Fast Generation of Poisson-Disk Samples on Mesh Surfaces by Progressive Sample Projection

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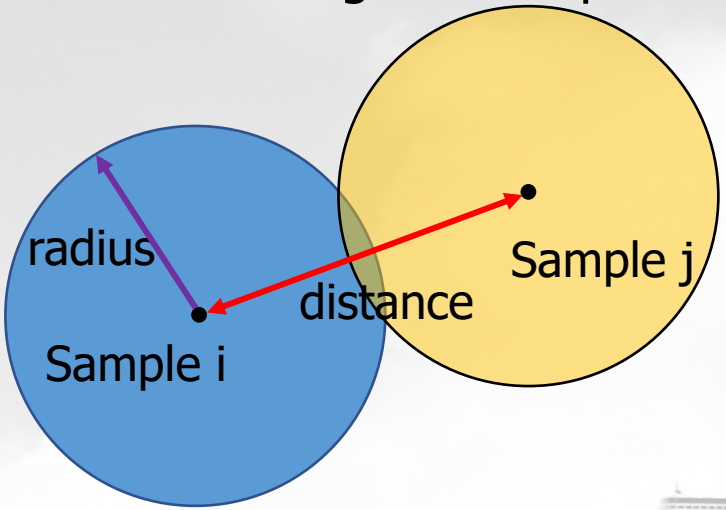
- A practical way to generate Poisson-disk samples on mesh surfaces effectively.
  - Simple inspiration
  - A new parallelization pattern

Poisson-disk Samples

- Randomly place samples, checks that any two are not too close.
  - Distance be larger than specified radius



- Computation time, often very high.

Sampling of nature

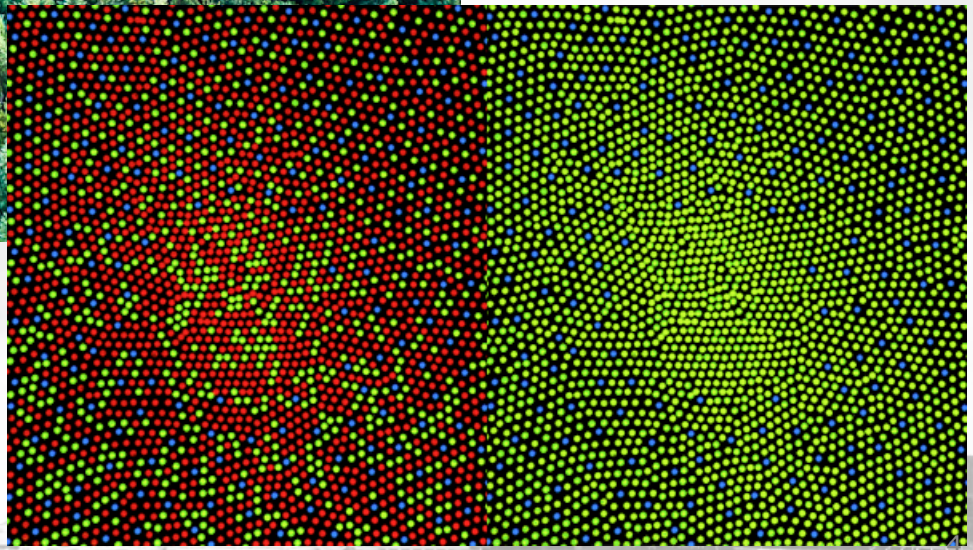
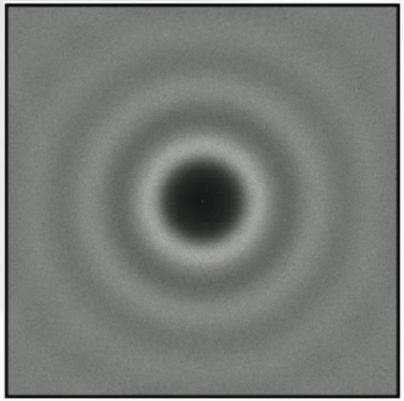


Image from Wikipedia

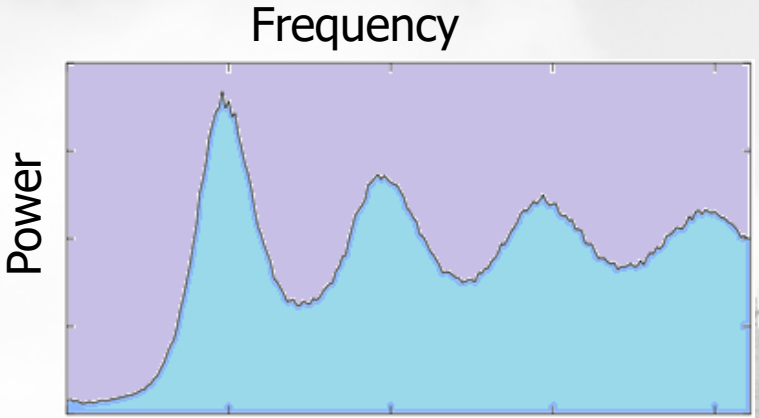
Blue noise feature

- One reason that Poisson-disk sampling is good for many applications is because of its blue noise spectral properties.

Samples



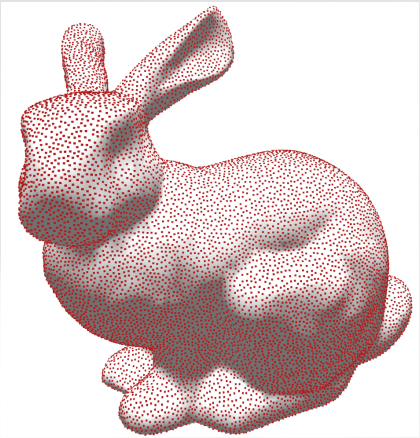
Power Spectrum

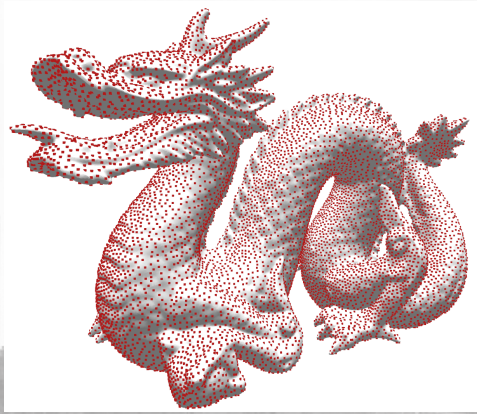


Radial Mean

Sampling mesh surfaces

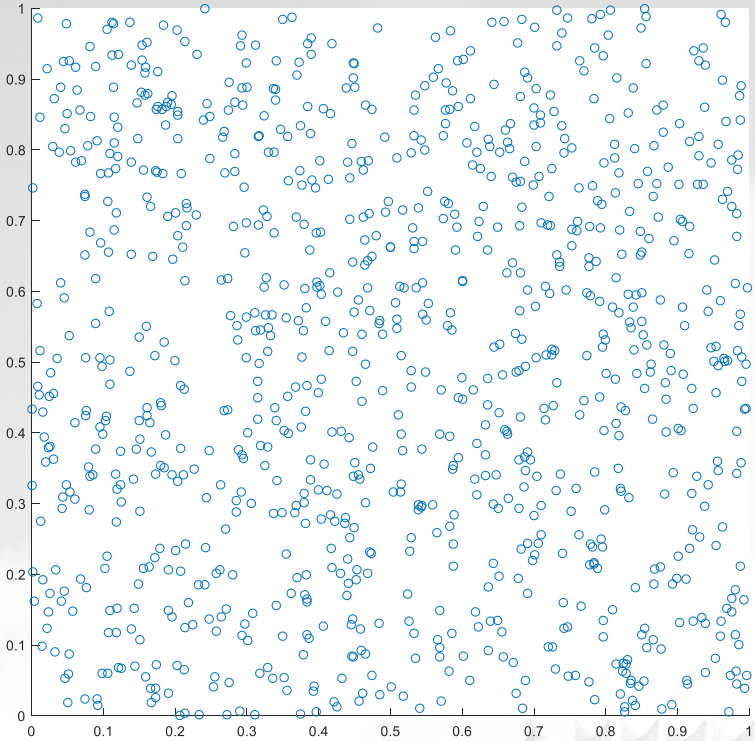
- Throwing darts in a clever way
  - Often unbiased, well defined.
  - Not so easy to parallelize.
  - Not very fast.
- Relaxation
  - Can generate more favorable pattern.
  - Need some iterations, often slow.
- Mass Elimination
  - Small bias.
  - Not maximal.
  - Fastest so far.



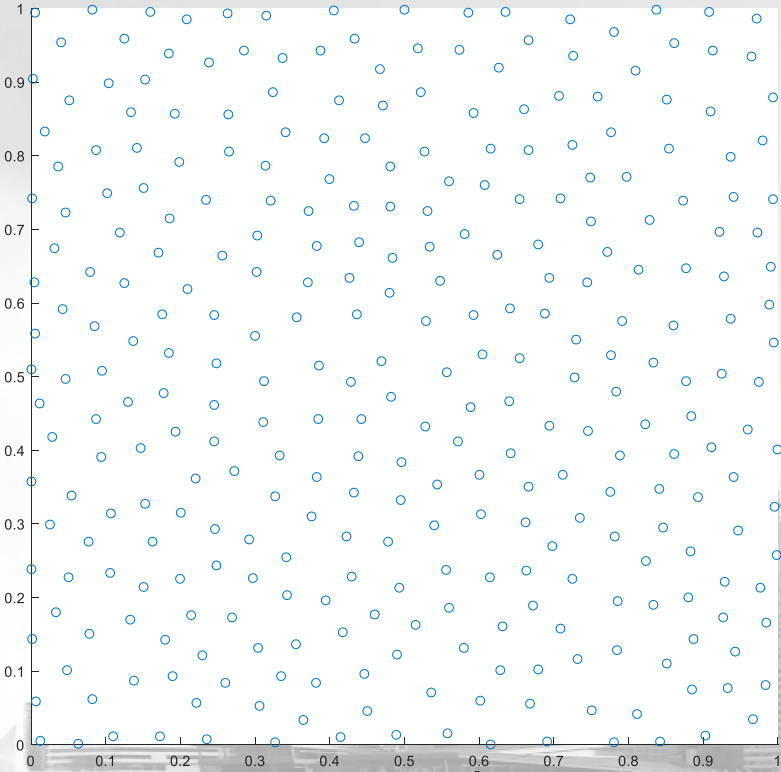


Elimination

- Process each sample in serial ([Yuksel 2015])



1000 samples

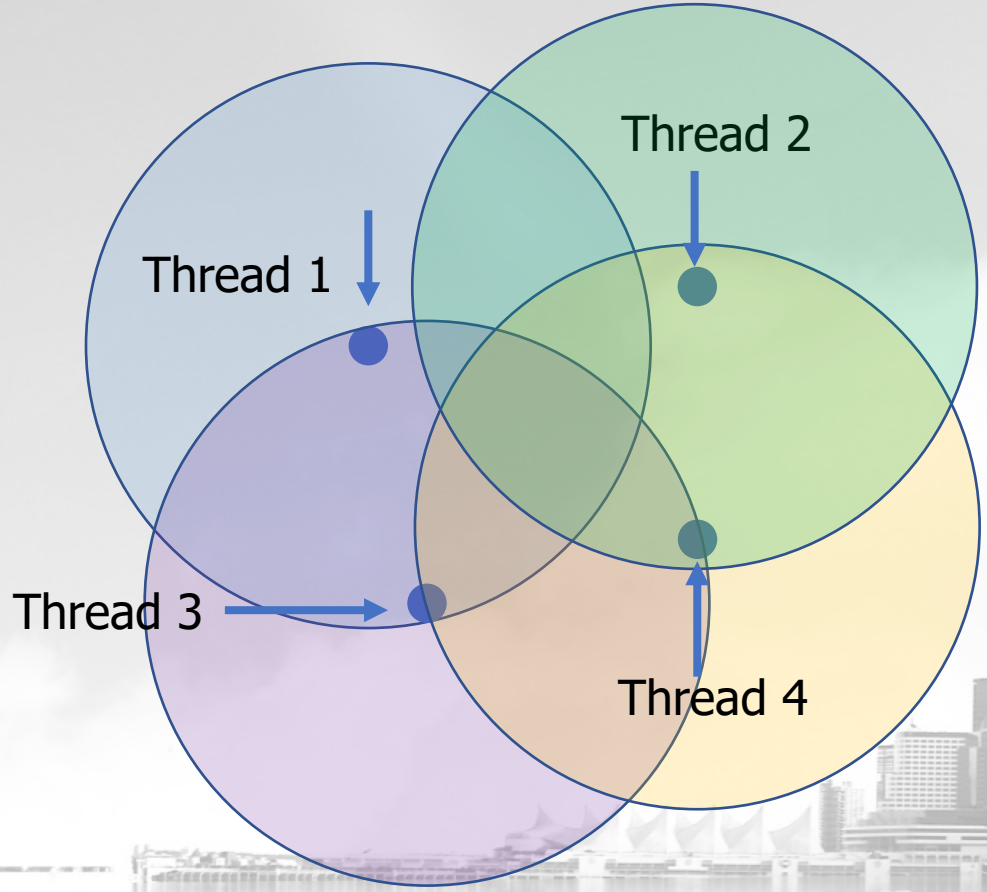


300 samples

Mass Elimination

- Eliminate from a massive amount of samples
  - Sometimes called *Sample pool* or *pre-sampling samples*.
- Eliminate samples in parallel.
  - [Bowers et al . 2010]
  - [Ying et al . 2013]

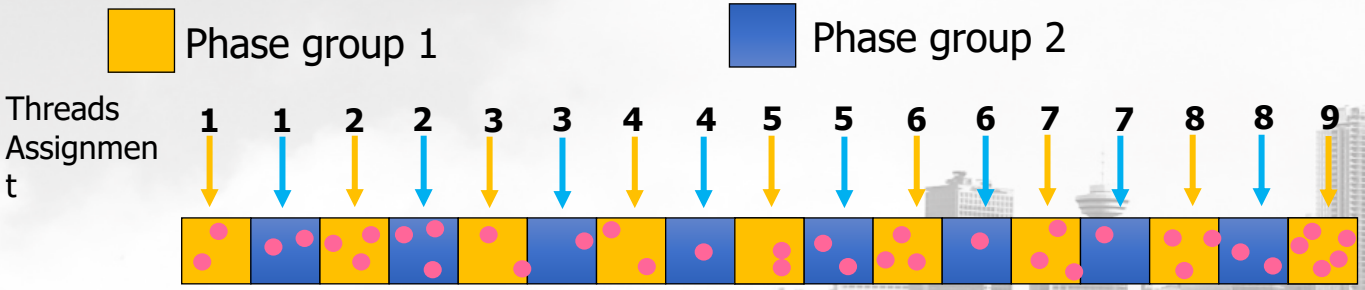
Problem in Mass Elimination



- Which to keep, which to eliminate.
  - Without causing chain reaction.
  - Without racing.

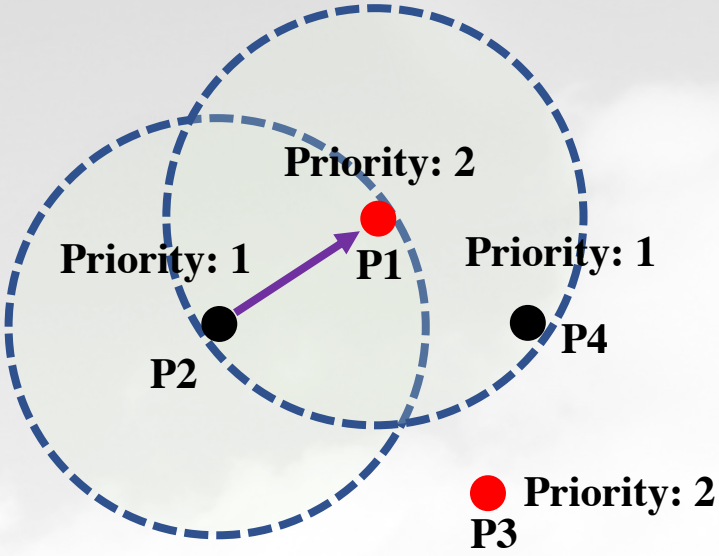
Parallelize elimination process

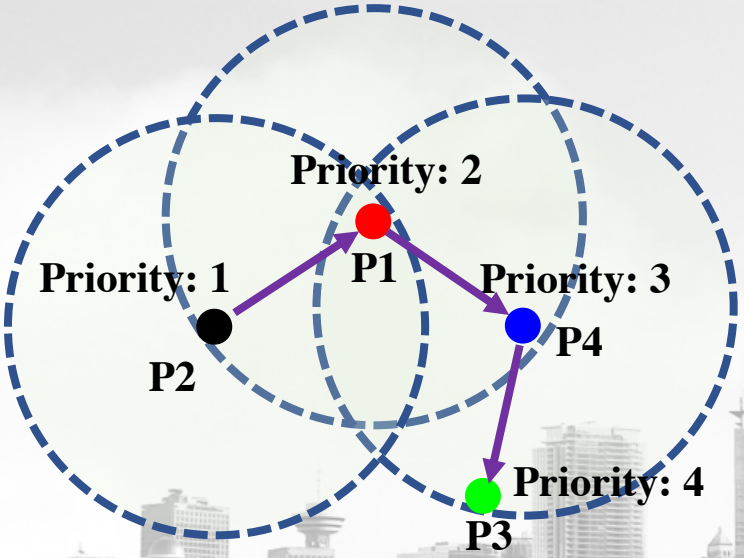
- Use phase groups. ([Bowers et al . 2010]
  - Divide space to phase groups.
  - Threads processing in the same phase group is isolated and have no interaction with other threads.
  - Lower parallelism, some unfavorable bias.



Parallelize elimination process

- Use priority ([Ying et al . 2013])



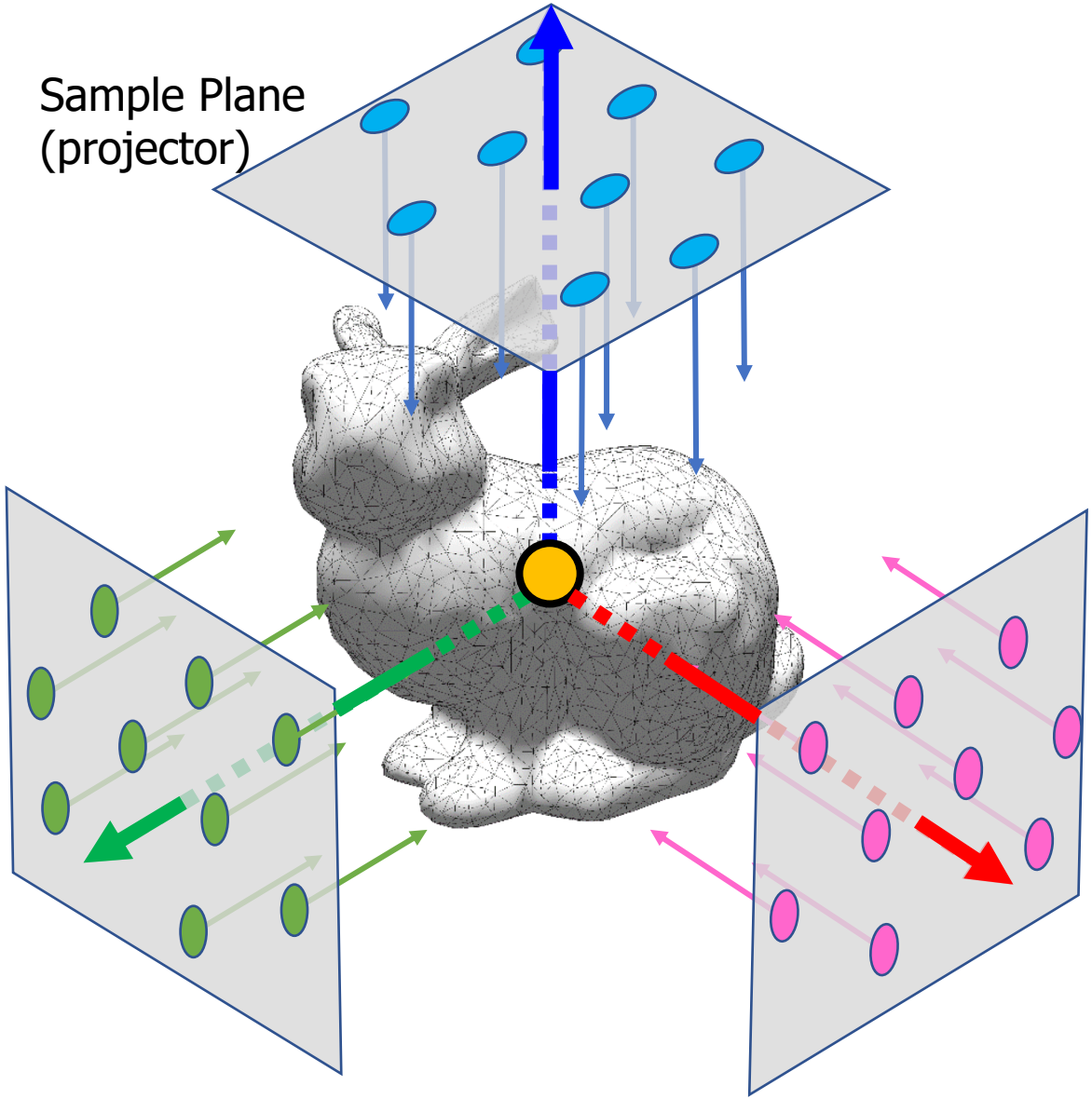


Sampling mesh surfaces

- Throwing darts in a clever way
  - Often unbiased, well defined.
  - Not so easy to parallelize.
  - Not very fast.
- Relaxation
  - Can generate more favorable pattern.
  - Iterations, often slow.
- Mass Elimination
  - Small bias.
  - Fast.
  - Low parallelism or irregular parallelization
- Sample Projection

Another parallel pattern

- Draw inspiration form phase group:
  - Samples added should have no intra-batch conflicts
- Draw inspiration from priority-based method:
  - Samples can have different priority.
- Also form food baking:
  - Rotating food to get better coverage of heat.


Sample Plane
(projector)

Sample Projection

- Prepare some 2D Poisson-disk sample patterns (projectors)
- Project samples on the projectors towards mesh surfaces (using ray tracing).
- Eliminate conflicts.
- Rotate projectors.
- Repeat.

What is needed

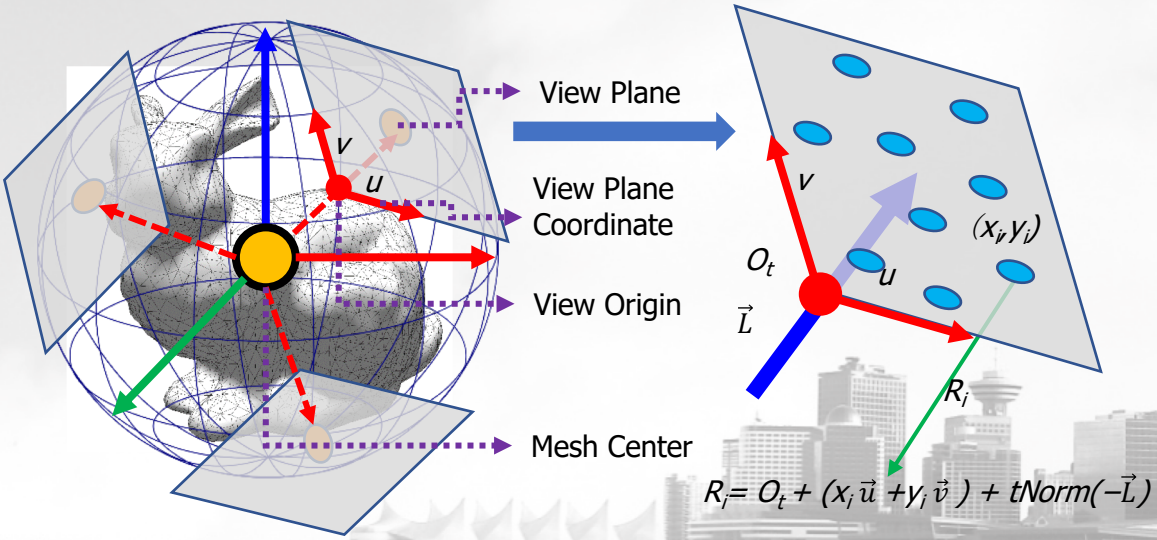
- A pre-generated 2D Poisson-disk sample pattern of a specified radius to start with.
  - Quality of the 2D pattern will not affect too much on samples of projection space.
- A fast ray tracer to do the projection.
  - Embree or
  - OptiX on NVIDIA GPUs.

Overview of the algorithm

- 1. Build Orthogonal Ray Batch Group (ORBG).
- 2. Project samples onto mesh by tracing rays.
- 3. Eliminate conflicts.
- 4. If meets demand, break and output.
- 5. Else, rotate the ORBG, go to 2.

Orthogonal Ray Batch Group (ORBG)

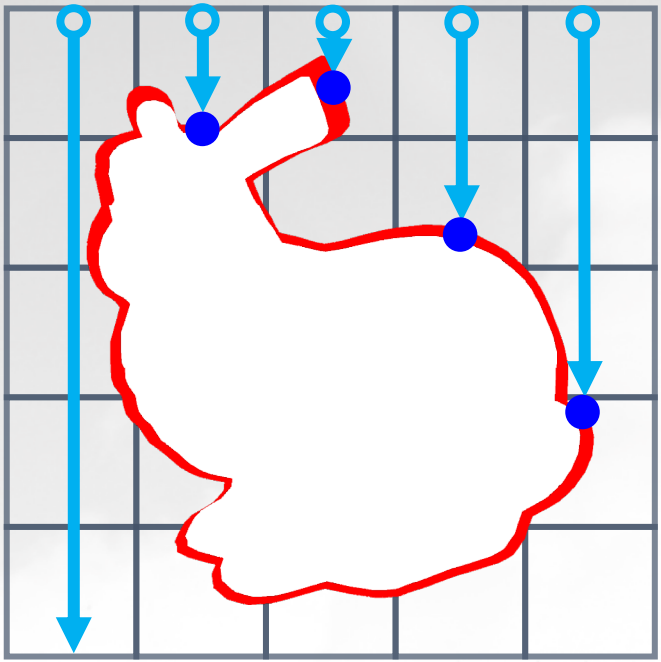
- 2D Sample plane is called a projector or view plane.
- Each plane will generate ray batch for projection.
- Three orthogonal planes form a group called ORBG.

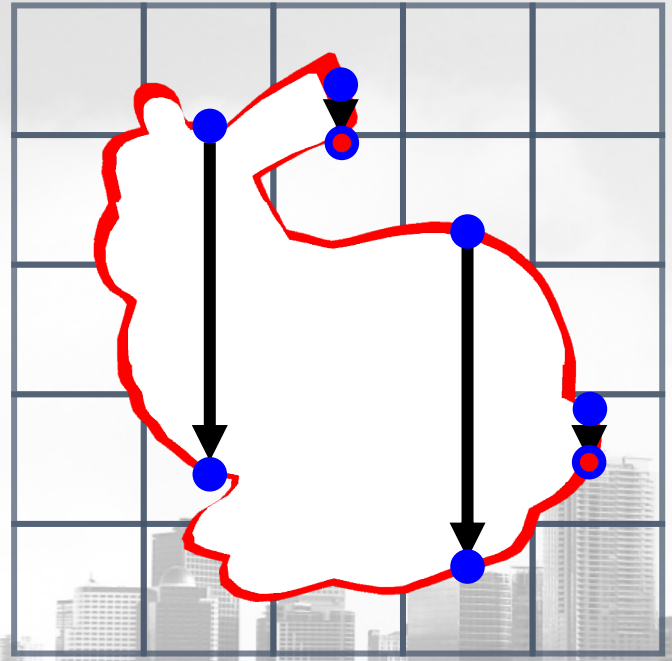


$$R_i = O_t + (x_i \vec{u} + y_i \vec{v}) + tNorm(-\vec{L})$$

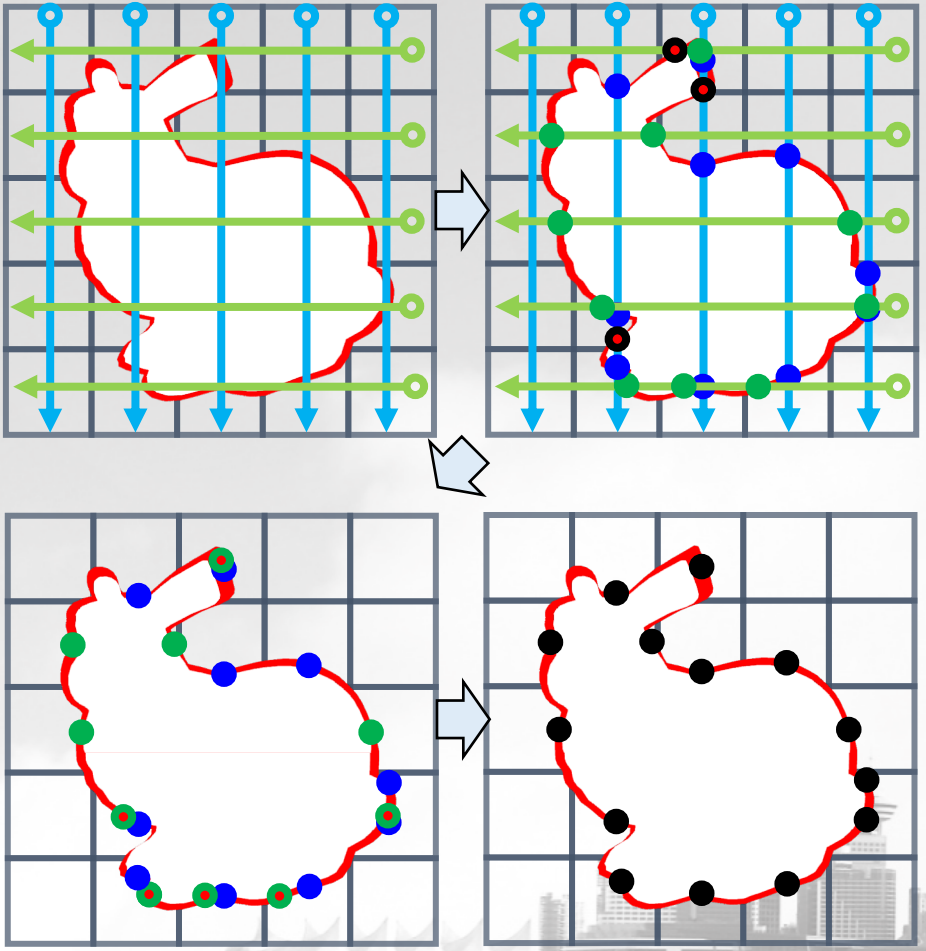
Project samples onto mesh surfaces

- Record every intersections through each ray.
- Deal with restart conflicts.



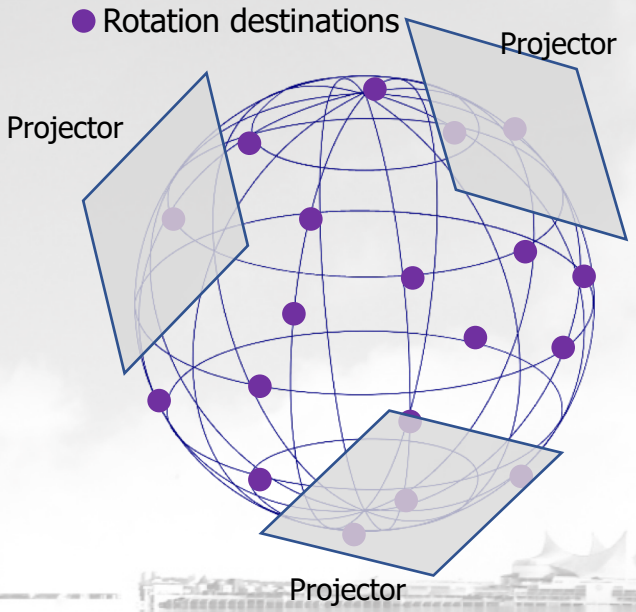


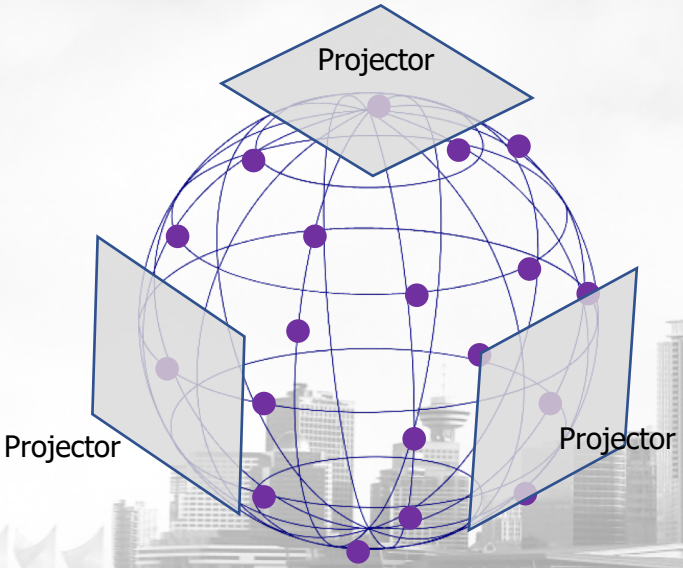
Conflict elimination



Rotate ORBG

- Rotate projectors that generate the ORBG.
- Rotation destinations should be low-discrepancy.





Conflict elimination

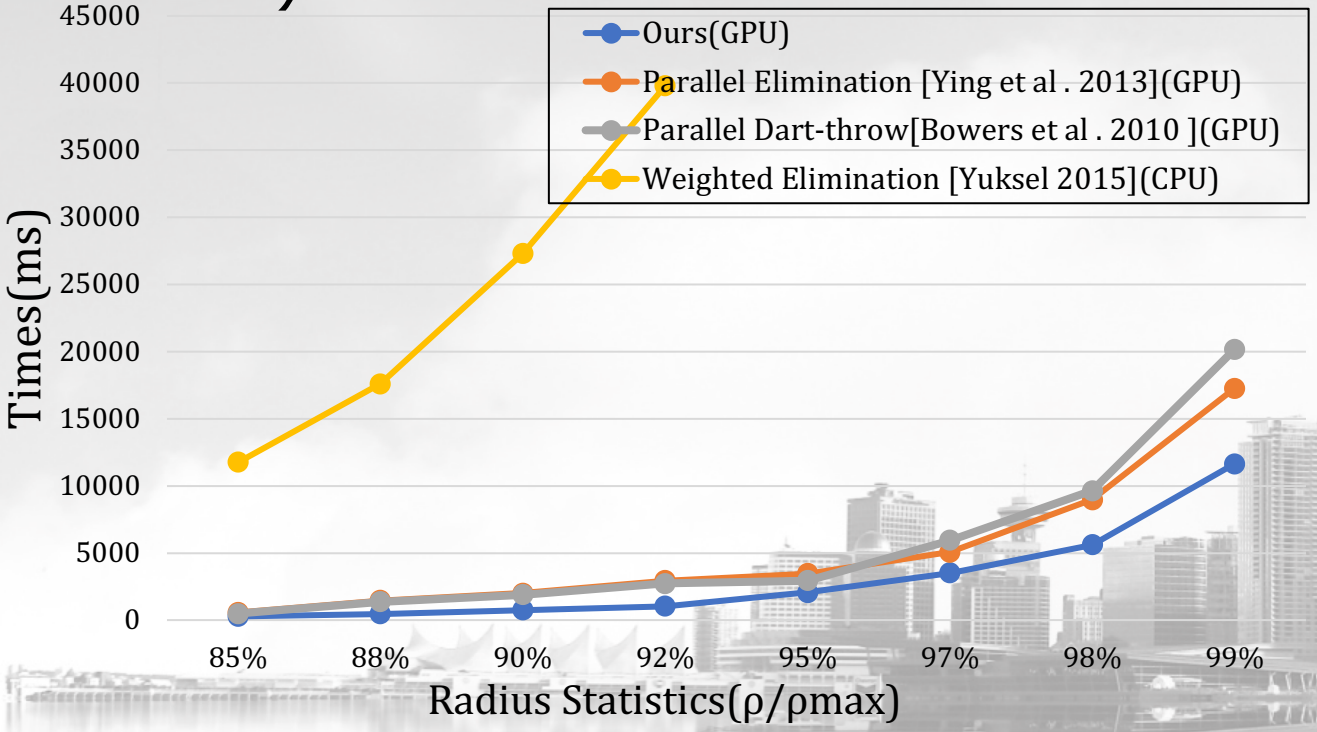
- Samples generated from the same projector have no conflicts.
  - Except restart conflicts.
- Resolve conflicts from different projectors using priority.
  - Very short priority chain.

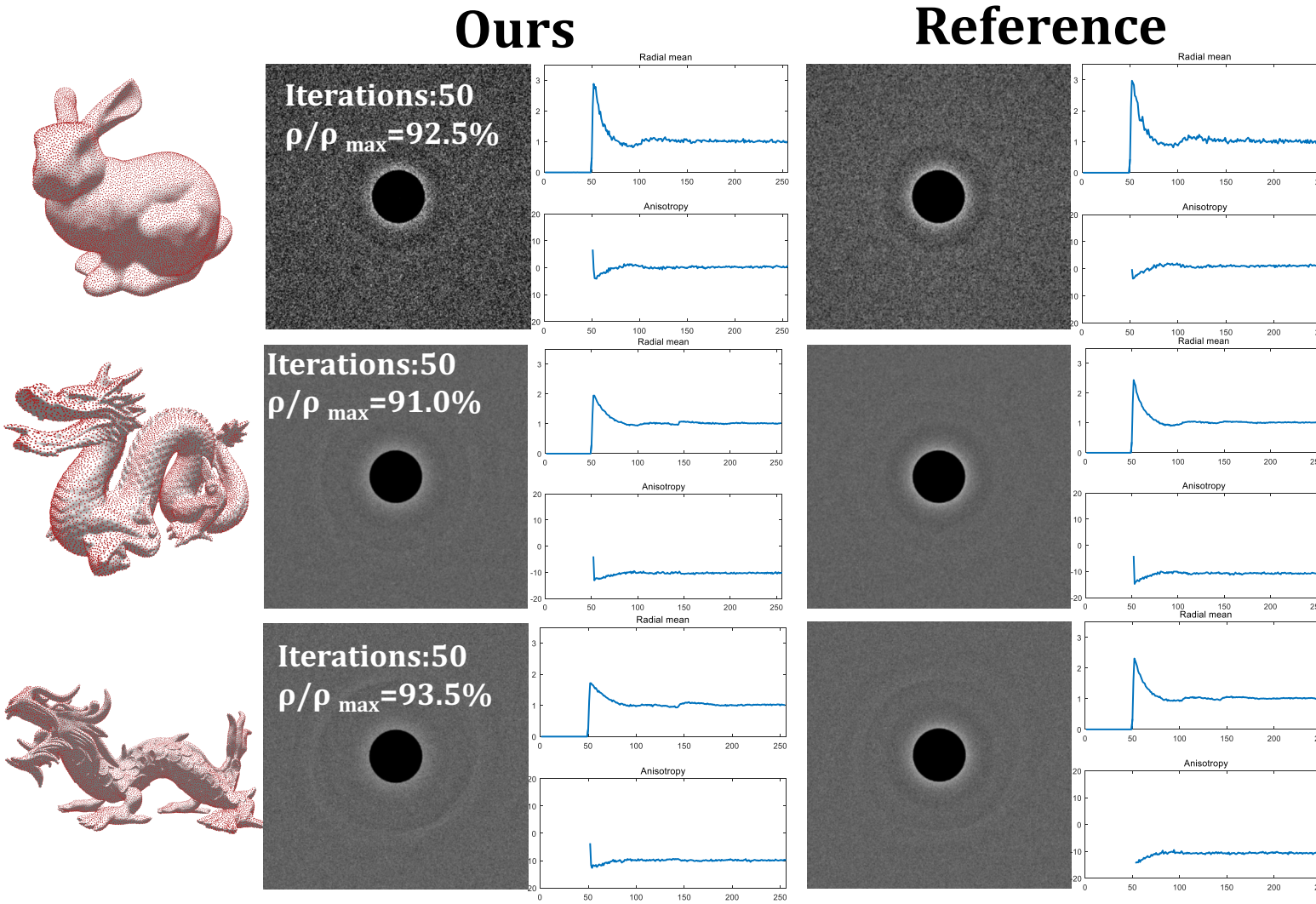
What's good about this pattern

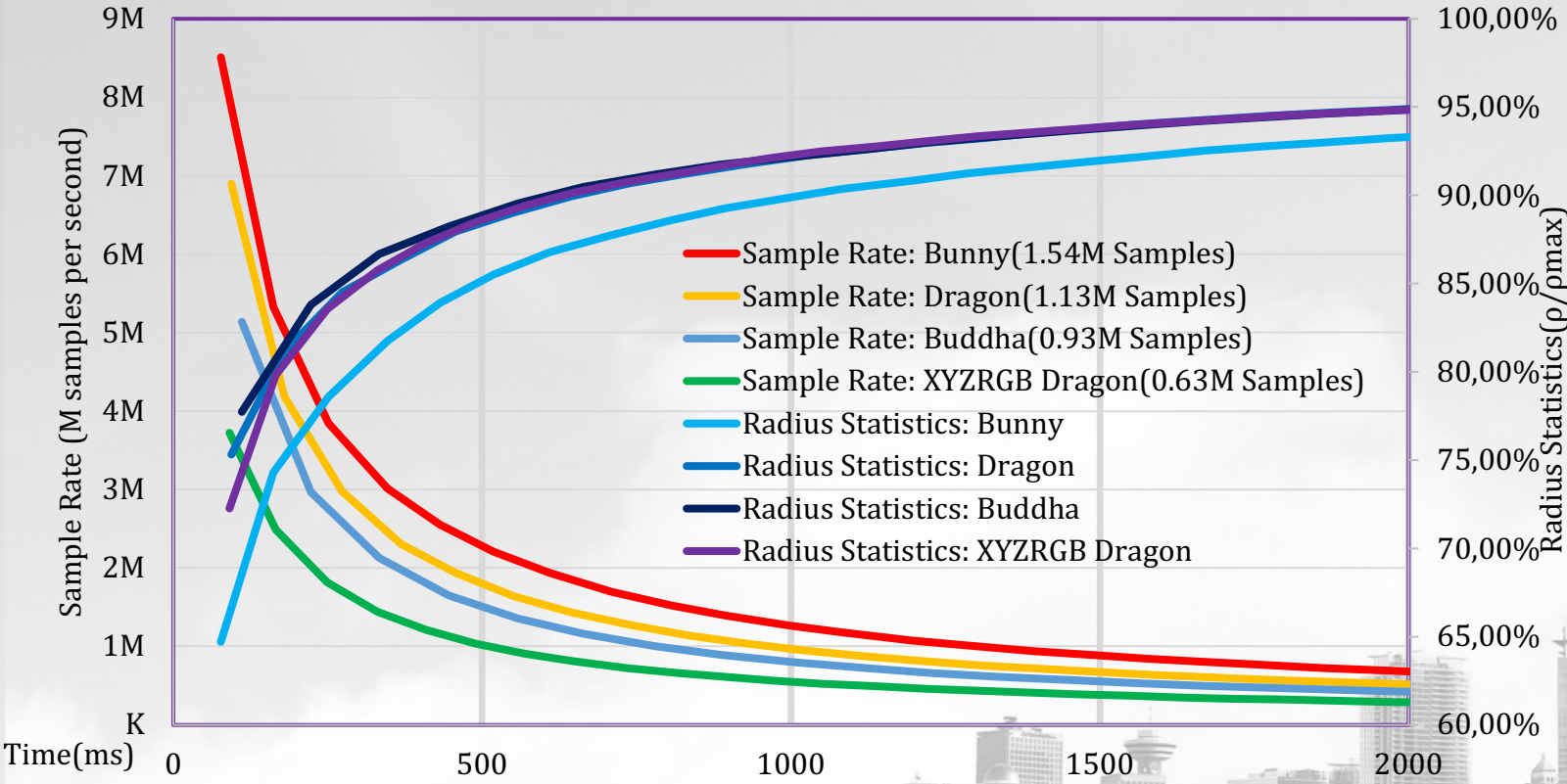
- No sample-pool needed (Sample-pool free)
  - Generating Poisson-disk sample from scratch.
- No intra-batch conflicts (intra-batch conflict free)
  - No nested priority problem during elimination phase.
  - Regular and GPU friendly.

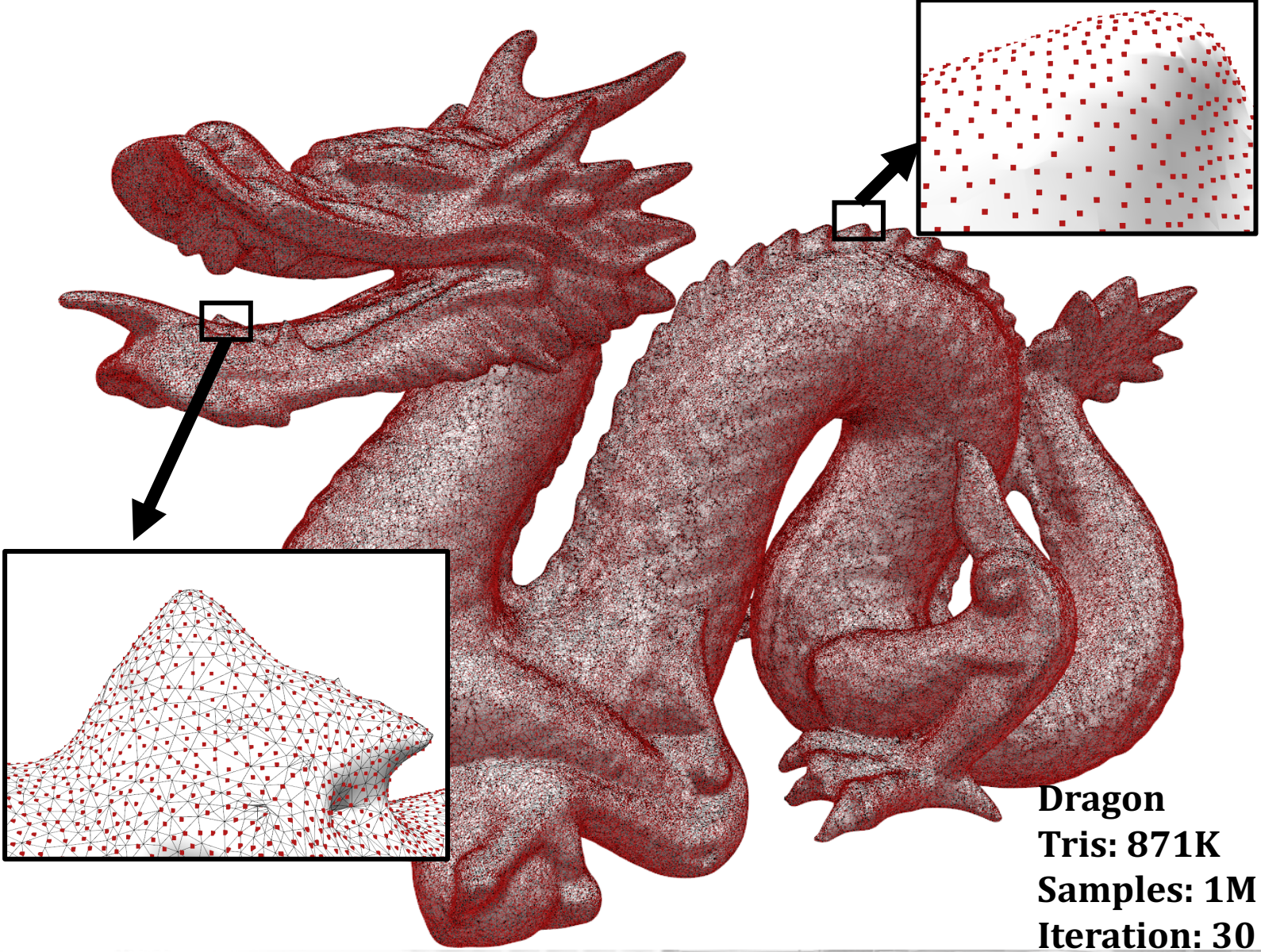
Results and analysis

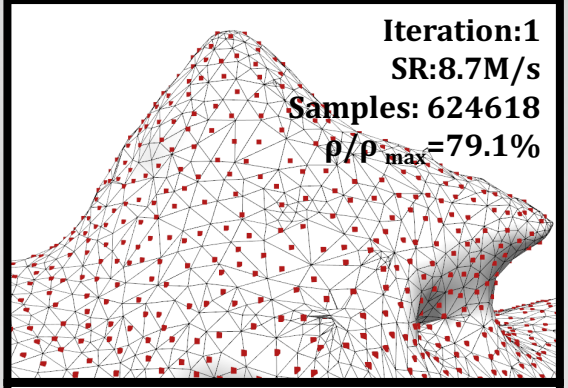
- Performance (CPU: i7-7700K, GPU: NV GTX1080)

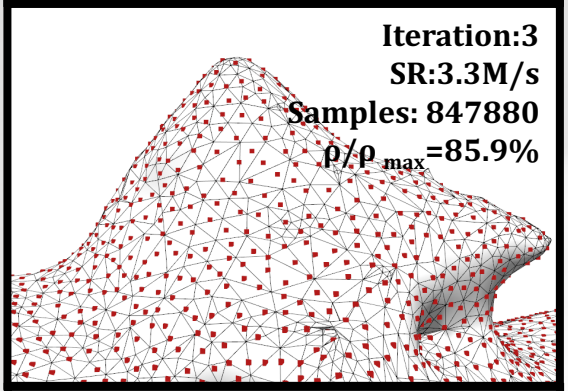


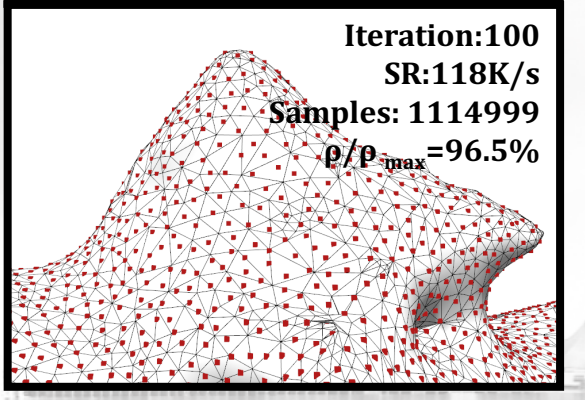

Ours
Reference
Iterations:50
ρ/ρ max=92.5%
Iterations:50
ρ/ρ max=91.0%
Iterations:50
ρ/ρ max=93.5%
Radial mean
Anisotropy

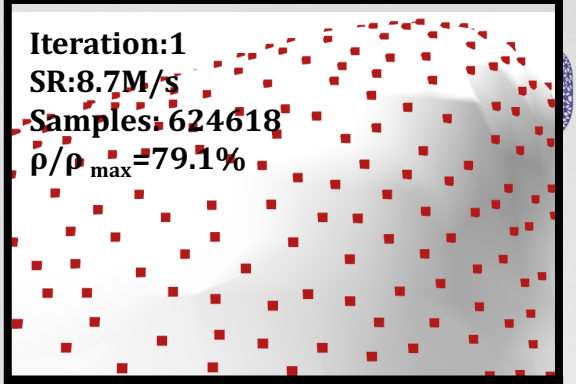

9M
8M
7M
6M
5M
4M
3M
2M
1M
K
Sample Rate (M samples per second)
100,00%
95,00%
90,00%
85,00%
80,00%
75,00%
70,00%
65,00%
60,00%
Radius Statistics(ρ/ρmax)
Time(ms)
0
500
1000
1500
2000
Sample Rate: Bunny(1.54M Samples)
Sample Rate: Dragon(1.13M Samples)
Sample Rate: Buddha(0.93M Samples)
Sample Rate: XYZRGB Dragon(0.63M Samples)
Radius Statistics: Bunny
Radius Statistics: Dragon
Radius Statistics: Buddha
Radius Statistics: XYZRGB Dragon

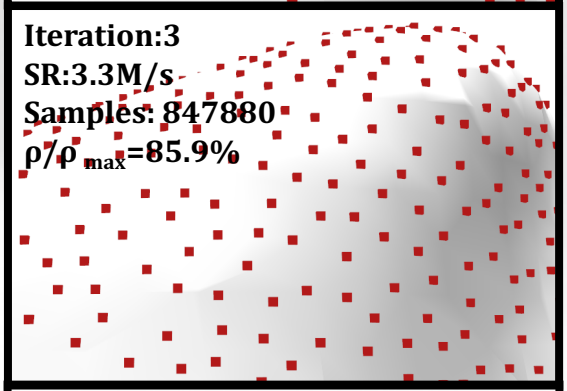

Dragon
Tris: 871K
Samples: 1M
Iteration: 30

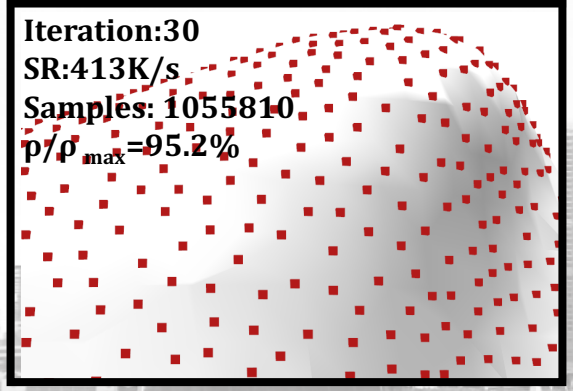

Iteration:1
SR:8.7M/s
Samples: 624618
ρ/ρ max=79.1%


Iteration:3
SR:3.3M/s
Samples: 847880
ρ/ρ max=85.9%


Iteration:100
SR:118K/s
Samples: 1114999
ρ/ρ max=96.5%

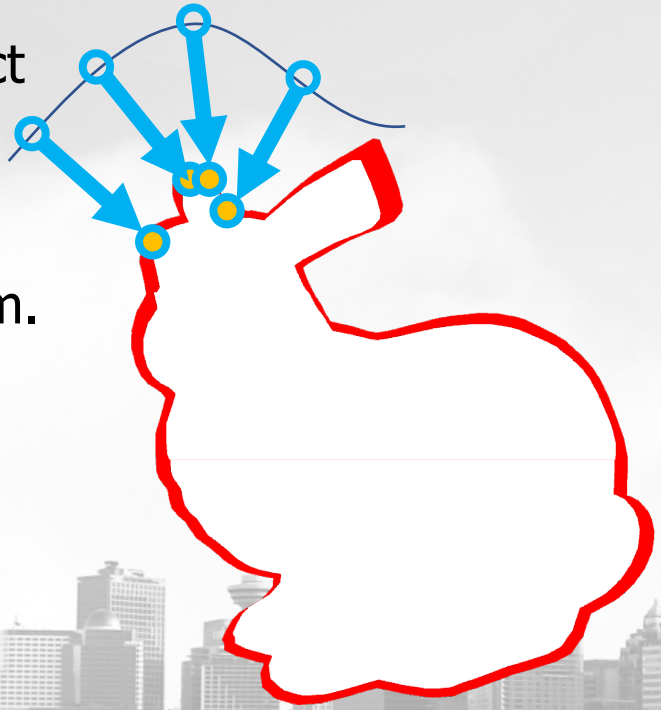

Iteration:1
SR:8.7M/s
Samples: 624618
ρ/ρ max=79.1%


Iteration:3
SR:3.3M/s
Samples: 847880
ρ/ρ max=85.9%


Iteration:30
SR:413K/s
Samples: 1055810
ρ/ρ max=95.2%

Some choice to explain

- Shape of projectors
  - Plane can ensure intra-conflict free criteria.
  - Non-Euclidean surface degenerate the merging step to a mass elimination problem.



Some choice to explain

- Size of each project set, project from an arbitrary polyhedron rather than hexahedron.
  - Complex priority setting.
  - The choice of cube is a balance between parallelism and regularity.
  - It is also possible to generate usable samples for only one or few iterations.

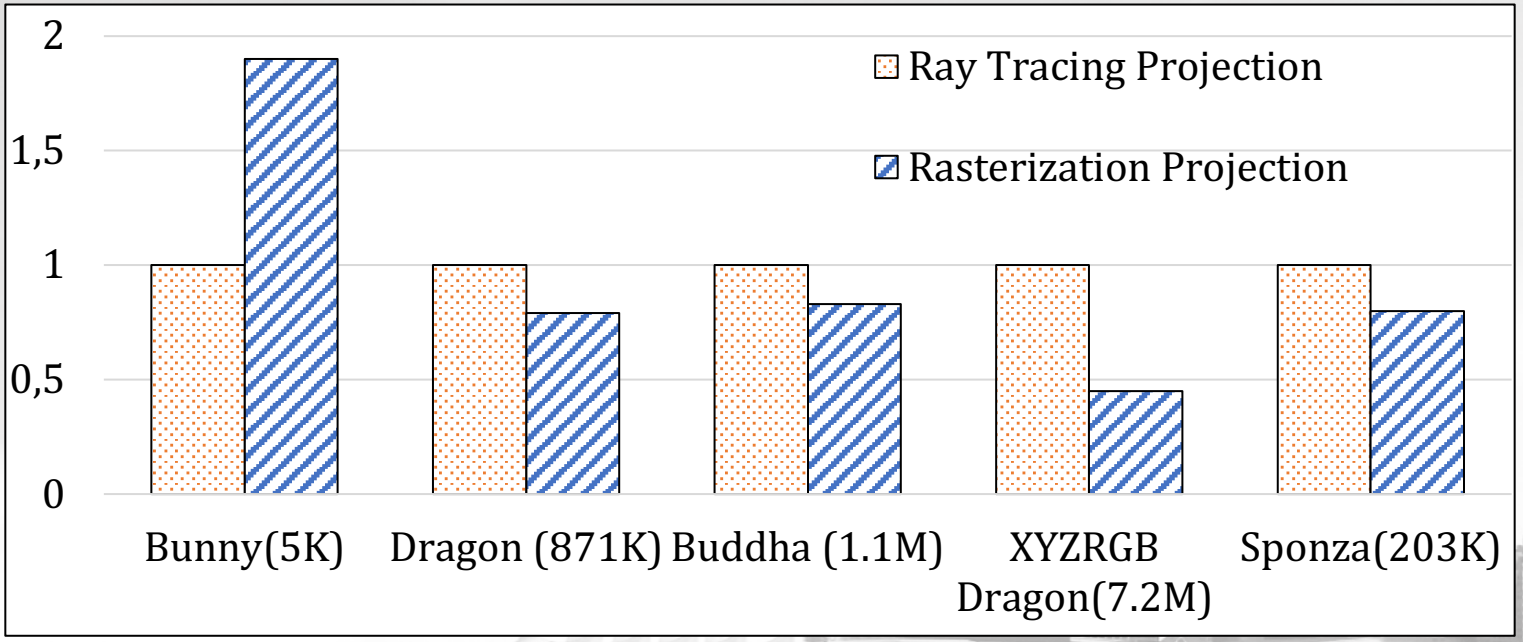
- Project one projector at a time.
  - Less parallelism
  - More kernel launch.
- Project X (X>3) projectors at a once.
  - More complex numbers, irregular execution, unbalanced workload.

Choice on ray tracing or rasterization

- Sample projection ➡ Sample rasterization
- Rasterization is basically a faster primary ray tracing.
- A brief flow
  - Rasterize mesh to 2D sample plane.
  - Fetch points from the target (2D sample plane) only on sample positions.
  - Eliminate conflicts the same way.
  - Iterate this process by rotating the object (or plane)

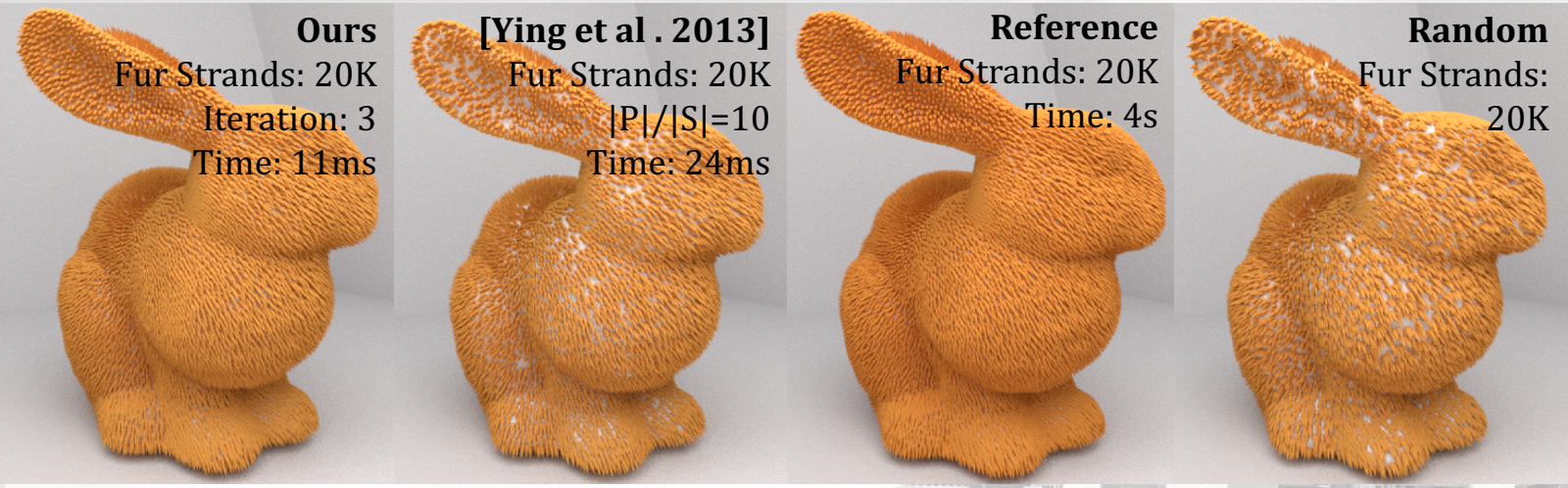
Test on equivalent implementation

- The implementation of rasterization method can greatly affect the result.



More applications

- Few iterations can generate usable results.



Easy to sample adaptively

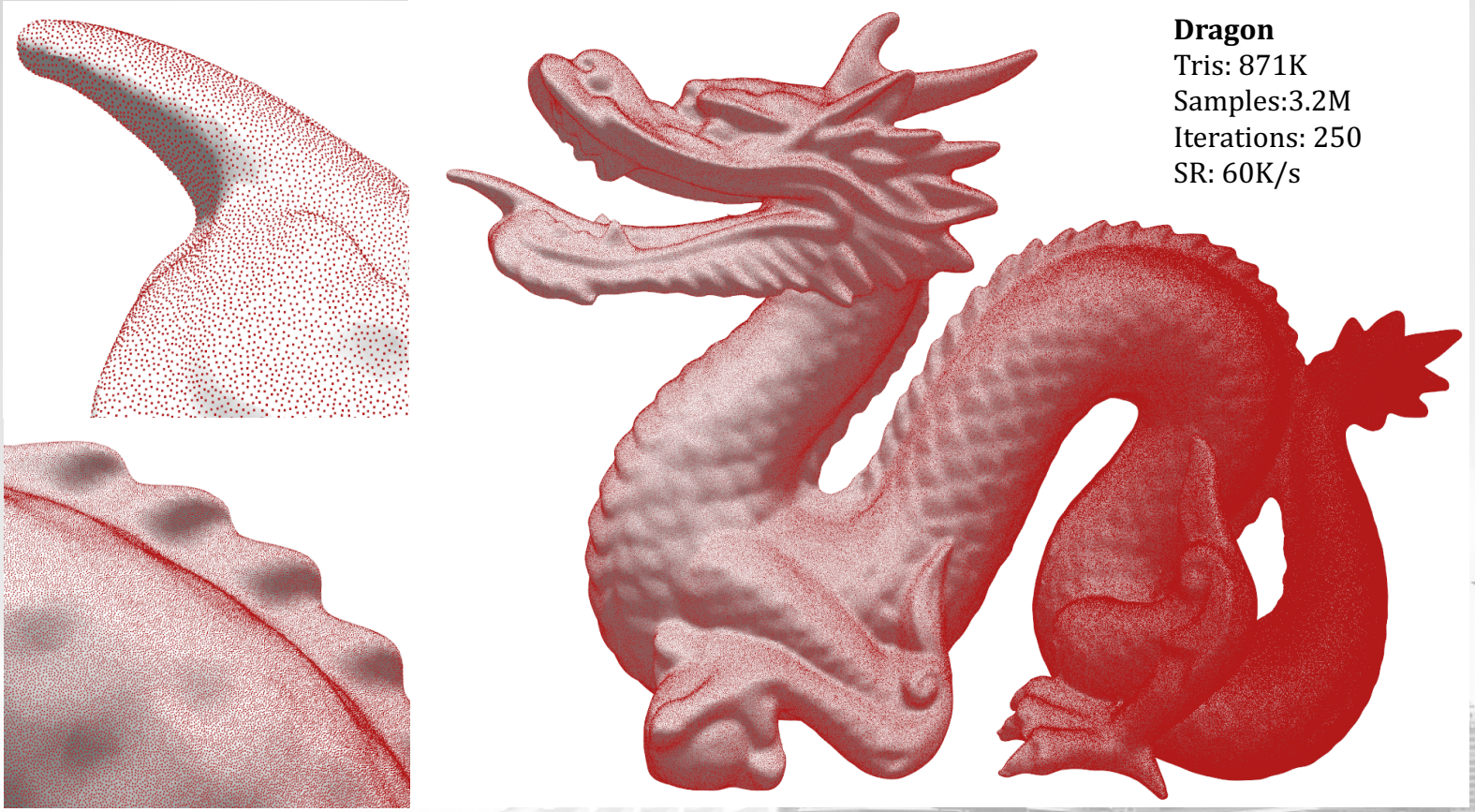
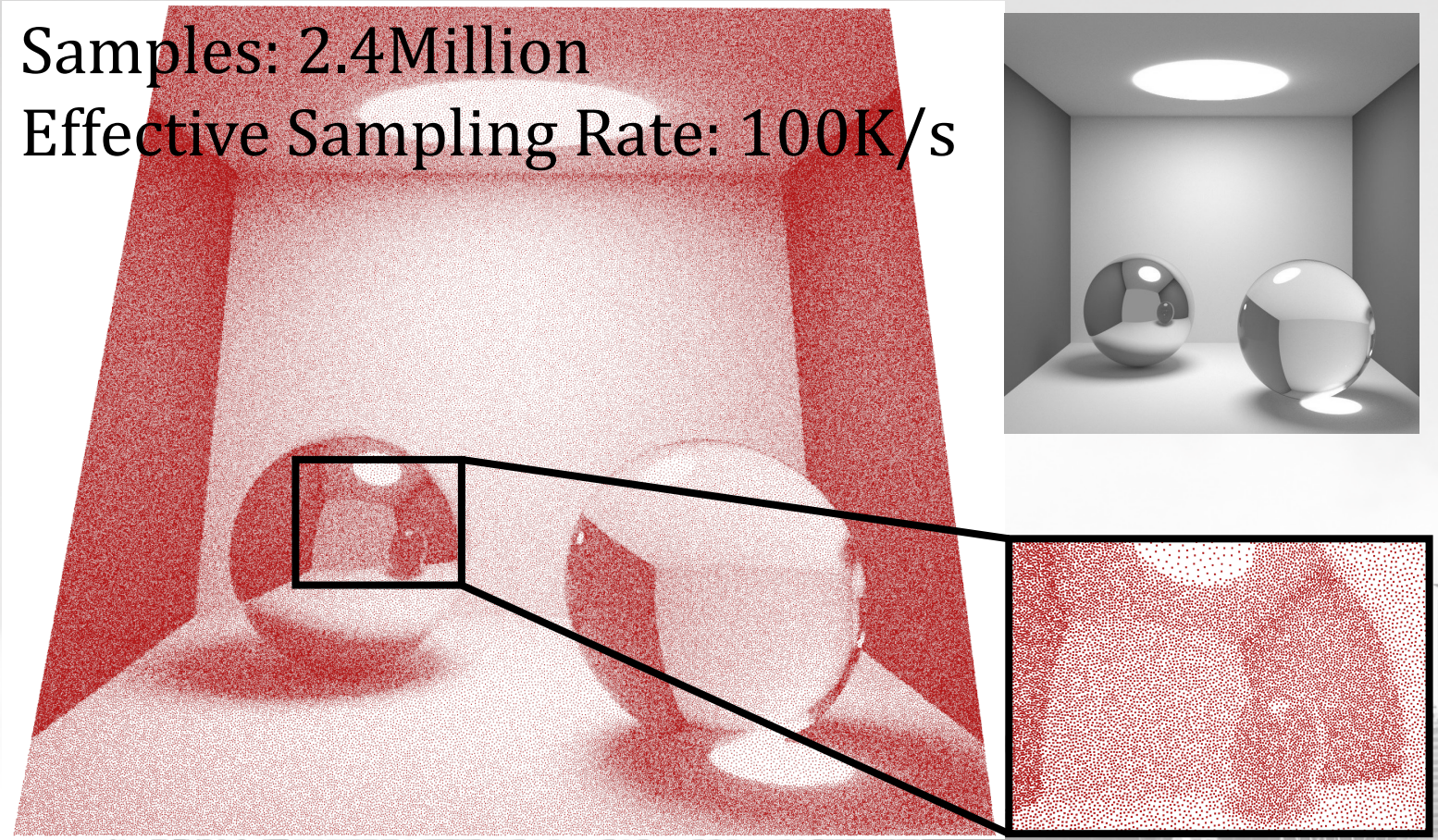


Image Stippling




Samples: 2.3Million
Effective Sampling Rate: 105K/s

Limitations

- Better for generation of massive amount of samples.
  - A little bit heavy on sparse samples.
- Convergence is non-linear.
  - Gap management will be a good future work.
- Radius based, hard to control the exact number of samples.
  - Combined with other methods to control the number.
- No theoretical explanation on the bias of this method.

Thank you!