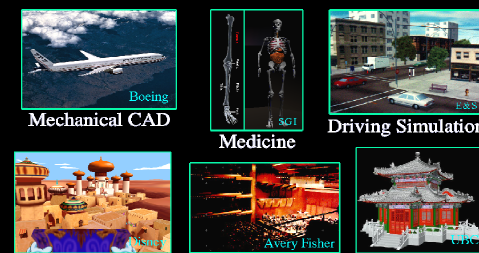
Interactive Visualization
of Complex Scenes

Thomas Funkhouser
COS 526, Fall 2006

Interactive Visualization

Render images with interactive control of viewpoint



Mechanical CAD, Medicine, Driving Simulation, Entertainment, Architectural CAD, Education

Interactive Visualization Goals

Realism
- Realistic enough to convey information

Frame rate:
- >10-60 frames per second

Latency
- <10-500 milliseconds response delay

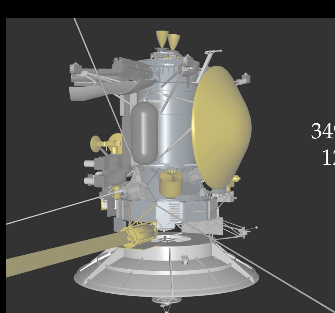
Computation
- Fast preprocessing
- Fast startup
- Low storage
- etc.

Scene Complexity

Examples:
- Automobile: ~20,000 parts
- Boeing Airplane: ~2,000,000 parts
- Aircraft Carrier: ~20,000,000 parts
- Sculptures: ~200,000,000,000 samples
- Outdoor Environments

Prototype Models

Cassini spacecraft



349,281 faces
127 objects

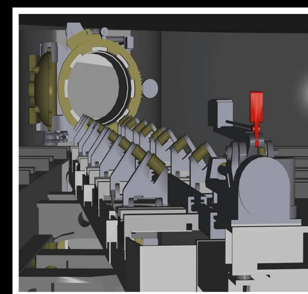
Architectural Models

Soda Hall Model (7.6M polygons)

Structural Engineering Models

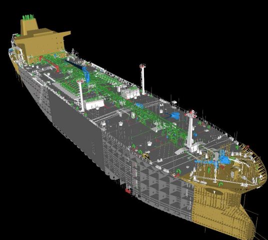
Coal-Fired Powerplant: 15 million triangles

Mechanical CAD Models



Submarine Torpedo Room (850K polygons)

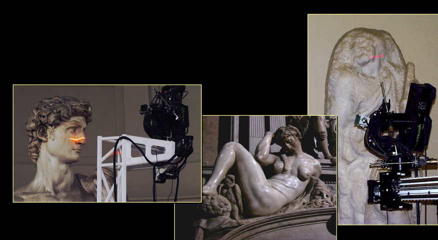
Mechanical CAD Models



82 million triangles; 126,000 objects

Newport News Shipbuilding

Range Scans



Michelangelo sculptures: 100M Samples

Stanford Graphics Lab

Range Scans

Michelangelo sculptures: 127M Samples

Stanford Graphics Lab

Rendering Acceleration Techniques

Visibility Culling
- Backface culling, view-frustum culling, occlusion culling, …

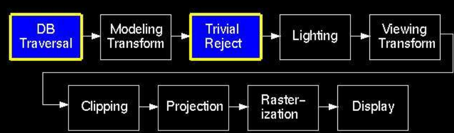
Detail Elision
- Levels of detail, multiresolution, …

Images
- Textures, billboards, imposters, …

Visibility Culling

Quickly eliminate large portions of the scene that will not be visible in the final image

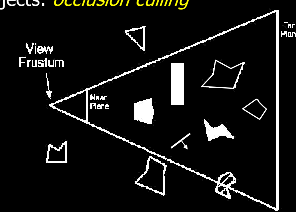
- Not the exact visibility solution, but a quick and conservative test to reject primitives that are not visible
  - Trivially reject stuff that is obviously not seen
  - Use Z-buffer and clipping for the exact solution



Visibility Culling

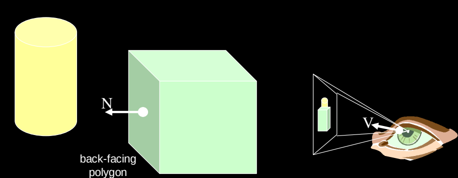
Basic idea: don't render what can't be seen

- Facing away from camera: *backface culling*
- Off-screen: *view-frustum culling*
- Occluded by other objects: *occlusion culling*



Back-Face Culling

Do not draw polygons facing backwards with respect to camera

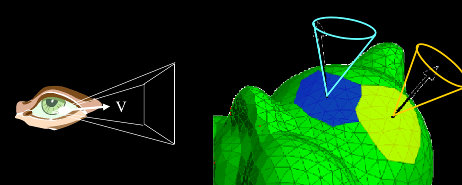


A polygon is backfacing if $V \bullet N > 0$

Back-Face Culling

Avoid testing every face separately

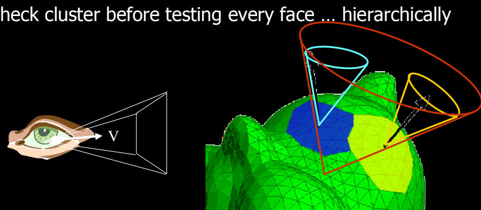
- Cluster faces
- Precompute range of normals for each cluster
- Check cluster before testing every face



Hierarchical Back-Face Culling

Avoid testing every face separately

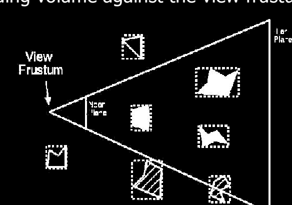
- Cluster faces hierarchically
- Precompute range of normals for each cluster
- Check cluster before testing every face … hierarchically



View-Frustum Culling

Don't draw primitives outside the view frustum

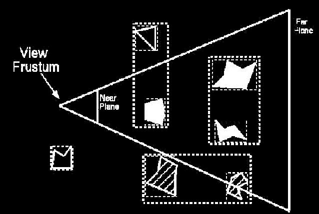
- Organize primitives into clumps
- Before rendering the primitives in a clump, test their bounding volume against the view frustum



View-Frustum Culling

Hierarchical bounding volumes

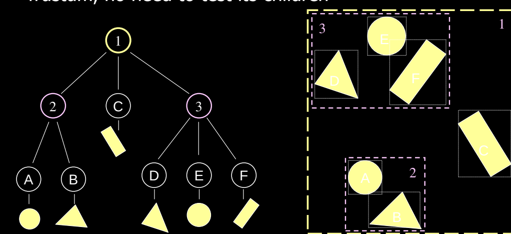
- If a clump is entirely outside or entirely inside view frustum, no need to test its children



Hierarchical View-Frustum Culling

Hierarchical bounding volumes

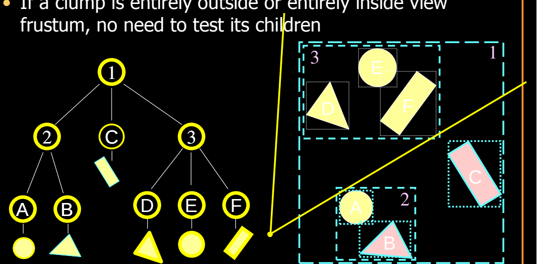
- If a clump is entirely outside or entirely inside view frustum, no need to test its children



Hierarchical View Frustum Culling

Hierarchical bounding volumes

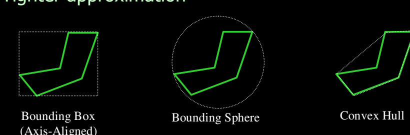
- If a clump is entirely outside or entirely inside view frustum, no need to test its children



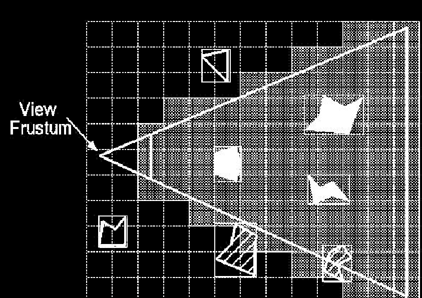
Hierarchical View Frustum Culling

What shape should the bounding volumes be?

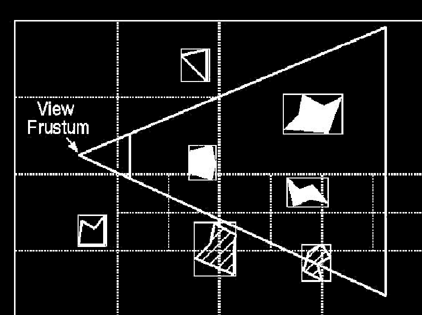
- Spheres and axis-aligned bounding boxes:
  - Simple to calculate/test
  - May be poor approximation
- Convex hulls:
  - More complex to calculate/test
  - Tighter approximation



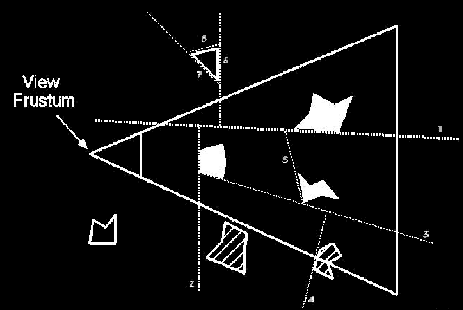
Uniform Grid Subdivision



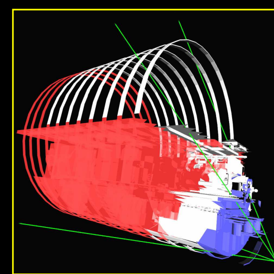
Octree Subdivision



BSP Subdivision



Occlusion Culling



Blue parts: occluders
Red parts: occludees

Occlusion Culling

Object-precision

- Cells and portals
- Shadow volumes

Image-precision

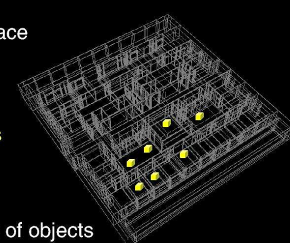
- OpenGL occlusion test
- Hierarchical Z-buffer
- Hierarchical occlusion maps

Cells and Portals

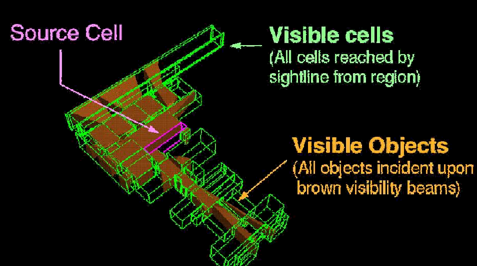
Subdivide space into cells.

Cluster polygons into objects.

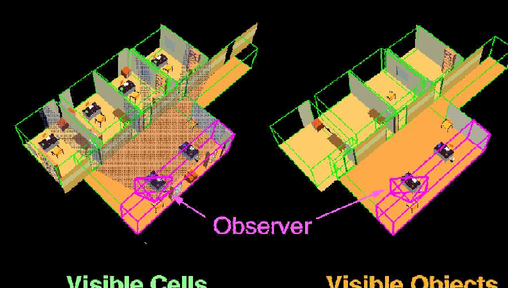
Build an index of objects incident upon each cell.



Cells and Portals



Cells and Portals



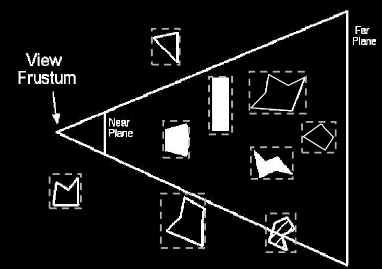
Occlusion Culling

Object-precision
- Cells and portals
- Shadow volumes

Image-precision
- OpenGL occlusion test
- Hierarchical Z-buffer
- Hierarchical occlusion maps

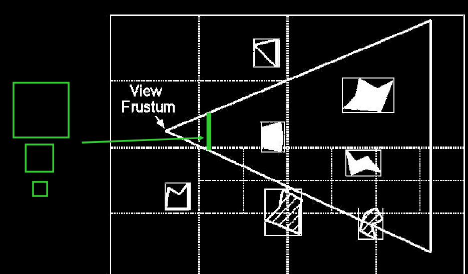
OpenGL Occlusion Test

Hardware returns how many z-buffer tests pass



Hierarchical Z-Buffer

Store z-buffer as pyramid and test depth hierarchically



Rendering Acceleration Techniques

Visibility Culling
- Backface culling, view-frustum culling, occlusion culling, …

Detail Elision ←
- Levels of detail, multiresolution, …

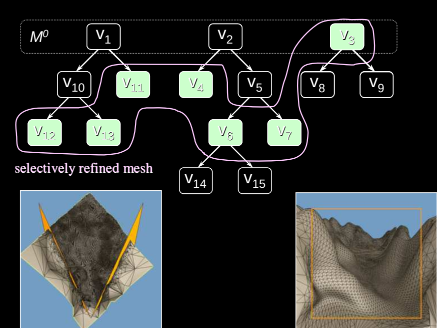
Images
- Textures, billboards, imposters, …

Levels of Detail

Triangles
: 41,855
27,970
20,922
12,939
8,385
4,766

courtesy of Division and Viewpoint

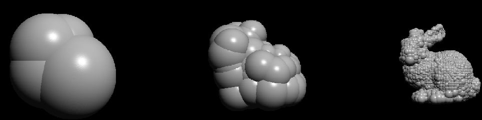
Multiresolution



QSplat

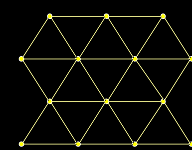
Key observation: a single bounding sphere hierarchy can be used for

- Hierarchical frustum and backface culling
- Level of detail control
- Splat rendering [Westover 89]



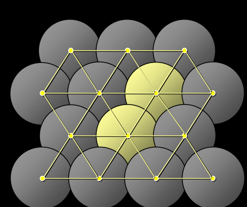
Creating the Data Structure

Start with a triangle mesh produced by aligning and integrating scans [Curless 96]



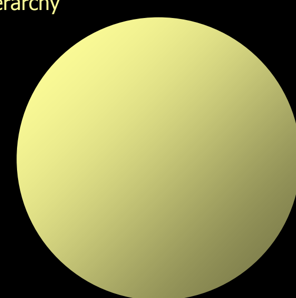
Creating the Data Structure

Place a sphere at each node, large enough to touch neighbor spheres

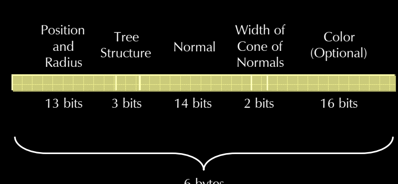


Creating the Data Structure

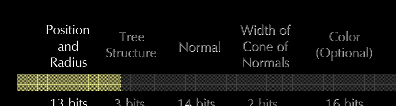
Build up hierarchy



QSplat Node Structure

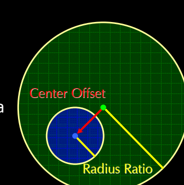


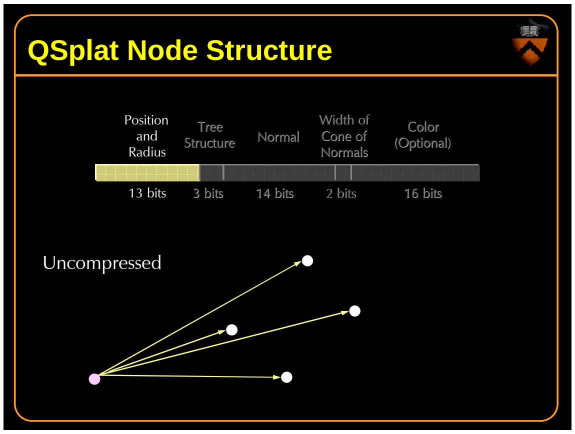
QSplat Node Structure

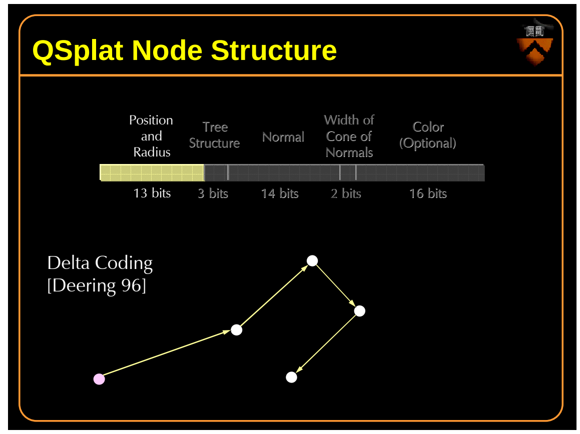


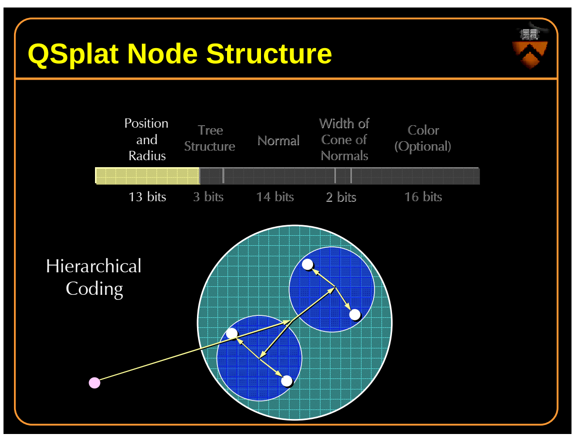
Position and radius encoded relative to parent node

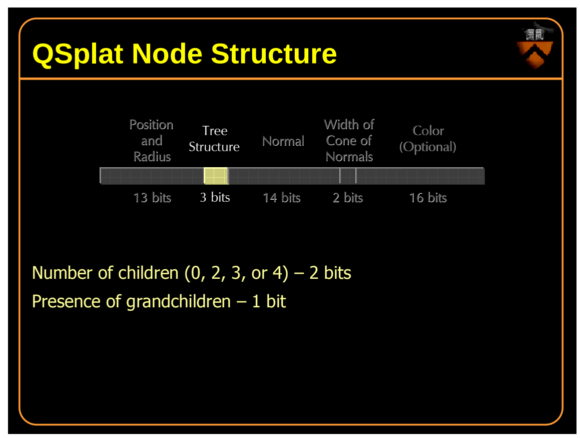
- Hierarchical coding vs. delta coding along a path for vertex positions

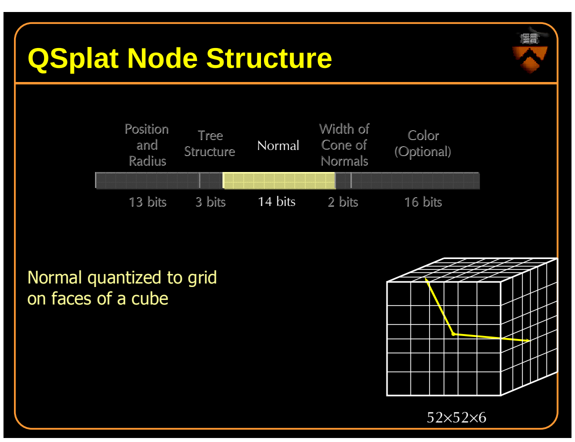


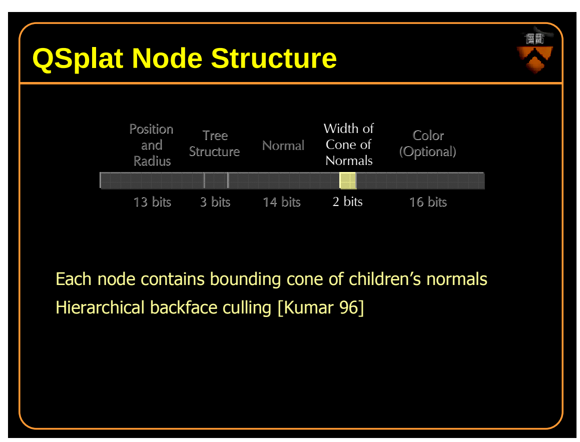

QSplat Node Structure
Position and Radius
Tree Structure
Normal
Width of Cone of Normals
Color (Optional)
13 bits
3 bits
14 bits
2 bits
16 bits
Uncompressed


QSplat Node Structure
Position and Radius
Tree Structure
Normal
Width of Cone of Normals
Color (Optional)
13 bits
3 bits
14 bits
2 bits
16 bits
Delta Coding
[Deering 96]

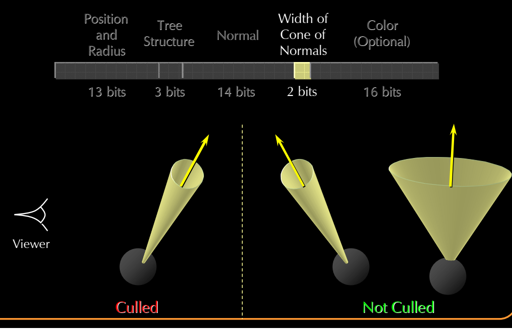

QSplat Node Structure
Position and Radius
Tree Structure
Normal
Width of Cone of Normals
Color (Optional)
13 bits
3 bits
14 bits
2 bits
16 bits
Hierarchical Coding


QSplat Node Structure
Position and Radius
Tree Structure
Normal
Width of Cone of Normals
Color (Optional)
13 bits
3 bits
14 bits
2 bits
16 bits
Number of children (0, 2, 3, or 4) – 2 bits
Presence of grandchildren – 1 bit

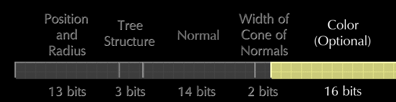

QSplat Node Structure
Position and Radius
Tree Structure
Normal
Width of Cone of Normals
Color (Optional)
13 bits
3 bits
14 bits
2 bits
16 bits
Normal quantized to grid on faces of a cube
52×52×6


QSplat Node Structure
Position and Radius
Tree Structure
Normal
Width of Cone of Normals
Color (Optional)
13 bits
3 bits
14 bits
2 bits
16 bits
Each node contains bounding cone of children's normals
Hierarchical backface culling [Kumar 96]

QSplat Node Structure



QSplat Node Structure



Per-vertex color is quantized 5-6-5 (R-G-B)

QSplat Rendering Algorithm

Traverse hierarchy recursively

if (node not visible)
    Skip this branch
else if (leaf node)
    Draw a splat
else if (size on screen < threshold)
    Draw a splat
else
    Traverse children

Hierarchical frustum / backface culling

Point rendering

Level of detail control

Adjusted to maintain desired frame rate

Frame Rate Control

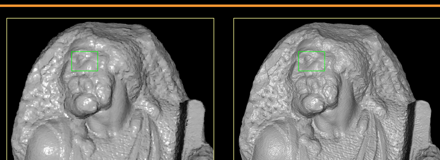
Feedback-driven frame rate control

- During motion: adjust recursion threshold based on time to render previous frame
- On mouse up: redraw with smaller thresholds
- Consequence: frame rate may vary

Alternative:

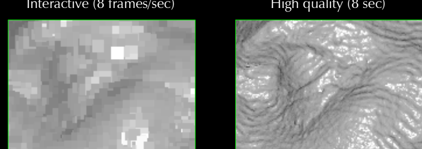
- Predictive control of detail [Funkhouser 93]

Results



Interactive (8 frames/sec)

High quality (8 sec)



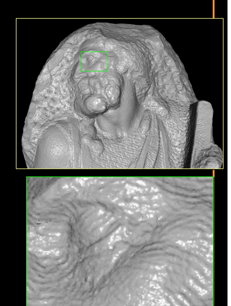
Demo – St. Matthew

3D scan of 2.7 meter statue at 0.25 mm

102,868,637 points

File size: 644 MB

Preprocessing time: 1 hour



Tradeoffs of Splatting

For rendering large 3D models, what are the tradeoffs of:

Polygons	QSplat
Good for large, flat or subtly curved regions	Good for models with detail everywhere
Highly-efficient rasterization with 3D graphics hardware	Higher per-pixel cost, but less slowdown in absence of 3D hardware
Decimation or creating LOD data structures is often expensive	Fast preprocessing

Rendering Acceleration Techniques

Visibility Culling

- Backface culling, view-frustum culling, occlusion culling, ...

Detail Elision

- Levels of detail, multiresolution, ...

Images ⟵

- Textures, billboards, imposters, ...

Imposters

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

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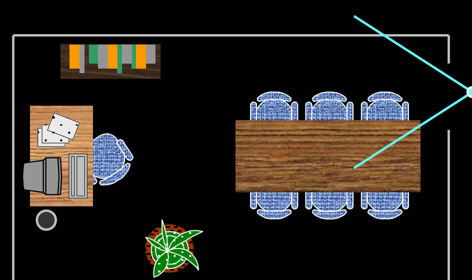
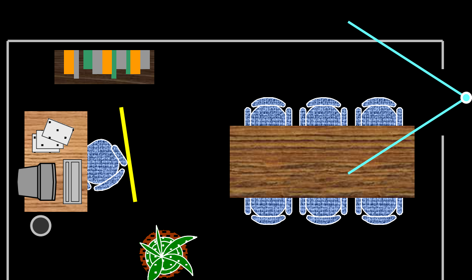
Simple Example



Aliaga

Simple Example



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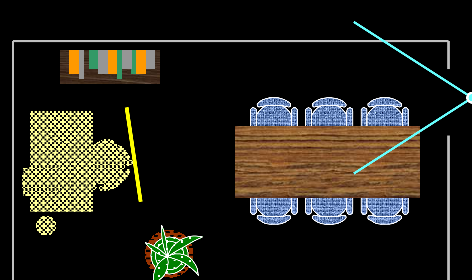
Simple Example



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Issues

Imposter placement

- What geometry should be replaced by images
- How should images be integrated into scene

Imposter representation

- What viewpoint(s) should be captured in image?
- How render from arbitrary viewpoints?

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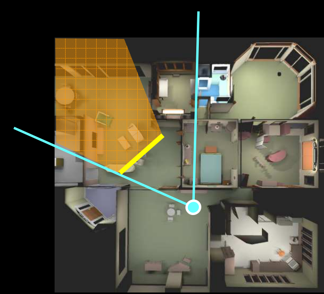
Imposter Placement



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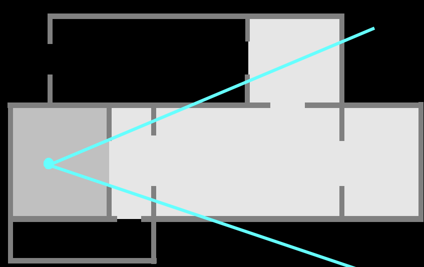
Cells and Portals



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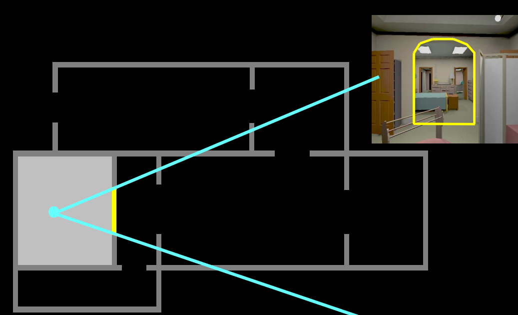
Portal Images



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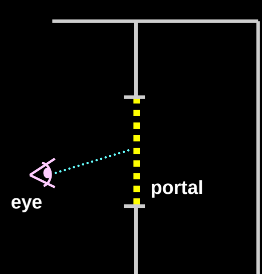
Creating Portal Images

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



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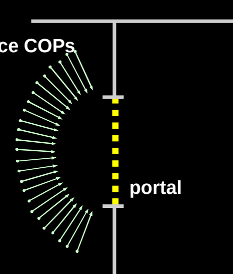
Creating Portal Images

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



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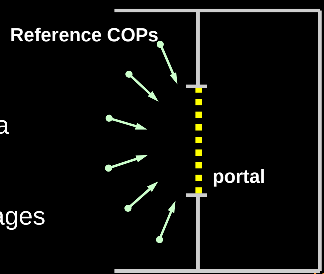
Creating Portal Images

or…

Warp one of a much smaller number of reference images



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Summary

Visibility Culling

- Backface culling, view-frustum culling, occlusion culling, …

Detail Elision

- Levels of detail, multiresolution, …

Images

- Textures, billboards, imposters, …

Recurring Themes:
Trivial reject checks
Hierarchical processing