



# The UTAH TEAPOT

Newsletter for Alumni and Friends of the  
SCHOOL OF COMPUTING

## IN THIS ISSUE

### New Ray Tracing Class



### ALUMNI PROFILE Rob Nelson



### Dave Hanscom Scholarship Update



### New Faculty Member Hal Daume



### *Tempest in a Teapot*



### SIGGRAPH Teapot Exhibit



### Advances in Ray Tracing Lead to SIGGRAPH Paper



### From Writing Code to Writing News

## New Ray Tracing Class Leads to Three Publications that Deal with Dynamic Scenes

By Ingo Wald

### INTRODUCTION

One of the core tasks of computer graphics is "rendering", i.e., the process of generating an image of a virtual 3D scene description. There are two main competing rendering algorithms: ray tracing and Z-Buffering (invented by Ed Catmull in his Utah dissertation). Z-Buffering is the algorithm used in \*all\* of today's graphics chips, and is thus at the core of all of today's interactive applications. Although tremendously fast, Z-Buffering has a hard time producing advanced lighting effects such as shadows, reflections, and refractions. Unfortunately, all of these advanced effects are important to achieving visual realism.

Ray tracing, in which virtual light rays are traced backwards into the scene, using the laws of optics to simulate the propagation of light. Ray tracing thus can produce advanced lighting effects, but has historically been too slow for interactive applications, often spending minutes to hours on each frame. Because of improvements both in ray tracing algorithms and commodity CPUs, ray tracing has recently become interactive. This can greatly improve the realism of interactive computer graphics.

### DYNAMIC SCENES -- THE PROBLEM

While ray tracing approaches real time, there has been a glaring problem that limits its potential for real interactive applications: ray tracing has been designed for static (non-moving) scenes. Having to intersect millions of rays with millions of triangles, ray tracing has always used spatial search structures such as grids, bounding volume hierarchies (BVHs,) or kd-trees. These allow for quickly enumerating all the triangles potentially intersected by a ray, but are built in a pre-process that precludes the scene geometry changing without an expensive rebuilding operation.

Until last year most of the performance breakthroughs have been achieved exclusively for kd-trees, which unfortunately are the most expensive data structure with respect to build time, and thus the worst one for dynamic scenes assuming the data structure is rebuilt every frame. As such, at SIGGRAPH 2005 ray tracing researchers agreed that dealing efficiently with dynamic scenes was the most important open problem in ray tracing.

Given the importance of the problem, by 2005 virtually all ray tracing groups started to work on dynamic scenes. In cooperation with Saarland University, we started working on a scheme that---at least for a very limited class of scenes---would incrementally update the kd-trees, and in Spring 2006 was published at the Eurographics conference.

*continued on page 7*

*The teapot was one of the first free-form models used in computer graphics. Since it was created at the University of Utah (by Martin Newell) in 1975, the teapot has become a favorite computer graphics benchmark. The teapot symbolizes Utah's distinguished leadership in computer graphics.*

# ALUMNI PROFILE

## Rob Nelson

The Teapot meets up with Rob Nelson (BS '94), local alumus and Technology Director at Avalanche Software in Salt Lake City.

*Utah Teapot:* What have you been up to since graduating from the U?

*Rob Nelson:* I started out at Evans and Sutherland writing programs to test their graphics libraries. After a couple of years I joined Sculptured Software as a support programmer in games. Teams were small then, and it was only a couple of years before I was leading my own game. A few years and a buyout later we were Acclaim Studios Salt Lake City, and I got the job of Technical Director. I eventually left there to join Avalanche Software, which is where I am today. It's an excellent company with many talented people. Last year Avalanche was purchased by Disney, and today we develop video games for the high-profile feature animation movies.

*UT:* What do you remember about your time at the U?

*RN:* I had a great time at the U. I loved all my computer science classes, which I took first before even touching any of the core classes. I remember taking Tom Henderson's robotics class. It was a killer. I thought we'd be programming

little fighting droids, and instead it was "math hell" with inverse kinematics and Jacobian matrices. Only 5 students started the class, and only 3 finished. It was hard, but some parts of his class were so important that I use them to this day. I also took a badminton class - don't knock it! I now have a deep respect for the sport, especially after having been beaten by Uwe the math professor.

*UT:* What are you working on at Avalanche?

*RN:* Currently my biggest focus is on core technology to support the Xbox360 and the Playstation3. This technology includes the run-time engine as well as art tools and workflow pipeline to support the asset creation process. I'm overseeing a team of great developers.

*UT:* What do you enjoy most about your job?

*RN:* I like to solve problems. Difficult bugs are my favorite. However, what I like best is being surprised by other people, which happens all the time here at Avalanche. The artists especially have a knack of pushing the envelope with the tools you give them, always delivering more than you thought



Rob Nelson

possible. That's awesome.

*UT:* What has been your biggest accomplishment?

*RN:* This is hard to say... through my career there are many mini-triumphs that come to mind, usually solving technical problems in unique ways. Overall I'd say my biggest accomplishment is finding a great work environment and doing something that I love for a living.

Outside of his job at Avalanche, Rob can be found spending time with his family and planning his next scuba trip. 🏔️

*If you are interested in contacting Rob, please send email to [rob.nelson@disney.com](mailto:rob.nelson@disney.com)*

## Dave Hanscom Scholarship Update

The School of Computing would like to thank the more than sixty of you who have generously donated to the David Hanscom Scholarship Fund! The scholarship fund is named in honor of recently retired Professor (Emeritus) Dave Hanscom, who many of us know from his many years running our undergraduate program. Dave was a great friend, mentor, tutor, and confidant to so many of us and is "tickled pink" that a scholarship in his name will help support incoming computer science undergraduates.

We are currently \$6,500 away from our \$25,000 goal. If you are willing to help us reach this goal, please contact Chris Coleman at [coleman@cs.utah.edu](mailto:coleman@cs.utah.edu) or call 801-581-8580. Donating is a great way to recognize Dave Hanscom's accomplishments and carry on his legacy of support for School of Computing undergraduate students. Your generous support will help a deserving student achieve his or her dream of attaining a Computer Science degree. For more information on the scholarship, including an up to date list of our generous donors, see <http://www.cs.utah.edu/info/hanscom>. 🏔️

*See back page for list of donors.*

## School of Computing Welcomes New Faculty Member

Hal Daume joined the School of Computing in July 2006 after completing his Ph.D. in Computer Science at the University of Southern California, where he spent most of his time in the Intelligent Systems group at the Information Sciences Institute. Prior to attending USC, Hal received his B.S. in Mathematics from Carnegie Mellon University.



Hal Daume

During his final year at CMU, Hal developed interests in natural language processing technology and decided to pursue this topic during his graduate studies. He now works at the boundary between natural language and machine learning and works on developing statistical models for complex language phenomena. From an applied perspective, Hal is most interested in developing technology that enables users to quickly find and understand all the information out there that is important to them. From a theoretical perspective, Hal focuses on developing statistical models and efficient algorithms for problems that exhibit complex structure, such as those found in natural language.

When not coding or doing math on his white board, Hal enjoys Aikido, skiing, badminton and rock climbing. You can recognize him most easily by noting that he rarely wears shoes. 🏔️



New Warnock Engineering Building scheduled for dedication February 2007. For more information go to [www.coe.utah.edu/web](http://www.coe.utah.edu/web)

## *Tempest in a Teapot*

### New Accommodations for the School of Computing

by Martin Berzins  
Director, School of Computing

It is always satisfying to report that major changes are taking place that will improve the facilities available to the School of Computing (SoC). Over the past 2 years the school has watched the creation of the new Warnock Engineering Building. The new building will house not only the SoC faculty in the Scientific Computing and Imaging Institute but also the Geometric Design and Computation Group run by Rich Riesenfeld and Elaine Cohen.

When completed the Warnock building will serve as the new physical hub for the College of Engineering. It will feature advanced computational facilities, modern teaching space, faculty offices and labs, and the College administrative center. Other features include the Michael O. Leavitt Student Learning Center with high tech classrooms and seminar rooms, computer-based teaching labs, team project rooms, quiet study areas, and a food service area. The new building will also have research areas that will feature faculty, graduate student and post doc offices, a visual supercomputer center, conference rooms, and administrative space. One of the major goals in creating the new space is to give engineering students a comfortable and functional environment to learn and interact with each other.

This move is also freeing up space in the Merrill Engineering Building, making it possible to improve accommodations for the rest of the school. Although the school will be more physically distributed, overall our accommodations will be much improved.

I am looking forward to the many challenges that lie ahead as we begin to move people into the new building and start the restructure of MEB. I believe that the new building along with the new accommodations in MEB will help in strengthening the educational and research programs here at the SoC and launch us into a new era of engineering at the University. 🏔️

Contact Martin Berzins at [director@cs.utah.edu](mailto:director@cs.utah.edu)

## Utah Teapots in Special Teapot Exhibit at SIGGRAPH


by Russ Fish

This year at SIGGRAPH in Boston, there was a special juried and curated Teapot Exhibit. For five days, forty-four “real teapots, virtual teapots, and teapot-inspired images” were displayed to “showcase the long association of the teapot with computer graphics, art, and Boston.”

SIGGRAPH is the yearly computer graphics conference of the ACM (Association for Computing Machinery.) SIGGRAPH was founded in 1977 as a forum for the computer graphics research community, prominently including many U of U Computer Science Department alumni, faculty, and, students. Over the years, SIGGRAPH has grown to include a huge technical conference and trade exhibition, as well as with many computer and multi-media art exhibits and performances, most visibly the massive Computer Animation and Electronic Theatre evenings.

The Utah Teapot was designed by Martin Newell, inspired by his real Melita teapot (now in the Computer History Museum in Mountain View, California.) Martin was then a grad student in the U of U Computer Science Department (Ph. D Summer, 1975, “The Utilization of Procedure Models in Digital Image Synthesis”) and joined C.S. graphics faculty in 1975-77.

This teapot was one of the first widely available and photogenic curved-surface 3D models, an early high-quality virtual object. It became a common benchmark model for image synthesis programs and a familiar icon in computer graphics research, later appearing in Pixar movies and even a “Simpsons” episode.

Five entries in the Teapot Exhibit from School of Computing illustrated the genesis and usage of the teapot in research. We told some of the Utah Teapot story in the Artist’s Notes and Technical Overview descriptions that accompanied each work in the Exhibit, which are still visible on the SIGGRAPH web site. 

**Russ Fish is a SoC alumnus and research staff member**



**“Martin Newell’s Original Teapot”**

An archived original publication print of Figure 29 from Dr. Newell’s PhD dissertation. A digital rendering of a tea setting scene, including a teapot, tea cups, saucers and spoons, and a milk pitcher, all on a table top with a draped curtain as a background.



**“Tempest (inquiry)” by Ann Torrence**

A photographic “tempest in a teapot”: an image assembled using Adobe Photoshop, transforming time into spectral space. Multiple digital photographs were taken of a glass teapot containing ordinary bubbles in plain water, using white strobe light without the use of any colored filters.



**“Plastic Utah Teapot” by Steve Sady**

These three functional plastic teapots with separate lids were created as paper-thin layers of white plastic, laid down by a Stratasys FDM (Fused Deposition Modeler) machine, based on the third-generation trimmed-NURBS solid model.



**“Machined Aluminum Utah Teapot” by Gershon Elber**

Research into geometric algorithms for computer-controlled manufacturing. The body of the teapot, including spout and handle, was sculpted from a solid block of aluminum, and the lid of the teapot separately turned on a lathe, in the Advanced Manufacturing Lab at the University of Utah.



**“Teapot Subdivision” by Russell Fish**

A third-generation updating of Martin Newell’s Bezier teapot, as an Alpha\_1 procedurally-generated trimmed-NURBS solid model. Rendered by the Alpha\_1 ray tracer in a kitchen scene, revealing the lovely new insides of the teapot by slicing it in half like an onion (slightly surreal, I admit).

Plastic Utah Teapot & Machined Aluminum Utah Teapot photographed by Ann Torrence

# Advances in Ray Tracing Lead to SIGGRAPH Paper

by Thiago Ize

At the close of the Acceleration Structures seminar in December (see [New Ray Tracing Class](#) article), we had the core algorithm for a faster method of traversing the grid acceleration structure. With the SIGGRAPH deadline only one month away, we had yet to get the algorithm fully working, implement an entire interactive ray tracer around it, and make sure the whole thing is blazingly fast. In the end, we not only accomplished our goals, we also created a ray tracer that far surpassed our expectations.

By simultaneously tracing a large packet of rays (usually 64) rather than one ray at a time, we improved the performance of grid acceleration structures by an order of magnitude. We accomplished this by enveloping the rays in a frustum (a pyramid with the top cut off) and traversing the frustum through slices of the grid (see figure). This results in an extremely fast traversal for several reasons:

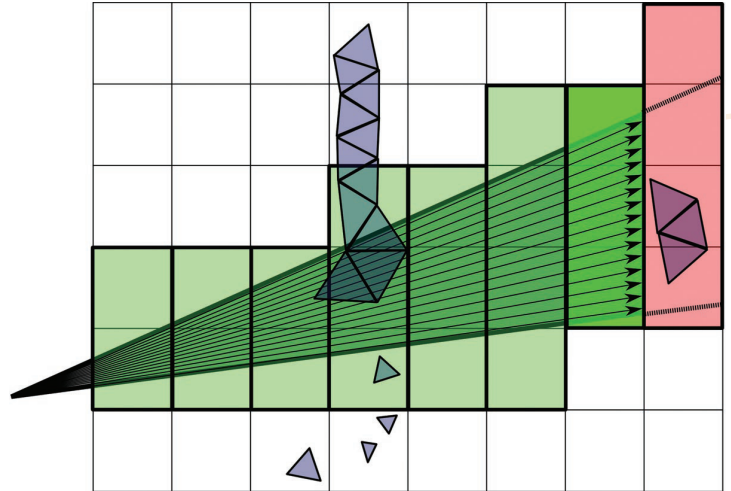
- It allows the use of SIMD instructions to operate on 4 rays at a time.
- Many traversal and intersection costs operate only on the frustum, thus amortizing the traversal cost among all the rays in the frustum.
- Because the rays are spatially close, it is likely they will traverse the same cells, so we also benefit from better memory coherence.

This places grids on equal footing with the fastest known ray tracing acceleration structures. Unlike other structures which are constructed using expensive optimization algorithms, the grid construction can be accomplished very quickly. This enables interactive ray tracing of fully deformable scenes! This is quite significant, as it demonstrates interactive ray tracers can be used for gaming. This work resulted in a SIGGRAPH paper Ñ the only ray tracing paper to be accepted at SIGGRAPH this year.

While the grid build is extremely fast, it still has a linear cost in the number of objects. Therefore, we are unable to achieve interactive rates for very large multi-million object scenes. Furthermore, since both general purpose CPU and graphics chip manufacturers are now producing faster chips by including multiple processing cores, it is critical that we parallelize the grid build so that we can take advantage of future hardware developments and handle extremely large scenes. At the Interactive Ray Tracing Symposium I presented a paper that analyzes the theory behind parallelizing the grid build and then demonstrated several different methods for accomplishing this.

With an acceleration structure capable of ray tracing millions of changing objects many times a second, we

applied our technique to the visualization of particle-based simulation data. While our coherent grid traversal already handled spheres at interactive rates, to further improve memory usage and ray tracing performance we developed an algorithmic enhancement for the special case of particle-based visualization. Ultimately, the grid based ray tracer works so well in this domain that even using only a couple



2D example of coherent grid traversal: Previously traversed grid sections are green and the current slice is highlighted in bright green. The next slice to be traversed is shown in red. The scene objects are depicted in blue and only those falling within the green sections have been tested for intersection with rays.

processors, it is able to outperform GPU-based approaches. We have submitted a journal paper detailing our work, and are actively collaborating with scientists from other universities to visualize their particle data.

After demonstrating that an interactive ray tracer running on a desktop computer can produce images of dynamic scenes with similar quality to GPU based methods, we are now focusing our efforts on handling advanced ray tracing techniques, such as soft shadows, glossy reflections, refractions, indirect lighting, etc..., to produce more realistic images than a GPU while maintaining interactive frame rates. Once this occurs, we can expect a shift in gaming, from the traditional rasterized GPU approach to a ray traced one. 🏔️

Acknowledgments: These papers were coauthored by: Ingo Wald, Steve Parker, Christiaan Gribble, Andrew Kensler, Aaron Knoll, and Chelsea Robertson.

*Thiago Ize is a PhD student working with Steve Parker*

# NEWS

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## ALUMNI

The doctoral dissertation of **Jason Yue Yang**, PhD '04, was selected by the University of Utah as its nominee for the 2006 Council of Graduate Schools / University Microfilms International Distinguished Dissertation Award. Jason is currently leading the concurrency analysis effort in the program analysis group at Microsoft.

## FACULTY

**Juliana Freire** has been awarded an NSF grant to study the design of novel data management techniques for semi-structured data. The project, titled "XML Data Management: Taking Order and Updates into Account", aims to develop techniques and scalable infrastructure that cater to the diverse needs of emerging applications, which use XML to

represent their data. This project was one of only eleven funded in the Database Management Systems program in 2006.

**Steve Parker** was selected as one of HPCwire's 20 People to Watch in 2006. The annual list recognizes the most influential, interesting and promising personalities having an impact on the world of High Performance Computing.

**Claudio Silva** was honored once again with a coveted IBM Faculty Award. This award is designed to promote innovative, collaborative research and honor outstanding faculty working in disciplines of interest to IBM. Dr. Silva is being recognized for his work developing efficient rendering techniques for large-scale scientific visualization.

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## From Writing Code to Writing News; Utah Grad Student Interns at the Chicago Tribune

by Miriah Meyer



Miriah Meyer

I spent my summer at sleep-away camp for scientists. Only without the cabins, the counselors, or the creepy-crawly critters.

Instead, I lived in the big city of Chicago for ten weeks, working as a science writer for one of the nation's leading newspapers. As the

American Association for the Advancement of Science Mass Media Fellow at the Chicago Tribune I reported on everything from renewable energy to open-source software, taking field trips to university labs and lunching with geeky superstars.

The AAAS's Mass Media program places graduate students studying science, mathematics and engineering fields into newsrooms across the country to "enhance coverage of science-related issues in the media and improve public understanding and appreciation of science and technology." The complementary goal of the program is to provide scientists and engineers the skills to effectively communicate their research to their peers as well as their parents.

Each story I worked on brought the surprise that people – smart, interesting, respected people – wanted to tell me

about their work. This past summer I had the opportunity to interview the U.S. Surgeon General, Olympic diving legend Greg Louganis, and the Hottest Hacker on Earth. I was invited to tour numerous research labs, and got the inside scoop on suspicions of drug research being exploited by competitive cyclists. The simple phrase "I'm a reporter with the Chicago Tribune" was the best tool a science-pickpocket could ever have.

I also learned what *newsworthy* research really is, knowledge that the scientist in me finds humbling. I discovered that people outside of small, niche research communities most often will not find the pleasure and intrigue in the details that are what excite scientists the most.

As scientists and engineers, we respect the depths of our fields and the details of our research. A respect that can often make it hard to present the two-minute summary of a decade of work – it was all important, right? Newsworthy research, however, must provide an insight into the bigger world around us in an accessible and understandable story.

I think this perspective will allow me to be a more effective advocate of science and technology in whatever career path lies ahead. And isn't that what summer camp is about? Learning a life lesson or two? 🏕️

*Miriah Meyer is a PhD Student working with Ross Whitaker*

# New Ray Tracing Class

*continued from page 1*

## THE EXPERIMENT

In parallel to the approach of incremental updating a kd-tree, we also approached the problem in a more unconventional way. Steve Parker, Pete Shirley and I created a new graduate course on the topic. Instead of teaching it in the conventional way with a single professor and readings/assignments, it was taught by all three of us in parallel, with teams in the class trying different ideas. The key was that for various historical reasons each of the professors



Recent ray tracing research efforts at the University of Utah have targeted the design of algorithms for interactively ray tracing dynamic, animated models like the ones shown in this figure. Right: A running "Poser" figure of ~78,000 animated triangles, with textures and shadows. Left: The "Utah Fairy", a animated fairy figure dancing through a complex forest environment; a very challenging scene for interactive ray tracing. The recent research at Utah now allows for ray tracing such scenes at interactive rates on desktop PCs.

preferred, and was an expert in, a different data structure: Parker for grids, Shirley for BVHs, and myself for kd-trees. Each professor then taught the students all he knew about "his" data structure, and tried to convince them of its merits. Similarly unconventionally, the students were not told what assignments to implement; instead, we formed several groups---each working on a different data structure with students choosing which group to join---and those groups were then told to compete against each other in writing a fast ray tracer.

## THREE SOLUTIONS

This experiment churned out several very interesting results. First of all, the competition motivated the students to push the boundaries of algorithm performance. Second, by interacting every week the competing groups often managed to improve "their" data structure with concepts that had originally been a specialty of another one. In particular, it turned out that virtually all of the last years' findings for kd-

trees could also be applied to BVHs, and that those could thus be made competitive with kd-trees. This was quite surprising, and, by implicitly solving the dynamic scenes problem (BVHs can easily be updated every frame) eventually turned into a paper in the ACM Transactions on Graphics. Similarly, it turned out that the key concepts of today's fast kd-tree ray tracers---packet- and frusta techniques, both of which had been believed to be unique to kd-trees---could also be applied to uniform grids, and that such grids could then achieve "dynamic" scene performance that was competitive to kd-trees for static scenes. This result even managed to get into ACM SIGGRAPH, the top venue in graphics.

Thus, for a problem originally believed to be hardly solvable at all, the research of fall 2005 produced three different solutions---most of which were achieved in the CS7960 experiment---which eventually led to a SIGGRAPH paper (grid), a TOG paper (BVH), a Eurographics paper (kd-tree), a patent application, and several follow-up research papers (also see the other article in this issue). In that sense, the CS7960

experiment was probably one of the most productive classes ever held. 🏔️

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*Ingo Wald is a research assistant professor at the School of Computing*



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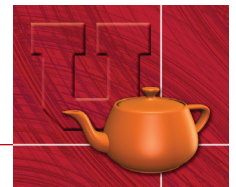
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