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14. ABSTRACT We investigated a variety of computation techniques to help speed up visibility, based on the premise that recent sampling techniques, traditionally used in 2D graphics computations, may now allow efficient computations in 3D as well. We assert that a key challenge in efficiently computing visibility is efficiently accessing geometric data to query it for possible occlusions. Our research aims to speed computation by optimizing access to geometry that will be queried simultaneously, using voxel sampling techniques, adaptive image-space multiresolution sampling, and					
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Report Title

Final Report for "STIR: Novel Interactive Visibility Techniques"

ABSTRACT

We investigated a variety of computation techniques to help speed up visibility, based on the premise that recent sampling techniques, traditionally used in 2D graphics computations, may now allow efficient computations in 3D as well. We assert that a key challenge in efficiently computing visibility is efficiently accessing geometric data to query it for possible occlusions. Our research aims to speed computation by optimizing access to geometry that will be queried simultaneously, using voxel sampling techniques, adaptive image-space multiresolution sampling, and sampling in novel spaces that group queries more efficiently.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u>	<u>Paper</u>
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TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u>	<u>Paper</u>
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TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>	<u>Paper</u>
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TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>	<u>Paper</u>
2012/02/27 1' 1	Chris Wyman. Voxelized shadow volumes, the ACM SIGGRAPH Symposium. 2011/08/04 01:00:00, Vancouver, British Columbia, Canada. : ,
2012/02/27 1' 2	Chris Wyman. Interactive voxelized epipolar shadow volumes, ACM SIGGRAPH ASIA 2010 Sketches. 2010/12/14 01:00:00, Seoul, Republic of Korea. : ,

TOTAL: 2

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

The supported work "Voxelized Shadow Volumes" from High Performance Graphics 2011 was one of the best 3 papers at the conference.

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	Discipline
Rajeev Penmatsa	0.50	
FTE Equivalent:	0.50	
Total Number:	1	

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Chris Wyman	0.01	
FTE Equivalent:	0.01	
Total Number:	1	

Names of Under Graduate students supported

NAME

PERCENT SUPPORTED

FTE Equivalent:

Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in
science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue
to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for
Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to
work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive
scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PhDs

NAME

Total Number:

Names of other research staff

NAME

PERCENT SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See attachment.

Technology Transfer

Final Report for ARO Grant #W911NF-10-1-0338

Covering August 1, 2010 through April 31, 2011

Title: *STIR: Novel Interactive Visibility Techniques*

Principle Investigator: *Professor Chris Wyman, University of Iowa*

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Appendix A:	(8 pages) Preprint of supported publication "Voxelized Shadow Volumes"
Appendix B:	(2 pages) Reprint of supported publication "Interactive Voxelized Epipolar Shadow Volumes"

Problem Statement:

Visibility algorithms play an important role in all simulation environments, from training simulations to ballistics simulations to entertainment applications. For defense applications, visibility plays vital roles in radio frequency propagation computations to determine the quality of wireless communications, when evaluating ballistic penetrations [BS07], and targeting computations. Unfortunately, naïve visibility has order $O(n^4)$ complexity [DDP02] scaling poorly with complex geometry required in many defense applications.

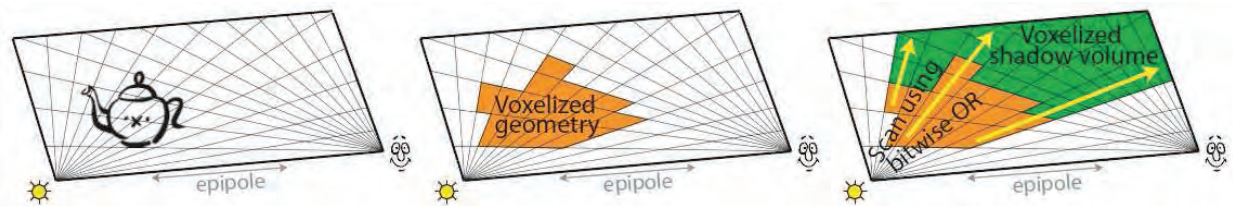
We investigated a variety of computation techniques to help speed up visibility, based on the premise that recent sampling techniques, traditionally used in 2D graphics computations, may now allow efficient computations in 3D as well. We assert that a key challenge in efficiently computing visibility is efficiently accessing geometric data to query it for possible occlusions. Our research aims to speed computation by optimizing access to geometry that will be queried simultaneously, using voxel sampling techniques, adaptive image-space multiresolution sampling, and sampling in novel spaces that group queries more efficiently.

Summary of Important Results:

In traditional ray tracing, visibility computations are accelerated by using ray acceleration structures such as kD-trees, bounding volume hierarchies, grids, and multiresolution grids. These eliminated brute-force comparisons between every ray and each scene triangle. However, typically, these structures are designed for single rays and are optimized for certain ray types (e.g., shadow rays [HM08]). This is fine when performing single point sampling of the visibility. However for more complex situations, such as rendering in participating media (including smoke, fog, snow, etc.), visibility must be queried continuously throughout the volume. Similarly complex visibility queries arise in ballistic penetration and RF propagation contexts.

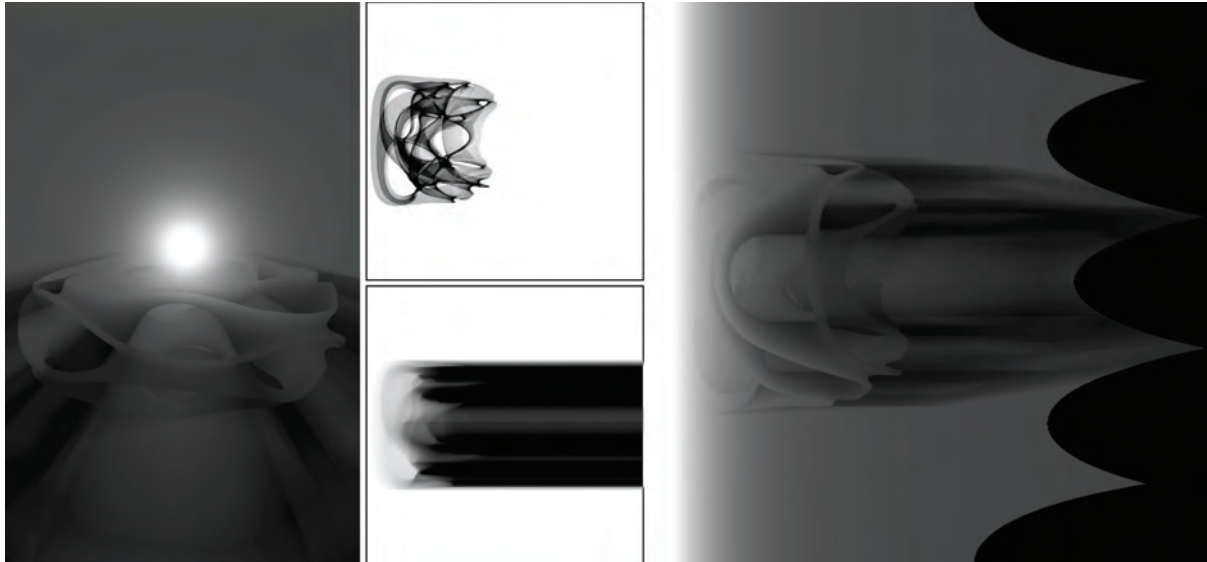
In these more complex scenarios, visibility needs to be densely sampled to identify shadowed regions. But while queries occur densely, the visibility complex generally changes quite slowly. In fact, queries along a single ray give the same result, except at surface discontinuities. This suggests visibility could be cached in some manner similar to light fields [LH96]. The question is how to efficiently store these cached visibility values.

We investigated two such caching schemes. **One approach** was initially explored in a SIGGRAPH Asia Sketch [Wym10] and will be published at High Performance Graphics 2011 [Wym11] using an *epipolar-space visibility voxelization*. In this space, grid axes emanate from the light and the eye.

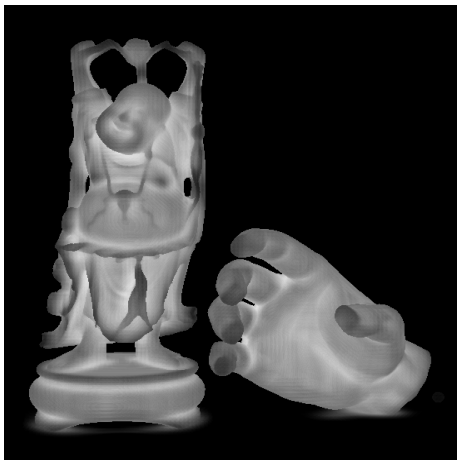


One key advantage to storing visibility in this space is that data along a grid row may be stored in a single cache line, thus allowing quick retrieval from memory. This means the visibility of many points along any eye ray can be queried using a single cache-line lookup. On massively parallel GPUs, this means 512 visibility samples can be retrieved in the time it takes to lookup a single texel. By organizing another grid axis along rays emanating from the light, we enable applications of parallel scan operators in the direction of these rays. As depicted in the figure, above, this means geometry can be voxelized into epipolar space and then extruded using a parallel scan (with a bitwise OR operator) to give a voxelized shadow volume. This entire process can be compute in only a few seconds. Our prototype enables computing a dense visibility sampling at every pixel in a HD resolution image at over 200 fps, even for multi-million polygon scenes.

Below are example results of our epipolar-space voxelization for computing a dense visibility inside a volume. At left the final rendering. At center top is the voxelized geometry in epipolar space, the bottom contains the extruded shadow volume in epipolar space. At right is an explanatory visualization of the final scene color, computed in epipolar space.



Our **second visibility approach** explored computing ambient occlusion using a scene voxelization and an image-space multiresolution sampling approach (similar to our prior work in [NSW09]). Prior screen-space ambient occlusion typically relies on single-layer depth peeling [Eve01] techniques, which introduce artifacts at discontinuities in image space. A voxel-based visibility representation (which can be computed in screen space [ED06] just like depth peeling) avoids this problem by maintaining sampled visibility information at all depths.



While querying voxels at every pixel to compute ambient occlusion works well, it is somewhat wasteful; as with most global illumination effects, ambient occlusion changes slowly in image space. We use a fast stencil-based multiresolution image space sampling scheme [NSW09] to accelerate

ambient occlusion computations. While ambient occlusion may have no apparent application for defense applications, it can provide a good visualization for depicting geometry. And ongoing work (to be funded on another project) is exploring applications of ambient occlusion to ballistic computations, allowing for more informative visualizations of data commonly depicted today using only cell plots.

List of Supported Publications:

- 1) Rajeev Penmatsa and Chris Wyman, "*Voxel Space Ambient Occlusion.*" Submitted to the Journal of Graphics Tools. (Under review)
- 2) Chris Wyman, "*Voxelized Shadow Volumes.*" Proceedings of the ACM / EG Conference on High Performance Graphics. August 2011. (To appear)
- 3) Chris Wyman, "*Interactive Voxelized Epipolar Shadow Volumes.*" ACM SIGGRAPH Asia 2010 Sketches Program. December 2010. (<http://dx.doi.org/10.1145/1899950.1900003>)

List of Supported Personnel:

Associate Professor, Chris Wyman	(1.5% effort for academic year)
PhD Student, Rajeev Penmatsa	(50% effort for academic year)

Report of Inventions:

None.

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- [Wym11] C. Wyman. "Voxelized Shadow Volumes." Proceedings of the 2011 ACM Conference on High Performance Graphics. (To appear)