

# A presentation on my background in computer graphics

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# Outline

- 1 Introduction
- 2 Master Thesis: Real-Time Stream Surface Computation and Rendering
- 3 Ray Tracing Revisited for Rendering CSG Models Consisting of Higher Order Primitives
- 4 Analysis of Voxel-Based Ray Tracing
- 5 Other Projects
- 6 VELaSSCo EC Funded Project
- 7 Dynamic Arc Tessellation

# About Me...

- My name is **Morteza Mostajab**
- B.Sc. Computer Engineering at  
*Hamedan University of Technology, Iran*
- M.Sc. Computer Science at  
*Technische Universität München*
- Working as Researcher at  
*Fraunhofer IGD, Darmstadt*
- Research interests:  
*Real-time physically-based rendering*  
*(Rasterization-based or Ray-tracing)*  
*Virtual reality*  
*Computer graphics and visualization*  
*Game Programming*



# Inspiration

- Games, Animations, Movies with Special Effects,...



(a) Last Ninja 3



(b) Gears of War



(c) Ratatouille



(d) The lord of the rings

- My firsts...



(e) First Computer (Commodore 64)



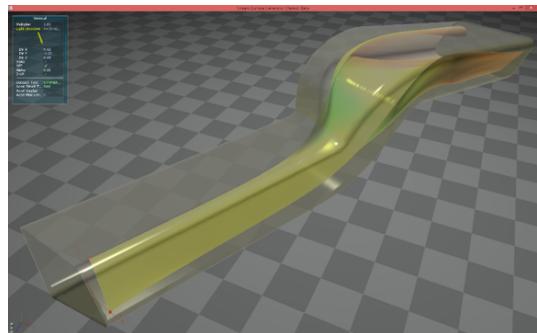
(f) First IBM compatible PC (Atari 2600)  
(80286)



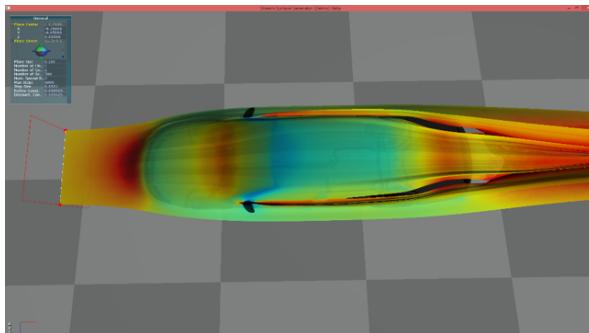
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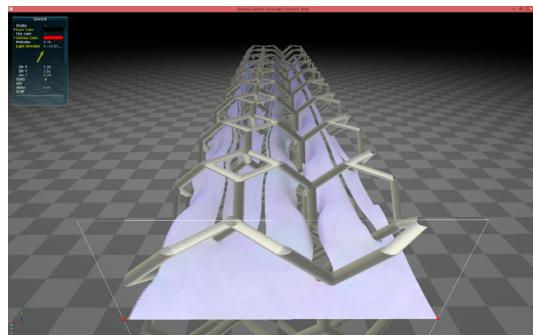
# Real-Time Stream Surface Computation and Rendering



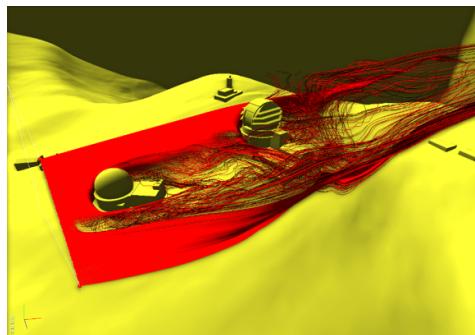
(h) Wind Tunnel



(i) Car



(j) Tethrahedradecal



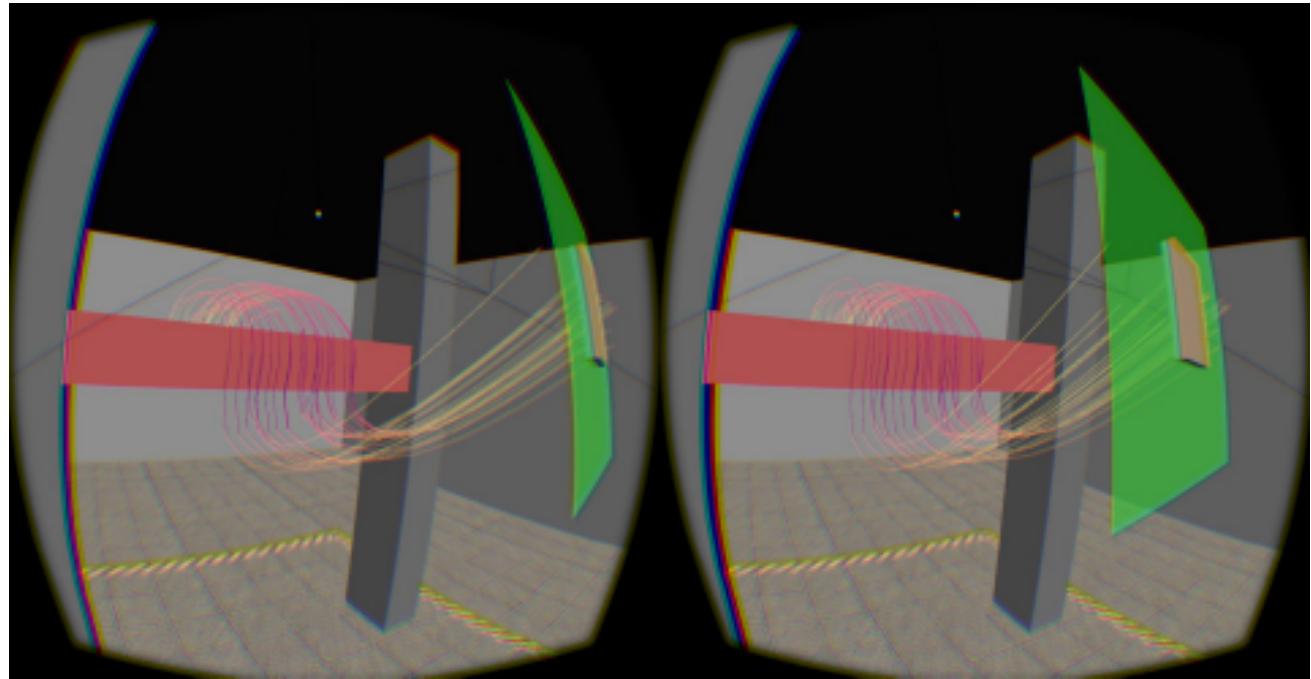
(k) Telescope

Figure 1: Final results of this master thesis.

# Motivation

- **Goal:** Use virtual reality to help engineers getting a better **understanding** of simulations, make **investigation** in flow field features easier.
- Virtual reality applications demands 75-140 frames per second scene update and rendering to reduce **latency**.
- **Initial motivation:**
  - **Immersive Streamline Demo:** a demo which user could stand in a simulation model to understand flow field features by:
    - Prototype demo which placed the user virtually in simulation model.
    - User could interact with virtual world by moving streamlines' seeding plane.
    - User could walk around in the simulation model, look closer into streamlines to understand flow field's features better.

# Immersive Streamline Demo



**Figure 2: Immersive Streamlines** was a prototype demo done at Fraunhofer IGD. The user is able to move inside the virtual world, interact with it, and look closely at the flow visualization results. The image shows a stereo pair, which is displayed on Oculus Rift HMD.

# Problem Definition

- Streamline's computation was 10 frames per second (latency was very visible to user).
- Streamline's accuracy was not high enough (straight lines in streamlines are visible in the screenshot).
- Stream surfaces can provide more information about flow fields features.
- So, we defined **Parallel Stream Surface Computation and Rendering** master thesis to solve these problems.

# Main Contributions

- **Contribution 1:** Using heterogeneous computing:
  - Scale streamline computation on all capable devices.
  - Scale rendering on all graphic processing units.
- **Contribution 2:** Investigation techniques from ray tracing field for application in accurate streamline computation:
  - Using acceleration structures
  - Using ray-packing

# Benefits

- Accurate streamline computation method (using **Runge-Kutta** integration method).
- **Adaptive Runge-Kutta** integration method to adapt steps to maximum integration error.
- Heterogeneous stream surface computation.
- Multi GPU stream surface computation and result

# Related Works

- Parallel stream surface computation for large data sets (Camp et al., 2012).  
proposed a distributed stream surface computation system.
  - **My method is not distributed but uses all available computation devices.**
- Interactive Streak Surface Visualization on the GPU (Buerger et al., 2009).  
Bue+09 samples the simulation mesh on a regular grid, then compute the streak surface.
  - **Reduces accuracy, ignores a lot of information exist in simulation mesh by sampling it on a regular grid.**

# Related Works

- Interactive particle tracing for the exploration of flow fields in virtual environments (Schirski, 2008).  
Sch08 uses the neighboring graph instead of acceleration structure on GPU.
  - **step size needed to be small enough.**
- Fast, Memory-Efficient Cell Location in Unstructured Grids for Visualization (Garth and Joy, 2010).  
introduces cell-tree acceleration structure use it for particle tracing.
  - **I have evaluated more acceleration structures to classify them based on memory requirements and performance.**

# Stream Surface Computation Algorithm (Camp et al., 2012)

**Data:** *seeds* list which contains all initial seeding points.

**Result:** Stream Surface Points

**while** *seeds* list is not empty **do**

**Tracing:** Trace streamlines originating from seeding points stored in *seeds* list and make *seeds* empty.

**Refinement:** **for** each pair of adjacent streamlines  $s_1$  and  $s_2$  **do**

$d \leftarrow Distance(s_1, s_2)$

**if**  $d \leq D_{disc}$  **then**

| **Discontinuity:** The surface is discontinued in that area.

**else**

$s_{new} \leftarrow (s_1[0] + s_2[0])/2$

| add  $s_{new}$  to list *seeds*.

**end**

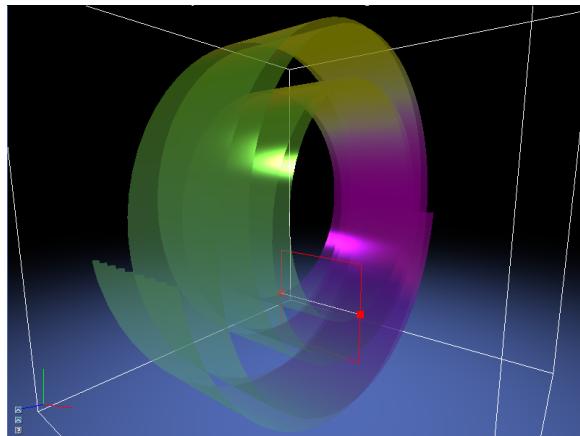
**end**

**end**

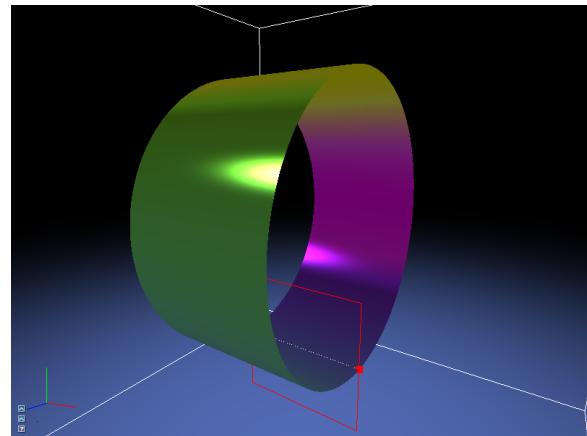
**Algorithm 1:** Stream Surface Computation Algorithm (Camp et al.,

# Accurate Streamline Computation

- Point-Inside-Cell checks & interpolating results inside cells.
- Using *adaptive Runge-Kutta* integration method (Cash-Karp).
- Adaptive stepping (faster and more accurate integration).
- Avoiding early terminations.



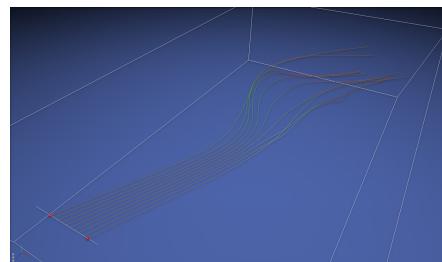
(a) Euler



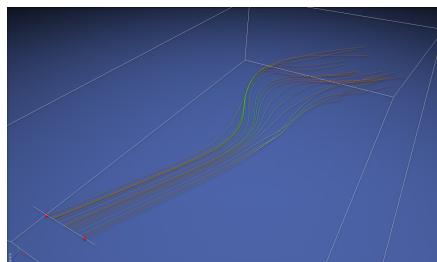
(b) Cash-Karp

Figure 3: Euler and Runge-Kutta integration methods in a perfect rotation around center which are integrated with the same step size.

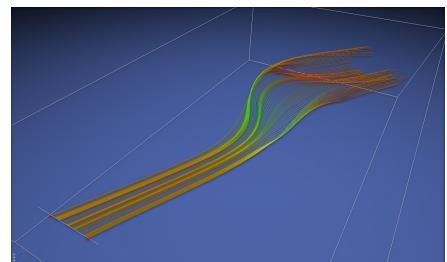
# Refinement Strategy Results



(a) No Refinements



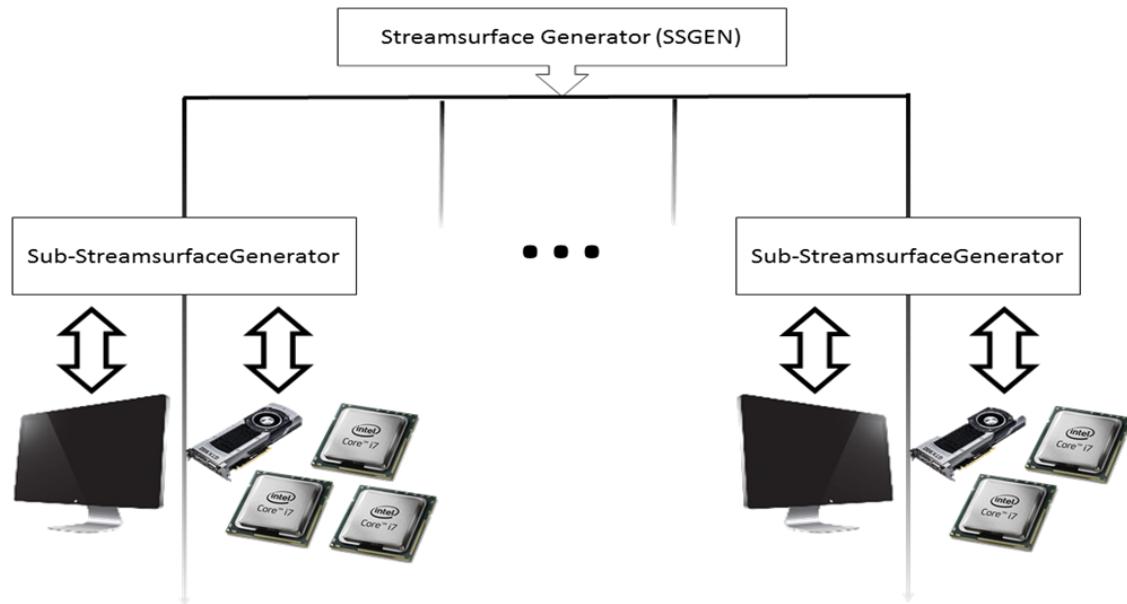
(b) The first refinement it-  
eration



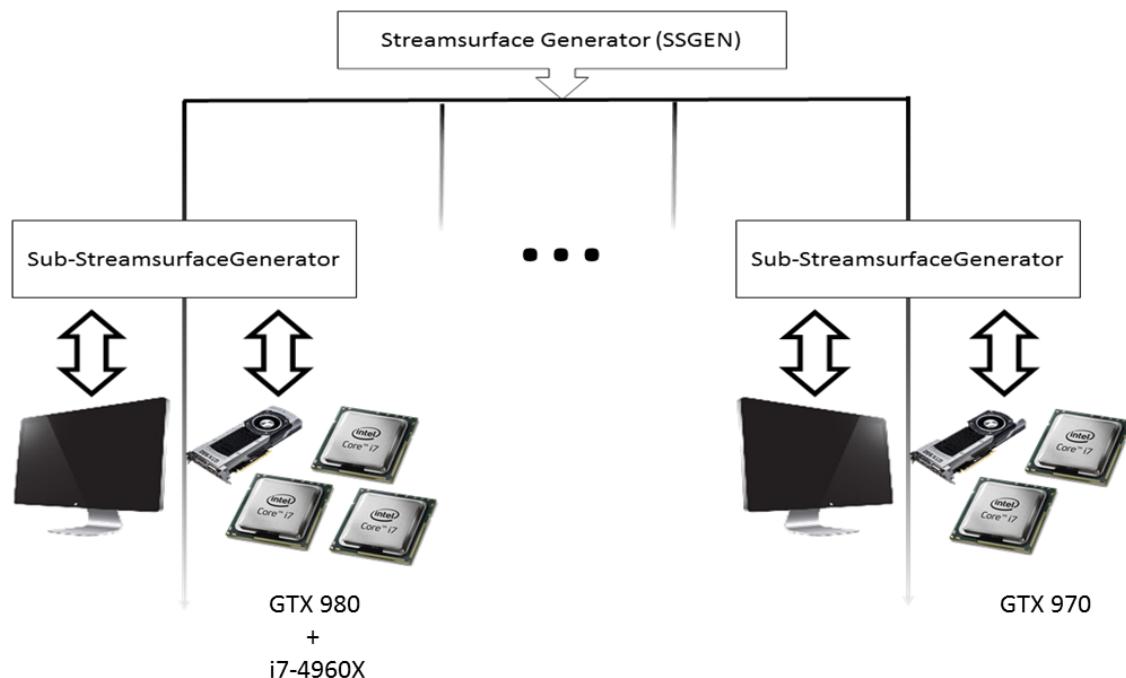
(c) The second refinement  
iteration

Figure 4: The result streamlines making skeleton of stream surface after 2 steps refinement.

# Contrib. 1: Heterogeneous Computing Arch. (1/7)



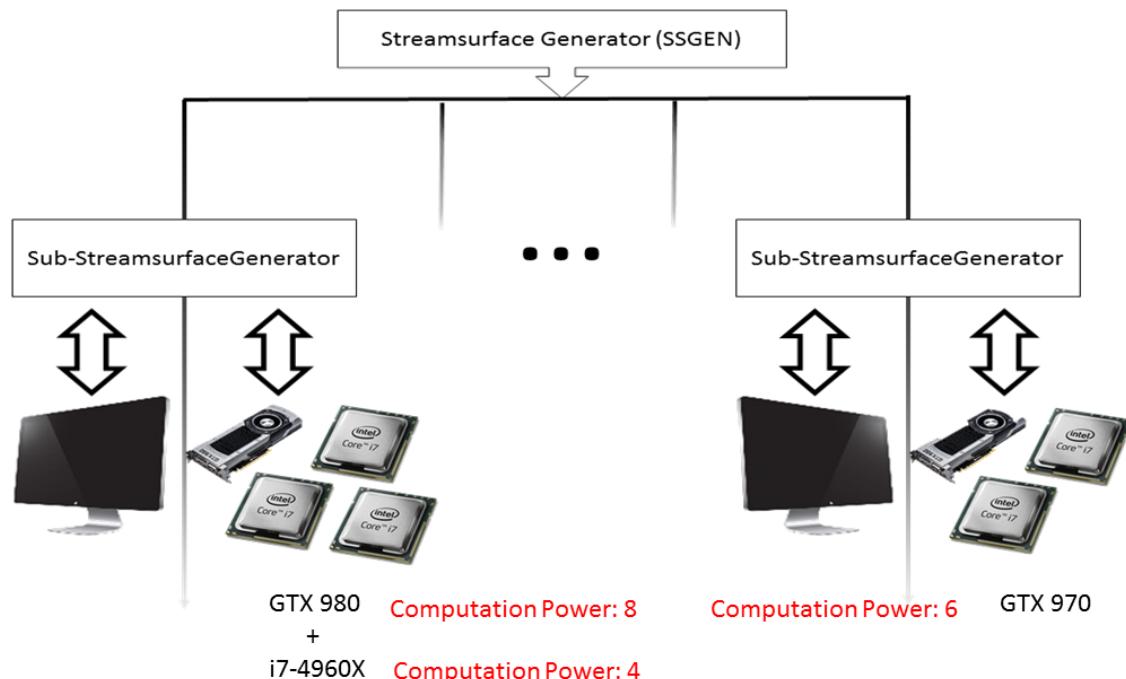
# Contrib. 1: Heterogeneous Computing Arch. (2/7)



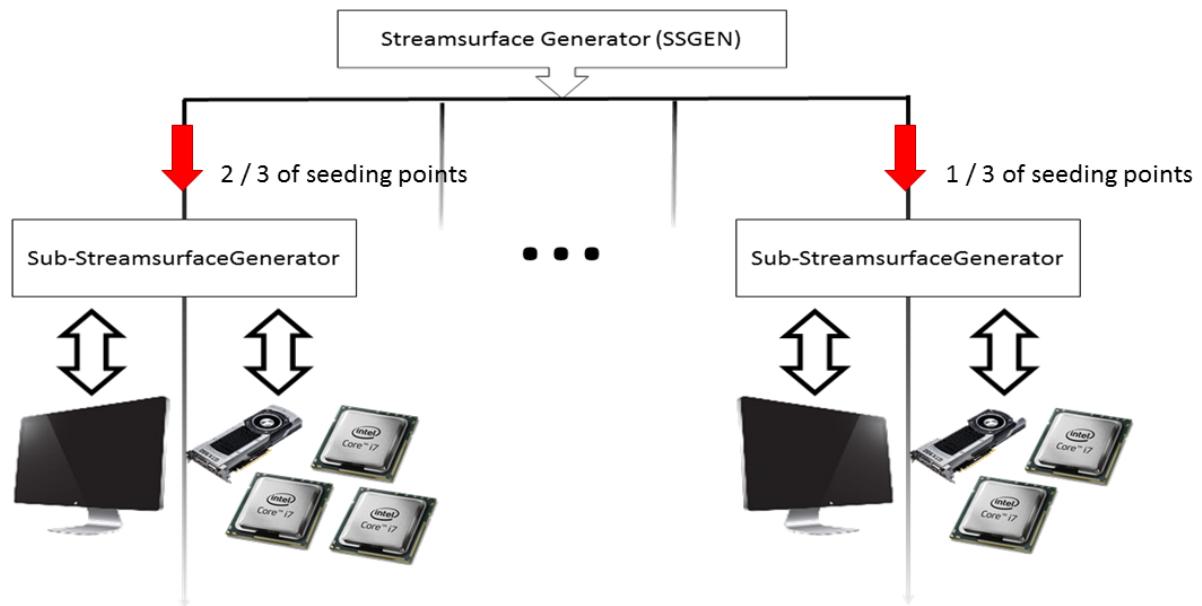
# Contrib. 1: Heterogeneous Computing Arch. (3/7)

Device Name	Computation Power Weight (CPW')
NVIDIA GeForce GTX 980	8.0
NVIDIA GeForce GTX 970	6.0
Intel Core i7-4960X	4.0
TAHITI (AMD Radeon R9 280X)	6.0
PITCAIRN (AMD Radeon HD 7850)	4.5
Intel Pentium G860	1.0

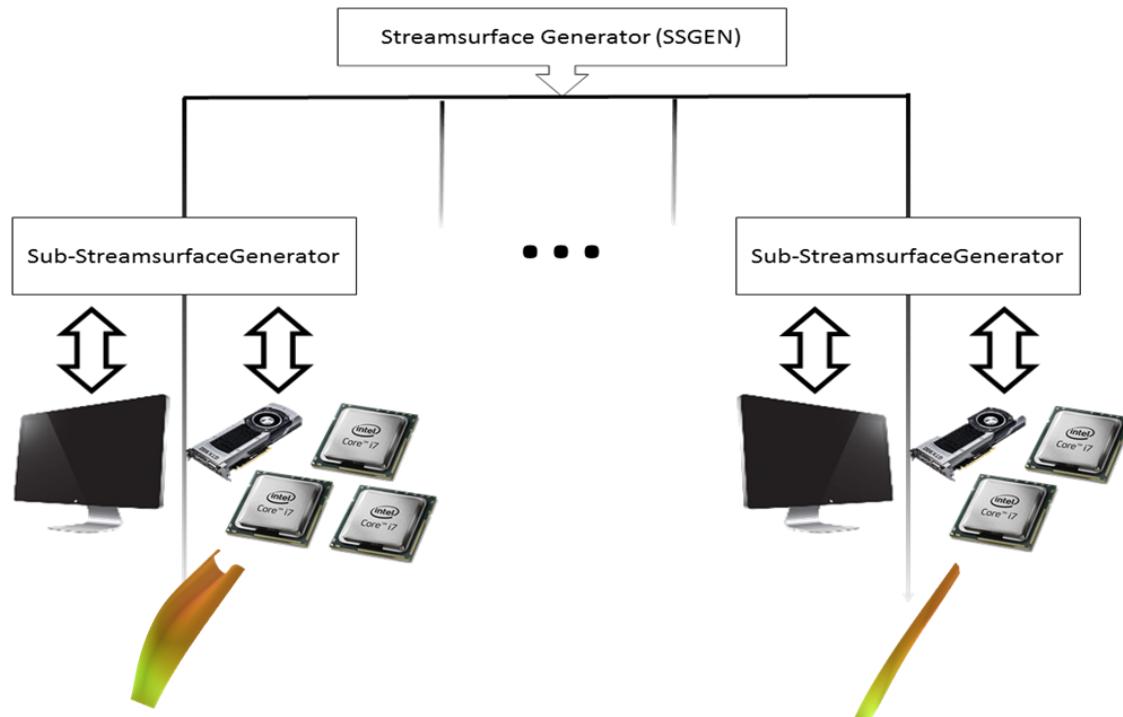
# Contrib. 1: Heterogeneous Computing Arch. (4/7)



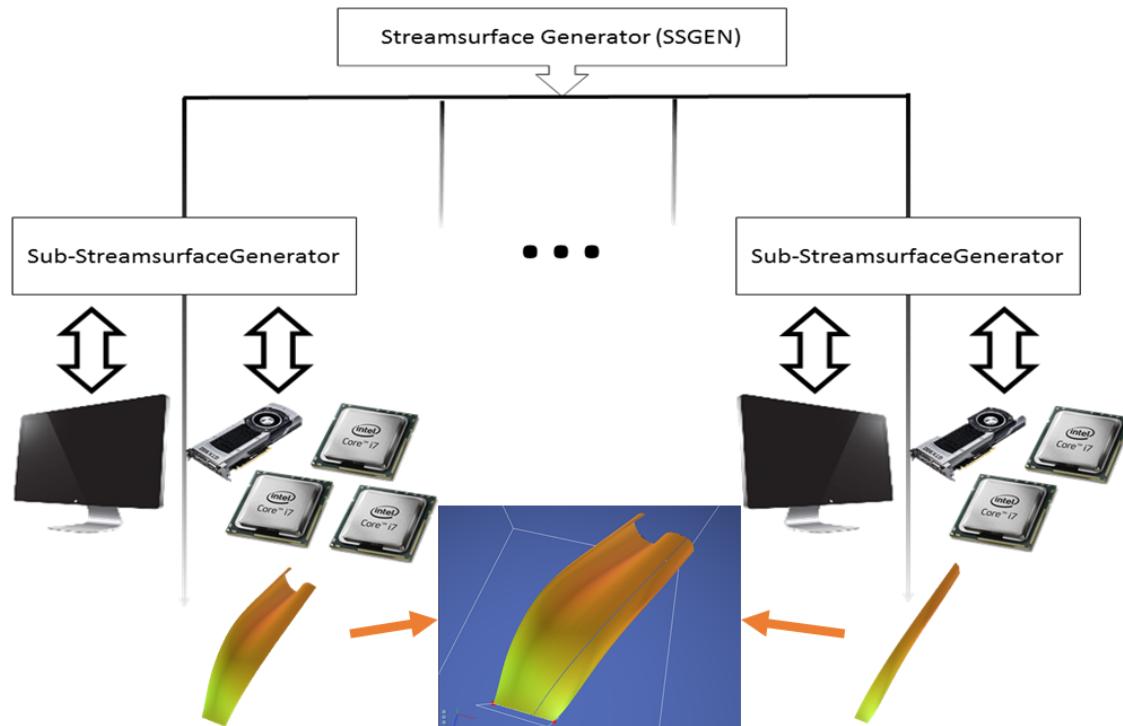
# Contrib. 1: Heterogeneous Computing Arch. (5/7)



# Contrib. 1: Heterogeneous Computing Arch. (6/7)

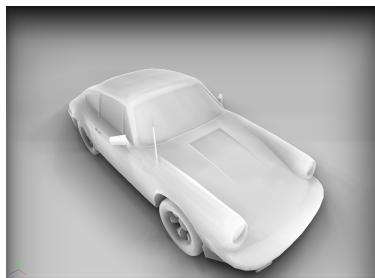


# Contrib. 1: Heterogeneous Computing Arch. (7/7)



# Multi GPU Rendering

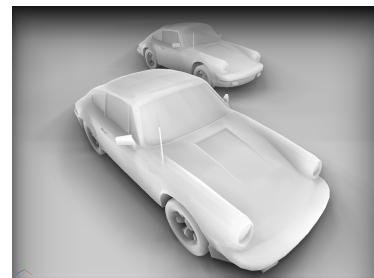
- Compositing screen cspace ambient occlusion results



(a) GPU #0

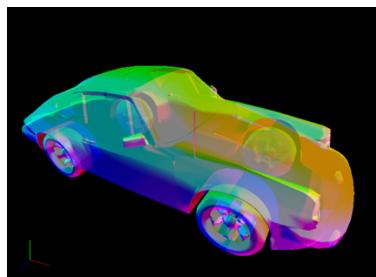


(b) GPU #1

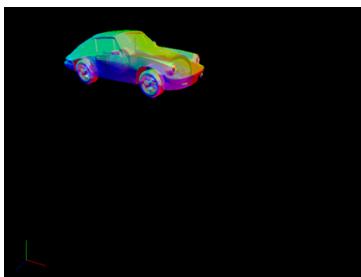


(c) Composed

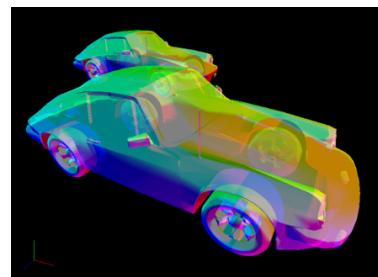
- Compositing order independence transparency results



(d) GPU #0



(e) GPU #1

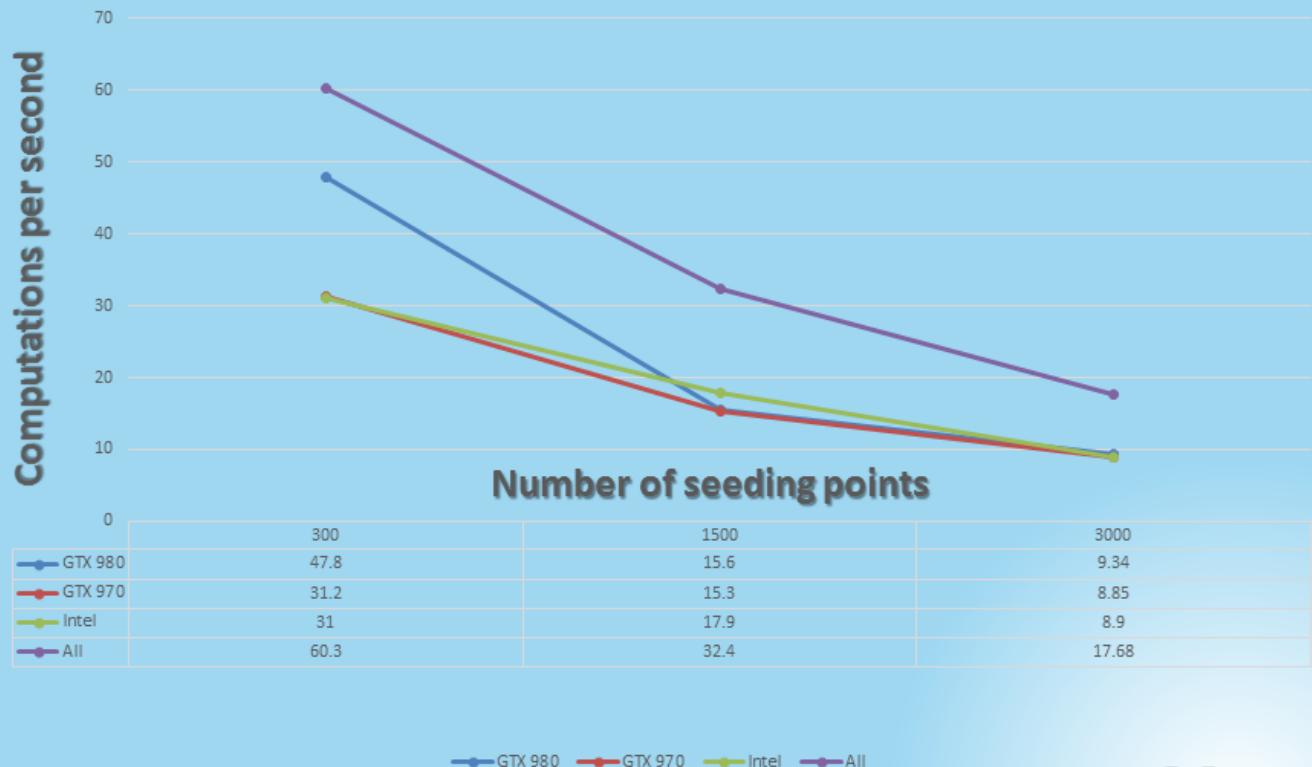


(f) Composed

# Heterogeneous Computing Results

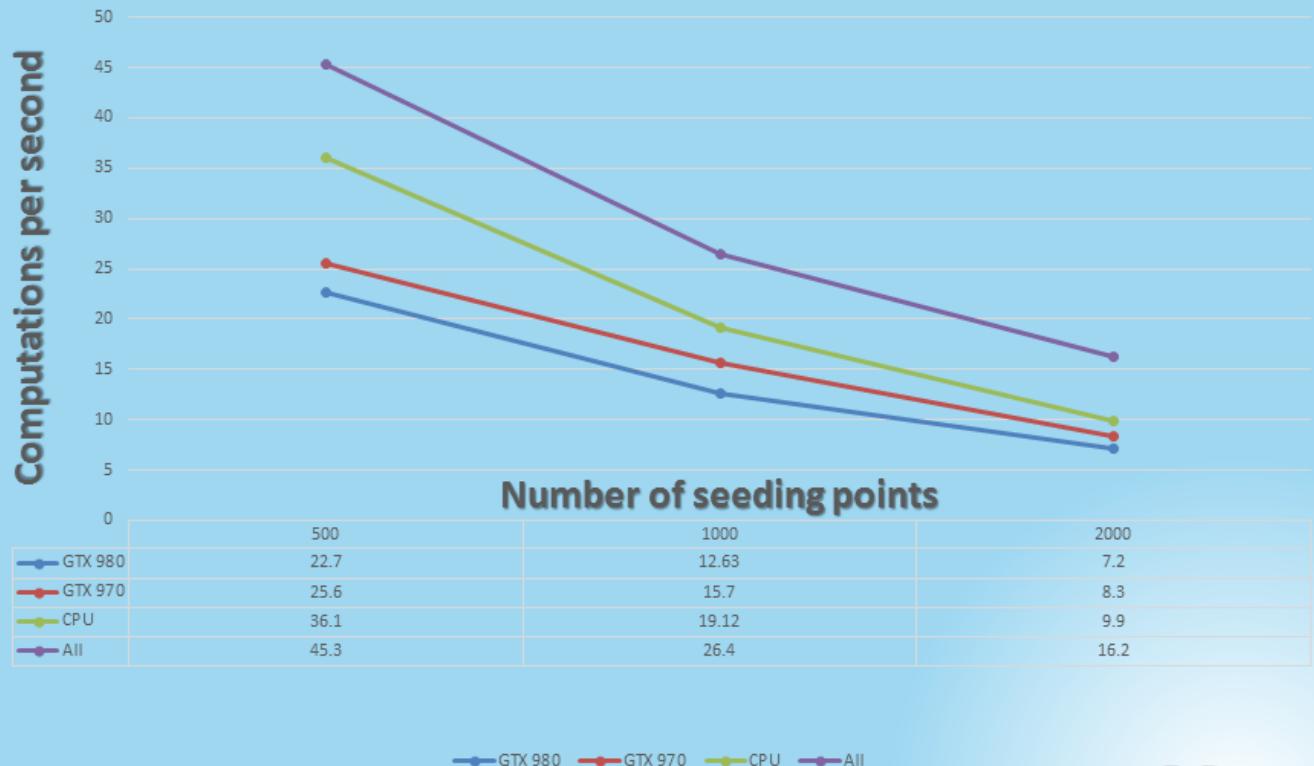
- Measured parameters:
  - **Computations per second:** It shows how many times the stream surface can be computed in every second. The unit is number of computation times per second.
  - **Number of seeding points:** Total number of seeding points for producing the final stream surface.

# Wind Tunnel Dataset



Real-time stream surface computation – April 2016  
Seyedmorteza Mostajabodaveh

# Car Dataset



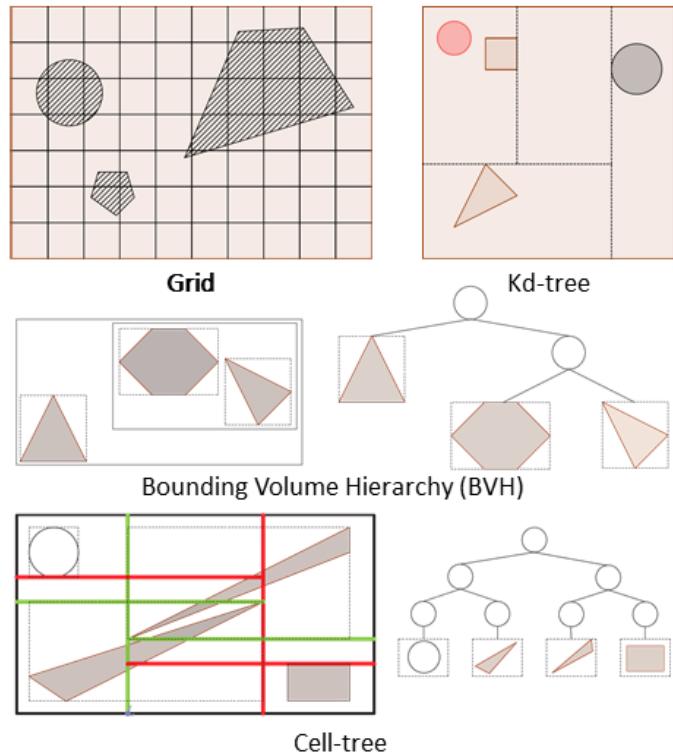
Real-time stream surface computation – April 2016  
Seyedmorteza Mostajabodaveh

# Heterogeneous Computing Results Conclusions

- As expected, the streamline computation is being scaled on all available computation devices.
- Using both GPUS and CPU, the computation performance is doubled.
- Limiting factors:
  - OpenGL operations cannot be parallelized.
  - Synchronization of threads are a overhead.
  - **Dynamic task scheduling** could be a better approach.
- There is an overhead for initializing computations on multiple devices.

# Acceleration Structures

- Grid
- Kd-tree
- Bounding Volume Hierarchy (BVH)
- Cell-tree (Garth and Joy, 2010)



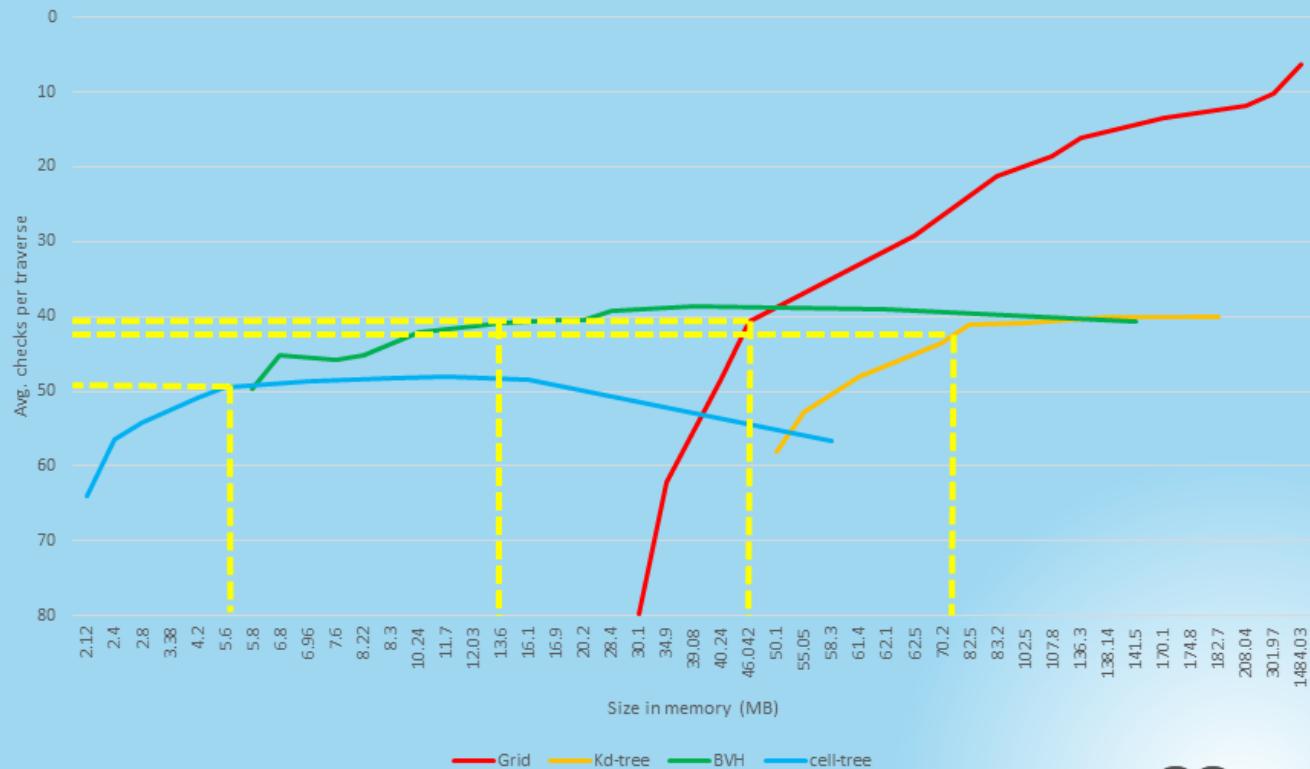
# Why Acceleration Structures?

- Accelerating cell look up for faster streamline computation.
- Ray tracing uses acceleration structures to find **nearest intersection point** in contrast to streamline computation which uses it to **sample result in a specific point**.
- Differences:
  - In streamline computation instead of *Surface Area* Heuristics, *textit{Volume}* Heuristics should be used.
  - *Traversal algorithms* for space partitioning cases does not need *stack*.
  - Hierarchy traversal algorithms need a greedy method to prefer one child to other one during traversal.

# Contrib. 2: Using Acceleration Structures for Streamline Computation Evaluations

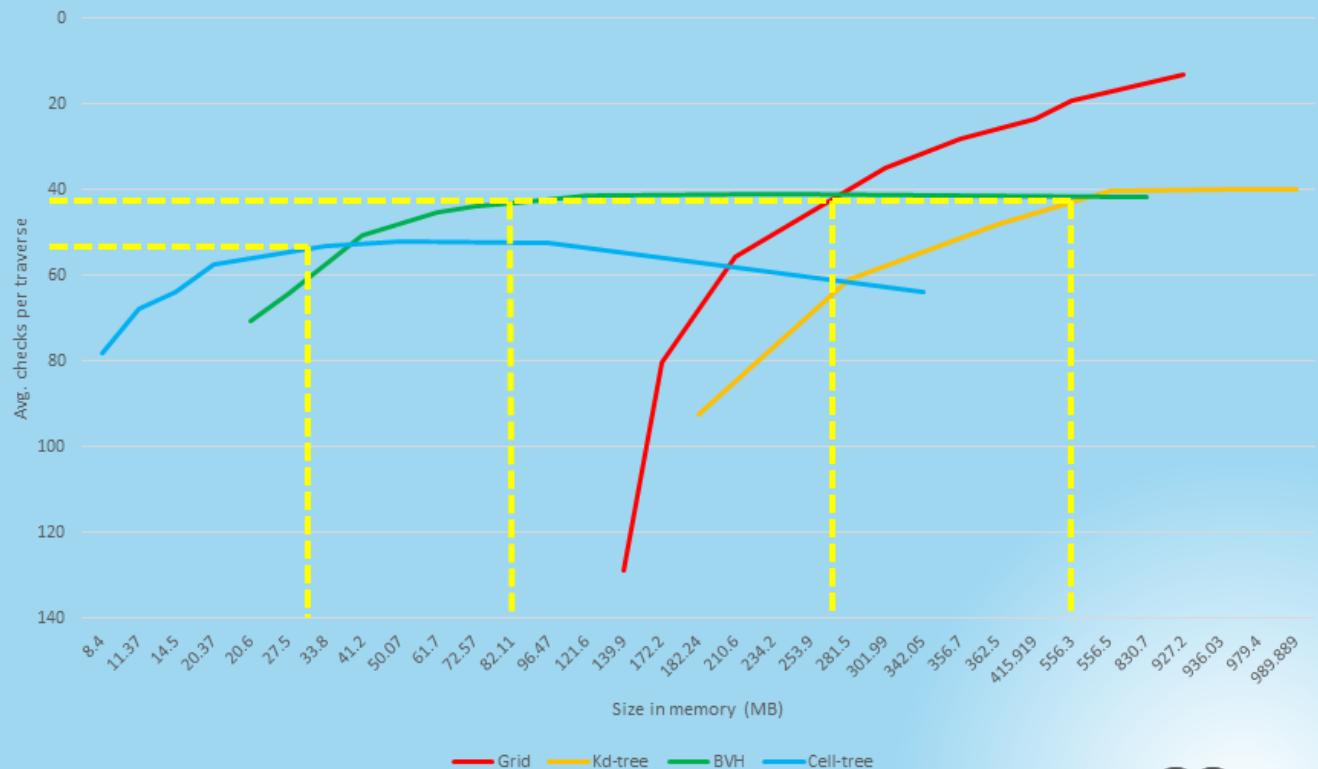
- Measured parameters:
  - **Avg. checks per traverse:** Average number of bounding box or point-inside-cell tests done to find the cell surrounding the sample point.
  - **Size in memory:** Size of the constructed acceleration structured in memory.

# Wind Tunnel ( $\sim 2.5$ M Tets, $\sim 133$ MB)



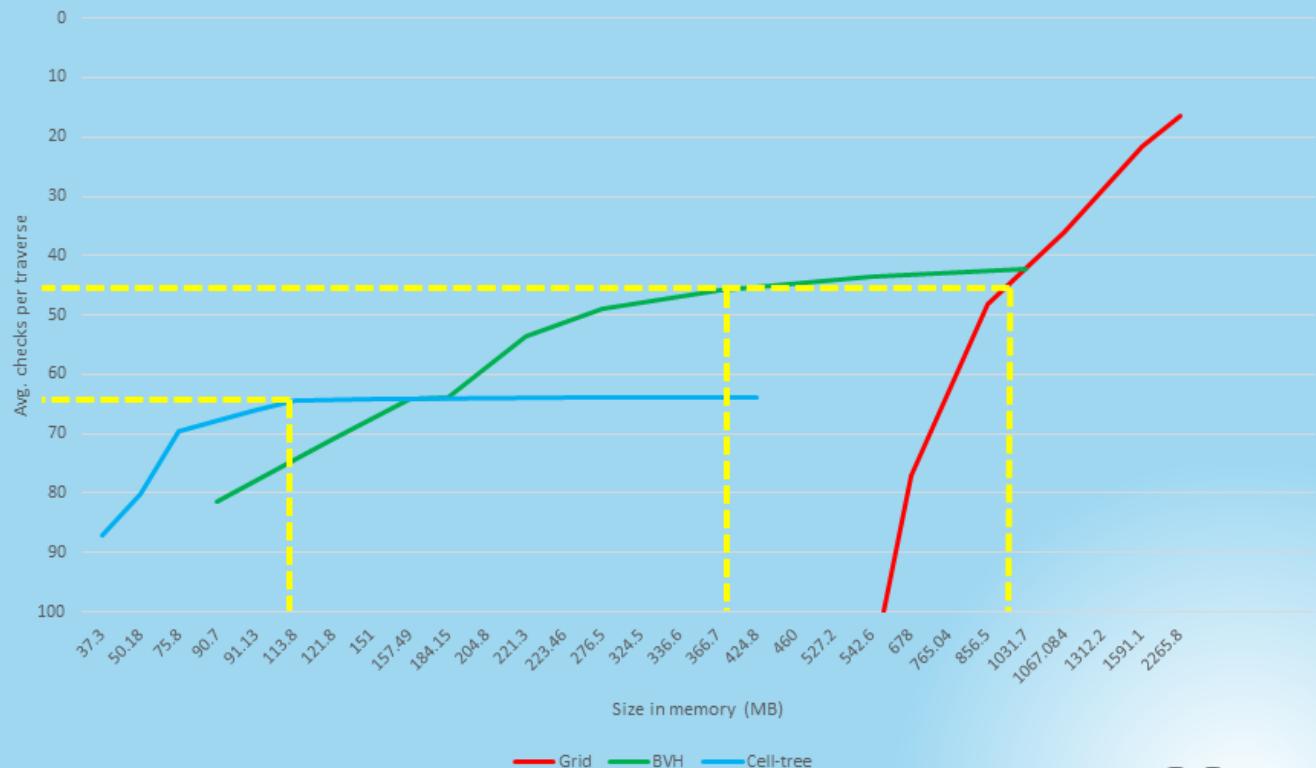
Real-time stream surface computation – April 2016  
Seyedmorteza Mostajabodaveh

# Wind Tunnel (~12.5 M Tets, ~800 MB)



Real-time stream surface computation – April 2016  
Seyedmorteza Mostajabodaveh

# Wind Tunnel (~54.1 M Tets, ~4.1 GB)



Real-time stream surface computation – April 2016  
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# Acceleration Structures Evaluation Conclusion



- When memory is the bottleneck *Cell tree* is suitable (Cell tree size in memory is around 4-6 percent of original dataset).
- Highest performance is achieved using *Grid* (Grid performance is higher than BVH and cell tree when its size is higher than 25 percent of original dataset).
- BVH seems like a balance between memory and performance (BVH size in memory in its highest performance is around 9-11 percent of original dataset).

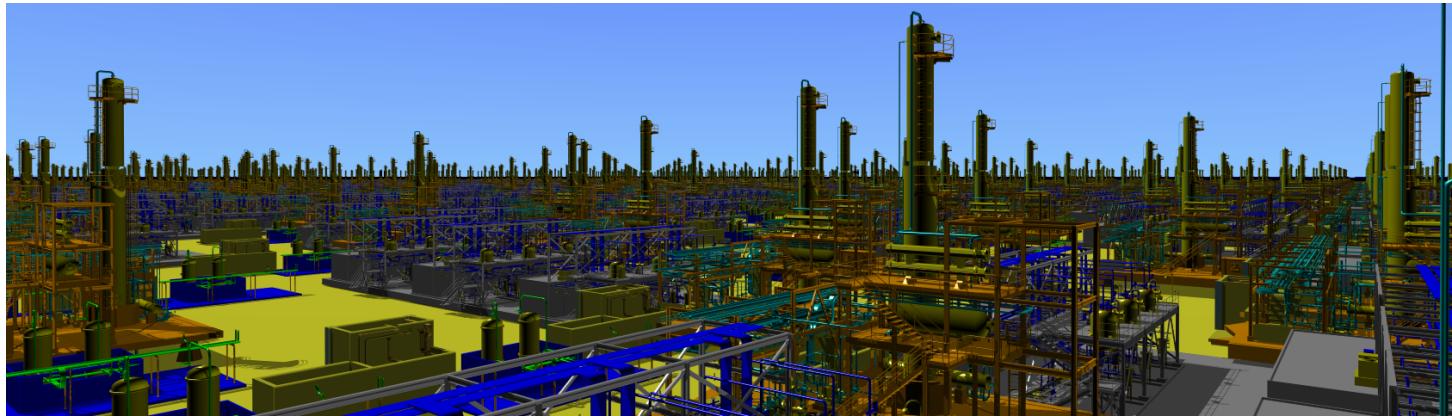
# More Information

- More information can be found in original thesis slides and document (sent separately).
- Available Result Videos:
  - Stream Surface in Wind Tunnel dataset:  
<https://www.youtube.com/watch?v=DmGjogQDpyE>
  - Stream Surface in TetrahedraDecal Dataset:  
<https://www.youtube.com/watch?v=rdoRs-VpGhw>
  - Streamlines in Telescope Dataset:  
<https://www.youtube.com/watch?v=mln05oIApY0>

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# Ray Tracing Revisited for Rendering CSG Models Consisting of Higher Order Primitives



**Figure 5:** A complex CAD scene built out of 8,000 individual plant models. In total, the scene consists of more than 100,000,000 non-planar second-order (cylinders, cones, etc.) and forth-order (tori) primitives, ray traced at more than 10 frames per second on 16 CPU cores, including pixel-accurate shadows.

- **On-the-fly compositing.**

- Boolean set operations are performed on a per-ray basis immediately during rendering.
  - No Preprocessing.

- **Low storage requirement.**

- small set of parameters for each primitive.
  - No prior triangulation of primitives. – Holding scenes in memory would be possible without triangulation.

- **Pixel-accurate higher order surfaces.**

- Ray-primitive intersection can be tested directly. – Usually a quadratic equation which is easy to solve (tori has a quartic equation).
  - No discretization artifacts are visible.
  - Surfaces appear perfectly smooth.

# Main Contributions

- a method to apply CSG operations in real-time during ray tracing while keeping the memory overhead low.
- Evaluation of the proposed method in comparison to other well-known rasterization-based real-time CSG model rendering techniques((Goldfeather et al., 1986), and (Stewart et al., 2002)).

# Contribution: Optimized Hitpoint Calculation

```
ray: current ray hitting a primitive
if entering primitive then
| delta := +1;
else
| delta := -1;
end
if positive primitive hit then
| ray.posDepth += delta;
else
| ray.negDepth += delta;
end
if (ray.posDepth > 0) && (ray.negDepth <= 0) then
| ReportHit(); // final hit in layer found
else
| ContinueRay(ray); // still inside a negative medium
end
```

**Algorithm 2:** RayTraceLayer(*ray*)

# Supported Higher Order Primitives



Pyramid



Box



Circular torus



Rectangular torus



Spherical dish



Elliptical dish



Snout



Cylinder



Sphere

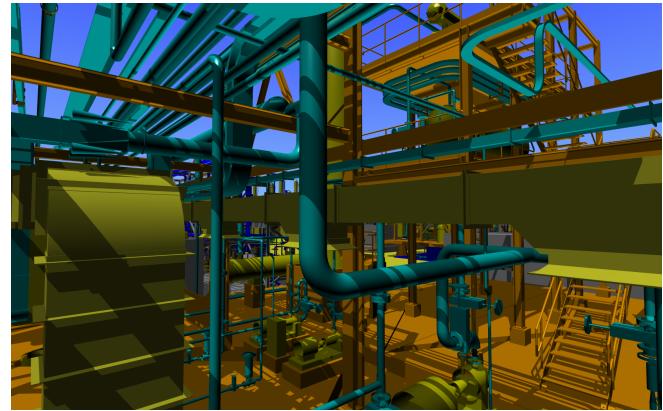
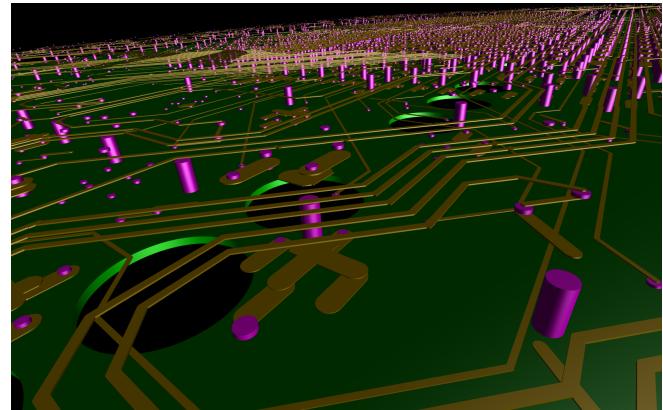
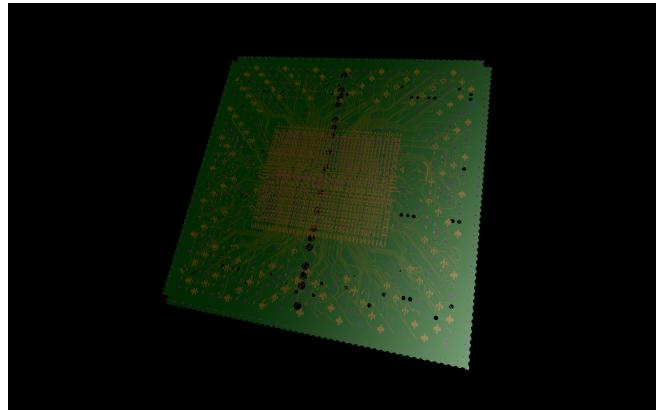


Plane



Triangulated mesh

# More Results



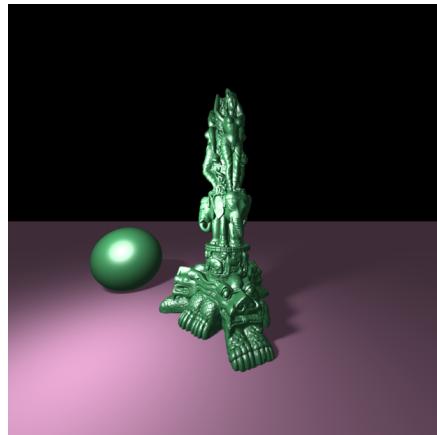
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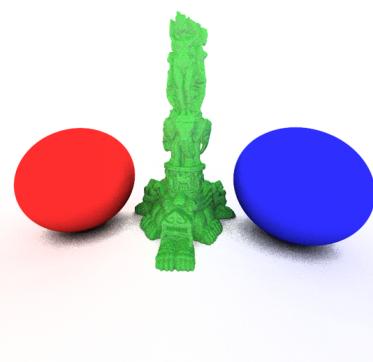
# Analysis of Voxel-Based Ray Tracing

- **Goal:** Instrumenting voxel-based path-tracer with SIMD simulator to measure ray-sorting algorithms impact on SIMD units' efficiency.
- **Main Contribution:** Measure the impact of improving coherency methods (ray sorting) on instruction coherency of the rays.

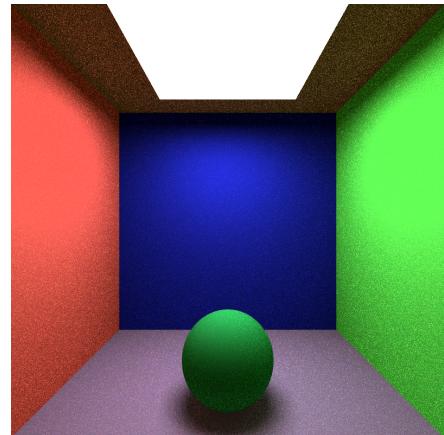
# Basis for Evaluations: Implementing a Voxel-Based Path-Tracer



(e) Soft Shadow with Area Light



(f) Global Illumination with Path Tracing



(g) Cornell Box

All scenes are described with a hierarchy of 3d voxels.

# BVH Traversal Main Operations Classification (1/2)

- **Push and Traverse** Ray is intersecting with both child nodes. One should be chosen and the other one should be kept in the stack.
- **Traverse** Ray is intersecting with one of the child nodes. The traversal path is clear.
- **Leaf Node Intersection** Intersection test should be done for leaf nodes.
- **Finished** Traversal is done.

# BVH Traversal Main Operations Classification (2/2)

```
while Finished ≠ true do
    if CurrNode is InteriorNode then
        if intersection with both childs then
            NextNode ← leftchild
            s.Push(RightChild)                                Push and Traverse
        else
            if intersection with one child then
                | NextNode ← IntersectedChild
            else
                | if not s.empty() then
                    | | NextNode ← s.Pop()
                else
                    | | Finished ← true
                end
            end
        end
    end
else
    Intersect with voxels related to the leafnode to find the
    intersection.                                         Leaf Node Intersection
    if found or s.empty() then
        | Finished ← true
    else
        | NextNode ← s.Pop()
    end
end
end
```

# Our SIMD Simulator

Reset all ray's *InstCounter* elements to zero.

*CurrStage*  $\leftarrow 0$

**while** *Finished*  $\neq$  true **do**

**if** All rays has done their first *CurrStage* operations **then**

*CurrStage* $\text{++}$

        Continue

**end**

*CurrOp*  $\leftarrow$  *FindNextOperationToExecute*(*CurrStage*)

*ExecuteSIMDUnitsWithNextOperation*(*CurrOp*)

**if** Any of SIMD Units are done **then**

        | deactivate the SIMD operation unit.

**end**

**end**

# Example of SIMD Simulation (Instruction Coherency)

Ray 0: T, P&T, T, IL, T, Done

Ray 1: T, T, T, Done

Ray 2: T, T, Done

Ray 3: T, P&T, T, IL, T, Done

T: Traverse

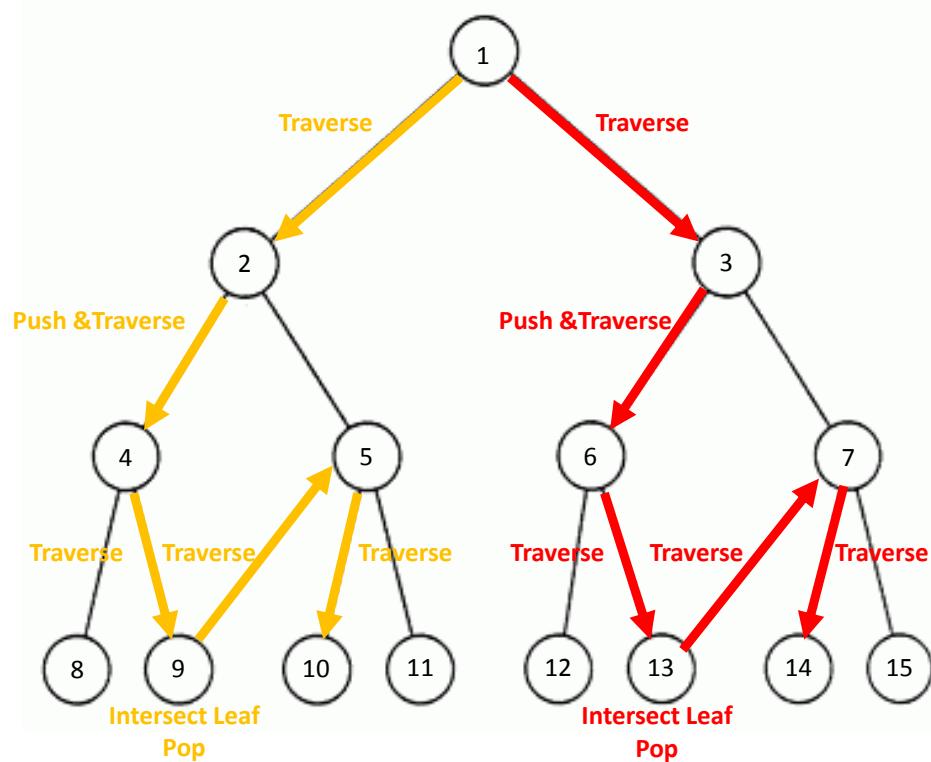
P&T: Push & Traverse

IL: Intersect Leaf

	Oper 0	Oper 1	Oper 2	Oper 3	Oper 4	Oper 5
Ray 0 ➔	OpUnit 0	T	P&T	T	IL	T
Ray 1 ➔	OpUnit 1	T		T		T
Ray 2 ➔	OpUnit 2	T		T		
Ray 3 ➔	OpUnit 3	T	P&T	T	IL	T
Coherency	100%	50%	100%	50%	75%	100%

Figure 6: An example of traversing the BVH-tree for 4 different rays on SIMD of width four.

# Instruction Coherency Vs. Data Coherency



Instruction Coherency			Data Coherency		
Ray1	Ray2	Coherency	Ray1	Ray2	Coherency
T	T	100%	1	1	100%
T	T	100%	2		50%
P&T	P&T	100%		3	50%
T	T	100%	4		50%
IL & Pop	IL & Pop	100%		6	50%
T	T	100%	9		50%
T	T	100%		13	50%
D	D	100%	5		50%
				7	50%
			10		50%
				14	50%

T: Traverse  
P&T: Push & Traverse  
IL & Pop: Intersect Leaf & Pop  
D: Done

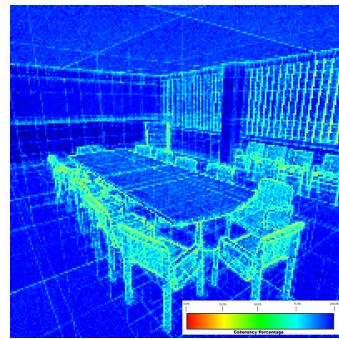
Figure 7: While both rays are perfectly instruction execution coherent, they are incoherent in data access.

# Contribution: Coherency Measurements Results for Path-Tracing "Conference Room" (1/2)

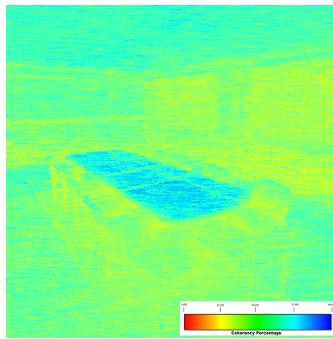
Case	Primary Rays	Bounce 1	Bounce 2
No Ray Sorting	79.14%	49.53%	45.63%
Ray Sorting by Direction	79.14%	49.70%	48.3%
Ray Sorting by Position	79.14%	46.68%	45.81%
Ray Sorting by Both	79.14%	49.73%	48.6%

Table 1: Total Ray Coherency For Different Bounces of Rays (SIMD width = 16) - Conference Room

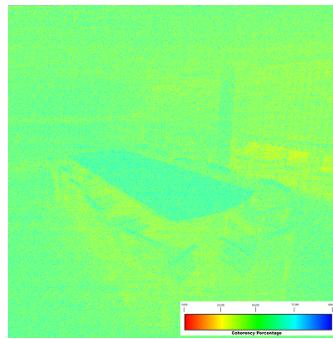
# Contribution: Coherency Measurements Results for Path-Tracing "Conference Room" (2/2)



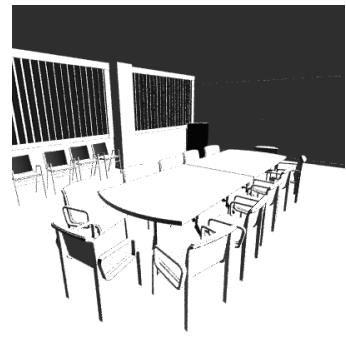
(a) Primary



(b) Bounce 1



(c) Bounce 2



(d) Result

**Figure 8:** Coherency textures for the case which rays are sorted based on their direction and orientation on every bounce (SIMD width = 16). Colormap used for visualizing coherency is shown in the bottom-right corner of the figures. The range is from 0-100 percent (red-blue).

## Similar Papers

- (Barringer and Akenine-Möller, 2014), and (Chajdas and Westermann, 2014)
- They also show that while ray sorting algorithms improve ray tracing performance, they are not very effective, i.e. hopefully new approaches can be devised to make voxel-based ray tracing even faster.

# Outline

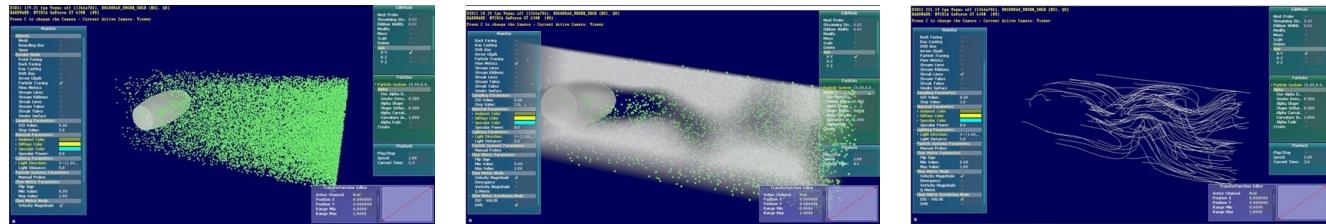
- 1 Introduction
- 2 Master Thesis: Real-Time Stream Surface Computation and Rendering
- 3 Ray Tracing Revisited for Rendering CSG Models Consisting of Higher Order Primitives
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- 5 Other Projects
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- 7 Dynamic Arc Tessellation

# Practical Courses

- Interactive Visual Data Analysis, Prof. Westermann Group.
- GPU Programming in Computer Vision, Prof. Cremers Group.
- Guided Research: Voxel-Based Path tracing, Prof. Westermann Group.
- Interdisciplinary Project: 3D-Visualization of electromagnetic field strength distribution, Prof. Guenthner (Fördertechnik Materialfluss Logistik group in TU-Munich).

# Interactive Visual Data Analysis

- Fundamental knowledge in the field of scientific visualization:
  - Volume Visualization
  - Flow Visualization
  - GPGPU Programming
  - Done with C++, D3D11, and HLSL.
- See results as a video on:  
<https://www.youtube.com/watch?v=7pIw5PjkjmY>



# GPU Programming in Computer Vision

- Implementing *Optical Flow* on GPU



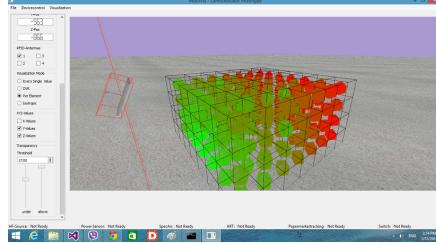
- Implementing *Super Resolution* on GPU



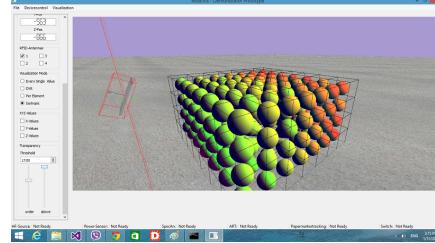
# Interdisciplinary Project: Implementing a Framework for 3D Visualization of Electromagnetic Field Strength Distribution

- Build a model of examined installation in 3d virtual world.
  - fast and intractable (Using tracking system)
- Visualizing 3d bars in virtual world to specify amount of data collected in each area.
- Visualizing collected data using different techniques.
  - Goal: Detecting weak/strong magnetic fields in different parts of environment.
  - Visualizing data using torus and sphere glyphs.
  - Visualizing data using direct volume rendering.

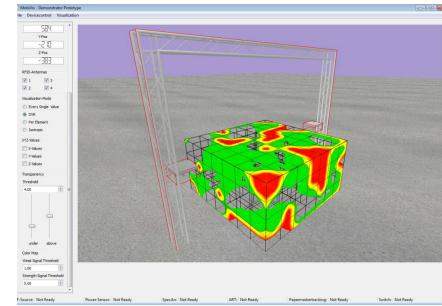
# Interdisciplinary Project: Implementing a Framework for 3D Visualization of Electromagnetic Field Strength Distribution



(i) Torus Glyph



(j) Sphere Glyph



(k) Direct Volume Rendering

Figure 9: Different visualization techniques used in this project (screenshots are not captured in for the same data).

# Related Courses

- Computer Graphics related: Computer Graphics, Image Synthesis, Scientific Visualization, Augmented Reality, Computer Animation and Simulation.
- Parallel Programming related: Parallel Programming, Advanced Computer Architecture.

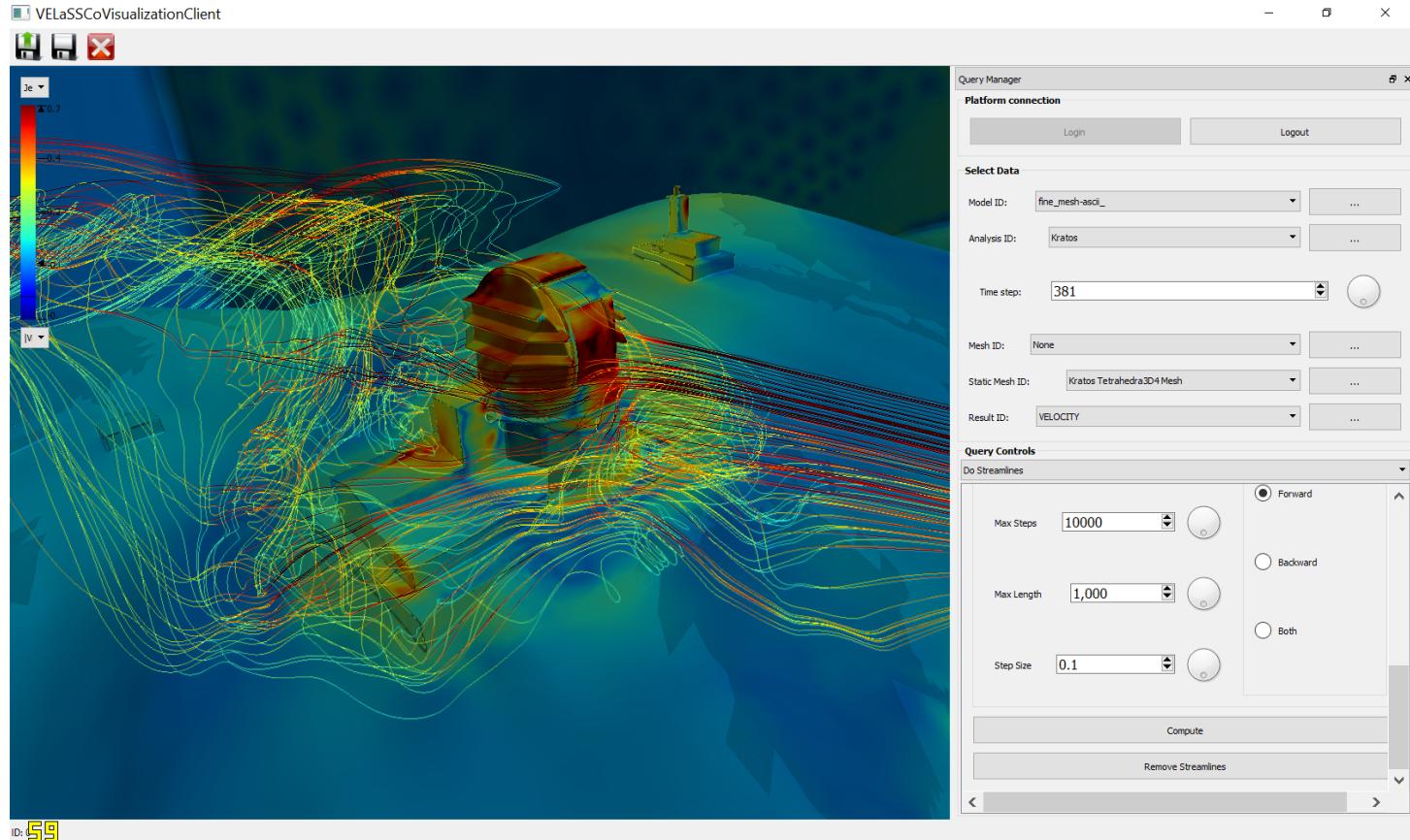
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# VELaSSCo EC Funded Project

- **Idea:** Using big data technologies (Apache's Hadoop in this case) to store and process the simulation data in a distributed manner.
- Post-processing was done on the HPC and the results were sent as triangle mesh for the client.
- My tasks in the project:
  - Fraunhofer IGD's visualization client
  - Data access queries on HPC side
  - Streamline computation post processing technique on the HPC side using map-reduce.
  - Design and implement the data format to be exchanged between HPC and visualization clients.

# VELaSSCo EC Funded Project

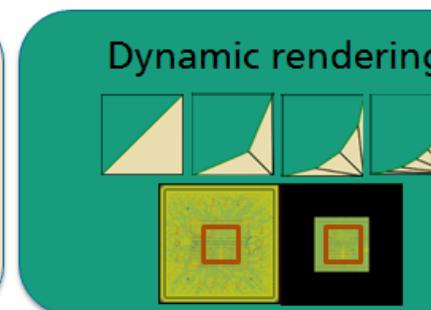
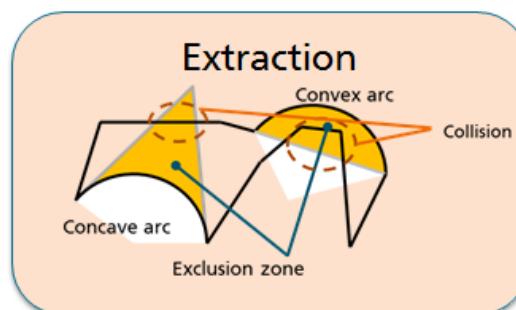
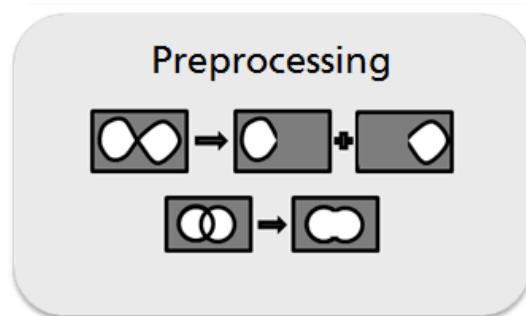


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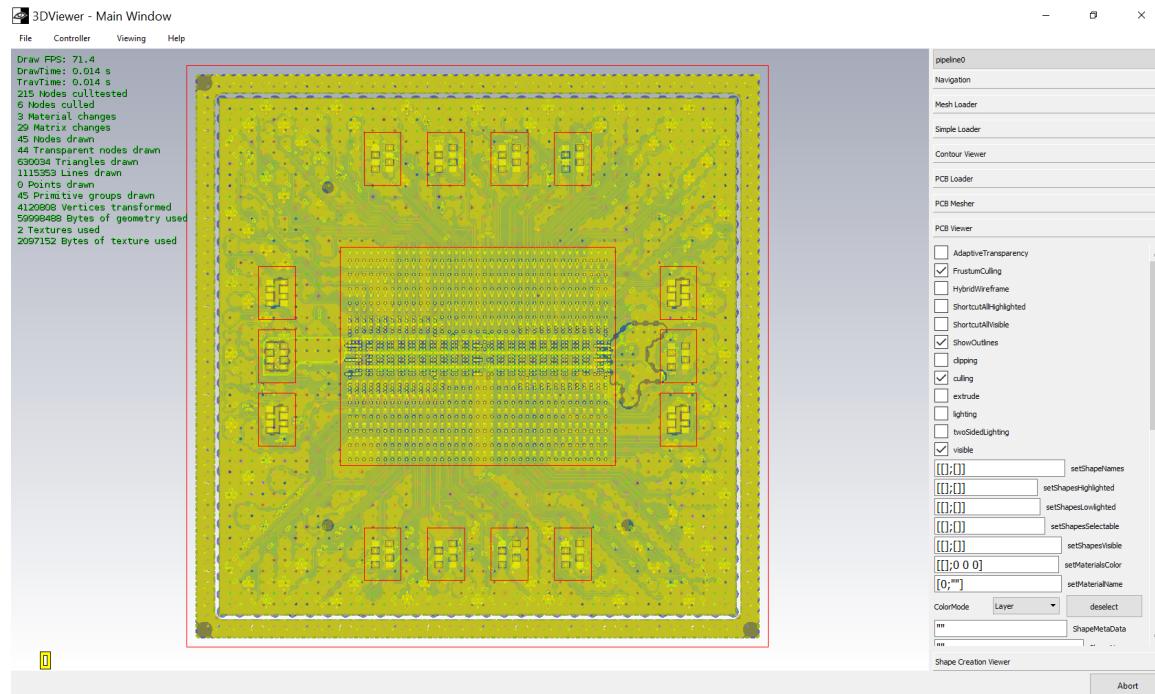
# Dynamic Arc Tessellation

- an industrial project in collaboration with CST AG.
  - Dynamic tessellating arc primitives in real-time on CPU and upload the triangles to the GPU to be rendered.
- Frustum culling and drop culling were used to only tessellated ones that are in the viewport.



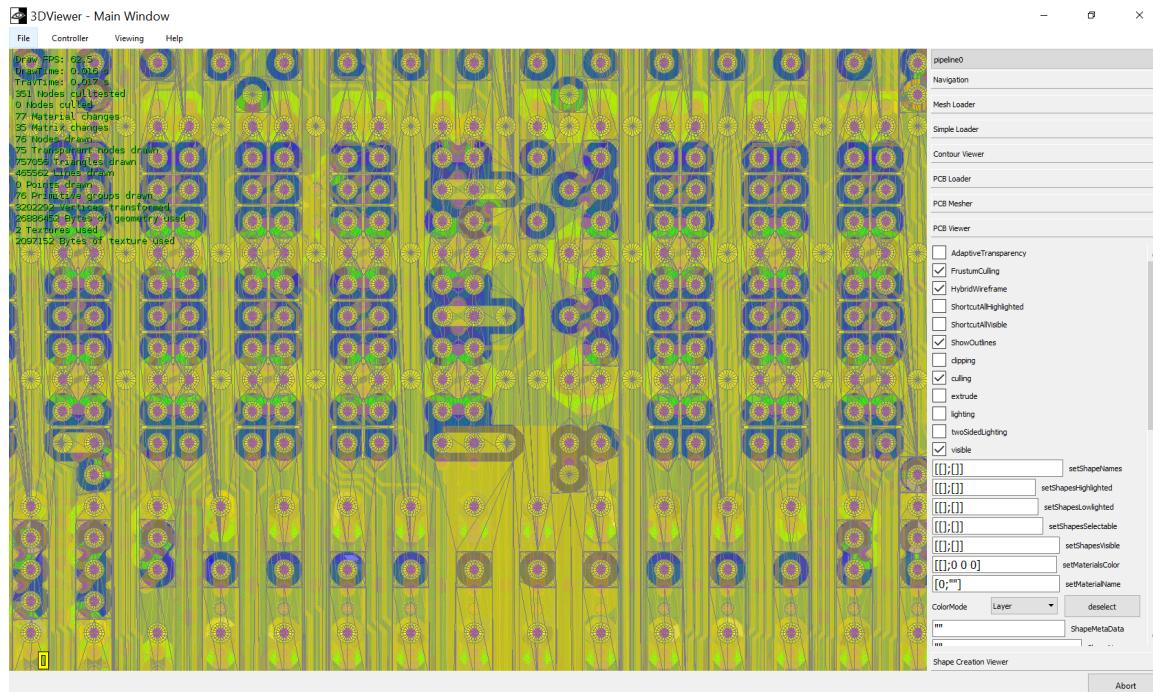
# Dynamic Arc Tessellation

- Approximately 162K dynamic triangles
- Approximately 468K static triangles



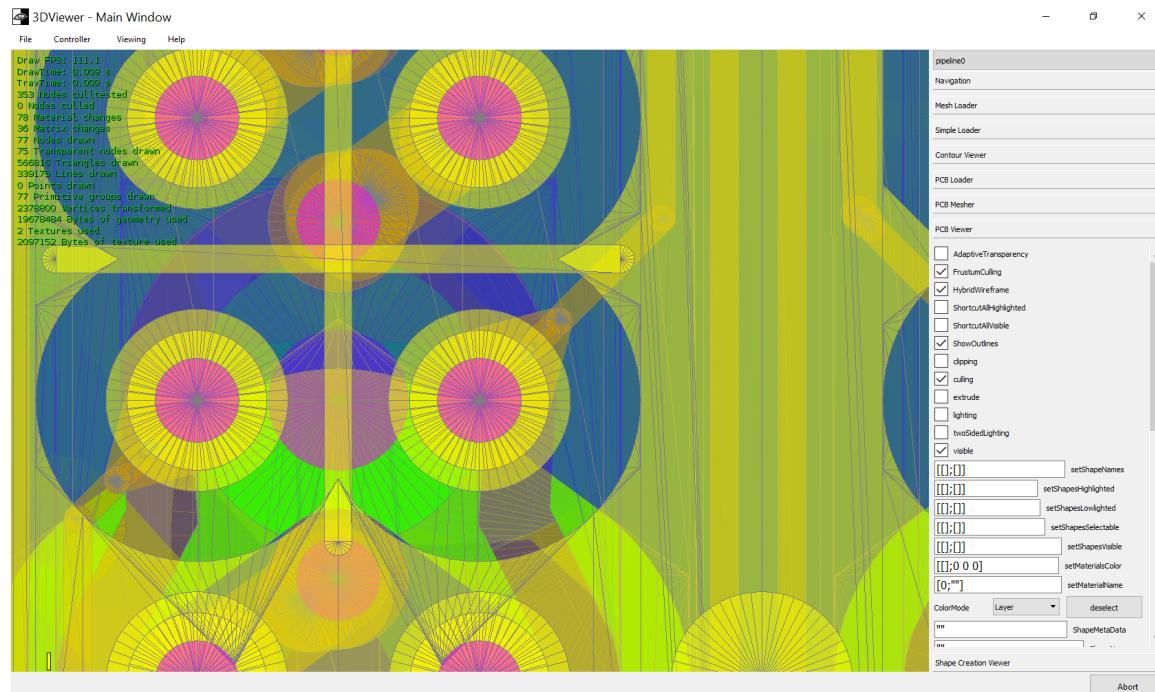
# Dynamic Arc Tessellation

- Approximately 290K dynamic triangles
- Approximately 468K static triangles



# Dynamic Arc Tessellation

- Approximately 98K dynamic triangles
- Approximately 468K static triangles



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