

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 Discussion

About Me...

- My name is **Morteza Mostajab**
- Bachelor studies:
Hamedan University of Technology, Iran
- Maserter studies:
Technische Universität München
- Present:
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



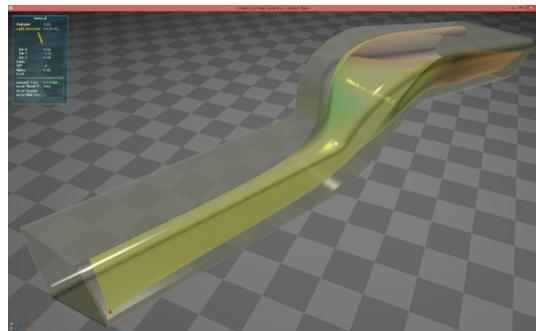
(f) First IBM
(g) First Console
compatiable PC (Atari 2600)



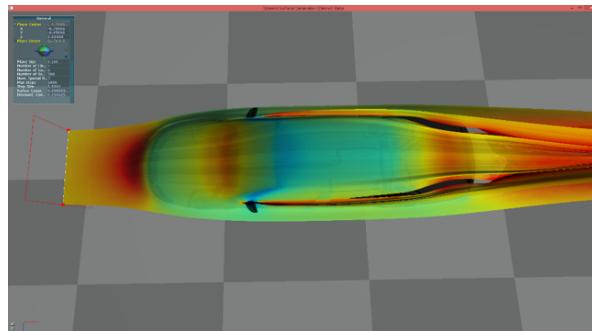
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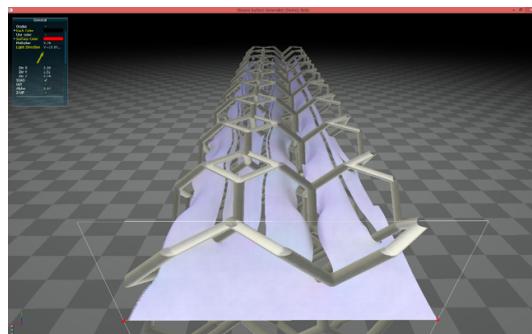
Real-Time Stream Surface Computation and Rendering



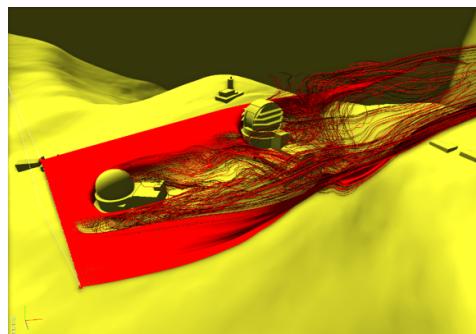
(h) Wind Tunnel



(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

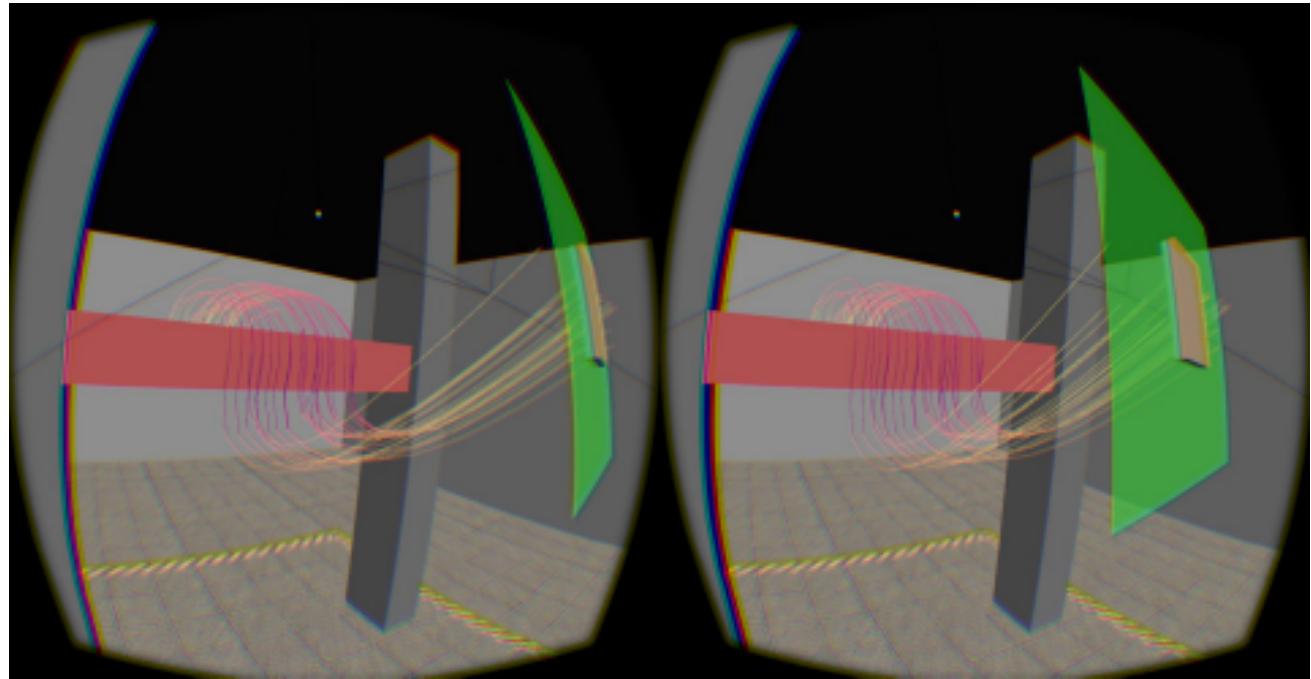


Figure 2: Immersive Streamlines was a prototype demo done at Fraunhofer IGD. The user is able to move inside the virtual world, interact with it, and look closely at the flow visualization results. The image shows a stereo pair, which is displayed on Oculus Rift HMD.

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

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

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 [CCG⁺12]. 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 [BFTW09]. 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 [Sch08].
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 [GJ10].
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 [CCG⁺12]

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

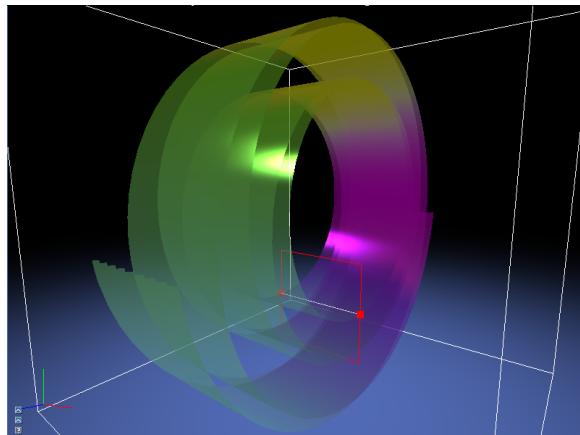
end

end

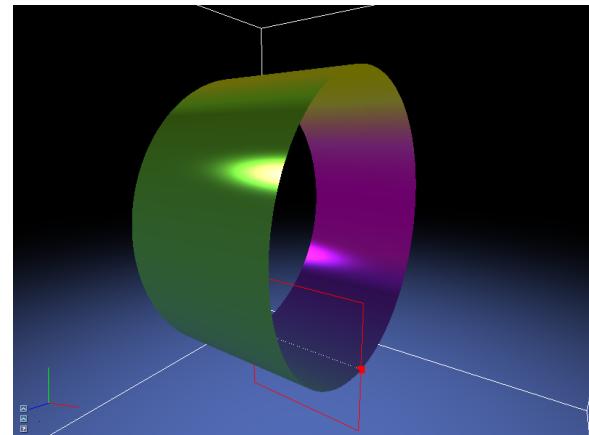
Algorithm 1: Stream Surface Computation Algorithm [CCG⁺12].

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.



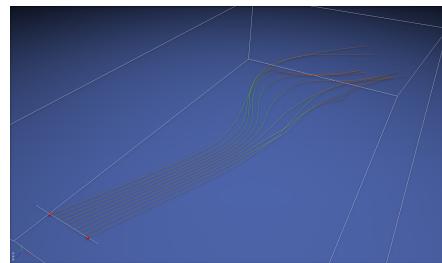
(a) Euler



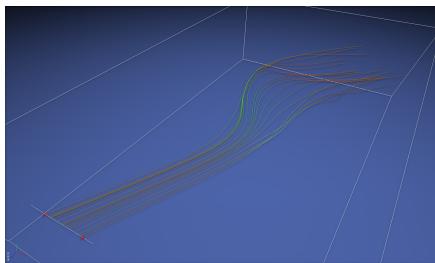
(b) Cash-Karp

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

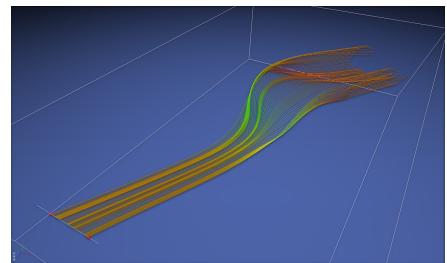
Refinement Strategy Results



(a) No Refinements



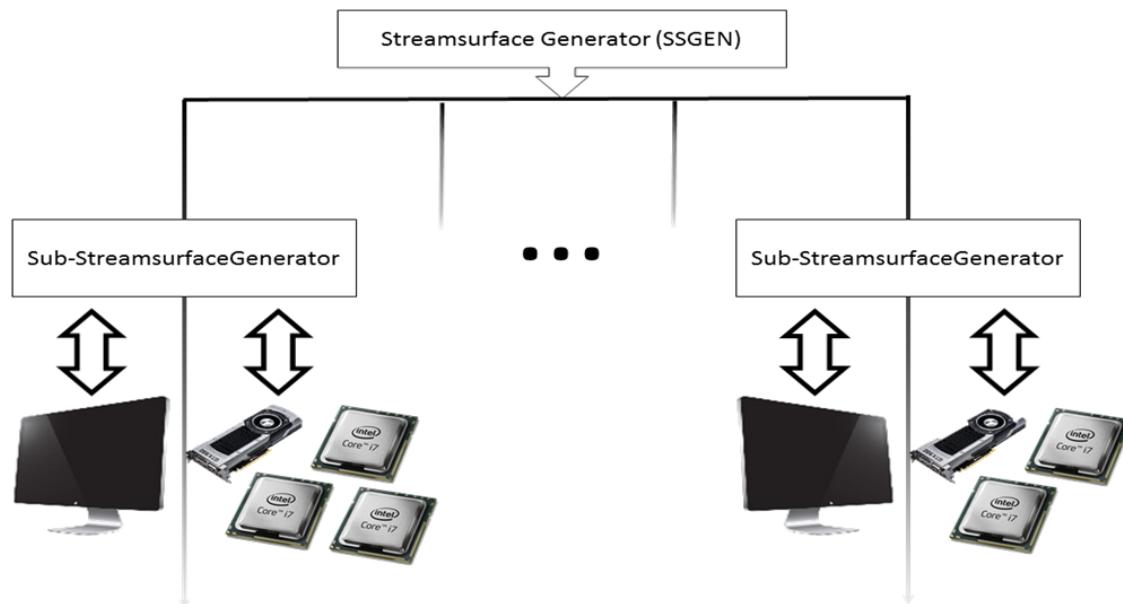
(b) The first refinement it-
eration



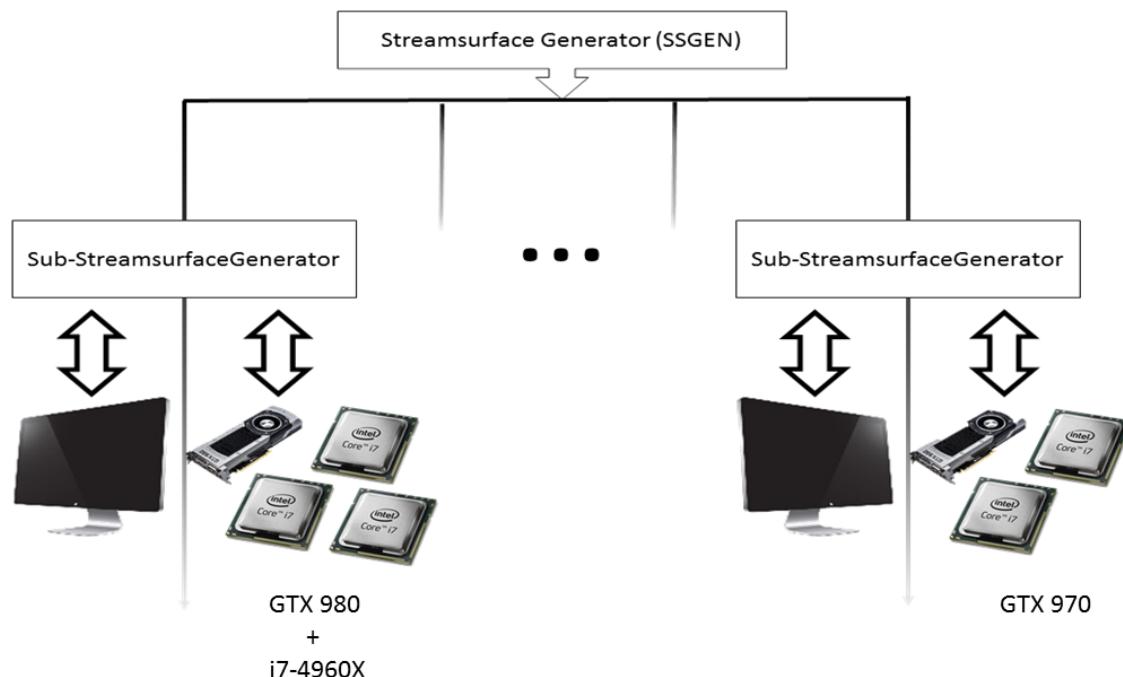
(c) The second refinement
iteration

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

Heterogeneous Computing Model (1/7)



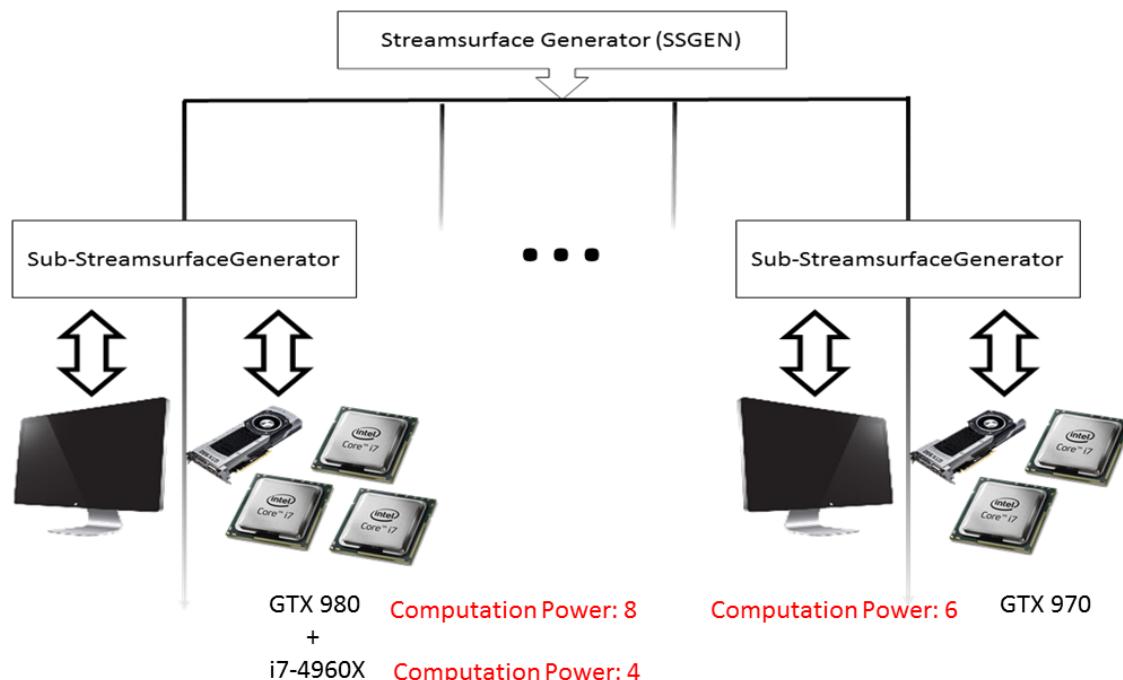
Heterogeneous Computing Model (2/7)



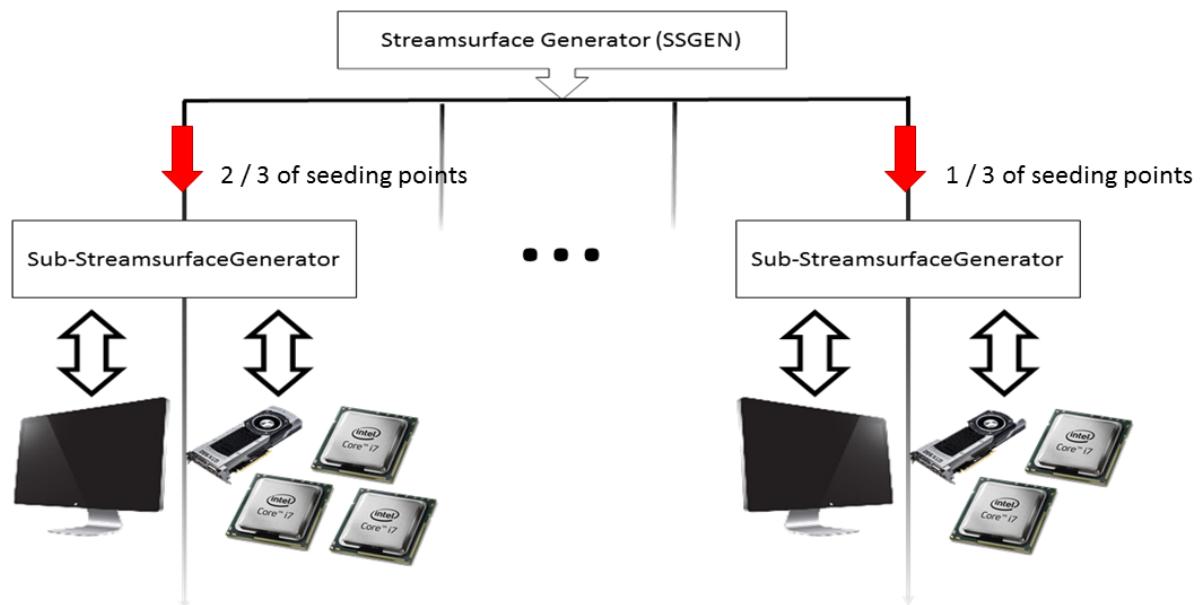
Heterogeneous Computing Model (3/7)

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

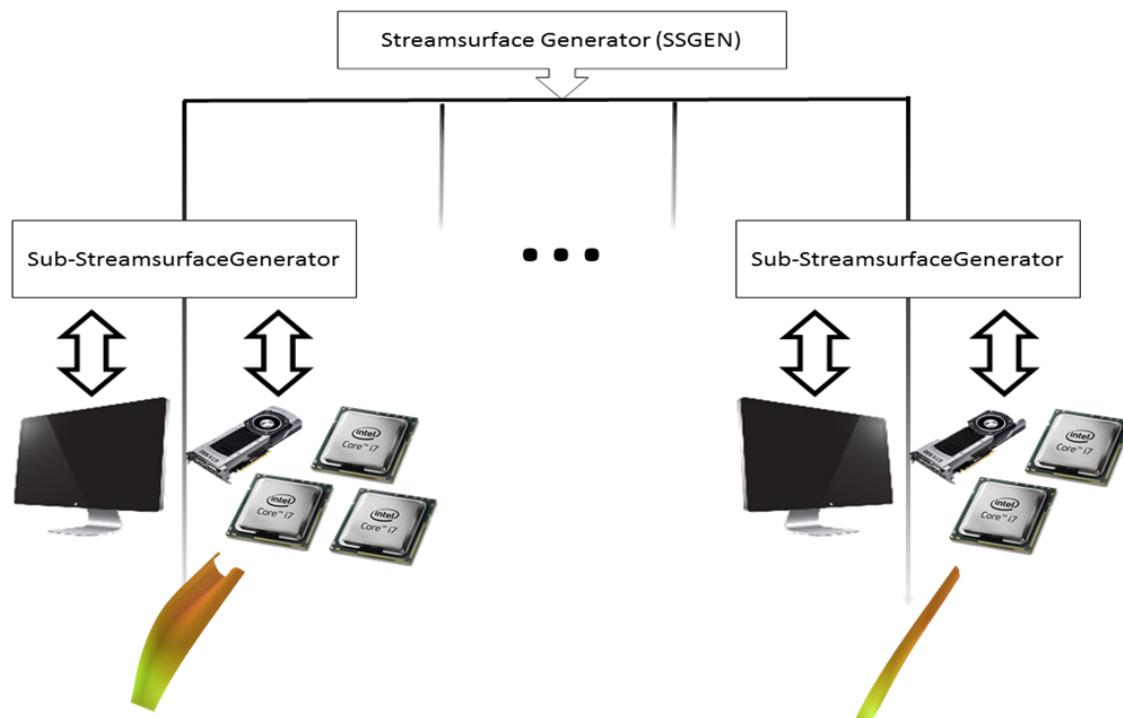
Heterogeneous Computing Model (4/7)



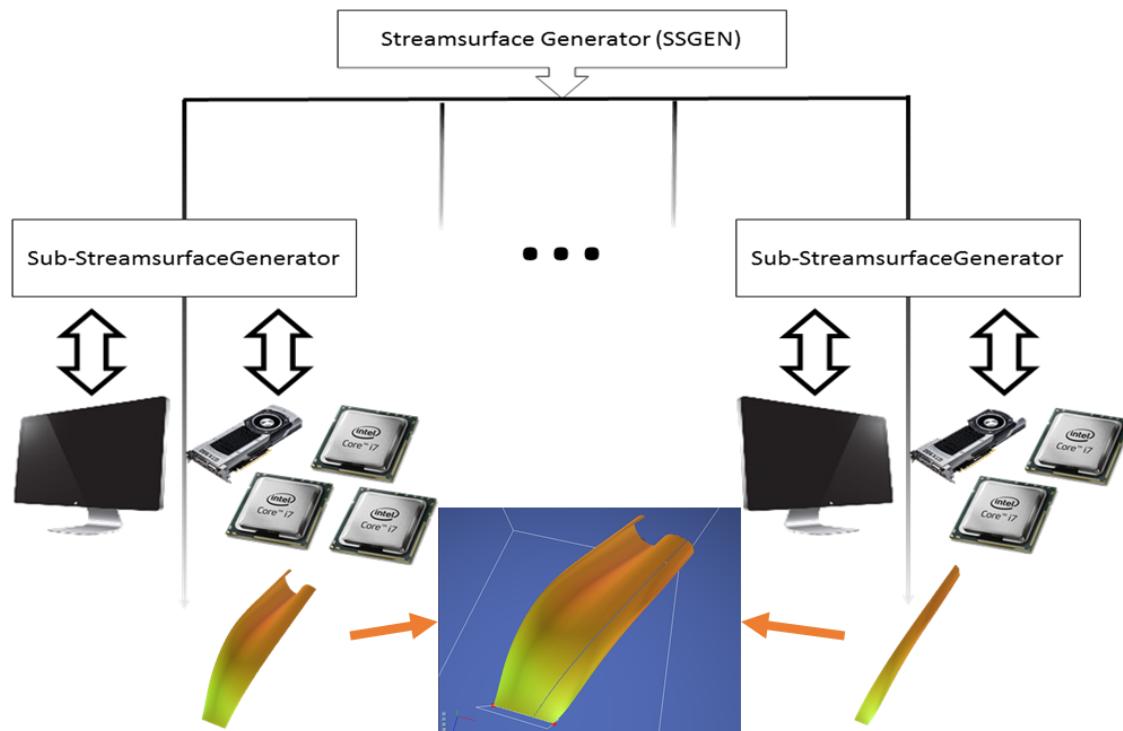
Heterogeneous Computing Model (5/7)



Heterogeneous Computing Model (6/7)

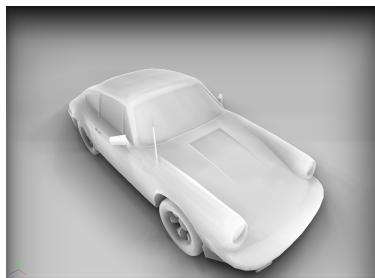


Heterogeneous Computing Model (7/7)



Multi GPU Rendering

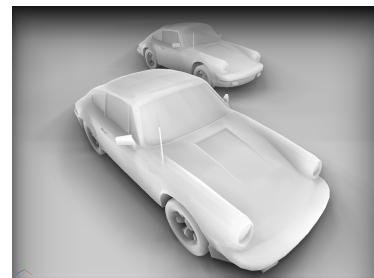
- Compositing screen cspace ambient occlusion results



(a) GPU #0

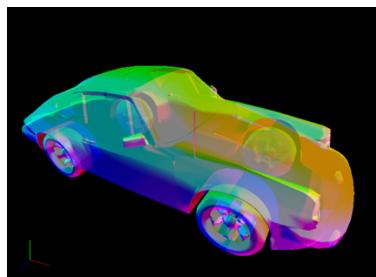


(b) GPU #1

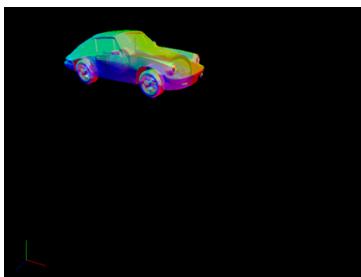


(c) Composed

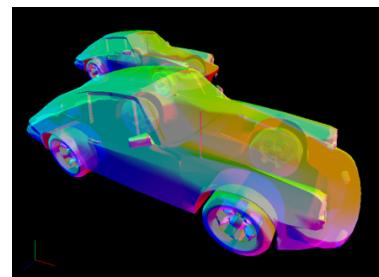
- Compositing order independence transparency results



(d) GPU #0



(e) GPU #1

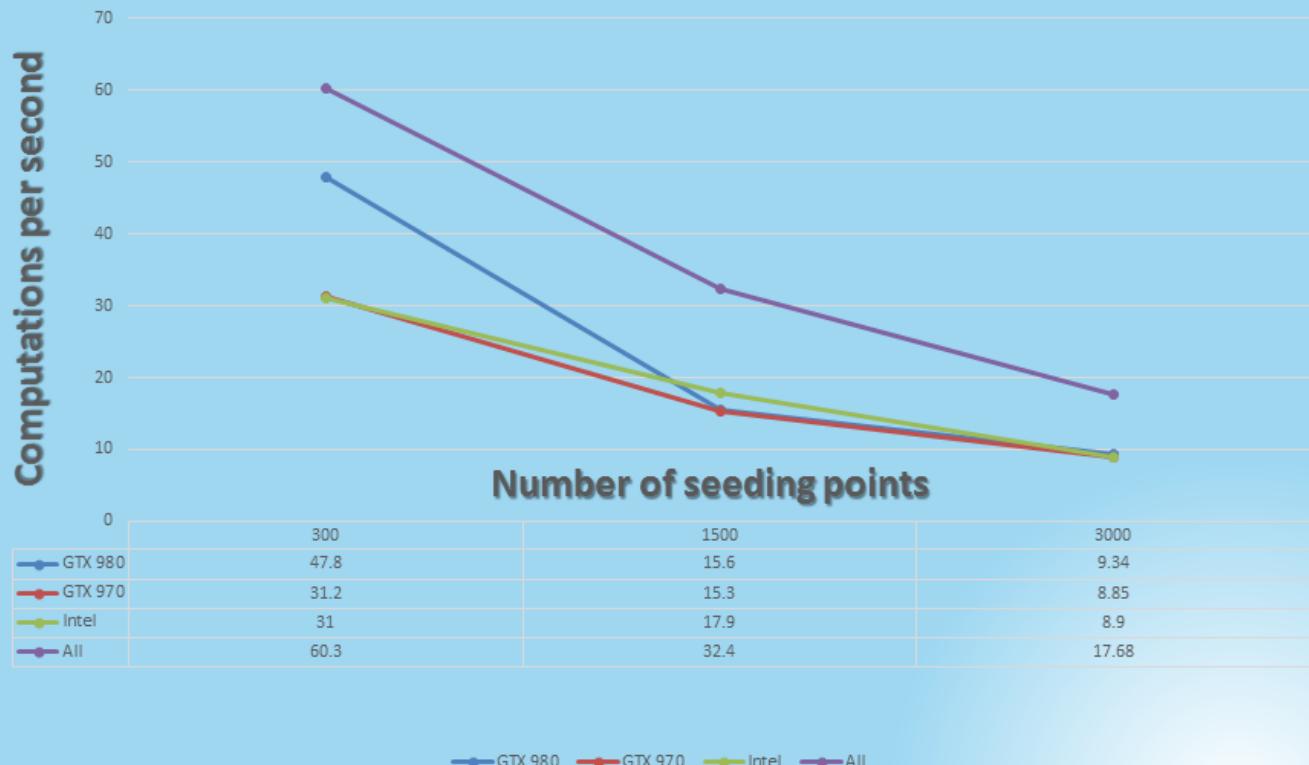


(f) Composed

Heterogeneous Computing Results

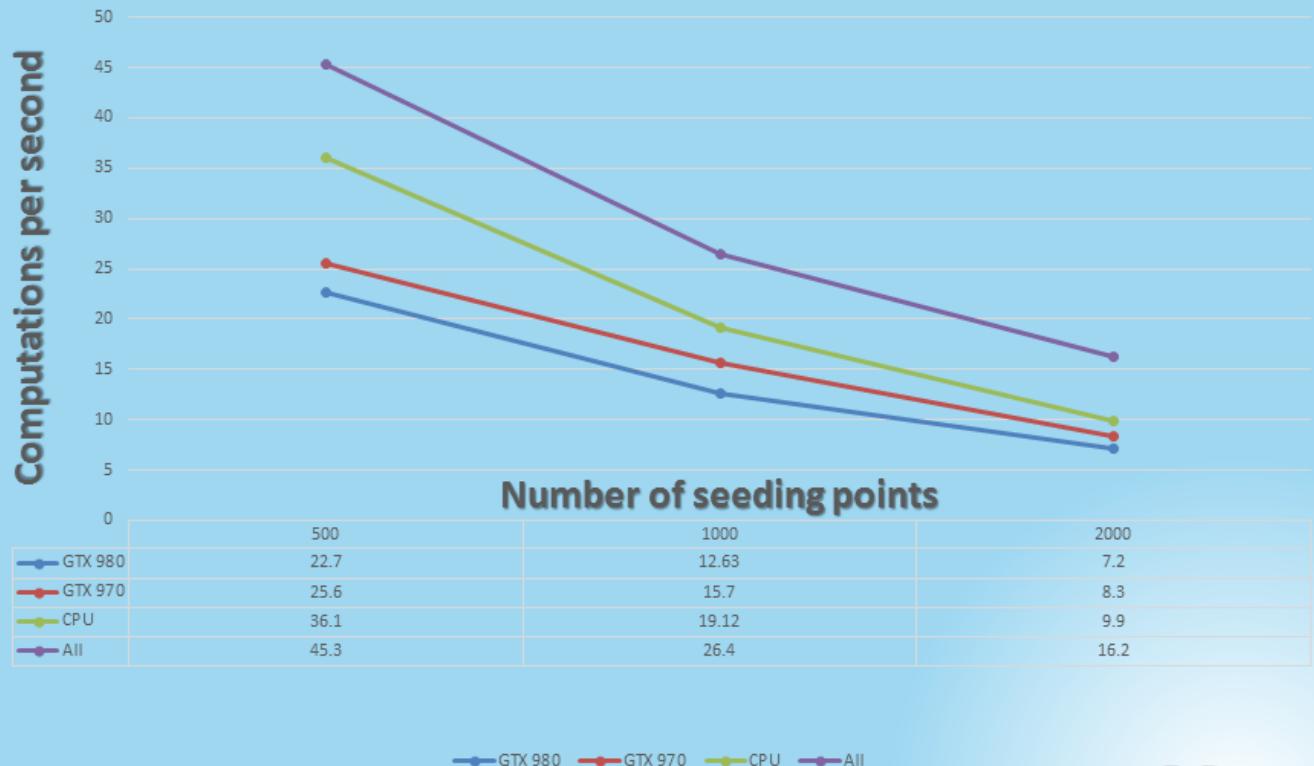
- Measured parameters:
 - **Computations per second:** It shows how many times the stream surface can be computed in every second. The unit is number of computation times per second.
 - **Number of seeding points:** Total number of seeding points for producing the final stream surface.

Wind Tunnel Dataset



Real-time stream surface computation – April 2016
Seyedmorteza Mostajabodaveh

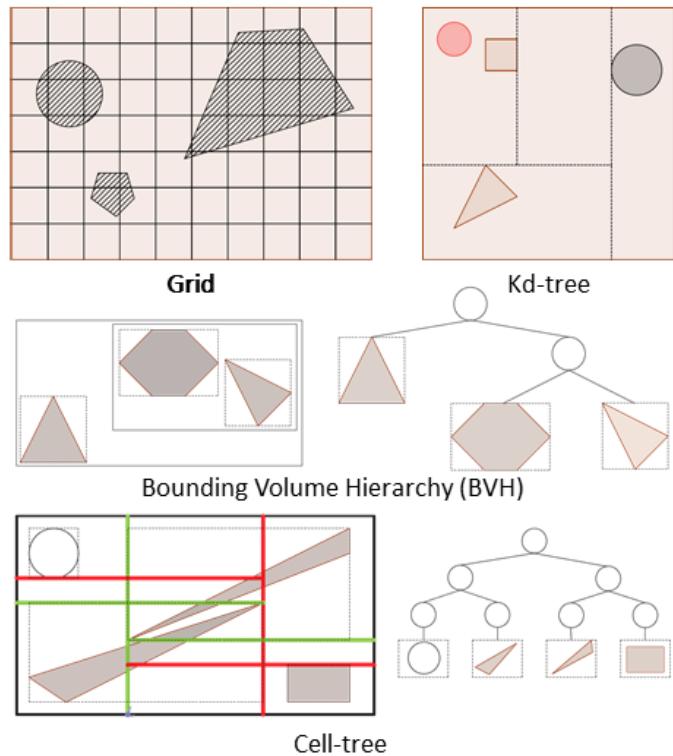
Car Dataset



Real-time stream surface computation – April 2016
Seyedmorteza Mostajabodaveh

Acceleration Structures

- Grid
- Kd-tree
- Bounding Volume Hierarchy (BVH)
- Cell-tree [GJ10]



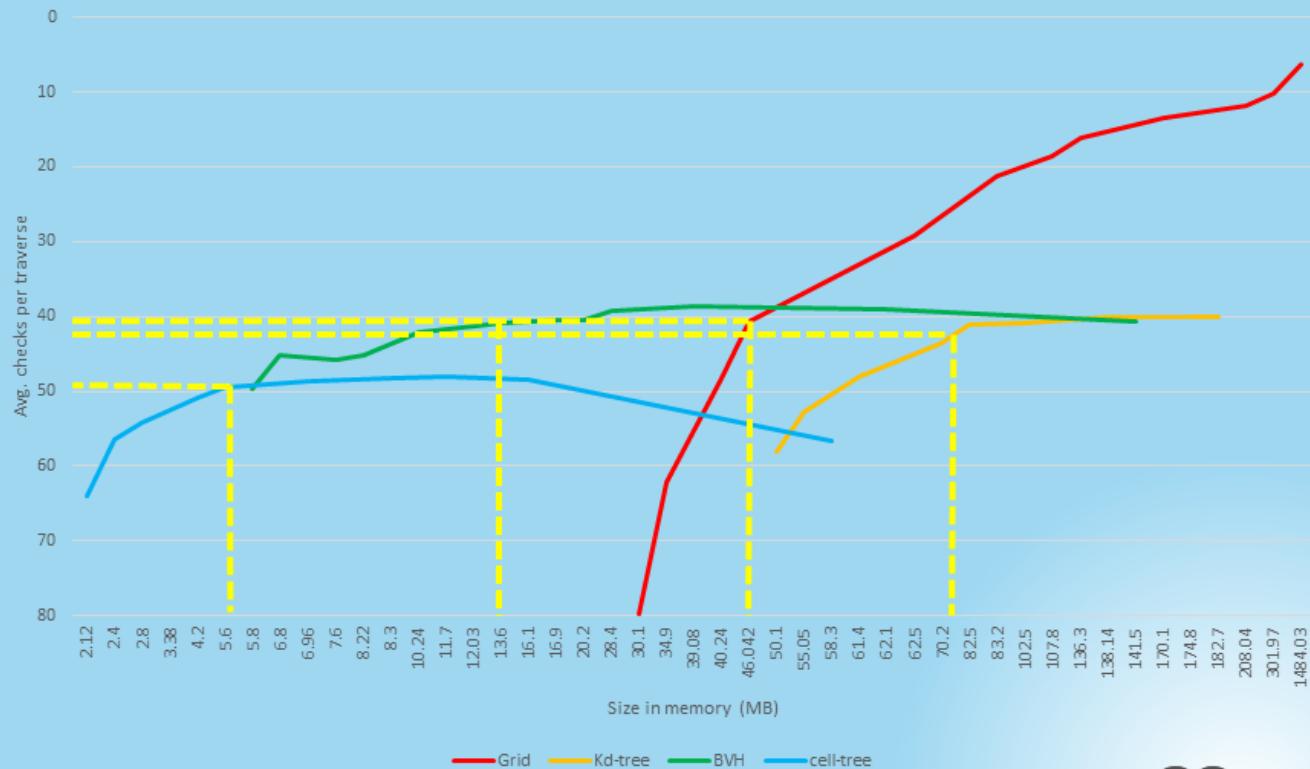
Why Acceleration Structures?

- 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.

Acceleration Structures Evaluation Results

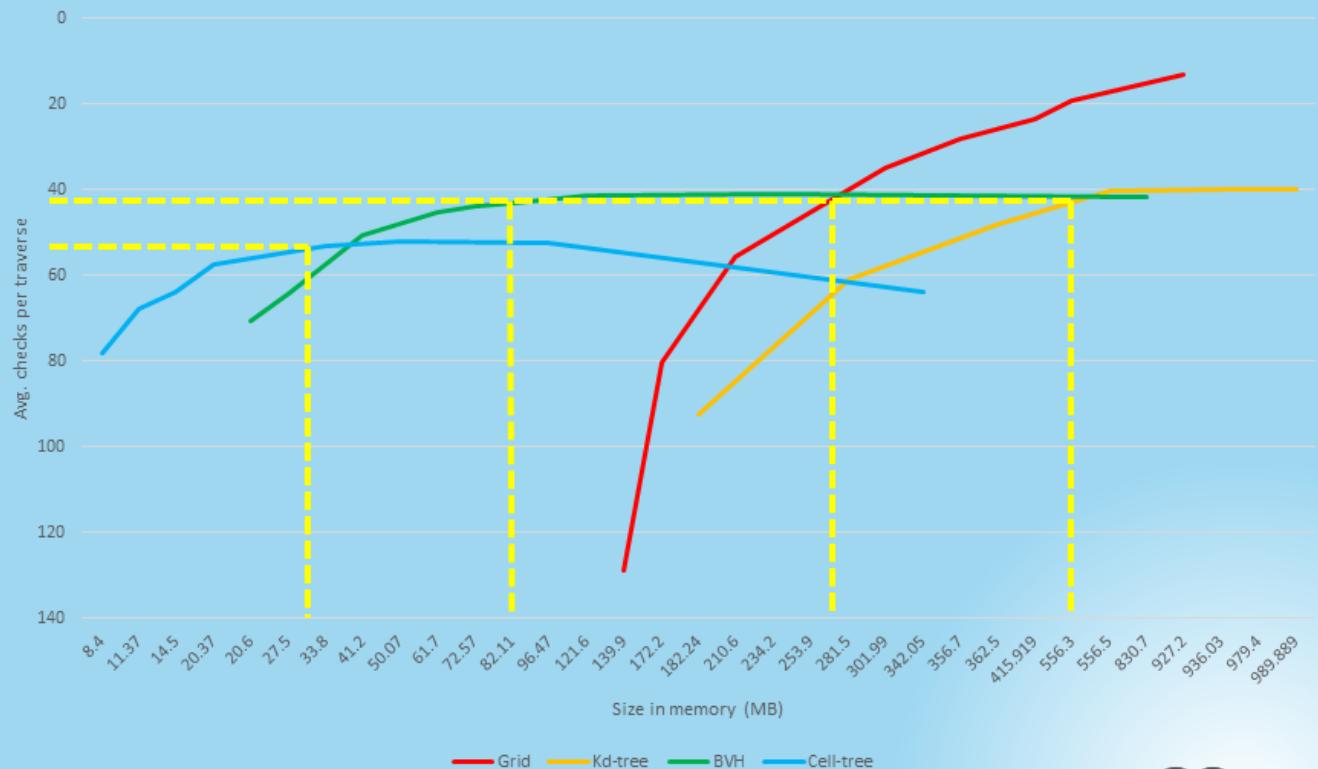
- Measured parameters:
 - **Avg. checks per traverse:** Average number of bounding box or point-inside-cell tests done to find the cell surrounding the sample point.
 - **Size in memory:** Size of the constructed acceleration structured in memory.

Wind Tunnel (~ 2.5 M Tets, ~ 133 MB)



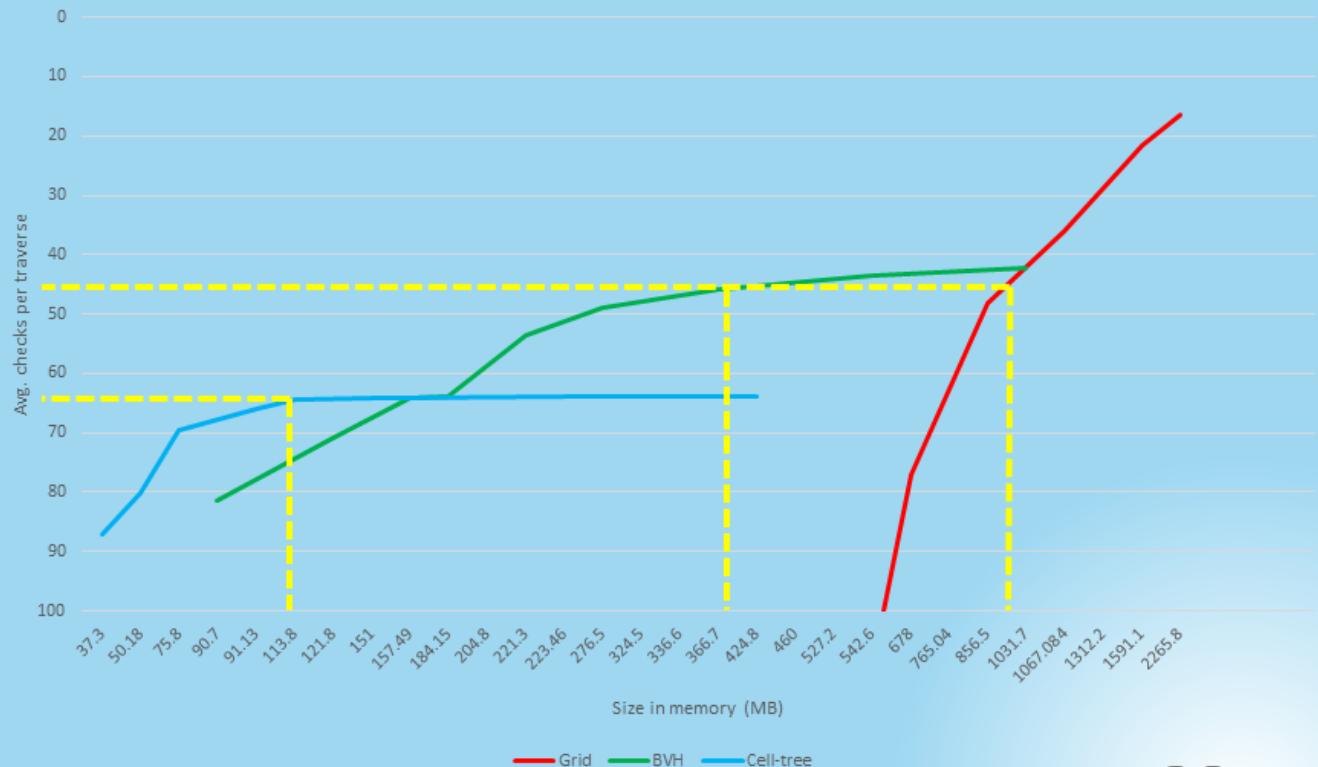
Real-time stream surface computation – April 2016
Seyedmorteza Mostajabodaveh

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
Seyedmorteza Mostajabodaveh

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

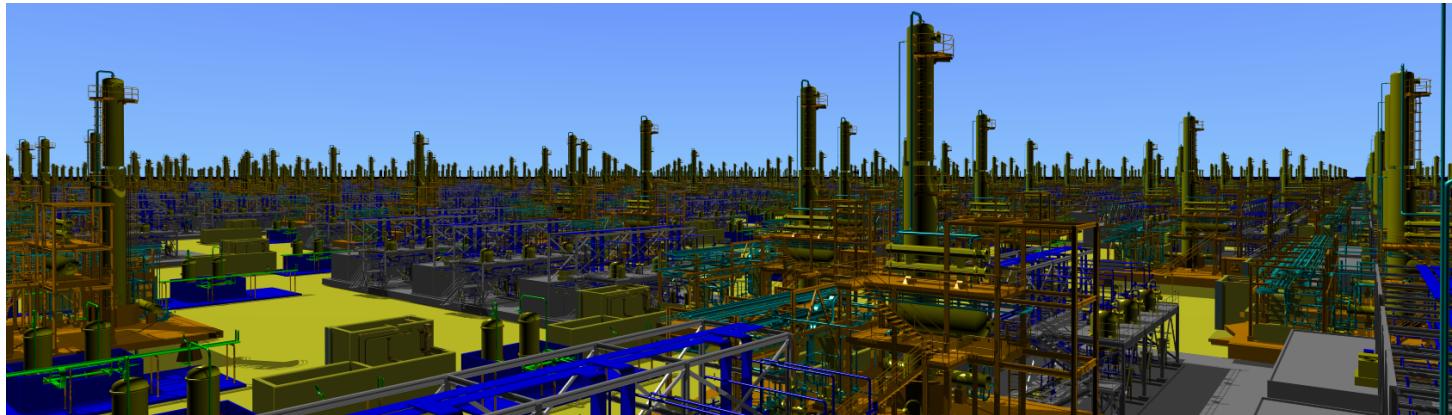


Figure 5: A complex CAD scene built out of 8,000 individual plant models. In total, the scene consists of more than 100,000,000 non-planar second-order (cylinders, cones, etc.) and forth-order (tori) primitives, ray traced at more than 10 frames per second on 16 CPU cores, including pixel-accurate shadows.

Benefits

- **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([GHF86], and [SLJ02]).

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



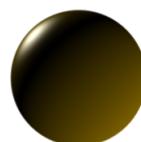
Elliptical dish



Snout



Cylinder



Sphere

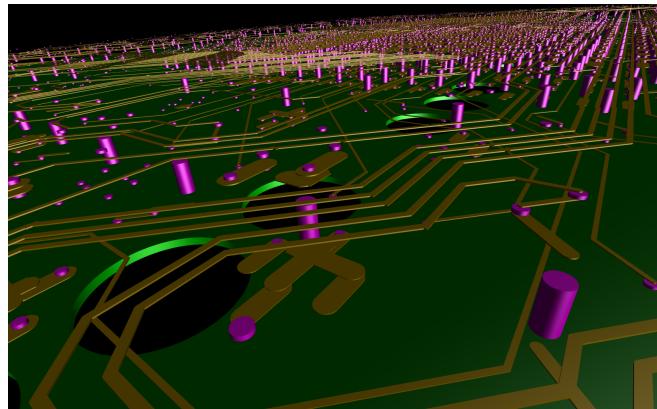
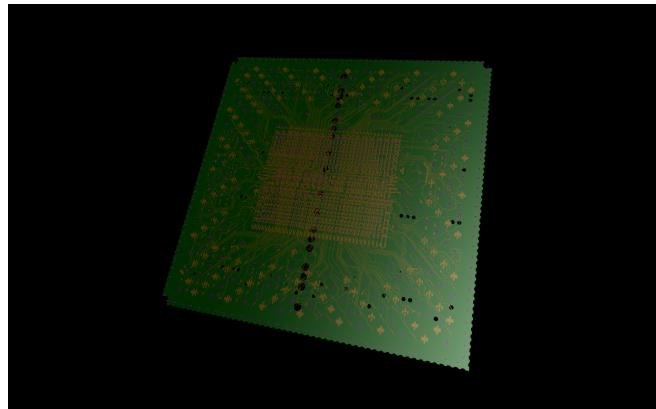


Plane



Triangulated mesh

More Results



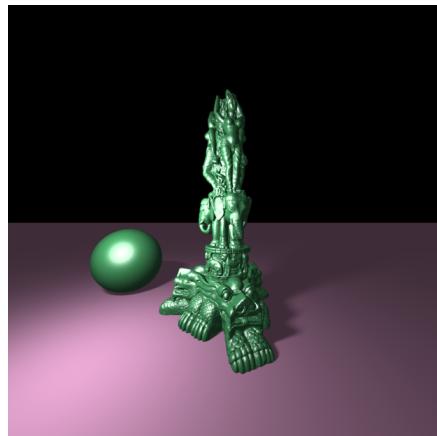
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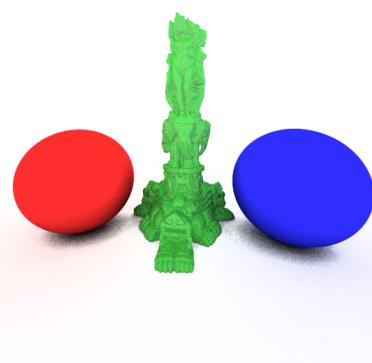
Analysis of Voxel-Based Ray Tracing

- **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.

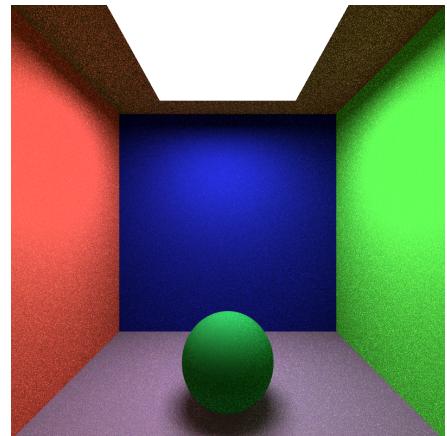
Step 0: Implementing a Voxel-Based Path-Tracer



(e) Soft Shadow with Area Light



(f) Global Illumination with Path Tracing



(g) Cornell Box

BVH Traversal Main Operations which Cause Divergence in Instruction Execution

```
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                  Traverse
            else
                if not s.empty() then
                    | NextNode ← s.Pop()
                else
                    | Finished ← true                            Finished
                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                            Finished
        else
            | NextNode ← s.Pop()
        end
    end
end
```

SIMD Simulator

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

$CurrStage \leftarrow 0$

while $Finished \neq \text{true}$ **do**

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

$CurrStage++$

 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

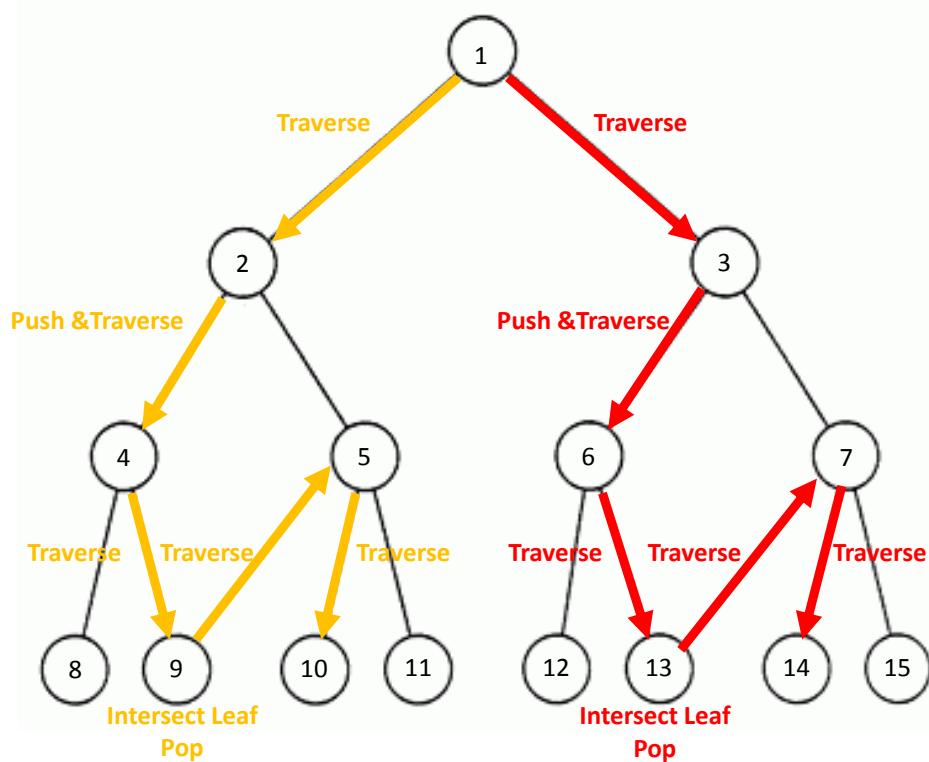
IL: Intersect Leaf

	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

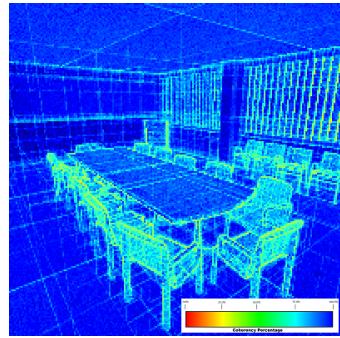
Figure 7: While both rays are perfectly instruction execution coherent, they are incoherent in data access.

Coherency Measurements for Path-Tracing Conference Room

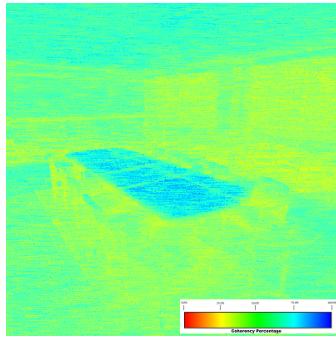
Case	Primary Rays	Bounce 1	Bounce 2
No Ray Sorting	79.14%	49.53%	45.63%
Ray Sorting by Direction	79.14%	49.70%	48.3%
Ray Sorting by Position	79.14%	46.68%	45.81%
Ray Sorting by Both	79.14%	49.73%	48.6%

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

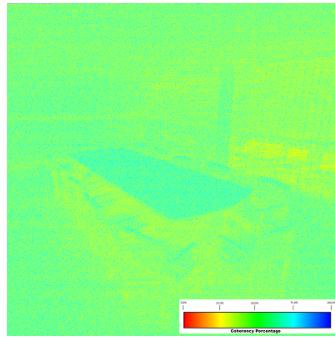
Coherency Measurements for Path-Tracing Conference Room



(a) Primarys



(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

- [BAM14], and [CW14]
- 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

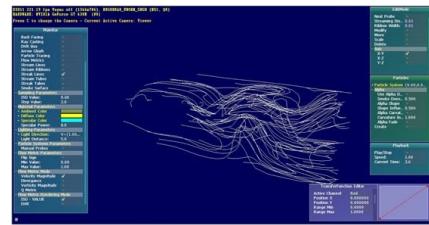
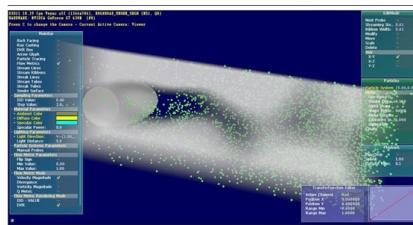
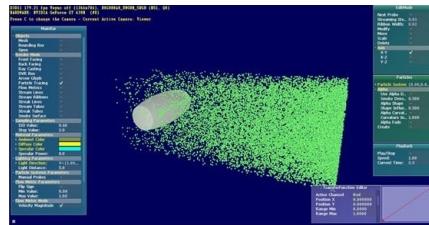
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Practical Courses

- 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



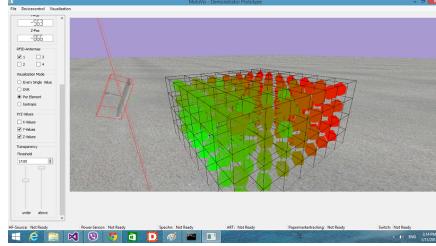
Guided Research: Analysis of Voxel-Based Ray Tracing

Described in previous slides...

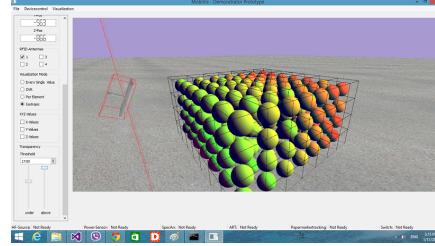
Interdisciplinary Project: Implementing a framework for 3D Visualization of electromagnetic field strength distribution

- 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.

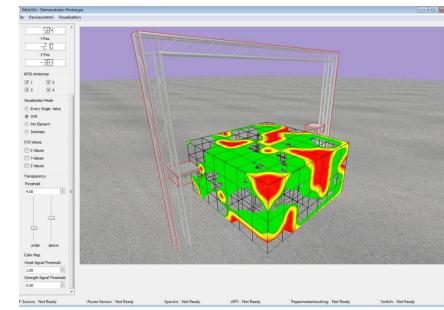
Interdisciplinary Project: Implementing a Framework for 3D Visualization of Electromagnetic Field Strength Distribution



(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.

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 Discussion

Discussion

- Prof. Slusallek: What do you want to be known for in next 5 years?
- Me: I like **real-time rendering**. I would like to be known for improving rendering for **virtual reality** applications.
- Prof. Slusallek: Are you mostly interested in implementation or theory?
- Me: I like theories and try to study and understand them but I am mostly interested in **implementation-wise** works.

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