

High-Quality Parallel Depth-of-Field Using Line Samples

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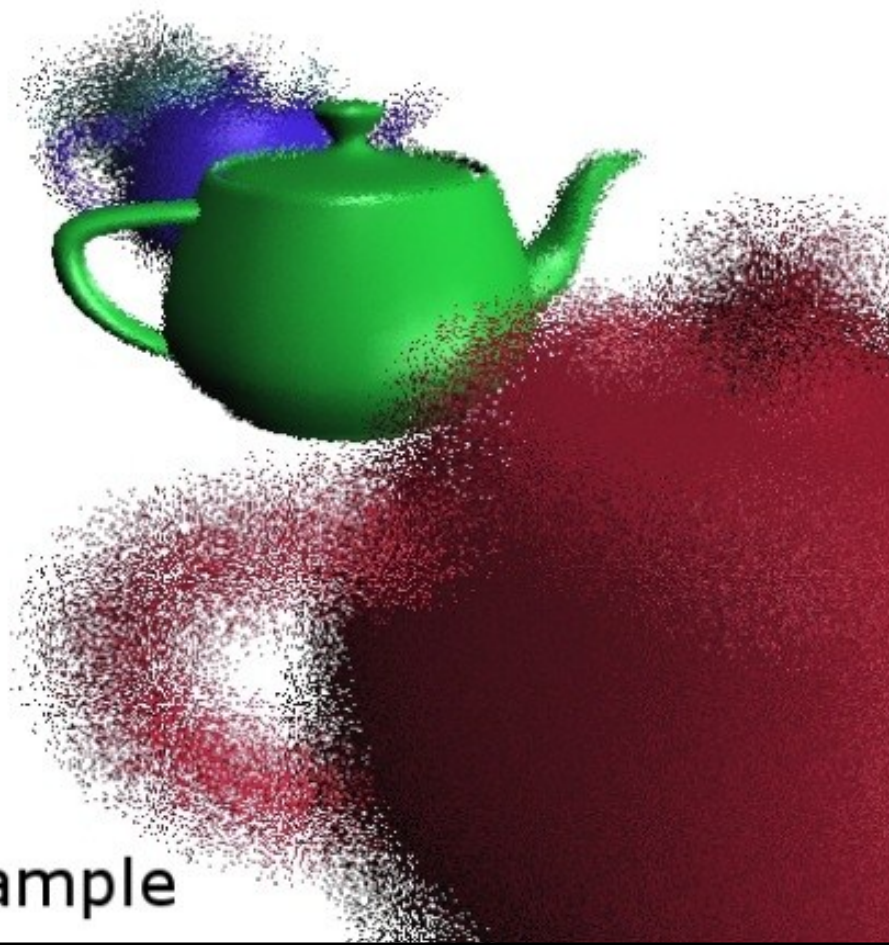
Depth of Field is Beautiful



Pixar's Toy Story 3

The Problem

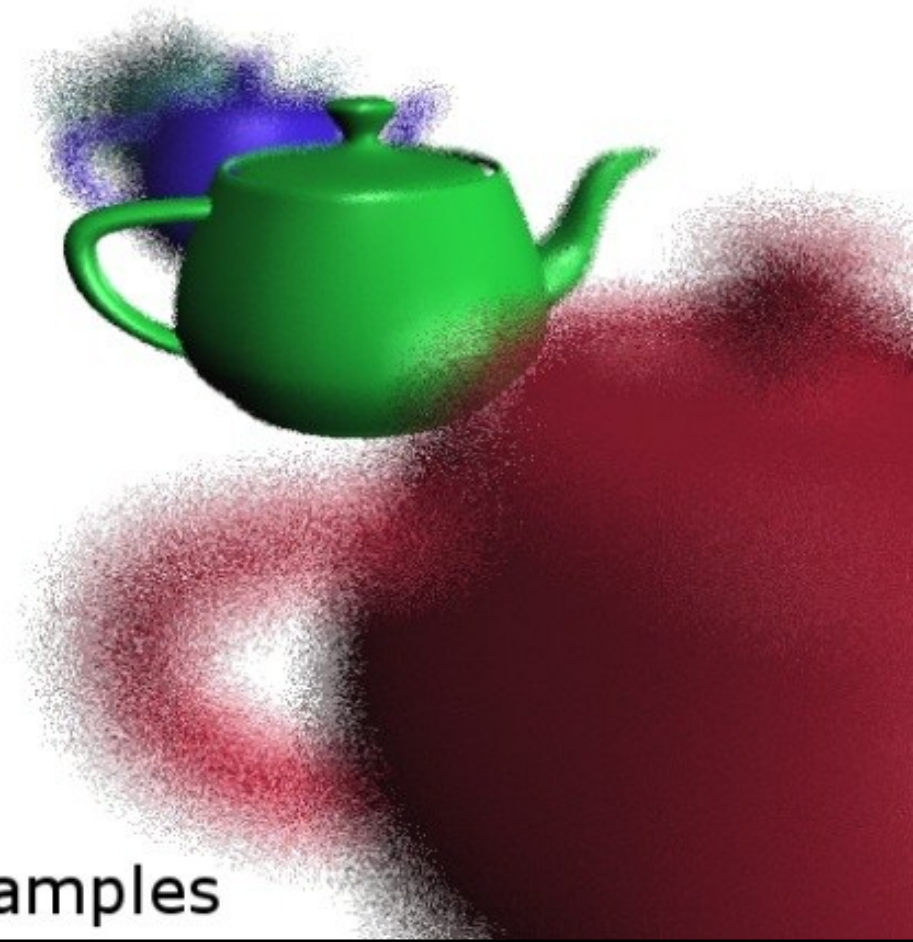
Good noise-reducing
Depth-of-Field effects
takes a lot of point
samples!



1 Sample

The Problem

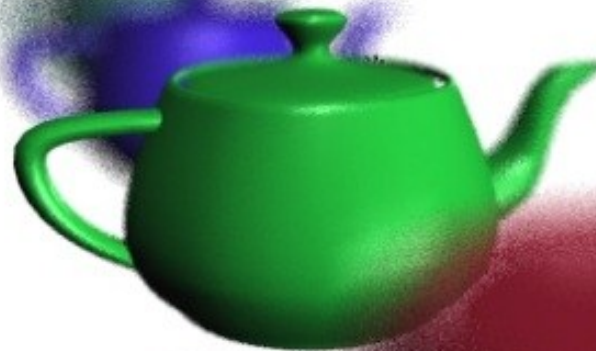
Good noise-reducing
Depth-of-Field effects
takes a lot of point
samples!



4 Samples

The Problem

Good noise-reducing
Depth-of-Field effects
takes a lot of point
samples!



16 Samples

The Problem

Good noise-reducing
Depth-of-Field effects
takes a lot of point
samples!



64 Samples

This Talk

- Instead of point samples, use **line samples!**
 - Heavier compute per sample, but need fewer samples for good results
- A tiled line sampling renderer for graphics hardware
 - How to make line sampling work within tight memory constraints?

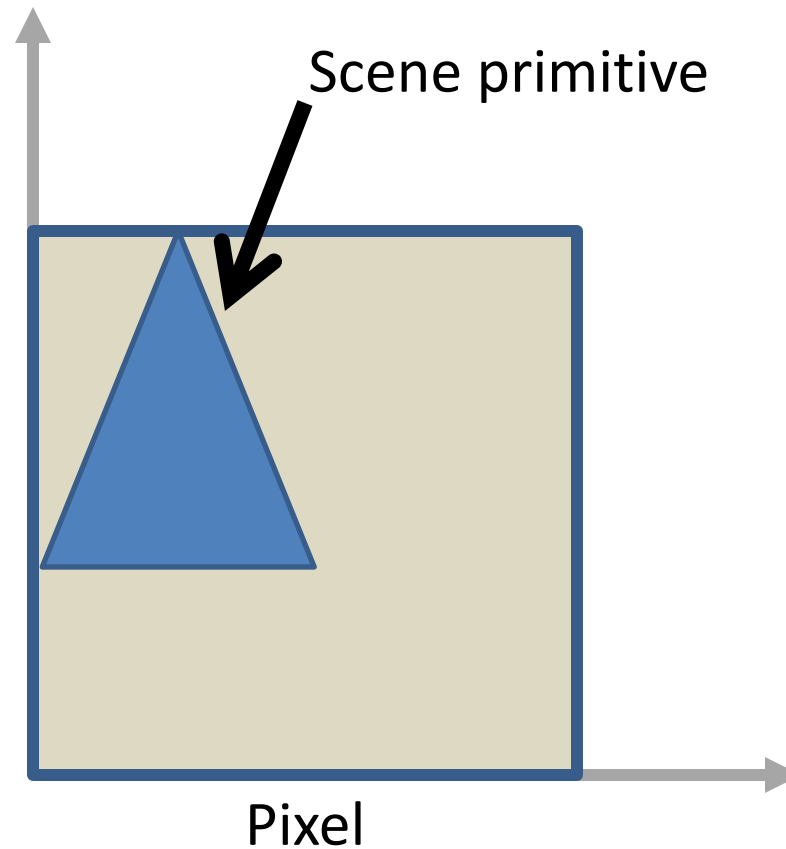
Line Samples

A dimensional extension of point samples

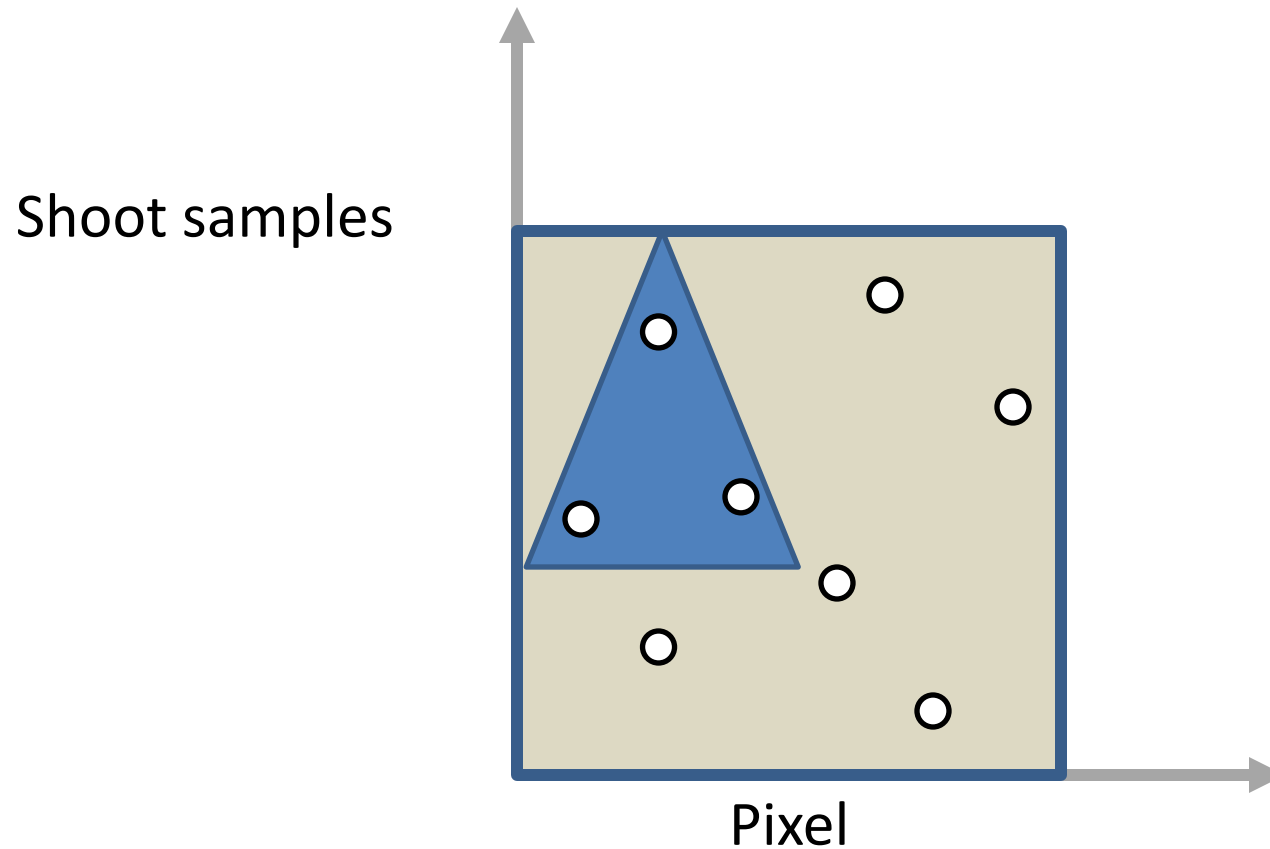
Gribel et al. : High-Quality Spatio-Temporal Rendering using Semi-Analytical Visibility

Jones and Perry: Antialiasing with Line Samples

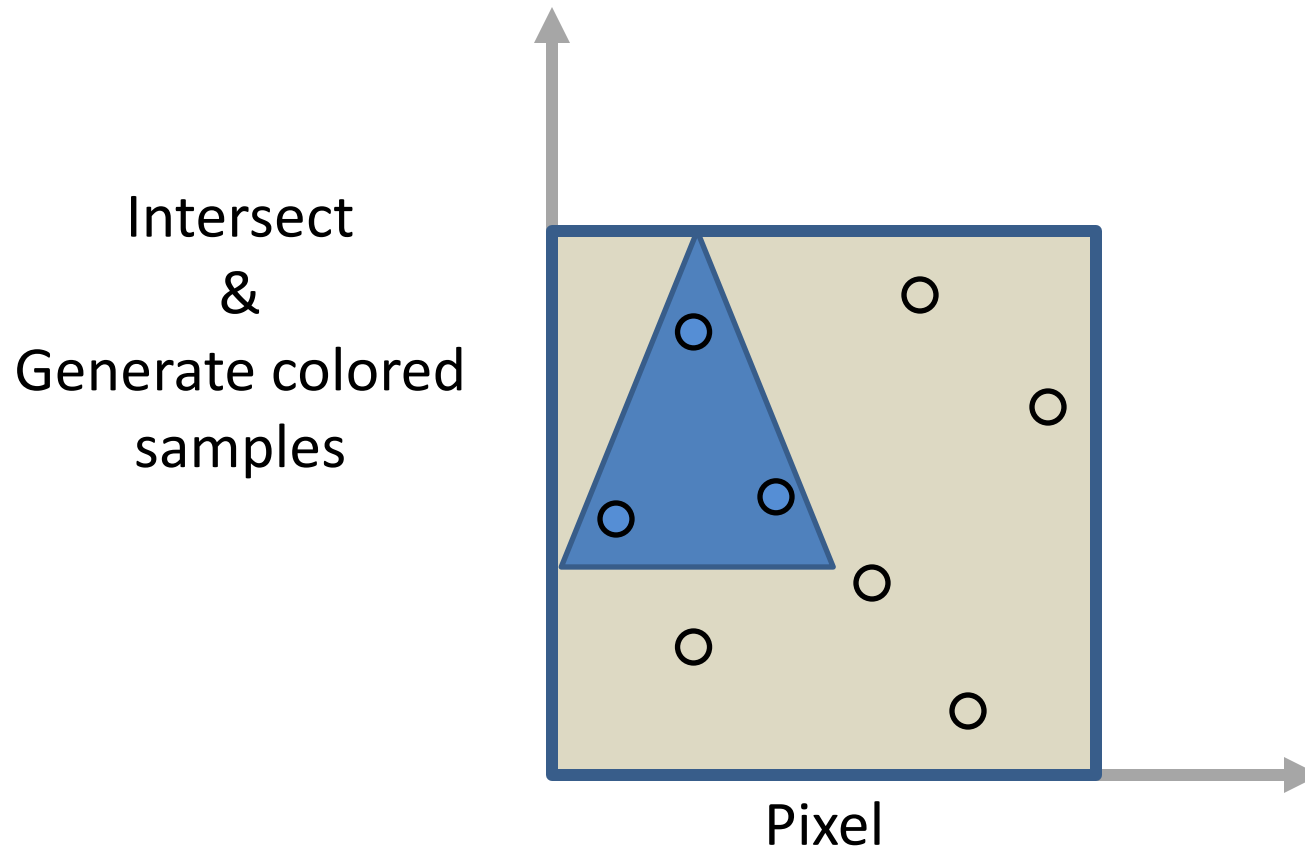
Point Samples in a pixel



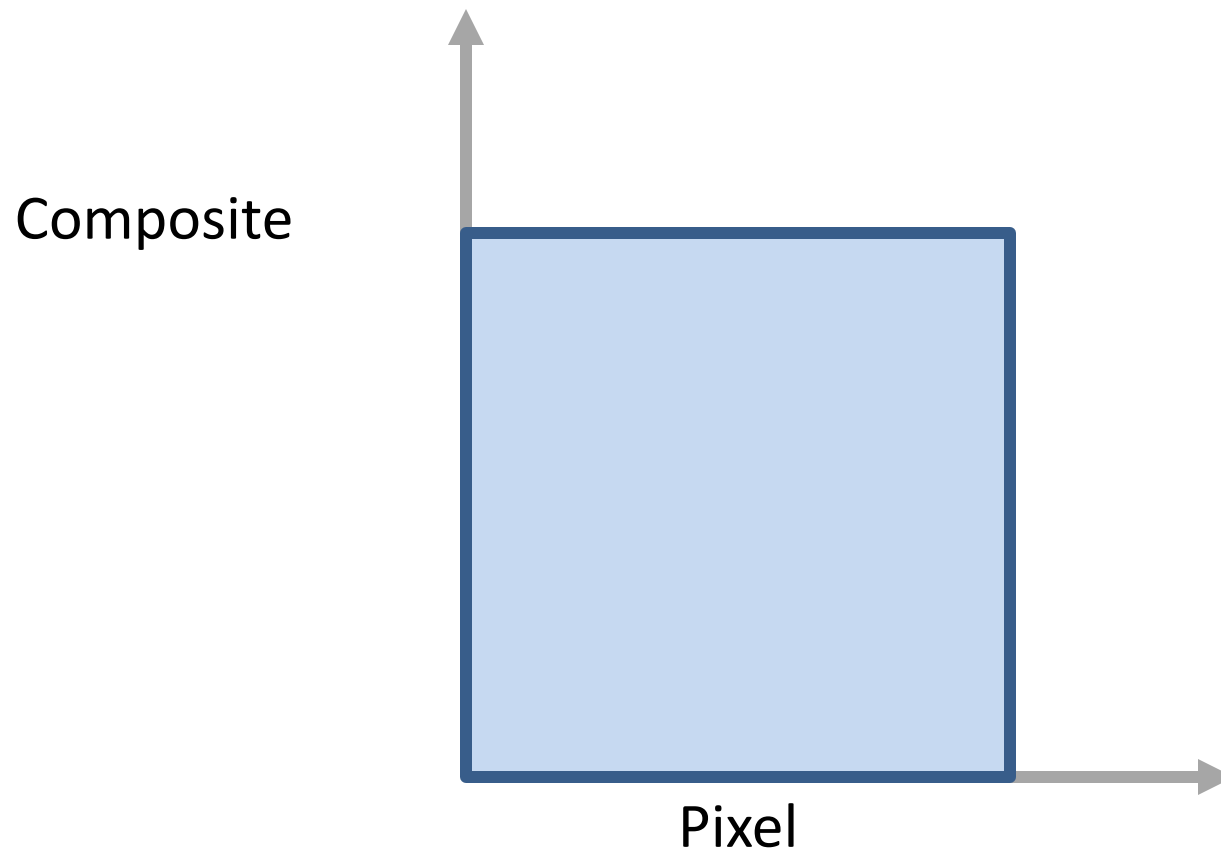
Point Samples in a pixel



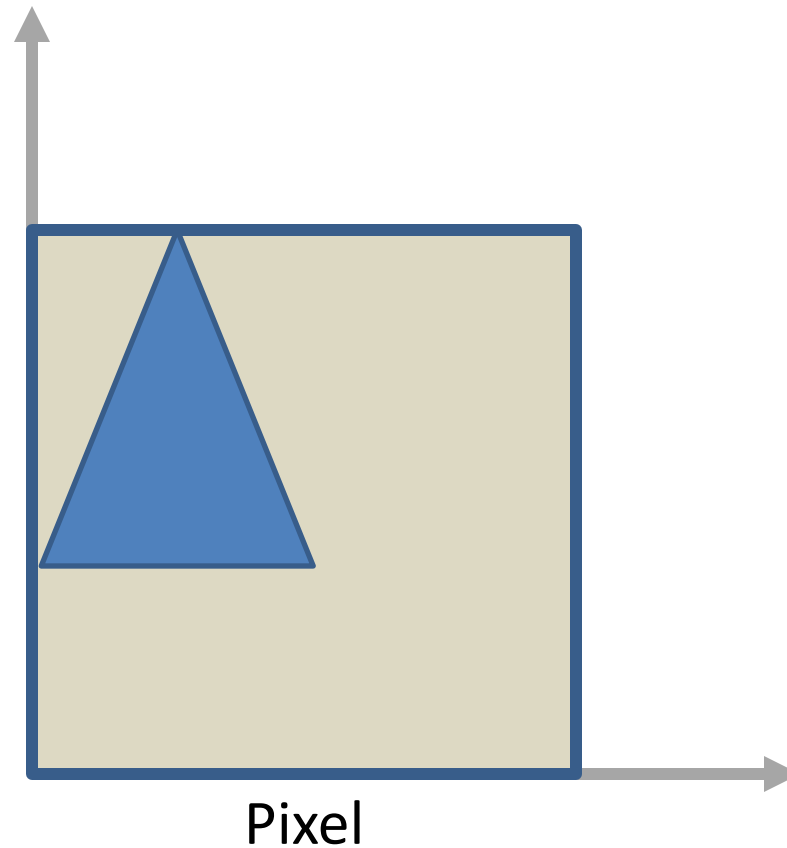
Point Samples in a pixel



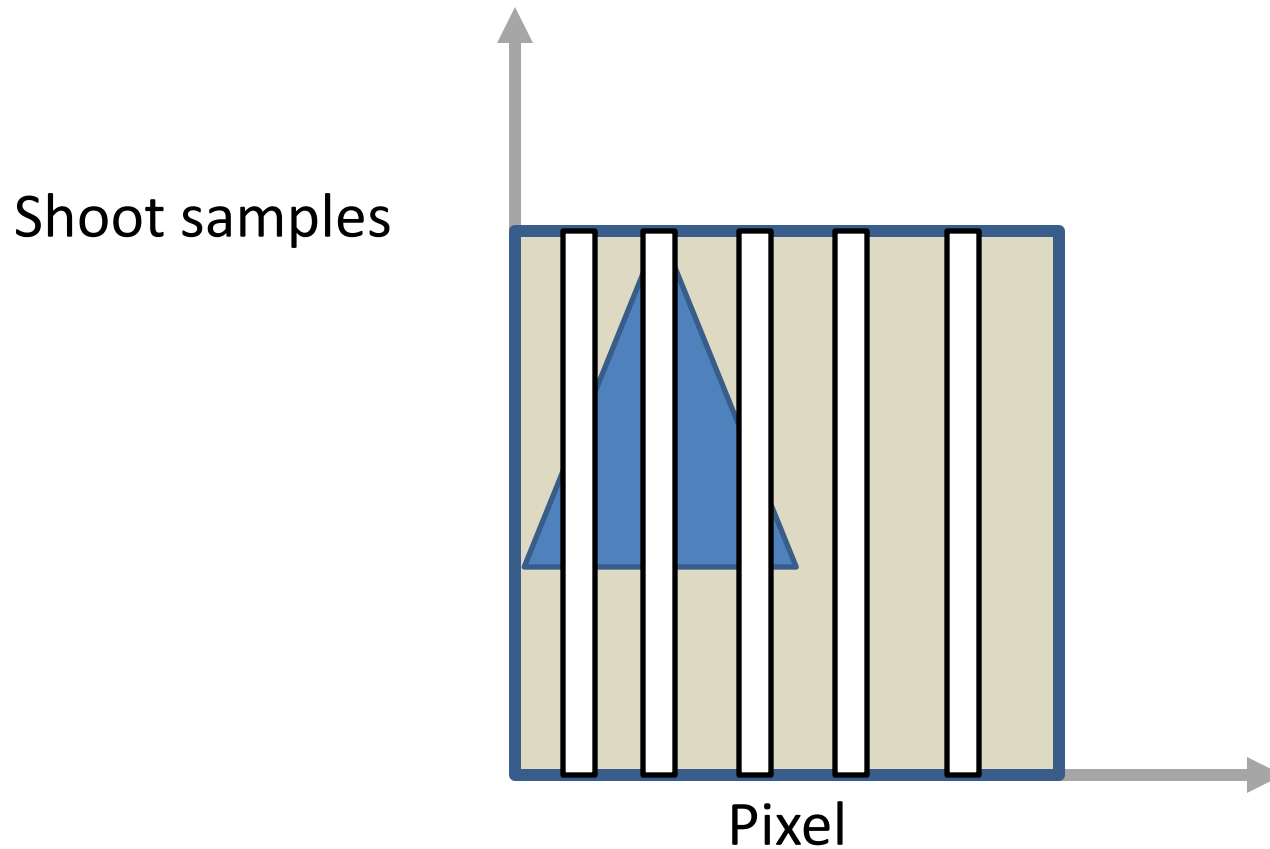
Point Samples in a pixel



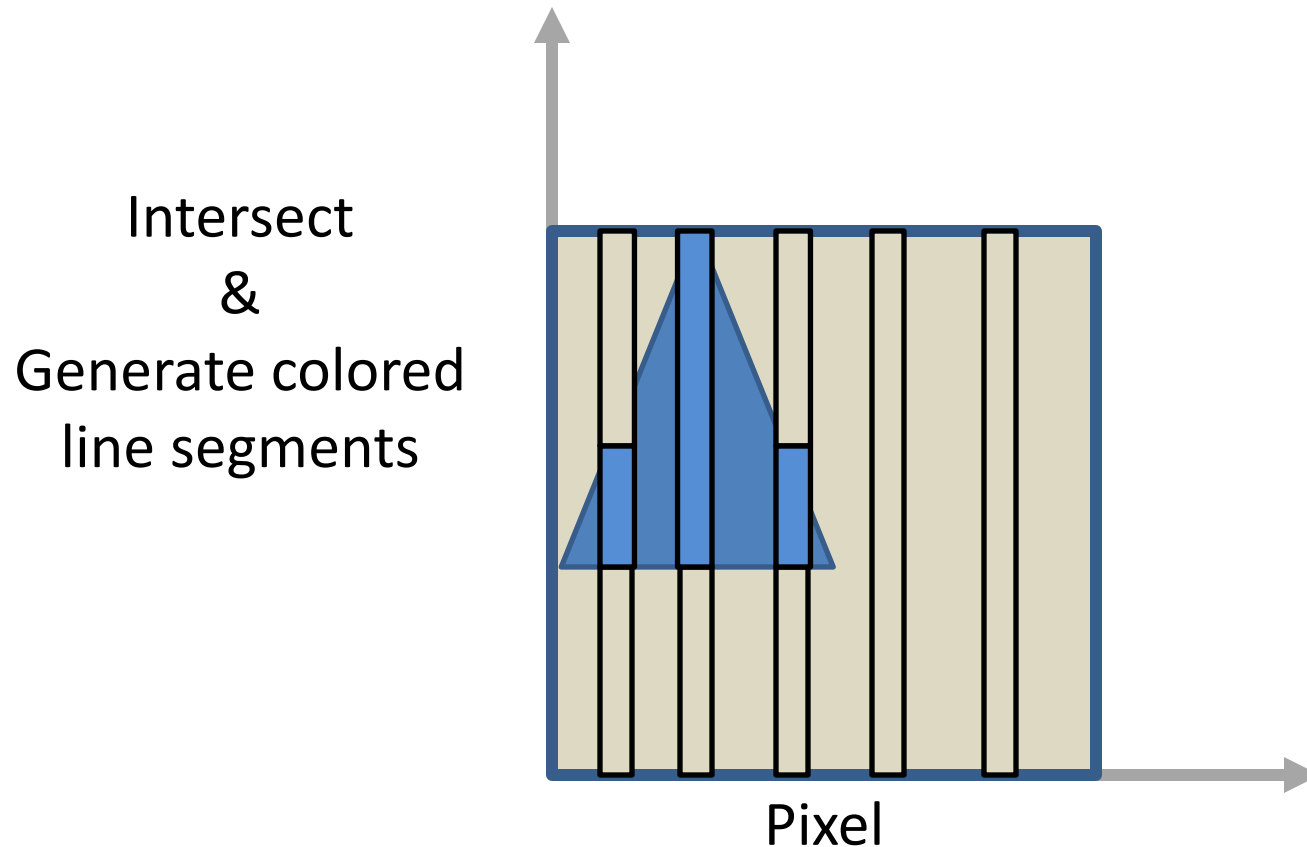
Line Samples in a pixel



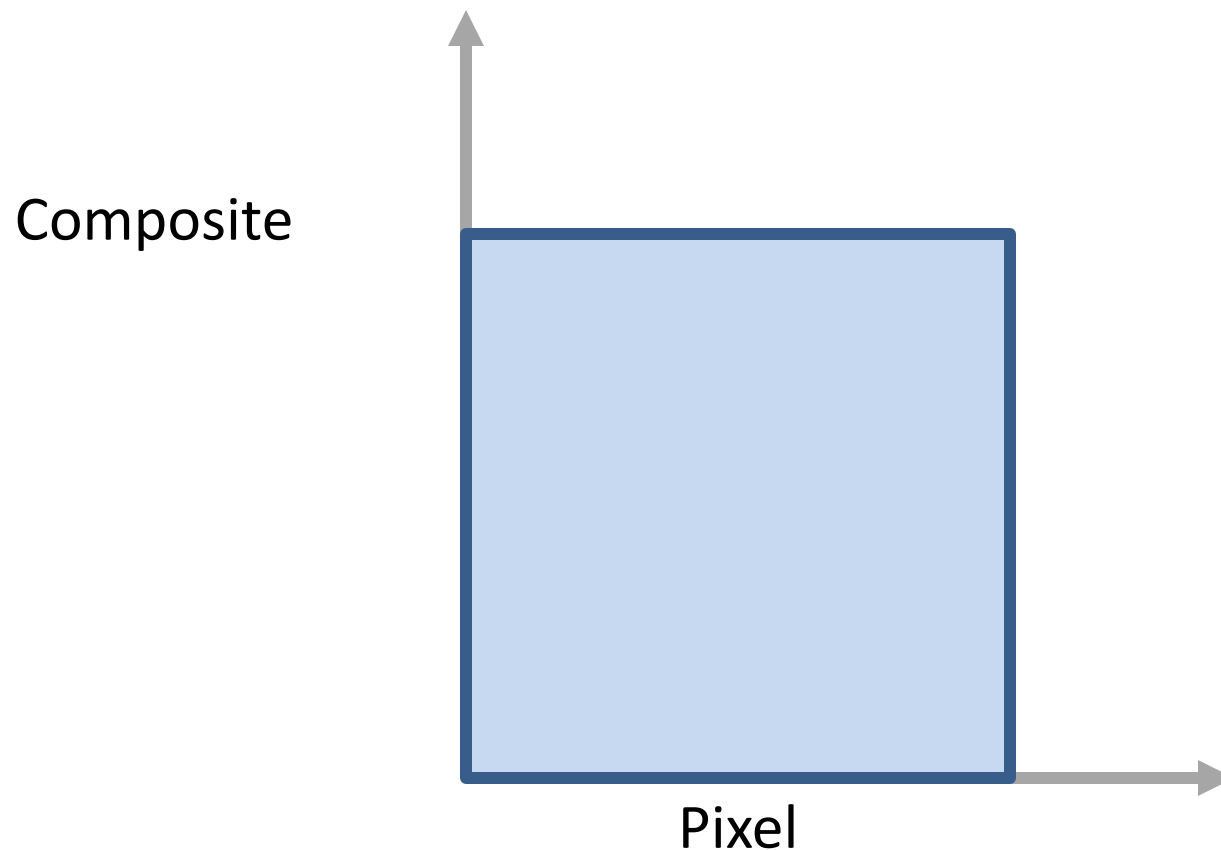
Line Samples in a pixel



Line Samples in a pixel

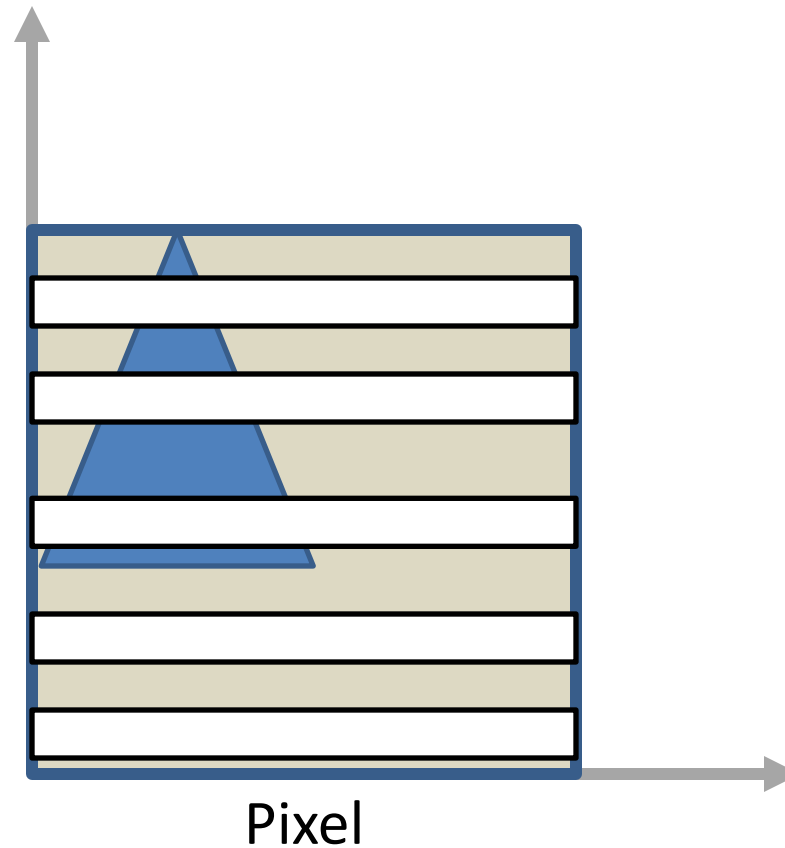


Line Samples in a pixel



Side Note

Samples can be in any arbitrary orientation.

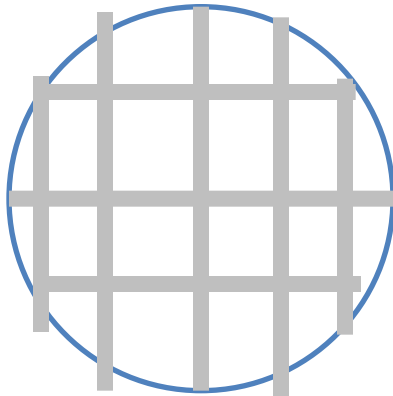


Depth of Field Sampling

- Point Sampling: Generate 4D point samples in (x,y,u,v) space.
 - Point on screen (x,y) +
 - Point on lens (u,v)
- Line Sampling: Fix a point in screen space (x,y) , sample along the lens in (u,v) space.

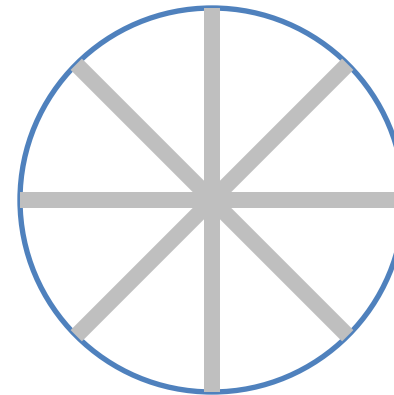
How to Sample Along the Lens?

Grid



- Good area coverage
- Uneven line lengths

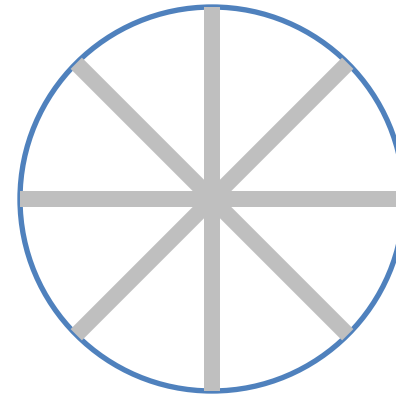
Pinwheel



- Even Line Lengths
- Bias towards center

How to Sample Along the Lens?

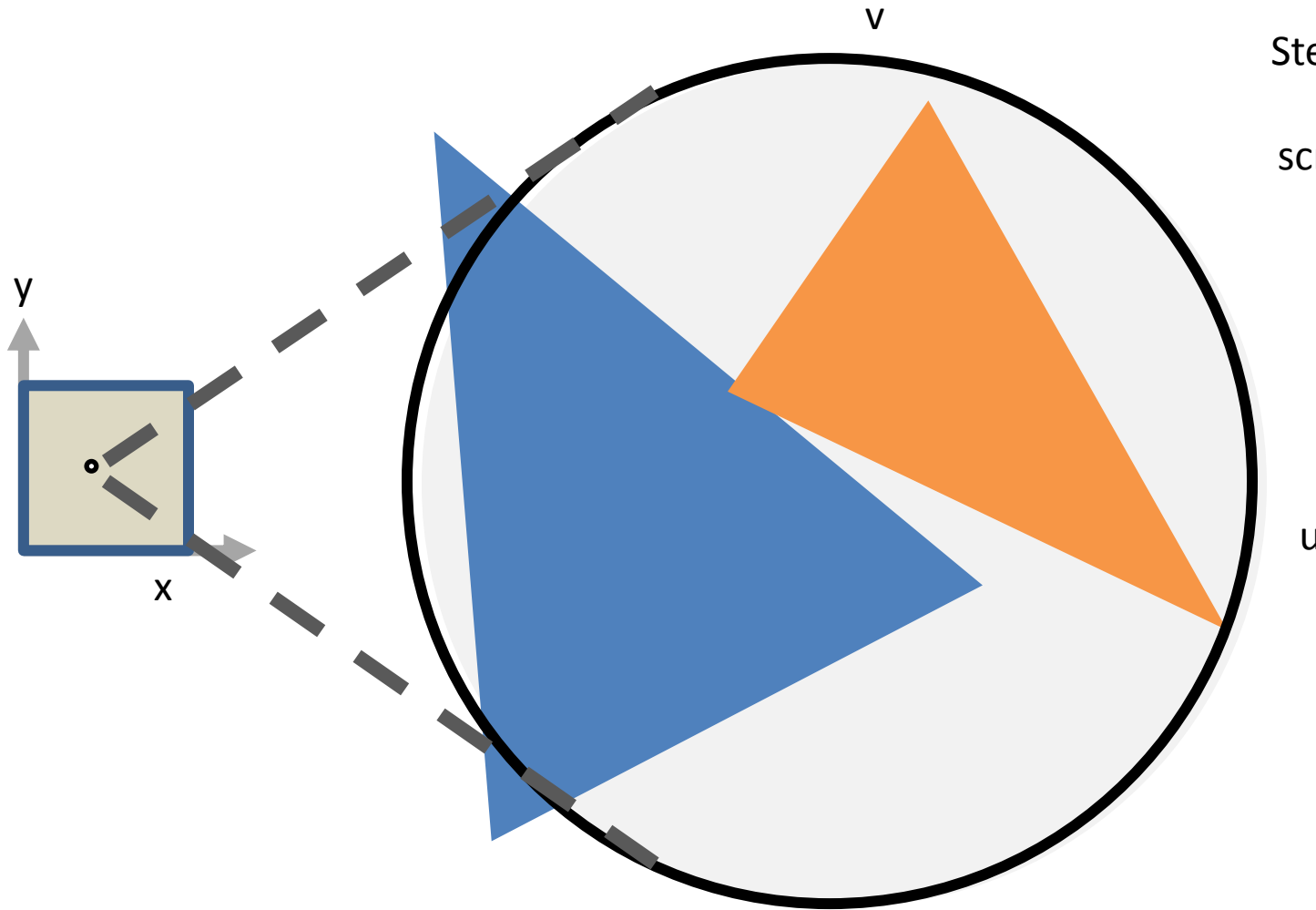
Pinwheel



- Even Line Lengths
- Bias towards center

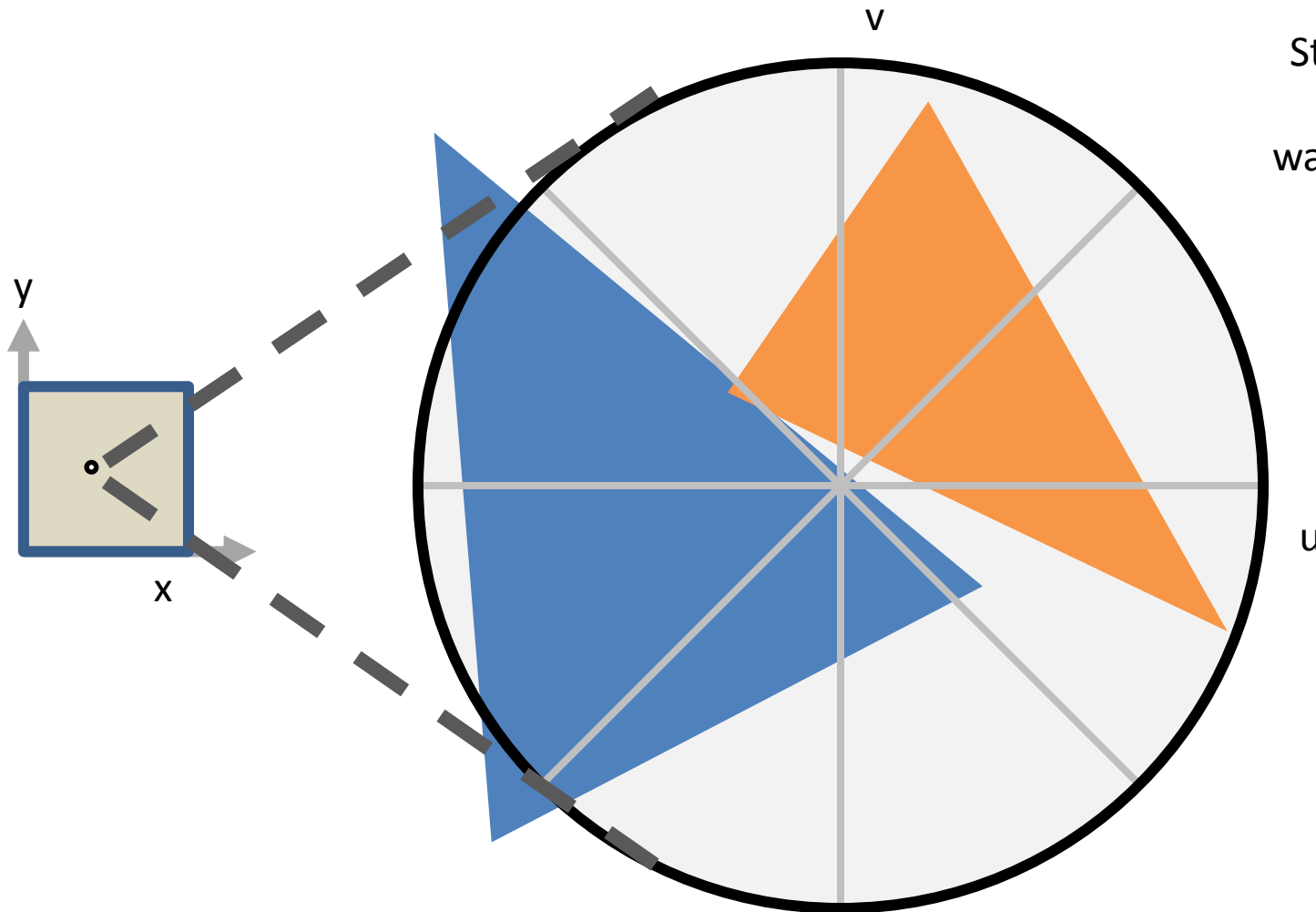
Reweigh the
samples obtained

Line Samples for DoF



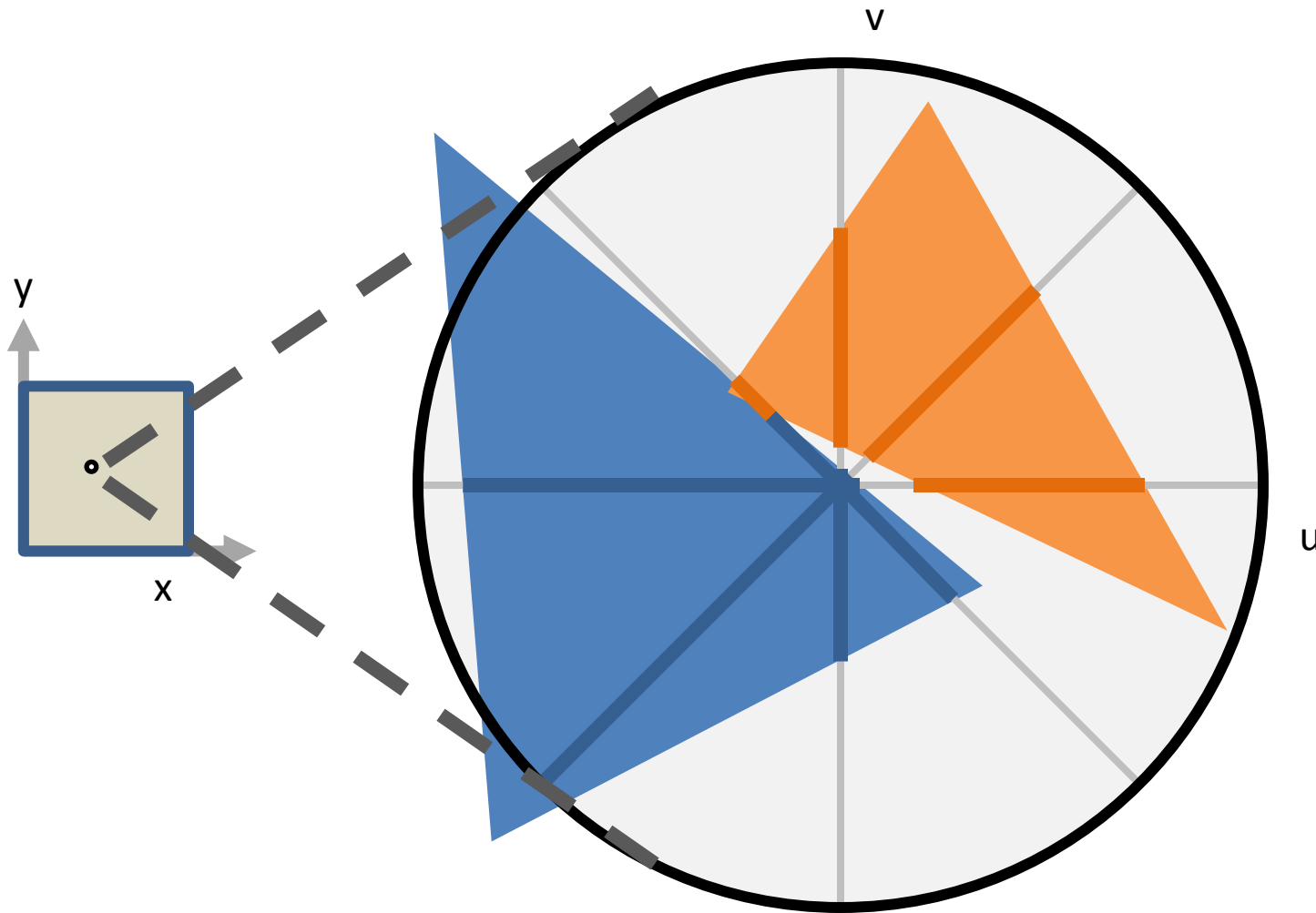
Step 1: Project scene geometry from screen space to lens space.

Line Samples for DoF



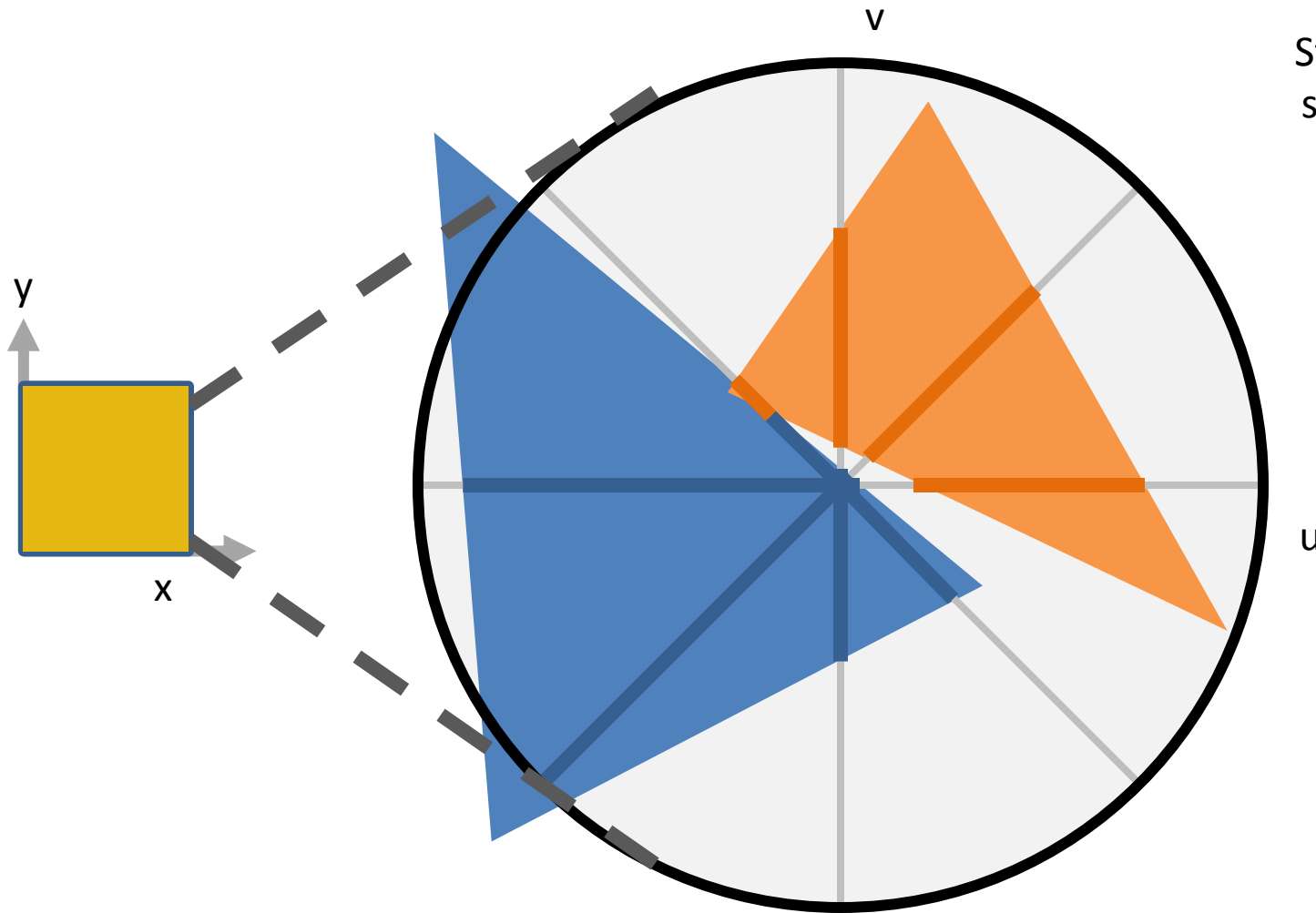
Step 2: Sample the lens using a wagonwheel pattern

Line Samples for DoF



Step 3: Record intersected segments

Line Samples for DoF



Step 4: Composite
segments to pixel
color

Line Samples using DoF



2 Line Samples

Line Samples using DoF



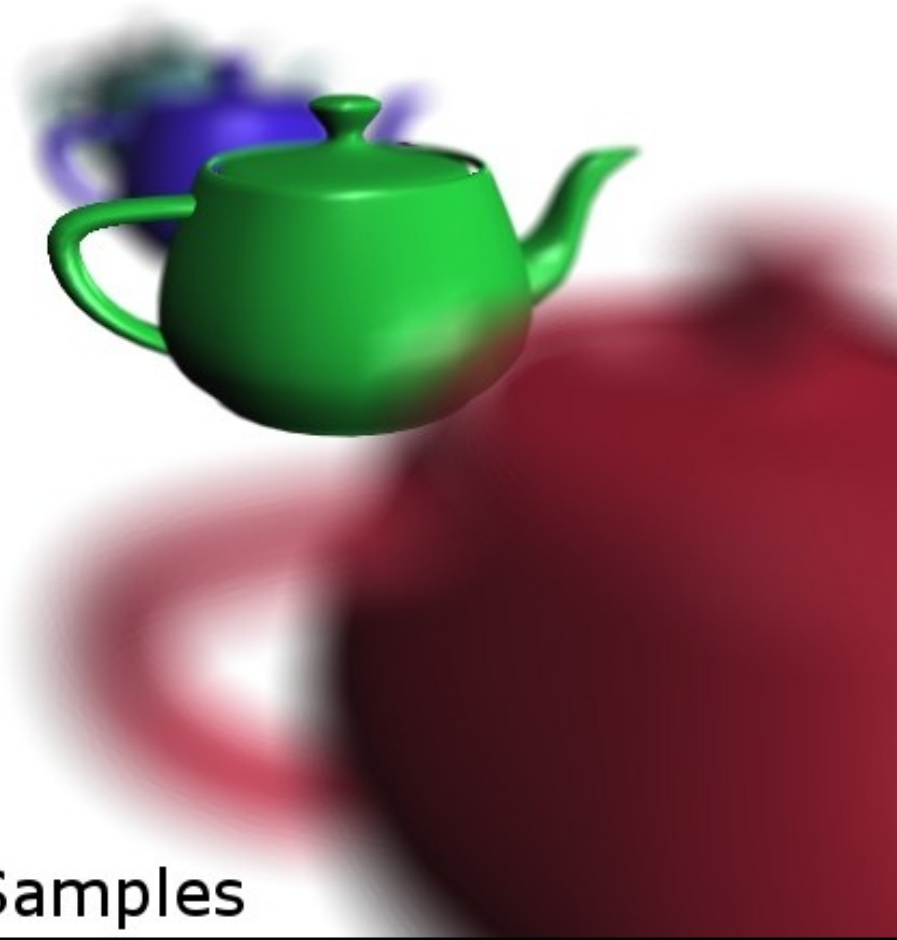
4 Samples

Line Samples using DoF



8 Samples

Line Samples using DoF



16 Samples

Comparison



16 Samples

Point Samples



16 Samples

Line Samples

Comparison



256 Samples

Point Samples



16 Samples

Line Samples

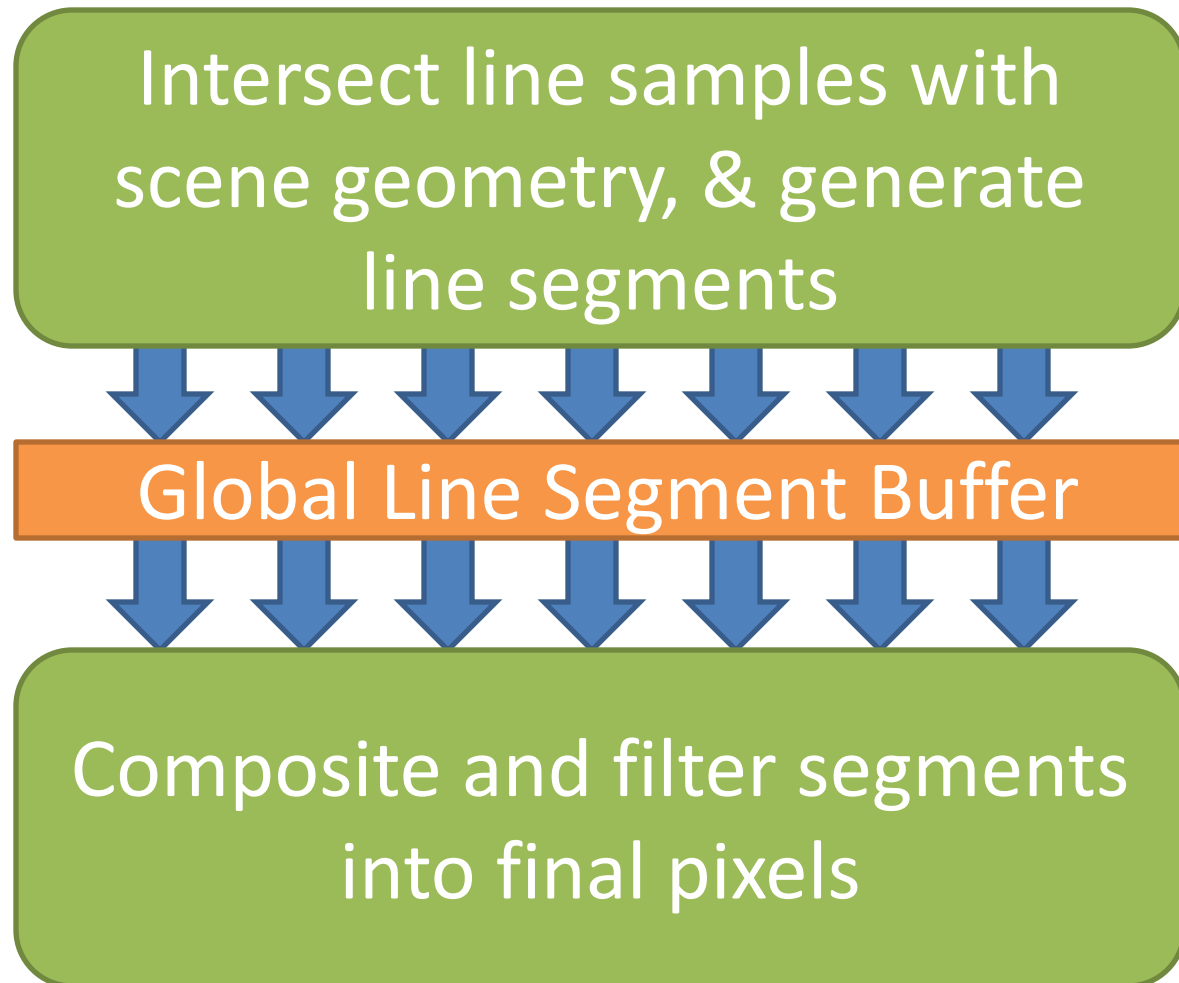
Metric of Comparison!

Line Sampling on the GPU

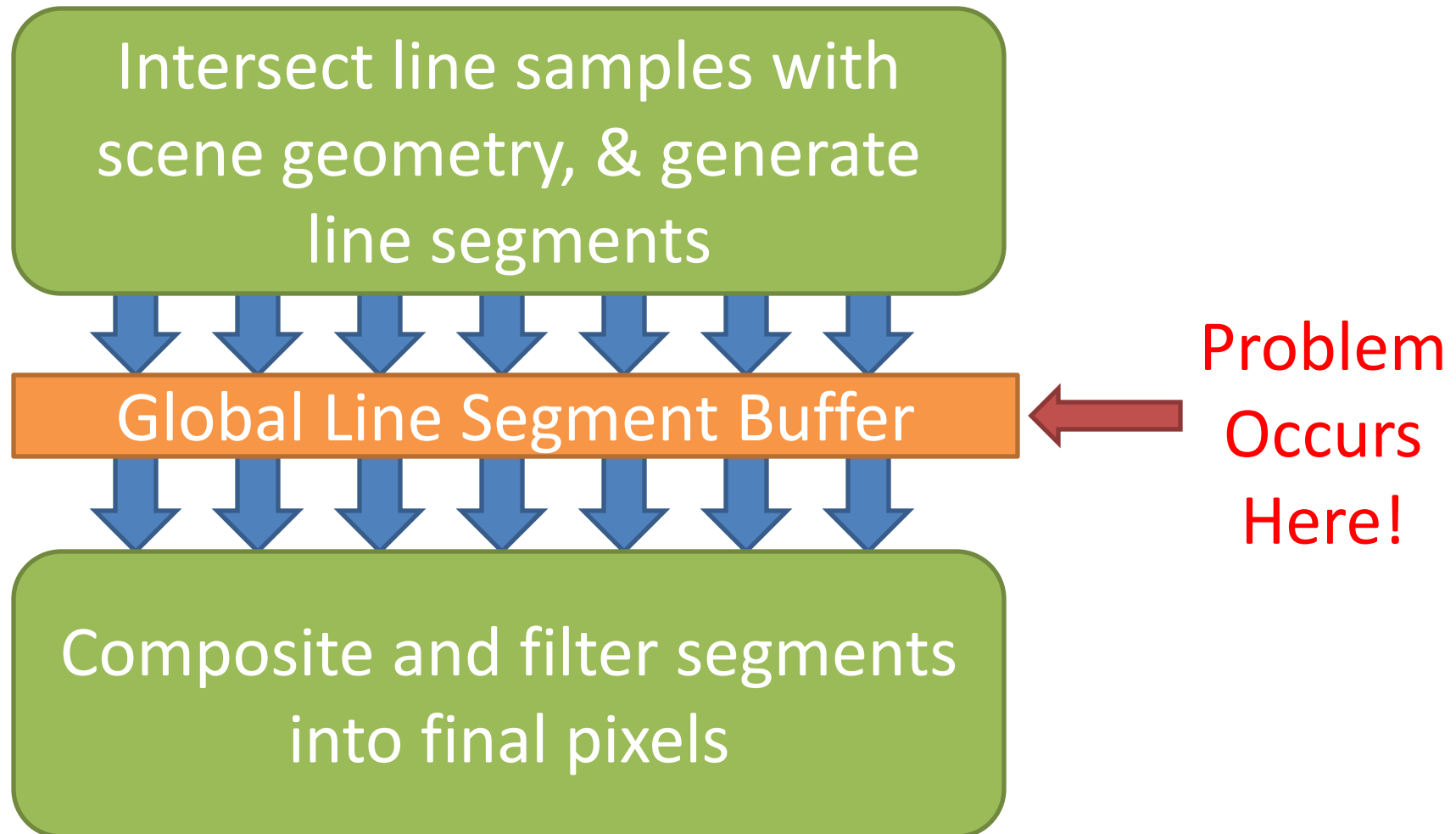
What's really important to us:

- Easy parallel processing
- Bounded memory requirements
 - Shared memory is limited
 - Games require fixed storage

Parallel Implementation: 2 Kernels

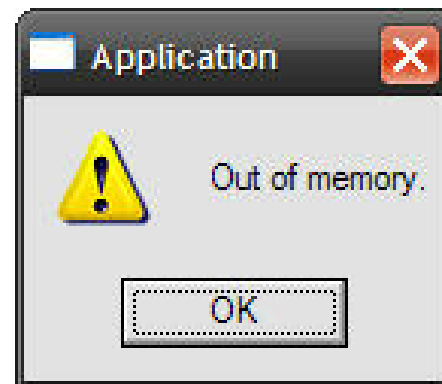


Parallel Implementation: 2 Kernels



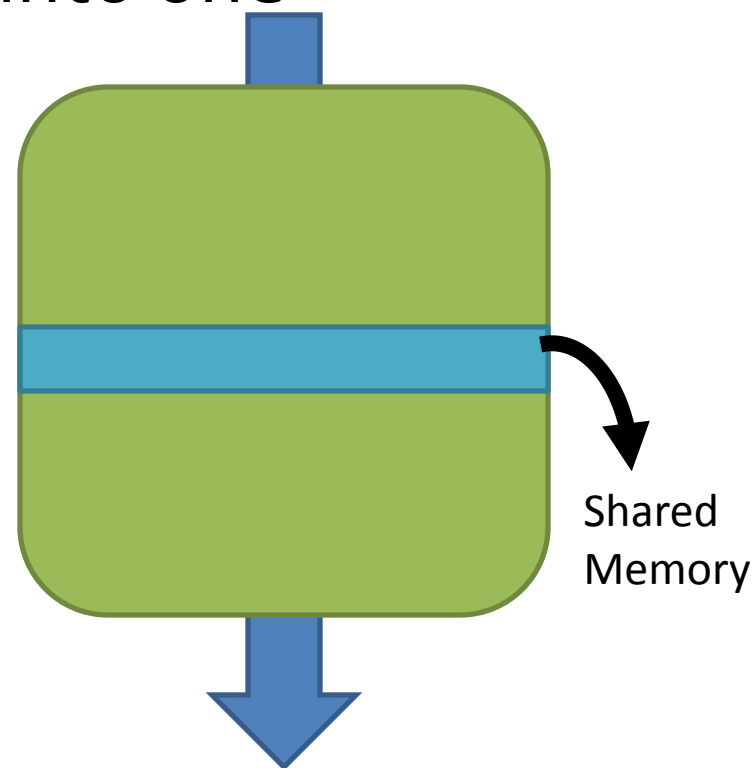
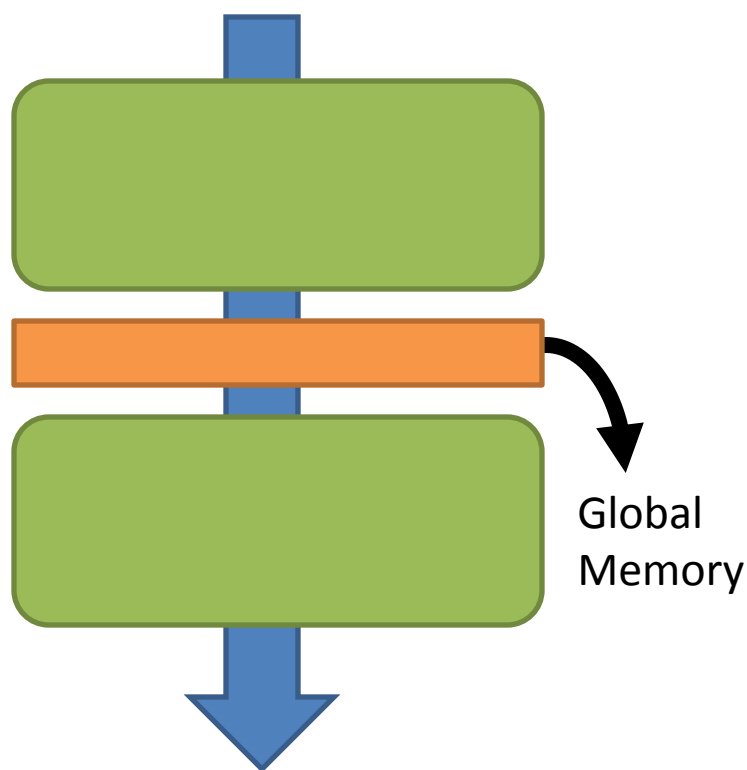
Problem

800 x 600 x 16 x 16 x 24
width height # line samples # line segments Bytes per segment



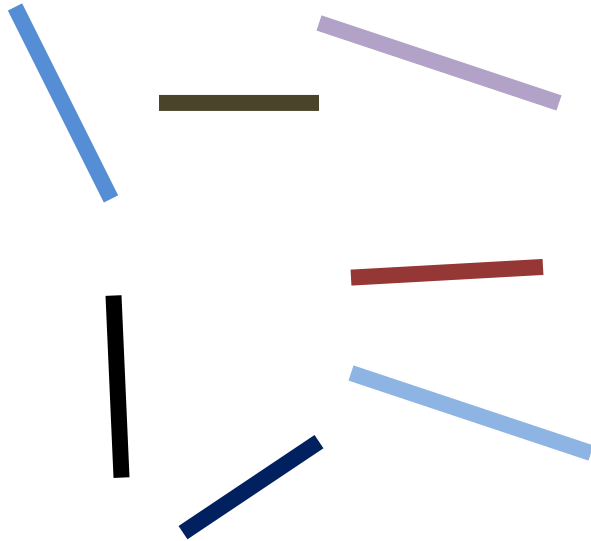
Binning

- Split screen into tiles – use shared memory instead of global memory
- Combine the two kernels into one

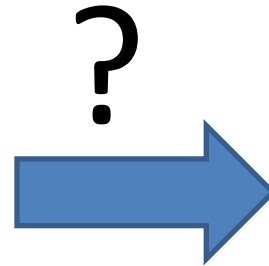


New Problem

- New problem: Shared memory is small.



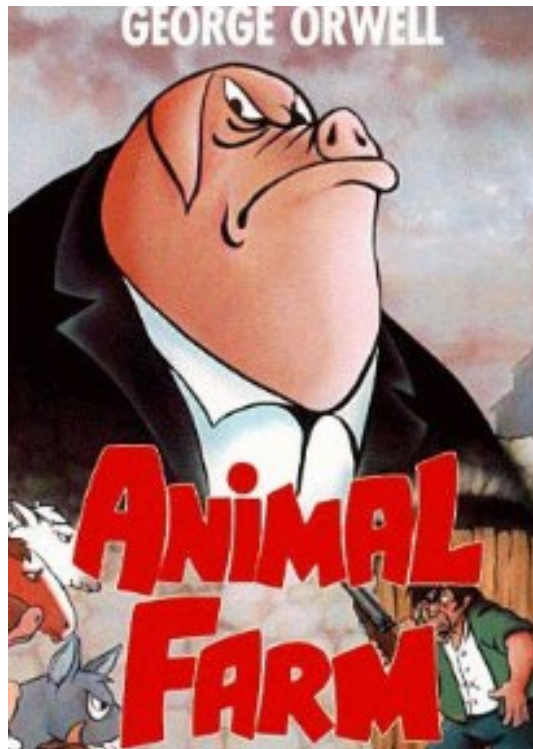
Line Segments



Line Segment Buffer

Solution:

Keep only the **important** line segments!



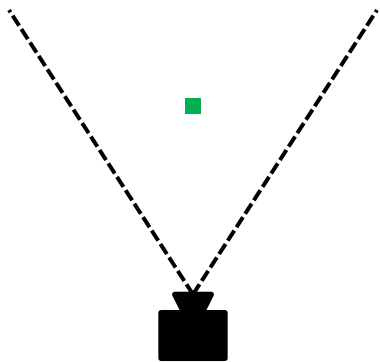
Line Segments

“~~All animals~~
are equal, but
some ~~animals~~
are more **Line Segments**
equal than
others.”

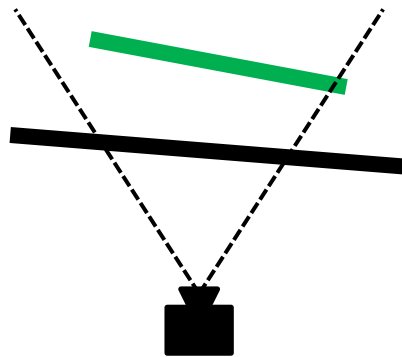
Animal Farm

Heuristics

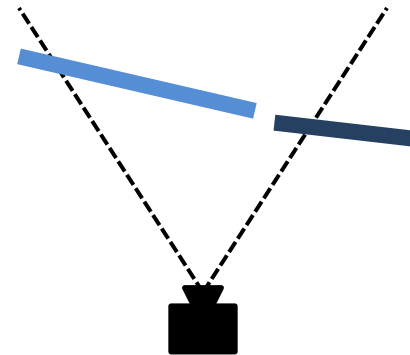
Only keep segments that contribute the most to the color of the sample



Green Segment
Too Small

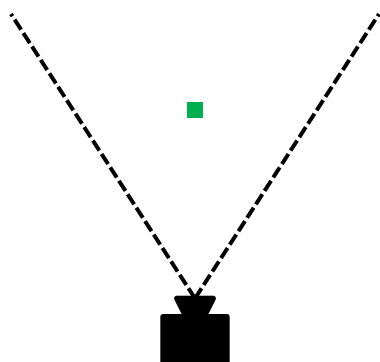


Green Segment
Occluded

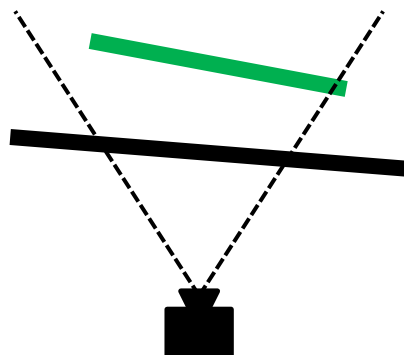


Heuristics

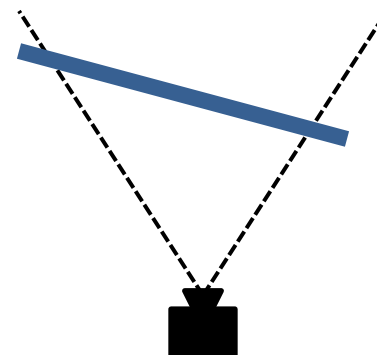
Only keep segments that contribute the most to the color of the sample



Green Segment
Too Small



Green Segment
Occluded



Blue Segment
Merged



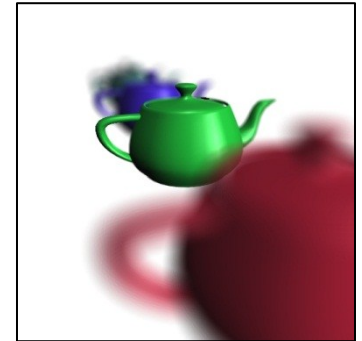
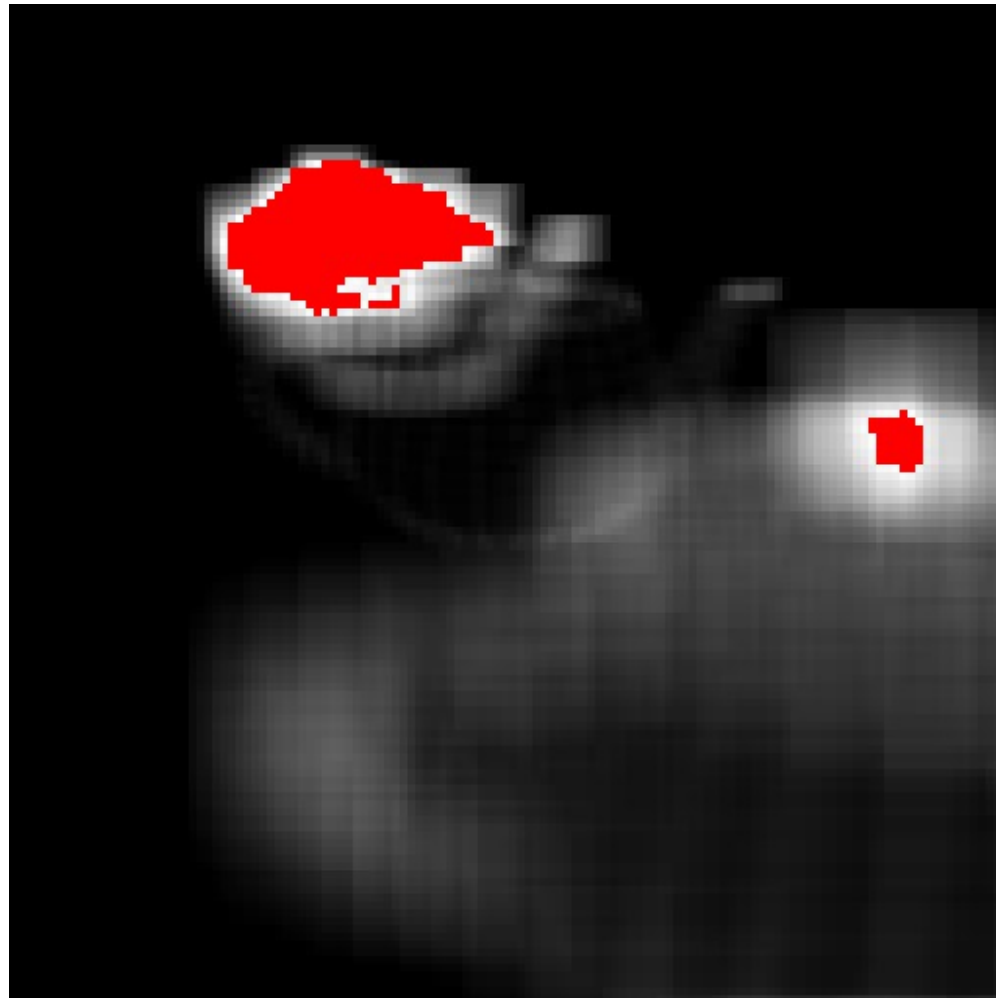
Heuristics

Rules:

- Discard if segment is too short
- Discard if segment is occluded
- Merge if segments are similar

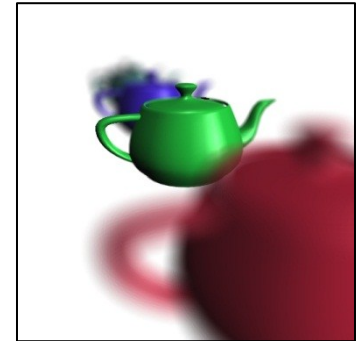
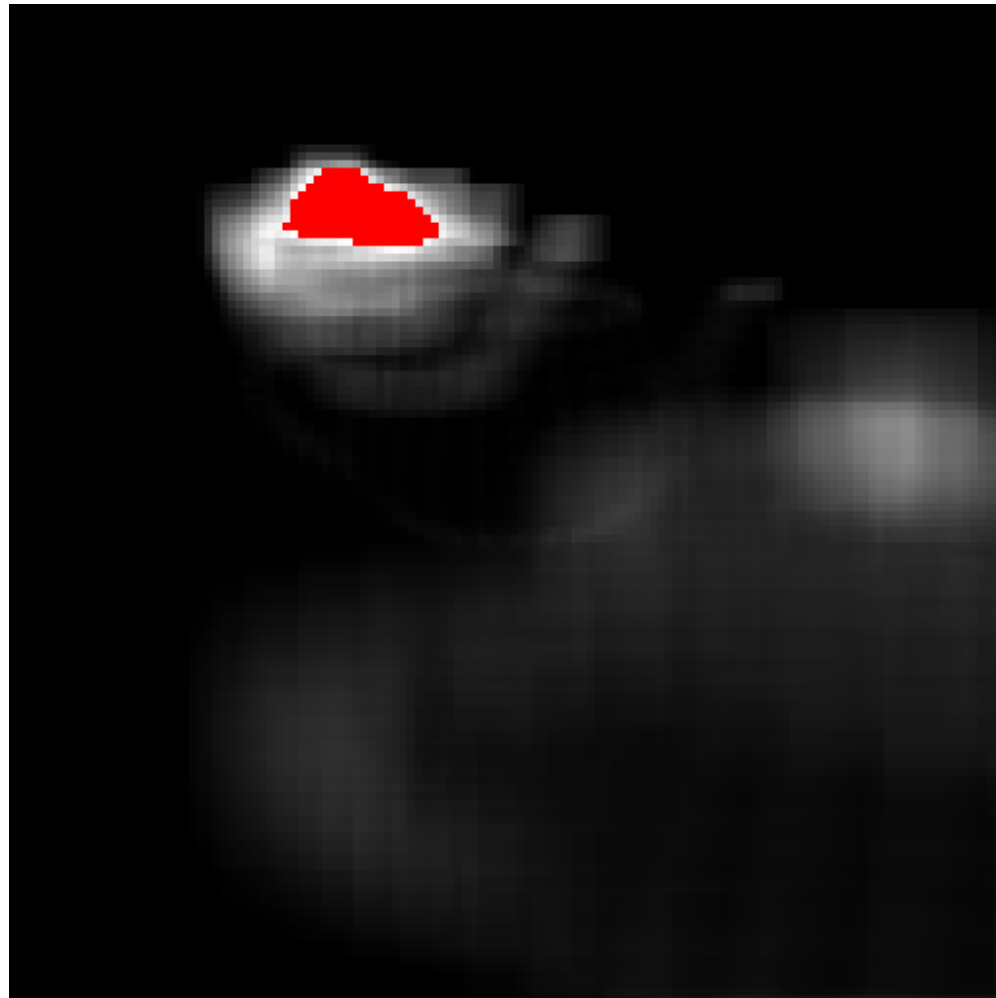
A small amount of shared memory = small tiles
Another Problem!

Bins Overflow



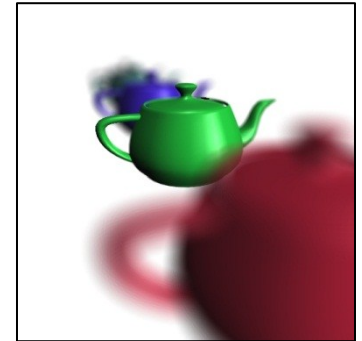
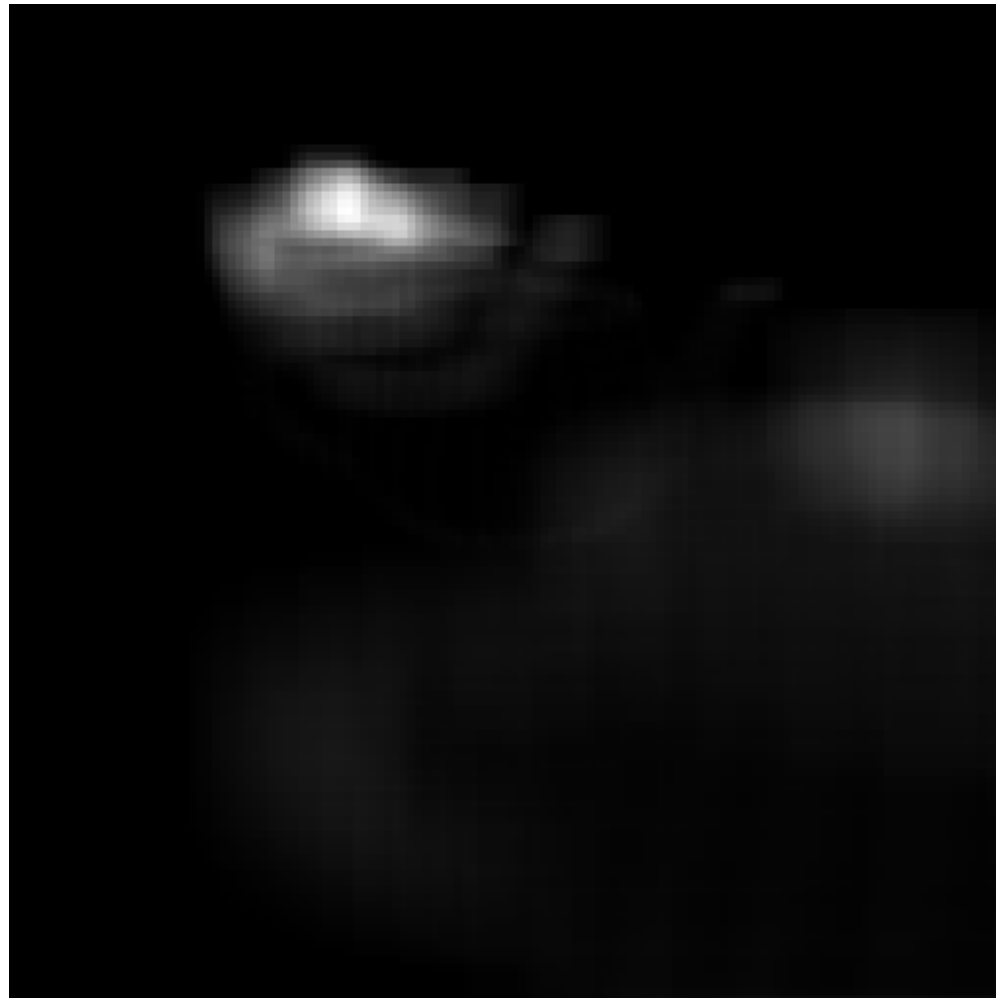
4x4 bins, 256 max triangles

Bins Overflow



4x4 bins, 512 max triangles

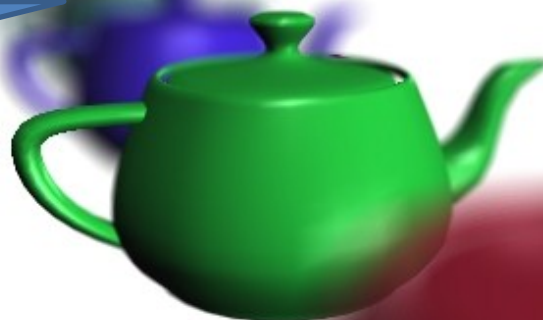
Bins Overflow



4x4 bins, 1024 max triangles

Bins Overflow

Overflow because
of depth



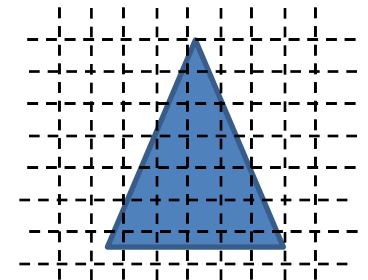
Overflow because
of large CoC.

Bins Overflow

Overflow because
of depth

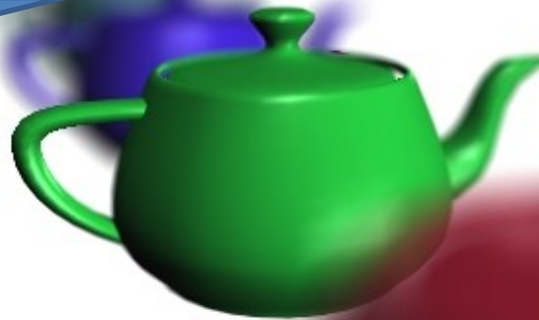


Overflow because
of large CoC.

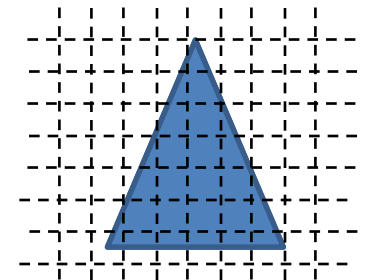


Bins Overflow

Overflow because
of depth

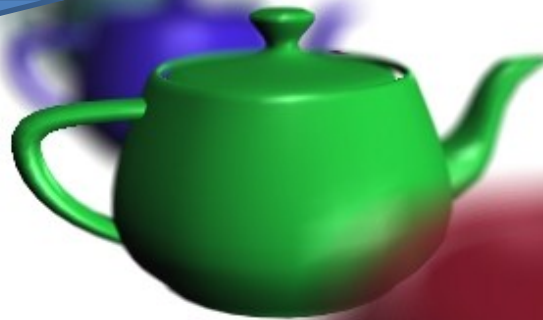


Overflow because
of large CoC.

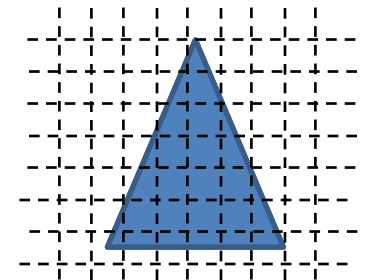


Bins Overflow

Overflow because
of depth



Overflow because
of large CoC.

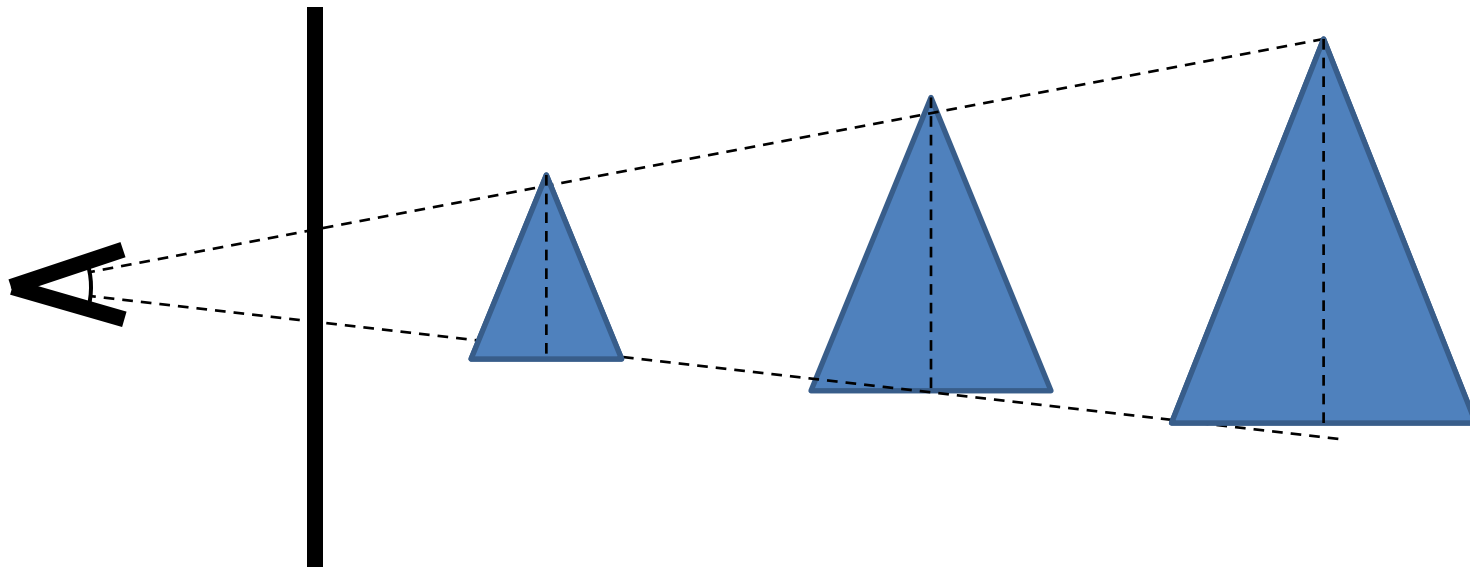


Level of Detail

Close and blurred
Low detail

Close and sharp
High detail

Far and blurred
Low detail



Level of Detail

c / a says, in addition to a traditional LoD scheme:

- If object is close but very blurred – choose lower LoD
- If object is far but still sharp – choose higher LoD



No LoD



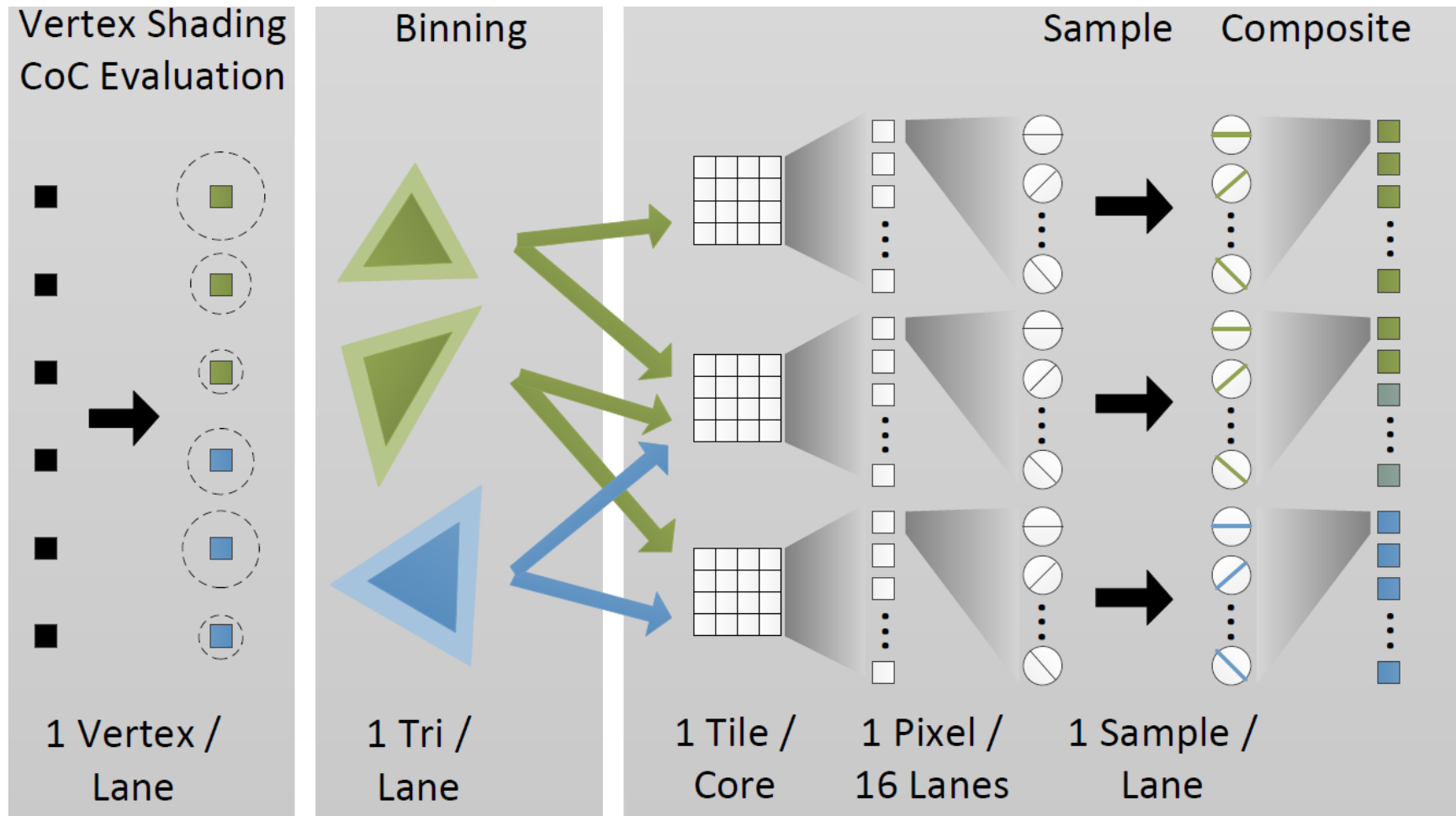
LoD



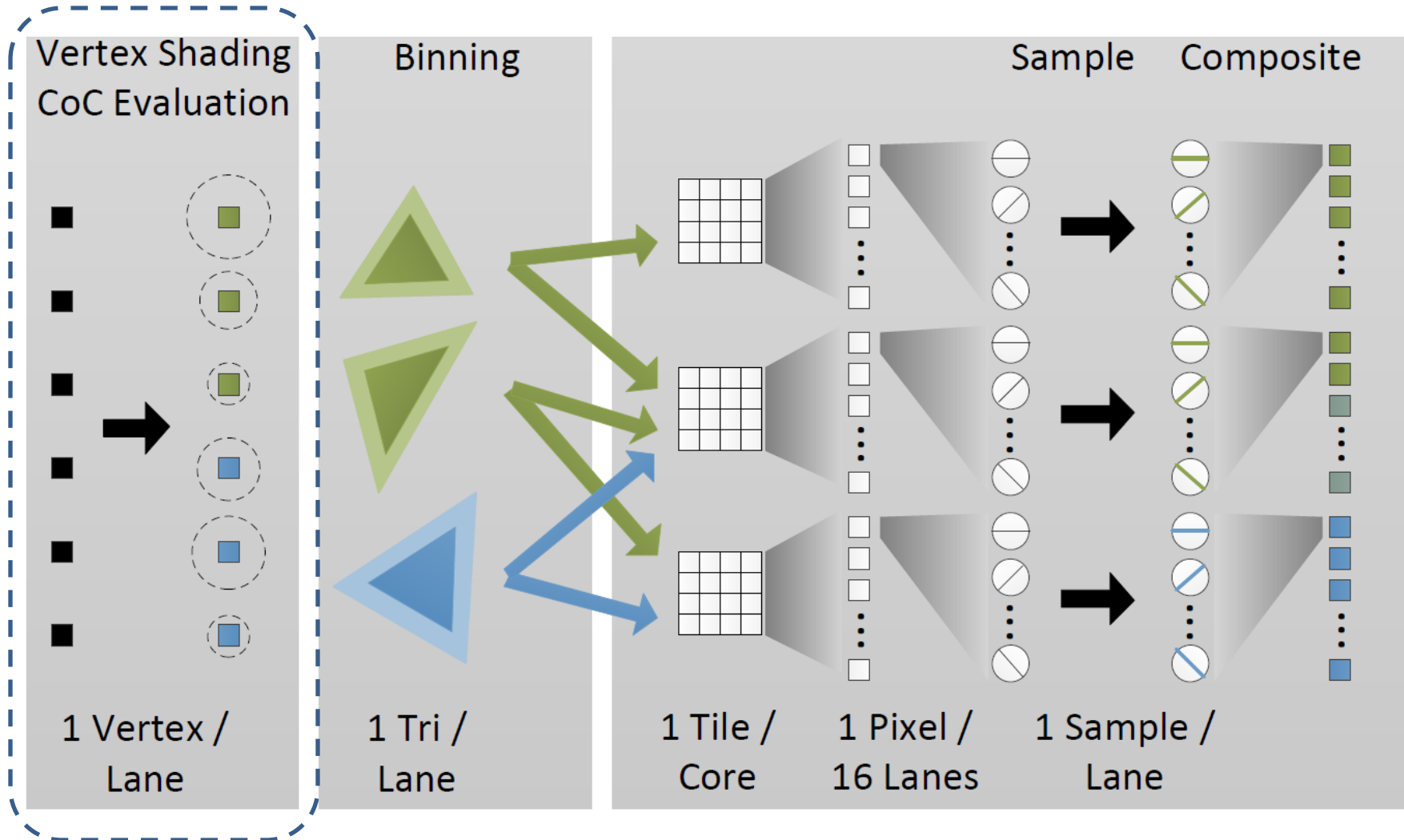
Ground
Truth

1/3 as many triangles, and
1.6 x improvement in speed

Final System Structure

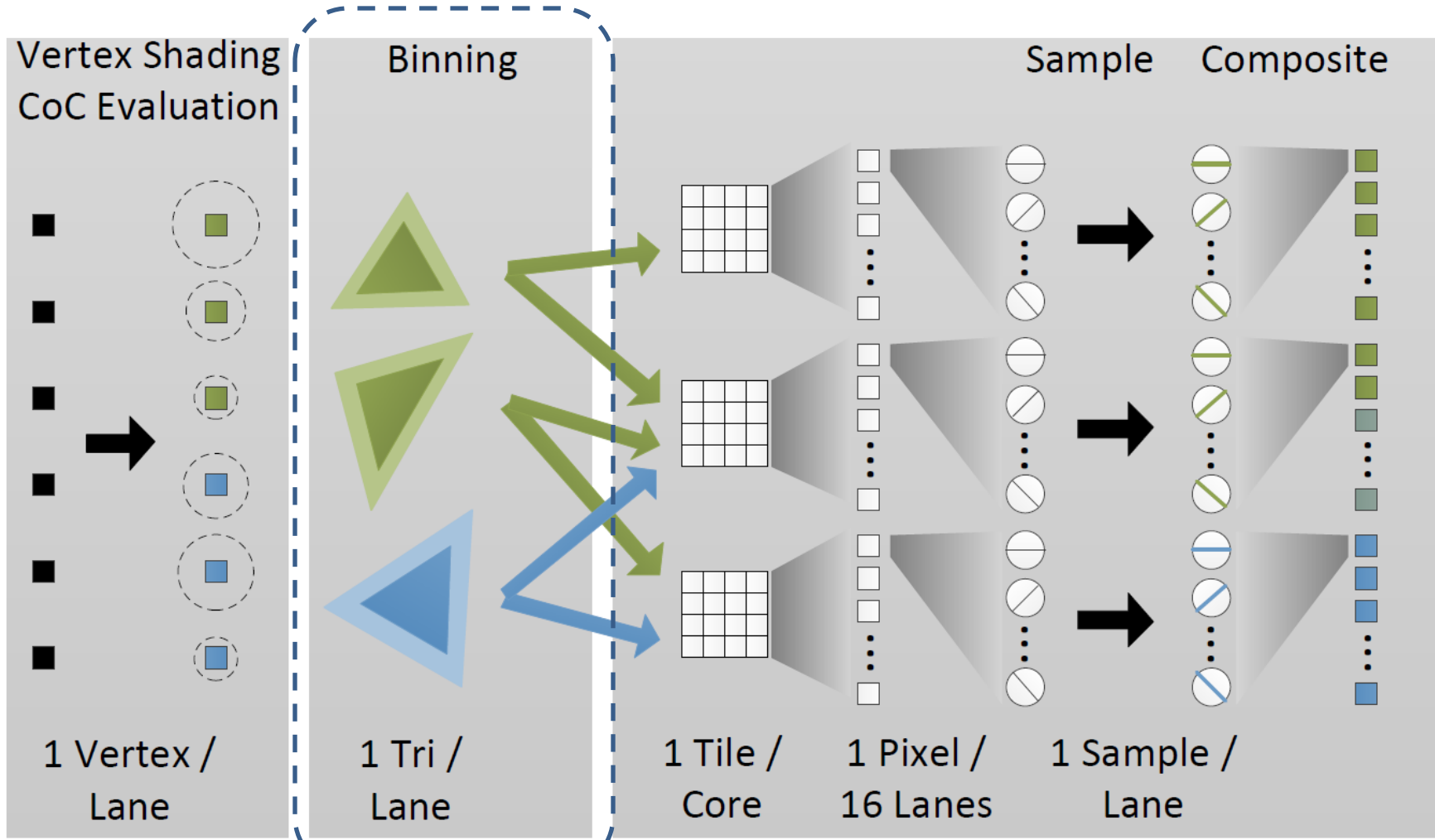


Final System Structure



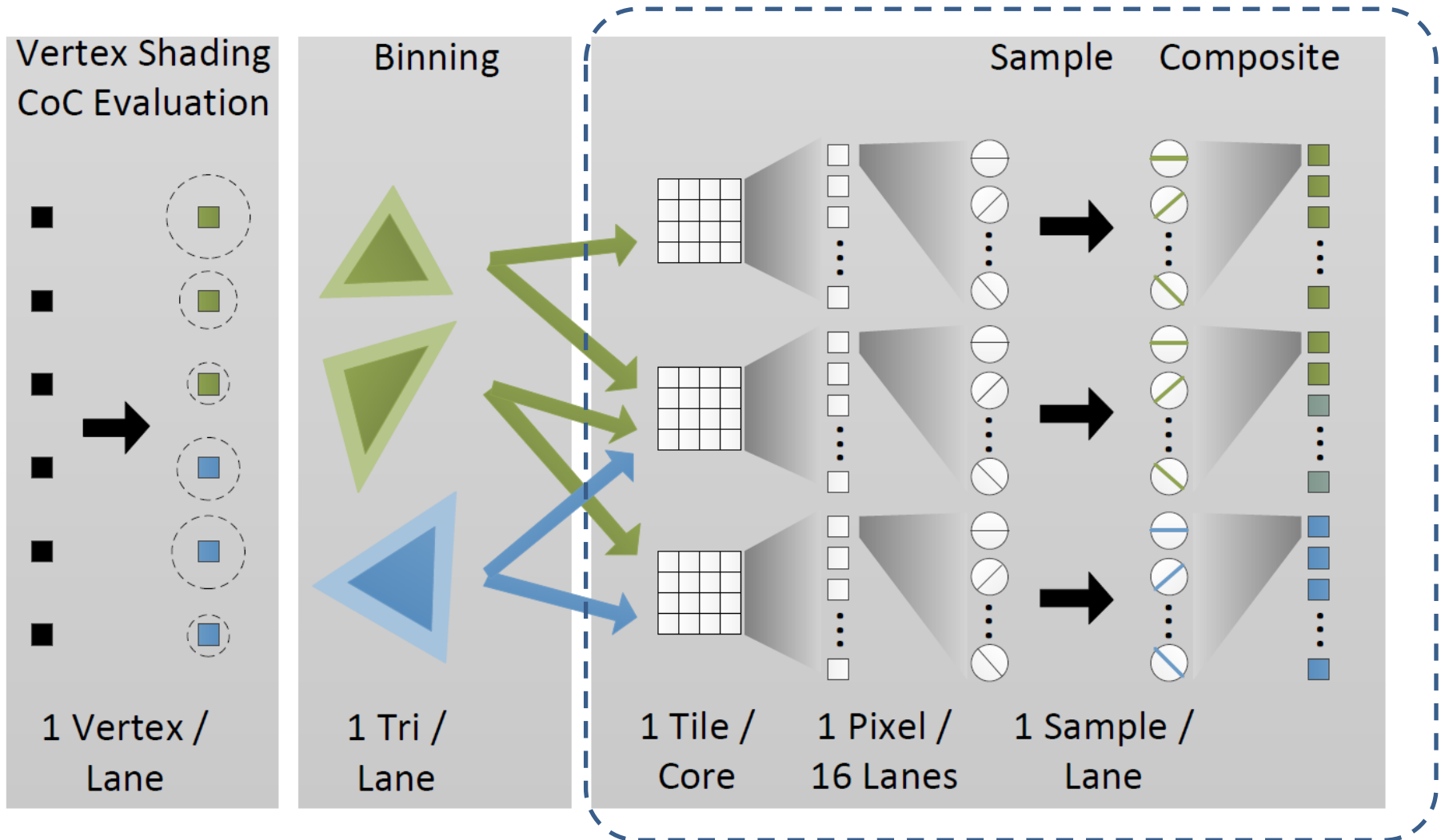
Stage 1: Vertex Transform and CoC computation.

Final System Structure



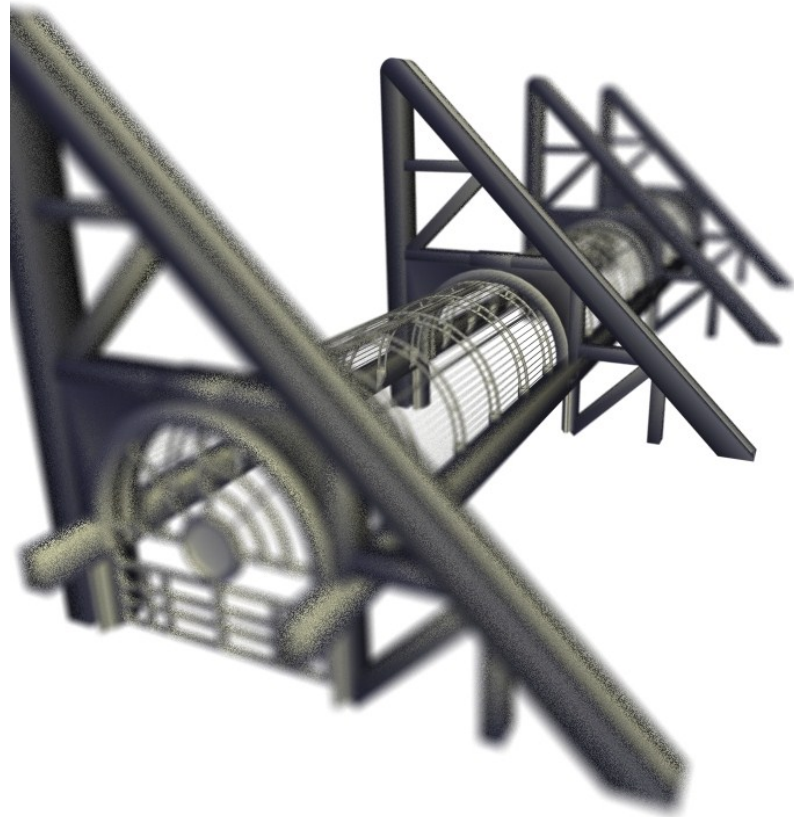
Stage 2: Triangle Binning into Tiles

Final System Structure

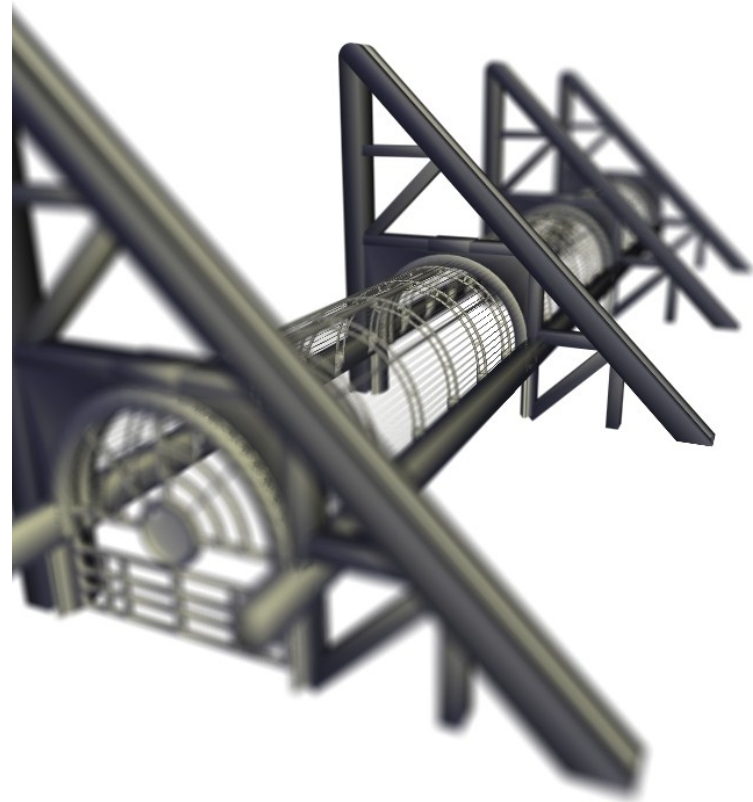


Stage 3: Tile Sample, Composite, and Filter

Results

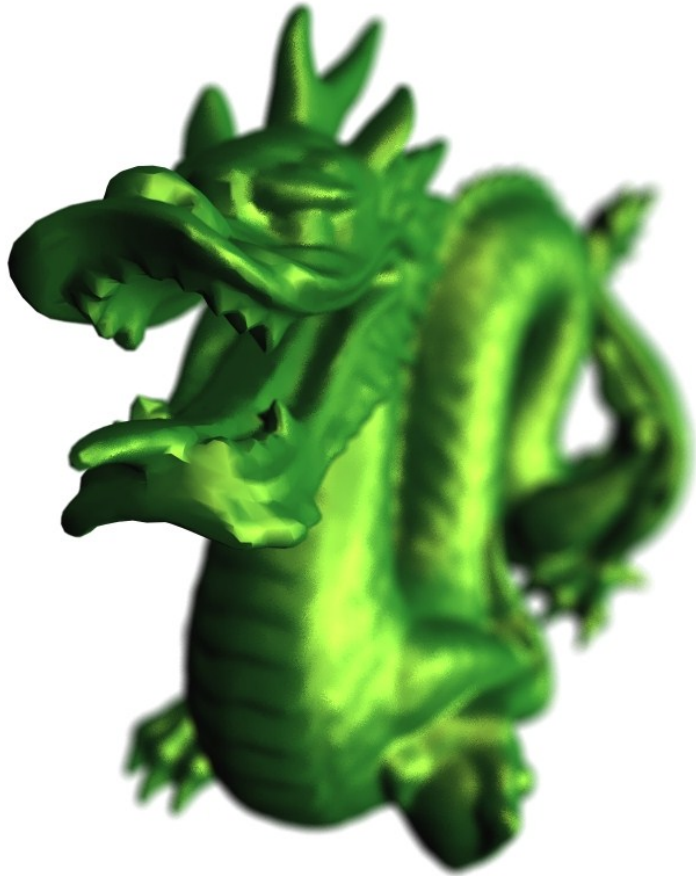


256 Point Samples
0.49 fps

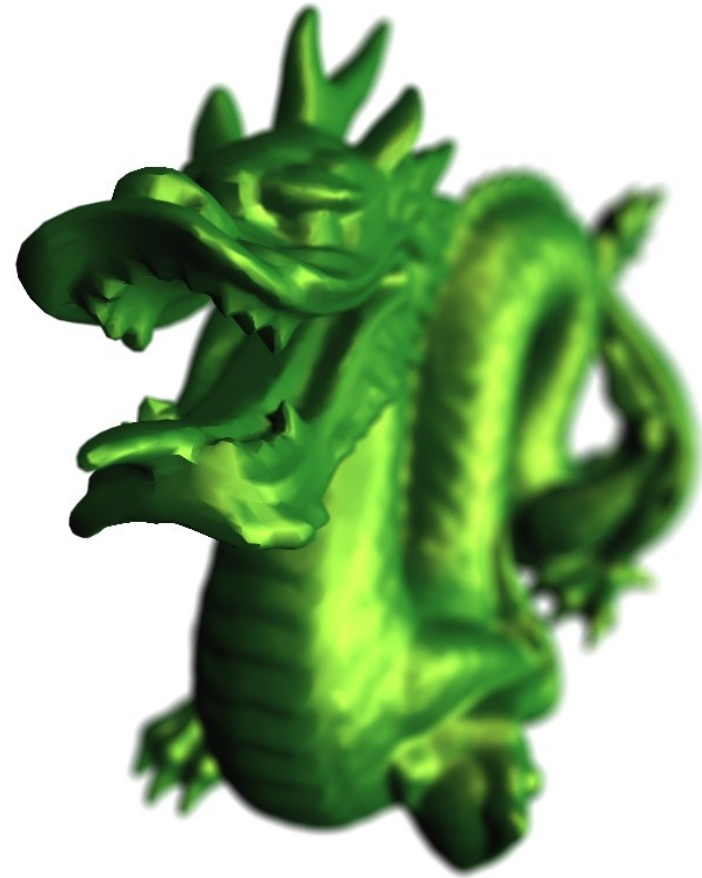


16 Line Samples
2.04 fps

Results



256 Point Samples
0.64 fps



16 Line Samples
2.86 fps

Drawbacks

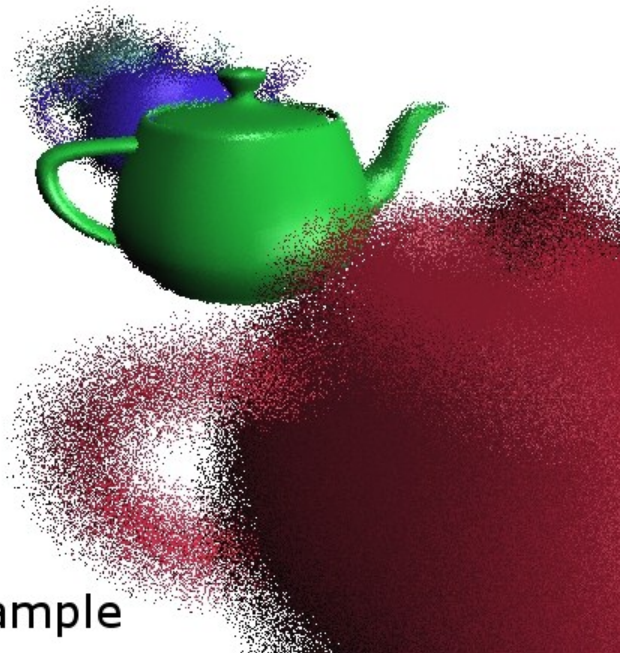
Several Problems to the current model

- Heavily dependent on shared memory.
- Not completely accurate – sometimes significant segments may be discarded.
- Shading is done once per line segment.
 - Can cause oversmoothing.

Artifacts

Point Samples

- Too few point samples causes noise



1 Sample

Line Samples

- Too few line samples causes ghosting



2 Line Samples

Convergence

Point Samples

- Takes many samples to converge



Line Samples

- Converges much faster than point samples



Contributions

- Depth-of-field using line sampling techniques
- Implementing tiled line sampler on GPUs
- Blur dependent level of detail

Future Work

- Line sampling in more aggressive stochastic rendering systems
 - Area lighting / Soft shadows
 - Global Illumination
- Better memory management
 - Better heuristics?

Thank you!



Alduin from TES V: Skyrim

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and NSF for funding!