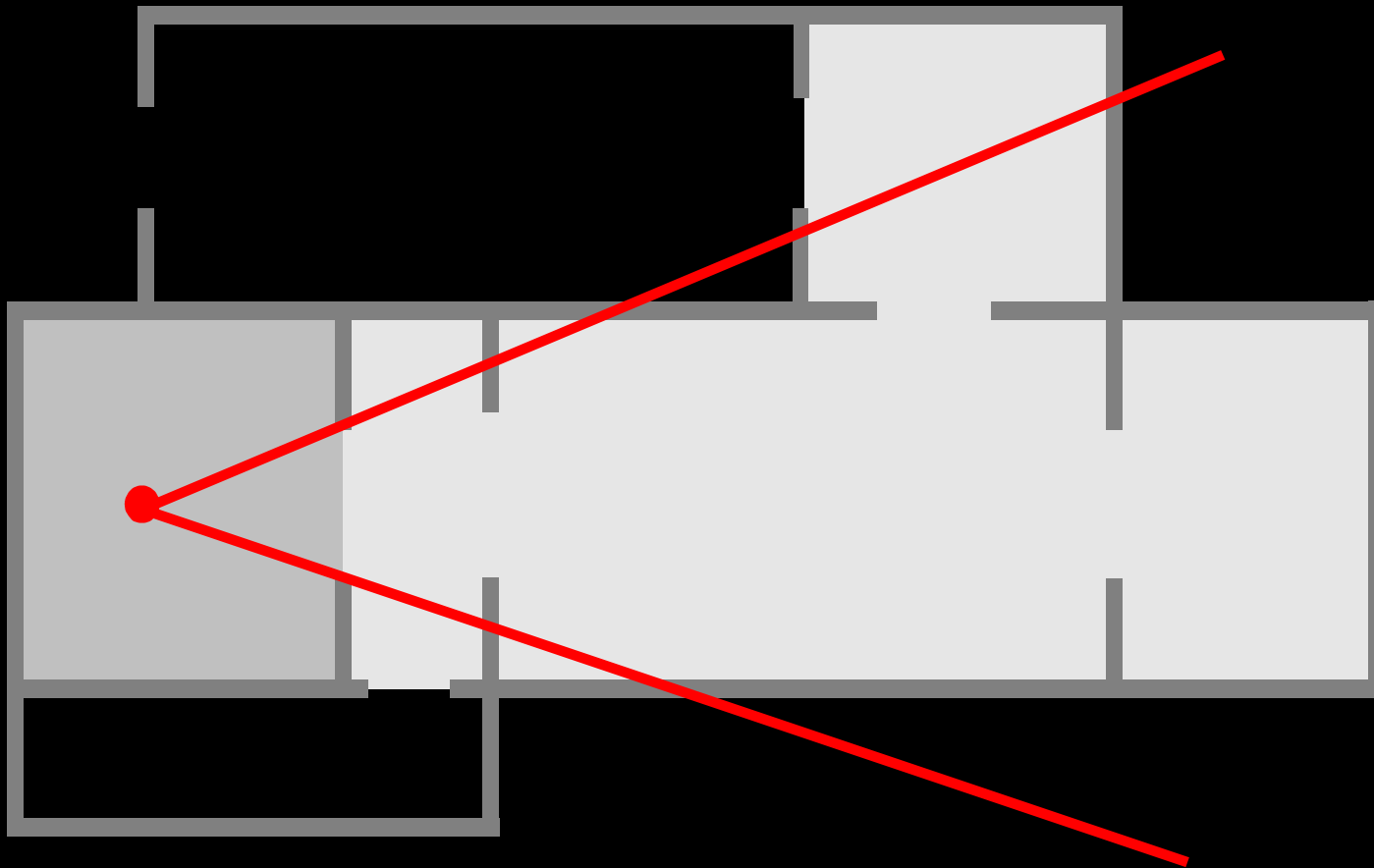
[Airey90, Teller91, Luebke95] 51
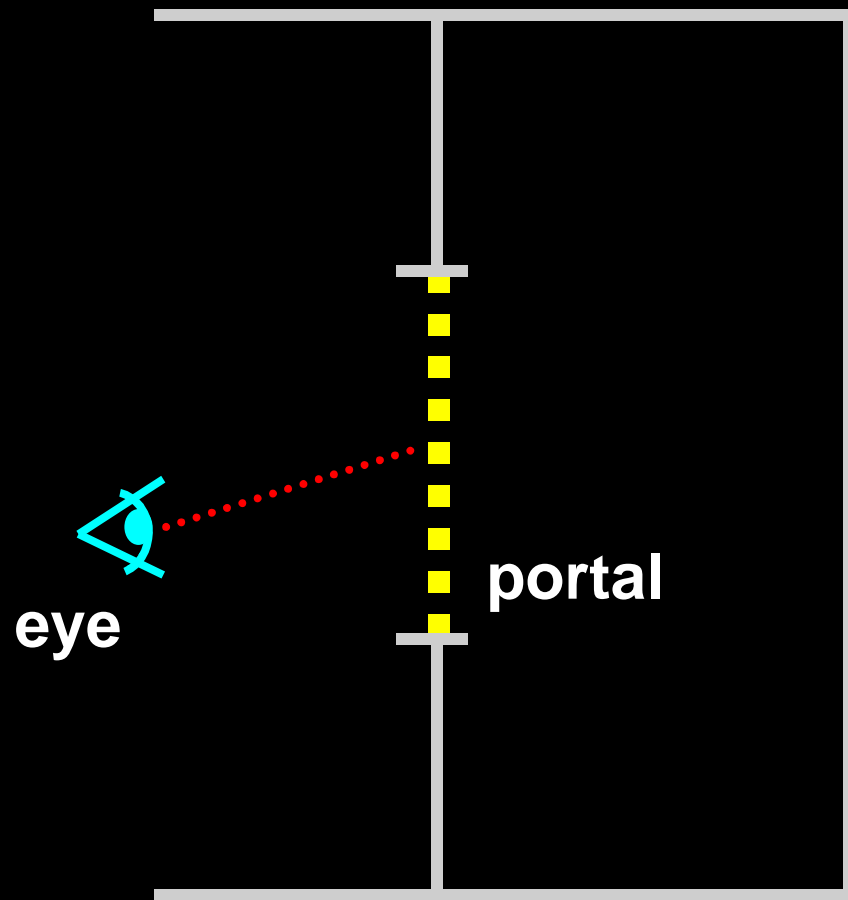
Portal Images

[Aliaga97]

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Creating Portal Images
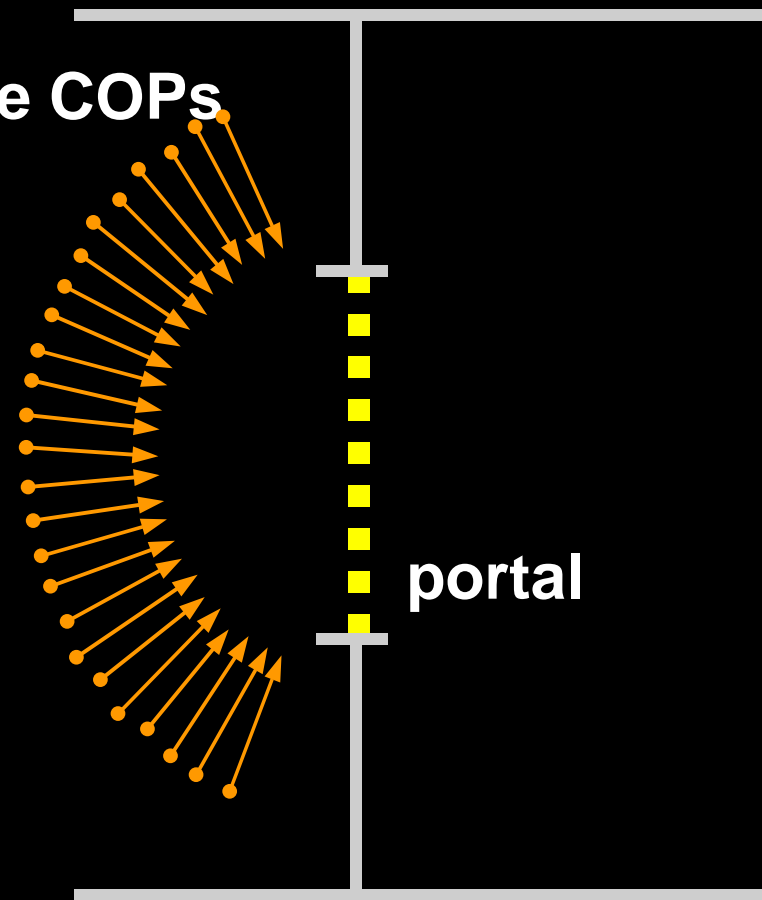
Ideal portal image would be one sampled from the current eye position

eye

portal

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Creating Portal Images

Display one of a
large number of
pre-computed
images (~120)

Reference COPs

portal

Creating Portal Images

or…

Warp one of a much smaller number of reference images

Reference COPs

portal

Brooks House

Onyx IR

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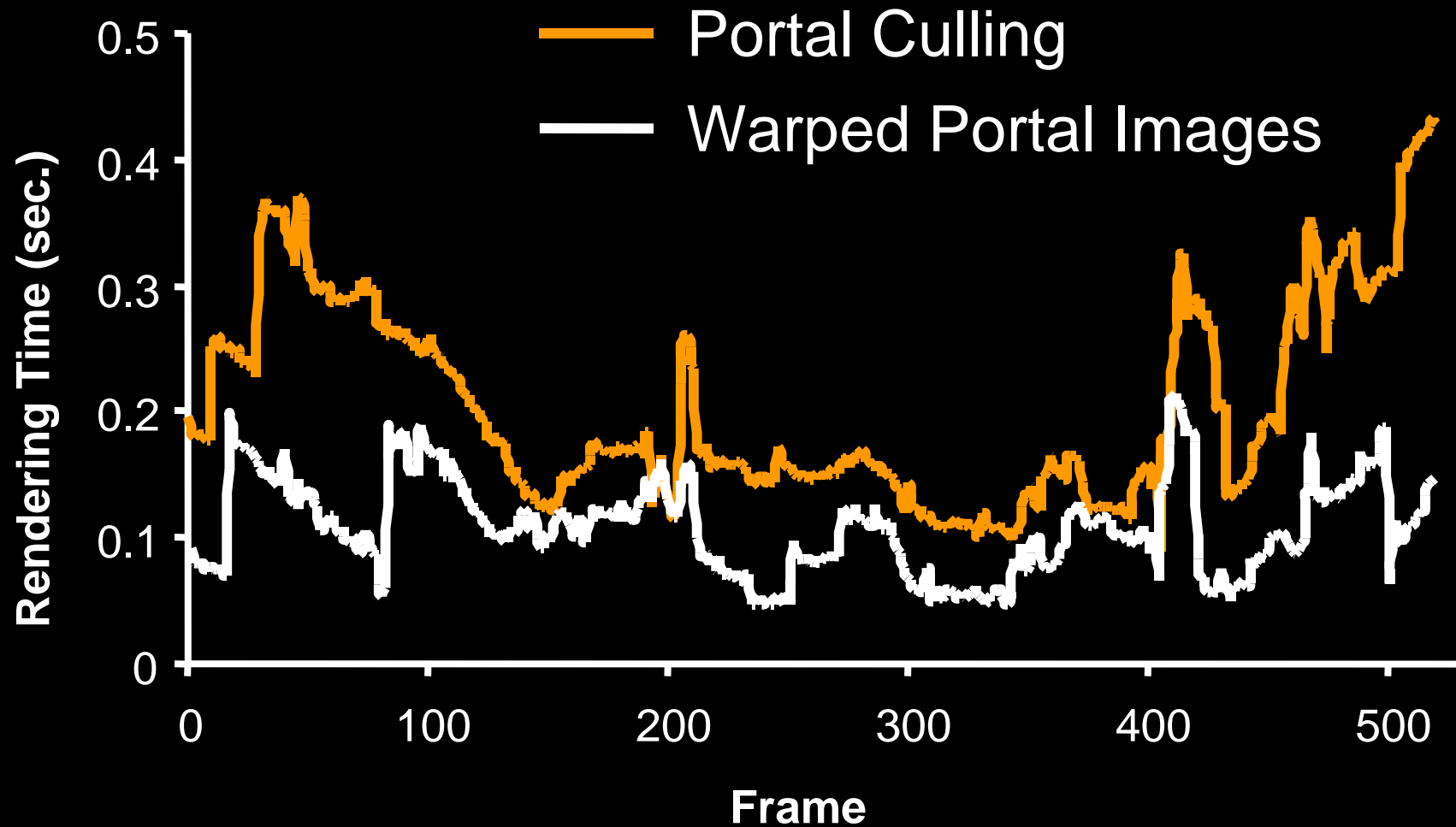
Brooks House

Onyx IR
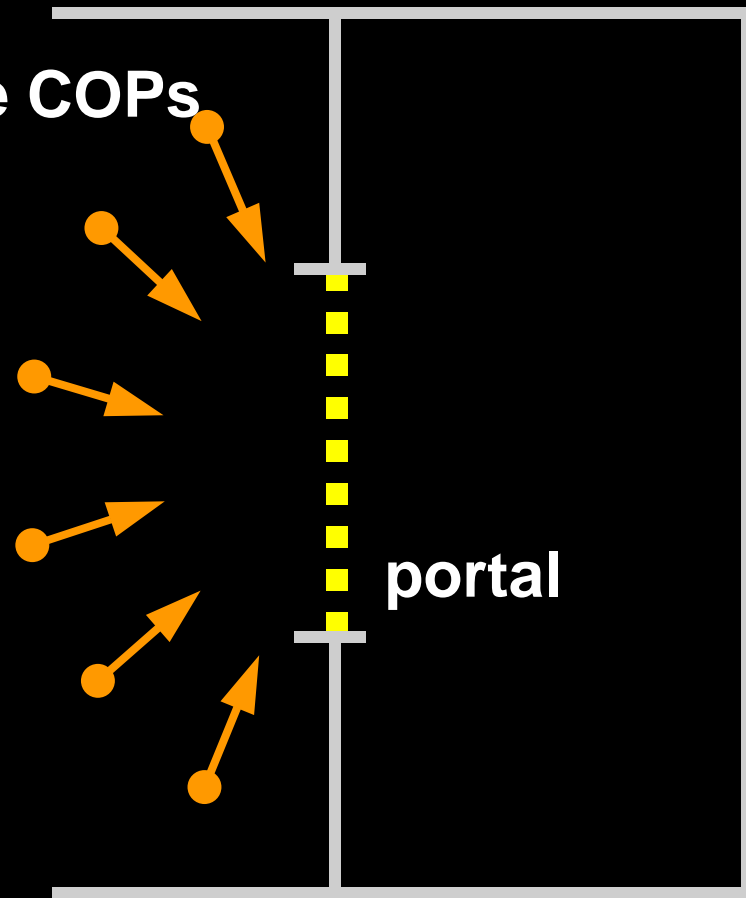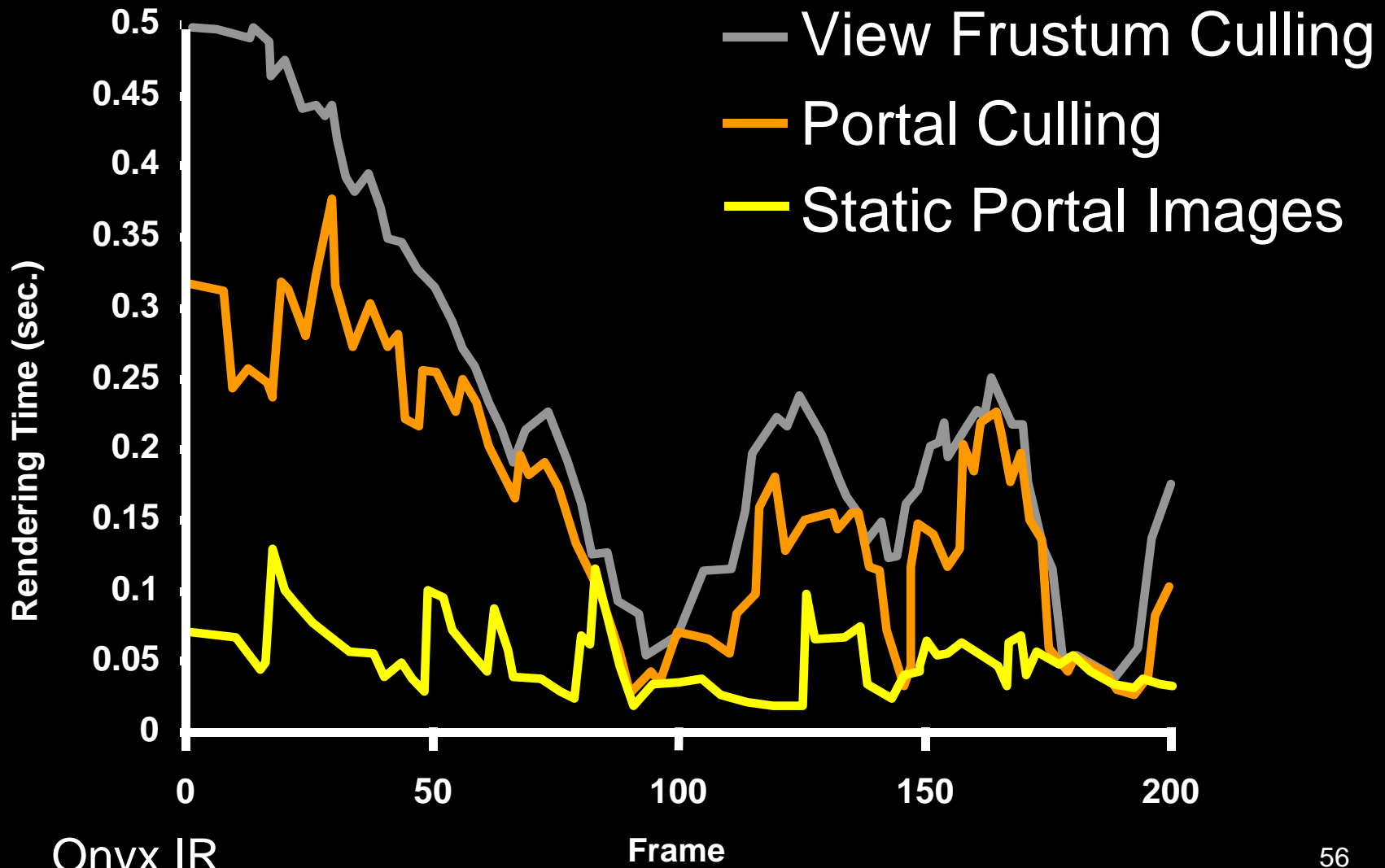
Video Segment VI

- Architectural Walkthroughs using Portal Images
  - Aliaga97, Rafferty98

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- **Conclusions**

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Image Quality

- What about measuring quality?
  - *Need a perceptual quality metric!*
- We know
  - Texture-mapping: bad perspective, small distortions believable (geometry warping)
  - IBR: correct perspective, disocclusions
  - Meshes: stretching of skins

Limitations

- Diffuse illumination

  - Deferred shading?

- Static models

  - Incremental updating?

- Cannot sample all visible surfaces

  - Smarter reconstruction/resampling?

- Can only sample surfaces at a fixed resolutions

  - Multi-resolution reference images?

Acknowledgments

- Authors of the Video Segments

- Models
  - Discreet Logic, UNC Walkthrough Group

- UNC-Chapel Hill
  - Walkthrough, PixelFlow, ImageFlow

- NSF, NIH, DARPA

- Lucent Technologies Bell Labs